Research on the Reservoir Characteristics and Lithology Recognition based on Asphalt Sandstone

Tingting Qi1*, Hui Zhao1 and Jia Fu2*

1 Center of Logging production, CNPC Logging, Xi'an 710000, China
2 School of Material science and engineering, Xi'an Shiyou university, Xi'an 710065, China
*Corresponding author’s e-mail: 794847134@qq.com; fujia@xsyu.edu.cn

Abstract. Silurian lithology in tower is complex, and it is very difficult to identify with conventional logging data. Taking the 12 well areas in the Silurian tower as an example, reservoir characteristics were analyzed by thin slice, physical properties, oil washing, salt washing, asphalt washing, and litho-electrical experiments. On this basis, the logging data such as conventional logging, electro imaging, and ECS were combined by point-by-point matching, and the single well lithology recognition is carried out. The response characteristics of different lithology on logging curve are analyzed. The standard and plate of lithology recognition in the research area are established by means of the crossplot technique and discriminant analysis. The results show that the lithology of the study area is mainly rock debris sandstone and feldspar debris sandstone, and the reservoir is poor in physical properties. The asphalt is distributed in the detritus, miscellaneous matrix, colloidal particles and intergranular pores in three forms: oily asphalt, colloidal asphalt and asphalt asphalt. A standard sample was established based on various logging data, and the complex lithology recognition of Silurian system was identified by Fisher discriminant analysis method, which was verified and the compliance rate meets the requirements.

1. Introduction
The distribution area of the Silurian in the Tarim Basin is approximately 24.9×104 km², of which the distribution area of bituminous sandstone accounts for 1/10 [1]. With the continuous expansion and extension of the oil and gas exploration fields in the tower and the north of the tower, a large amount of active oil and gas displays and finds movable industrial oil flows in the Silurian sandstone [2], with mining value. After previous studies, the distribution of Silurian asphalt sandstone is mainly controlled by the oil source area, the ancient uplift, the sedimentary system, the cover layer, and the physical properties of the reservoir [3]. The strata of the Silurian deposit in the tower is divided, from bottom to up, sub-sections of the lower asphalt sandstone, the gray mudstone sub-section, the upper asphalt sandstone sub-section, the red mudstone section, the upper sandstone section, and the upper mudstone section.

This paper mainly studies the Silurian bituminous sandstone section in the 12-well area of the tower (upper and lower bituminous sandstone sections). According to the longitudinal continuous well profile of the research area, it can be seen that the bituminous sandstone is mainly distributed in the III subsections and the I subsections are normal viscosity crude oil [4-6]. Asphalt sandstone crude oil has high viscosity, high density, high colloidal particles + asphaltene content, poor fluidity, affecting the recovery ratio of crude oil, and difficult lithology recognition [7-8]. Drilling coring and outcrops are
usually used to identify lithology, but the cost is relatively high, only in the exploration well at the beginning of exploration [9]. In order to solve the problem of complex lithology and difficult identification in the research area, this paper will establish a log characteristic database with different lithology by combining long-term high alongtrack resolution, continuous conventional logging data, ECS logging and imaging logging with rock core data. Fisher discriminant analysis method is introduced to identify the complex lithology of bituminous sandstone section.

2. Reservoir characteristics

2.1 Reservoir lithologic characteristics

The lithology of the Kepingtage Formation in the well 12 area of the tower is dominated by rock debris sandstone and sub-feldspar rock debris sandstone, and a small amount is quartz sandstone, containing silty sand and gray mass blocks. Among them, the quartz content of the I subsection is 44~64 %, with an average of 49.73 %. It is dominated by single quartz, and secondary growth phenomenon is common; The feldspar content is 6~21 %, an average of 17.27 %; Rock debris content is 26~36 %, an average of 33 %; The quartz content of the III subsections is 40~75 %, with an average of 59.37 %; The feldspar content in III subsection is lower than the previous I-subsection, mostly 1~27 %, with an average of 6.74 %; The rock debris content is 21~49 %, with an average of 34.21 %. Its structural characteristics in III-subsection are similar to those of the previous I-subsection. The particle sorting in the III-subsections of the 12 well area in the tower is mainly good, and the roundness is mainly secondary prism and secondary circle, followed by secondary prisms and secondary circle. The debris is generally supported by particles, and the particles are mostly point-line contact. The type of cementation is mainly pore type.

2.2 Reservoir physical characteristics

The porosity of the I sub-section of the Silurian in the 12 well area in the tower was distributed between 1.68% and 16.08%, with an average of 9.79%; Permeability is distributed between 0.06 and 92.33×10^{-3} μm², with an average of 12.65×10^{-3} μm². The porosity of the III sub-sections of the Silurian in the 11 well area of the tower was distributed between 0.45 and 18.26%, with an average of 8.94%; Permeability is distributed in 0.06 to 0.307μm², with an average of 10.16×10^{-3}μm², and it generally belongs to a low-porous and low-permeability reservoir. The storage space of bituminous sandstone section in the 12 well area of the tower is mainly intergranular holes.

2.3 Asphalt Type

Through the analysis by fluorescence sheet data, it is found that asphalt is mainly distributed in detritus, miscellaneous matrix, colloidal particles and intergranular pores, and it is distributed in three forms: oily asphalt, colloidal asphalt and asphalt asphalt [10-11]. The stronger liquidity oily asphalt is mainly distributed in the intergranular pores, and the less mobile colloidal asphalt and asphalt asphalt are only distributed in detritus, miscellaneous matrix and colloidal asphalt, in which the oily asphalt and colloidal asphalt are heavy oils (oil colloidal asphalt), while asphalt asphalt is an immovable dry asphalt[4].

2.4 Porosity model

In the 12 well areas of the tower, some old well walls are prone to collapse and cause well diameter expansion [12], leading to distortion of the density instrument signal of the wall of the pit, with measurement of the mud signal. In order to solve this problem, this paper uses the GR and RT as the input, which have a small expansion diameter. Using the neural network method, the density curve is reconstructed as: 

$$DEN = 1.92389 * GR^{0.85414} * RT^{0.0319} - 0.02.$$
2.5 Litho-electrical parameters

On the basis of the analysis of the litho-electrical experiments of asphalt sandstone, the litho-electrical parameters need to be established in different physical properties and pore structures, and the litho-electrical parameters \( a, m \):

\[
 m = 2.3945 \times 10^{-147} \quad (a=1)
\]

are established respectively. The difference of pore structure affects the conductivity, and the degree of influence of dry asphalt on the conductivity of different physical reservoirs is different, and \( b \) and \( n \) values need to be determined by reservoir types. The Arch formula \((b, n)\) is used according to the flow unit index method, when the reservoir contains asphalt and \( FZI > 10; b=1.01, n = 1.61; \)

When \( 0.63 < FZI < 10, b = 1.00, n = 1.87; \) When \( FZI < 0.63, b = 1.01, n = 2.13. \) When the reservoir does not contain asphalt and \( FZI > 10, b = 1.00, n = 1.59; \)

When \( 0.63 < FZI < 10, b = 1.00, n = 1.77; \) When \( FZI < 0.63, b = 1.00, n = 1.93. \)

3. Lithology recognition

Through the rock core description data of studied area and core observation after well coring, the Silurian reservoir in the tower is extremely heterogeneous, rock particle size changes greatly, and the reservoir lithology is very complex. It includes glutenite (some of which contain gravel), middle sandstone, fine sandstone(bituminous fine sandstone, gray fine sandstone, muddy fine sandstone), siltstone(muddy siltstone), mudstone(silty mudstone) and other lithology(shown in Table 1).

3.1 Well logging response characteristics of different lithologies

(1) Fine sandstone

The characteristics of fine sandstone on conventional logging curves are: natural gamma low value, natural electric potential is obviously negative anomaly. The resistivity increases, the density and neutrons decrease, and the low value in sound waves. The electroimaging image is characterized by a clear bright color stripe of dynamic and static images (as in Table 1).

(2) Asphalt fine sandstone

The characteristics of bituminous fine sandstone on conventional logging curves are: natural gamma is between 65-80 APIs, ECS logging has low clay content, and the natural electric potential is significantly negative. When \( Pe \) decrease, resistivity is high, the resistivity increased and affected by fluid properties, low density, neutrons, and sound waves. The electroimaging static picture is bright yellow and the dynamic picture mostly shows bright(as in Table 1).

(3) Fine gray sandstone

The characteristics of grey fine sandstone on conventional logging curves are: natural gamma value is lower than that of normal fine sandstone, and natural electric potential is negative abnormal. Neutrons and sound waves decrease, density increases, and resistivity is unusually high. The rock core photo has coarse rock granules containing gray-white gray matter(as in Table 1).

(4) Siltstone

The characteristics of siltstone on conventional logging curves are: the natural gamma value is higher, and the natural electric potential anomaly decreases. The density is medium to high, which is between fine sandstone and mudstone. The neutron density and resistivity increase, the array induction curve basically coincides. The rock core has fine particle size and low or no oil level (in Table 1).

(5) Mudstone

The characteristics of mudstone on conventional logging curves are: the natural gamma value is higher, and the natural electric potential anomaly decreases. The density is medium to high, which is between fine sandstone and mudstone. The neutron density and resistivity increase, the array induction curve basically coincides. The rock core has fine particle size and low or no oil level (in Table 1).

(6) Glutenite

The characteristics of glutenite on conventional logging curves are: low gamma value, and negative natural electric potential anomaly. When \( Pe \) increases, the resistance and the density is high, the
neutron decreases, and the sound wave is low. Electro images are characterized by a bright yellow color showing in dynamic and static image (as in Table 1).

Table 1 Well logging response characteristics database of different lithology in studied blocks

| Lithology               | Core picture | Normal curve feature | Imaging pattern |
|-------------------------|--------------|----------------------|-----------------|
| Fine sandstone          |              |                      |                 |
| Asphalt fine sandstone  |              |                      |                 |
| Fine gray sandstone     |              |                      |                 |
| Siltstone               |              |                      |                 |
| Mudstone                |              |                      |                 |
| Glutenite               |              |                      |                 |

3.2 Lithology recognition by the crossplot technique

Fig. 1 The crossplot technique for lithology recognition
Using core description and well logging data, the crossplot of gamma, density, neutron and resistivity in studied blocks were established. Among them, the recognition of sand and mud rock by gamma and density crossplot is good, and the recognition of gray fine sandstone by gamma and neutron crossplot is obvious (Fig.1). The disadvantage of this method is that the boundary between different lithology is relatively vague, and only qualitative lithology can be identified. It is necessary to use human-machine interaction way to accurately identify lithology.

3.3 Lithology recognition by the Fisher discriminant analysis

Fisher discriminant analysis was proposed by British statistician Fisher in 1936. The basic idea of this method is to extract a number $p$ of indicators of sample observation data from two populations, and to build a discriminant function or discriminant formula based on the idea of variance analysis, which is as:

$$y = c_1 x_1 + c_2 x_2 + \cdots + c_p x_p = \sum_{j=1}^{p} c_j x_j$$

Here the principle of determining the coefficients $c_1, c_2, \ldots, c_p$ is to make the difference between the two groups as much as possible. While the degree of dispersion within each group is as small as possible. After having a discriminant, for a new sample, submitting its individual indicator $p$ values into the discriminant formula to obtain the $y$ values, and then compare with the discriminant threshold values to determine which group it should belong to.

Taking XX1 well as a discriminant analysis sample, the M2RX, RXO, GR, DEN, AC, and PE were selected as observation indicators. Here I stands for siltstone, II for mudstone, and III for fine sandstone, the original data of different wells and stones are shown in Table 2.

| Well number | M2RX  | RXO  | GR   | ZDEN | AC   | PE   | Type |
|-------------|-------|------|------|------|------|------|------|
| XX1         | 10.87 | 11.6 | 86.96| 2.62 | 66.6 | 3.14 | I    |
| XX1         | 11    | 11.49| 89.53| 2.62 | 66.34| 3.16 | I    |
| XX1         | 11.64 | 11.62| 91.02| 2.61 | 65.89| 3.19 | I    |
| XX1         | 14.86 | 13.61| 95.8 | 2.62 | 63.71| 3.29 | II   |
| XX1         | 15.53 | 13.98| 92.18| 2.61 | 63.58| 3.22 | II   |
| XX1         | 21.68 | 16.64| 89.24| 2.64 | 77.22| 3.36 | II   |
| XX1         | 20.33 | 15.51| 95.58| 2.65 | 76.12| 3.36 | II   |
| XX1         | 17.74 | 13.45| 103.19| 2.67 | 71.75| 3.36 | I    |
| XX1         | 17.09 | 12.92| 102.07| 2.67 | 69.16| 3.35 | II   |
| XX1         | 16.97 | 12.78| 97.51 | 2.66 | 66.77| 3.35 | II   |
| XX1         | 15.68 | 14.43| 79.21 | 2.65 | 64.94| 3.26 | III  |
| XX1         | 17.08 | 15.41| 73.4  | 2.64 | 65.15| 3.27 | III  |
| XX1         | 21.97 | 18.93| 60.56 | 2.6  | 65.52| 3.28 | III  |

Using Fisher discriminant analysis method, the discriminant function is established as follows:

$$F_1 = -19.359 \times M2RX + 25.355 \times RXO - 8.537 \times GR + 4263.250 \times DEN + 28.777 \times AC - 87.993 \times PE - 6023.170$$

$$F_2 = -18.137 \times M2RX + 21.541 \times RXO - 8.382 \times GR + 4278.927 \times DEN + 29.153 \times AC - 85.510 \times PE - 6105.186$$

$$F_3 = -20.101 \times M2RX + 24.033 \times RXO - 9.285 \times GR + 4292.812 \times DEN + 29.326 \times AC - 90.757 \times PE - 6075.900$$

(a) 4325-4331 m thin interlayer of siltstone (b) 4344.2 m fine sandstone core

Fig.2 Discriminant analysis and lithology recognition effect of XX2 well
The results in the Fig. 2 a) shows that the section of 4325-4331 m is mainly a thin interlayer of sand shale, and the thinnest sand layer is 0.05 m. Affected by the resolution of the well logging curve, the overall section is identified as silt and fine sandstone, which is roughly consistent with the precision tracing data of the sandstone core; The core extraction shows that a set of 0.3 m thick fine sandstone was developed in the stone section of 4344.2 m, which is consistent with the discriminant analysis and recognition results (Fig. 2 b).

Fig. 3 is an example of discriminant analysis and lithology recognition in the study area of XX2 well. The fifth part in Fig. 3 is the lithological discriminant index for the discriminant analysis function calculation, the seventh is the precision tracing data of the sandstone core, and the eighth is the discriminant analysis lithology recognition.

| Type                  | lithologic recognition |
|-----------------------|------------------------|
|                       | glutenite | gray fine sandstone | fine sandstone | siltstone | mudstone | glutenite |
| Sandstone core description |    |    |    |    |    |     |
| Thickness (m)         | 5.149     | 0.00   | 0.31  | 0.4   | 0.00   |     |
|                       | 0.00      | 9.68   | 0.00  | 1.12  | 0.00   |     |
|                       | 0.00      | 0.00   | 124.16| 18.126| 1.97   |     |
|                       | 0.08      | 0.00   | 12.85 | 99.98 | 4.58   |     |
|                       | 0.00      | 0.31   | 1.45  | 8.54  | 60.81  |     |
|                       | 87.88     | 0.00   | 5.29  | 6.83  | 0.00   |     |
|                       | 0.00      | 89.63  | 0.00  | 10.37 | 0.00   |     |
Table 3 is an analysis table for the lithologic recognition effect of the research area, in which thickness of the glutenite is accurately identified about 5.149 m, with the accuracy rate of 87.88 %. Besides, the thickness of gray fine sandstone is 9.68 m, and the accuracy is 89.63 %; The thickness of fine sandstone is 124.16 m and the accuracy is 86.07 %; The thickness of siltstone is 99.98 m and the accuracy is 85.10 %; The thickness of mudstone is 60.81 m and the accuracy rate is 85.52 %. The accuracy of different lithology is 86.84 %, which satisfies the compliance rate of the research area.

### 4. Conclusions

Based on rock physics experiment, the response characteristics of different lithology on logging curve are analyzed by point-by-point matching method, combining conventional logging, electro imaging, ECS and other log data. The standard and plate of lithology recognition in the research area are established by means of the crossplot technique and discriminant analysis. Based on this, a single well lithology recognition is carried out. Conclusions are as follows:

1. Through the process of the thin slice, physical property, washing oil, washing salt and washing asphalt and the experiment of rock electric, the lithology of the study area is mainly composed of lithic sandstone and sub-feldspar lithic sandstone, and a small amount of quartz sandstone.
2. The reservoir has poor physical properties and belongs to low porous and low permeability reservoirs.
3. Asphalt is mainly distributed in detritus, miscellaneous, colloidal particles and intergranular pores, which is mainly distributed in three forms: oily asphalt, colloidal asphalt and asphalt asphalt.

### References

[1] Zhang Jun, Pang Xiongqi, Liu Luofu et al. Distribution characteristics of Silurian asphaltic sandstone in Tarim Basin and geological significance of stone drainage[J]. Science China, 2004,34 (Supplementary Issue I): 169-176. (In Chinese)

[2] Guo Jian-jun, Chen Jian-fa. Geologic Featur e and Study Progress of Silurian Asphaltic Sandstone in Tazhong Area Tarim Basin [J]. Xinjiang Petroleum Geology, 2006,27(2):151-155. (In Chinese)

[3] Hu Jian,Wang Tie Guan,Chen Jianping,et al. Source recognition and charging analysis of oil in the Silurian bituminous sandstone in the Tarim Basin:Evidences from biomarker compounds[J]. Natural Gas Geoscience, 2015, 26(5): 930-941. (In Chinese)

[4] Qi Tingting, Su Bo, Liao Maojie. Asphalt Influence on Reservoir Characteristics and Quantitative Evaluation [J]. Well Logging Technology, 2018, 42(2): 169-174. (In Chinese)

[5] Chenshi Jia, Wangming Fa, Lujun Gang, Fanxiao Jun, Yangguo Ping. Reservoir bitumens impact on reservoir physical property and reservoir productivity [J]. Journal of Southwest Petroleum University (Science & Technology Edition), 2010, 32(2): 1-5. (In Chinese)

[6] Ji Youliang, Zhang Shiqi, Li Hongnan, Zhang Liqiang etc. The effect of solid reservoir bitumen on reservoir quality [J]. Petroleum Exploration And Development, 1995,22(4):87-90. (In Chinese)

[7] Wang Kun, Zhang Feng, Zhang Yi, Wang Dongkun. Identification of the Lithology of Carboniferous and Its Reservoir Characteristics in Chepaizi Uplift, Junggar Basin [J]. Journal of Southwest Petroleum University (Science & Technology Edition), 2014, 36(4):21-27. (In Chinese)

[8] Larter S R, Wilhelm A, Head I, et al. The controls on the composition of biodegraded oils in the deep subsurface, part 1: Biodegradation rates in petroleum reservoir [J]. Organic Geochemistry, 2003, 34(4): 601-613. (In Chinese)
[9] Chen Shijia, Fan Xiaojun. Impact of bitumen on reservoir properties and hydrocarbon accumulation [J]. Petroleum Exploration And Development, 2010, 37(1): 70-76. (In Chinese)

[10] Liu Luofu, Jianzhang Zhao etc. The Depositional And Structural Settings And The Bituminous Sandstone Distribution Characters Of The Silurian In Tarim Basin [J]. Acta Petrolei Sinica, 2001,22(6):11-17. (In Chinese)

[11] Chen Qianglu, Fan Ming, You Donghua. Non-traditional method for evaluating physical property of Silurian bitumen sandstone reservoirs in Tarim Basin[J]. Acta Petrolei Sinica, 2006, 27(1): 30-33. (In Chinese)

[12] Qi Tingting, Chen Rong, et al. Discussion on the correction method of density and nuclear magnetic resonance logging data based on diameter expansion[J].Journal of Well Logging Technology, 2017,38(6):30-34. (In Chinese)

[13] Ying Fang-fang, Li Peng. The Application of Fisher Discriminant Analytical Method in Oil Shale Identification[J]. Journal of Yangtze University(nat sci edit). 2014,11(4):16-20. (In Chinese)

[14] Zhao Lu-zi, Zhou Yan, Xia Ji-wen, Wu Chang-long, Zeng Wan-quan. Application Of Fischer Parameter Discriminance To Gas Reservoir Identification Of Jialingjiang Formation In Southern Sichuan Area [J]. Natur. Gas Ind, 2008, 28(5): 44-46. (In Chinese)