Application of chromatographic fingerprint technology in study of single layer capacity contribution of multi-zone shale oil well in Jimsar Sag

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Abstract. Based on the principle of chromatographic fingerprinting technology, P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-1, P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-3 single layer shale oil chromatographic fingerprint libraries of upper sweet spot in Jimsar Sag were established by laboratory matching experiment. The partial least squares method was used to realize the capacity contribution calculation and dynamic monitoring of the single layer in two layer and three layer shale oil of the dessert in Jimsar. The result shows, upper sweet shale oil of Lucaogou Formation in Jimsar Sag are mainly supplied by P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-1 layer and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 layer. Oil mainly supplied by P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-1 layer in the wells of JI 37 and JI 171, which are combined with P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-1 and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2. Oil mainly supplied by P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 layer in the wells of JI 174 and JI 176, which are combined with P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-3. Oil mainly supplied by P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-3 in the wells of JI 25 and JI 173, which are combined with P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-3. Oil mainly supplied by P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-1 in the wells of JI 174 and JI 176 well is gradually reduced, and P\textsubscript{2}l\textsubscript{2}\textsuperscript{2}-2 becomes the main oil supply layer. The physical properties and oil saturation of the corresponding reservoirs in each well were analyzed. And the results proved the accuracy and rationality of the calculation results.

1. Introduction
Lucaogou Formation in Jimsar Sag is an important shale oil exploration area in Junggar Basin. At present, there are two main technologies for the exploitation of shale oil in Jimsar Sag: vertical well splitting and horizontal well splitting. For multi-layered shale oil vertical wells, it is important to understand the contribution ratio of each single oil layer to the multi-zone wellhead crude oil, which has important guiding significance for improving shale oil production efficiency and oilfield production plan. Therefore, oil chromatographic finger-print analysis technology was used to study single layer production of multi-zone shale oil well in Jimsar Sag. Oil chromatographic fingerprint technology is based on high-precision gas chromatography instruments to distinguish the subtle differences in chromatographic fingerprint characteristics between different single-layer crude oils and multi-zone oil. According to laboratory matching experiments, a mathematical model for the
contribution of single-layer capacity is established. Then calculate the capacity contribution of the single layer in the multi-zone production well.

2. Experimental

2.1. Sample
The Permian Lucaogou Formation (P2j) in Jimsar Sag is in integrated contact with overlying Wutonggou Formation (P2wt) and lower Jiangjunmiao Formation (P1j). It is divided into Lu 1 segment (P2j1) and Lu 2 segment (P2j2) from bottom to top. Among them, the Lu 2 segment is divided into P2j21, P2j22, P2j23, P2j24, P2j25. The target layer of this study is the upper “dessert” sand layer located on P2j2 in the lower part of the Lu 2 section. The main fracturing layer includes P2j21, P2j22, P2j23 layers. And the selected samples are shown in Table 1. It can be seen from Table 1 that the shale oil of Lucaogou Formation is heavier and the density is between 0.8740 and 0.8964 g/cm³, the viscosity of the crude oil is between 32.0 and 55.2 mPa·s at 50 °C.

| Well | Formation | Density (g/cm³) | Viscosity (mPa·s) |
|------|-----------|----------------|------------------|
| JI 301 | P2j21 | 0.8796 | 44.8 |
| JI 302 | P2j22 | 0.8740 | 32.0 |
| JI 302 | P2j23 | 0.8798 | 37.1 |
| JI 303 | P2j24 | 0.8820 | 33.7 |
| JI 31 | P2j25 | 0.8890 | 43.1 |
| JI 37 | P2j21 + P2j22 | 0.8817 | 30.9 |
| JI 171 | P2j21 + P2j22 | 0.8897 | 48.1 |
| JI 25 | P2j21 + P2j23 | 0.8964 | 55.2 |
| JI 173 | P2j22 + P2j23 | 0.8788 | 33.0 |
| JI 174 | P2j21 + P2j22 + P2j23 | 0.8811 | 41.1 |
| JI 176 | P2j21 + P2j22 + P2j23 | 0.8794 | 36.2 |

2.2. Instruments and materials
The whole oil gas chromatographic (GC) analysis were carried out using a Agilent7890 GC-FID equipped with DB-5ht (30m×0.32mm×0.10μm) capillary columns respectively. The carrier gas is nitrogen (purity is up to 99.999%), and the flow rate was 1.5ml/min. Split injection mode with a 20:1 split ratio, inlet temperature of 350 °C, FID temperature was set at 370 °C, oven temperature starts from 40 °C for initial isothermal period of 3min, then raised to 230 °C at 4 °C/min, and then raised to 370 °C at 10 °C/min for the final isothermal period 20min. Typically, 1 lm of oil samples diluted by GC grade CS2 were injected. It is worth mentioning that a 5 m long capillary guard column without stationary phase was connected between the column and the inlet with a quartz tube to prevent the column from being contaminated or blocked by crude oil.

3. Results and discussion

3.1. Chromatographic fingerprint characteristics of crude oil
In this study, 50 chromatographic fingerprint peaks and a total of 25 chromatographic fingerprint peak pairs were selected in shale oil (Fig. 1). On this basis, chromatographic fingerprint libraries of P2j21, P2j22, P2j23 layers were established (Fig. 2).
Figure 1. The chromatographic fingerprint peaks of shale oil in Lucaogou Formation, Jimsar Sag. (The numbers 1, 2, 3...50 in the figure are different chromatographic fingerprint peaks, and the colors represent the areas of fingerprint peaks)

Figure 2. Chromatographic fingerprinting of different single-layer crude oils in Lucaogou Formation, Jimsar Sag.

Oil in P212-2 layer and P212-3 layer of JI 302 well were selected for laboratory matching experiment, the mixing ratios were 0:100, 25:75, 50:50, 75:25, 100:0. Taking the ratios of P212-2 oil in multi-zone oil as the ordinate, and the ratio of the peak area of the chromatographic fingerprint as the abscissa, the regression line of the crude oil ratio experimental relationship was established (Fig. 3). The result shows, the chromatographic fingerprint peak pairs have good comparability, such as the adjacent chromatographic fingerprint peak pairs: 5/6, 9/10, 23/24 and 37/38, the linear function correlation coefficient $R^2$ between the peak area ratio and the end element ratio is above 0.9. It is indicated that difference in chromatographic fingerprint of crude oil between single layers is caused by the difference of crude oil itself, which can represent the characteristics of single layer, rather than the error of chromatographic fingerprint analysis. The fingerprint peak pairs with high regression coefficient were used as the final chromatographic fingerprint characteristic parameter in this study.

3.2. Contribution rate of single-layer capacity to multi-zone oil well
In this study, the results of two-layer ratio experiment of sweet shale oil in Lucaogou Formation, Jimsar Sag were calculated by partial least squares method. It can be seen from Table 2 that the maximum error between the actual ratio of laboratory matching experiment and the theoretical calculation ratio calculated using chromatographic fingerprint parameters is 4.2%. The results shows
that the experimental method has high precision and can be used for actual production. The contribution rate of single-layer capacity in two-layer and three-layer production wells is calculated by this method (Table 3).

![Figure 3. Relationship between proportion of P2l2-2 layer in combined layer and the ratio of the peak area of the chromatographic fingerprint.](image)

Table 2. Comparison of actual ratio and theoretical calculation ratio of laboratory matching experiment.

| Number | P2l2-2 (%) | P2l2-3 (%) | P2l2-2 (%) | P2l2-3 (%) | Absolute error (%) |
|--------|------------|------------|------------|------------|-------------------|
| 1      | 26.0       | 74.0       | 22.5       | 77.5       | 3.5               |
| 2      | 38.4       | 61.6       | 42.6       | 57.4       | 4.2               |
| 3      | 48.3       | 51.7       | 52.4       | 47.6       | 4.1               |
| 4      | 68.5       | 31.5       | 68.3       | 31.7       | 0.2               |

In three-layer production wells, oil mainly supplied by P2l2-2 layer in the wells of JI 174 and JI 176, which are combined with P2l2-2 and P2l2-3, and the contribution rates are 47.3% and 49.2%, respectively, followed by P2l2-3, the contribution rates were 37.3% and 37.7%, respectively. In addition, it is found that with the progress of oil exploitation, the contribution rate of P2l2-2 in JI 174...
well and JI 176 well is gradually reduced, with contribution rates of 27.9% and 41.7%, respectively, and P212 is the main oil supply layer, with contribution rates of 57.3% and 42.7%, respectively. The contribution rate of P222-3 layer is low, about 15%.

It can be seen from the porosity, permeability and oil saturation profile of JI 37 that the dessert in the well is generally a set of medium-low porosity, low-extra low permeability reservoir(Fig.4). The porosity of bottom of P212-1 layer and top of P212-2 layer is relatively high, ranging from 7.00% to 18.00%, porosity of middle and lower part of P212-2 layer is relatively low, less than 10.00%; permeability of P212-1 layer and P212-2 layer is relatively close, ranging from 0.1 to 10.0 mD; oil saturation of P212-1 layer is high, while the oil saturation at the top of P212-2 layer is close to that of P212-1 layer, but the oil saturation at the bottom of P212-2 layer is low, less than 10.00%. According to the above analysis, the reservoir properties of P212-1 layer and P212-2 layer in JI 37 well are similar, but oil saturation of P212-1 layer is slightly better than P212-2 layer, which is consistent with the calculation of productivity contribution rate.

Table 3. Calculation results of contribution rate of single-layer capacity of multi-zone oil wells in Lucaogou Formation, Jimsar Sag.

| Well  | Sampling date | Single-layer of multi-zone oil well | Contribution rate of single-layer |
|-------|---------------|-------------------------------------|----------------------------------|
| JI 37 | 2013-12       | P212-1, P212-2                       | 54.6%, 45.4%                    |
| JI 171| 2011-05       | P212-1, P212-2                       | 76.7%, 23.3%                    |
| JI 173| 2012-06       | P212-1, P212-2, P212-3              | 71.4%, 28.6%                    |
| JI 25 | 2012-08       | P212-1, P212-2, P212-3              | 63.6%, 36.4%                    |
| JI 174| 2015-12       | P212-1, P212-2, P212-3              | 47.3%, 15.4%                    |
| JI 174| 2017-08       | P212-1, P212-2, P212-3              | 27.9%, 14.8%                    |
| JI 176| 2015-12       | P212-1, P212-2, P212-3              | 49.2%, 13.1%                    |
| JI 176| 2017-08       | P212-1, P212-2, P212-3              | 41.7%, 15.6%                    |

Figure 4. Vertical characteristics of porosity, permeability and oil saturation of the sweets reservoir in Lucaogou Formation of JI 37 well.

4. Conclusions
(1) Using the crude oil chromatographic fingerprint technology, combined with the laboratory matching experiment and the partial least squares method, the capacity contribution calculation and dynamic monitoring of the single layer in the two layer and three layer shale oil of the dessert in
Jimsar.
(2) The upper sweet shale oil in the Lucaogou Formation of the Jimsar Sag is mainly supplied by layers of $P_{2l2-1}$ and $P_{2l2-2}$, and the contribution rate of $P_{2l2-3}$ layer is low. In the two layers of multi-zone crude oil, JI 37 and JI 171 are mainly supplied by $P_{2l2-1}$, and the productivity contribution rate is over 50%. JI 25 and JI 173 mainly supply by $P_{2l2-2}$, and the capacity contribution rate reaches over 60%.

(3) It is found that from 2015 to 2017, the contribution rate of $P_{2l2-1}$ layer production capacity in the three-layer multi-zone crude oil of JI 174 and JI 176 wells gradually decreased, and the $P_{2l2-2}$ layer became the main oil supply layer. The contribution rate of $P_{2l2-1}$ layer capacity of JI 174 well decreased from 47.3% to 27.9%, the contribution rate of $P_{2l2-2}$ layer capacity increased from 37.3% to 57.3%, and the contribution rate of $P_{2l2-1}$ layer capacity of JI 176 well decreased from 49.2% to 41.7%, the $P_{2l2-2}$ layer capacity contribution rate increased from 37.7% to 42.7%.

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