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Study on flow unit division and production dynamics of tight sandstone reservoir in Huaqing oilfield

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In this paper, the Chang 6 ultra-low permeability reservoirs in Huaqjing area of Ordos Basin are studied. The reservoir is divided into four types of flow units by using Q-type multi-parameter clustering analysis and SPSS statistical analysis software. The characteristics of reservoir physical properties, sedimentary characteristics, capillary pressure curve and production dynamics were analyzed. The rationality of the results were verified from the static and dynamic points of view. Results show that I type flow unit has good reservoir properties and development effect is fast. The main development target is to maintain long-term stability. The distribution areas of II and III types are large, and cover the main production layer of oil field development and the remaining oil enrichment area. The reservoir properties of the IV type flow unit are worst, and the development is difficult. Efficient development of such reservoirs through the scientific division of the flow unit is important and of practical significance.

[Keyword: Movable fluid saturation; Q-type multi-parameter; Flow zone index; Chang 6 reservoir; Ordos Basin]

Introduction

The flow unit is horizontal and vertical continuous with rock physics features similar to those of the reservoir belt[1]. Its research has an important significance on qualitative characterization, quantitative identification of reservoir heterogeneity, determination of oily desert area, evaluation of high quality reservoir sand, and understanding of remaining oil distribution [2,5]. This paper used Q-type multi-parameter clustering analysis and SPSS statistical analysis software to the Huaqing area of Chang 6 low permeability reservoir of flow unit division to verify the rationality of the division through the study of the static and dynamic characteristics, which provides the reference for efficient development of similar tight sandstone reservoir.

Huaqing oilfield is located in the territory of Gansu Huachi and Qingcheng, belonging to the Tianhuan depression and the yishaan slope transition zone; the main belt of the main oil-bearing layers Chang 6 section, under the control of the south-west and north-east major source. It is a semi-deep lake gravity current deposit multichannel through the cross plane and vertical superposition, and forms a reservoir with large thickness. The location of the study area is shown in Figure 1. Huaqing area of Chang 6 reservoir porosity distribution interval is 0.45%~23.1%, and the average value is 9.68%. The reservoir permeability distribution interval is $0.005\times10^{-3}\mu m^2$~$67.106\times10^{-3}\mu m^2$, the average is $0.245\times10^{-3}\mu m^2$. The sample data is mainly distributed in the range of permeability less than $1.0\times10^{-3}\mu m^2$. The permeability distribution shows a very negative skewness[6,7].

The core observation and casting slice experiment, showed that the Chang 6 section of Huaqing oilfield is dominated by grayish brown and light grey lithic sandstone (81.5%), followed by feldspar sandstone (18.5%) (Fig. 2). Sand body with fine granularity and very fine granularity, the overall sorting belongs to the medium - preference, positive skewness kurtosis skewness is very sharp, rounded; detrital grade by edge (94.20%). The classic particles in the study area are subjected to stronger compaction and reconstruction, mainly by point-line contact.

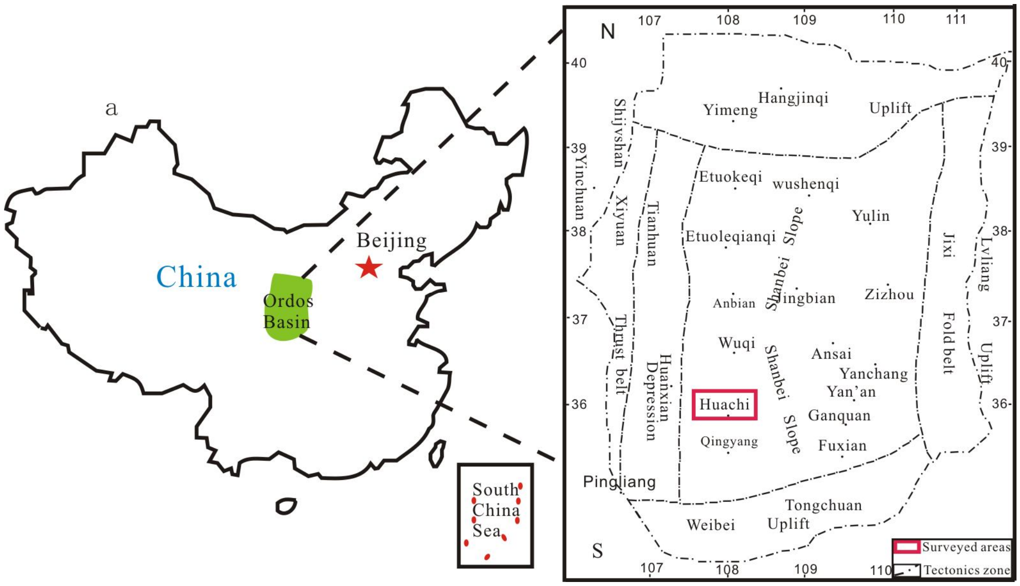

Fig. 1 — Location of Huaqing oil field

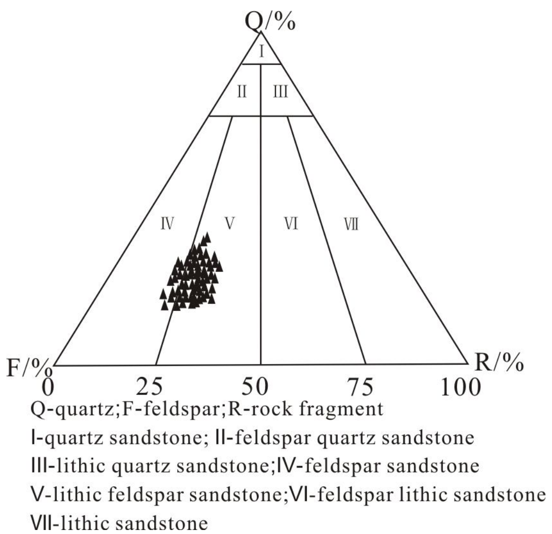

Fig. 2 — Characters and types of Chang 6 Reservoir Huaqing area

Method and Principle

Selection of characteristic parameters

It is only when the correct characteristic parameters are selected and the rational division method is adopted can the geological and fluid properties of reservoirs be truly reflected and the flow units can be accurately divided. Therefore, while selecting flow cell partition parameter, it is important to include as much as possible reservoir porosity, permeability, saturation and other physical parameters, micropore structure parameters (hole roar ratio, median radius), deposition and diagenesis (median particle size and clay mineral content), fluid saturation and so on[8,9].

The test data of Chang 6 reservoir in Huaqing area has been analyzed and arranged. Flow zone index (FZI), sand thickness (H), permeability (K), porosity (PHI) and oil saturation (So) are selected as five indicators of the division of flow unit. The flow band index is widely used in low permeability reservoirs as an index to evaluate the quality of micropore structure, an based on the theory of relationship between porosity and permeability by Kozeny Carman which can effectively describe the influence of micropore characteristics on fluid seepage. The larger the value of flow band index, the better the physical properties of reservoir as per the calculation formula[10,11]:

Reservoir quality index:

$$RQI = 0.0314\sqrt{\frac{K}{\phi_e}} \quad \text{(type-1)}$$

Normalized porosity index:

$$\phi_z = \frac{\phi_e}{1-\phi_e} \quad \text{(type-2)}$$

The flow band index is:

$$FZI = \frac{1}{\sqrt{Fs}\tau S_{gv}} = \frac{RQI}{\phi_z} \quad \text{(type-3)}$$

Cluster analysis principle of Q sample

Q cluster analysis is a multivariate statistical analysis method to establish a scientific classification according to the relationship. The principle is to first select several objects and the research object of high correlation and then through classification statistics as the basis of classification the degree of intimacy is classified as a class object. In this paper, based on the principle of minimum Euclidean distance, the flow unit is divided by the method of sum of squares of deviations from the pedigree clustering. The principle is[12,14]:

$$D_{ij} = \sqrt{\sum_{k=1}^{m}(X_{ik} - X_{jk})^2} \quad \text{(type-4)}$$

The smaller the D_{ij}, the closer are the objects, so the smaller objects of D_{ij} can be put in the same class. To ensure the accuracy of the division, the D_{ij} should not be too large, so the upper form is modified to:

$$D_{ij} = \frac{1}{m}\sum_{k=1}^{m}(X_{ik} - X_{jk})^2$$

(i, j=1, 2, Λ, n (type-5)

$[D_{ij}]_{n\times n}$ is Real symmetric matrix, and $D_{11}=D_{22}=\ldots\ldots D_{nn}=0$

When the observation distance is $d(x, y) = |x - y|^2 / 2$, the recurrence formula would be: DJM=((NJ+NK)+DJK+(NJ+NL)DJL-NJDKL)/(NJ+NM)

Flow Unit Division Standard

According to the above cluster analysis principle, SPSS software is used to cluster the study area, and finally the reservoir in the study area is classified as I, II, III and IV flow units (Table 1, Fig. 3).

As can be seen from Table 1 and Figure 3, the distribution areas of various flow units are obvious. Therefore, it is reasonable to divide the flow units in the study area into four categories.

Results and Discussion

The flow units are different in size and lateral continuity due to the difference of hydrodynamic conditions of the river, the time of the cutoff and transfer, and the sedimentation rate of the sedimentary basins. At the same time, it also has different characteristics in lithology, physical property, capillary force curve, and sedimentary characteristics[15].

Physical properties of four types of flow unit reservoirs

Flow units in Category I (very good): The average value of the permeability is $0.32\times10^{-3}\mu m^2$, the average porosity is 11.2%, the oil saturation average value is 46.75, the flow zone index mean value is 0.377, the average reservoir thickness is 33 m, Reservoir flow unit in the best reservoir permeability.

Class II flow unit (good): The average value of the permeability is $0.28\times10^{-3}\mu m^2$, the average porosity is 10.9%, the average oil saturation value is 45, the flow zone index mean value is 0.374, the average thickness is 18 m, Reservoir flow unit with good reservoir permeability.

Flow units in category III (general): The average

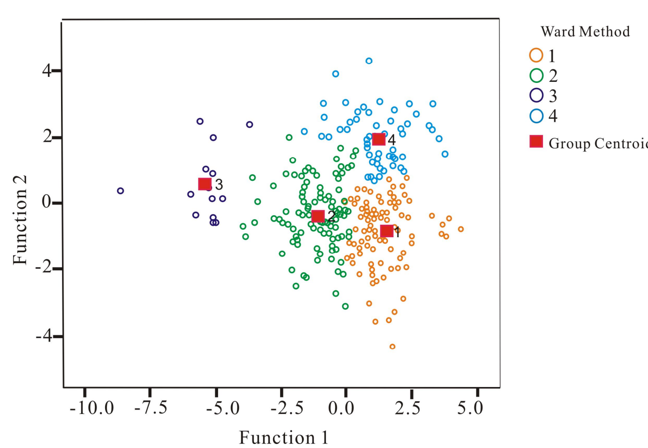

Fig. 3 — Classification of flow units in the Chang 6 Reservoir of the Huaqing area

Table 1 — Statistics of characteristic parameters for flow units in the Chang 6 Reservoir of the Huaqing area

Flow unit classification	permeability/$\times10^{-3}\mu m^2$	porosity/%	oil saturation/%	Sand thickness/m	Flow band index
I category	0.11 – 2.43 / 0.32	8.5 – 19.4 / 11.23	43 – 59 / 46.75	26 – 46 / 33.33	0.211 – 0.53 / 0.377
II category	0.08 – 1.04 / 0.28	8.2 – 15.1 / 10.9	38 – 48 / 45.45	2 – 29 / 18.38	0.216 – 0.815 / 0.374
III category	0.05 – 1.43 / 0.21	8.3 – 15.0 / 9.49	31 – 52 / 42.55	4 – 23 / 16	0.206 – 0.59 / 0.386
IV category	0.08 – 0.53 / 0.14	8.6 – 12.8 / 9.01	7 – 33 / 24.24	3 – 21 / 10.69	0.255 – 0.576 / 0.373

Notes: Represented by a molecular formula: minimum value – maximum value/average value

value of the permeability is $0.21\times10^{-3}\mu m^2$, the average porosity is 9.5%, the average oil saturation value is 43, the flow zone index mean value is 0.3857, the average thickness is 16 m, Flow characteristics of ordinary flow units.

The flow unit type IV (worst): The average value of the permeability is $0.14\times10^{-3}\mu m^2$, the average porosity is 9%, the average oil saturation value is 24%, the flow zone index mean value is 0.384, the average thickness is 11m-Reservoir flow unit is the worst performance.

Sedimentary characteristics of four types of flow units

The rock types of I type flow unit are mainly lithic feldspar sandstone, diagenetic facies types of feldspar dissolution and intergranular pore chlorite film cementation facies, intergranular pore illite and chlorite film cementation facies, dissolved pore intergranular pore as the main pore combination (Figs 4-a, b). The type I flow units on the plane are mainly distributed in the main sand bodies of the main channel, sandy debris flow and underwater distributary channel microfacies, with small distribution area and poor continuity.

Class II flow unit rock types are mainly lithic feldspar sandstone, containing a small amount of feldspar sandstone, intergranular pore - illite and chlorite film cementation facies and intergranular pore illite cementation facies as the main diagenesis of the reservoir diagenetic facies type (Figs 4-c, d). The type II flow unit on the plane is distributed in the underwater distributary channel and the sandy gravel flow microfacies of the main channel, and the distribution area is larger, and the degree of connectivity is better as shown in Figure 5.

Flow units in category III rock types are mainly lithic feldspar sandstone and feldspar sandstone diagenetic facies types of illite cementation and dissolution and illite and chlorite cementation dissolution phase (Figs 4-e, f). The type III flow unit in the plane is mainly distributed at the edge of the sandy clastic flow microfacies of the main channel and the underwater distributary channel. On the surface, the sand bodies are banded, with larger area and good continuity, as shown in Figure 5.

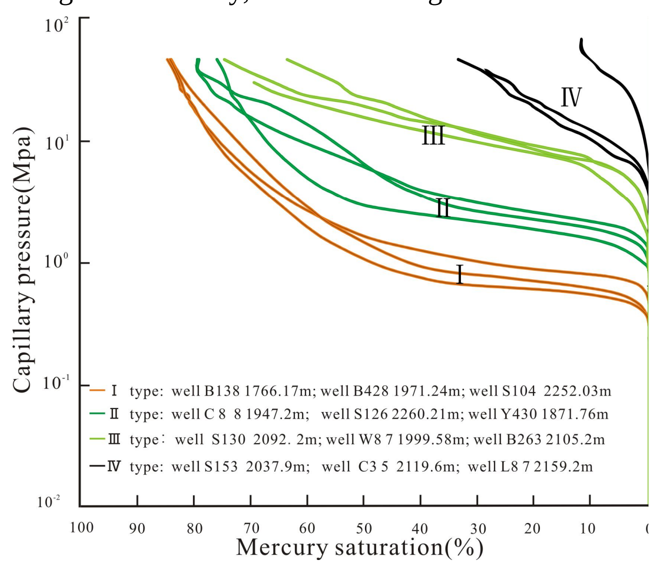

Fig. 5 — Capillary pressure curves in four flow units

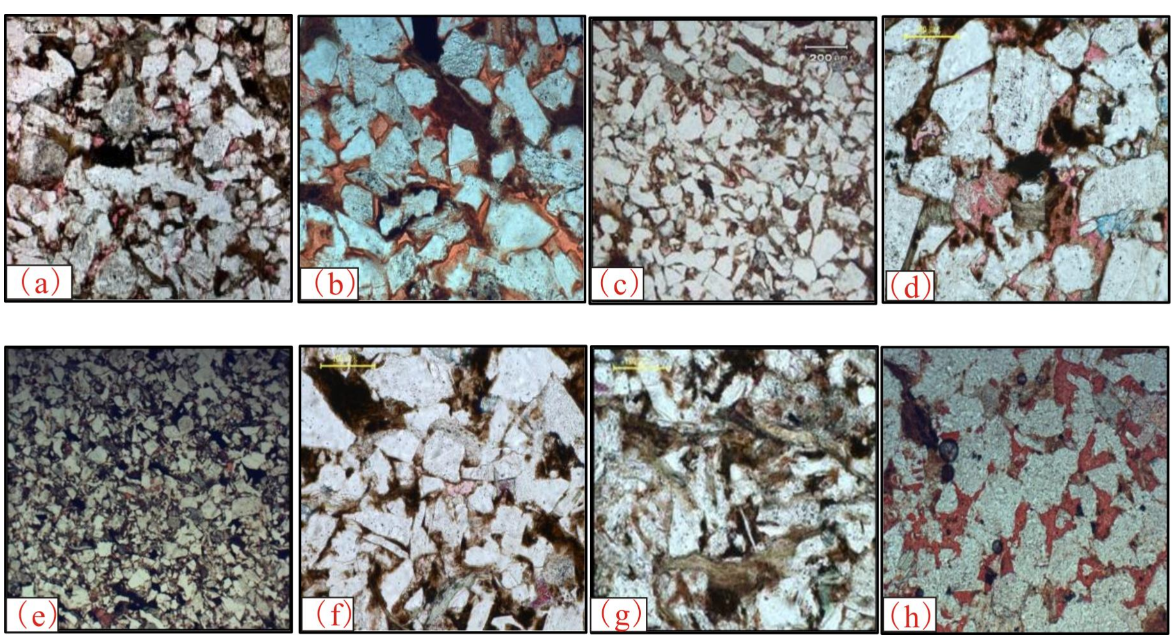

Fig. 4 — Micro-characteristics of Pore and Throat in the Chang 6 Reservoir of the Huaqing area

The flow unit type IV lithology is mainly siltstone, grain sorting is bad, Arris. The contact mode is line contact, illite cementation facies and carbonate cementation of dense phase is the main diagenesis of the reservoir diagenetic facies type (Figs 4-g, H). The flow units are mainly distributed between the distributary bay and the river side, with small distribution area and poor continuity.

Characteristics of capillary pressure curves in four types of flow units

By means of high pressure mercury injection test on reservoir samples in the study area, the curves of mercury injection curves and seepage parameters are obtained. It can be seen that the capillary pressure curves of the four types of flow units are obviously different from those of[16], as shown in Table 2 and Figure 5.

I type flow unit displacement pressure is low, the average is 0.63 MPa, the maximum mercury injection saturation and the average value is 86.7, the radius of the pore throat from 0.381～1.463 μm, the capillary pressure curve platform in the left lower position, hole roar coarse, sorting medium, low discharge pressure and large pore throat of reservoir.

a—syrosem arkose, white 168 well 2084.47 m; b—micro cracks, yuan 436,2082.47 m; c—feldspar sandstone, white 123 well, 2119.6 m; d—the development of intergranular pore and feldspar dissolved pores, white 34 well, 2260.21 m; e—secondary margin dominated, yuan 293 well, 2170.38 m; f—isolated distribution of intergranular pores,yuan 424 well, 1952.63 m; g—strong compaction, white 143 well, 1942.28 m; h—carbonate cementation, white 123 well, 2119.6 m

Class II flow unit displacement pressure medium, the average 1.46 MPa, the displacement pressure is higher than that of type I, but relatively lower compared to III and IV, the largest mercury saturation average value is 76.26%, the contribution of mercury large pore throat mainly concentrated in 0.22～0.67 μm. The capillary pressure curve platform is located at the right upper part of the curve of type I flow unit (see Table 2 and Fig. 5), better sorting, pore coarse, belongs to intermediate displacement pressure and pore throat.

Class III reservoir flow unit displacement pressure higher than the previous two, average 5.47 MPa, maximum mercury saturation average value is 67.6%, the contribution of mercury large pore throat is mainly distributed in the 0.09～0.563μm (see Table 2 and Fig. 5), capillary pressure curve platform short and high, class III reservoir flow unit pore throat is thinner, high flow resistance, it belongs to the low pore throat reservoir of middle displacement pressure.

The flow unit type IV reservoir displacement pressure is the highest, the average is 11.839 MPa, the radius of the pore throat is mainly concentrated during 0.01～0.12 μm (see Table 2 and Fig. 5), the capillary pressure curve is high and short, fine pore throat, poor sorting, belongs to high displacement pressure and pore throat poor reservoir.

Production dynamics analysis of four types of flow units

In the process of reservoir development, the characteristics of water flooding, water injection

Table 2 — Statistics of characteristic parameters with high pressure injection of four flow units in Chang 6 Reservoir

type	Well Number	porosity/ %	Permeability $\times10^{-3}\mu m^2$	Displacement pressure/MPa	Median pressure/MPa	Sorting coefficient	Maximum hole radius/μm	Median radius /μm	Maximum mercury saturation/%	Mercury withdrawal efficiency/%
I	G126	15.7	1.301	0.5509	1.6382	2.083	1.3349	0.4489	86.07	20.482
I	Y436	13.4	1.568	0.5021	1.1259	2.129	1.4647	06532	84.25	17.553
I	B224	9.4	0.439	0.7461	1.7534	1.841	0.9857	0.4194	86.7	25.537
II	Z79	8.39	0.179	1.9692	6.3889	1.309	0.3735	0.1151	74.532	29.396
II	B 34	10.8	0.289	1.0951	3.6901	1.647	0.6715	0.1993	76.26	22.475
II	Z 22	9.3	0.123	1.3082	3.1419	1.541	0.5621	0.2341	75.236	21.421
III	Z 71	6.8	0.028	5.5767	20.276	0.836	0.1319	0.0363	72.7	21.874
III	Y424	4.7	0.01	5.248	16.921	0.051	0.1401	0.0435	66.529	15.954
III	Z 76	7.3	0.049	5.6084	23.979	0.876	0.1311	0.0307	63.7	30.094
IV	B229	3.6	0.017	7.4622	0	0.617	0.0986	#	62.3	34.925
IV	B123	3.8	0.032	8.9873	0	0.500	0.0818	#	71.4	17.937
IV	B226	2.7	0.011	19.067	0	0.702	0.0386	#	12.9	19.302

Nnotes：In a fourth kind of flow unit, there is no median radius because there is no median pressure

Table 3 — Relationship between flow unit and oil production of Chang 6 Reservoir in Huaqing oilfield

Flow unit type	Oil well number	The number of statistical wells accounted for the total number of wells Percentage(%)	Average oil production(t)	Average water yield (m^3)
I	62	23	11.18	2.70
II	93	36	7.80	1.39
III	85	33	3.70	1.50
IV	18	7	1.19	0.00

efficiency and seepage characteristics are different among flow units. Therefore, different flow units should be developed in a targeted way.

I type flow unit: The reservoir rock physical properties are good, but the continuity is poor. Mostly potato like scattered distribution, and the distribution range is small. The sand distribution is stable and porn throat structure is similar in the same flow unit, so during the water flooding, the law of oil and water movement is the same, Waterline advancing evenly, quick effect, high yield, stable yield but short period; the appropriate injection production ratio should be adopted in the early stage of reservoir development, avoiding water channeling, earlier water breakthrough phenomenon. In the middle and late development stages, controlling water and increasing oil is the main production target.

II type flow unit: The reservoir rock physical property is good and the distribution area is big. It is advantageous to implement the large-scale water injection development technology. The mining degree is relatively high, it is the main production layer of the oil field development. The remaining oil is mainly affected by internal heterogeneity. In addition, the residual distribution in the edge is due to the layout of the injection well network. The well pattern layout and injection production parameters should be paid attention in developing uniform propulsion of control waterline.

III type flow unit: Poor reservoir property, strong heterogeneity and the area is large. The difficulty of exploitation, development level is low; therefore, large amounts of remaining oil are accumulated in the reservoir. It is the main target layer for oil field adjustment, tapping potential and increasing production.

IV type flow unit: The reservoir property and permeability is the worst; Many of them are located in the edges of sand bodies and cannot be used effectively. Most of them belong to ineffective reservoir[17,18].

As shown in Table 3, I, II types of flow units which accounted for 59% of the total development wells, and oil production average values of 11.18 and 7.80 t, are the main development units; The III flow unit accounted for 34% of the total number of wells, but the average yield is only 3.7 t, and the development is difficult. The flow unit has a good correlation with production dynamics, which indicates that the flow unit division is reasonable.

Conclusion

(1) Based on Q type clustering principle and SPSS statistical analysis software, The Huaqing area of Chang 6 reservoir flow units can be classified into four categories. The type I flow unit has good reservoir property, high flow zone index, coarse pore throat, low displacement pressure and the maximum value of mercury. In type II and III flow units, the characteristic parameters take second place. In type IV flow unit, the physical parameters are the worst and can be regarded as invalid reservoir.

(2) In I type flow unit, where waterflood development is quick, how to make the longer stable production period is the main development target. The II flow unit is the main layer of oilfield development, distributed largely in the oil field, the remaining oil is the main object of adjustment. The III flow unit has poor physical properties and low oil production. However, the III flow unit is the main purpose layer of oil further production because of the sand body thickness.

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