

Application of Flow Unit Study in Development Carbonate Reservoir

- A Case from Z Oilfield, Kazakhstan

Tao Ye^{1, a}, Sun Wei¹, Zheng Qiang^{2, b}

¹ State Key laboratory of continental Dynamics/ Department of Geology, Northwest University ,
Xi'an, China, 710069

² Research Institute of Exploration and Development, Xinjiang Oilfield Company, Petrochina,
Karamay, Xinjiang, 834000, china

^axataoye@126.com, ^b464568153@qq.com

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Abstract. For carbonate reservoirs with great heterogeneity, the flow unit study can provide fine anatomical sand-bodies and more accurately characterize the internal heterogeneities of sand-bodies. By using the mode of flow unit study, it can provide guidelines for the research and adjustment of remaining oil in the later stage of reservoir development. In this paper, a case of carbonate reservoir characteristics from Kazakhstan, by using theory of flow unit, combined with lithology, physical properties and its micro-pore structure for the characteristics of the carbonate reservoir of KT- I in Upper Carboniferous. By the corresponding cluster analysis method, the flow unit types, characteristics of the carbonate reservoir and the relationship between the flow unit index and the logging response are studied, and the method of logging response curve evaluation is realized. On basis for the classification of flow units, established a more reasonable permeability evaluation model, analyzed and expounded the different relationships between flow unit and capacity of reservoir. The application of guiding the arrangement of oil and gas wells, predicting the position with high productivity, quantitative analyzing reserve production conditions are included.

Introduction

The Z oilfield is located in the uplift belt on the eastern edge of Pre-Caspian Basin in the western part of the Republic of Kazakhstan. The oilfield structure is north-east striking brachyanticline with two high spots which divide the oilfield into south zone and north zone (Figure 1). In the area, the carboniferous system has carbonate platform facies, which was evolved from terrigenous debris continental shelf since early carboniferous epoch. The platform facies area is 50 km wide from east to west and 100 km long from south to north, with more than 1000m-thick carbonate rocks deposited.

In the target stratum, the Moscovian upper substage KT-I of the middle-upper carboniferous system presents frequently alternative deposition of mixed continental shelf, open marine platform facies and limited marine platform facies, and it is divided into sands group A, B and V and ten members from top to bottom. In terms of lithology, the stratum has bioclastic limestone mainly, followed by aplite-micritic dolomite, where the reservoir space includes dissolution pores and cavities with developed dissolution fractures and diagenetic fractures (Table 1). Based on the core measurement results, the reservoir stratum has porosity of 4.0 - 25.6%, an average porosity of 14.3%, a permeability range of 0.12 - 675.3 md and an average permeability of 44.5 md, which shows a reservoir stratum with low porosity, low permeability and strong heterogeneity.

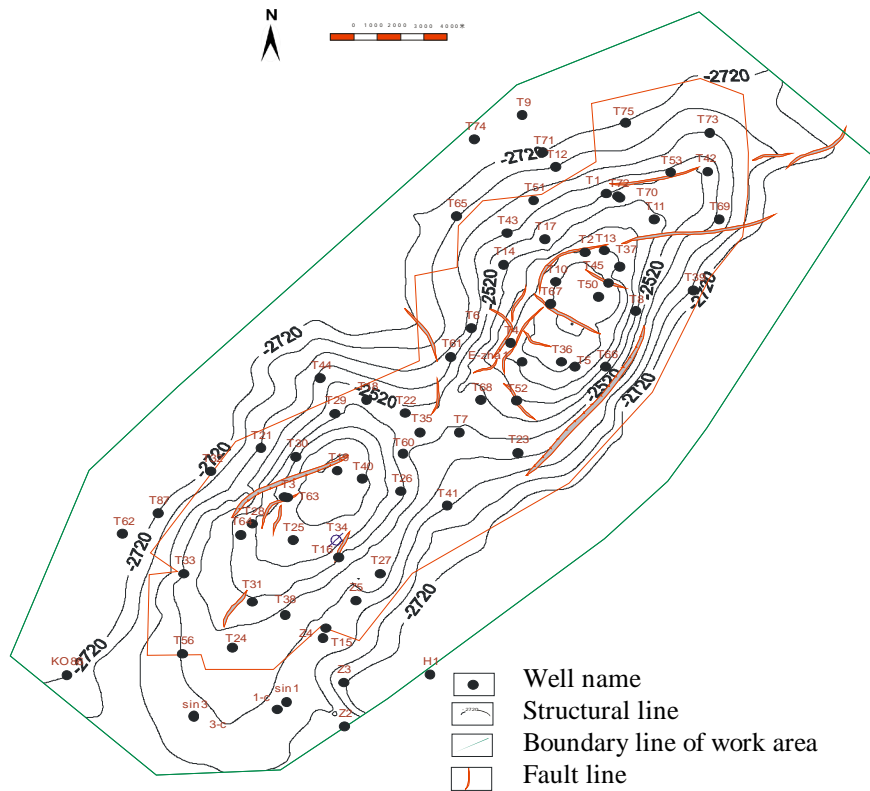


Figure 1 Collective development geology diagram of Z oilfield

Table 1 Pore space type distribution of KT-I horizon

Pore space	Percentage (%)	
	Dolomite	Limestone
Intercrystalline dissolution pores	36.3	10.2
Interparticle dissolution pores	18.0	28.0
Particle mould pores	8.8	2.2
Intragranular dissolution pores	0.7	31.1
Dorsal foramen	24.2	14.6
Shell wall pores	3.9	12.8
Dissolution pore	3.3	0.0
Fracture	4.8	0.9

Flow unit research

Flow unit theory

The reservoir flow unit refers to reservoir rocks that are laterally and vertically continuous and have the same flow characteristics parameters. Each flow unit represents a specific sedimentary environment and has a specific fluid flow characteristic. By referring to the concept of average hydrodynamic unit radius, and taking the pore space as a series of capillaries, Kozeny and Carmen obtained the relationship between porosity and permeability (Kozeny-Carman equation) based on Poissuille and Darcy laws:

$$k = \frac{j_e^3}{(1-j_e)^2} \left[\frac{1}{F_s t^2 S_{gv}^2} \right] \quad (1)$$

where, k is permeability (mm^2), f_e is effective porosity and decimal, F_s is pore geometry index, S_{gv} is particle surface area of unit particle volume, and t is curvature of flow path.

If flow zone index K_{FZI} and reservoir quality index H_{RQI} are defined as:

$$K_{FZI} = \frac{1}{\sqrt{F_s t S_{gv}}} = 0.0314 \left(\frac{1-j_e}{j_e} \right) \sqrt{\frac{k}{j_e}} \quad (2)$$

$$H_{RQI} = \sqrt{\frac{k}{j_e}} \quad (3)$$

and the ratio of pore volume to particle volume is defined as:

$$j_z = \frac{j_e}{1-j_e} \quad (4)$$

Then, formula (1) is converted to

$$\lg H_{RQI} = \lg j_z + \lg K_{FZI} \quad (5)$$

According to the double logarithmic coordinate graphs of the parameters H_{RQI} and j_z , sample points with similar K_{FZI} values will be distributed on a straight line with a slope of 1, and these with different K_{FZI} values will be distributed on other parallel lines. The sample points on the same straight line have similar pore throat characteristics and thus can constitute a flow unit.

Flow unit division

The flow unit division methods mainly include clustering analysis, neural network, gray correlation, fuzzy optimization, etc. In this study, the parameters K_{FZI} , H_{RQI} and j_z are gained according to physical property analysis data of 174 sample points after core location treatment, and these parameters are subject to Q-type clustering analysis and K-Means analysis to obtain the average value K_{FZI} of 6 types of flow units. Based on H_{RQI} - j_z double logarithmic crossplot drawn according to the average value K_{FZI} of each flow unit, 6 types of flow units have good separability (Figure 2).

By fully considering reservoir lithology, physical properties and micro-pore structural characteristics, the division limits of 6 types of flow units are determined on the basis of clustering analysis:

Class I flow unit ($18 \leq K_{FZI} < 25$): It is featured by pore throat median radius R_{50} of not less than 5.0 μm , intensively distributed coarse pores and large throats, good sorting of pore throats, low displacement pressure of the reservoir (less than 0.04 MPa), porosity of more than 16% and permeability of more than 100 mD. In terms of lithology, this unit is dominated by biolithite limestone and dolomite. In this unit, the reservoir space mainly includes primary pores, intergranular dissolution pores and cavities with developed microfractures and good displacement efficiency.

Class II flow unit ($10 \leq K_{FZI} < 18$): It is featured by pore throat median radius R_{50} between 1.0 μm (including 1.0 μm) and 5.0 μm , coarse pores and medium throats and reservoir displacement pressure of being generally 0.04 - 0.09 MPa. In terms of lithology, this unit is dominated by dolomite, with porosity distribution range of 10% - 18% and permeability distribution range of 20 mD - 100 mD. In this unit, the reservoir space mainly includes intergranular dissolution pores and cavities with developed microfractures, the maximum mercury injection saturation is smaller than that of Class I flow unit, and the displacement efficiency is moderate.

Class III flow unit ($7 \leq K_{FZI} < 10$): It is featured by pore throat median radius R_{50} between 0.2 μm (including 0.2 μm) and 1.0 μm , obvious medium-fine pores and medium throats, displacement pressure

of 0.1596 MPa, porosity distribution range of 7% - 15% and permeability distribution range of 10 mD – 20 mD. In addition, intergranular pores and dissolution pores are not frequently observed, and microfractures are developed.

Class IV flow unit ($2 \leq K_{FZI} < 7$): It is featured by pore throat median radius R_{50} between 0.05 μm (including 0.05 μm) and 0.2 μm , good sorting, obvious medium-fine pores and small throat pores, displacement pressure of 0.1955 MPa, porosity distribution range of 5% - 12% and permeability distribution range of 1 mD – 10 mD. In addition, microfractures are not developed and connectivity among pores is poor.

Class V flow unit ($1 \leq K_{FZI} < 2$) and Class VI flow unit ($K_{FZI} < 1$) are dense stratus, with pore throat median radius R_{50} of less than 0.05 μm , pore throats with obvious micro-ultramicropores and displacement pressure of more than 100 MPa. In terms of lithology, the two units are dominated by mudstone and dense limestone.

In order to classify reservoirs at non-coring intervals by flow unit, it is necessary to establish a relation model of logging data and flow unit index. In this study, based on single correlation analysis of K_{FZI} , H_{RQI} , j_z and logging response, and taking combined parameters of corrected sensitive K_{FZI} interval transit time log and depth detection resistivity log as variables, the multi-parameter fitting equation of K_{FZI} flow zone indicator is established as follows:

$$K_{FZI} = -2.36 + 4.26 \times \lg(R_i) - 1.17 \times \lg(D_i) \quad (6)$$

Fitting correlation coefficient $R = 0.616$, sample points $N = 283$. Based on flow zone indicators of the above 6 types of flow units, flow units and respective types of the study area KT-I reservoir can be determined separately.

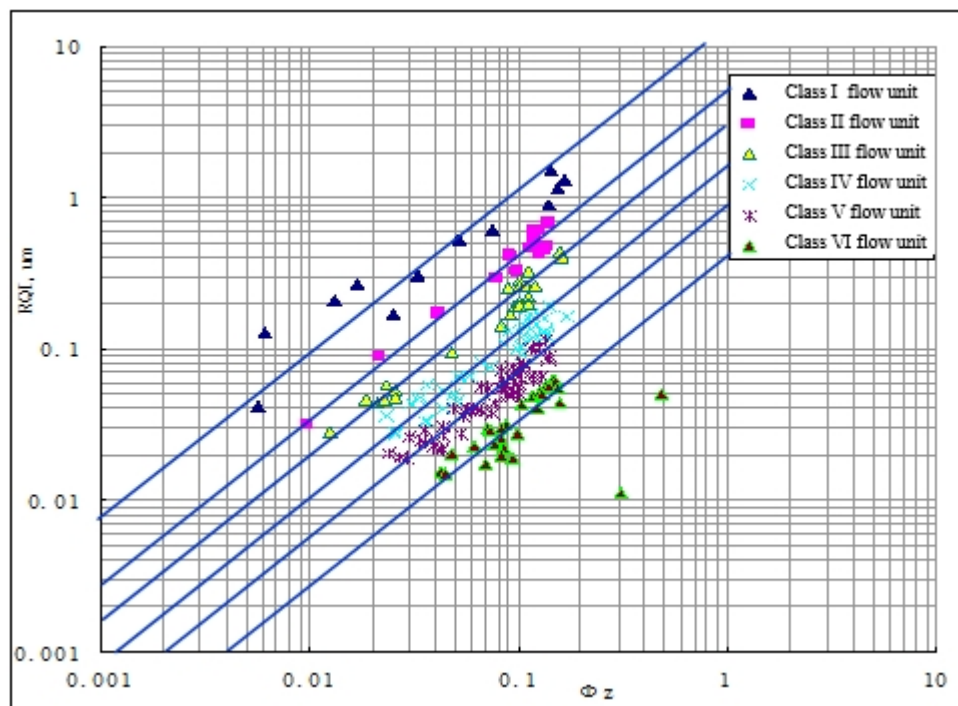


Figure 2 $H_{RQI} - j_z$ cross-plot of cored well in KT-I horizon

Application of flow unit

Establishment of permeability interpretation model

Based on flow unit division results, porosity-permeability relation model of different types of flow units can be established (Figure 3). By contrastive analysis of porosity-permeability relation calculation results of 174 samples across this area, porosity-permeability relation of reservoir cores classified by flow unit is obviously better than that of unclassified reservoir cores (Table 2). The model can reflect the permeability distribution rule under different deposition conditions, which reduces impact on permeability calculation results due to heterogeneity of carbonate reservoir and can obtain a permeability model with high precision.

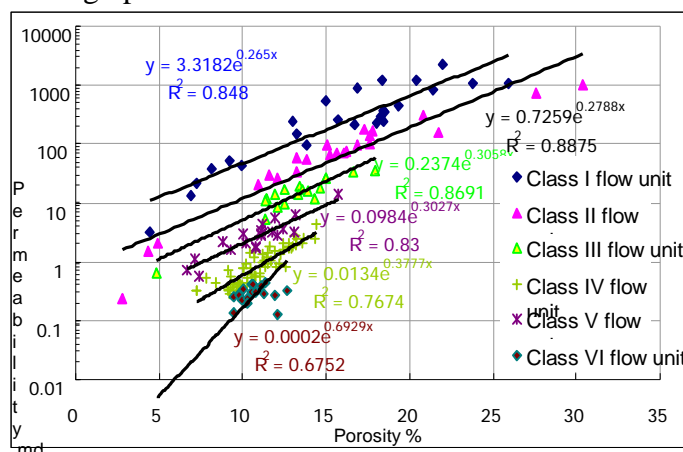


Figure 3 Permeability model based on flow unit

Table 2 Porosity-permeability relation established according to flow unit

Flow unit	Sample	Permeability interpretation model	Correlation coefficient
Class I	28	$K = 3.31828 \times e^{0.265 \times j}$	0.84
Class II	24	$K = 0.7259 \times e^{0.2788 \times j}$	0.89
Class III	20	$K = 0.2374 \times e^{0.3058 \times j}$	0.86
Class IV	20	$K = 0.0984 \times e^{0.3027 \times j}$	0.83
Class V	60	$K = 0.0134 \times e^{0.3777 \times j}$	0.76
Class VI	22	$K = 0.0002 \times e^{0.6929 \times j}$	0.67
Area	174	$K = 0.2513 \times e^{0.2777 \times j}$	0.48

Prediction of reservoir properties

According to the formula (6), flow zone indicator of corresponding layer point is calculated. Combined with reservoir structure and seepage barrier analysis, spatial distribution of flow units in the connected body is identified. In this area, Class I and II flow units, as good oil and gas reservoir, are vertically distributed on members A_1^1 , A_2^1 , A_2^2 , A_3^1 and B_1^2 and show good plane connectivity (Figure 4); Class III and IV flow units, as poor oil and gas reservoir, are mainly distributed on each member of B_2 , and irregularly distributed on the plane in the form of strips and tongues; Class V and VI flow units are mainly distributed on members A_3^2 and B_2^3 , and distributed sporadically on the plane as non-seepage layer.

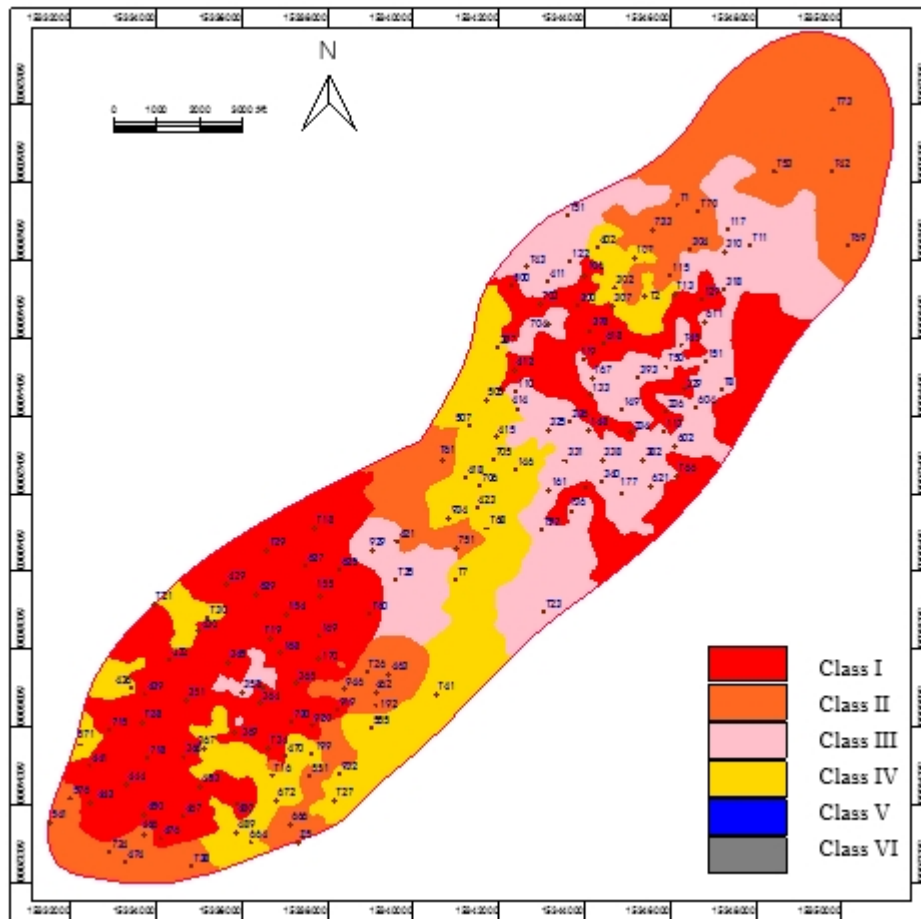


Figure 4 Flow unit plane distribution of member A_1^1 of KT-I horizon

Oilfield development guidance

(1) Evaluation of oil well production capacity. The plane distribution characteristics of reservoirs can be divided into three types based on initial well productivity, effective thickness and weighted average permeability calculated according to flow unit. Class I reservoir corresponds to Class I flow unit reservoir bed with high and stable yield, accounting for 16.8% of total wells. Class II reservoir mainly correspond to Class II and III flow unit reservoir beds with high initial productivity but poor stable yield effect compared with Class I reservoir, accounting for 25.3% of total wells. Class III reservoir includes Class III and IV flow unit reservoir beds with low initial productivity and poor stable yield effect, accounting for 57.9% of total wells (Figure 5, Table 3).

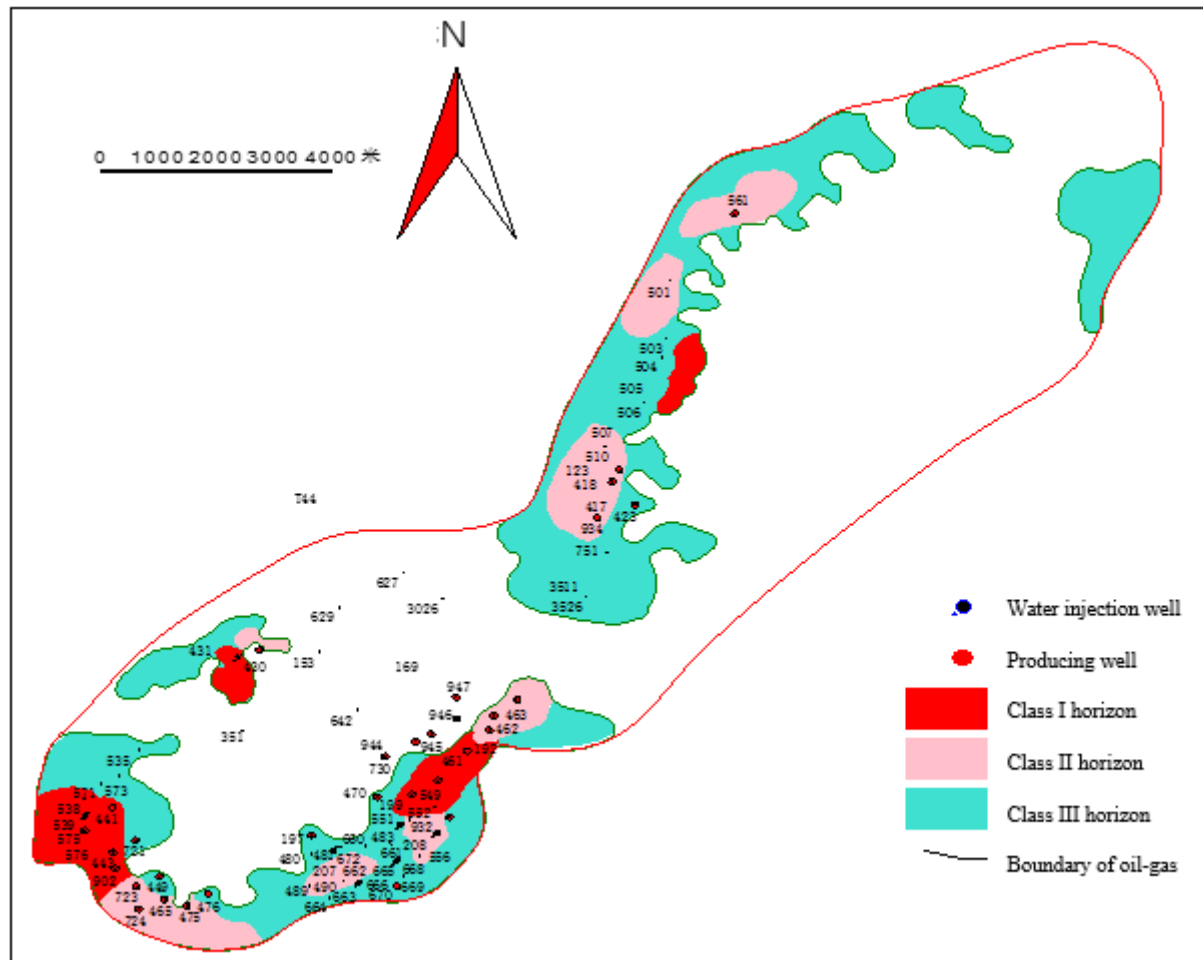


Figure 5 Reservoir type plane distribution of KT-I A horizon

Table 3 Evaluation of reservoir productivity of restricted flow unit

Reservoir type	Flow unit	Effective thickness (m)	Average porosity (%)	Average permeability (Md)	Initial productivity (t/d)	Percentage (%)
Class I reservoir	I	10.5	10.2	63.8	>30	16.8
Class II reservoir	II,III	8.7	8.9	15.2	10-30	25.3
Class III reservoir	III,IV	6.8	8.2	2.7	<10	57.9

(2) Qualitative analysis of reserve utilization. Different types of flow units have different development effects in the development process due to different reservoir quality. In the flooded expansion area, reserves flow along Class I and II flow units with good physical activity and strong flowability, and highly seepage channel can be formed easily. However, remaining oil enrichment area is formed from such channels due to relatively low submerged degree. Therefore, plane remaining oil enrichment area is mainly distributed in the edge of Class I and II flow units and in Class III and IV flow units.

According to the plane distribution characteristics of reservoir flow unit and reservoir classification, it was proposed to deploy 7 step-out wells in the south of layer A at the end of 2011, of which well 760 has been drilled completely and can produce oil 34 t/d. It is predicted that the place 510m from the

southwest of well 462 own Class II flow unit and Class I reservoir, which meet actual production conditions.

Conclusions

- (1) Based on comprehensive geological research and internal structural characteristics of carbonate reservoirs, it is necessary to carry out the research of flow unit, including reasonably division of reservoirs as well as prediction of reservoir distribution and properties.
- (2) The permeability interpretation model established by the flow unit reduces the impact on permeability due to the heterogeneity of carbonate reservoir, thus improving the accuracy of the permeability model of the pore type carbonate reservoir.
- (3) Flow unit research can be used for production capacity evaluation and remaining oil distribution prediction, or guide deployment and adjustment of oil and water wells as one of reserve utilization means.

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