Ecology, Pollution and Environmental science: Open Access (EEO)

Research Article

The Low-permeability-layers of Dolomite Reservoir and Its Influence on Remaining Oil Distribution

Peng Cao[1,2*], Shaoying Chang[1,2], Zhanfeng Qiao[1,2], Chuanrui Dai[1,2], Jiangli Liu[1,2]

[1]PetroChina Hangzhou Research Institute of Geology, Hangzhou 310023, China

[2] Key Laboratory of Carbonate Reservoir, CNPC, Hangzhou 310023, China

Abstract

The high water-production stage has started in the YM dolomite reservoir. It is found that there are many thin low-permeability layers in the formation and affect the fluid flow. This paper presents a method, which characterizes the thin low-permeability layer. The method takes into consideration that the outcrop research, core, well log, porosity and permeability testing. The main controlling factors that affect the heterogeneity are identified by geological statistical knowledge. The approach combines with well logging and seismic inversion technology, quantitative study distribution of low-permeability layers. At the same time, the reservoir numerical simulation sensitivity analysis is a good job. The results show that the thin low-permeability layers of the dolomite reservoir is closely related to lithology. The low-permeability layers developed at the bottom of the sedimentary cycle are mainly putty crystal dolomite and powder crystal dolomite, permeability is less than 0.1mD. And the good formation is mainly developed at the top of the sedimentary cycle, fine-grained dolomite is the most lithofacies, and the permeability is between 8mD~10mD. Finally, there are 6 low-permeability layers in the YMX dolomite reservoir. And the static and dynamic model could good match the wells and oil field history..

Keywords: *Dolomite Reservoir; Low-permeability-layers; Characterization; Heterogeneity; Remaining oil*

Introduction

Reservoir characterization of reservoir heterogeneity is the key point of reservoir description. Heterogeneity has created the current hydrocarbon accumulation, and it has also directly affected the fluid migration law. It has a direct impact on the distribution of remaining oil in the reservoir development stage.

At present, scholars have studied the geological factors affecting the fluid flow of reservoirs, such as interlayers and low-permeability zones [1, 2]. The research mainly focuses on the genetic, classifications, and the impact on reservoir development and seepage characteristics [3-8]. Li Chuanliang [9,10] successively presented the formula for predicting water breakthrough time in oil wells with barriers and semi-permeable barriers in bottom water reservoirs. Studies have shown that low-permeability or impermeable barrier have a large impact on the water breakthrough time of individual wells, and it also affects the remaining oil distribution characteristics of the reservoir.

The YMX buried hill dolomite reservoirs in the Tarim Basin have entered the stage of high water cut development. The characteristics of fluid flow in the reservoir development stage and the remaining oil distribution characteristics are currently urgent problems to be solved. Through five years of research, the project team preliminarily confirmed the existence of "low-permeability-layers" in this type of reservoir, which is similar to the "semi-permeable barrier [10] proposed by Li Chuanliang, and affects fluid flow law and remaining oil distribution characteristics in the reservoir production stage.

The research team began with the field geological outcrop research, combined with the single well and the comparison characteristics between wells, identified the main controlling factors of the low-permeability-layers, and used the thin-layer seismic inversion technique to perform quantitative tracking. At the same time, combined with the sensitivity analysis, it has been clear about the control of the low-permeability-layers in the fluid transport in the reservoir. And a fine geological model and a reservoir numerical model were established.

Description of Low-permeability-layers

Outcrop

The outcrop of Penglaiba Formation located in the Bachu, Tarim Basin. Three geological sections were selected for the research. The study shows that the dolomite reservoir has strong heterogeneity in the vertical direction and is composed of several shallowing-upward sequence. The upper part of the shallow high-frequency sequence is mainly putty crystal dolomite and powder crystal dolomite.

And the upper part is a coarse-grained deposit under high-energy environment. The lithology is mainly fine-medium dolomite.

It drilled 137 rock samples in the outcrop, and 52 rocks were selected to test porosity and permeability characteristics. Physical property analysis shows that the porosity of putty crystal dolomite is mainly distributed between 1.88~2.41% and the permeability is mainly distributed between 0.01~0.09mD. The average porosity is 2%, and permeability is 0.05mD. The porosity of power crystal dolomite is mainly distributed between 2.48~4.23% and the permeability is mainly distributed between 0.02~1.17mD. The average porosity is 3.19% and permeability is 0.41mD. The porosity of fine-medium dolomite is mainly distributed between 4.28-5.03% and the permeability is mainly distributed between 0.12-1.29mD. The average porosity is 4.65% and permeability is 0.46mD. The porosity of medium-coarse dolomite is

Corresponding author: Peng Cao, PetroChina Hangzhou Research Institute of Geology, no.920 xixi road, Hangzhou, Zhejiang, 310023, China, Tel: 15068899302; Fax: 15068899302; E-mail: caop_hz@petrochina.com.cn

Received: May 10, 2018; **Accepted:** May 21, 2018; **Published:** May 24, 2018

mainly distributed between4.17-4.71% and the permeability is mainly distributed between 0.18-0.51mD. The average porosity is 4.45% and permeability is 0.35mD, as shown in Table 1. The results show that the average permeability of putty crystal dolomite is only 0.05mD without the effect of fractures, which is much lower than the average permeability of fine-medium dolomite.

The three measured profiles used in this study were located at a distance of 330m, where profile 1 and profile 2 were 150m apart, and profile 2 and profile 3 were 180m apart. There are three obvious marker beds in the lithofacies profile. The marker bed 1 and 3 are putty crystal dolomite and powder crystal dolomite. The marker bed 2 is a limestone layer with a thickness of about 30cm. Four sets of high-frequency cycle control were identified. The upper part of the upward shallow sequence is mainly putty crystal dolomite, and the permeability is mainly distributed in the range of 0.01 to 0.09mD. It is a low-permeability-layers with stable and stable distribution controlled by the lithofacies. The layers are developed and laterally distributed, as shown in Figure 1.

The outcrop studies indicate that the heterogeneity of the reservoir is mainly controlled by sedimentation and diagenesis, and the lithofacies characteristics play a major role in controlling the permeability distribution of the reservoir.

Characteristic of Wells

With reference to the results of field outcrops, a quantitative well-identification method [11] was used to finely identify the structural components of rocks in the single well of the YMX dolomite area. In the study, it divided the main distribution areas of fine-medium dolomite and medium-coarse dolomite into sweet reservoirs. And the main distribution areas of putty crystal dolomite and powder crystal dolomite were divided into two types based on the longitudinal thickness. That is, a layer with a thickness of about 10 m or more is defined as a low-permeability zone (mainly controlled by depositional cycles), and a layer with a thickness less than 10 m (most of which is less than 3 m) is defined as a low-permeability-layer (mainly controlled by lithology).

Table 1: Dolomite porosity and permeability of Penglaiba Formation in Bachu

Lithology	Porosity / %				Permeability / mD			
	Max	Min	Average	Main distribution range	Max	Min	Average	Main distribution range
putty crystal dolomite	1.22	2.99	2.11	1.88~2.41	0	0.36	0.06	0.01~0.09
powder crystal dolomite	1.79	4.75	3.19	2.48~4.23	0	2.17	0.41	0.02~1.17
fine-medium dolomite	3.93	5.81	4.65	4.28~5.03	0.05	1.9	0.46	0.12~1.29
medium-coarse dolomite	4.17	4.72	4.45	4.17~4.71	0.01	1.02	0.35	0.18~0.51

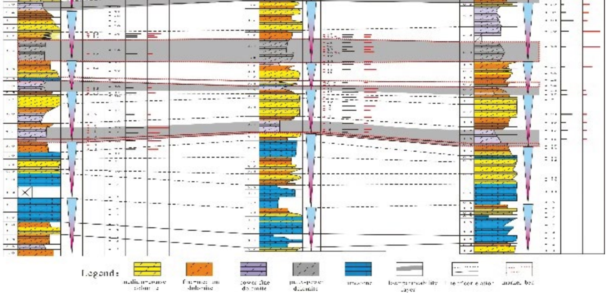


Figure 1: The lithofacies model of Penglaiba Formation in Bachu outcrops.

For a detailed analysis of 11 wells in the dolomite area, the thickness of the low-permeability zone is mainly distributed between 9.2 and 17.9m, and the thickness of low-permeability-layer is mainly distributed between 0.7 and 3.5m. Due to the big dip angle of the YMX buried hill hydrocarbon reservoir, mainly horizontal wells, and completion on the buried hill, resulting in incomplete formations encountered by single wells. The team adopted wells-seismic combination method for calculating true thickness of strata [12,13], and integrated the location and depth of each well drilled, splice and establish the complete stratigraphic sequences of Ordovician Penglaiba Formation in YMX Oilfield. The heterogeneity of the reservoir provides guidance for building up the stratigraphic framework.

The study showed that the lithology of low-permeability zone is dominated by putty-powder crystal dolomite with contents ranging from 60.6% to 97.0%, forming low-permeability-layer, as shown in Table 2, which is also a barrier to fluid flow.

According to the actual drilling characteristics of the YMX dolomite area, single wells can be used to accurately identify the rock structural components in the vertical direction. Because the big dip angle, it is impossible to laterally divide and contrast the low-permeability zones between wells. The research team used the high-precision thin layer reflection coefficient inversion technique [15], which decomposed the “odd and “even” reflection coefficient pair to improve the resolution of the conventional section, thereby identifying the space distribution characteristics of the deep thin layer. The result of seismic interpretation has a good corresponding relationship with the single well’s characteristics. It identified 6 low-permeability zones in the formation, and the data can be applied to constrain the establishment of a formation frame model.

Percolation Characteristics of Low-permeability-layers

Originating from the production contradiction of a development well in the bottom water reservoir of the Tarim Basin that has low water avoidance and a long production period without water, Li Chuanliang proposed the concept of “baffle” as early as in 1997 [9] and gave the prediction formula for water breakthrough time in a single well of the type reservoir. In 2001, Li Chuanliang [10] put forward the concept of “semipermeable partition” and unified the water breakthrough time prediction formula with the “non-baffle” conditions.

The low-permeability-layer of this type of buried-hill dolomite reservoir resembles a “semipermeable partition”. Although it cannot change the fluid migration path, it can delay the fluid flow rate under certain conditions. As shown in Figure 2a, for a reservoir without low-permeability-layers, the single-well bottom water coning route is ①→②→③, and the remaining oil after the high-water cut is mainly distributed in the area between ③ to ④. When the low-permeability-layers are existence and stable development in the formation, shown in Figure 2b. The bottom water coning route may be converted to ①→⑤→⑥ due to the presence of low-permeability-layer, and the remaining oil is mainly distributed between ⑥ to ④ after the oil well enters the high water cut stage. The low-permeability-layers better control the remaining oil between ⑥ and ④ in a certain period of time, and this area is also an important direction for future production. In

Table 2: The putty-powder crystal dolomite content in different single well.

Zone	Putty-powder crystal dolomite content / %	Well
Low-permeability zone1	78.6	YMX1-H9
Low-permeability zone2	75	YMX1-H4
Low-permeability zone3	68	YMX1
Low-permeability zone4	60.6	YMX1
Low-permeability zone5	66	YMX1-H3
Low-permeability zone6	97	YMX1-H5

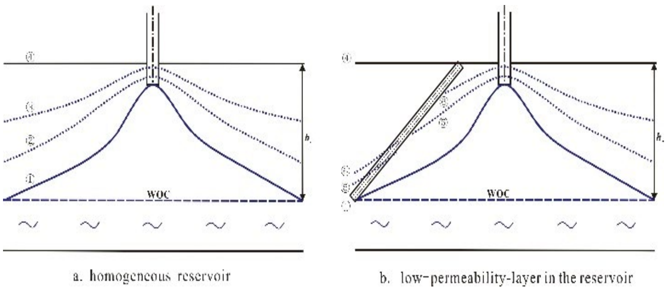


Figure 2: Reservoir bottom water coning diagram.

the figure, WOC stands for the oil-water interface and h_ofor the oil layer thickness.

In view of the limited data on the permeability interpretation of the reservoirs in the area, especially the low-permeability-layer reservoirs. It is difficult to determine the development characteristics and physical characteristics of the low-permeability-layer, acts as a barrier in the production, by the basic methods of percolation mechanics or reservoir engineering. Using the reservoir geological model and numerical simulation techniques to quantify the control of low-permeability-layers on the distribution of remaining oil.

Sensitivity Analysis

According to the reservoir geology and fluid physical characteristics of the YM dolomite buried hill reservoir [16], a mechanism model was established. The values of parameters can be found in [14]. This study used Petrel E&P Software Platform to perform sensitivity analysis from four aspects: low-permeability-layer's permeability, sweet reservoir permeability, low-permeability-layer's thickness, and low-permeability-layer's pattern.

According to the actual characteristics of the reservoir, the sweet reservoir permeability (K_h) is selected to be 500mD, the low-permeability-layer thickness is 1m and the distribution is stable. And compare the control of remaining oil distribution in the Region1 under the condition of different permeability of the low-permeability-layer.

In order to facilitate the study and uniform measurement, the research set the economic limit conditions for the oil well's water cut of 90%. The water cut is according to the actual production characteristics of the single well and could provide early warning of the next step. When the water cut reach to 90%, it can be considered for the optimization of old wells, on the other hand, sidetracking and other measures can be considered to exploit the potential of the surrounding remaining oil enrichment zone. The following text refers to the sweet reservoir permeability expressed in K_h, Permeability of low-permeability-layer is denoted by K_l.

The low-permeability layer exists in various forms and patterns in the subsurface [17]. The low-permeability-layer develops mainly along the formation.

There is a discontinuity in the development of the low-permeability-layer, and six types of pattern characteristics are designed. Type I: continuous and stable distribution; Type II: "open " near the oil-water interface; Type III: "open " in the middle of the reservoir; Type IV: "open " on the top of the reservoir, Type V: There are two sets of low-permeability-layers, with "open "/under "open" combination; Type VI: There are two sets of low-permeability-layers, the next "open " / upper "open" combination. The opening in the middle of the low-permeability-layer is called "open ", and the design of the "open " is 40m and 20m, respectively, as shown in Figure 3.

Research indicates as shown in Figure 4:

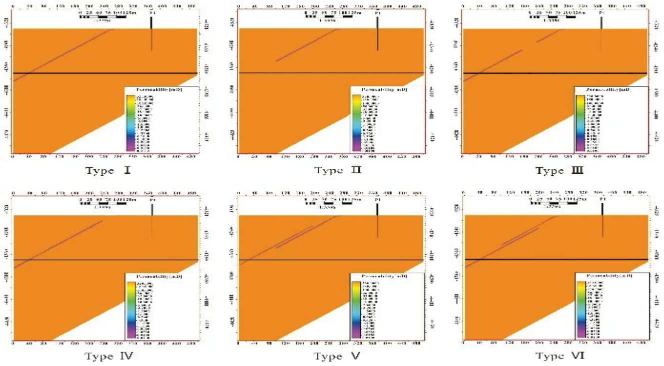
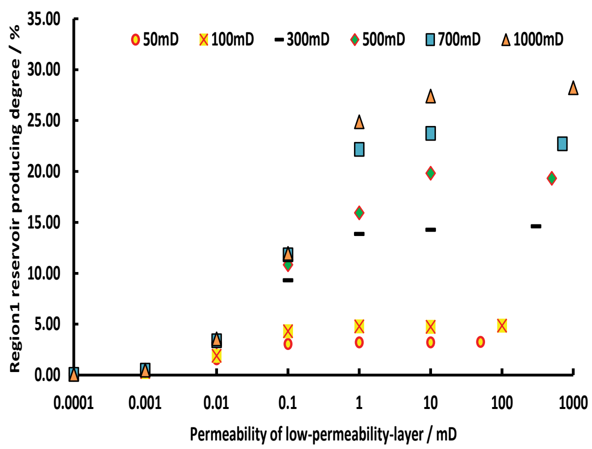
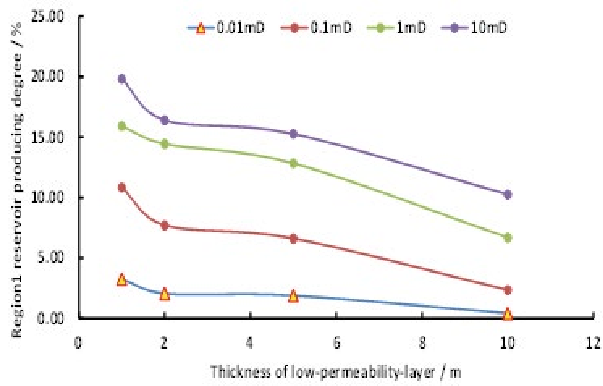


Figure 3: The design classification figure of low-permeability-layer's attitude.





1) The low-permeability-layer will not change the fluid's migration path but can delay the fluid's migration speed in a certain production period and can control the remaining oil distribution under certain conditions.

2) Under the condition that K_l is less than 0.01mD, reserve utilization of Region1 is less than 5%, and the remaining oil of Region1 can be controlled better. The original well sidetrack drilling is a good measure to product the remaining oil in the reservoir. When K_h is less than 100mD, the reservoir producing degree is limited, and the reservoir producing degree of Region1 is kept within 5%. The remaining oil can be produced by infilling well pattern or sidetracking. When K_h is greater than 500mD, K_l is greater than 1mD, the reservoir producing degree is more than 15%, and the remaining oil in the surrounding area can be used through original well's measures.

3) Under the same conditions, the remaining oil in the Region1 has a small increase with the increase of the thickness of the low-

permeability-layer.

4) Different low-permeability-layers have different effects on the distribution of remaining oils due to their morphology and style characteristics. Under the same conditions, if there is only one low-permeability-layer, the degree of control of the remaining oil is Type I> Type II> Type III> Type IV. If there are two staggered low-permeability-layers, the degree of control over the remaining oil is Type V> Type VI; under the same conditions, the smaller the size of the "open" of the low-permeability-layer, the higher the degree of control over the remaining oil.

Static Model

Matrix model

Selecting the sequential indicator simulation method, multi-attribute fusion data was used to obtain plane and vertical variograms to control stochastic simulations, and synergy was used to identify low-permeability-layers. And then lithofacies model was built. The lithology in the 50m below the buried hill surface is mainly fine-medium crystal dolomite, gradually thinning from the southwest to the northeast. And deeper then 50m below the buried hill surface, it is dominated by powder-fine dolomite, with a small amount of crystalline dolomite. The vertical heterogeneity of the reservoir is strong, and the established lithofacies model is consistent with the geological features revealed during the development of oil and gas.

Based on the data analysis and the obtained variograms model, the simulating characteristics of single wells and the reservoir permeability model are used to simulate the porosity and permeability and refine each type of lithofacies according to the development characteristics of the lithofacies. And it controls establishment of porosity and permeability model, as shown in Table 3 and Figure 5.

Fracture Model

imaging logs, it is believed that the fractures in the study area are developed, with high angle joints as the main, and the crack surface is filled-semi-filled. The main distribution interval of fracture aperture in the dolomite area is 6.4~60.33μm.

There are a few fracture developed in the putty crystal and powder crystal dolomite, and the fracture aperture is about 0.1~10μm. The fracture aperture is about 10~100μm in the fine-medium dolomite. As shown in Table 4. The research shows that the development of micro-fractures is mainly to improve the seepage channels for fine-medium crystalline dolomite of sweet reservoirs.

Table 3: Dolomite porosity and permeability of Penglaiba Formation in wells.

Lithology	Porosity / %				Permeability / mD			
	Max	Min	Average	Main distribution range	Max	Min	Average	Main distribution range
putty crystal dolomite	1.22	2.99	1.98	1.88~2.41	0.01	0.36	0.06	0.01~0.09
powder crystal dolomite	1.79	4.75	3.19	2.48~4.23	0.01	2.17	0.41	0.02~1.17
fine-medium dolomite	3.93	5.81	4.65	4.28~5.03	0.05	1.9	1.46	0.12~1.29
medium-coarse dolomite	4.17	25.6	6.1	4.17~8.71	3.2	25.8	5.8	4.00~18.00

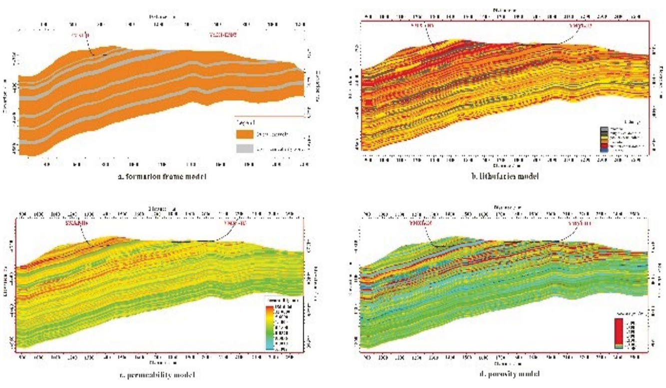


Figure 5: The wells profile of matrix permeability model.

Dynamic Model

Combined with the actual production well production dynamics and well test interpretation characteristics, the oil wells in the dolomite reservoirs all exhibit similar characteristics with the homogeneous reservoir. And the fracture mainly improve the flow speed of sweet formation on the production stage. So, it can be characterized by the characteristics of a homogeneous reservoir and the fluid flow law [14, 16].

Therefore, an equivalent media model is established, and the calculation mode of the attribute model is handled as Eq. (1).

Equivalent medium porosity and permeability model have a good coincidence with the well test interpretation, anastomosis rate of more than 92%, as shown in Table 5. And it also verify the correctness of the numerical model, can be used for the study of the remaining oil distribution characteristics.

Conclusion

It obtained the following four points of understanding by the dynamic evaluation of the YMX dolomite reservoir:

(1) Through the existence of the low-permeability-layer result

Table 4: The fracture development characteristics of wells.

Wells	Subfacies	Microfacies	Thickness / m	Fracture / numbers	Fracture density / numbers.m^{-1}
YMX	intraplatform shoal	fin-medium dolomite	15.5	14	0.9
	interbank sea	putty-powder dolomite	11	8	0.73
YMX1	intraplatform shoal	fin-medium dolomite	64.2	36	0.56
	interbank sea	putty-powder dolomite	28.4	3	0.11
	mud	mud	6	0	0
YMX2	intraplatform shoal	fin-medium dolomite	50	12	0.24
	interbank sea	putty-powder dolomite	30.1	7	0.23
	mud	mud	4.9	0	0
YMX1-H3DY	intraplatform shoal	fin-medium dolomite	66	19	0.29
	interbank sea	putty-powder dolomite	19	0	0
YMX1-5HDY	intraplatform shoal	fin-medium dolomite	31.7	7	0.22
	interbank sea	putty-powder dolomite	7.2	2	0.28
YMX1-H6	intraplatform shoal	fin-medium dolomite	293.7	220	0.75
	interbank sea	putty-powder dolomite	50.9	34	0.67

Table 5: Permeability comparison between geological model and test well.

Wells	Permeability gained through well test / mD	Model permeability / mD	k_{max}/k_{min}/%
YMX1	99.13	102.81	96.42
YMXC	494.95	458.62	92.66
YMX1-H3	861.13	817.67	94.95
YMX1-5H	62	64.22	96.54
YMX1-H6	665.16	644.95	96.96

in reservoir's heterogeneity in the YMX dolomitic reservoir. The development of the low-permeability zone was controlled by the depositional cycle, and the development of low-permeability-layer is controlled by lithology characteristics.

(2) The micro-fractures in dolomite reservoirs are mainly developed in fine-medium crystal dolomites. There is little development in mudstone dolomites, so the existence of micro-fractures expands the seepage of sweet reservoirs, while the mudstone dolomite-based low-permeability layer has limited permeability improvement effects.

(3) The existence of the low-permeability-layer in the reservoir has been implemented to differentiate the seepage flow of the reservoir fluid, resulting in the formation of a large amount of remaining oil, and clarifying the distribution of the remaining oil.

(4) Based on reservoir heterogeneity characterization, reservoir geological models and reservoir numerical models are established to quantify the remaining oil distribution scale and provide ideas for the development of oilfield development adjustment plans.

Equations

$$\phi_T = \phi_f + \phi_m - \phi_f \phi_m \approx \phi_f + \phi_m \quad (1)$$

$$K_T = K_f + K_m$$

$\varnothing_T$: equivalent porosity; $\varnothing_f$: fracture porosity; $\varnothing_m$: matrix porosity; K_T: equivalent permeability, mD; K_f: fracure permeability, mD; K_m: matrix permeability, mD.

References

1. ZHAO Xinzhi, ZHU Shengju (2012) Prediction of water breakthrough time for oil wells in low-permeability bottom water reservoirs with barrier[J]. *Petroleum Exploration and Development* 39: 471-474.
2. LIU Feng, HONG Jianwei, REN Jianhong, et al. (2014) Study on water Breakthrough time prediction for oil wells in low-permeability bottom water reservoirs with semi-permeable barrier [J]. *Drilling & Production Technology* 37: 51-53.
3. DENG Ya, GUO Rui, TIAN Zhongyuan, et al. (2016) Geologic features and genesis of the barriers and intercalations in carbonates: A case study of the Cretaceous Mishrif Formation, West Qurna oil field, Iraq [J]. *Petroleum Exploration and Development* 43: 136-144.
4. ZHAO Hong, LUO Xiaorong, XIAO Zhongyao, et al. (2014) Interlayer features and petroleum geology meaning of Donghe sandstones in the Hadson Oilfield [J]. *Natural Gas Geoscience* 25: 824-833.
5. XU Yin, XU Huaimin, GUO Chuntao, et al. (2012) Origin, Characteristics and Effects on Oilfield Development of Interlayer of Shore Sandstone Reservoir in Tazhong Area[J]. *Science & Technology Review* 30: 17-21.
6. ZHOU Guowen, TAN Chengqian, ZHENG Xiaowu, et al. (2006) Research on recognition of barrier/ interbed via logging in H Oilfield[J]. *Geophysical Prospecting for Petroleum* 45: 542-545.
7. Rahimpour-bonab H, Enayati-bidgoli AH, Navidtalab A, et al. (2014) Appraisal of intra reservoir barriers in the Permo-Triassic successions of the Central Persian Gulf, Offshore Iran[J]. *Geologica Acta* 12: 87-107.
8. TANG Renxuan (2003) Simulation of water coning performance and prediction of water breakthrough time in bottom-water reservoirs [J]. *Xinjiang Petroleum Geology* 24: 572-573.
9. LI Chuanliang (1997) Forecasting Formula for water breakthrough time in baffle based bottom water reservoir well[J]. *Petroleum Geology & Oilfield Development in Daqing* 16: 49-50.
10. LI Chuanliang (2001) Prediction formula for water breakthrough time of semipermeable partition bottom water reservoir [J]. *Petroleum Geology & Oilfield Development in Daqing* 20: 32-33.
11. LI Chang, GUO Qingxin, SHEN Anjiang, et al. (2013) A method of logging quantitative identification about rock texture component of carbonate rock and its application: ZL201310722539.3[P]. 2013–12–24.
12. Luo X., Zou W., Xiong R (2014) The application in calculation of the horizontal wells' true thicknesse -An example of Penglaiba Formation in the northern Tarim Basin[J]. *Advanced Manufacturing and Industrial Engineering* 1006-1007 (2014): 101-106.
13. Luo X, Dai C, Yan X (2014) Discussion on a new calculation method for missing true formation thickness-A case study from YMX Area in Northern Tarim Basin[J]. *Advances in Mechatronics and Control Engineering III* 678 (2014): 98-102.
14. CAO Peng, DAI Chuanrui, MA Hui, et al. (2017) Influence of Low-permeability Layers on Remaining Oil Distribution in Dolomite Reservoir[J]. *Journal of Southwest Petroleum University (Science & Technology Edition)* 39: 143-154.
15. XIONG Ran, YANG Cun, LUO Xianying, et al. (2015) Application of seismic sedimentology to prediction of interbeds in dolomite reservoir: A case study of Penglaiba Formation in Yingmai 32 block of Tarim Basin[J]. *Lithologic Reservoirs* 27: 116-120.
16. CAO Peng, ZHU Yongfeng, DAI Chuanrui, et al. (2016) Numerical simulation of immiscible nitrogen flooding for dolomite reservoirs with strong bottom water [J]. *Fault-Block Oil & Gas Field* 23: 202-205.
17. YIN Senlin, WU Shenghe, FENG Wenjie, et al. (2013) Patterns of inter-layers in the alluvial fan reservoirs: A case study on Triassic Lower Karamay Formation, Yizhong Area, Karamay Oilfield, NW China[J]. *Petroleum Exploration and Development* 40: 757-763.