Application of multivariate linear methods to the development of a stratified system in Block II of Area A

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Abstract: This study is a numerical simulation study of different stratigraphic development schemes for three encrypted well networks based on historical fitting by establishing a fine geological model for Block II of Area A. The relationship between reservoir physical parameters and recovery rates for different stratigraphic combinations is obtained by applying multiple linearity regression methods to guide the delineation of stratigraphic development sections in multi-layered non-homogeneous reservoirs.

Key words: multiple linearity; thin differential reservoirs; stratigraphic development; inter-stratigraphic conflicts.

1. Introduction

As the three cryptographic adjustments continue to be carried out in the Xingbei Development Zone, the proportion of thin and poor reservoirs in the output is gradually increasing. Due to the differences in the development and physical properties of the reservoir groups, some of the reservoirs are not effectively utilized and the degree of utilization is low, which affects the field development effect. As an effective method to reduce inter-stratigraphic interferences, stratigraphic development was applied to three encryption wells in Area B in 2012 and achieved good adjustment results. However, the optimal stratigraphic boundary and combination of stratigraphic systems for stratigraphic system development is not clear, and further research is needed to guide the adjustment of stratigraphic system development in subsequent blocks.

The reservoir up-return combination to accompany the stratigraphic development is unclear, and the most efficient up-return reservoir combination needs to be predicted.

2. Numerical simulation modeling

The geological model of the test area has a step length of $\Delta X=\Delta Y=10m$ in plan and is divided vertically into 97 sub-layers according to the sedimentary unit, for a total of 10.2 million nodes. The numerical model has a step length of $\Delta X=\Delta Y=30m$ in the plane, and is divided into 97 small layers according to the depositional units in the longitudinal direction, with a total number of 1.2 million nodes. The geological model and numerical model developed for the test area are shown in Figure 1.

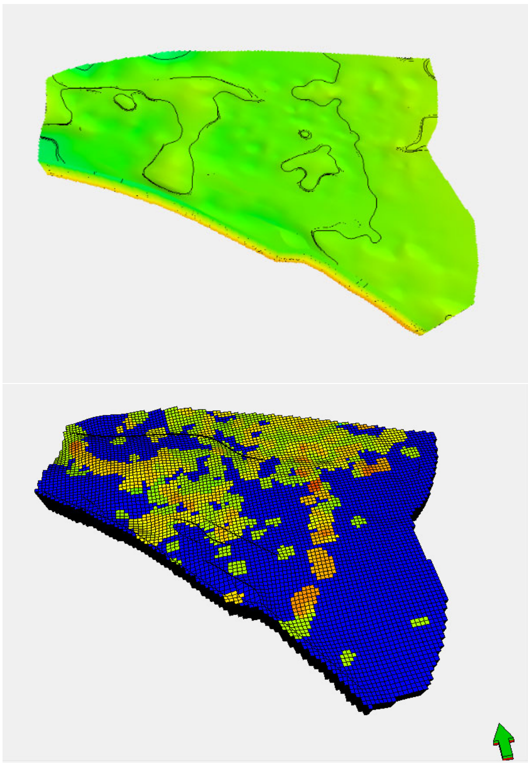

Figure 1 Geological and numerical model of the test area

3. Final recovery of different formations

The study of the technical boundaries of the first open section of the three encrypted wells requires consideration of the matching relationship between the three encrypted well networks and the existing well networks. Based on full consideration of the remaining oil distribution pattern under the existing well network conditions, mutual interference between different well networks, interpretation of water flooding in oil wells and other influencing factors such as oil and water well set losses, the first open hole section of the three encrypted wells was studied and different options for the development of the stratified system were developed (see Table 1), of which Option 1 was conventional injection. In order to obtain the relationship between formation properties and recovery rates, the development was completed when the water content in the first open section of each option reached 98% and the water content reached 98% again. Numerical simulations are used to predict the development effect of the different options, and on this basis the relationship between the development effect of the field and the physical properties of the reservoirs included in each option (thickness, reserve size, etc.) is investigated, and the technical limits of the reasonable stratification of the first open section of the three encrypted well networks are then obtained. The recovery rate of each scenario and its improvement over the recovery rate of the current well network are shown in Table 1, and its trend is shown in Figure 2.

Table 1 Comparison of recovery rates between different options

Program Number	First opening floor section	Recovery rate / %	Value added of recovery rate / %
Option 1	SⅡ5 and below	49.70	4.21
Option 2	SⅡ15and below	50.07	4.68
Option 3	SⅢ1 and below	50.55	5.16
Option 4	SⅢ4 and below	50.92	5.53
Option 5	SⅢ7 and below	51.31	5.92
Option 6	PⅠ4 and below	51.36	5.97
Option 7	PⅡ1 and below	50.91	5.52

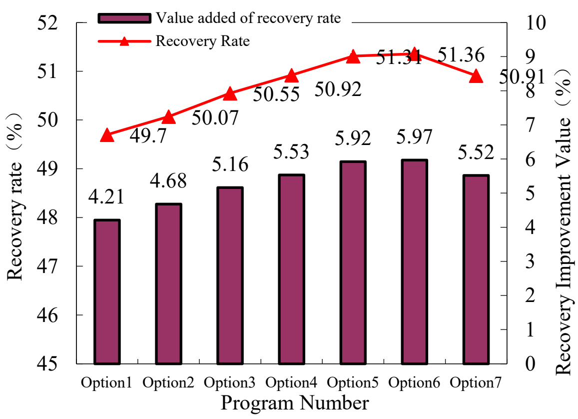

Figure 2 Comparative recovery curves between different options

4. Derivation of multivariate linear equations for recovery rates

In order to study the relationship between the stage recovery and the formation properties in the first open section and the upper return section, the mechanisms of recovery enhancement in different sections were considered separately, and the corresponding formation properties parameters in each section were calculated as shown in Tables 2 and 3.

Table 2 Reservoir properties for each option within the first open section

Program Number	Layer	oil layers /个	the coefficient of variation of permeability	the average formation pressures / MPa	stage recovery rate / %
Option 2	SⅡ15 and below	44	0.671	11.294	8.59
Option 3	SⅢ1 and below	36	0.635	11.431	8.95
Option 4	SⅢ4 and below	29	0.603	11.519	9.55
Option 5	SⅢ7 and below	24	0.583	11.585	10.02
Option 6	PⅠ4 and below	17	0.572	11.782	10.40
Option 7	PⅡ1 and below	11	0.556	11.913	10.64

Table 3 Physical properties of the reservoirs in each option within the upper return section

Option Number	Layer	oil layers /个	the coefficient of variation of permeability	stage recovery rate / %
Option 2	SⅡ15 and below	5	0.531	10.93
Option 3	SⅢ1 and below	13	0.561	10.83
Option 4	SⅢ4 and below	20	0.594	10.73
Option 5	SⅢ7 and below	25	0.619	10.48
Option 6	PⅠ4 and below	32	0.646	10.25
Option 7	PⅡ1 and below	38	0.685	9.98

4.1 Multiple linear regression of stage recovery within the first open stratigraphic section.

The relationship between the number of oil layers (X_1), the coefficient of variation of permeability (X_2), the average formation pressure (X_3) and the stage recovery rate (ΔR_1) are plotted separately in Figure 3.

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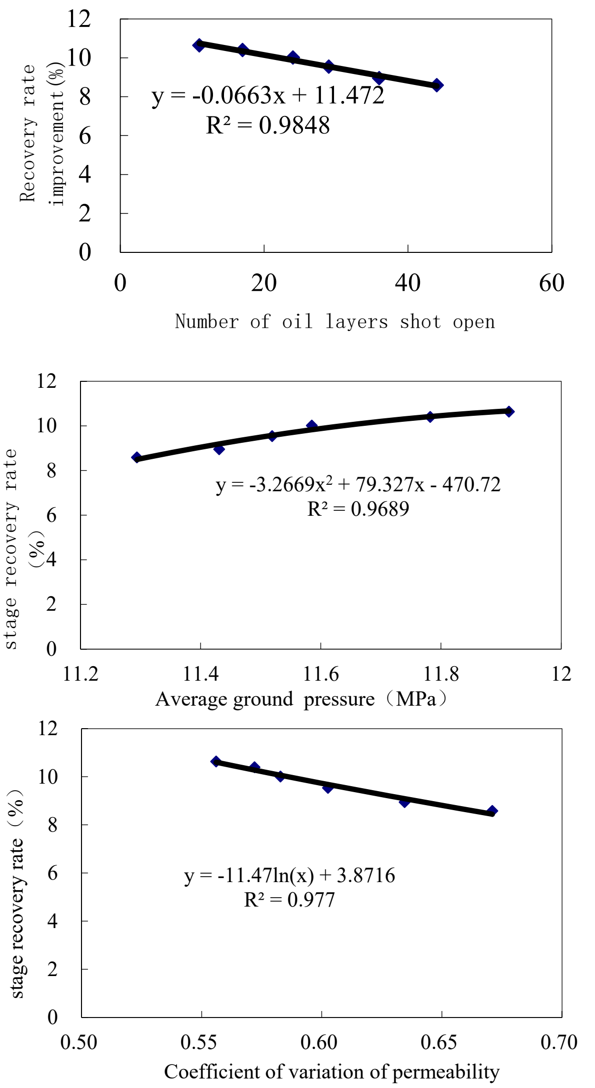

Figure 3 Formation physical properties versus stage recovery curve

Figure 3 shows that there is a good linear relationship between the number of oil layers and stage recovery, a good parabolic relationship between the average formation pressure and stage recovery, and a good logarithmic relationship between the coefficient of variation of permeability and stage recovery. Based on this, the above parameters were processed to obtain Table 4.

Table 4 Results of processing the physical parameters of the oil formation within the first open section

Option Number	Layer	oil layer X_1	the coefficient of variation of permeability ln (X_2)	the average formation pressures X_3^2	the average formation pressures X_3	stage recovery rate / %
Option 2	SII15and below	44	-0.40	127.55	11.29	8.59
Option 3	SIII1and below	36	-0.45	130.67	11.43	8.95
Option 4	SIII4and below	29	-0.51	132.69	11.52	9.55
Option 5	SIII7and below	24	-0.54	134.21	11.59	10.02
Option 6	PI4and below	17	-0.56	138.82	11.78	10.40
Option 7	PII1and below	11	-0.59	141.92	11.91	10.64

Different variables often have different units, and using different units for the same variable can produce too much care for variables with large variances, X_j, and not enough for variables with small variances. In order to eliminate some possible unreasonable effects due to the different units, the original variables are often standardized. That is, such that

$$X_j^* = \frac{X_{\max} - X_j}{X_{\max} - X_{\min}} (j = 1,2,3...)$$

The raw data in Table 4 was normalized to give Table 5.

Table 5 Results of the normalization of the physical parameters of the oil formation within the first open section

Option Number	Layer	Developing oil layer X_1	the coefficient of variation of permeability ln (X_2)	the average formation pressures X_3^2	the average formation pressures X_3	stage recovery rate / %
Option 2	SII15and below	0.00	0.00	1.00	1.00	8.59
Option 3	SIII1and below	0.24	0.30	0.78	0.78	8.95
Option 4	SIII4and below	0.45	0.57	0.64	0.64	9.55
Option 5	SIII7and below	0.61	0.75	0.54	0.53	10.02
Option 6	PI4and below	0.82	0.85	0.22	0.21	10.40
Option 7	PII1and below	1.00	1.00	0.00	0.00	10.64

A multiple linear regression method was applied to the curve regression to obtain the relationship between the number of developed oil layers *(X_1)*, the coefficient of variation of permeability *(X_2)*, the average formation pressure *(X_3)* and the stage recovery rate (ΔR_1) within the first open section.

$$\Delta R_1 = -2.12X_1 + 3.44\ln(X_2) - 77.49X_3^2 + 76.75X_3 + 9.33$$

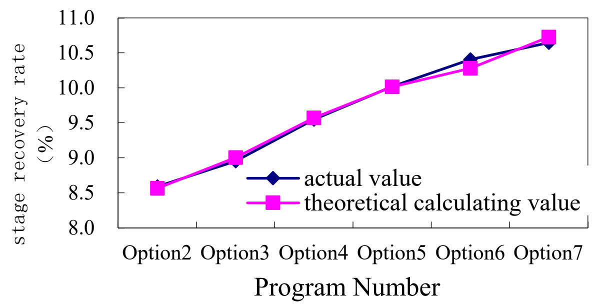

Figure. 4 Fitting effect of the first open layer section

4.2 Multiple linear regression of stage recovery within the upper return section.

The relationship between the number of developed oil layers *(X_1)*, the coefficient of variation of permeability *(X_2)* and the stage recovery (ΔRi) are plotted separately in Figure 5.

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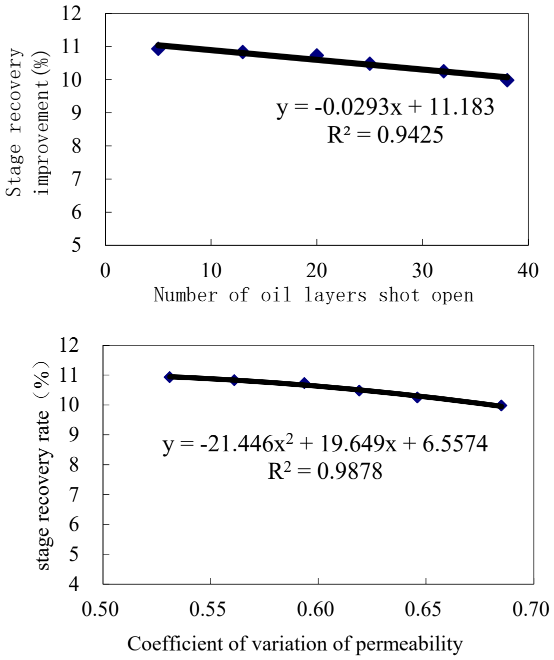

Figure 5 Relationship between formation physical properties and stage recovery

Table 6 Results of data processing of oil formation physical parameters within the upper return section

Option number	Layer	Oil layer X_1	Coefficient of variation of permeability X_2^2	Coefficient of variation of permeability X_2	stage recovery rate / %
Option 2	SⅡ 15and below	5	0.282	0.531	10.93
Option 3	SⅢ1and below	13	0.315	0.561	10.83
Option 4	SⅢ4and below	20	0.352	0.594	10.73
Option 5	SⅢ7and below	25	0.383	0.619	10.48
Option 6	PⅠ4and below	32	0.417	0.646	10.25
Option 7	PⅡ1and below	38	0.469	0.685	9.98

Table 7 Results of the normalization of the physical parameters of the oil formation within the upper return section

Option number	layer	Oil layer X_1	Coefficient of variation of permeability X_2^2	Coefficient of variation of permeability X_2	stage recovery rate /%
Option 2	SⅡ 15and below	1.00	1.00	1.00	10.93
Option 3	SⅢ1and below	0.78	0.83	0.81	10.83
Option 4	SⅢ4and below	0.63	0.62	0.59	10.73
Option 5	SⅢ7and below	0.53	0.46	0.43	10.48
Option 6	PⅠ4and below	0.37	0.28	0.25	10.25
Option 7	PⅡ1and below	0.00	0.00	0.00	9.96

A multiple linear regression method was applied to the curve regression to obtain the relationship between the number of oil layers in the upper return section *(X_1)*, the coefficient of variation of permeability *(X_2)* and the stage recovery rate (ΔRi).

$$\Delta R_2 = 1.01X_1 + 5.67{X_2}^2 - 5.7X_2 + 9.96$$

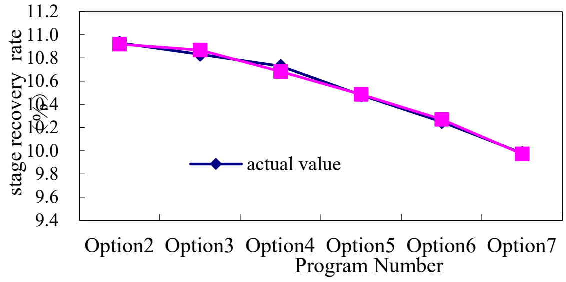

Figure 6 Fitting effect of the upper return layer section

The method of calculating the recovery rate for the whole area phase is obtained by the method of reservoir weighting within each layer section, i.e.

$$\Delta R = \frac{\Delta R_1 N_1 + \Delta R_2 N_2}{N_1 + N_2}$$

Where: N is the remaining geological reserves within the developed stratigraphic section.

5. Application of multivariate linear methods to determine the stratification system to develop stratified sections

According to the development thickness of the oil layer and the relevant model recovery results, it is more reasonable to use Portuguese Group I or Sa III7 for the first opening section, which can ensure the thickness of the first opening layer and at the same time, the final recovery rate increase is higher; the upward return section can be divided into one upward return section or two upward return sections, the former has high production efficiency and the latter has a large recovery rate increase.

Table 8 Statistics on the thickness and adjustable thickness of each oil formation development

Classification	Developmental thickness (m)		Developmental thickness (m)	
	Sandstone	Effective	Sandstone	Effective
SⅡ and below	45.0	14.2	37.6	8.0
SⅢ and below	28.9	8.0	24.3	4.5
SⅢ7 and below	23.5	6.4	19.6	3.5
PⅠ4 and below	18.6	4.8	15.5	2.5
PⅡ and below	11.8	2.6	9.8	1.3
GⅠ	3.9	0.5	3.9	0.5

SIII7 and below, PI4 and below as the first open stratigraphic section, divided into one section up return, two section up return two models for development (two section up return from one section up return calculation formula used $\Delta R = \dfrac{\Delta R_1 N_1 + \Delta R_2 N_2 + \ldots + \Delta R_i N_i}{N_1 + N_2 + \ldots + N_i}$), predicted final recovery rate of 51.31%, 51.67%, 51.36%, 51.77% respectively.

Table 9 Comparison of recovery rates between different options

Option number	First opening floor section	Phase Development 1	Phase Development 2	Recovery rate / %
option5.1	SIII7a nd below	SII~ SIII	\	51.31
option 5.2	SIII7a nd below	SIII	SII	51.67
option 6.1	PI4an d below	SII~ SIII	\	51.36
option 6.2	PI4an d below	SIII	SII	51.77

6. Conclusion

1. The results of the numerical simulation study show that the first open layer section is P Ⅰ 4 and below, and the highest recovery enhancement effect can be achieved in 2 upward return sections, and its recovery rate is 2.07 percentage points higher than the conventional generalized shot hole.

2. Based on the numerical simulation study, the linear relationship between recovery rate and formation properties is obtained by applying multivariate linear analysis method, which can provide technical support for the adjustment of stratified system development in similar blocks.

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