Application of Fuzzy Comprehensive Evaluation Method for Reservoir Well Logging Interpretation While Drilling

Zhaohua Zhou[1], Shi Shi[1], Shunan Ma[2(✉)], and Jing Fu[1]

[1] PetroChina Research Institute of Petroleum Exploration and Development, Beijing 100083, China
{zhaohua69,shishi69}@petrochina.com.cn, fujing0602@126.com

[2] Institute of Information Engineering, Chinese Academy of Science, Beijing 100093, China
mashunan@iie.ac.cn

Abstract. Reservoir classification and evaluation is the base for gas reservoir description. Well logging interpretation while drilling technique collects drilling logging signal in real-time through the sensor module, and transmits to the database server wirelessly. Well logging interpretation model is applied to reservoir information analysis, which is important to describe gas reservoirs accurately. Because of complicated geological conditions, there is a deviation in single well logging interpretation model. To solve the problem, a reservoir well logging evaluation while drilling method based on fuzzy comprehensive evaluation is proposed. Key parameters affecting reservoir evaluation, such as porosity, permeability and gas saturation are considered. Fully mining the information contained in GR, SP, AC and RT well logging data. Firstly, the reservoir is divided into gas, poor-gas, dry layer and water layer. For each well logging method, statistical method is used to calculate the subordinate intervals of each reservoir's parameters, and the membership degree is calculated to form the evaluation matrix of the well logging method. Then, the weight of each parameter is selected to form the comprehensive evaluation weight matrix, and fuzzy comprehensive evaluation result of well logging is computed. Finally, the comprehensive evaluation results of different well logging methods are composed to evaluation matrix, and fuzzy comprehensive evaluation method is used again to get the final reservoir evaluation category, so as to provide scientific basis for gas field development decision making.

Keywords: Fuzzy comprehensive evaluation · Well logging · Reservoir

1 Introduction

Well logging is an important oil field service work. It is important to quickly process and send the log data to the user at the oil field company on time. Oil and gas mines are mostly located in the swamps, deserts, basins and shallow sea area, where the transportation infrastructure is relatively backward and the construction environment is complex.

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The application of mobile network technology in the oil and gas industry provides a powerful guarantee for the real-time control of oil and gas exploration and production process. Equipment detector transfers the collected production data back to the background system through wireless transmission equipment. In this way, each production and management department can grasp the working state of oil and gas well accurately and timely, which can improve production efficiency and provide new means for fine management of oil and gas well. Well logging interpretation while drilling collected drilling logging signal in real-time through the sensor module, and transmitted wirelessly to the database server. Then well logging interpretation information platform is applied to analyze the layer information of the current drilling rig, and the ground staff can monitor the results in real-time.

Well logging interpretation is an inversion problem. The parameters required for oil and gas geology can not be measured directly from the logs, but need to be gained by inversion of the interpretation model. Well logging interpretation should pay attention to the analysis of four properties of reservoir: electrical property, lithology, physical property, and hydrocarbon-bearing property.

Among the four properties of reservoir, hydrocarbon-bearing property is affected by the interaction of multiple geological factors. Such as, the gas volume is high, probably because of thin reservoir, low permeability, and difficult to mine. On the other hand, the gas volume is low, because of high permeability, thick gas, easy to mine. At present, the difficulty of well logging interpretation while drilling lies in the complicated geological conditions which leads to a large deviation in single well logging interpretation model. It is necessary to make use of several logging methods to improve accuracy of reservoir evaluation. In this paper, real-time data acquisition of mobile well logging while drilling is applied, and the comprehensive fuzzy evaluation method is applied to optimize the use of several logging methods, and a reservoir well logging evaluation while drilling method based on fuzzy comprehensive evaluation is proposed. Considering the parameters of each reservoir, especially the main parameters which affect the reservoir quality, the reservoir information contained in the well logging data is fully excavated, and the reservoir is comprehensively evaluated by the fuzzy mathematics method, which is more comprehensive and accurate to provide the basis for gas field development and favorable zone optimization.

2 Related Works

In the process of well logging interpretation, the parameters such as reservoir porosity, permeability and saturation are evaluated quantitatively. However, due to the technical conditions, the evaluation accuracy of these parameters is not high. In order to solve this difficulty, domestic and foreign scholars have proposed various methods to improve the accuracy of parameter calculation.

Ding et al. proposed the JMOD interpretation model by establishing the relationship between the capillary pressure and the J function of underground tight sandstone reservoir [1]. This method has been widely used in practical production, which has effectively improved the calculation accuracy of tight sandstone reservoir parameters, provided more information about logging parameters, and played a vital role in the exploration and development of tight sandstone reservoir. Abu-Shanab et al. used the data of Nuclear Magnetic Resonance logging (NMR) and density logging (DEN) data in the calculation of porosity and other parameters, taking full account of the changes of lithology and pore fluid in tight sandstone reservoirs, and significantly improved the accuracy of porosity calculate, and provide good foundation for the calculation of other reservoir parameters [2].

Domestic scholars also made a lot of efforts in the research of tight sandstone reservoir parameters. Chai et al. used the BP neural network to calculate the parameters of tight sandstone reservoir [3]. Liu et al. changed the overall evaluation method of the tight sandstone, and evaluated the tight sandstone reservoir by system method, the important composition and the layer-by-layer method [4]. Yang et al. introduced the new evaluation parameters into the evaluation of the tight sandstone reservoir by experiment, and formed a new evaluation method [5]. Meng and Zhou proposed new methods to judge the dry layer, water layer and gas layer accurately according to accurate judgment of fluid parameters in the formation of Nuclear Magnetic Resonance logging [6, 7]. Wen et al. proposed that the pore parameters and pore throat parameters should not be considered only in the evaluation of tight sandstone reservoirs, and environmental factors should be added to improve the evaluation effect [8]. Wang used acoustic data on the reservoir fluid identification and quantitative evaluation, which shows unique advantages in actual processing [9]. Li used the support vector machine (SVM) algorithm based on particle swarm optimization to identify and predict the tight sandstone reservoir fluid, and establish a complete set of compact sandstone reservoir fluid logging evaluation software [10]. Zhuang used BP, wavelet and Elman neural networks to predict the production capacity of Sulige tight sandstone reservoir. The Elman neural network method with the best prediction effect was selected as the prediction model of fracturing productivity in Sulige region [11].

3 Selection of Reservoir Well Logging Comprehensive Evaluation Index

From variety of well logging information, reservoir well logging fuzzy comprehensive evaluation method is comprehensive evaluation of many reservoir parameters, including the qualitative and quantitative of the reservoir to find out their intrinsic relationship, so as to make classification of reservoirs and productivity estimation. The key factors affecting the reservoir are considered as much as possible. According to their geological factors to reflect the credibility and geological factors contribute to reservoir quality, the corresponding weights of these factors are given, and the formula is used to calculate the weights of various reservoir evaluation indexes. Finally, these indexes are integrated as the final index of reservoir evaluation.

The GR (Natural Gamma), SP (Spontaneous Potential), AC (Acoustic) and RT (Resistivity) well logging were selected based on the statistics of 755 wells, and the logging data were respectively normalized.

Based on the comprehensive analysis of reservoir evaluation indexes proposed by predecessors, three key evaluation indexes, porosity, permeability and gas saturation are selected according to the characteristics of comprehensive evaluation of gas reservoirs in Su 25 block.

Reservoir evaluation classification results: gas layer, poor-gas layer, dry layer and water layer.

Given the evaluation reservoir, the data objects that need to be processed are shown in Table 1.

Table 1. Well log information of evaluation reservoir

Well logging method	Porosity	Permeability	Gas saturation
GR	$¢_G$	K_G	S_G
SP	$¢_S$	K_S	S_S
AC	$¢_A$	K_A	S_A
RT	$¢_R$	K_R	S_R

The values of each parameter in Table 1 are the fuzzy values obtained by their corresponding logging curves.

According to the actual test result of perforation gas, the evaluation indexes of various well logging methods are analyzed. Using the statistical analysis method, we get the parameters' maximum and minimum values of each reservoir type in each logging method. For example, the statistical results of gas reservoir evaluation indexes are shown in Table 2.

Table 2. Statistical results of gas reservoir evaluation indexes

Gas reservoir evaluation indexes	Porosity		Permeability		Gas saturation	
	Max	*Min*	*Max*	*Min*	*Max*	*Min*
GR	$Max\ ¢_G$	$Min\ ¢_G$	$MaxK_G$	$MinK_G$	$MaxS_G$	$MinS_G$
SP	$Max\ ¢_S$	$Min\ ¢_S$	$MaxK_S$	$MinK_S$	$MaxS_S$	$MinS_S$
AC	$Max\ ¢_A$	$Min\ ¢_A$	$MaxK_A$	$MinK_A$	$MaxS_A$	$MinS_A$
RT	$Max\ ¢_R$	$Min\ ¢_R$	$MaxK_R$	$MinK_R$	$MaxS_R$	$MinS_R$

In the same way, the statistical evaluation indexes of other reservoir types can be calculated, such as water layer, dry layer and differential gas layer.

For the data of each well logging method, the membership function of each index X in the evaluation reservoir is constructed as follows.

$$\text{If } \mathrm{Min}_i < \mathrm{X}_i < \mathrm{Max}_i,\ \mathrm{F(x)} = \frac{\mathrm{X}_i - \mathrm{Min}_i}{\mathrm{Max}_i - \mathrm{Min}_i};$$

$$\text{If } \mathrm{X}_i \geq \mathrm{Max}_i,\ \mathrm{F(x)} = 1.0;\ \text{else, } \mathrm{F(x)} = 0.$$

According to the membership function, membership degree of the evaluation results of each well logging method is calculated. For example, the membership degree of each index for SP well logging is shown in Table 3.

Table 3. Index membership degree for SP well logging

Evaluation class	Porosity	Permeability	Gas saturation
Gas layer	0.7	0.8	0.1
Poor-gas layer	0.4	0.9	0.6
Dry layer	0.3	0.6	0.5
Water layer	0.5	0.2	0.8

The membership degree of each evaluation index is normalized:

$$X_{ij} = \frac{X_{ij}}{\sum_{i=0}^{n} X_{ij}};$$

The result is shown in Table 4.

Table 4. Normalized result of index membership degree for SP well logging

Evaluation class	Porosity	Permeability	Gas saturation
Gas layer	0.37	0.32	0.05
Poor-gas layer	0.21	0.36	0.3
Dry layer	0.16	0.24	0.25
Water layer	0.26	0.08	0.4

In the same way, the normalized results of index membership degree for other well logging methods can be calculated.

4 Well Logging Comprehensive Evaluation Method

Fuzzy comprehensive evaluation, which provides a high level of confidence in decision-making based on fuzzy logic, is a branch of artificial intelligence. It classifies or distinguishes things by means of analyzing fuzzy information as much as possible. By considering the various factors that influence a certain thing, fuzzy comprehensive evaluation method uses fuzzy mathematical methods and makes a scientific evaluation of its merits and shortcomings [12].

Fuzzy comprehensive evaluation uses some concepts in fuzzy mathematics to evaluate actual problems which are comprehensive and complex. Fuzzy comprehensive evaluation is one application of fuzzy mathematical method. The basic principle is as follows:

(1) Identifying the factors that can be used to judge the target set and evaluation set;
(2) Respectively determining the weights of the factors and their membership degree vector and obtaining a fuzzy evaluation matrix;
(3) Operating the fuzzy evaluation matrix of factors and the fuzzy weight vector to normalize the result. The final result is the fuzzy evaluation result.

The method uses fuzzy mathematics theory, easy to understand and effective to judge complex problems, which can be applied to many fields [13]. In this paper, we use fuzzy comprehensive evaluation method to evaluate multiple well logging parameters reservoir.

Following is the algorithm procedure for completing the multiple well logging parameter reservoir evaluation:

(1) The subordinate intervals of each evaluation index of each well logging method are obtained;
(2) The membership degree of each evaluation index of each logging method is calculated to form the evaluation matrix R.
(3) For each well logging method, the weight of each evaluation index is selected to form a weight matrix E, which can be computed by artificial intelligence methods such as neural networks.
(4) According to step (2) and step (3), the fuzzy comprehensive evaluation is carried out to get the judgment results of each well logging method to the evaluation layer. Namely, $B = E\,o\,R$.
(5) According to the effective sensitivity of each well logging method to the block, the index weight E_L of each logging method is chosen, and the weight of each logging method can be selected by classification statistics.
(6) The judgment result B of each well logging method is used to form the well logging information evaluation matrix $R_L = [B_0, B_1, B_2, B_3]$.
(7) According to step (5) and step (6), the fuzzy comprehensive evaluation is carried out again, to get the judgment results of various well logging methods on the evaluation layer. Namely, $B_L = E_L\,o\,R_L$.
(8) Based on the principle of maximum subjection, the interval to which maximum subjection scale corresponds is selected $b_i \in B_L$. Namely, the evaluation reservoir is eventually evaluated as *i*th class.

5 Application Instance

Similar to Table 4, the normalized result of index membership degree for GR well logging is shown in Table 5.

Table 5. Normalized result of index membership degree for GR

Evaluation class	Porosity	Permeability	Gas saturation
Gas layer	0.27	0.23	0.18
Poor-gas layer	0.31	0.42	0.43
Dry layer	0.06	0.04	0.15
Water layer	0.36	0.31	0.24

Evaluation indexes weights of various logging methods are selected:

$$E_{4\times4} = \begin{bmatrix} 0.4 & 0.07 & 0.32 & 0.21 \\ 0.53 & 0.12 & 0.28 & 0.07 \\ 0.37 & 0.18 & 0.23 & 0.22 \\ 0.38 & 0.16 & 0.3 & 0.16 \end{bmatrix}$$

$$R_L = E_i \circ \mathrm{R}_i = \begin{array}{c} \text{gas layer} \quad \text{poor- gas layer} \quad \text{dry layer} \quad \text{water layer} \\ \begin{bmatrix} 0.75 & 0.46 & 0.54 & 0.42 \\ 0.28 & 0.69 & 0.31 & 0.345 \\ 0.18 & 0.84 & 0.27 & 0.03 \\ 0.52 & 0.35 & 0.86 & 0.47 \end{bmatrix} \end{array}$$

The weights are selected as: $E_L = [0.13, 0.34, 0.38, 0.15]$.

$B_L = E_L \circ R_L = [0.28, 0.38, 0.31, 0.34]$. The maximum membership is 0.38, and the reservoir evaluation gained by the well logging information is poor-gas layer.

Note: In order to avoid the same final evaluation values, the calculation accuracy can be improved.

6 Conclusions

In this paper, a reservoir well logging evaluation while drilling method based on fuzzy comprehensive evaluation is proposed, and the real-time data acquisition of mobile well logging while drilling is applied. Key parameters affecting reservoir evaluation, such as porosity, permeability and gas saturation are considered. Firstly, the reservoir is divided into gas, poor-gas, dry layer and water layer. For each well logging method, statistical method is used to calculate the subordinate intervals of each reservoir's parameters, and the membership degree is calculated to form the evaluation matrix of the well logging method. Then, the weight of each parameter is selected to form the comprehensive evaluation weight matrix, and fuzzy comprehensive evaluation result of well logging is computed. Finally, the comprehensive evaluation results of different well logging methods are composed to evaluation matrix, and fuzzy comprehensive evaluation method is used again and the final reservoir evaluation category is gained.

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