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The Quantitative Description of Tight Sand Reservoir Fracture in Sulige Gas Field

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Abstract
The Sulige gas field is a typical tight sand reservoir, Ordos Basin, the fracture development degree directly affects the development of the natural gas, especially affects the volume fracturing effect of horizontal well and the deliverability of the natural gas, the appropriate method to describe the fracture is very important. At present, outcrop, core and FIM are general methods to describe the fracture development degree, but they have inherent shortages. In the Sulige gas field, a few of cores and poor representativeness can not illustrate the fracture distribution in well bore, and imaging logging data are especially absent. Su53 gas field was used as an example in the Sulige gas field, during the research of the fracture, based on fractal theory, through using the amplitude difference data between deep investigate double lateral resistivity (Rd) and shallow investigate double lateral resistivity (Rs), and other conventional logging data, in combination with the response characteristics of fracture in the logging curve, reservoir fracture was quantitatively identified by the analysis method of *R*/*S*, the relationship between fractal dimension value and fracture density was quantitatively analyzed , the vertical heterogeneity of fracture distribution was analyzed, and the relationship between fractal dimension value of fracture and initial deliverability of gas well was researched. The results which were tested by the data of drilling cores and productions available, indicate that the method of *R*/*S* is feasible to quantitatively describe the fracture development degree; the relationship between fractal dimension value and fracture density is positively relative, fractal dimension value is bigger, the fracture is more developed; there is a good corresponding relationship between fractal dimension value and deliverability of gas well, fractal dimension value decreases with a decrease of deliverability.

Key words: Fractal; *R*/*S* analysis; Logging curve; Tight sand reservoir fracture; Fracture description

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INTRODUCTION
Development practices of unconventional natural gas show that, the natural fracture are precondition to realize reservoir volume fracturing and fracture network[1-2], which make the research of reservoir fracture have become an important part of the volume fracturing adaptability evaluation of horizontal well, and the urgent need of effectively developing the unconventional gas field.

At present, there are many identification and description methods of reservoir fracture[3-6]. But it is often difficult to identify and predict the natural fracture distribution of most oil and gas field because of constraints of the data type and number. Borehole imaging logging and drilling core as directly observed data, only in a few wells, and core data, not all well sections have 100 percent core recovery. In the Su53 gas field, image data are absent, the existing data in addition to a small amount of core data, the other is almost conventional logging data, whether establish a logging response mechanism model to identify the fracture development degree with conventional logging data, is a practical problem that has to face. Through extensive literature research, found that fractal geometry theory was applied to the identification and prediction of fracture and reservoir evaluation[7-14]. Therefore, through combining the features of tight sandstone reservoir of He8-Shan1 interval in the Su53 gas field, based on fractal theory, using the amplitude difference data between deep investigate double lateral resistivity (Rd) and shallow investigate double lateral resistivity (Rs), and other conventional logging data, the natural fracture development was quantitatively identified and predicted by the analysis method of *R*/*S*, the relationship between fractal dimension value and fracture density was quantitatively analyzed, the vertical heterogeneity of fracture distribution was analyzed, and the relationship between fractal dimension value of fracture and initial deliverability of gas well was researched. The results show that the method of *R*/*S* is feasible to quantitatively describe the fracture development degree of single-well, which give some guidance for volume fracturing of horizontal well in the Sulige gas field.

1. FRACTAL IDENTIFICATION METHOD OF RESERVOIR FRACTURE

1.1 The Analysis Method of *R*/*S*

Fractal geometry as a branch of nonlinear science has been widely used in reservoir pore structure, reservoir heterogeneity, reservoir parameters stochastic simulation between wells, and fracture identification and prediction, and so on[7-14]. Among them, the analysis method of *R*/*S* (variable scale fractal technique) is one of the fractal statistics methods that are currently the most widely used and mature. The method was proposed by Hurst in 1965, in which *R* is called the range, which is the difference between maximum cumulative deviations and minimum cumulative deviations, represents the complex level of time series; *S* is called the standard deviation, which is the square root of the variation, represents the average trend of time series. The *R*/*S* value represents the relative fluctuation intensity of dimensionless time series.

For a one-dimensional process $Z(t)$, the analysis process of *R*/*S* is as follows:

$$R(n)=\max_{0<u<n}\left\{\sum_{i=1}^{u}Z(i)-\frac{u}{n}\sum_{j=1}^{u}Z(j)\right\}-\min_{0<u<n}\left\{\sum_{i=1}^{u}Z(i)-\frac{u}{n}\sum_{j=1}^{u}Z(j)\right\} \tag{1}$$

$$S(n)=\left\{\frac{1}{n}\sum_{i=1}^{u}Z^2(i)-\left[\frac{1}{n}\sum_{j=1}^{u}Z(j)\right]^2\right\}^{\frac{1}{2}} \tag{2}$$

where, n is the logging sample point numbers of analysis interval point by point; u is the sample point numbers between 0 and n order to increase; i and j are the variable of sample point numbers; $R(n)$ is the total stratum range of process sequence; $S(n)$ is the total stratum standard deviation of process sequence.

$R(n)/S(n)$ is the *R*/*S* value at n sample point, during the change process of n from 3 to the total numbers of interval logging sample point, a n value, there is a $R(n)/S(n)$ value corresponding to n value. If $R(n)/S(n)$ is a double logarithmic linear relation with n, the sequence of $Z(t)$ has a self scale similar fractal characteristic. The slope H of $R(n)/S(n)$ curve is called Hurst index. The D value is calculated with the formula $D = 2 - H$ is the fractal dimension value of $Z(t)$, which represents the change complex degree of $Z(t)$ in the one-dimensional t.

In theory, *R*/*S* can reflect the change degree of time series. For logging data sequence, if the reservoir fractures are relatively developed, there are some log responses in the *R*/*S* analysis curve of relatively sensitive parameter on reservoir fracture.

1.2 The Response Characteristics of Fracture in the Analysis Curve of *R*/*S*

The original log parameter for *R*/*S* analysis is used, there are two main reasons: first, the logging data have certain sampling interval, and distribution is complete in each well layer; second, the logging parameters are redundant, the comparison of *R*/*S* can be carried out between the different parameters, to determine the logging parameters can sensitively respond fracture.

According to the principle of *R*/*S* analysis, the slope of the regression line of double logarithmic relationship between *R*/*S* and *n* can indirectly reflect the complexity degree of curve, which is mainly controlled by lithology and fluid. The conventional logging curves through contrast and combination of parameters were used to identify the fracture, and the conventional logging curve must be the most obvious response to the fracture. Through the application of data of Su53-4, including the gamma ray curve (GR), acoustic curve (AC), caliper curve (CAL), deep investigate double lateral resistivity curve (Rd), shallow investigate double lateral resistivity curve (Rs), and the amplitude difference data between deep investigate double lateral resistivity (Rd) and shallow investigate double lateral resistivity (Rs), logarithmic values of *R*/*S* and *n* were calculated according to the above method, and *R*/*S* analysis curves of the fracture sections corresponding cores were mapped, by contrast, the correlation between the amplitude difference data and the fractures in cores was the best. Therefore, based on the analysis method of *R*/*S*, the amplitude difference data between Rd and Rs were used to identify fracture, identification process as follows: First, according to the procedure input format requirements, the deep and shallow dual laterolog resistivity data were sorted; Second, the value of *R*/*S* at point *n* was calculated; Third, the double logarithmic diagrams between *R*/*S* and *n* were mapped, and a straight line with all data was regressed, which were shown in Figure 1a; Fourth, the concave curves in the diagram (less than slope of regression line) were selected to identify fracture. Accordingly, the amplitude difference data of several other wells were analyzed by the method of *R*/*S* in the Su53 gas field, the results were shown in Figure 1b, 1c and 1d, which all reflected the characteristics of natural fracture.

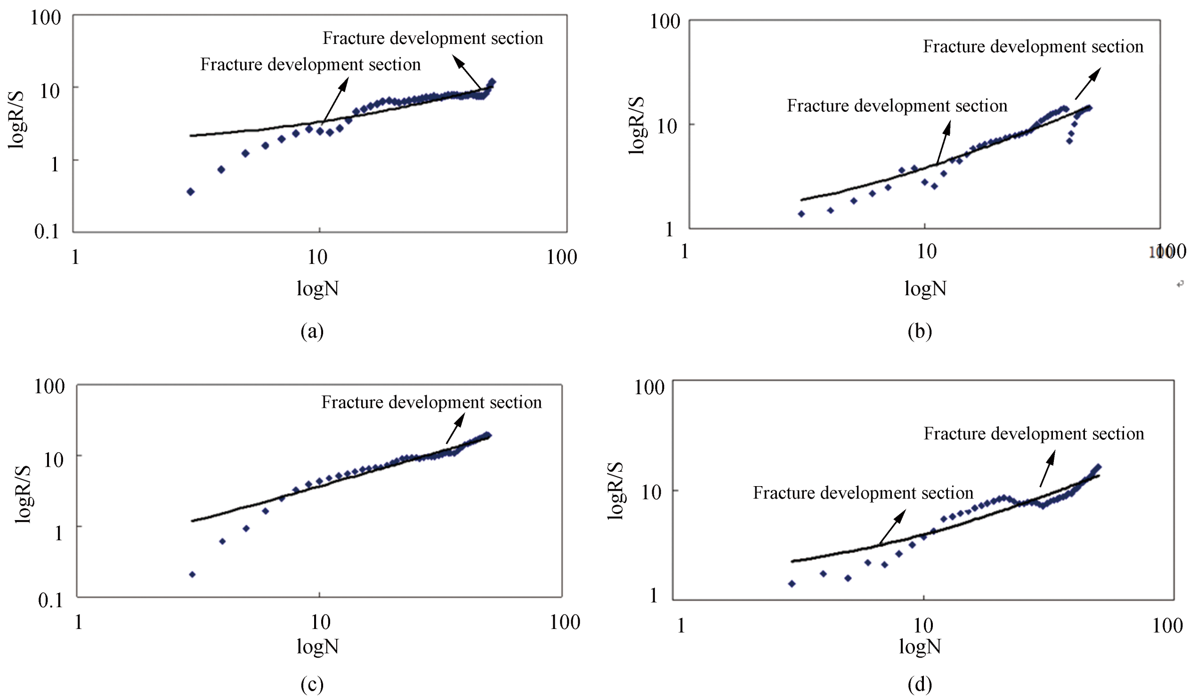

Figure 1
The Double Logarithmic Relationship Diagram Between *R*/*S* and *n* of the Amplitude Difference Data. (a) Su53-4, Depth Interval: 3,229.735 - 3,235.860 m, (b) Su53-8, Depth Interval: 3,168.25 - 3,174.375 m, (c) Su 53-78-46H, Depth Interval: 3,475.625 - 3,481.75 m, (d) Su 53-78-58H, Depth Interval: 3,395.825 - 3,401.95 m

2. THE RELATIONSHIP BETWEEN FRACTAL DIMENSION AND FRACTURE DENSITY

The fractal dimension can be used as a quantitative parameter to describe reservoir fracture density. The five wells' drilling cores were observed and limned, the average fracture density was counted, the relationship between fractal dimension value and fracture density was analyzed. Table 1 shows that the fractal dimension value has highly significant linear correlation with fracture density, with the increase of fracture density, fracture fractal dimension value increases. The fractal dimension value is feasible to describe the fracture density.

Table 1
Statistical Data of Fractal Dimension and Fracture Density in Su53 Gas Field

Well name	Depth interval (m)	Fractal dimension *D*	Average fracture density (m^{-1})
Su53-4	3,229.735 - 3,235.86	1.069	1.19
Su53-8	3,168.25 - 3,174.375	1.118	1.83
Su53-76-45	3,263.325 - 3,269.45	0.798	0.17
Su53-78-46H	3,475.625 - 3,481.75	0.801	0.32
Su53-78-58H	3,395.825 - 3,401.95	1.236	2.65

3. THE VERTICAL HETEROGENEITY OF FRACTURE DISTRIBUTION

The fractal dimension can be used to evaluate the vertical heterogeneity of reservoir[9-10]. The bigger the fractal dimension, the vertical heterogeneity of reservoir parameters is stronger. If the fractures are relatively developed, the vertical heterogeneity of reservoir will be increased. For example, Figure 2a shows that the fractal dimension values of Su53-4 are higher in depth interval: 3,229.74 - 3,235.86 m, 3,235.99 - 3,242.11 m, 3,242.24 - 3,248.36 m, 3,279.74 - 3,285.86 m, 3,317.24 - 3,323.36 m. Figure 2b shows that the fractal dimension values of Su53-78-46H are higher in depth interval: 3,707 - 3,713 m, 3,738 - 3,744 m, 4,013 - 4,019 m, 4,050.6 - 4,056.8 m, 4,219.4 - 4,225.5 m, 4,225.6 - 4,231.8 m, which indicate that these reservoir fracture development are obvious, which often represent the characteristics of the high-quality reservoir. The fractal dimension values of high angle fractures and emposieues in composite development section are significantly higher than fractal dimension values of only micro fractures, the fractal dimension values of fracture section are higher than section without fracture development.

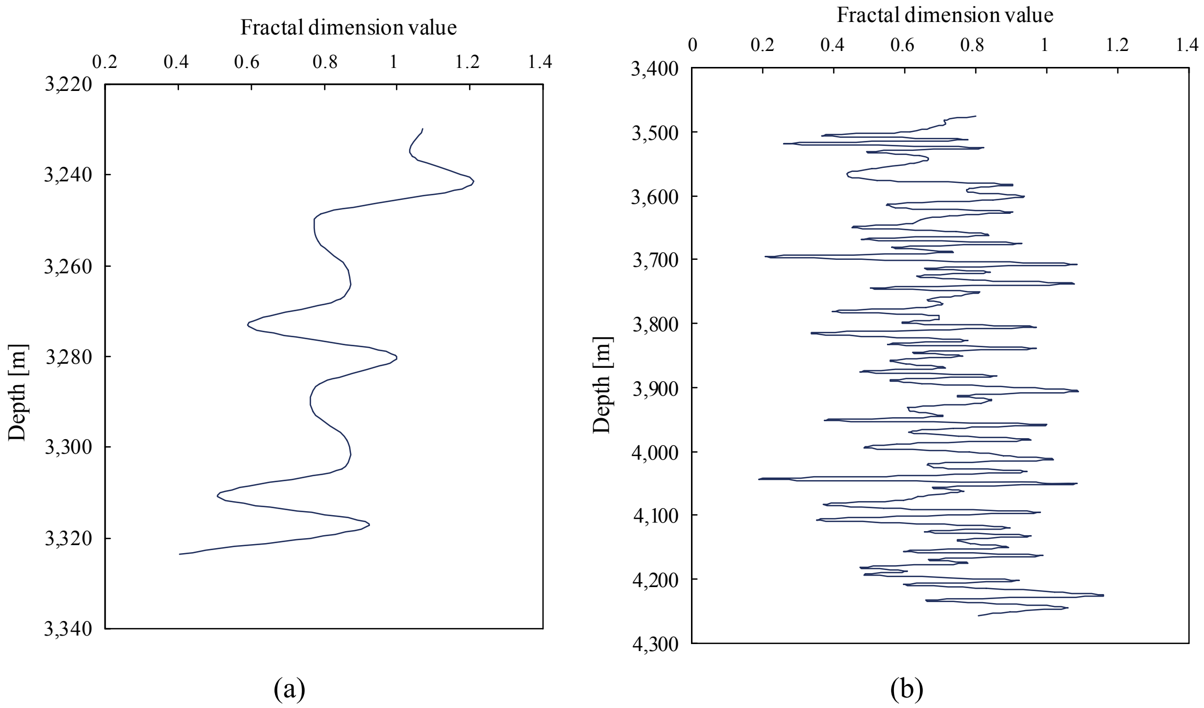

Figure 2
Distribution of Vertical Fractal Dimension Value. (a) Su53-4, (b) Su 53-78-46H

4. THE RELATIONSHIP BETWEEN FRACTAL DIMENSION OF FRACTURE AND DELIVERABILITY OF GAS WELL

In order to analyze and verify the actual effect of fractal dimension in the fracture evaluation, the relationship between fractal dimension of reservoir and initial deliverability of vertical well and horizontal well was analyzed. The logging fractal dimension values of some interval were counted. And the statistics laws were analyzed. They are shown in Table 2 indicate that the fractal dimension value decreases with a decrease of deliverability. There is a good corresponding relationship between fractal dimension and initial deliverability, and further shows that the fracturing effect of reservoir that natural fractures are relatively developed is good, natural fracture is one of the main factors affecting the initial deliverability of gas well in the Sulige gas field. Therefore, the method of *R*/*S* is feasible to quantitatively describe the fracture development degree of single-well in theory and practice.

Table 2
Comparison Table Between Fractal Dimension and Deliverability of Vertical Well and Horizontal Well in the Su53 Gas Field

Well name	Number of layers	Statistics item	Fractal dimension *D*	Daily gas production [10^4 m^3]	Cumulative gas [10^4 m^3]	
					Monthly	Calendar year
		Maximum	0.859			
Su53-22	16	Minimum	0.362	1.8097	10.8189	515.8225
		Average	0.705			
		Maximum	1.133			
Su53-27	16	Minimum	0.470	3.2624	19.5021	2,609.07
		Average	0.855			
		Maximum	0.987			
Su53-76-45	16	Minimum	0.384	1.0931	6.3189	371.5925
		Average	0.678			
		Maximum	1.146			
Su53-78-46H	126	Minimum	0.197	8.2	/	/
		Average	0.747			
		Maximum	1.133			
Su53-78-58H	138	Minimum	0.470	6.5	/	/
		Average	0.734			

CONCLUSION

(a) Based on fractal theory, using the amplitude difference data between Rd and Rs, the method of *R*/*S* is feasible to quantitatively describe the fracture development degree.

(b) The response characteristics of fracture in the analysis curve of *R*/*S* of the amplitude difference data between Rd and Rs show that, the analysis curve of *R*/*S* appears concave segments that deviate from the original straight line segment, and the slopes become very low, result in the fractal dimension value increasing, the curve shape is complicated, those are visual symbol for fracture identification.

(c) The fractal dimension value can quantitatively indicate the development degree of fracture, the fractal dimension value is bigger, and the fracture is more developed. There is a good corresponding relationship between fractal dimension value and initial deliverability of gas well.

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