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A Method of Quantitative Evaluation of Diagenetic Reservoir Facies of Tight Gas Reservoirs With Logging Multi-Parameters: A Case Study in Sulige Area, Northern Ordos Basin, China

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Abstract

Reservoir and flow characteristics of low, ultra-low permeability tight sandstone reservoir were largely controlled by diagenesis in reservoir assessment. In previous studies, diagenesis were researched only by using core analysis data, and it was difficult that diagenetic reservoir facies of the interval and the well without core analysis data were evaluated. Therefore, it was easy and quick that diagenetic reservoir facies were characterized with logging response characteristics which were extracted effectively. Taking tight gas reservoirs for example in Sulige area, northern Ordos Basin, China, logging response characteristics of different classification were analyzed by multiple samples with core analysis data, and the quantitative evaluation index of diagenetic reservoir facies based on logging multi-parameter was set up. A method of quantitative evaluation of diagenetic reservoir facies of tight gas reservoirs with logging multi-parameters was formed in the method of integration of analysis technology of Grey theory, and the accuracy and availability of the method were evaluated. The results shown that non-digitalized problems of diagenetic reservoir facies evaluation was solved by the digitalization method of logging multi-parameters, and the rate of accuracy, of returned classification using methods of mutual test, reached to 91.2%. The results provided a new and effective evaluation approach of low, ultra-low permeability tight sandstone reservoir.

Key words: Tight gas reservoir; Quantitative evaluation of diagenetic reservoir facies; Logging multi-parameters; Grey theory

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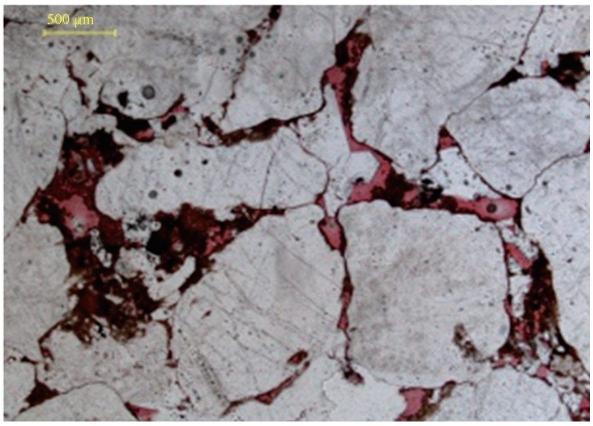
INTRODUCTION

For the ultra-low permeability tight sandstone reservoir, diagenesis ultimately determines the performance of the reservoir. At present, diagenesis and diagenetic reservoir facies which control the development and distribution of a reservoir chiefly become the focus also the difficulty of the research. Most of the previous studies focuses on the analysis of diagenesis and diagenetic reservoir facies characteristics and diagenetic porosity evolution mainly. The research of diagenetic reservoir facies quantitative evaluation and its relationship with the distribution of high-quality reservoir is relatively meager. References [1-9] investigated the formation mechanism, division program and evaluation methods comprehensively basing on the diagenetic and diagenetic facies controls on reservoir development and distribution.

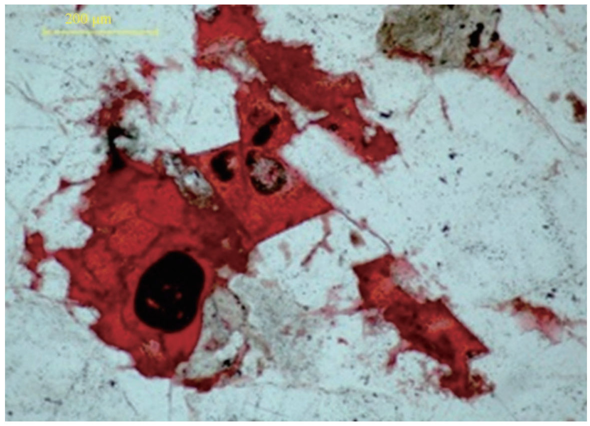
The quantitative classification of diagenetic reservoir facies above need a comprehensive analysis of a large number of core analysis data. So, more adequate core data information was needed to discuss the plane distribution of the favorable reservoir unit with diagenetic reservoir facies. However, the data mentioned above is very limited during exploration and development of oil and gas fields. Thus, it's necessary to transform the large amounts of logging information to a practical method to identify and evaluate a classification diagenetic reservoir facies tight gas systematically and orderly. In view of the imitations to identify and evaluate diagenetic reservoir facies with core analysis data, this paper takes the Shan 1 in the tight gas reservoir of SuLige east area for an example to establish a comprehensive evaluation index system and evaluation method of diagenetic reservoir facies logging multi-parameter quantitative classification. The diagenetic reservoir facies could be quantitatively evaluated and classified with logging data. The results provided a new and effective evaluation approach of low, ultra-low permeability tight sandstone reservoir.

1. CHARACTERISTIC OF DIAGENETIC RESERVOIR FACIES

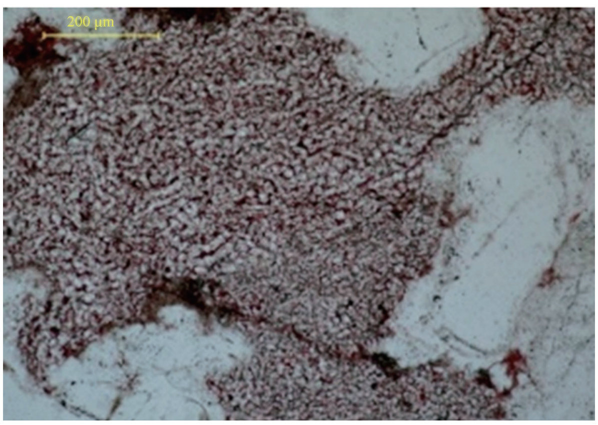
Upper Paleozoic Shan 1 period of the SuLige Eastern tight gas reservoir is a meandering river deposition. Its sediments sorted poorly, diagenesis was complex, compaction and cementation was strong. And the reservoir diagenesis section stopped in the diagenetic stage B so that it did not reach the late diagenetic stage during which large-scale secondary porosity developed. So the reservoir was tight and the densification time was before the period of a large number of gas generating and exhausting which lead to the Shan 1 heterogeneous tight gas reservoirs of this area. Microscope thin section analysis showed that the Rock composition was complicated and varied, mainly a lithic quartz sandstone, partially lithic sandstone and minor amounts of quartz sandstone. The interstitial material was mostly siliceous, iron calcite, kaolinite and hydromica with high content of argillaceous matrix. Minor chlorite also can be found. Overall, the composition, structure and terrigenous matrix contents of reservoir debris and its interstitial material varied greatly. In the reservoir, debris was in a high quantity, but feldspar with a comparatively coarse grain size and tight structure was lacking. The maturity of sandstone is low. These debris tended to be compacted to deform in diagenetic process which can block pore and throat. All of this make its native pore disappear heavily, secondary porosity relatively develop leading to the formation of different classes diagenetic reservoir facies tight gas reservoir of this area[1, 10].



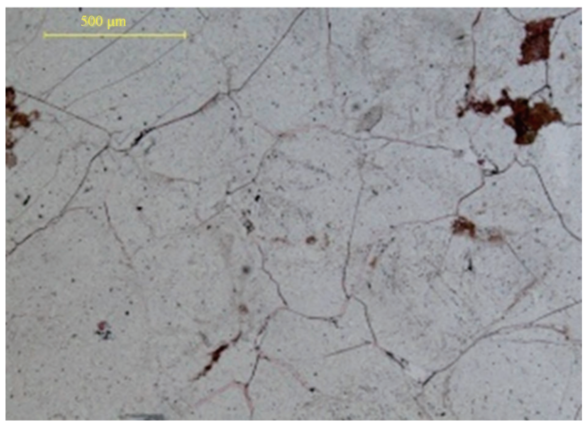
(a) S299 well, 3,456.20 m, intergranular pores-solution pores of I



(b) S124 well, 3,628.32 m, dissolution pores of II



(c) S110 well, 3,736.42 m, alteration kaolinite intercrystalline pores of III



(d) S300 well, 3,292.75 m, micropores of IV

Figure 1
The Intergranular Hole-Vugular Pore Development Graph of Diagenetic Reservoir Facies

Early compaction and interim cementation of the Shan 1 were destructive diagenesis which was unfavourable to the formation and evolution of diagenetic reservoir facies. Otherwise, widely developed dissolution and cracks were constructive diagenesis which was advantageous to the formation of diagenetic reservoir facies. According to the basic characteristics of the diagenetic reservoir facies formation, combining with the core observation, main diagenesis types were compaction, compaction solution, siliceous cement, kaolinite cementation, carbonate cementation, matrix alteration and dissolution and so on. Through the research of favorable and unfavorable formation conditions of diagenetic reservoir facies in this area, the basic laws of porosity evolution, parameters change and its pore combination, pore structure characteristics during diagenetic process was analyzed. Four types of diagenetic reservoir facies were classified: siliceous weakly cemented intergranular holes - dissolved pores (I), quartz overgrowth and kaolinite filling dissolved hole (II), kaolinized intergranular holes (III), strong compaction and cementation tight type (IV)[1, 6, 10], and the intergranular hole-vugular pore development graph of the kind diagenetic reservoir facies are shown in Figure 1.

Figure 2 shows that the I, II diagenetic reservoir facies have a lower compaction, cementation and strong dissolution, and indicate the reservoir is in a favorable deposition and diagenesis storage unit which have a better lithology, physical properties, pore structure characteristics and infiltration storage capacity, and III, IV diagenetic reservoir facies have a higher compaction, cementation and weak dissolution.

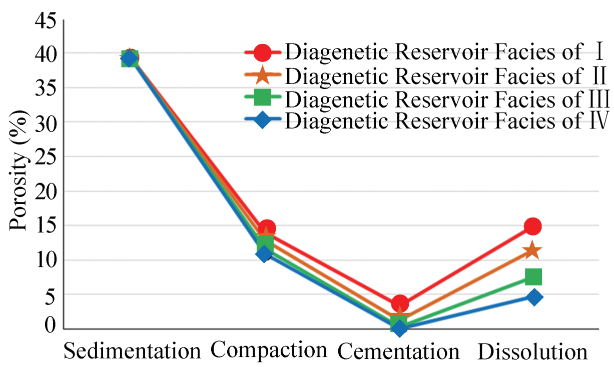


Figure 2
The Porosity Evolution Model of Diagenetic Reservoir Facies in Diagenetic Stages

2. LOGGING RESPONSE CHARACTERISTIC OF DIAGENETIC RESERVOIR FACIES

Core identification and statistical analysis of classification diagenetic reservoir facies logging response 137 samples of Shan 1 in 52 exploratory oil wells demonstrate that different diagenetic reservoir facies logging response characteristics and their sensitivity of the evaluation and division of diagenetic reservoir facies are significantly different.

Density and acoustic logging are most sensitive to determine distribution range of diagenetic reservoir facies (see Figures 3, 4). Spontaneous potential logging and the gamma spectroscopy potassium logging have an obvious difference in the distribution and range of the classification diagenetic reservoir facies which is sensitive to identify diagenetic reservoir facies (see Figures 5, 6). Resistivity logging has a relatively obvious difference and are relatively sensitive. The differences in the classification diagenetic reservoir facies of these well logs provide a very effective message for tight gas reservoir evaluation and division. Meanwhile, natural gamma, thorium, uranium content, the photoelectric absorption cross section index, section gauge logging and neutron porosity logging differences are also provide the mutual-matching information to tap the potential of tight gas reservoirs.

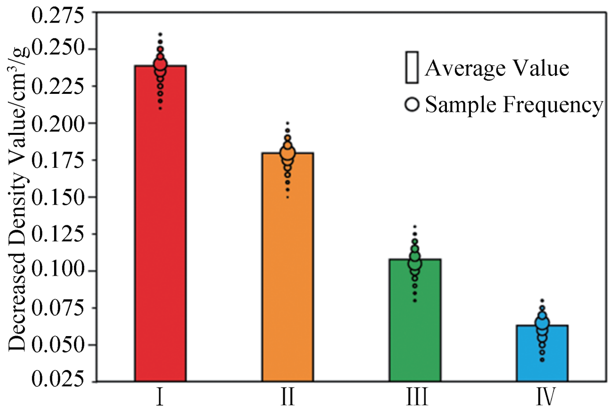


Figure 3
The Frequency Distribution of Decreased Density Value of Diagenetic Reservoir Facies

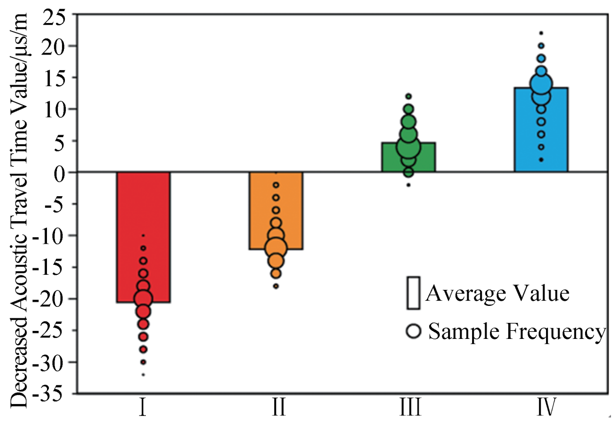


Figure 4
The Frequency Distribution of Decreased Acoustic Travel Time Value of Diagenetic Reservoir Facies

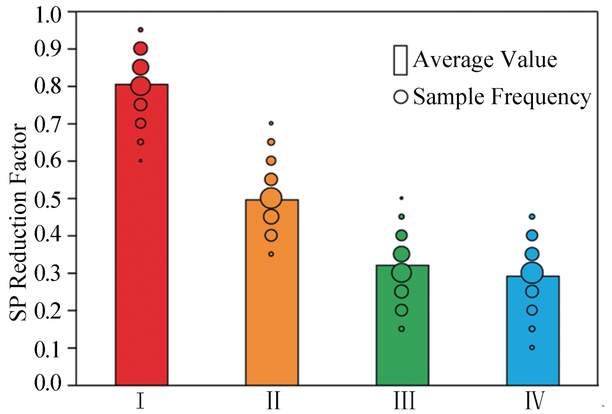


Figure 5
The Frequency Distribution of SP Reduction Factor of Diagenetic Reservoir Facies

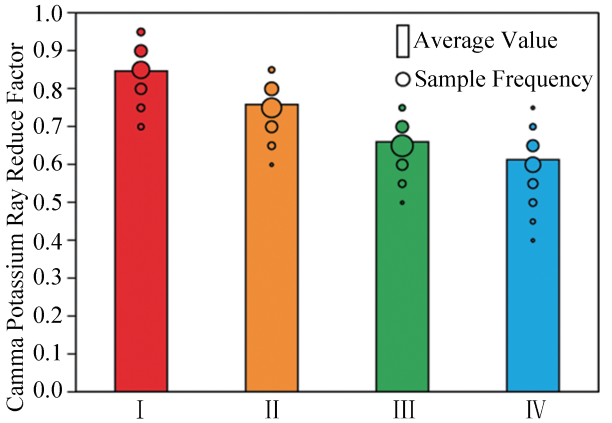


Figure 6
The Frequency Distribution of Gamma Potassium Ray Reduce Factor of Diagenetic Reservoir Facies

3. QUANTITATIVE EVALUATION OF DIAGENETIC RESERVOIR FACIES WITH LOGGING MULTI-PARAMETERS

3.1 Quantitative Evaluation Index of Diagenetic Reservoir Facies

Reservoir diagenetic reservoir facies classification can't be characterized exactly with the single logging parameter value. So, we used Grey Theory integration which integrated the logging parameters with sensitive log response evaluated former to count the diagenetic reservoir facies of Shan 1 of this area. Statistical average data column was the indicators to evaluate and divide diagenetic reservoir facies[1, 4, 6]:

$$X_{oi} = \{ X_{oi}(1), X_{oi}(2), \ldots, X_{oi}(n) \}. \tag{1}$$

X_{oi} is statistical average data column; $i = 1, 2, \ldots, n$.

After calculating the above evaluation parameters and division indicators, using a combination analysis of the accuracy and resolution analysis of the parameters to give different weights to the parameters, the parameters can be statistically analyzed and adjusted based on the sensitivity of logging response of different diagenetic reservoir facies of the area. Thus, the 5 parameter indicators and weights of tight sandstone reservoir diagenetic reservoir facies logging multi-parameter comprehensive evaluation was established (see Table 1).

Table 1
Diagenetic Reservoir Facies Logging Multi-Parameter Comprehensive Evaluation Index System

Characteristic evaluation parameters	Reservoir diagenetic reservoir facies evaluation criteria				Weight coefficient
	I	II	III	IV	
Decreased density value (g/cm^3)	0.2386	0.1795	0.1077	0.0630	0.99
Decreased acoustic travel time value (μs/m)	-20.61	-12.23	4.59	13.27	0.96
SP reduction factor	0.805	0.496	0.321	0.292	0.90
Gamma potassium ray reduce factor	0.846	0.758	0.659	0.612	0.93
Resistivity (Ω·m)	33.68	37.01	38.99	53.56	0.83

3.2 Quantitative Evaluation Index of Diagenetic Reservoir Facies

Calculate the gray multivariate weighting coefficients with matrix analysis, standardization and extreme value weighted combination, amplification and normalizing analysis of standard indicators absolute difference[1, 10-11]:

$$P_i(k) = \frac{\min_i \min_k \Delta_i(k) + A \max_i \max_k \Delta_i(k)}{A \max_i \max_k \Delta_i(k) + \Delta_i(k)} Y_o(k), \tag{2}$$

where $\Delta_i(k) = |X_o(k) - X_i(k)|$.

In above two equations, $P_i(k)$ is defined as the gray multivariate weighted coefficient of the parameters of the point k of X_o and X_i. $\min_i \min_k \Delta_i(k)$ is the minimum difference of two standard indicators. $\max_i \max_k \Delta_i(k)$ is the maximum difference of two standard indicators. $\triangle_i(k)$ is the absolute difference between the standard indicators of the k points of X_o and X_i. A is grey distinguishing coefficient.

The gray weighted coefficient sequence can be drawn:

$$P_i(k) = \{P_i(1), P_i(2), \ldots, P_i(n)\}. \tag{3}$$

The comprehensively unitary techniques is selected to centralize the values of each point to one, it is presented by the following expression:

$$P_i = \frac{1}{\sum_{k=1}^{n} Y_o(k)} \sum_{k=1}^{n} P_i(k), \tag{4}$$

where P_i is the row matrix of gray multivariate weighted normalized coefficient.

Finally, after processing columns of data with matrix, using the principle of maximum membership:

$$P_{\max} = \max_i \{P_i\}, \tag{5}$$

as the forecast conclusion of grey comprehensive evaluation.

4. CHECKOUT AND ANALYSIS OF THE METHOD

A computer program of quantitative evaluation of diagenetic reservoir facies was established, and the 137 samples were evaluated, the rate of accuracy, of returned classification using methods of mutual test, reached to 91.2%, and the accuracy and availability of the method were confirmed.

Figure 2 shows evaluation result of the diagenetic reservoir facies with logging response characteristic parameters in Shan 1 of the Z29 well. Number 43, 44, 45 layer were evaluated into the diagenetic reservoir facies of II, IV, III. Number 43 layer was tested, daily gas 1.75×10^4 stere, which reflected the effectivity of classification of diagenetic reservoir facies with the method.

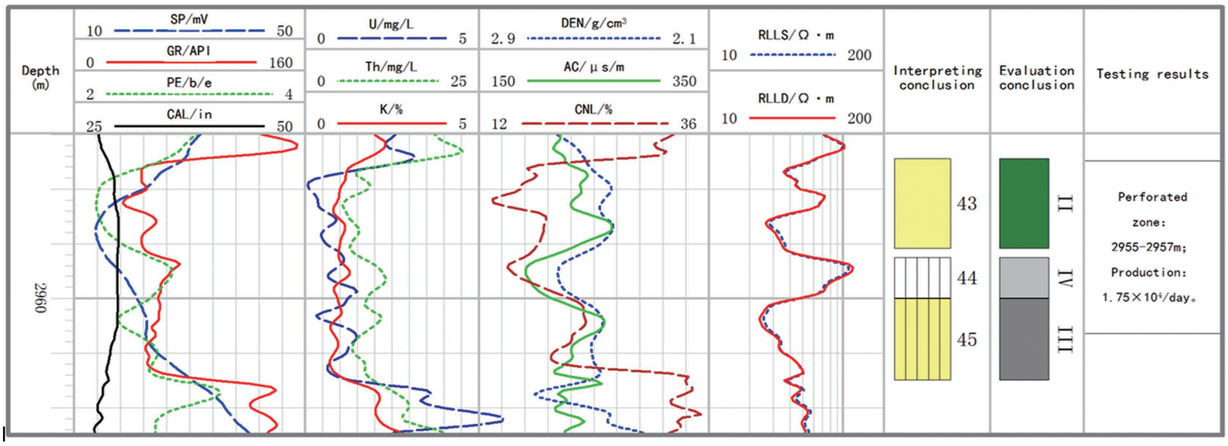


Figure 7
The Evaluation Result of the Diagenetic Reservoir Facies With Logging Response Characteristic Parameters in Shan 1 of the Z29 Well

CONCLUSION

(a) Density and acoustic logging have an obvious difference in the distribution and range of the classification diagenetic reservoir facies, being the most sensitive to classify diagenetic reservoir facies. Spontaneous potential logging and the gamma spectroscopy potassium logging are sensitive to identify diagenetic reservoir facies. Resistivity logging is relatively sensitive. Different logging parameters have different sensitivities.

(b) A comprehensive evaluation index system of diagenetic reservoir facies logging multi-parameters quantitative classification was established with the results of comprehensive analysis and evaluation of different categories of diagenetic reservoir facies logging response characteristics and the sensitivity of heir parameters. Non-digitalized problems of diagenetic reservoir facies evaluation was solved by the digitalization method of logging multi-parameters.

(c) A computer program of quantitative evaluation of diagenetic reservoir facies was established, and the 137 samples were evaluated, the rate of accuracy, of returned classification using methods of mutual test, reached to 91.2%, and the accuracy and availability of the method were confirmed.

REFERENCES

[1] Jing, C., Pu, C. S., & Zhou, Y. (2014). Quantitatively evaluating relatively beneficial reservoir of tight gas reservoirs based on diagenetic reservoir facies log response feature. *Natural Gas Geoscience*, (5), 657-664.

[2] Zou, C. N., & Tao, S. Z. (2008). Genesis, classification and evaluation method of diagenetic facies. *Petroleum Exploration and Development*, (5), 526-540.

[3] Wang, R. F., & Chen, M. Q. (2007). Quantitative analysis of porosity evolution during the reservoir sedimentation-diagenesis. *Acta Geological Sinica*, (10), 1432-1438.

[4] Song, Z. Q., Wang, R. F., & Sun, Y. (2011). Based on the quantitative classification mode of diagenetic reservoir facies to filter relatively excellent quality. *Acta Sedimentologica Sinica*, (1), 88-96.

[5] Wu, X. C., Tang, J., & Ren, L. Y. (2012). Diagenetic facies and high-quality reservoir study of Shanxi-2 member in Jing bian gas filed, Ordos basin. *Narural Gas Geoscience*, (6), 1004-1010.

[6] Song, Z. Q., Wang, J., & Lu, X. W. (2006). An quantitative assessment method of the diagenetic reservoir facies in extra-low permeability oil-gas reservoir. *Petroleum Geology and Recovery Efficiency*, (2), 21-23.

[7] Chu, M. J., Guo. Z. Q., & Qi, Y. L. (2013). Quantitative diagenesis and diagenetic facies analysis on Chang 8 reservoir of Yanchang formation in Ordos basin. *Natural Gas Geoscience*, (3), 477-484.

[8] Yang, H., Fu, J. H., & Wei, X. S. (2005). Characteristics of natural gas reservoir formation in E'erduosi Basin. *Natural Gas Industry*, (4), 5-8.

[9] Luo, J. L., Liu, X. H., & Lin, T. (2006). Impact of diagenesis and hydrocarbon emplacement on sandstone reservoir quality of the Yanchang formation (Upper Triassic) in the Ordos basin. *Acta Geological Sinica*, (5), 664-673.

[10] Cheng, Z. G., Song, Z. Q., & Jing, C. (2012). Classfication and characteristics of reservoir diagenetic facies for tight gas reservoir in eastern area of Sulige. *Fault-Block Oil & Gas Field*, (5), 577-582.

[11] Song, Z. Q., Lei, Q. H., & Liu, D. F. (1997). A study on quantitative reservoir evaluation norms and weight coefficient. *Logging Technology*, (5), 351-355.