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Performance of the synergetic wavelet transform and modified K-means clustering in lithology classification using nuclear log

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ABSTRACT

Accurate lithology identification is fundamentally crucial to reservoir evaluation from geophysical well logs. However, the traditional way of lithological identification is carried out in laboratory, which is not only expensive, but also time consuming in its interpretation. In this study, the synergetic wavelet transform and modified K-means clustering techniques are performed to classify metamorphic rocks from Chinese Continental Scientific Drilling Main Hole (CCSD-MH). At the beginning, different wavelet functions in different well logs are presented to detect lithologic interfaces. Meanwhile, the Haar wavelet and GR are determined to be the optimum wavelet function and well log, and the range of the optimum scales is about 8–15 m in the reference well. After that, a fast and practical K-means clustering algorithm is employed to make a classification of stratigraphy into 5 groups, which are demarcated from the performance of wavelet transform. The results achieved are in accordance with the stratigraphic column and have a higher accuracy compared to the previous studies, indicating that the combination of the wavelet transform and modified K-means clustering can improve the accurate rate for the classification of metamorphic rocks in CCSD-MH.

1. Introduction

On petroleum exploration and exploitation, the lithological characterization description is routine and essential work in dealing with geophysical and geological data. Well logs, which can reflect the physical properties of the subsurface material, are useful for the analysis of lithological characterization. However, the inherent complexity of well logs which is complicated and diversified makes well log interpretation difficult (Crain, 1986; Dewan, 1983). Traditionally, most previous analysis of well logs involved direct interpretation through visual inspection and comparison between different well logs which depends on the experiences of the workers (Chandrasekhar and Eswara Rao, 2012). Also, the detailed lithological characterization description can be obtained by direct measurement of cores in laboratory, while the core recovery is time consuming and expensive (Chang et al., 2000).

To address this issue, recently many lithology identification methods have been proposed. The most important of these is signal processing technique, such as Fourier analysis (Weedon, 2003), Walsh transform (Lanning and Johnson, 1983; Maiti and Tiwari, 2005), and wavelet transform (Bolton et al., 1995; Guyodo et al., 2000; Briqueu et al., 2010; Arabjamaloei et al., 2011). Lanning and Johnson (1983) were the first time to apply the Walsh transform, which is a low-pass filter method, to analyze well logs for detecting the rock boundary. They used the depth corresponding to the beginning of the data as the first boundary value, however, the first step may not always be the boundary. After that, Maiti and Tiwari (2005) performed the Walsh transform in analyzing well logs to develop an automated method to detect the lithologic boundaries, and with the specific criteria. The Fourier analysis can only tell whether or not some particular frequency (representative of formation) of interest are present in the signal, and thus they fail to explain which frequencies (formations) occur at what depths (Chandrasekhar and Eswara Rao, 2012). Wavelet transform of well logs can detect the formation interfaces, and providing the thickness and spatial localization of different formations.

Pan et al. (2008) analyzed geophysical well logs though wavelet transform and Fourier transform technique, and obtained the similar formation interfaces. However, their method can only work on the well log signals which are both fluctuation and intensity. Chandrasekhar and Eswara Rao (2012) performed different wavelet functions on different well logs to identify formation interfaces. And they found that Gauss 1 was the most appropriate wavelet for the determination of the space-location of formation boundary. Recently, Teresa et al. (2013) applied wavelet functions analysis in well logs (radioactivity, resistivity and sonic) to identify

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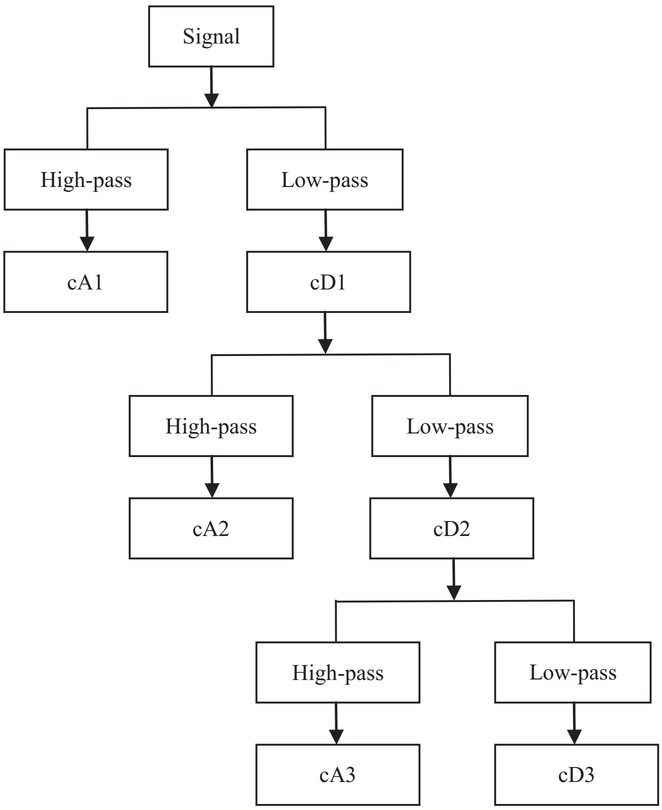

Fig. 1. Block diagram for decomposition into three level of a signal.

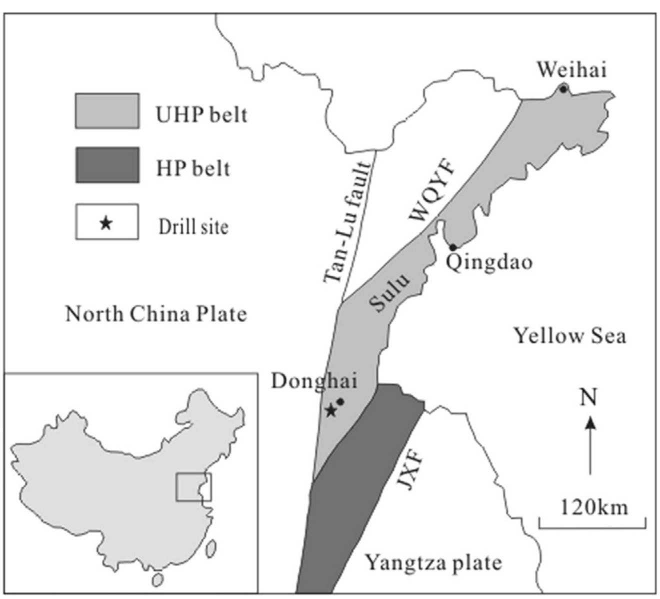

Fig. 2. Simplified geological location of CCSD-MH by a star symbol (Zhang et al., 2006).

lithology. They analyzed that the rocks types can be identified based on the correlations between color patterns represented in wavelet scalograms and electro-facies associations, but without giving the specific criteria.

In the present study, we have proposed the application of the synergetic wavelet transform and modified K-means clustering technique to classify metamorphic rocks using CCSD-MH drilling data. Firstly, we have performed the continue wavelet transform (CWT) which applied different wavelet functions (Haar wavelet, Symlet2 wavelet, Morlet wavelet, Gauss3 wavelet) in different well

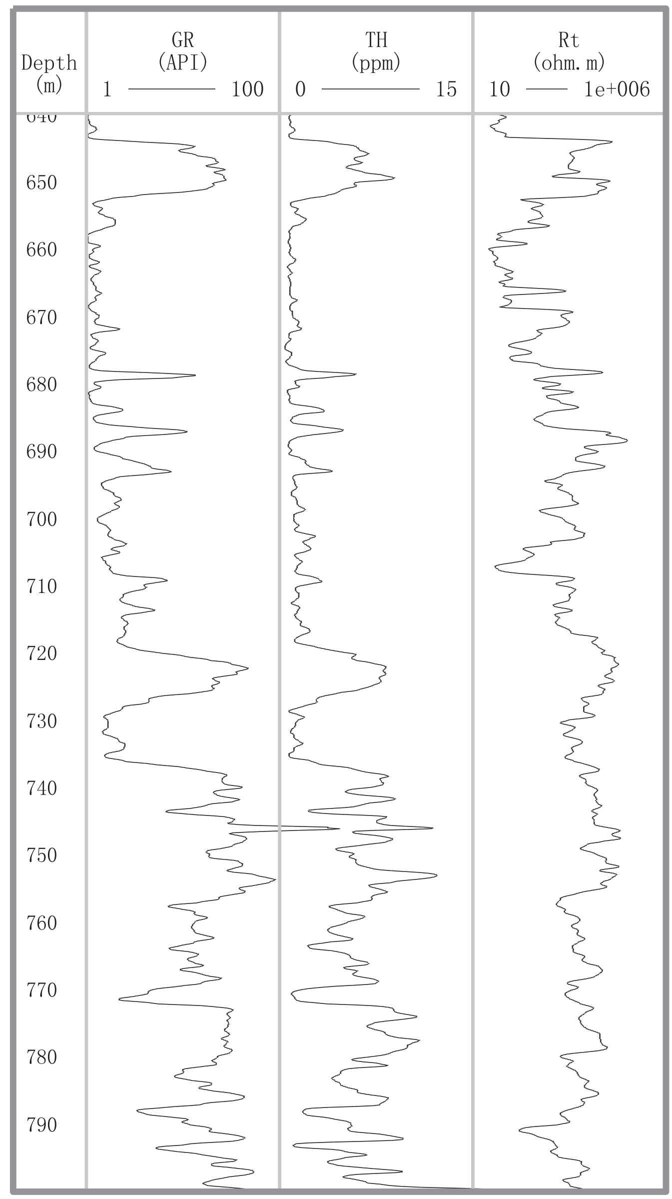

Fig. 3. Well logs (GR, TH and Rt) of CCSD-MH, the depths from 640.0 to 800.0 m.

logs (GR, TH, Rt) from CCSD-MH for formation interfaces detection. Also, discrete wavelet transform (DWT) in GR well log was also displayed, the formation boundary information was included by the detailed coefficients. After that, a fast and practical K-means clustering algorithm was employed to make a classification of stratigraphy into 5 groups, which were demarcated from the performance of wavelet transform. All results were compared and corroborated by core data. Finally, the data of the whole CCSD-MH with depths from 110 to 5000 m were processed, and the accuracy of the results have been significantly improved.

2. The methodology of wavelet transform

2.1. wavelet transform

The kernel function of wavelet transform is defined as follow (Pan et al., 2005; Yu, 2013):