Rapid detection of bedding boundaries based on borehole images

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Abstract

The bedding is an important sedimentary structure phenomenon. The rock bedding structure, the direction of sedimentary transportation and the ancient sedimentary environment analysis can be studied by extracting the bedding boundaries and dips. Electric imaging logging can provide rich information of a borehole wall and circumference, which reflects formation resistivity variations. The bedding boundaries are detected by using the electrical imaging logging data based on an image recognition method in this paper. On an oriented, unwrapped image of a cylindrical borehole, the trace of a planar-bedding boundary appears as a sine wave. The bedding boundaries are detected by the recognition of the sine curves in borehole image. The influence problems of bedding boundary detection caused by fractures and other geological events are solved by statistical analysis technology. Through the techniques of the slope fitting, the speed and accuracy problems of bedding boundary detection are solved, which has good anti-interference performance. The processed results of the theoretical models and the measured borehole images at the varied dip segment indicate that the detected bedding boundaries reflect the real situation, which are identical to those derived by the Autodip.

Keywords: imaging logging, bedding boundary, object detection, image recognition

1 Introduction

Sedimentary bedding is an important sedimentary structure along the vertical evolution of sedimentary structures, through mineral composition, structure, colour or textures, which is a reflection of the fluid flow direction and hydrodynamic mechanisms and biologic activities at the depositional moment. The extracted bedding boundaries and dip trends can study the direction of sedimentary transportation, ancient sedimentary environment and the favourable exploration object [1].

Electrical imaging logging is an advanced logging technology providing a lot of information of a borehole wall and circumference, in which the conductivity differences of various geological characteristics are the physical basis of electrical imaging logging. Electrical intensity measurements reflecting formation resistivity variations are converted into variable-intensity (gray-scale) images. By convention, black is low and white is high resistivity. Some formation boundaries, fractures and structure are identified from electric imaging logging. Borehole images can be quantitatively processed through image processing techniques to extract parameters of the bedding and dips [2]. Currently, there are some electrical imaging logging tools, such as Schlumberger FMI, Atlas StarII and Halliburton EMI, which all have the image mode and the dip mode. For example, FMI have three working modes: the full well wall mode, the four-pad mode and the dip mode [3]. The Full well wall mode can obtain greater coverage and high-resolution images of the borehole. Compared to the full well wall mode, the speed of the four-pad mode measurement is higher, the cost is lower and the coverage is the half of the full well wall mode. Eight electrodes are only used in the dip mode to collect information of borehole formation, in which the effect is the same that in the dip meter.

Accurate identification of bedding boundaries and their dips is very important to the exploration of oil-gas resources, electrical imaging logging is an effective means of extracting the bedding boundaries and their dips. Due to the influence of the heterogeneity of rock structures, fracture and hole structures, sutures, fault and other complex geological background factors, the detected bedding boundaries are often distorted. So, three factors, the interference, the speed and the accuracy, need to be considered in the detection of bedding boundaries.

The bedding boundaries are detected by using the electrical imaging logging data based on an image recognition method in this paper, which is similar to the method proposed by S-J Ye. The algorithm consists of four main steps:

1) determining the direction of the bedding by statistical analysis technology;

2) fitting the sinusoid curves by using the bedding orientations based on the Least-Mean-Squares method;

3) optimizing the location of the sine curves based on the interactive shift technology;

4) defining the reliability criterion of the detected bedding boundaries based on the comprehensive quality index. Through statistical analysis technology, the influence problems of bedding boundary detection caused by fractures and other geological events are solved.

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Through the techniques of the slope fitting, the speed and accuracy problems of bedding boundary detection are solved.

2 The previous methods on the bedding dip detection

2.1 THE CORRELATION METHOD

When electric imaging logging is worked in the dip modes, some curves, such as conductivity, azimuth, radius or diameter, are obtained to calculate the formation dip and azimuth. The bedding dips are calculated by synthesizing one curve from multiple conductivity curves, combined with diameter and azimuth curves in the image mode. The morphology of the conductivity curves is similar in the same structure layer, and the formation dip can be calculated on the basis of the depth differences of the same bedding boundary. For example, the bedding dips are calculated by four six-arm bedding dip processing methods: the vector multiply method, the least square method, the clustering method and spherical imaging method, after taking out the dead electrodes and depth shift in Liu Yaowei paper [4]. Liu Yingming analysed the processing procedure of imaging logging data of STAR, and directly calculated the bedding dip using the imaging logging data by adopting the correlation analysis [5].

Different types of the bedding boundaries can fast extracted from the borehole images based on the side by side and pad to pad correlation. However, this method is very difficult to eliminate the affection of complicated geological background interference, such as fractures, and it cannot accurately determine the bedding boundaries, thus affects the precision of the bedding boundaries detection.

2.2 THE IMAGE RECOGNITION METHOD

The bedding boundaries are usually a set of parallel or nearly-parallel conductivity anomaly, and the abnormal width is narrow and uniform, which are often characterized by linear features. The bedding boundaries are continuous, similar and regular among different pads, which are a grey level change between the up and down images. A bedding boundaries perpendicular to the well presents a horizontal line, but a bedding boundaries inclined to the well presents a sine curve in a unfolded image [6].

Compared with fractures, the bedding boundaries in the imaging logging are numerous, therefore, the interactive processing method, in which three or more than three points on a bed boundary are selected to calculate its dip by fitting a sine curve according to the sine parameters, cannot be adopted [7]. Neither the time-consuming Hough transformation nor the Radon transformation method could be adopted to automatically extract dip parameters [8-10]. The fractures boundaries are accurately detected, and fast identified by the image processing analysis technology [11]. Shi Yongqian defined the rock structural bedding dip using 3D geometry mathematics methods according to the imaging logging, deviation well parameter [12]. Jean Pierre Leduc analysed the bedding boundaries automatically based on the image processing method by FMI data, with the help of the lithology and texture changing features [13]. Zhu Qiangjun et al. derived the bedding boundaries of the core image by the edge detection algorithm based on the fuzzy edge detection [14]. Jean-Noel Antoine et al. detected the bedding boundaries and dips in electric imaging logging by the edge tracing and matching method [15]. Firstly, the gradient field is extracted to get stream lines based on the boundaries tracing method, and derive boundaries from stream lines; then, the bedding boundary traces of the different pads are connected by the matching algorithm. However under the condition of complex background, accurate stream lines and traces of the bedding boundary are hardly gotten by the edge tracing method. T.Quiniou detected the bedding boundaries and derived the dips in the core images by using the edge detection and the adaptive Hough transformation method [16]. Although the Hough transformation method has a good robustness, it is very time-consuming. Thus, this method can be used to detect the relatively small number of fractures, but cannot derive the bedding boundaries in the imaging logging. S.Ye and Naamen Keskes et al. directly derived the bedding boundaries from the original electric imaging on each pad, then performed the edge matching and statistical analysis for the bedding boundaries on each pad [17, 18]. David J.Rossi derived the bedding dips using the edge detection and multi-target tracking method from imaging logging [19]. Compared with the Hough transformation method, these methods have a fast speed. But these methods directly derive the bedding boundaries based on the original electric imaging, which are influenced by the blank areas between each pad, the precision of the dip calculation is affected.

3 The rapid detection method of the bedding boundary

In the image of electrical logging, a plane which inclines with the well is shown as a sinusoidal line. Compared with the fractures, on the one hand, the bedding planes in the borehole image are often a set of parallel or nearly parallel conductivity abnormities, the abnormal widths are narrow, uniform, regular, which occur in group, the characteristics of adjacent bedding planes are similar. On the other hand, the number of bedding planes is large, therefore, the method of fitting the slope of the bedding plane is used to detect the bedding boundaries.

3.1 DETERMINATION OF THE BEDDING DIRECTION

The bedding direction is the local orientation of an image. In a given window, the pixels are gotten at the corresponding direction, and the grey variance is calculated on all straight lines at the same direction on each pad image. The minimum variance direction in all the straight lines is the bedding direction, which is shown in Figure 1. The calculation of grey variance is defined as follows:

$$Var_\theta = \sum_{i=1}^{M}\sum_{j=1}^{N}\frac{G_{ij}-\overline{G_i}}{M*N}, \qquad (1)$$

where, Var_θ represents the grey variance of all the straight lines in the direction θ; $\overline{G_i}$ represents the grey mean value of all pixels of the straight line *i* in the direction θ; G_{ij} represents the grey value in the straight line *i* and pixel *j* in the direction θ.

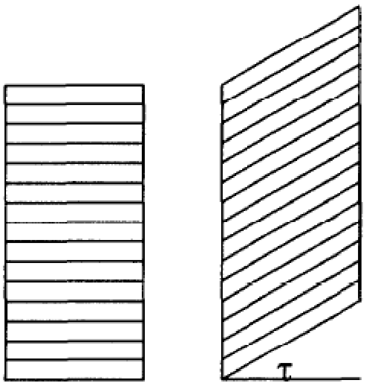


FIGURE 1 Estimation of the predetermined direction

3.2 THE FITTING OFSINUSOID CURVES USING THE BEDDING ORIENTATIONS

Considered the influence of fractures, caves and other electrical heterogeneity factors, it is hard to detect the trajectory coordinates of the bedding boundaries, therefore, the effective way of automatic calculation of the sine curves is the fitting of the sine curves based on the slope of the sine curves, not based on the trajectory coordinates of the sine curves. The tangents of the sinusoid can be approximated by the tangents of the bedding orientations. The bedding sine curves are then fitted by the tangents of slope.

In the four parameters of the standard sinusoid curve, two parameters are already determined, respectively, the angular frequency $\omega = \frac{2\pi}{T}$ and the offsets y_o, which is the height of the center line of the local window. Therefore, the fitting of the four-parameter sine curves is in fact that of the two parameters A and ϕ, the standard sinusoid curve is defined as follows:

$$y = ASin(\omega x + \phi) + y_o . \qquad (2)$$

Taking the derivative of the Equation (2), the slope is obtained as following:

$$T = \frac{dy}{dx} = A\omega\cos(\omega x + \phi) . \qquad (3)$$

Two parameters A and ϕ, are fitted by the Least-Mean-Squares method.

3.3 THE LOCATION OPTIMIZATION OF THE SINE CURVES BASED ON THE INTERACTIVE SHIFT TECHNOLOGY

In the process of defining the sine curve, because the local direction is the trend direction of the bedding, the sine curve based on the fitting of the curve slope is located in the center of the given window, not in the bedding boundaries. There is a mismatch deviation between the sine curve and the bedding boundary, but the sine curve can be shifted to the bedding boundaries by searching the maximum image grayscale contrast. In a general way, the extreme position of the differential curve is corresponding to the bedding boundary. Therefore, the differential curve is gotten by the filtering processing of the gray value in the vertical direction, then, the detected sine curve is moved to the extreme value position of the differential curve

3.4 THE RELIABILITY CRITERION OF THE DETECTED BEDDING BOUNDARIES BASED ON THE COMPREHENSIVE QUALITY INDEX

Considered the influence problem of some geological events in the bedding boundaries detection, the reliability measure of the detected sine curves is a very important problem.

A comprehensive confidence measurable parameter *Q*, which includes the sine fitting error, the taken pads number and the contrast of sine curve, is defined as following:

$$Q = Q_C \times Q_E \times Q_N , \qquad (4)$$

where, Q is the comprehensive quality index, which reflects the reliability of the detected sine curve; Q_C is the contrast of the sine curve, which the sum of first-order differential value along the sine curve; Q_E is the fitting error of the least mean squares; Q_N is the taken pads number in the fitting of the sine curve.

4 The processing results analysis

4.1 ANALYSIS ON THE THEORETICAL MODEL

In order to evaluate the effectiveness of the bedding boundaries detection method, a kind of formation theoretical model is designed, which includes four types of dip vector modes: the green mode (the dips do not change with the depth), the red mode (the dips increase with the increasing depth), the blue mode (the dips decrease with the increasing depth) and the Chaotic mode (the dips change irregularly). The theoretical model is shown in Figure 2, and the red curves in Figure 3 are the detected bedding boundaries using the method described above. Compared Figure 2 with Figure 3, it can be seen that other detected boundaries are consistent with that in the designed model except that the first (top) detected bedding boundary is affected by the blank formation.

FIGURE 2 The theoretical formation model

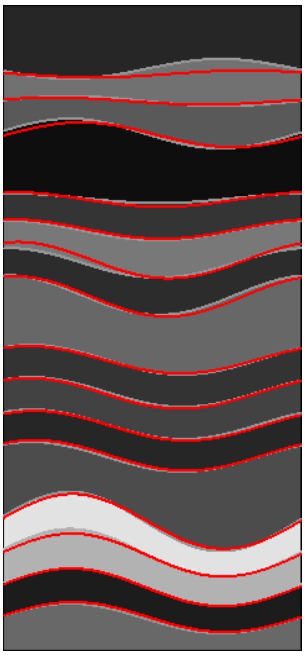


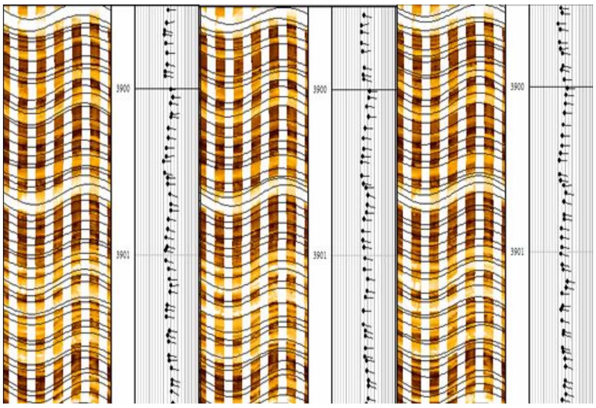
FIGURE 3 The detected formation boundaries

4.2 ANALYSIS ON THE REAL BEDDING BOUNDARIES

In order to verify the validity and practicability of the above algorithm, the bedding boundaries detection are processed in borehole images in the following situations, which results are compared with that obtained by the AutoDip.

4.2.1 Analysis at different window lengths

Figure 4a, 4b and 4c are the detected bedding boundaries at different window lengths of 90, 120, and 150, respectively. From Figure 4, it can be seen that there are similar results in above three window lengths. That is to say, the detection results will be not affected by the window length.



a) Window Length=90 b) Window length=120 c) Window length=150

FIGURE 4 Results at different window length

4.2.2 Analysis at the varied dip segment

Figure 5 shows the processed results at the varied dip segment. There are nearly 5 dip modes in this segment, which are the blue mode, the red mode, the green mode, the blue mode and the green mode in turn from the top to the bottom. The detected results of this algorithm are shown in the left of Figure 5, the results of the AutoDip are in the right. It can be seen from Figure 5, the dip modes basically reflect the real situation, which are consistent with those obtained by the AutoDip.

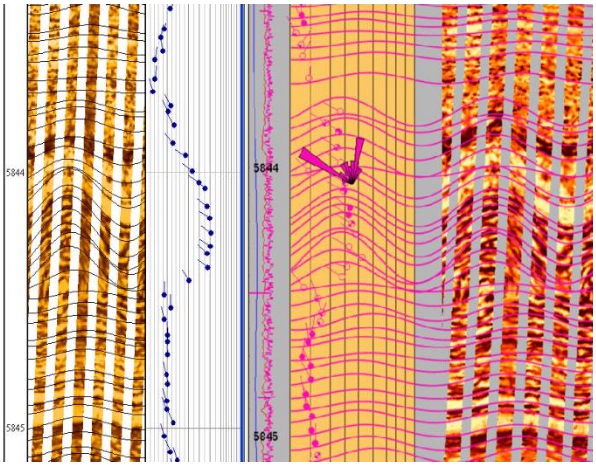


FIGURE 5 Comparison of the processed results at the varied dip segment

5 Conclusions

1) The bedding is an important sedimentary structure phenomenon in sedimentary rocks. The rock bedding structure, the direction of sedimentary transportation and the ancient sedimentary environment analysis can be studied by extracting the bedding boundaries and dips, which would be helpful in searching for favorable exploration direction.

2) Electric imaging logging is one of the advanced logging technique, which can provides rich information of a borehole wall and circumference, not only can

qualitatively identifies the various boundaries, fractures and structural configurations from the borehole images, but can derive the bedding boundaries and dips by quantitatively image processing and analysis using image processing technology.

3) The bedding boundaries are detected by using the electrical imaging logging data based on an image recognition method. The influence problems of bedding boundary detection caused by fractures and other geological events are solved by the statistical analysis technology. Through the slope fitting technique, the speed and accuracy of the bedding boundary detection method are solved, which has good anti-interference performance. The processed results of the theoretical models and the measured borehole images at the varied dip segment indicate that the detected bedding boundaries reflect the real situation, which are identical to those derived by the Autodip.

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