Application of Well Logging Data in Fault Identification

Ruiwen Dai, Xuewei Li

School of Earth Science and Engineering, Shandong University of Science and Technology, Qingdao 266590, Shandong, China.

Abstract

In this paper, the methods of fault identification based on logging data are summarized based on the previous research results. The dip Angle vector data combined with lithostratigraphic correlation is the main method of logging fault interpretation. Different faults have different variation rules reflected in the dip Angle vector map. FMI imaging logs can roughly determine the presence of faults by using repeated stratigraphic features combined with core and seismic tectonic interpretation. When it is difficult to determine the location of a fault by a certain logging curve, the combination characteristics of different logging curves can be established to find the common law from the combination of RN and GR curves, and then the fault can be identified. The fault can be identified by the electrical imaging data through the judgment and analysis of the phenomenon of the associated structure of the fault. Comprehensive use of electrical imaging and dip log data to identify faults. The position of faulted structures and faults can be determined by using the standard layer acoustic time difference anomaly method. For the variation of geophysical characteristics (such as acoustic time difference) of the standard layer in the study area, the fault can be identified.

Keywords

Logging Method; Fault Identification; Well Logging Curve; Logging Data.

1. Introduction

As is known to all, logging data have multiple interpretations, so logging interpretation needs to be combined with a variety of data for comprehensive analysis. For a long time, the dip Angle vector data combined with litho-stratigraphic correlation is the main method for logging fault interpretation. By combining core calibration with conventional logging data constraints, the visual images provided by the electric imaging logging can be widely used in geological interpretation by matching the electrical imaging logging information with geological features. Different lithologies have different geophysical characteristics, so the morphologic characteristics reflected by logging curves are different, and different logging curves are formed in different intervals.Based on the above principles, through the comparison of the same or similar combination characteristics of logging curves, the repetition or absence of strata can be determined, and then the existence of faults, their properties and locations can be distinguished. The fault associated structures mainly include fault fracture zone, associated joint, traction fold, rub and step, among which fault fracture zone, associated joint and traction fold can be easily identified on the imaging map and can be used to analyze the existence of faults. The sedimentary environment of the standard beds in different locations is the same. After diagenesis and later tectonic movement, the physical properties of the standard bed will change with different locations and continue to change with different intensity of tectonic movement. When there is no fault in the zone, the acoustic time difference of the standard layer will follow a trend surface and change. When there is a fault in the area, it will no longer follow a trend surface due to the great difference of the acoustic time difference between the standard layers.

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2. Dip vector mapping method

Formation dip log mainly calculates the formation dip and dip of the corresponding depth, and then directly expresses it with the log vector graph. On the vector graph, the abaxial axis at the end of each vector arrow is the formation dip Angle, the vertical axis is the drilling depth, and the direction of the arrow indicates the inclined azimuth. The combination model theory of petroleum geology points out that different faults have different change rules in the vector map.

According to the corresponding relationship between the formation dip vector points and logging depth, the variation characteristics are summarized into four basic models (Fig.1), which are the theoretical basis for the evaluation of formation dip data. At the same time, the geological features such as faults can be further determined by combining the imaging data with the characteristics of dip patterns.

The red pattern indicates that the directions of two or more adjoining tadpoles remain the same but the angles increase with increasing depth. This pattern is formed by sediments deposited on the surface of the slope, or by sedimentary rocks that change the tilt after the action of quiescence.

The blue pattern means that the orientation of two or more adjoining tadpoles remains the same and the Angle decreases with increasing depth. This is mainly caused by the strata on top of the precalluvium. The direction of the blue pattern produced by the foredeposit indicates the direction of water flow during deposition.

The green pattern refers to the fact that two or more tadpoles adjacent to each other have the same dip Angle and orientation, which is caused by the formation of parallel interbedding and horizontal deposition followed by tectonic uplift. The green pattern is the only one that can indicate the structure at present, and it is also the one with the least scattering on the tadpole map.

Disturbance mode refers to the random change of inclination and azimuth of adjacent tadpoles. It is formed by sediments in high-energy environments, such as shallow water, strata altered by biodisturbance, and strata subjected to sedimentation and movement.

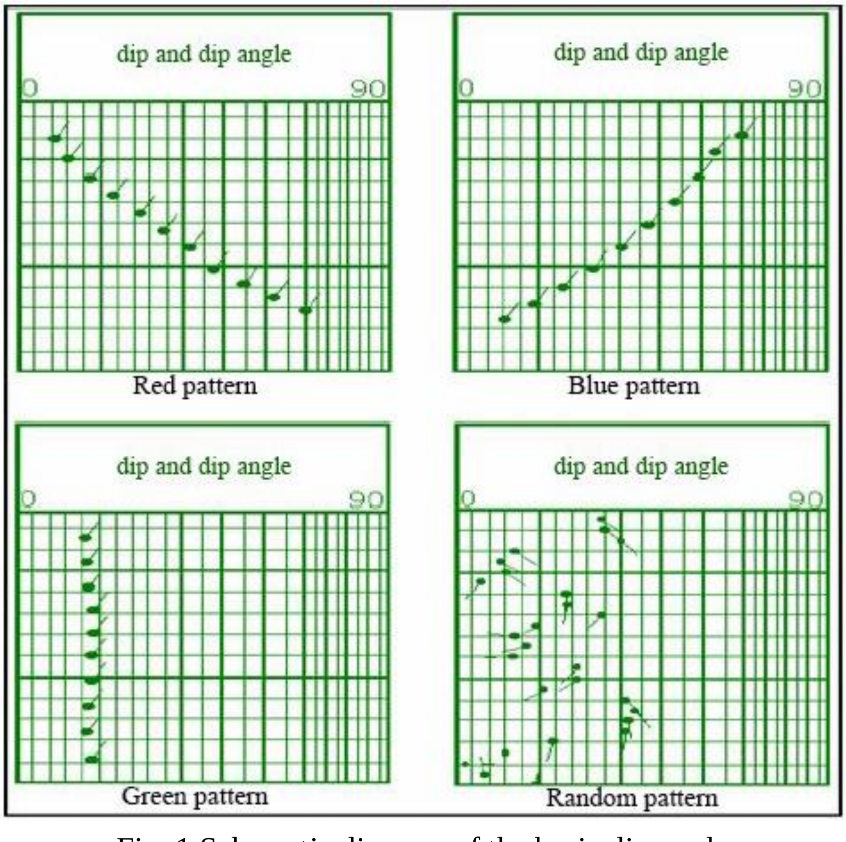

Fig. 1 Schematic diagram of the basic dip mode

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The fault plane is usually a fracture zone rather than a surface, and the width of the fracture zone may be several centimeters or even tens of meters. In the case of large width, it is difficult to pick up the occurrence or disorderly tendency of the strata due to the complexity of the strata in the broken zone. For faults with no deformation on the fault plane or with no traction structure on both sides of the fault, the dipping vector map shows the same green pattern as the monoclinal structure (Fig.2a). Dipping logs cannot be used to determine such faults. If the stratum is hard, the rock strata will form a fracture zone along the fault plane, and the bedding in the fracture zone is basically undeveloped or relatively chaotic. The dip data shows a green-to-chaotic green-to-green pattern (Fig.2b).

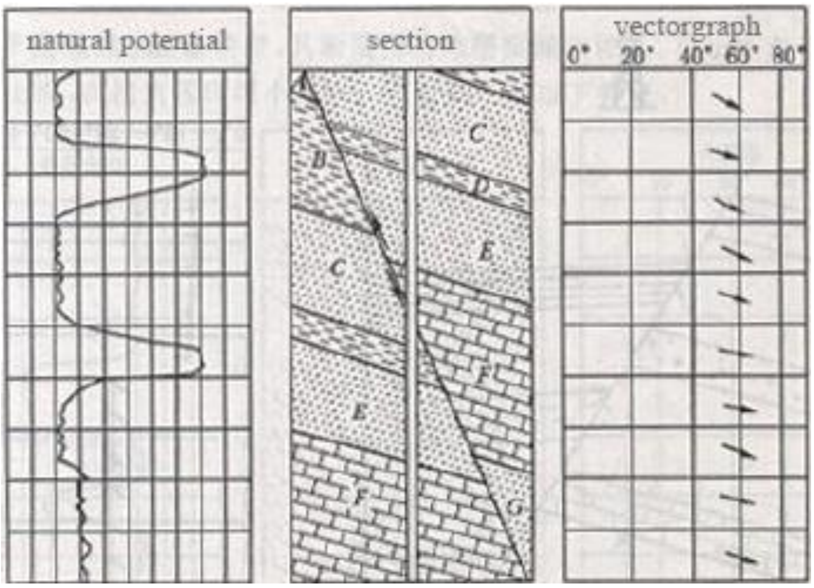

Fig. 2a Schematic diagram of fault-plane without deformation

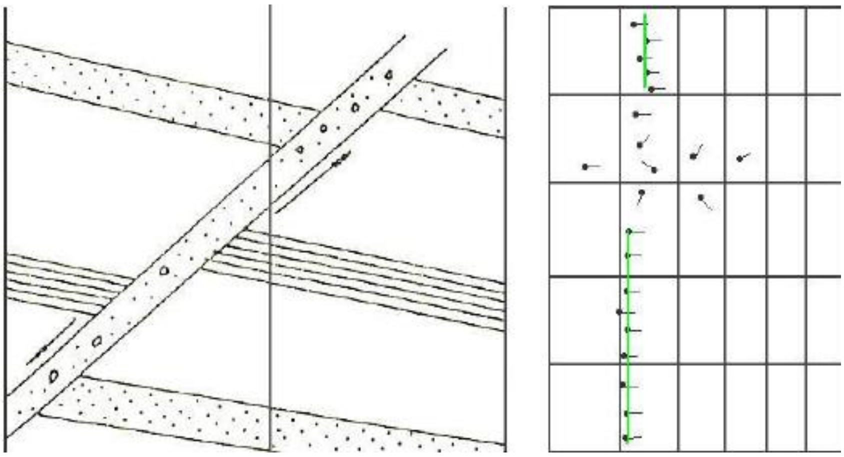
Fig. 2b Fault schematic diagram of fracture zone

When a fault is formed in a plastic formation, the footwall of the fault moves and rubs along the fault plane, creating deformation near the section and usually producing what is known as a drag (or traction) fault.

Normal fault: the fault plane tendency is the same as the stratigraphic tendency: the vector points show a green-red, blue-green pattern (Fig.3a). The fault plane dips are opposite to the stratigraphic dips: vector points are usually in a green-blue-red-green pattern (Fig.3b). Reverse fault: the fault plane dipping is the same as the stratigraphic dipping: the vector points are usually green - red - blue - green pattern. The fault plane dip is opposite to the stratigraphic dip: vector points are usually green - blue - red - green. Overthrust fault: the overthrust fault with fault plane dip Angle less than 4-5° is called overthrust fault: vector points are usually green-red, blue-green (Fig.3c) [1].

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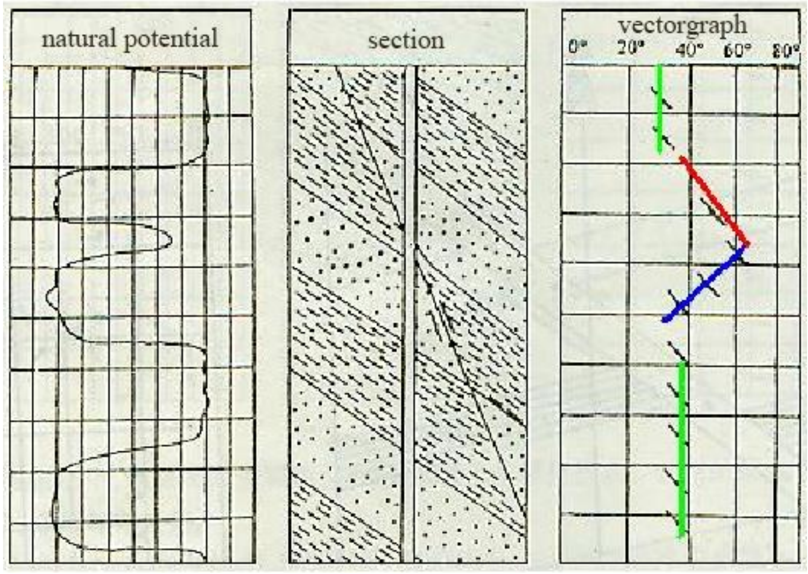

Fig. 3a Diagram of faults with the same fault plane dipping and stratigraphic dipping

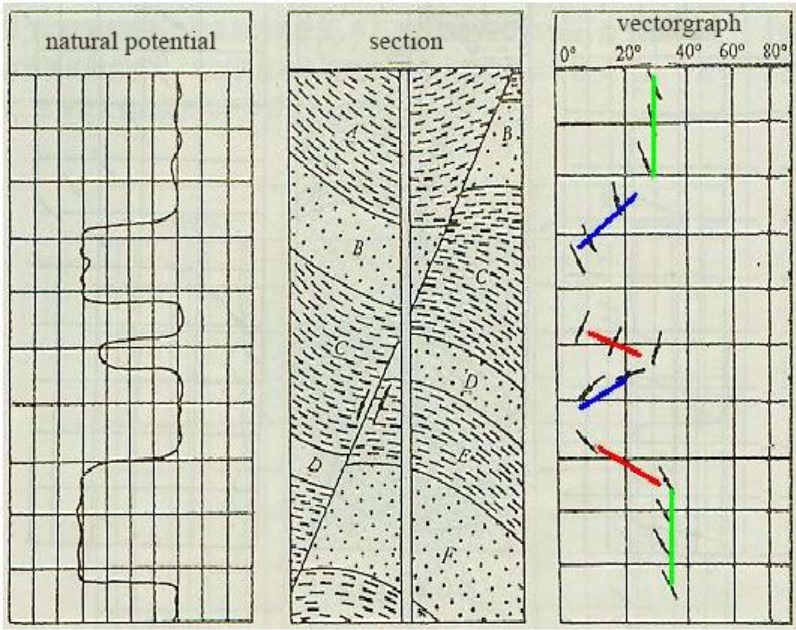

Fig. 3b Diagram of fault plane dipping opposite to stratigraphic dipping

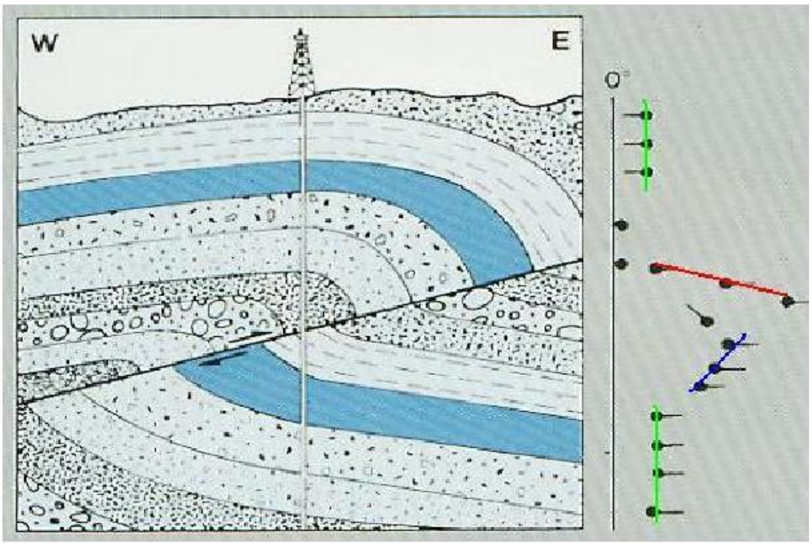

Fig. 3c schematic diagram of overthrust

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3. FMI imaging logging

FMI imaging logging mainly reflects the difference of physical parameters of resistivity through the change of image characteristics and geometry, so as to reveal the difference of different lithology and sedimentary structure of the formation. FMI imaging logging is an important logging tool for geological research, which can provide important information for the interpretation of sedimentary and structural phenomena [2]. In the case of insufficient coring data, predecessors used the advantages of continuity and intuitiveness of FMI imaging logging in vertical direction to effectively apply the phenomena of fractures, faults and sedimentation in strata and solve a large number of geological problems.

Under the condition that the lithology of the stratum is relatively uniform and the longitudinal change is not obvious, the existence of faults can be roughly determined by the combination of tectonic seismic interpretation.Taking the X2 well as an example [3], the stratigraphic picking and occurrence statistics of the well show that the stratigraphic dip changes significantly in the longitudinal direction. The specific change features are (Fig.4): in the middle and upper well sections of the formation at 6255-6398m, the stratigraphic dip is SW and the dip Angle is 8°-16°;In the middle and lower sections of the formation at 6398-6424m, the formation interface is not clear and the fractures are relatively developed (Fig.5). In the lower section of the formation from 6424 m to 6460 m, the dip of the formation is opposite to that of the upper section. The dip of the formation is NE, and the dip of the formation increases slightly downward, generally ranging from 8° to 26°.According to the vertical characteristics of formation occurrence, it is believed that the well was drilled into a fault. Due to the action of the fault, the formation occurrence of the upper and footwall wall is different. It is speculated that the depth of fault fracture zone is 6338-6424 m.

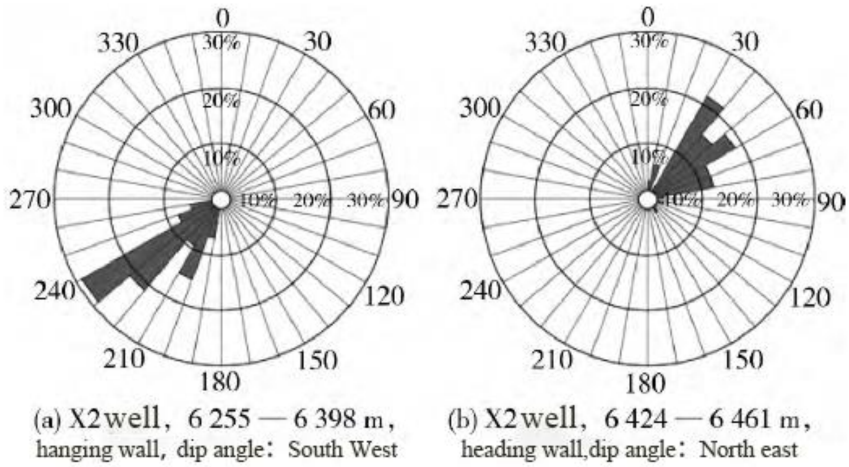

Fig. 4 Fault dip-orientation interpretation diagram of Well X2

Fig. 5 FMI image features of the fault fracture zone of well X2

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In general, the X2 well first drilled into the uplifting wall of the fault, and then drilled into the fault fracture zone, which is a blank zone with concentrated stress, developed fractures and unclear stratigraphic interface. Finally, below 6424 m, the well encountered the foothall of the fault.Since the lithology of the whole FMI imaging logging interpretation section is basically the same, and the image features of the two fault walls are similar, the existence of the fault cannot be completely determined. However, in combination with the structural map of the top surface of Yingshan Formation in the X2 well area (Fig.6), there is a NE -- SW striking fault near the X2 well. Combined with the above analysis, it is considered that the well was drilled into a small fault associated with the fault.

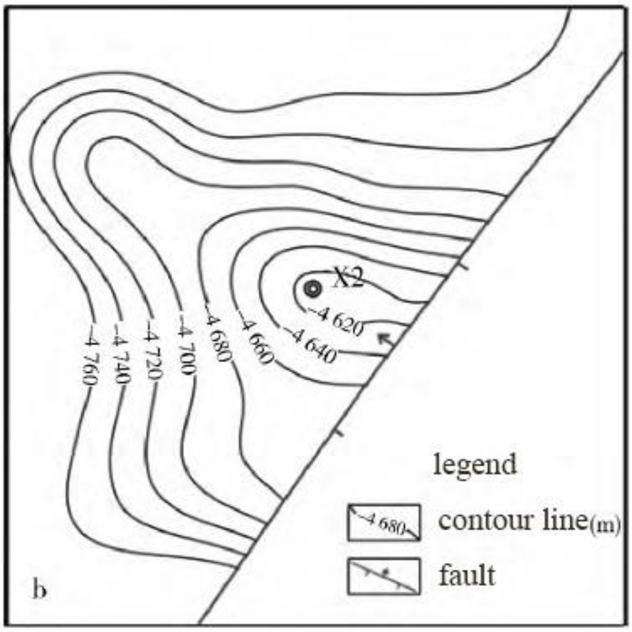

Fig. 6 Structural map of the top surface of Yingshan Formation in well X2

4. Rn and GR curve combination

Different lithologies have different geophysical characteristics, so the morphologic characteristics reflected by logging curves are different, and different logging curves are formed in different intervals. On the contrary, the same interval, within a certain range, generally has similar material sources, transport media, sedimentary environment and diagenetic conditions, and therefore has the same or similar lithologic assemblage, and should also have the same or similar assemblage characteristics on the logging curve. Normal fault causes obvious shortening or missing of the formation, while reverse fault causes obvious increase or repetition of the formation. This phenomenon will also be reflected on the logging curve, resulting in missing or repeating of logging curve combination [4].Based on the above principles, through the comparison of the same or similar combination characteristics of logging curves, the repetition or absence of strata can be determined, and then the existence of faults, their properties and locations can be distinguished.

When it is difficult to determine the location of a fault from a single logging profile, a combination of different logging profiles can be established to find a common pattern and then a fault can be found.As shown in Fig.7, borehole ZKY1403 is a complete formation with obvious logging curve combination features, and the combination of RN and GR curves presents regular changes.By comparing the combination of RN and GR curves of ZKY1402 and ZKY1401 with the curve characteristics of ZKY1403, it can be found that the peak value of GR curve increases suddenly at A, A', and A'', which are the same contrast points. When the curve characteristics change, Dotted lines P and P' are used to separate the logging curve from the lithologic column. This is the break point, and it extends to the lithologic column of ZKY1403 borehole.By comparing the combination

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characteristics of the lower curve, it is found that at B, B' and B", the GR curve has a sharp peak, which is taken as the same contrast point, and dotted lines M and M' are drawn. Fault drop is the depth difference of P, P', M and M' curves on ZKY1403 borehole.

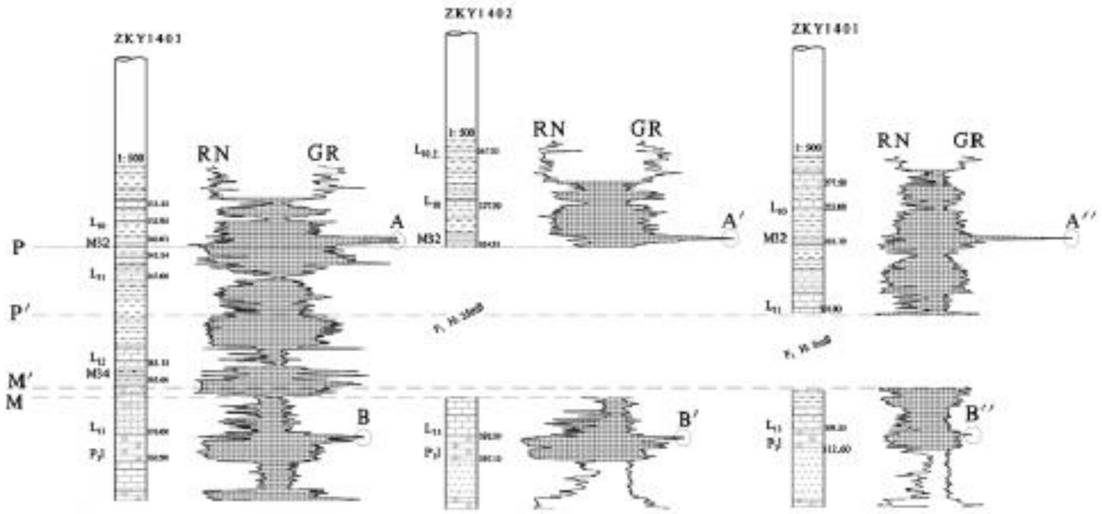

Fig. 7 Normal fault contrast diagram of ZKY1403, ZKY1402 and ZKY1401 boreholes

5. Imaging method of fault associated structure

Fault associated structures mainly include fault fracture zone, associated joint, traction fold, rub and step, among which fault fracture zone, associated joint and traction fold can be easily identified on the imaging map and can be used to analyze the existence of faults [5].

Fault contact is a tectonic contact. The interface between intrusive rock and surrounding rock is a fault plane or fault zone. Electrical imaging formation in fault contact relations on the graph, there are obvious changes of dip vector, both can sufficient conditions for fault interpretation, fault contact on imaging figure, like shooting contact, sedimentary contact, the depth of the same strata appear discontinuous or interrupt phenomenon, but the sedimentary contact is usually characterized by unconformity surface, has regional; The intrusive igneous rocks are lithologically obvious, with bright yellow (high resistance) and cooling shrinkage joints on the image.

Most fracture zones in the dip vector map are chaotic mode or no vector points, while the strata in the imaging data will show bedding deformation, fracture or visible fault breccia and other evidences reflecting the existence of faults.

Traction fold is a common associated structure of fault, which is the plastic bending of the strata on both sides of the fault during fault formation. The dip vector model method is an indirect method for fault interpretation and identification, and the electric image method is an indirect method for fault interpretation and identification, while the electric image method can directly observe the subtle geological structure changes.

The associated joints of faults are caused by faults. The fractures near the faults appear regularly and in groups on the electrical imaging, and the occurrence is nearly the same, showing sinusoidal linear dark stripes. The associated joints can be used as the basis of analysis and interpreted by combining other data.

6. Standard layer acoustic time difference method

The standard beds are widely distributed with clear lithologic and electrical characteristics, which are easy to identify in stratigraphic correlation. Its characteristics are: in the adjacent well section of the target layer, to ensure that the fault passes through the layer, and to ensure that the logging

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environment between the standard layer and the target layer is similar; The lithology is stable and widely distributed in the whole area, the formation thickness is large, and the lithology and logging response characteristics are obvious (curve shape).

The depositional environment of the standard beds at different positions is the same. After diagenesis and later tectonic movement, the physical properties of the standard bed will change with the location, and continue to change with the intensity of tectonic movement. When the tectonic movement is gentle, the geophysical characteristics (such as acoustic time difference) are similar due to the similar late transformation of different positions; When the tectonic movement is intense, the compaction degree and physical properties are different due to the different late reformation, which leads to the difference of geophysical characteristics. That is to say, when there is no fault in the area, the acoustic time difference of standard layer will follow a certain trend surface and change; When there are faults in the area, because of the great difference of acoustic time difference between the standard layers of fault blocks, it will no longer follow a certain trend surface and change.

When there is no fault structure in the area, the variation of acoustic time difference of standard layer can meet the variation of a trend surface. In the trend surface analysis, the distribution of the residual value is random, showing a normal distribution with zero mode on the histogram, and no local anomaly on the residual plane contour map, showing a random distribution.

When there is a fault structure in the area, the variation of acoustic time difference of standard layer no longer meets a certain trend surface. When the trend surface analysis is used to approach the value of acoustic time difference, the abnormal zone of acoustic time difference always appears near the fault, and this anomaly usually appears in pairs. On the residual frequency diagram, it is no longer the normal distribution with zero mode, but a local anomaly. In the residual isoline map, there is an abnormal zone of acoustic time difference, and its zero line position is the position of the fault on the structural map of the standard layer.

Because of the calibration error of logging tools, the logging data read from the logging curve can not be directly analyzed by the trend surface, so it is necessary to standardize the logging data, and then analyze the trend surface of the standard interval acoustic time difference.Figure 8 shows the residual frequency diagram of primary and secondary trend surface analysis of acoustic transit time [6]. It can be seen from the figure that the residuals do not have normal distribution, which indicates that there are local anomalies in the acoustic transit time in the whole region. After eliminating the instrument error and lithologic anomaly, this kind of local anomaly still exists, which is caused by the local tectonic change, so the existence of fault can be qualitatively judged.

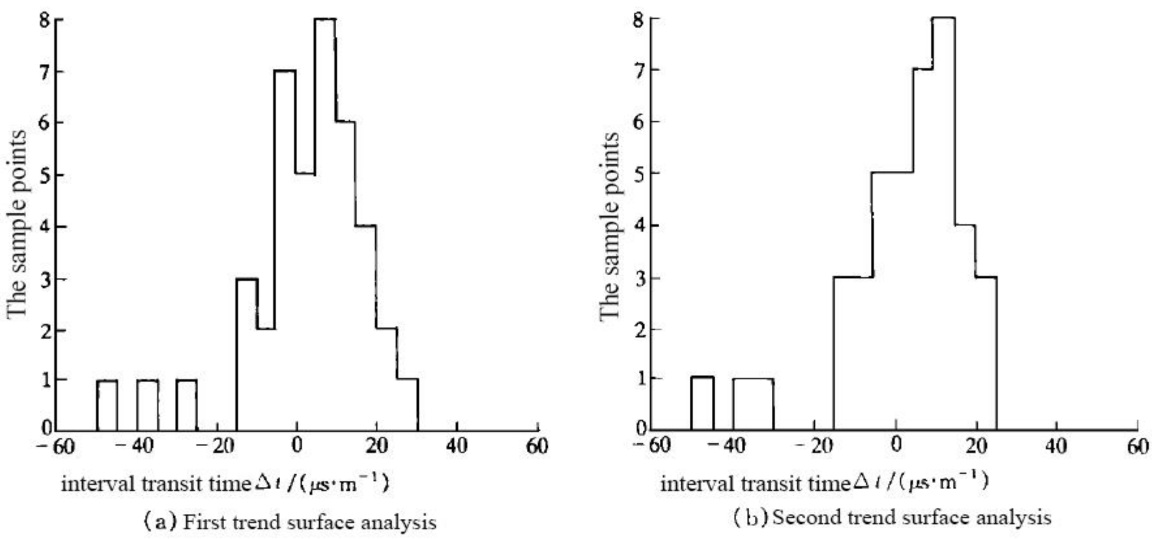

Fig. 8 Residual frequency distribution of trend surface analysis of acoustic time difference in standard layer

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7. Conclusion

(1) For the fault without deformation, the dip vector map shows the same green pattern as monoclinic structure;The rock stratum forms a fracture zone along the fault plane, and the dip angle data shows a green chaos green model.When deformation occurs near the fault that produces the so-called drag phenomenon, there are five patterns: the green-red-blue-green model, the green-red-red-green model, the green-red-blue-green model, the green-red-red-green model, the green-red-red-green model, and the green-red-red-green model.

(2) FMI imaging logs can also be used to roughly determine the existence of faults and to identify the basic features of more finely delineated faults and fault fracture zones through stratigraphic repetition, combined with core and seismic tectonic interpretation.

(3) When it is difficult to determine the location of a fault from a single logging profile, a combination of different logging profiles can be established to find a common pattern and then a fault can be found.

(4) The fault can be identified by the electrical imaging data through the judgment and analysis of strata displacement, fault contact relationship and associated structure. The comprehensive use of electrical imaging and dip log data to identify faults makes the interpretation more intuitive and the occurrence of faults easier to determine. The two complement each other and the interpretation is more accurate.

(5) The position of faulted structures and faults can be determined by using the standard layer acoustic time difference anomaly method. For the variation of geophysical characteristics (such as acoustic time difference) of the standard layer in the study area, when there is no fault structure in the area, it conforms to the variation of a certain trend surface. When there is a fault structure in the area, it does not conform to the change of a trend surface.

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