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Fracture properties from wireline logs to improve seismic capability for fracture detection

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Summary

In this paper we focused on evaluating petrophysical fracture properties to improve seismic capability for fracture detection and then cross-validate seismic attributes with petrophysical properties to overcome the uncertainties and limitations we encountered in seismic fracture detection.

Usually in fractured carbonate reservoir evaluation, it is known that dual-resistivity (deep and shallow) and fast-slow shear velocity pairs from wireline logs are two direct tools to detect the fracture-related properties, which motivate us to improve seismic methods to estimate seismic fracture-related anisotropy properties.

Seismic attributes have uncertainties and limitations for fracture detection. Perz, Li, et al. (2015) generated four different fracture attributes (SWS, AVAZ, VVAZ and curvature) from the Washout Creel 3C-3D dataset. Unfortunately they found that anisotropy maps generated by different methods show inconsistent relationships in some areas. In fact the seismic anisotropy can be induced by fracture, fault, stress and overpressure. Usually the different methods detect different seismic signatures. In our study, we also found that AVAZ, curvature and coherence attributes have the capability for detecting the seismic discourteous events, such as faults, but they are still challenge to detect the fracture after cross-validating with petrophysical fracture properties. In order to overcome the uncertainties and limitations, we present the petrophysical methods to estimate petrophysical properties, such as pore pressure, fracture porosity and fracture dipping, from wireline logs and then seek the relationships between these petrophysical properties with seismic attributes to improve our combining method of AVAZ and VVAZ to classify whether the anisotropy anomalies are induced by fractures, stress and/or overpressure.

Petrophysical Fracture Properties

According to Archie's equation if the formations are clean sand or carbonate, the fracture properties, such as fracture porosity and fracture dipping, can be estimated from the separations between deep and shallow resistivity. Many authors (Boyeldieu and Winchester, 1982; Shaogui et al., 2006) studied these methods and also successfully applied for studying on the fractured carbonate reservoirs.

Fracture Porosity (Boyeldieu and Winchester, 1982)

Archie's equation has been developed in order to estimate the fracture porosity in hard formations by the following equation:

$$\emptyset_{fracture} = \sqrt[m]{\frac{C_{LLS}-C_{LLD}}{C_{mf}-C_w}} = \sqrt[m]{\frac{R_{LLD}-R_{LLS}}{R_{LLD}\times R_{LLS}}(R_w - R_{mf})} \quad (1)$$

C_{LLS} and C_{LLD} are conductivity measured directly by dual laterolog, C_{mf} mud filtrate conductivity and C_w is formation water conductivity

R_{LLS} and R_{LLD} are resistivity, m is the Archie's cementation exponent

Fracture Dipping **(**Shaogui et al., 2006)

The parameter Y in equation (2) defines the dip of fracture. If Y is more than 10, the fracture is sub-vertical ($> 70^0$); If Y is between 0 and 10 the fracture is a dipping ($50^0 \sim 70^0$); if Y is less than 0, the fracture is sub-horizontal ($0^0 \sim 50^0$).

$$Y = 100 * \frac{R_{LLD} - R_{LLS}}{\sqrt{R_{LLD} \times R_{LLS}}} \quad (2)$$

Resistivity Splitting Anisotropy

Like shear wave splitting anisotropy(γ), we present the fracture splitting anisotropy based on the separations of dual resistivity. The definition of anisotropic dual-resistivity separation:

$$\gamma = \frac{\log(R_{LLD}) - \log(R_{LLS})}{2\log(R_{LLD})} \quad (3)$$

Seismic Anisotropy Properties

Amplitude-versus-Azimuth (AVAZ) has gained popular to extract anisotropy signatures, such as anisotropy intensity and the orientation from azimuth seismic data. And VVAZ also has the capability of inferring the anisotropy intensity using the velocity variation with seismic azimuth. We found that the AVAZ are sensitive to strong seismic amplitudes, but VVAZ are insensitive to the seismic amplitudes.

In petroleum industry there are different definitions between fracture and faults. Conventionally, a fracture is defined as a plane where there is hardly any visible movement parallel to the surface of the fracture; otherwise, it is classified as a fault. Because there are no any displacements in fracture, the seismic events are almost no discontinuous, which are difficult to detect using the coherence and curvature, even the AVAZ methods, in which the methods heavily depend on seismic amplitudes.

The combing method of VVAZ and AVAZ (Liu, 2014) was presented to estimate anisotropy intensity anomalies (denoted Thomsen(δ)), which demonstrated the good relationships with the fracture intensity. In order to detect small scale fracture, the AVAZ methods were used to estimate the anisotropy orientation and VVAZ methods to detect the velocity perturbation because of velocity anisotropy. In practical application, the combining method of AVAZ and VVAZ was found that it can detect the seismic azimuthal variation (anisotropy) away from faults, but it is difficult to detect the fault discontinuity. After cross-validating against petrophyscal properties, it is possible to identify whether the anisotropy anomalies were induced by fractures, stress and/or overpressure

Examples

The petrophysical fracture properties were estimated in our case study. In the carbonate reservoir, for example, there are separations between the deep and shallow resistivity, which demonstrated the fracture aperture and dipping. Figure 1 is the fracture splitting anisotropy and fracture dipping angle results according to dual-resistivity splitting. Based on equation (3) (Shaogui et al. 2006) when Y is more than 10, the fracture is sub-vertical; If Y is between 0 and 10, the fracture is a dipping; and if Y is less than 0, the fracture is sub-horizontal. In the intervals of 1100m to 1150m, the Y is more than 10. The fracture is sub-vertical. But in the intervals of 1250m to 1300m, the Y is less than 0, the fracture is sub-horizontal.

Figure 2 is the seismic anisotropy anomalies from our combining methods. In the lower part the anomalies (hot color) demonstrated good relationships with fracture-induced anisotropy, which are crossvalidated with the petrophysical properties. The overpressure-induced anisotropy will be discussed in the presentation.

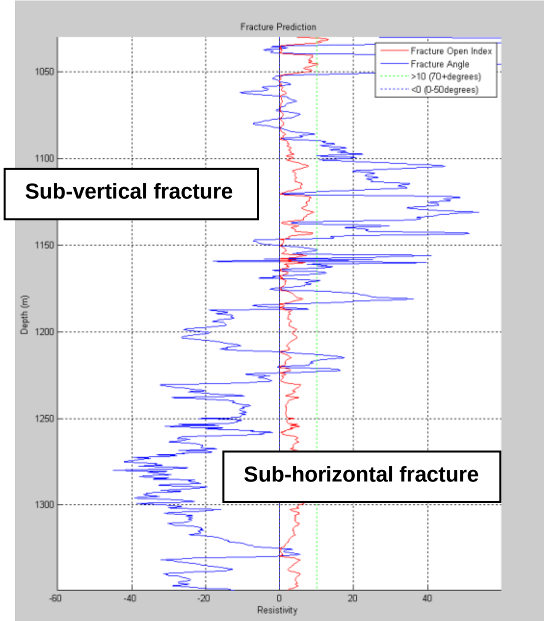

Figure 1: fracture properties from dual-resistivity

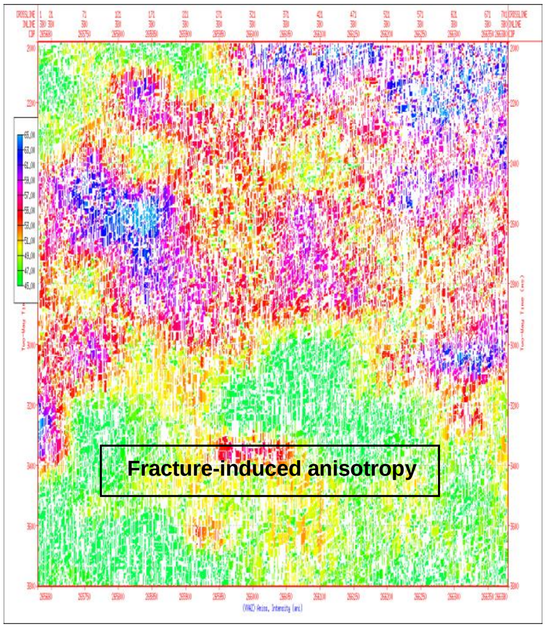

Figure 2: seismic anisotrpy anomalies

Conclusions

The petrophyiscal fractured properties from dual-resistivity have been studied and the equation of resistivity splitting anisotropy from the dual-resistivity was firstly presented. After cross-validating with petrophysical properties, the combining method of VVAZ and AVAZ was improved to estimate the anisotropy anomalies and the anomaly can be classified whether it is induced by fracture, stress and/or overpressure. In our case examples for HTI and/or VTI anisotropic media, the following conclusions can be temporarily made:

1) Thomsen's anisotropic parameter gamma (γ) (Thomsen, 1986) can be estimated from both resistivity splitting and shear wave splitting
2) Resistivity splitting anisotropy has direct relationship with shear wave splitting
3) Resistivity splitting has relationship with fracture aperture and dipping
4) No laboratory data about the relationships between fracture intensity (density) and the splitting
5) Thomsen's anisotropic parameter delta (δ) (Thomsen, 1986) can be estimated from our combining methods of AVAZ and VVAZ
6) Thomsen's anisotropic parameter delta (δ) has strong relationship with the fracture intensity
7) Thomsen's anisotropic parameter delta (δ) is sensitive to stress and overpressure
8) Thomsen's anisotropic parameter gamma (γ) has inverse relationship with anisotropic parameter delta (δ)

We will continue to investigate the relationships among these Thomsen's anisotropic parameters in future studies. The method and workflow can be easily extended to tight sand and shale plays if the fracture exists.

Reference

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