Practical Aspects of Seismic Fracture Analysis

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Summary

P-wave fracture analysis provides a means to extract fracture density and orientation of an underground reservoir. Good methods are important for fracture analysis, and moreover, careful handling of some practical issues is crucial. These issues include, but are not limited to, avoiding cycle skip when applying dynamic trim statics, the impact of an anisotropic overburden, and also consideration of the boundaries between two fractured zones. Any improper treatment on any of these issues can lead to incorrect outcomes of the analysis and/or misinterpretation of the analysis results.

Introduction

Much work has been done in seismic fracture analysis on P wave data (e.g. Lynn et al., 1996; Teng and Mavko, 1996; Li, 1999; Gray and Head, 2000; MacBeth and Lynn, 2001; Zheng and Gray, 2002; Chapman and Liu, 2004; Chi et al., 2004; Parney, 2004; Zheng et al., 2004). Typically, a fractured zone is mathematically simplified as a Horizontally Transverse Isotropic (HTI) layer, which implies all fractures are vertical and oriented in one direction. There are two categories of methods for fracture analysis. One detects the Amplitude Variation with offset and AZimuth (AVAZ), and another detects the Velocity Variation with AZimuth (VVAZ). We have experimented with both categories on synthetic and real datasets, and have achieved successful results. For AVAZ we use Rüger's method (Rüger, 1998), and for VVAZ, use the δ inversion (Zheng, 2006) which is a horizon based, layer stripping method. Obviously the use of a good algorithm is a must for good fracture analysis. However, there are also some practical issues which may degrade the quality of fracture analysis if they are not handled properly. Some of these issues are related to processing procedures, and some of them are due to the limitation of the method employed. Here, we are going to talk about three of these issues.

Dynamic Trim Statics

It is a common practice to calculate dynamic trim statics on some key horizons to obtain the Residual MoveOut (RMO) for VVAZ, and apply the dynamic trim statics to flatten seismic gathers for AVAZ. The trim statics are calculated by cross correlation between each individual trace in the gather and a pilot trace. The pilot trace is often a stacked trace (either full or partial offset). The correlation window is typically short in order to focus on a particular horizon. A problem arises when the reflection shows a polarity reversal with increasing offset. Specifically, the trim statics computation may erroneously "force" a half-cycle shift in the seismic trace if that trace has a different polarity from the pilot trace. In other words, the short window trim statics process may do more harm than good for class II AVO if a stacked trace is used as a pilot trace. Figure 1 shows a gather of a class II AVO (~1524 ms) and there is a polarity reversal at the offset of 1500 m. The main lobe is a peak at near offsets and changes to a trough at far offsets. Dynamic trim statics which were calculated and applied using a stacked trace as a pilot trace, focused on three events at 1472, 1524 and 1566 ms, respectively. After applying the trim statics, the near offset traces were incorrectly shifted by a half cycle (central panel).

To solve this problem, we developed a new method for forming the pilot trace for correlation. We use the AVO intercept and gradient (Shuey, 1985) to project a pilot trace at the same offset as the trace to be correlated, thereby avoiding correlating two traces of different polarity. In practice, we run AVO inversion first to extract the AVO intercept and gradient using the same gathers which are used for fracture analysis. Then, when we calculate the trim static for a trace (target trace), we generate a pilot trace on-the-fly by using the intercept and gradient, plus the offset of the target trace based on Shuey's equation. Therefore, the pilot trace will have the same polarity as the tartget trace. The right panel of Figure 1 shows the gather after applying dynamic trim statics using the AVO projected pilot trace. This method successfully avoids the trouble of polarity reversal.

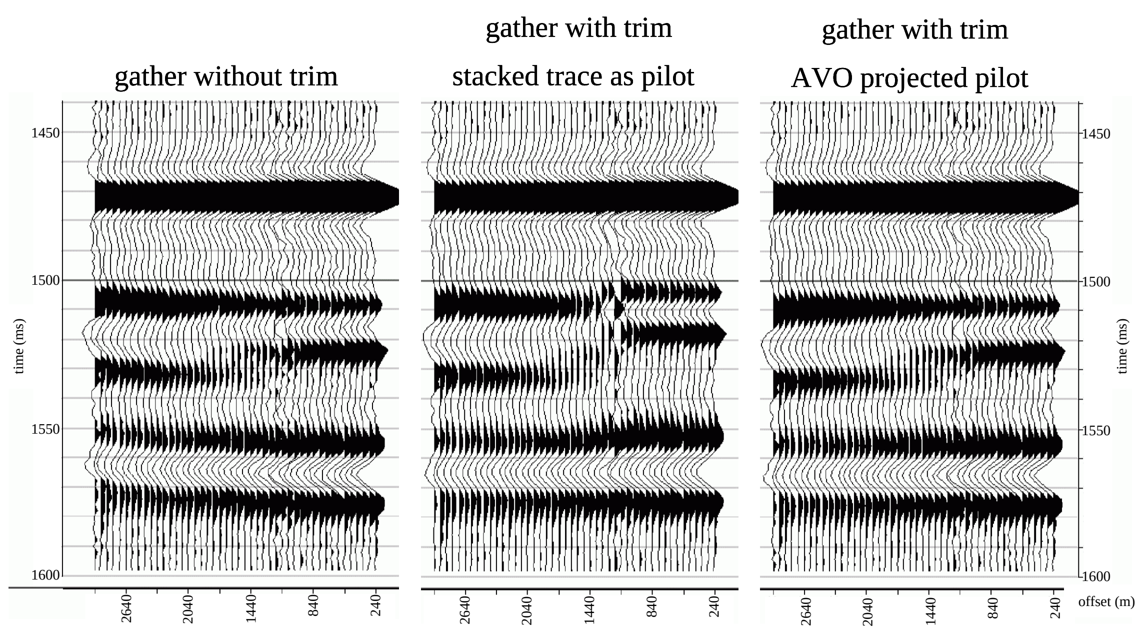
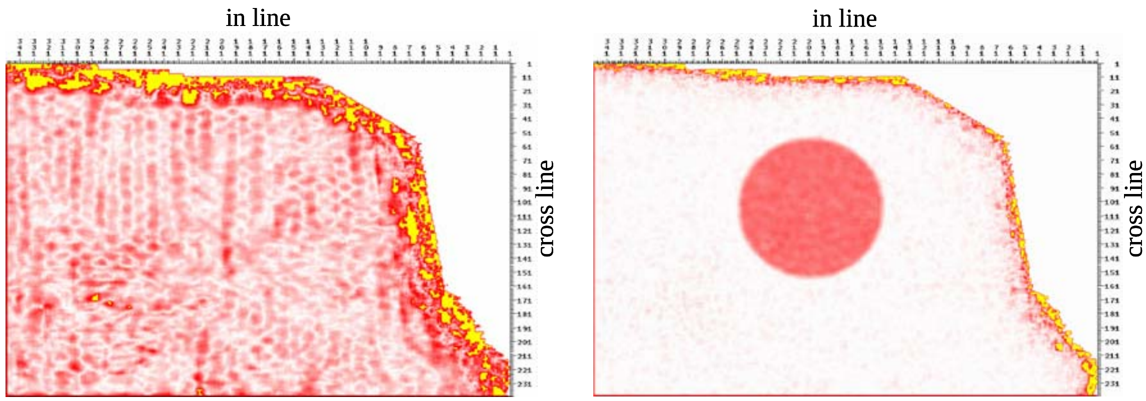


Figure1: the left panel shows a gather before applying dynamic trim statics. There is an AVO class II event at 1524 ms. It changes polarity around an offset of 1500 m. Obviously, some residual moveout is also present. If a stacked trace is used as a pilot trace, some traces are forced to skip half a cycle after applying trim statics (central panel). If we use a pilot trace generated from AVO attributes, the problem of half-cycle skip is avoided (right panel).

To further verify the advantage of the AVO projected pilot trace, we built a synthetic dataset with two interfaces. The top interface is a class I AVO reflection at 1472 ms. The second is a class II AVO at 1524 ms. The layer between these two interfaces is isotropic at most places with a circular anomaly of anisotropy centred at inline 200 and cross line 105 with a radius of 50 CDPs. We used both the stacked trace and the AVO projected trace as pilot traces followed by the δ inversion. The results of the δ inversion are shown on figures 2. When AVO projected pilot trace is used, the VVAZ result matches the input model, and the circular anisotropic anomaly is properly resolved. (right panel). However, when the stacked trace is used as the pilot trace, the δ inversion result is erroneous. The inversion of anomaly of the layer is not stable (left panel) and the false statics caused by cycle skip (figure 1) introduce false anisotropy shown all the way across the survey.



δ inversion using stacked trace as a pilot δ inversion using AVO projected pilot trace

Figure2: synthetic test of fracture analysis using different pilot traces. In the synthetic data, it was built in a fracture anomaly centred at inline 200, cross line 105 with a radius of 50 CDPs. The reflection from the base of the target zone is a case of class II AVO. When a stacked trace is used as a pilot trace for trim statics, the result from δ inversion is not correct, because there is a problem of cycle skip and the statics are not correct (left panel). When the AVO projected pilot trace was used, the δ inversion is correct, because the polarity changes at different offsets was handled properly.

Overburden Influence

The amplitude of the reflected wave from the boundary of a fractured zone varies with azimuth, and so does the transmitted wave. Therefore, in general, the amplitude of a reflection wave from the interface below a fractured zone will vary with azimuth, even this interface is between two isotropic layers. In other words, the influence of a fractured zone will be carried over from the shallow section down to the deep section. Therefore, the result of AVAZ on a particular horizon contains the fracture information accumulated from the surface all the way down to this horizon. In general, AVAZ suffers the problem of overburden impact. Interpreters should pay close attention to the overburden impact when interpreting the fracture attributes from AVAZ.

Travel time based VVAZ has the similar overburden impact as AVAZ, but fortunately, the δ inversion is able to strip off the impact by using the difference of RMOs on the top and base horizons (Zheng, 2006). Therefore, this method uses the traveltime variation solely caused by a specific layer and inverts this variation to yield an estimate of fracture density and orientation for this layer.

Boundary Between Fractured Layers

In the industry, AVAZ method is based on Rüger's equation (Rüger, 1998). This equation expresses the amplitude variation with offset and azimuth for a reflection wave from an interface between two

HTI layers with same orientation. As a special case, one of the HTI layer may be isotropic. However, in real world, the fracture orientations of different layers may not be the same. Therefore, it breaks the condition of Ruger's equation. In such a case, the amplitude variation of the reflection wave from the interface between two fractured layers with different orientation will be influenced by both layers. Therefore, if we use Rüger's equation for AVAZ inversion, the resulting fracture density and orientation will be the properties of neither upper nor lower fractured layer, but the combination of the properties of both layers.

Since the δ inversion (Zheng, 2006) scheme we use for VVAZ can effectively remove overburden impact, it can still produce useful results when reflections emanate from the interface between two fractured layers.

Conclusions

The quality of fracture analysis largely depends on the data preparation. In the case of AVO class II, the seismic traces may shift half a cycle if a stacked trace is used as a pilot trace, thereby resulting in erroneous fracture attributes. By using the AVO projected pilot, the problem can be avoided.

Interpreters should pay attention to the overburden impact on fracture analysis. The fracture anomaly may not be a vertically localized anomaly, but rather it may carry the influence from the shallower layers, depending the method used for fracture analysis.

AVAZ may yield incorrect results if the interface is between two fractured zones and the fractures are oriented in different directions. The δ inversion used for VVAZ removes the overburden impact and is still valid for the interfaces between fractured layers.

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