Azimuthal NMO as an indicator of natural fracturing

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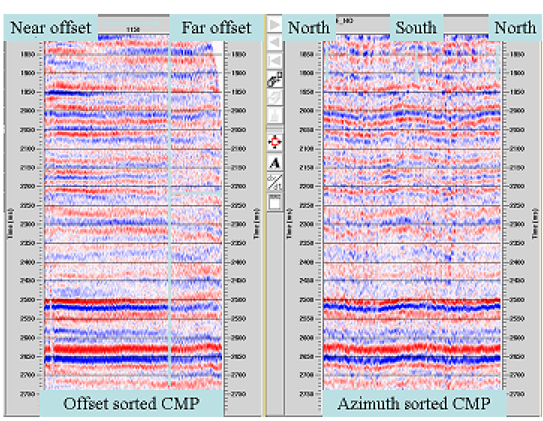
Introduction

New technologies in seismic acquisition, processing and interpretation are being utilized to reduce the uncertainty in locating natural fracture trends. However, approaches which assume that the information derived from seismic attributes can be translated from fracture intensity volumes into “drill here” maps implicitly assume that high fracture intensity equals high productivity – and as a result frequently fail. The problem with this approach is that in fractured reservoirs connectivity is the critical issue. Fractures provide high permeability pathways between the well locations and the lower permeability matrix in which the hydrocarbons are stored. What becomes critical then is not the fractures intersected by a well, but what those fractures are connected. An approach is presented which looks at seismic based fracture information in context of fracture connectivity, using a Discrete Fracture Network (DFN) Models. Examples are also presenting in which seismic imaging of fractures is used to delineate lithology in conventional reservoirs.

Seismic processing under fracture induced anisotropy

The occurrence of fractures in both reservoir non reservoir units can have a strong influence on the stacking velocity necessary to effectively image seismic data (Jenner and Williams 2003, Williams and Jenner 2002). Open, fluid or gas field fractures can act as compressive “springs” which act to slow down compressional (P) seismic waves as they travel through the earth. Because fractures occur in directional aligned sets the influence of fractures on seismic velocities can be measured and corrected for by azimuthal approaches. In Figure 1a, a CMP gather is sorted by offset from near offset to far offset. As standard NMO velocity is applied. Data to the left of the marked line appear coherent and should stack effectively. Data to the right of the marked line appear scattered- in other words inclusion of the far offsets would degrade the final stack. When these far offsets are sorted by azimuth a sinusoidal pattern appear. The simple interpretation is that the seismic waves traveling perpendicular to the fractures are slowed down by the springiness of the fractures. The sinusoidal patterns can be flattened, and the time shifts stored and converted to velocities (figure 2). A least squares fit can be determined for these velocities, so that in during processing the azimuthal velocity effects can be corrected for. As a byproduct of this correction this least squares fit can be converted into a number of velocity volumes which describe the anisotropy, and hence the fracturing within the reservoir.



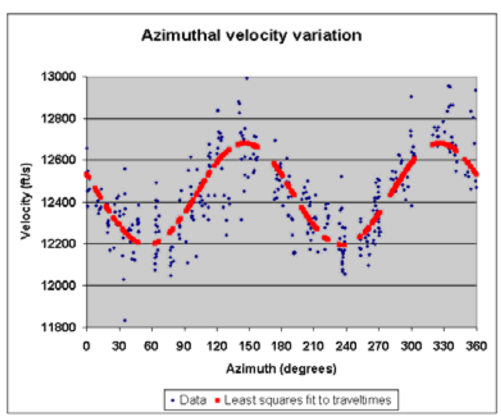


Figure 1. Offset and azimuth sorted gathers, Rocky Mountains

Figure 2. Time shifts converted to velocities and least square fit of azimuthal velocity

Interpreting fractures from Velocity Volumes

One example of these velocity volumes is given in Figure 3. A time-slice of the fast minus slow velocity is shown from a field in the Rocky Mountains. A sand channel is highlighted as a high anisotropy anomaly because the lithology of the sand channel supports the development of fractures, while the surrounding shales and mud-stones surrounding the channel do not. This and other cases will demonstrate that seismic is presently imaging fracture properties, and that the value of the seismic images includes mapping fractures that influence reservoir behavior, and fractures that do not influence reservoir but help differentiate lithologies.

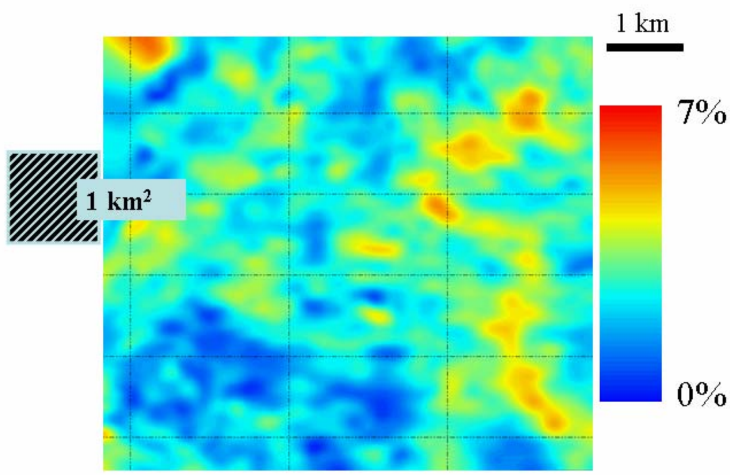


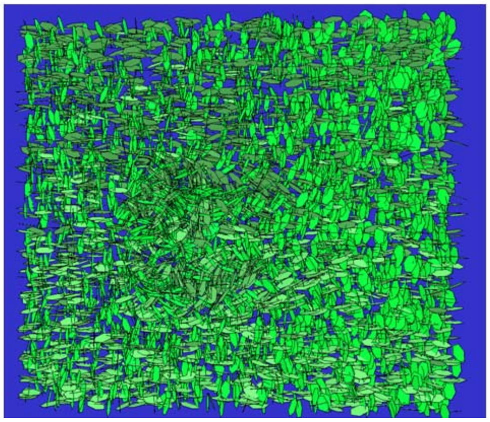
Figure 3. Fast velocity – slow velocity time slice, Rocky Mountains showing channel with high anisotropy embedded in shales and mudstones with low anisotropy.

Building DFN models from Velocity Volumes

The value of the anisotropy data can only be fully realized it is applied appropriately when making exploration and/or development decisions. If the data is assessed applying the logic that seismic anisotropy is proportional to fracture intensity, and that fracture intensity is then proportional to production, significant errors are likely to be made and the value of the data is to be missed.

Discrete Fracture Network Models, originally developed for nuclear waste repository applications, have been applied in a number of reservoir settings. The power of DFN models is been to quantized the connectivity of fractures within the reservoir. The weakness of these models has been the lack of fracture data between well locations. The combination of seismic anisotropy data and DFN models enables reservoir properties to be predicted from seismic data.

In Figure 4 a DFN model, based on a model seismic and as such be data shows the influence of the structure or fracture orientation and fracture intensity changed to accommodate the occurrence of the structure. By placing a grid over this DFN model and calculating permeabilities in each of the grid cells, the permeability can be mapped over the structure, figure 5.



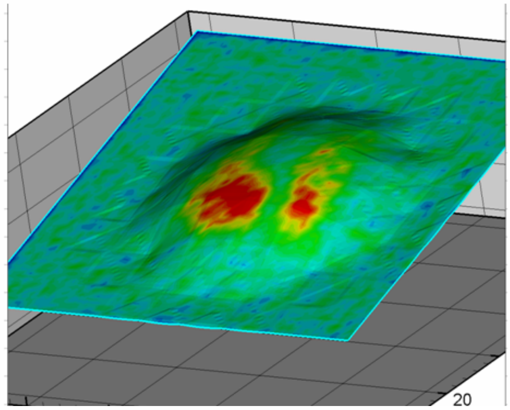


Figure 4 Discrete Fracture Network (DFN) model based on modeled seismic anisotropy data around dome structure.

Figure 5 Permeabilities calculated using seismic based DFN model projected on structure for dome model structure.

Characterizing/modeling fractured reservoir data using Geologic analogues

Fractures influence seismic by changing the response in isotropic velocity, amplitude vs. offset, and pressure induced velocity anomalies. Sometimes these changes enable direct imaging of pressure and fracture attributes. However, simply understanding these attributes are not sufficient to develop an effective drilling strategy in most naturally fractured reservoirs. For example, it has been recently demonstrated in the Moxa arch that fracture intensity increases close to faults. However, in the area immediately adjacent to faults the high fracture intensity is associated with low production due to fault gauge (Miskimins and Knight, 2003). The best production occurs some distance away from faults in which the fracture intensity is still relatively high, but the influence of fault gouge is diminished, so that a combination of fracture and matrix porosity in permeability results in an economic wells. Analysis of this type of reservoir would fail if a seismic attribute that predicted fracture intensity was interpreted under the assumption that fracture intensity is equivalent to productivity.

A case study is presented showing varying predictions that would be made using the same fracture indicators from seismic data, with and without applying recently developed geologic models and mapped analogs to fractured Rocky Mountain reservoirs (Flodin 2003 and Sternlof et. al. 2003). These DFN models range from entirely data driven to placing data in very restrictive geologic models. The influence of fractures on seismic data and the influence of geologic models on the final interpretation are characterized for a Rocky Mountain tight gas sand reservoir.

Summary

- Velocity Anisotropy volumes that are a by-product of improved imaging techniques have advanced imaging of natural fracture patterns in the subsurface
- In fractured reservoirs these volumes are providing the missing fracture information between wells that make DFN models viable
- In non fracture-controlled reservoirs changes in the rock fabric allow lithology differentiation in thin beds.
- Best application of this data is improved by the use of geologic analogues and a more complete understanding of the role fractures play within a reservoir.

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