Fracture Anisotropy Modeling

BENEFITS

- Plan a completion program to avoid damaging natural fractures
- Predict complex hydraulic fracture geometry
- Calibrate seismic and reservoir attributes for future well placement

APPLICATIONS

- Automatic zoning of open natural fractures and differential horizontal stress for hydraulic fracture design
- Discrimination between drilling-induced and natural fractures
- Well placement within fractured reservoirs
- Seismic attribute calibration
- Interpretation of microseismic results for complex fracturing
- Fracture compliance attributes for coupled reservoir-stress simulation

FEATURES

- Consistent interpretation between borehole image and sonic logs
- Fully 3D fracture and stress modeling in vertical, deviated, and horizontal wellbores
- Graphical display with colored flags indicating different anisotropy mechanisms—fractures, stress, or mixed
- Unbiased zoning of the reservoir to predict complex hydraulic fracturing
- Distinguishing between productive and nonproductive fractures for single or multiwell reservoir simulation

Image and sonic log integration for stress and fracture anisotropy characterization

KEY CONCEPT FOR QUANTITATIVE INTEGRATION

Fracture Anisotropy Modeling is an integrated methodology designed to model and interpret borehole dipole sonic anisotropy related to the effect of geological fractures using a forward modeling approach. This method provides a consistent approach to interpretation by integrating borehole images and sonic logs that probe the formation at different depths of investigation around the borehole. With this information you can discriminate between productive and nonproductive fractures, and thus plan a completion program to avoid damaging natural fractures, predict complex hydraulic fracture geometry, and calibrate seismic and reservoir attributes for future well placement.

The methodology uses a classical excess-compliance fracture model that relies on the orientation of the individual fractures, the elastic properties of the host rock, and the normal and tangential fracture compliance parameters. Orientations of individual fractures are extracted from borehole image log analysis (FMI* Fullbore Formation MicroImager, UBI* Ultrasonic Borehole Imager, and OBMI* Oil-Base MicroImager). Figure 1 illustrates the concept of combining the image interpretation with the Sonic Scanner* acoustic scanning platform anisotropy results into a fracture model, resulting in an interpretation that diagnoses the stress and fracture state around the borehole.

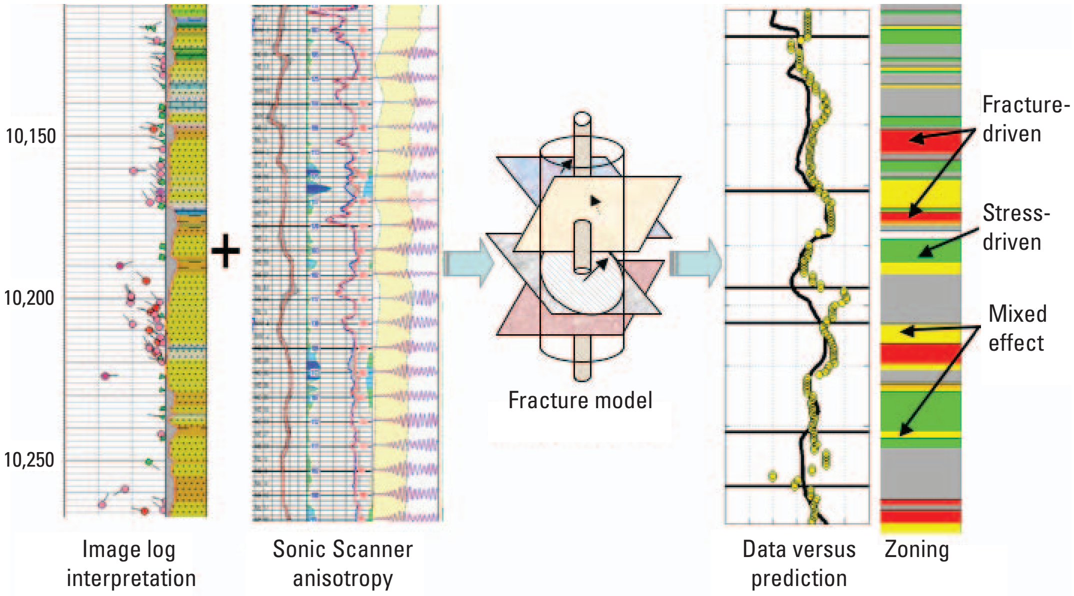

Figure 1. Concept for Fracture Anisotropy Modeling. Image interpretation with Sonic Scanner anisotropy is integrated with a fracturing model to determine the source of anisotropy.

Fracture Anisotropy Modeling

HIGH-RESOLUTION SONIC AND IMAGE LOGS

Sonic Scanner acoustic scanning platform is the latest waveform sonic acquisition tools with its 13 axial receivers. It provides comprehensive acquisition of broadband waveforms from all borehole modes—monopole, dipole, and Stoneley. The dipole source is fired in "chirp" mode, sweeping the formation with a frequency range of 900 to 9,000 Hz. The high-resolution waveforms produce flexural-wave anisotropy results to a resolution of 2% for detecting sonic anisotropy.

Resistivity or ultrasonic image data from the FMI imager, OBMI imager, or UBI imager can provide high-resolution electrical or acoustic contrasts between the formation and drilling fluid along the borehole wall. The images quantify the fracture attributes such as dip, aperture, porosity, and trace length. Combining the acoustic and image data permits the borehole and surrounding formation to be characterized for quality and quantity of the fractures.

FIELD TEST IN THE US ROCKIES

The model was first validated using borehole resistivity image and sonic logs in a gas-sand reservoir over a 160-ft vertical well interval. Significant amounts of sonic anisotropy were observed in 3 zones with a fast-shear azimuth exhibiting 60º of variation and slowness difference between 2% and 16%. Numerous quasivertical fractures with varying dip azimuths were identified on the image log at the locations of strong sonic anisotropy. The maximum horizontal stress direction, given by breakouts and drilling-induced fractures, was shown not to be aligned with the strike of natural fractures (Figure 2). Stoneley wave analysis combined with the image interpretation showed that the majority of the natural fractures were open and permeable.

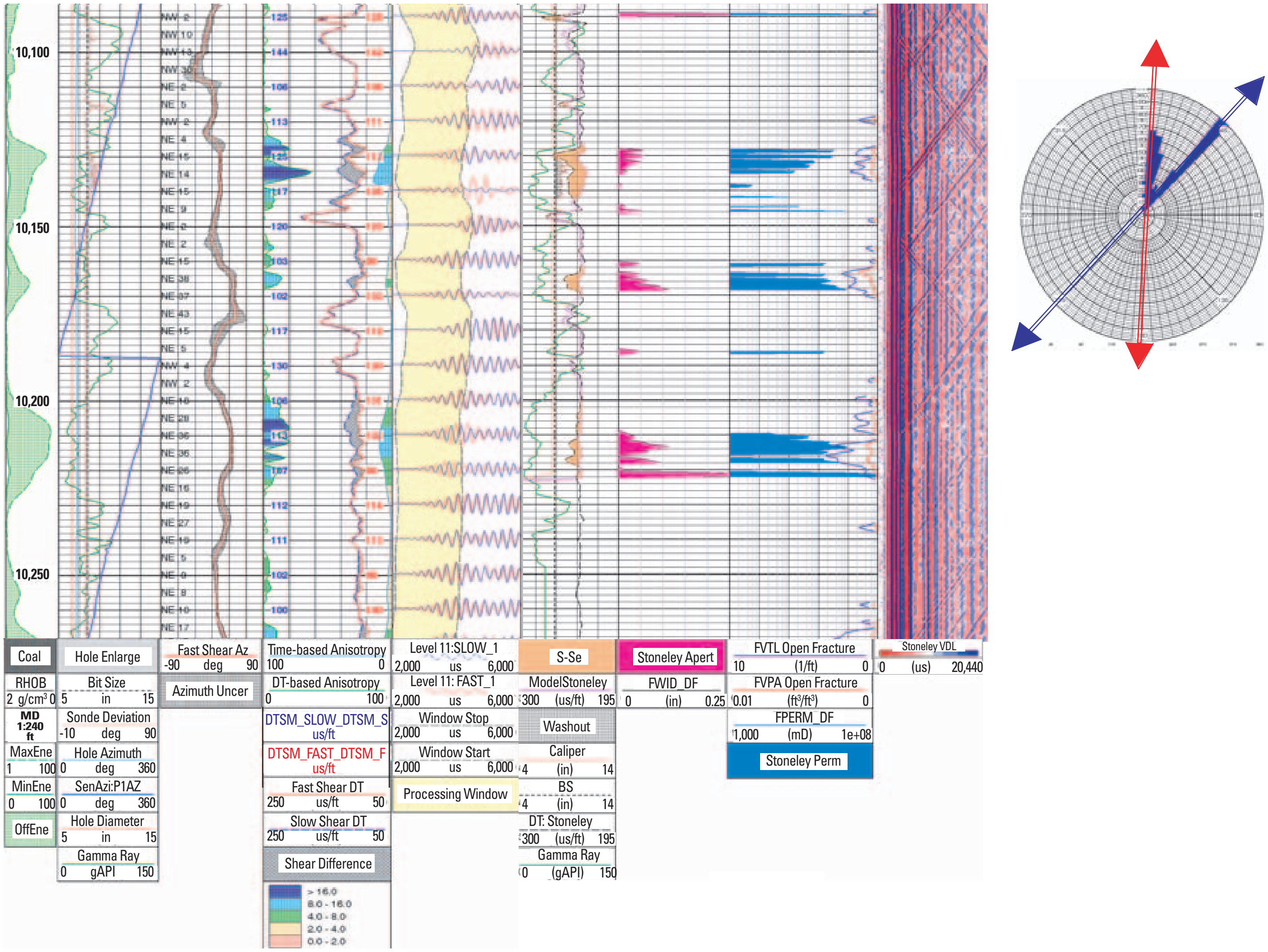

Figure 2. Detailed Sonic Scanner anisotropy (left) and Stoneley fracture analysis (right) interpretation from US Rocky Mountains. Dipole sonic anisotropy results are used as input to the Fracture Anisotropy Modeling. Rose diagram (top right) indicates that there are two dominant directions of anisotropy caused by stress and fractures. Red is stress direction. Blue is fracture strike.

Using just two adjustable fracture compliance parameters, one for natural fractures and one for drilling-induced fractures, is an excellent first-order approximation to explain the fracture-induced anisotropy response over a depth interval of 130 ft. Predicted fast-shear azimuth matches measured fast-shear azimuth over 130 ft of the 160-ft studied interval (Figure 3). Predicted slowness anisotropy matches the overall variation and measured values of anisotropy for two of the three strong anisotropy zones.

DISCRIMINATION OF FRACTURE AND STRESS EFFECTS FOR COMPLETION DESIGN

Analysis of each independent fracture type showed that the anisotropy was mainly driven by open or partially healed fractures, but it was also consistent with stress-related, drilling-induced fractures. Therefore, the measured sonic anisotropy was caused by the combination of stress and fracture effects where the predominance of one mechanism over the other was depth-dependent. This information led to the design of an automatic algorithm that provides colored zones for the different mechanisms: fracture-driven, stress-driven, and the combination of both (Figures 3 and 4). Such information can be used for improving the design of hydraulic fracture and completion strategy. When making the decision to stage zoning for hydraulic fracture stimulation, grouping reservoir intervals with similar stress profiles was important for maximum efficiency. However, the complexity of the hydraulic fracture that initiated at the wellbore wall depended on the orientation and magnitude of the present-day stress compared with the dip and strike of the natural fractures.

IMPACT ON WELL PLACEMENT AND RESERVOIR DRAINAGE PATTERNS

The relationship between present-day stress and natural fracture orientation defines reservoir drainage geometry, thus impacting future well placement for field development. Hydraulic fracturing fluids that leak off into the fractured formation may not efficiently extend into the reservoir as designed. In Figure 5, two scenarios are presented in which the present-day stress field is at an oblique angle to the fracture strike direction. Figure 5a shows a hydraulic fracture that has a relatively short half-length because of the inefficiency of the treatment caused by the leakoff of the fluids into the fractures. Figure 5b depicts a hydraulic fracture that is propagated across multiple fracture sets with limited leakoff. Bridging packages that combine variable-sized proppant and dissolving material, such as FiberFRAC* fiber-based fracturing fluid technology, allow for the natural fractures to be temporarily plugged, thus maintaining the efficiency of the propped hydraulic fracture.

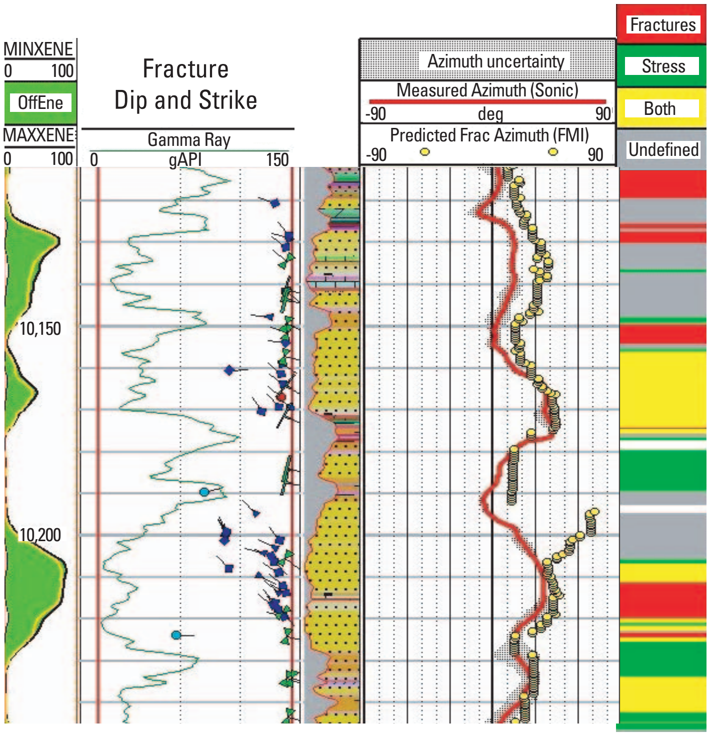

Figure 3. Final GeoFrame results for the Fracture Anisotropy Modeling with automatic zoning of the anisotropy mechanism.

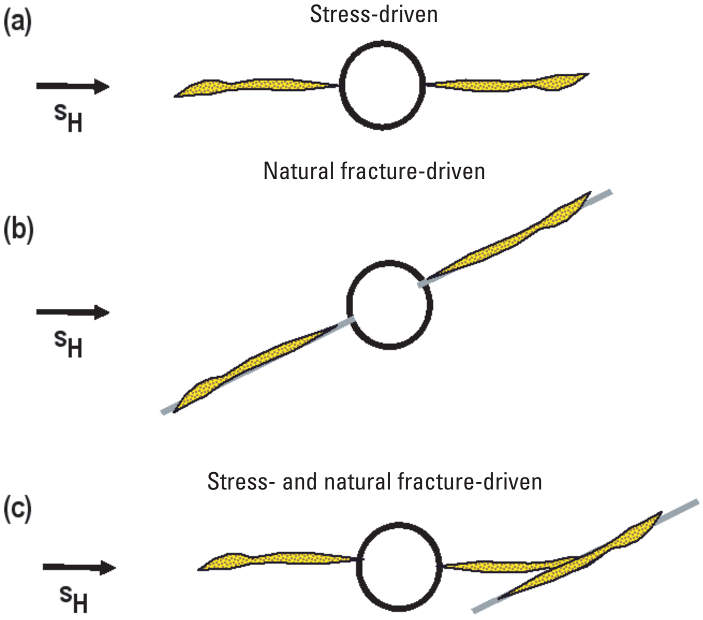

Figure 4. Schematic diagram of three mechanical scenarios that might occur while hydraulically fracturing the medium: (a) the hydraulic-fracture propagates in a direction orthogonal to the minimum principal stress; (b) only the system of natural fractures is reactivated and eventually extended; and (c) both newly generated hydraulic fractures and natural fractures intersect and propagate in a complex manner.

Fracture Anisotropy Modeling

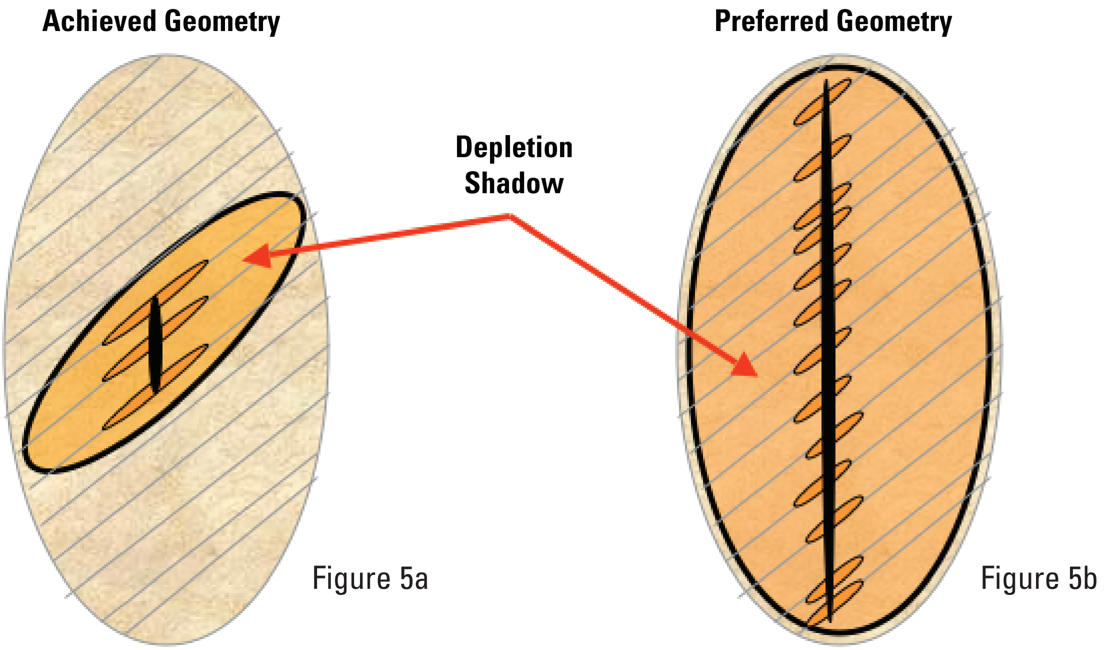

Figure 5. Two scenarios of drainage patterns in naturally fractured reservoirs. Fracture Anisotropy Modeling helps to design well stimulation programs to achieve preferred depletion geometry.

SCALEABLE RESULTS FOR VERTICAL SEISMIC PROFILE AND SEISMIC INTEGRATION

Fracture-induced and stress-induced anisotropy directions obtained at the borehole scale can be easily upscaled to vertical seismic profile and seismic scales using this fracture forward modeling approach. Nonambiguous anisotropy mechanisms can be attributed to 3D seismic maps for integrated reservoir approach.

DEVELOPING A NEW APPLICATION FOR INTEGRATED RESERVOIR SYSTEMS

A new application was created in GeoFrame* integrated reservoir characterization system that provides one piece of the near-wellbore geomechanical model in naturally fractured reservoirs. It discriminates the effect of natural fractures from those of the stress field on the elastic medium. It gives preferential directions of the elastic medium for different depth zones and a mechanism for when the principal stress directions and the fracture planes are not aligned.

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