Characterization of In-Situ Stress and Permeability in Fractured Reservoirs

DE-FC26-02NT15346

Goal

The purpose of this project is to develop and implement large-scale numerical models (running on parallel Linux clusters) to quantify the effects of fracture parameter variations on seismic reflection signals and in-situ stress variations on flexural modes in boreholes. These forward-modeling efforts will be used to develop data analysis and inversion routines for estimating the heterogeneous fracture distribution in fractured reservoirs from seismic and borehole field data.

Performer

Massachusetts Institute of Technology
Cambridge, MA

Results

Fracture orientation and spacing are important parameters in reservoir development. This project resulted in the development and testing of a new method for estimating fracture orientation and two new methods for estimating fracture spacing from seismic data. The methods developed were successfully applied to field data from fractured carbonate reservoirs.

Researchers have:

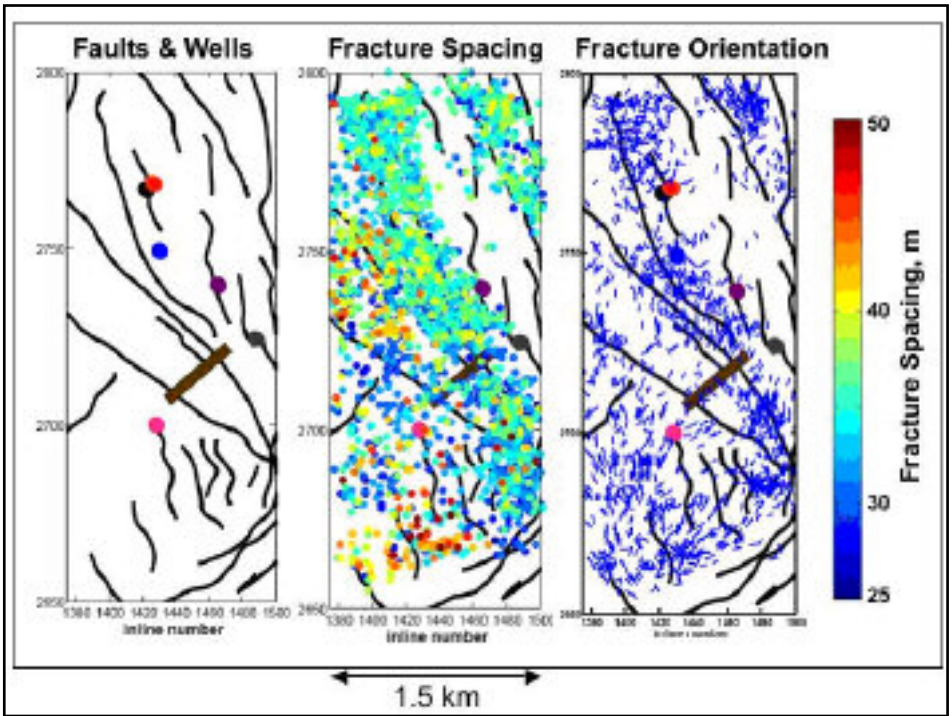
- Developed a new method for estimating fracture orientation from scattered energy in seismic data.
- Developed two new methods for estimating fracture spacing from scattered energy in seismic data.
- Tested these methods on numerical model data and field data from two fractured carbonate reservoirs.
- Validated fracture orientation results with borehole data from the two fields.

Benefits

This work provides a method to estimate fracture property distributions from seismic data. This information can be used in reservoir simulators to predict oil recovery and identify areas most promising for drilling.

Background

Fractured reservoirs historically have been difficult to produce because of the inability to predict fracture location, orientation, and permeability. This project addresses these problems by developing a method to image fractures from seismic data.



Scattered wavefield analysis of 3-D seismic data volume in a fractured carbonate reservoir (Emilio field). The left panel shows the seismic faults and well locations. The right panel shows the spatial distribution of fracture density and orientation (the direction of each line segment gives the orientation estimate). The center panel shows the estimated spacing of fracture corridors, with the spacing values given by the color bar on the far right.

Summary

Two approaches for estimating fracture spacing from scattered seismic energy were developed. The first method relates notches in the amplitude spectra of the scattered wavefield to the dominant fracture spacing that caused the scattering. The second uses conventional frequency-wavenumber (FK) filtering to isolate the backscattered signals and then recovers an estimate of the fracture spacing from the dominant wavelength of those signals. Both methods were tested on synthetic data and then applied to the Emilio field data with similar results. Emilio field is a fractured carbonate reservoir in the Adriatic Sea.

The first method is based on the observation that discrete, vertically aligned fracture systems impart one or more notches in the spectral ratios of stacked reflected seismic traces. This apparent attenuation is due to the azimuth-dependent scattering introduced by the fractures. The most prominent notch is located at the frequency where the P wavelength is about twice the fracture spacing. The frequency location of the notches can be used to determine the fracture spacings. The method was applied to Emilio field data, resulting in the fracture spacing estimates of about 30-40 meters.

In the second method, the seismic data in the FK domain was analyzed. In studies on the scattering effects of discrete fractures on synthetic seismic data, the presence of both forward and backscattered signals were observed. In particular, the backscattered signals (the energy that is propagating back towards the source) appear to be at a maximum when the acquisition direction is normal to the fractures and at a minimum where the direction is parallel to the fractures. In the FK domain, the backscattered energy can be separated to determine the fracture spacing from its dominant wavelength. The technique was tested on synthetic model data and then applied to the data from Emilio field, resulting in a fracture spacing estimate of about 48-53 meters.

Current Status (January 2006)

The project is in the final stages of completion. Methods for estimating fracture orien-

tation, fracture spacing, and fracture density from the seismic scattering signals have been tested with numerical modeling data and field data from two different oil fields. The results have been validated against well log measurements, other seismic analysis methods, and existing geologic models of the fields. Based on these comparisons, the methods appear to be robust and accurate. The next step is to use these seismically derived fracture parameters as the basis for improving input into flow models. This phase will be conducted in collaboration with industry partners after this project has been completed.

Funding

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-01NT41048, focus area Critical Upstream Advanced Diagnostics and Imaging Technology.

Publications

Burns, D.R., Willis, M.E., Minsley, B.J., and Toksoz, M.N., Characterizing subsurface fractures from reflected and scattered seismic energy, 7th Annual SEG Japan International Symposium on Imaging Technology, 2004.

Minsley, B.J., Willis, M.E., Krasovec, M. Burns, D.R., and Toksoz, M.N., Investigation of a Fractured Reservoir Using P-wave AVOA Analysis: a Case Study of the Emilio Field with Support from Synthetic Examples, expanded Abstract, 74th SEG Annual Meeting, 2004.

Rao, R., Willis, M., Burns, D., Toksoz, M.N., and Vetri, L, Fracture spacing and orientation estimation from spectral analyses of azimuth stacks, expanded abstract, 75th SEG Annual Meeting, 2005.

Willis, M., Pearce, F., Burns, D.R., Byun, J., and Minsley, B., Reservoir Fracture Orientation and Density from Reflected and Scattered Seismic Energy, expanded abstract, EAGE Meeting, Paris, 2004.

Willis, M., Rao, R., Burns, D., Byun, J., and Vetri, L., Spatial Orientation and Distribution of Reservoir Fractures from Scattered Seismic Energy, expanded abstract, 74th SEG Annual Meeting, 2004.

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Project End: June 30, 2006

Anticipated DOE Contribution: $940,945
Performer Contribution: $550,000 (37% of total)

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