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Please fill in your abstract title.	Time Lapse Seismic Monitoring of Individual Hydraulic Frac Stages Using a Downhole DAS Array: Theoretical Findings and Full Wavefield Modelling

Please fill in your author name(s) and company affiliation.

Given Name	Surname	Company
Gary	Binder	Colorado School of Mines
Aleksei	Titov	Colorado School of Mines
Diana	Tamayo	Colorado School of Mines
Jim	Simmons	Colorado School of Mines
Ali	Tura	Colorado School of Mines
Grant	Byerley	Apache Corporation
David James	Monk	Apache Corporation

Abstract

Objectives/Scope:
In 2017, Apache Corporation conducted a time-lapse Vertical Seismic Profiling (VSP) survey before and after each of the 78 stages of hydraulic fracturing along a horizontal well utilizing fiber optic Distributed Acoustic Sensing (DAS) technology. A ~4 ms time delay in P-wave arrivals was observed with respect to the pre-fracturing baseline for each stage. Here, full seismic wavefield modeling is used to investigate mechanisms causing the observed time delay, and the potential of DAS VSP surveys for fracture geometry characterization.

Methods, Procedures, Process:
Two mechanisms causing the time delay are considered: scattering of seismic waves on an open, water-filled fracture and stress-induced velocity changes around the fracture zone. Because of the large seismic wavelength compared to the size of the fracture zone, full finite-difference wavefield modeling is needed, and time delays are computed through cross correlation. Interference of scattered wavefields can produce an observable time shift through cross correlation. Additionally, a region of low effective stress caused by high pore pressure or damaged rock in the fracture zone may induce a low-velocity zone that produces a time delay.

Results, Observations, Conclusions:
For the case of waves scattering on a water-filled fracture, interference of scattered wavefields causes time delays comparable in magnitude to observed data, but not always at the right position along the fiber optic cable. When additionally considering a region of low effective stress, time delays comparable to observed data in both magnitude and location along the optical fiber can be obtained. Stress-induced velocity changes are a promising mechanism, but more detailed modelling of the stress field and rock stress-velocity relations are required to make reliable predictions.

Since the predicted time delays depend on the height of the assumed fracture zone, this may open a new route to characterize fracture geometry using a DAS VSP survey. The results also depend on the frequency content and angle of incidence of seismic waves and thus can be used to optimize the design of future DAS VSP surveys to maximize time-lapse effects.

Novel/Additive Information:

This study makes use of the relatively new technology of DAS VSP surveys to obtain unique information about the stage-by-stage effectiveness of hydraulic fracturing at unparalleled spatial resolution near the fracture zone. These are the first efforts to connect observed data to full wavefield modelling near the fracture zone. It is expected this work will contribute to the advancement of DAS VSP surveys as a cost-effective tool for fracture geometry characterization.