Imaging fracture networks using crosshole seismic logging and change detection techniques

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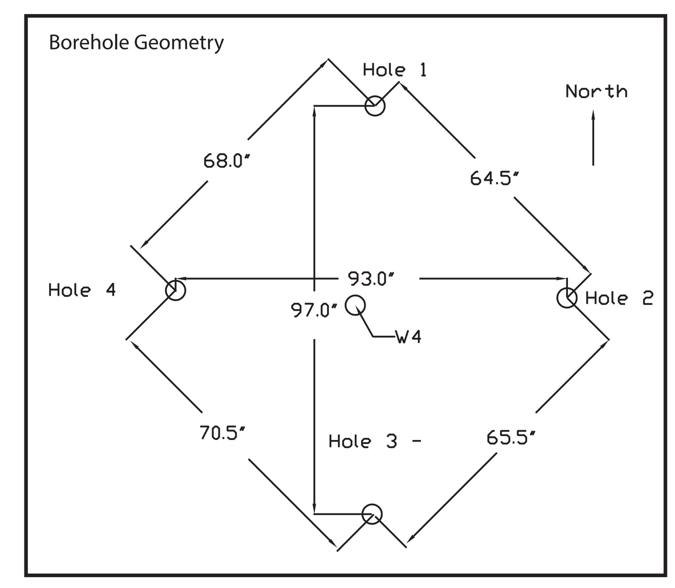
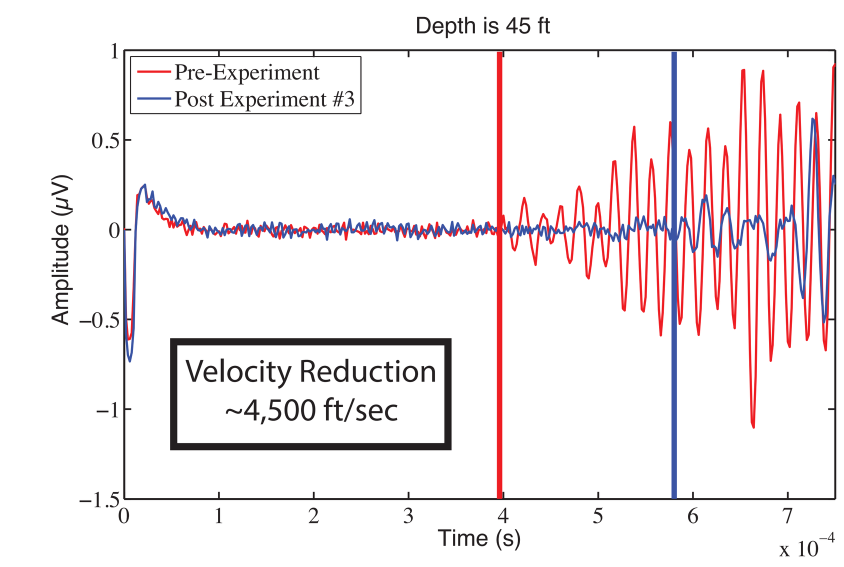
Abstract

We present results from a SubTER funded series of cross borehole geophysical imaging efforts designed to characterize fracture zones generated with an alternative stimulation method, which is being developed for Enhanced Geothermal Systems (EGS). One important characteristic of this stimulation method is that each detonation will produce multiple fractures without destroying the wellbore. To date, we have collected six full data sets with ~30k source-receiver pairs each for the purposes of high-resolution cross borehole seismic tomographic imaging. The first set of data serves as the baseline measurement (i.e. un-stimulated), three sets evaluate material changes after fracture emplacement and/or enhancement, and two sets are used for evaluation of pick error and seismic velocity changes attributable to changing environmental factors (i.e. saturation due to rain/snowfall in the shallow subsurface). Each of the six datasets has been evaluated for data quality and first arrivals have been picked on nearly 200k waveforms in the target area. Each set of data is then inverted using a Vidale-Hole finite-difference 3-D eikonal solver in two ways: 1) allowing for iterative ray tracing and 2) with fixed ray paths determined from the test performed before the fracture stimulation of interest. Utilizing these two methods allows us to compare and contrast the results from two commonly used change detection techniques.

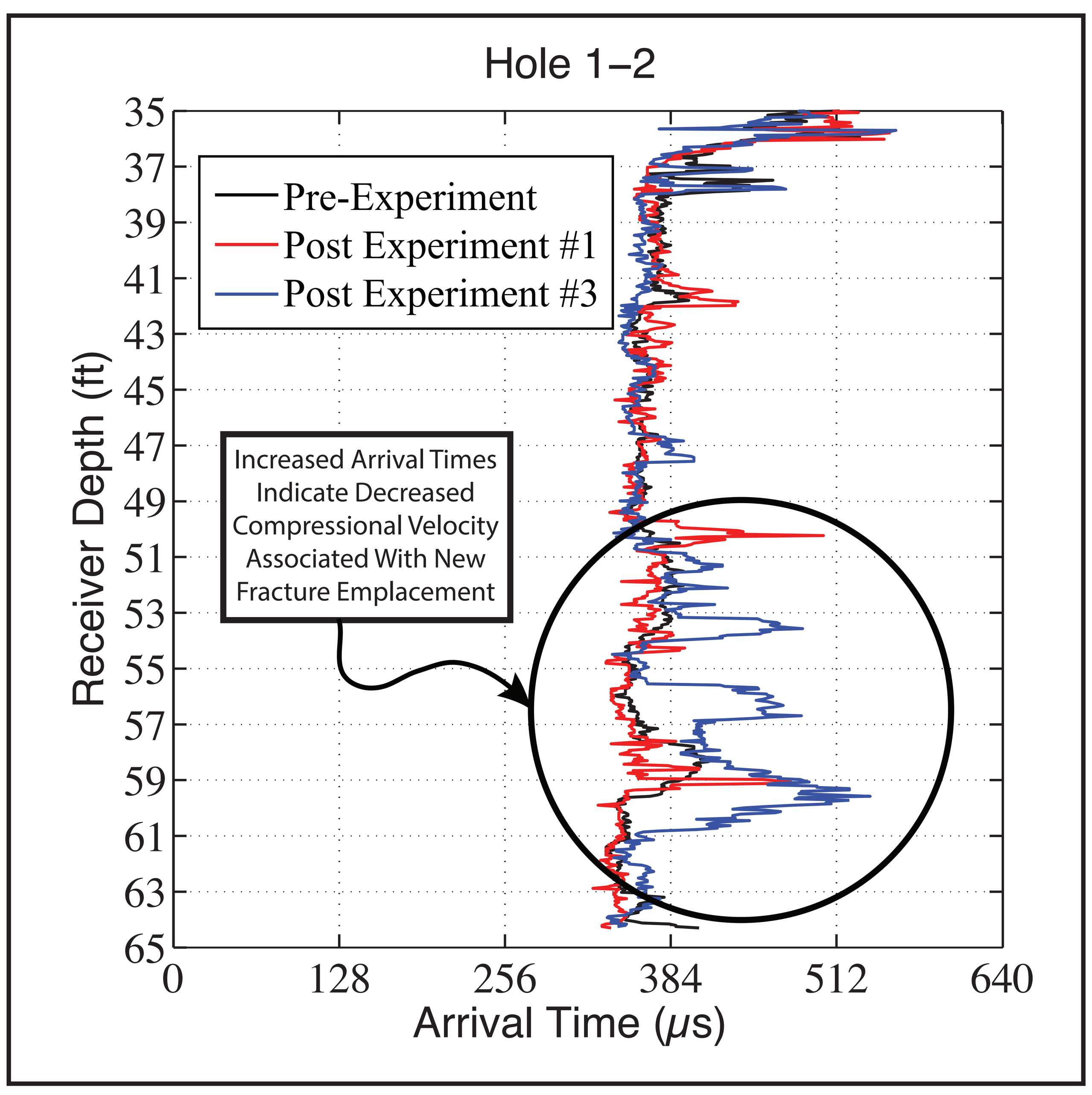
Acquisition & Data Example





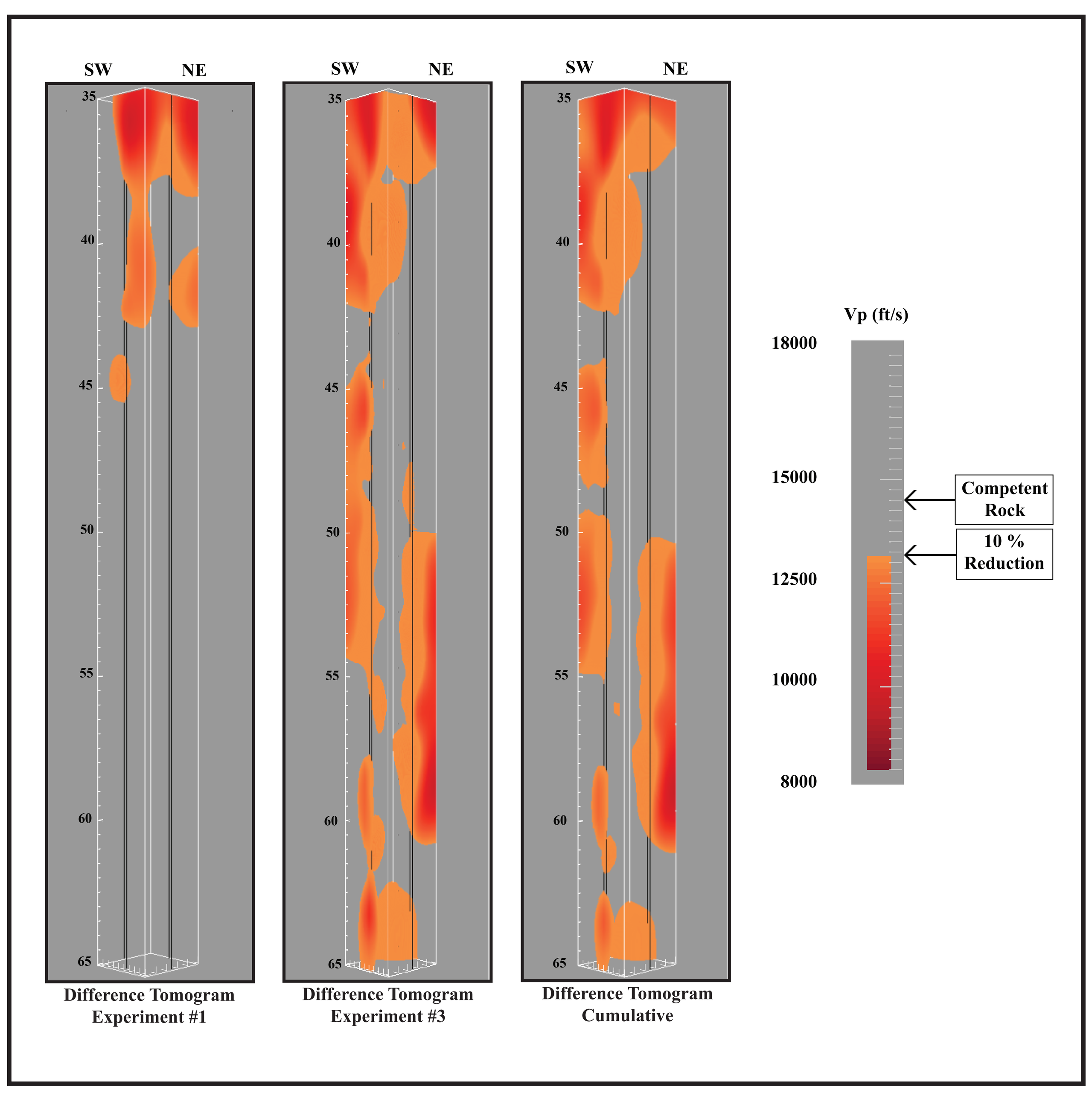
The crosshole seismic logging was performed using Olson Instrument's Crosshole Sonic Logging (CSL) system in four uncased drilled holes nominally 4 feet off center in the cardinal directions (See Figure Upper Left). The CSL system uses piezoelectric crystals with a center frequency of 42 kHz. The diameters of the holes were 3.77" ID. Testing was performed in all 6 available tube pairs (1-2, 2-3, 3-4, 1-4, 1-3, and 2-4). Nine logs (source-receiver offsets of 0º, +/-15º, +/-30º, +/-45º, and +/-60º) were acquired between each tube pair for a total of 54 logs. The data was acquired such that a source and receiver pair was recorded every 0.56". This survey geometry was designed achieve 3-inch or better resolution for the individual 2-D and 3-D tomograms. Testing was performed before and after each explosive experiment to image the fracture extent through changes in seismic velocity (See Figure Upper Right).

Logging Data



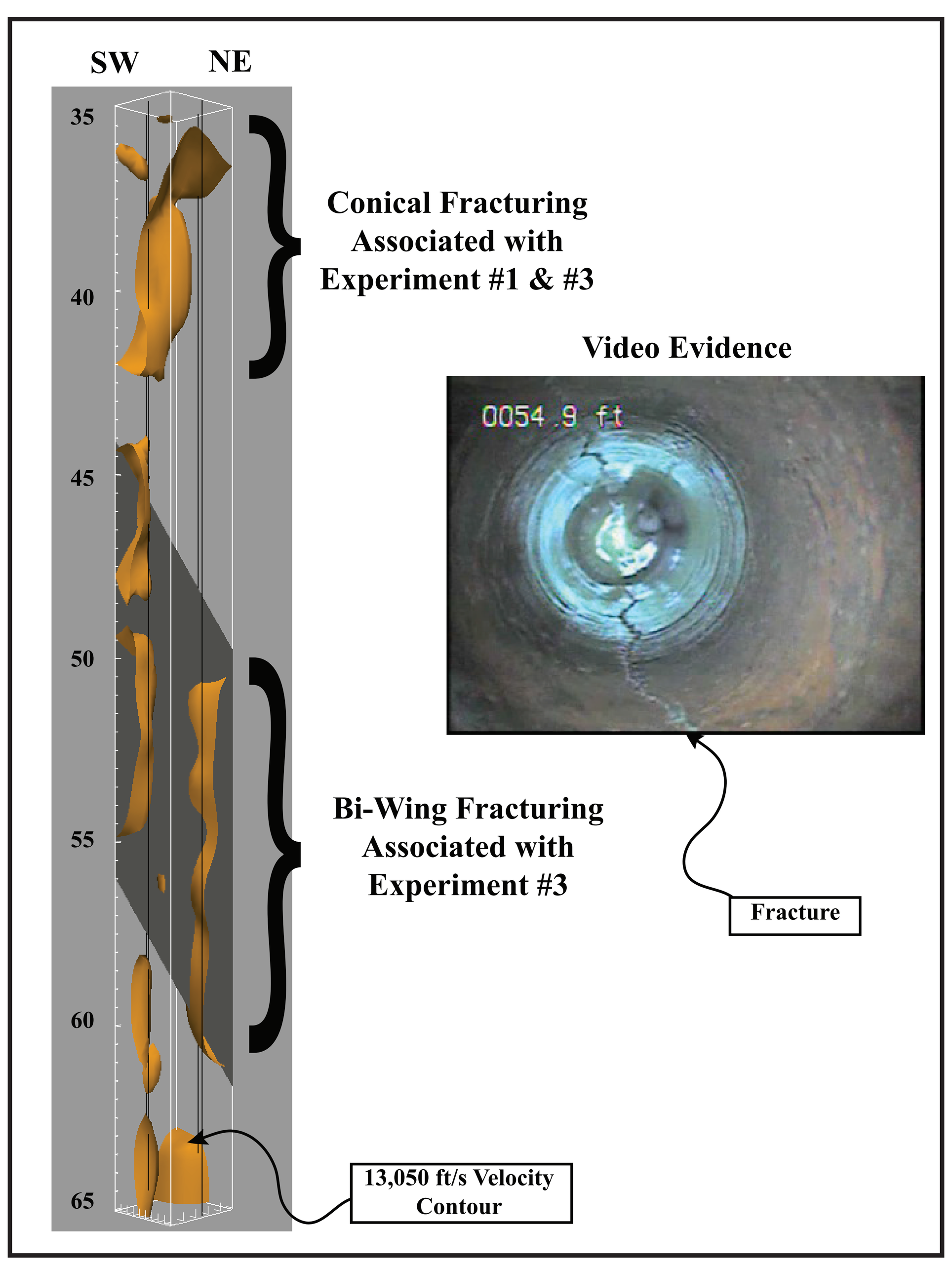
Arrival time data displayed as a function of depth between the Northern (1) and Eastern (2) holes for the pre-, post #1, and post #3 experiments. Post #2 experiment data is not shown here because the explosive detornation was unsuccessful in generating any change.

Differenced Tomograms



Tomographic images computed with a Vidale-Hole finite-difference 3-D eikonal solver with fixed ray paths, which are determined from the previous (in time) test. This method highlights the changes is seismic velocity attributable to the individual experiments. The value indicated for competent (i.e. unfractured) rock is the mean of the measured background model .

Fracture Interpretation



Contoured velocity image for the cumulative differenced tomogram along with the interpretation of the primary induced fracture geometry. Note the video evidence for the dipping bi-wing fracture.

Future Work & Acknowledgements

Testing is ongoing with different explosive mixtures in nearby boreholes. The most recent testing has increased ray coverage and includes imaging between the center and monitoring holes. We continue to use innovative ways to visualize 3D differenced seismic velocity tomograms and understand the relationship between changes in compressional wave velocity and fracture density. Under a recently funded SubTER grant, a multi-disciplinary team began preparing for a field experiment that will record the explosive blast, image the fractured volume, and detect changes during a tracer injection. The field efforts will build on work presented here by incorporating the high resolution seimic testing with real time imaging (i.e. Electrical Resistance Tomography (ERT)), real time active source data acquisition (ERT and ML-CASSM), a Zero Valent Iron (ZVI) injection, borehole logging tools, and continuous distributed fiber-optic sensing. Results from these tests will be incorporated into geomechanical models so that changes can be related back to stress based perterbations.

This project would not have been possible without tremendous help from both Olson Engineering, INC and New Mexico Tech's Energetic Materials Research and Testing Center (EMRTC).

National Nuclear Security Administration

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