Direct Arrival Travel Time Tomography for Time-Lapse Hydraulic Fracture Monitoring using a Walk-Above DAS VSP

R. Meek, R. Hull, K. Woller, Pioneer Natural Resources; R. Van Dok, N. Tamimi, Sigma[3]

Introduction

Direct arrival travel times from both P-wave and S-wave sources were recorded into a Distributed Acoustic Sensor (DAS) fiber array deployed in a horizontal well. Sources were located above and along the horizontal well and repeated before and after the hydraulic stimulation of the well. Differences in the travel times were analyzed using a direct-arrival travel time tomography algorithm to help determine where changes in seismic velocity were occurring with respect to the wellbore. Variations in both P- and S-wave velocity were observed above the treatment well, potentially attributed to changes in the formation related to the hydraulic stimulation. This presentation describes the survey design, data acquisition, data processing and tomographic inversion results. In addition, theoretical and measured directionality results will be compared for both P- and S-waves along with some recommendations for future survey designs.

Survey Design and Data Acquisition

In 2017 Pioneer Natural Resources acquired a series of borehole and surface seismic experiments in the Midland Basin in west Texas with the objective of monitoring changes in the Wolfcamp formation related to the hydraulic fracture treatment. This included the use of P-wave and S-wave vibrators (inline and crossline) before and after the stimulation - 6 weeks apart. These sources were recorded by a DAS array cemented outside the well casing. The source locations used in this analysis were taken directly above and along the horizontal well. Seismic response from the DAS array was recorded with a spatial sample rate of 6.56ft. (2m) and gauge length of 32.8 ft. (10m). The fiber extended the length of the horizontal well for the baseline survey but was truncated about 3,500 ft. from the toe due to perforation during treatment.

Data Processing and Tomographic Inversion

Direct arrival travel times were picked for the P-wave and inline S-wave sources. The crossline S-wave sources showed no direct arrival energy on the DAS array. Prior to picking, the data were processed to remove the horizontally occurring interrogator noise followed by FX deconvolution and bandpass filter to enhance the direct arrival signal. Only sections that could be confidently picked were used and the same depth ranges were picked on both the baseline and monitor surveys to help eliminate observational bias in the final results.

Tomography Results

Tomographic velocity inversion of the direct arrival travel times was performed using the same 3D anisotropic algorithm used for determining velocity field for microseismic event location. However, due to the limited geometry of the experiment and longer travel paths this was limited to a 2D isotropic model. Overburden layer velocities were determined using the vertical DAS array and were fixed for the baseline and monitor survey inversions. Model layers up to 1000 ft. above the treatment well were allowed to vary for each survey and the subsequent velocity models were compared to show the difference before and after the well treatment (Figure 1). This was performed for both the P-wave and inline S-wave sources. The two results show a similar pattern of increases and decreases in velocity but variations in the useable ray paths between the two source types may be contributing to the more subtle differences. These differences will be discussed in more detail with recommendations for future surveys.

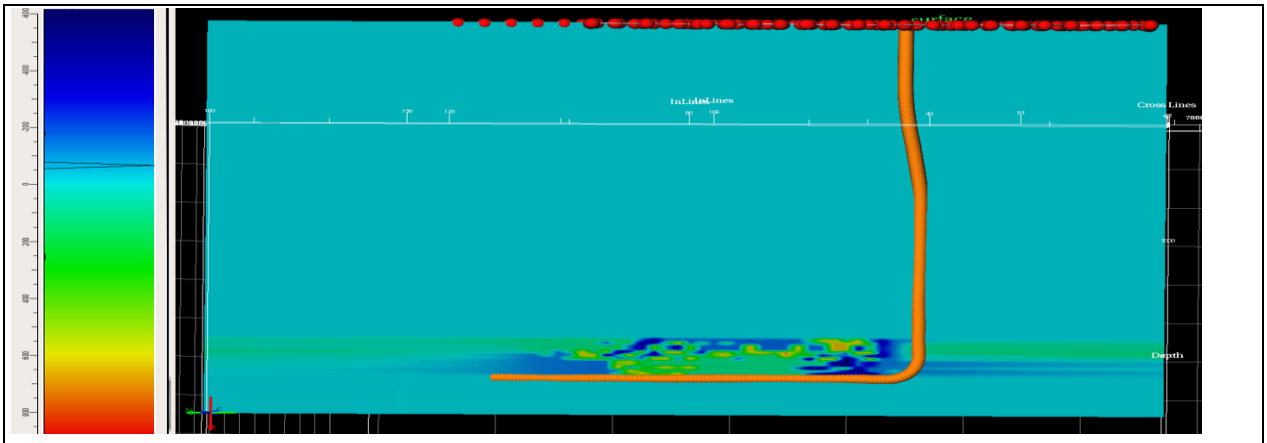

Figure 1: Side view showing the difference in the P-wave velocity determined using the direct-arrival travel time tomographic inversion. Source locations are shown as red spheres and the DAS fiber array as orange. Decreases in velocity are blue, increases are green to red. Overburden velocity was held consistent between surveys and shows up as zero on the difference (teal). Changes beyond the DAS fiber are extrapolation artifacts.