Determining Effective Hydraulic Fracture Volume Utilizing PSO and Seismic Deformation

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Introduction

Microseismic monitoring is used to understand the extent of fracturing and the interaction with fault networks resulting from the injection of proppants into the reservoir. Typically, a wireline array of triaxial geophones is temporarily clamped into a shut-in well located in close proximity to the treatment well. In this study, data were acquired using an 8-level geophone array with a total aperture of 215m for a 14 stage hydraulic fracture treatment. In total, 2905 events were located over 14 stages using a Simplex based Azimuth Ray Tracing approach and a velocity model derived from a dipole sonic log in the observation well. Utilizing a Particle Swarm Optimization (PSO) approach, we were able to identify, on average, velocity changes of 10% for V_p and 12% for V_s for the stimulation stages. Additional spatial and temporal analysis of the seismic deformation were used to identify regions with higher deformation (accounting for >90% of the observed deformation), and therefore increased permeability resulting in an increased contribution to production.

Theory and/or Method

With increasing pressures, fluid concentrations and resulting fracture growth from the hydraulic treatment, the geophysical characteristics of the reservoir are altered; specifically the P and S wave velocities. These changes in velocities are unique to each reservoir and to each fracture treatment depending on the composition and the nature of the host rock. Particle Swarm Optimization (PSO) is a stochastic optimization technique which can identify these changes. PSO is an iterative process where a particle represents a set of parameters of interest and event locations and layered velocity model are varied until it converges on a solution that minimizes the residuals of the given events.

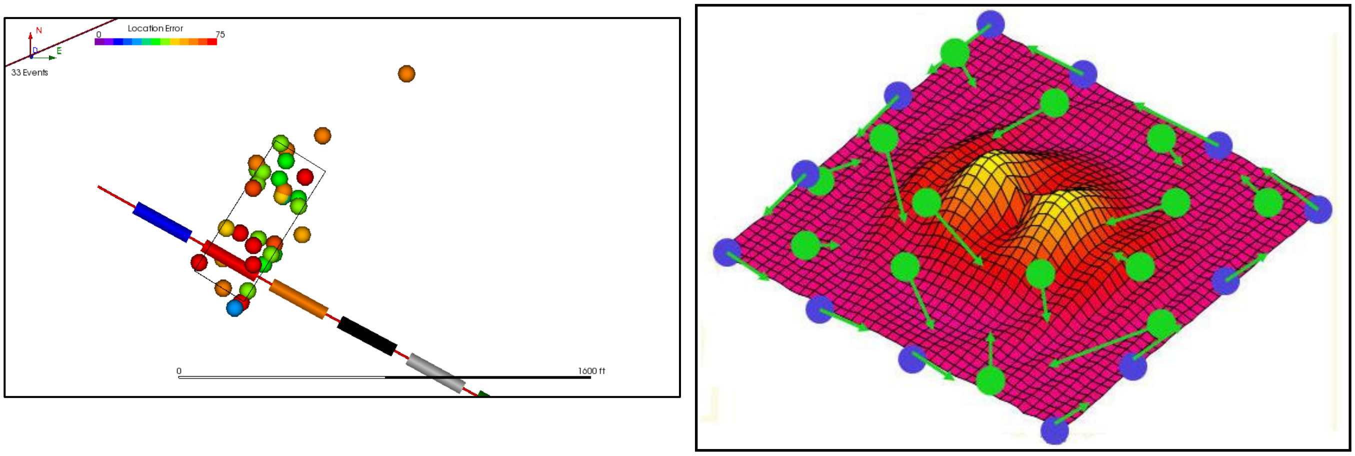

Figure 1(a) A set of 33 events with 3 coordinates results in 99 coordinates. A nine layer velocity model structure (18 parameters) results in 117 parameters in total and over 350 particles. Figure 1(b) PSO iteratively moves the particles (altering both location and velocity structure) around in space until it converges on a solution which minimizes location accuracy and time residuals between travel time picks and calculated theoretical picks of a given event.

In addition to PSO, seismic deformation analysis was also performed on the data from each stage. Seismic deformation is the sum of the seismic moment divided by the target volume and shear modulus. It is proportional to the degree of fracturing which has occurred, i.e. volumes that have small seismic deformation will tend not be extensively fractured, whereas volumes that have large seismic deformation will either have a complex network of many small fractures, a number of large fractures, or both. In terms of hydraulic fractures, volumes with high seismic deformation will show increased permeability and therefore, would likely contribute to reservoir production more effectively. Based on the deformation analysis of each hydraulically fractured stage, an effective fracture volume is estimated.

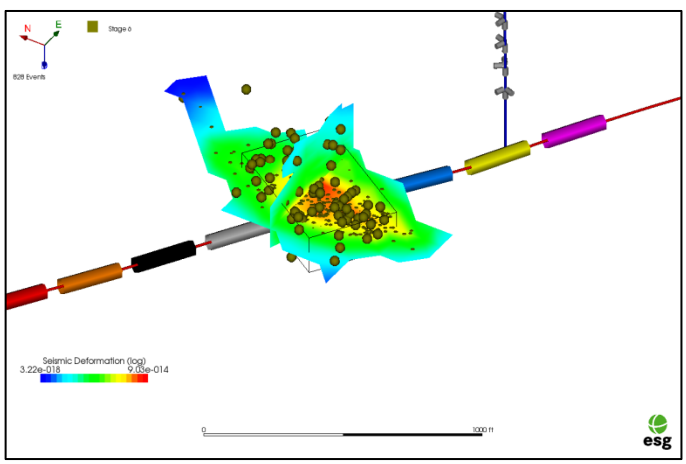

Figure 2: Seismic deformation analysis for a single hydraulic fracture treatment stage. Colored contours illustrate that higher levels of deformation occur directly around the treatment zone, indicating good communication with the treatment zone.

Conclusions

Incorporating the velocity changes calculated by PSO into the velocity model allowed for events to be located with reasonable confidence giving a more clear understanding of the resulting fracture dimensions and orientations. From there, seismic deformation analysis was successful in calculating an effective fracture length, width, height and volumes, providing field operators with a map of effective drainage that can aide in optimizing future well locations and fracture treatments.