Case Study

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Analysis of Vertical Breakout in a Diatomite Steaming Operation in California

ESG successfully monitored a steaming operation in a diatomite reservoir in the San Joaquin Valley in South-Central California. Advanced analysis of microseismic events identified very different fracture behavior during contained and uncontained vertical fracture growth, leading to advanced understanding of vertical breakout conditions.

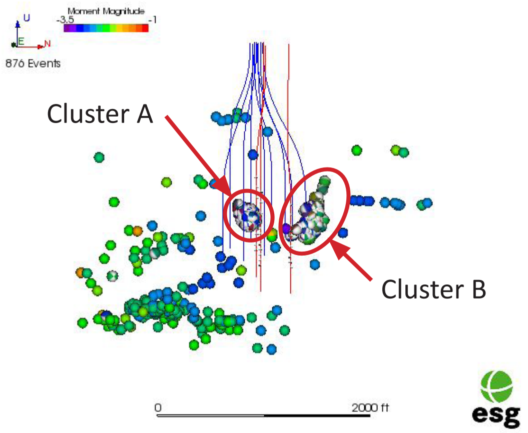

Fig. 1: Illustration of microseismic events recorded over a two month steaming period. Cluster A is indicated on the left and Cluster B is on the right.

Diatomite is a rock formation primarily composed of the biogenic siliceous deposits of diatoms (single-cell algae). In South-Central California, large heavy oil bearing diatomite reservoirs are found within the Miocene Monterey and Reef Ridge formations. The diatomite formation has relatively low permeability and thus benefits from extensive hydraulic fracturing to increase permeability. Hydraulic fractures are then followed by thermal steaming to enhance recovery.

Challenge

ESG installed three permanent high-temperature microseismic monitoring arrays in three vertical observation wells and provides continuous monitoring of fracture and steaming operations in the diatomite formation. Each observation well contains a 12-level toolstring equipped with triaxial sensors. Two clusters of seismicity (Fig. 1) were generated from the steam production of the reservoir; the first (Cluster A) was contained while the

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second (Cluster B) exhibited unconstrained vertical movement. Cluster A consisted of 127 events while Cluster B included 164 events. Advanced seismic moment tensor inversion analysis was performed on the two clusters to further examine the failure mechanisms associated with each cluster.

ESG Solution

While standard location analysis of microseismicity answers where and when the events occur, Seismic Moment Tensor (SMT) analysis can answer how these events occur. As part of its ResMap™ services, ESG performed SMT analysis on the data recorded for Cluster A and Cluster B and determined that the failure mechanisms for each cluster were very different.

A helpful way to display the results of SMT analysis is with a source-type diagram (Fig. 2). Several types of failure mechanisms are indicated on this plot: double couple (DC), or pure shear mechanisms will cluster in the centre; isotropic or pure opening or closing events will be positioned at the top or bottom of the figure, respectively; pure compensated linear vector dipole (CLVD) events, which plot at either side of the figure; and finally linear dipole and tensile cracks opening and closing can be found on the upper-left and lower-right of the diagram.

The source-type plot in Fig. 3 for Cluster A places events closer to the middle of the top and bottom halves of the plot. The events in these regions are suggestive of mixed mode tensile opening and closure (top and bottom of source-type diagram, respectively) coupled with pure shearing type failure mechanism (found at the centre of the source-type plot). This pattern is very typical of how steam chambers develop, and reinforces the observation that the steam is behaving in an optimal manner.

One interpretation of this observation is that these events are fracturing through the pore spaces in the reservoir, and the volume changes of the pore spaces are alternatively dilating and compacting in response to the treatment. Through SMT analysis we can therefore show how the permeability of the reservoir has changed through fracturing these pore spaces.

For Cluster B, the source-type plot in Fig. 4 indicates that the events are primarily linear dipole and tensile opening/closing events. One interpretation of this observation is that the steam is pushing through a preexisting fault or fracture that is in a vertical orientation. By following this path of least resistance, the fluid propagates upwards in an uncontrolled manner.

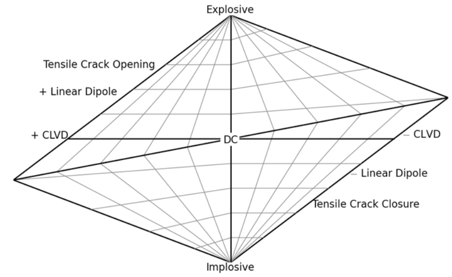

Fig. 2: A source-type plot with the position of several mechanisms noted

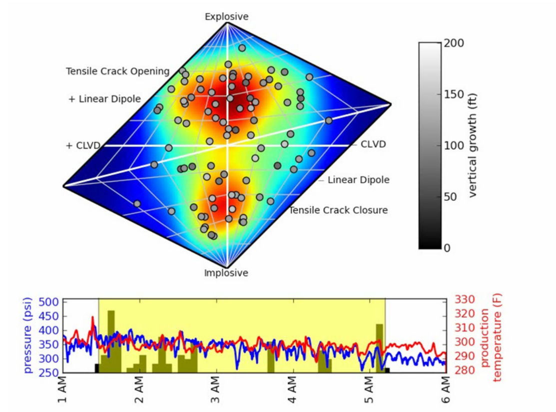

Fig. 3: Source-type plot and production parameters (temperature in red, pressure in blue and event rate histogram) for the events depicted in Cluster A for contained fracture growth. The events are grayscaled by vertical growth overtop a density plot for the distribution.

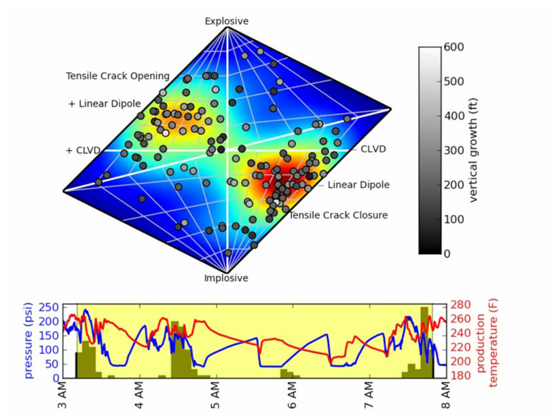

Fig. 4: Source-type plot and production parameters (temperature in red, pressure in blue and event rate histogram) for the events depicted in Cluster B for uncontained fracture growth. The events are grayscaled by vertical growth overtop a density plot for the distribution.