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The Potential for Predicting Production by Characterizing Fluid Flow and Drainage Patterns Using Microseismicity

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Introduction

Working with the supposition that the spatiotemporal behaviour of microseismic events can reveal variations in rock properties, we move beyond conventional static microseismic interpretations and analyses to identify processes that play important roles in the dynamic expansion of a fracture network during hydraulic fracture stimulations. It is understood that many small microseismic events lead to a finite and macroscopic deformation. While an individual microseismic event corresponds to slip on a discrete surface, the combined deformation of a group of events results in a collective behaviour. Our investigation considers whether these macroscopic properties of the fracture system can be extracted through analysing the spatiotemporal growth of events and their properties within selected rock volumes. This is achieved by considering that disturbances in the rock and reservoir trigger inelastic deformation as stress and fluid transfer through the rockmass thereby suggesting that this deformation can be considered as flow (of the stress field). In other words, the characteristics of flow are mirrored in the seismicity and that large fluctuations in stress in the reservoir comprise turbulence in this flow. In this study we consider how turbulence in flow can compromise the uniformity of production along treatment wells and how the complexity of flow also relates to production levels along treatment wells.

Seismicity and Flow

In general, we can identify key factors that will control flow behavior, such as, local geology and rock properties, local stress state and pre-existing fracture network, treatment design (eg., well spacing, well landing, azimuth, stage spacing), and treatment schedule (eg., pressure, flow rate, fluid and proppant type, timing). Seismic Moment Tensor Inversion (SMTI) can be utilized to obtain details on the stress-strain state, the underlying fracture network and their interaction. By assuming that flow will occur along cracks that are preferentially oriented to the minimum principal strain axis, we can identify potential preferred flow pathways. By mapping these pathways through the strain field, it is possible to identify drainage patterns of individual ports (centres of the perforations for each stage) throughout the stimulated reservoir volume. In this way, we identify streamlines that represent the trajectories of particles in a steady flow, where the streamlines are tangent to the velocity vector of the flow and perpendicular to equipotential lines. In other words, streamlines aid in identifying the origin of the hydrocarbon flow arriving at each port (See figure 1). By complementing flow maps with seismic deformation as a proxy for generated free surface area, we can identify areas of high seismic deformation and parallel stream lines that will drain hydrocarbons quickly and easily and areas where ports associated with convoluted streamlines and low seismic deformation will drain more slowly.

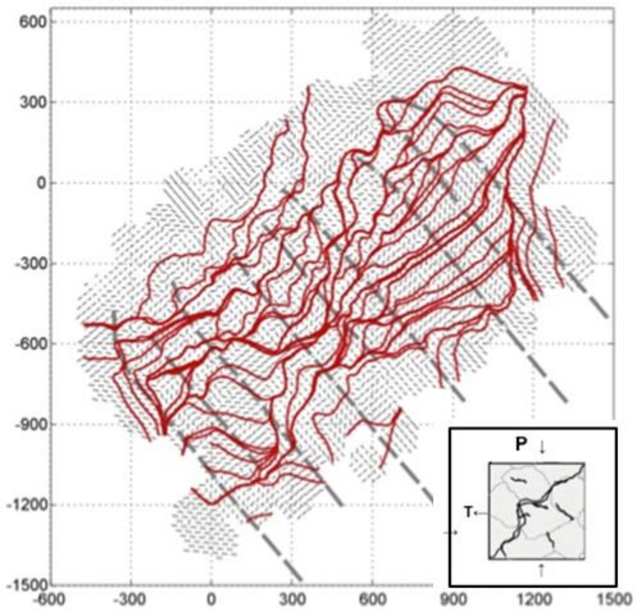

Figure 1 *Stream- or flow lines representing the trajectories of particles in a steady flow underplayed by orientation vectors of the minimum principal stress showing both trend and plunge (vector length).*

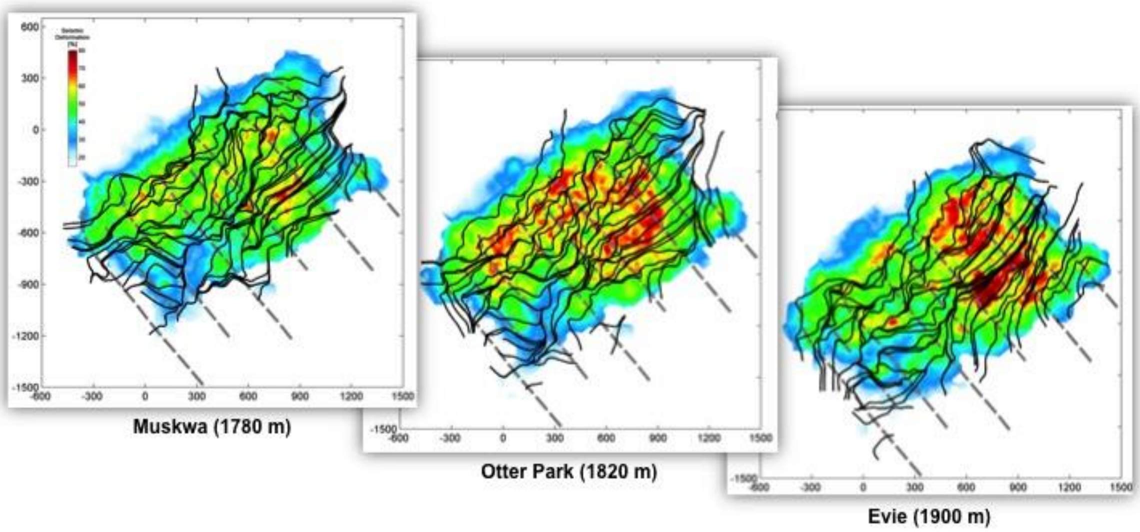

Figure 2 *Streamlines with contoured seismic deformation for the three formations within the Horn River Basin.*

Characterization of flow is also possible through the defined use of dynamic parameters, such as Plasticity Index (PI) which combine source parameters of microseismic events as a function of their timing and spatial distribution and provides insight into the ease with which the reservoir deforms in response to fluid injection where PI is defined as

$$PI(\Delta V, \Delta t) = \frac{\tau_T}{\tau_s} = \frac{\mu \tau_T}{\eta_S}$$

where τ_s is the seismic relaxation time and τ_T is the treatment time scale. PI represents the spatiotemporal rate of deformation of the underlying rock and is a function of the rock properties themselves and pre-existing fracture state. The interaction of these properties defines the ease at which seismicity develops, the level of seismicity and the associated degree of deformation.

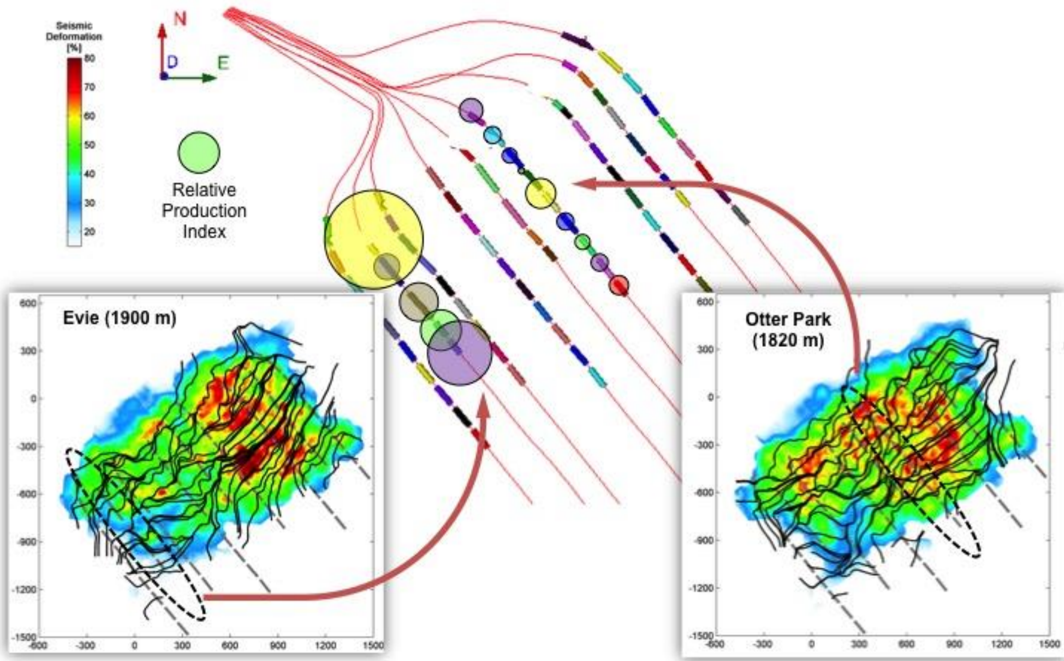

Figure 3 *Relative Production indices based on PLT data for wells within the Otter Park and Evie formations along with streamline and seismic deformation relationships.*

Examples

To test these concepts we examine microseismicity associated with stimulations in the Muskwa, Otter Park and Evie formations in the Horn River, NE British Columbia. The data set examined in this study consists of over 30,000 inversions as associated with a zipper frac with over 90 stimulation stages. As part of the analysis, PLT (Production Logging Tool) data from a producing well, used to quantify and assess flow behaviour of the production, is compared to the dynamic parameters obtained in our analysis.

As shown in figure 2, complementing the flow maps with seismic deformation identifies areas of high seismic deformation that align with parallel streamlines and areas of low seismic deformation that appear to align with convoluted streamlines within the different formations. These observations suggest that drainage in the reservoir is not uniform and some wells will drain hydrocarbons more quickly and easily than others that will drain more slowly. The response within each formation also provides insight into the nature of each formation to produce. In figure 3, comparing PLT results for wells within the Otter Park and Evie formations, we find that high seismic deformation and uniform parallel flow lines, or drainage fairways, coincide with a more homogeneous distribution of production values, whereas tortuous flow paths and low seismic deformation coincide with irregular production, respectively. The PLT data for a well within the Evie formation, as shown in figure 4, highlights the variability of production along the well. Similarly, the Plasticity Index is equally variable. There is, however, a good agreement between which ports or stages with higher production volumes and observed high Plasticity Index values and vice-versa. Interestingly, the distribution and number of observed events for the various stages cannot be directly related back to the PLT data.

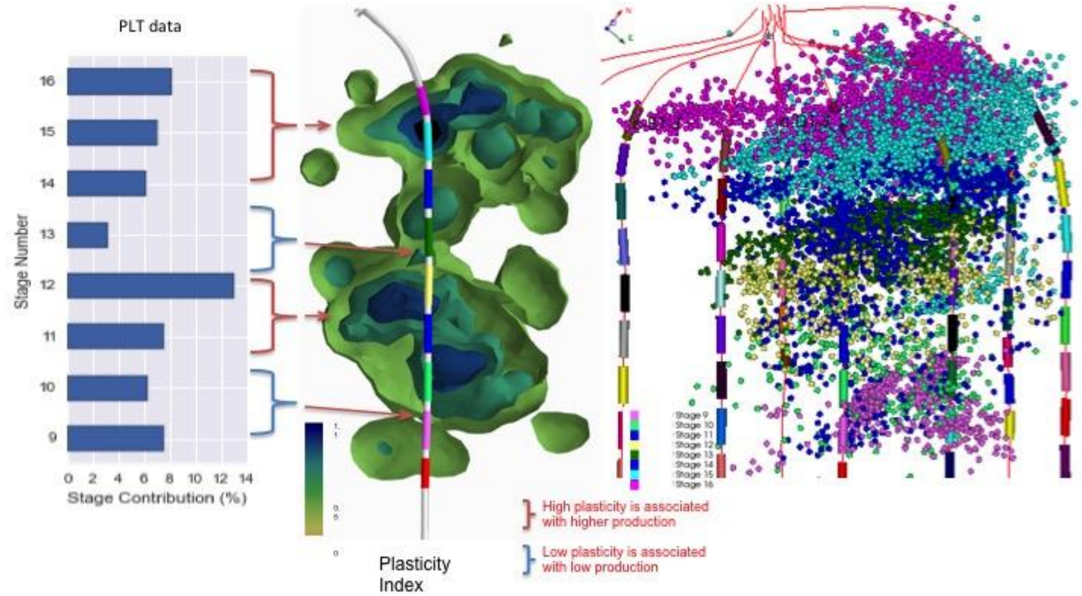

Figure 4 *Contoured log of Plasticity Index along a singular well within the Otter park, along with observed seismicity colour-coded by stage and equivalent by stage production from PLT data.*

Summary

Based on our observations, utilizing the spatiotemporal behaviour of microseismic events and considering that deformation can be considered as flow, appears to have analogous response to production, suggesting that calculated flow parameters can be used as a proxy for identifying production regularity for wells. Inherently, it also suggests that we can further use these flow parameters to optimize stimulation, including for example, well spacing and landing, and stage spacing. Streamlines, not only can be used to define laminar flow or drainage pathways, inherently provides information on the rock properties, which when tied to identified rock properties can be used to enhance stimulation programs.