Fracture Evaluation

Completions Evaluation for Hydraulic Fracture Monitoring in Unconventional Resources

Today 'fracture evaluation' is performed using various simulations that use microseismic data to qualitatively calibrate the model. This article demonstrates new developments that enable valuable information to be extracted by combining contextual information such as geology, well logs, treatment data, etc with deterministic analysis of the microseismic measurements, providing quantification of the hydraulic fracturing.

Microseismic is now an accepted technology used to monitor hydraulic fracturing. It is used to measure the geometry, location and complexity of the fractures. Although microseismic monitoring has added value in understanding hydraulic fractures, there is still significant information and value that can and should be extracted from any microseismic monitoring programme. Most of the microseismic analysis performed to-date is qualitative and has provided limited value in optimising completions.

To fully optimise the completion and fracture treatment, it is important to understand various aspects of fracturing treatment such as – differentiating propped and un-propped fractures, fracture growth and geometry, fracture overlap between stages and wells, stress shadowing effects, and treatment efficiency. Currently this is achieved by a qualitative comparison of microseismic points with simulation models.

Figure 1 shows an idealised process for completions and fracture optimisation. Today 'fracture evaluation' is performed using various simulations that use microseismic data to qualitatively calibrate the model. This article will demonstrate new developments that enable valuable information to be extracted by combining contextual information such as geology, well logs, treatment data, etc with deterministic analysis of the microseismic measurements. The result of this deterministic analysis provides quantification of the hydraulic fracturing. Some of the key aspects of this analysis are:

- Fracture geometry - height, length, and azimuth
- Fracture complexity and tortuosity
- Fracture coverage (overlap between stages and wells)
- Characterisation of fracture mechanisms (dip-slip, strike-slip, etc.)
- Identification and avoidance of geo-hazards such as faults

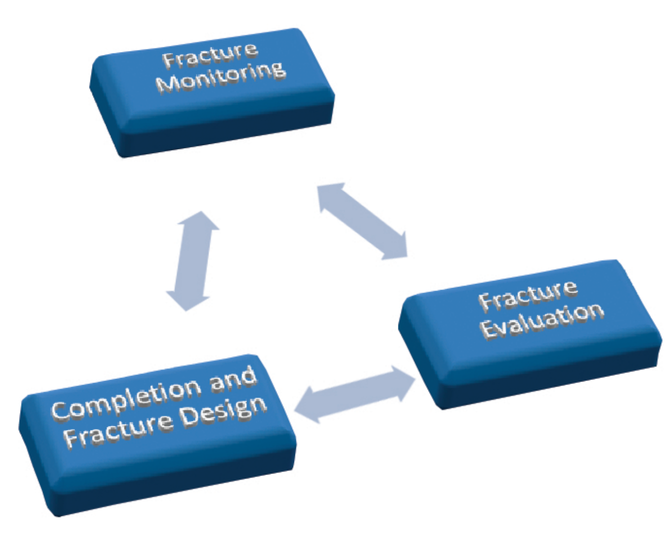

Figure 1: Completion and Fracture Optimisation

Completions Evaluation Analysis

The completions evaluation analysis provides a mechanism to better calibrate and build underlying geo-mechanical and reservoir models; improving forecasting of fracture placement and production helping to accelerate optimisation of future wells and treatment designs.

This distinct process of Completions Evaluation consists of a workflow and tools to perform diagnostic analysis of microseismic data, enabling accurate evaluation of the fracture treatment.

It is designed to precisely characterise the fracture network growth and complexity, while providing a methodology to evaluate the wellbore spacing, stage lengths, cluster spacing, and treatment parameters. The basic workflow is outlined in Figure 2.

>> To fully optimise the completion and fracture treatment, it is important to understand various aspects of fracturing treatment such as – differentiating propped and un-propped fractures, fracture growth and geometry, fracture overlap between stages and wells, stress shadowing effects, and treatment efficiency.

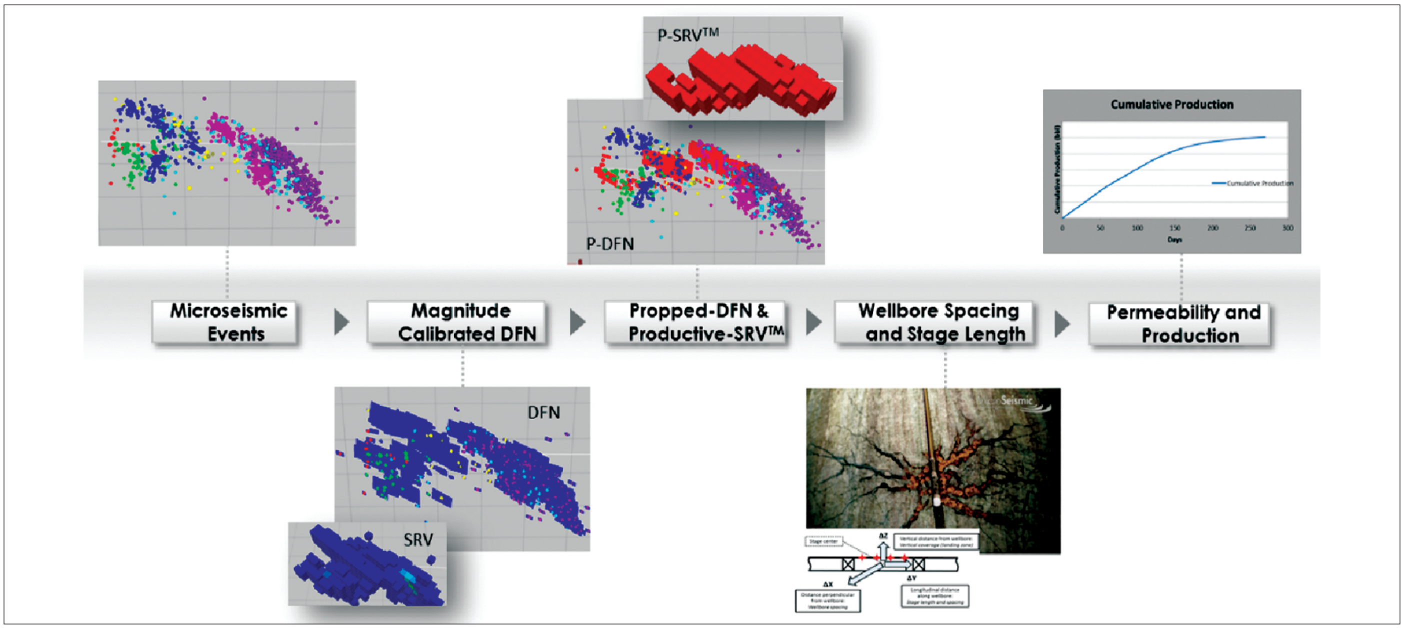

Figure 2: Completions Evaluation Workflow

The workflow consists of the following steps:

1. Compute a magnitude calibrated Productive Discrete Fracture Network (P-DFN) and Productive-Stimulated Reservoir Volume (P-SRVTM)
2. Quantify optimum well spacing, stage lengths, and treatment efficiency based on P-DFN and P-SRV
3. Quantify permeability for the P-SRV and predict long term production

Magnitude Calibrated DFN

To accurately define a distributed fracture network, it is essential to start with a microseismic data set that enables computation of the absolute magnitude of each event. There are special processing techniques that preserve the signal amplitude and enable computation of the absolute magnitude.

Once acquisition has commenced and magnitude calibrated, microseismic point sets are created, a DFN is modeled onto the microseismic events in two steps:

1. Through source mechanism analysis, strike and dip of the failure plane are identified for each individual event. The geometry of each individual failure plane is then determined through the magnitude of an event, incorporating rock and fluid properties resulting in a Discrete Fracture Network (DFN), shown in Figure 3.
2. Length, height, and aperture of the fractures are obtained using a methodology incorporating the magnitude of a microseismic event, the rigidity of the reservoir rock, the injected fluid volumes, and, if available, fluid efficiency. Using a relationship between the aperture of the fracture and its length, along with an assumed aspect ratio for a layer cake medium, the geometry of the three-dimensional fracture is obtained and a fracture volume can be computed. Assuming that the total detected seismicity is directly related to the injected fluid volume, and that the change in volume is completely accommodated by the seismic failure, minus leak-off, the calculated fracture volume should equal the injected fluid volume.

Magnitude Calibrated Productive Stimulated Rock Volume

Events in the hydrocarbon-bearing target zone are most likely to represent rock failure that contributes to production in the long term. Estimating the propped fracture length and volume is performed by filling the DFN set with proppant from the wellbore outwards on a stage-by-stage basis. The packing density of the proppant is variable and can be adjusted based on the specific gravity of the proppant and available fracture models. The default value is approximately the density of loosely packed sand. Proppant filling is constrained by tortuosity of the flow path using a

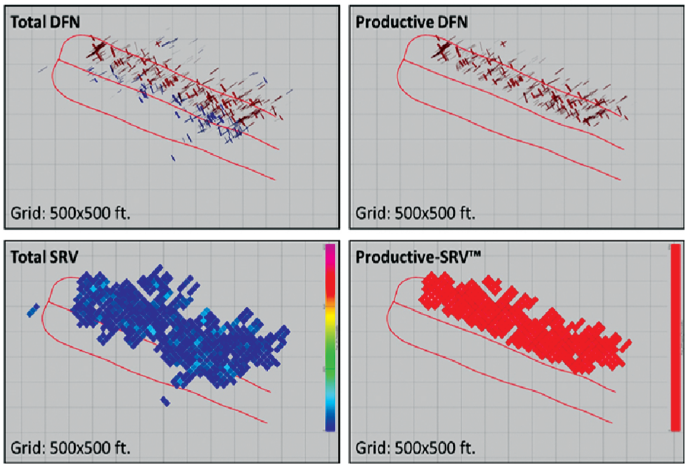

Figure 3: Distributed Fracture Network and Productive Stimulated Rock Volume

proprietary method. The fracture volume inside the respective stage DFN is filled with proppant until all proppant that was pumped is accounted for. The estimated propped half-length is determined by taking the distance between the last fracture that contains proppant and the center of the stage at the wellbore.

In order to calculate the total Stimulated Rock Volume (SRV), a three-dimensional grid is applied to the total DFN. Every grid-cell containing a non-zero fracture property is included in the magnitude calibrated SRV. The total SRV is dependent on the size of the model cells and can be adjusted based on known reservoir flow properties. It represents the total rock volume that was affected by the treatment. In order to discern between the part of the SRV that is assumed to be drained over the lifetime of the well, the same workflow is applied to the proppant filled DFN. The subset SRV that is calculated from the part of the DFN containing proppant then represents the Productive-SRV that is expected to contribute to production in the long term, as illustrated in Figure 3.

Wellbore Spacing and Stage Length Evaluation

One of the most important aspects of evaluating a hydraulic fracture treatment is to determine the effectiveness of the treatment as measured by the fracture growth and fracture complexity. Key parameters of the fracture growth can be determined directly using a sub-set of fractures that are filled with proppant or the P-DFN. Selecting fractures that are filled with proppant allows accurate determination of the effective propped fracture growth in all directions from the wellbore. It is these propped fractures that will ultimately control the long term production from the well and should be used to determine the required well spacing and stage lengths.

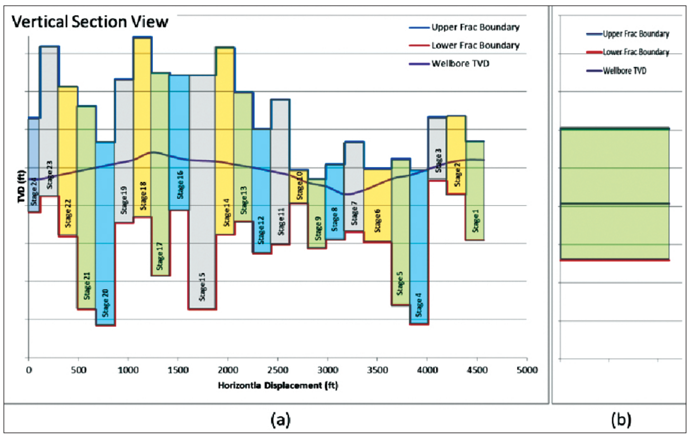

Figure 4: Stage-by-Stage Vertical Fracture Growth

Figure 4(a) shows the stage-by-stage analysis of the vertical fracture growth while Figure 4(b) shows the average vertical growth for the entire well. It clearly shows where the stages with fracture growth are effective, and the stages with limited fracture growth are less effective. Combining this with other contextual information – such as structure, geology, and stress regimes enables a better understanding of the treatment effectiveness in creating the desired fracture geometry.

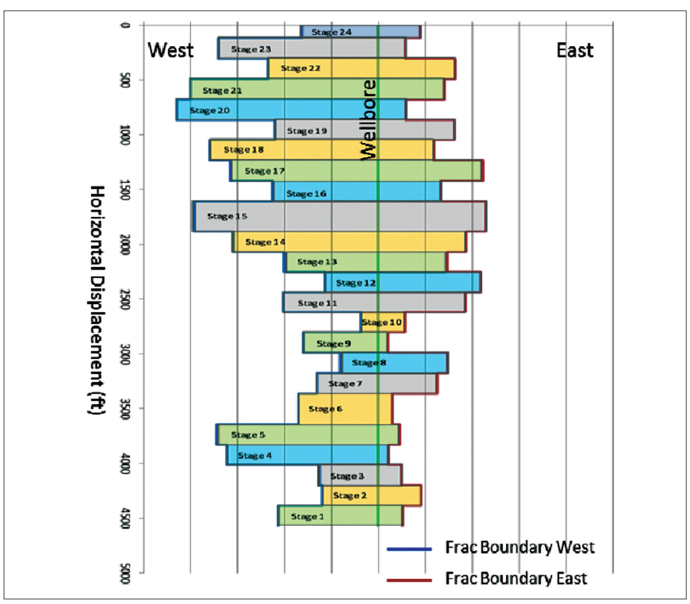

Figure 5: Stage-by-Stage Horizontal Fracture Growth

Figure 5 shows the fracture growth in the horizontal plane. In this instance, there is a very clear bias of the fracture growth towards the west. This bias may be caused by several factors such as geology, structure, stress shadow from previous wells, depleted zones, etc. Analysing this data with reference to contextual information will enable the engineer to better diagnose the fractures as well as improve design for future wells.

Another aspect of evaluating the fracture growth is to look at the cumulative fracture growth as a function of pumped fluid and proppant volume. The fracture surface area can be estimated from the absolute seismic moment of any event. The seismic moment is a measure of the size of a fracture, based on the area of fracture, the average amount of slip, and the force that was required to overcome the friction holding the rocks

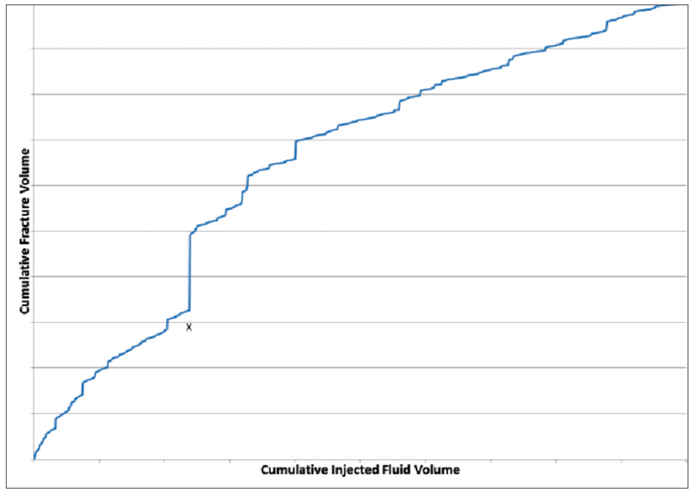

Figure 6: Fracture Volume

together. Figure 6 shows a cumulative fracture volume plot as a function of normalised pumped volume. A linear increase in the fracture volume as seen at the start of the pumping indicates generation of new fractures or opening of pre-existing fractures resulting in additional open fracture area. The sudden increase in the fracture volume at point 'X' indicates potential activation of a much larger pre-existing fracture. After pumping about 75 per cent of the fluid, a reduction in generation of a new fracture volume can be seen. During this period, it is possible that existing fractures are being opened by the pumped fluid and proppant. The cumulative fracture volume plot thus provides a very useful diagnostic tool to evaluate whether new fractures are being created, or if existing fractures are being opened.

Summary

Completions Evaluation provides a deterministic analysis of microseismic data. This, in conjunction with contextual information, provides a valuable tool in evaluating the effectiveness of hydraulic fracturing treatment. This analysis allows operators to finally answer the questions- where did the proppant go? How far do my propped fractures extend? How many stages do I need? With this analysis, it can be determined if hydrocarbons are being left behind, if there is over-spending on the number of wells, and the optimum number of stages required in completing each well.

Sudhendu Kashikar
Vice President - Business Development
Microseismic Inc
E-mail: skashikar@microseismic.com