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New Fractal Analysis technique aiding fracture geometry imaging

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Summary

Throughout scientific publications, microseismic data is often referred to in a derogatory fashion as “dots-in-the-box”. Such choice of words can be understood- microseismic event locations are an arrangement of points in 3 dimensions, and it is difficult for a human eye to distinguish relationships that are not extremely pronounced. Better use of the spatial location data can, and has to be made to visualize such trends. The information contained in them can provide a very useful tool in aiding a geoscientist in interpreting pre-existing natural fracture systems. It can be integrated with other datasets (seismic, petrophysical and lithological) to derive a coherent model of system-wide behavior.

This report presents a novel technique of analyzing the spatial data based on fractal analysis methods. The technique is applied on a hydraulic fracturing microseismic dataset and analyzed in conjunction with seismic, well logs and engineering completions data.

Introduction

The hydraulic fracturing project comprised 18 stages in a horizontal treatment well. Only the first six stages were recorded as microseismic events due to lower signal levels in the later stages. Sliding-sleeve completion-type was used. The vertical observational well, located near the treatment well toe, included a 24-level geophone array. The schematic diagram is given in Figure 1.

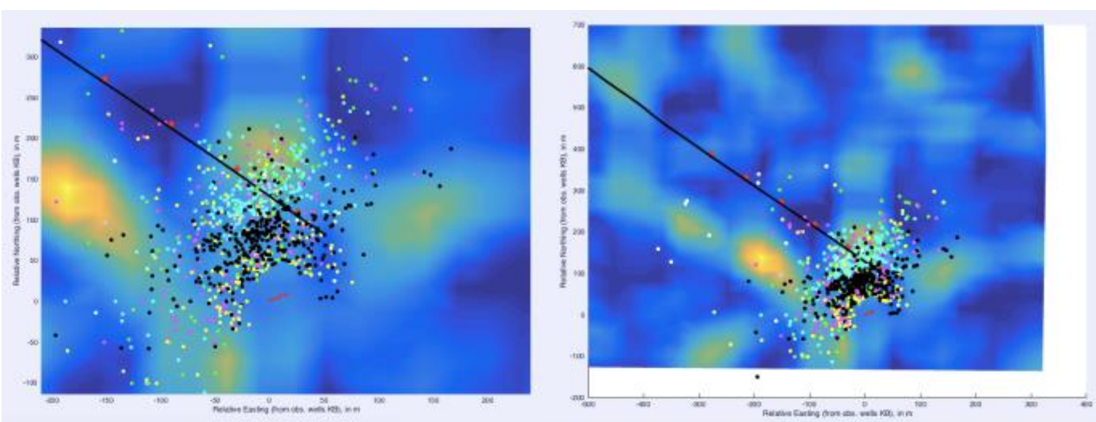

Figure 1 Plan view of ms events (right). Zoom-in on the toe of the treatment well (left).

Treatment well-in black, observation well- in red, port locations-red diamonds. Ms events are sorted by stage color wise: stage 1-black, stage 2-cyan, stage 3- yellow, stage 4-magenta, stage 5- green, stage 6- white. In the background is the maximum curvature seismic amplitude map of the Montney horizon (yellow-greatest curvature, blue-smallest). Northing (in m) is on the vertical axis, easting (in m) is on the horizontal axis. Both Easting and Northing are measured here relative to the obs. well kelly bushing. Seismic data courtesy Pulse.

The project was done in the D1 member of the Montney formation. The microseismic data was acquired by Pinnacle, and re-processed by Reservoir Imaging. The seismic data was acquired by Pulse. Figure 1 identifies a significant clustering of microseismic events besides the locations of ports 1 and 2 (two of the most downhole ports). However, the areas in the vicinity of ports 3-6 are significantly less populated. The aim of this research is to identify the cause of this behavior and explain the mechanism of the microseismic event migration from ports 3-6 to ports 1-2.

Theory and/or Method

Fractal dimension analysis is commonly used to detect the presence of trends in a dataset comprised of points with three dimensional coordinates. It is applied in a similar fashion in microseismics. First, one point is set as an origin. A vector of radiuses (r) spanning the smallest distance to the largest distance between each point set if created. For every value of r, the number of points (N(R<r)) away from the origin a distance smaller than r (R) is found. The procedure is then repeated with the next value of r. Each value of N(R<r) is then normalized by the total amount of points in the dataset (N) according to the formula below (from Grassberger and Procaccia, 1983):

$$C(r)=\frac{2}{N(N-1)}N(R<r)$$

The C(r) and r have been found to form a power-law relationship (Grassberger and Procaccia, 1983). The power that the r is raised to determines the behavior of the dataset. It is referred to as the D-value/ fractal dimension. The D-values of one correspond to purely linear distributions, D-values of two- to planar, and three- to spherical. The conventional use of the fractal dimension analysis was to split the dataset piecewise according to time/stages and compute an average D-value for each period or inside a moving window (Grob and Van der Baan, 2011). Changes in D-values were then interpreted independently or alongside B-values (covered below).

In this research, the approach to using D-values was modified. Same fundamental formula (as above) was used, but D-values were calculated differently on the dataset. A different means of data visualization and interpretation was used as well. Whereas commonly D-values are plotted against time/ order of event occurrence, a conversion to a novel coordinate system was completed (expressed as a position alongside the treatment well length, in meters MD). This conversion was completed in order to better differentiate the expected and unexpected spatial fracture trends and better characterize the latter.

B-values are indicative of the stress regime in the area (Schorlemmer et al., 2005), and are used to find stress regime changes that can later be interpreted as natural fractures/ faults/ other anomalies. B-values are defined as the slope of the binned cumulative frequency magnitude distribution of the microseismic events.

Examples/ Results

The results of the D-value calculations were plotted on a measured depth (md) vs. D-value plot (Figure 2). Utilizing this set of coordinates is an effective way of finding semi-orthogonal fracture growths (growing at nearly perpendicular angles to the treatment well) and non-orthogonal fracture growths (growing at more acute angles). These two types of fracture systems were both identified in this dataset. The earlier corresponded to two horizontal distributions on Figure 2, and the later- to the vertical trends on it. The earlier were identified by the primary microseismic contractor, Pinnacle (Figure 3) as two event clouds travelling laterally and downward inside Montney and upwards into the overlying Nordegg formation. The later were identified in this research as planes (having D-values of ~2.2) of different orientations, shapes and sizes lined with fractures.The semi-orthogonal growths matched uplifts in the Montney seismic amplitude horizon, continuity features and changes in lithological logs. Further image log/ core analysis is required to determine the nature of this preferential growth, but given the above observations and ms interpretation below, they are comprised of rock highly susceptible to brittle deformation. They comprise the majority of the events of stages 1 and 2, and locate beside their corresponding ports. The non-orthogonal growths were interpreted as planes of weakness along which fractures propagate easier than through surrounding rock. They were not interpreted as pre-existing fractures due to the lack of corresponding clear evidence from the B-value analysis of the presence of different stress modes. The fractures propagating along the planes of weakness hypothesis helps to identify the mechanism of fluid migration local to each stage. For example, Stage 1 mechanism can be broken in three phases (color-coded with arrows on Figure 2). The black arrow represents semi-orthogonal altering-shape fracture growth in distribution #1. This is the expected behavior, as the fracture travelling from the port will initially travel semi-orthogonally to the treatment well, and will change its shape as it propagates further in the formation. This is followed by growth inside a planar fracture system (green arrows), ending in semi-orthogonal variable-shape fracture growth in distribution #2.

Such stage-by-stage interpretation helps to explain the global mechanism of late-stage event locations' migration. Stages 1 and 2 events propagate in the directions semi-orthogonal to the treatment well (expected behavior), until they each encounter a plane of weakness. They travel both uphole and downhole along them. The later stages (3-6) behave much differently: they immediately travel through the weakness planes (without exhibiting excepted, semi-orthogonal growth). Complications arise when these planes intersect each other and the semi-orthogonal systems created by the first two stages. In the latter case, the fluids from these planes leak into the semi-orthogonal systems. This is manifested by the visible clustering of events in vertical trends 5,6,7,8 inside the pink and black boxes (Figure 2).

Conclusions

A new technique based on fractal dimension analysis was implemented in this research. An uncommon, but effective coordinate system was used for data visualization. It provided the basis of explaining the migration of late-stage events to the early stages' port locations. The interpretation of this mechanism was completed with correlations to seismic data, lithologs, B-value and SNR (signal-to-noise) analyses. The interpretation included two sets of fracture systems- one located semi-orthogonally to the treatment well (and being less rigorously defined in terms of shape), and the other- consisting of constant-shape fracture-lined planes of weakness. Complex inter- and intra- system interactions were identified, such as fluid leakage and migration along these systems. A methodology on refining complex behavior of these systems is given. Further research is still required to test this method and further improve it.

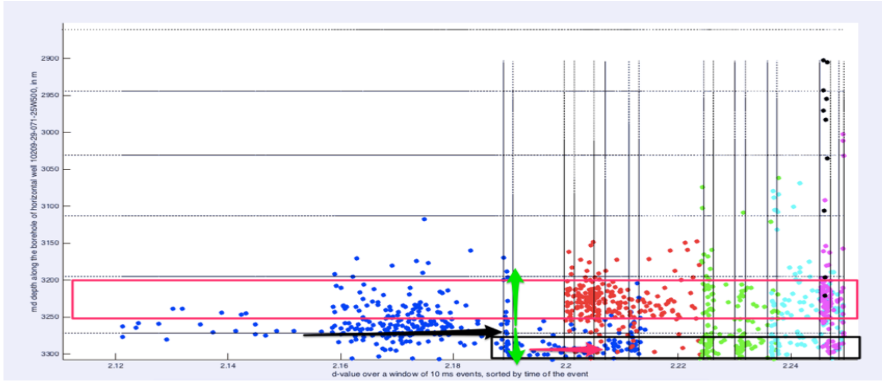

Figure 2 D-value plot for stage 1, with mechanism interpretation

Plot of ms event position along the tr. well (in m MD) vs. its D-value. Legend: ms events: blue-stage 1, red-stage 2, green- stage 3, light blue- stage 4, purple- stage 5, black- stage 6. Horizontal dashed lines represent the port locations, in meters MD of the treatment well. Vertical dashed lines represent identified planes of weakness. Horizontal event distributions: earlier distribution (black box, centered at ~3290m md) and the later distribution (pink box, centered at ~ 3225m md).

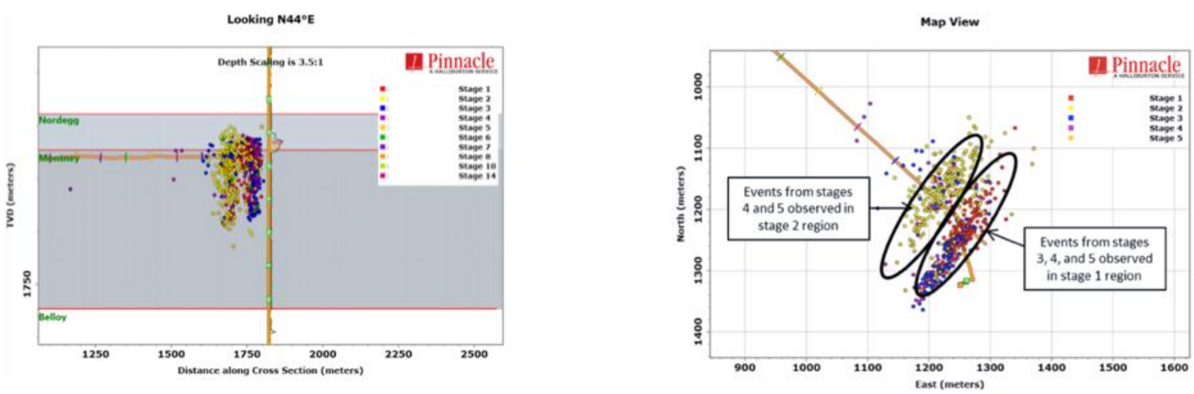

Figure 3 Orthogonal and plan view to the treatment well

Left: orthogonal view to the treatment toe, all stages. Right: plan view of the treatment toe, stages 1-3. Ms events are colored by stages. Note the ms events travelling both below the treatment well (into Montney) and upwards into the Nordegg formation and sideways along ~N40-44E direction (i.e. semi-orthogonal to the treatment) in two distinct trends. Figure from Pinnacle report.

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