

# Comparison of Microseismic Results in Complex Geologies Reveals the Effect of Local Stresses on Fracture Propagation

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## Summary

**Understanding the role geology plays on fracture growth is integral to the planning and completion program of a hydraulic fracture treatment. In general, fractures will propagate in the direction of maximum horizontal stress which is controlled by the regional stress in the area. In contrast, local complex geologies often influence fracture growth and orientation in unexpected ways.** In this study, we examine the microseismic results acquired during hydraulic fracture treatments in different North American Shale plays. The presence of geological structures such as anticlines and dipping layers resulted in considerably different fracture response in some stages compared to other stages not affected by the same local stresses.

## Introduction

Microseismic monitoring has become an accepted method for monitoring fracture growth and stimulation effectiveness during hydraulic fracturing. In addition to delineating fracture dimensions and orientation, microseismic methods can also provide insight into local stress states adjacent to geological structures and their influence on fracture propagation. Understanding the role geology plays on fracture growth is integral to the planning and completion program of a hydraulic fracture treatment. In general, fractures will propagate in the direction of maximum horizontal stress which is controlled by the regional stress in the area. However, in the presence of complex geology, local stresses may overcome regional stresses and influence fracture propagation in unexpected ways.

The microseismic response illustrates the influence structures such as anticlines and dipping layers have on fracture growth, both in number of events as well as dimensions and types of fractures. We compare the differences in fracture dimensions, fracture intensity and microseismic response to injection parameters from treatments that targeted zones in varying geological settings and structures. It will be shown how fractures activated during hydraulic fracture treatments traced the boundaries of the geological structures and conformed to the local stresses.

## Local Stresses at the Apex of an Anticline

Microseismic monitoring was performed for a multi well vertical hydraulic fracturing program in a shale formation. Two stages in adjacent wells were isolated for further analysis; Stage A was positioned in a shale at the peak of a sharp anticline while Stage B was located within a steeply dipping shale layer. Both stages received similar treatments, however, microseismic results were dramatically different.

Stage A yielded 397 microseismic events with a total frac length of 228m and frac height of 130m. Over time, the fracture growth conformed to the anticlinal structure and formed an arc around the apex as seen in Figure 3. In contrast, Stage B produced five times as many microseismic events as Stage A but resulted in a total fracture length of just over half that of Stage A. The total fracture length for Stage B was 162m and the fracture height was 112m. The fracture growth of Stage B was restricted by the dipping shale layers which resulted in fracture growth that propagated parallel to the bedding planes

During formation of the anticline, the rock experienced increased stress, particularly on the apex. As a result, it is likely that the rock contains open fold fractures at the apex and is in a relaxed state. In this relaxed state, more energy is required to stimulate new fractures or bring existing fractures to a point of failure. In contrast, rock along the flanks of the anticline (Stage B) have not experienced equivalent stress and deformation, and as such are more susceptible to fracturing, particularly along pre-existing joints or bedding planes. An evaluation of apparent stress from the microseismic data corroborates this hypothesis, as apparent stress was much higher for events in Stage A than Stage B. Stage A exhibited an average apparent stress of 6.3 MPa while apparent stress for Stage B was much lower at 1.76 MPa, meaning that the events in Stage A required much more energy input in order to fracture (See Figure 1).

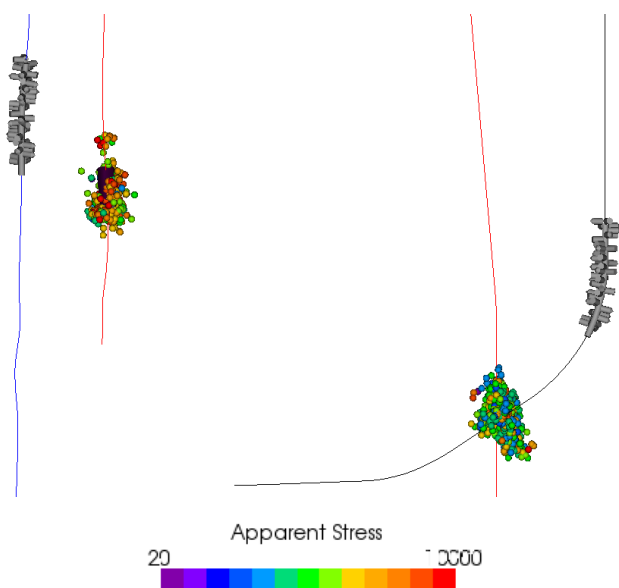


Figure 1: Apparent stress values for Stage A (top left) and Stage B (bottom right)

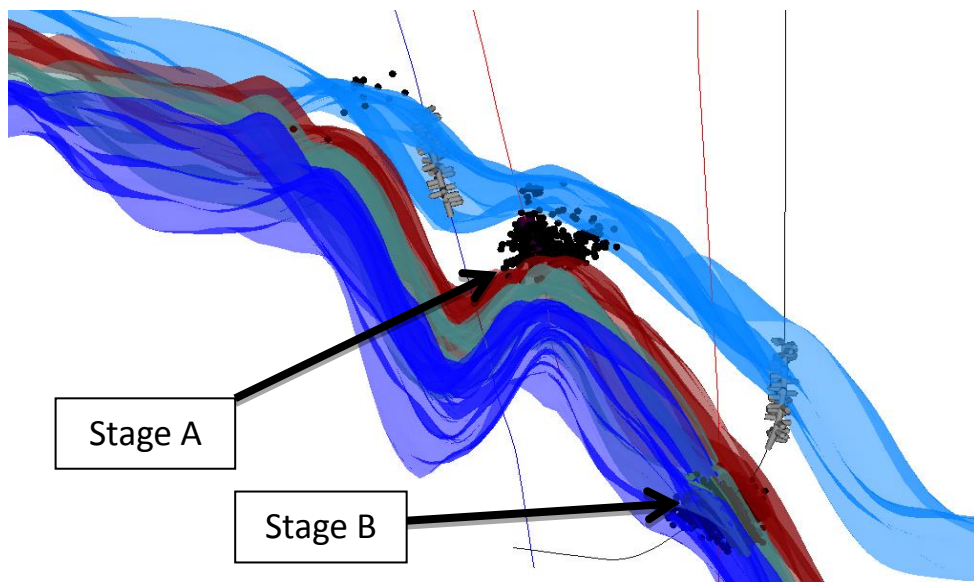
To better understand how the anticline affects local stresses in the treatment zone for Stage A, microseismic results from a second multi-well hydraulic fracture program may provide some insight. Data for the second dataset was acquired using multiple downhole geophone arrays. The use of multiple arrays allowed for advanced seismic moment tensor inversion analysis to be performed on the microseismic data. Using this method, individual fracture mechanisms and orientations were determined. Four stages were examined across two wells (Well C and Well D) as shown in Figure 4. Each stage was equidistant to the observation arrays and was not biased by detection ranges. Well C was drilled through the apex of a shallow anticlinal structure and Well B was drilled along the flank of the anticline.

Along the apex of the anticline, the stages in Well C exhibited height growths of 140m and 125m respectively and grew beyond the treatment formation. Along the flank of the anticline, the stages in Well D only grew to heights of 83m and 50m respectively and stayed well within the treatment zone. The Well C stages had longer fracture lengths compared to the Well D stages, averaging to 562 m and 458 m, respectively.

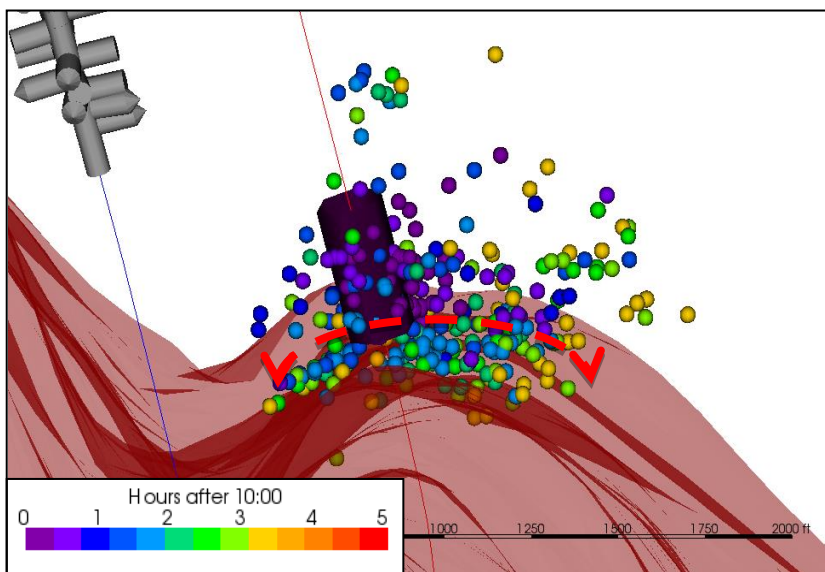
Calculating the double couple moment tensors for all the events allowed for the discrete fracture network to be calculated and plotted. The results showed that the fractures in the apex of the anticline were primarily vertical or sub-vertical and the fractures along the flank were primarily horizontal or sub-horizontal fractures. Plotting each fracture orientation by stage identified two main fracture orientations for the Well C stages and one main fracture orientation for the Well D stages. The Well C fractures correlated with known joint sets that were measured from outcrop data and the D well fractures were more in line with bedding planes within the formation.

## **Conclusions**

Through detailed analysis of microseismic data, we can suggest that the role of local stress perturbations related to complexities in geology can have a definitive role in the observed fracturing. This can then lead to an understanding of whether the stimulation was contained within zone, what volumes were stimulated, and potentially the effectiveness of the stimulation leading to production.



**Figure 2:** Example 1; Stage A treated a zone on the apex of a sharp anticline and Stage B treated a steeply dipping shale layer.



**Figure 3:** Example 1, Stage A- scaled by elapsed time, view is parallel to hinge of anticline. Fracture growth initiates on zone and over time grows downwards and conforms to anticlinal structure.

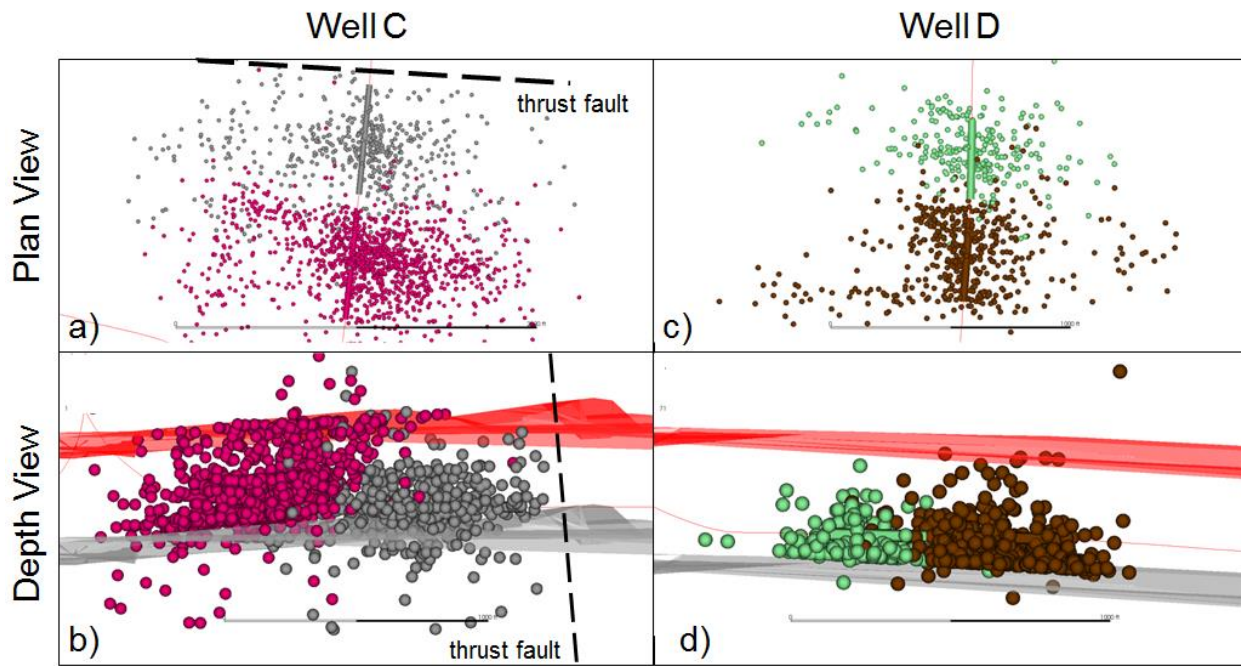


Figure 4: Example 2- Well C was drilled through the apex of a shallow anticline and Well D was drilled along the flank of the anticline.