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The Degree of Uniformity of Microseismic Moment Tensors and the Question of Complexity of Hydraulic Fracturing

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Introduction

The ability to resolve moment tensors associated with microseismicity from hydraulic fracture completions of shales or tight sand reservoirs has had the effect of obtaining direct constraints on models of the progression of fracturing into the medium. This type of analysis is facilitated through developments of multi-azimuth geophone arrays, either through multi borehole-deployed tool strings, or extensive surface networks. In both cases, as moment tensor inversion is driven through confident observations in obtaining polarities and amplitudes of first motions, the resolving ability is controlled by the extent of array coverage over which high-quality seismic waveforms can be observed.

Using these techniques, and some simplifications thereof, a number of authors have suggested very different models of hydraulic fracturing. Many measurements from large-scale surface arrays seem to suggest very uniform P-wave radiation patterns, consistent with pure double couple dip-slip mechanisms. Some authors prefer a model (equally consistent with the observed radiation patterns) of bedding plane slip around a relatively quiet hydraulic (tensile) fracture. However, such studies are usually impaired by only considering the P wave to determine the mechanisms, the general sparsity of the data of high-enough quality to be observed on individual surface stations, and the limited bandwidth afforded by the conventional geophones that are usually employed. When surface array processing has incorporated S-wave first motions, as recorded on lower-frequency triaxial sensors, non-double-couple components have been resolved, with less uniformity observed in the slips of the events.

Similarly, downhole data has also been used to argue for both uniformity and complexity. Measurements of the angular distribution of the ratio of P wave to SH wave amplitudes have been used in some reservoirs to suggest uniformity of double-couple mechanisms based on the apparent consistency with a pure shear slip mechanism. Full moment tensor inversion shows that non-double-couple mechanisms are resolved and that more complicated networks of fractures may be activated, although the degree to which both of these are significant can depend on the formation and the injection program.

Obviously, there are some fundamental disagreements on the types of moment tensors that occur during hydraulic fracturing. These differences translate to fundamentally different models of how the seismicity is related to the injections, touching on how the hydraulic fracture penetrates into the formation. Simple models of uniform mechanisms are used to argue for single bi-wing models of hydraulic fracturing. Observations of complexity suggest a highly dynamic process involving stimulations of pre-existing fracture networks together with the generation of new ruptures in the reservoir. To attempt to resolve these questions, we present a simple methodology, based on mapping the P-wave first motions for clusters of microseismic events to the focal sphere to highlight the degree of similarity or complexity of the events themselves, as shown in figure 1. We apply this methodology to a number of datasets and validate our observations through full moment tensor inversion.

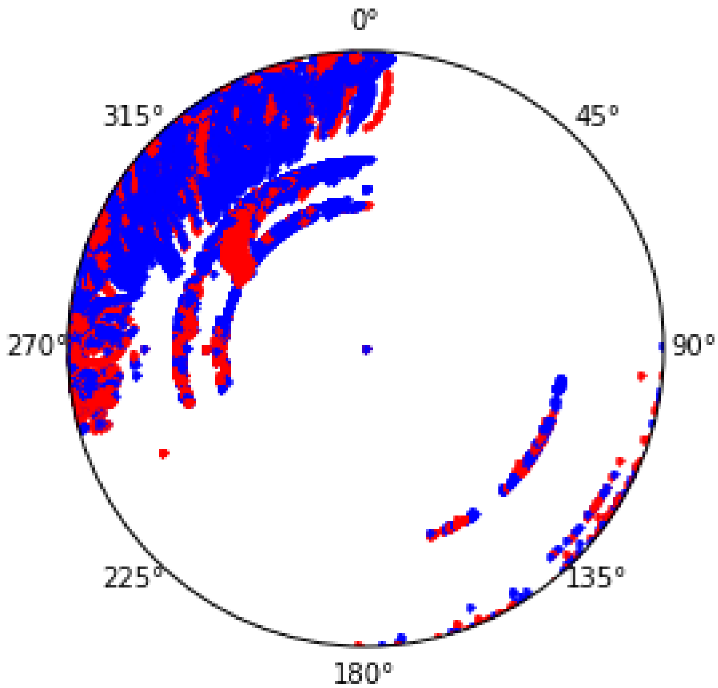

Figure 1. Mapping P-wave polarities of first motions for general solution events for a stage on the focal sphere reveals a complex pattern that is inconsistent with a single mechanism for the stage.