3D Geomechanics Model Integration With Microseismic Surveys Using Fluid-Induced Seismicity Constraints

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Summary

Information from static 3D geomechanics models may be integrated with microseismic survey data to better understand and predict fracture behavior during stimulation programs. We review how 3D static geomechanics models may be developed from calibrated 1D geomechanics models and seismic inversion volumes, which can be interpreted to determine the possible extent of hydraulic fracture development. Complementary interpretation of microseismic data can be complicated by multiwell, multistage stimulation programs. We employ a fluid-induced seismicity framework to enhance the interpretation of microseismic surveys, including assigning microseismic events to the proper stimulation stages. Examples from the Montney are presented to illustrate the workflow.

Workflow

Static 3D geomechanics models may be developed by integrating 3D seismic volumes and 1D geomechanics models that are calibrated to field stress tests and drilling experience, including the prediction of the presence and absence of drilling-induced stress features in a wellbore, and satisfying equilibrium on existing faults within the inferred tectonic setting. These static models provide a useful basis to predict fracture behavior including the extent of the stimulated reservoir volume (SRV) via hydraulic fracture simulation software, and also to interpret the SRV from microseismic surveys acquired during hydraulic fracture operations. Profiles of minimum horizontal stress are useful for the identification of intervals likely to limit vertical propagartion of induced fractures (i.e., frac barriers).

Microseismic data has long been used to image the extents of induced hydraulic fractures (Maxwell et al., 2009). Interpretation of a microseismic survey performed as part of a multiwell, multistage stimulation operation is complicated by the need to associate microseismic events with a given completion stage. This association is generally built around the timing of microseismic observations relative to the completion stage. However, different well trajectories combined with alternating (zipper) completion scheduling can confound standard interpretations and provide misleading observations and poor information for well planning

The work of Shapiro (2015) provides a theoretical framework to unravel these interfering effects through the modeling of the pressure front that is induced during each completion stage. Local formation diffusivity may be calibrated by evaluating the initial stage time-distance behavior of microseismic events such that all subsequent microseismic events can be partitioned accordingly.

This process aids the interpretation of induced fracture extent and reduces the chance that previous frac events are associated with a current stage completion

Results, Observations, Conclusions

We examine case studies from the Montney formation in British Columbia, Canada. A summary of 1D geomechanics modeling is presented, illustrating how lab rock mechanics test results, field stress test (DFIT) results, and image log interpretation of present-day stress indicators allow for development of a model based on poroelastic strain equations (Thiercelin and Plumb, 1994). The 1D model is integrated with seismic inversion volumes to develop a 3D model. The 3D model results are compared to the microseismic event locations to interpret the extent of fractures.

Figure 1 shows a cross-section through 4 horizontal wells, with minimum stress magnitude plotted in color and microseismic event locations plotted in different colors for one stimulation stage at each of the 4 wells. The vertical extent of microseismic events appears to be constrained above by a thin interval the top of the Montney and below by a thicker continuous interval within the Montney. In this case there is good agreement between the static geomechanics model and the extent of microseismic events. This type of analysis is useful to ascertain the extent of fracking and interpret likely future drainage.

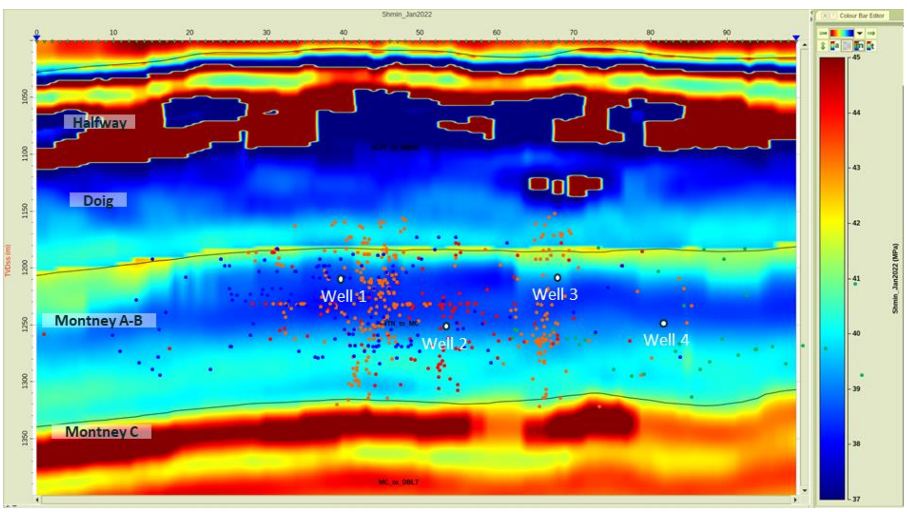
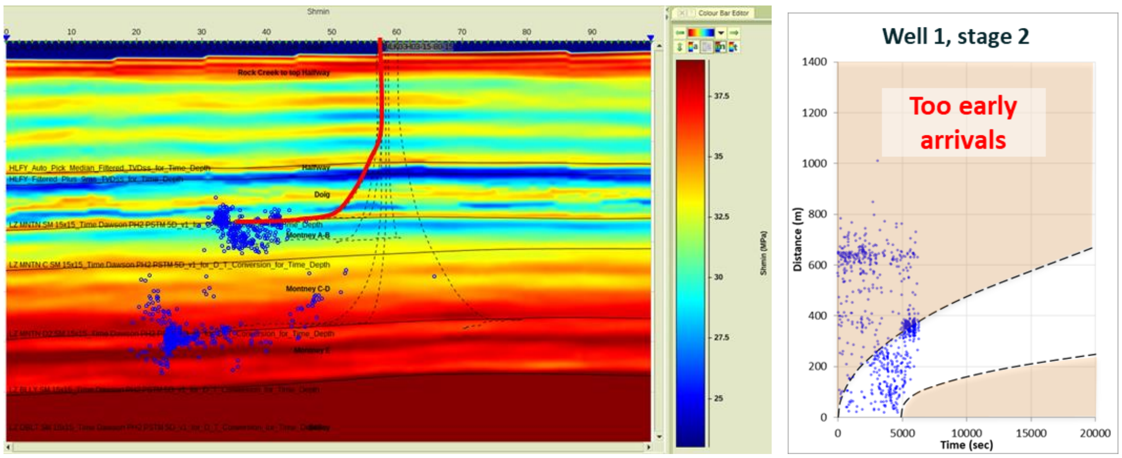


Figure 1: Cross-section through a single-tiered development with four horizontal wells. Minimum horizontal stress is plotted in color, supplemented by microseismic source locations from 1 stimulation stage at each well.

Figure 2(a) shows a second example at another Montney play developed over several separate intervals, with minimum stress magnitude again plotted in color and microseismic event locations for one stage plotted. Figure 2(b) shows the time-distance plot for all microseismic events as well as the previously established triggering and back fronts, illustrating that many of the recorded events are 'early arrivals' ahead of the triggering front.



(a) (b)

Figure 2: (a) Cross-section through a multi-tiered development with several horizontal wells. Minimum horizontal stress is plotted in color, supplemented by microseismic source locations from 1 stimulation stage at 1 well. (b) Time-distance relation for a single stage with triggering and back fronts highlighting the associated microseismic events window. Note many 'early arrival' events fall outside the envelope.

Figure 3 shows the same cross section of minimum stress and microseismic events, this time with the early arrivals omitted. It may be seen that the apparent out-of-zone microseismic events are largely the early arrivals and thus are not associated with the triggering pressure front of the current stage; the microseismic events properly asociated with the current stimulation stage are contained within the interval of the well being stimulated.

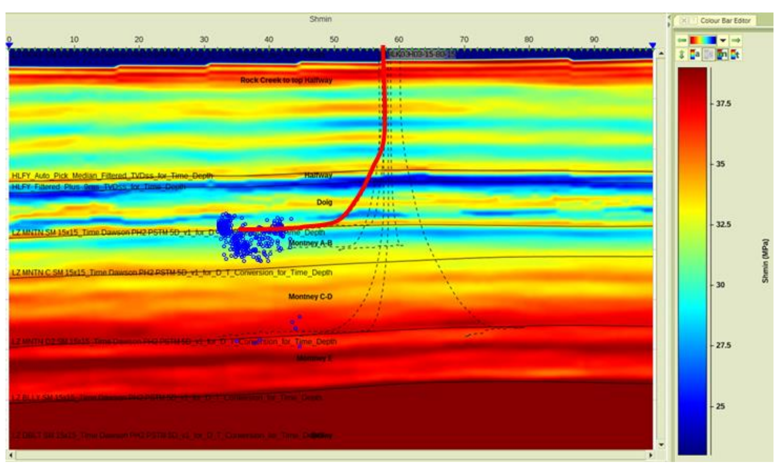


Figure 3: Cross-section through a multi-tiered development repeated from Figure 2. 'Early arrival' microseismic events have been omitted. Remaining microseismic events lie within the interval of low minimum stress, consistent with the 3D geomechanics volume.

Crosstalk between stages may be filtered out based on the envelope constraints of triggering and back pressure fronts. Comparison of Figure 2 and Figure 3 show the microseismic event extents before and after elimination of the crosstalk events; we see that the SRV and inferred extent of fractures has been significantly reduced. It is also noted that the reduced set of microseismic events is consistent with the minimum horizontal stress profile through the well, which indicates that the microseismic events are contained within an interval characterized by relatively low minimum stress.

Novel Information

We have shown an improvement on the current best practice for interpretation of well / frac drainage using microseismic data. The adjustment due to propagation time can improve this interpretation by reducing some of the crosstalk between frac stages and give a better interpretation of the efficacy of well completions.

Acknowledgements

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