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The Importance of 3-D in Stimulation Modeling of Unconventional Reservoirs

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Abstract

Successful stimulation of unconventional plays, that is, mud-rock plays in which matrix permeability is less than a micro-Darcy, is generally believed to require creation of a complex network of enhanced conductivity fractures. However, practical considerations limit our ability to model in full detail the processes which act during network formation. In particular, currently available (commercial) software does not accurately capture network geometry. Pre-existing and created fractures are generally modeled as being vertical with perhaps analytical corrections to account for their finite height, rock mechanical properties are assumed to be isotropic, geological structures are assumed to have simple planar geometries, and the influence of bedding planes and horizontal laminations on complexity is not accounted for. This paper presents for discussion a series of examples in which the predictions of 2-D or quasi-3-D codes fail to model the geometry of the resulting system. For example, Figure 1 shows the growth of parallel fractures in a low-stress "channel" through a medium with variable properties, highlighting that fracture height and opening are highly variable.

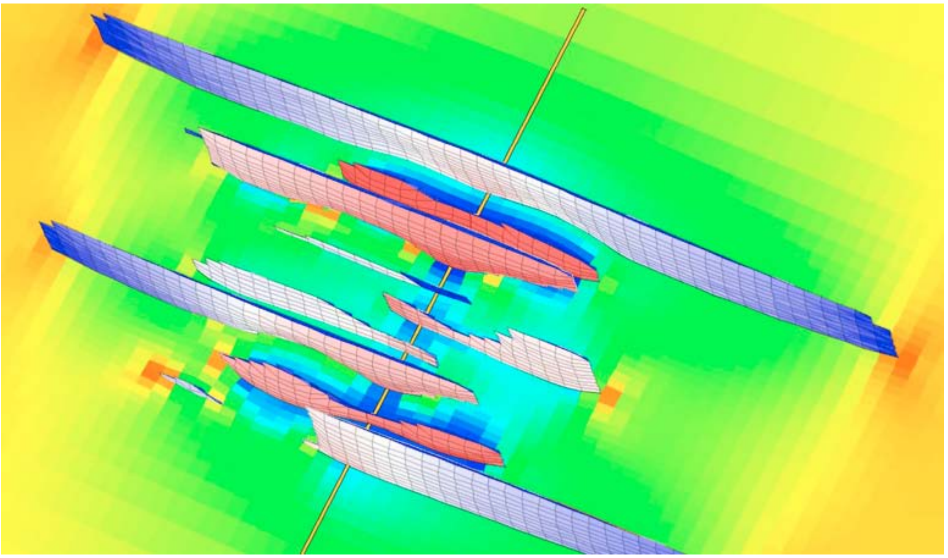

Figure 1. Results of modeling the growth of a series of fractures induced by injection along a horizontal well shows how complex the fracture geometry can be when effective physical properties vary spatially (results generated using the full 3-D simulator GEOS developed by Lawrence Livermore Laboratory; see Fu et al., 2012). Stress shadow effects and variations in elastic moduli combine to induce a highly heterogeneous set of induced fractures. Background color is stress; fracture aperture is exaggerated.

As a further example, Figure 2 shows a model (set up to approximate the conditions of a lab experiment by Bahorich et al., 2013) of the interaction of a propagating hydrofrac with a finite-height fracture. Diversion and complexity enhancement can result, even when the conditions for crossing or diversion of a 2-D fracture are not met. 2-D models, or "3-D" models in which fractures are vertical and cross the entire height of the model, cannot capture this behavior.

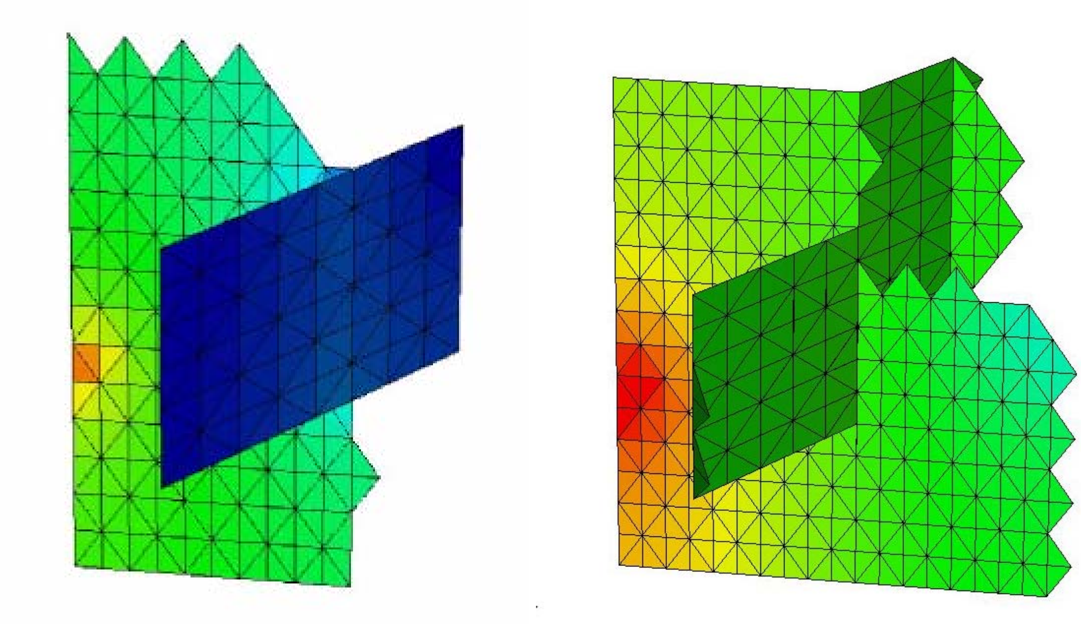

Figure 2. A simple low-resolution analysis of a fracture approaching a finite-height inclusion reveals that bypass and diversion both can occur given suitable conditions. The left-hand image shows the propagating frac stopping at the inclusion, and growing downward and upward, slowly inflating the inclusion. The right-hand image shows a later stage of evolution when the fracture has both bypassed from below and is wrapping around the inclusion. Pressure is plotted in false color. These results were generated using the full 3-D simulator GEOS developed by Lawrence Livermore Laboratory; see Fu et al., 2012.

These and other examples presented in this paper are intended to stimulate discussion of the importance not only of creating accurate geometrical models of stimulation, but also of whether that is even necessary to capture behavior and to simulate and diagnose the results of fracture treatments.

REFERENCES

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Fu, P., S.M. Johnson and C.R. Carrigan, 2012, An explicitly coupled hydro-geomechanical model for simulating hydraulic fracturing in arbitrary discrete fracture networks, Int. J. Numer. Anal. Meth. Geomech.