OilFieldGeomechanics

Geomechanics for Unconventionals Series, Vol II:

Geomechanics And Unconventionals:
A Match Made in Heaven – or Just (Occasional) Friends?

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Geomechanics – in both completions and drilling operations – has become a critical technology in the development of Unconventional Plays. And in today's cost-conscious market, technology - and the training behind it - will often be the difference between success and failure.

It is now widely acknowledged that geomechanics is important for the understanding, optimization, and, ultimately, data integration for Unconventional Plays. In particular, the science of geomechanics – the evaluation of the interplay between stress, pressure, mechanical properties and strength in rock and soil – has become a critical, go-to technology in the characterization and engineering of Unconventional Plays. Geomechanics plays a critical role in many Unconventionals chiefly due to the complicated and variable geomechanical impact of natural fractures and weakness planes in completions and drilling.

Unfortunately, understanding what geomechanics can do for your Unconventional operations (as well as what it can't) requires a solid foundation in geomechanics principles and a detailed review of the limitations of common pseudo-geomechanics concepts like brittleness, complexity, fracability, and SRV. Equally important, critical geomechanics issues, like Stress Shadow effects, must also be taken into account.

In order to develop nano/microdarcy permeability Unconventional reservoirs, multistage hydraulic fracturing (HF) is often needed to make economic wells. At OFG, we believe three main HF/formation scenarios are commonly present in Unconventional plays (and, perhaps, in a single well): a) a highly fractured rock mass (e.g., a fault zone) where HFs cannot be created because of the flow capacity of the natural fractures (left, below); b) formations with cemented or nonexistent discontinuities where traditional HF design applies (right); or c) formations with weakly cemented or open/partially open natural fractures and bedding planes where a primary stimulation objective is to stimulate these weak planes (center). The understanding of these scenarios (via resource characterization) is critical because the hydraulic fracturing

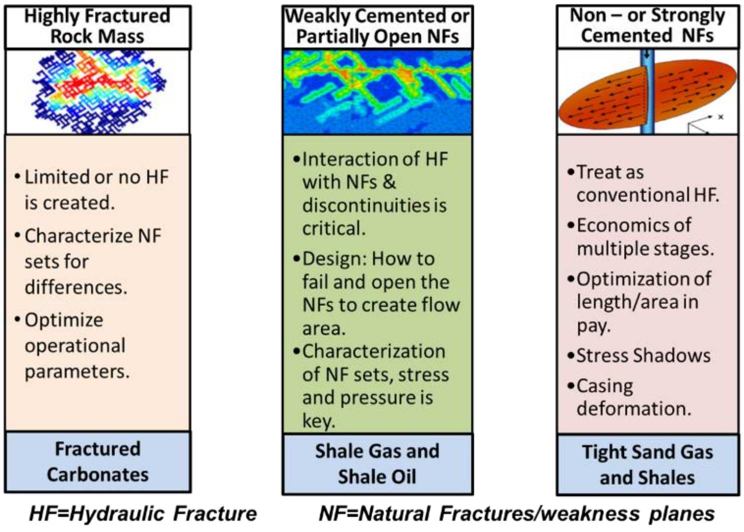

Figure 1: Hydraulic fracturing scenarios for Unconventionals.

design objective and strategy will be different for each case.

The critical issues to consider are:

- The presence of the resource (TOC, maturity);
- The presence of natural fractures and/or weak planes (free surfaces to be converted to flow area) and their connectivity and hydro-mechanical properties;
- Fluid pressure and fluid type – high pressures favor the stimulation of natural fractures, as the effective stresses are low and less shear is needed for stimulation - and whether or not pressure can be increased in offset wells during a stimulation;
- The influence of stresses and mechanical properties on HF geometry and SRV – some conditions are more favorable than others; and
- The influence of operational parameters and HF design on HF geometry and SRV.

Each of these issues, other than the presence of the resource, are controlled by the geomechanical behavior of the rock mass (stresses/strains and failure) coupled with fluid flow and pressure changes. From a geomechanical perspective, a ‘fractured’ rock mass includes formations that are composed of well-defined, open fractures separated by matrix blocks, formations that are composed of poorly-defined, partially open/partially cemented fractures separated by matrix blocks, and formations without defined fractures but with planes of weakness separating matrix blocks. These formations will obviously have significantly different geomechanical behavior during oilfield operations (e.g., drilling and completions); however, this variation in behavior can largely be captured by different input values to common behavior models (e.g., Mohr-Coulomb), though it is important to use models that incorporate the right physics for coupled geomechanics and fluid flow, including the natural fractures, to represent rock mass failure, stress capture effects, changes in the shape of HFs with multiple stages, changes in ISIP (stress shadows) and its effect on the natural fractures, microseismic behavior, casing deformations, etc. Field data (microseismics, injection pressures, PLTs, tracers and ultimately production), together with numerical models, help in the understanding and quantification of the effects of geomechanical, reservoir, geological and operational parameters on stimulation efficiency (increased SRV) and optimization strategies.

Clearly, hydraulic fracturing in naturally fractured shale plays (or those with weakness planes) involves significant heterogeneity and the need to develop complex fracture systems. A fundamental frac design question for Unconventionals becomes “Do I want to create all my surface area via a hydraulic fracture or do I want to use the hydraulic fracture to connect to natural fractures (or weakness planes), which will provide the needed surface area?”.

The concept of connecting to, and stimulating, natural fractures and/or weakness planes was given the term “Shear Stimulation” (largely after Warpinski from his papers in the late 1980s and early 1990s), wherein a hydraulic fracture caused nearby natural fractures and weakness planes to slip in shear and ride up on surface asperities (both generating microseismic energy and increasing the aperture and effective permeability of the natural fracture system). The primary field evidence for Shear Stimulation became the pattern of the recorded microseismic events (recall that microseismicity is the acoustic representation of rock failure). When the pattern was linear (or planar in 3D), this was taken to represent solely the creation of a hydraulic fracture. When the microseismic pattern was more symmetric, this was taken as proof of Shear Stimulation of natural fractures and weakness planes, and the greater the symmetry of the pattern of MS events, the greater the "complexity" of the stimulated area around the hydraulic fracture. Furthermore, this led to the common perception (now disproven in many Unconventional Plays) that increasing complexity was, *a priori*, proof of a better stimulation and would lead to better production from the hydraulic fracturing stage.

Much is now also made about "Stress Shadows" (SSs) and its impact on hydraulic fracturing. In fact, many (most?) of the major commercial hydraulic fracturing models are reported to have the ability to calculate and account for SSs. Unfortunately, there is no standard definition of SSs and, as a result, there is much confusion over what it is, what it isn't, and, most importantly, why it can potentially have a significant impact on hydraulic fracturing operations in both Conventional and Unconventional Plays.

When the injection rate entering an initiated HF exceeds the leakoff rate (the loss rate of fluid from the HF into, perhaps, the matrix pore structure or natural fractures), the injection pressure rises, which causes: 1) the HF to deform and increase in width to accommodate the new volume of fluid; and/or 2) the formation to fail (again, often in tension) at the leading edge of the HF and the HF to increase in dimension (length and/or height) to accommodate the new volume of fluid. The deformation of the HF, both the changing width along the body of the HF and the increased dimension (length and/or height) of the HF along the leading edge cause a change in the stress field in the formation. "Stress Shadows" is the colloquial term for these stress changes induced by the formation deformations caused by the HF.

Recall that the injection pressure, which is often principally a result of an injection rate greater than the flow capacity of the formation, acts omni-directionally. As a result, injection pressure will act to deform the rock at the lowest possible energy regardless of orientation. This means, for example, that an HF will open against the S3 principal stress as it is the lowest stress and would require the least injection pressure. In a normal faulting environment, this means the HF will propagate towards SHmax and open against Shmin (because this orientation, all other things being equal, will require the least injection pressure). And "Stress Shadows", then, is at least partially defined by the HF deformation in the Shmin direction and the resulting increase in Shmin.

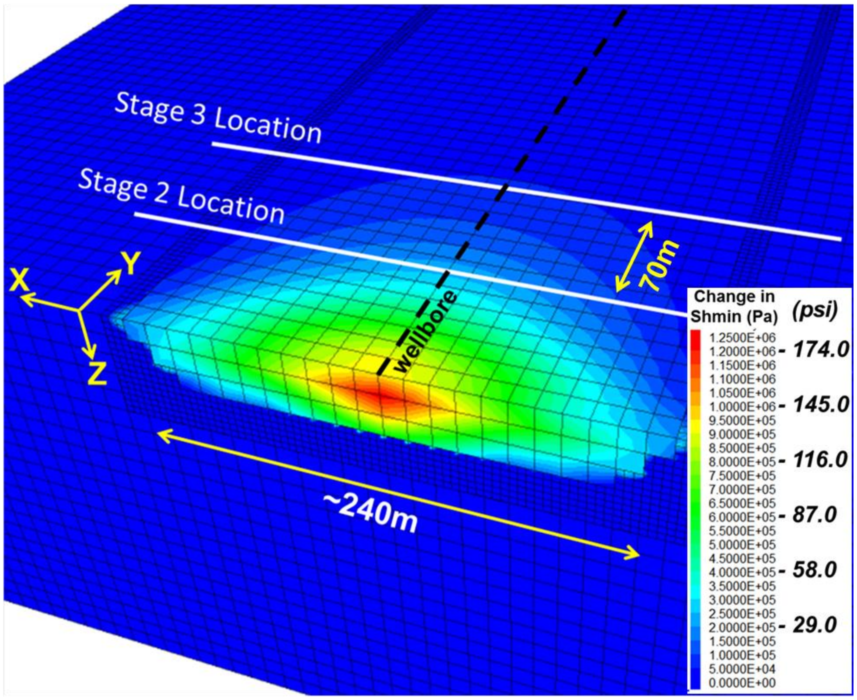

Figure 2: Contours of "Stress Shadows" (the increase in Shmin) from a hydraulic fracture simulation. The model is cut along the vertical and horizontal centerline of the hydraulic fracture.

The common perception of "Stress Shadows" is that it is synonymous with the increase in Shmin due to an HF. Unfortunately, this is potentially a significant oversimplification. Note that an HF causes not only deformation in the width of the HF, but also deformations at the HF leading edge. Ahead of the physical HF tip, Shmin is reduced (and, in fact, goes into tension at the micro-location of the HF tip). In addition, the HF tip generates significant shear stresses. Finally, due to the Poisson's ratio effect, the increase in Shmin due to the change in HF width also causes a local increase in both SHmax and Sv. In summary, the "Stress Shadow" may be dominated by the increase in Shmin along the body of the HF, but other important normal and shear stress changes are also induced by an HF.

Geomechanics for Unconventionals – and the geomechanics training necessary to disseminate this knowledge - should introduce the nature and geomechanical behavior of natural fractures and weakness planes and how in-situ stress, pressure, and mechanical properties affect their response to hydraulic fracturing. With this foundation, the role of microseismic monitoring – as it portrays rock failure – can be understood as well as common geomechanical issues (i.e., brittleness, complexity, stimulated rock volume - SRV) in the characterization and engineering optimization (i.e., stage spacing, landing location, etc.) of Unconventionals.

See all the articles in the OFG "Geomechanics for Unconventionals Series":

I. *"ge-o-me-chan-ics, A Better Explanation"*
II. *"Geomechanics And Unconventionals: A Match Made in Heaven – or Just (Occasional) Friends"*
III. *"Hydraulic Fracturing: Of Magic and Engineering"*
IV. *"The 'Complexity' Paradigm: Shifting Our Understanding in Order to Optimize Completions in Unconventionals"*
V. *"Stress Shadows Explained: What It Is, What It Isn't, And Why You Should Care"*
VI. *"Why 100 Mesh in Unconventionals"*
VII. *"On the Geomechanics of Zipper Fracs"*
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