[PS]Full-Physics Thinking in Unconventional Plays*

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Abstract

Unconventionals, perhaps more than other plays, demand consideration of process interactions. Geomechanical interactions occupy a central role in Unconventionals: geohistory, and the mechanical processes that operate, creates pre-cursor conditions; manufacturing the reservoir is a dominantly mechanical activity; and during reservoir production, mechanical interactions play a governing role. Classical methods of geomechanical interpretation and analysis fail to address the physics interactions, and can lead to incorrect deductions and decisions. These difficulties arise because the classical approaches assume that rock stress is an independent parameter and can be assigned a value. That view is physically impossible. The key point is that the concept of stress can be expressed in multiple ways – the most important one is that stress is the specific (mass/volume-related) elastic energy. Using this "take" on stress, we examine some important aspects of Unconventional reservoirs, focusing on hydrofracture stimulation. We assess some notions that inhibit understanding and interfere with the discovery of better practices. The hydrofracture process involves injecting a medium (usually water-based) into perforations, aiming to create new openings in the rock mass that will allow better hydrocarbon flow. The injected fluid pressure (an energy measure) and volume define the energy input. Some energy is consumed in making new discontinuities, and in shifting rocks. Where is the rest? As discontinuities open, the adjacent rocks become strained, typically in ways that lead to local contractions and volume loss, so their stress (elastic energy) state increases. In poro-elastic terms, the pre-existing pore fluids gain some of this added energy, so have higher pressures. Calculations show that injected fluids do not invade the pore system of the matrix rocks, and therefore, those not yet recovered in flowback must be located in newly created (or enhanced) openings – typically fracture-like features. After one hydraulic fracture stage, the subsurface state is considerably altered, with impacts on subsequent stages. After multiple stages, the state is characterised by high energy levels that work against the maintenance of the permeability created by the stimulation activities. The full-physics interactions, expressed in terms of energy components and partitioning, lead to new insights, and provide a framework within which new operational practices can be contemplated.

Full-Physics Thinking in Unconventional Plays

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Introduction

Poro-mechanical understanding allows us to explain:

- Prior history of reservoir region, incl consolidation state, tectonics and shape, natural fractures
- Processes that operate during stimulation ← This poster
- Flow performance during reservoir production

However, we have to cast our geomechanical knowledge into suitable forms

Here, this means that we need to acknowledge alternate meanings of common terms like stress and pressure

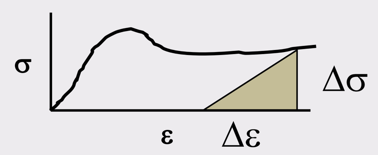
Stress/Pressure ↔ Energy

Stress

Dimensional unit of stress (actually, stress component/traction) is the Pascal: 1 Pa = $N.m^{-2}$

If this is multiplied by unit volume, we get N.m, which is energy (i.e. a Joule)

But wait: not stress itself, but product of stress and strain (strain has no units), is energy (here illustrated in 1D for graphical communication)



So: $½ . \sigma . \varepsilon_e = U_e$ (specific elastic energy), an intensive parameter (a state, like temperature)

When multiplied by local volume ($V = V_o.\rho_o/\rho$), we get extensive energy, which adds up

Since ε_e is (for linear strain) $\sigma/E \rightarrow$ $U_e = \sigma.\sigma/E = \sigma^2/E$

Pressure

Dimensional unit of pressure (P) is also the Pascal: 1 Pa = $N.m^{-2}$

This is also an indicator of the specific deformation energy

For fluid, this "deformation" is the volume strain: the extent to which the fluid is compressed into a smaller volume than it would occupy at the reference pressure (at surface)

Water has a compressibility, C = ~$4E^{-10}.Pa^{-1}$, which is the inverse of the bulk modulus

The volume strain is P.C – so the specific deformation energy is $U_{fluid} = ½ P^2.C$ (intensive, state)

Again, multiplication by the volume gives extensive energy content

Energy Changes

For both stress and pressure, we are often concerned with changes of energy, associated with some event. This calculation uses $\Delta\sigma$ and ΔP in the above expressions of specific energy

Application Example: Hydraulic Stimulation

Energy Budget

Where does the net input energy go?

Fluid invasion into matrix pore space?
Elastic strain of rock volume?
Plastic work (creating fractures, moving rocks)?

Formulating these questions in terms of extensive quantities, we can look at the energy budget

Some Numbers for a Stage

$8000m^3$ fluid pumped, at $\Delta P = P_{frac} - P_{res}$ = 16MPa → 410GJ
Assume bi-wing crack formed, 50mx800mx30mm → frac vol = $600m^3$
50% fluid recovered in flowback → net energy input: 205GJ

So, $3400m^3$ of fluid "lost" (where is it...?)
And, flowback is not instantaneous... so actually need almost entire fluid volume of new space at time of frac job

Fluid Invasion into Matrix Pore Space?

If initial pore fluid is water (not true!), then:

Assume 5% porosity, and inter-frac volume (frac area x stage spacing = $1e6m^3$), so pore volume → $2x10^5m^3$

If $3400m^3$ water added to this volume, the resulting pressure would be **125MPa** (larger than P_{inj} = 36 MPa)

Also:

Low perms, so invasion distance small in short time frame (<1mm)

Pores with gas or oil, so relperms inhibit entry

So, we need to create some new pore space!

Increase Elastic Strain Energy?

Look at inter-frac volume ($1x10^6m^3$)

Avg strain ⊥ main frac = 0.0006 (30mm aperture over 50m stage length), E = 8GPa, so $\Delta\sigma$ = 4.8MPa, and total added elastic energy of inter-frac volume ~1.4GJ

But crack tip, above/below → volume maybe twice that?

Since we need ~6X more "crack" volume to hold "lost" fluid, maybe reasonable to estimate another 10GJ of added elastic energy??

Plastic Work (Deformation)

A large discrepancy between input energy, and the work associated with pore pressure increases and elastic state changes in the rock mass: 205 GJ, less 10GJ, less perhaps 5GJ of pore pressure increase (poroelasticity)

The energy "used up" (180+GJ) can be attributed to:

Creating new fractures (main one, if it exists, but many others too)

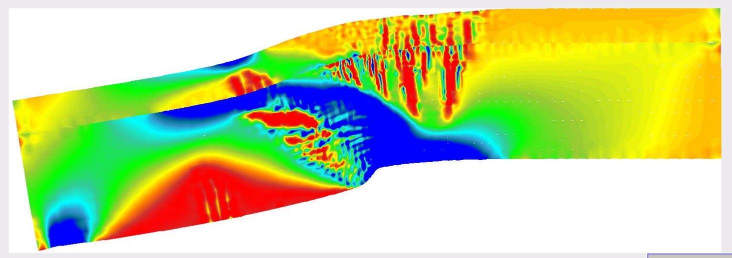
Shifting rock blocks using bedding planes, pre-existing natural fractures, newly-created fractures

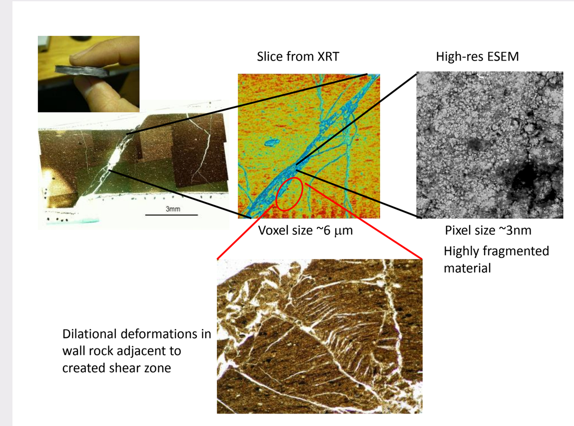
Altering stress in a larger volume (similar to what occurs in a stress "arch")

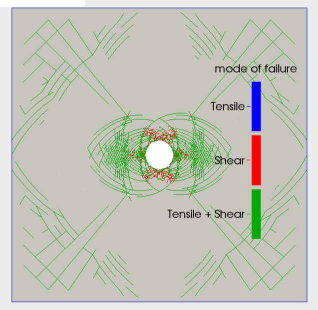
Some energy "released" as acoustic waves (microseismic events), or "lost" as heat

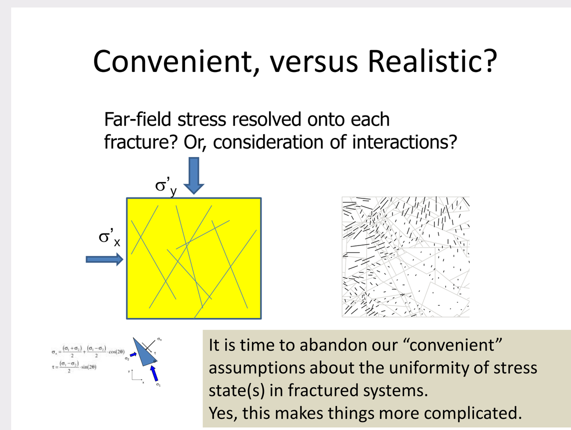
Other plastic work: compactional strain, non-discrete shear strain, etc??

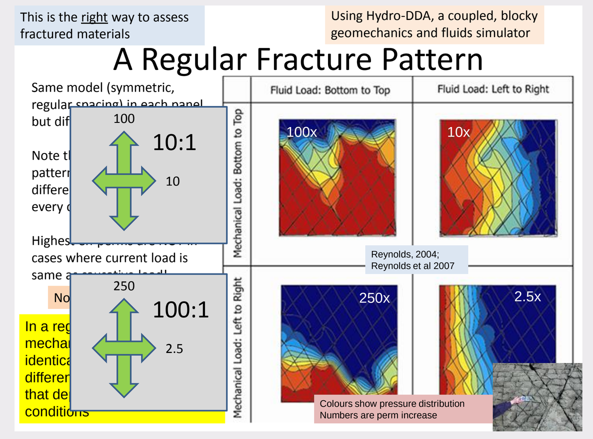
(Brief) Look at Tectonics, Wellbore Construction, Fractures and Flow











Some Thoughts on Multi-Stage Fraccing

Each stage "installs" a lot of energy into the ground

Some of that energy changes the in situ stress state, and some (mainly by poroelasticity) is transferred to pore pressure increases

Some of the consequences of multi-stage jobs are:

Our pumps may not have enough power to overcome the in situ state on later stages

The competition between creating openings, and the increase in elastic energy, may be "won" by stress increases, since the rocks may be stiffer than the fluids. The elastic stress state changes can impact a region much larger than the stimulated volume.

If so, we are probably hurting the cause by doing too many stages up-front

Re-fraccing, or deferred stimulation, may be worth consideration (but some non-trivial issues with production technology!)