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Non-conventional Geomechanics for Unconventional Resources

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Outline

• Importance of geomechanics to development of unconventional resources
• Special geomechanical considerations for unconventional resources:
  – Non-conventional vs. conventional geomechanics
  – Rock property estimation (anisotropic formations)
  – Near wellbore stresses and development of breakouts
  – Wellbore stability in anisotropic formations
  – Under-balanced drilling feasibility
  – Hydraulic fracturing and determination of formation brittleness
  – Maximizing production from critically stressed fractures
  – Reservoir evolution due to depletion
• Summary and conclusions

North American Shale Plays

~2300 TCF (85% Shale Gas)
“100 years of Natural Gas” U.S.
Global Shale Plays

~22,600 TCF of Recoverable Reserves
Current use ~160 TCF/year

How Important is Geomechanics for Unconventional Resources?

- Geomechanics for unconventional resources differs from conventional reservoirs due to:
  - Inelastic matrix behavior
  - Stress sensitivity
  - Rock anisotropy (Cleats, laminations and natural fractures)
  - Rock rheology
  - Low matrix permeability
- Effective horizontal drilling and hydraulic fracturing technologies required.
- Success heavily dependent on the stress regime and rock property.
Where Does Geomechanics Help?

- Select optimum mud weight and mud chemistry for safe drilling
- Optimize well trajectory
- Maximize production from critically stressed natural fractures
- Design and optimize hydraulic fracturing operation
- Model depletion effect on the reservoir productivity and compaction
- Underbalanced drilling feasibility

For:
- Heavy oil
- Gas shale
- Oil shale
- Tight sand
- Coal bed methane
- Gas hydrates

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Non-conventional vs. Conventional Geomechanics

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Anisotropic Formations

• Properties are different in different directions.
• If properties are the same along different directions in one horizon but different normal to that, rock is Transversely Isotropic (TI). Then 5 elastic constants are required:
  \[ E, \nu, \lambda, G, \]

• Shear failure characteristics of weak planes are overriding.

How About Unconventionals?

• Shales and coals are usually TI.
• Spacing between weak planes is small relative to the borehole diameter.
• The effect MUST be taken into account in even borehole scale analysis.
Anisotropic Log-based Rock Properties

Cross Dipole Sonic logs are usually the best source of data for rock mechanical properties estimation. In transversely isotropic (TI) formations, the travel time is different in two perpendicular directions.

Lamination

Fast

Shear

Slow

Shear

Weak PR

Strong PR

Weak E

Strong E

b = 0°

b = 90°

b = 60°

b = 30°

Anisotropy Effect on Compressive Strength

Formation strength is strongly affected by the orientation of weak planes to the axis of loading.
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Near Wellbore Stresses

- Max hoop stress acts perpendicular to $h_{min}$ direction
- Min hoop stress acts perpendicular to $H_{max}$ direction
- Shear failure expected along $h_{min}$ while tensile fracture along $H_{max}$
Borehole Breakout in Isotropic Formations

- Isotropic borehole failure in anisotropic stress regime
- Isotropic borehole failure in isotropic stress regime

(CSIRO, 2006) (Haimson, 2008)

Borehole Breakout in Anisotropic Formations

- Anisotropic rock failure in anisotropic stress regime
- Borehole breakouts in isotropic vs. anisotropic formations

- 4-lobbed Breakouts
- Normal Breakouts
- 4-lobbed Breakouts
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Wellbore Stability and Under-Balanced Drilling Feasibility

- Pore Pressure
- MW
- Fracturing Pressure
- Under-balanced Drilling
- Wellbore Stability Problems
- Kick or blowout
- Losses
- Wellbore Collapse Pressure
Example: UBD Feasibility in Iraq

- UBD Possible in Carbonate
- UBD Impossible in Shale and Silt
- UBD Possible in Carbonate

Effect of Anisotropy on Wellbore Stability

- Collapse gradient for isotropic formation
- Collapse gradient for anisotropic formation
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Hydraulic Fracturing and Geomechanics

Applications

• To enhance well productivity/injectivity
• To introduce thermal energy (steam fractures)
• To measure stress (Minifrac, LOT, XLOT)
• To re-inject drill cuttings and massive waste injection

Geomechanics benefits to hydraulic fracturing

• Increase efficiency with identifying fracable intervals
• Control growth of hydrofrac
• Predict orientation of hydrofrac
• Optimize drilling direction to minimize hydraulic fracturing pressures
Stress regime is the dominant factor controlling direction and height growth of hydraulic fractures.

Hydraulic Fracturing – Stress Effect

The hydraulic fracture is vertical & parallel to the maximum horizontal stress and the strike of the fault.

Hydraulic Fracturing – Stress Effect

The hydraulic fracture is vertical and parallel to the maximum horizontal stress, 20°-35° from the strike of the fault with a larger height.
Hydraulic Fracturing – Stress Effect

Stress regime is the dominant factor controlling direction and height growth of hydraulic fractures.

Reverse Stress Regime

\[ \sigma_3 = \sigma_0 \]

\[ \sigma_1 > \sigma_{max} \]

\[ \sigma_0 > \sigma_{min} \]

The hydraulic fracture is horizontal.

How to Manipulate Fracture Morphology?

Single Fracture

Multiple Fractures

Reorientation

Multiple wellbores

Multiple fractures emanating from wellbore
Where to Frac?

- In brittle rocks hydrofracture is more likely to be long enough to connect the highest amount of rock volume to the parent wellbore.

- Thus, it is very important to find intervals that are brittle, in order to maximize hydraulic stimulation.

How to Determine Brittleness?

Mineralogy Approach

- Q-C-C (Quartz-Clay-Carbonate) \[^{(Jarvie \text{ et al.} 2007)}\]

Ternary Diagram for Barnett Shale \[^{(SPE 115258)}\]
How to Determine Brittleness?

Anisotropy Method

• Less anisotropic formations are more brittle!

Brittle rocks have higher YM and lower PR

\[
\begin{align*}
YM_{BRTT} &= \frac{YM - YM_{FRR}}{(YM_{FRR} - YM_{DRT})} \times 100 \\
PR_{BRTT} &= \frac{PR - PR_{DRT}}{(PR_{FRR} - PR_{DRT})} \times 100 \\
BRIT_{DRP} &= \frac{YM_{BRTT} + PR_{BRTT}}{2}
\end{align*}
\]

How to Determine Brittleness?

Dynamic Elastic Constants Method

B值岩体有更高的YM和较低的PR

(SPE 125525, SPE 132990, Schön et al. 2006)

(SPE 106623)
How to Determine Brittleness?
Laboratory Methods

- Punch penetration test
- Compressive and tensile strengths measurement:
  - \( BI = (\sigma_c - \sigma_t) / (\sigma_c + \sigma_t) \)
  - \( BI = (\sigma_c \times \sigma_t) / 2 \)

\[
\begin{array}{|c|c|c|}
\hline
\text{Class} & \text{BI} & \text{Description} \\
\hline
1 & > 25 & \text{Very brittle} \\
2 & 15-25 & \text{Brittle} \\
3 & 10-15 & \text{Moderately brittle} \\
4 & 10 & \text{Low brittleness} \\
\hline
\end{array}
\]

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Maximizing Production from Critically Stressed Fractures

- Not all the fractures are productive.
- Critically stressed fractures should be recognized.
- Wellbore should intersect this type of fractures.

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Reservoir Evolution Due to Depletion

Effect of depletion on in-situ stresses

Effect of depletion on hydraulic fracturing

Reduction of permeability due to effective stress increase (depletion) in coal bed methane

Summary and Conclusions

- Geomechanical modeling is critical for development of unconventional resources.
- Non-conventional geomechanical approaches should be utilized for unconventional resources.
- Anisotropic rock mechanical properties must be taken into account.
- Planes of weakness have remarkable influence on wellbore stability of unconventional wells.
- UBD is an added value to exploration of unconventional reservoirs, however, geomechanical study is essential to determine feasibility.
- Success and efficiency of hydraulic fracturing operation depend strongly on the accuracy of the geomechanical model.
- Fracture analysis under stress is a requirement to maximize production from tight formations.
- Knowledge of stress and reservoir property evolution during production is a key to increase the life of the reservoir.