OilField Geomechanics (OFG) Services

Geomechanical Services for the Oil&Gas Industry

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OilField Geomechanics, OFG, is an independent geomechanics consulting company.

OFG can be your third party experienced advisor, part of your team, providing the geomechanics expertise needed to tackle challenges from exploration to abandonment – whether for conventional or unconventional developments.

OFG can deliver turn key geomechanics projects for oil and gas applications.
OFG Geomechanics Services

**Near Wellbore**
- Wellbore Stability evaluations
- Conventional and Unconventional HF Design & Optimization
- BHS / Drilling – conventional, salt/sub-salt, HPHT
- Sand Production
- Casing Deformation
- Cuttings Reinjection
- Pre-Salt/Sub-Salt Analysis

**Sector and Reservoir Scale**
- 3D Geomech. Models
- Reservoir Compaction / Subsidence - effects in the overburden
- Coupled Flow / Stress-Strain Evaluations
- Multistage - Multi-well HF Evaluations
- Fault Seal / Reactivation Analysis
- Integrated Fractured Reservoir Characterization
- Integrated Unconventional Reservoir Analysis
3D GEOMECHANICAL MODELS
3D Geomechanical Model

Stratigraphic horizons, reservoir Eclipse layering and near-reservoir faults

North Sea HP/HT Case
3D Geomechanical Model - Horizons and Faults

Gulf of Mexico Carbonate Case
A 3D geomechanical model can be used to evaluate an entire range of production or injection schemes and determine the stress changes within the reservoir or along faults (as shown here).

The critical issues for fault modeling include stress magnitude changes and rotations (as shown in this figure of principal stress tensors) as well as fault movement.
GEOMODEL (e.g. PETREL)

Model imported into a geomechanics simulator

One-way or two-way iterative coupling between the reservoir simulator and the geomechanics simulator (HTM coupling)

Reservoir Simuator (i.e. ECLIPSE, STARS, Psim, etc)
THREE-DIMENSIONAL GEOMECHANICAL MODEL

Including faults and stratigraphic layers from surface to underburden, calibrated with well and core data.

FRACTURE DISCRETE MODEL AT FIELD SCALE

Calibrated for intensity, geometry and hydraulic properties of fractures, and scaled to the dual porosity model.
Critically Stressed Fractures

Fracturas en KS

\[ S_{\text{max}} \] 

\[ \sigma_{\text{Hmax}} \]

\[ \frac{\tau}{S_{\text{v}}} \]

\[ \frac{(\sigma_n - P_p)}{S_{\text{v}}} \]

\[ \mu = 1.0 \]

\[ \mu = 0.6 \]

\[ \Delta P \text{ psp} \]

\[ \sigma_{\text{Hmax}} \]

*Critically stressed fractures*
HYDRAULIC FRACTURING FOR UNCONVENTIONALS
# Unconventional Play Scenarios

<table>
<thead>
<tr>
<th>Highly Fractured Rock Mass</th>
<th>Weakly Cemented or Partially Open NFs</th>
<th>Non – or Strongly Cemented NFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractured Carbonates</td>
<td>Shale Gas and Shale Oil</td>
<td>Tight Sand Gas and Shales</td>
</tr>
</tbody>
</table>

- **Highly Fractured Rock Mass**
  - Limited or no HF is created.
  - Characterize NF sets for differences.
  - Optimize operational parameters.

- **Weakly Cemented or Partially Open NFs**
  - Interaction of HF with NFs & discontinuities is critical.
  - Design: How to fail and open the NFs to create flow area.
  - Characterization of NF sets, stress and pressure is key.

- **Non – or Strongly Cemented NFs**
  - Treat as conventional HF.
  - Economics of multiple stages.
  - Optimization of length/area in pay.
  - Stress Shadows
  - Casing deformation.

*HF=Hydraulic Fracture  NF=Natural Fractures/weakness planes*
Critical Issues in Unconventionals

- **Presence of the resource** (TOC, maturity…..);
- **Presence of natural fractures** and/or weak planes (free surface to be converted to flow area) and their connectivity and hydro-mechanical properties;
- **Fluid pressure** and fluid type – high pressures favor the stimulation of nat. fractures as the effective stresses are low and less shear is needed for stimulation and can the fluid pressure be increased in the nearby wells;
- **Influence of stresses and mechanical properties** on HF geometry and SRV – some conditions are more favorable than others; and
- **Influence of operational parameters/design, well landing and spacing** on HF geometry and SRV.
Our Approach - Geomechanics is Key

- **Characterization - multidisciplinary**

- **Geomechanical Models** - OFG uses models that incorporate the right physics of coupled geomechanics and fluid flow, including the natural fractures to represent rock mass failure, changes in the shape of HFs with multiple stages, changes in ISIP (stress shadows) and its effect on the natural fractures.

- **Calibration** - The field data (microseismics, injection pressures, PLTs, tracers and ultimately production) together with the models help us understand and quantify the effects of geomechanical, reservoir, geological and operational parameters on the stimulation efficiency (increased SRV) and optimization strategies.
Summary of Services for HF

Resource Characterization Support
- Geomechanical assessment (stress, pore pressure, and rock mechanical properties - 1D or 3D sector models).
- Design of Data Acquisition Program

Geomechanical Evaluation of Microseismic Data
- Numerical geomechanical simulations of synthetic microseismicity

Hydraulic Fracture Stimulation Design and Optimization
- DFIT/FET/Mini-frac design and interpretation
- Evaluation and optimization of operational parameters (rates, volumes, etc.)
- Evaluation and optimization of stage spacing-stress shadows
- Post-frac analyses
- Simulation history-matching to field MS data and injection data

Multi-Stage/Multi-Well Completions Design and Optimization
- Stage spacing/Cluster evaluation and optimization
- Evaluation and optimization of multi-well stimulation strategies (Simul-Frac, Zipper-Frac, etc)
- Evaluation and optimization of well placement and orientation

Upscaling of Propped/Stimulated Volume for Flow Simulations
- Single porosity, Directional permeability, Double porosity/double permeability models
Applications Examples - DFN

(a) Sparse DFN

(b) Dense DFN
• The DFN was populated in an inner core domain.

• An outer boundary domain, extended twice of the size of the inner core domain, was used to decrease the boundary effects.
Sparse DFN @15 min Injection

Plan view contours of pore pressure distribution

HF plane
Plotting plane

Pore pressure
- 5.2000E+07
- 5.1500E+07
- 5.1000E+07
- 5.0500E+07
- 5.0000E+07
- 4.9500E+07
- 4.9000E+07
- 4.8500E+07
- 4.8000E+07
- 4.7500E+07
- 4.7000E+07
- 4.6500E+07
- 4.6000E+07
- 4.5500E+07
- 4.5000E+07

Shmin
Stim. DFN
Inj. Pt.
HF
Dense DFN @15 min Injection

Plan view contours of pore pressure distribution

Horizontal wellbore

Plotting plane

HF plane

Pore pressure:
- 5.2000E+07
- 5.1500E+07
- 5.1000E+07
- 5.0500E+07
- 5.0000E+07
- 4.9500E+07
- 4.9000E+07
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- 4.6500E+07
- 4.6000E+07
- 4.5500E+07
- 4.5000E+07

Shmin

Stim. DFN

HF

Inj. Pt.
Effect of Injection Rate

- Injection rate ↓; ratio of stimulated DFN area to HF area ↑.
- Injection rate ↓; leakoff ratio ↑.
- Dense DFN was more sensitive to the change of injection rate.
Influence of Fracture Network

• The Dense DFN had as much as a 5.2 x DFN stimulated area to HF area....

• The Dense DFN had as much as 70% of the fluid go to stimulate the DFN....
Influence of Fracture Network

Plan view (at injection pt) of pressure & MS events

Sparse DFN

Dense DFN

MS Events

Pressure

HF Trace

Inj. Pt.
Sparse vs. Dense DFN – HF Width

Sparse DFN

Dense DFN

X-section view (at injection pt) of HF aperture

Proppant Transport???????
**Effect of Initial Pressure and Stress Ratio**

<table>
<thead>
<tr>
<th>Initial Fluid Pressure</th>
<th>$\frac{Sh_{min}}{Sh_{max}}=30/30$ MPa</th>
<th>$\frac{Sh_{min}}{Sh_{max}}=30/33$ MPa</th>
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<tr>
<td>15 MPa</td>
<td>(a) Invaded fracture length: 1942.8m</td>
<td>(b) Invaded fracture length: 2603.6m</td>
</tr>
<tr>
<td>20 MPa</td>
<td>(c) Invaded fracture length: 2113.9m</td>
<td>(d) Invaded fracture length: 2827.9m</td>
</tr>
<tr>
<td>25 MPa</td>
<td>(e) Invaded fracture length: 2220.7m</td>
<td>(f) Invaded fracture length: 2914.2m</td>
</tr>
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Stimulated length increases with:
- initial pressure (lower effective stress); and
- in-situ stress ratio.
Effect of Initial Pressure and Stress Ratio

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<th>Shmin/Shmax=30/30 MPa</th>
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<tr>
<td>15MPa</td>
<td>(a) Wet events: 75; Dry events: 75.</td>
<td>(b) Wet events: 46; Dry events: 40.</td>
</tr>
<tr>
<td>20MPa</td>
<td>(c) Wet events: 72; Dry events: 125.</td>
<td>(d) Wet events: 584; Dry events: 68.</td>
</tr>
<tr>
<td>25MPa</td>
<td>(e) Wet events: 799; Dry events: 366</td>
<td>(e) Wet events: 724; Dry events: 121</td>
</tr>
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MS wet events increase with:
- initial pressure (lower effective stress); and
- in-situ stress ratio.

MS dry events significant increase with pressure but decrease with stress ratio.
Scaling for Flow Analysis

Pressure changes
Fracture Aperture Changes
Directional Perm Changes

Kxx
Kyy

5 hrs
10 hrs
5 hrs
10 hrs

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Stress Shadows: ISIP Field Data
Under certain conditions, the stress shadow will cause fracture rotation.

What is the significance for MS evaluations??
Stress Shadows

Axes
Color scale of ΔShmin (MPa)

- 10 psi
- 20 psi
- 30 psi
- 40 psi
- 50 psi

wellbore

HF Plane
Shmin $\sim f(\text{Height})$ – One stage

Shmin Wellbore Stress Profile: 1st Stage Only

Distance Along Wellbore (m)

Shmin Stress (MPa)

- 40_Shmin
- 60_Shmin
- 80_Shmin

Wellbore

HF Location

H=40m
H=60m
H=80m
Shmin – Two Stages, Sp=56m

![Shmin Wellbore Stress Profile: 56m Stage Spacing](image)

- **Shmin Wellbore Stress Profile: 56m Stage Spacing**
- Distance Along Wellbore (m):
- **Shmin Stress (MPa):**
- **56m_40**
- **56m_60**
- **56m_80**

*OFG Geomechanics Services for the Oil&Gas Industry*
$\Delta \text{Shmin: 12 Stages - Irregular Spacing}$
Zipper Fracs - Overlapping HFss

Shmin (29 to 34 MPa)

Sxy Shear (0 to 5 MPa)

Planview at injection point
Integrated Unconventional Evaluations

RESERVOIR CHARACT.
Static Model (TOC, Petroph: Poro, perm, reserv geometry, structures, seismic attrib, elast. seismic inversion)
Geological Model (Natural fracs, weak planes, intensity, open/closed, mineralization)
Geomech. Model (Stresses, Pore Press, Mech. Properties matrix and fractures)
‘Sweet’ Spots, Well Location, Landing Location

STIMULATION
Modeling, Completion Design and Optimization

- Shale Play & DFN Scenarios (construct HF models)
- HF Modeling & Hist. Match (pressure, MS and prelim flow area from product.)
- HF Geometry and Improved SRV (HF + Nat. fractures)

Flow Area Optimization
(parametric analysis: rate, fluid, proppant)
Stress Shadows (opt. stage spacing, near-wellbore effects)
Multiwell HF - Zipper Fracs (designs to max. flow area)

Upscaling of Propped Flow Area (HF & Stimul. Nat Fracs) to Double Poro/Perm Model
Pressure Saturations Flow Area

Reserv. Eng.
FLOW SIMULATION
Production Optimization

- Most Likely Reservoir Parameters + # stages, well length
- Production History Matching (post-frac, few days, months, years). Use improved SRV
- Model of Well/Multi-well/ Reserv. (single/double poro-perm)

Optimum Well Spacing & Landing Location
Forecast Scenarios
Exploitation Plan (NPV, etc.)

Coupling @ specific times

Most Likely Reservoir Parameters + # stages, well length
Production History Matching (post-frac, few days, months, years). Use improved SRV
Model of Well/Multi-well/ Reserv. (single/double poro-perm)
Optimum Well Spacing & Landing Location
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