Drilling Integrity Analyses in Conventional and Unconventional Environments: Common Practices and Current Challenges

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October 15, 2015
Presentation outline

• Introduction
• Conventional failures
• Unconventional failures
• What’s next? …
• Concluding remarks
Introduction: Well Centric Geomechanics (1D)

Performed building a Mechanical Earth Model (MEM)
Continuous description of mechanical properties and stresses along the well calibrated against measurements and observations

- Formation tops
- Unconformities
- Faults

- Rock Fabric
- Mechanical support
- Deformation Mechanisms

Predict Wellbore Failure
Conventional failures

- Knowledge of in-situ stresses is not a trivial task
- Calibration is correlated with wellbore failure
Other conventional failures

6 x Shear

3 x Tensile

After Bratton et al., 1983 (SPWLA)
Single Well Drilling Geomechanics Modelling

Calibration is fundamental

Inputs
- Mechanical Properties
- Pore Pressure
- Overburden Stress
- Tectonics Strains
- Horizontal Stresses

Wellbore Stability (WBS)

Mechanical Properties and PP reliable?

Matches Observations?

Matches drilling events?

Drilling
- LWD (sonic), PP, Mudlog

DrillMAP

DrillCAST

Model Update

Real Time Drilling Geomechanics (RTDG)

Drilling Integrity Analysis

Sanding Fracturing
... others

Yes

No

Yes

No

Yes

No

Yes

No
Mud Weight Window

Wide Breakout
Mud weight too low

Safe
Stable

ECD
ESD

Pore pressure
Minimum ESD
Minimum horizontal stress
Fracture pressure

Tensile Induced Fractures
Mud weight too high
Classical 1D approaches – Kirsch’s solution

- The simplest stress calculation approach is the Linear Elastic rock behavior model
- Calculated at the borehole wall
- Minimum pressure to keep all the points around the wellbore in the elastic range

\[
\sigma_r = P_w \\
\sigma_\theta = \sigma_H + \sigma_h - 2(\sigma_H - \sigma_h)\cos(2\theta) - P_w \\
\sigma_\phi = \sigma_z - 2\nu(\sigma_H - \sigma_h)\cos(2\theta) \\
\tau_{r\theta} = \tau_{\theta z} = \tau_{rz} = 0
\]

After Zang & Stephansson (2010)
Classical 1D approaches – Breakouts angle

- Stresses vary away from wellbore wall
- Rock obeys Mohr-Coulomb failure criterion
- Clear physical meaning
- Not easy to calibrate also relying on available wellbore images (fluids effects, filtering, pads contact)
- Extension of breakouts (failure angle) is a function of the stress contrast (stress polygons). Vertical wells would have different breakouts angle than horizontal

*After Zang & Stephansson (2010)*
Depth of Damage (DoD) model

Can we drill with less than the collapse pressure?
Motivation

- Tectonically active area
- Initial models had no mud window
- What mud weight to use?
- How to define a fast and effective solution that includes real rock behaviour?

After Frydman et al. (2011)
Strain hardening/softening behaviour

Mechanical Facies: Grain Support
Load: Normal to bedding
Porosity: 5%

Elastic $E = f(P_c)$

Increasing crack density

Seating

Macrocracking

Depth of damage

$\sigma_1 - \sigma_3$, MPa

Axial Strain, millistrain

$P_c = 0$ MPa

$P_c = 5$ MPa

$P_c = 20$ MPa

$P_c = 40$ MPa

$P_c = 100$ MPa

Szd (0 MPa)

Szd (5 MPa)

Szd (20 MPa)

Szd (40 MPa)

Szd (100 MPa)
• Stresses vary away from wellbore wall
• Failure quantified via DoD percentage \( r_{\text{damage}} / r_{\text{well}} \)
• Calibrated on wellbore stability and actual MW (offsets wells)
• An optimum DoD is identified over the studied area based on observations from DDRs
Mud Weight Window and Wellbore Damage

**Wellbore damage - LOW**

**Wellbore damage - MEDIUM**

**Wellbore damage - HIGH**

**Mud Loss**

**Breakdown**

**Kick**

**MW_MW**

8 lbm/gal 18

**ECD_MW**

8 lbm/gal 18

**Borehole Geometry**

- **Kick**
- **Loss**
- **Breakdown**

**Relative Mud Weight or ECD or cementing pressure**

- **Low**
- **High**

**Possible mud losses if bottom hole pressure is above this line**

**Engaged hole condition if bottom hole pressure is above this line (conservative & ideal)**

**Medium risk curve**: Limits of “manageable failure” tight spot is likely to occurs

**High risk curve**: Potential “borehole collapsed or packed-off” if bottom hole pressure is below this line
### Drilling events & depth of damage

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Casing Design</th>
<th>Drilling Events</th>
<th>Stratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>TVD</td>
<td>Other</td>
<td>Other Risk</td>
</tr>
<tr>
<td>14,000</td>
<td></td>
<td>Difficult to get WLT tools down</td>
<td></td>
</tr>
<tr>
<td>14,555</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14,800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14,555</td>
<td>Lost cone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15,329</td>
<td>Cavings 50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas Spikes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16,144</td>
<td>Cavings 20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15,920</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas - Mud cut 9.8 ppg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16,080</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas - Mud cut 9.1 ppg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16,211</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Well came in Gas - Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16,221</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Full pipe after well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16,221</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17,000</td>
<td>TD @ 16,211 ft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Difficult to get WLT tools down
- Lost cone
- Cavings 50% Gas Spikes
- Cavings 20%
- Gas - Mud cut 9.8 ppg
- Gas - Mud cut 9.1 ppg
- Well came in Gas - Oil
- Full pipe after well

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*Source: Schlumberger*
Radial profile & depth of damage
Improvement in Drilling Performance

Drilling to TD: Days/1000m (no coring)

- NDS PD900
- 13 CMT LOG+TRIP
- 16” PDC 9 SHOE ST
- MEM 8½ PD675
- Pilot ST
- 16” BHA Liner
- PD+QDR PD825

NPT reduction
Unconventional failures: anisotropy

• Material and strength anisotropy of shales can effect the stability of any kind of cavity such as boreholes, tunnels, caves etc.

• The initiation of fractures as well as the collapse of cavities depends on stress field, orientation, pre-existing fractures and intrinsic anisotropic properties of the rocks.

• Especially for boreholes the anisotropic nature of shales has significant impact on magnitude and orientation of failure.

• It is crucial to provide an analytic solution for the borehole stress concentration as well as an anisotropic failure criterion.
Anisotropies

Stress-Induced

Max. stress

Min. stress

Stress

\[ V_S(r,\theta) \]

Intrinsic

Bedding (transverse isotropic vertical)

\[ V_S(\theta) \]

Fractures

\[ V_S(\theta) \]
### Elastic Mechanical Properties from Acoustic

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Available Sonic Measurements</th>
<th>Unknown Parameters</th>
</tr>
</thead>
</table>
| Isotropic | **2** VERTICAL COMPRESS. SLOWNESS  
              VERTICAL SHEAR SLOWNESS | **2** YOUNG’S MODULUS  
              POISSON’S RATIO |
| TIV       | **3** VERTICAL COMPRESS. SLOWNESS  
              VERTICAL SHEAR SLOWNESS  
              HORIZONTAL SHEAR SLOWNESS | **5** VERTICAL YOUNG’S MODULUS  
              HORIZONTAL YOUNG’S MODULUS  
              VERTICAL POISSON’S RATIO  
              HORIZONTAL POISSON’S RATIO  
              VERTICAL SHEAR MODULUS |

Use anisotropic stress models and **core data** to define the remaining 2 unknowns.
# Rock Fabric, Mechanical Properties & Stresses

## Elasticity

<table>
<thead>
<tr>
<th>#</th>
<th>Matrix Composition</th>
<th>$E_h/E_v$</th>
<th>$v_h/v_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carbonate</td>
<td>1.03</td>
<td>0.97</td>
</tr>
<tr>
<td>2</td>
<td>Calcareous Mudstone</td>
<td>1.05</td>
<td>0.88</td>
</tr>
<tr>
<td>3</td>
<td>Silty Mudstone</td>
<td>1.52</td>
<td>1.25</td>
</tr>
<tr>
<td>4</td>
<td>Siliceous Mudstone</td>
<td>2.06</td>
<td>1.47</td>
</tr>
<tr>
<td>5</td>
<td>Organic/Argillaceous Mudstone</td>
<td>2.49</td>
<td>1.34</td>
</tr>
<tr>
<td>6</td>
<td>Argillaceous/Siliceous Mudstone</td>
<td>2.99</td>
<td>1.60</td>
</tr>
<tr>
<td>7</td>
<td>Argillaceous/Calcareous Mudstone</td>
<td>3.79</td>
<td>1.26</td>
</tr>
<tr>
<td>8</td>
<td>Argillaceous Shale</td>
<td>4.01</td>
<td>2.07</td>
</tr>
</tbody>
</table>

- **ISOTROPIC**
  \[ \sigma_h = \frac{v}{1-v} (\sigma_v - \alpha P_p) + \alpha P_p + \sigma_{h\text{-tect}} \]

- **ANISOTROPIC (TIV)**
  \[ \sigma_h = \frac{E_h - v_h}{E_v 1 - v_h} (\sigma_v - \alpha P_p) + \alpha P_p + \sigma_{h\text{-tect}} \]

### Shear from Stoneley
- **Compressional Waves**
- **Shear Waves**

**SONIC SCANNER LOGS**
Strength Anisotropy in Shale

**Samples Oriented at 0°, 30°, 45°, 60°, 75° and 90° to Bedding**

- **Compressive Strength (psi)**
  - 16,000
  - 12,000
  - 8,000
  - 4,000
  - 2,000

- **Orientation to Bedding (deg)**
  - 0
  - 15
  - 30
  - 45
  - 60
  - 75
  - 90

**Legend**

- **V-well**
- **H-well**
- **Deviated-well**

**Charts**

- Low confining pressure
  - $0^\circ \leq \theta \leq 15^\circ$
  - $15^\circ \leq \theta \leq 60^\circ$
  - $65^\circ \leq \theta \leq 90^\circ$

- High confining pressure

**Note**

- After Niandou et al., 1997 (IJRMMS)
Stress Concentration

- Based on classical elastic solutions for anisotropic media by Lekhnitskii (1963), Amadei (1983)

- This solution computes the state of stress around borehole for any
  - stress field
  - borehole orientation
  - material anisotropy and orientation

- The analytical solution is fast, accurate and 3D

- Validated via FEM analysis

*After Gaede et al., 2012, (IJRMMS 51)*
Anisotropy Impact on Stress Concentration

Borehole Stresses for Increasing Ratio of Young’s Moduli

The Hoop stress remains the smallest stress and it decreases \( \rightarrow \) it will be easier to create a L-frac

\[ \sigma_v = 30 \text{ MPa} \]
\[ \sigma_h = 10 \text{ MPa} \]
\[ \sigma_h = 20 \text{ MPa} \]

\( \frac{E_h}{E_v} = 1 \)
\( \frac{E_h}{E_v} = 1.2 \)
\( \frac{E_h}{E_v} = 1.5 \)
\( \frac{E_h}{E_v} = 2 \)
\( \frac{E_h}{E_v} = 3 \)

After Prioul et al. (2012)
SPE 147462
Effect of Shale Lamination (anisotropy) on Failure

- Kirsch’s solution no longer valid
- Amadei’s solution for anisotropic media

Lower stress needed for Tensile failure in anisotropic rock
Anisotropic Failure criterion

- Anisotropic failure model: Plane-of-Weakness model (Jaeger’s sliding model, 1960), other possible (Pariseau, Pei, etc.)
- Mohr-Coulomb – intact rock failure
- Plane of Weakness – sliding on weak surfaces
- Validated against analytical solution for vertical well
- Required inputs – cohesion and friction angle for intact rock and weak plane
- Evaluation of failure criteria: both criteria are evaluated for a given depth
- Various ways of analysis:
  - single depth – for full borehole circumference
  - single depth 3D – provides stress directions around borehole circumference and zone of failure
  - single depth Schmitt plot – e.g. fixed material orientation changing borehole orientation
  - evaluation of failure criteria along well – mudweight window & pseudo image
Wellbore Stability Vs. Borehole Orientation

Well trajectory optimization considering borehole stability

Well pressure by Intact Rock M-C Failure ($\sigma V = 100\text{MPa}$)

Well pressure by PoW Failure model (PoW dip/angle = 90/30)

BH Attack Ang & Azim to PoW = 0.00

BH Attack Ang & Azim to PoW = 60.0

BH Attack Ang & Azim to PoW = 76.0

BH Attack Ang & Azim to PoW = 42.41

Schlumberger
Field Example – Clair Field

Field data published in SPE 124464

- Borehole drilled successfully
- Borehole lost
- Mismatch not understood
Field case study – Clair Field in UK Continental Shelf

Field data published in SPE 124464 (BP)
WBS with PoW Model  (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
WBS with PoW Model (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
WBS with PoW Model (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
WBS with PoW Model (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
WBS with PoW Model (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
WBS with PoW Model (PoW dip 0 – 30 – 45 – 60 – 75 - 85)
Unconventional failures: time dependent behaviour

- Pre-drill analysis identified likely shear failure, 9300' - 9400'
- Time lapse monitoring with CDR, showed progressive hole enlargement
- Drillers tripped through this identified section carefully to avoid unnecessary disturbance
- Minimal breakout maintained for 25 days, after 30 days significant enlargement and cavings production. One further trip to complete section ready to case
- Tight hole plotted on time vs. depth plot shows troublesome depths
Unconventional failures: time dependent behaviour

While drilling data

15 days after drilling

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>MD (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10400</td>
<td>10400</td>
</tr>
<tr>
<td>10500</td>
<td>10500</td>
</tr>
<tr>
<td>10600</td>
<td>10600</td>
</tr>
<tr>
<td>10700</td>
<td>10700</td>
</tr>
</tbody>
</table>

Comparison

- ATR R4 RH
- PSR R4 RH
- ATR R7 POOH
- PSR R7 POOH

<table>
<thead>
<tr>
<th>ATR R4 RH</th>
<th>0.2 ((\text{ohm.m})) 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSR R4 RH</td>
<td>0.2 ((\text{ohm.m})) 2000</td>
</tr>
<tr>
<td>ATR R7 POOH</td>
<td>0.2 ((\text{ohm.m})) 2000</td>
</tr>
</tbody>
</table>

Electrically Conductive shales with OBM filled fractures
Unconventional failures: time dependent behaviour

Shale STability Analysis (SSTA)

- Petrophysical and chemical properties of formations (cores)
- Properties of drilling fluids
- Overbalance pressure
- Formation temperature

Mud pressure penetration $P_p$ increases, mud support decreases, swelling, unstable conditions

Chemical potential mechanism due to osmotic outflow (low mud activity, i.e. high salt concentration), $P_p$ decreases, stable conditions

After Chee et al., 2009 (SPE 126052)
Unconventional failures: time dependent behaviour

Table 1: Petrophysical and chemical properties of cores, cavings and cuttings of Wara Shale

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Average Total Clay (%)</th>
<th>Porosity (%)</th>
<th>Permeability (nano-Darcy)</th>
<th>Shale Activity</th>
<th>Membrane Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bentonite Mud</td>
</tr>
<tr>
<td>Wara-1</td>
<td>50.3</td>
<td>9.32</td>
<td>33.35</td>
<td>0.016</td>
<td>25.4</td>
</tr>
<tr>
<td>Wara-2</td>
<td>25.0</td>
<td>13.31</td>
<td>40.68</td>
<td>0.016</td>
<td>18.6</td>
</tr>
<tr>
<td>Wara-3</td>
<td>46.4</td>
<td>7.11</td>
<td>29.14</td>
<td>0.016</td>
<td>28.7</td>
</tr>
<tr>
<td>Wara-4</td>
<td>27.0</td>
<td>12.73</td>
<td>39.87</td>
<td>0.016</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3: Properties of drilling fluids used in offset wells

<table>
<thead>
<tr>
<th>Mud Type</th>
<th>Adhesion (dynes/cm)</th>
<th>Kinematic Viscosity (cStokes)</th>
<th>Membrane Efficiency (%)</th>
<th>Salt Concentration (wt%)</th>
<th>Water Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCl₂ Polymer Mud</td>
<td>65.8</td>
<td>Temperature Dependant (0.90 – 0.97)</td>
<td>Pore Size Distribution Dependant (20.0 – 28.7%)</td>
<td>15.6% CaCl₂</td>
<td>0.89</td>
</tr>
<tr>
<td>Bentonite Mud</td>
<td>65.8</td>
<td>Temperature Dependant (0.93 – 0.95)</td>
<td>Pore Size Distribution Dependant (19.6 – 31.0%)</td>
<td>9.4% - 4.0% NaCl</td>
<td>0.97 - 0.03</td>
</tr>
<tr>
<td>KCl Polymer</td>
<td>58.8</td>
<td>Temperature Dependant (0.75 – 0.77)</td>
<td>Pore Size Distribution Dependant (13.8 – 24.7%)</td>
<td>12.8% KCl</td>
<td>0.94</td>
</tr>
</tbody>
</table>
Unconventional failures: time dependent behaviour

Table 4: Summary of back-analysis of time-dependent wellbore instability events in Wara Shale

<table>
<thead>
<tr>
<th>Well</th>
<th>Depth (ftMD)</th>
<th>Mud Type</th>
<th>Mud Weight Used (ppg)</th>
<th>Mud Activity</th>
<th>Openhole Duration (Day)</th>
<th>Hole Enlargement (% of Wellbore Diameter)</th>
<th>Calculated Pore Pressure Change After Maximum Exposure Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>X22</td>
<td>CaCl2 Polymer (15.5%CaCl2)</td>
<td>0.99</td>
<td>9.7</td>
<td>4</td>
<td>4.7%</td>
<td>257.1</td>
</tr>
<tr>
<td>A1</td>
<td>X37</td>
<td>CaCl2 Polymer (15.5%CaCl2)</td>
<td>0.99</td>
<td>9.7</td>
<td>4</td>
<td>8.2%</td>
<td>237.6</td>
</tr>
<tr>
<td>A2</td>
<td>X58</td>
<td>Bentonite (3.5% NaCl)</td>
<td>0.98</td>
<td>9.4</td>
<td>4</td>
<td>15.0%</td>
<td>138.4</td>
</tr>
<tr>
<td>A2</td>
<td>X59</td>
<td>Bentonite (3.5% NaCl)</td>
<td>0.98</td>
<td>9.4</td>
<td>3</td>
<td>34.0%</td>
<td>131.8</td>
</tr>
<tr>
<td>A2</td>
<td>X42</td>
<td>Bentonite (3.5% NaCl)</td>
<td>0.98</td>
<td>9.4</td>
<td>3</td>
<td>7.0%</td>
<td>267.2</td>
</tr>
<tr>
<td>A2</td>
<td>X43</td>
<td>Bentonite (3.5% NaCl)</td>
<td>0.98</td>
<td>9.4</td>
<td>3</td>
<td>40.0%</td>
<td>125.3</td>
</tr>
<tr>
<td>A2</td>
<td>X44</td>
<td>Bentonite (3.5% NaCl)</td>
<td>0.98</td>
<td>9.4</td>
<td>3</td>
<td>8.4%</td>
<td>172.3</td>
</tr>
</tbody>
</table>

Wara Shale Activity: 0.916

Positive net change indicates that pore pressure increases with time in the formation.
Unconventional failures: impact on NPT

Offset well: 28 days (13 3/8” and 9 5/8”)

Planned Well: 13 days (13 3/8” and 9 5/8”)

<table>
<thead>
<tr>
<th>Planned Well</th>
<th>Formation</th>
<th>Recommended Mud Weight (ppg)</th>
<th>Recommended Salinity for Water-based Mud A &amp; B</th>
<th>Mud Weight Used During Drilling (ppg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
<td>Ahmadi Shale</td>
<td>11.0</td>
<td>15.0 – 15.5% KCl</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Warta Shale</td>
<td>11.5</td>
<td>14.0 – 14.5% KCl</td>
<td>11.5 – 11.7</td>
</tr>
</tbody>
</table>
Unconventional failures: partial saturation

- Time exposure to water based mud due to coring increased water saturation
- Rock exhibits stress-strain-strain rate behaviour (isotach behaviour) – Sukljje (1957)
- Yield stress is rate dependent (yield stress increases with increasing strain rate)
- Rate dependency is a function of saturating fluid (strain rate increases with increasing fluid saturation)
- This behaviour doesn't impact only drilling, reservoir stimulation in shales induces a similar effect → swelling, creep, fracture closing

*After De Gennaro & Pereira, 2013 (Computers & Geotechnics 54)*
Unconventional failures: viscoplasticity & partial saturation

\[ p_r(\dot{\varepsilon}_v) = p_r^{\text{ref}} \left( \frac{\dot{\varepsilon}_v^{\text{ref}}}{\dot{\varepsilon}_v^{\text{ref}}} \right)^{\alpha(s)} \]

- Extended plastic hardening (rate hardening)  
  Dragon & Mroz (1979), Lemaitre & Chaboche (1985)
- Cam-clay partially saturated models family  
  Alonso & Gens (1990)

Data after Priolo et al., 2007 (Springer Proc. Physics 112)
Unconventional failures: viscoplasticity & partial saturation
What’s next? 3D seismic geomechanics and wellbore and casing integrity analysis

• State of stress underground is generally more complex than the simple scheme addressed by the well centric approach:
  ✓ Challenging environments – deep water, HPHT, tectonic areas, salt
  ✓ More complex well geometries – extended reach, multi-lateral, high dogleg
  ✓ Recovery – depleted fields, shale gas drilling

• Advanced 3D modelling is often mandatory

• Applications are numerous, wellbore and casing integrity analysis are just some

After Onaisi et al., 2015 (ARMA)

After Rodriguez-Herrera et al., 2014 (EAGE Dubai)
3D seismic geomechanics and casing integrity analysis

**Acoustic**

Seismic - Geology

Core data - HRA

Drilling data

1D MEMs along wells

Boundary Conditions (Tectonics)

Stress Calculation

Magnitude and Direction

Static Properties

Structural Framework

Pore pressure

Pressure change
Mech. Prop. update

Porosity change
Permeability up

Well Placement
Drilling and Casing Integrity Analysis

Mud Weight Cube

Mud Weight Window
DrillMAP

Casing Integrity Analysis

DATA SCREENING

DATA INTEGRATION

ANALYSIS

WELL DESIGN

Schlumberger
Example from Deepwater Nakai Trough

- Detection and estimation of gas hydrates saturation using rock physics and seismic inversion
  *Dai et al., 2004 (The Leading Edge)*

Well integrity evaluation for methane-hydrates production

*After Qiu et al., 2015 (SPE Drilling and Completion)*
Well integrity evaluation for methane-hydrates production

- Correlations derived to determine mechanical properties from petrophysical properties, seismic velocity, hydrates saturation, overburden stress

- Hydro-mechanical coupled effects of hydrates production simulated by a third party methane-hydrate production simulator coupled to Schlumberger geomechanical simulator (1-way or explicit coupling)

- Degradation of mechanical properties due to hydrate dissociation (stiffness & strength) correlated to hydrates saturation and mean effective stress change
  
  Sultan et al., 2012 (Geotechnique 62(9))
Sector model

Full Model

Sector Production Well

Schematic Completion
Fig. 18—Vertical-displacement distribution in cross section (Y–Z) after production: (a) on original geometry and (b) on deformed grid.
Cement-Casing integrity analysis

Fig. 19—Horizontal displacement (ZZ) distribution: (a) on the original grid geometry and (b) on deformed grid in the near-wellbore region.
Cement-Casing integrity analysis

Fig. 21—Equivalent plastic strain after 20-day production: (a) including casing results; (b) excluding casing results.
Concluding remarks

• The proposed integrated geomechanics workflows enhances reservoir characterization and cross-discipline capabilities.

• Access to data for validation is essential, this is often a major missed information

• Solutions need to comply often, if not always, with operational needs: fast implementation, simplicity, scalability; all this while ensuring sound technical solutions.

• Operational needs are often conflicting with natural complexity of the problem, especially for drilling