A novel geomechanical characterization methodology for quantifying fine scale heterogeneity

Jesse Hampton (jhampton@ner.com)
Greg Boitnott
Laurent Louis

© New England Research, Inc. 2017
Outline

- Problem statement
  - importance of fine scale info,
  - how to handle fine scale info,
  - implications/example

- Introduction to workflow incorporating fine scale heterogeneities

- Equipment and measurements

- Wolfcamp example dataset
Problem Statement

- Plug scale data
- Log scale data
- Fine scale data
- Rock types at each
- Interrelation between scales

- How do we incorporate fine scale data into log scale model building? - or even plug scale??
Wolfcamp AutoScan dataset

- 8 rock types identified with plug dataset

- Much of this Wolfcamp dataset is made up of mixtures of these 8 rock types

- Random 3’ section of core is made up of same space as all 8 rock types
Big Picture Workflow

Whole core CT scanning, core description, well logs

Upscaling and core-log integration

SMART Sampling using petrophysical rock types

FAST rock typing through petrophysical core scanning

Plug measurements and trend/model building per rock type

Plug to core integration

Data present:
- Log-scale
- mm-scale log
- Plug scale

Output:
- log-scale model
- mm-scale model
Big Picture Workflow

Whole core CT scanning, core description, well logs

Upscaling and core-log integration

Includes possible combinations at log scale (end members)

SMART Sampling using logs, core description, mineralogy, geochem, etc...

Plug measurements and trend/model building per rock type

Data present:
- Log-scale
- Plug scale

Output:
- Log-scale model
- End-member predictions of possible scenarios

Major assumptions:
- Rock types captured with plugging

ner.com
AutoScan Overview
A unique integrated tool for rapid reservoir characterization...

mm to cm scale core scanning & mapping
- Permeability
- P- and S-wave velocity
- Impulse Hammer
- FTIR
- Core Photography
- Electrical Resistivity

- Rock Typing and Plug Selection
  Optimize special core analysis

- Core-Log Integration and Upscalin
  Ties to geologic models, depth shifting

ner.com
AutoLab Overview
NER Single Plug Protocols
static and dynamic elastic anisotropy, anisotropic Biot poroelastic coefficients

Dynamic Cij
VTI
C11, C33, C44=C55, C12, C66, C13
E11, E33, n12, n31, n13, G

Static Cij
VTI
C11, C33, C12, C66, C13
E11, E33, n12, n31, n13

Anisotropic Biot Coefficients
Sgh, Sgv
αh, αv
Stress Profile Development

\[ S_h - \alpha_H P = \frac{C_{13}}{C_{33}} (S_V - \alpha_V P) + \left( C_{11} - \frac{C_{13}^2}{C_{33}} \right) e_h + \left( C_{12} - \frac{C_{13}^2}{C_{33}} \right) e_H \]  

(1)

\[ S_H - \alpha_H P = \frac{C_{13}}{C_{33}} (S_V - \alpha_V P) + \left( C_{12} - \frac{C_{13}^2}{C_{33}} \right) e_h + \left( C_{11} - \frac{C_{13}^2}{C_{33}} \right) e_H \]  

(2)

DFIT and Well Testing

Regional Tectonic Strain

Mineralogy and/or laboratory measurements  
(Biot Poroelastic Coefficient Protocol)

Well logs and Static/Dynamic Transforms and/or measurements  
(Static/Dynamic Single Plug Protocol)
Wolfcamp Example Dataset
Example: Wolfcamp Shale

- Plug data
  - Incomplete
- AutoScan data
  - Incomplete
- Log data

<table>
<thead>
<tr>
<th>Permeability</th>
<th>Velocities</th>
<th>Organic Geochemistry</th>
<th>XRD</th>
<th>Major and Trace Elements</th>
<th>Static Elastic Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph showing a ternary plot with points and labels for CCB1, CCB2, CCL, GC2M, ILM, M1, M2, M3, MX, S1Y, 3PCC.
Interpolation for Grain Stiffnesses
Filling in gaps in current dataset

- Similar textures (i.e. predictions from grain stiffnesses from composition worked here because the rock types were similar in texture and would NOT work for other textures)

- Data from 8 chosen rock types from current dataset along with several other end member cases (i.e. Berea and others) having anisotropic grain stiffness data
Rock types at sub-log resolution compared with log resolution

If log scale core is made up of mixtures of finer scale rock types (i.e. this core)

n possibilities
where: 8 rock types exist in a section of core divided by 5 sub-sections

If you know log response: < 32,768 possible combinations

If you don’t know log response: = 32,768 possible combinations
Plug scale correlations vs upscaled correlations

Relationships typically used in horizontal stress profile workflow:

- Static/dynamic $C_{ij}$
- Static $C_{33}$ -> other $C_{ij}$

Black crosses indicate all possible upscaled predictions of 8 rock types in a 3 foot core interval subdivided into five pieces.

- Note: plug scale correlations between $C_{11}$ and $C_{33}$ can underestimate $C_{11}$ predictions from $C_{33}$ (important!)
Implications wrt horizontal stress
What if we had 9 rock types instead of 8?
“Oh, no we forgot one!”

8 rock types:

9 rock types (inclusion of low stiffness, low Biot coefficients, similar composition (texture differences)):
What if we had 9 rock types instead of 8?

8 rock types:

9 rock types (inclusion of low stiffness, low Biot coefficients, similar composition (texture differences):
Implications

- Blue curve: upscaled horizontal stress profile using plug scale correlations only
- Red and magenta curves: maximum and minimum horizontal stress from all possible combinations of rock types that contain a particular observed dynamic C33 at the log scale
- Curves will not necessarily bracket the plug scale correlation curve, i.e.:
2.7' Section of Core with AutoScan Information
2.7’ section of fine scale data present (AutoScan)
What if core is **not** compositionally or texturally similar?

2.5’ section from same well
What if core is **not** compositionally or texturally similar? 2.5’ section from same well

- Optimize sampling strategy!
  - plug scale data was under-sampling the rock types
  - AutoScan (fine scale) information would catch this and alter sampling programs (i.e. reduce duplication, increase coverage)

- Create upscaling workflow that alters by texture/composition

- i.e. workflow shown is not meant to be applied directly to this section of core without addition of data from these rock types
Conclusions

- Fine scale heterogeneity information vital in sample selection
- Plug scale correlations do not necessarily get applied directly to log scale (even in a standard upscaling workflow)
- Possible combinations of rock mixtures can help produce a lower and upper bound of horizontal stress profiles
- Anisotropy at the log scale can be significantly different than what has been sampled at the plug scale
- And more