Competing Effect of Pore Fluid and Texture -- Case Study

Negative velocity contrast at gas-oil contact
Elastic Moduli and Crossplot

Elastic Moduli vs. Depth

Cross-Plot

Cross-Plot by Zones and Common Fluid Substitution
Rock Texture Diagnostic by Effective-Medium Models
GRANULAR ROCK EFFECTIVE-MEDIUM MODELS

Velocity-Porosity

Dry Sandstones
30 - 40 MPa

Diversity in Sandstones

Well

Critical Porosity Concept

Diagenesis

Quartz Sandstone Sand Suspension

Frame-Supported Fluid-Supported

Porosity

M-Modulus (GPa)

SANDSTONES

Porosity

Shear Modulus (GPa)

SANDSTONES

Porosity
Critical Porosity -- Two Extreme Examples

Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Critical Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstones</td>
<td>40%</td>
</tr>
<tr>
<td>Limestones</td>
<td>40%</td>
</tr>
<tr>
<td>Dolomites</td>
<td>40%</td>
</tr>
<tr>
<td>Pumice</td>
<td>80%</td>
</tr>
<tr>
<td>Chalks</td>
<td>65%</td>
</tr>
<tr>
<td>Rock Salt</td>
<td>40%</td>
</tr>
<tr>
<td>Cracked Igneous Rocks</td>
<td>5%</td>
</tr>
<tr>
<td>Oceanic Basalts</td>
<td>20%</td>
</tr>
<tr>
<td>Sintered Glass Beads</td>
<td>40%</td>
</tr>
<tr>
<td>Glass Foam</td>
<td>90%</td>
</tr>
</tbody>
</table>
Critical Porosity Models and Diagenesis
Contact Cement and Diagenesis

![Graph and images showing contact cement and diagenesis](image-url)

- **Graph**: P-Wave Velocity (km/s) vs. Porosity for different types of cement (Quartz, Clay, Contact Cement, Non-Contact Cement) in saturated and core data.
- **Images**: Back-scatter and Cathodoluminescent images from Well 1, showing cementation details.
- **Notations**: Well 1 Back-scatter, Cathodoluminescent, 0.1 mm.
Contact Cement Theory

Uncemented Grains

Cemented Grains

Contact Stress

Contact Stress

Normal Stress

Contact Stress

Contact Stress
Importance of Contact Cement

![Glass Beads](image1)

**GLASS BEADS**

- Confining Pressure (MPa)
- Porosity (Percent)
  - Cemented
  - Uncemented

![Cemented Glass Beads](image2)

**CEMENTED GLASS BEADS**

- LOOSE GLASS BEADS AFTER

![Porosity Chart](image3)

- Normal Stress
  - Why Cement Preserved Grains

![Coordinate Chart](image4)

- Coordinate along Cement Layer
  - No CEMENT
  - CEMENT
Contact Cement Examples

ARTIFICIAL MATERIALS

- GLASS-EPOXY
  - Upper HS
  - JC
  - Self-Consistent
  - Lower DEM

- QUARTZ-ICE
  - Upper HS
  - Self-Consistent
  - JC
  - Lower DEM

Compressional Modulus (GPa)

Porosity (Void Concentration)

RESERVOIR-RELATED

- QUARTZ CEMENT
- CLAY CEMENT

Dry-Rock Vp at 20 MPa (km/s)

Porosity

Sleipner
Well 16 Log

Troll

Oseberg

CONTACT
CEMENT

CONTACT
CEMENT

CLAY
CEMENT

FRIABLE

CONTACT CEMENT
Grains without Cement -- Hertz-Mindlin Contact Theory

Hertz-Mindlin Contact Solution
Contact Stiffness

\[
\frac{a}{R} = \sqrt{\frac{3(1-\nu)}{2G}} \frac{\pi}{C(1-\phi)} P
\]

\[
S_n = \frac{4aG}{1-\nu}
\]

\[
S_t = \frac{8aG}{2-\nu}
\]
Modified Lower Hashin-Shtrikman -- Applications

Wilmington Field -- Oil Behind Casing

Shallow Sea-Bottom Sediment

Neutron Porosity

P-Wave Velocity (km/s)
Appendix -- Elastic Bounds

\[ M_V = \sum_{i=1}^{N} f_i M_i \]
\[ M_R = (\sum_{i=1}^{N} f_i M_i^{-1})^{-1} \]

Hashin-Shtrikman Bounds: Realization

\[ \left[ \sum_{i=1}^{N} f_i K_i + \frac{4}{3} G_{\text{min}} \right]^{-1} - \frac{4}{3} G_{\text{min}} \leq K_{\text{eff}} \leq \left[ \sum_{i=1}^{N} f_i K_i + \frac{4}{3} G_{\text{max}} \right]^{-1} - \frac{4}{3} G_{\text{max}} \]
\[ \left[ \sum_{i=1}^{N} f_i G_i + \frac{G_{\text{min}}}{6} \left( \frac{9K_{\text{min}} + 8G_{\text{min}}}{K_{\text{min}} + 2G_{\text{min}}} \right) \right]^{-1} \leq G_{\text{eff}} \leq \left[ \sum_{i=1}^{N} f_i G_i + \frac{G_{\text{max}}}{6} \left( \frac{9K_{\text{max}} + 8G_{\text{max}}}{K_{\text{max}} + 2G_{\text{max}}} \right) \right]^{-1} \]
Cementation in Well Log Data