Estimation of Permeability with Seismic “I really did mean to say permeability not porosity”

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Outline

• rock physics model
• supporting measurements (log and core)
• numerical rock assembly model
• model based seismic inversion & practical detectability
• conclusions
Floating grain model - the link of deposition physics to grain scale properties, permeability

Abundance of potential floating grains in the system is due to two factors:

1. Overall abundance of silt/mud-sized particles (related to nature of clastic input and system-scale proximal vs distal position)
2. Local variation due to depositional processes (e.g. rapid fallout vs traction)
Capture ratio is another key concept.

At a constant Effective Stress - For every 3 small grains, 1 becomes part of matrix and 2 will float.

Bimodal grain sizes (big and small)

Capture Ratio = 1 - (1/1.5) = 33%

ie 1/3 of small grains are captured into the load bearing matrix of the rock. The capture ratio will depend on the geometries of the original grains.

porosity in % = -1.5 * float in % - 88% * (1 - exp(-Pe/800 psi)) + 110% ± 0.2%

(B is a constant for a particular constant Pe)
Petrophysical evidence for the floating grain model

![Graph showing density vs. Vp (ft/s) with data points for different wells and lines for standard and floating conditions.](image)
Relationship between size distribution and floating grain fraction

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>stddev</th>
<th>%floating</th>
</tr>
</thead>
<tbody>
<tr>
<td>well #1</td>
<td>2.03</td>
<td>0.55</td>
<td>0%</td>
</tr>
<tr>
<td>well #2</td>
<td>1.58</td>
<td>0.60</td>
<td>3%</td>
</tr>
<tr>
<td>well #3</td>
<td>1.42</td>
<td>0.68</td>
<td>5%</td>
</tr>
</tbody>
</table>
Good regression found between the permeability, porosity, and floating grains.

\[
\log(\text{perm in mD}) = 0.198 \times \text{porosity in %} - 0.325 \times \text{floating in %} - 1.76 + \frac{0.37}{x/2.3}
\]
Floating grains seen in CAT scan and SEM of well #2

Sample #3, moderate sorting, 300 mD, 24%
Numerical rocks give important understanding of floating grain model

- Create sphere packings (two size) representative of unconsolidated sediment through “cooperative rearrangement” algorithm
- Quantify the number of loose grains in packings
- Understand capture fraction
Floating grain fraction & capture ratio demonstrated

- Capture fraction:
  - 0
  - 1/3
  - 2/3
  - 1

- Critical point:
  - 5 vol% (large grain load support)
  - 40 vol% (small grain load support)

- Little dependence on RR

- RR = radius ratio

- "Thermodynamics of random packing", Physics Today (June 2007)
Phase diagram for random packing of binary mixture of spheres

Guide to AVO interpretation

- Increasing NG 0% to 100%
- Brine to Oil

Diagram:
- Dimming AVO
- Brightening AVO
- Decreasing Float 6% to 0%
- Increasing perm 1 mD to 1000 mD
- Decreasing Effective Stress 1000 psi

- Good
- Bad
Implementation of floating grain model in DELIVERY

\[ v_p^2(\phi_{fl}, \lambda) = \frac{K_g}{\rho_g (1-\phi) + \rho_f \phi} \left( \frac{3(1-v)}{1+v} \left(1 - \frac{\phi + \phi_{fl}}{\phi_0}\right)^{\lambda} + \frac{(1 - (1 - (\phi + \phi_{fl})/\phi_0) \lambda)^2}{\phi(K_g/K_f - 1) + 1 - (1 - (\phi + \phi_{fl})/\phi_0) \lambda} \right) \]

- \( \phi = A_{\phi} + B_{\phi} \nu_p + C_{\phi} \phi_{fl} + \varepsilon_{\phi} \)
  - (from numerical inversion of above, using clusters)

- \( \nu_p = A_p + B_p d + C_p LFI/V + D_p \phi_{fl} + \varepsilon_p \)
  - (inverted from this regression, direct from log data and clusters)

  \[ \phi = A' + B'd + C' \phi_{fl} + \varepsilon_{\phi}, \quad \text{with} \quad d \leftarrow (1 - \exp(-\sigma_{eff}/P_0)) \]
  \[ C = -1/(1-f_c), \quad f_c \text{ is 'capture fraction'} \]

- \( V_s = A_s + B_s \nu_p + \varepsilon_s \)
  - direct from log data
Layer based model derived from blocking for well #2
Multiple stack inversion Bayesian inversion is used

before inversion, ignore seismic

after inversion, honour seismic to within noise level
Floating grain fraction and porosity are determined by seismic

time of layer boundary - seismic determines

N/G - seismic does not determine

float fraction & porosity - seismic determines ==> permeability
Conclusions

• floating grain model:
  • explains well log measurements
  • relates seismic to the sorting and the permeability
  • strong link between the microscopic picture and the mesoscopic effective media model

• support given by:
  • standard core measurements (laser grain size, permeability)
  • acoustical core measurements
  • CAT scan & SEM of core
  • numerical rock assembly modelling showing critical behaviour

• practical application shown to be feasible
  • deployed in stochastic model based inversion
  • applied to case of deepwater turbidite
  • porosity and floating grain percentage determined by seismic, therefore permeability
Acknowledgments

- CSIRO
  - Michael Glinsky, James Gunning
- University of Texas
  - Stephen Bryant, Cynthia Thane
- Lone Star Geophysical
  - David DeMartini
- Australian National University
  - Mark Knackstedt
- Colorado School of Mines
  - John Scales, Brian Zadler
- Down Under Geosolutions
  - Troy Thompson
- BHP Billiton Petroleum
  - Stanislav Kuzmin, Kai Soon Tan, Chris Lerch, Dean Stoughton, Bruce Asher, Gabriela Schell