Porosity and permeability measurement of rock cores and porosity/permeability-depth relationship

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Outline

• Introduction
• Methodology
• Result
• Conclusion
• Future works
Introduction

(http://www.powerengineeringint.com/articles/2015/01/ccs-less-effective-than-thought-researchers-say.html)
Porosity & Permeability of sedimentary rocks

- Lithology (mineral composition, grain size, sorting)
- Mechanical compaction
- Stress-history

Wu (2015) predicted the porosity and permeability with depth by proposed model. However, he only categorized two lithologies which are sandstone and mudstone.

This study tries to improve the lithology categorization, and predict the porosity-depth by proposed model.
TPCS-M1 borehole samples

Laser particle size distribution

Porosity measurement under various confining stresses

Stress-history dependent porosity model

Core log

Gamma-ray log

In-situ stress

Geological model

Porosity log

Lithology Categorization

Porosity-depth prediction
• TPCS-M1 borehole

Laser particle size analysis

★ Particle size distribution curve
→ lithology categorization

★ Porosity-effective stress curve
→ Stress-history dependent porosity model

★ Permeability-effective stress curve
→ Stress-history dependent permeability model
Results

Laser particle size distribution

<table>
<thead>
<tr>
<th>TPCS</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250-1A</td>
<td>95</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>248-2A</td>
<td>94</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>344-1</td>
<td>89</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>486-1</td>
<td>83</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>272-1A</td>
<td>82</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>294-1</td>
<td>81</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>364-2B</td>
<td>74</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>371-1A</td>
<td>73</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>241-2A</td>
<td>68</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>327-1</td>
<td>51</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>316-2</td>
<td>39</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>131-3</td>
<td>36</td>
<td>45</td>
<td>18</td>
</tr>
<tr>
<td>133-1</td>
<td>35</td>
<td>46</td>
<td>18</td>
</tr>
<tr>
<td>351-1B</td>
<td>31</td>
<td>44</td>
<td>23</td>
</tr>
<tr>
<td>193-1B</td>
<td>29</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>096-3</td>
<td>18</td>
<td>51</td>
<td>30</td>
</tr>
<tr>
<td>204-2B</td>
<td>14</td>
<td>55</td>
<td>29</td>
</tr>
</tbody>
</table>

Sandstone: Sand > 80 (%)
Muddy sandstone: 80 > Sand > 50 (%)
Sandy mudstone: 50 > Sand > 20 (%)
Mudstone: 20 > Sand (%)
Porosity & permeability measurement

Sandstone: Sand > 80 (%)  
Muddy sandstone: 80 > Sand > 50 (%)  
Sandy mudstone: 50 > Sand > 20 (%)  
Mudstone: 20 > Sand (%)
Porosity:

\[ \phi_{NC} = \phi_0 \cdot \left(\frac{P_e}{P_0}\right)^{-q} \]

\( \phi_{NC} \): porosity for normally-consolidated
\( \phi_0 \): initial porosity in atmospheric pressure
\( q \): material constant for NC stage
\( P_e \): effective confining stress
\( P_0 \): atmospheric pressure

Stress-history dependent porosity model

TPCS site is in the virgin compaction stage
**Porosity:**

\[ \phi_{NC} = \phi_0 \cdot \left(\frac{P_e}{P_0}\right)^{-q} \]

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\( P_e \): effective confining stress

\( P_0 \): atmospheric pressure

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**Stress-history dependent porosity model**

TPCS site is in the virgin compaction stage

Virgin-compaction

Slope:

(ideal compaction curve on a log–log scale. Wu and Dong, 2012)
### Stress-history dependent porosity model

<table>
<thead>
<tr>
<th>TPCS</th>
<th>Sample</th>
<th>$\varphi_0$ (%)</th>
<th>$q$</th>
<th>Average $\varphi_0$ (%)</th>
<th>Average $q$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sandstone</strong></td>
<td>272-1A</td>
<td>43.31</td>
<td>0.1125</td>
<td>46.067</td>
<td>0.10710</td>
</tr>
<tr>
<td></td>
<td>R425-1</td>
<td>45.98</td>
<td>0.093</td>
<td></td>
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<tr>
<td></td>
<td>R478-2</td>
<td>48.91</td>
<td>0.1158</td>
<td></td>
<td></td>
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<tr>
<td><strong>Muddy sandstone</strong></td>
<td>371-1A</td>
<td>34.2</td>
<td>0.1127</td>
<td>33.675</td>
<td>0.13885</td>
</tr>
<tr>
<td></td>
<td>327-1</td>
<td>33.15</td>
<td>0.1650</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sandy mudstone</strong></td>
<td>316-2</td>
<td>28.83</td>
<td>0.1741</td>
<td>30.860</td>
<td>0.13080</td>
</tr>
<tr>
<td></td>
<td>131-3</td>
<td>39.52</td>
<td>0.1344</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>133-1</td>
<td>29.29</td>
<td>0.0947</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>351-1B</td>
<td>25.8</td>
<td>0.12</td>
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<tr>
<td></td>
<td>193-1B</td>
<td>29.08</td>
<td>0.1258</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mudstone</strong></td>
<td>96-3</td>
<td>34.91</td>
<td>0.1344</td>
<td>28.667</td>
<td>0.11787</td>
</tr>
<tr>
<td></td>
<td>204-2B</td>
<td>22.01</td>
<td>0.0934</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Geological model

TPCS-M1 borehole

Sandstone
Muddy sandstone
Sandy mudstone
Mudstone
Geological model

TPCS-M1 borehole

Sandstone
Muddy sandstone
Sandy mudstone
Mudstone

???
Geological model

Sandstone
Muddy sandstone
Sandy mudstone
Mudstone

Core log

Gamma-ray log
Geological model

**Sandstone**
**Muddy sandstone**
**Sandy mudstone**
**Mudstone**

Core log

Gamma-ray log

- **API**
- **Depth (m)**
**In-situ stress**

- Total vertical stress gradient: 21.9 MPa/km
- Pore pressure gradient: 10.1 MPa/km
- Effective vertical stress gradient: 11.8 MPa/km


**Porosity**:

\[ \varphi_{NC} = \varphi_0 \cdot \left( \frac{P_e}{P_0} \right)^{-q} \]

<table>
<thead>
<tr>
<th>TPCS</th>
<th>Average ( \varphi_0 ) (%)</th>
<th>Average ( q )</th>
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<tbody>
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</tr>
</tbody>
</table>

**Power law**

**Virgin-compaction**
Porosity prediction
Porosity prediction V.S Neutron porosity log

- Neutron porosity in **sandstone** layer
- Neutron porosity in **muddy sandstone** layer
- Neutron porosity in **sandy mudstone** layer
- Neutron porosity in **mudstone** layer
Porosity prediction V.S Neutron porosity log
Porosity prediction V.S Neutron porosity log

- Neutron porosity – calculation porosity (%)
- Depth (m)

Average error:
- 0.1380 %
- 10.1233 %
- 19.4127 %
- 15.3531 %

Sandstone
- Muddy sandstone
- Sandy mudstone
- Mudstone

What logs measure:
- Neutron log
- Density log
- Connected pore volume
- Isolated pore volume
- Effective porosity
- Total porosity
- Grain volume or totally dried core

Porosity prediction V.S Neutron porosity log

Average error:
- 15.3531 %
- 19.4127 %
Conclusions

• The porosity prediction is consistent with neutron porosity logging in sandstone formation.

• With larger clay content, the deviation between porosity calculation and neutron porosity are larger.
Future works

• Compare the porosity calculation with porosity derived from density log and sonic log.

• Build the stress-history dependent permeability model and predict the permeability-depth curve.
Thank you for listening