Abstract
Reservoir quality modeling was conducted on the thick (5 km) series of Oligocene-Miocene siliciclastic sediments in the Malay basin, offshore NE Malaysia (blocks PM303-PM324) using the Touchstone software. The goal was threefold: 1) constrain the variation of reservoir quality as a function of burial depth/temperature and sand composition; 2) define maximum depth at which acceptable reservoir quality is preserved; 3) provide a range of expected porosity-permeability for deeply buried prospects. Calibration of the model was done by use of quantitative mineralogy-petrography available from nearby wells located to the NE and SW of the prospected blocks. At these locations, similar tertiary sandstones exhibit sub-litharenite to litharenite compositions with highly variable clay content (0-50%), limited quartz cementation and significant diagenetic kaolinite. Quality of available point-counting data was not perfect and adjustments were made to correct for obvious inaccuracies. Burial/thermal histories at locations of interest were derived from 1D Genex basin modeling. In the absence of constrain on the timing of hydrocarbon emplacement, the latter was estimated using the Touchstone model by setting activation energy to 59kJ/mole and tuning timing of HC charge until proper matching of quartz cement was obtained. In spite of all these uncertainties, the predictive model provided valuable information for preliminary exploration considerations: 1) compaction is the primary factor of porosity loss over the investigated burial/thermal range (0-5km, 0-175°C); 2) intergranular porosity falls below ~10% by ~2.5 km depth in cleaner sands (<5% clay) and by ~1.5 km in shalier sands ( >5% clay); 3) impact of quartz cementation on reservoir quality is very limited below 120°C due the young age (7-25Ma) of sediments; 4) early timing of HC charge is key to the preservation of reservoir quality (quartz retardation) in deeply buried (>120°C) prospects. These conclusions were partly verified in the first well drilled in the exploration zone.
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Forward modeling of reservoir quality in the Oligocene-Miocene siliciclastic series, offshore NE Malaysia, and implication for exploration

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OUTLINE

- Context and objectives
- Background information & input data
- Touchstone Modeling - Forward prediction of RQ
- Conclusions
CONTEXT AND OBJECTIVES

Work done (2009-2010) as a preliminary guide for exploration in the Tertiary series off shore Malaysia

Main objectives

- Build a reservoir quality model for the Oligocene-Miocene sands in the Malay basin (PM303 & 324)
  - Petrographic and basin modeling data
  - Touchstone software (Geocosm™)

- Perform forward modeling to evaluate pre-drill reservoir quality of the entire Oligocene-Miocene section
  - Constrain possible variation in Φ-k values for prospects a.a.f. depth/temp
  - Define economic basement (depth with acceptable RQ)
BACKGROUND INFORMATION AND INPUT DATA
Off shore Malaysia
Oligocene-Miocene sand-shale series
HP/HT area (170-200°C & 600-800 bar)
THICK TERTIARY SEDIMENTARY SERIES

Extensive exploration done at < 3 km
What about deeper targets?
CALIBRATION WELLS USED IN THE STUDY

- South Bundi-1  Fm E & H (1.2-2.3 km)
- Kenarong-3    Fm E, F, H & I (1.5-2.9 km)
- Resak-A6      Fm I & J (2.0-2.7 km)
- Laba Barat-1  Fm E, H & I (1.2-2.6 km)
- South Bundi-1  Fm E & H (1.2-2.3 km)
- Kenarong-3    Fm E, F, H & I (1.5-2.9 km)
- Resak-A6      Fm I & J (2.0-2.7 km)
- Laba Barat-1  Fm E, H & I (1.2-2.6 km)

Analog wells in or within ~50km of prospective blocks

Samples mainly in Lower Miocene sandstone units

Burial depth range: 1.2-2.9 km
SANDSTONE COMPOSITION - QFL PLOT

Large variability!

Two lithological trends

- Lithic trend - rich in Rock Fragt. (Resak & Kenarong)
- Arkosic trend – rich in Feldspar (Laba Barat & South Bundi)

Potential for significant differences in diagenetic effects & Reservoir Quality
MAIN DIAGENETIC FEATURES

Deposition

Pyrite
Siderite
Kaolinite
Late Fdps dissolution
Quartz overgrowths
Secondary porosity
Intercrystalline microporosity
Mechanical compaction

Main factor of porosity loss is compaction

Top hard overpressure
HC charge

Pyrite
Siderite
Kaolinite
Late Fdps dissolution
Quartz overgrowths
Secondary porosity
Intercrystalline microporosity
Mechanical compaction

Unit D
Unit E
Unit F
Unit H
Unit I
Unit J
Unit L

Deposition <100’s m <1km

HC charge

0 Ma

Total cements %
IGV (minus matrix) %

Φ = 0%
Φ = 10%
Φ = 20%
Φ = 30%
Φ = 40%
Data quality revealed highly heterogeneous, and insufficient for South Bundi & Laba Rabat wells

=> Only Kenarong & Resak (lithic trend) were used for model calibration

Model used two different lithologies:
- SHALY LITHIC SANDS
- CLEAN LITHIC SANDS
TOUCHSTONE MODELING OF RQ
TOUCHSTONE MODELING
Forward modeling of sandstone reservoir quality

**INPUT DATA**
- petrographic data (thin sections)
- petrophysical data ($\Phi$ k)
- burial-P-T history data (basin model)

**CALIBRATION**
- calibration wells – analogs

**PREDICTIONS**
- probabilistic $\Phi$-k distributions
TOTAL POROSITY a.a.f. TIME

Kenarong-like model - WATER-BEARING RESERVOIRS

The error bars are derived from Monte Carlo simulations taking texture and sand composition variations into account.

Resak-like model - WATER-BEARING RESERVOIRS

The error bars are derived from Monte Carlo simulations taking texture and sand composition variations into account.

All runs in aquifer conditions

SHALY SAND

Moderate range = 10 to 25%

Strong effect of compaction

Limited quartz cement

Not bad!

CLEAN SAND

Wide range: 7 to 30%

Limited compaction

Significant & variable quartz cement

Better but riskier!
TOTAL POROSITY a.a.f. DEPTH

All runs in aquifer conditions

SHALY SAND

$\Phi < 10\%$ at 2.5-3.0 km

CLEAN SAND

$\Phi < 10\%$ at 2.8-3.5 km
INTERGRANULAR POROSITY a.a.f. TIME

All runs in aquifer conditions

SHALY SAND

Φ < 10 % in 3-9 my

CLEAN SAND

Φ < 10 % in 7-15 my
Kenarong-like model - WATER-BEARING RESERVOIRS

Resak-like model - WATER-BEARING RESERVOIRS

The error bars are derived from Monte Carlo simulations taking texture and sand composition variations into account.

All runs in aquifer conditions

**SHALY SAND**

- $\Phi < 10\%$ at ~ 1.5 km
- $\Phi$ killed at ~ 3.0 km

**CLEAN SAND**

- $\Phi < 10\%$ at ~ 2.5-3.0 km
- $\Phi$ killed at ~ 3.5 km

Better
POST-MORTEM of PROSPECT drilled in PM324 in 2012

Lower Miocene at 1.5 to 3.3 km depth
Sub-litharenites to sub-arkoses
Some clay matrix (13% avg)
TD (3.3km): T = 184°C  P = 700 bar
Non economical gas condensate

<table>
<thead>
<tr>
<th>Sand Unit</th>
<th>Predicted total porosity</th>
<th>Log porosity</th>
<th>Core plug porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group H</td>
<td>21%</td>
<td>25%</td>
<td>-</td>
</tr>
<tr>
<td>Group I</td>
<td>12%</td>
<td>13%</td>
<td>11%</td>
</tr>
<tr>
<td>Group J</td>
<td>7%</td>
<td>11%</td>
<td>-</td>
</tr>
</tbody>
</table>
Main results from Touchstone forward modeling:

- Sand lithology is important but shaly vs clean is a trade off. Shaly sands more prone to compaction, clean sands more prone to quartz cement.

- In spite of high temperature, quartz cementation is rather limited due to limited duration in quartz window.

- Most favorable prospects to be looked for are:
  - sandy (arkosic) facies
  - showing long residence time at <2.5 km burial
  - charged with HC within 10 my after deposition

Refinement of the preliminary Touchstone model is needed, and is achievable provided better quality input data & basin modeling constraints.
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THANK YOU
for your attention