LES PÉTROLE ET GAZ DE SCHISTES.
LA GÉOMÉCANIQUE DEVIENT LE « 4ÈME G » DE L’EXPLORATION PÉTROLIÈRE

By Philippe Charlez - Total
2006 & 2008: the start of an oil & gas revolution

- Oil production increases by 38%
- Oil import decreases by 22%
- Gas production increases by 30%
- Gas imports decrease by 92%

**BP outlook 2013**
- Qatar: 21.00 Bcf/day
- US growth: 17.10 Bcf/day

**Chart 1:**
- Mbbl/day
- Production
- Import
- Irak: 3.14 MMbbl/day
- US growth: 3.22

**Chart 2:**
- Bcf/day
- Production
- Import
- Date: 2000, 2006, 2013
- Oil (Mbpd) Prod: 7.7, 6.8, 10
  - Import: 12, 14, 8.8
- Gas (Mboepd) Prod: 8.9, 8.6, 11.3
  - Import: 1.9, 1.5, 0.8

**Table:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Oil (Mbopd) Prod</th>
<th>Oil (Mbopd) Import</th>
<th>Gas (Mboepd) Prod</th>
<th>Gas (Mboepd) Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>7.7</td>
<td>12</td>
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</tr>
</tbody>
</table>
How hydrocarbons are manufactured?

1. Sedimentation of minerals (quartz/lime/clay)
2. Sedimentation of biomass (C+H+O+N)

- Biodegradation
- Biogenic gas
- Kerogen (C+H)
- Thermal alteration
- Oil + gas
- Gas + oil
- Gas

Sea floor biomass mud
- Bacteria
  - $T^\circ < 80^\circ C$

Biodegradation process:
- Kerogen (C+H) at $T^\circ < 80^\circ C$
- Thermal alteration at $80^\circ C$ to $130^\circ C$

- Oil window
- Pressure increase
- Temperature increase

Depth:
- 2 km
- 3.5 km

CFMR - 16 October 2014
Oil & gas system: from source rock to reservoir

Conventional exploits reservoir
Unconventional exploits source rock

Reservoir
1. Medium to coarse grains,
2. High permeabilities (mD to D)
3. Limited extension (1000 km²)

Source rock
1. Very fine grains
2. Very low permeabilities (nD)
3. Very large extensions

Manuturation of HC = Temperature + Time (Myrs)
Time condition = very low permeability
Production of conventional & unconventional reserves

Conventional
- Economic production
- Non economic production

Economic permeability to be "manufactured" artificially

HC in place are not “naturally” transformed in reserves

Unconventional
- Economic production
- Non economic production

HC in place are not “naturally” transformed in reserves

Economic permeability to be “manufactured” artificially

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Coupling horizontal and HF to build a SRV

- Original rock permeability
- Improved rock permeability
- Main fractures
- Flow back = 25% to 50%

Per frac stage, 0.5 to 1 olympic pool
= 1000 to 2000 m$^3$

Sand from 0.5 to 4 ppg
Per frac stage (0.75 ppg)
= 150 to 200 tons of sand

Quick decline
Low recovery
✓ 5 to 10% for oil
✓ 10 to 20% for gas

Border of macroparcell
Microparcell are drained

Well

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SRV quality

- Mature HC
- Uneconomic k
- Pore pressure

- Stresses
- Natural fractures
- Brittleness

Hydrocarbon in place

Reserves ?

3G

4thG

Sweet spots = play quality + SRV quality

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Main parameters controlling SRV quality

1. In-situ stresses
   - Wellbore breakouts

2. Natural fractures
   - Outcrop analysis
   - Drilling Induced fractures
   - Well imagery
   - Core analysis

3. Britteness (mineralogy)
   - Fracture Complexity
   - Fracture Branching

Completion becomes a “geosciences problem”
Sweet spots = play quality + SRV quality

Logs data
Core data
Seismic data

Upscaling
Multivariate & ranking

SRV quality
Play quality

1. Low play & SRV
2. High play & low SRV
3. High play & SRV

Locate sweet spots = minimizing wells
Economical & acceptability challenge

Unproductive zone
Unproductive wells
SRV modeling to optimise completion strategy

A R&D TOPIC
LPG alternative fluids to water

Flow back
= 20% to 40% of injected volume

Per frac stage
1 olympic pool
= 2000 m³ of water

Physical properties

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Propane</th>
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</thead>
<tbody>
<tr>
<td>Viscosity (cps)</td>
<td>0.66</td>
<td>0.08</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.02</td>
<td>0.51</td>
</tr>
<tr>
<td>Surface Tens (d/cm)</td>
<td>72</td>
<td>7,6</td>
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<tr>
<td>Clay sensitivity</td>
<td>Reactiv</td>
<td>Inert</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Scale</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

SAFETY issue

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Contamination of aquifers

Fracture tops & bottom can be mapped real time monitoring µseismic activity

Typical aquifer depth

After Warpinski et al

Fracture tops

Fracture bottoms

Average perforation depth

Fracture stages

Reservoir several thousand meters below the fresh aquifer

11 Eiffel towers

1,000 1,500 2,000 2,500 3,000 3,500

0.5 1

Probability

Upward fracture height growth (ft)

All shale data

Weibull

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Conclusion: from source rock to reservoir

From « play ».......to.........reservoir

Rock mechanics transforms the « trial »