Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

The Society is grateful to those companies that allow their professionals to serve as lecturers

Additional support provided by AIME
Operational Geochemistry at Work: Integrate or Perish!

Dr. Daniel E. McKinney
Sarawak Shell Bhd.

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl
Where fluid properties affect our business:

- Basin Modeling
- Acoustic Fluid Properties
- Pay/Show Evaluation And Fluid Pressures
- Crude Processing & Refining Requirements
- Facility Design, Flow Assurance & System Selection
- Reservoir Performance & Recovery Optimisation
Agenda

The role of Geochemistry in E&P

Workflow = Planning + Execution

Brief word on Technology Application

Examples from Case Studies

- Oil fingerprinting for production allocation.
- Low level H2S evaluation.
- Identifying compartmentalization during operations.
Impact of Geochemistry on the Business

**Exploration**
- Source(s) type & distribution
- SR time/temperature, history and kinetics
- Gas vs. Oil expulsion
- Oil-Oil & Oil-Source correlations
- Number/Timing of charge events
- Migration paths

**Common**
- Reservoir temp/biodegradation
- Water washing
- Trap failure
- CGR/GOR prediction
- Viscosity and API prediction
- Fill/depletion history

**Appraisal, Development and Production**
- Reservoir connectivity
- Compositional grading
- Viscosity and API analysis & variation
- CGR/GOR
- Bubble/dew point
- Wax/Asphaltenes
- Emulsions & water chem

**IMPACTS ON:**
- Regional Acreage Evaluation
- Prospect Risking
- Portfolio Management, etc.

**IMPACTS ON:**
- Field Development/Management Options, Produce ability Risk, Surface Facility Design, etc.
Simple Example: Reservoir Temperature and the Impact of Biodegradation

Well-A

Tres: 90° C

in situ Viscosity: ~0.1 cP
Simple Example: Reservoir Temperature and the Impact of Biodegradation

Tres: 70°C

*in situ* Viscosity: ~1 cP

Well-B
Simple Example: Reservoir Temperature and the Impact of Biodegradation

Tres: 60° C
in situ Viscosity: 5 cP
Operational Geochemistry at Work

It is not a spectator sport.
We must bridge the gap between subsurface and surface through:

• Planning
• Flexible Execution
• Delivering Consistent Results

The business driver: Get it right from the start!
What do we mean by “Planning and Flexible Execution”?

Define the objectives and get buy in from ALL stakeholders including:

• Sub-surface
• Surface
• Drilling Foremen AND
• Service Providers

Use decision tree analysis to risk objectives.
Example: Did the beaver satisfy the objectives?
The Workflow and Tools

Petroleum System Analysis (PSA)

Drilling & Formation Evaluation

Lab Measurements

Sampling

Refer: McKinney et al., SPE109861
Elshahawi et al., SPE 109684, SPE 94709
And...Apply Technology **When Needed**

Do we always need the best, most expensive piece of machinery? It all depends on the objectives!
Case Study Example

Oil Fingerprinting for Compartmentalization and Forward Thinking During Exploration/Appraisal

Chua et al., IMOG 2015
Tools for Assessing Reservoir Continuity

- Geological and sediment controls on gross depositional environment.
- Static and dynamic pressure.
- Fluid property variations both laterally and vertically.
- Fluid fingerprinting.
- Structural assessment of faults and seals.
Overview of Heavy Mineral Analysis (HMA)

What is HMA?

- Analysis of core and drill cuttings for metamorphic minerals such as zircon, garnet, tourmaline, rutile and apatite.
- It has been proven useful in other deep water depositional environments and application to stratigraphic compartmentalization.
- In this study, the garnet-zircon index (GZi) and apatite-tourmaline index (ATi) were most useful to define vertical and lateral stratigraphic changes.

Multi-Dimensional Gas Chromatography (MDGC)

Key references: Kaufman et al., 1987; Westrich et al. 1999; Rojas et al., 2013.
Multi-Dimensional Gas Chromatography (MDGC)
MDGC Output

Typically, for reservoir connectivity questions, the difference in fluid fingerprints is subtle.
**MDGC Output-Spider Diagrams**

Global rules of thumb:
- Connected reservoirs: <2% variability.
- Disconnected reservoir: >2% variability.
Cross Section Cartoon Through Our Example

Well 1

Well 2

2773 m
Log Character and Fluid Sample Set

<table>
<thead>
<tr>
<th>Well 1</th>
<th>Well 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Open-hole sampling points</td>
<td>DST = Drill stem test</td>
</tr>
<tr>
<td>1*: OIL</td>
<td>5*: OIL</td>
</tr>
<tr>
<td>2*: OIL</td>
<td>6*: OIL</td>
</tr>
<tr>
<td>3*: OIL</td>
<td></td>
</tr>
<tr>
<td>4*: OIL</td>
<td></td>
</tr>
<tr>
<td>DST</td>
<td></td>
</tr>
</tbody>
</table>

DST = Drill stem test
Results from exploration & appraisal drilling
No obvious pressure breaks observed between the upper and lower sands.
Heavy Mineral Associations

Basic Heavy Mineral Stratigraphy across the field defines fan lobe architecture.
HMA Output

Both zones are separated by a mass transport deposit (MTD)

HM Sand 1A
Net Sand Isopach

Sand 1A is thinner, more channel-like and not aerially extensive.

HM Sand 1 Main
Net Sand Isopach

Main Reservoir is thicker (>100 ft. net sand) and more extensive.
Oil Fingerprinting Results

- Well-1 Sample-1
- Well-2 Sample-5
Oil Fingerprinting Results
Summary of Exploration & Appraisal Results

Sand-1:
- Sand-1A and Sand-1 Main in pressure equilibrium.
- HMA indicates two separate sand systems.
- Geochemical fingerprinting indicates they may act as two separate flow units during production.

Thus, the initial “Wells, Reservoir and Facilities Management (WRFM)” document explicitly included sample collection and geochemical fingerprinting from each well at start-up.
Production and Surveillance
Cross Section Cartoon
Through the Reservoir

Well 1

Producer

Well 2

2773 m
Log Character and Fluid Sample Set

*Open-hole sampling points

DST = Drill stem test
Assume oil viscosity between units is the same.

**SAND-1 MAIN SAND-1A**

Average Permeability (k) = 900 mD
True stratigraphic thickness (h) = 43 ft.
kh = 38700 mD ft.

Average Permeability (k) = 670 mD
True stratigraphic thickness (h) = 68 ft.
kh = 45560 mD ft.

Theoretical mixture: 38700:45560 ~45:55 Sand-1A:SAND-1 Main
Production Data
The best ratios were chosen based upon calibration of lab mixtures, known samples and instrument stability.
Initial Results & Prediction: What’s Going On?

- 25:75
- 50:50
- 75:25
Time Lapse
Time Lapse

![Graph showing time lapse with markers at 25:75, 50:50, and 75:25]
Time Lapse

kh lines

%Sand-1A
%Sand 1 Main

Sampling Date

Oct-12 May-13 Nov-13 Jun-14 Dec-14

Volume%
Reservoir Monitoring in the Future

[Diagram showing a reservoir with labels for Water Injector, Producer, Well 1, Gas Injector, and Well 2. The distance between Well 1 and Well 2 is marked as 2773 m.]
Time Lapse

- %SAND-1A
- %SAND-1 MAIN

Sampling Date

- Apr-12
- May-13
- Jun-14
- Jul-15
- Aug-16
- Sep-17

Volume %
Case Study #1 Summary

– Reservoir architecture was established by the integration of a complete set of sub-surface data in the exploration/appraisal phase.
– Results indicated two separate units within Sand-1.
– WRFM system initiated critical baseline sampling and time lapse to monitor changes through production life.
Case Study #1 Summary

Business Impact:
– Material balance and impact on Phase II development for by-passed oil
– Monitor water and gas sweep efficiency.
– Avert or avoid production logging for reservoir contribution.
  • Cost differential is at least 4X orders of magnitude for PLT vs. geochemical fingerprinting.
Case Study Examples

Identifying Compartmentalization during Operations

McKinney et al., SPE 109861
Tools for Assessing Compartmentalization

- Geological and sediment controls on gross depositional environment.
- Static and dynamic pressure.
- Fluid property variations both laterally and vertically.
- Fluid fingerprinting.
- Structural assessment of faults and seals.
Introduction and Framing

Sub-salt discovery well found the following fluid distributions:

Sand A: Black Oil
Sand B: Water
Sand C: Gas/Condensate

Note trajectory of the well and impact on wireline logging!
Apply Technology Where Needed

What is mud logging?

Courtesy of Geoservices
Apply Technology Where Needed

Typical mud logging product: mud gas C1-C5, cuttings description, fluorescence, & show analysis.
Apply Technology Where Needed: Advanced Mud Gas Logging

Advanced mud gas logging (AMG) infers advances in all aspects of mud gas logging:

- Efficient mud gas extractors, less prone to drilling and environmental effects.
- Improved gas transfer lines.
- Modernized analytical devices (e.g., gas chromatography-mass spectrometry).

Data sets are now both precise and quantitative.

Key References: Ellis et al. (1999 IMOG), Brumboiu et al. (SPE 62525), Kandel et al., (SPE 75307), Breviere et al. (2007 IMOG), Stankiewicz et al. (2007 IMOG), McKinney et al. (SPE 109861, SPE 112947, 2011 IMOG).
Appraisal Well Results

Gas Wetness (WH) =
\[(C2+C3+C4s+C5s)/(C1+C2+C3+C4s+C5s)\]*100

Gas Balance (BH) =
\[(C1+C2)/(C3+C4s+C5s)\]

Gas Character (CH) =
\[(C4s+C5s)/C3\]

Appraisal Well Results

**Sand A:** Mud Gas and LWD indicate oil.

**Sand B:** Mud Gas and LWD indicate oil.

**Sand C:** LWD ambiguous but mud gas indicates gas/condensate.

A & B have nearly identical AMG data indicating similar fluids.

Sand C: Upper & Lower show variability—vertical barrier?
Sand C: AMG Compositional Results

Subtle variation in “Pixler ratios” between Upper and Lower members indicates barriers (fluid density inversion).

C1/C2 = 47
C1/C3 = 73
C1/C2 = 68
C1/C3 = 87

B.O. Pixler (1969), SPE 2254
Sand C: Formation Testing

Pressure gradient data confirm both vertical and lateral barriers and the density inversion highlighted by AMG.
Appraisal data gathering during development can be tricky because of competing well objectives.

What if the team decides against advanced mud gas deployment (added cost) and not risking the well to gather formation testing data? What value is lost?

- Full understanding of geology and compartmentalization?
- Volumetric uncertainty and ultimate recovery for the reservoir and for the well?
- Intervention, side-track, and new completion?
Summary: Integrate or Perish!

- From an exploration point of view: “Knowing where your hydrocarbons come from helps you understand…”
- From a reservoir development point of view: “The reservoir fluid chemistry has a story to tell…”
- Integrating these two “truths” into our daily business can bridge the gap between subsurface and surface.
Your Feedback is Important

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