The Power of Integrated Solutions Using Both Production Geochemistry and PVT*

Ellie Chuparova¹

Search and Discovery Article #42480 (2019)**
Posted December 16, 2019

*Adapted from oral presentation given at 2019 AAPG Hedberg Conference, The Evolution of Petroleum Systems Analysis: Changing of the Guard from Late Mature Experts to Peak Generating Staff, Houston, Texas, United States, March 4-6, 2019
**Datapages © 2019. Serial rights given by author. For all other rights contact author directly. DOI:10.1306/42480Chuparova2019

¹EC Petroleum Geochemistry Consulting, LLC, Houston, TX, United States (elli26@yahoo.com)

Abstract

Petroleum geochemistry is one of the main petroleum system analysis (PSA) tools and has a proven record of value-added applications along the whole lifecycle of petroleum asset development – from exploration and appraisal to development, production, abandonment and environmental remediation. Reservoir and production geochemistry refers to the applications of petroleum geochemistry mainly during the development and production of an asset. Appraisal is also a very important stage for production geochemistry because the information gathered at that stage defines the static conditions baseline of the reservoir to which the following dynamic production data are compared for many years to come. Reservoir and production geochemistry is one of the more recently developed (late 1980s - early 1990s) applications of petroleum geochemistry to oil and gas business. It utilizes subtle but measurable compositional differences in reservoir fluids (oil, gas, water) that are controlled by two main groups of factors: 1) variations in charge history (e.g., maturity and/or source rock of the fluids accumulating in the reservoir); 2) post-accumulation in-reservoir processes (e.g., biodegradation, leakage, water washing, charge mixing). The advancement of reservoir and production geochemistry clearly showed the need for integration of geochemistry with reservoir characterization, development geology and petroleum engineering, including PVTx (Pressure-Volume-Temperature-Composition). The present talk will discuss how geochemists and engineers apply PVTx, provide a brief historical overview of several concepts related to in-reservoir charge accumulation and alteration processes, and their impact on reservoir fluid properties for conventional reservoirs. Static and dynamic reservoir compartmentalization, compositionally graded columns and depletion, impact of in-reservoir charge mixing processes on reservoir fluid properties, production allocation, solving flow assurance (wax and
asphaltene deposition) and production (well, pipeline leaks, oil spills) problems are some of the main integrated geochemistry-engineering applications to be reviewed. The unconventional oil and gas revolution of the last decade presented new challenges and opportunities for integration of geochemistry with engineering, including integration with drilling and completion engineering. Main applications to be discussed include identification of oil “sweet spots”, fractured/fault zones and reservoir compartments along lateral wells, evaluation of reservoir fluid properties from surface data, time-lapse geochemistry to monitor dynamic changes in stimulated and effective drained reservoir volumes and production allocation.
The Power of Integrated Solutions Using Both Production Geochemistry and PVT

Ellie Chuparova
EC Petroleum Geochemistry Consulting, LLC

Presentation prepared for AAPG Hedberg Research Conference
Houston, TX, March 4-6th, 2019
Outline

- The role of petroleum geochemistry in an asset lifecycle

- Basic principles
  - Reservoir and production geochemistry
  - PVTx and phase behavior

- Case study examples
  - Static and dynamic reservoir compartmentalization
  - Compositionally graded fluid columns
  - Unconventionals
Role of Geochemistry in an Asset Lifecycle

**Conventional Play/Asset**

- **Exploration**
  - Basin Modeling (regional)
  - Exploration (+ Reservoir) Geochemistry

- **Appraisal**
  - Static reservoir model
  - Reservoir/Production Geochemistry

- **Development**
  - Dynamic reservoir model

- **Production**

**Scale of Investigation**

- **Regional**
  - 100-1000s sq miles

- **Local**
  - <10-100s sq miles

**Power of Integrated Solutions**

- Reduced Uncertainties
- Business impact = Economic value

Copyright @ 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
Reservoir and Production Geochemistry

Reservoir and production geochemistry evolved during the late 1980s and early 1990s in two complementary trends:

- **Solving problems on production time-scale** by using the lateral and vertical variability in reservoir fluid (oil, gas, water) composition and liquid-solid phase transitions (e.g., wax, asphaltene, diamondoids deposition)—*reservoir compartmentalization, production allocation of commingled fluids, operational problems, flow assurance.*


- **Understanding the control factors on the variability** in reservoir fluid compositional fingerprints *on a geological time-scale* prior to production-charge filling history (source, maturity, migration directions), *in-reservoir post-accumulation processes* (e.g., biodegradation, water washing, leakage, de-asphalting).

Reservoir Fingerprinting Technology

❑ **Premise:** Fluids in different reservoir compartments have subtle but detectable geochemical composition differences.

❑ **Assumption:** Post-accumulation homogenization of HC fluids after filling the trap is rapid. (e.g., Kaufman et al., 1990; Larter and Aplin, 1995; Stainford, 2004)

❑ **Enablers:** Technological and analytical developments in:
  - High-resolution gas chromatography (HRGC)
  - Multi-dimensional gas chromatography (MDGC)
  - High-temperature gas chromatography (HTGC)
  - Two-dimensional gas chromatography (GCxGC)
  - *In-situ* real time Downhole Fluid Analyzer (DFA) using visible to near-infrared spectroscopy
Reservoir Fingerprinting Technology

C7 region

HRGC
MDGC

Oil 1
Oil 2
Oil 3

n-C₈
n-C₉
n-C₁₀

OBM Contamination
~C₁₄–C₁₆

Biomarkers
HMW paraffins

Time / Temperature Increase

Copyright © 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
PVTx and Fluid Properties

- **PVTx** = Pressure, Volume, Temperature, X – Composition

- **Fluid properties** (e.g., GOR, density/API Gravity, FVF, reservoir viscosity, $P_{\text{sat}}$, compressibility) are extremely important for a number of *engineering correlations and applications*:
  - reserve calculations, development strategy (e.g., predict and optimize reservoir performance, manage production rates and well placement, identify unswept reservoir volumes), surface facilities design.

- **Control factors on fluid properties:**
  - **Primary – Petroleum System** – thermal maturity, source rock type and facies, migration
  - **Secondary – In-reservoir post-accumulation processes** – biodegradation, water washing, trap leakage, migration fractionation, charge mixing
Phase Behavior and Classification of Reservoir Fluids

Copyright © 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved

Modified after Terry & Rodgers (2014)
Phase Behavior and Classification of Reservoir Fluids

Classification of Reservoir Fluids using Production Information*

<table>
<thead>
<tr>
<th>RESERVOIR FLUID TYPE</th>
<th>OIL GRAVITY</th>
<th>INITIAL PRODUCING GOR</th>
<th>COLOR</th>
<th>INITIAL OIL FVF</th>
<th>C7+ IN RES. FLUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLACK OIL</td>
<td>&lt;45</td>
<td>&lt;2000</td>
<td>DARK/BLACK</td>
<td>&lt;2</td>
<td>30</td>
</tr>
<tr>
<td>VOLATILE OIL (Tcrit&gt;Tres)</td>
<td>&gt;=40</td>
<td>2000-3300</td>
<td>BROWN, ORANGE, GREEN</td>
<td>&gt;2</td>
<td>12.5-30</td>
</tr>
<tr>
<td>RETROGRADE GAS (Tcrit&lt;Tres)</td>
<td>40-60</td>
<td>3300-50,000</td>
<td>LIGHT COLOR, BROWN, GREENISH, WATER-WHITE</td>
<td>&lt;12.5</td>
<td>30</td>
</tr>
<tr>
<td>WET GAS</td>
<td>40-60</td>
<td>&gt;50,000</td>
<td>WATER WHITE</td>
<td>12.5</td>
<td>30</td>
</tr>
<tr>
<td>DRY GAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Reservoir fluid type could be confirmed only by PVT lab experiments (McCain, 1990)

Producing GOR and gravity increase as Pres falls below Psat
Condensate drop out in reservoir <Psat
No liquid is formed in the reservoir. Some —at separator. Producing GOR remains constant
No liquid is formed on the surface except some liquid water.

CP = Critical Point
Applications of Petroleum Geochemistry during Development and Production

- Reservoir Compartmentalization
  - Static
  - Dynamic – using time-lapse geochemistry
- Compositionally graded fluid columns
- Operational problems – case leakage
- Production allocation of commingled fluids
- Production surveillance using Time-Lapse Geochemistry
  - Predict water breakthrough during primary depletion or secondary water flood recovery
  - Monitor CO₂ break-through during tertiary recovery
- Flow assurance
  - Wax and asphaltene deposition problems in well equipment and pipelines and their remediation

Field Case Studies and Examples

- Static and Dynamic Reservoir Compartmentalization using time-lapse geochemistry

- Compositionally graded fluid columns
Integrated approach: 4D seismic, geologic model, pre-production pressures, history matching and time-lapse geochemical fingerprinting.

Business impact: Identified bypassed oil volumes in RU2 block for future infill drilling.

- Can RU2 block oils be drained from the existing wells in RU1 block?
- Are there bypassed volumes of oil in RU2 block?

J2 sand structure map with geochemical fingerprinting using C$_8$-C$_{10}$ alkylbenzenes (MDGC).
Approximate extent of O2 sand distribution

Seismic Amplitude Map

Fluid Content
1994 2001

A-19ST Well Log with Pulsed Neutron results

O Laminate
O Massive Upper
O Massive Lower
O Stray
O2

Red = Gas
Green = Oil
Blue = Water
The Geological Hypothesis

Do O2 oils contribute to the gas/condensate reserves of O massive sand?

- O Upper Massive sand is in juxtaposition against shale across fault and is undrained in the updip well A19ST.
- O2 sand is drained without updip completion from well shown.
- O2 sand pinch out.
- O2 sand is in juxtaposition against O Lower Massive sand across the fault. Both sands are drained in the updip well A19ST.

Reservoir Fluid Properties

<table>
<thead>
<tr>
<th>Date sampling</th>
<th>Well</th>
<th>Sand</th>
<th>Measured Depth (ft)</th>
<th>Sample Source</th>
<th>GOR (scf/bbl)</th>
<th>Tres (F)</th>
<th>Pres (psi)</th>
<th>Psat (psi)</th>
<th>Undersat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul-94</td>
<td>A14</td>
<td>O Mass Blue</td>
<td>17253</td>
<td>surface</td>
<td>3410</td>
<td>176</td>
<td>10540</td>
<td>8000</td>
<td>2540</td>
</tr>
<tr>
<td>Jun-97</td>
<td>A13</td>
<td>O Stray Blue</td>
<td>16362</td>
<td>RFT</td>
<td>4012</td>
<td>175</td>
<td>9951</td>
<td>8121</td>
<td>1830</td>
</tr>
<tr>
<td>Mar-97</td>
<td>A09</td>
<td>O2 Lower Blue</td>
<td>16356-16410</td>
<td>surface</td>
<td>1032</td>
<td>174</td>
<td>10471</td>
<td>5555</td>
<td>4916</td>
</tr>
</tbody>
</table>
Time-lapse Geochemistry Evidence Strongly Supports the Geological Hypothesis

O Massive condensates
10/2001
A14, A16ST, A19ST

O2 oil
1997-1998
A9

O Massive condensates
2/2000
A14, A16ST

O Massive condensates
1994-1999
A14

Chuparova et al. In “Reservoir Compartmentalization”
Static and Dynamic Pressures

Reservoir Pressure (psi)

Pressure drawdown in the O Massive sand from production

Dynamic pressure differential (O Mass-O2 ca. 1400 psi)

Static pressure differential (O Mass-O2 ca. 500 psi)

Static pressures
- A9 4/97 O2
- 427-1 O Mass
- 471-1 O Mass
- 426-1 O Mass
- 471-1ST1 O Mass

Dynamic pressures
- A9 10/02 & 7/03 O2
- A14 O Mass
- A16 O Mass
Auger Case Study - Summary

- Integrated approach:
  - 4D seismic
  - Geologic model
  - 4D production logging (pulsed neutron logs)
  - Pre- and post-production pressure measurements (wireline tools and downhole pressure gauges)
  - PVT
  - Production data
  - Time-lapse geochemistry and fingerprinting

- Business impact:
  - Updated static and dynamic reservoirs models
  - Improved field development strategy
  - Improved hydrocarbon recovery efficiency
Additional Examples of Integrated Studies on Dynamic Reservoir Compartmentalization

- Contribution through baffles between different fault blocks during production was indicated by identification of static and dynamic reservoir compartments using integration of the stratigraphic and structural controls on the compartments, seismic, logs, static and dynamic pressures, PVT, production data and geochemistry in Genesis field, DW GOM (Sweet and Sumpter, 2007; Beeunas et al., 1999).

- Reservoir fault/baffle breakdown during production was identified by time-lapse geochemical fingerprinting in Pierce field, North Sea related to gas injection in shallower horizons (van Bergen and Gordon, 2018).

- In contrast, production induced reservoir compartmentalization due to faults becoming less leaky with decreasing reservoir pressure over 100 years of production has been suggested for Elk Hills field, California (Morris et al., 2012)
Compositionally Graded Fluid Columns

- Continuous reservoir *
- Fluid column properties and composition vary
- Could lead to false reservoir compartmentalization and production allocation conclusions if not recognized
- Could exist under thermodynamic equilibrium or dis-equilibrium conditions
- Engineering (EOS) models can’t adequately predict main fluid properties (e.g., GOR, API, viscosity) in graded columns under dis-equilibrium conditions—major impact on development decisions and reserve estimates

A series of dead liquids illustrate the variability of the fluid column in a compositionally graded reservoir

GOR, $P_{\text{sat}}$, API, Sat/ Aro INCREASE - Reservoir viscosity DECREASES updip

A. Ranch field, WY (Metcalfe et al., 1988)

* Sage and Lacey (1938): “Variations in the composition of the liquid phase of natural reservoirs, which are continuous through significant ranges in elevation…”
Factors controlling compositional grading

1. Gravity
✓ Gravitational segregation from density driven convection – heavier components segregate towards the bottom and lighter components towards the top of the column

2. Temperature gradients
✓ Thermal diffusion – segregates lightest components towards the bottom (higher temperatures) and heavier components towards the top of fluid column (lower temperatures)
✓ Thermally induced convection – results in “mixed” fluid systems with close to constant compositions

3. Processes that could cause dis-equilibrium in the fluid column
✓ Dynamic flux of aquifer contacting only part of laterally extensive reservoir could create a sink for continuous depletion of lighter components such as methane
✓ Biodegradation – usually creates lateral and vertical fluid property variation
✓ Charge and accumulation history
  - incomplete charge mixing due to insufficient time since accumulation
    • mixing of fluids from multiple charges (e.g., different source rock, maturity)
✓ Tar mat, Wax and Asphaltene deposition

Compositionally Graded Column under Dis-equilibrium Conditions

- Continuous reservoir
- GOR gradient range (~1480-8100 scf/bbl)
- API Gravity gradient range (~ 27-40°API)
- Gradient in methane carbon isotopes.
- Mixing of gases from two sources – thermogenic and “biogenic”.
- “Biogenic” gas component increases updip
- Large gradient in the proportion of “biogenic” and thermogenic gases suggests dis-equilibrium conditions, likely due to insufficient time for mixing in the reservoir.

\[ \frac{20/80}{0.25} = \text{Thermogenic gas} \%-\text{“Biogenic” gas} \%-\text{Ratio of thermogenic: biogenic gas} \]

Modified from Zuo et al. (2011)
Depletion of Compositionally Graded Column and Water Breakthrough Prediction

- Single PVT data point at appraisal.
- Time-lapse geochemistry monitoring revealed a dramatic decrease in gravity (9°API), fluid color, SARA and fingerprints seven months after first production.
- The fluid properties’ change occurred 2 months before the reservoir watered out and illustrates a production depletion of a compositionally graded column.

Copyright © 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
Unconventional Play / Assets

Conventional Plays/Assets

- Exploration
- Appraisal
- Development
- Production

- Basin Modeling (regional)
- Static reservoir model, e.g. Petrel
- Dynamic reservoir model, e.g. Eclipse
- Exploration (+ Reservoir) Geochemistry
- Reservoir/Production Geochemistry

Scale of Investigation

Regional
100-1000s sq miles

Local
<10-100s sq miles

Unconventional Plays/Assets

- Exploration
- Production
- Development
- Appraisal

- Basin Modeling (regional)
- Dynamic reservoir model
- Static reservoir model
- Exploration Geochemistry
- Exploration/Reservoir/Production Geochemistry

Time

Copyright @ 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
Reservoir and Production Geochemistry Applications for Unconventional Assets

- Time-lapse geochemistry and production allocation
- Vertical drainage heights and contribution
- Finding bypassed oil zones
- Oil sweet-spot identification and geological targeting
- High permeability-fracture–fault zones detection along lateral wells
- Compartments – lateral and vertical
- Estimate PVT properties from gas and field data
- Reservoir depletion (e.g., faulting, nearby wells)
- H₂S origin identification, including induced vs natural
- Origin of produced waters

Permeability Indicators and Reservoir Compartments from Mass Spec Mud Gas Data

12 ft flare; Oil in the shakers while drilling at ~14600 ft

Copyright @ 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
The studies have **identified, tested and validated** multiple mud gas applications:

**Geologic Targeting**
- Sweet spot identification

**Reservoir Compartments**
- Lateral (stratigraphic)
- Vertical (faults)

**Permeability Indicators**

**Reservoir Depletion**

*Chuparova et al. (2014); Romanoski et al. (2014).*

© 2014 AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 6–9, 2014
Concluding Remarks

- The power of integrated Geochemistry-PVT solutions comes from reduced uncertainties, increased business impact and economic value.

- Reservoir fluid type always has to be considered when performing sampling and geochemistry interpretations of fluid samples.

- Fluid composition and fluid properties are Geochemistry-PVT common denominator.

- Multi-disciplinary integration of geochemistry with other geoscience (e.g., geology, seismic, petrophysics) and broader engineering disciplines (e.g., reservoir, drilling, completions) is a powerful approach when working in unconventional settings as well.
Acknowledgements

❑ Professor Roy Knapp (OU-Norman)
❑ Professor Curtis Whitson (OU-Norman)
❑ Dr. Naji Nagarajan (Mobil-Exxon-Hess)
❑ Professor R. Paul Philp (OU-Norman)
❑ Dr. Joe Westrich (Shell)
❑ Dr. Birol Dindoruk (Shell)
❑ Dr. Robert Elsinger (Shell)
❑ Dr. Alan Kornacki (Shell)

❑ Session Chairs and Organizers of the 2019 AAPG Hedberg conference
References


References


References


Copyright @ 2019 EC Petroleum Geochemistry Consulting, LLC. All rights reserved
References


- Reed, J. D., K. Ferworn, S. Brown, J. Zumberge. 2010. Hydrocarbon phase prediction in unconventional resource plays using geochemical and PVT data. AAPG Hedberg Conference, December 5-10, 2010, Austin, Texas, AAPG Search and Discovery article # 90122.


- Slentz, L. W. 1981. Geochemistry of reservoir fluids as a unique approach to optimum reservoir management. SPE paper 9582.


References


• Westrich, J. T., N. Fuex, P. M. O’Neal, H. I. Halpern. 1999. Evaluating reservoir architecture in the Northern Gulf of Mexico with oil and gas geochemistry. SPE paper 59518.

