The Whys and Wherefores of Geochemistry and Basin Modeling From Exploration to Production*

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Abstract

Petroleum geochemistry and basin modeling, also known as petroleum systems analysis, are used along the entire subsurface value chain from exploration to production. Traditionally these disciplines have been applied mainly in Regional Exploration and Prospect Evaluation to evaluate source rock properties, charge and fluid property risk. Exploration wells have for decades been a key way to acquire data on source rock properties and thermal maturity, which are used in further evaluation of a basin. Fluid data from discovery wells are used to calibrate basin models, as well as in Appraisal and Development. Geochemistry plays a key role in the assessment of failure in dry holes, which can be critical in evaluation of remaining prospectivity in a basin. A detailed fluid property description across a field from geochemical and PVT fluid data, combined with a thorough filling history from basin modeling, can be used in Appraisal and Development of a field to help assess connectivity and compartmentalization. These data can also help predict the likelihood of compositional grading, tar mats, flow assurance issues (wax, asphaltenes and organic soaps), and biodegradation (heavy oil). Petroleum geochemistry can be used to help address a wide range of Production issues. These include routine monitoring, allocation, casing issues, water injection problems, compartmentalization, H_2S generation or tar mobilization in heavy oil fields. This is probably the main area where geochemistry is currently underutilized. Basin models have been mainly used in the past as a "one way" technology, where the output is the end product, and not used routinely to model at field scales. However, this has slowly changed over the last two decades, as basin modeling has become more integrated into an iterative, full cycle workflow. Rock properties from seismic are fed into basin models, and pore pressure predictions back into seismic until the pressure and rock properties are in agreement. Reservoir quality prediction on a prospect scale uses basin modeling derived pressure and temperature (p-t) histories as inputs to a reservoir quality models, which are used to either predict porosity, or evaluate if the p-t history can explain the measured porosities. An overview of these synergetic technologies and workflows, and their importance in constraining many subsurface uncertainties, will be presented using published and in house examples.

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The Whys and Wherefores of Geochemistry and Basin Modeling from Exploration to Production

Richard Patience & Friedemann Baur

APT **Chevron**

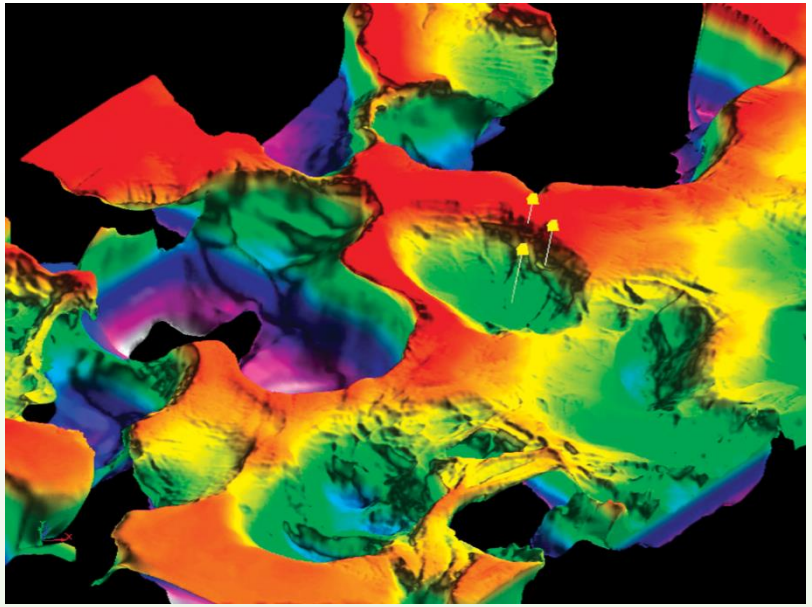
Petroleum System Studies – Why and Where?

Upstream Value Chain	Main component	Geochemistry	Basin Modeling
Exploration Basin & Play Analysis Prospect Evaluation Drilling	Effective source	SR presence, character & maturity data	SR maturity
	Petroleum migration	Oil-source-correlations	HC migration, entrapment & alteration
	Petroleum properties	Analog fluid studies	Fluid properties prediction P,T prediction
Discovery Appraisal & Development	Field wide controls on fluid and rock properties	Filling history Connectivity Compositional grading Flow assurance	Reservoir quality support Integrated filling history
Production	Fluid composition Fluid "issues"	Monitoring Problem solving	NA

Outline

Applications of Geochemistry and Basin Modelling in:

1. **Exploration (Frontier to Drilling)**
2. Appraisal and Development
3. Production



Exploration – Geochemistry and Basin Modeling = HC Charge Evaluation

Hydrocarbon (HC) Generation

- Source presence,
- Source properties
- Source maturation & generation

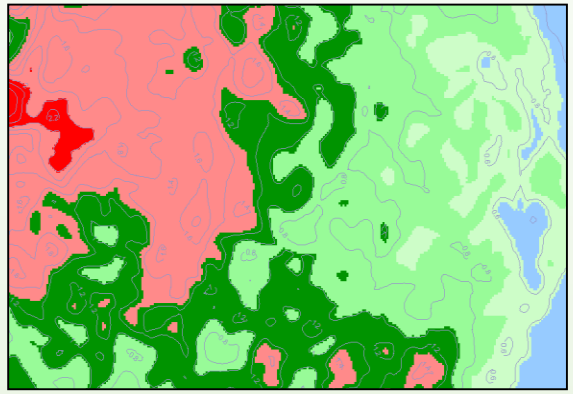
HC Migration and Accumulation

- Expulsion efficiency
- Migration
- Entrapment

HC Properties, Volumes & Sensitivity

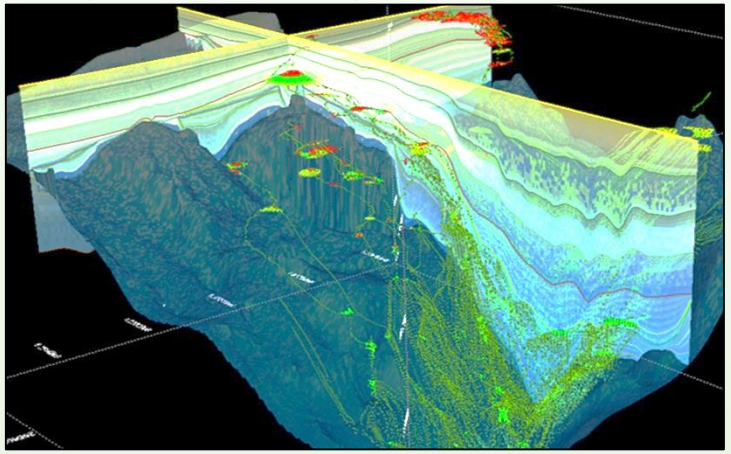
- P,T reservoir conditions
- Timing of migration relative to trap formation, seal competence, alteration (filling history)

Vitrinite Reflectance Ro [%]

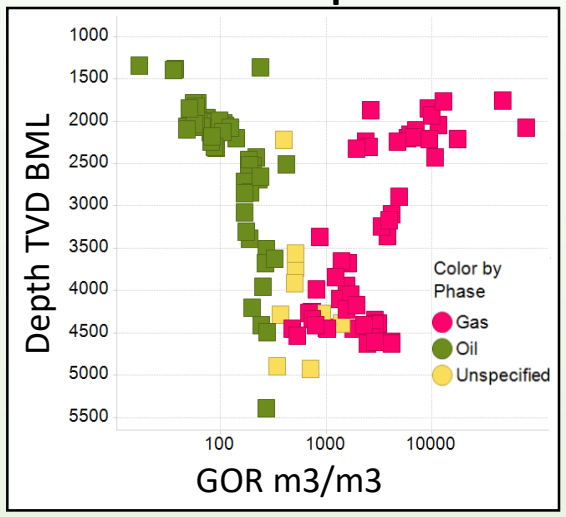


Immature
Early Oil
Main Oil
Late Oil
Cond./Wet Gas
Dry Gas

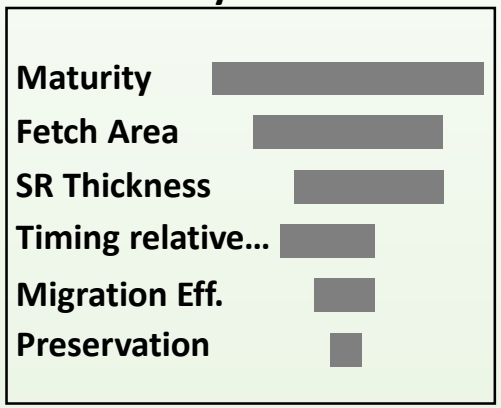
Migration Pathways & Accumulations



GOR vs Depth Plot



Sensitivity HC Volumes



Exploration – Basin Modeling Pressure Prediction

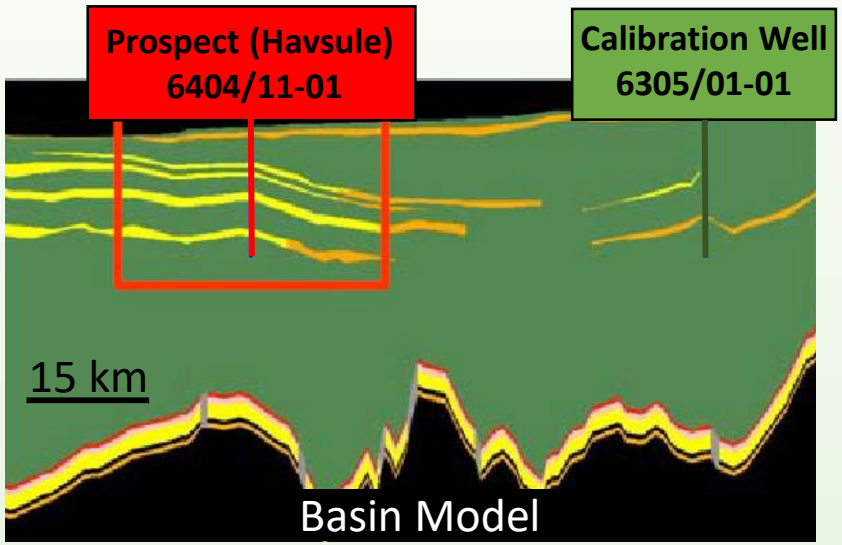
Traditional Approach

Offset Wells

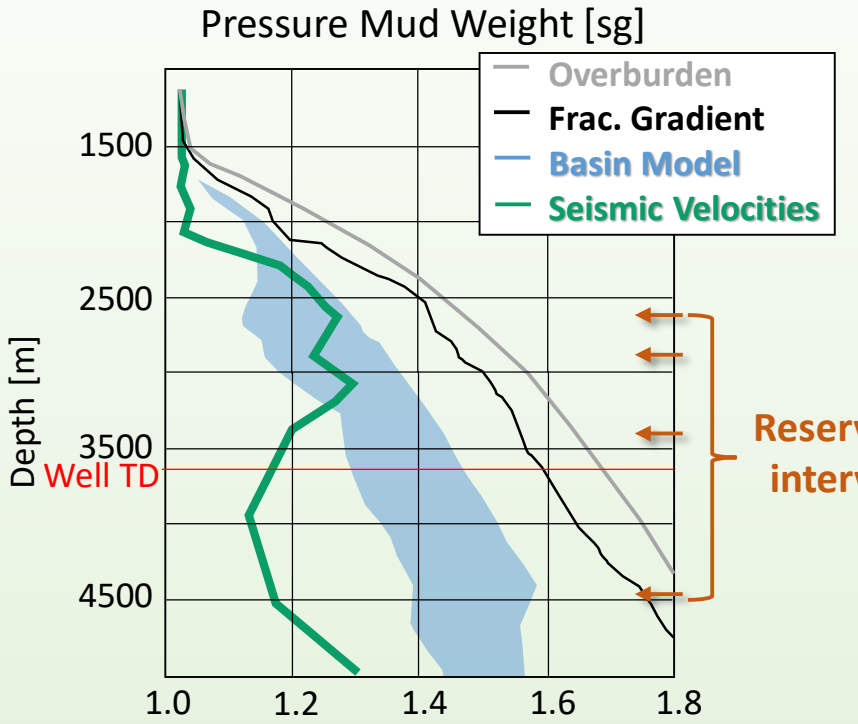
→ Velocity data, Sonic, checkshots → Checkshot calibrated velocity cube → Seismic velocity derived pressure prediction

→ Pressure data, DST, MDT → Pressure calibrated basin model → Basin model derived pressure prediction

Independent — Integrated



Northern Møre Basin, Norway
Prospect located 75 km northwest of Ormen Lange field



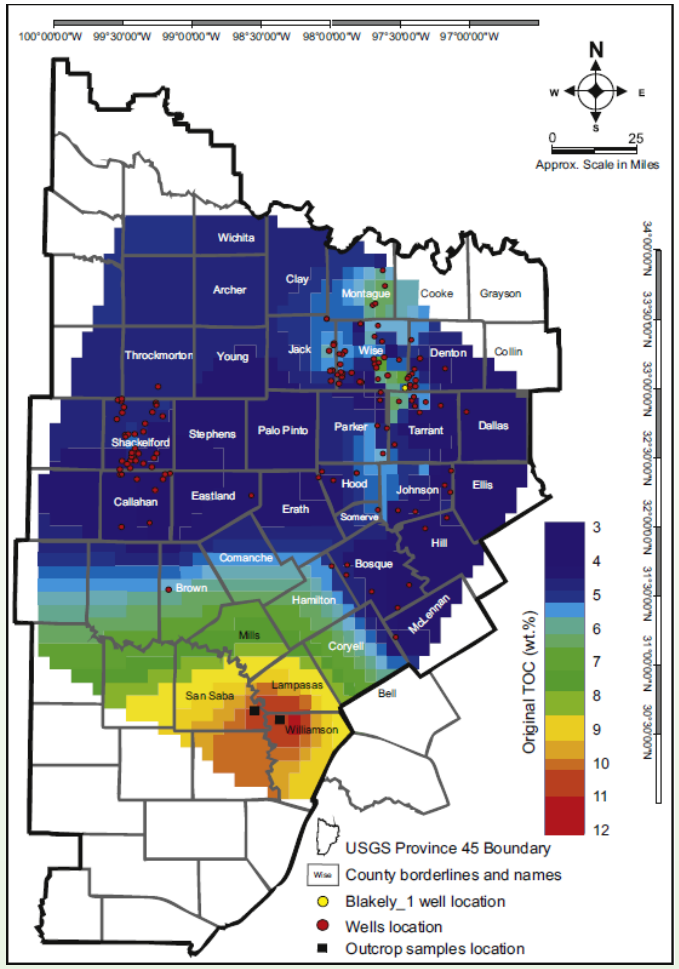
Doyle et al. (2003), SPE/IADC 79848, 1-7

Unconventional Plays

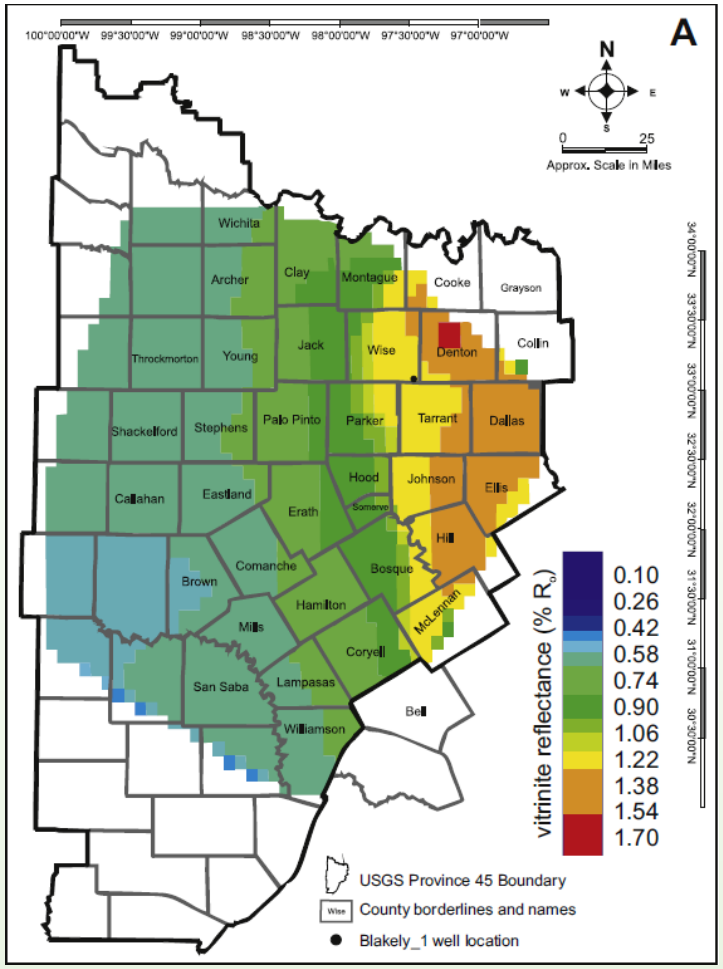
- An unconventional play is not very unconventional geochemically
  - TOC
  - Pyrolysis (Rock Eval)
  - Vitrinite reflectance
  - Gas data
- Additional unconventional specific data such as…
  - Organic porosity,
  - Adsorption and expulsion
- It is analogous to starting a review of a conventional basin or play

Lower Barnett Shale

Original TOC distribution



Modeled thermal maturity (Ro)



Romero-Sarmiento et al. (2013), Mar. Pet. Geol. 45, 315-330

Outline

Applications of Geochemistry and Basin Modelling in:

1. Exploration (Frontier to Drilling)
2. **Appraisal and Development**
3. Production

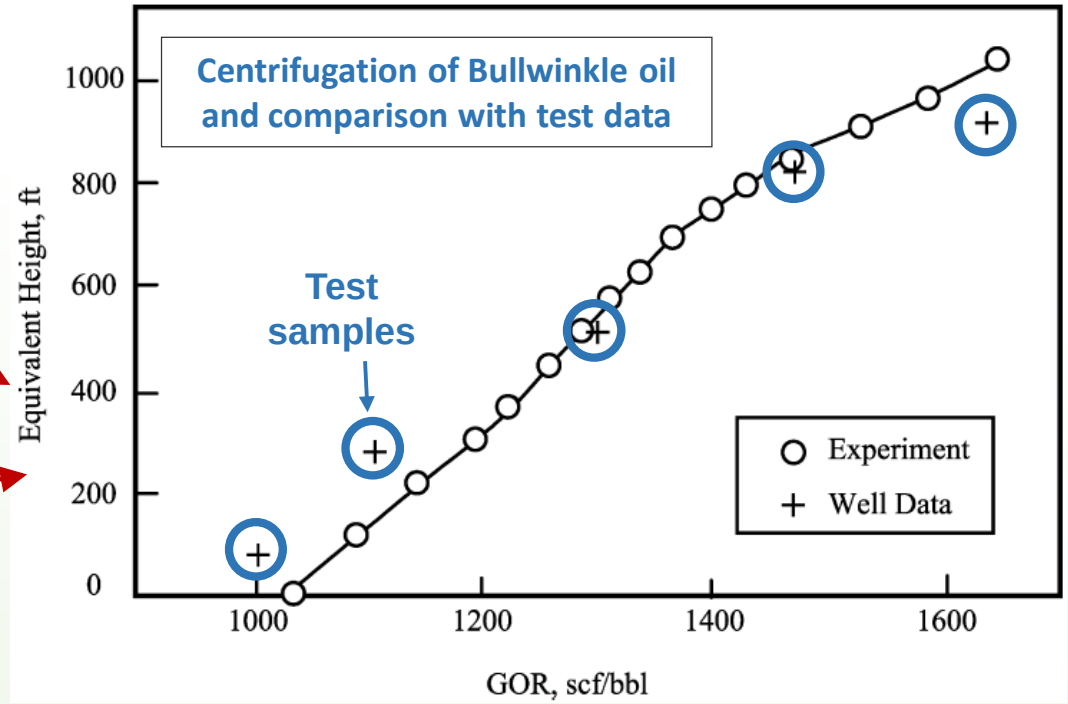
A&D – What Causes Differences in Fluid Compositions in a Field?

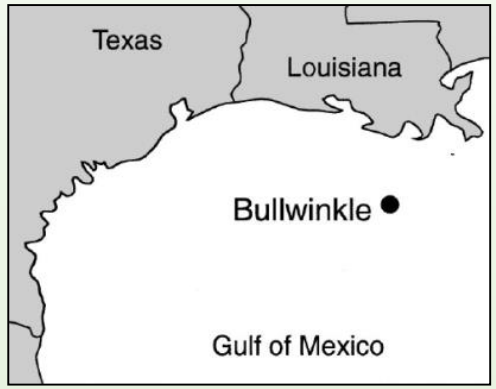
- Variations in fluid properties due to:
  - Filling history (may = disequilibrium)
  - Post-filling mixing (may = equilibrium)
  - Alteration (biodegradation)

- Reflected in properties such as:

Asphaltenes	GOR
Density	Viscosity
GC fingerprints	Biomarkers
Gas isotopes	Etc.

- Connected? or Compartmentalized?
  - Need multiple data points

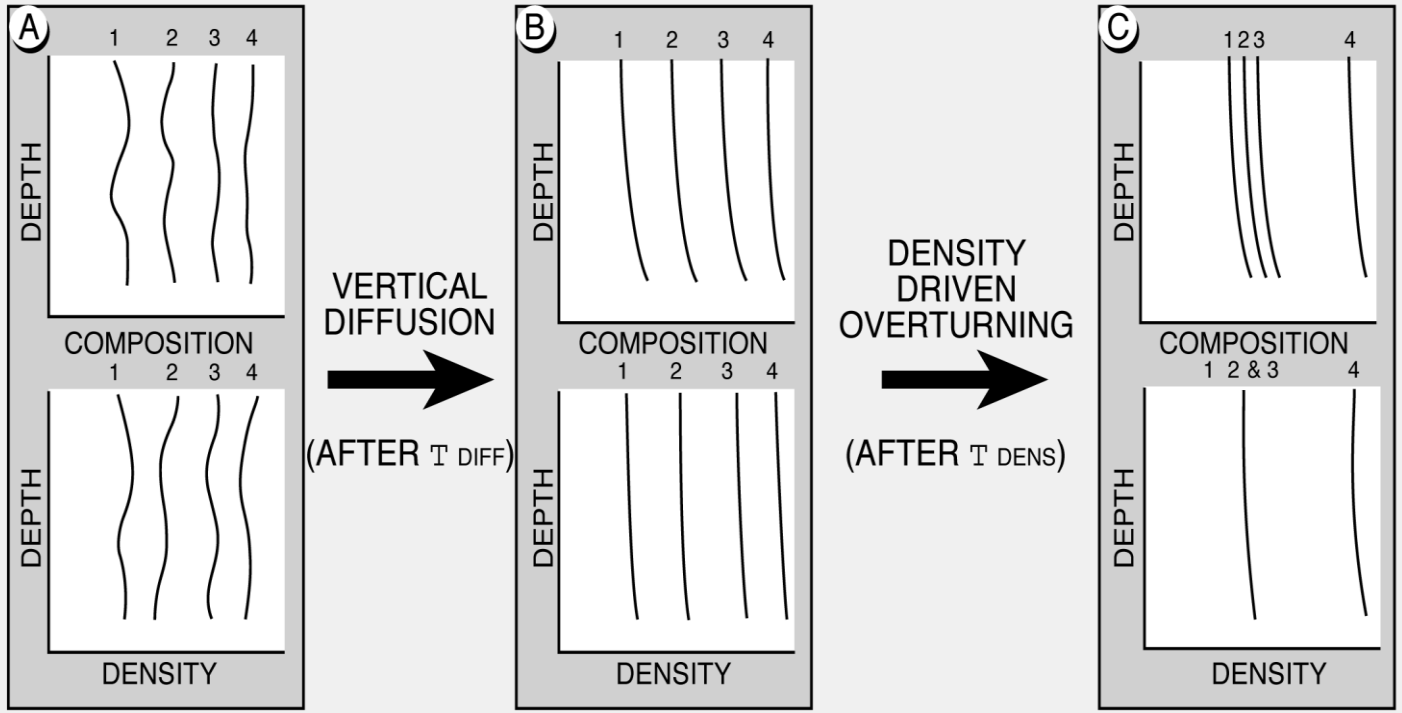


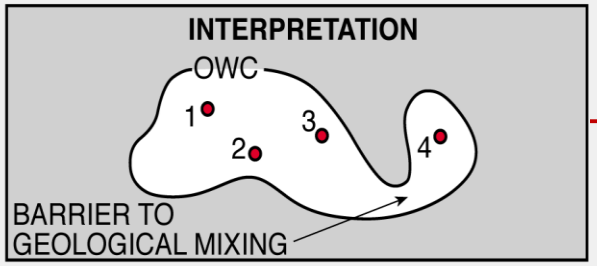


Ratulowski et al. (2003), SPE84777 Res Eval & Engineering, 168-175

A&D – Effect of Filling and Mixing Processes on Fluid Composition

"Filling history" → Post-Filling mixing → "Equilibrium"

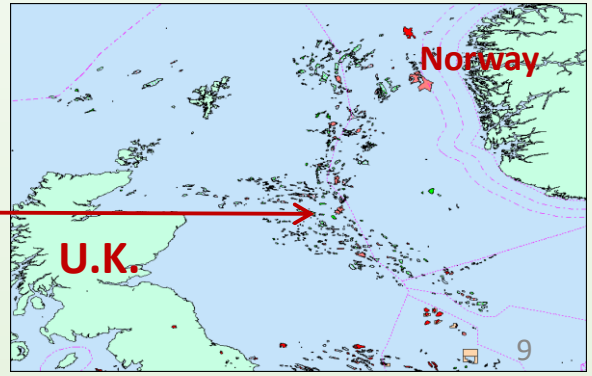




1,2,3: Gradual vertical change
- Compositional grading
- Communication

4: Abrupt lateral change
- Barrier

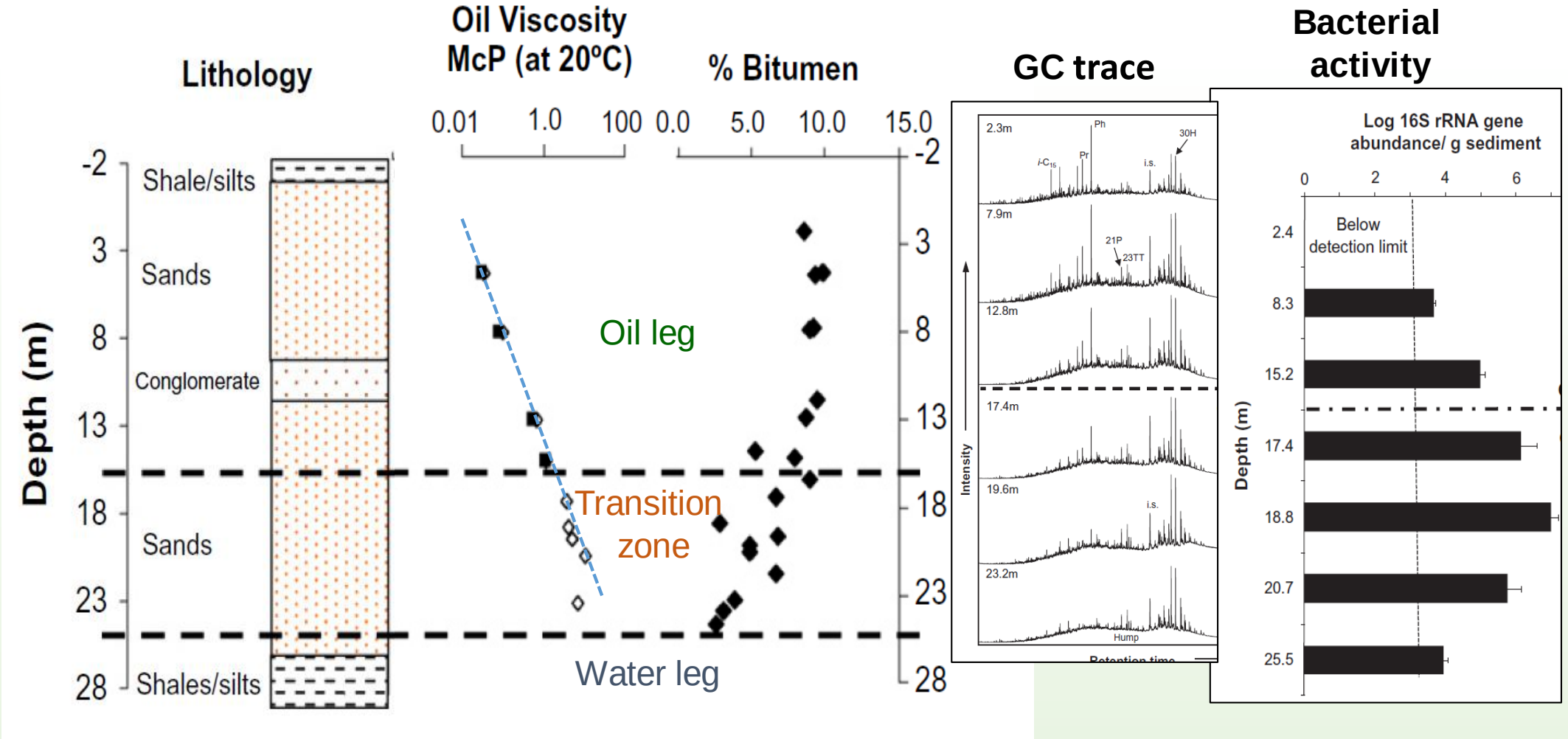
England (1990), Organic Geochemistry 16, 415–425.



A&D – Biodegradation & Compositional Grading

Peace River Oil Sands, Alberta, Canada

Compositional gradients

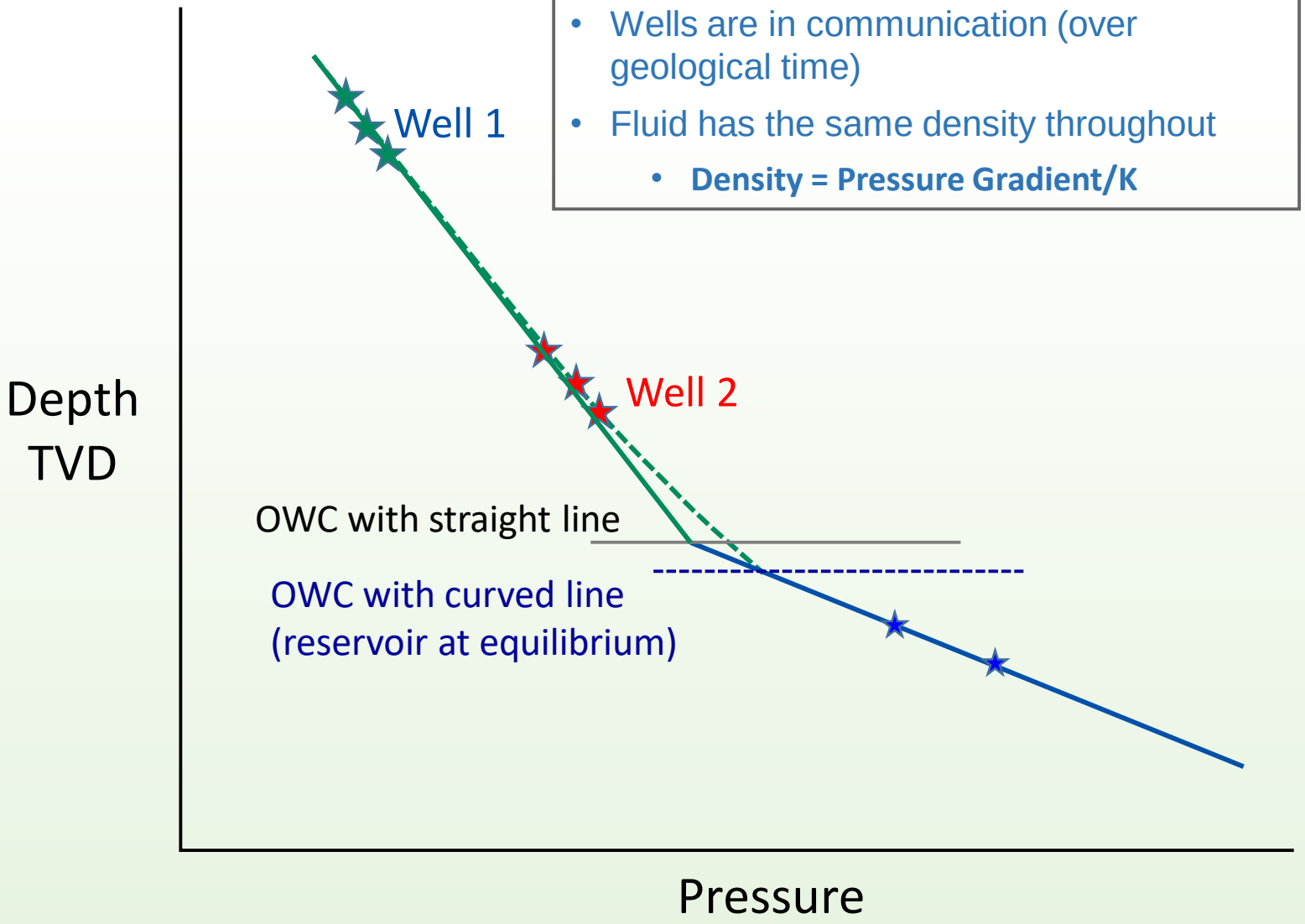


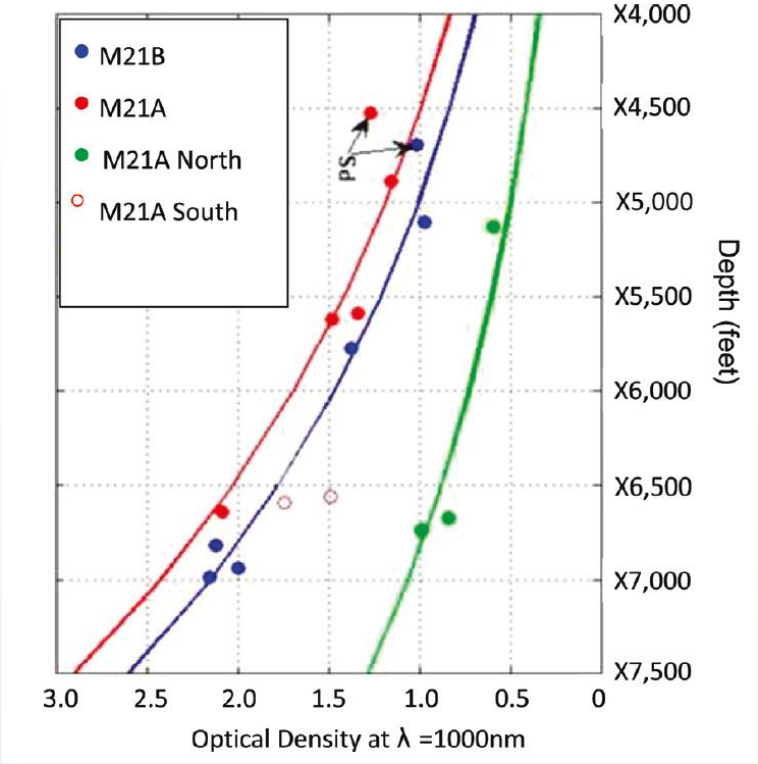
Bennett et al. (2013), Organic Geochemistry 56, 94–105

A&D – Effect of Compositional Grading on OWC

Conclusion:

- Wells are in communication (over geological time)
- Fluid has the same density throughout
  - **Density = Pressure Gradient/K**

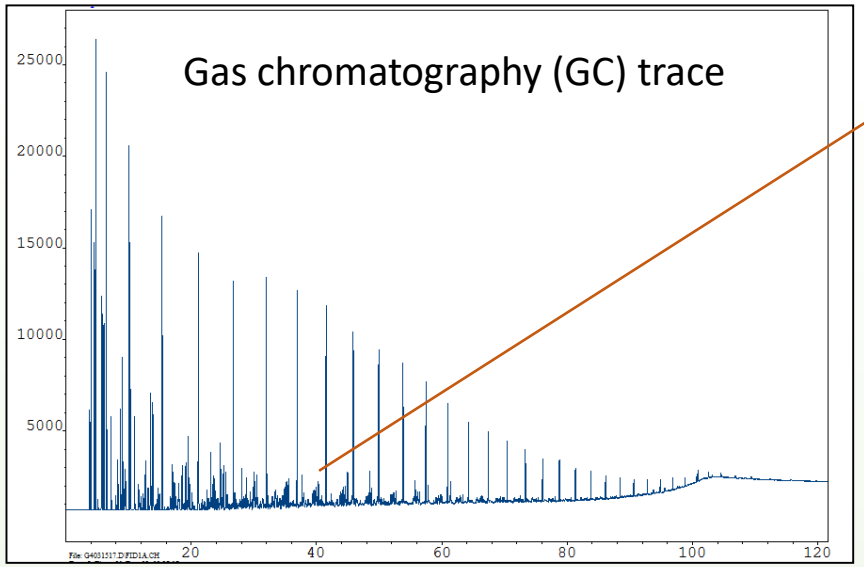




Asphaltene gradient in the Tahiti Field, GOM

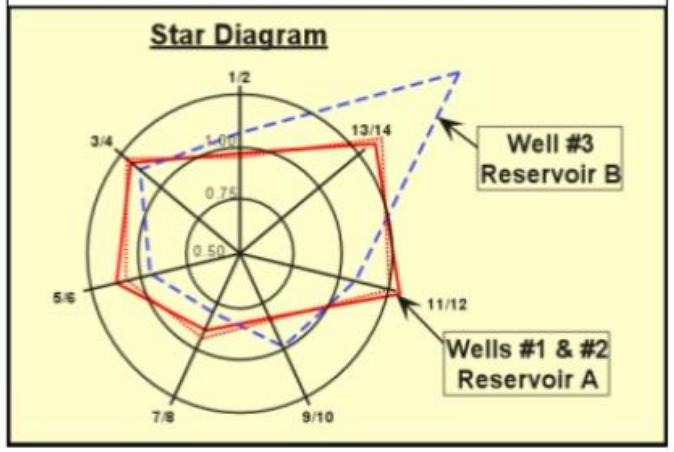
Freed et al. (2010), Energy & Fuels 24, 3942-3949

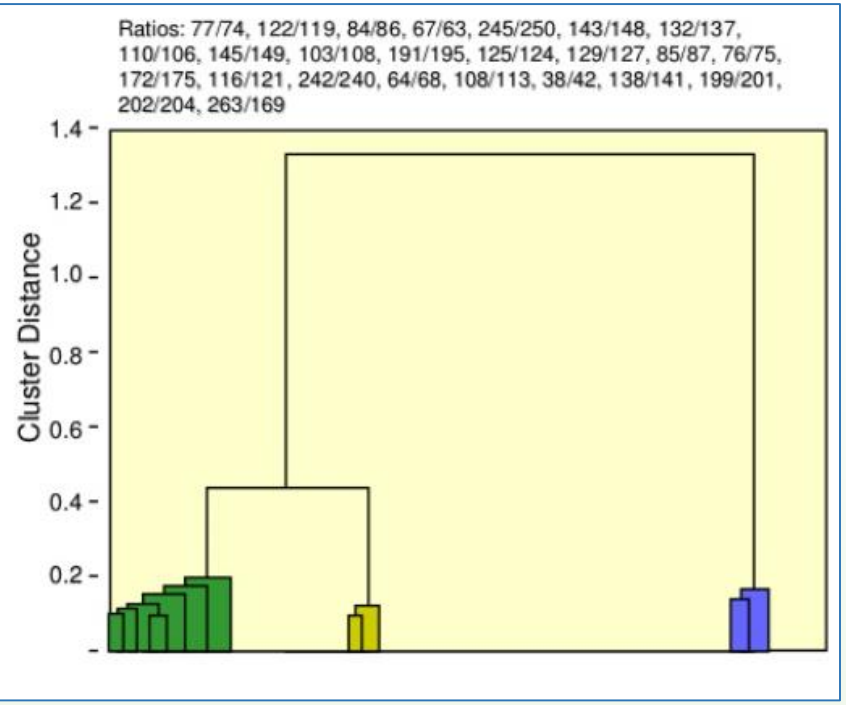
A&D – Compartmentalization from GC Fingerprinting



Hydrocarbon Peak Ratio Table

Well	1/2 Ratio	3/4 Ratio	5/6 Ratio	7/8 Ratio	9/10 Ratio	11/12 Ratio	13/14 Ratio
#1	0.90	1.17	1.12	0.85	0.82	1.26	1.26
#2	0.86	1.19	1.09	0.87	0.82	1.25	1.29
#3	1.04	1.10	0.90	0.79	0.98	1.05	1.71



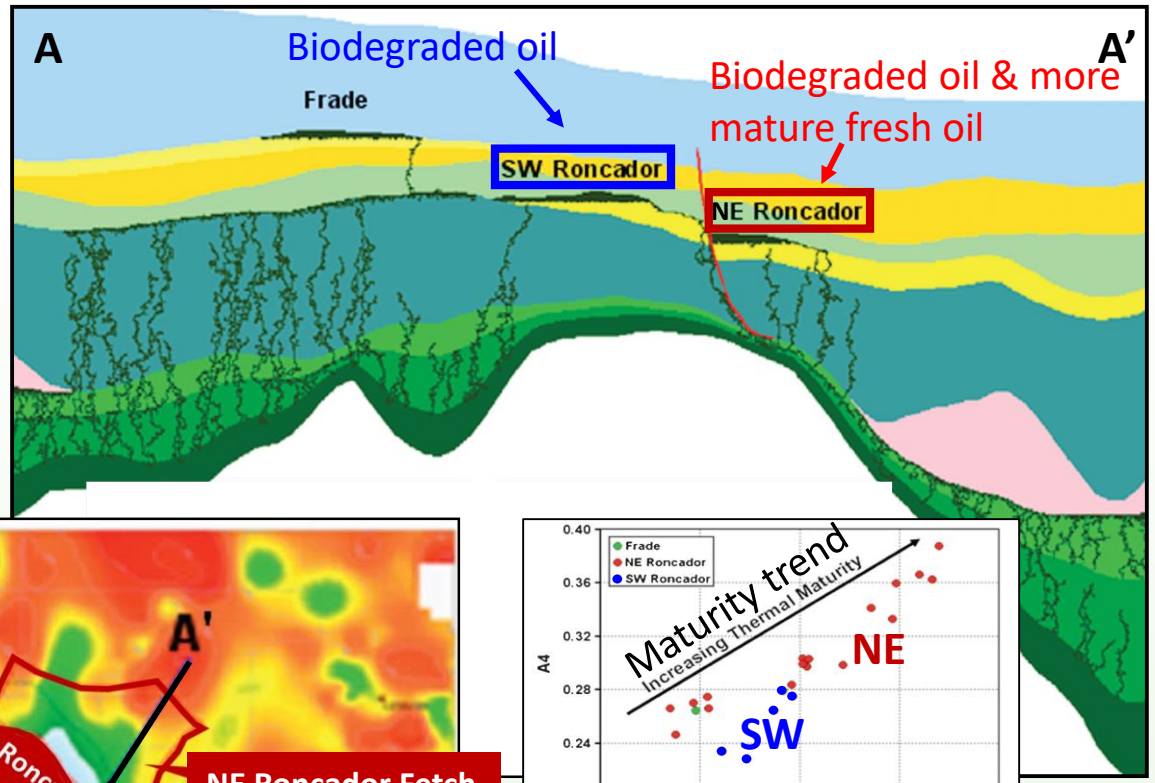


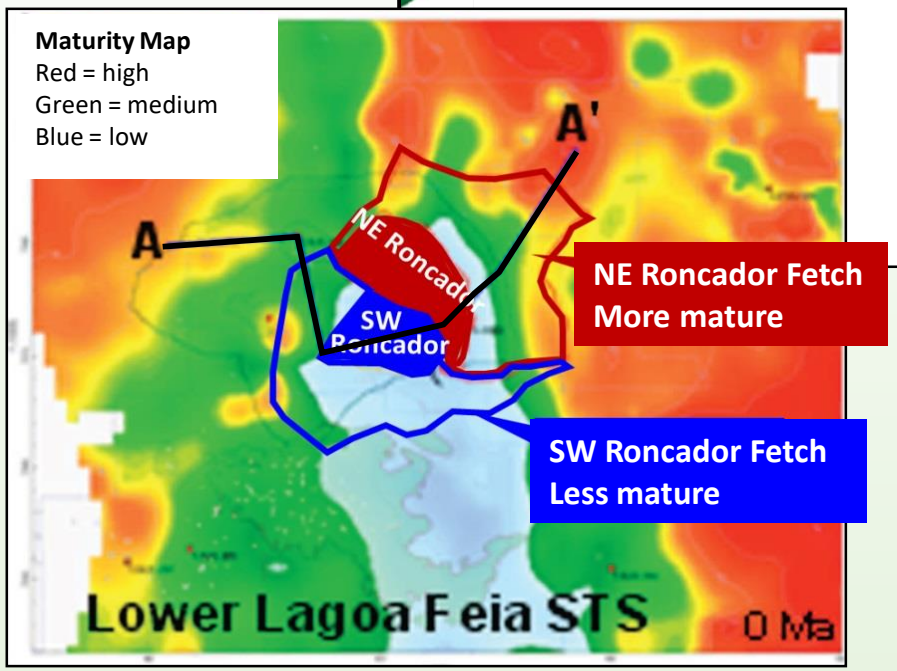
- Understand filling, equilibration and alteration history
- Integrate fluid geochemistry and PVT, pressure, rock data

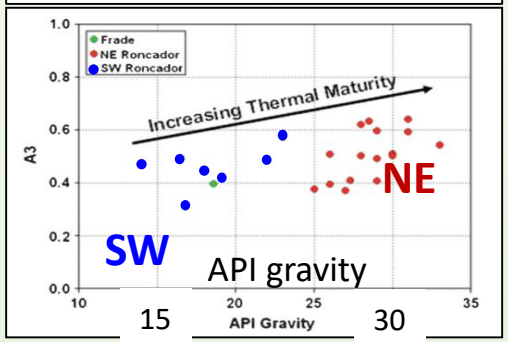
Modified using Slide 18 in:
www.slideshare.net/romance13/practical-wellbore-formation-test-interpretation-120009-2009
Talk by B. Cribbs at AAPG Geoscience Technology Workshop, Houston, 2009

A&D – Integrated Field Scale Basin Modeling and Geochemistry

Brazil Campos Basin



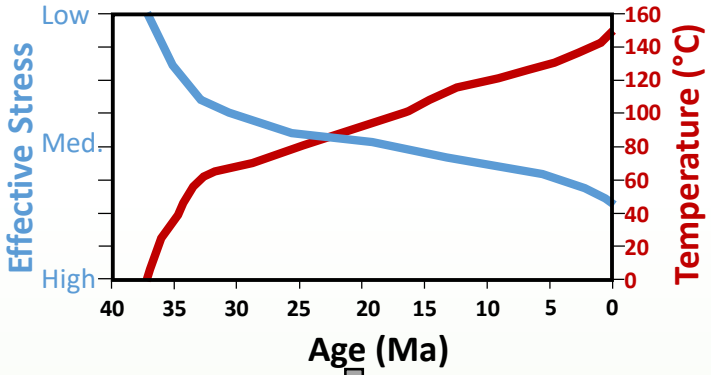




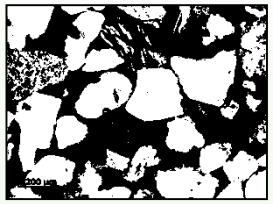
- Most fields are charged from kitchens with spatially varying maturities
- When field compartmentalization occurs concurrently with filling, different fluids are expected in different compartments
- Basin models and geochemistry can predict fluid properties in undrilled compartments, including biodegradation risk

Guthrie et al. (2012), AAPG Hedberg Series no. 4, 159-174

A&D – Basin Modeling Reservoir Quality Support

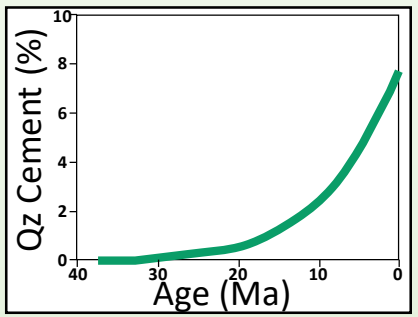


Basin Model Effective Stress & Temperature for Well / Prospect



Predicted Petrography & Paragenesis

Touchstone™ (Qz cement kinetics)

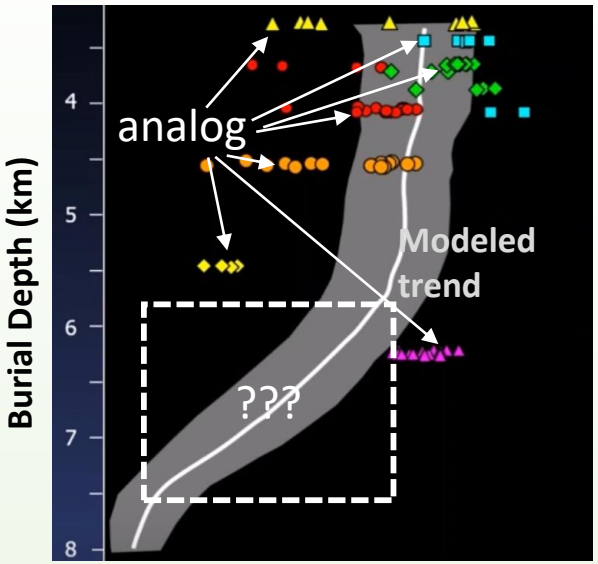


Final Qz Cement prediction in %

After Taylor et al., (2010): AAPG Bull., 94, 1093-1132

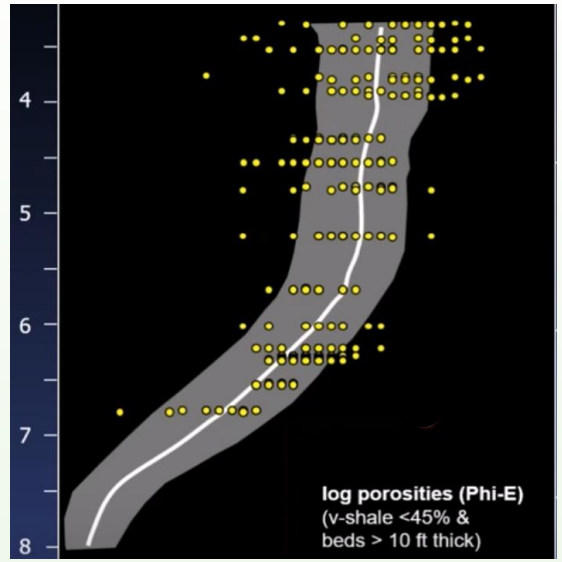
Case Study

Pre-Drill Prediction



Porosity Ambient (%)

Post-Drill Results



Porosity (%) Ambient

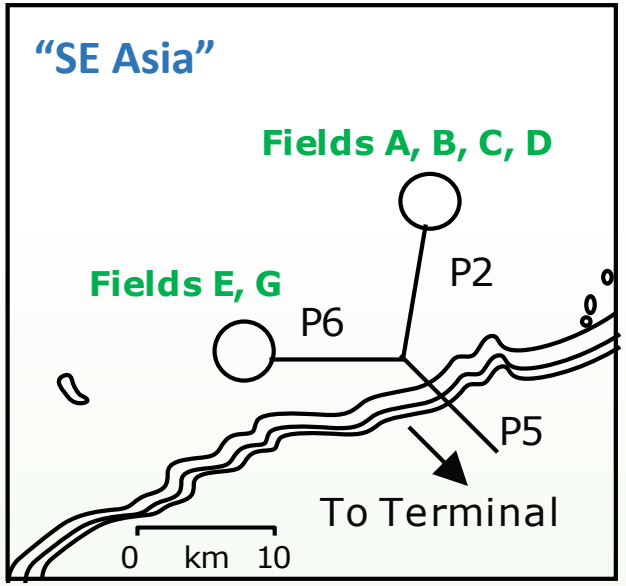
Lander, R., (2016): Model the Rock – using diagenesis simulation for rock property prediction. https://www.youtube.com/watch?v=c2yPPp84Tro (accessed 21st Feb. 2017)

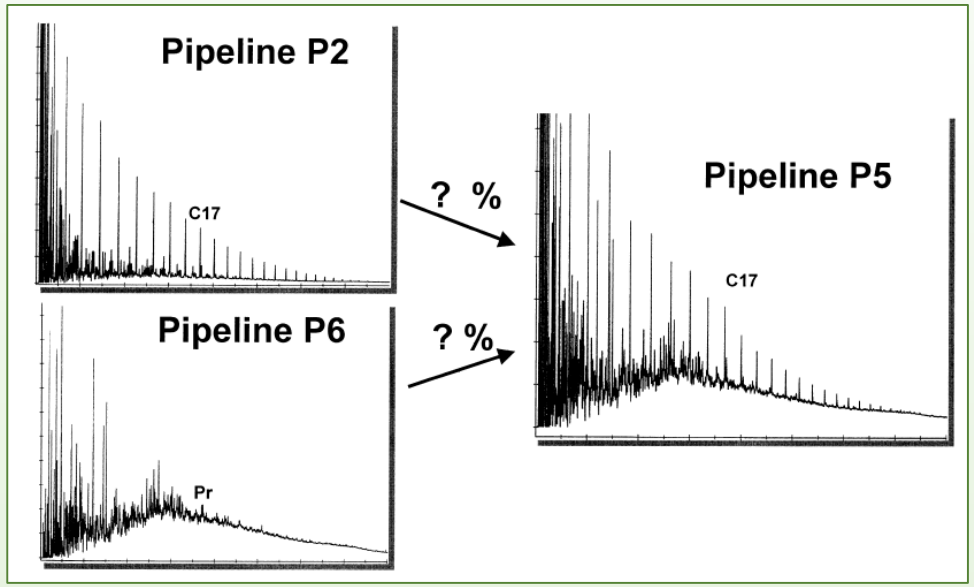
Outline

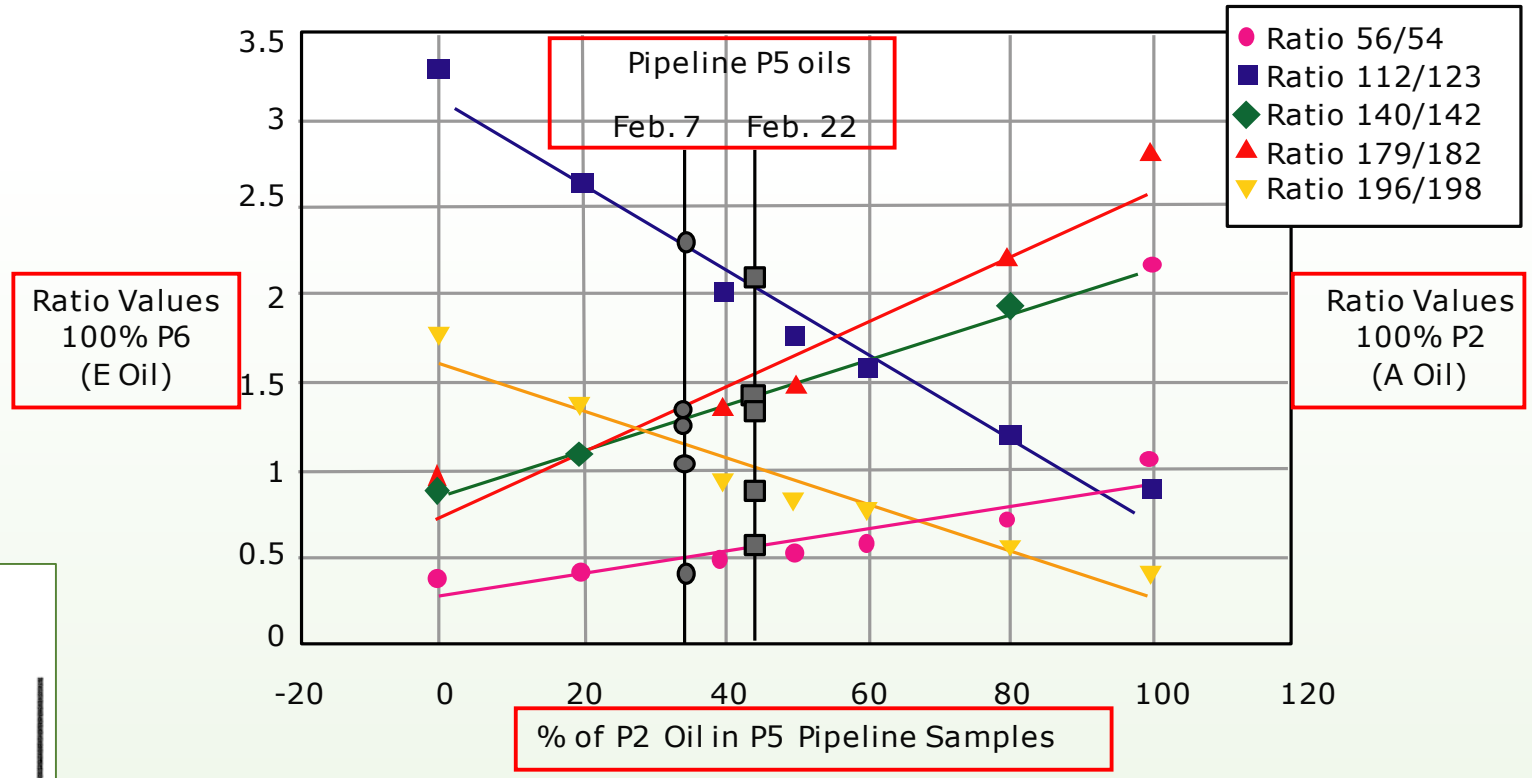
Applications of Geochemistry and Basin Modelling in:

1. Exploration (Frontier to Drilling)
2. Appraisal and Development
3. **Production**

Production – Routine Monitoring/Allocation





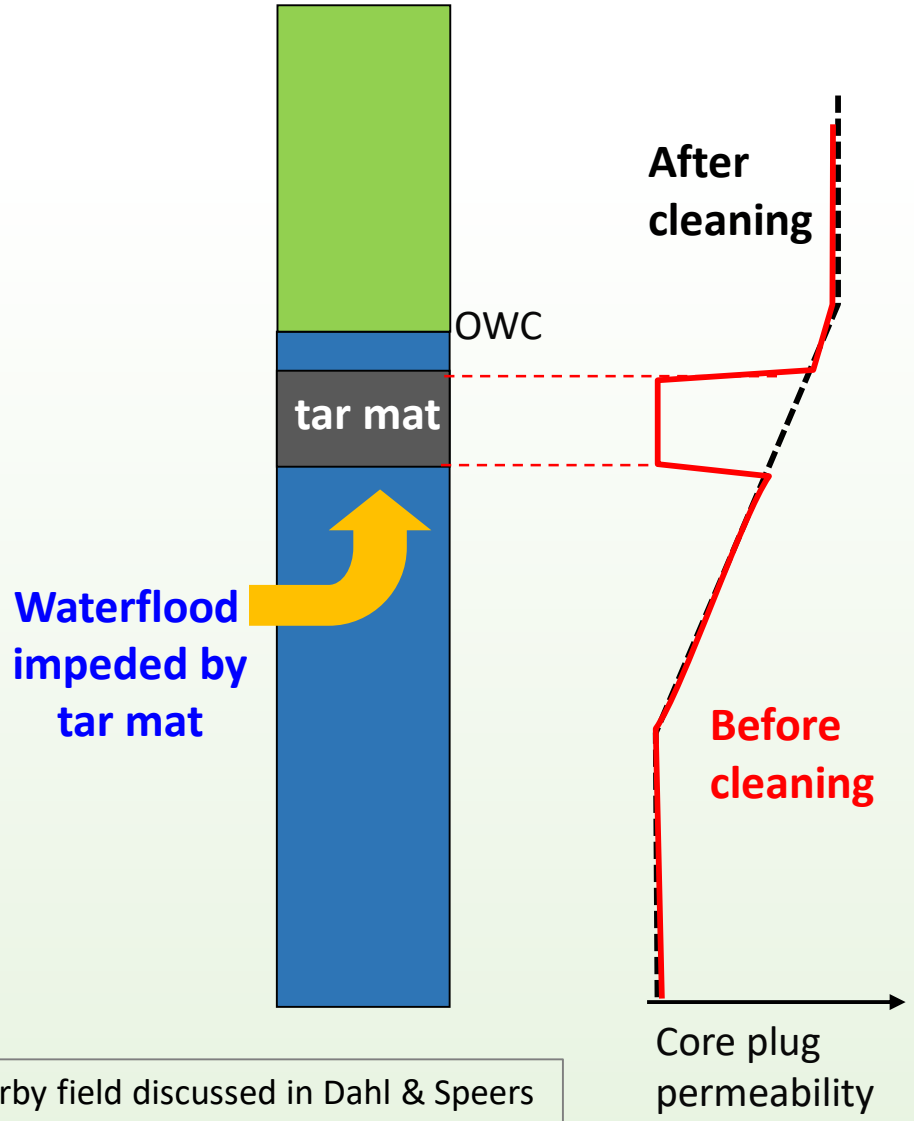


- Oil fields A, B, C, and D have produced **black oil** and taxed as normal.
- Oil fields E and G now produce **gas/condensate**; tax exempt for the first two years.
- Flow meter only installed on pipeline P5.

Hwang et al. (2000), Organic Geochemistry 31, 1463-1474

Production – Problem Solving

- Behind casing pressure due to breaks (authority threatens closure)
- Tar flowing to the surface during steamflooding (lost wells, environmental concern)
- No flow from water injector due to unknown tar mat (waste of time & money)
- Solids problems
  - Unexpected organic soap formation (scale) due to interaction of water and oil
  - Hydrates, Wax, Asphaltenes



Origin of similar tar mat in nearby field discussed in Dahl & Speers (1986), Organic Geochemistry 10, 547-558

Summary

- Petroleum geochemistry and basin modeling address a wide range of issues from exploration to production
- These tools are well established in exploration of both conventional and unconventional plays
  - Source properties and maturity on a basin and play level
  - Prediction of likely phase and potential fluid properties for prospects
  - Temperature, pressure and effective stress prediction
- In appraisal and development, these tools can help explain the reasons for, and make quantified predictions of, variations in fluid and rock properties
  - Filling history, post-filling alteration
  - Compositional grading vs. compartmentalization
  - Reservoir rock quality
- And many production issues can be addressed
  - Routine monitoring
  - Solving a wide range of problems