The role of Petroleum Geochemistry in Basin Evaluation & Field Development has changed significantly over the past 50 years. It will continue to change as industry develops energy resources to power society for the future. It is critical to remember that we deal with a PETROLEUM SYSTEM. To impact Value and Success, we need to understand all aspects of the five petroleum system parameters of: Source Rock; Reservoir Rock; Seal Rock; Migration Route and Trap. As Geologists, we also need to understand the sequential timing of all these critical parameters. We must ensure that we integrate these parameters across the Earth Science and Engineering platforms. Early exploration focused on finding reservoirs / traps. Classic structural and stratigraphic geology drove exploration. The development of seismic and well logging technologies utilized simple models. Many fields were discovered and developed near seeps and existing fields. Most offshore programs were limited to stepouts. Saudi Arabia’s major discovery was made by identifying a slight dip anomaly sighted from Bahrain. As seismic technology and sequence stratigraphic concepts were developed, more “wildcat” exploration plays were pursued with improved mapping and modeling of geologic trends, aided by newly developing tectonic concepts. Exploration risk decreased as worldwide experience grew. The 1960’s and early ‘70’s ushered in an expansion of exploration with data from the Deep Sea Drilling Project and the continued development of plate tectonic concepts (Cox, 1969). Oceanographic ideas of source material types, accumulation, preservation and burial were added to the “System’s” approach (Lisitzin, 1972; Degens & Ross, 1974; Tissot & Welte, 1978; Hunt, 1979). This period increased the use of geochemistry in the spectrum of technologies, to better define the petroleum system (Katz, ed., 1994). “Early” geochemistry was used with electric and petrophysical logs, development of models for water/rock chemistry, and isotopic measurements of oils and gases. Organic geochemistry started making an impact not only for Production, but also Exploration as various types of oils were identified. “Biomarkers” were identified and studied relative to various source materials and thermal alteration processes. 1970’s - 80’s the FUN begins: Computer technologies and modeling concepts stepped in with “Super” computers. The Oil/Gas industry was a first user along with the military and automobile industries. Seismic processing and modeling took leaps forward. However, without good geologic and geochemical data, “Nintendo” geology and “End of Oil” hysteria drove research as well as Exploration/Production efforts, leading to poorly defined Exploration plays. Fortunately, some research and development programs “allowed” geologists/geochemists to “Beta” test seismic modeling packages, adding “real” rock and fluid properties to geophysical modeling programs. Satellite remote sensed data improved oceanographic circulation.
models and our understanding of global tectonics. For example, early exploration (and related geophysics) in the Gulf of Mexico was driven by the “model” that the oil was sourced from post-Salt deposited source materials – the salt was considered a “basement”. When biomarkers indicated that the oil was from pre-Salt sources, geophysical research shifted to developing “through/under” salt seismic techniques. Salt “tectonic” models were improved as data from post-salt fields indicated migration of fluids up salt dome flanks and through fault systems. Satellite images enabled identification of coastal salt and mud diapiric structures. R&D projects reexamined “old” DSDP cores, core data and maps to identify “new” offshore/deep water plays. Today: Computer research and development experienced a dilemma seen by geochemists in the 1970-80’s – “the study of petroleum is too complicated...too many variables!” Exploration and Production groups have tried to deal with “BIG DATA” for decades. We were early adopters of Cray and other Super computers, now we need to drive new developments in computing technologies. Automated SCADA systems and power micro-grids are being tested to continuously monitor fields for fluid production, pump efficiencies, power grid usage, etc. The key is to use the data in real time for continuous optimization: increased efficiency, lower operating costs, and improved reservoir drainage. New procedures are being developed for drilling and oilfield production monitoring including fluid DNA analyses to optimize well placement and completions, and Frac patterns. Continuous, “real-time” seismic networks are “listening” to well operations and micro-seismic responses. Measurement while drilling capabilities and logging tools are improving. EOR concepts also are improving. To add value, these technologies must be incorporated into dynamic reservoir/production models. The old days of using static models with infrequent updating are over. We must move toward real time, inline, geochemical analyses and monitoring to improve reservoir production optimization. Identifying changing fluid flow patterns in the reservoir can lead to significant improvement in optimization. It also must lead to increased value through volume/quality of hydrocarbons produced. We need to increase our fundamental understanding of reservoir compartmentalization, fluid flow, and changes in rock/fluid properties. We need to build “intelligent” systems that will improve company performance and stay away from Nintendo geology! There is still a strong future for Oil & Gas Exploration and Production technology development: conventional, unconventional, or alternative energy.

References Cited


The role of Petroleum Geochemistry in Basin Evaluation & Field Development has changed significantly over the past 50 years. It will continue to change as industry develops energy resources to power society for the future. It is critical to remember that we deal with a PETROLEUM SYSTEM. To impact Value and Success, we need to understand all aspects of the five petroleum system parameters of: Source Rock; Reservoir Rock; Seal Rock; Migration Route and Trap. As Geologists, we also need to understand the sequential timing of all these critical parameters. We must ensure that we integrate these parameters across the Earth Science and Engineering platforms.
Geochemistry across the Petroleum Value Chain

**Petroleum System**

- Basin & Prospect Evaluation
- Risk Assessment
- Rock, Fluid & Gas Characterization
- Reservoir models
- Reserves Assessment
- Flow Assurance
- Upgrading
- Model Characterization
- Refinery Operations
- Crude Assay
- New Product Development
- Alternative Energy
- Product Release
- Product Quality
- Oil Field Chemicals
- Production Optimization
- IOR/EOR
- Environmental
- Corrosion/Scale
- Safe Lab & Sampling Practices
- QA/QC
- Modeling

Henshaw
Petroleum Geochemistry – Source to Oil & Gas

- Oil Composition: Pre-1960’s
  - Saturated Hydrocarbons: Straight Chain, Branched & Cyclic Paraffins
  - Aromatic Hydrocarbons
  - Resins: Nitrogen, Sulfur & Oxygen (NSO)-Containing Hydrocarbons
  - Asphaltenes

- Oil Analysis by Chromatography – pre-1960’s

- How Oil Composition and Properties Are Affected by: 1960’s-Present
  - Source Rock Type
  - Thermal Maturity Levels
  - Petroleum Alteration Occurring in Reservoirs (e.g., Biodegradation)

- Biomarkers – Fossil Compounds dissolved in petroleum: 1970’s - Present
  - Source Rock Type and Age (Oil Correlation to Source)
  - Thermal Maturity (Extent of Oil and Gas Generation)
  - Oil Biodegradation (Formation of Heavy Oils in Reservoirs)

- Diamondoids: Nanodiamonds that survive metagenesis: 1980’s to present

- DNA: Deoxyribonucleic Acid – Genetic compound (bacterial): 2014 to present

EPS – 111, RM Carlson, PC Henshaw
Petroleum Formation is a Series of (Organic-Geo-) Chemical Reactions

**Diagenesis**
- Ancient Biological Material
- Kerogen: Solid Organic Matter from which Petroleum is Generated

**Catagenesis**
- Bitumen: Un-expelled Oil (Extractable) in Source Rock

**Metagenesis**
- Carbon Residue (Low Hydrogen Content)
- CH$_4$

**Source Formation**

**Expulsion/ Migration**

**Reservoir Formation**
- Oil: Expelled from Source Rock
- CH$_4$ + Carbon Residue
- Gas
- Early: CO$_2$, CH$_4$

Source Rock & Oil Characterization for compound classes, biomarkers, etc.
- GC
- GC-MS
- Infra-red, etc.

EPS-111, RM Carlson
SEDIMENTARY DEPOSITIONAL SYSTEMS

All play a role in petroleum systems – some good, some not so good

- Source Rock
- Reservoir Rock
- Seal Rock
Plate Tectonics & Development of Source Rocks

Significant Anoxia – Oceanographic Models

Atlantic – 20 Myrs + of Anoxia

Figure 5. Paleogeographic maps of the Cretaceous breakup of Africa and South America, showing the approximate location of the Gulf of Guinea and the Walvis Ridge. Modified from Tissot and others (1980).
Geochemistry & Mineralogy can impact fluid flow and reservoir continuity.
Pay “Continuity” Changes With Increased Data

Early in Field History
40 Acre Spacing

Field Production & Geologic Data
1980’s

Later in Development
10 Acre Spacing
Oil Peak height Ratios to assist in Zonal Variations

Out-Dated (Obsolete) Geochemical Allocation of Two-Zone Commingled Production From OilTracers
Source Rock for Petroleum – Core Data

Organic-Rich

Thin Laminae

Measured Values

Total Organic Carbon
3.39

Hydrogen Index
378

In-Place Petroleum
S₁
2.24

Pyrolytically Generated Petroleum
S₂
12.80

LOMPOC Quarry Sample
Monterey Formation, CA
Petroleum System Processes

It is **ALL** or nothing
Exploration Geochemistry:

Characterizing the type, history and origin of petroleum

Inorganic and Organic Sedimentology
Identification of Compartmentalization

Early Indicators
• 3-D Seismic
• RFT / MDT Data
• Oil / Water Geochemistry
  – GC Fingerprinting / DNA (?)
  – Oil Maturity Indexing
  – Water Analyses
• PVT Data
• Well Tests
• Depositional Models
• Formation Water (Residual Salt Analysis - RSA)
  – 87SR/86SR ratios extracted from non-preserved cores
• Fault Seal Modeling
• Depositional Model / High-resolution stratigraphy

Integration of Several of these ‘tools’ usually required for confirmation

Production Geochemistry:

Correlation of hydrocarbon types to define reservoir connectivity

Hydrocarbon Occurrence

Project Goals:
- Predicting Reservoir Continuity
- Predicting HC Quality
- Modeling Frac & Remediation
- Training

Applications:
- Exploitation / Development
- Producing

Geochemistry
Processed gas chromatographic data is used with geologic information to help determine reservoir continuity.
It is all about reading the rocks & fluids

Lot’s of Tools “measure” properties downhole and in labs:

- Physical properties: resistivity, density, fluid saturations
- Rock properties: type, porosity, sonic velocities, organic matter maturity, diagenesis/cementation
- Fluid properties: type, salinity, permeability

Combination of Interpretation & Models:

- Geology: Sedimentology, Stratigraphy, Characterization
- Geophysics: Remote measurements & imaging
- Rock & Fluid Properties: PKS
### Log Data: Measured vs Calculated (using “Models”)

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Caliper/DR</th>
<th>Correlation</th>
<th>Depth</th>
<th>PhotoElec</th>
<th>(K_\text{v})</th>
<th>Res</th>
<th>Phi (Greek) Curves</th>
<th>Sonic</th>
<th>Lith/Show</th>
<th>Chromatography</th>
<th>Pore Space</th>
<th>Archie (S_w)</th>
<th>Reserves</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type / Measured vs Calculated</td>
<td>Hole size &amp; DR Rate / Measured</td>
<td>GE - Gamma Ray / Measured</td>
<td>KDI - Measured Depth / Measured</td>
<td>Photo Electric Effect / Measured Downhole &amp; Core</td>
<td>(K_\text{v}) - Permeability / Modeled Downhole, Measured - Core</td>
<td>Res - Resistivity / Measured</td>
<td>Core Porosity / Modeled</td>
<td>Sonic - Rock Sound Velocity / Measurement</td>
<td>Rock Types and Oil Presence / Observed (Mudlog data)</td>
<td>GC- GC Chromatography / Measured online samples from mudline/pit</td>
<td>Pore Space Various / Calculated</td>
<td>Archie Equations / Calculated</td>
<td>Oil / Gas Reserves / Calculated</td>
<td>Special Equations / Calculations</td>
</tr>
<tr>
<td>GP - Spontaneous Potential / Measured</td>
<td>TVD - Total Vertical Depth / Calculated</td>
<td>MEWL - “Merr” wellbore</td>
<td>Spalt - Density Porosity / Calculated</td>
<td>Rhod (Greek) - Bulk Density / Calculated</td>
<td>Rock Types observed Mudlog/Holebore Geologist</td>
<td>Photoelectric data / Calculation</td>
<td>Core (S_w) - Water Saturation / Measured</td>
<td>Water Saturation (better log) / Calculated</td>
<td>Hydrocarbon Pore Volume / Calculated</td>
<td>Clay Water - sometimes called “bound water” / Calculated</td>
<td>Oil Cut - Solvent put on cuttings / Observed Natural &amp; UV light</td>
<td>depends on your model</td>
<td>Depends on your model</td>
<td></td>
</tr>
<tr>
<td>LDI - Intermed distance from Well bore</td>
<td>Spalt - Neutron Porosity / Calculated</td>
<td>DT - Delta Time / Measured 2 way time (density is calculated from model)</td>
<td>BVW - Bulk Volume Water / Calculated</td>
<td>Core (S_w) - Oil Saturation / Measured</td>
<td>BBL - Barrels of Oil Reserves / Calculated</td>
<td>HCPV - Hydrocarbon Pore Volume / Calculated</td>
<td>Core (S_o) - Oil Saturation / Measured</td>
<td></td>
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</tr>
<tr>
<td>GRT - Gamma Total / summation</td>
<td>Xplot / Neutronography / Calculated</td>
<td>Nphi - Neutron Porosity / Calculated</td>
<td>Clay Water - sometimes called “bound water” / Calculated</td>
<td>Archie’s Eq (S_w) (Archie’s Eq) / Calculated</td>
<td>Archie’s Eq (S_o) (Archie’s Eq) / Calculated</td>
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### How Collected
- Drilling equipment & caliper logging tool
- Gamma Ray logging tool
- Resolvability logging tool
- Core Sample in lab / Model of log data for non-cored intervals

### Reliability
- Very good
- Fair
- Good
- Core - good “log” - Fair
- Very good
- Core - good “log” - Fair
- Very good to good
- Good
- Good
- Bad

### Color KEY
- Measured, Independent Variable
- Calculated from other logs

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### Color KEY
- Measured, Independent Variable
- Calculated from other logs
Basin Modeling Workflow – Include Geochem

Real System → Conceptual Model → Mathematical Model → INPUT → Solution

Unsuccessful Model

Return to:
- a) INPUT
- b) Conceptual Model

Successful

Implement Development Program

Comparison w/ Real System
Oil Quality/Producibility
Weight % Sulfur vs Vanadium ppm

• Consistent with a similar source for the oils and varying degrees of biodegradation
• Variations within fields show impact of multiple processes. Carlson et al, 1998

Henshaw et al, JPT - 1998
How many Critical Moments?

Array of Data Elements

Notes:
- Multiple Potential Sources
  - Pre-Salt lacustrine
  - Neocomian-Barremian
  - Alagoas
  - Coquina - Jiquia
  - Buracca?
  - Post-Salt Marine
  - Albian (?)
  - Turonian/Cenomanian
- Multiple Reservoirs
  - Cretaceous - Santonian, Maastrichtian

- Multiple Pulses - Hydrocarbon Migration
- Preservation
  - Biodegradation
Run the Model – Semi Quantitative

How much oil is there?

Which prospect contains more oil?

Prospects

Flow paths
From possible Source Rock areas

Oil
Gas

0.11 BBO
1.25 BBO
0.53 BBO
3.4 BBO
3.6 BBO
Reservoir Characterization - Dynamic Process

• Requires continual updating and upgrading due to:
  – Data becoming available only in a piecemeal manner
  – Data applicability and reliability is often uncertain and improves with time
  – Rock & Fluid properties may vary with time
  – Better interpretation techniques become available
  – Newer insights are gained with time
  – Unanticipated problems surface during the productive life requiring a different/fresh look
Monitoring Oil Composition through Time - 4D Monitoring

- 6 wells shown in 3 dimensions with 1 geologic horizon

- Oil samples taken on 2 different days, plus 1 replicate sample - spheres

- Colors of spheres indicate oil composition factor

- **A5 & A14** well samples are from shallower horizon
  - Different from other oils and each other

- **A2, A3, A12, & A4** well samples are from same horizon
  - Differences within horizon
  - Some changes with time
Oil Composition Data in Reservoir Simulation 3-Dimensional Grid

7 Wells shown in 3 dimensions

3 projections are shown through the reservoir model
• 1 geologic horizon
• 1 W-E vertical
• 1 N-S vertical

Oil samples were extracted from core at multiple depths - spheres

Colors of spheres indicates oil composition factor

White, Red and Green areas indicate different reservoir zones - created from statistical analysis of oil data
Geology as objects incorporated into Models
Well Bore Track with Rock “Properties” - Geology
We may have diverse data sources
Channel System Boolean Models

Difficult to constrain to data – Geochem can help constrain models

Choose lengths and sinuosities from statistical distributions obtained from analogues
The Plate Tectonic paradigm – “the unifying theory of geology” – has just turned 50. One objective, to model paleoclimate and thence source rock presence, requires knowledge of ocean currents. Mid-Jurassic/Miocene shallow-water deposits and subaerially weathered rocks, now 1 – 7 kilometers deep, in Deep Sea Drilling Project sites in the Atlantic, Indian and Pacific Oceans must have been influenced by these, but reconstructions do not show them. Those large subsided continental masses need to be taken into account as well.