Exploiting Upstream/Downstream Synergies for Improved Risking of Hydrocarbon Quality and Development Economics in Deepwater Plays

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Crude Oil Quality Group Meeting

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E, D & P: New Strategies for a Changing World

- Discovering and producing new deepwater reserves will require accepting increased costs and risks
- Higher costs are acceptable if risk is lowered

**Deepwater Oil Quality Issues:**

- Recovery efficiency
- Crude value/debits (high sulfur, metals, TAN)
- Flow assurance/facilities (organic solids or scale precipitation, emulsion proneness, de-salting)
- Prepare refineries for upcoming feedstock changes

*Oil quality modeling needed for realistic economic evaluation & development risking with major capital commitments*
Presentation Outline

• Controls on Petroleum Quality

• Current Approaches to Oil Quality & Value Risking

• A Holistic Approach to Oil Quality Prediction from Upstream/Downstream Synergies

• Summary
Geologic Controls on HC Composition

Reservoir Processes
- Cracking
- TSR
- Water Washing
- Gravity Segregation

Anthropogenic Alteration
- Phase Separation
- Gas De-asphalting

BIODEGRADATION
- Nutrients
- Salinity
- Oxidation Source
- Temperature

Reservoir Props
- PT conditions
- Fluid Mixing
- Connectivity
- Geometry
- Mineralogy

Generative Processes
- SOURCE
- MATURATION
- $C_{15+}$
- $C_6-C_{14}$
- $C_1-C_5$

Migration
- CO$_2$ & N$_2$ from inorganic sources

Leakage
- History of reservoir conditions, charge

HC quality, value & producibility
Hydrocarbon Systems Maps provide HC Quality/Type Information

U.S. Gulf of Mexico:
after Hood et al., 2001

Mexican GOM:
after Guzman-Vega et al., 2001

Lacustrine-High Maturity-Triassic
Carbonate-High Sulfur-Jurassic
Marine-Elevated Sulfur-Jurassic
Marine-Elevated Maturity-Jurassic
Carbonate-High Sulfur-Lwr. Cret
Marine-Low Sulfur-U. Cretaceous
Marine-Low Sulfur (Marine OMT)-Lwr. Tertiary
Marine-Low Sulfur (Terrestrial OMT)-Lwr. Tertiary
Generative API Gravity: Source Type & Maturity Control

- Generative API° gravity increases with increasing maturity
- Generative API° ranges vary with source type
Biodegradation Lowers Oil Quality

- Lowers recovery efficiency
- Lowers oil value
- Increases oil acidity (TAN: Total Acid Number)
- Increases proneness for emulsion formation & foaming
- Significant risk for deepwater, cool reservoirs
Mixing and Intra-compartment Gradients

- Gradients reflect balance between rates of mixing / transport (diffusion, dispersion, convection) and compositional change (alteration or charge).

- Compositional variability also affected by analysis and sampling.

- Modeling must take into account input, output, alteration and mixing processes.

1. Rate of mixing >> rate of change
   - Generally homogeneous composition - possible density gradients

2. Rate of mixing << rate of change
   - Compositional gradients – biodegradation and/or fill
Drilling Mud Contamination Impacts Geochemistry & PVT

- Must determine % Enhanced Mineral Oil (EMO) contamination
  - Use wireline oil and mud-filtrate
  - Components $<nC_{12}, >nC_{22}$ are OK
  - No biomarkers from base oil
  - HOWEVER, re-used muds may pick up compounds: analyze mud-filtrate from each well

- Must correct fluid properties
  - Simple API° & GOR corrections
  - Live viscosity & saturation pressure corrections require equation-of-state modeling
API Gravity prediction – deepwater reservoirs

Empirical Models

• Generative gravity controlled by source & maturity
• Predict intensity of biodegradation and average column API gravity based on predicted prospect temperature
• Viscosity predicted from API gravity, temperature, GOR using reservoir simulation models
• API variability of column predicted from other models
• Requires local calibration
**API Gravity prediction – deepwater reservoirs**

**Empirical Models**
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**Basin Modeling Approach**
- Detailed modeling of trap timing, yield timing, yield volumes and reservoir temperature history does not significantly improve API gravity predictions
- *Qualitative* evaluation of migration efficiency and temperature/charge history can help in risking paleo- or recent charge
Oil Quality Variability

- Column penetrated by Well A & B gravity-segregated
  - WOGCs equivalent throughout (equivalently biodegraded)
  - Differences in heavy-end only (e.g., vacuum residua)
- Column not continuous across fault to Well C
- Shallow reservoir penetrated by Well C has anomalously good quality due to recent recharge
  - Recharge front entering reservoirs east of major fault zone
Oil Quality Scenarios for Salt-bounded Reservoirs

**Quality better than expected**
1. Salt provides high-salinity water, warmer temperatures - reduced intensity of biodegradation
2. Migration along salt focuses recent charge, improves oil quality in reservoir

**Quality worse than expected**
3. Difficult to define/image full reservoir extent - reservoir tail very shallow & cool?
4. Reservoir isolated from main charge by tectonic movement - difficult to image near salt flank
Crude Valuation: What Differentiates Crude Values?

**Downstream Approach***

(*based on full refinery assay, if available)

- Crude distillation yields
- Crude qualities
- Market for the crude?
- Freight issues
- Crude price discounts
- Product price spreads

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**Upstream Analog Approach***

(*calibrated for specific HC Systems)
Petroleum Quality Prediction: The Way Forward

**Current Practice:**
- Various uncoupled empirical approaches
- No integrated model for all reservoir alteration
- Focus on bulk properties, specific processes
- Require local calibration

**Petroleum Quality Simulator:**
- First-principles based, integrated approach
- Chemical physics and reaction kinetics on 8000+ components
- Models multiple alteration processes
- Geohistory is still key uncertainty

**Impact:**
- **Inverse modeling:** understand how composition and physical properties of fluids tie to alteration and reservoir history
- **Forward modeling:** consistent, global estimations of oil composition and quality ranges, including asphaltene dropout, phase behavior and oil value/pricing
Petroleum Quality Simulator (PQS)

API/temperature models:
- Low temperature (biodegradation)
- High temperature (In-reservoir cracking)

Oil analyses

Compositional yields

Charge history, reservoir history

Molecular models

PQS transforms
- Phase effects
- Biodegradation
- In-reservoir cracking
- Asphaltene precip.
- Water washing
- TSR

PQSim simulator

Charge history, reservoir history

PQSim simulator

Physical properties

Refinery reactions

Upstream

Downstream

Undersaturated

Saturated

Phase behavior & Equations of State

Molecular Weight

Solubility Parameter

Temperature

Pressure

API = 34.1

Backup

UPSTREAM

Asphaltene Precipitation

No Precipitation

Precipitation

Saturates

Boiling pt °F

Wt %

API = 34.1
Oil Composition in PQS

Oil is described by the distribution homologous saturated, aromatic, and NSO compounds with known structures (~<C_{40})

High Definition Hydrocarbon Analysis (HDHA)

+ a series of pseudo components that represent >C_{40} species

“Asphaltene-like molecules”

Primary Gases + Dead Oil (<1100°F) + Resid (>1100°F) = Live Primary Oil

- Molecular description of whole crude oil by ~8000 components
- Library includes 32 oils & gases representative of various source environments (kerogen types) at different levels of thermal maturity
- Intermediate or “tuned” compositions can be obtained by mixing
- Compositional input from basin models or measured properties
Building a Biodegradation Transform

Empirical models of compositional change based on HDHA datasets of related oils that are biodegraded to varying degrees

- Most major compound classes degraded in a linear fashion.
- Some compounds classes are enriched via preservation
- Some compounds classes are generated via hydrocarbon transformations
Ultra-high mass resolution of CHN polars via ESI-ICR-FTMS.

Incorporate latest findings that indicate polar compounds are biodegraded

- Removal of alkyl sidechains
- Depletion of carbazoles and benzocarbazoles
- Enrichment of more condensed structures

Coupling compositional transformations with biodegradation kinetic model allows for the modeling physical and chemical properties as a function of time in reservoir.
Anthropogenic Controls on Petroleum Quality

1. Drilling Additives
   - oil-based vs. water-based muds
   - formation activity control

2. Production Chemicals
   - flow assurance
   - facilities operations

3. Well Stimulation Processes
   - fracturing
   - acidization

4. Storage/Handling
   - FPSOs, tankage
   - blending, compatibility

5. Transportation
   - pipelining
   - tanker specs

6. Trading/Markets
   - consistent quality?
   - clean vs. dirty differentials

7. De-watering/De-salting
   - solids/contaminant removal
   - waste water disposal

8. Refining
   - distillation foulants
   - catalytic cracking, coking

9. Tightening
   Product Quality
Summary

• Accurate estimation of petroleum quality is critical in deepwater

• It is difficult to accurately estimate petroleum quality using uncoupled, locally calibrated empirical models

• PQS draws heavily on detailed Downstream molecular descriptions and reaction models and provides a platform for integration of all relevant processes

• Oil quality issues occur from the reservoir to the refinery

• Additional complexities involving reservoir compositional gradients and charge efficiency to specific traps will be considered in future refinements