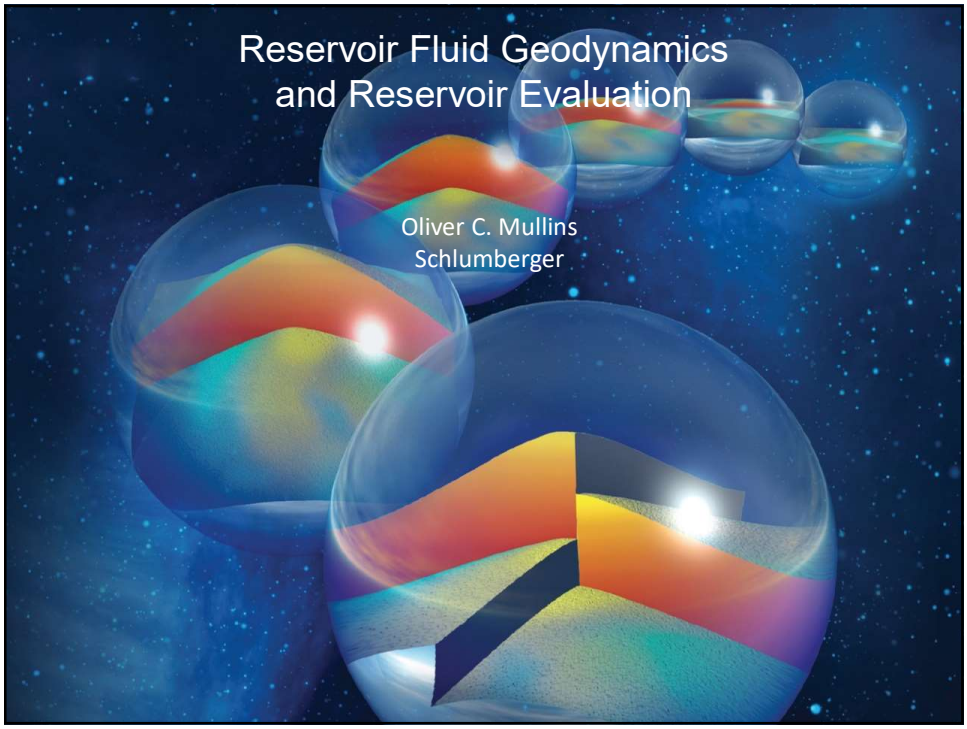


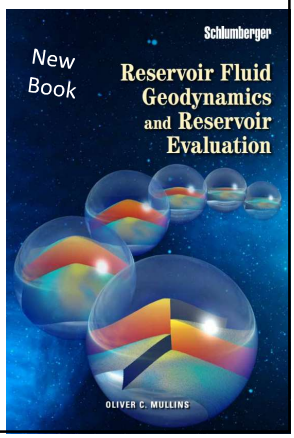
1

Outline

1) A New Method to Evaluate Reservoirs:
Reservoir Fluid Geodynamics (RFG); a New Technical Discipline;
- Definition and Enablers

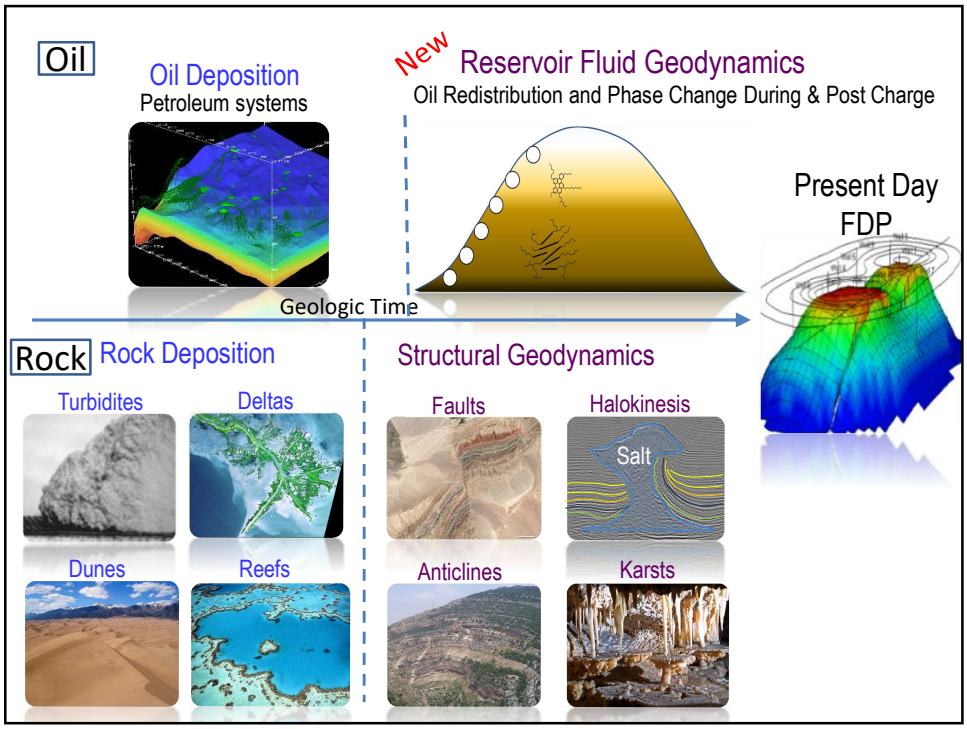
2) RFG Reservoir Case Studies
- Equilibrium Gradients/ Connectivity
- Diffusive Gradients (over geologic time)
- Viscous Oil and Tar Mats

3) Conclusions



https://www.slb.com/resource-library/book/reservoir-fluid-geodynamics-and-reservoir-evaluation

2



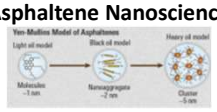
3

Reservoir Fluid Geo*dynamics* Enablers:

FHZ EoS Thermodynamics identify crude oils or are not equilibrated.

Comprehensive Science

Asphaltene Nanoscience



Asphaltene Thermodynamics

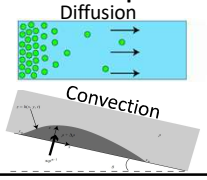
FHZ EoS

$$\frac{OD(h_2)}{OD(h_1)} = \frac{\phi_v(h_2)}{\phi_v(h_1)} = \exp\left[\frac{v_u g(\rho-\rho_f)(h_2-h_1)}{RT} + \frac{v_u}{RT}\left[(\delta_u-\delta_{f_1}^{\circ})^2-(\delta_u-\delta_{f_2}^{\circ})^2\right] + \left[\left(\frac{v_f}{v}\right)_{h_2}-\left(\frac{v_f}{v}\right)_{h_1}\right]\right].$$

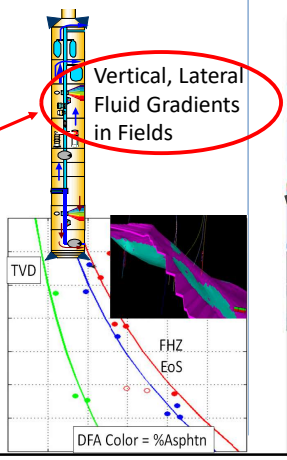
No time !

Mass Transport

Diffusion



DFA Data of Reservoir

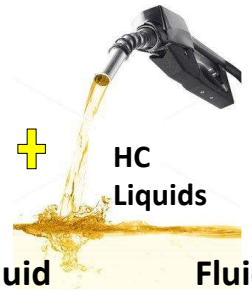


70 RFG Oil Reservoir Evaluation Case Studies

4

Crude Oil Thermodynamics: Asphaltenes Now Included and *Required* for RFG.

+



+

Gas-Liquid

Cubic EoS Gas-Liquid

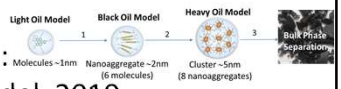
Van Der Waals EoS 1873

Peng-Robinson EoS 1976

Fluid-(dissolved) Solid

Flory-Huggins-Zuo EoS 2010

Asphaltene Size:



Yen-Mullins Model, 2010.

Can *Now* Solve

Newton's 2nd Law, **F = mg**

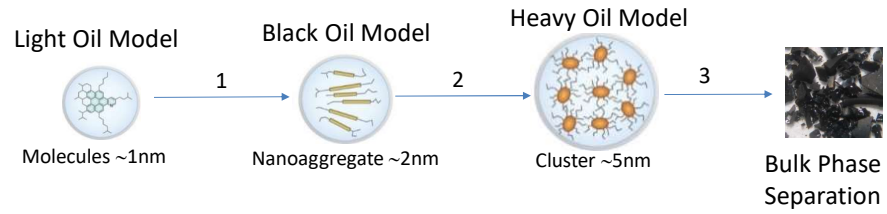
for Gravity on Asphaltenes.

5

5

Asphaltenes have ***THREE*** Aggregation Thresholds, not One.

Yen-Mullins Model of Asphaltenes



Small Gradients (unless big GOR)

Moderate Gradients

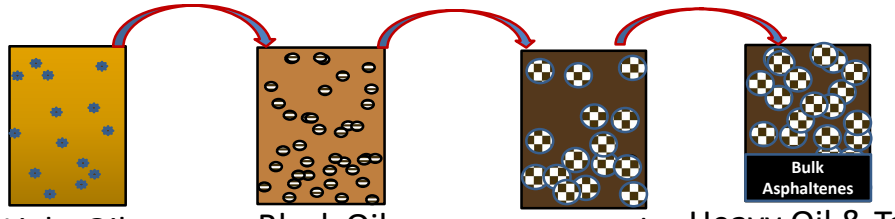
Big Gradients

Big Gradients & **Tar**

Add Asphaltene

Add Asphaltene

Add Asphaltene



Light Oil

Black Oil

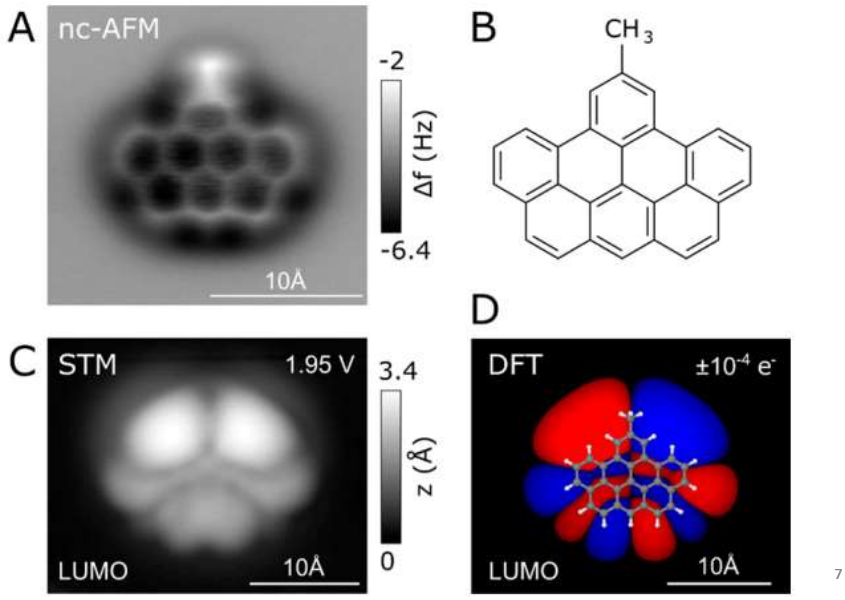
Heavy Oil

Heavy Oil & Tar

6

6

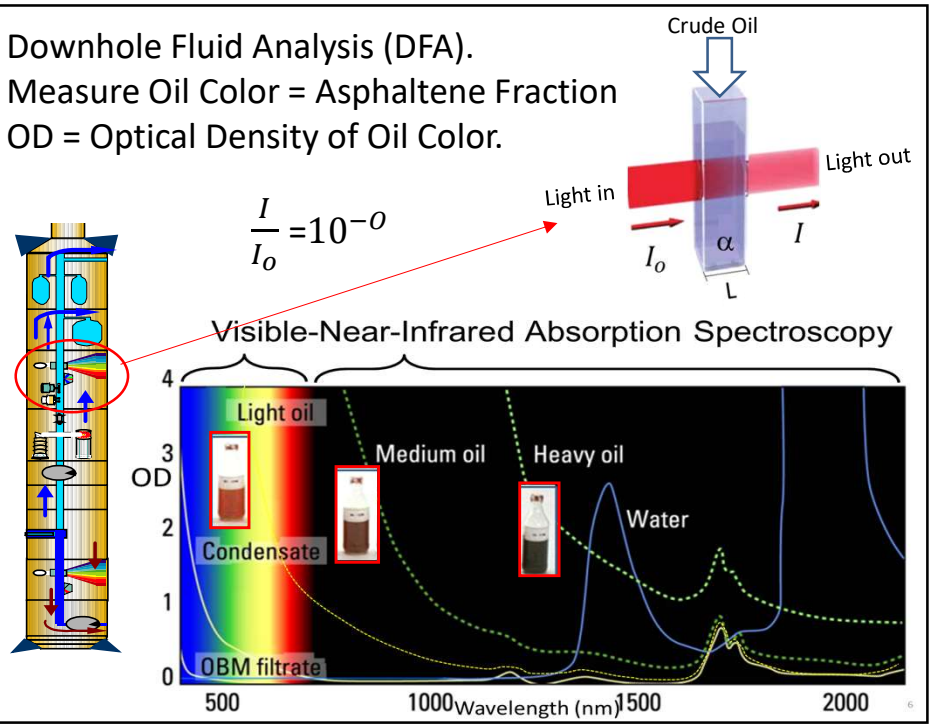
AFM, STM Image of Asphaltene Molecule.
Bruno Schuler, Leo Gross…, ***IBM Zurich***, Mullins, *SLB*…



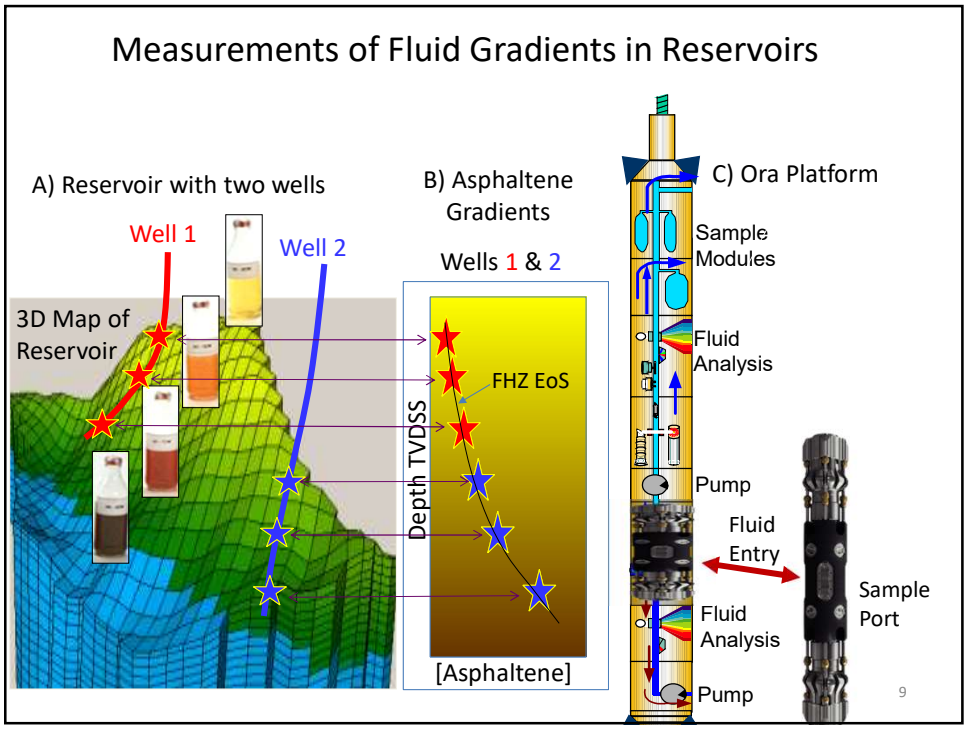
7

7

Downhole Fluid Analysis (DFA).
Measure Oil Color = Asphaltene Fraction
OD = Optical Density of Oil Color.



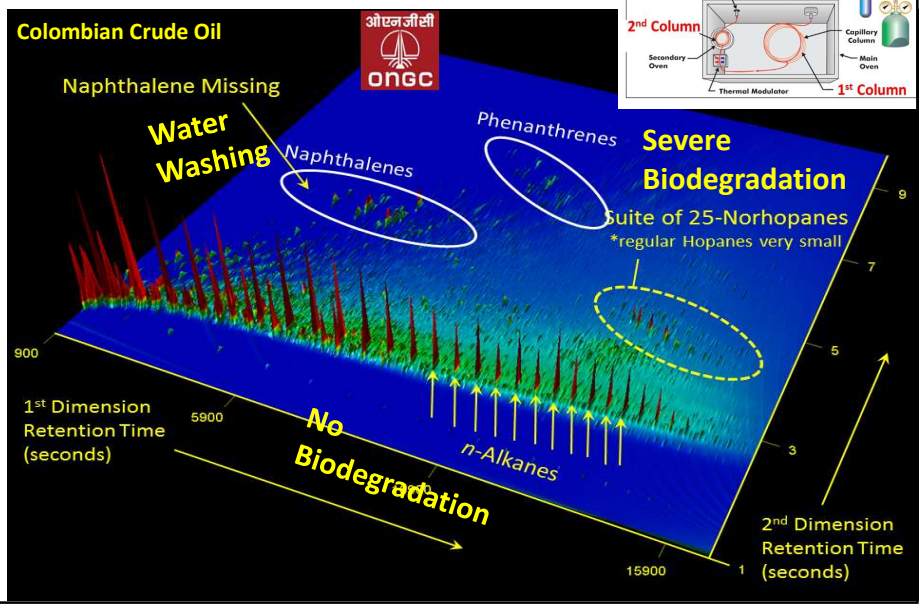
8



9

Integration with Geochemistry, Analytical Chemistry. Lab

GCxGC. Two-Dimensional Gas Chromatography



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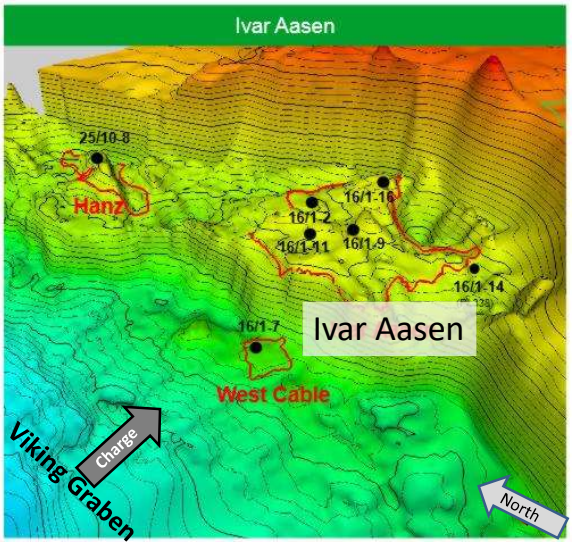
Ch. 2. Case Study 1.

AkerBP

Ivar Aasen Charged from Viking Graben from West

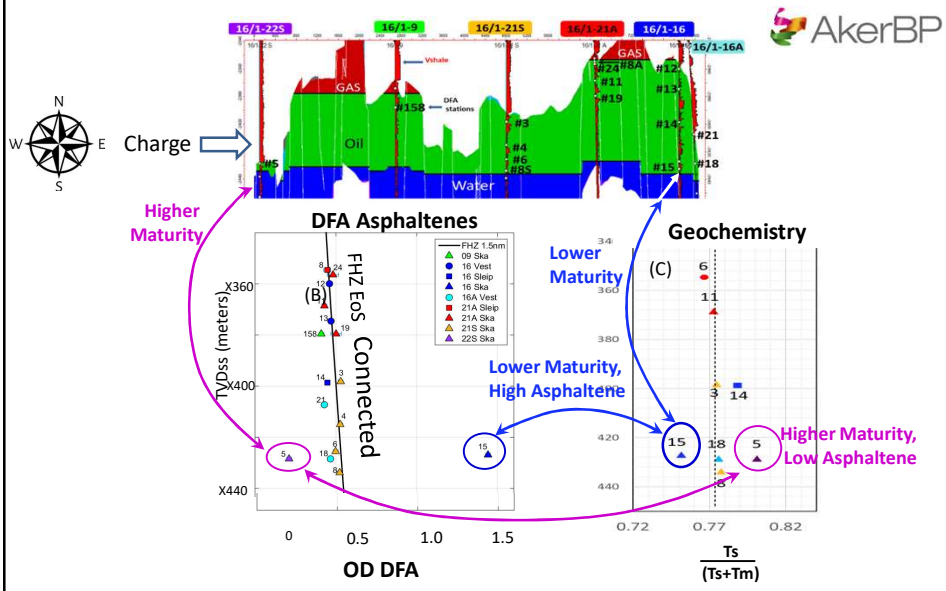


11

11

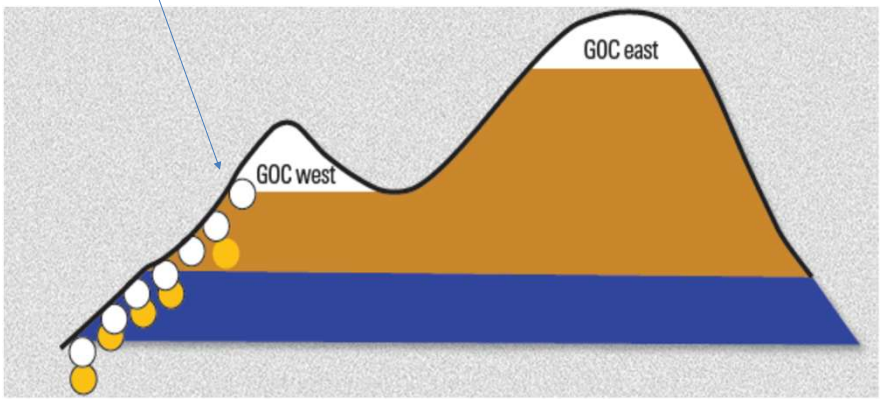
Light Oil: Equilibrated Asphaltenes (FHZ EoS) → Connected.
Proven in Production. Isolated Outliers, Thermal Maturity

AkerBP



12

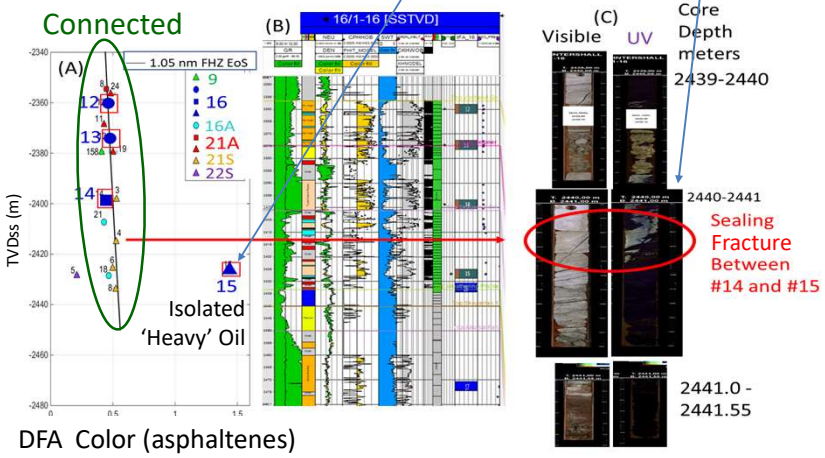
Deeper GOC in West Due to Charge;
This higher Psat in West.
Thus higher Solution Gas in West
Thus Lower Density in West.



13

13

Lower Maturity, Heavier Oil #15 Isolated by Fracture



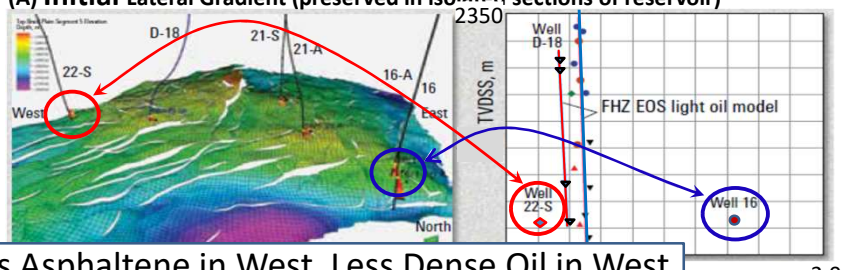
DFA Color (asphaltenes)

14

14

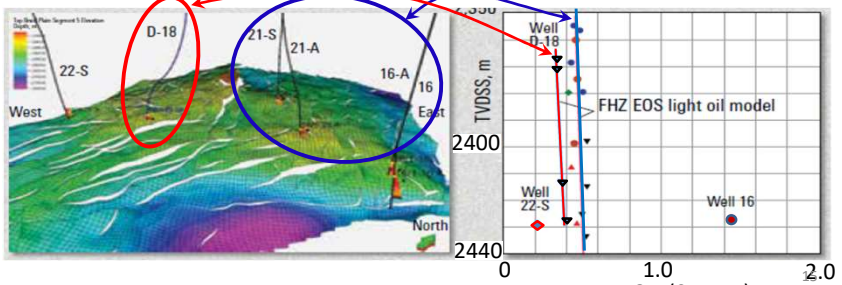
Unique Data: Preserved Pleistocene and Current Lateral Fluid Gradient

(A) **Initial** Lateral Gradient (preserved in isolated sections of reservoir)



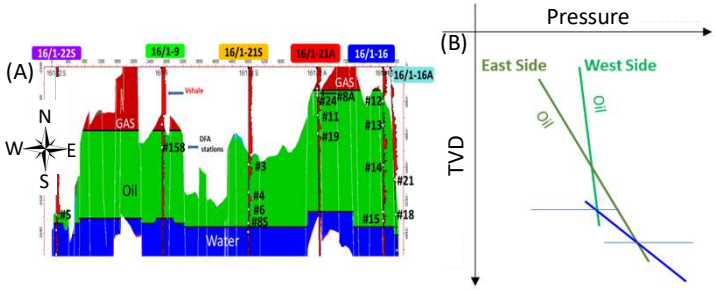
Less Asphaltene in West, Less Dense Oil in West

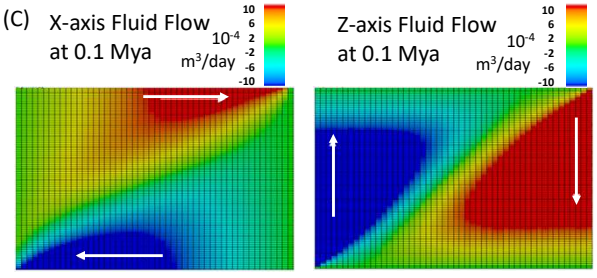
(B) **Current** Lateral Gradient (in connected reservoir)



15

Low density fluid in west, higher density fluid in east:
Cross pressure gradients and convection follow.





16

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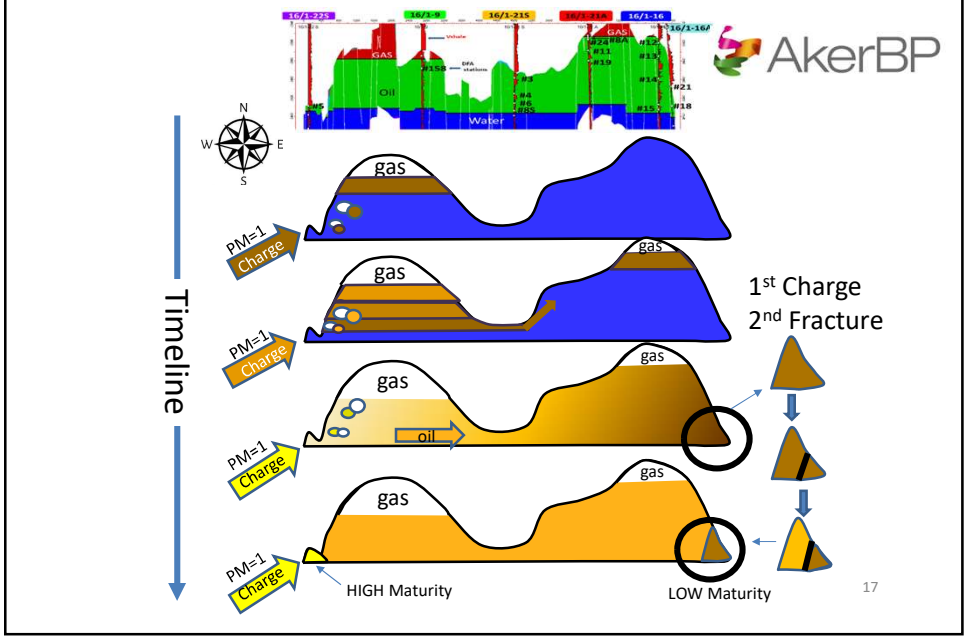
Geo-Scenario For GeoModeling:

Reservoir Fluid & Structural Geodynamics



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Ch. 2. Case Study 3

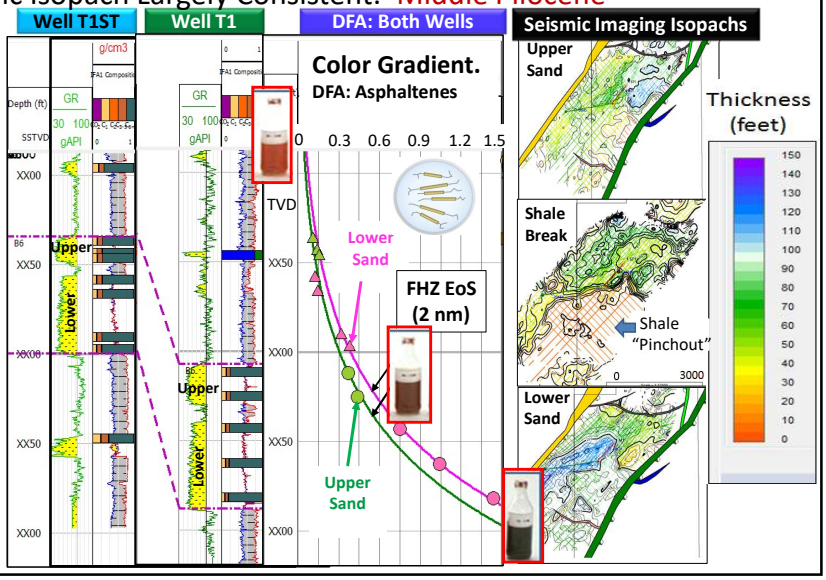
Black Oil:

Asphaltene Equilibrated Laterally, FHZ EoS. Connected Laterally.

Not Equilibrated Vertically. Baffle at least.

Seismic Isopach Largely Consistent. Middle Pliocene

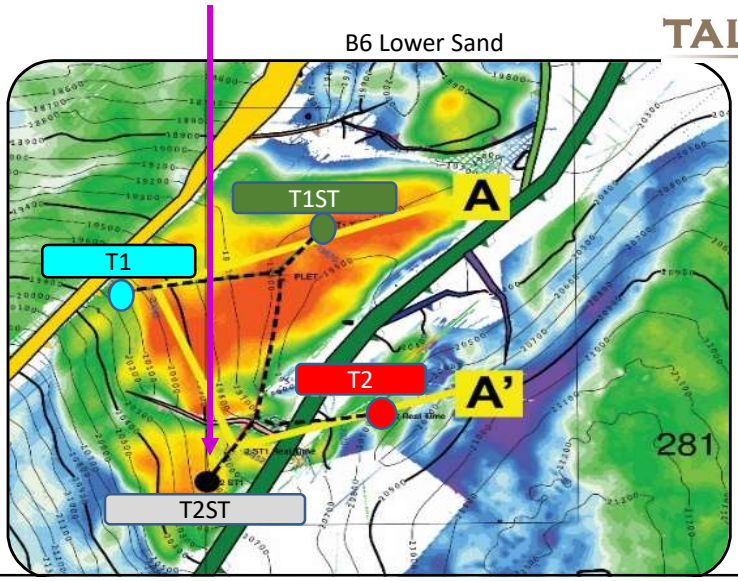
TALOS ENERGY



18

T2ST After Production. Upper and Lower Sand Connected?

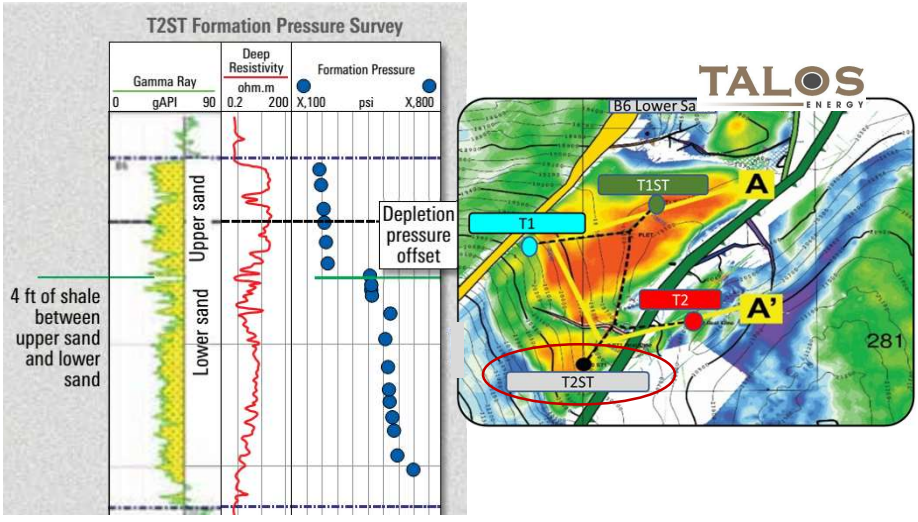
T2ST South of Scissors Fault.



19

Different depletion pressure **confirms** Shale baffles in "pinchout".

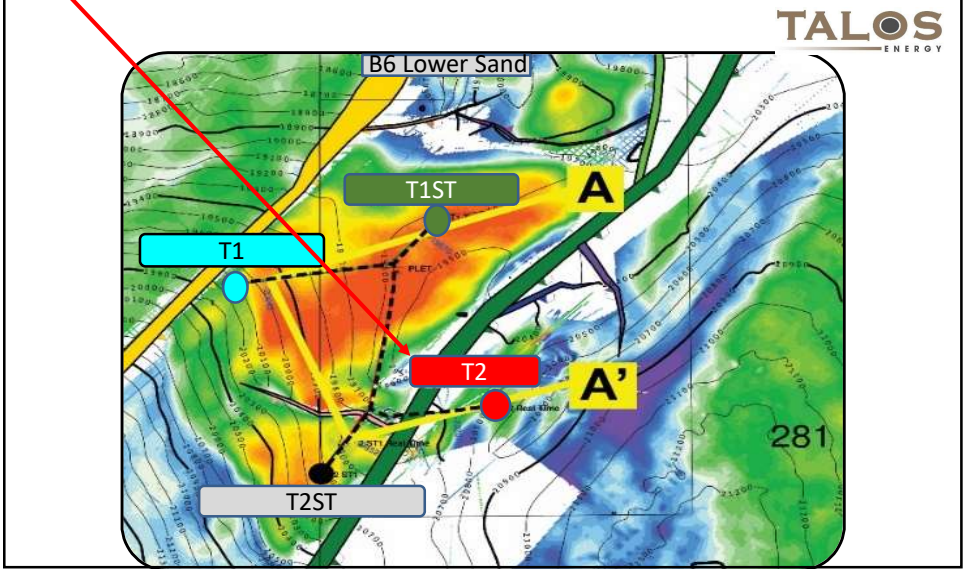
South of scissors fault, pressure survey confirms Shale Baffle/ Barrier **after production started North of the Scissors fault.**



20

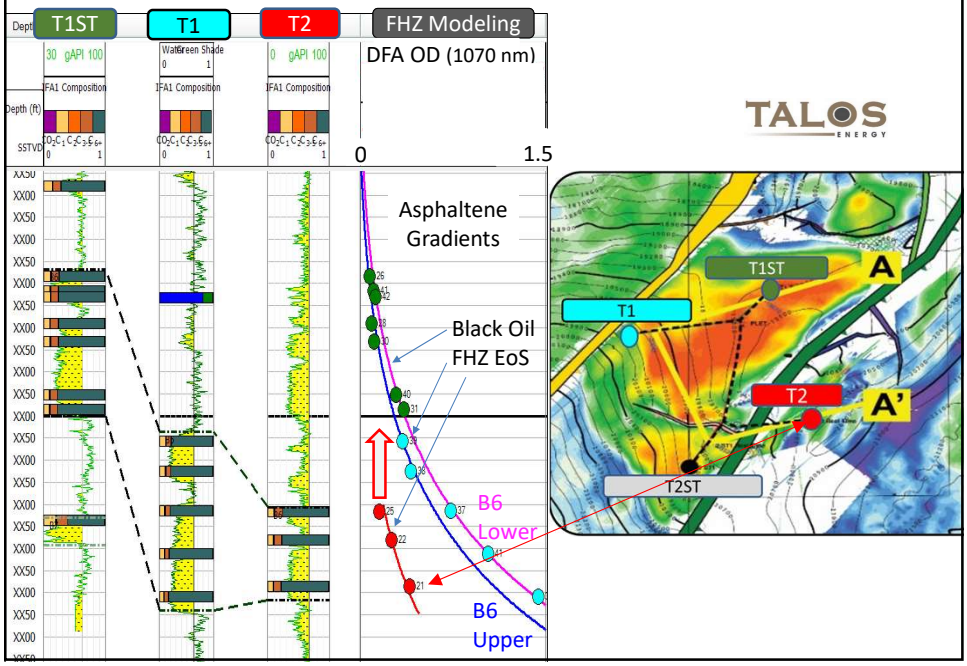
Comprehensive Geodynamics: Structural & Reservoir Fluids

T2 well on far side of Fault. Vertical Offset ~380 Feet Seismic Imaging.



21

Reconstruct Reservoir Prior to Fault Throw



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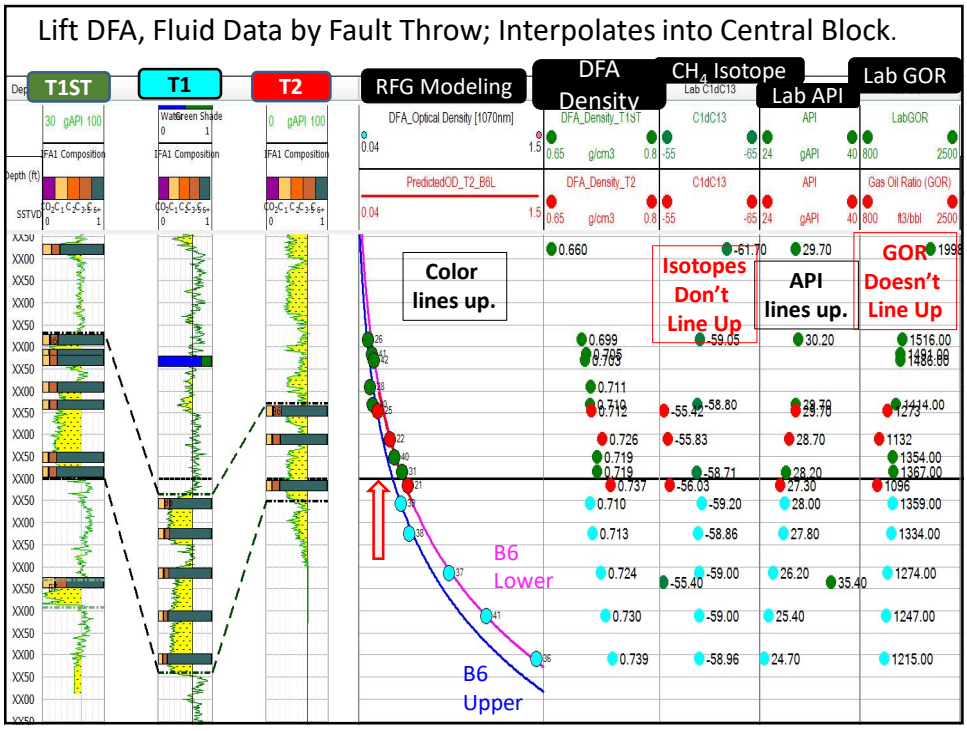
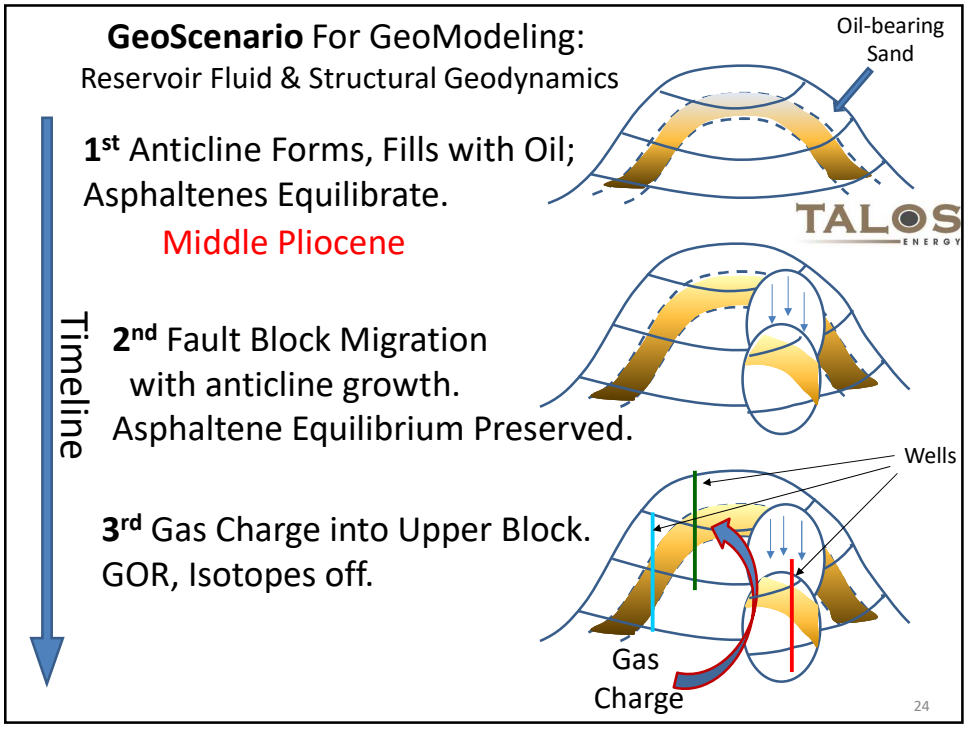

Lift DFA, Fluid Data by Fault Throw; Interpolates into Central Block.
T1ST
T1
T2
RFG Modeling
DFA Density
CH_4 Isotope
Lab API
Lab GOR
Color lines up.
Isotopes Don't Line Up
API lines up.
GOR Doesn't Line Up
B6 Lower
B6 Upper

23


GeoScenario For GeoModeling:
Reservoir Fluid & Structural Geodynamics
Timeline
1st Anticline Forms, Fills with Oil; Asphaltenes Equilibrate.
Middle Pliocene
2nd Fault Block Migration with anticline growth.
Asphaltene Equilibrium Preserved.
3rd Gas Charge into Upper Block.
GOR, Isotopes off.
Oil-bearing Sand
Wells
Gas Charge
TALOS ENERGY
24

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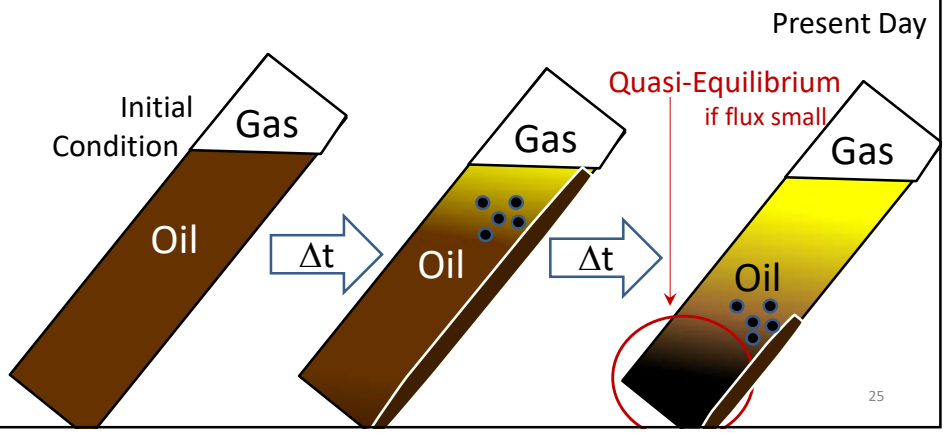
Geo-Scenario: Gas and Oil Charges into Reservoir

- High Solution Gas Expels Nanocolloidal Asphaltenes
- Asphaltenes accumulate at base of interval
- Boycott Convection to Base of Reservoir
- Local Diffusive Equilibration of Asphaltenes



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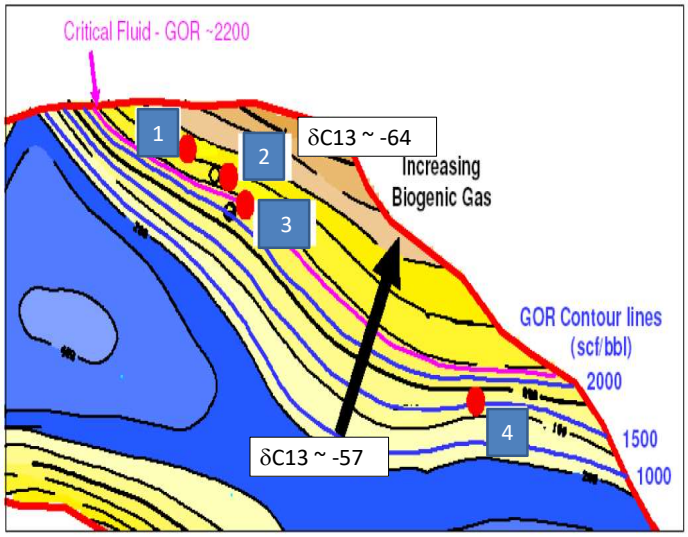
Ch. 2. Case Study 8

Large Gas Diffusion into Reservoir and Asphaltene Migration.

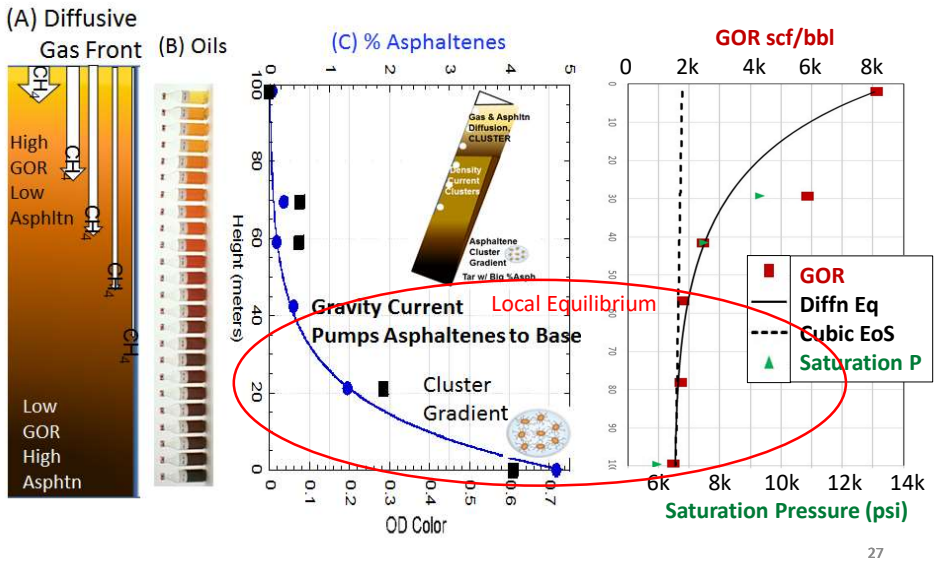
Huge Asphaltene Gradients, Huge GOR Gradients.



26

26

Diffusive Gradient of Solution Gas. Asphaltene Expulsion, Migration to Oil-Water Contact



27

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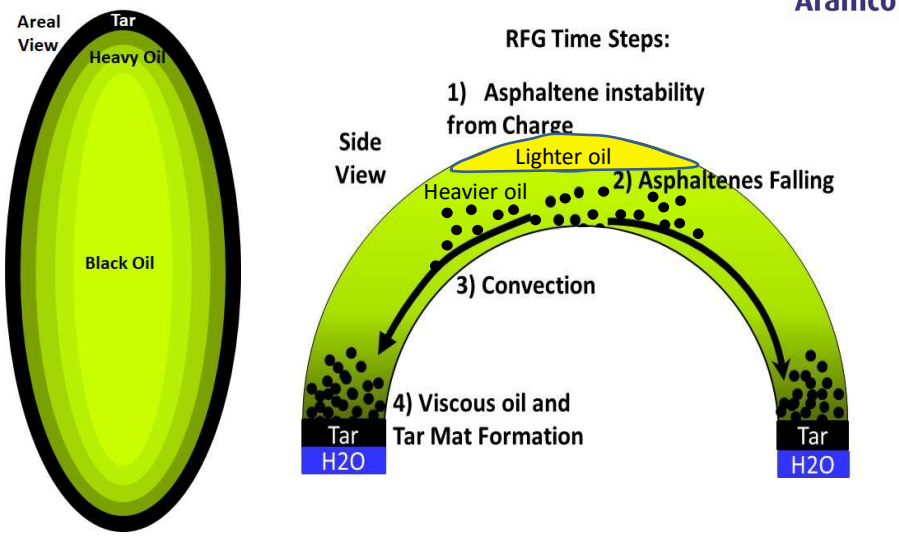
Geo-Scenario: Heavy Oil and Light Oil

Formation of Heavy Oil, Mat in Rim of 4-Way.

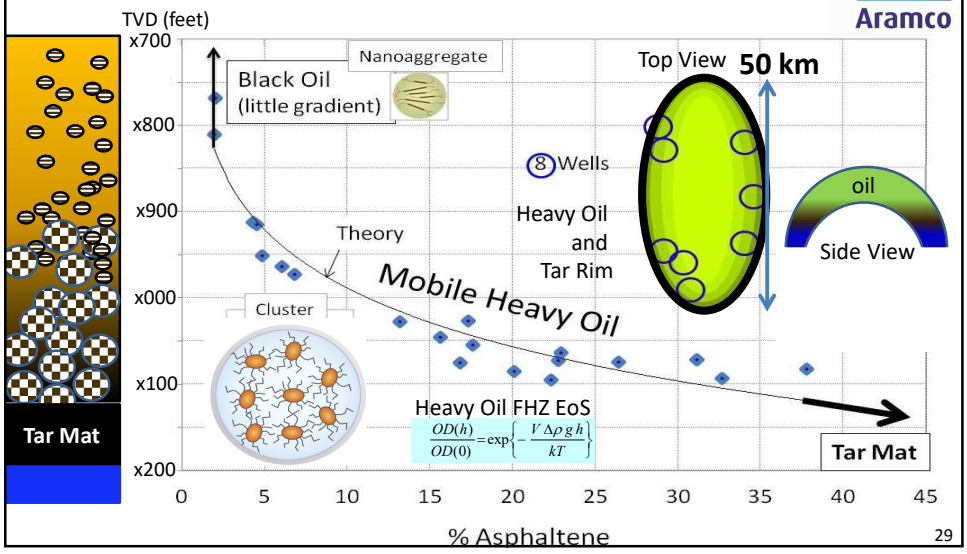
Ch. 2. Case Study 7.



28

28

Heavy Oil. Asphaltenes Equilibrated (FHZ EoS) → Connected.
Known in Production.
HUGE Viscosity Gradients Matches FHZ exactly over 100 km.



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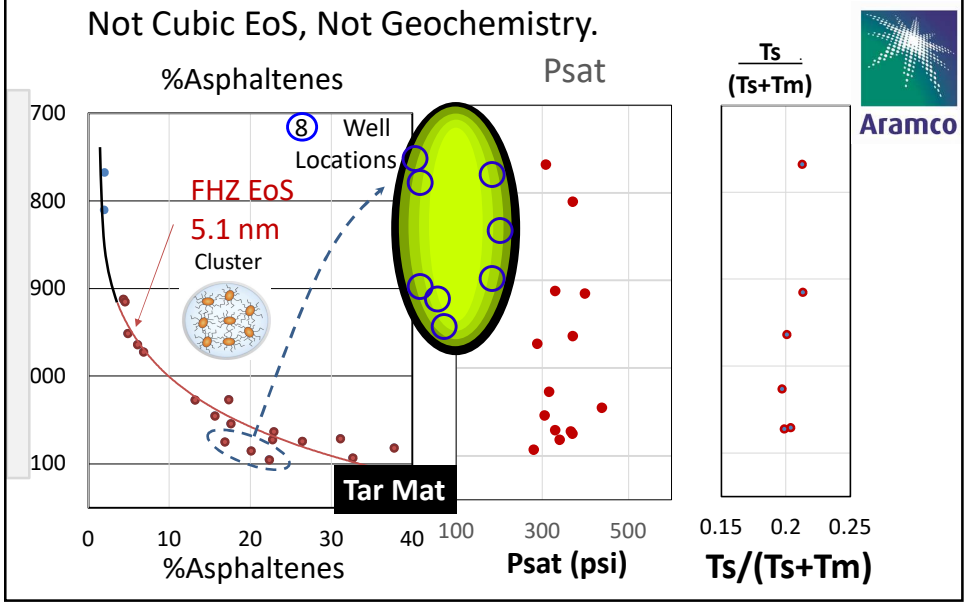
Reservoir Concerns: Viscosity, Tar Mat, Water Injection.

***ONLY* Asphaltenes** Define Reservoir Concern.
Not Cubic EoS, Not Geochemistry.



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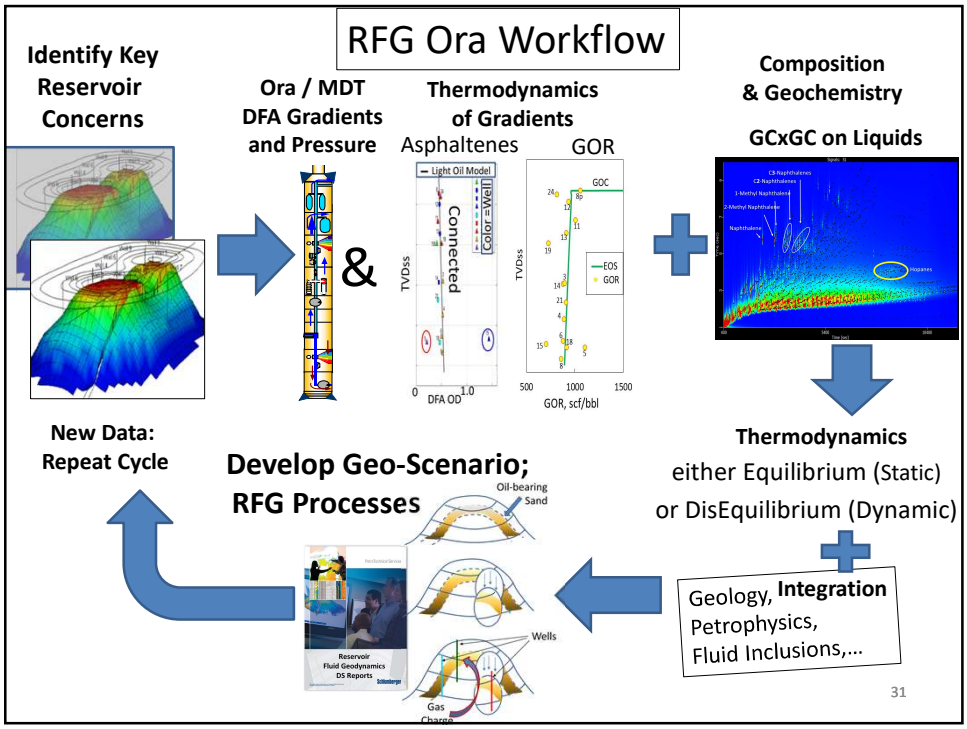

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PDF of RFG Book!

Here is the link: https://www.slb.com/resource-library/book/reservoir-fluid-geodynamics-and-reservoir-evaluation

Chapters

Front Matter: RFG Matrix →

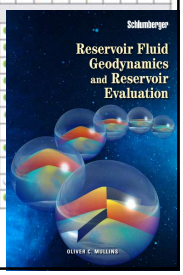
1. Introduction to RFG
2. (18) RFG Case Studies
3. The Asphaltenes, the Yen-Mullins Model and the Flory-Huggins-Zuo EoS
4. Basic Concepts of Petroleum Systems and Organic Geochemistry
5. Mass Transport in Reservoir Hydrocarbons Over Geologic Time

Reservoir Fluid Geodynamics Case Studies Matrix

RFG Case Studies →

	Case Studies	1 Alaer BP, Ivar Aasen, Norway	2 Presalt, Brazil	3 Talos, Fault Blocks, GOM	4 Four Fault Blocks, GOM	5 Pressure vs. Fluids, GOM	6 Wilcox, GOM	7 Giant, Middle East	8 Gradient Borders, GOM	9 Lundin, Fault Blocks, Norway	10 Formation Overturn, GOM	11 Stacked reservoirs, gas and oil, GOM	12 Condensate and Oil, GOM	13 AOP and Bitumen, GOM	14 Biodegradation and diffusion, India	15 Catcher Oil Fields, UK	16 Llanos Basin, Colombia	17 Two Charges, Brazil	18 Oil, Gas, and CO_2, SE Asia
Reservoir Concern	**Reservoir concerns**																		
	Connectivity	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	○	●	●
	Compartments	●	●	●	●	●	●			●	●	●	●		●	●		●	●
	Viscous oil or gradient		●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Tar mat or bitumen							●		●		○	●	●	●	○			
	GOR gradient		●	◡	●				●	●		●	●	●					●
	Fault block migration (structural geodynamics)	◡		●	●		◡			●	●					●			●
	Baffles or heterogeneity	●	●	●		◡	◡			●	●	●	●	●		◡		●	●
	CO_2	◡	●									●							●
	Flow assurance		◡	◡					◡	◡		●	●	●					◡
RFG Process	**RFG processes**																		
	Equilibrium	●	●	●	●	●	●	●											
	Quasi-equilibrium or disequilibrium gradients		●	◡					●										
	Diffusion	●	●	◡	◡	◡	◡	◡	●										
	Convection	●	●	◡	◡	◡	◡	●	●										
	Gas and oil charges		●	●					●										
	Flashing of charge fluids	●	●																
	Multiple oils and maturities	●				◡		●											
	Biodegradation	●																	
	Gas washing and evaporative fractionation	◡	●																
	Water washing																		
	Lateral sweep or charge	●	●	●															

● = Applies
◡ = Partially applies



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Conclusions:

1) Reservoir Fluid Geodynamics (RFG) New Way to Evaluate Reservoirs.

2) RFG addresses all manners of reservoir concerns including connectivity, compartments, baffling, GOR gradients, **CO2**, viscosity gradients, aquifer support, tar mats, low PI, wax,…

3) New Opportunities for technologists. e.g. Many new modeling problems now constrained with unique reservoir data.

New: PDF of RFG Book!

Here is the link: https://www.slb.com/resource-library/book/reservoir-fluid-geodynamics-and-reservoir-evaluation

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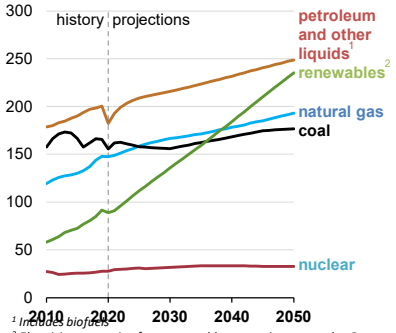
Energy Projections for Next Three Decades;

1) Oil and Gas (and coal) continue for decades, thus
2) CCS is required for sustainability

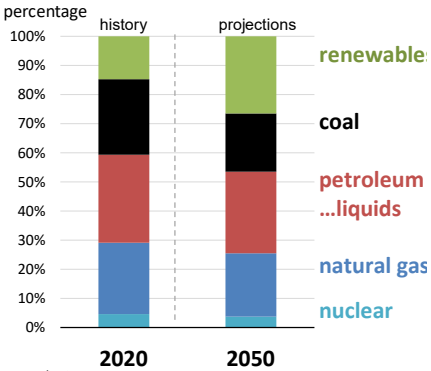
eia U.S. Energy Information Administration

Primary energy consumption by energy source, world

quadrillion British thermal units



Share of primary energy consumption by source, world



[1] Includes biofuels
[2] Electricity generation from renewable sources is converted to Btu at a rate of 8,124 Btu/kWh

https://www.eia.gov/outlooks/ieo/index.php

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