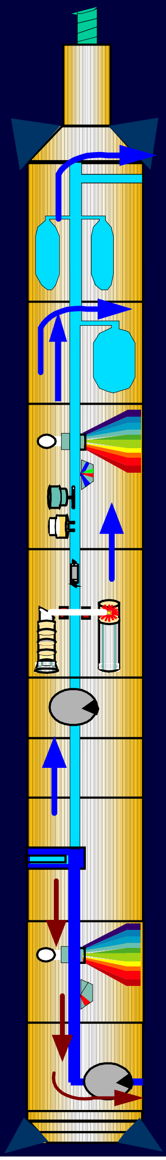
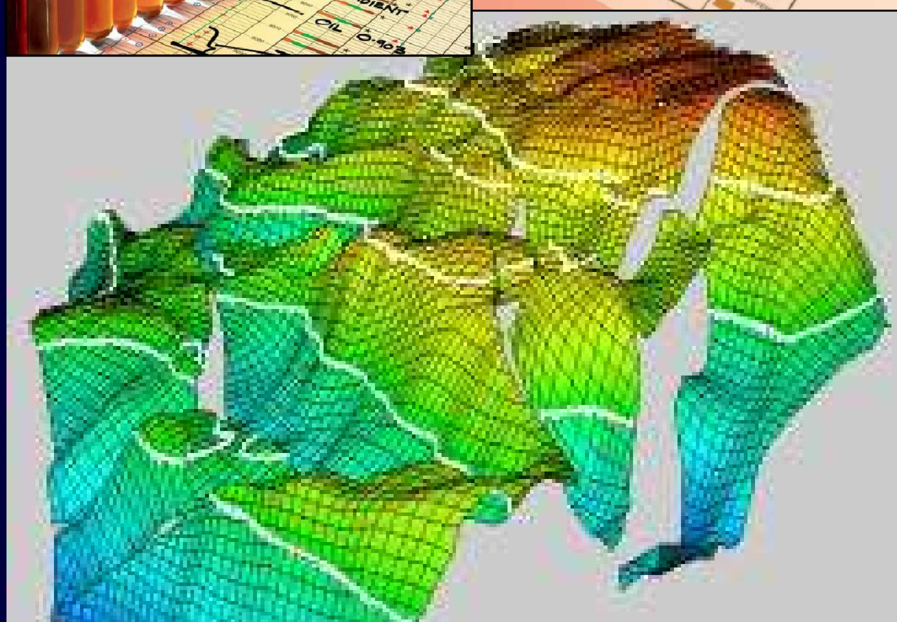
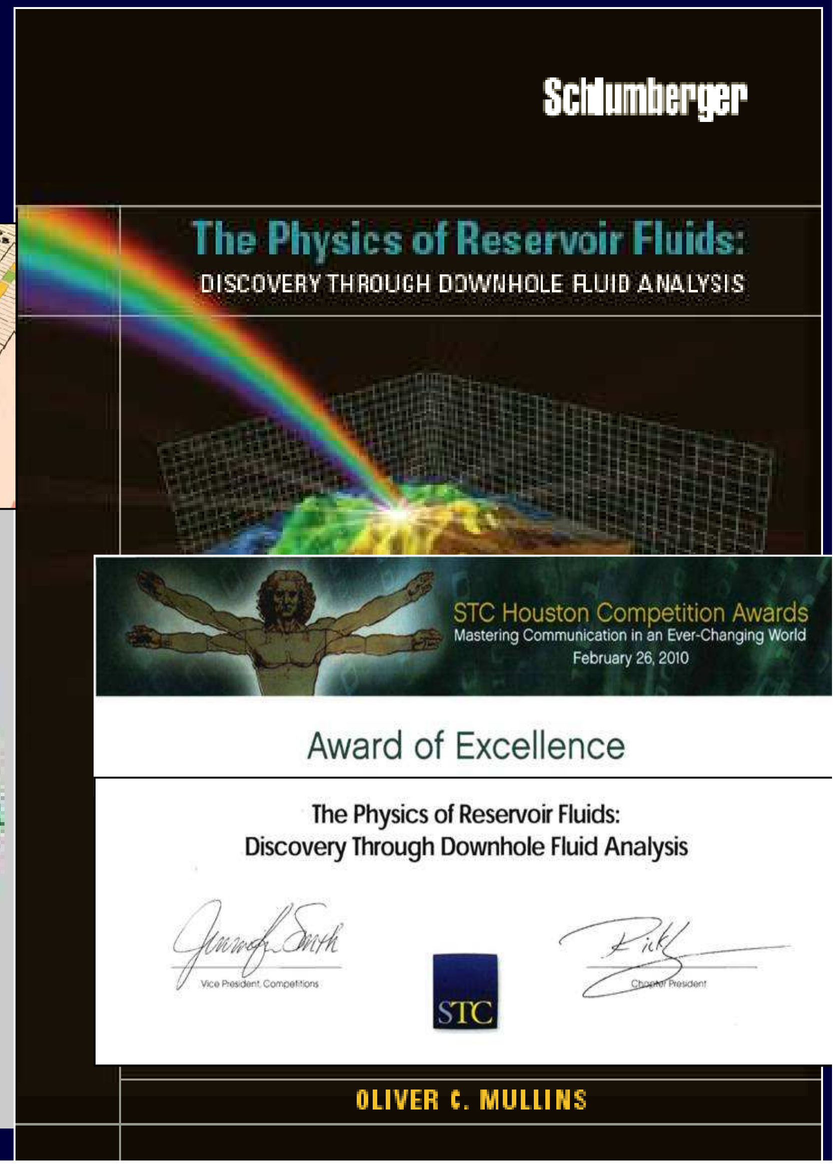
Downhole Fluid Analysis & Novel Asphaltene Science For Reservoir Evaluation

Oliver C. Mullins
Schlumberger
SPWLA Distinguished Lecture







Downhole Fluid Analysis (DFA)

Outline:

1) New Understanding of Reservoirs.

2) DFA & Compositional Variations & Compartments.

3) Reservoir Evaluation
   - New Technology. DFA
   - New Asphaltene Science
   - New Work Flows

4) Conclusions

Reservoir Issues

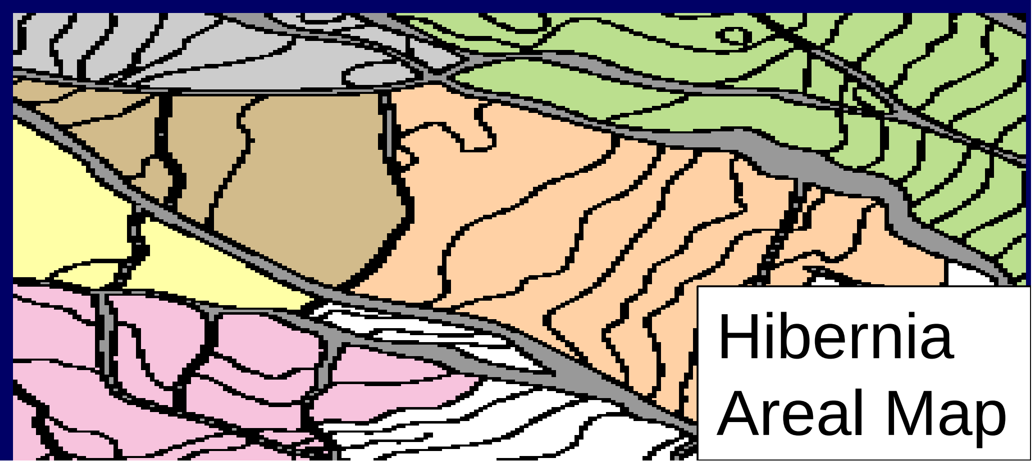
I. Compositional Grading (Heavy Ends !)

Reservoir Fluids are often highly graded and often *NOT* in equilibrium.

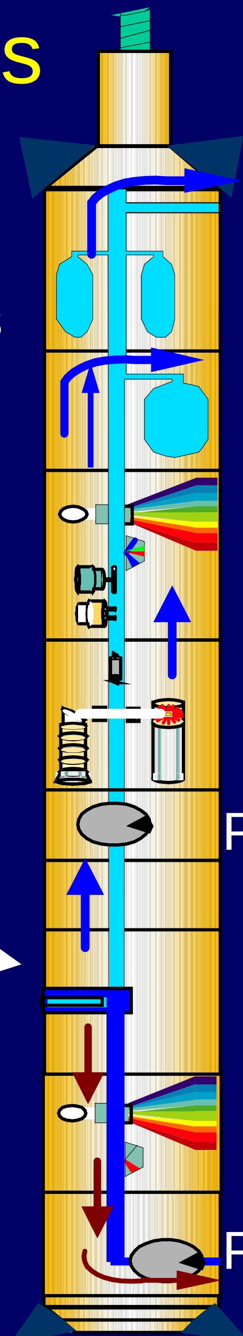
II. Reservoir Architecture

Compartments, sealing barriers, baffles

Different Fault Blocks
Different GOR (colors)



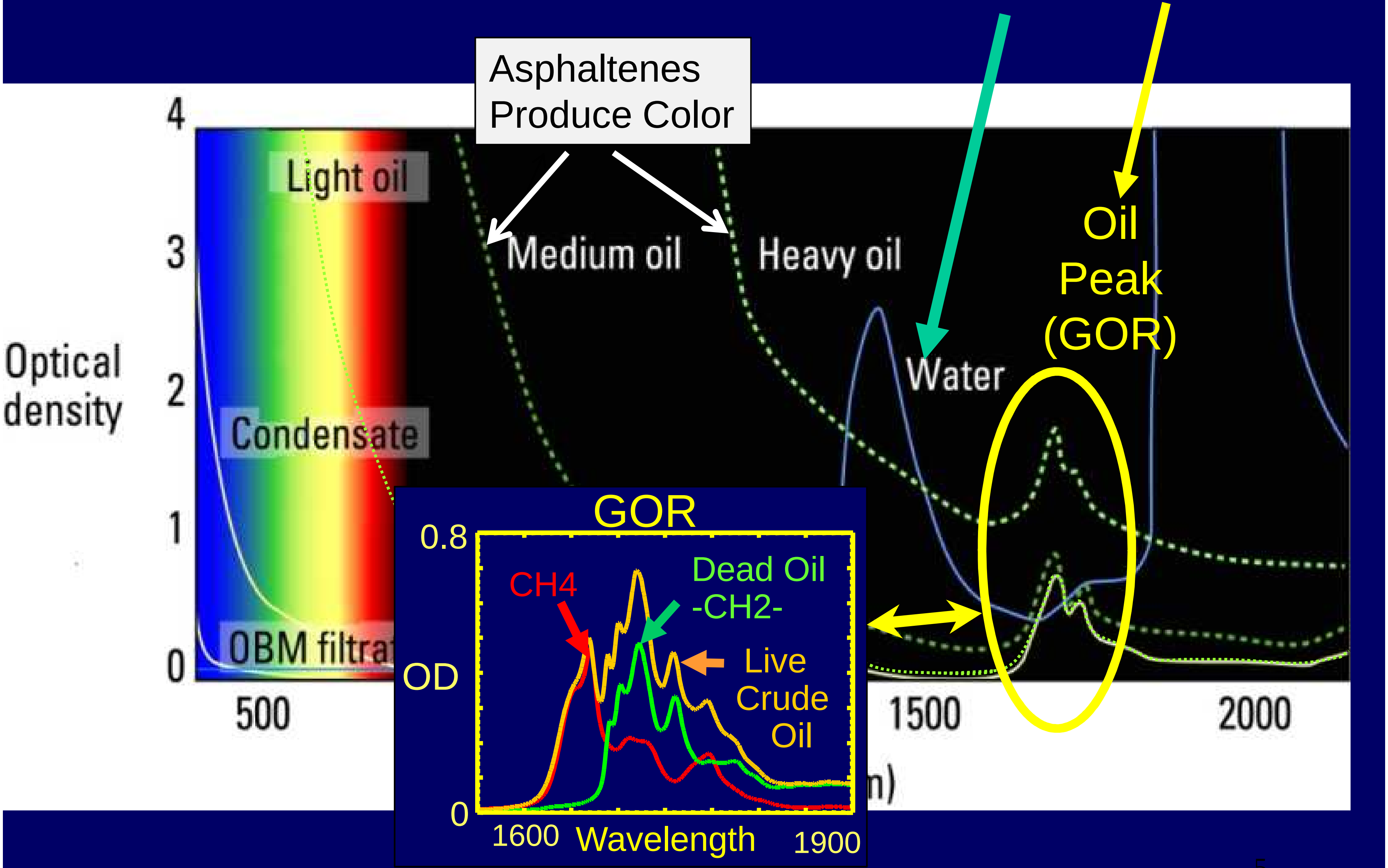
Downhole Fluid Analysis on the MDT



DFA Tools

Contamination
Phase change
GOR
Composition
CO_2
Density
Viscosity
Asphaltene

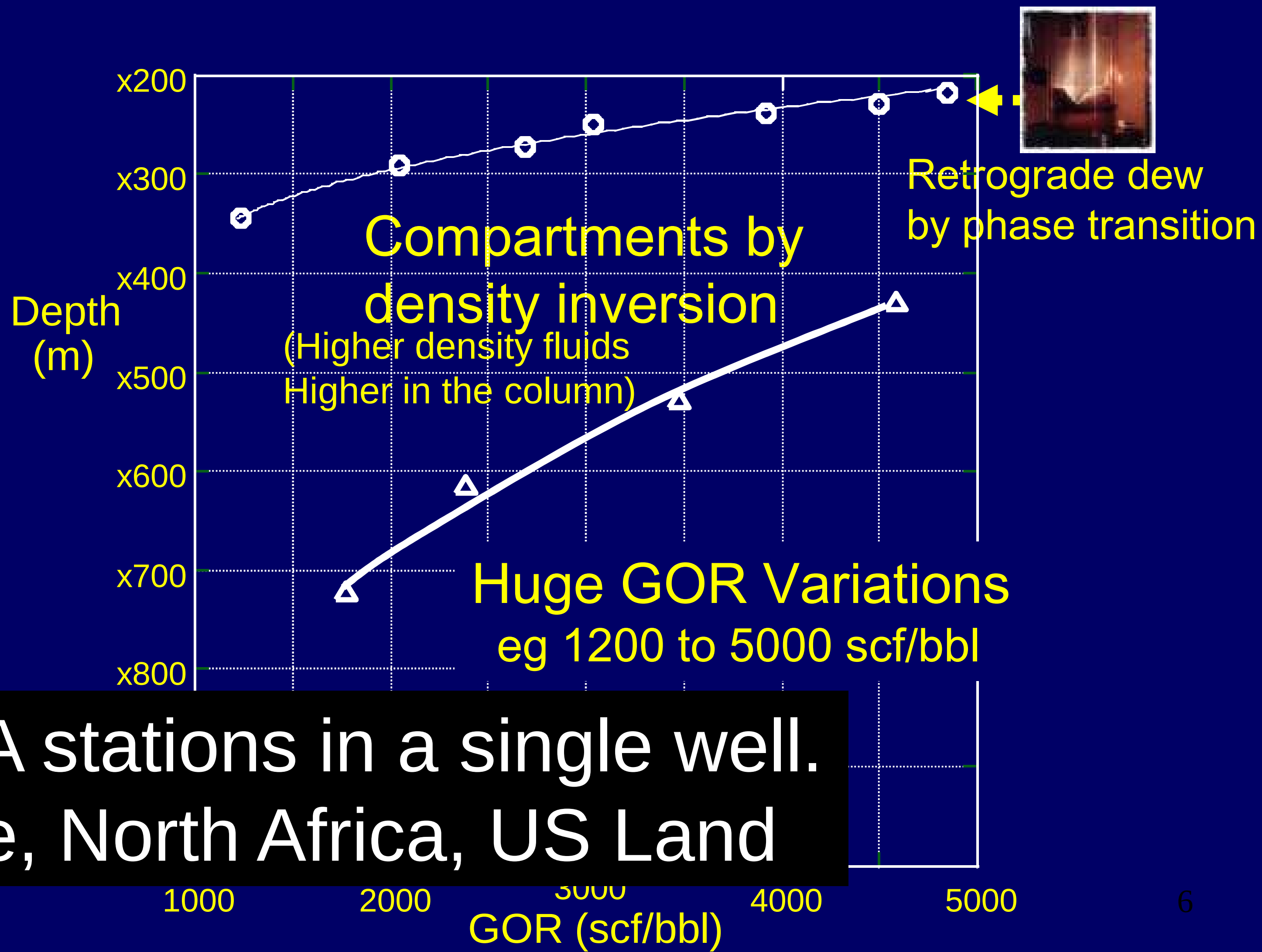
DFA uses Downhole Optical Spectroscopy . Water vs Oil



DFA finds

1) Compartments,

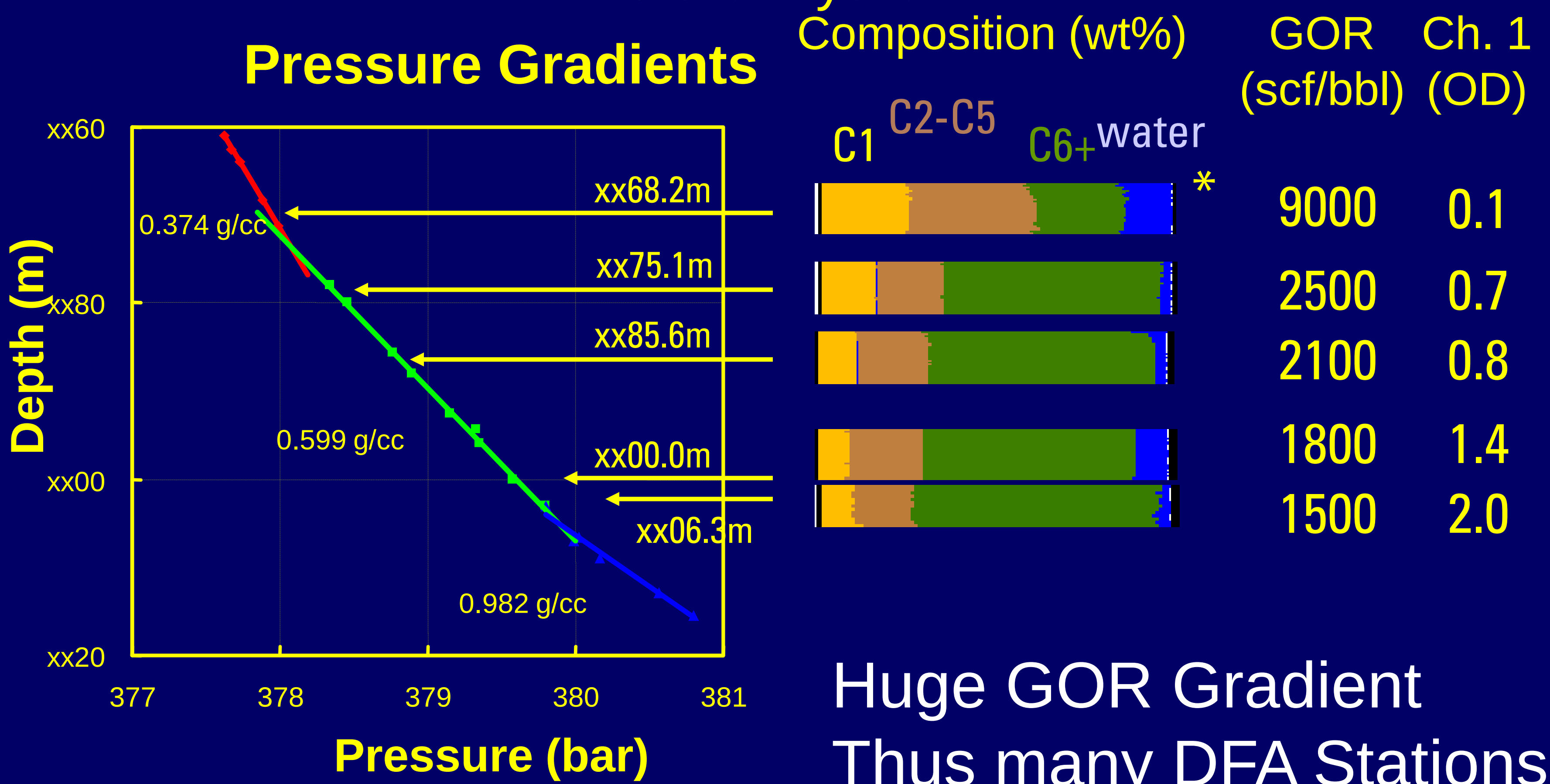
2) Fluid Compositional variations



>30 DFA stations in a single well.
Offshore, North Africa, US Land

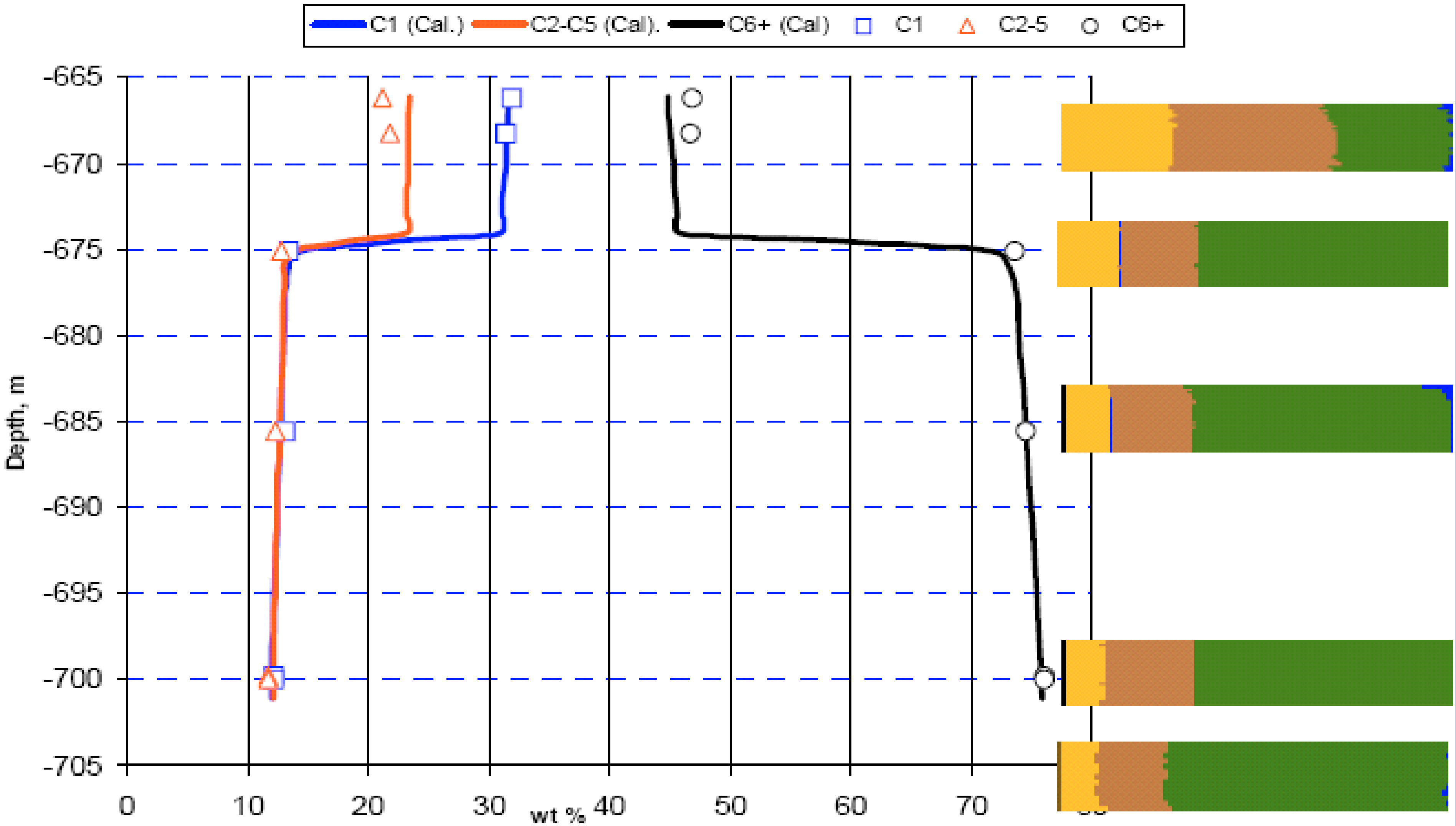
Dowhole Fluid Analysis
New Technology for Reservoir Evaluation

StatoilHydro



Huge GOR Gradient
Thus many DFA Stations

EoS Fits DFA Data, thus Equilibrium. Likely Connectivity (vertical)

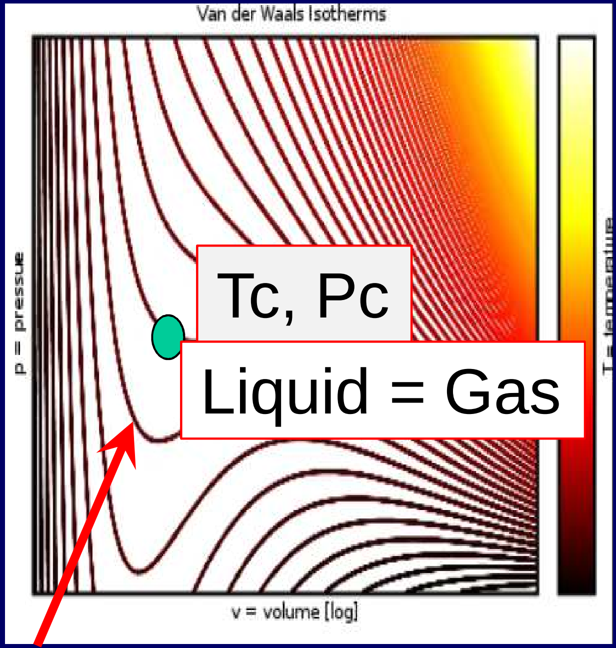


Equations of State

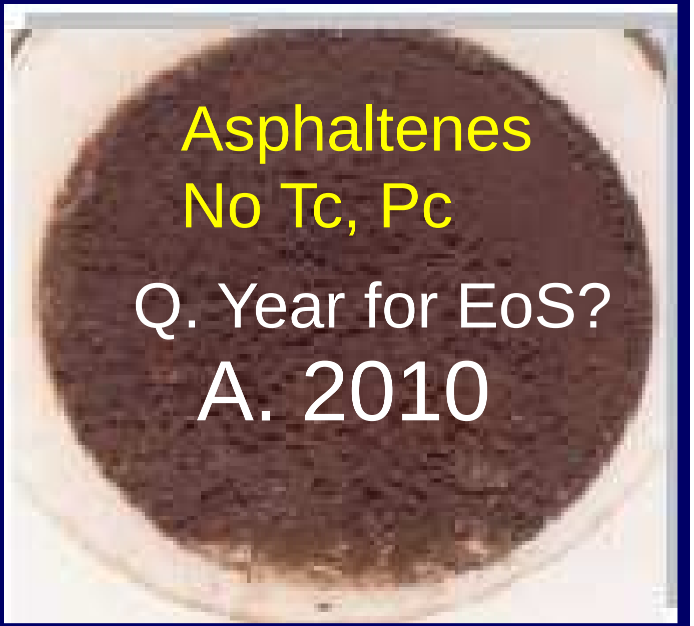
Ideal Gas Law
PV = nRT
1834
Clapeyron, Boyle

HC gases

Cubic EoS
Gas-Liquid



What about
the Solids ?



Cubic Eqn. $y = f(x^3)$

Van der Waals EoS 1873

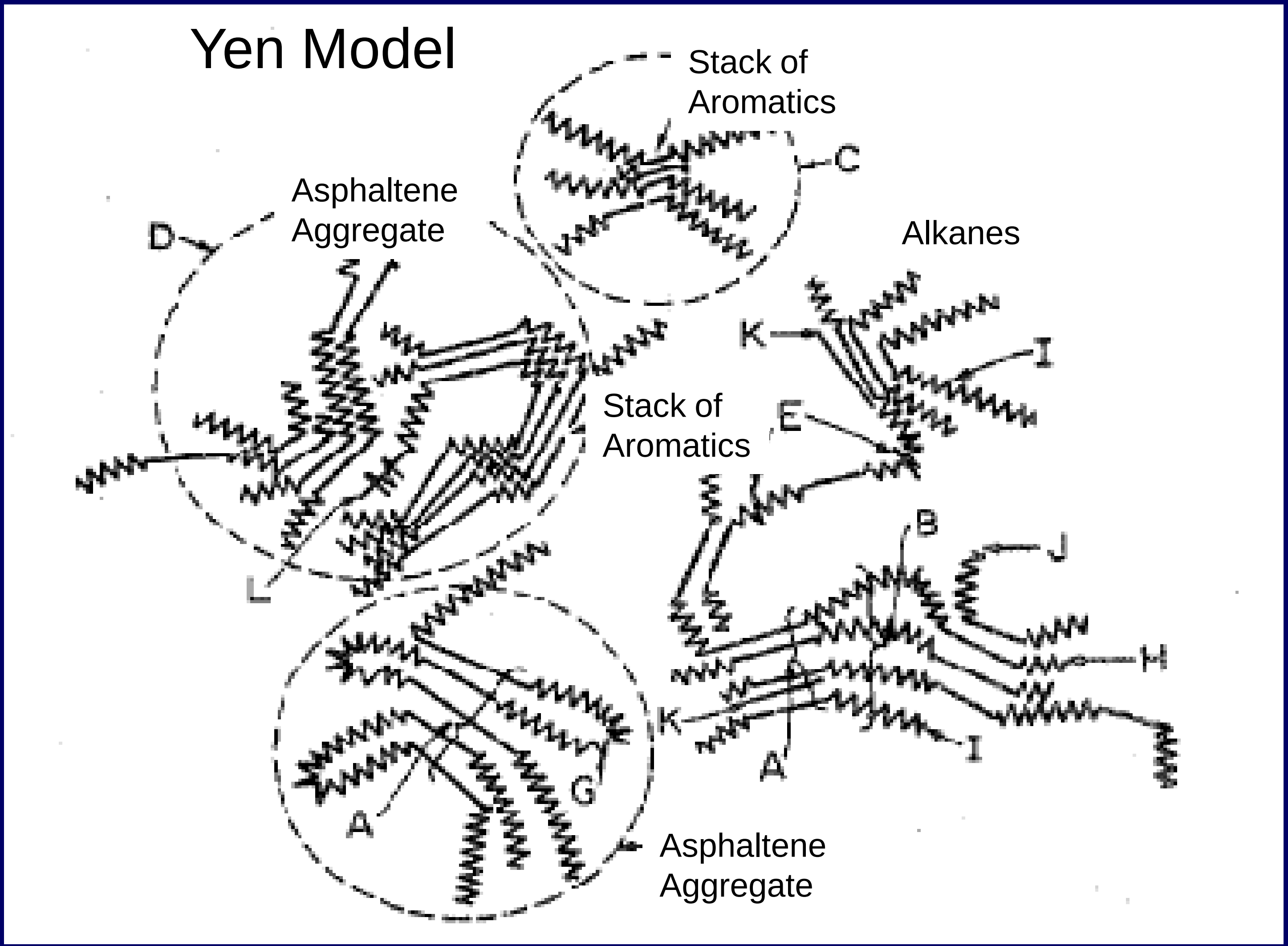
$$\left(P + \frac{a}{V^2}\right)(V - b) = nRT$$

Peng-Robinson EoS 1976

$$\left(P + \frac{a\alpha}{(V^2 + 2bV - b^2)}\right)(V - b) = nRT$$

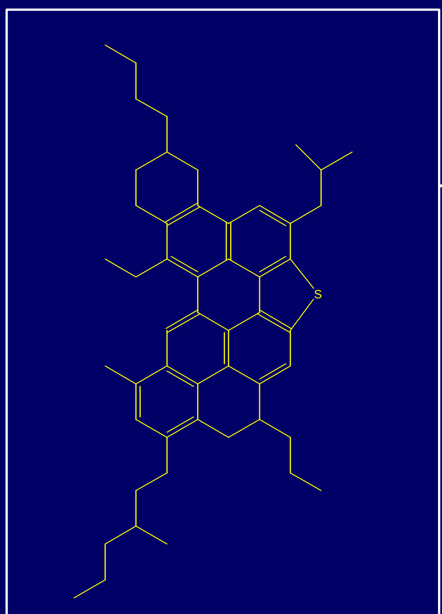
Yen Model Dominated Asphaltene Science for 40 years.
HOWEVER, useless for Reservoir Evaluation.

Heavy Ends **not** Understood and **not** used in EoS.

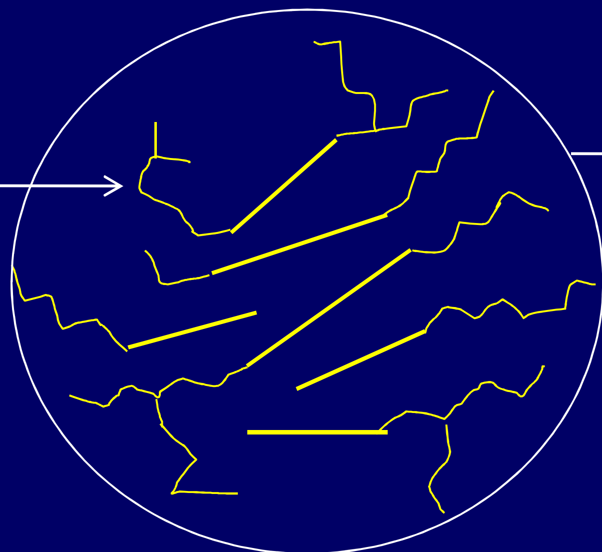


Connectivity: New Asphaltene Science & DFA

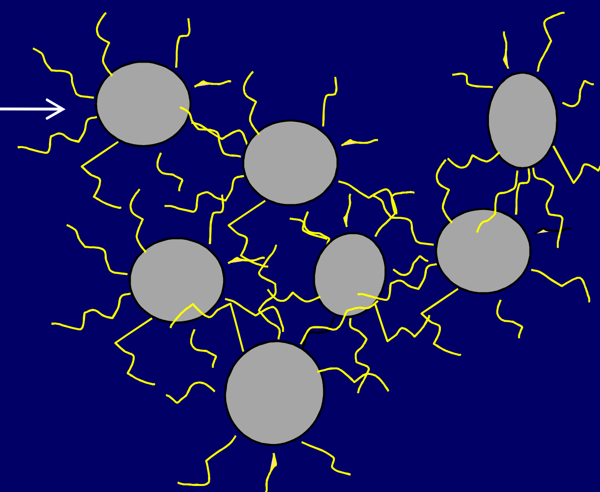
1. Gravity Term (size of objective below)



Asphaltene
Molecule



Asphaltene
Nanoaggregate
(made of ~6 molecules)



Asphaltene Cluster
(made of ~7
Nanoaggregates)

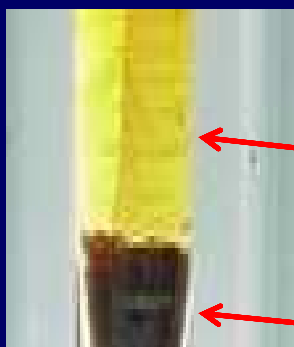
(See OC Mullins 30 page Review Article)

Connectivity: New Asphaltene Science & DFA

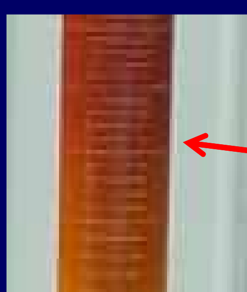
2) Solubility Term

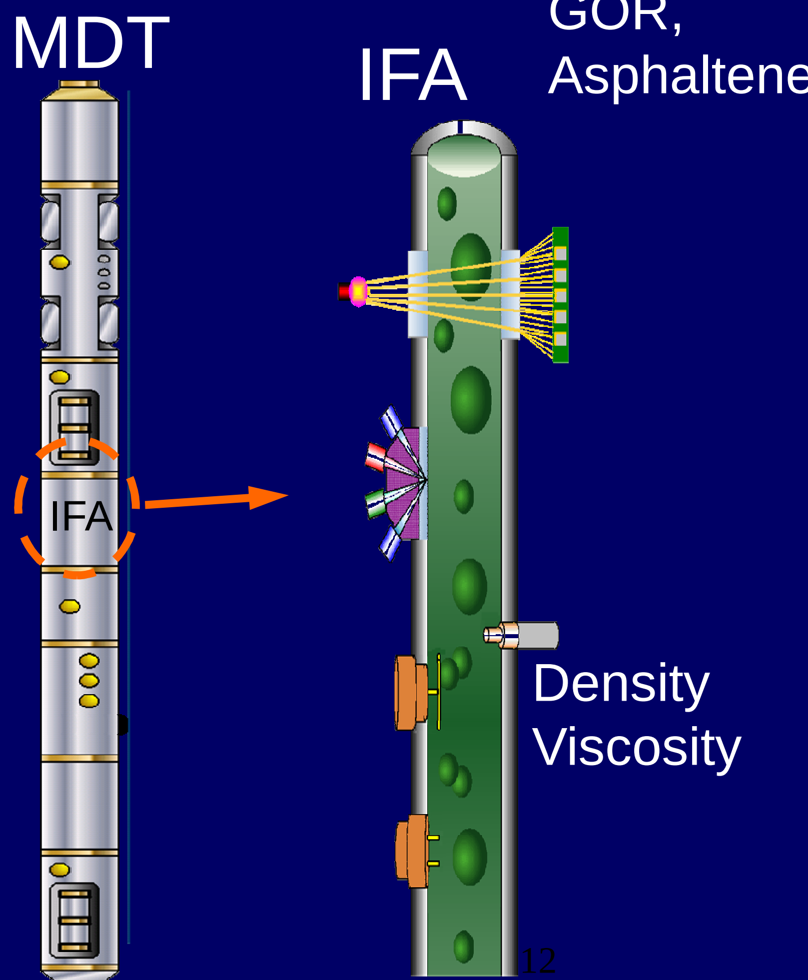
<u>Must</u> know GOR Gradient & Color Gradient.

High GOR Fluid *Precipitates* Asphaltene

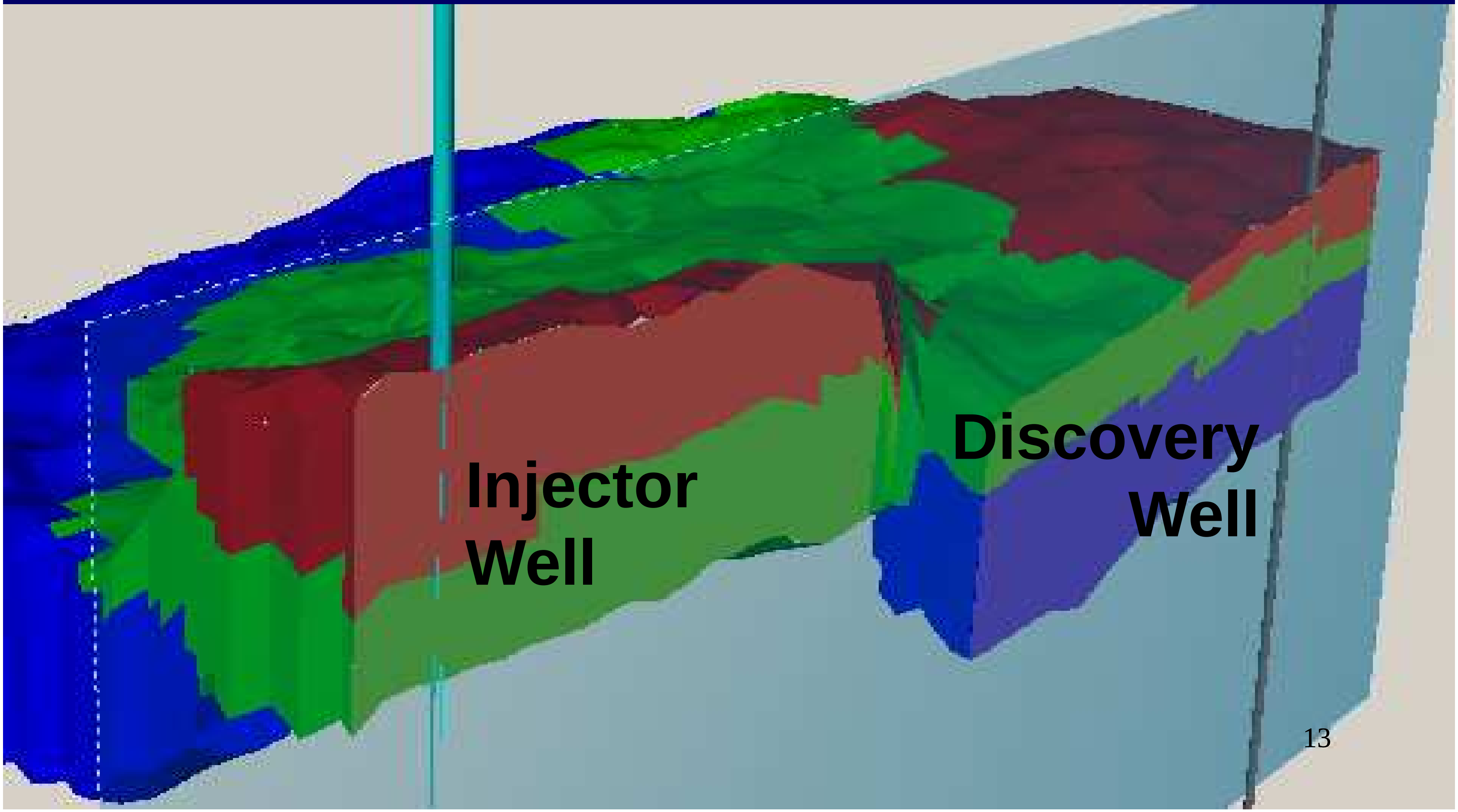


Low GOR Fluid *Dissolves* Asphaltene

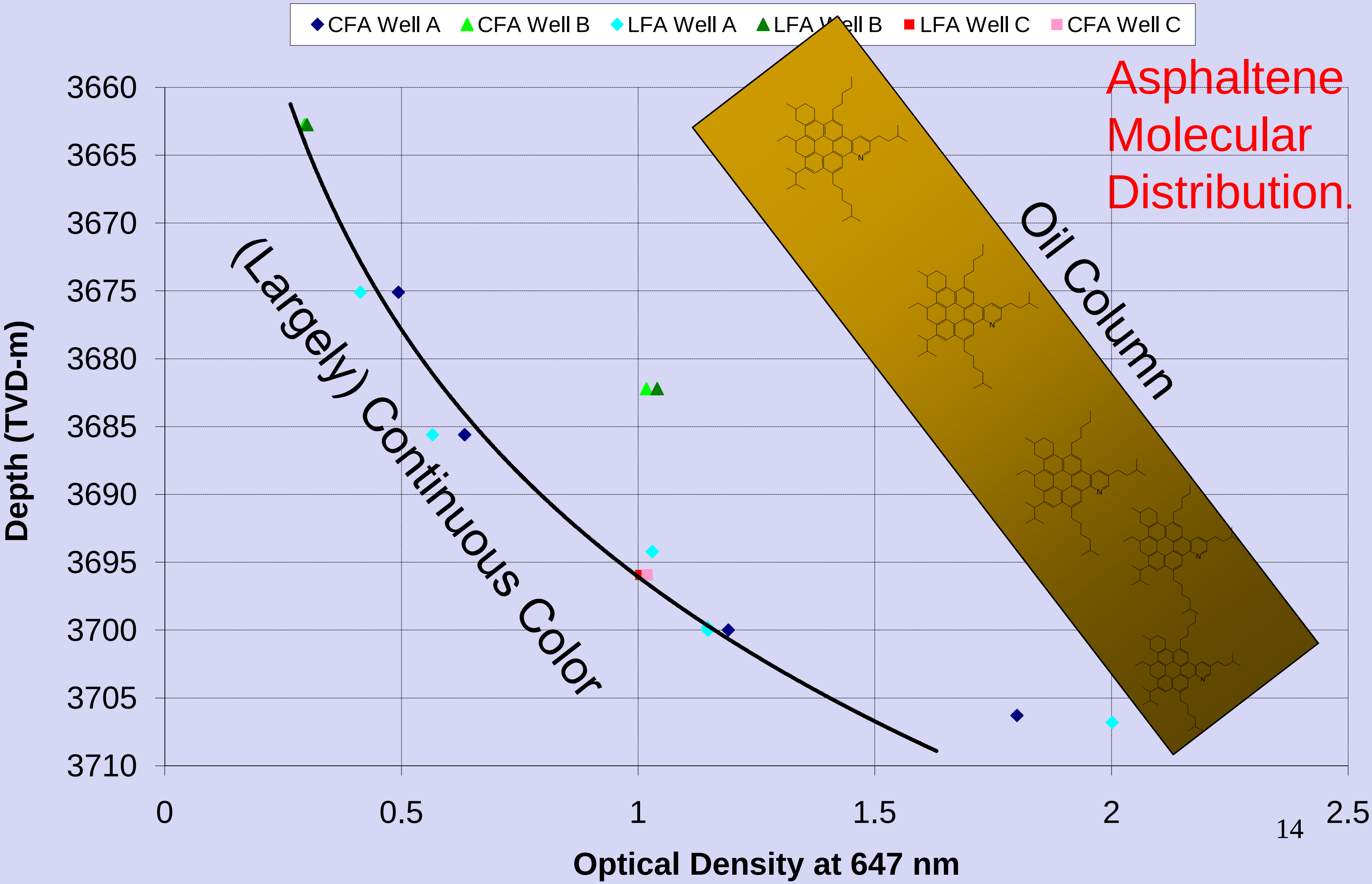




Two Separate Gas Caps in "One" Sand. Two GOCs differ by 20 Meters TVD. WHY? Compartment or Lateral Disequilibrium?

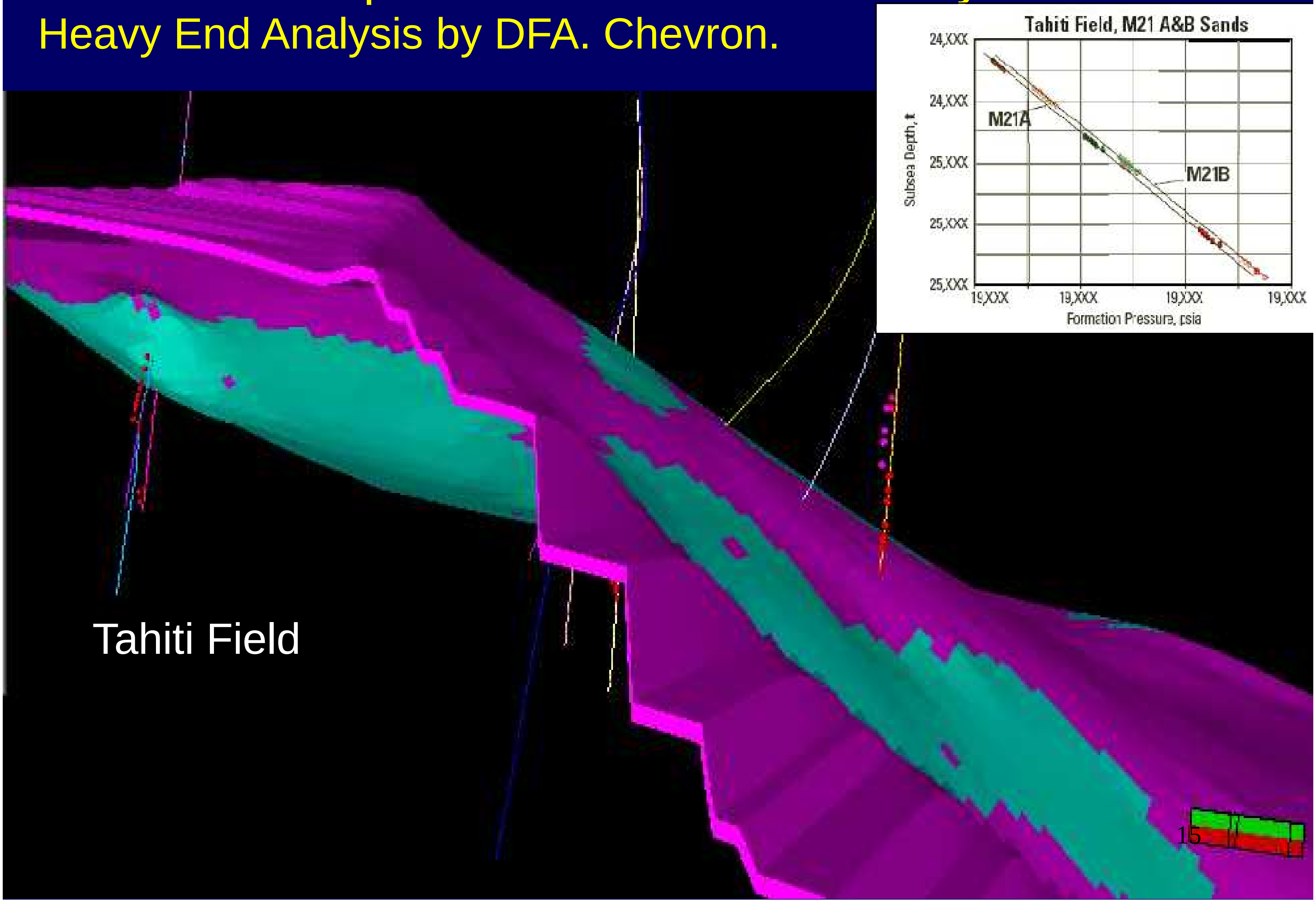


Color Seems to be continuous (neglecting lowest point !)
DFA says Connected. *Proven in Production*.

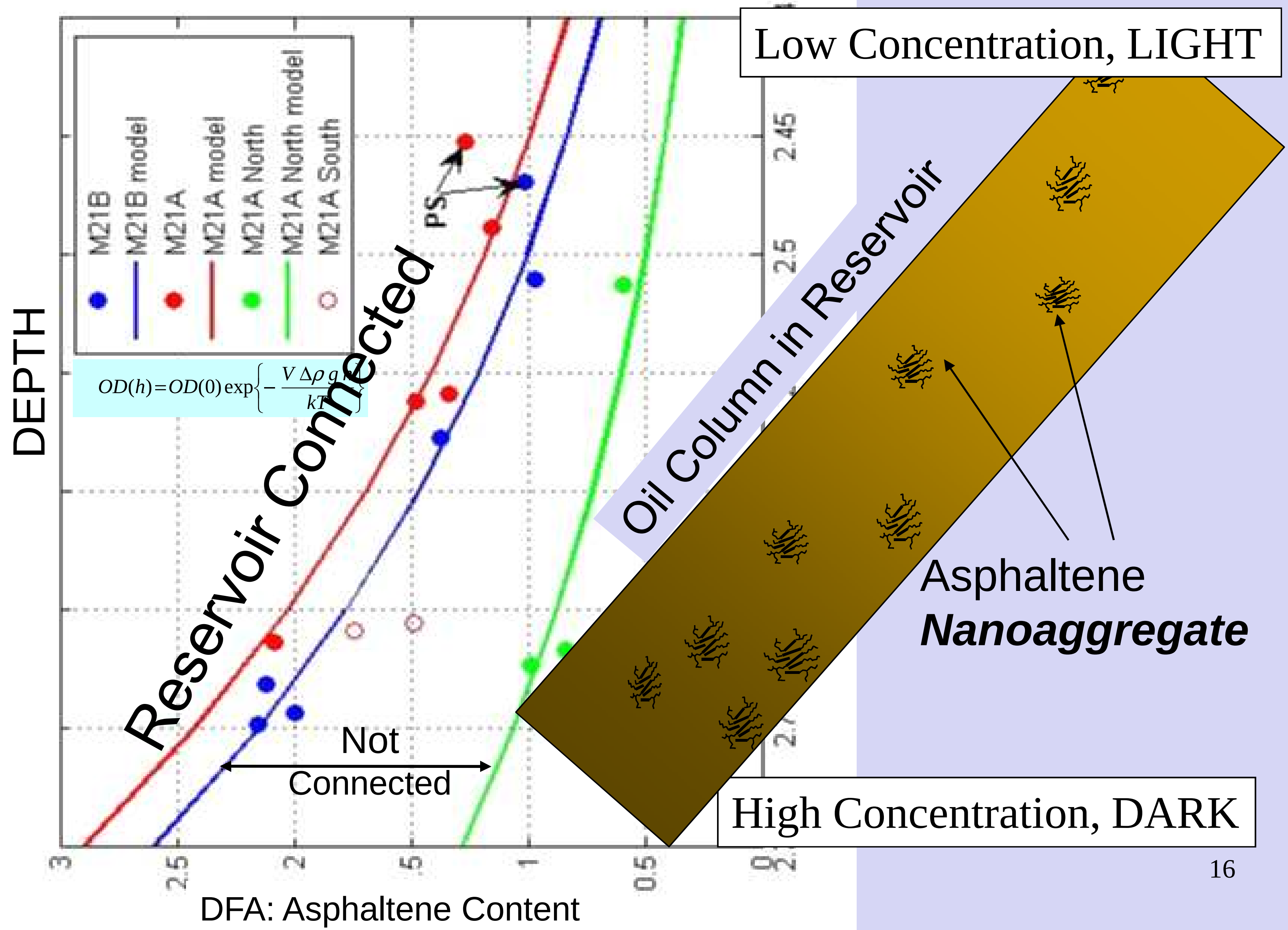


Case #2. Compartments and Connectivity

Heavy End Analysis by DFA. Chevron.

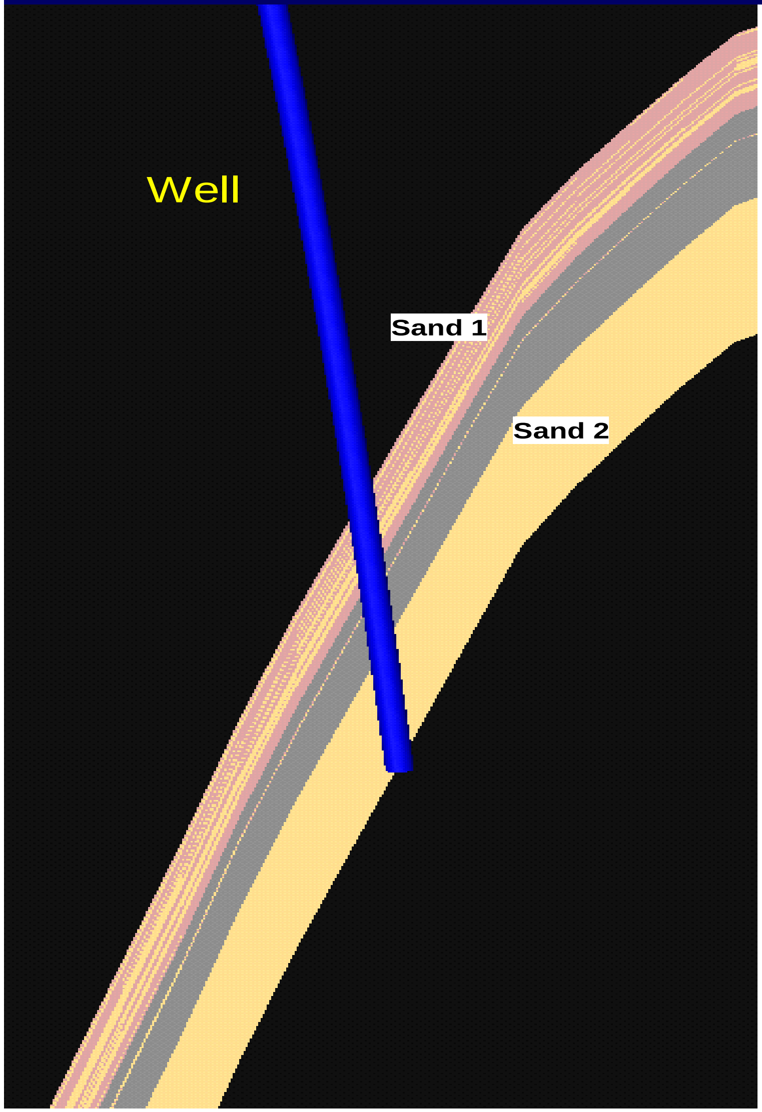


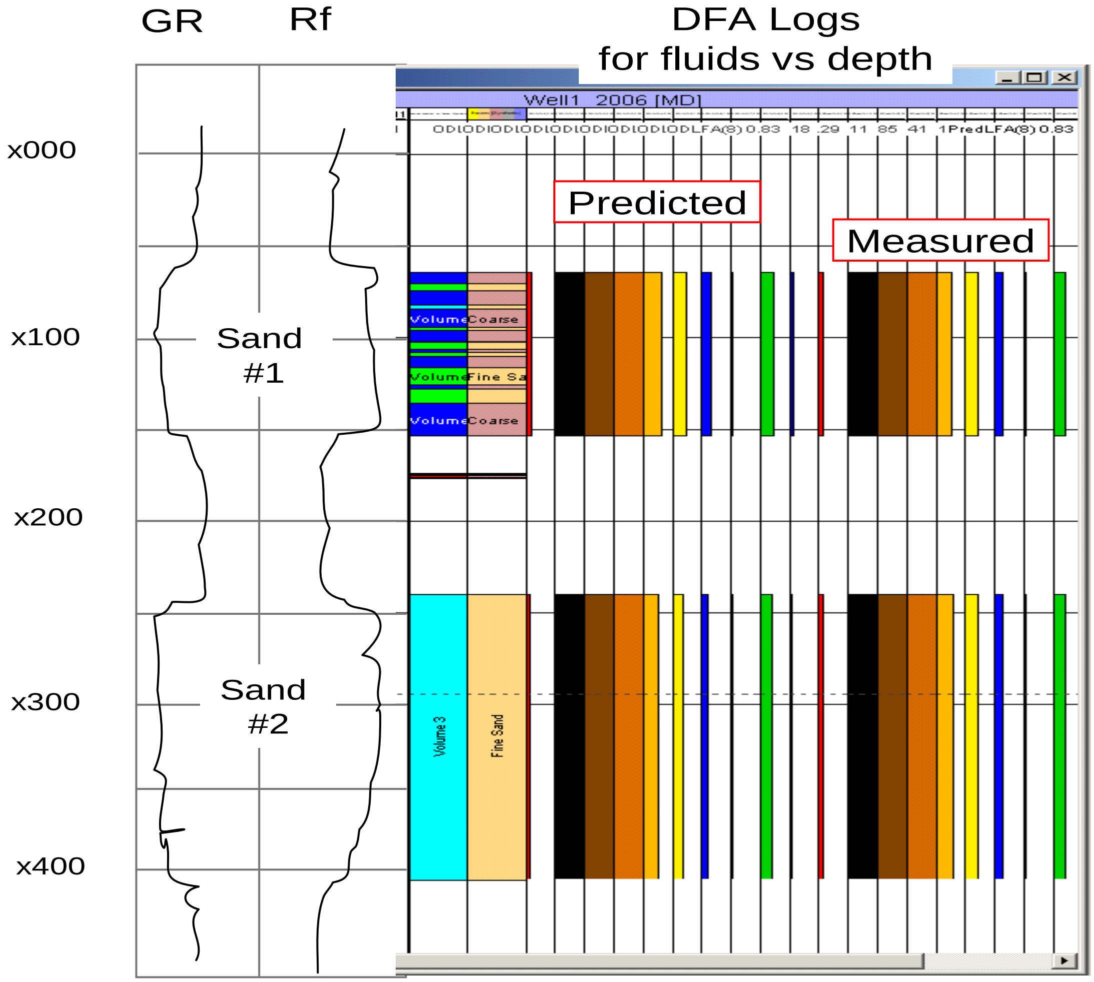
DFA says Reservoir Connected. *Proven in Production*



New Work Flows for Reservoir Evaluation

Predicting DFA data for Heavy Ends.

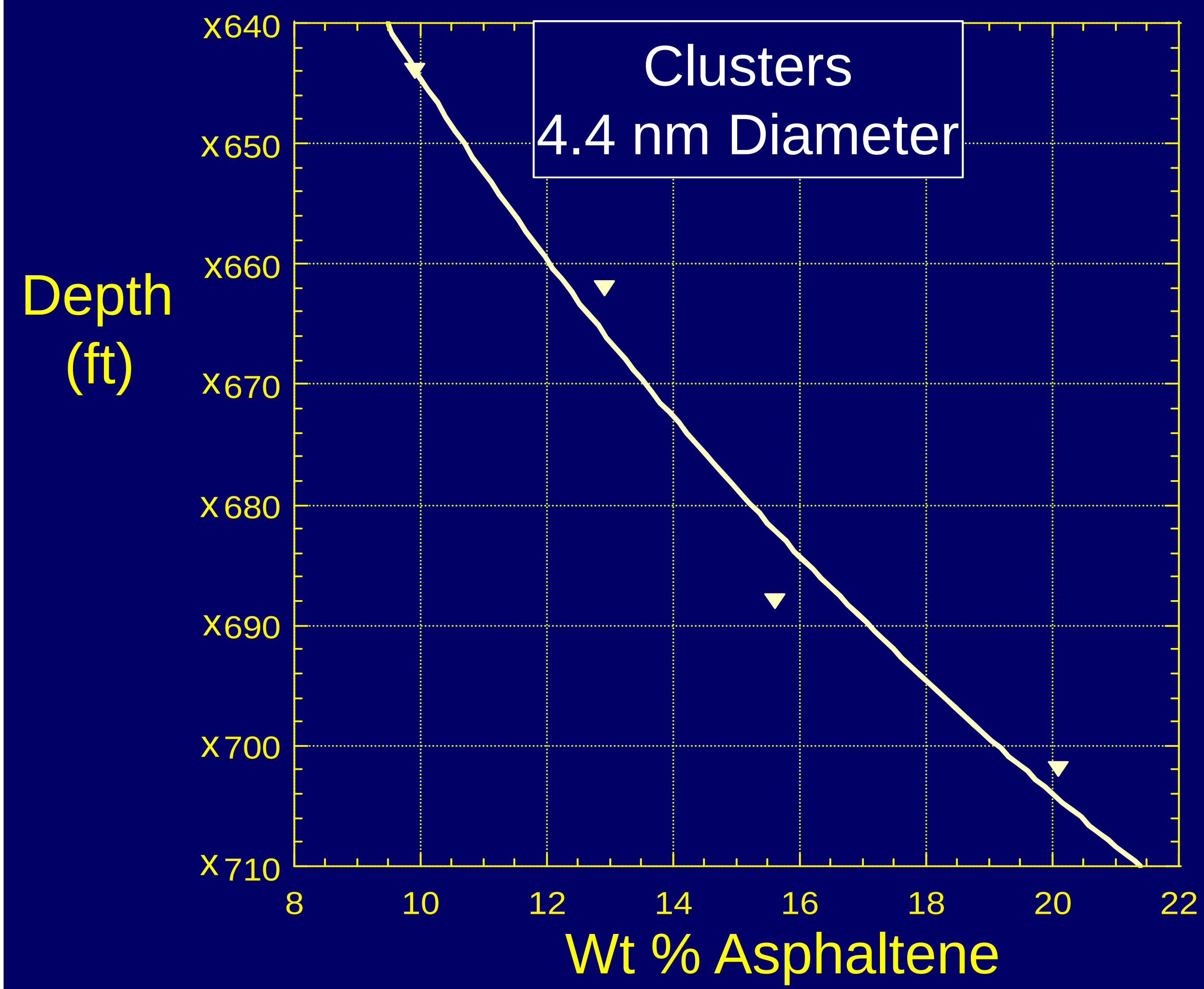


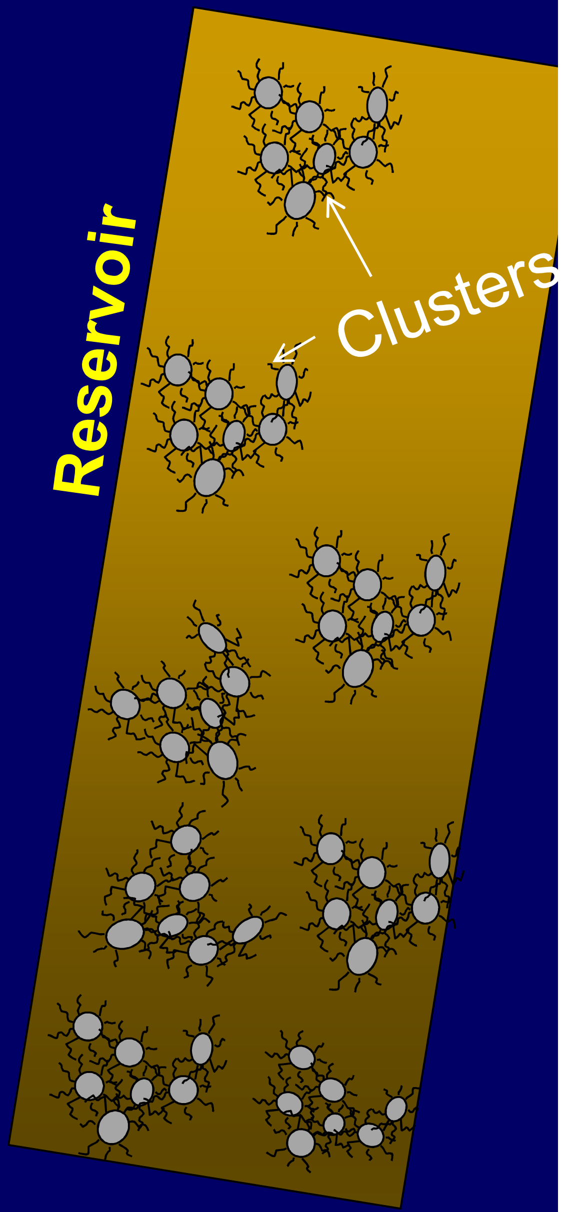


Asphaltene Clusters Dominate Heavy Oils.

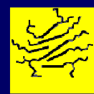
Viscosity varies from 5 to ~200 cP.

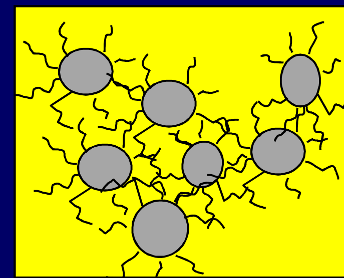
Connected Reservoir.

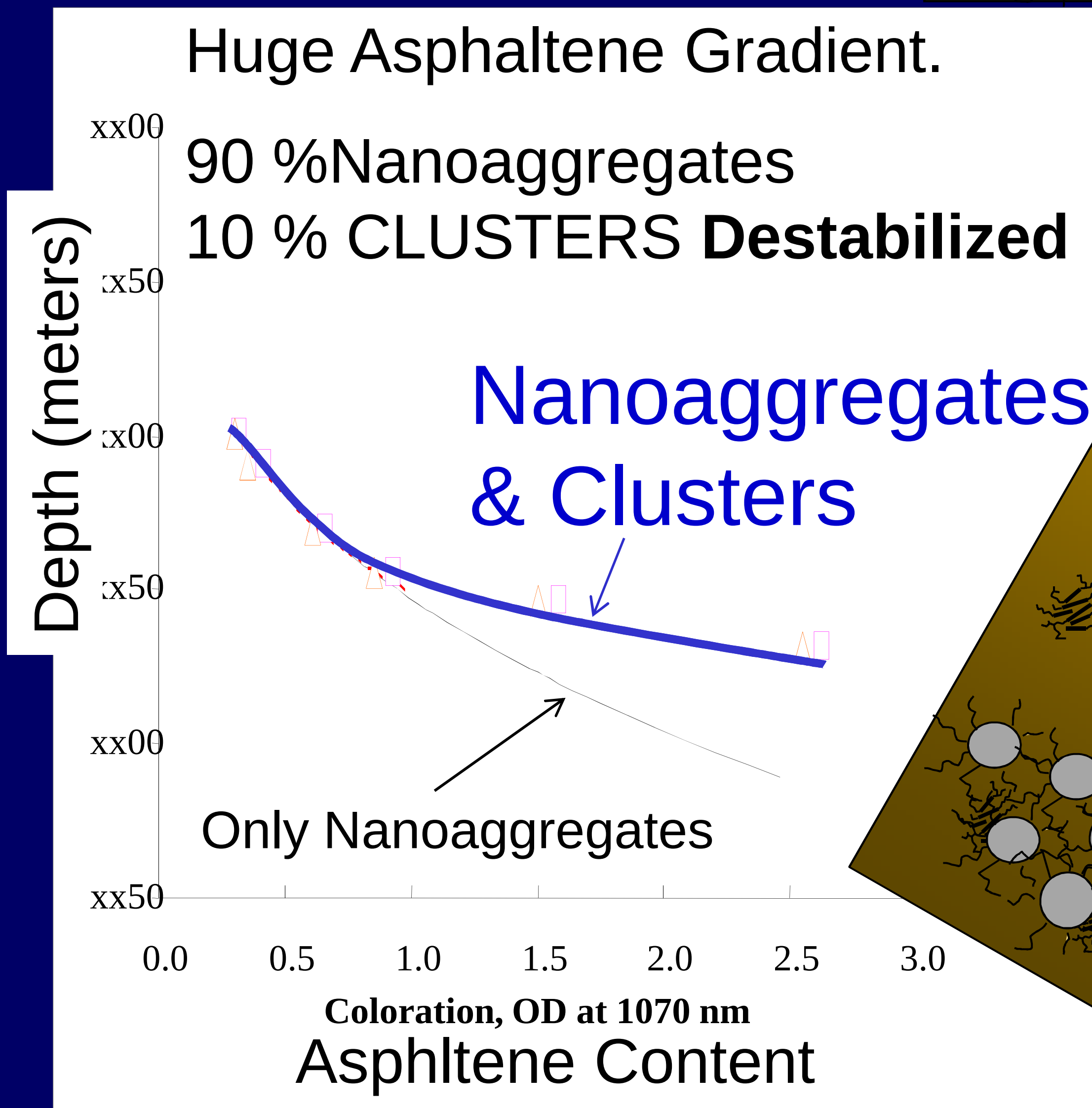


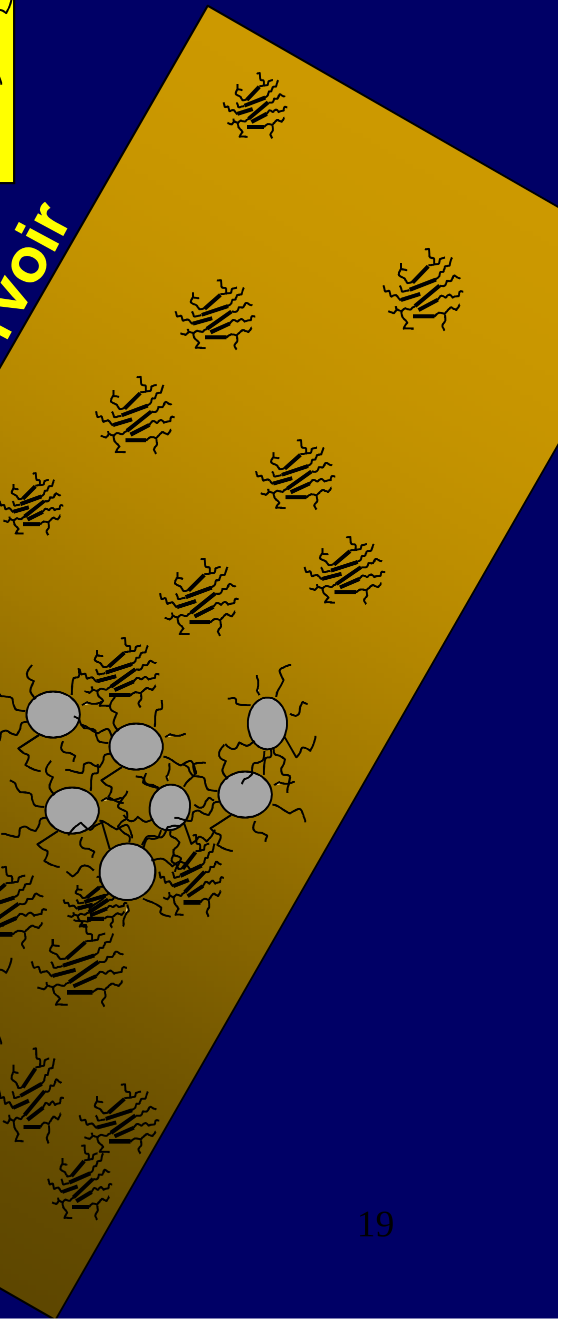


Nanoaggregate *CLUSTERS*





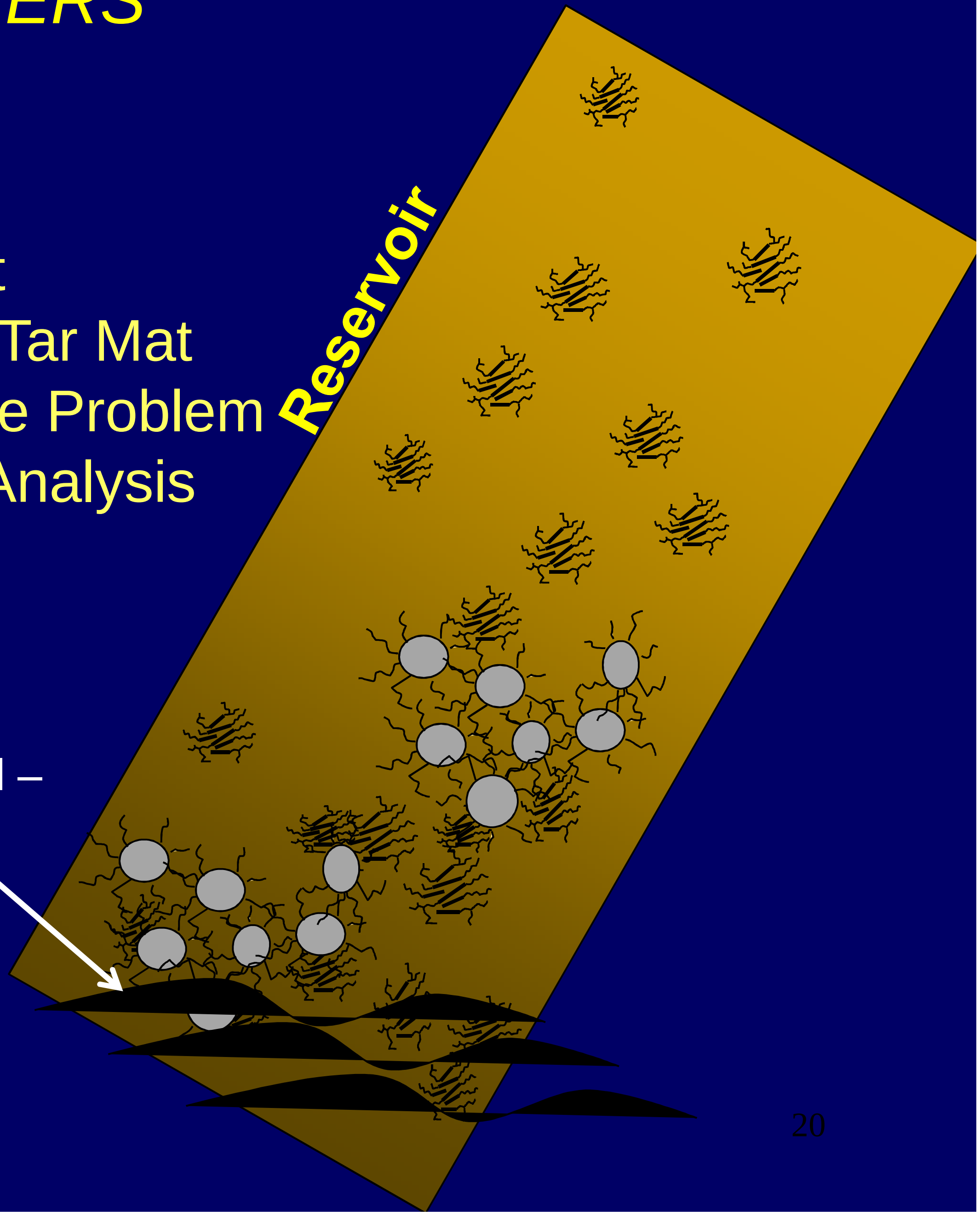




Nanoaggregate *CLUSTERS*

Implications.

1) Huge Viscosity Gradient
2) Possible Allochthonous Tar Mat
3) Possible Flow Assurance Problem
4) Reservoir Connectivity Analysis

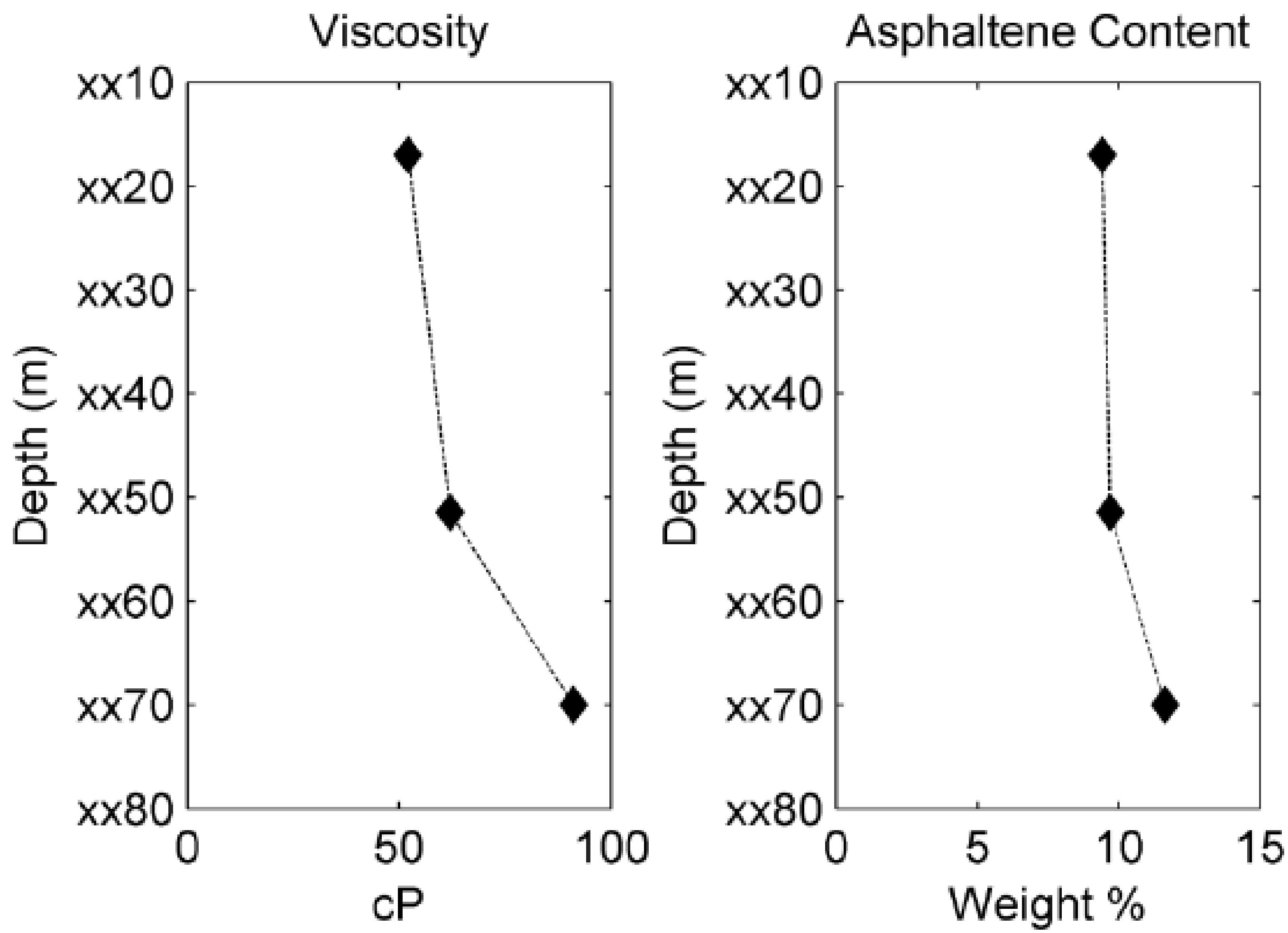


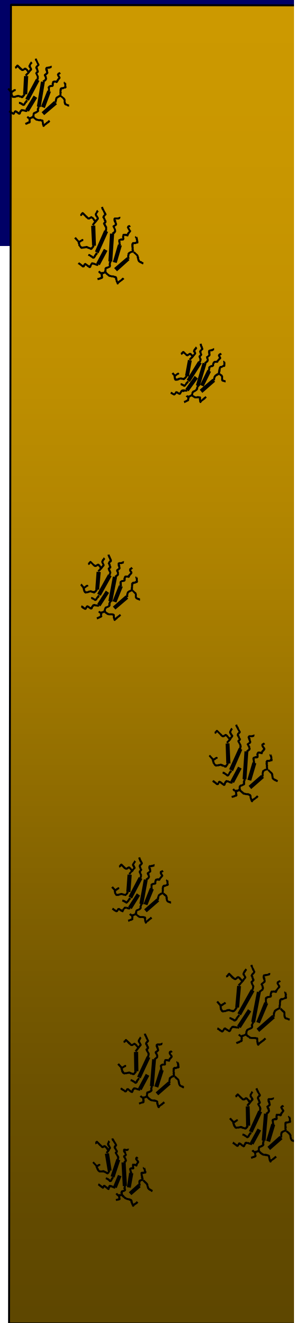
Allochthonous Tar Mat
(asphaltene destabilization in bulk oil – fall to low point forming tar mat)

vs. Autochthonous Tar Mat
at OWC by biodegradation

Devon.

Asphaltene Gradient Consistent with Equilibrated Nanoaggregates. Connected.

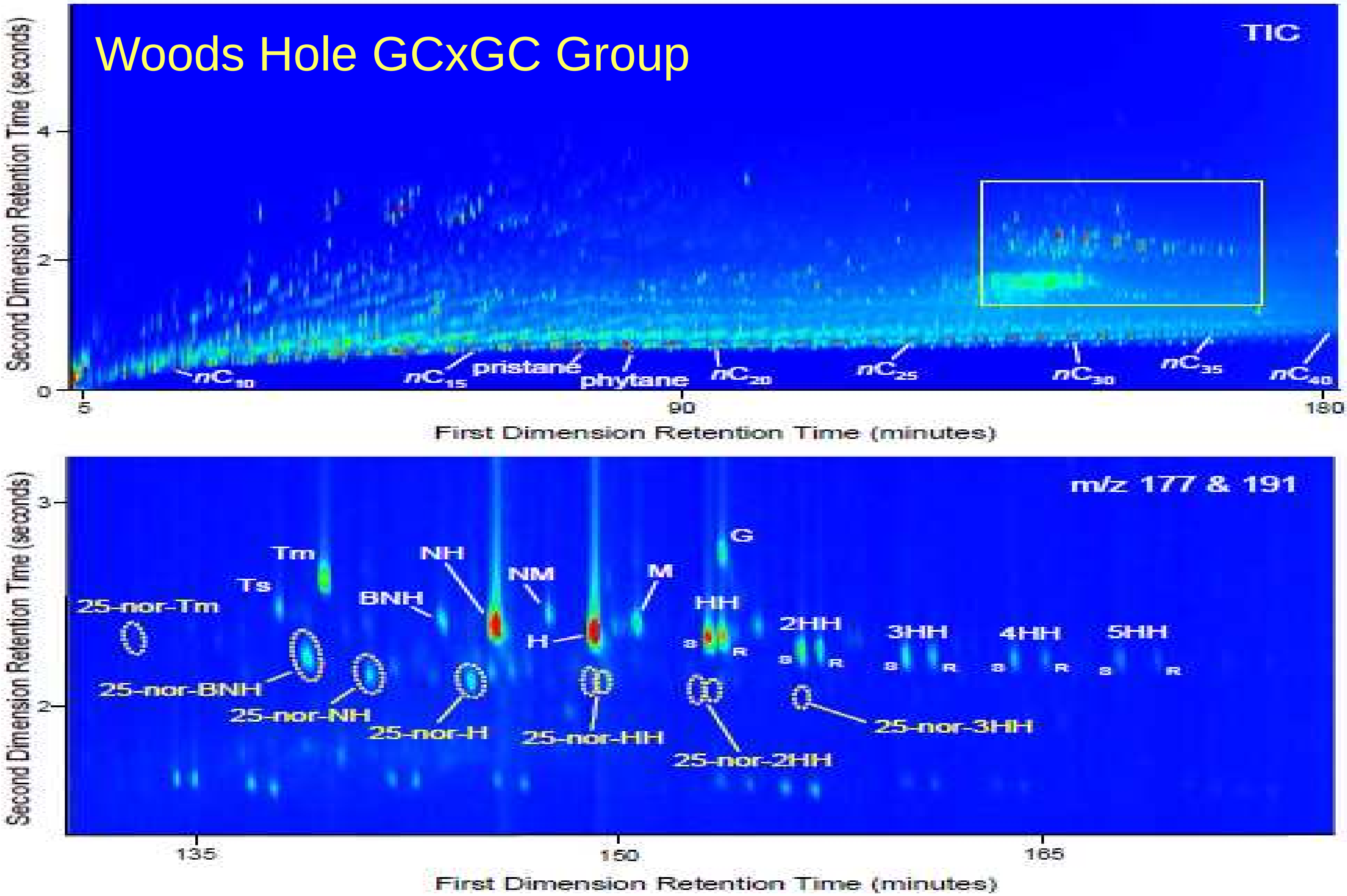




GCxGC Analysis.

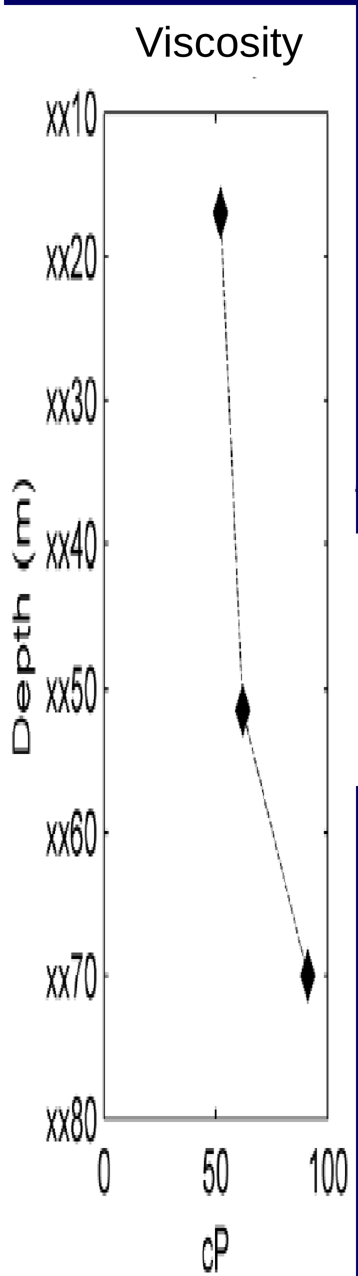
Loads of n-alkanes. No Biodegradation.

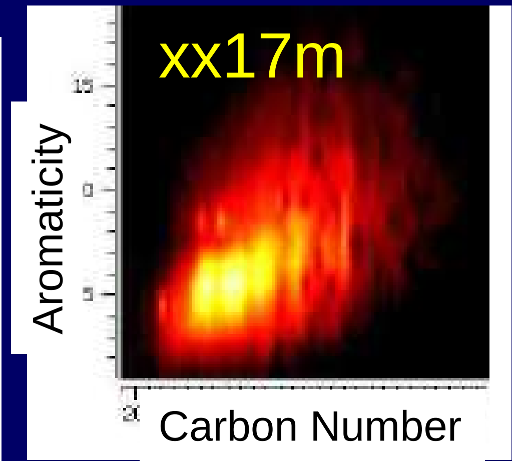
Loads of norhopanes. Lots of Biodegradation.

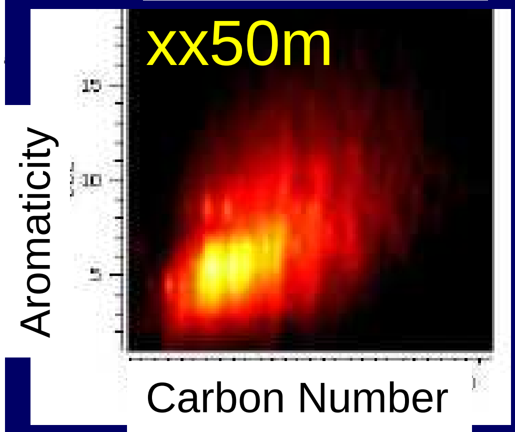


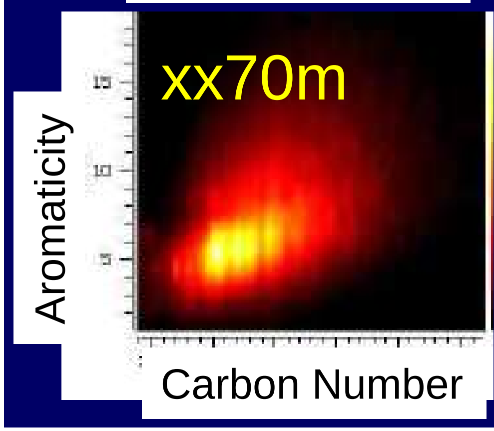
Devon.

High Resolution Mass Spec. (Florida State U.)







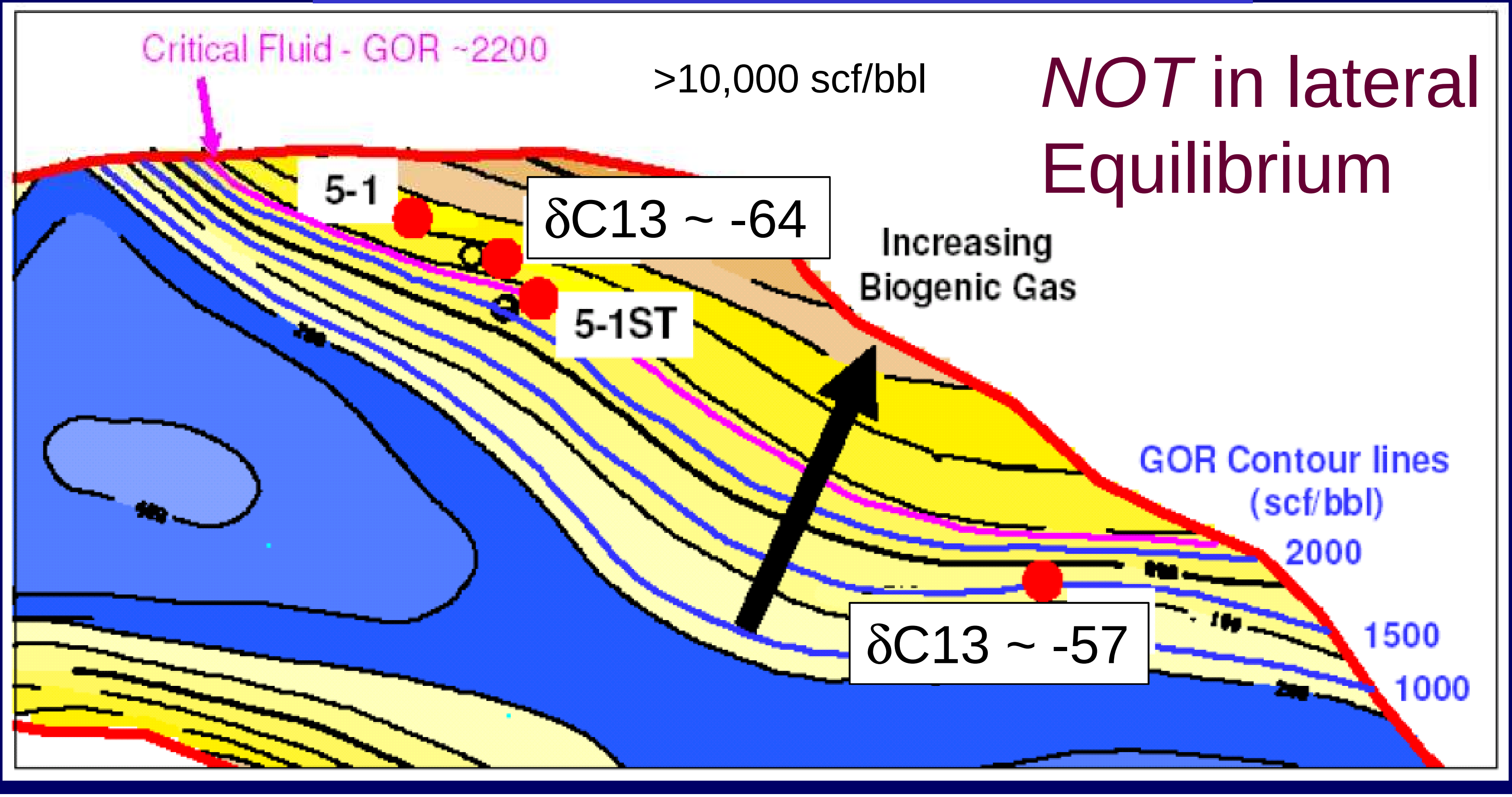


1. Organic Acids are Aromatic. Biodegraded.

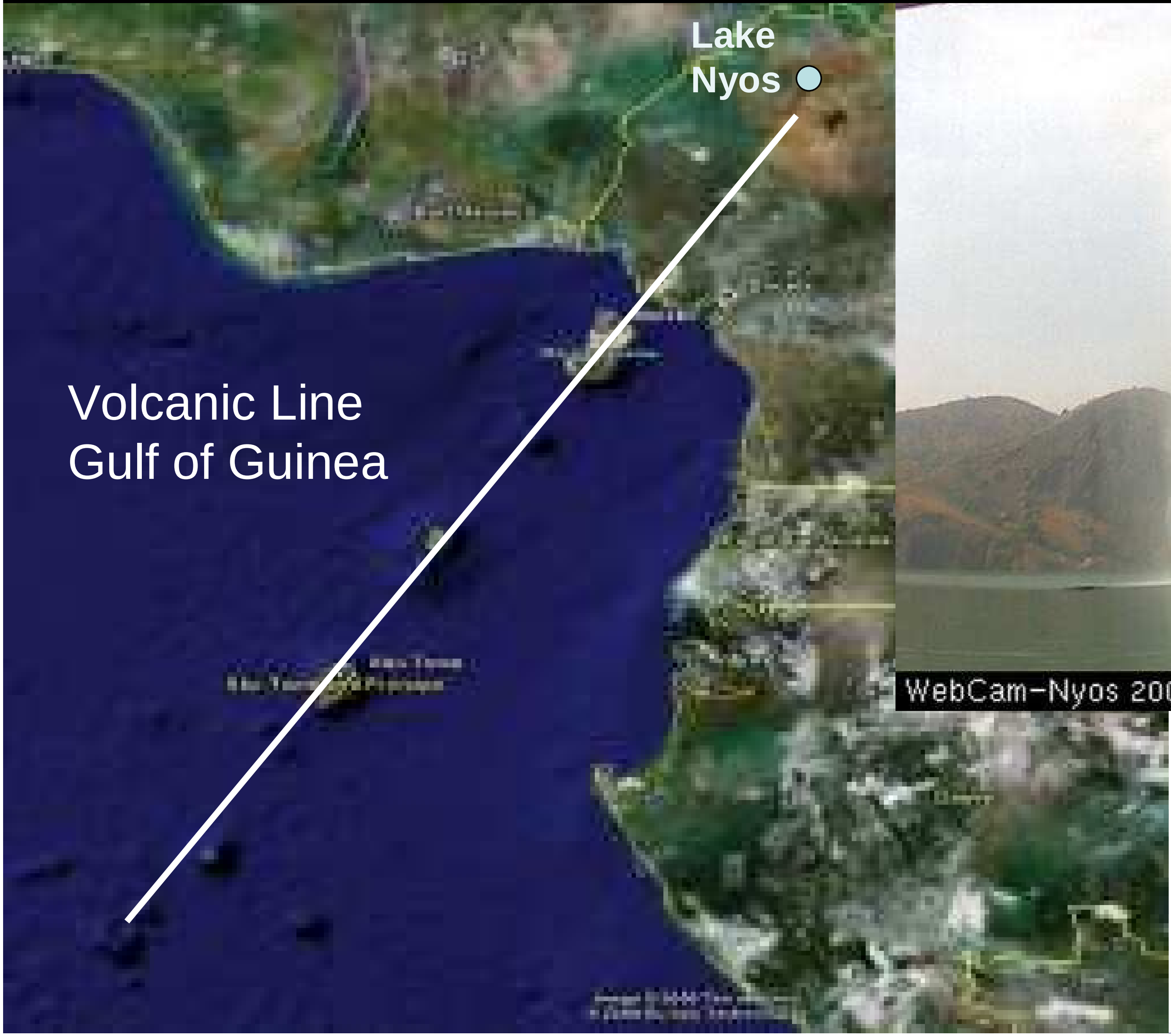
2. Acids same top to bottom. Equilibrated.

Two Separate Charges.
Asphaltenes were Disequilibrium
Now Equilibrium.
Vertical Connectivity Implied.

Large Methane Influx into Black Oil



Disequilibrium for 'Reservoir' Due to Recent Charging.



Petronas

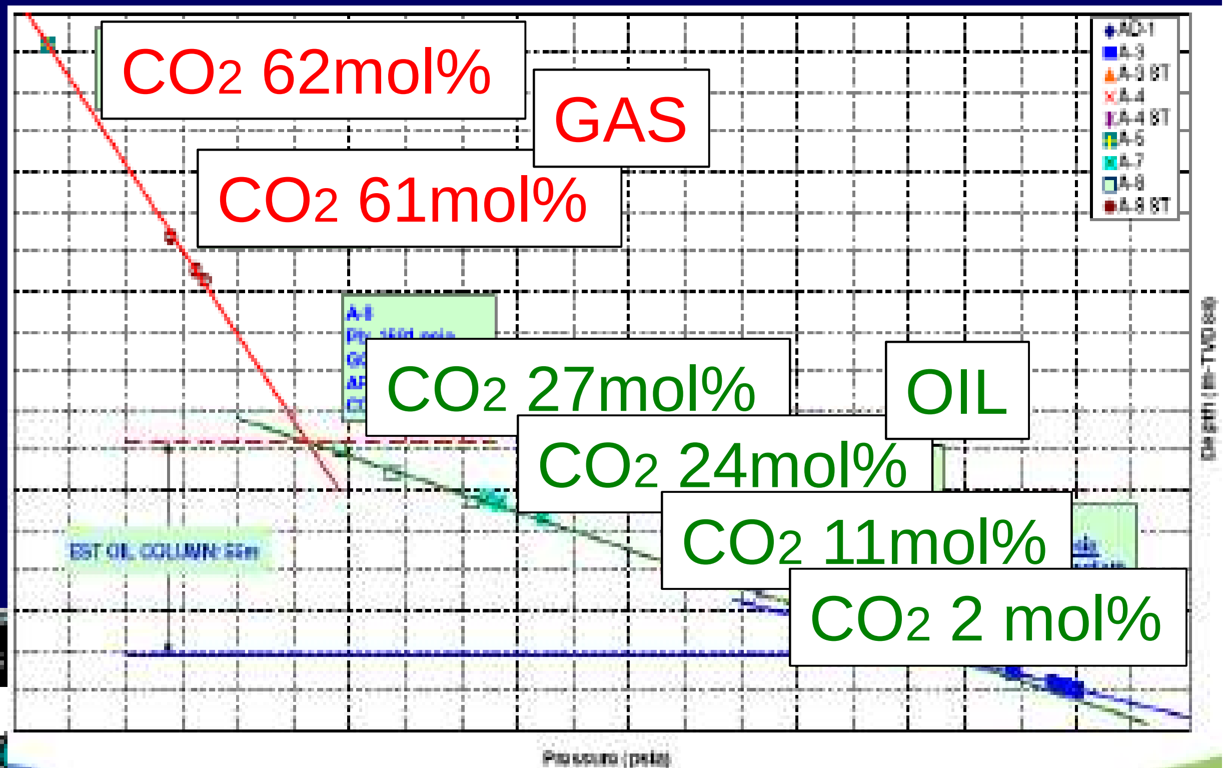
IFA:
CO_2 *NOT* Equilibrated.

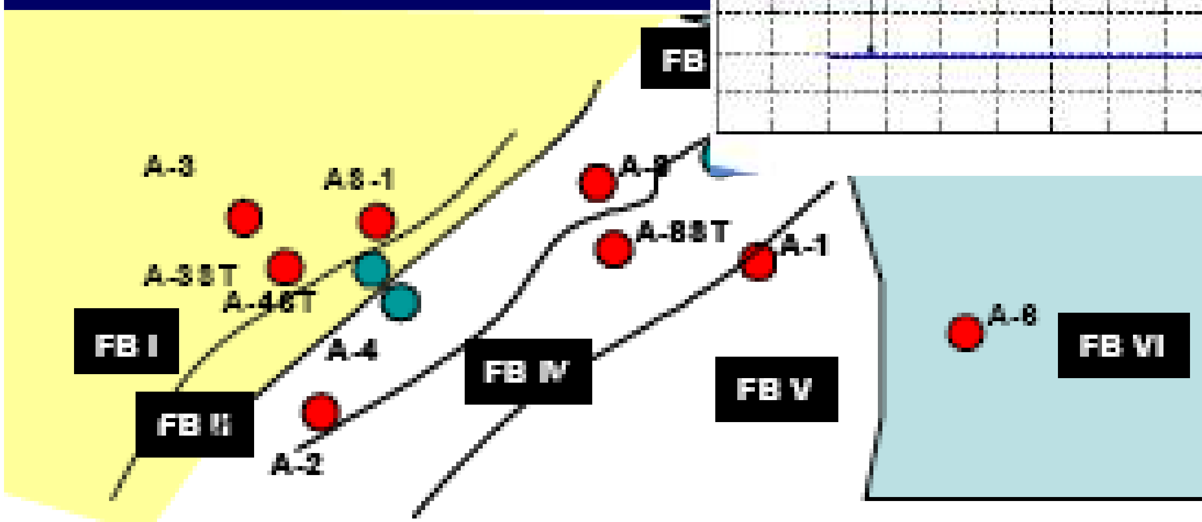
Either

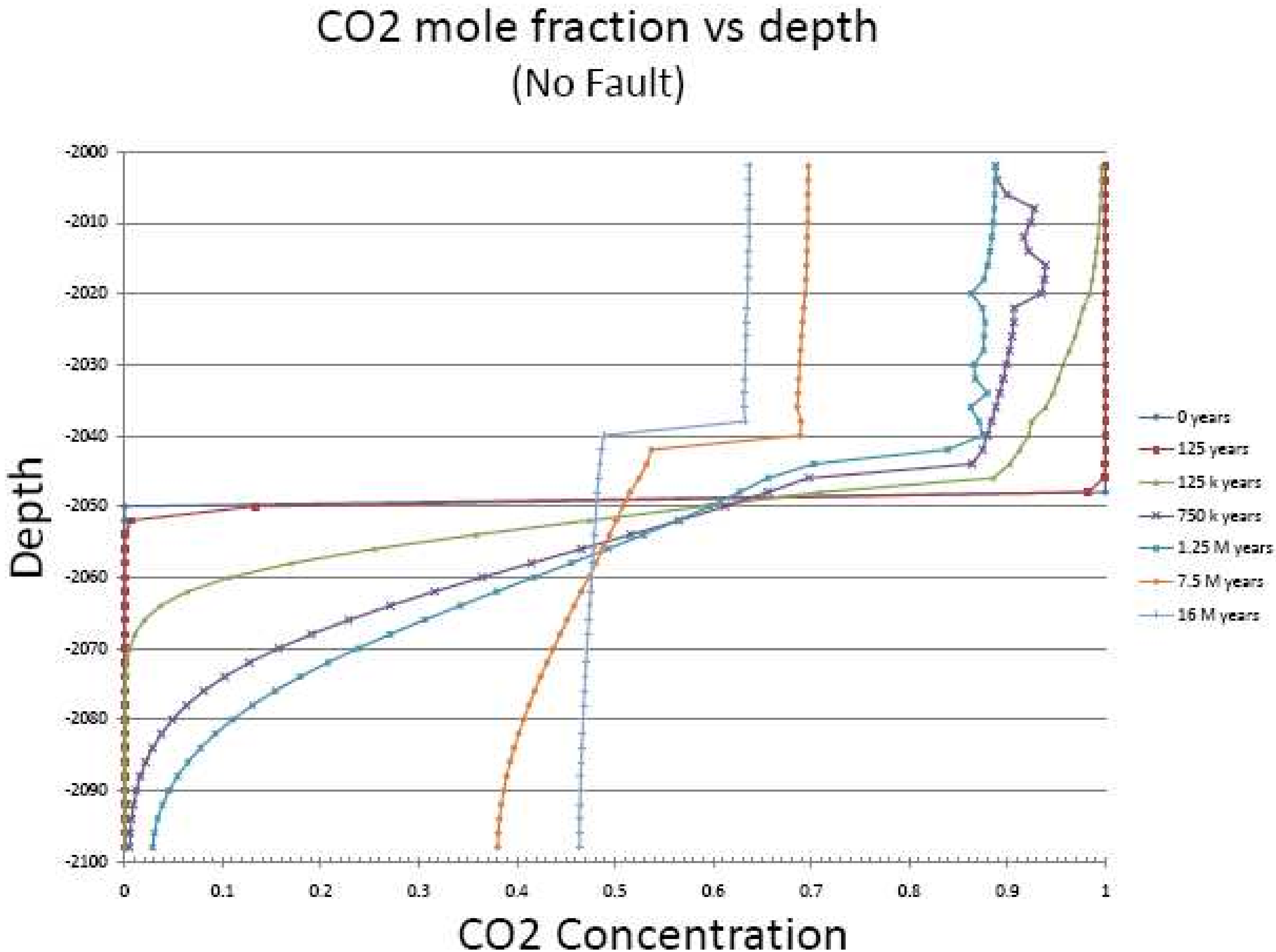
1) Compartment
(FB = Fault Blocks)
Discard FDP

or

2) (Slow) Diffusion
Employ FDP







CO2 mole fraction vs depth
(No Fault)
Depth
CO2 Concentration
-2000
-2010
-2020
-2030
-2040
-2050
-2060
-2070
-2080
-2090
-2100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0 years
125 years
125 k years
750 k years
1.25 M years
7.5 M years
16 M years

Conclusions:

1) Fluid complexities and compartmentalization are large unresolved issues in reservoir management.

2) DFA is required to optimize finding *fluid compositional variation*

3) DFA is a new tool to *find compartments & connectivity* especially using new Asphaltene Science.

4) DFA is path to Continuous Downhole Fluid Log

5) Reservoir Evaluation
New Technology. DFA
New Asphaltene Science
New Work Flows