Qualifying Source Rock Properties with Reservoir Fluid Geodynamics*

Armin I. Kauerauf[1], Oliver C. Mullins[1], Kang Wang[1], and Oluwaseun A. Fadipe[1]

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[1] Schlumberger (ofadipe@slb.com)

Abstract

The distribution of hydrocarbon fluid compounds within a reservoir is of great interest for production. Properties and distribution of compounds and phases determine production constraints. For example, GOR defines generally the type of producible hydrocarbons and asphaltene content has a serious impact on viscosity and thus on oil flow and production rates. Within this work we model the distribution of hydrocarbons over geological time in a reservoir for two different charging scenarios. The first scenario is a rather homogeneous charging according to established compositional generation and expulsion models, which are common in basin and petroleum systems modeling. The other scenario is based on charging with strongly varying reservoir influx coming from a SARA-type (Saturates, Aromatics, Resins, Asphaltenes) source rock generation and expulsion model. We assume that the hydrocarbons, which are expelled from the source, are gathered in a reservoir in a first modeling step and that the reservoir has been filled initially with a hydrocarbon column in thermodynamic dis-equilibrium. In a second step, we model how the trapped hydrocarbon distribution moves towards equilibrium. This process shows a continuous crossover of different GOR, biomarker and asphaltene gradients within the hydrocarbon column. Each gradient might be in a different state at a different time not necessarily reaching equilibration at the same time. This second step represents geologic modeling of in reservoir processes on a geological time scale. This approach is rather new and has been named "Reservoir Fluid Geodynamics"*. The evolution of the compositional distribution over geological time provides valuable input to the risk management prior to production.

Reference Cited

Wang, K., A.Kauerauf, J.Y. Zuo, Y. Chen, C. Dong, H. Elshahawi, and O.C. Mullins, 2015, Differing Equilibration Times of GOR, Asphaltenes and Biomarkers as Determined by Charge History and Reservoir Fluid Geodynamics: Petrophysics, v. 56/5, p. 440-446.

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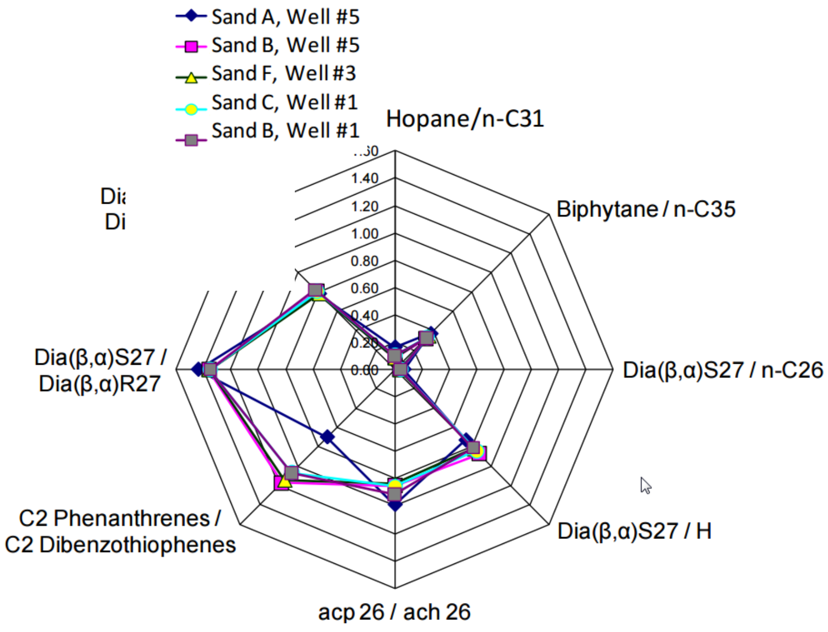
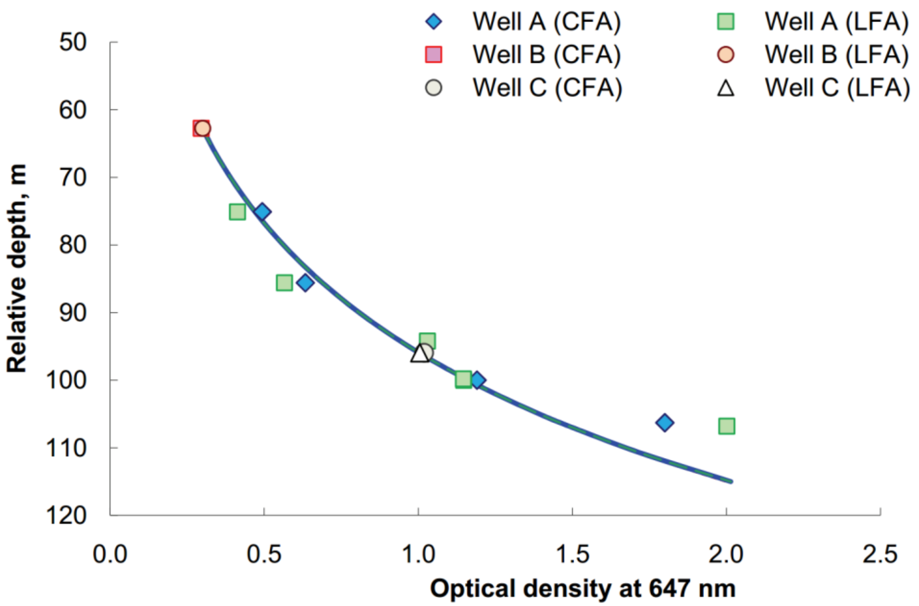
Deepwater GoM

Biomarker Disequilibrium



Disconnected?

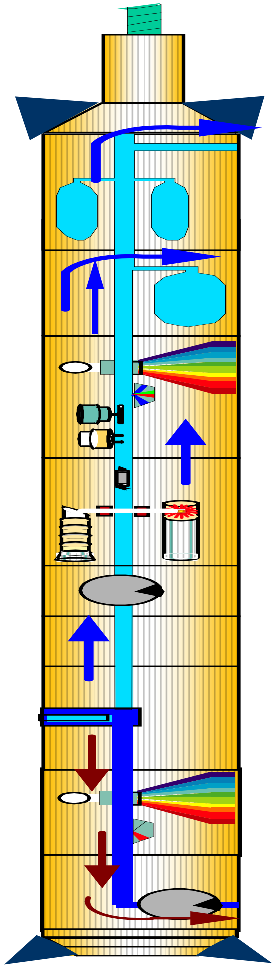
Asphaltene Equilibrium



Connected?

Fluid Sampling Tools

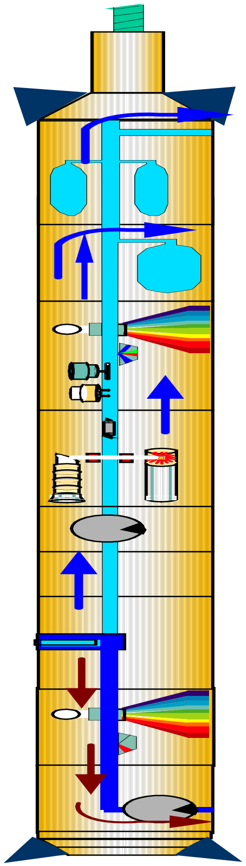
DFA MDT

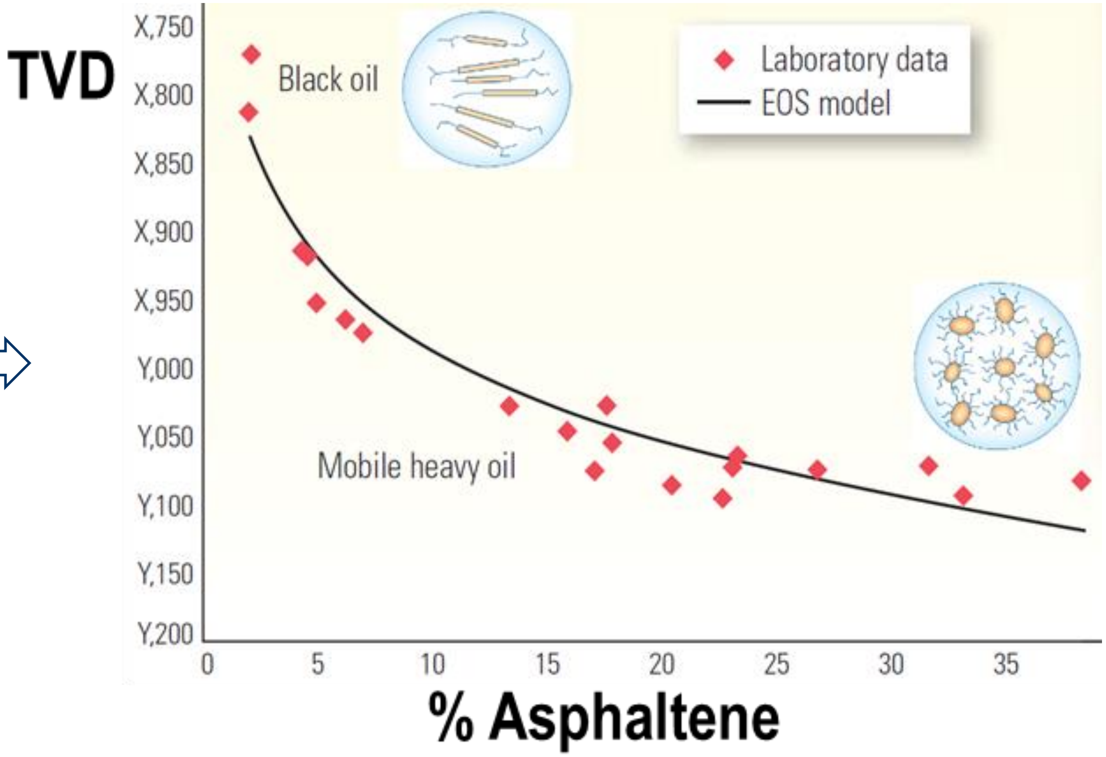


Fluid Samples

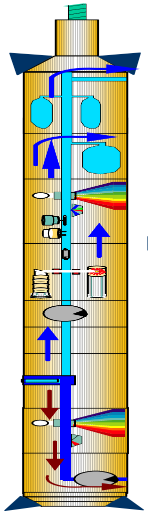
Ubiquitously Performed

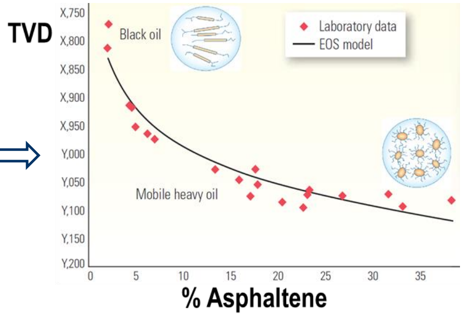
Compositional Gradient

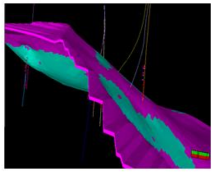




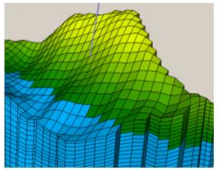
Key Production Concerns





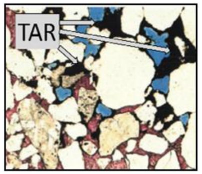


Connectivity

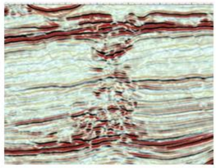


Reservoir context

Heavy oil gradient



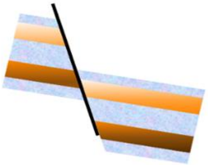
Tar mat



Gas charge

Flow assurance

Equilibrium & disequilibrium



Fault migration

Explosion of new applications!

All in a Nutshell

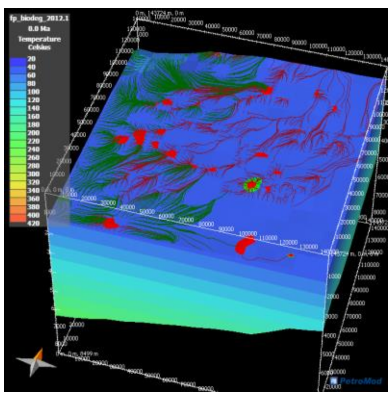
But...

There is Little Modeling of How Reservoir Fluids Equilibrate.

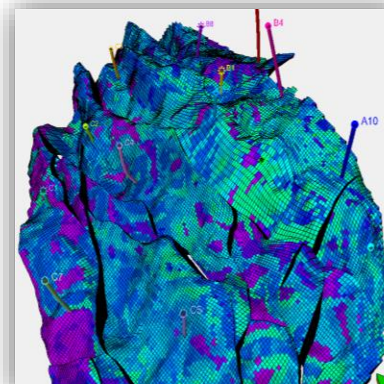
Basin / Petroleum Systems Modelling

Reservoir Fluid Geodynamics

Production Simulation



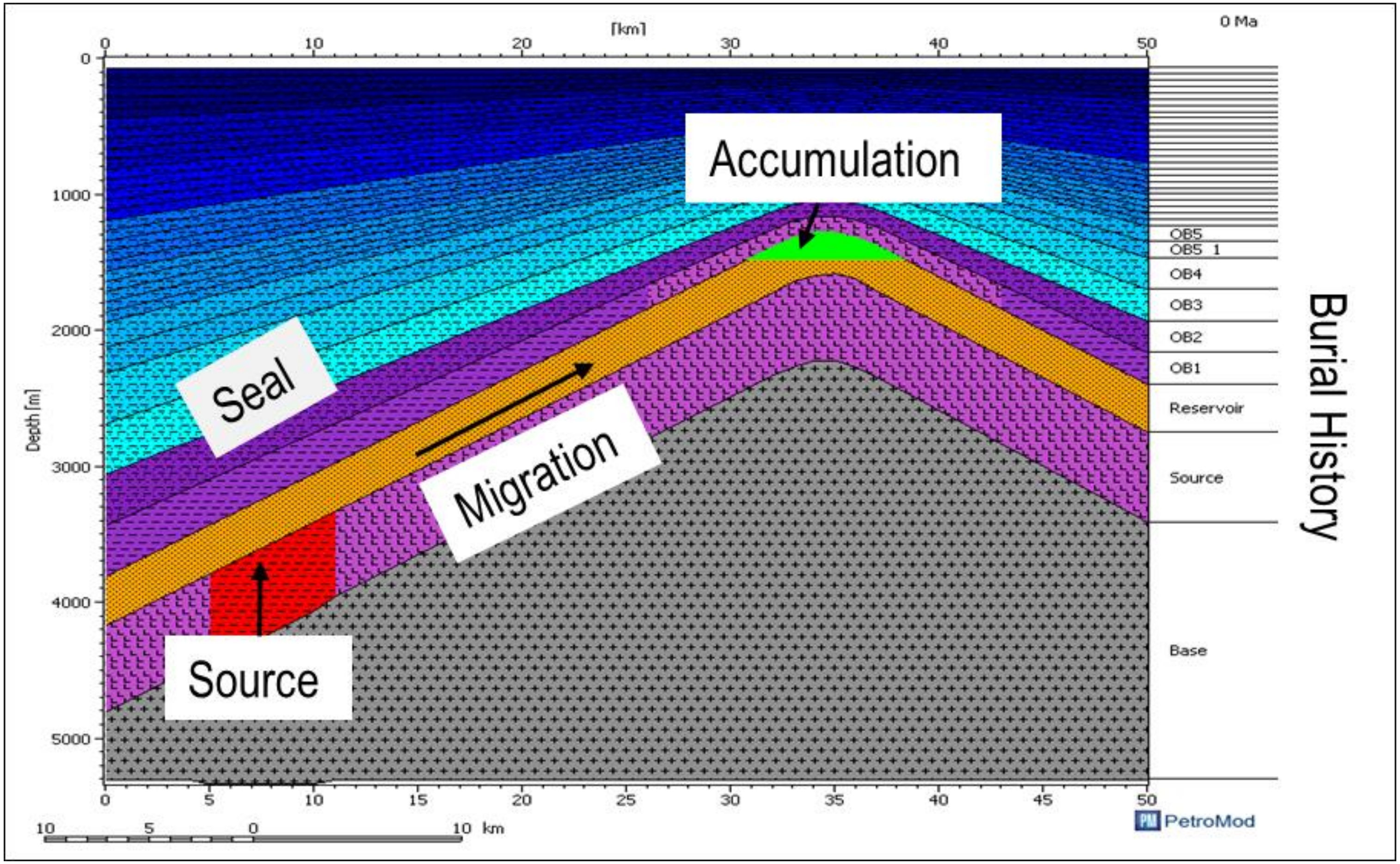
Little Modeling



Geological Time ⟹ Toward Equilibrium ⟹ Production Time

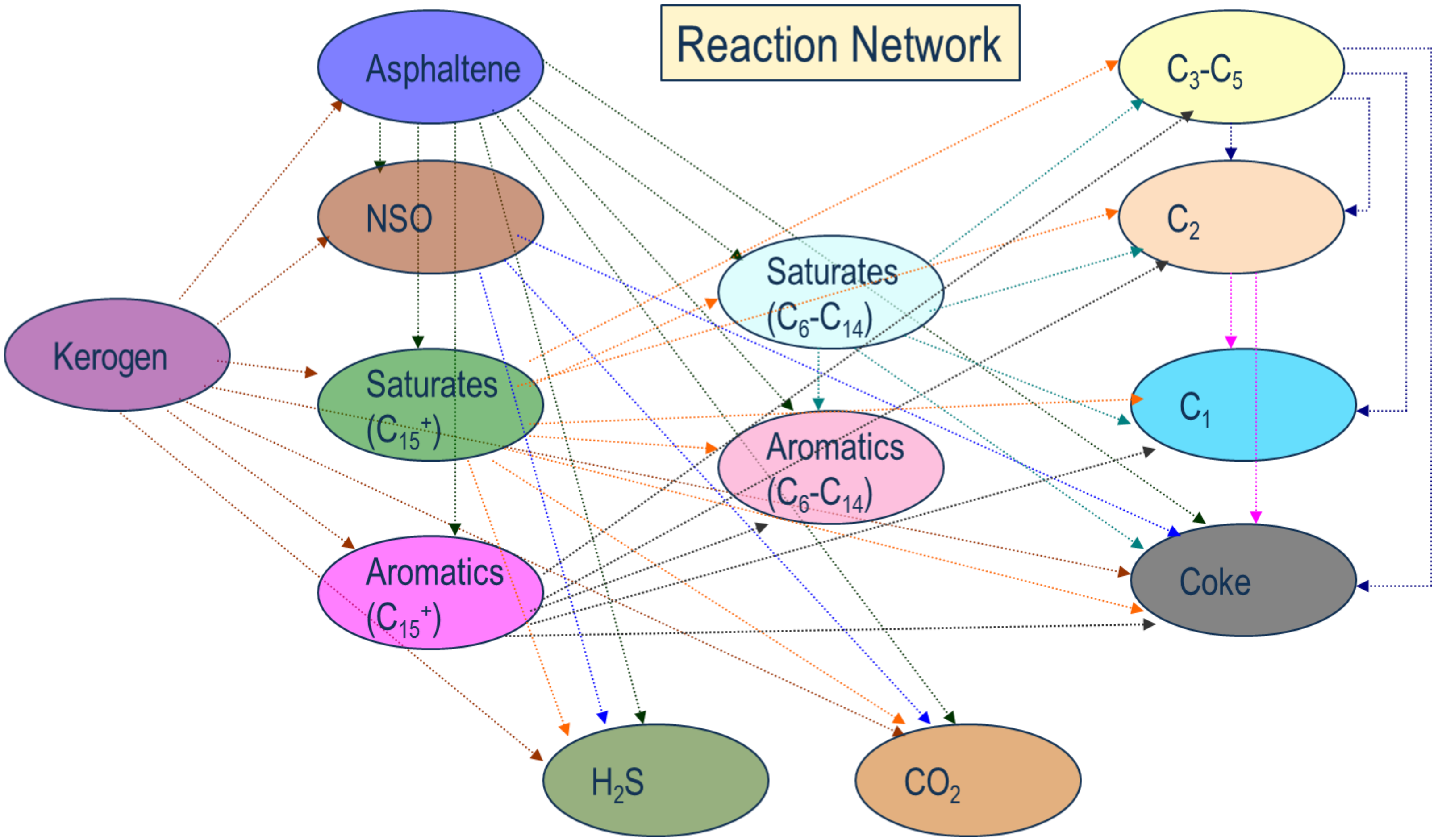
Until Now...

Charging: Petroleum Systems



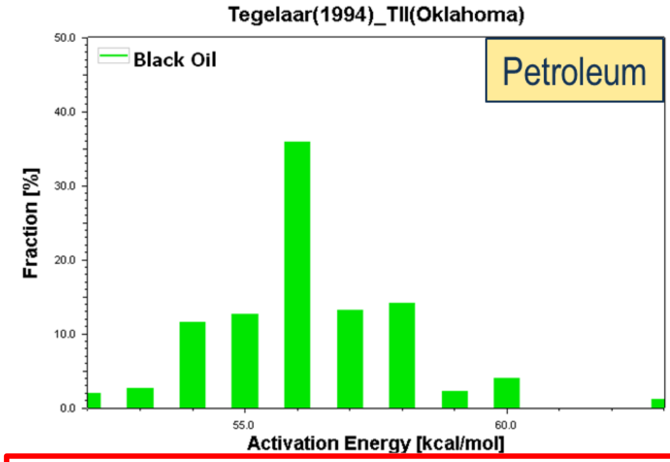
Solubility Class Kinetics

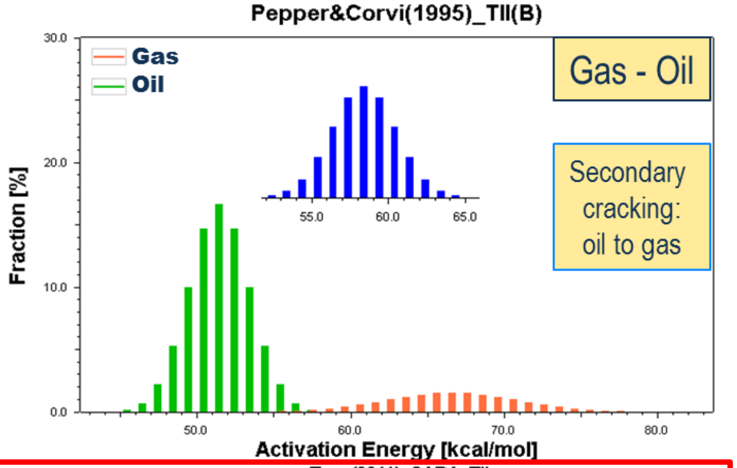
Saturates, Aromatics, Resins, Asphaltenes (SARA)

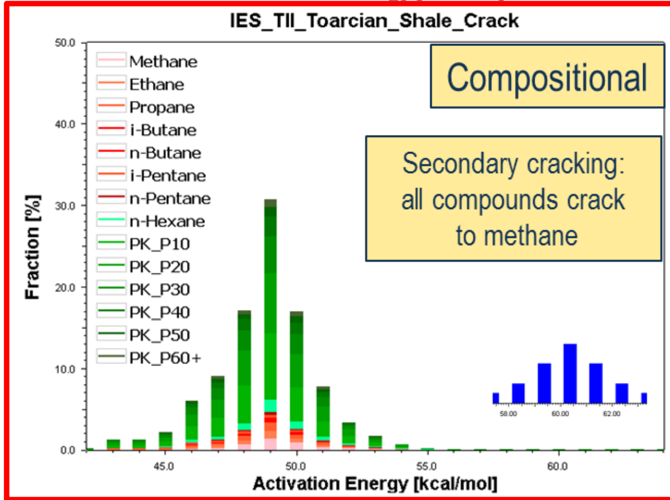


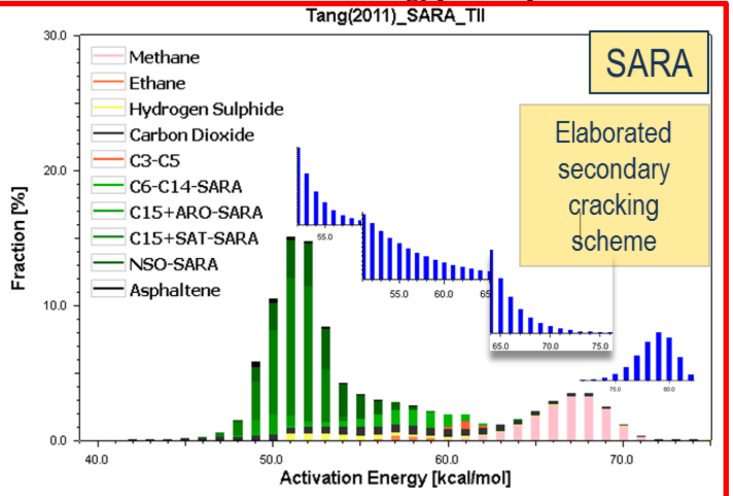
Hydrocarbon Generation

Arrhenius Reaction Kinetics with Activation Energy Distribution

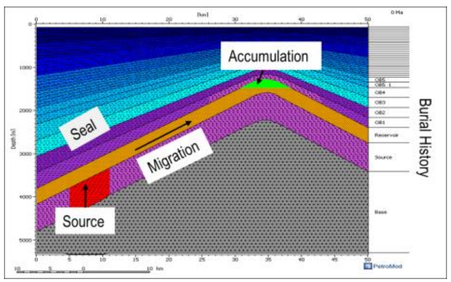








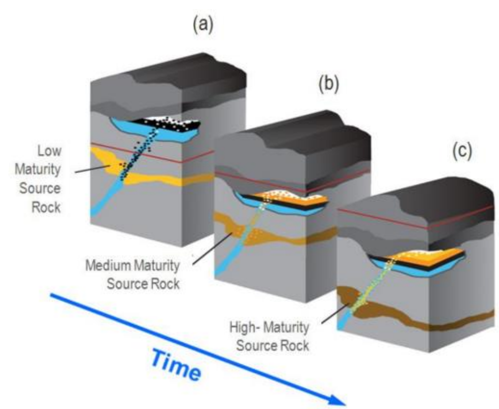
Distinct Charge Mechanism



Homogeneous Charge

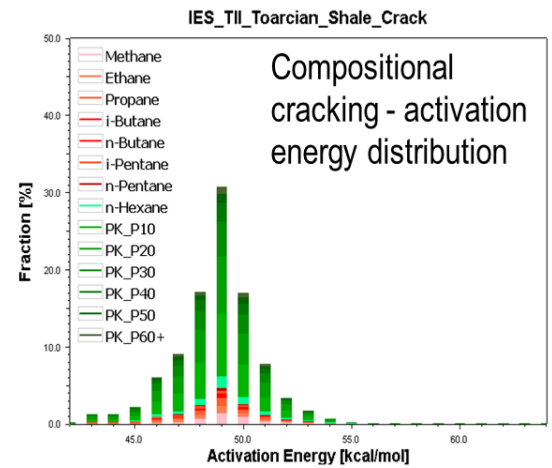
VS.

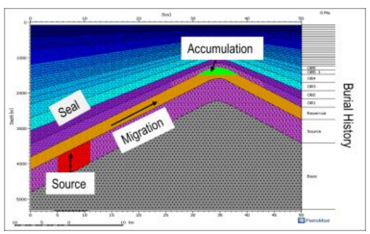
Layer-cake Charge



Cracking Kinetics

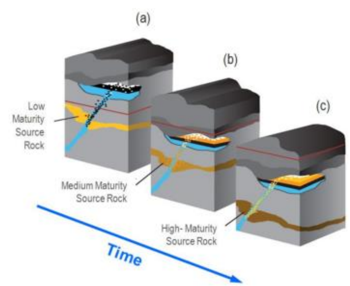
Homogeneous Charge

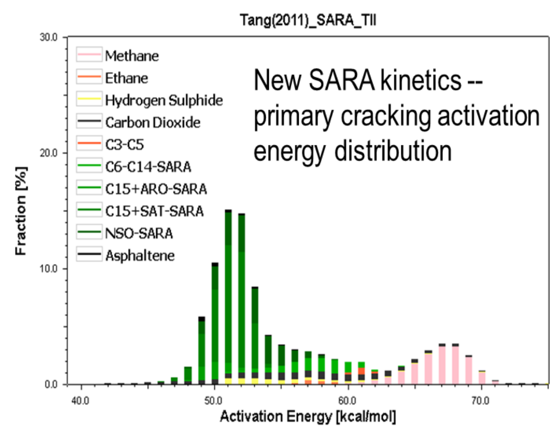




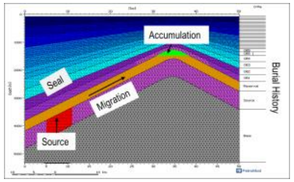
VS.

Layer-cake Charge



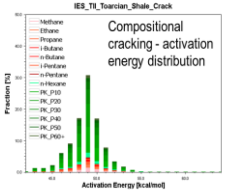


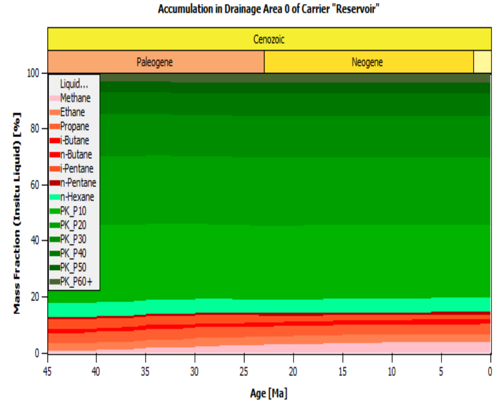
End of Charge



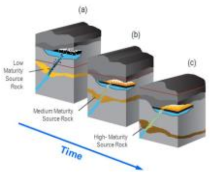
VS.

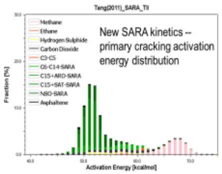
Homogeneous Charge

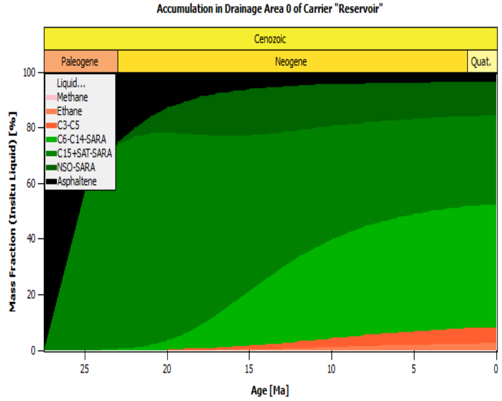




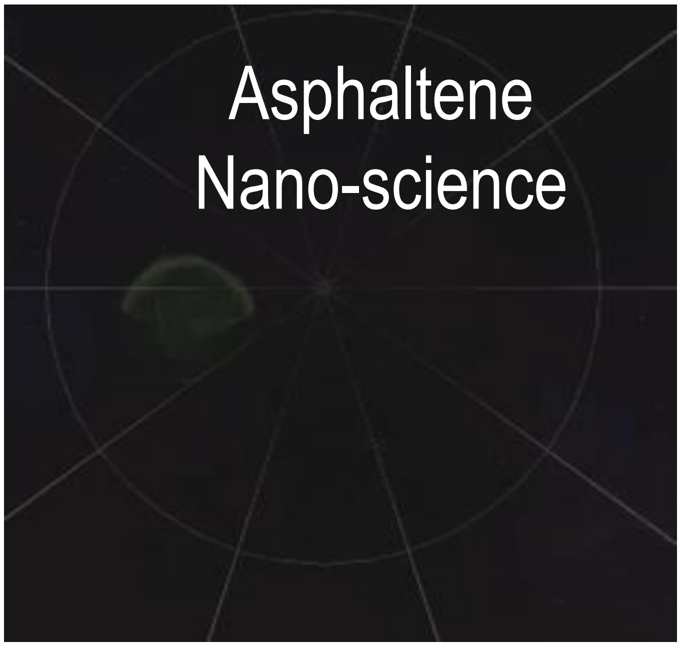
Layer-cake Charge

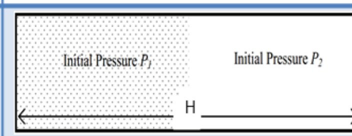
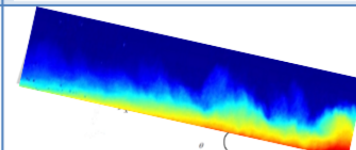
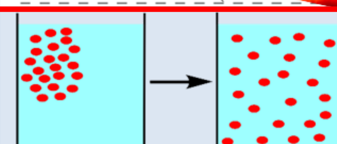






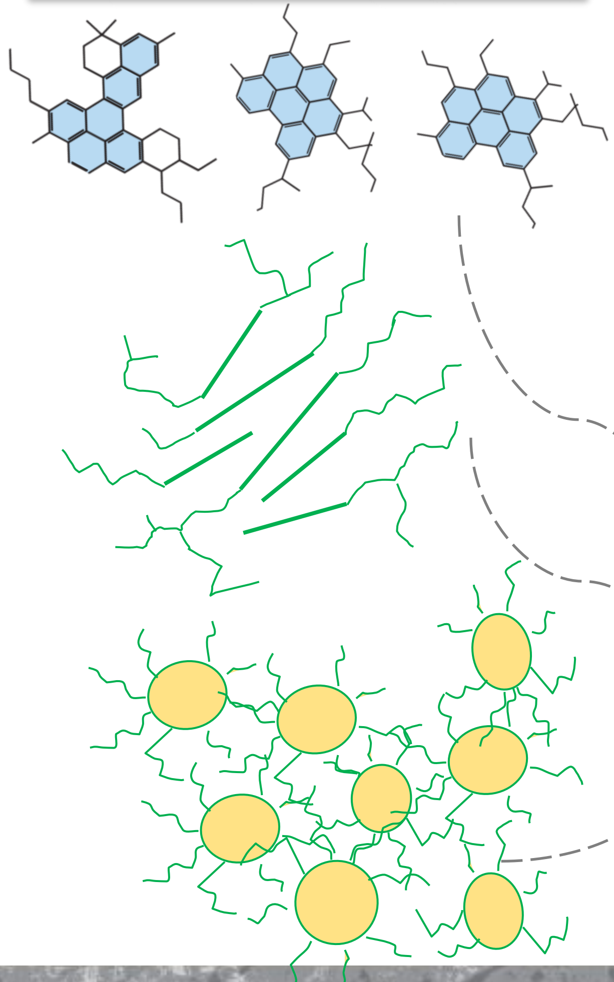
Fluid Dynamics Modeling

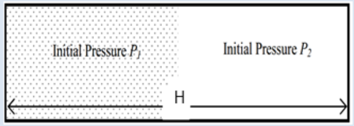
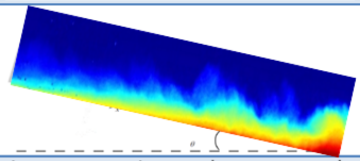
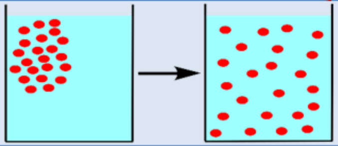


<table>
<tr><th>Mechanism</th><th>Physics</th><th>Basic Formula</th><th>Scale of Interest</th></tr>
<tr><td>Pressure diffusion</td><td>
</td><td>$\rho c_t \frac{\partial P}{\partial t} = \nabla \cdot (\rho \mathbf{u})$</td><td>Production time</td></tr>
<tr><td>Convection</td><td></td><td>$\frac{\partial h}{\partial t} = \frac{\Delta\rho g k}{\phi\mu}\left(-\sin\theta \frac{\partial h}{\partial x} + \frac{\cos\theta}{2}\nabla^2 h^2\right)$</td><td>$10^3$~$10^6$ years</td></tr>
<tr><td>Molecular diffusion</td><td></td><td>$\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}\left(D_{12}\frac{\partial x_1}{\partial z}\right)$</td><td>Geologic time</td></tr>
<tr><td>Gravitational diffusion</td><td>
</td><td>$\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}\left(D_{12}\frac{\Delta\rho g V_1}{RT}x_1\right)$</td><td>Geologic time</td></tr>
</table>

Fluid Dynamics Modeling

Yen-Mullins Model



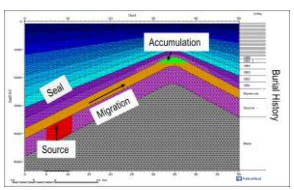
Mechanism	Physics	Basic Formula	Scale of Interest
Pressure diffusion		$\rho c_t \frac{\partial P}{\partial t} = \nabla \cdot (\rho \boldsymbol{u})$	Production time
Convection		$\frac{\partial h}{\partial t} = \frac{\Delta\rho g k}{\phi\mu}\left(-\sin\theta \frac{\partial h}{\partial x} + \frac{\cos\theta}{2}\nabla^2 h^2\right)$	$10^3 \sim 10^6$ years
Molecular diffusion		$\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}\left(D_{12}\frac{\partial x_1}{\partial z}\right)$	Geologic time
Gravitational diffusion		$\boxed{\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}\left(D_{12}\frac{\Delta\rho g V_1}{RT}x_1\right)}$	Geologic time

Charge Process

Initial
(End of Charge)

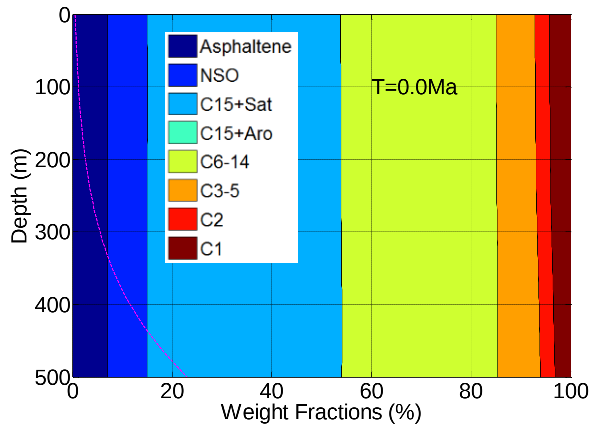
VS.

Final
(Equilibrium)



VS.

Homogeneous Charge



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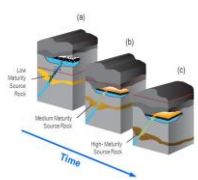
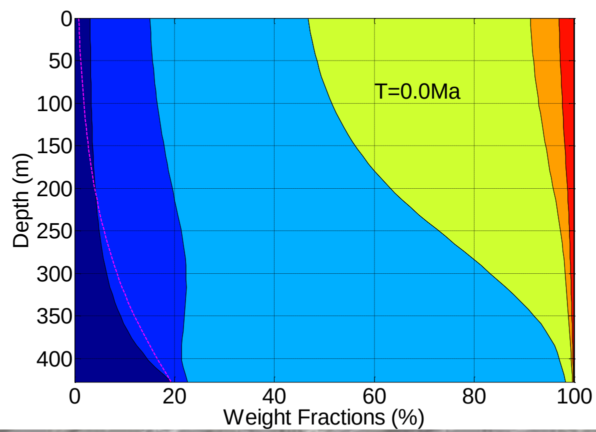
Layer-cake Charge





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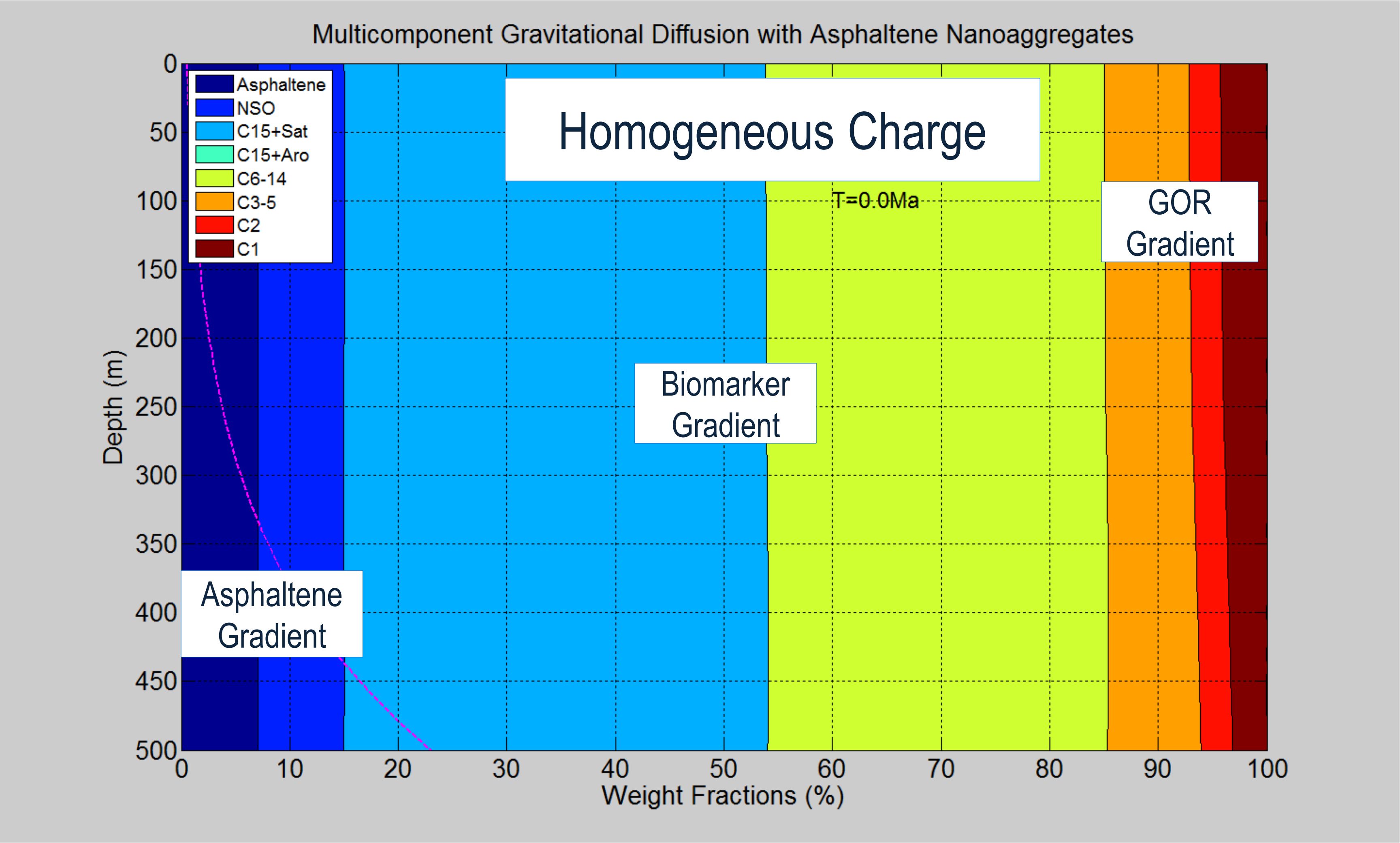
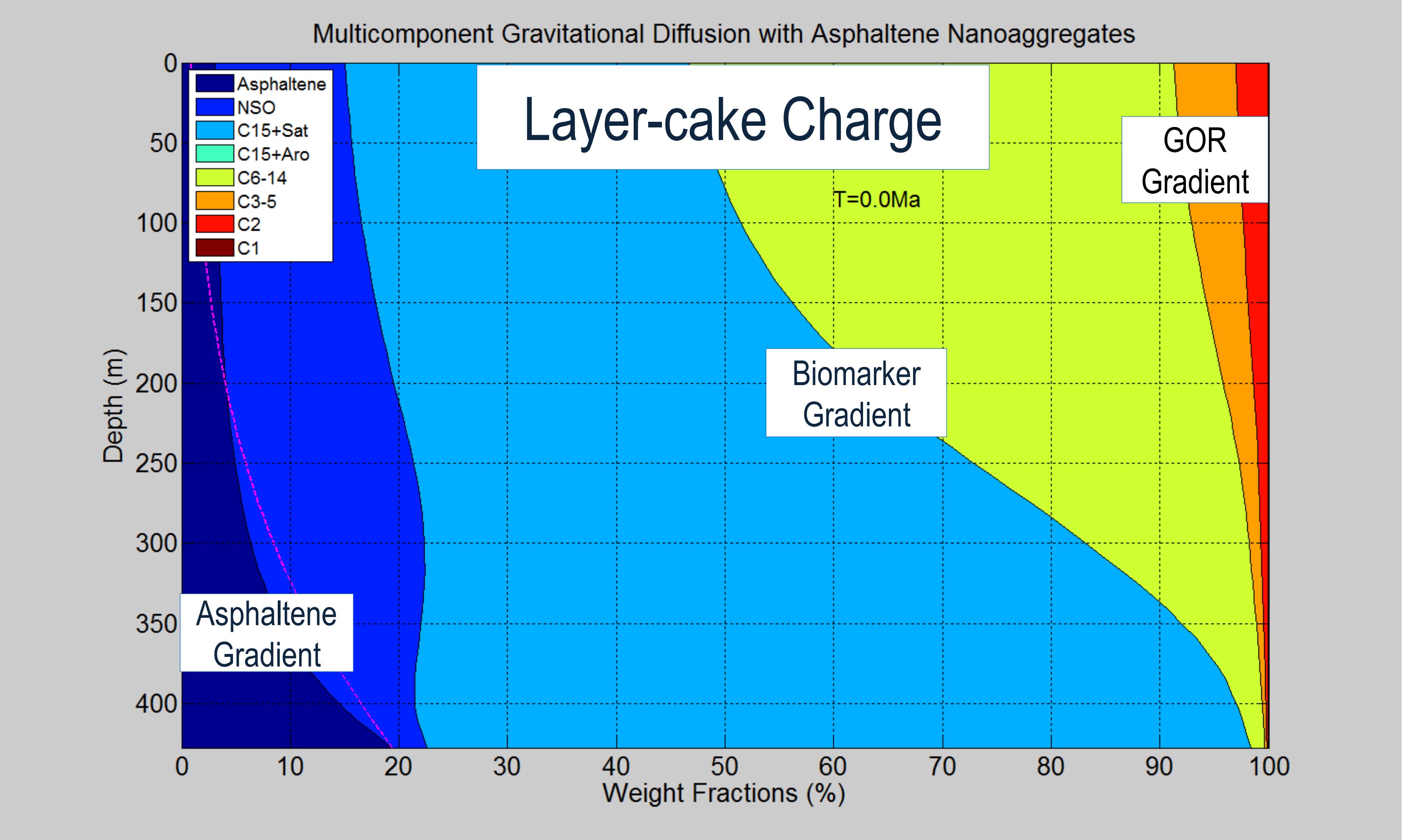
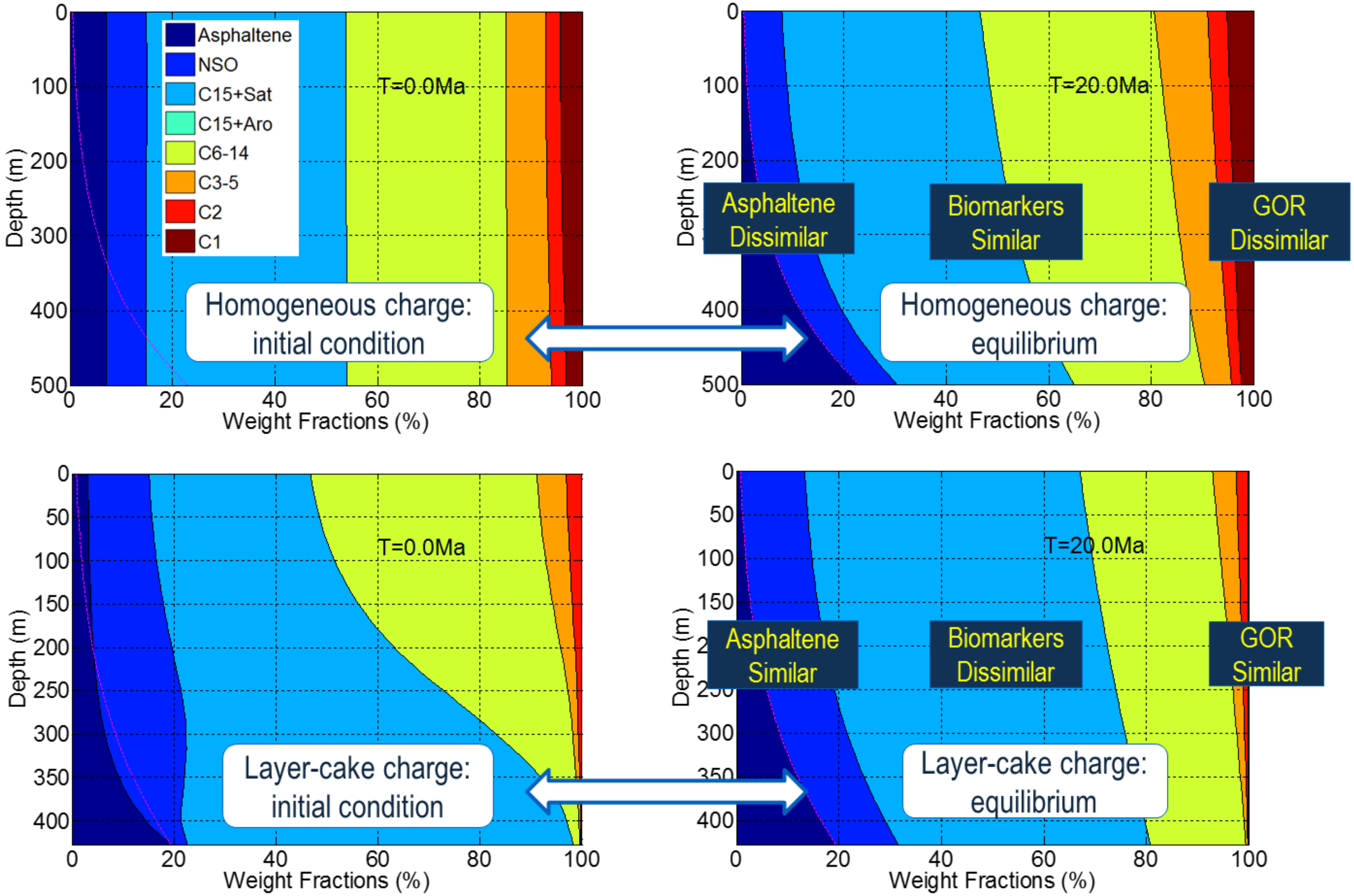
Charge Result: Scenario I



Charge Result: Scenario II

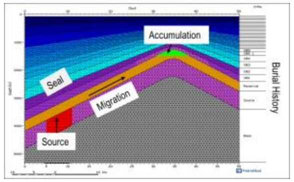


Charge Results: Holistic View

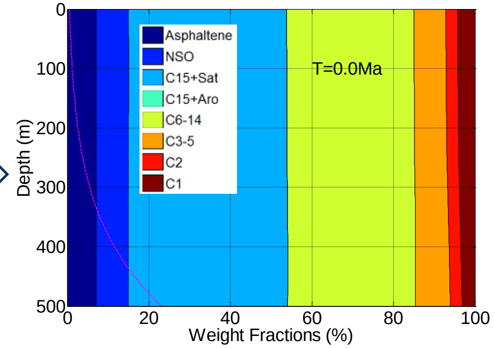


Compositional Distribution

Initial (End of Charge) VS. Final (Equilibrium)



Homogeneous Charge



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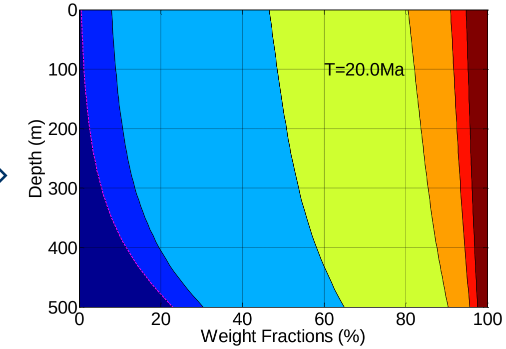
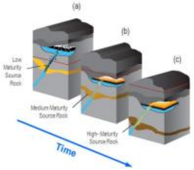
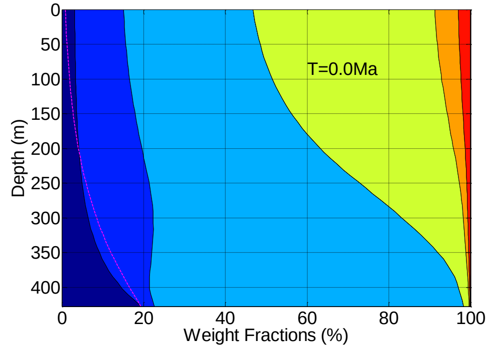


VS.

Layer-cake Charge





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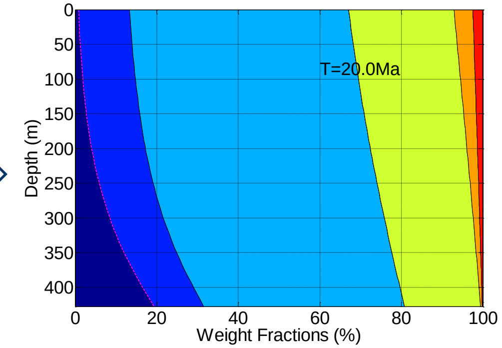


“Statement of Fact”

Equilibrium or dis-equilibrium…

is dictated by the ‘thermodynamic distance’

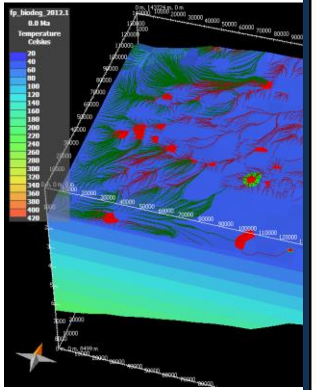
from initial to final condition

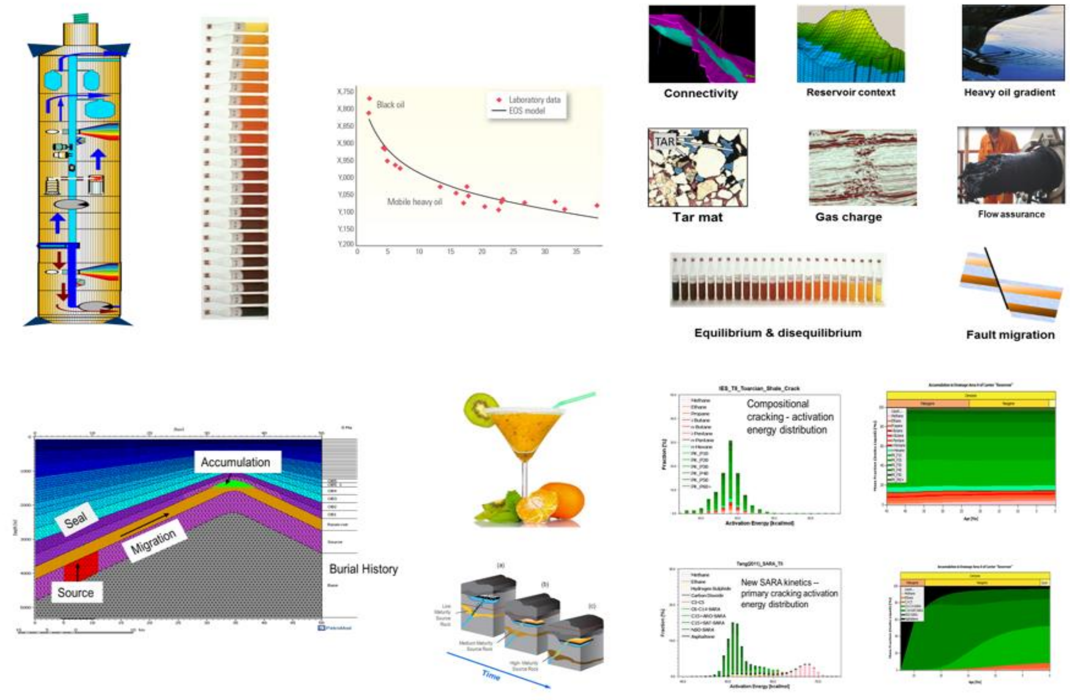
of different components.

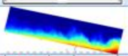
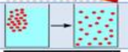
*------ O. C. Mullins, K. Wang, A. Kauerauf, J. Y. Zuo, Y. Chen, C. Dong, H. Elshahawi, 56th **SPWLA** Symposium, Long Beach, CA, Jul 18-22, 2015.*

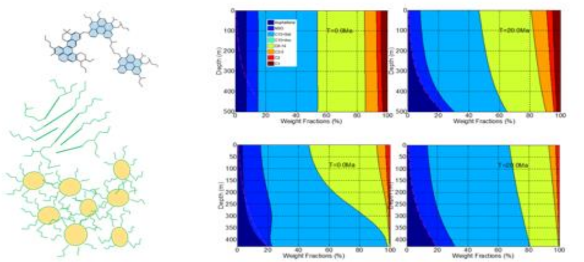
Reservoir Fluid Geodynamics

Basin / Petroleun
Systems Modellin

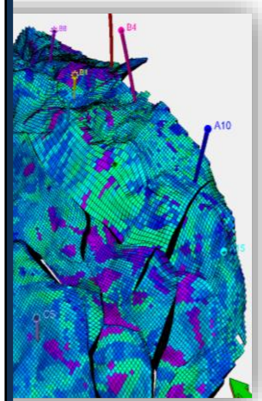




Mechanism	Physics	Basic Formula	Scale of Interest
Pressure diffusion		$\rho c_t \frac{\partial P}{\partial t} = \nabla \cdot (\rho u)$	Production time
Convection		$\frac{\partial h}{\partial t} = \frac{\Delta\rho g k}{\phi\mu}\left(-\sin\theta \frac{\partial h}{\partial x} + \frac{\cos\theta}{2}\nabla^2 h^2\right)$	10^3–10^6 years
Molecular diffusion		$\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}\left(D_{12}\frac{\partial x_1}{\partial z}\right)$	Geologic time
Gravitational diffusion		$\frac{\partial x_1}{\partial t} = \frac{\partial}{\partial z}(D_{12}\frac{\Delta\rho g V_1}{RT}x_1)$	Geologic time



roduction
imulation



Geological Time

on Time

Reference

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