Sweet Spots in Shale Gas and Liquids Plays: Prediction of Fluid Composition and Reservoir Pressure*

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Abstract

Prediction of fluid composition and reservoir pressure are essential elements in the assessment of shale oil and gas plays. The most profitable part of a fairway can often be defined by the intersection of high reservoir pressure with the right gas-oil ratio. In this study, an in-house source rock kinetic model (Osborne and Barwise, 2011) was coupled with regional basin modeling in the Eagle Ford and Woodford fairways to predict fluid compositions and to evaluate the effect of petroleum generation on pore pressure. The in-house kinetic model accounts for petroleum retained in both organic and inorganic porosity. With this kinetic model, maps of thermal stress were converted to maps of gas-oil ratio, viscosity, and BTU content to predict flow of both petroleum and revenue from wells across the fairway. In both the Eagle Ford and Woodford, petroleum compositions are closer to an instantaneous product over a narrow thermal stress range rather than a cumulative product from expulsion and migration over a broad range of thermal stress. The petroleum is in near equilibrium with the thermal stress state of the rock and most petroleum was generated in situ and retained as the last generated product with limited lateral migration.

Several authors have proposed that petroleum generation creates most of the over-pressure in source rocks. Basin modeling performed in this study suggests that petroleum generation can account for much of the over-pressure within the Eagle Ford Shale gas fairway (as measured in psi above hydrostatic). However, for both the Anadarko and Maverick basins, the majority of regional over-pressure was generated from disequilibrium compaction during rapid burial associated with foreland subsidence. Late exhumation altered shale reservoir pore pressure states in both basins. Therefore, whereas retained petroleum properties can be linked closely to thermal stress, creation and retention of over-pressure is not strictly due to petroleum generation and a broader, basin-scale interpretation is required in order to define regions where revenue generation will be highest. Because it is often the foreland phase of rapid subsidence and

burial that catalyzes both disequilibrium compaction and source rock maturation, the generation of petroleum and over-pressure are often coeval and their effects on reservoir pressure, effective stress, permeability, and reservoir deliverability can be difficult to differentiate.

References

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Momper, J.A., 1979, Domestic oil reserves forecasting method, regional potential assessment: Oil and Gas Journal, v. 77/33, p. 144-149.

Osborne, M., and T. Barwise, 2011, Beyond Orgas-BP's new predictive model for biogenic and thermogenic gas expulsion from source rocks: International Meeting of Organic Chemistry (IMOG) 2011, Unpublished.

Sweet Spots
in Shale Gas and Liquids Plays

Prediction of Fluid Composition and Reservoir Pressure

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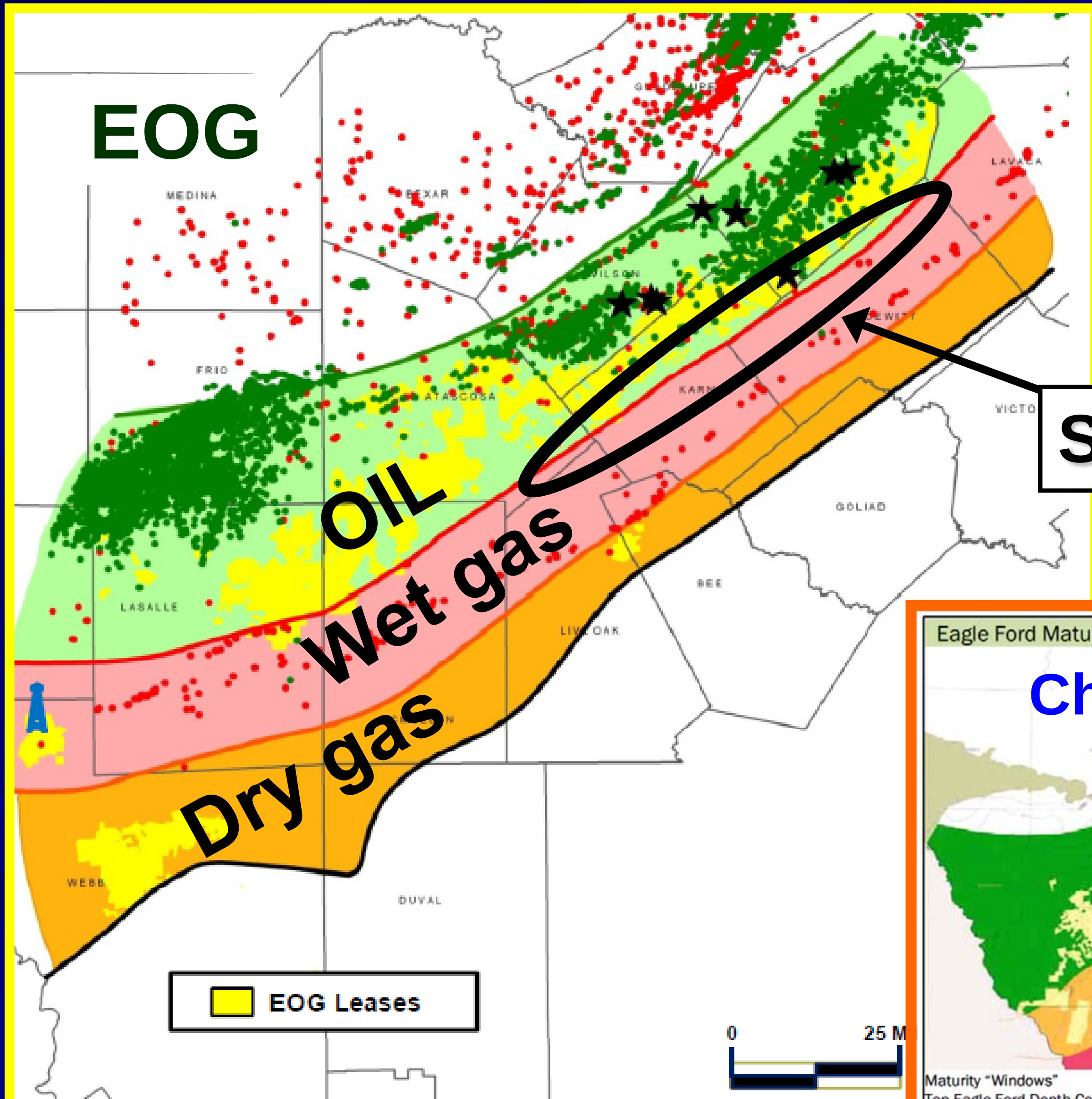
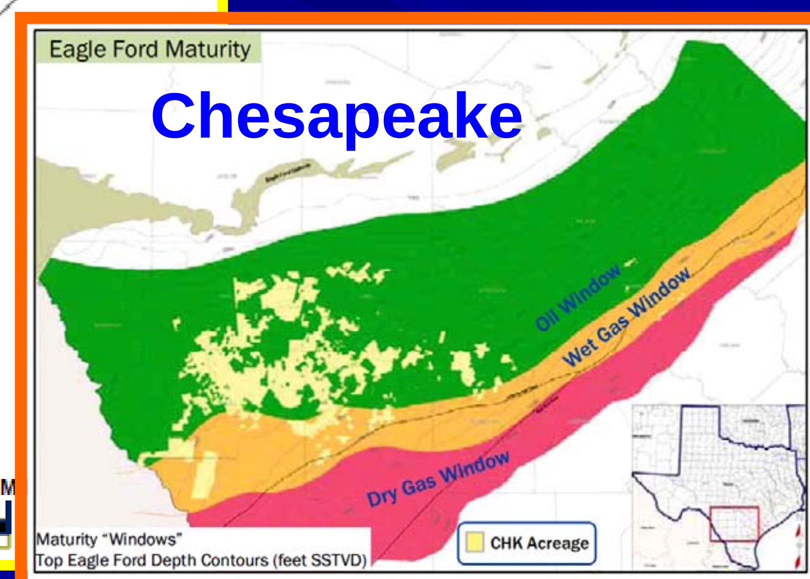
2012 AAPG Annual Convention

Eagle Ford Fluid Fairways





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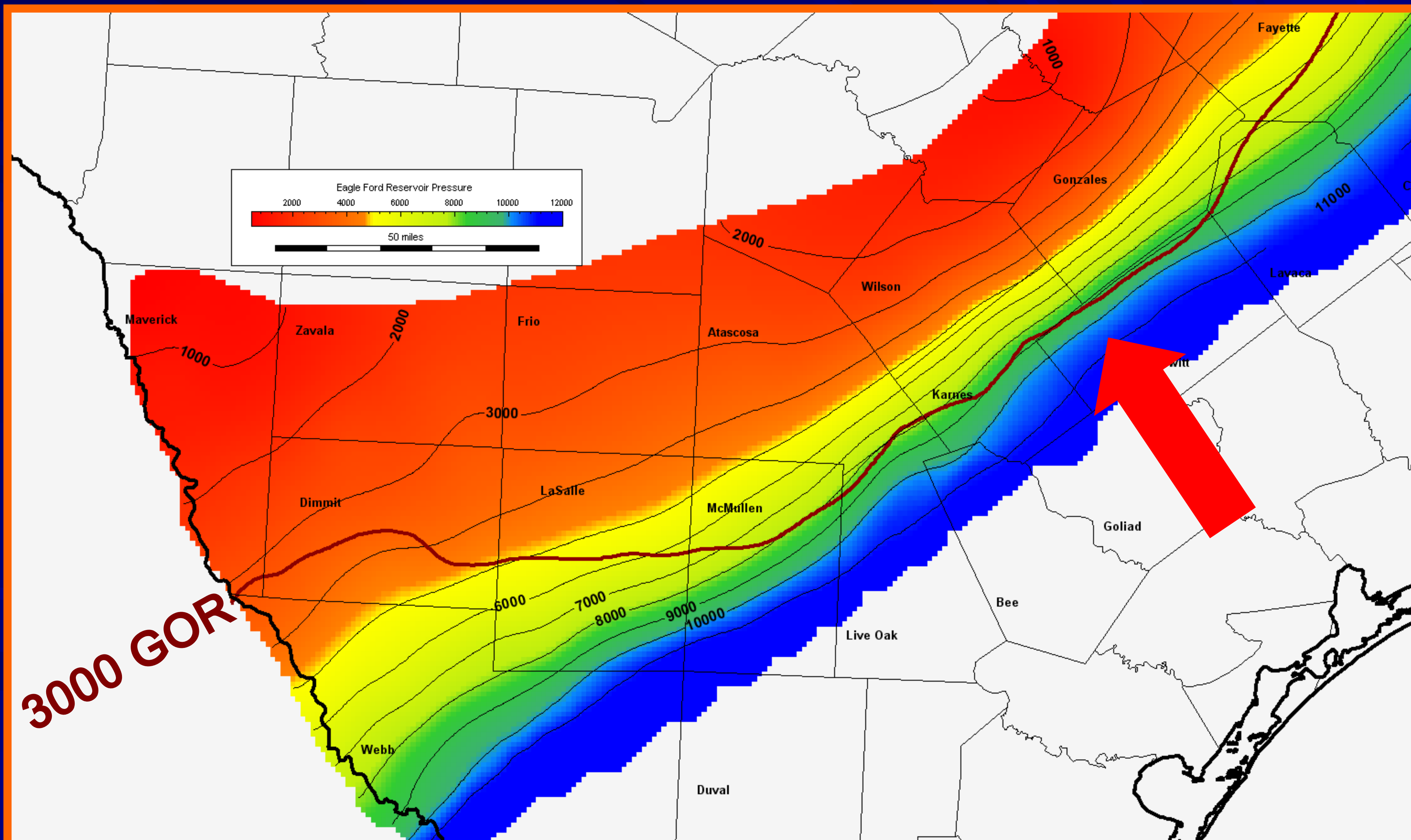
Eagle Ford liquids sweet spot
Intersection of GOR and High Pressure



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"Unconventional" but still obey principles

$$Q = \frac{k * H * \Delta P}{\mu}$$

Q = well flow rate

k = permeability

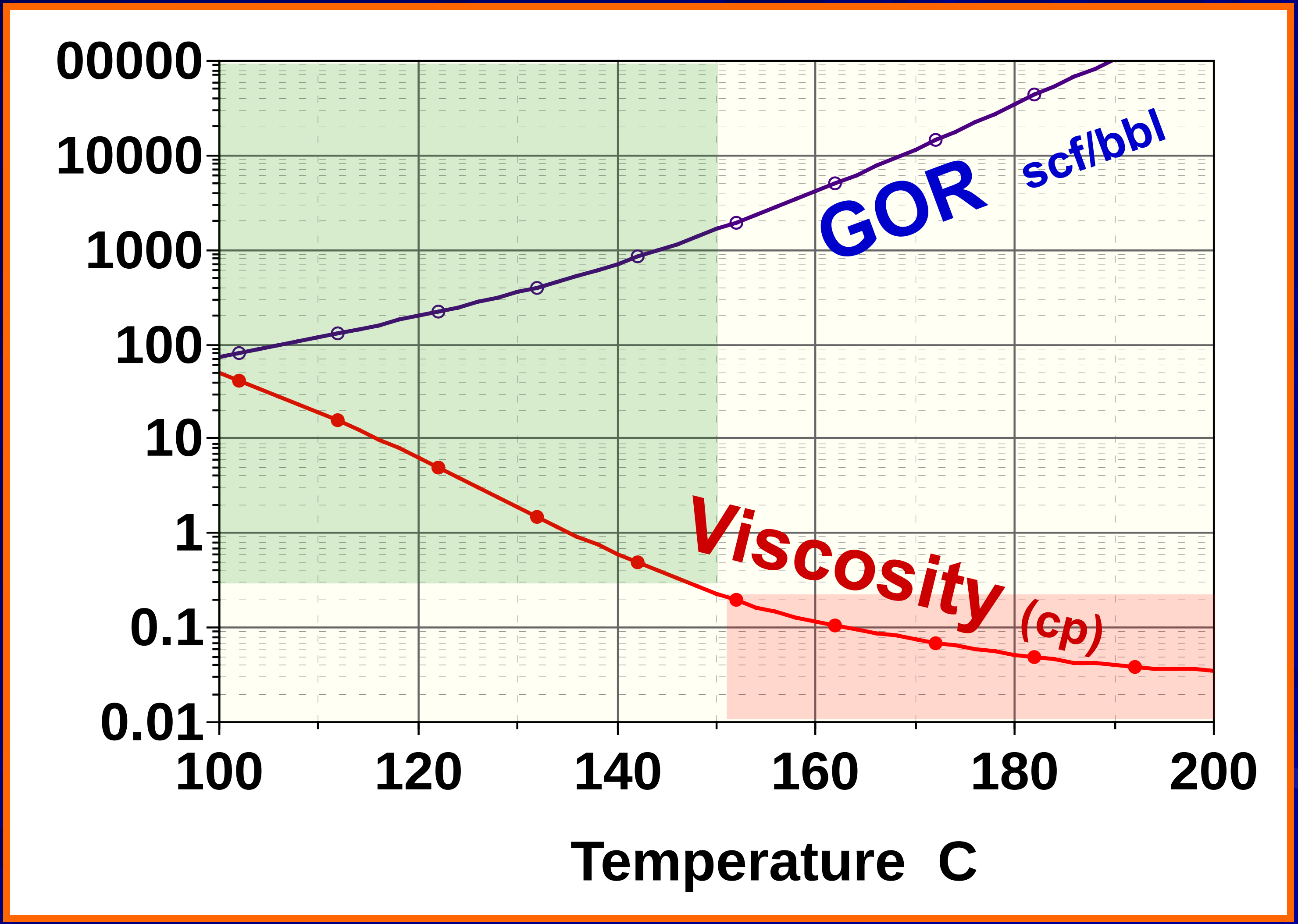
H = thickness

ΔP = Reservoir Pressure – wellbore pressure

μ = viscosity

Viscosity and reservoir pressure are critical for understanding mobility of petroleum in ∠shales⊒ (i.e source rocks).
Viscosity is a function of GOR, which is a function of maturity♍ ♍ and viscosity changes a lot in a typical shale fairway!

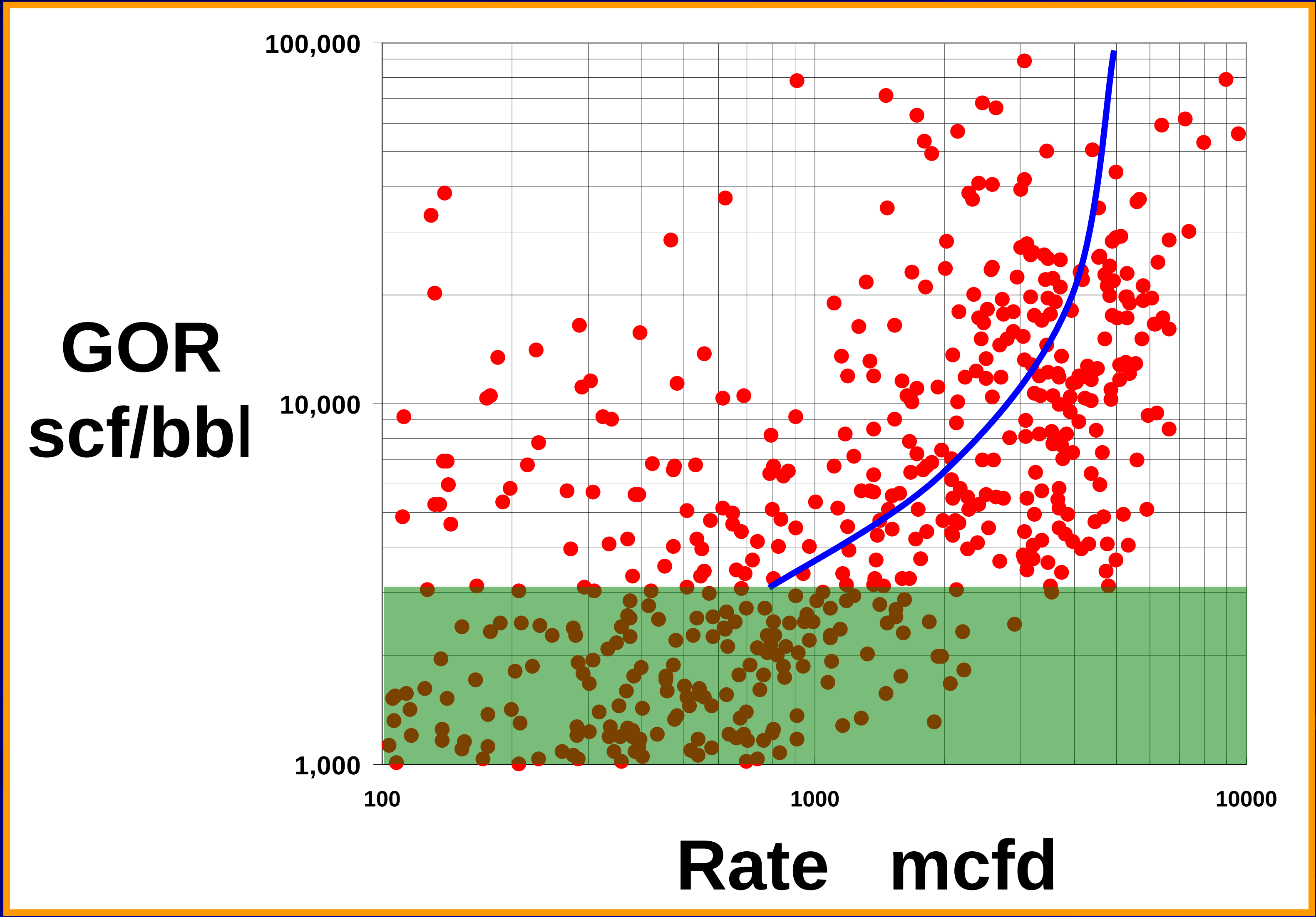
Maturity vs. GOR & Viscosity



As maturity increases, GOR increases four orders of magnitude and viscosity decreases three orders of magnitude

Eagle Ford Gas Rate

Influence of viscosity



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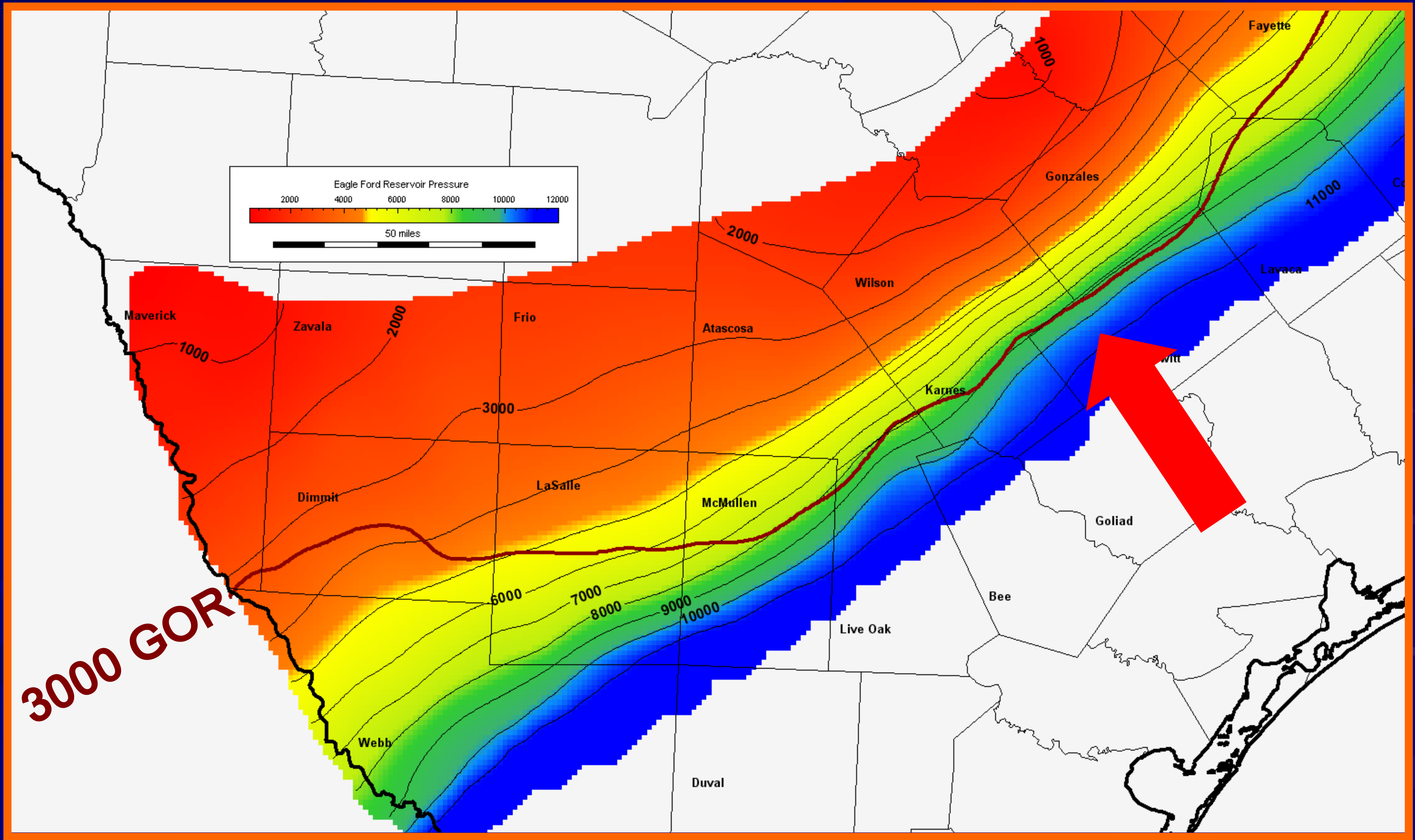
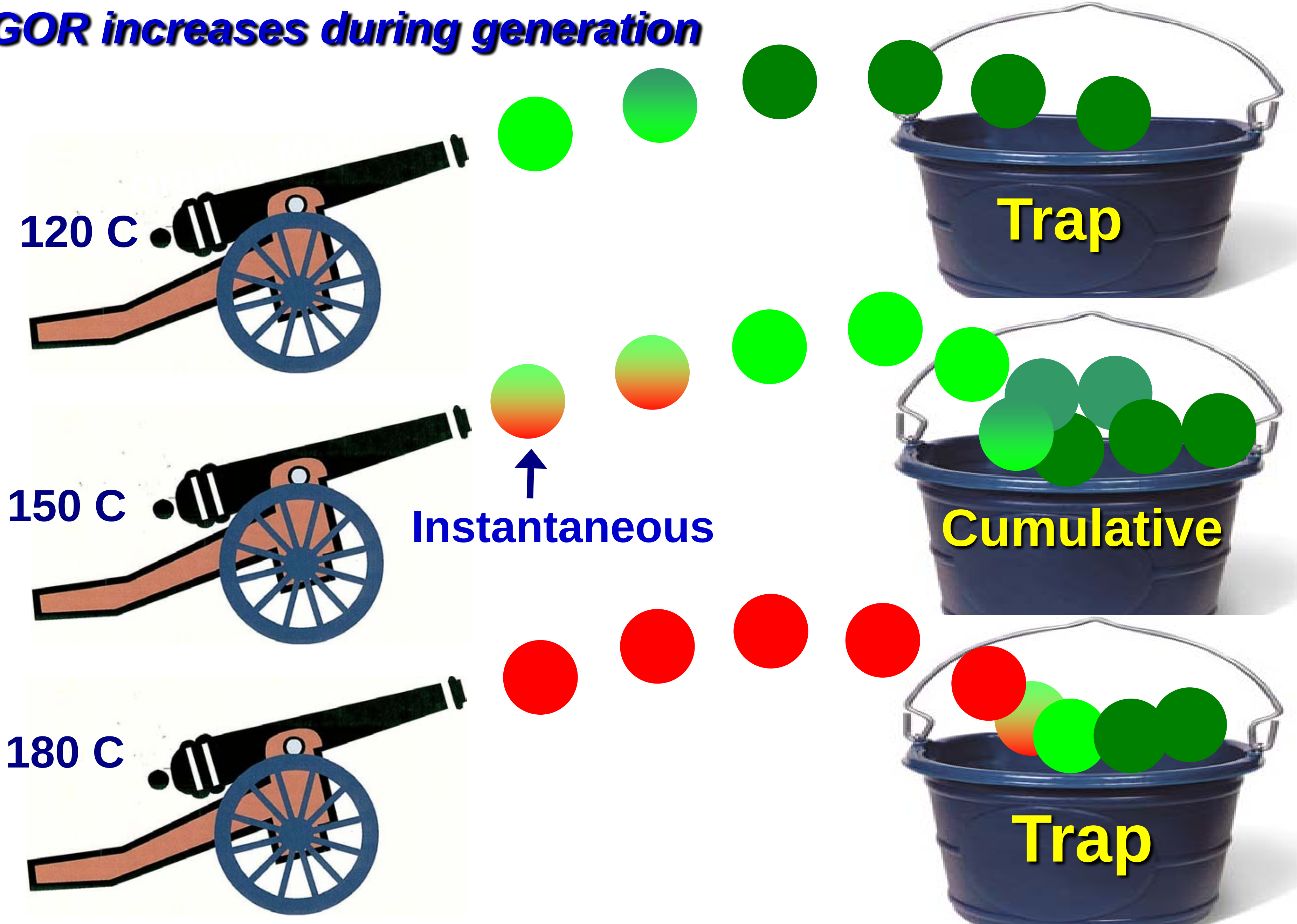
Eagle Ford liquids sweet spot
How to predict composition and pressure?



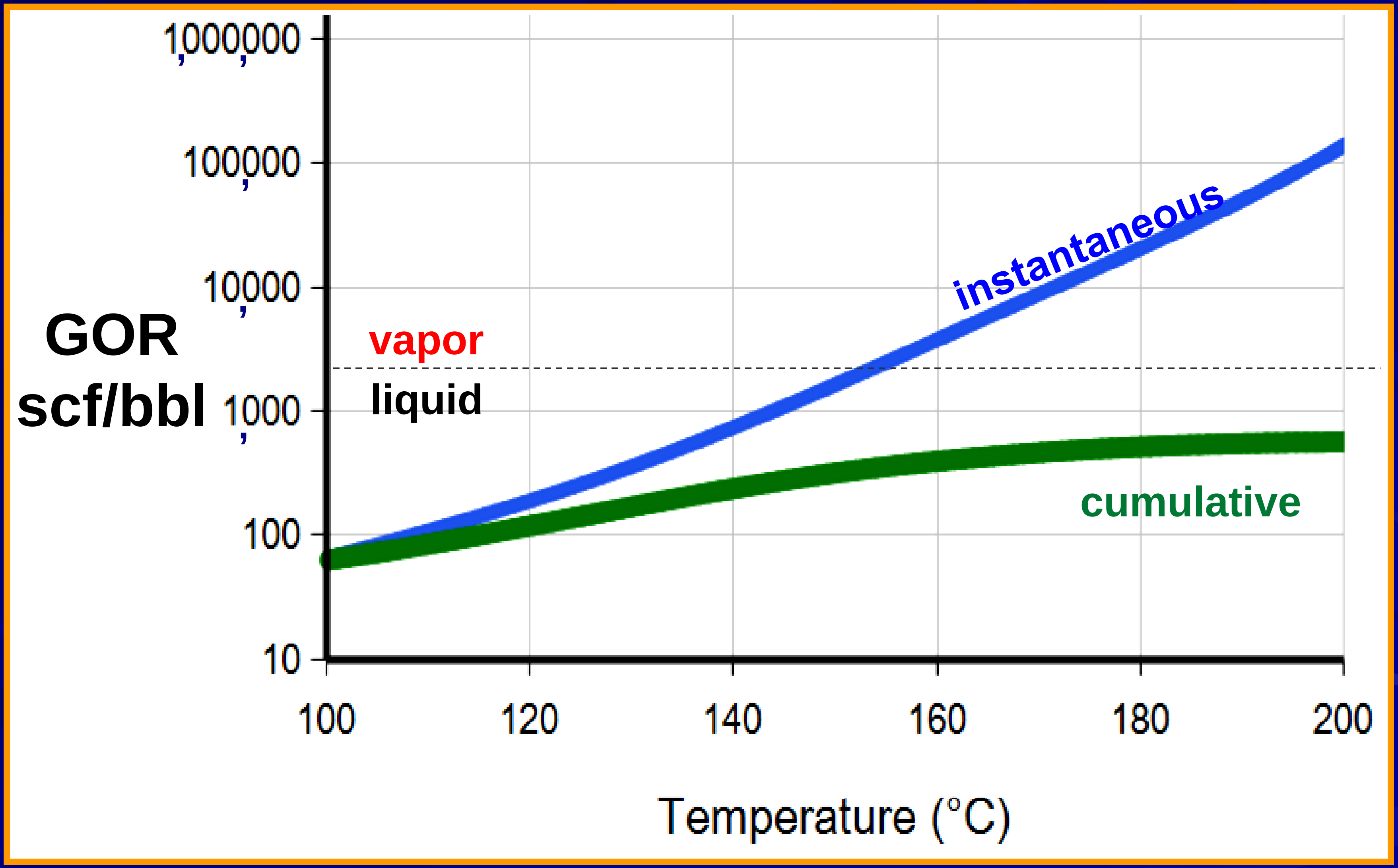
Instantaneous vs. Cumulative

GOR increases during generation



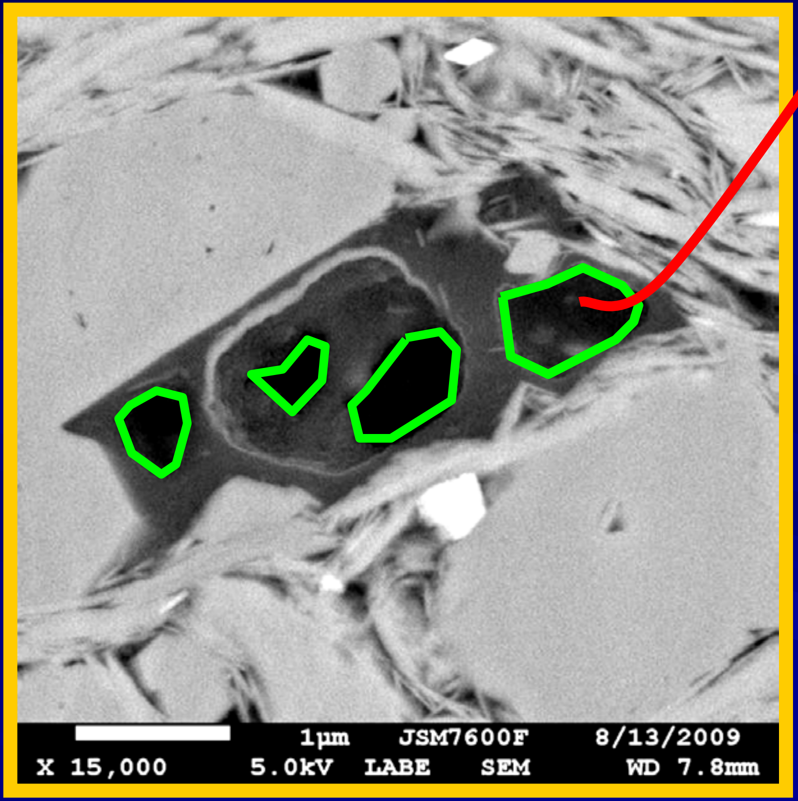
Instantaneous vs. Cumulative GOR

"Western" Eagle Ford model



Previous kinetic model

Reach “sorption” threshold of kerogen and then “expulsion”



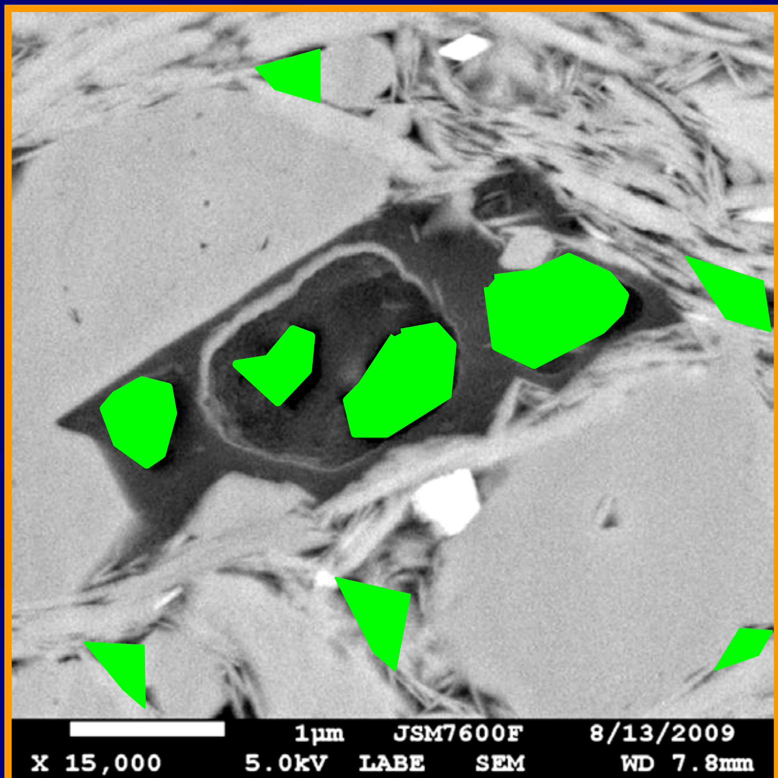
<u>Problem</u>

Source rocks <u>retain more</u> petroleum than previously thought

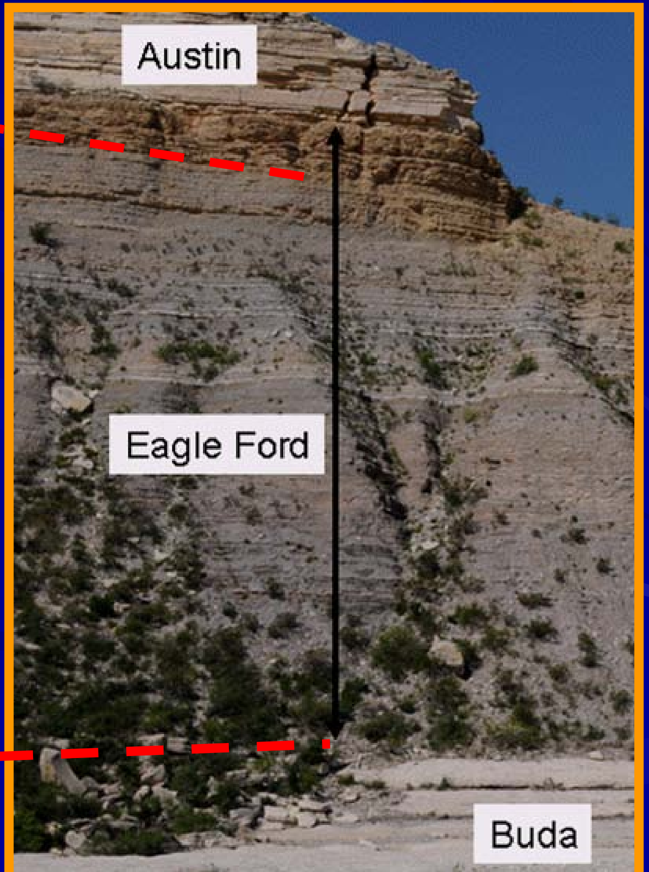
<u>Expel less</u> than previously thought

Updated BP model

- **Storage in evolving *organic* and *inorganic* porosity**
- **Different % Petroleum Saturations for organic and inorganic porosity**
- **Calculate volume of retained petroleum in source rock**
- **"Instantaneous" composition (GOR) is a "source rock" calculation**
- ***See Osborne and Barwise, 2011, IMOG***



Source interval



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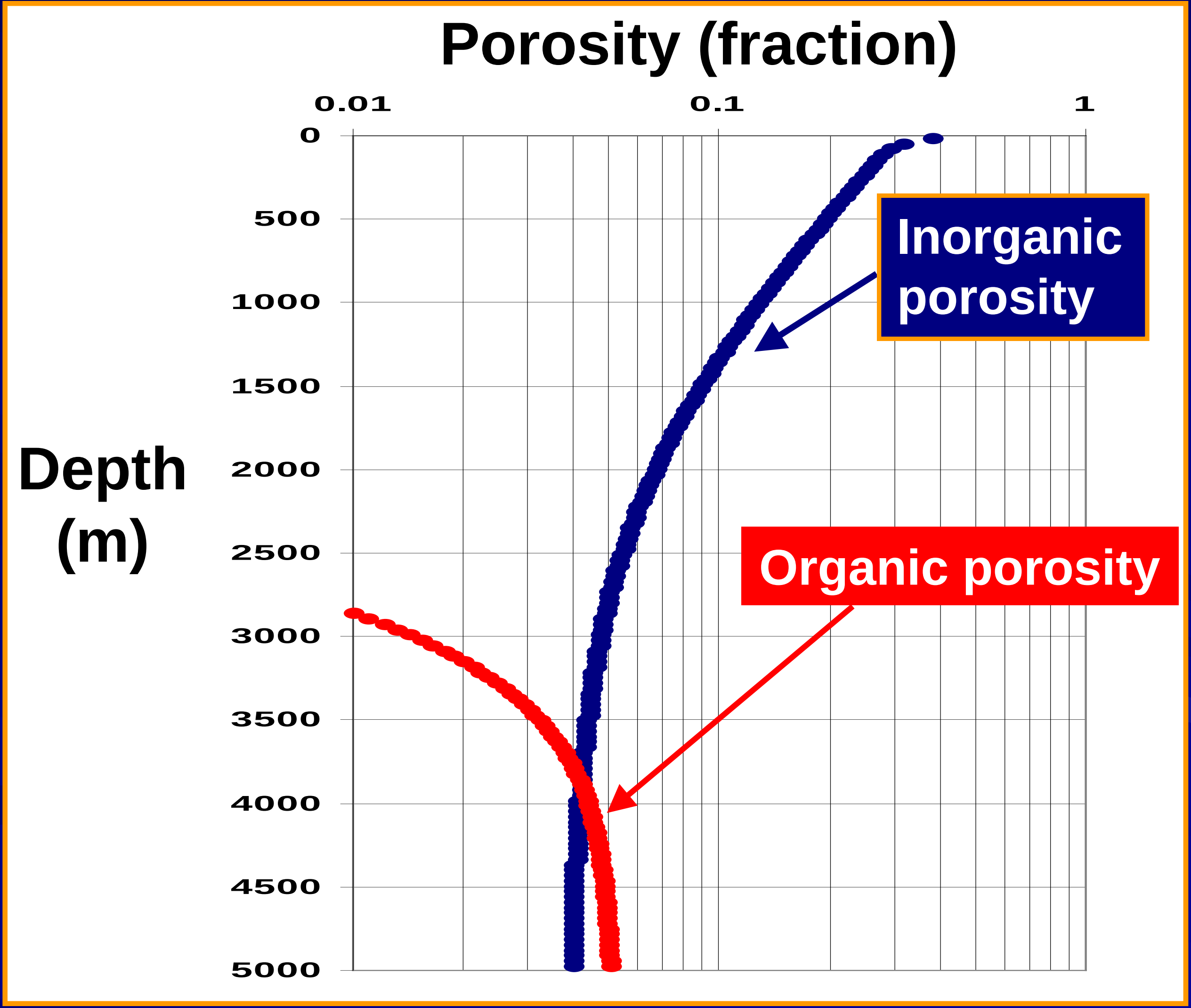
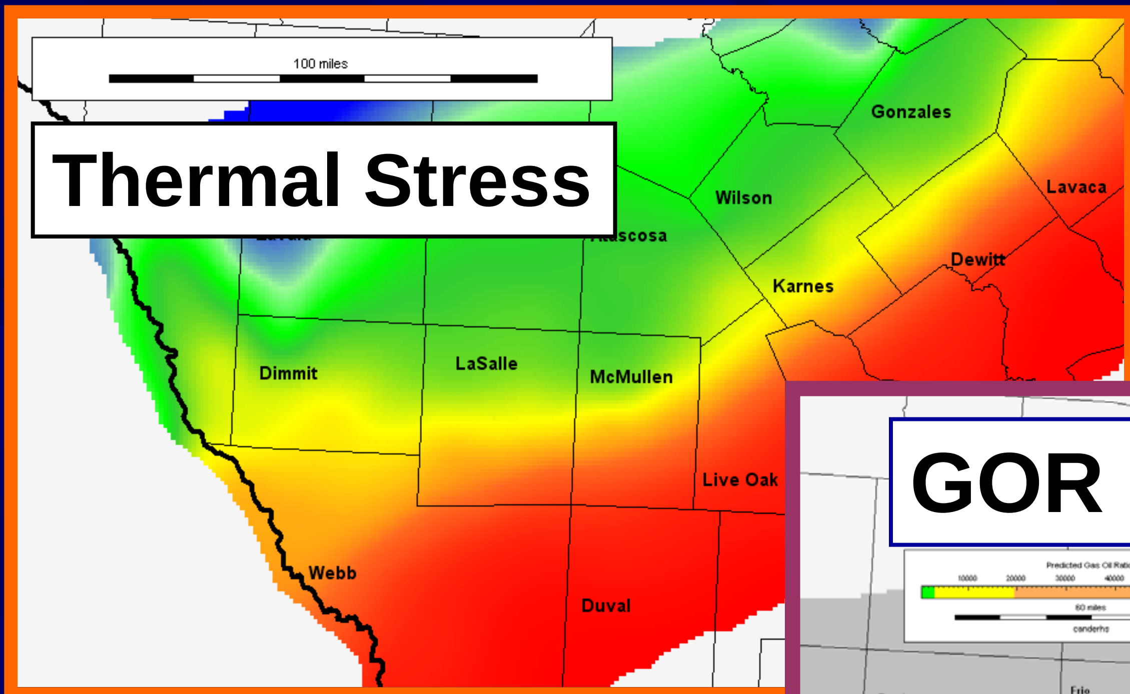
Kinetic model, plus…

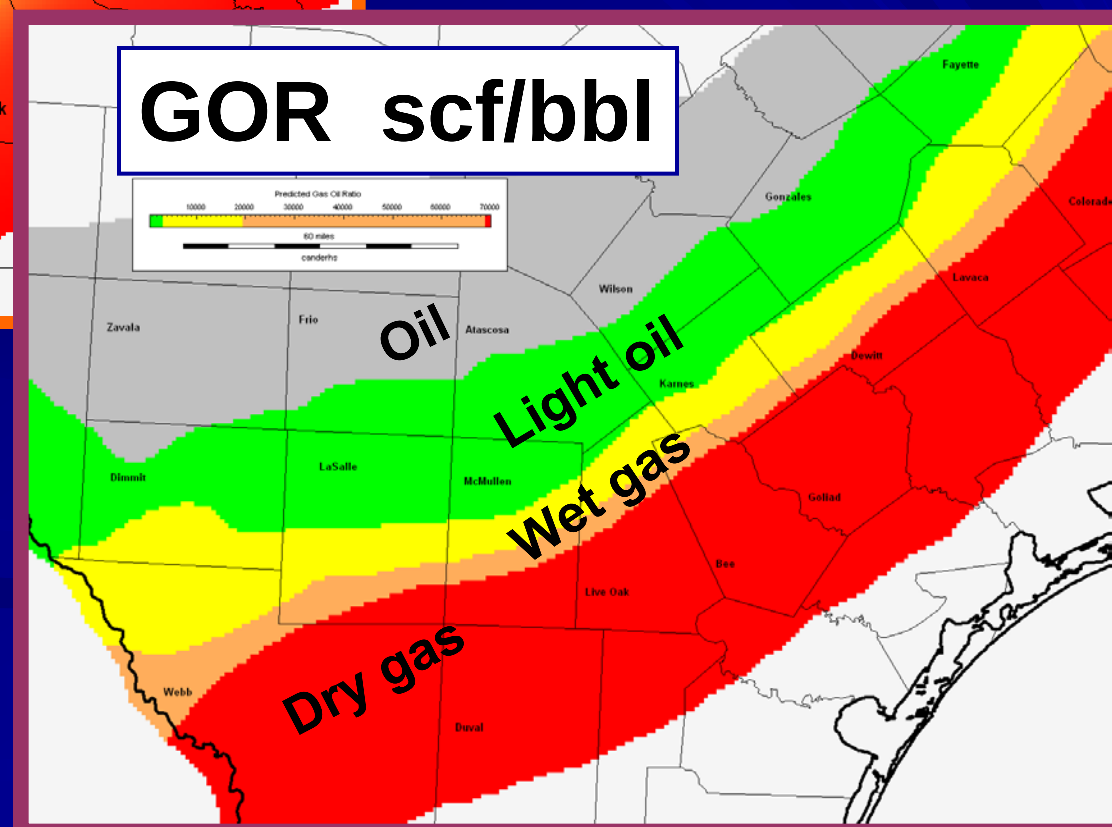
Changes in inorganic and organic porosity with or without over-pressure



GOR predicted from Thermal Stress

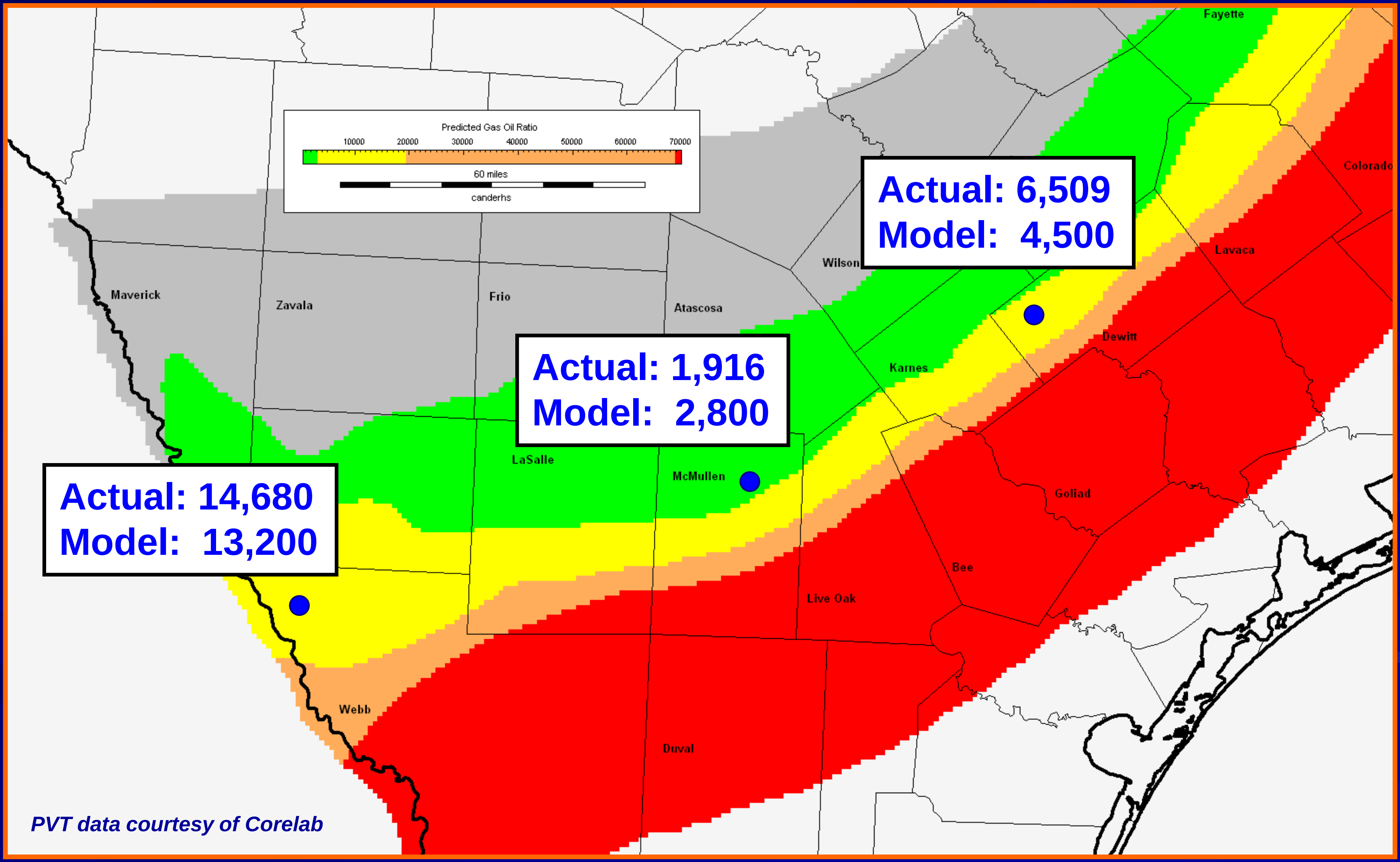
GOR is close to an Instantaneous Composition





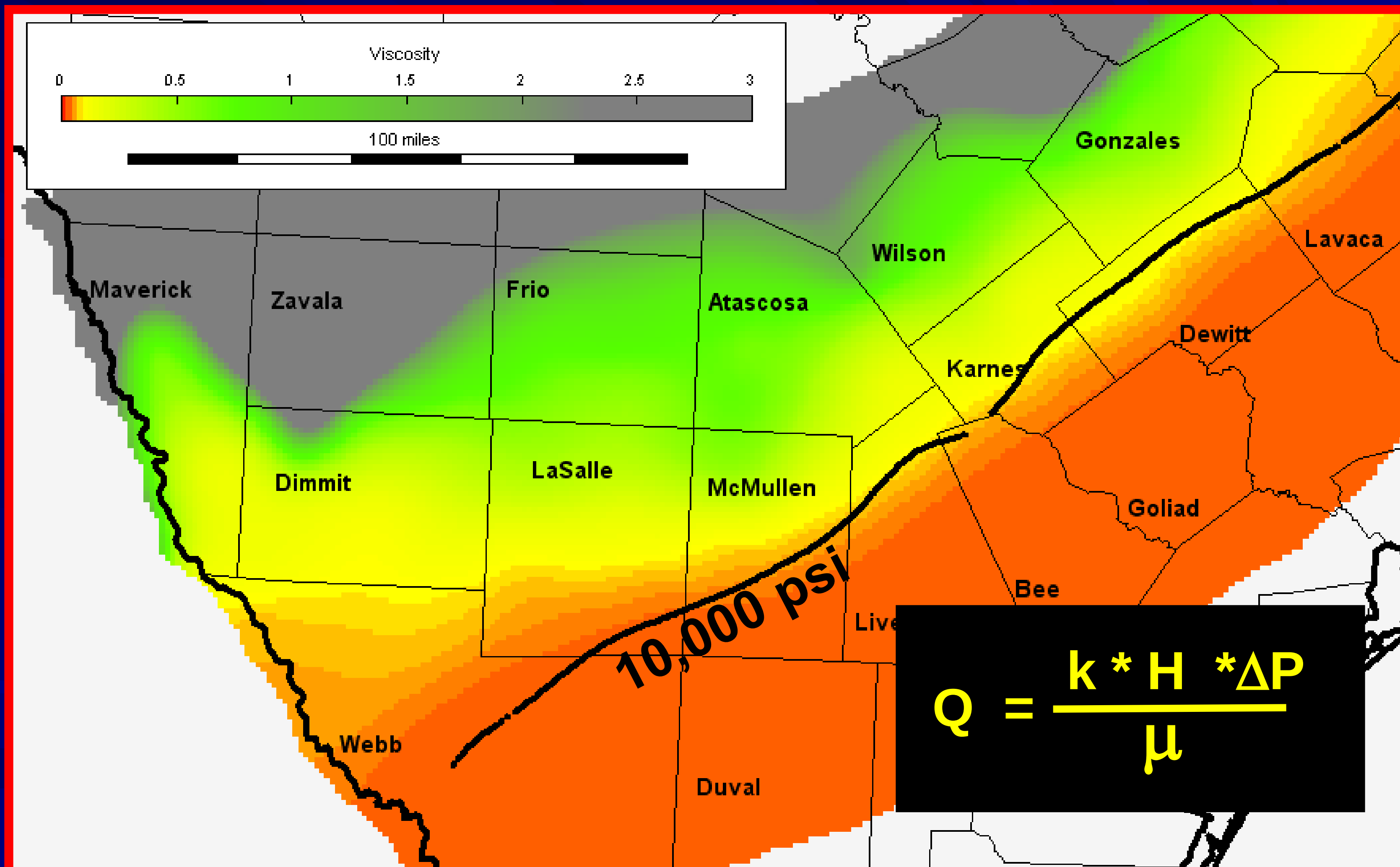
PVT GOR vs. Predicted GOR

Reasonable prediction of composition



Eagle Ford Viscosity

(approximated viscosity estimated from model)



$$Q = \frac{k * H * \Delta P}{\mu}$$

High pressure helps mobility of more viscous liquid phase fluids

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Over-pressure in source rocks

- **Petroleum generation?**
- **Rapid burial?**
  - **Compaction disequilibrium**
- **How is over-pressure preserved?**

Petroleum generation & over-pressure

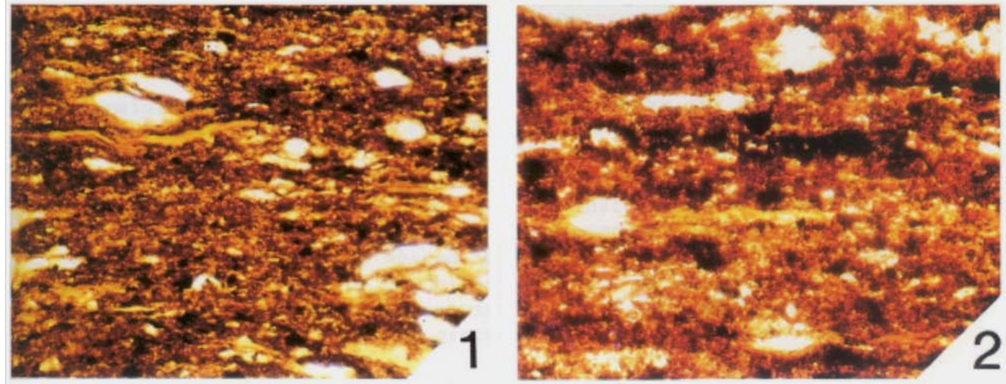
Momper, 1979

- Volumetric expansion

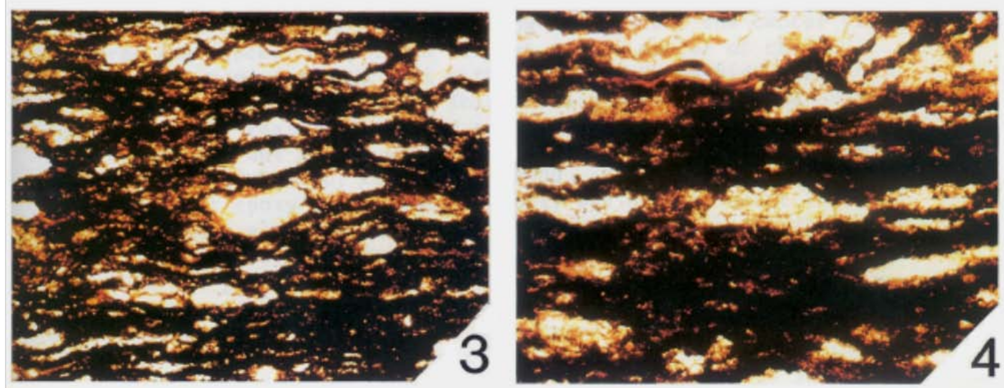
Lewan, 1985

- Hydrocarbon generation increases pore pressure
- Bitumen network
- Microfractures
- Expulsion to other beds

Lewan: Pyrolysis of Woodford Shale

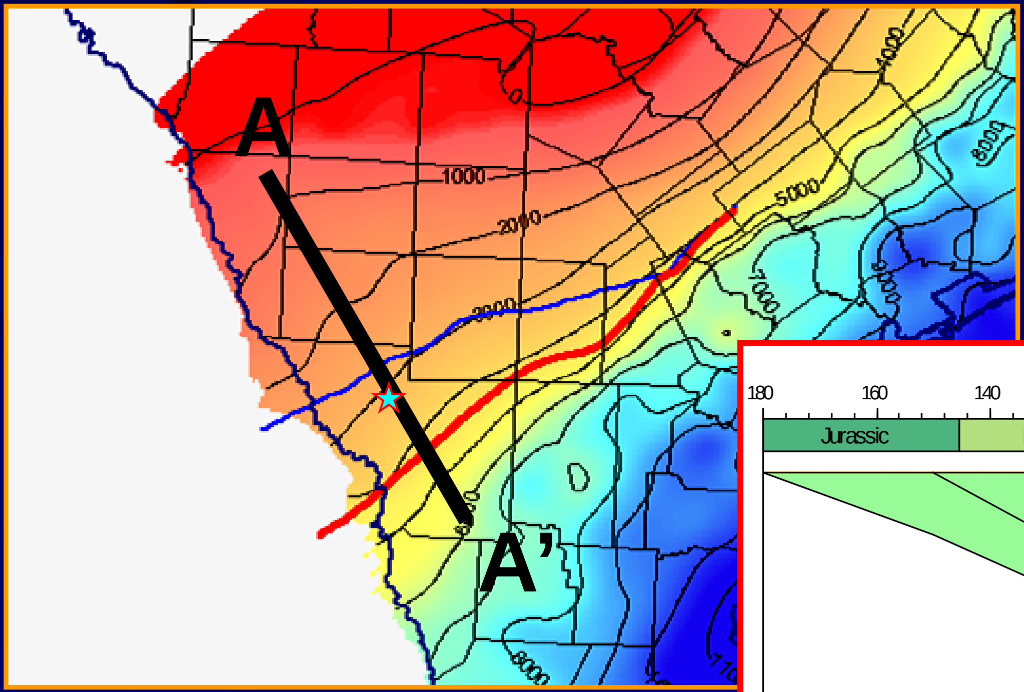


Immature – dispersed organic matter

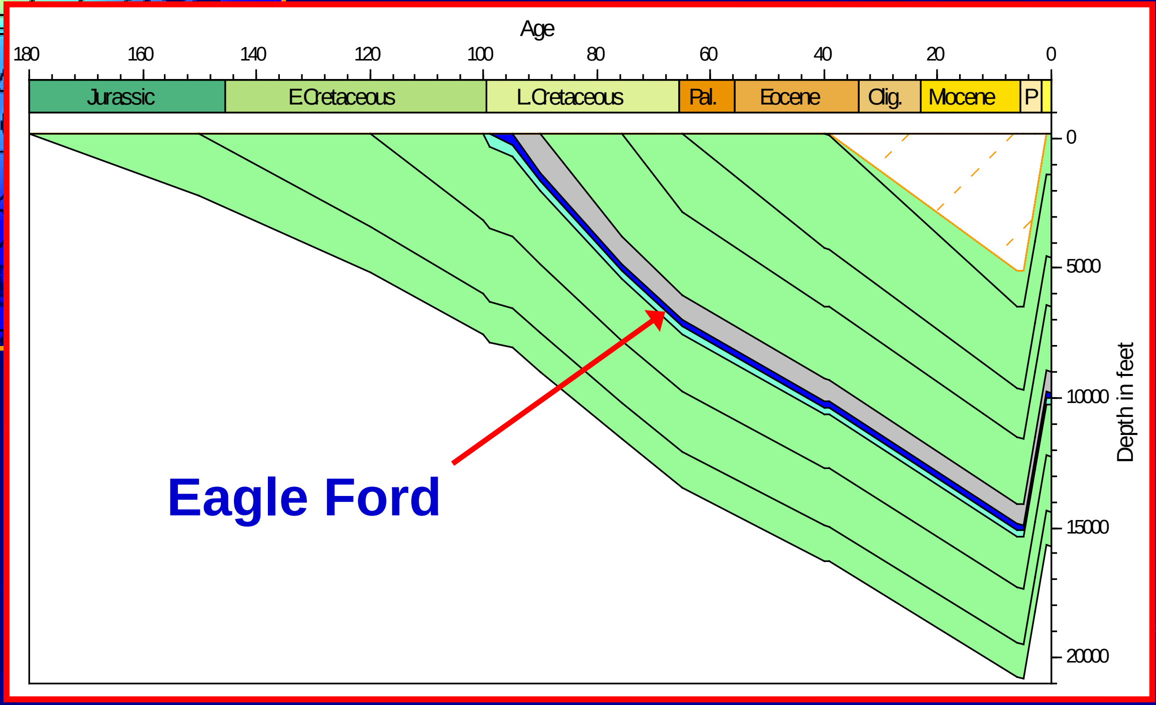


Mature – bitumen network develops

Eagle Ford Shale South Texas

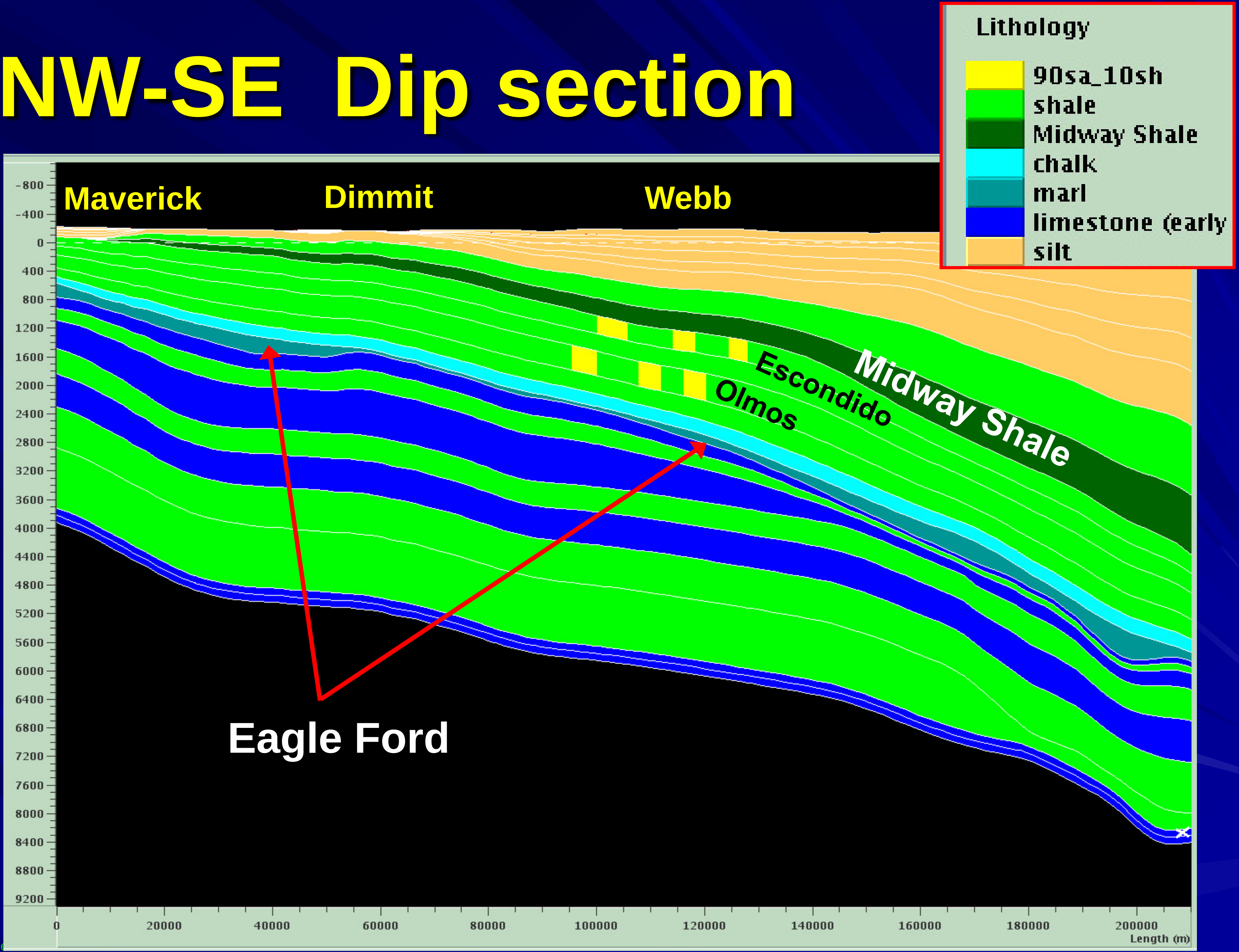


Eagle Ford Structure (m)



3000 – 7000 feet of exhumation in west; Less in east part of fairway

NW-SE Dip section



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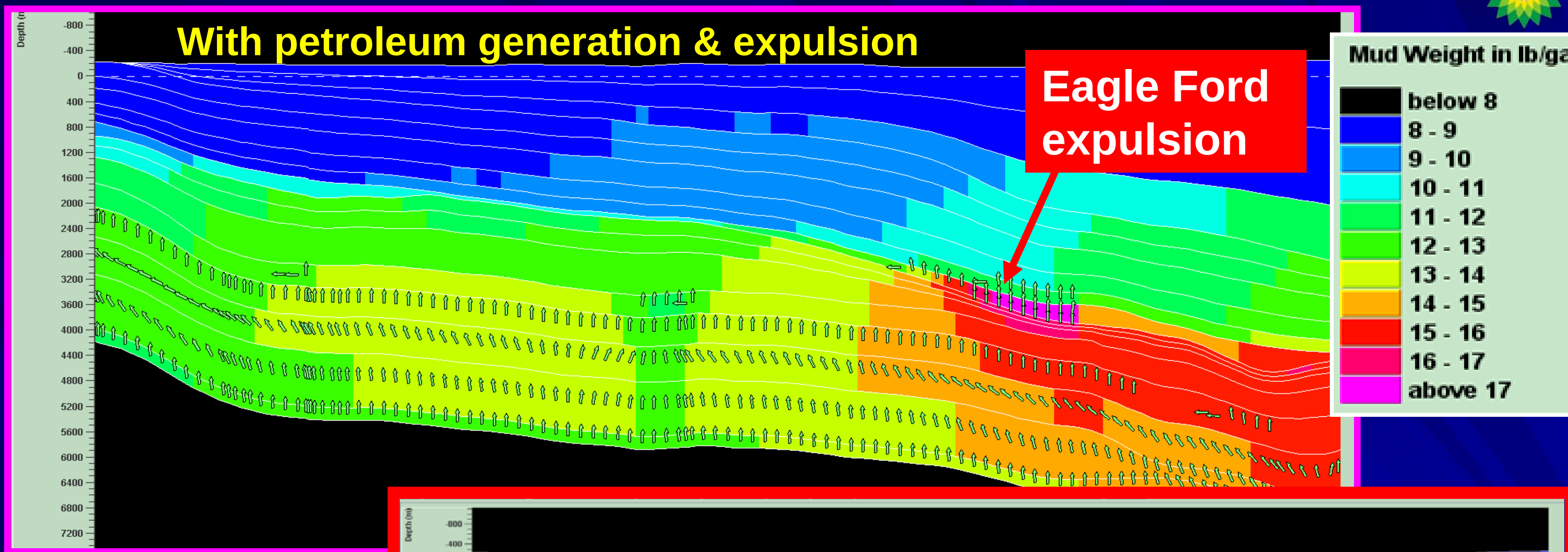
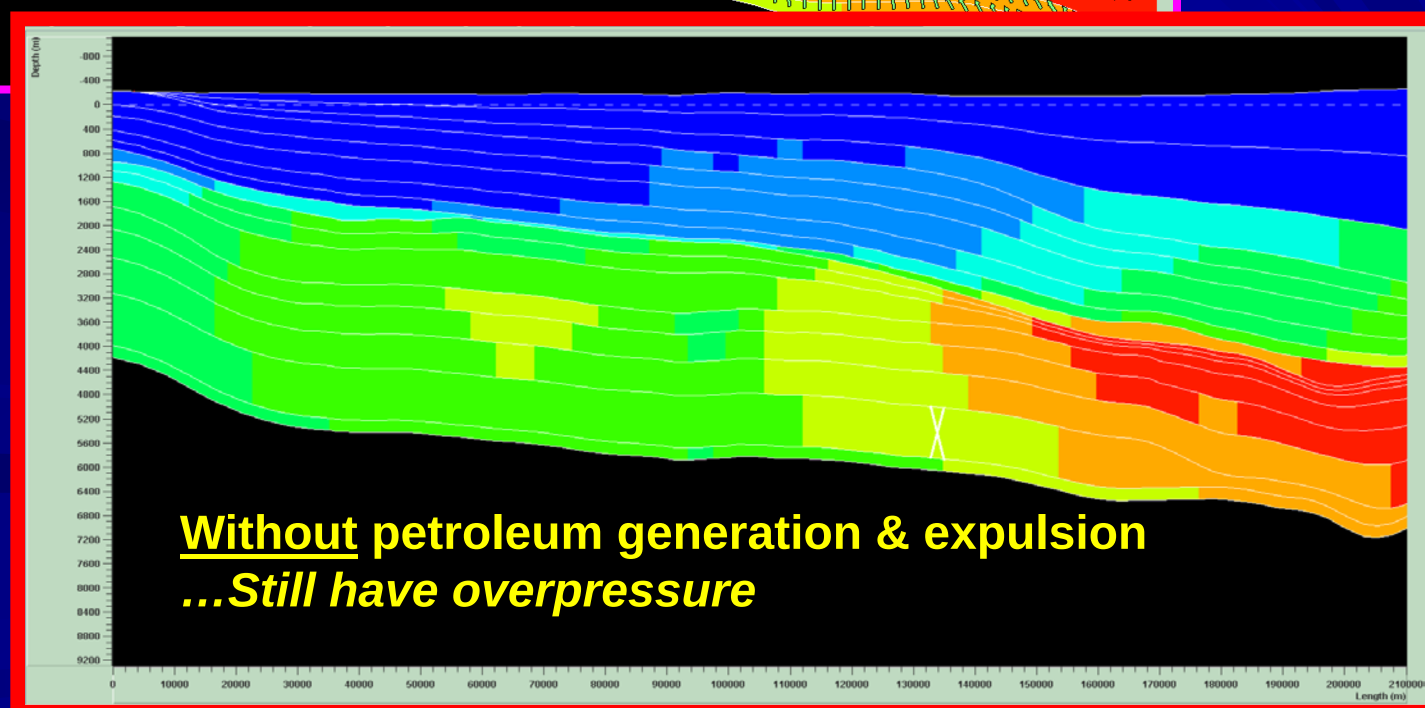
Basin overpressure during Eocene





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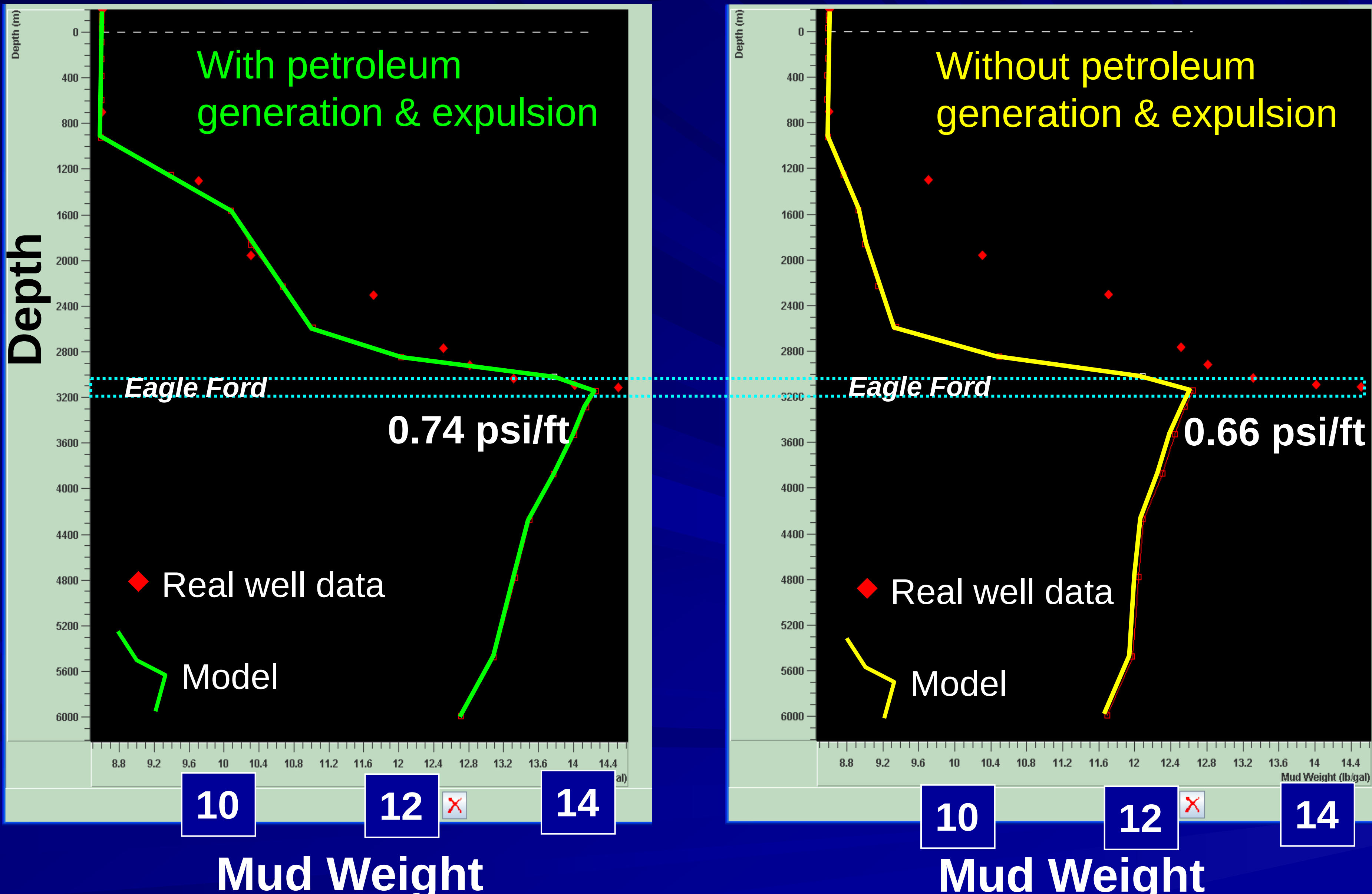
Difference in over-pressure

With and without petroleum generation & expulsion



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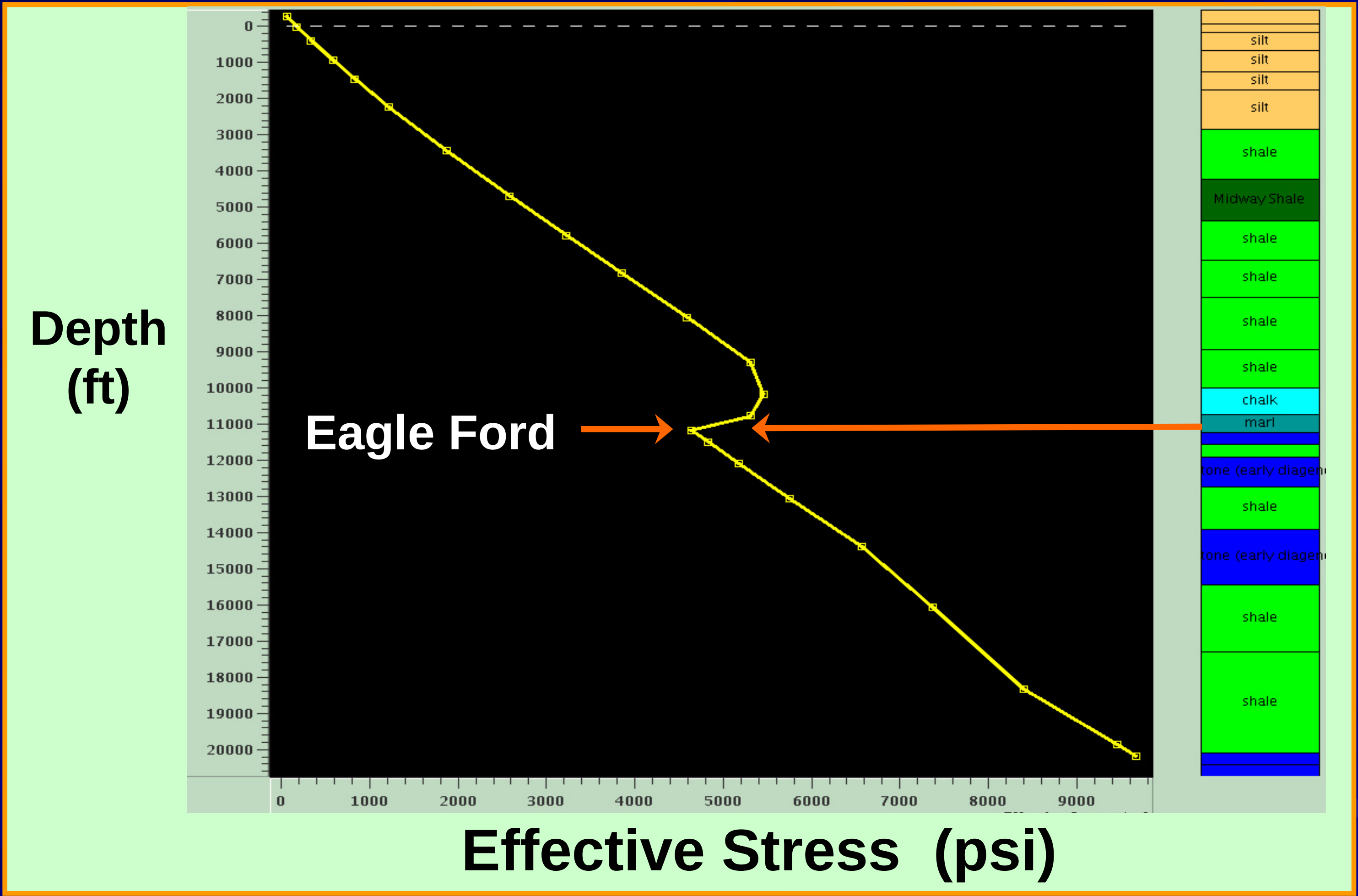
Drop in Effective Stress in Eagle Ford

Preservation of pore throats



Permeability is not just a function of facies or the rock
Permeability is also a function of pore pressure

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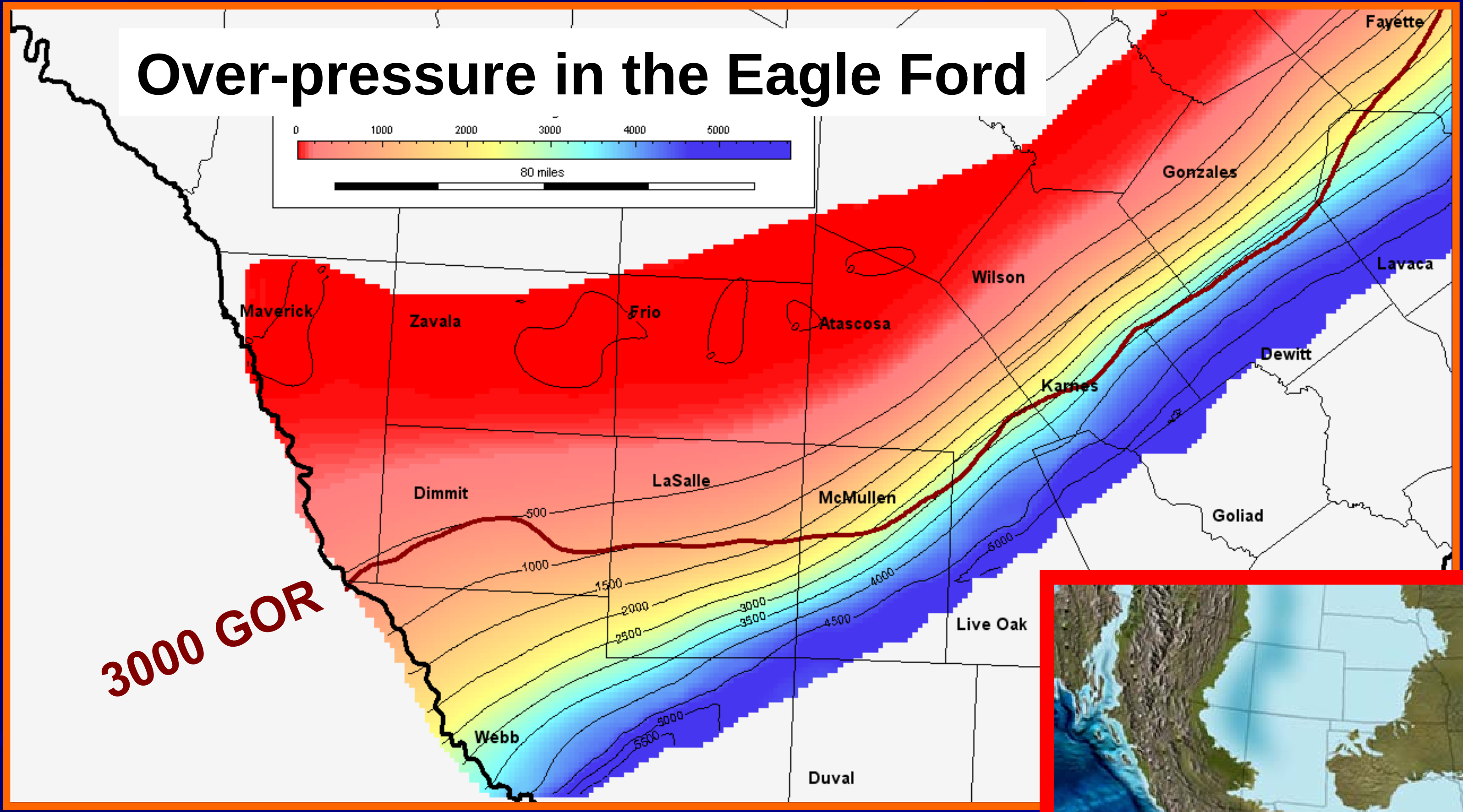
Gas window and Over-pressure

Not completely linked

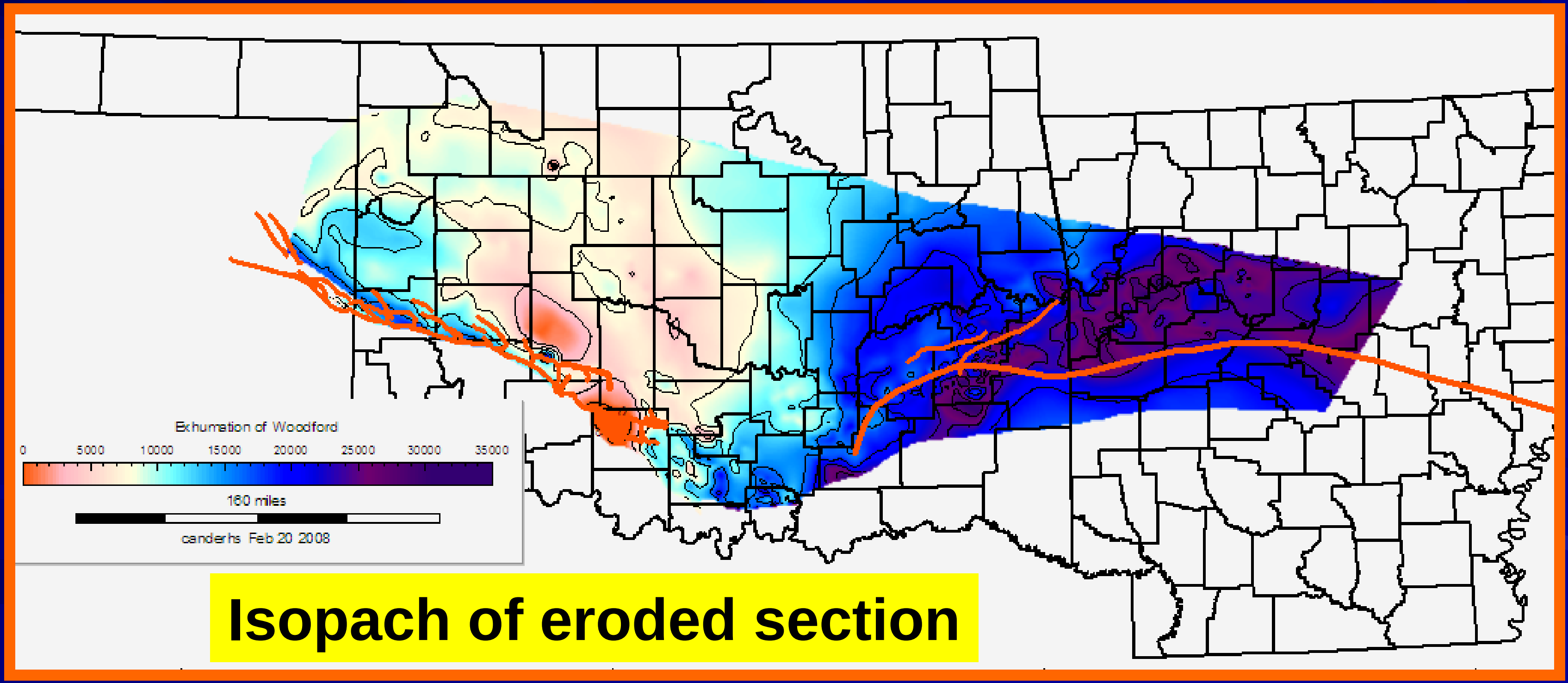


Post-Laramide exhumation in west causes loss of over-pressure and decoupling of GOR and pressure contours

Exhumation: loss of pressure

Anadarko
Minor exhumation
Over-pressure preserved

Arkoma
High exhumation
Over-pressure lost



Summary: Sweet Spots

$$Q = \frac{k * H * \Delta P}{\mu}$$

- Fluid viscosity and reservoir pressure
  - First order controls on sweet spots in shale
  - Fluid mobility… Darcy's Law matters…
- Petroleum composition and viscosity can be predicted
  - Source flushes itself during maturation
  - Retained petroleum is close to an instantaneous composition
  - Retained petroleum is in equilibrium with the thermal stress state of the rock
  - Viscosity and GOR are directly linked to maturity… and can be predicted
- Over-pressure
  - Results from both petroleum generation *and* compaction disequilibrium
  - Basin-wide over-pressure helps preserve over-pressure in the source rock
  - Over-pressure can be preserved if exhumation is limited
  - Over-pressure is often lost by substantial exhumation
  - Must understand burial *and* uplift history!

Thanks!

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BP

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