Activation Energies and RockEval Analyses of Kerogenites in the Red River Formation in North Dakota

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- Petroleum Systems
- Role of Kerogen Kinetics and Permeability in accumulating “basin centered” petroleum.
- Red River Petroleum System
  - Examples of accumulation
    - Oil Generation Rates
    - Oil Migration Rate

Petroleum System

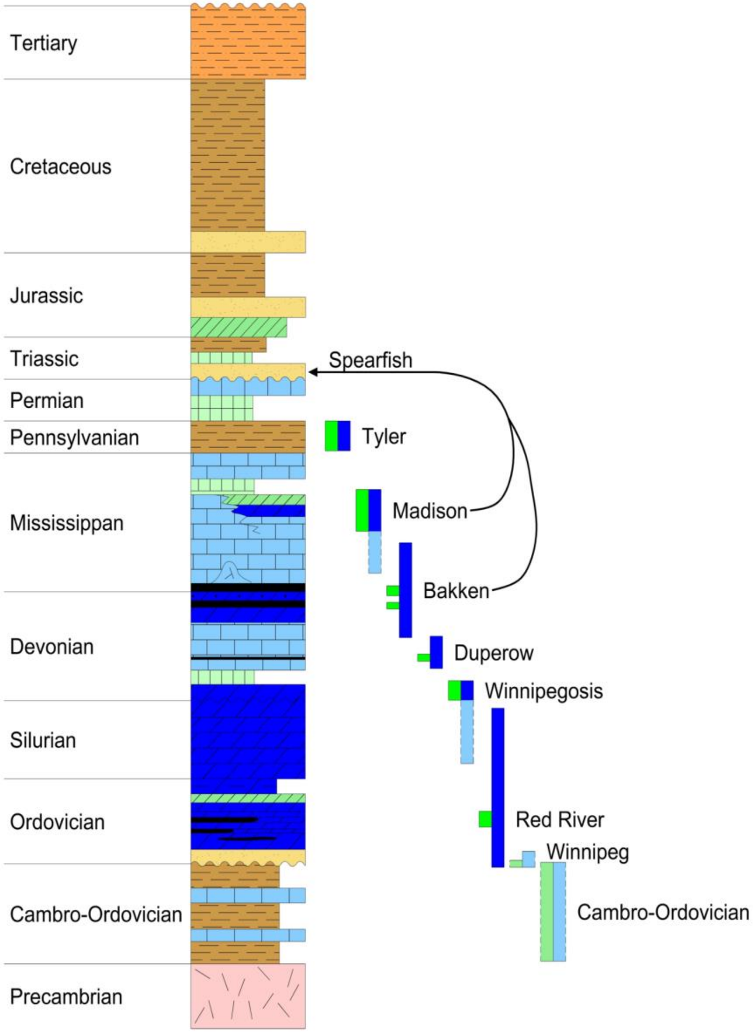
"A pod of ***active*** source rock and all genetically related oil and gas accumulations. It includes all of the geologic elements and processes that are essential if an oil and gas accumulation is to exist." (Magoon and Beaumont, 1999)

Essential geologic elements:

- Petroleum sources – Organic Rich
- Reservoirs – Porous &Permeable
- Seals – Poorly Permeable
- Overburden – Thermal Insulation

Processes include:

- Trap formation
- Hydrocarbon generation
- Migration
- Accumulation



Petroleum Systems

- Dow (1974) Open system
  - All of the oil expelled from source beds migrates.
  - Reservoir pressures are at or close to hydrostatic.
  - Trapping efficiency low
- Something in between.
- Meissner (1978) Closed system
  - None of the oil expelled from source beds migrates.
  - Reservoir pressures are significantly above hydrostatic.
  - Trapping efficiency high

Closed Petroleum System

"A pod of ***active*** source rock and all genetically related oil and gas accumulations. It includes all of the geologic elements and processes that are essential if an oil and gas accumulation is to exist." (Magoon and Beaumont, 1999)

Essential geologic elements:

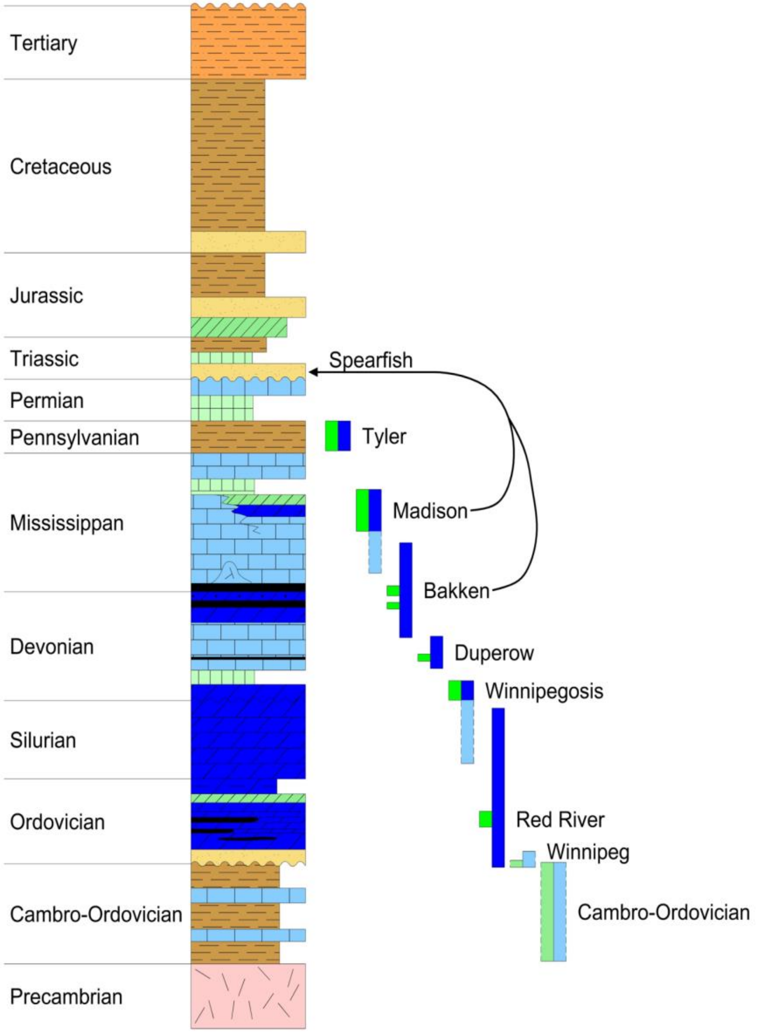
Petroleum sources – Organic Rich
Reservoirs – Porous &Permeable
Seals – Poorly Permeable

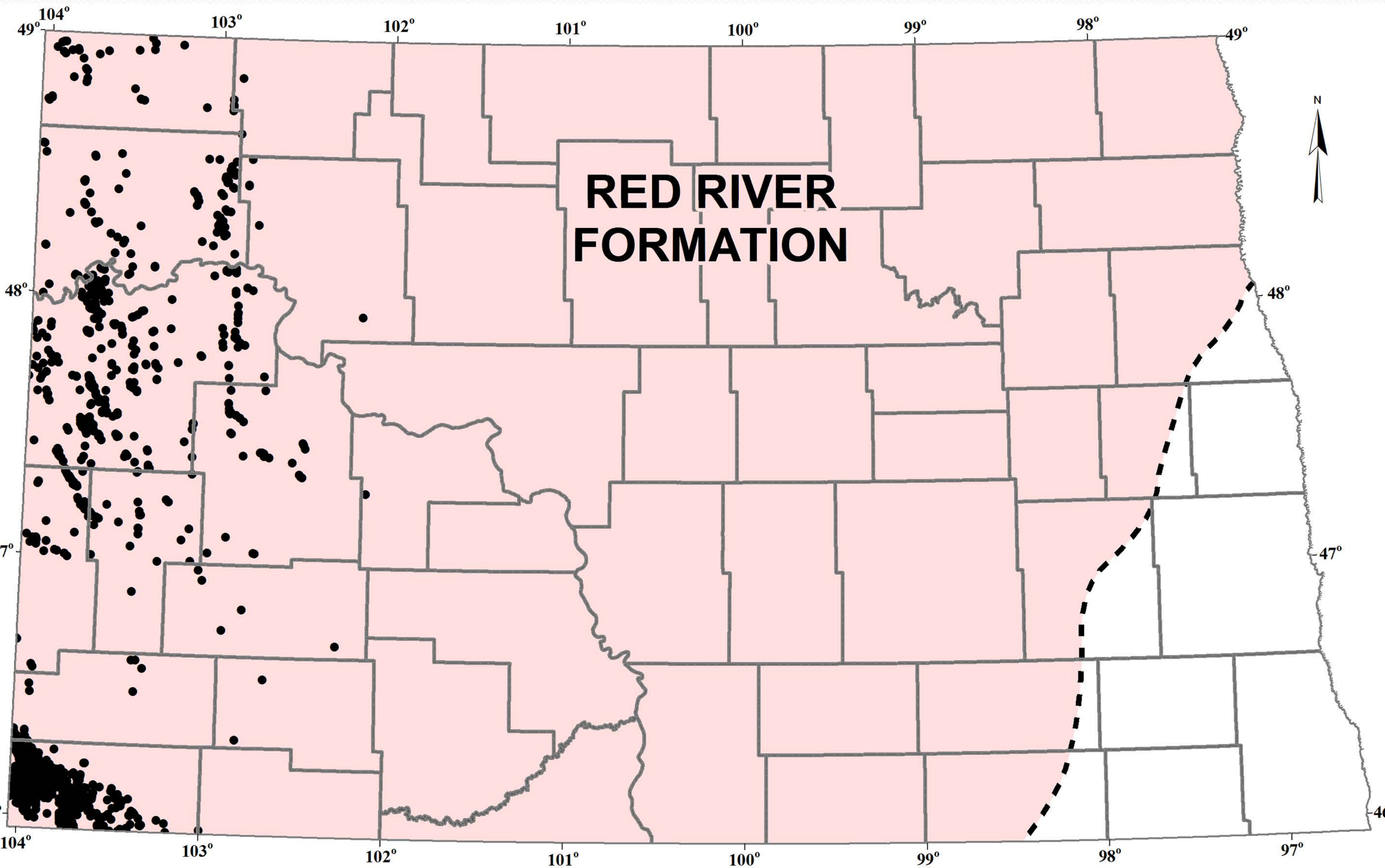
Organic Reservoir Seal Complex – Organic, Porous & Poorly Permeable

Overburden – Thermal Insulation

Processes include:

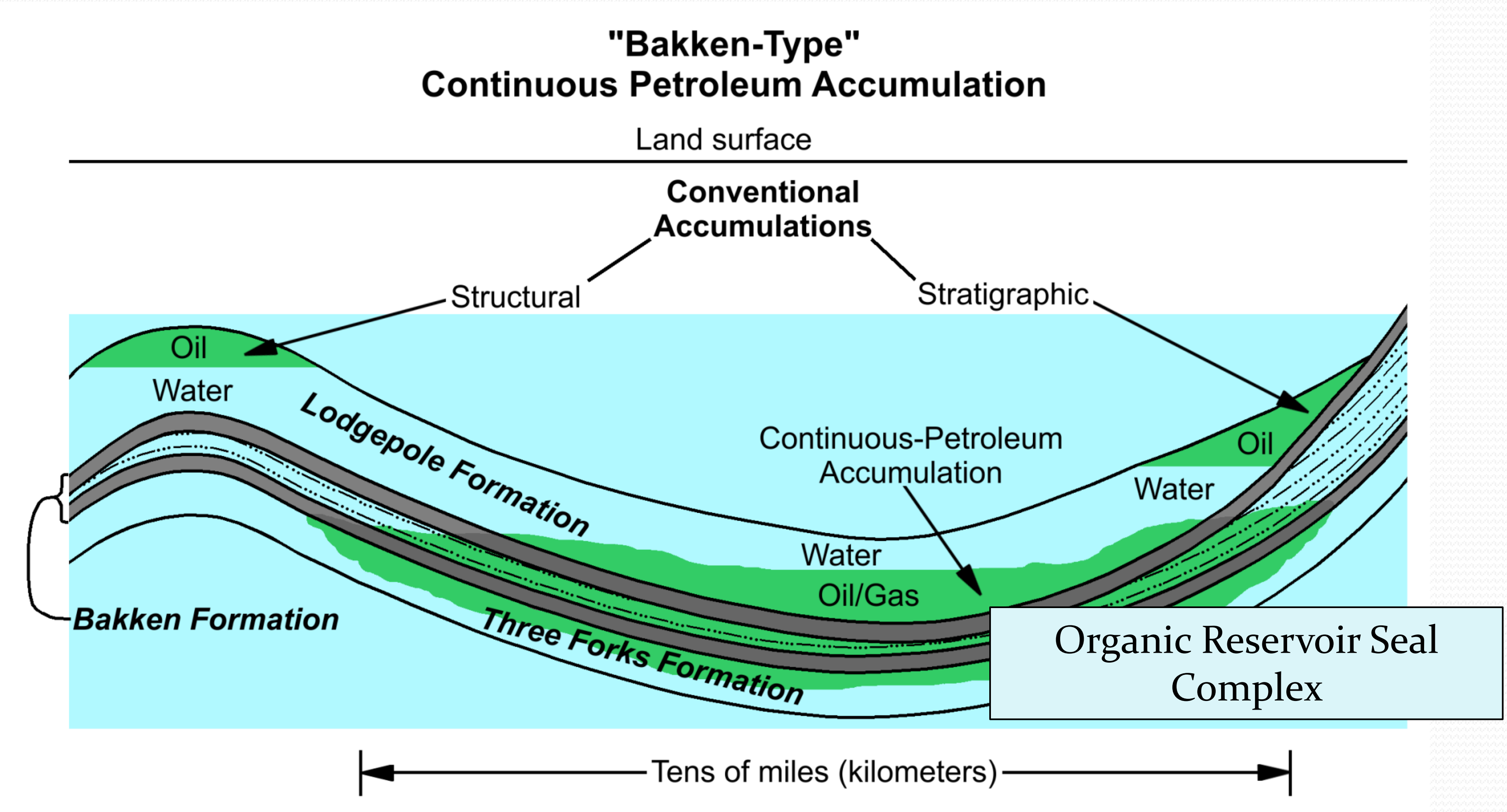
Trap formation
Hydrocarbon generation **rates**
Migration **rates**
Accumulation





RED RIVER
FORMATION
N
104°
103°
102°
101°
100°
99°
98°
97°
49°
48°
47°
46°

Generation Rate < Migration Rate → Migration → Accumulation



Generation Rate > Migration Rate → Local Accumulation

Kerogen Kinetics and Rock Permeability are Critical

Source Rock Adjacent Rock

Generation Rate < Transmission Rate → Migration

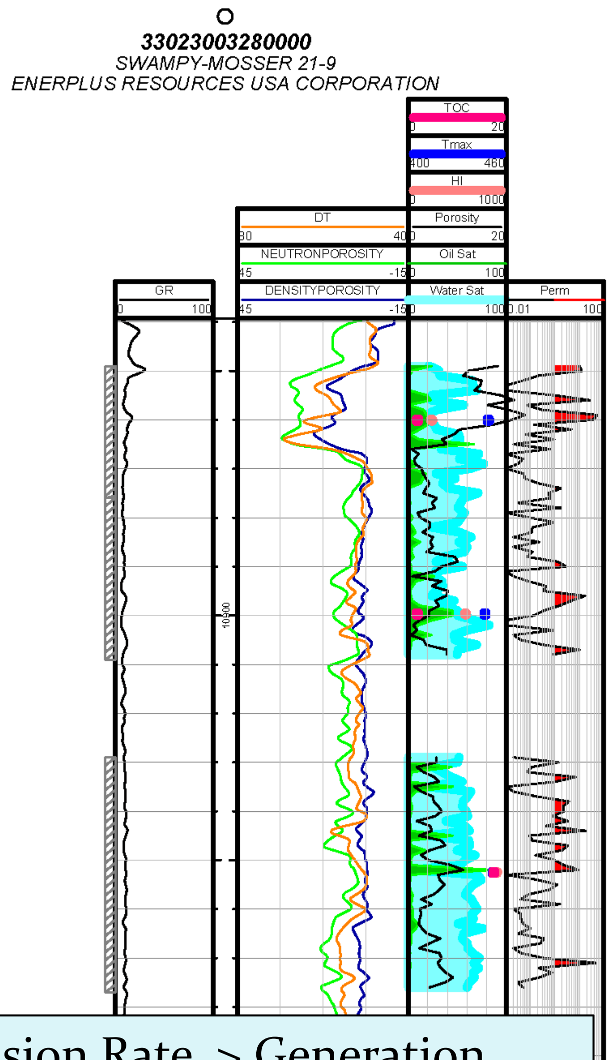
Kerogen Kinetics
Activation Energy
Frequency Factor
Temperature
Kerogen Mass

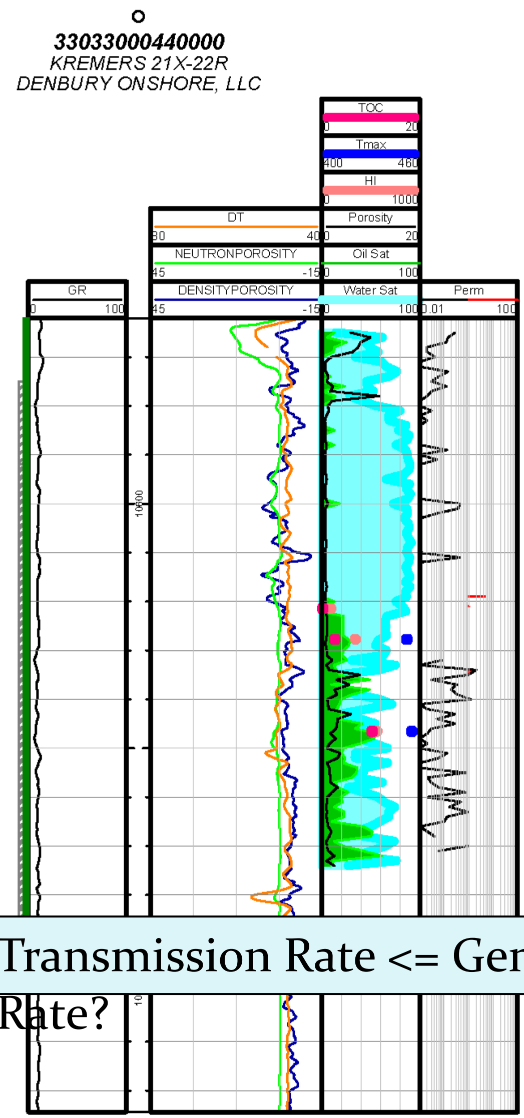
Permeability
Fluid Viscosities
Pore Space Texture
Pressure Difference

Open
High Water Saturations
Hydrostatic Fluid Pressure

Generation Rate > Transmission Rate → Local Accumulation

Organic Reservoir Seal Complex
Closed
High Oil Saturations
Elevated Fluid Pressure





Transmission Rate <= Generation Rate?

Transmission Rate > Generation Rate?

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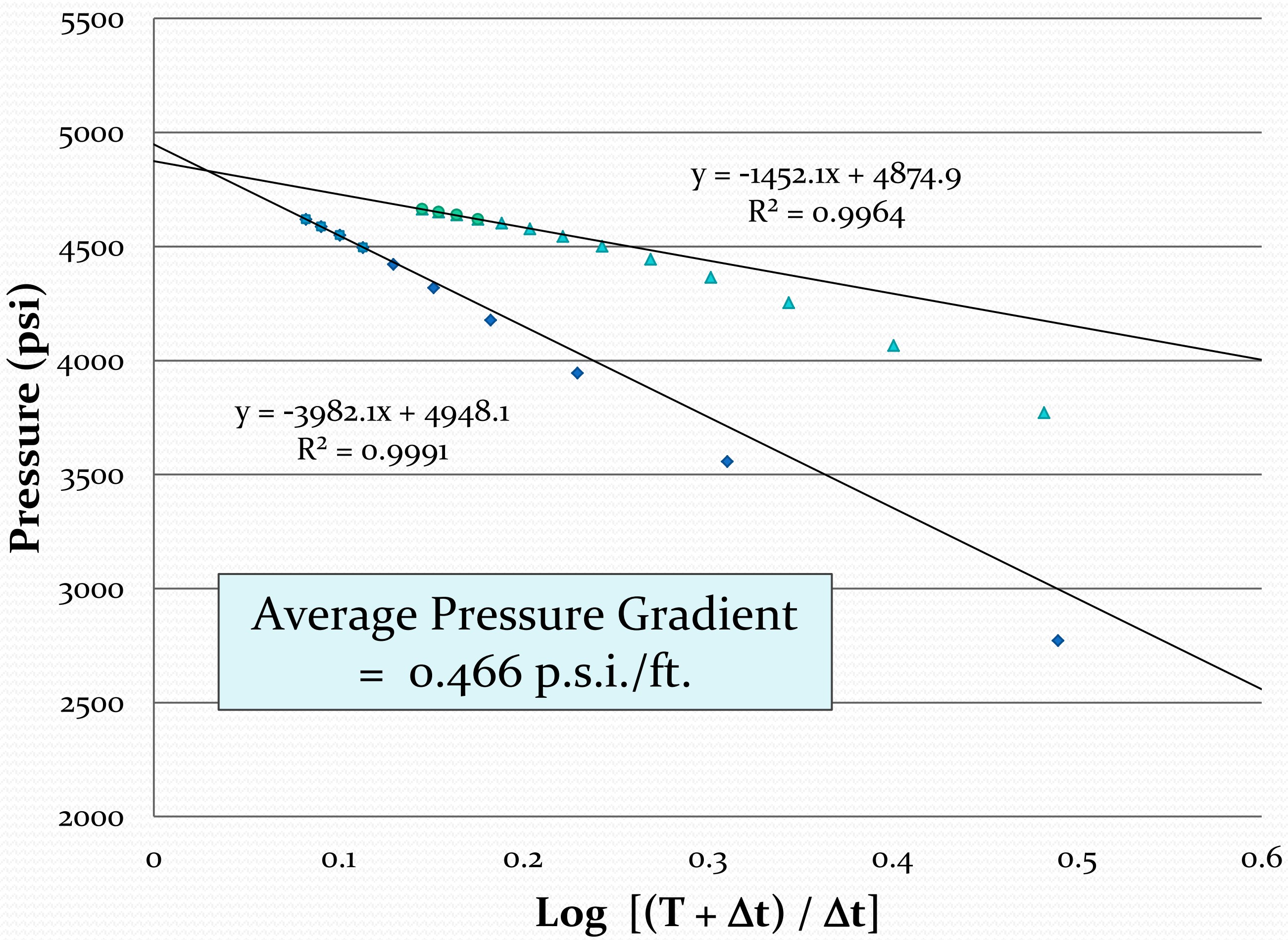
Horner Plot - Kremers 21X-22R

NDIC: 6272

DST Interval: 10528 - 10665' depth



Kerogen Kinetics and Rock Permeability are Critical

Source Rock Adjacent Rock

Generation Rate < Transmission Rate → Migration

Kerogen Kinetics
Activation Energy
Frequency Factor
Temperature
Kerogen Mass

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Pressure Difference

Open
High Water Saturations
Hydrostatic Fluid Pressure

Generation Rate **=** Transmission Rate → **Local Accumulation**

Organic Reservoir Seal
Complex
Semi-Closed
High Oil Saturations ?
Elevated Fluid Pressure?

Evaluating the Organic Component Generation Rate = Kerogen Kinetics

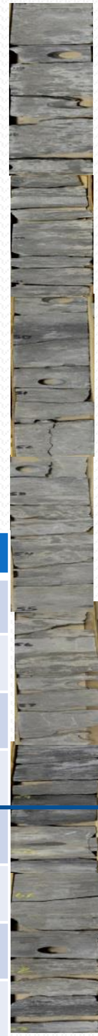
- How fast **ARE** HCs generated?
  - Arrhenius Equation

$$dx/dt = A\, e^{-Ea/RT}\, x$$

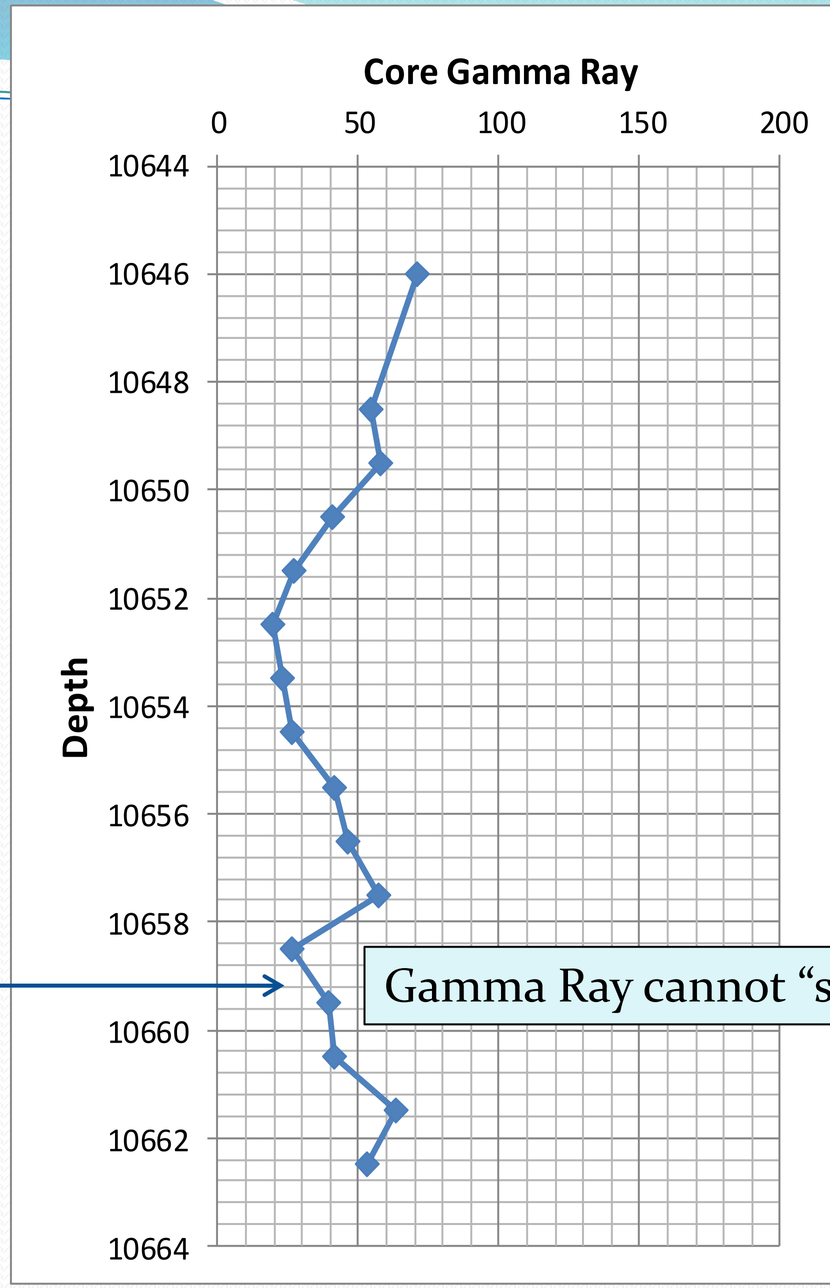
Where:

T = Temperature (^oK)
x = kerogen mass
t = time
E_a = Activation Energy
A = Frequency Factor
R = Gas constant

Kremers 21-22
Core Gamma Ray

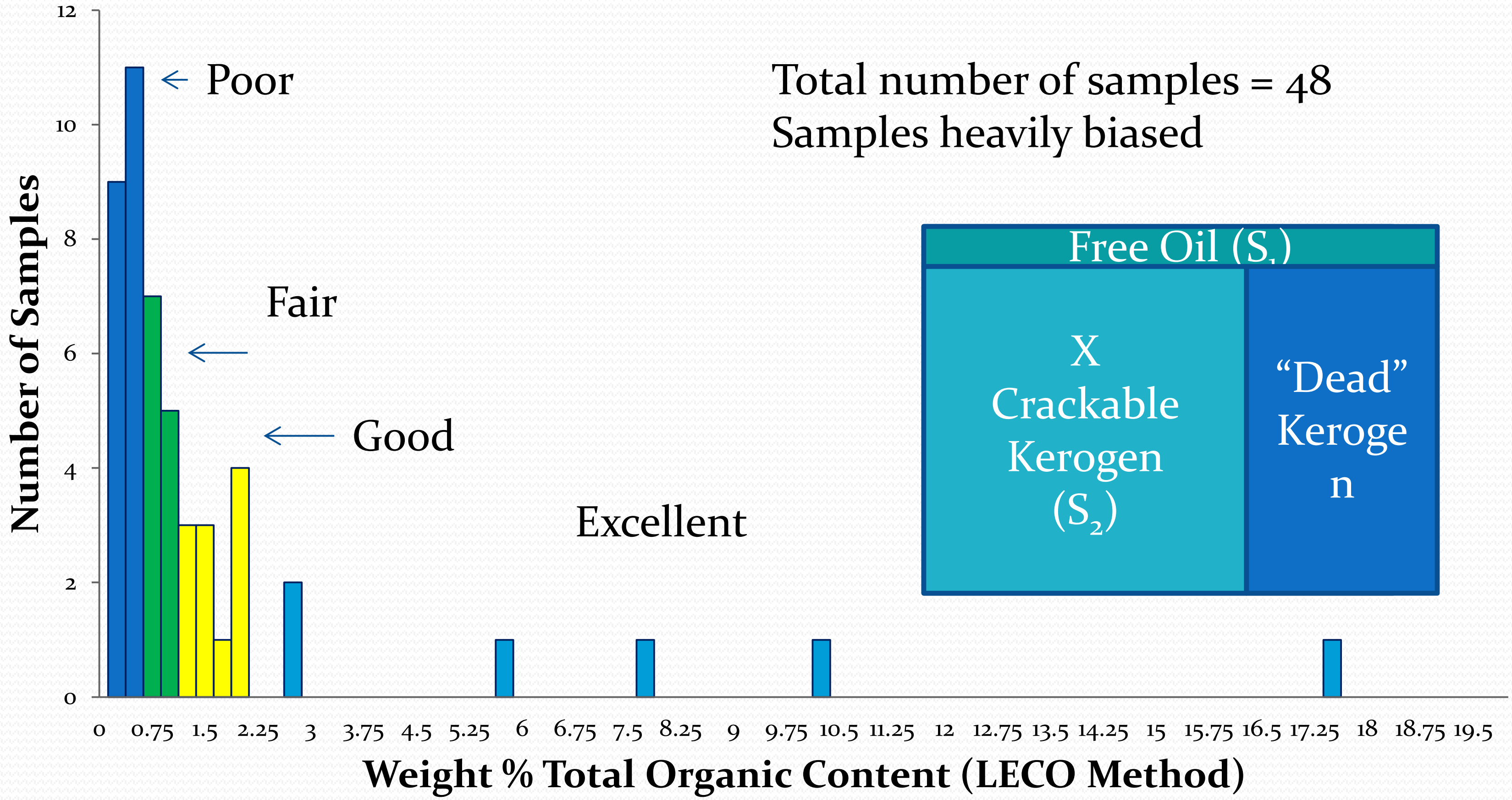


Sample ID	6272-10659.1
Well Name	Kremers 21X-22R
Depth	10659.1
Formation	Red River
TOC (wt.%)	10.25
S_2 (mg/g)	57.65
T_{max} (°C)	455
HI	562
OI	5



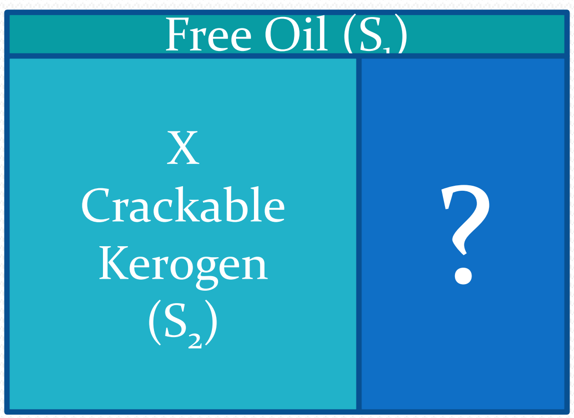
Gamma Ray cannot “see” organic carbon

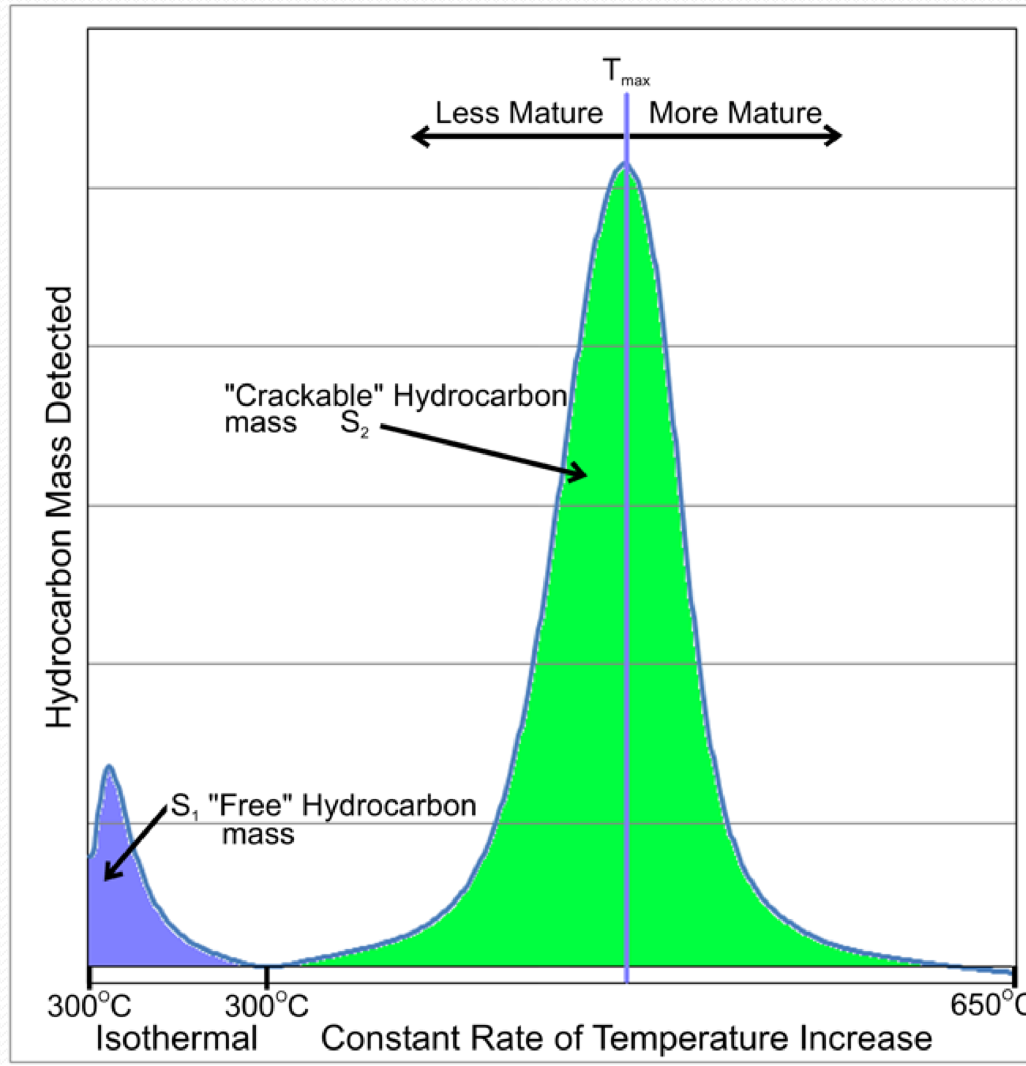
How much reactive kerogen (x) is there?



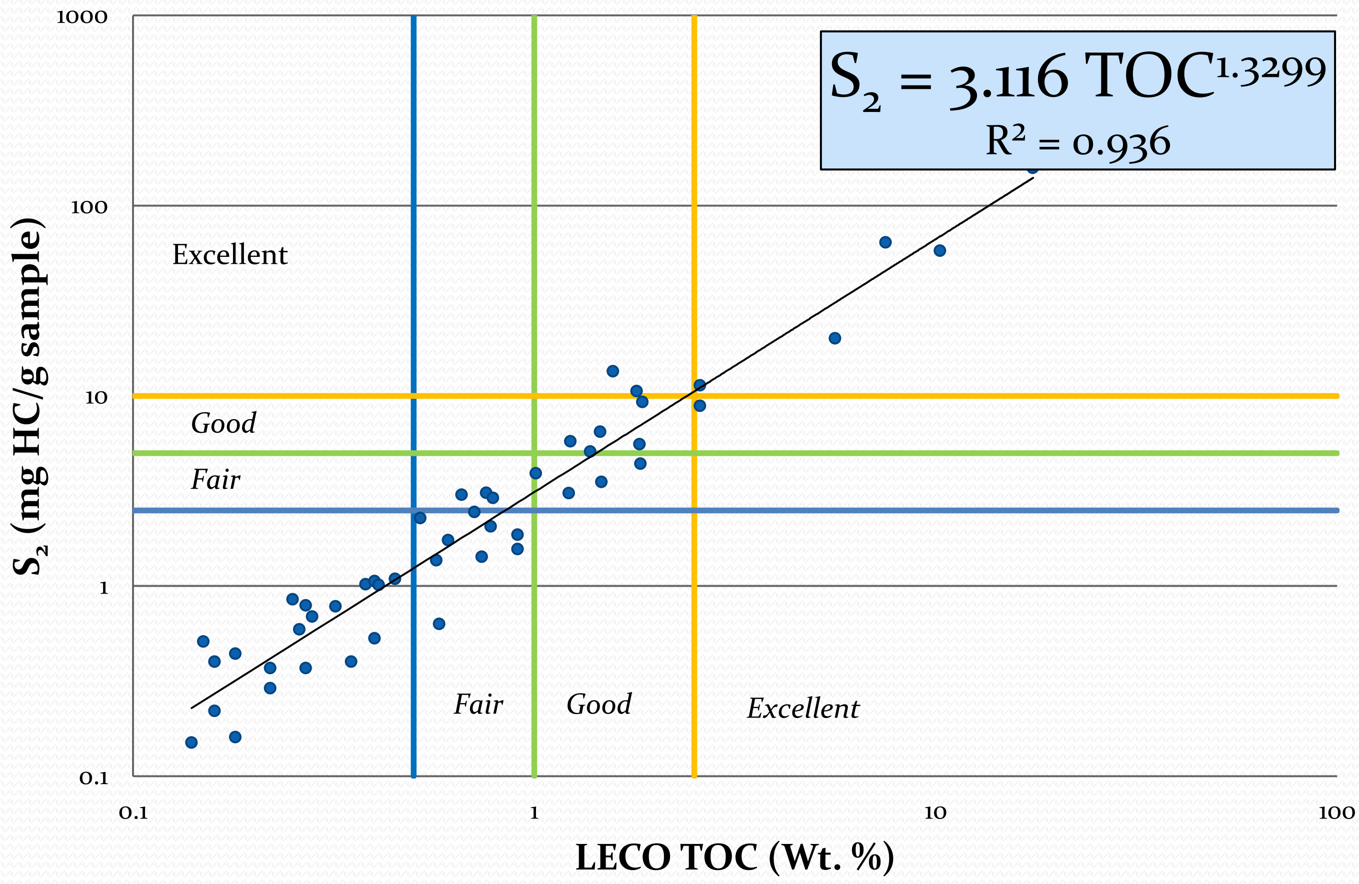
Rock Eval Pyrogram

- Heating Rate – 25°C/min
- ~ 0.1 g sample
- **S_2 – Mass crackable kerogen (mg/g)**

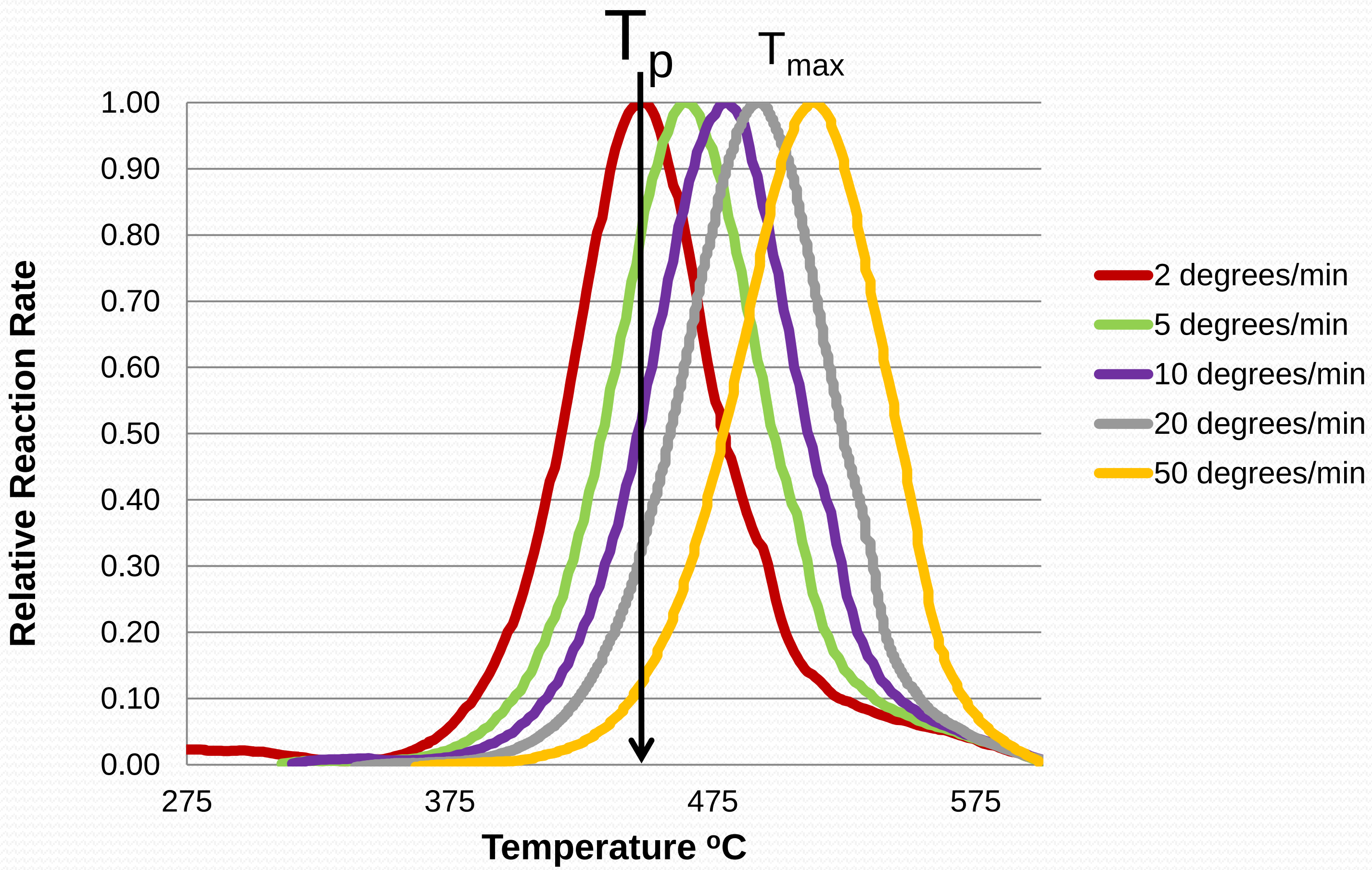




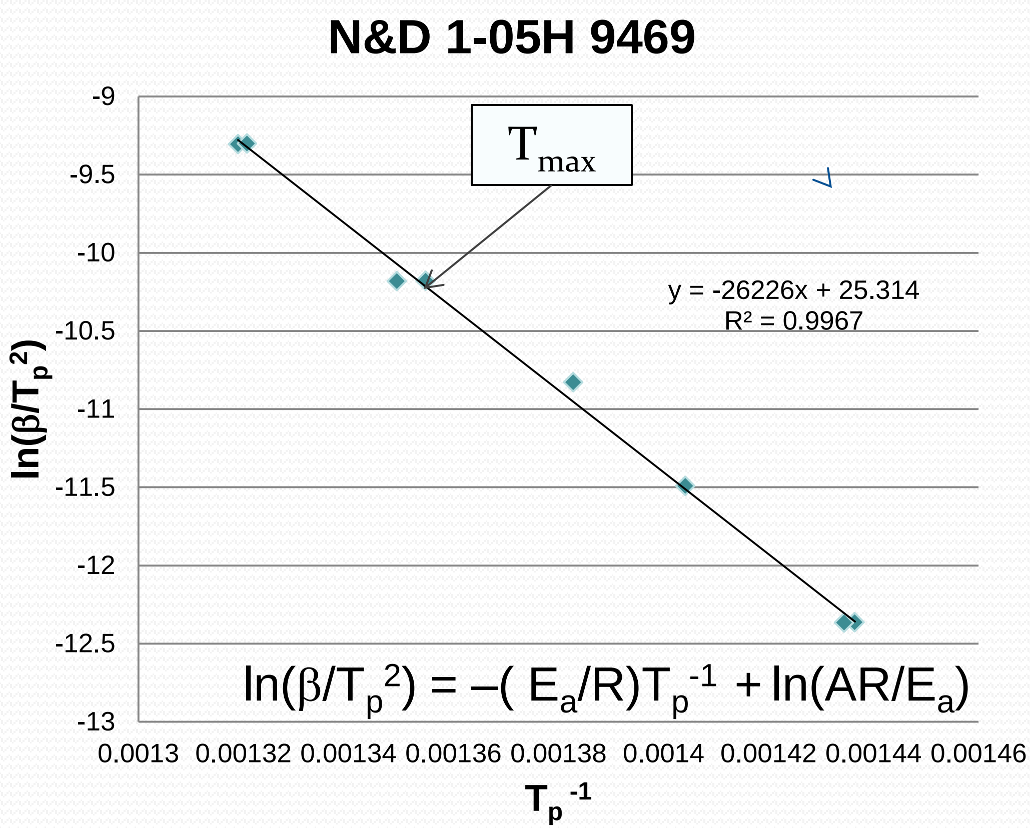
Red River % TOC to S_2 Conversion (Provisional)



Oil Generation Rates from Non Isothermal Pyrolysis



Experimental Determination of E_a and A. How T_{max} Fits In



β = Heating Rate (°K/Min)

T_p = Peak Reaction Temp. (°K)

E_a = Activation Energy

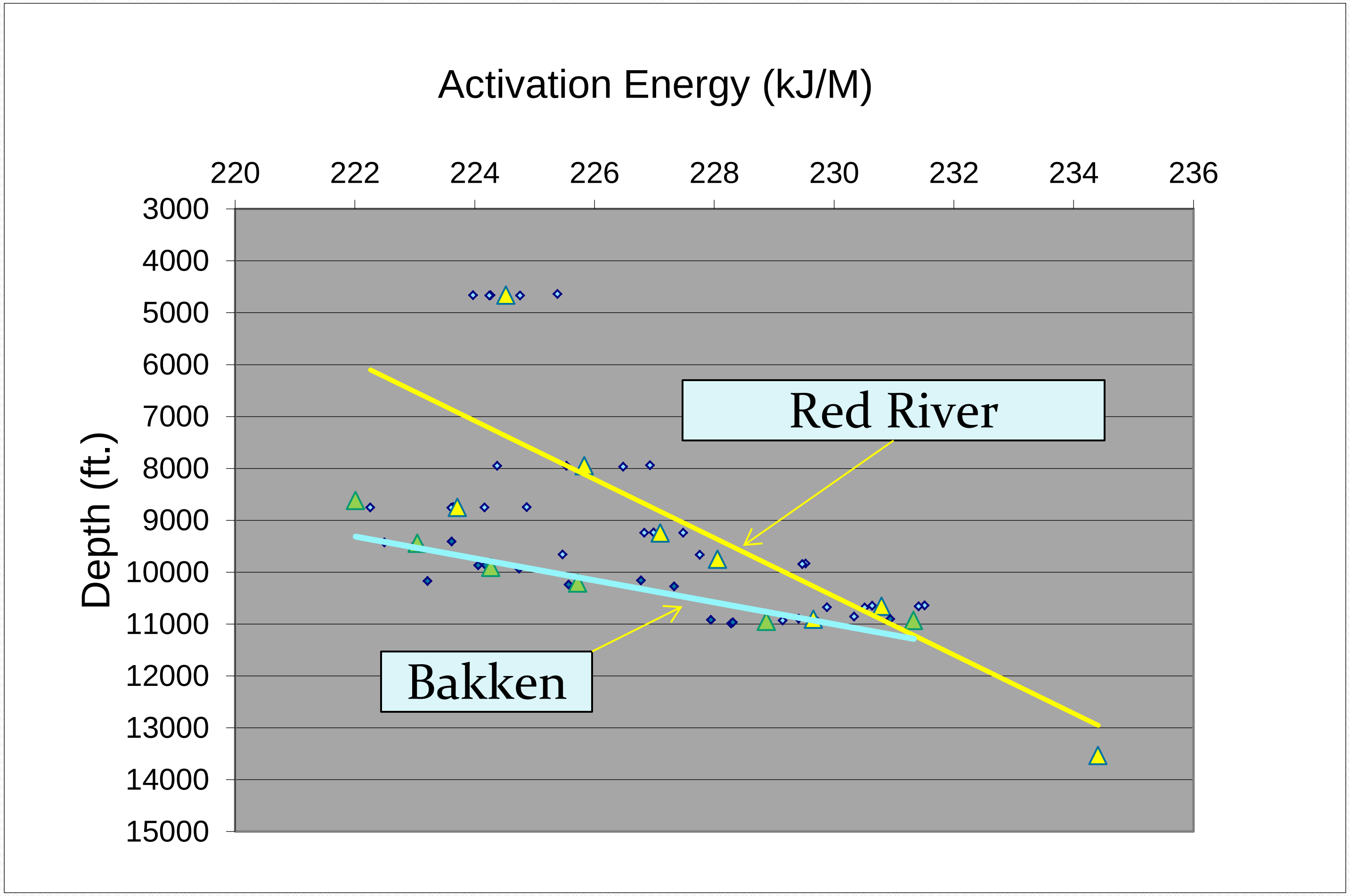
A = Frequency Factor (1/min)

R = Gas Constant (kJ/°K-mole)

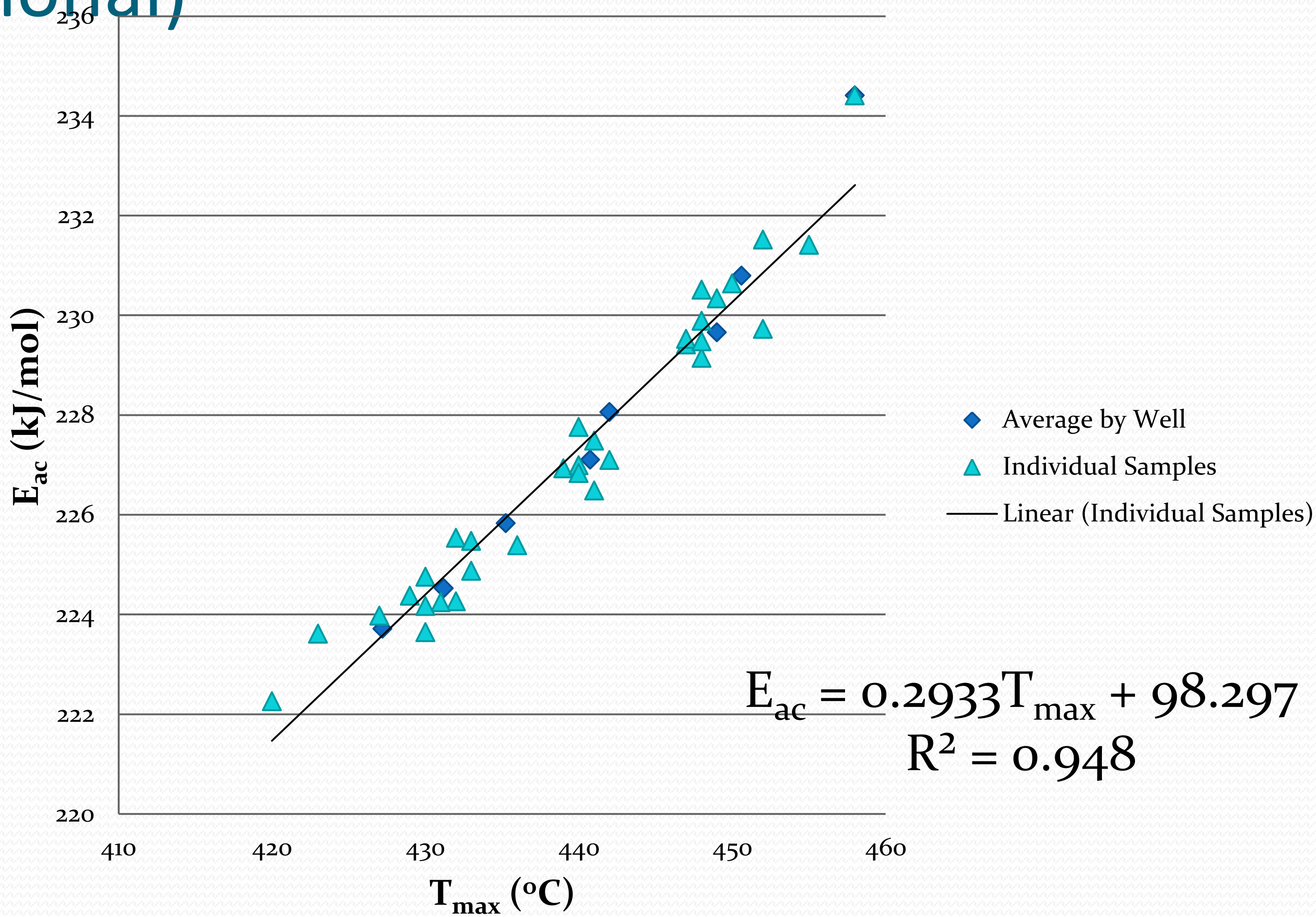
Bakken Comparison

Well	E_a kJ/mol	Est. Temp (oC)	k mol/my	Well	E_a kJ/mol	Est. Temp (°C)	k mol/my
Stenejhem HD 27-1	***229***	***138***	***2.54E-02***	***Grant Carlson No.1***	***234***	***160***	***1.90E-01***
Federal DG-1	***231***	***134***	***7.28E-03***	**Miller 1-21**	**228**	**121**	**1.92E-03**
Texel 21-35	***226***	***121***	***3.53E-03***	**Kremers 21X-22R**	**231**	**124**	**1.31E-03**
Braaflat 11-11H	224	109	7.59E-04	**Swampy-Mosser 21-9**	**230**	**122**	**1.24E-03**
N&D 1-05H	223	106	5.97E-04	**E-M Leland 10-15**	**227**	**116**	**1.07E-03**
Dobrinski 18-44	222	100	2.64E-04	Karch 1	224	100	1.39E-04
				Little Boot 15-44	226	87	5.25E-06
				Naaden No.1	225	66	6.98E-08

“Maturation” of the Red River is not the same as the Bakken



Red River T_{max} to E_{ac} conversion (provisional)



Estimating Reaction Rates from RockEval6

$dx/dt = A \exp^{-Eac/RT} x$

$dS_2/dt \sim= A \exp^{-Eac/RT} S_2$

S_2 = mg Hydrocarbon / g Sample

$A = 3.15 \times 10^{27}$ m.y.$^{-1}$

R = 0.008314 kJ/mol

$E_{ac} = 0.29\, T_{max} + 98.3$

T = Formation Temperature (°K)

t = time (m.y.)

$$dS_2/dt = A\, e^{-(0.29\, Tmax + 98.3)/RT}\, S_2$$

Conclusions

- Assaying the organic carbon content of the Red River is difficult without core.
- Activation energies of Red River kerogenites increase with maturation.
- Maturation induced variations in activation energies for the Red River Fm. are not the same as for the Bakken Fm.
- It may be possible to estimate an "index" that is proportional to the oil generation rate in the Red River using experimentally determined relationships between RockEval data and nonisothermal kinetic data.