[AV]OOIP Utilizing GEOCHEM [ECS] Data, Triple Combo Data Only, and Pyrolysis S1 Data, Permian Wolfcamp "A" and "B" Shales, Midland Basin, Texas*

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Search and Discovery Article #110207 (2015)**
Posted August 31, 2015

*Adapted from presentation at the AAPG DPA Forum Midland Playmaker, Midland Texas January 14, 2015.
Editor's note: A closely related article by the author is, OOIP Utilizing GEOCHEM [ECS] Data, Triple Combo Data Only, and Pyrolysis S1 Data, Permian Wolfcamp "A" and "B" Shales, Search and Discovery Article #41406 (2014).

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Abstract

As a result of a very complete data set including Pyrolysis S1 data over an interval of 8035ft to 8497ft at 5ft intervals on a Wolfcamp well in the Midland Basin of Texas enabled the author an opportunity to compare different methods of calculating Oil in Place. The first OOIPstb calculation was done using only resistivity (AIT90), bulk density (ρb), and neutron porosity (ϕnls) data with TOC determined by the Schmoker Equation. The volume of clay (Vcl), volume of quartz (Vqtz), and total porosity ($\phi total$) were determined by the Simultaneous Equation Method developed by Rick Lewis with Schlumberger. Effective porosity (ϕe) was calculated as $\phi e = \phi total - (Vcl*\phi clay)$. Using a permeability cut-off of ka > 100nD $\{ka = [(0.0108*\phi oil) - 0.000256]*10^6\}$ the OOIPstb/160 acres over for the Wolfcamp "A" is 3.4mmbo and 7.5mmbo [no cutoff]. The Wolfcamp "B" is 2.7mmbo [ka > 100nD] and 10.8mmbo [no cutoff].

The next OOIPstb calculation was done using AIT90, ρb, and ϕnls data along with GEOCHEM [ECS] data. TOC was determined by the Schmoker Equation. The $\phi total$ was determined with a variable matrix analysis using Vqtz, Vcalcite, Vkerogen, Vcl, and Vpyrite. Effective porosity (ϕe) was calculated as $\phi e = \phi total - (Vcl*\phi clay)$. Using a permeability cut-off of ka > 100nD $\{ka = [(0.0108*\phi oil) - 0.000256]*10^6\}$ the OOIPstb/160 acres over for the Wolfcamp "A" is 4.6mmbo and 8.4mmbo [no cutoff]. The Wolfcamp "B" is 3.2mmbo [ka > 100nD] and 10.7mmbo [no cutoff].

The third method to determine Oil in Place was based on the method outlined by Downey el al. (2011) using Pyrolysis S1 data. The equation used is listed below:

$$\text{Oil in Place/160acres} = \Sigma[1241.34*\rho b*S1*(1/\rho oil)*0.5']$$

Using the above OOIP equation with S1 values calculated from the TOClab Pyrolysis S1 Transform illustrated above, the calculated Oil in Place/160acres are Wolfcamp "A" 5.6mmbo [no cutoff] and 2.9mmbo [$\phi e > 4\%$ cutoff], and for the Wolfcamp "B" 9.6mmbo [no cutoff] and 3.5mmbo [$\phi e>4\%$ cutoff].

The general agreement of OOIPstb determined from Triple Combo/GEOCHEM [ECS] and Triple Combo only with Oil in Place from Pyrolysis S1 data suggest that the use of a permeability cut-off of ka > 100nD and $\phi e > 4\%$ may have validity in establishing a net pay cut-offs for the Wolfcamp. In addition, the OOIPstb values calculated with only the Triple Combo data [AIT90, ρb, and ϕnls] gave reasonable values [6.1mmbo] versus [7.8mmbo] using GEOCHEM [ECS] data is important, because a great many wells have only Triple Combo data.

The calculation of OOIP using Pyrolysis S1 data has the advantage in that values for formation water resistivity (Rw), porosity (ϕ), tortuosity factor (a), cementation exponent (m), and saturation exponent (n) are not required.

Selected References

Asquith, G.B., 2014, OOIP Utilizing GEOCHEM [ECS] Data, Triple Combo Data Only, and Pyrolysis S1 Data, Permian Wolfcamp “A” and “B” Shales”:Search and Discovery Article #41406 (2014). Website accessed July 27, 2015, http://www.searchanddiscovery.com/documents/2014/41406asquith/ndx_asquith.pdf.

Downey, M.W., J. Garvin, R.C. Lagomarsino, and D.F. Nicklin, 2011, Quick look determination of oil-in-place in oil shale resource plays: Search and Discovery Article #40764 (2011). Website accessed July 27, 2015, (http://www.searchanddiscovery.com/documents/2011/40764downey/ndx_downey.pdf).

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Schmoker, J., 1979, Determination of Organic Content of Appalachian Devonian Shales from Formation-Density Logs, American Association of Petroleum Geologists Bulletin, v. 63, p. 1504-1537.

Schmoker, J., 1980, Organic Content of Devonian Shale in Western Appalachian Basin: American Association of Petroleum Geologists Bulletin, v. 64, p. 2156-2165.

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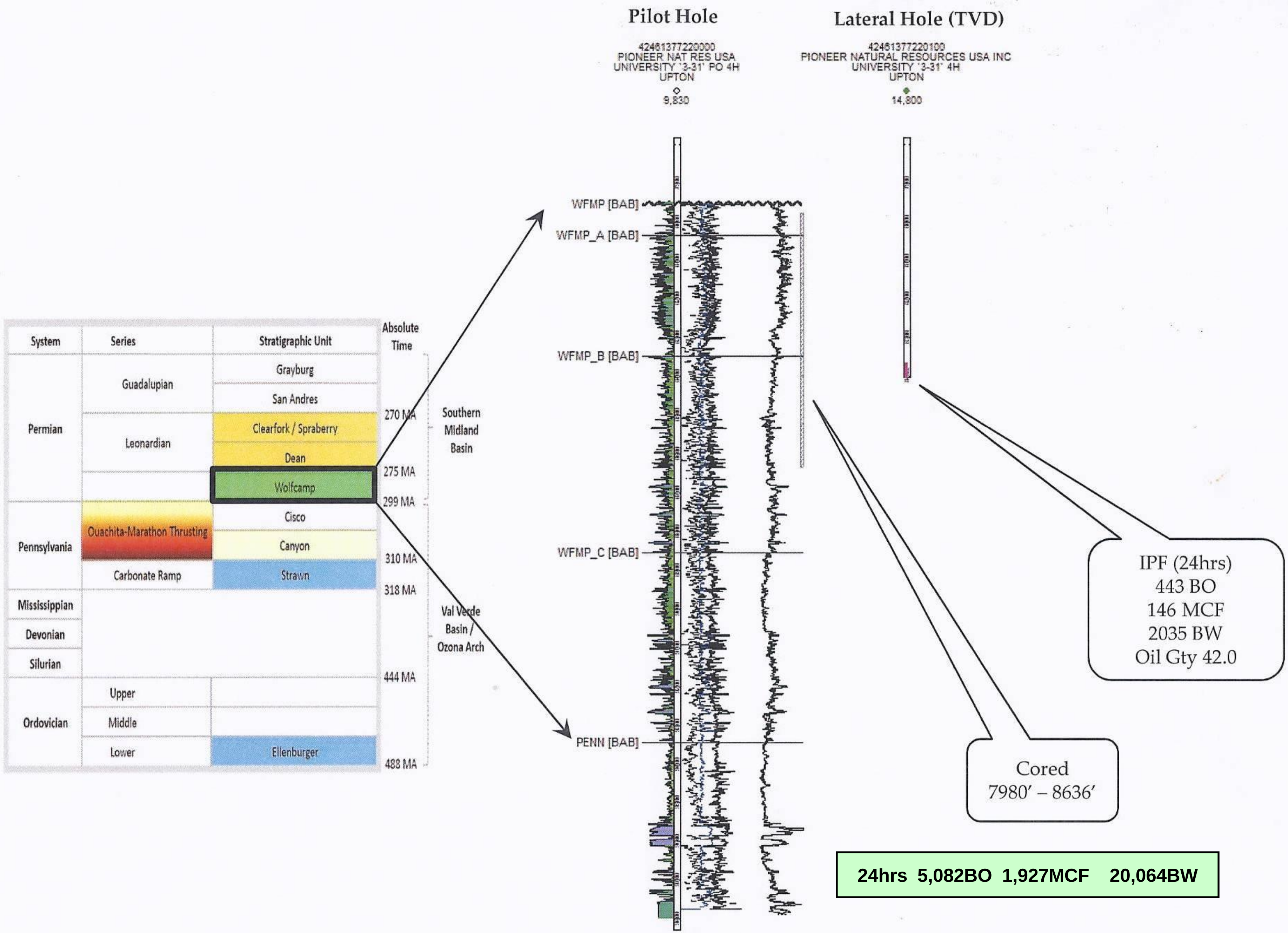
OOIP UTILIZING
GEOCHEM [ECS] DATA
TRIPLE COMBO DATA ONLY
PYROLYSIS S1 DATA
PERMIAN
WOLFCAMP “A” & “B” SHALES
MIDLAND BASIN, TEXAS

G.B. Asquith, TEXAS TECH UNIVERSITY



Pilot Hole
42461377220000
PIONEER NAT RES USA
UNIVERSITY '3-31' PO 4H
UPTON
9,830
Lateral Hole (TVD)
42461377220100
PIONEER NATURAL RESOURCES USA INC
UNIVERSITY '3-31' 4H
UPTON
14,800
System
Series
Stratigraphic Unit
Absolute Time
Permian
Guadalupian
Grayburg
San Andres
270 MA
Leonardian
Clearfork / Spraberry
Dean
275 MA
Wolfcamp
299 MA
Pennsylvania
Ouachita-Marathon Thrusting
Cisco
Canyon
310 MA
Carbonate Ramp
Strawn
318 MA
Mississippian
Devonian
Silurian
444 MA
Ordovician
Upper
Middle
Lower
Ellenburger
488 MA
Southern Midland Basin
Val Verde Basin / Ozona Arch
WFMP [BAB]
WFMP_A [BAB]
WFMP_B [BAB]
WFMP_C [BAB]
PENN [BAB]
IPF (24hrs)
443 BO
146 MCF
2035 BW
Oil Gty 42.0
Cored
7980' – 8636'
24hrs 5,082BO 1,927MCF 20,064BW

KEY FACTORS for ECONOMIC SHALE

[from: Rick Lewis (2013) w/ SCHLUMBERGER]

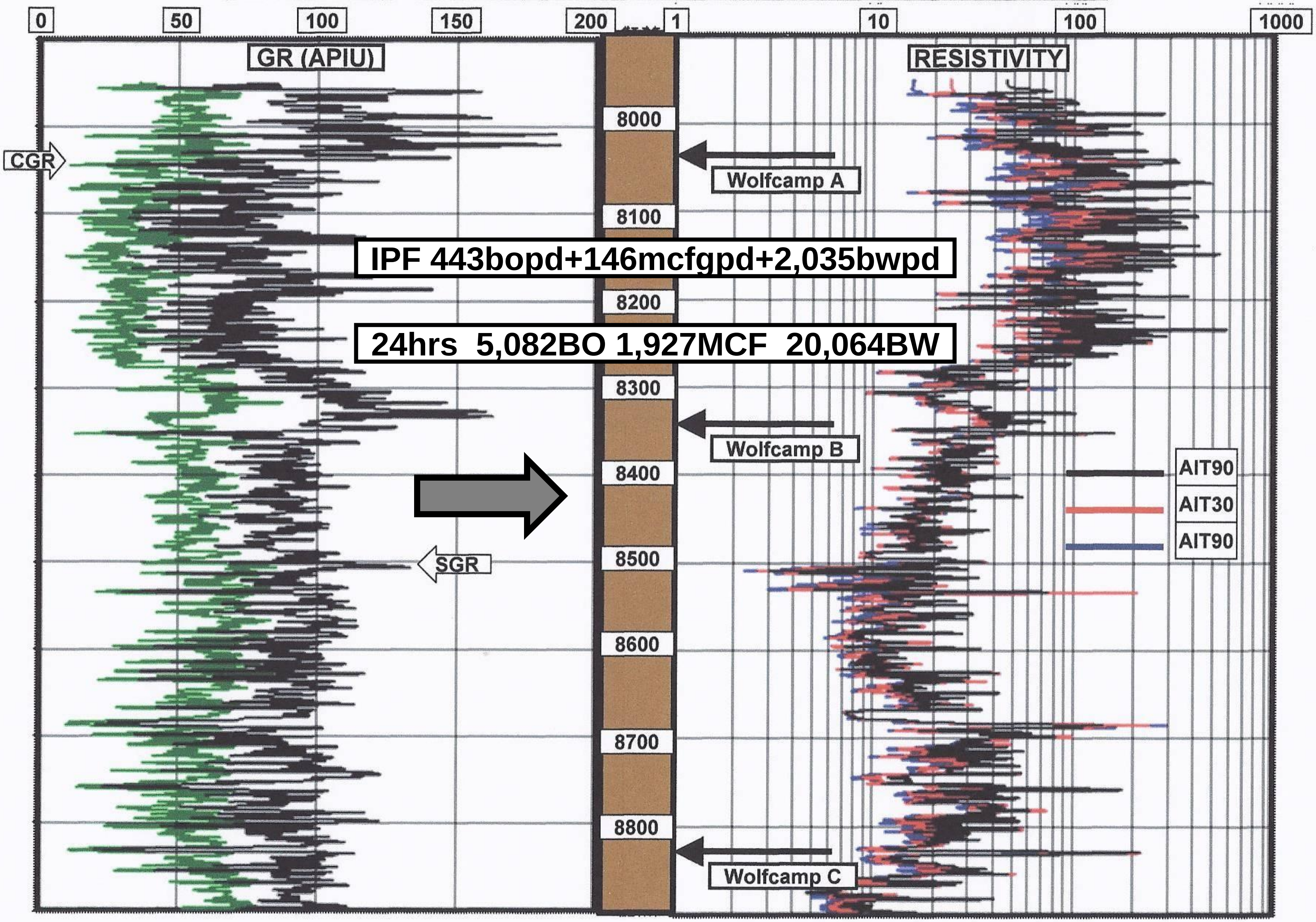
RESERVOIR QUALITY

- **Hydrocarbons in Place**
- **Matrix Permeability**
- **Pore Pressure**

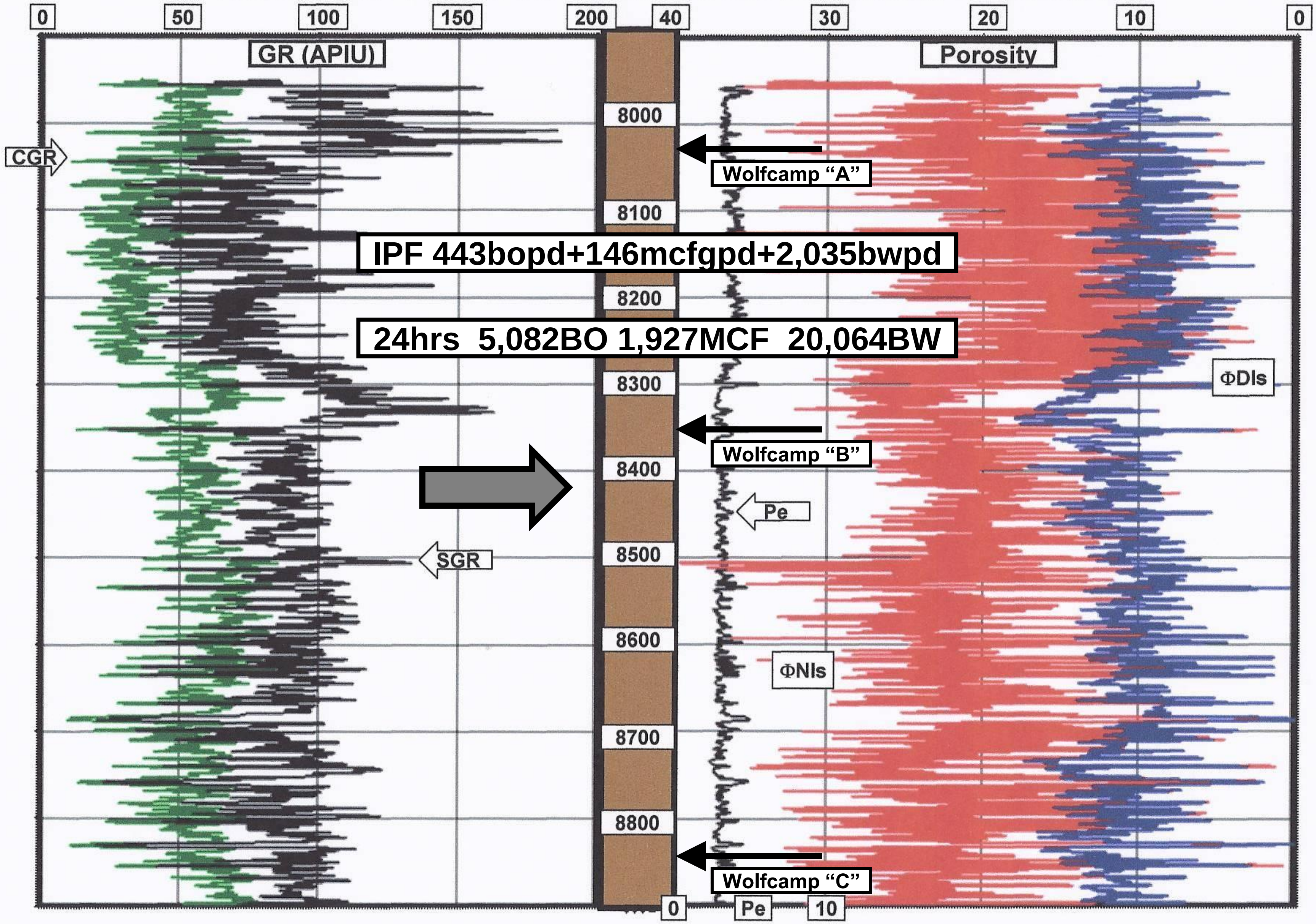
COMPLETION QUALITY

- **Hydraulic Fracture Surface Area**
- **Hydraulic Fracture Conductivity**
- **Hydraulic Fracture Containment**

PERMIAN WOLFCAMP: Midland Basin Texas



PERMIAN WOLFCAMP: Midland Basin Texas



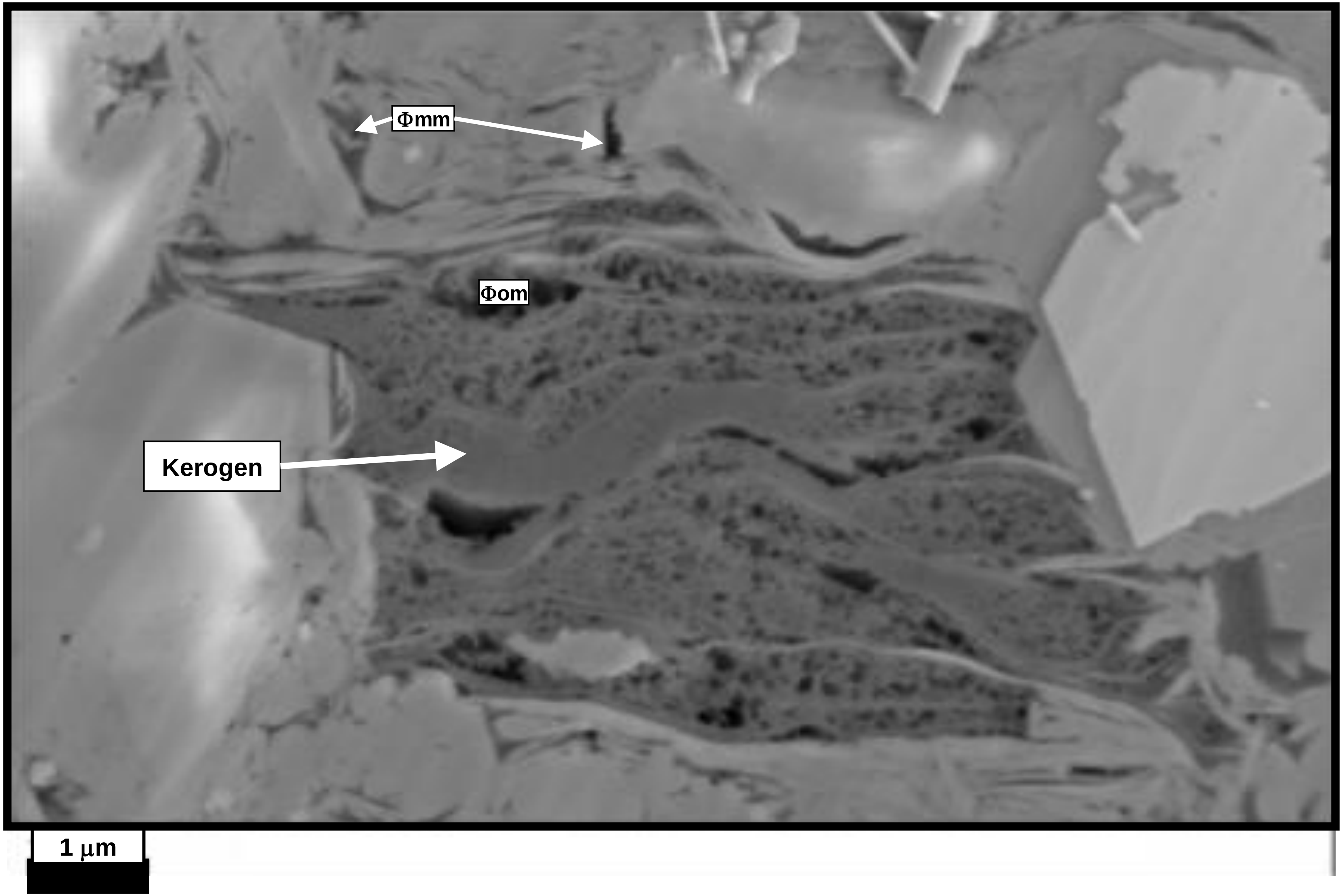
TOClab & TOCschmoker

- TOClab(wt%):
- 0.43 to 8.7 avg. = 3.3wt% N = 94

- TOCschmoker(wt%):
- 1.46 to 6.8 avg. = 3.8wt% N = 94

- $Vke = (TOC * Kvr * \rho b)/\rho kerogen$

ORGANOPOROSITY [Φom] & MINERAL MATRIX POROSITY [Φmm]
[Courtesy of Rick Lewis w/ SCHLUMBERGER]



POROSITIES
in
ORGANIC-RICH SHALES

Φtotal and Vcl from Simultaneous Equations or ECS and Variable Matrix Analysis

Φe = Φtotal – CBW   CBW = Vcl∗Φclay

Φe = Φom + Φmm   Φclay = 0.10 [Illite]

Φom = Vke∗OM   OM = Intra-Kerogen Porosity

OM = 0.30 [OM = 0.22 to 0.45]

Ke = 1.1g/cc to 1.5g/cc during HC generation

Φmm = Φe – Φom

OOIPstb
DUAL POROSITY PROCEDURE

OOIPstb ORGANOPOROSITY [Φom]:

$\Phi oil = \Phi om * (1-Sw)$ $Sw = 0.0$

$OOIPstb = \Sigma[(7758 * \Phi oil * h * A)/BOI]$

$h = 0.5ft.$ $A = 160ac.$ $BOI = 1.4$

OOIPstb MINERAL MATRIX POROSITY [Φmm]:

$\Phi oil = \Phi mm * (1-Sw)$

$Sw = (Ro/Rt)^{0.5}$ $Ro = 1/\Phi^2$ $\Phi = \Phi total - \Phi om$

$OOIPstb = \Sigma[(7758 * \Phi oil * h * A)/BOI]$

$h = 0.5ft.$ $A = 160ac.$ $BOI = 1.4$

OOIPstb TRIPLE COMBO DATA ONLY AIT90, ρb, and ΦNls

MINERAL VOLUMES and TOTAL POROSITY

- $V_{cl} + V_{qtz} + V_{ke} + \Phi_{total} = 1.0$ $V_{ke} = (TOC*K_{vr}*\rho_b)/\rho_{kerogen}$
- $V_{cl}*\rho_{cl} + V_{qtz}*\rho_{qtz} + V_{ke}*\rho_{ke} + \Phi_{total}*\rho_f = \rho_b$
- $V_{cl}*\Phi_{ncl} + V_{qtz}*\Phi_{nqtz} + V_{ke}*\Phi_{nke} + \Phi_{total}*\Phi_{nf} = \Phi_n$

$TOCwt\% = (156.956/\rho_b) - 58.271$ ← Schmoker Equation

Vcl = volume of clay

ρcl = density of clay Φncl = neutron porosity of clay

Vqtz = volume of quartz

ρqtz = density of quartz Φnqtz = neutron porosity of quartz

Vke = volume of kerogen

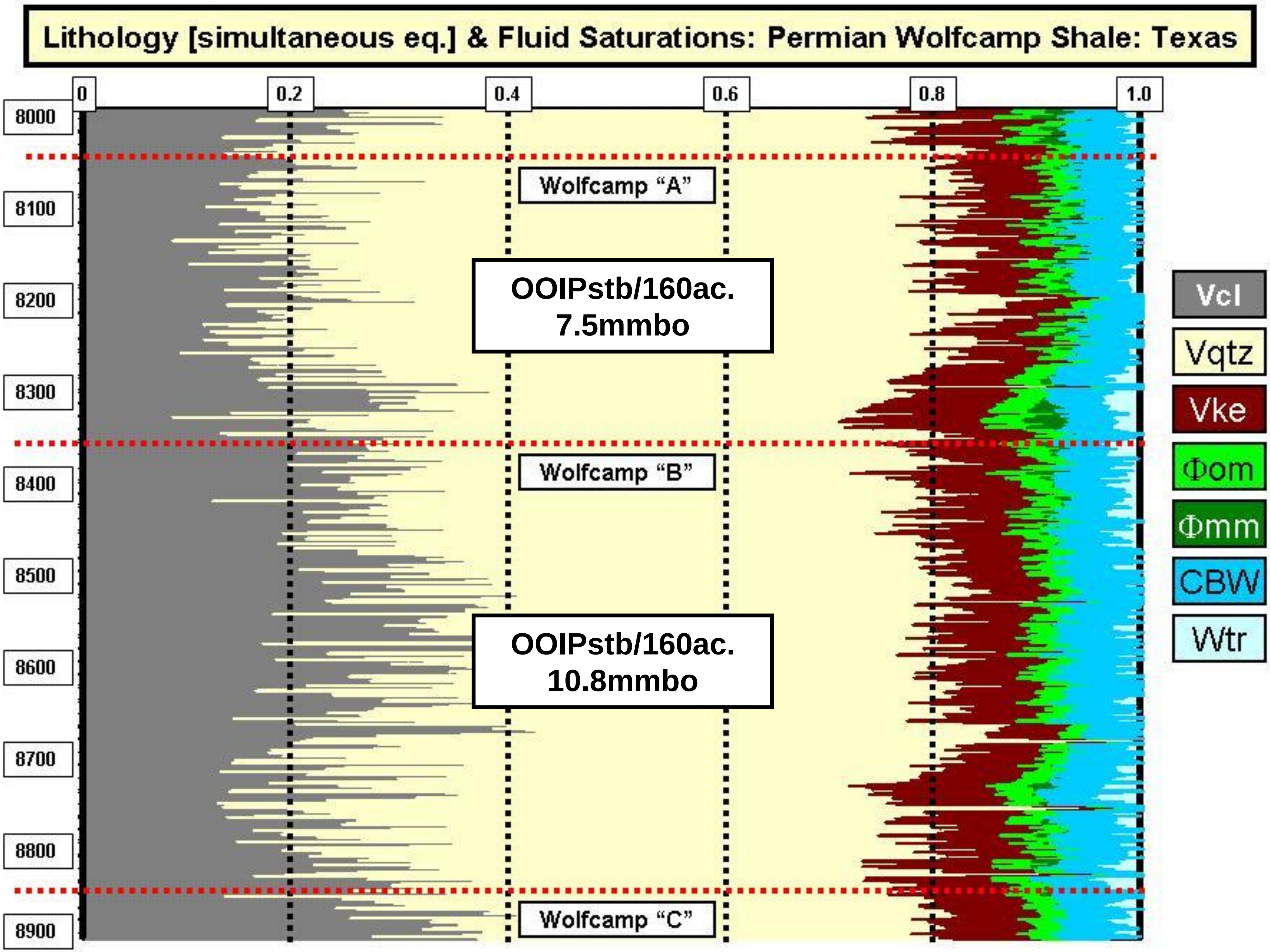
ρke = density of kerogen Φnke = neutron porosity of kerogen

Φtotal = total porosity

$\rho_f = S_w*\rho_{water} + (1-S_w)*\rho_{oil}$

$\Phi_{nf} = S_w*\Phi_{nwater} + (1-S_w)*\Phi_{noil}$

Modified After Lewis (2009)



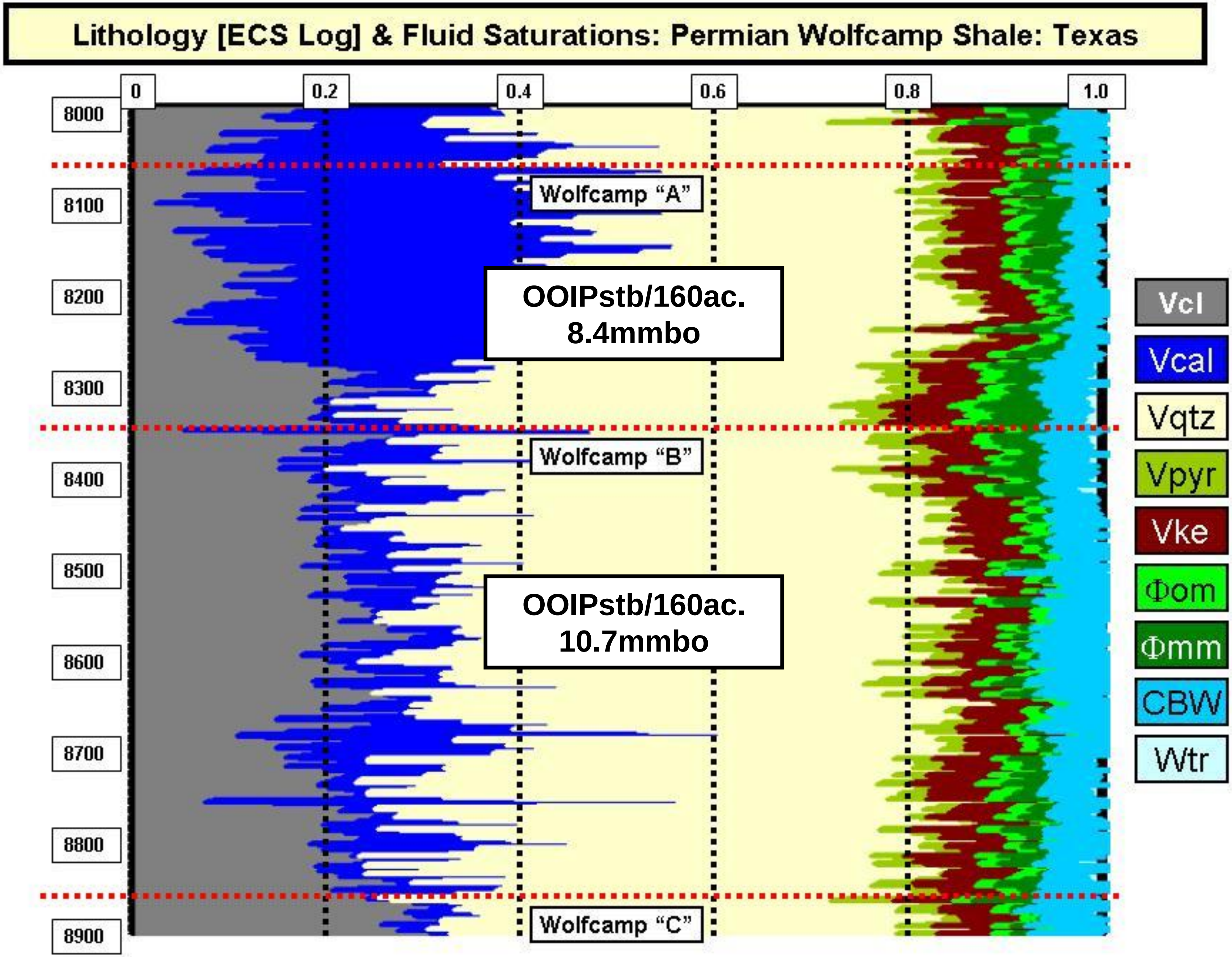
Lithology [simultaneous eq.] & Fluid Saturations: Permian Wolfcamp Shale: Texas
0
0.2
0.4
0.6
0.8
1.0
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
Wolfcamp “A”
OOIPstb/160ac.
7.5mmbo
Wolfcamp “B”
OOIPstb/160ac.
10.8mmbo
Wolfcamp “C”
Vcl
Vqtz
Vke
Φom
Φmm
CBW
Wtr

OOIPstb
TRIPLE COMBO DATA
+
GEOCHEM DATA [ECS]

VARIABLE MATRIX [GEOCHEM DATA]

- $\rho ma = (Vcl*\rho cl)+(Vcal*2.71)+(Vqtz*2.65)+(Vpyr*5)+(Vke*\rho ke)$
- $\rho ke = 1.5$ g/cc $Vke = (TOC*Kvr*\rho b)/\rho kerogen$
- ρcl
  - Kaolinite = 2.61g/cc
  - Chorite = 2.92g/cc
  - Illite = 2.71g/cc
  - Illite/Smectite = 2.45g/cc
  - Smectite = 2.26g/cc

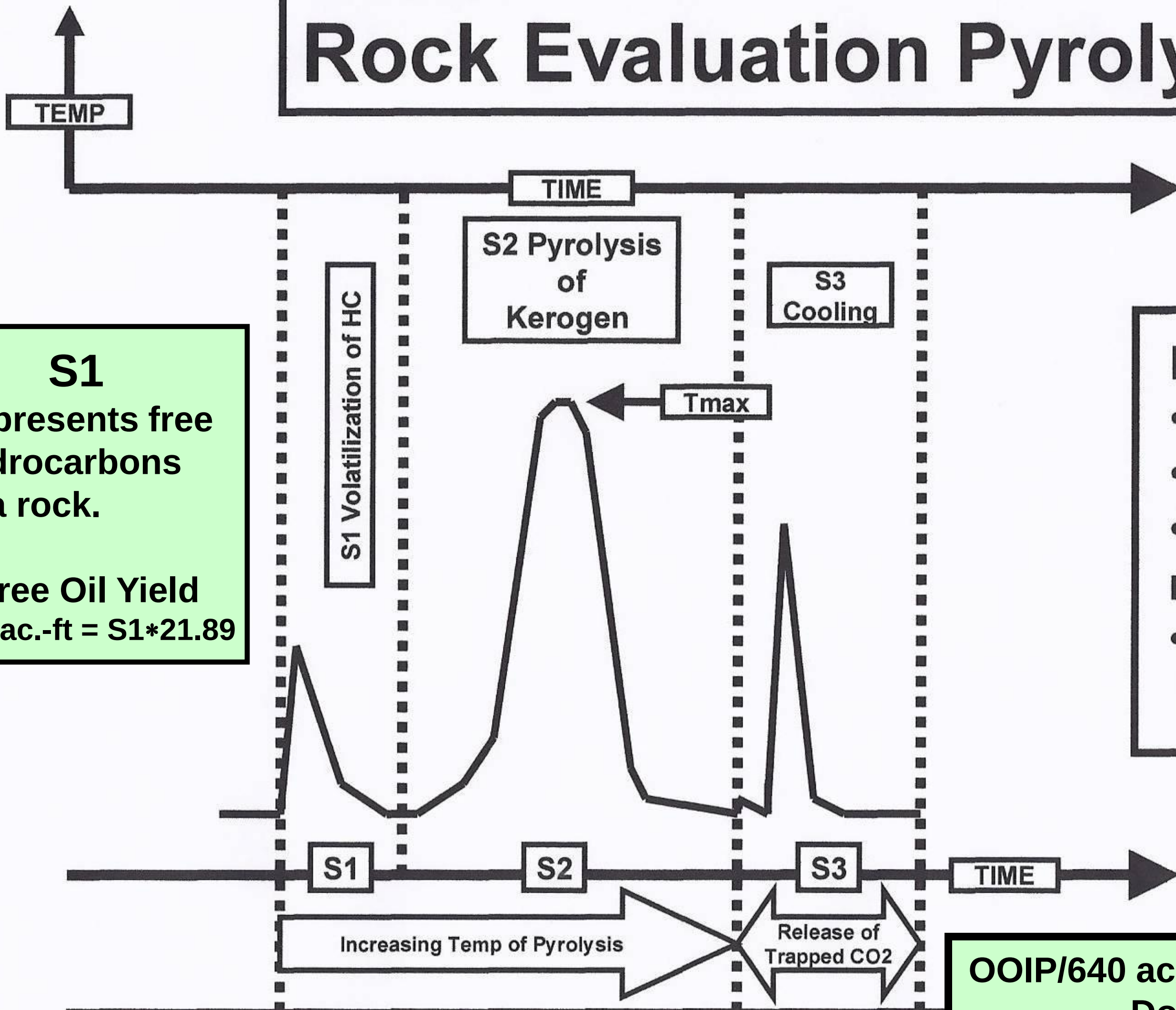
- $\Phi total = (\rho ma - \rho b)/(\rho ma - \rho f)$
- $\rho f = (Sw*1.1) + [(1-Sw)*\rho hc]$ $\rho gas = 0.1$g/cc $\rho oil = 0.85$g/cc



Lithology [ECS Log] & Fluid Saturations: Permian Wolfcamp Shale: Texas
0
0.2
0.4
0.6
0.8
1.0
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
Wolfcamp "A"
Wolfcamp "B"
Wolfcamp "C"
OOIPstb/160ac.
8.4mmbo
OOIPstb/160ac.
10.7mmbo
Vcl
Vcal
Vqtz
Vpyr
Vke
Φom
Φmm
CBW
Wtr

OIL in PLACE PYROLYSIS S1 DATA

Rock Evaluation Pyrolysis



S1

Represents free hydrocarbons in a rock.

Free Oil Yield
BO/ac.-ft = S1∗21.89

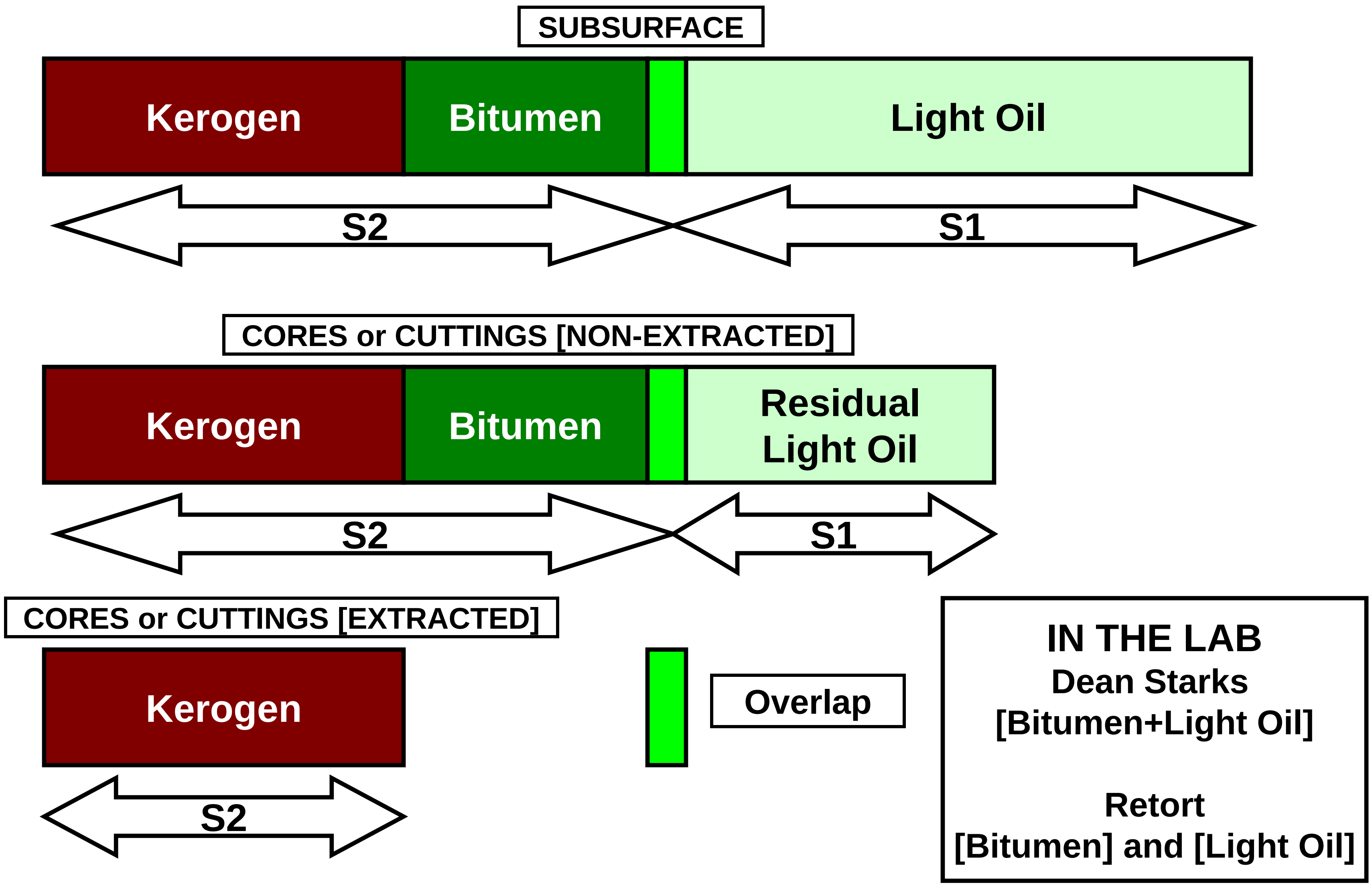
Determines:

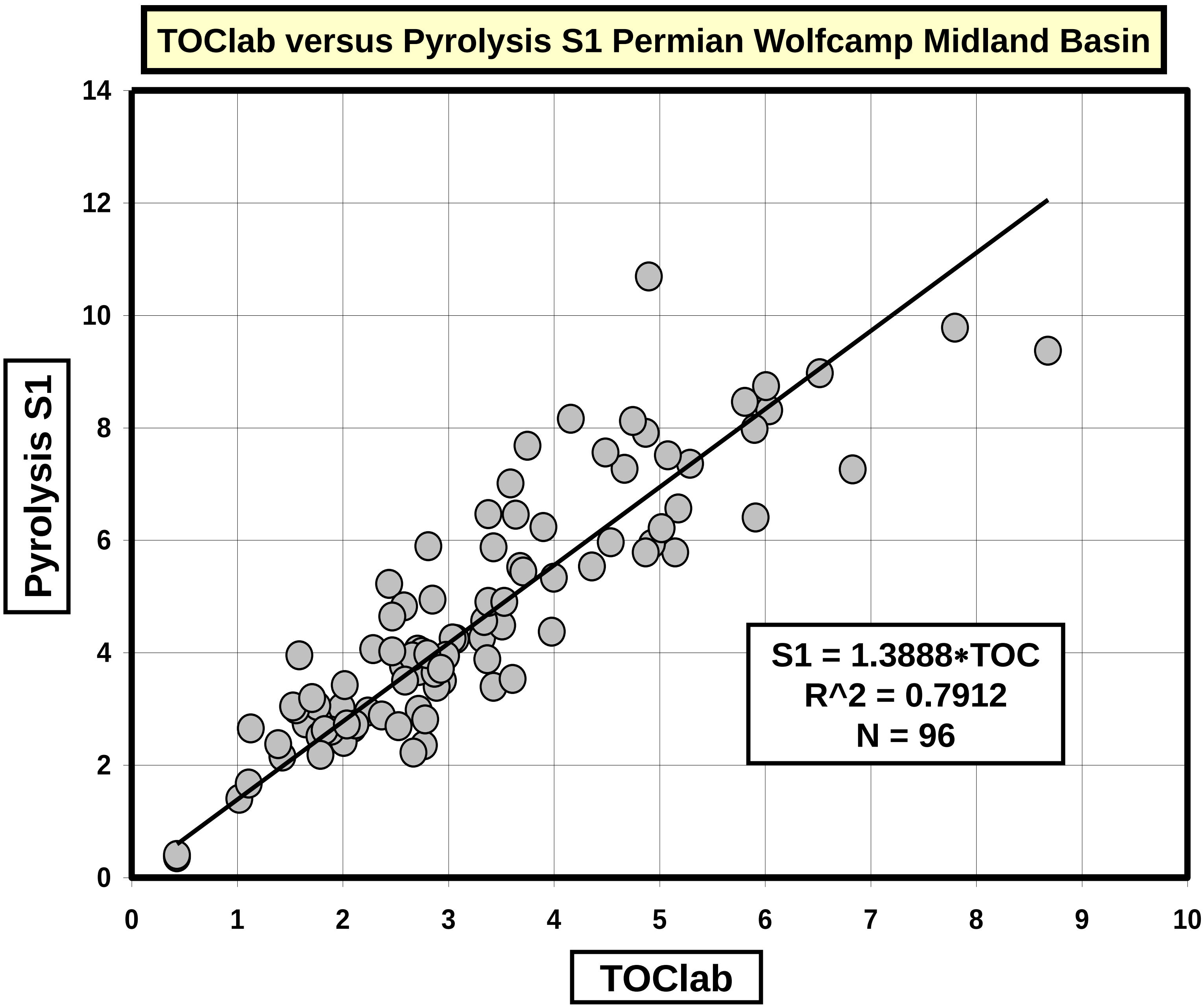
- **TOC content**
- **Kerogen type**
- **Kerogen maturity**
- **Amount of free hydrocarbons**

OOIP/640 ac/ft = 4965.36∗ρb∗S1∗(1/ρoil)
Downey et al. (2011)

Hydrocarbon Index(HI) = S2∗(100/TOC)

TOTAL ORGANIC CARBON [TOC]




TOClab versus Pyrolysis S1 Permian Wolfcamp Midland Basin
Pyrolysis S1
0
2
4
6
8
10
12
14
0
1
2
3
4
5
6
7
8
9
10
S1 = 1.3888*TOC
R^2 = 0.7912
N = 96
TOClab

OOIP from Pyrolysis [S1] Data

- **OOIP/640 ac./ft = 4965.36∗ρb∗S1∗(1/ρoil)**

  [Downey et al., 2011]

- **OOIP/160ac. = Σ[1241.34∗ρb∗S1∗(1/ρoil)∗0.5']**

  TOC = (156.956/ρb) - 58.271 [Schmoker Equation]

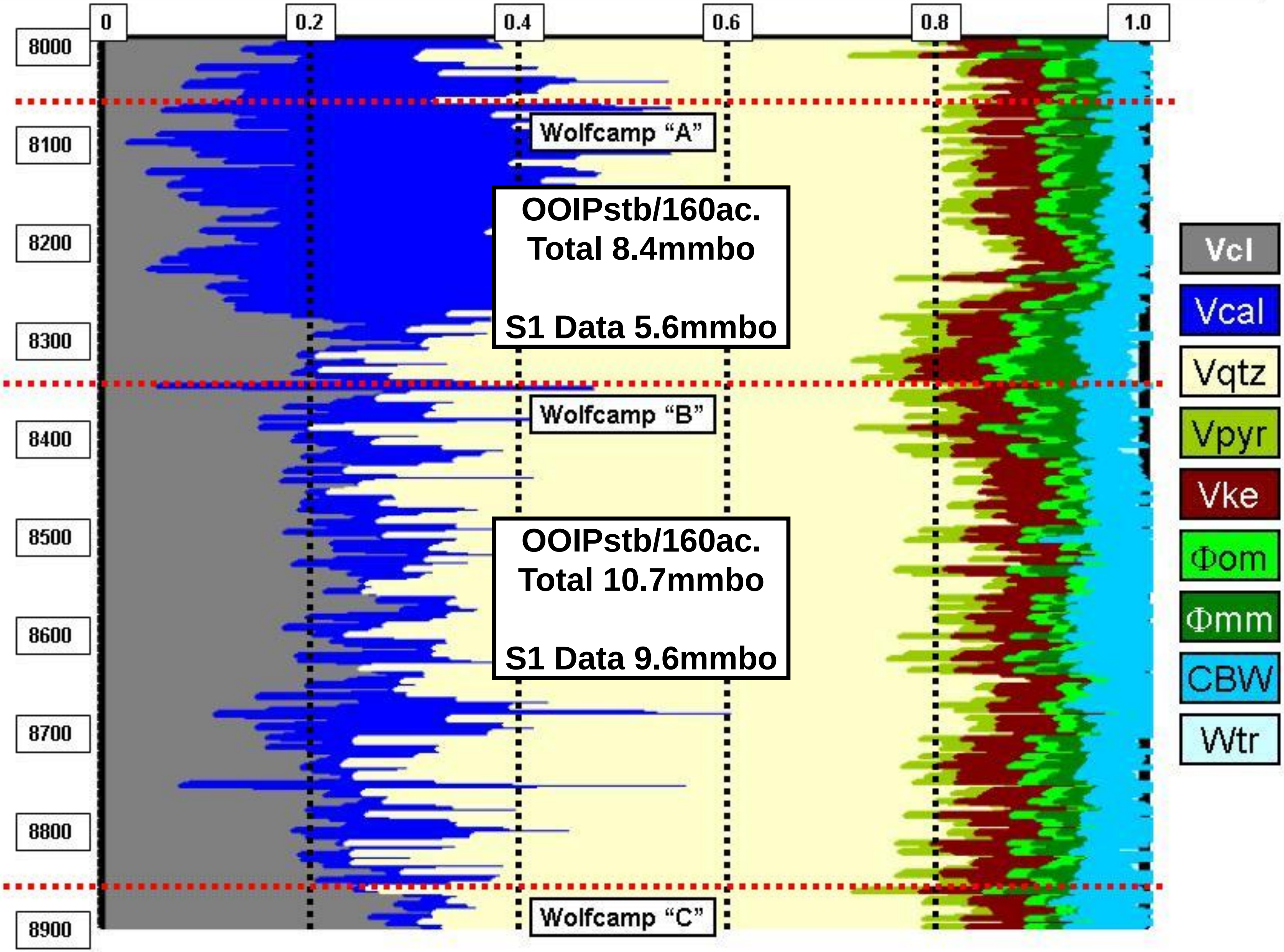
  ρb = bulk density from well log

  S1 = 1.3888∗TOClog

  ρoil = oil density [default value: 0.85g/cc]

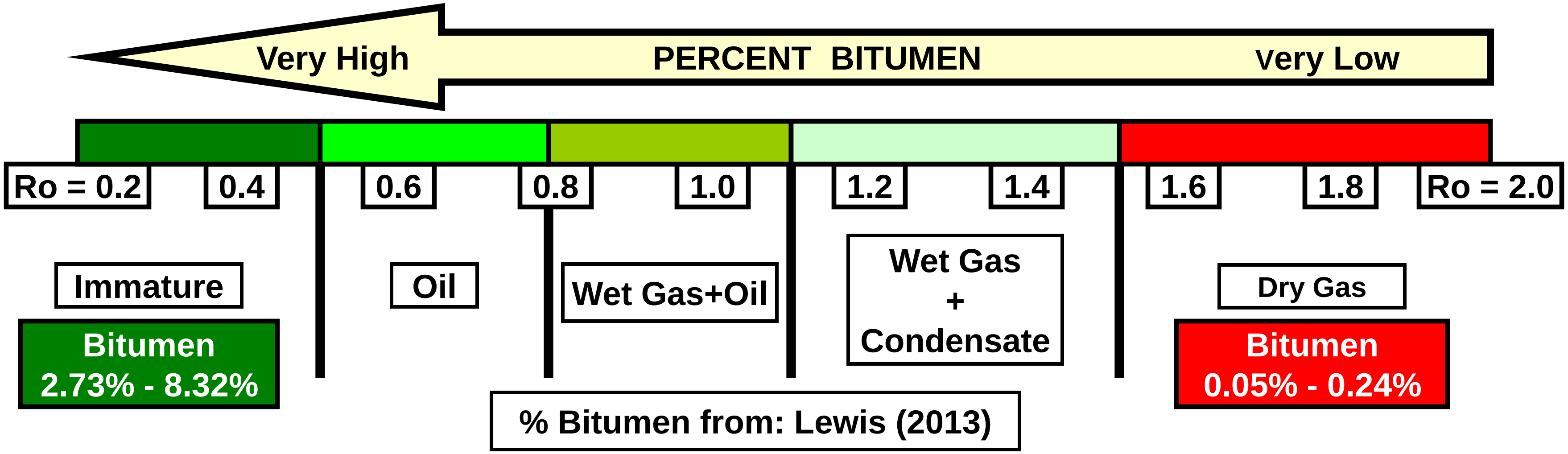
  0.5ft. = log data interval

Lithology [ECS Log] & Fluid Saturations: Permian Wolfcamp Shale: Texas



OOIPstb CORRECTED for NON-MOVEABLE BITUMEN

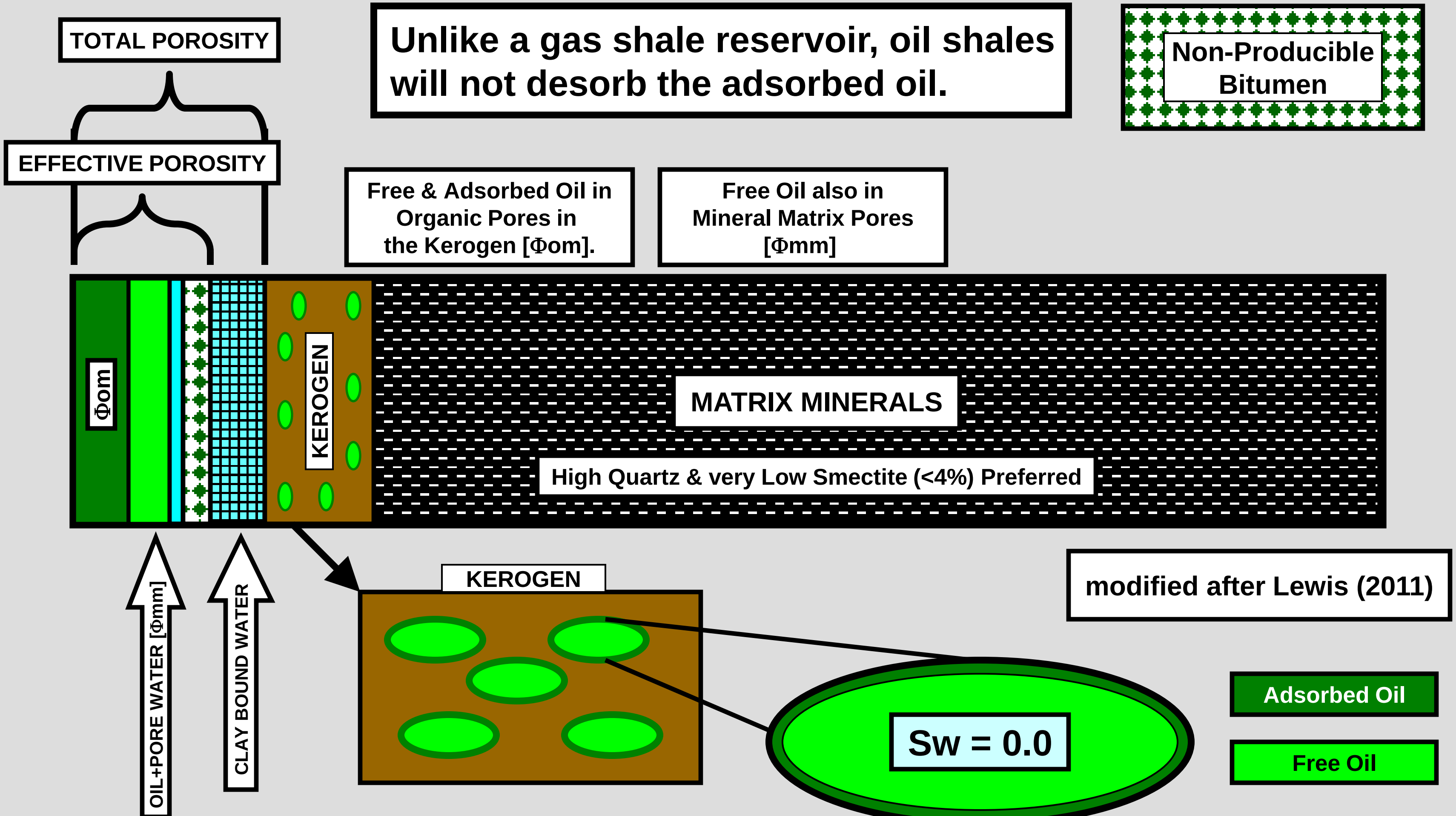
NON-MOVEABLE BITUMEN and the IMPORTANCE of THERMAL MATURITY



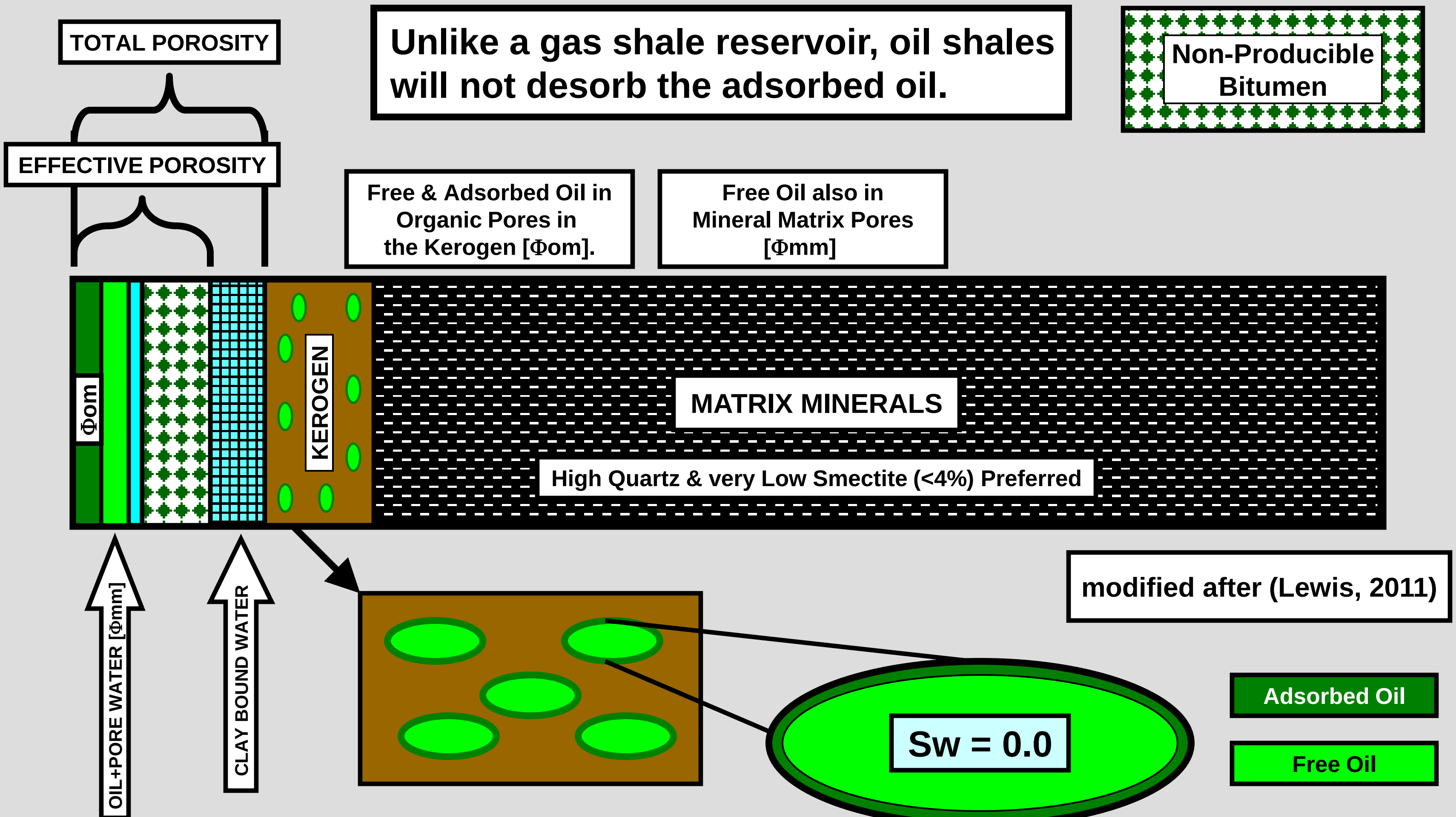
NOTE: As maturity increases the non-producible bitumen is converted to producible oil and gas. The problem is that the non-producible bitumen is calculated as potentially producible oil in a standard log analysis [OOIPstb].

Wolfcamp Midland Basin Well: Ro(avg.) = 0.84 N = 96

SHALE POROSITY [High Maturity]



SHALE POROSITY [Low Maturity]



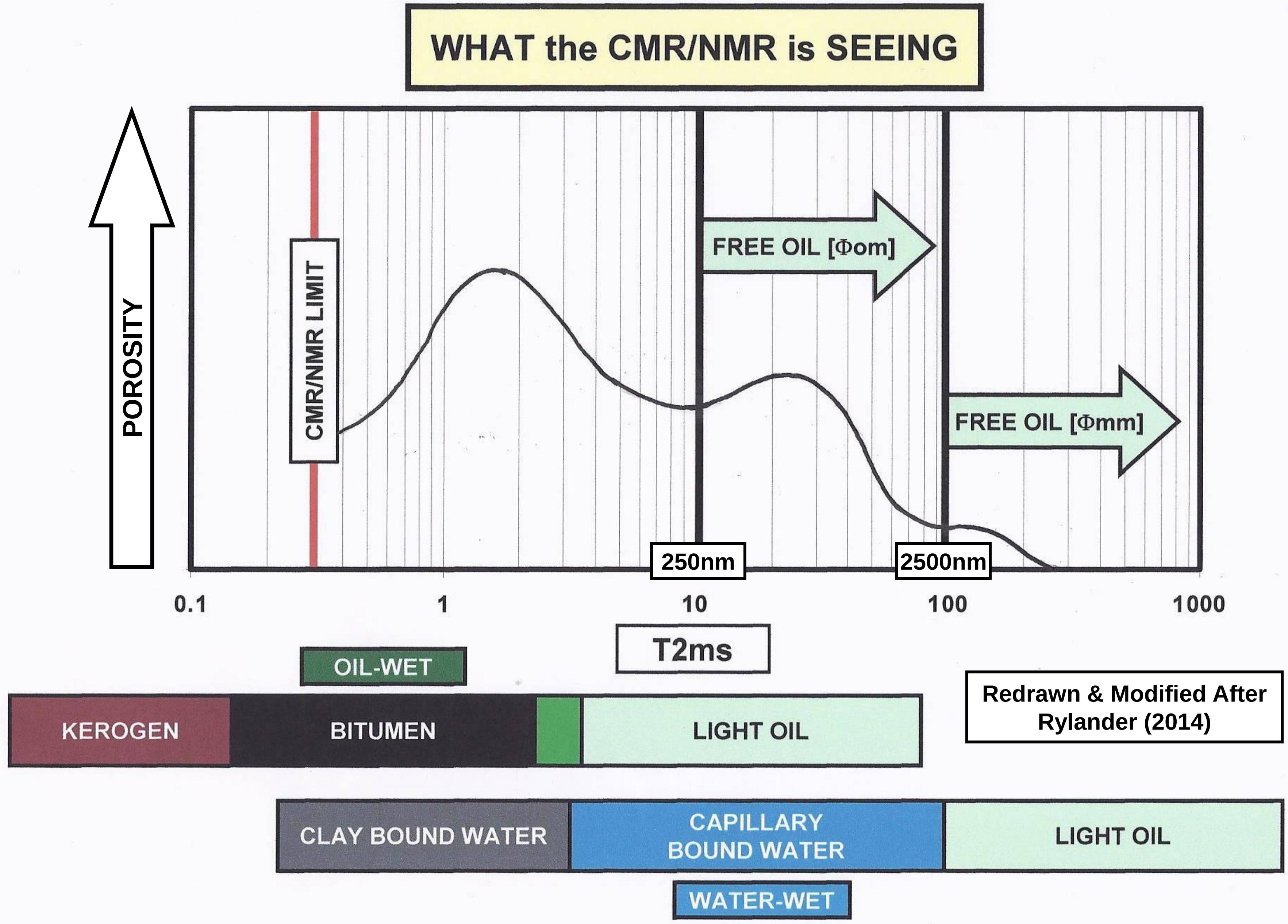
CORRECTING for NON-PRODUCIBLE BITUMEN

- **NMR/CMR Method [Rylander et al., 2013]**

NO NMR/CMR LOG

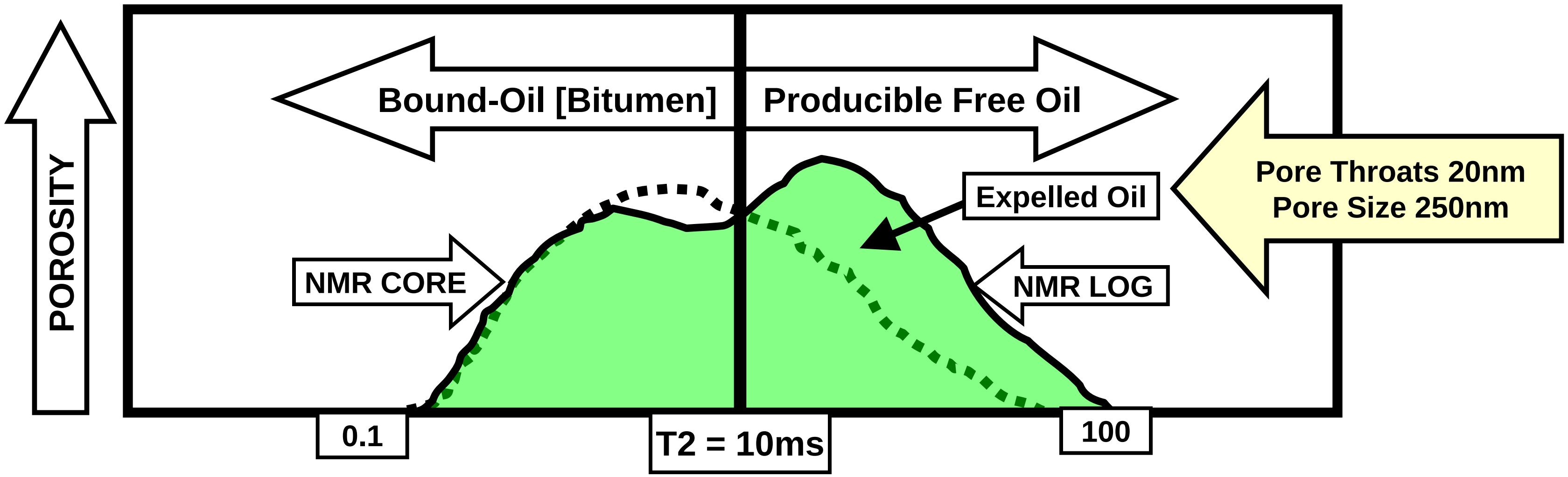
- **Ro [vitrinite reflection] versus Non-Producible Bitumen [Φbitumen] Method [Asquith, 2014]**

$$OOIPstb = \Sigma[7758 * (\Phi oil - \Phi bitumen) * 0.5' * 160ac.]/BOI$$

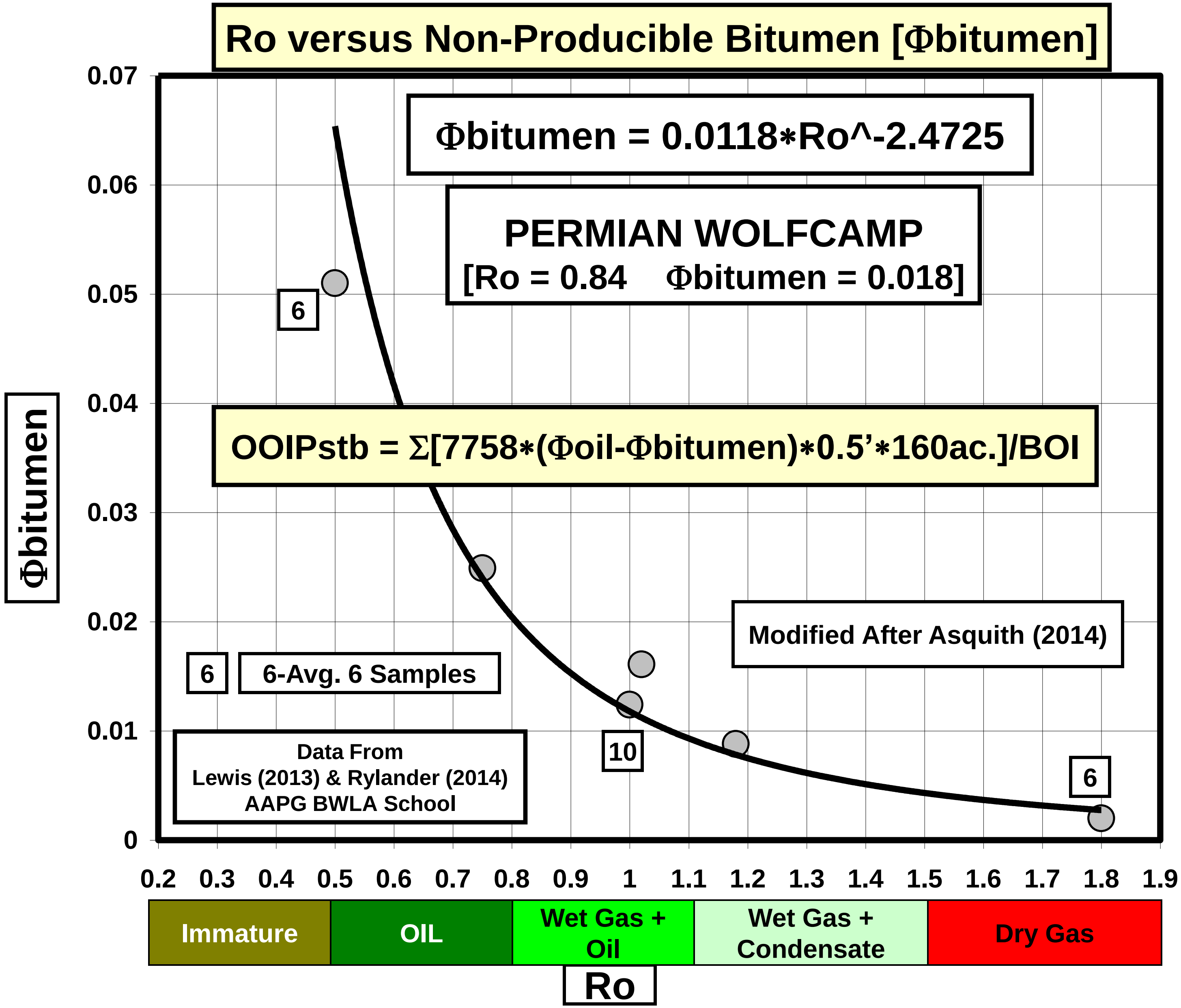

WHAT the CMR/NMR is SEEING
POROSITY
CMR/NMR LIMIT
FREE OIL [Φom]
FREE OIL [Φmm]
250nm
2500nm
0.1
1
10
100
1000
T2ms
OIL-WET
KEROGEN
BITUMEN
LIGHT OIL
CLAY BOUND WATER
CAPILLARY BOUND WATER
LIGHT OIL
WATER-WET
Redrawn & Modified After Rylander (2014)

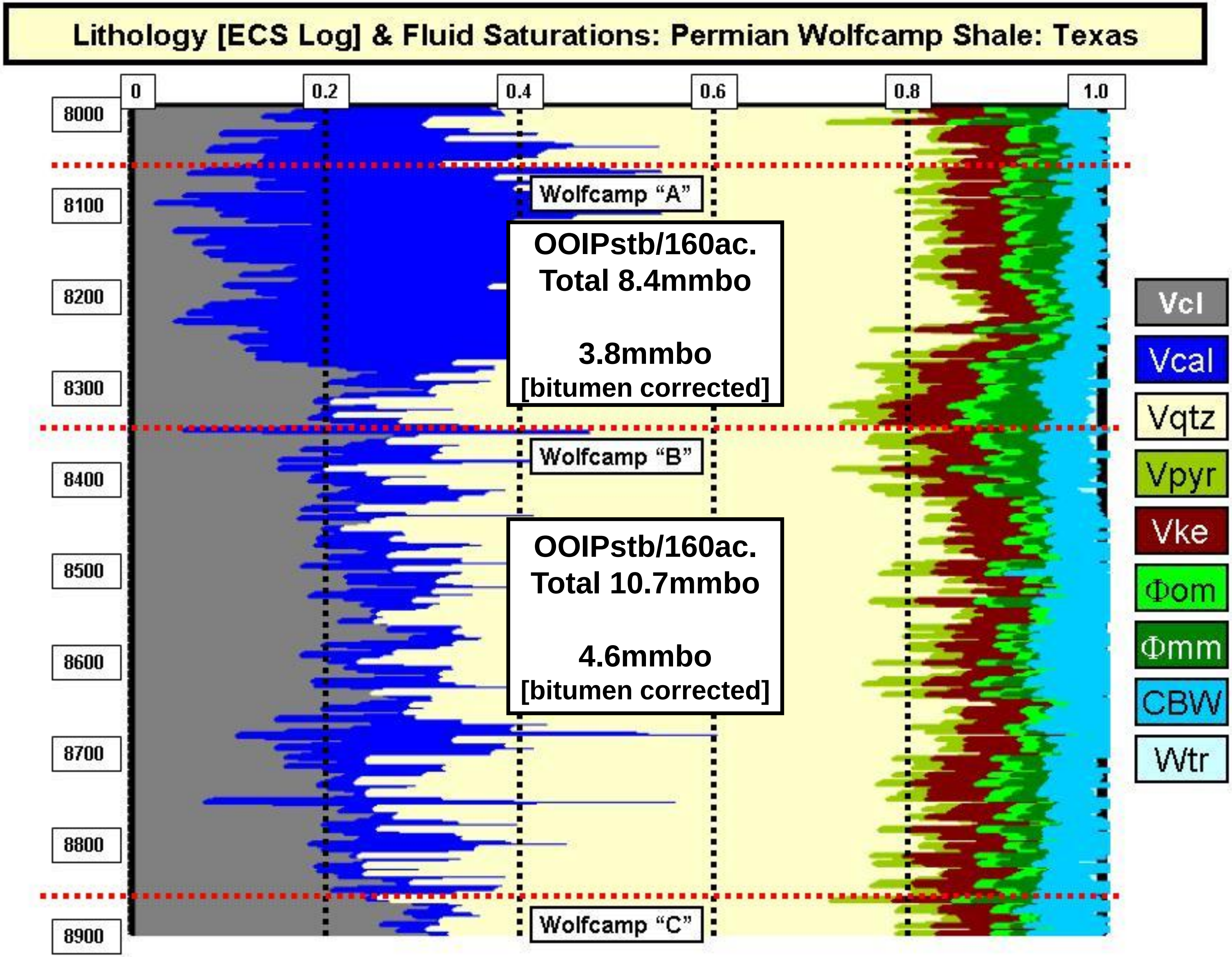
T2 DISTRIBUTIONS from CMR/NMR CORE and CMR/NMR LOG [Downhole]

[redrawn from examples in Rylander et al., 2013]



WATER SIGNAL SUBSTRACTED


Ro versus Non-Producible Bitumen [Φbitumen]
Φbitumen = 0.0118*Ro^-2.4725
PERMIAN WOLFCAMP
[Ro = 0.84 Φbitumen = 0.018]
OOIPstb = Σ[7758*(Φoil-Φbitumen)*0.5'*160ac.]/BOI
Modified After Asquith (2014)
6
6-Avg. 6 Samples
Data From
Lewis (2013) & Rylander (2014)
AAPG BWLA School
10
6
6
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Φbitumen
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9
Immature
OIL
Wet Gas + Oil
Wet Gas + Condensate
Dry Gas
Ro



Lithology [ECS Log] & Fluid Saturations: Permian Wolfcamp Shale: Texas
0
0.2
0.4
0.6
0.8
1.0
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
Wolfcamp "A"
OOIPstb/160ac.
Total 8.4mmbo
3.8mmbo
[bitumen corrected]
Wolfcamp "B"
OOIPstb/160ac.
Total 10.7mmbo
4.6mmbo
[bitumen corrected]
Wolfcamp "C"
Vcl
Vcal
Vqtz
Vpyr
Vke
Φom
Φmm
CBW
Wtr

Summary: Volumetric OOIPstb[mmbo], Pyrolysis S1 OOIP[mmbo], & Bitumen Corrected Permian Wolfcamp "A" and "B" Zones: Midland Basin Texas [160ac.]

DATA	Triple-Combo	Triple Combo/ECS	Pyrolysis S1	Bitumen Corrected
WOLFCAMP "A"	7.5	8.4	5.6	3.8
WOLFCAMP "B"	10.8	10.7	9.6	4.6
TOTAL	18.3	19.1	15.2	8.4

$OOIPstb = \Sigma[7758 * (\Phi oil - \Phi bitumen) * 0.5' * 160ac.]/BOI$

CONCLUSIONS

OOIPstb calculated using GEOCHEM data compared well with OOIPstb calculated using only Triple Combo data in both Wolfcamp “A” and Wolfcamp “B”.

However, in the Wolfcamp “A” and “B” OOIP from Pyrolysis S1 data and bitumen corrected are lower.

CONCLUSIONS

OOIP calculated from Pyrolysis S1 Data has the following advantages:

1.) NO Rw Needed

2.) NO Porosity Needed [no a, m, n]

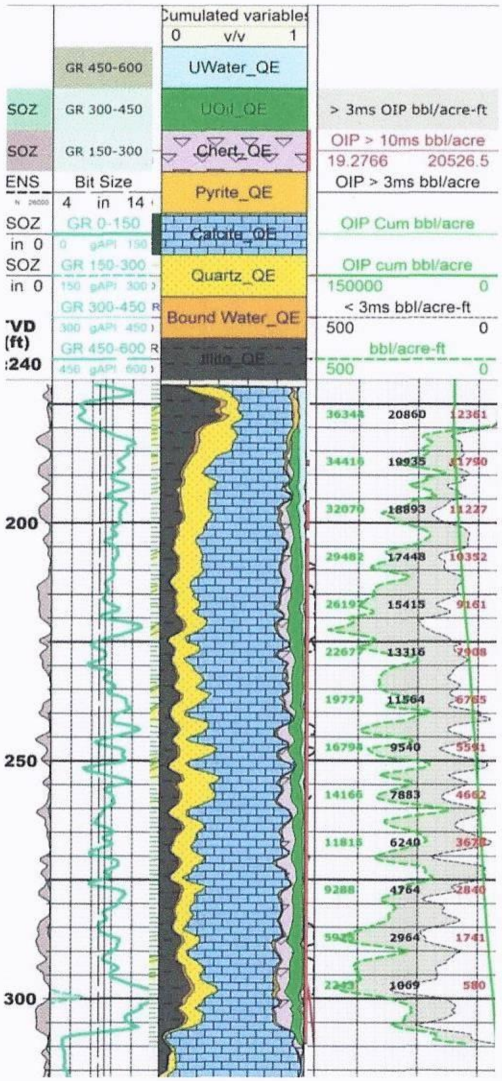
3.) NO BITUMEN in the Calculation

CONCLUSIONS

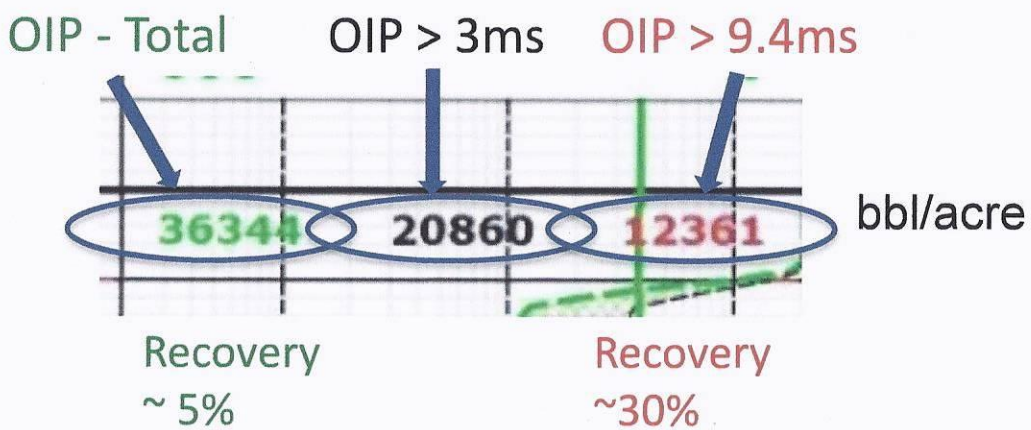
OOIP determined from Pyrolysis S1 data and/or OOIPstb corrected for non-moveable bitumen [Rylander, 2013; Asquith, 2014] represent free-hydrocarbon volumes.

[SEE: LAST SLIDE]

Resource w/ T2 [ms] Cut-Offs Applied



Modified After Rylander (2014) w/ SCHLUMBERGER



Comparing recovery efficiencies computed from the free hydrocarbon volume is a superior way of comparing the effectiveness of hydraulic fracture stimulations