Permian Wolfcamp Interesting Log Interpretation Problem*

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Abstract

In the log analysis of a Permian Wolfcamp well the Wolfcamp was subdivided into two zone labeled Wolfcamp 1 and Wolfcamp 2. Using GEOCHEM [ECS] data the total porosity [PHItotal] was calculated from the bulk density log using variable matrix analysis. Effective porosity [PHIe] was then determined [PHIe = PHItotal − CBW].

The OOIPstb for both the Wolfcamp 1 and Wolfcamp 2 are listed below:

Wolfcamp 1
OOIPstb 12.7mmbo

Wolfcamp 2
OOIPstb 5.1mmbo

The logging suite for this well also included a CMR Log therefore OOIPstb could be calculated at different T2 Relaxation Times. The results are listed below:

Wolfcamp 1 [T2 3ms Pore Size 76.5nm]
OOIPstb 8.8mmbo

Wolfcamp 1 [T2 10ms Pore Size 250nm]
OOIPstb 5.3mmbo

Wolfcamp 2 [T2 3ms Pore Size 76.5nm]
OOIPstb 5.5mmbo
Wolfcamp 2 [T2 10ms Pore Size 250nm]
OOIPstb 2.0mmbo

Note, in the above OOIPstb values Wolfcamp 1 has much greater OOIPstb values than Wolfcamp 2. An examination of the lithologies indicate that Wolfcamp 2 is more clay rich, and has a higher minimum closure stress [SHmin] and lower Brittleness Coefficient compared to Wolfcamp 1. Therefore the better reservoir with more hydrocarbons is Wolfcamp 1.

However, because the well was logged with a High Resolution Array Laterolog [HRLA] the author examined the log for invasion profiles [HRLA5>HRLA2>Rxo], which indicate zones of moveable hydrocarbons due to invasion. The better invasion profiles were located in Wolfcamp 2, not Wolfcamp 1 as I would have expected.

Next OOIPstb was calculated based on the degree of invasion (Tixier, 1956 and Asquith, 2015).

\[ Y = \left( \frac{Rmf}{Rxo} \right)^{0.5} - \left( \frac{Rw}{Rt} \right)^{0.5} \]

\[ OOIPstb = \frac{7758 \times Y \times h \times A}{BOI} \]

The results are listed below:

- Wolfcamp 1 [Y Method : Tixier, 1956]
  OOIPstb 1.5mmbo

- Wolfcamp 2 [Y Method : Tixier, 1956]
  OOIPstb 3.8mmbo

Unlike the other OOIPstb values the OOIPstb determined from the Y Method are just the reverse, indicating the Wolfcamp 2 is the better reservoir [i.e. greater invasion]. The author has used the Y Method for years in many reservoirs including the Wolfcamp, and found it to be reliable [Asquith, 2015: WTGS Fall Symposium]. So the question is what is causing the Y Method to indicate that the better reservoir is Wolfcamp 2, when the other calculated OOIPstb values and Geomechanical properties indicated Wolfcamp 1 has the better reservoir potential?

**Selected References**


PERMIAN WOLFCAMP INTERESTING LOG INTERPRETATION PROBLEM

G.B. Asquith, TEXAS TECH UNIVERSITY
KEY FACTORS for ECONOMIC SHALE
[from: Rick Lewis (2013)]

RESERVOIR QUALITY
• Hydrocarbons in Place
• Matrix Permeability
• Pore Pressure

COMPLETION QUALITY
• Hydraulic Fracture Surface Area
• Hydraulic Fracture Conductivity
• Hydraulic Fracture Containment
Gamma Ray [SGR & CGR] and Neutron-Lithodensity Permian Wolfcamp

Wolfcamp 1

Wolfcamp 2

SGR

CGR

Pe

ΦNls

ΦDls

200ft
Higher absolute permeability than in gas shales (~1 microDarcy minimum and preferably much higher). NanoDarcy-scale mudstone permeabilities are too low for economic oil production rates. (Brown, 2015: SW AAPG).
OOIPstb [T2 100ms] & K_{SDR} Permeability [\mu D] Permian Wolfcamp

Wolfcamp 1

T2 100ms 2,500nm

T2 100ms 0.8mmbo

T2 100ms 0.3mmbo

200ft

1\mu D

K_{SDR} Perm [\mu D]
TOClab versus Pyrolysis S1 [mgHC/g] Permian Wolfcamp Midland Basin

OOIP = \[21.89 \times S1 \times 0.5' \times 160\]

\[S1 = 1.2013 \times \text{TOC} \]
\[R^2 = 0.83 \]
\[N = 140\]
OOIP [Pyrolysis S1] & KSDR Permeability [µD] Permian Wolfcamp

Wolfcamp 1
S1 Pyrolysis 9.1mmbo

Wolfcamp 2
S1 Pyrolysis 3.9mmbo

OOIP/160ac.

KSDR Perm [µD]
Ro versus Non-Prodicible Bitumen [Φbitumen]

Φbitumen = 0.0118*Ro^-2.4725

PERMIAN WOLFCAMP
[Ro = 0.84  Φbitumen = 0.018]
Wolfcamp 1 [ECS DATA]
5.4 mmbo
Wolfcamp 2 [ECS DATA]
1.1 mmbo

OOIPstb = Σ[7758*(Φoil-Φbitumen)*0.5*160ac.]/BOI

Data From:
Lewis, 2013 & Rylander, 2014
AAPG BWLA School

Asquith, 2014
Walls & others 2012

Pe<3 & RHOb<2.5
Pe<4 & RHOb<2.53

Lewis, 2010

1
10
100
1000
10000

KSDR/PHI3ms

Wolfcamp 1

Avg. KSDR/PHI 357

Wolfcamp 2

Avg. KSDR/PHI 188

KSDR in µD

Walls & others 2012

Pe<3 & RHOb<2.5
Pe<4 & RHOb<2.53

Lewis, 2010

1
10
100
1000
10000

KSDR/PHI3ms

Wolfcamp 1

Avg. KSDR/PHI 357

Wolfcamp 2

Avg. KSDR/PHI 188

KSDR in µD
PERMIAN WOLFCAMP FLOW UNITS [K_{SDR}/PHI_{3ms}]

Walls & others 2012
Pe<3 & \(\text{RH}_b<2.5\)

Pe<4 & \(\text{RH}_b<2.53\)

Average \(K_{SDR}/\Phi_{3ms}\)

Wolfcamp 1

Wolfcamp 2

K_{SDR} in \(\mu D\)
Lithology [ECS] & Geomechanics Permian Wolfcamp

Wolfcamp 1
- T2 3ms 8.8mmbo
- T2 10ms 5.3mmbo

Wolfcamp 2
- T2 3ms 5.5mmbo
- T2 10ms 2.0mmbo

Brittleness Coefficient
Avg. Ksdr/PHI 357
Avg. Ksdr/PHI 188

σHmin
psi

200ft
CONCLUSION

LATERAL LANDING POINT
WOLFCAMP 1
HIGHER OOIP_{stb}
BETTER GEOMECHANICS
HIGHER K_{sdr} PERM
TO BE SURE
LET’S TRY ONE MORE
METHOD of DETERMINING
OOIPstb
USING
RESISTIVITY INVASION
PROFILES
“effective log interpretation requires more than evaluating oil saturation, it requires identification of moveable oil.”

MAXIMUM PRODUCIBLE OIL INDEX ($Y$)


$$ Y = \frac{1}{2} \left( \frac{R_{mf}}{R_{xo}} \right)^{0.5} - \frac{1}{2} \left( \frac{R_w}{R_t} \right)^{0.5} $$

$Y$ = Maximum Producible Oil Index at Reservoir Conditions
(i.e. the amount of oil per unit volume which is displaced by mud filtrate)

Mobile $OOIP_{stb} = \left\{ 7758 \times \Phi \times \left[ (1 - Sw) - RHS \right] \times h \times A \right\} / BOI$

Mobile $OOIP_{stb} = (7758 \times Y \times h \times A) / BOI$

Where:
- $OOIP_{stb} =$ original oil in place in stock tank barrels (stb)
- 7758 = barrels of oil in an acre-foot
- $\Phi =$ porosity
- $Sw =$ water saturation [$Soil = 1 - Sw$]
- RHS = residual hydrocarbon saturation
- $A =$ area
- $h =$ thickness
- BOI = shrinkage factor (reservoir barrels to surface barrels of oil)
Gamma Ray [SGR & CGR] and Resistivity [HRLA] Permian Wolfcamp

Wolfcamp #1

Wolfcamp #2

CGR

SGR

Asquith, 2015
WTGS Fall Symposium
Gamma Ray [SGR & CGR] Neutron-Lithodensity Log Permain Wolfcamp

Asquith, 2015
WTGS Fall Symposium
Lithology [ECS], Porosity and Saturation Permian Wolfcamp

Wolfcamp #1
Total OOIPstb/160ac. 11.8mmbo
Wolfcamp #2

Asquith, 2015
WTGS Fall Symposium
NOTE:
Resistivity Curves Only Plotted If:
HRLA5 > 1.2*HRLA2 &
HRLA2 > Rxo
Mobile OOIP/160ac. from [MPOI] Permian Wolfcamp

MAXIMUM PRODUCIBLE OIL INDEX
[Tixier, 1956]

\[ Y = (\frac{Rmf}{Rxo})^{0.5} - (\frac{Rw}{Rt})^{0.5} \]

Mobile OOIPstb = \[\frac{7758 \times Y \times 0.5' \times 160}{1.4}\]

Mobile OOIPstb = 2.2mmbo
Petrophysical Characterization of the Pore Space in Permian Wolfcamp Rocks
[Rafatian and Capsan, 2015]
PETROPHYSICS VOL. 56, No. 1, p. 45-55.

“the largest pore spaces and, by proxy, the largest continuous connected pore throats, have the largest impact on fluid flow”

and therefore the largest impact on the degree of invasion.
[Asquith, 2015 WTGS FALL SYMPOSIUM]
Gamma Ray [SGR & CGR] and Resistivity Invasion Profiles Permian Wolfcamp

Only Plotted if: HRLA5 > 1.3 * HRLA2 & HRLA2 > 1.2 * Rxo
MAXIMUM PRODUCIBLE OIL INDEX \( (Y) \)
(Tixier, 1956)

\[
Y = [(Rmf/Rxo)^{0.5} - (Rw/HRLT)^{0.5}]
\]

\( Y \) = Maximum Producible Oil Index at Reservoir Conditions
(i.e. the amount of oil per unit volume which is displaced by mud filtrate)

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Permian Wolfcamp  \( Rmf = 0.021 \)  \( Rw = 0.05 \)
Area = 160ac. (assumed)  BOI = 1.4 (assumed)

\[
\text{Mobile OOIPstb} = \sum [(7758 \cdot Y \cdot 0.5' \cdot 160)/1.4] \]

5.3MMBO [Mobile OOIPstb]
Mobile OOIPstb [Y] & K<sub>SDR</sub> Permeability [μD] Permian Wolfcamp

Wolfcamp 1

Wolfcamp 2

[Y] Method 1.5mmbo

[Y] Method 3.8mmbo

OOIPstb/160ac.
QUESTION?

Why does the Wolfcamp 2 have such good invasion profiles indicating permeable reservoir with high OOIPstb values, and yet all other methods indicate lower OOIPstb values compared to Wolfcamp 1?

In addition, why do the Brittleness Coefficient and SHmin indicate poorer GEOMECHANICAL values in Wolfcamp 2, compared to Wolfcamp 1, when the invasion profiles indicate Wolfcamp 2 is the better reservoir?