DEVONIAN WOODFORD IN OKLAHOMA: LOG ANALYSIS AND OGIP DETERMINATION IN A GAS-BEARING SHALE USING STANDARD LOGGING SUITE

G.B. Asquith
Dept. of Geosciences, Texas Tech University

In a potential gas-bearing Woodford shale reservoir (Ro% = 2.62 and MI = 11.3 DRY GAS) with a standard logging suite [Array Induction – Neutron-Lithodensity] it is possible to calculate the following log parameters:

Reservoir pressure (Pr)
Weight Percent Total Organic Carbon (TOC)
Volumes of Clay (Vcl), Quartz (Vqtz), and Kerogen (Vke) plus Total Porosity (Φtotal) using simultaneous equations plus ρb and Φnls Data
Effective Porosity (Φe) = Φtotal – CBW CBW – Clay-Bound Water
Water Saturation Swe = Ro/Rt)^0.5
Gas-Filled Porosity (Φgas) = Φe $*$ (1.0-Swe)
Permeability (k) in nannodacies (nD) = [(0.0108*Φgas) – 0.000256] $*$ 10^6
Adsorbed Gas (gc) and Free Gas (Gf) in scf/area

In addition to log data laboratory analyses was done on samples from three depths [9480', 9500', and 9520']. A comparison of Vcl, Vqtz, and Vke values determined in the laboratory with Vcl, Vqtz, and Vke values determined from log data are listed below:

Depth	Vcl(lab)	Vqtz(lab)	Vke(lab)	Vcl(log)	Vqtz(log)	Vke(log)
9480	24.3	65.1	10.8	21.6	65.6	12.8
9500	24.4	62.6	13.0	16.7	67.0	16.3
9520	18.7	68.5	12.7	17.7	69.5	12.8

The data listed above reveals that the Simultaneous Equation Method using only ρb and Φnls data (Lewis, 2009; see: below) predicts the laboratory results fairly accurately. However, if large amounts of calcite or dolomite were present in the Woodford, the results would be much less reliable. In the Woodford Shale in this well the amount of calcite was 0.0% and the amount of dolomite ranged from 1.8% to 2.5%.

MINERAL VOLUMES and TOTAL POROSITY [Lewis, 2009]

Vcl + Vqtz + Vke + Φtotal = 1.0 Vke = (TOC$*$Kvr$*\rho$b)/ρkerogen

(Vcl$*\rho$clay) + (Vqtz$*\rho$qtz) + (Vke$*\rho$ke) + (Φtotal$*\rho$f) = ρb

(Vcl$*\Phi$nclay) + (Vqtz$*\Phi$nqtz) + (Vke$*\Phi$nke) + (Φtotal$*\Phi$nf) = Φnls

Of the entire gross organic shale interval (9448' to 9548') with high gamma ray (GR > 200 API) and high resistivity (AT90 > 15ohm-m up to AT90 = 320ohm-m) only 52 feet is

net pay as defined by the following cut-offs: 1.) TOC > 2%, 2.) Φe > 4%, 3.) Φgas > 2%, 4.) Swe < 45%, and 5.) permeability (k) > 100 nD. In the net pay intervals the total gas (adsorbed+free gas) in was recorded in BCF/sec using the equation below:

Adsorbed Gas-in-Place Volume

$$Gs = 1{,}359.7 * A * h * \rho * gc$$

Gs = adsorbed gas-in-place volume, scf/area
A = area (acres)
h = thickness
ρ = bulk density, g/cc
gc = adsorbed gas content, scf/ton [gc = (Vlc∗Pr)/(Plt+Pr) or
gc = (16.527∗TOC)+3.5917]
1,359.7 (units conversion) = 43,560 ft^3 per acre/32.0369 scf/ton per cc/g

Free Gas-in-Place Volume

$$Gf = 43{,}560 * A * h * \Phi e * Sg * (1/Bg)$$

Gf = free gas-in-place volume, scf/area
A = area (acres)
h = thickness
Φe = effective porosity
Sg = gas saturation
Bg = gas formation volume factor [reservoir volume/surface volume]

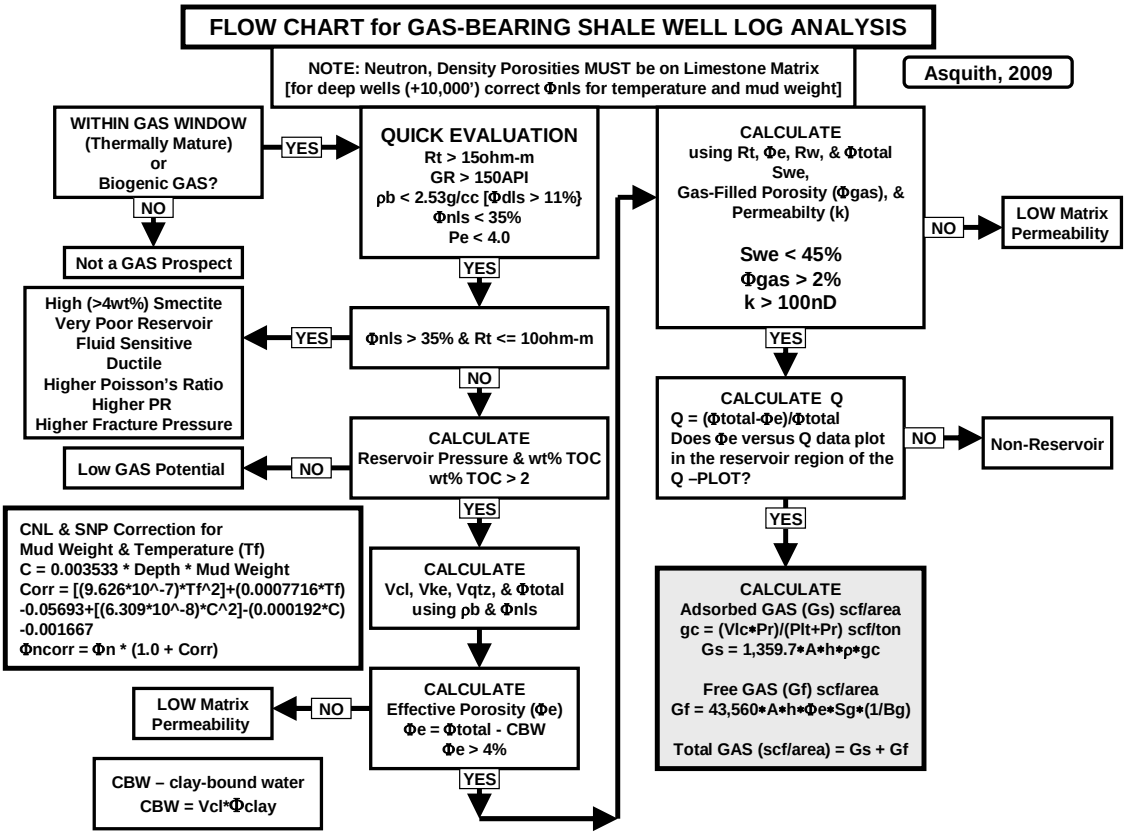
Calculated total adsorbed plus free gas using a 100nD cut-off is 24BCF/sec. The well was a horizontal completion with an IPF of 4.36mmcfgpd and an EUR of 5.2bcf.

Three conclusions maybe reached from this study:

1.) Log analysis is possible on Gas-Bearing shales using only Deep Resistivity, Bulk Density, and Neutron Porosity.

2.) The determination of Vcl, Vqtz, Vke, and Total Porosity using Bulk Density and Neutron Porosity data is reliable if only small amounts of calcite and/or dolomite are present.

3.) The Shaly Sand Producible Plot (Q-PLOT) maybe useable in Gas-Bearing shales as an indicator of reservoir versus non-reservoir shale.


FLOW CHART for GAS-BEARING SHALE WELL LOG ANALYSIS
NOTE: Neutron, Density Porosities MUST be on Limestone Matrix
[for deep wells (+10,000') correct Φnls for temperature and mud weight]
Asquith, 2009
WITHIN GAS WINDOW
(Thermally Mature)
or
Biogenic GAS?
YES
NO
Not a GAS Prospect
QUICK EVALUATION
Rt > 15ohm-m
GR > 150API
ρb < 2.53g/cc [Φdls > 11%}
Φnls < 35%
Pe < 4.0
YES
Φnls > 35% & Rt <= 10ohm-m
YES
High (>4wt%) Smectite
Very Poor Reservoir
Fluid Sensitive
Ductile
Higher Poisson's Ratio
Higher PR
Higher Fracture Pressure
NO
CALCULATE
Reservoir Pressure & wt% TOC
wt% TOC > 2
NO
Low GAS Potential
YES
CNL & SNP Correction for
Mud Weight & Temperature (Tf)
C = 0.003533 * Depth * Mud Weight
Corr = [(9.626*10^-7)*Tf^2]+(0.0007716*Tf)
-0.05693+[(6.309*10^-8)*C^2]-(0.000192*C)
-0.001667
Φncorr = Φn * (1.0 + Corr)
CALCULATE
Vcl, Vke, Vqtz, & Φtotal
using ρb & Φnls
CALCULATE
Effective Porosity (Φe)
Φe = Φtotal - CBW
Φe > 4%
NO
LOW Matrix
Permeability
YES
CBW – clay-bound water
CBW = Vcl*Φclay
CALCULATE
using Rt, Φe, Rw, & Φtotal
Swe,
Gas-Filled Porosity (Φgas), &
Permeabilty (k)
Swe < 45%
Φgas > 2%
k > 100nD
NO
LOW Matrix
Permeability
YES
CALCULATE Q
Q = (Φtotal-Φe)/Φtotal
Does Φe versus Q data plot
in the reservoir region of the
Q –PLOT?
NO
Non-Reservoir
YES
CALCULATE
Adsorbed GAS (Gs) scf/area
gc = (Vlc*Pr)/(Plt+Pr) scf/ton
Gs = 1,359.7*A*h*ρ*gc
Free GAS (Gf) scf/area
Gf = 43,560*A*h*Φe*Sg*(1/Bg)
Total GAS (scf/area) = Gs + Gf