Using Conventional Open Hole Log Data to Generate Petrophysical Models for Unconventional Reservoirs

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Niobrara Oil/Gas Shale and Williams Fork Tight Gas Sand Examples

INPUT:

- Conventional Open Hole Log Data

OUTPUT:

- Lithology Model
- Saturation Model
- Organic Carbon Model
- Rock Mechanics Model

INPUT: Conventional Open Hole Log Data = Triple Combo

- Gamma Ray (GR)
- Temperature (TEMP)
- Resistivity - Deep (RLD)
- Neutron Porosity (PHIN)
- Litho-Density
    - Bulk Density (RHOB)
    - Photoelectric Absorption (PE)

Additional INPUT: Sonic Log Data = Quad Combo or Dipole Sonic

- Quad Combo Compressional (DTC) Wave Data
- Dipole Sonic Compressional (DTC) & Shear (DTS) Wave Data

Core Data: Needed to Calibrate Petrophysical Model for Best Results

- Effective Porosity (PHIE) & Total Porosity (PHIT)
- X-ray Diffraction (XRD) Data on Volume & Weight Percent Basis
- Organic Carbon on Volume Percent Basis (VOC)
- Total Organic Carbon (TOC) on Weight Percent Basis

OUTPUT: Lithology Model = Multi-Mineral Method Volume Percent

- Deterministic Model (*e.g., PowerLog*)
  - Standard Correlations

- Shale Volume (VSH = VCL + VQFM)
  - Clay (VCL)
  - Non-Clay (VQFM = Qtz + Feldspar + Mica)

- Triple Combo with Litho-Density Data
  - 3-Component Lithology Solution

- Quad Combo with Litho-Density Data
  - 4-Component Lithology Solution

OUTPUT: Lithology Model = Component Volume Percent

- Quartz Sand Volume (VSS)
- Carbonate Volume (VCARB = VLS + VDOL)
  - Limestone (VLS)
  - Dolomite (VDOL)
- Organic Carbon Volume (VOC)
  - Coal if applicable (VCOAL)
- Accessory Mineral Volumes
  - Chlorite (VCHL)
  - Feldspar (VKSP)
  - Pyrite (VPYR)
- Effective Porosity (PHIE)
  - D-N Cross Plot w/ VCL Correction

OUTPUT: Saturation Model = Straight Archie or Dual Water Method

- Percent Basis
  - Water (SW)
  - Hydrocarbon (SHC)

- Bulk Volume Basis
  - Water (BVW = SW x PHIE)
  - Hydrocarbon (BVHC = SHC x PHIE)

OUTPUT: Organic Carbon Model = Multi-Mineral & Delta-LogR Methods

- Multi-Mineral
  - Volume Percent Organic Carbon (VOC)
    → Density Transform ←
  - Weight Percent Total Organic Carbon (TOC_LOG)

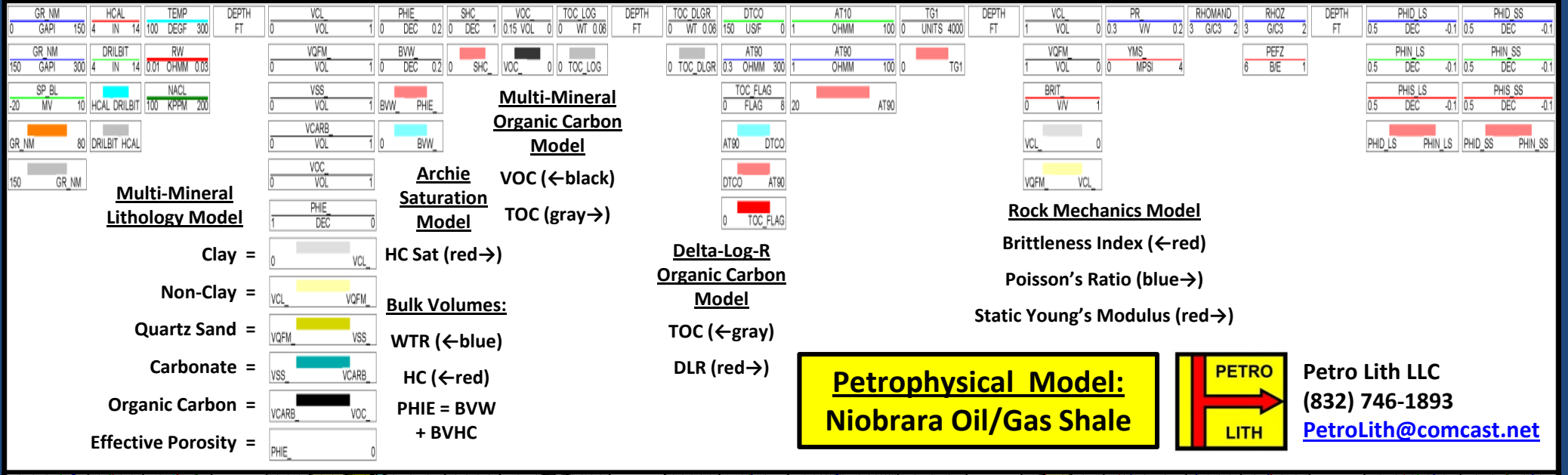
- Sonic and Resistivity Delta-LogR (*Passey et al 1990*)
  - Required Data
    - ◊ Sonic Compressional (DTC)
    - ◊ Deep Resistivity Log (RLD)
  - Weight Percent Total Organic Carbon (TOC_DLGR)
    → Calibrate to Core ←
  - Level of Maturity (LOM)

OUTPUT: Rock Mechanics Model = Brittleness Indicators

- Required Data
  - Dipole Sonic Compressional (DTC) & Shear (DTS)

- Relative Indicators
  - Brittleness Index (BRIT) from *Mullen et al 2008*
  - Clay Volume (VCL) from Lithology Model
    - ◊ VCL↑ = BRIT↓

- Absolute Indicators (*Mullen et al 2007*)
  - Poisson's Ratio (PR)
    - ◊ PR↑ = BRIT↓
  - Static Young's Modulus (YMS)
    - ◊ YMS↑ = BRIT↑



Petrophysical Model: Niobrara Oil/Gas Shale

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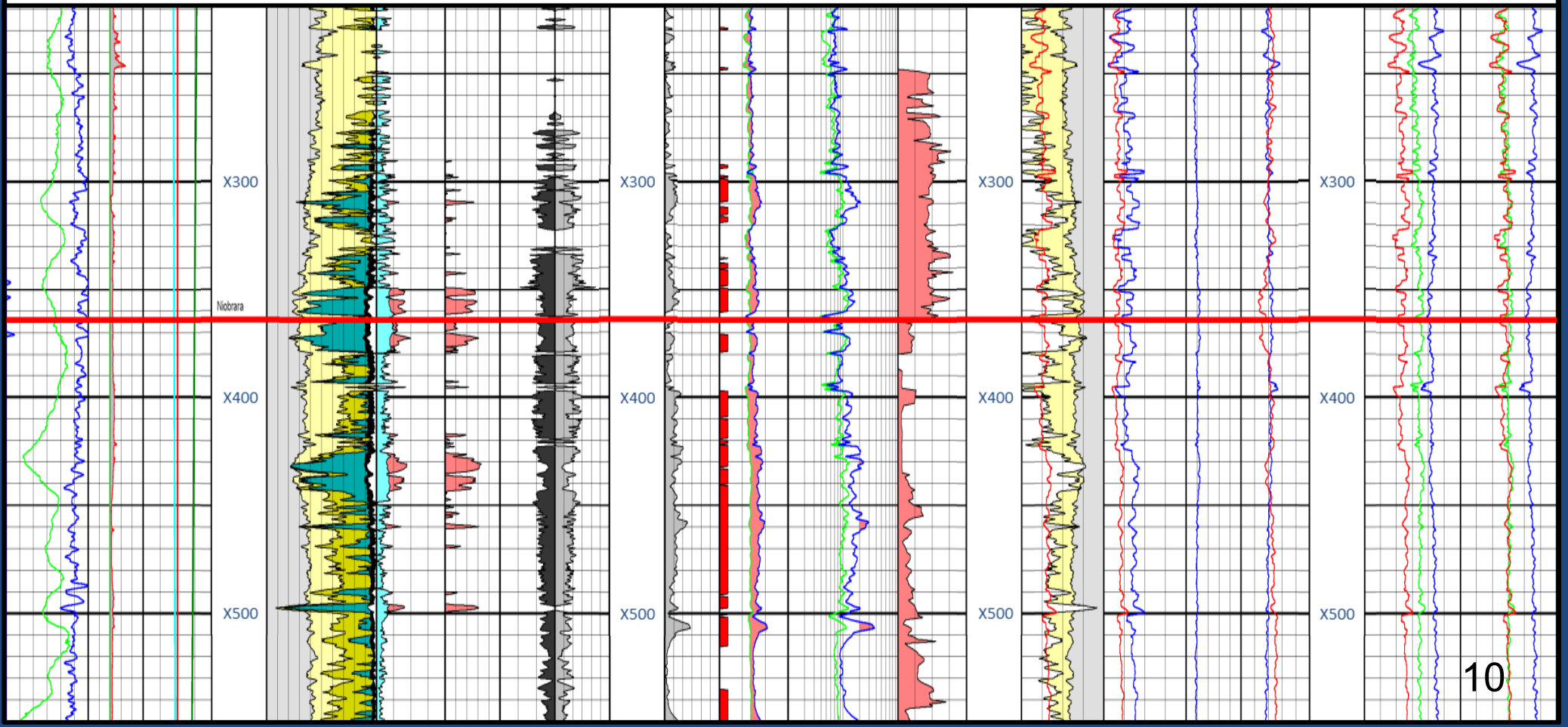

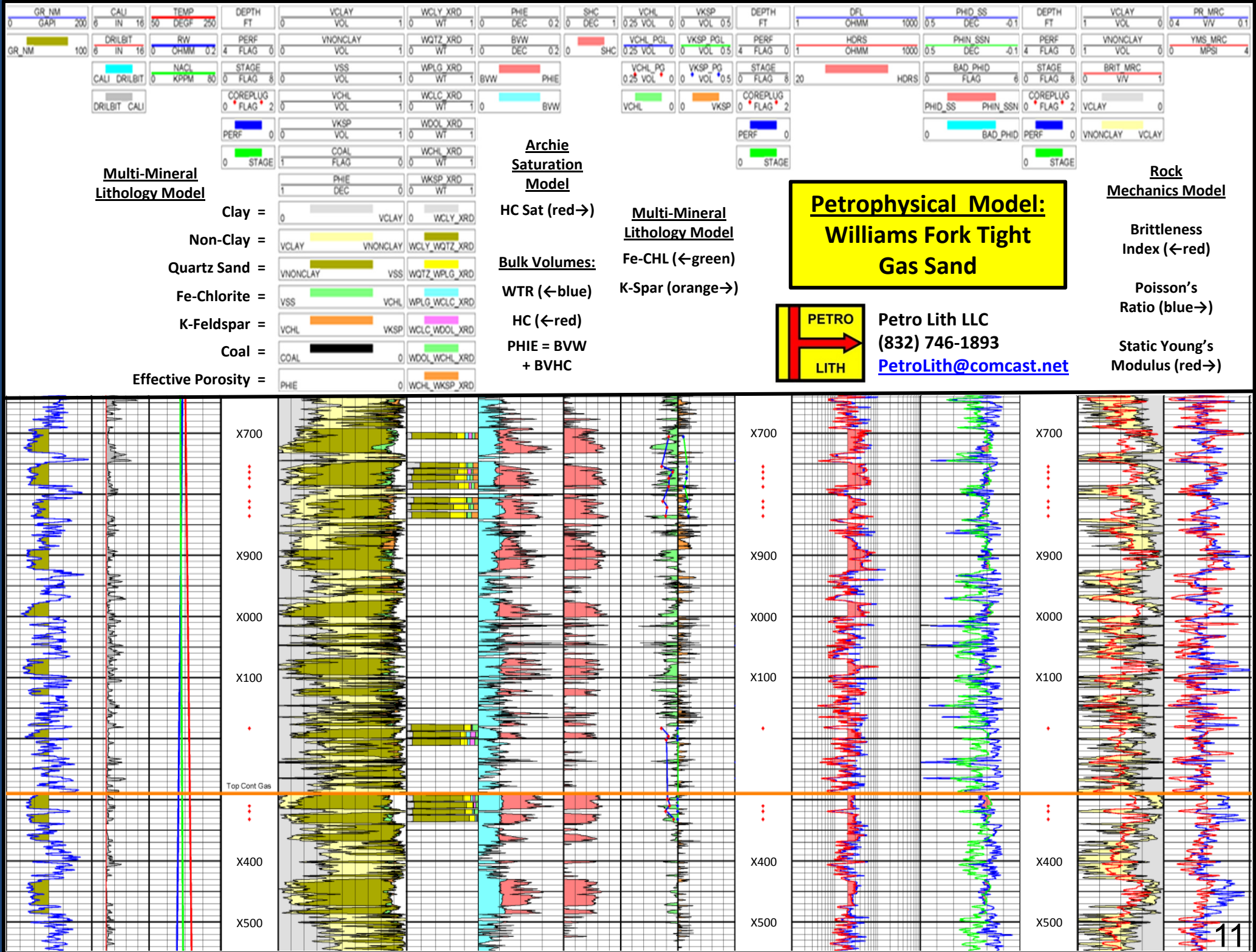
GR_NM
CALI
DRILBIT
TEMP
RW
NACL
DEPTH
PERF
STAGE
COREPLUG
VCLAY
VNONCLAY
VSS
VCHL
VKSP
COAL
PHIE
WCLY_XRD
WQTZ_XRD
WPLG_XRD
WCLC_XRD
WDOL_XRD
WCHL_XRD
WKSP_XRD
SHC
BVW
VCHL_PGL
VKSP_PGL
VCHL_PG
VKSP_PG
DFL
HDRS
PHID_SS
PHIN_SSN
BAD_PHID
BRIT_MRC
PR_MRC
YMS_MRC
Multi-Mineral Lithology Model
Clay =
Non-Clay =
Quartz Sand =
Fe-Chlorite =
K-Feldspar =
Coal =
Effective Porosity =
Archie Saturation Model
HC Sat (red→)
Bulk Volumes:
WTR (←blue)
HC (←red)
PHIE = BVW + BVHC
Multi-Mineral Lithology Model
Fe-CHL (←green)
K-Spar (orange→)
Petrophysical Model:
Williams Fork Tight Gas Sand
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Rock Mechanics Model
Brittleness Index (←red)
Poisson's Ratio (blue→)
Static Young's Modulus (red→)
X700
X900
X000
X100
X400
X500
Top Cont Gas

Marc Connolly established **Petro Lith LLC** to provide the petroleum industry new and innovative ways to use conventional open hole well data in analyzing unconventional reservoirs. He is a multi-faceted petroleum professional with 30-years industry experience in geological, reservoir, and reserves engineering. His specialties include shale oil/gas, tight gas sand, and coalbed methane petrophysical modeling along with reservoir characterization, resource valuation, and economic analysis for development, acquisition/disposition, and new venture projects.

Connolly worked three years for El Paso Exploration and Production after retiring from 27 years of service with ConocoPhillips. He is a member of both the *Society of Petroleum Engineers* and *American Association of Petroleum Geologists*, and does pro bono consulting as a graduate thesis advisor and university guest lecturer on the topic of basic petrophysics. Connolly holds a Master of Science degree in geology from the University of Minnesota, a Bachelor of Science degree from the University of Wisconsin, and is a licensed Professional Geoscientist in the state of Texas.