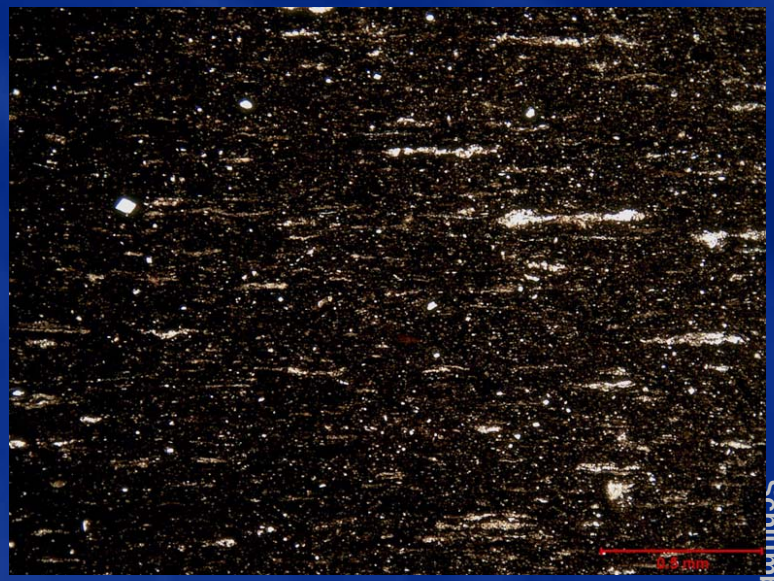


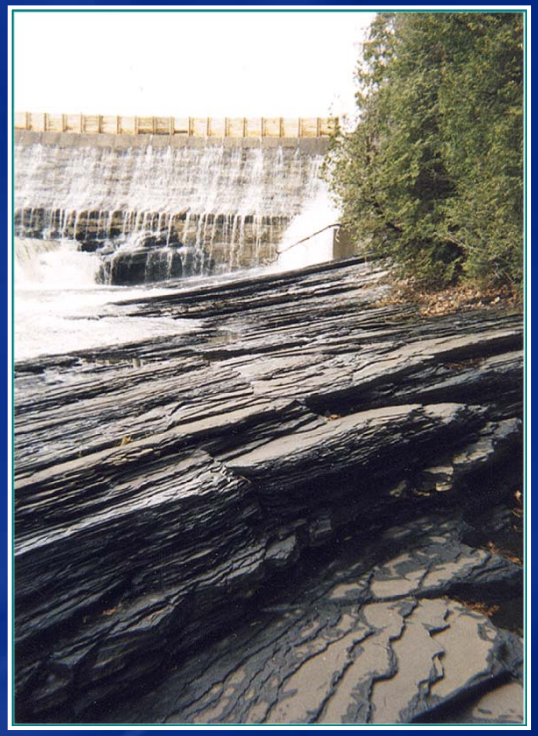
Evaluation of Shale Gas Reservoirs Focus on Haynesville

Keith Bartenhagen

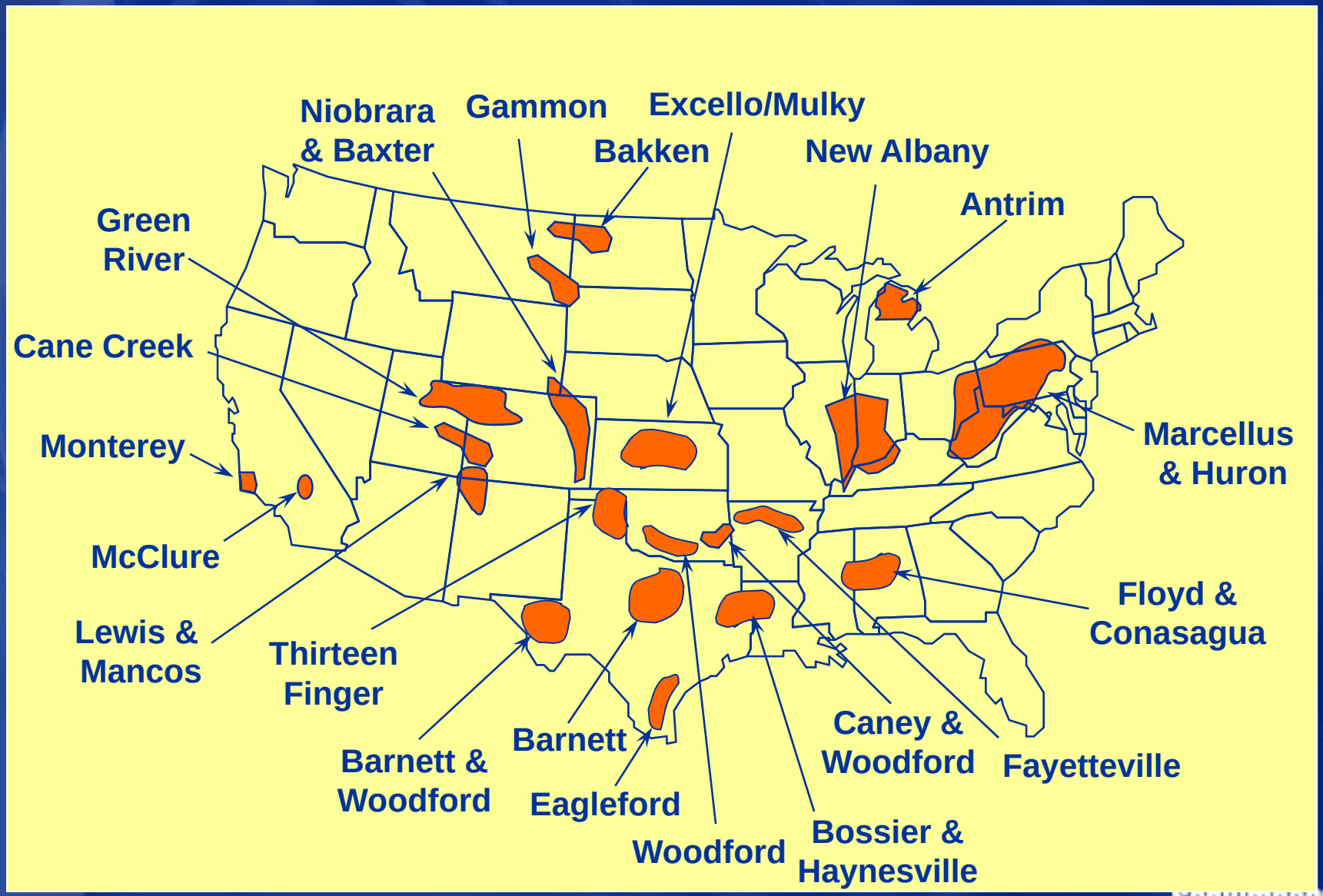
Oklahoma City

Gas Shales

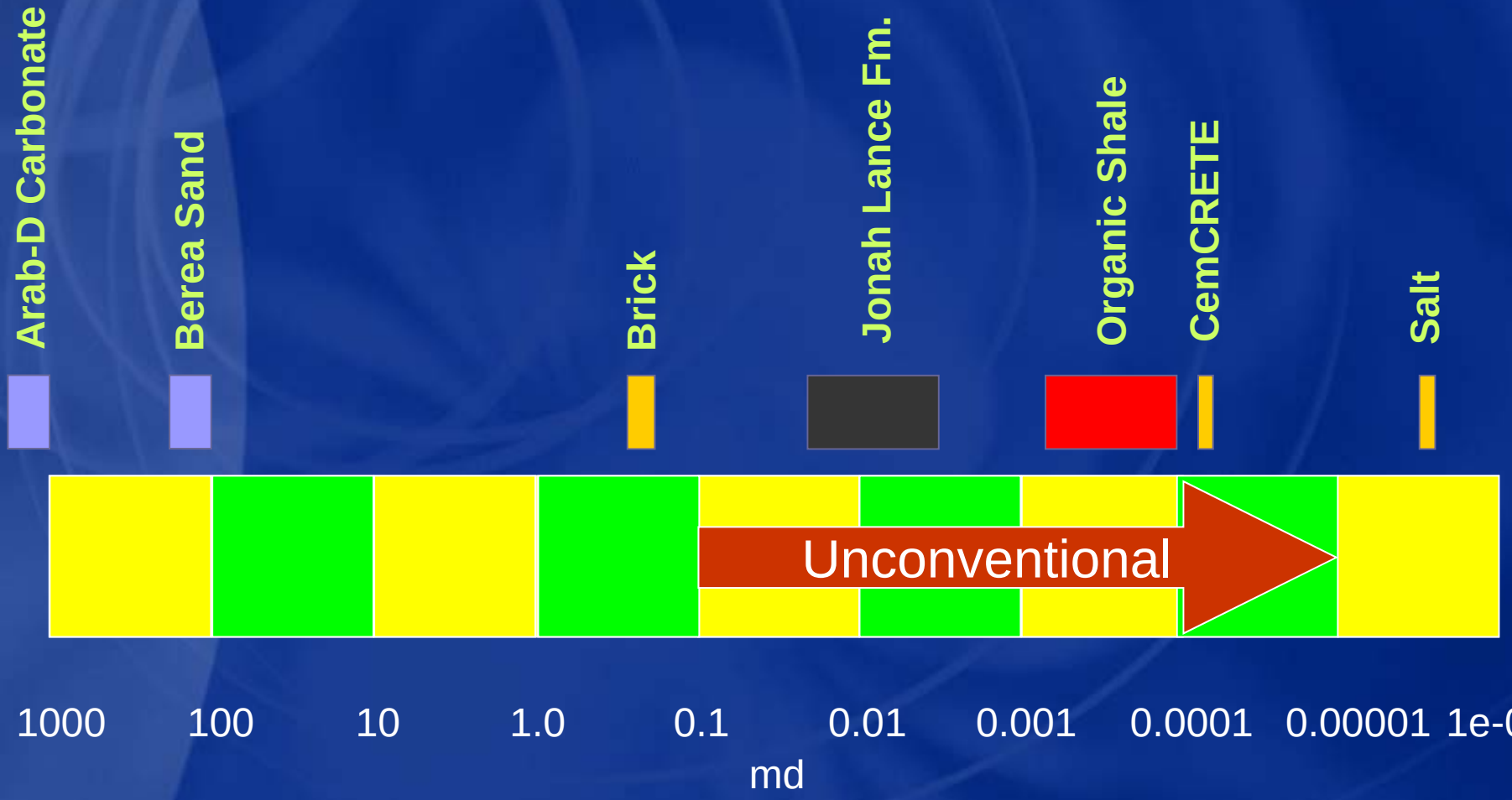
- What are they?
  - Organic-rich shales
  - Source rocks
  - Adsorbed and free gas
  - Ultra-low permeability
- Common traits of gas shale reservoirs
  - Abundant gas (20 to 500 BCF/section)
  - Low recovery efficiency (8 to 12%) ???
  - Large developments (economies of scale)
  - Fracture stimulation required
  - Horizontal wells
  - Long well life
  - Variable reservoir quality within any shale



Gas Shales of the United States

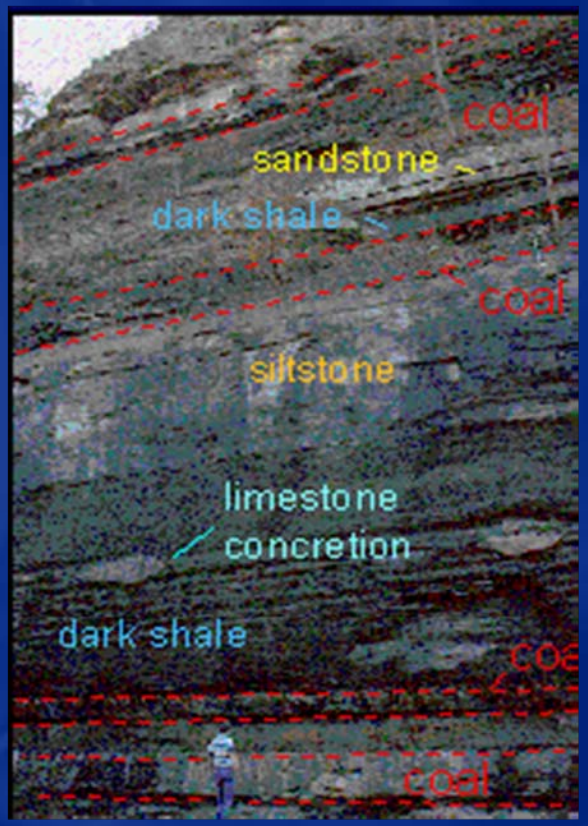


Shale in Perspective: Permeability

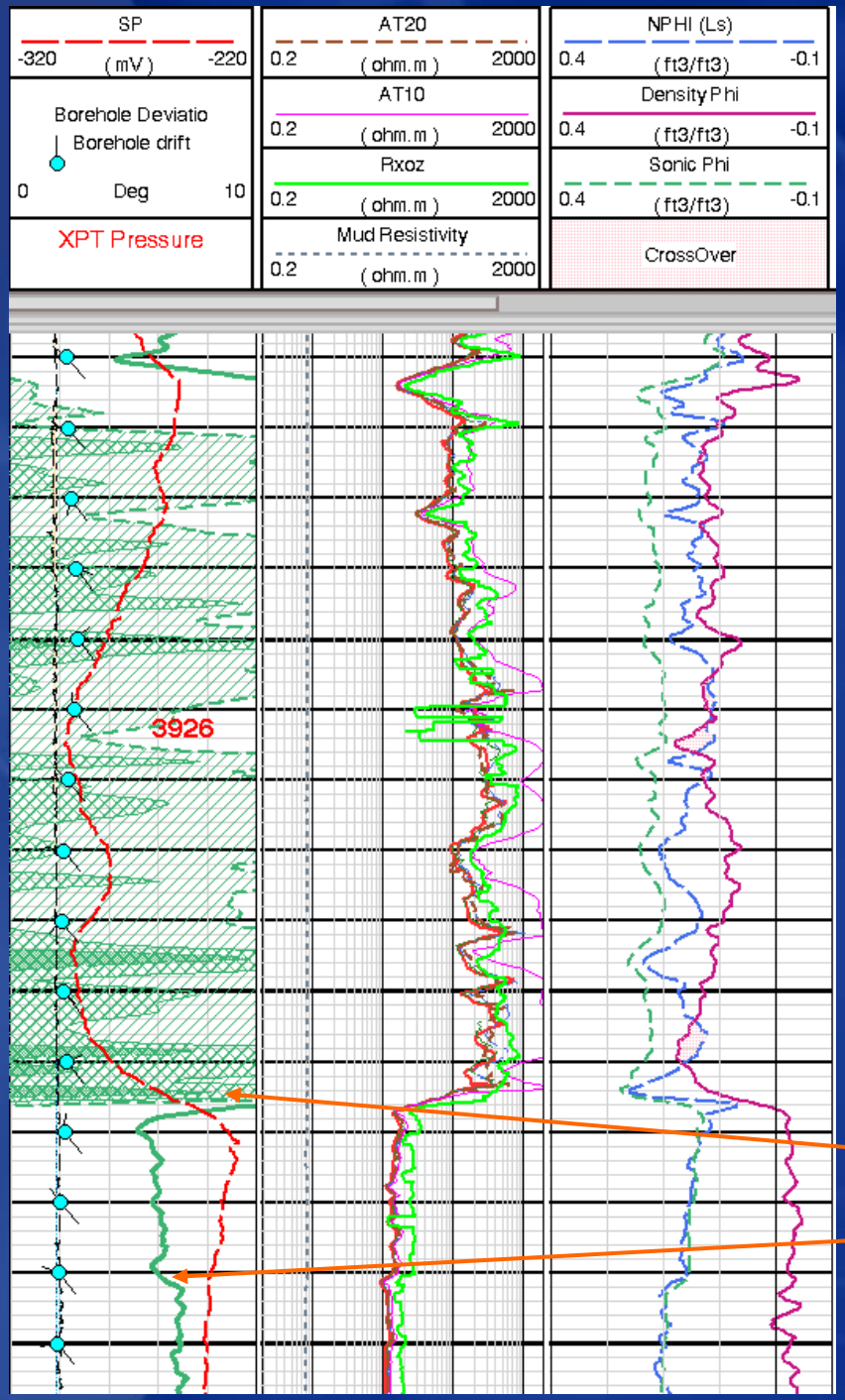


Shale Gas Evaluation Needs

- Delineation of shale gas beds
- Quantify mineralogy
  - Accurate log evaluation
  - Completion design
- Quantify gas
  - Adsorbed
  - Free
- Producibility
  - Matrix permeability
  - Amount and type of fractures
  - System permeability
  - Pressure
- Production prediction



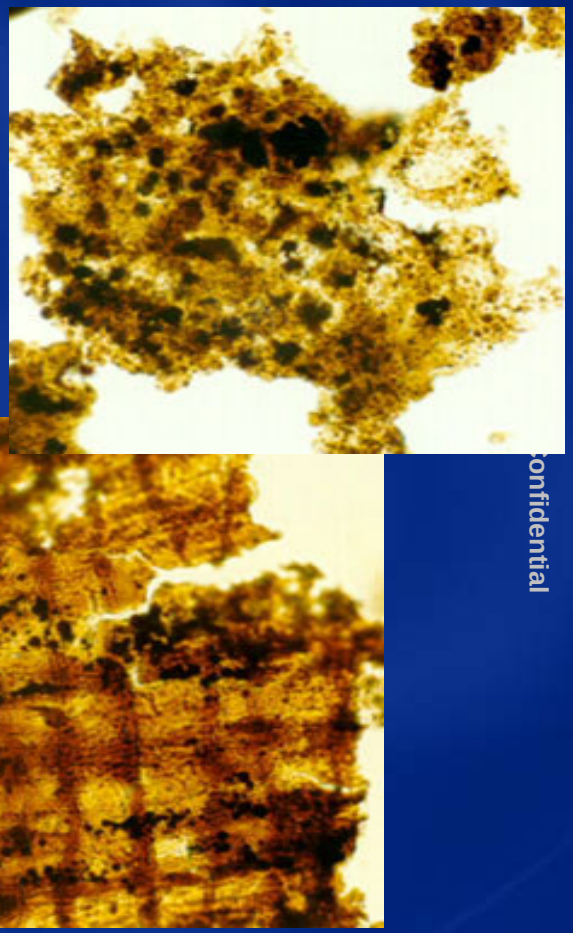
Triple Combo Log



- Gamma ray activity > 150 gAPI
  - May not be valid for Cretaceous and Tertiary shales
- Resistivity > 15 ohm-m
  - Thermal maturity, swelling clays
- Density porosity > 8 pu (Ls matrix)
  - Bulk density < 2.57 g/cm3
  - Presence of kerogen and/or porosity
- Neutron reflects clay content, type

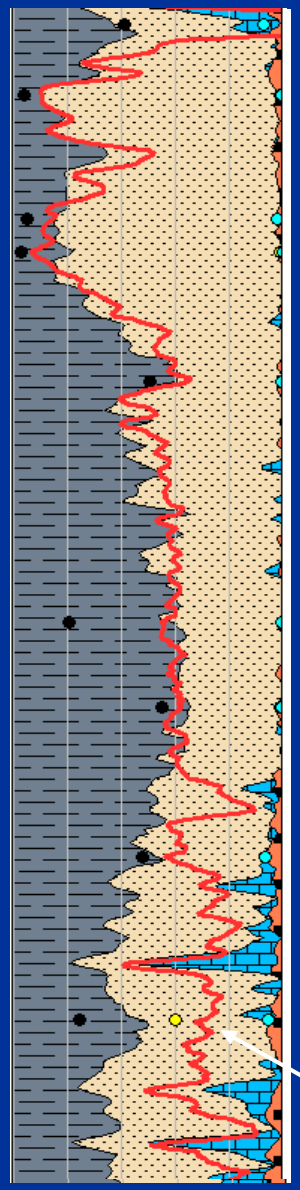
Kerogen

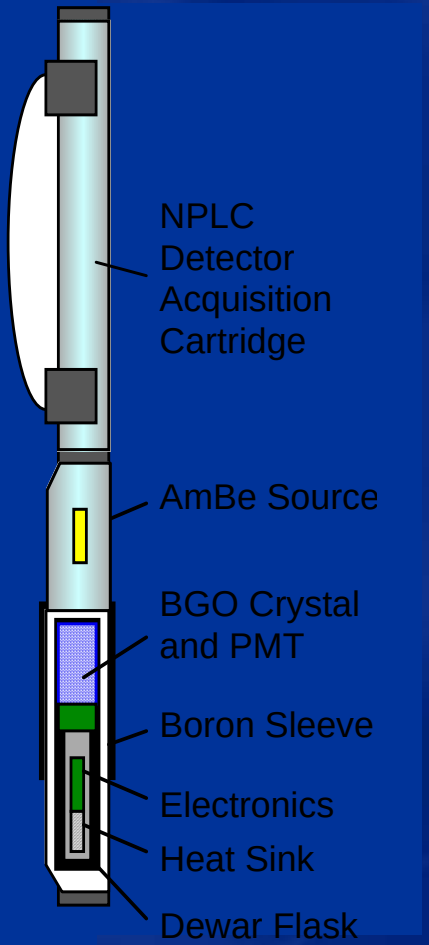
- Methane adsorbs to kerogen
  - Insoluble organic matter
  - Equivalent to TOC
- Kerogen
  - Deposited in anoxic environments
  - Mississippian and Devonian best (Jurassic ?)
- Kerogen petrophysical properties
  - Low density (1.1 to 1.4 g/cm^3)
  - Very high GR activity (350 to 6000 gAPI)
  - Low P_e (0.28)
  - High neutron porosity (30 to 60 pu)



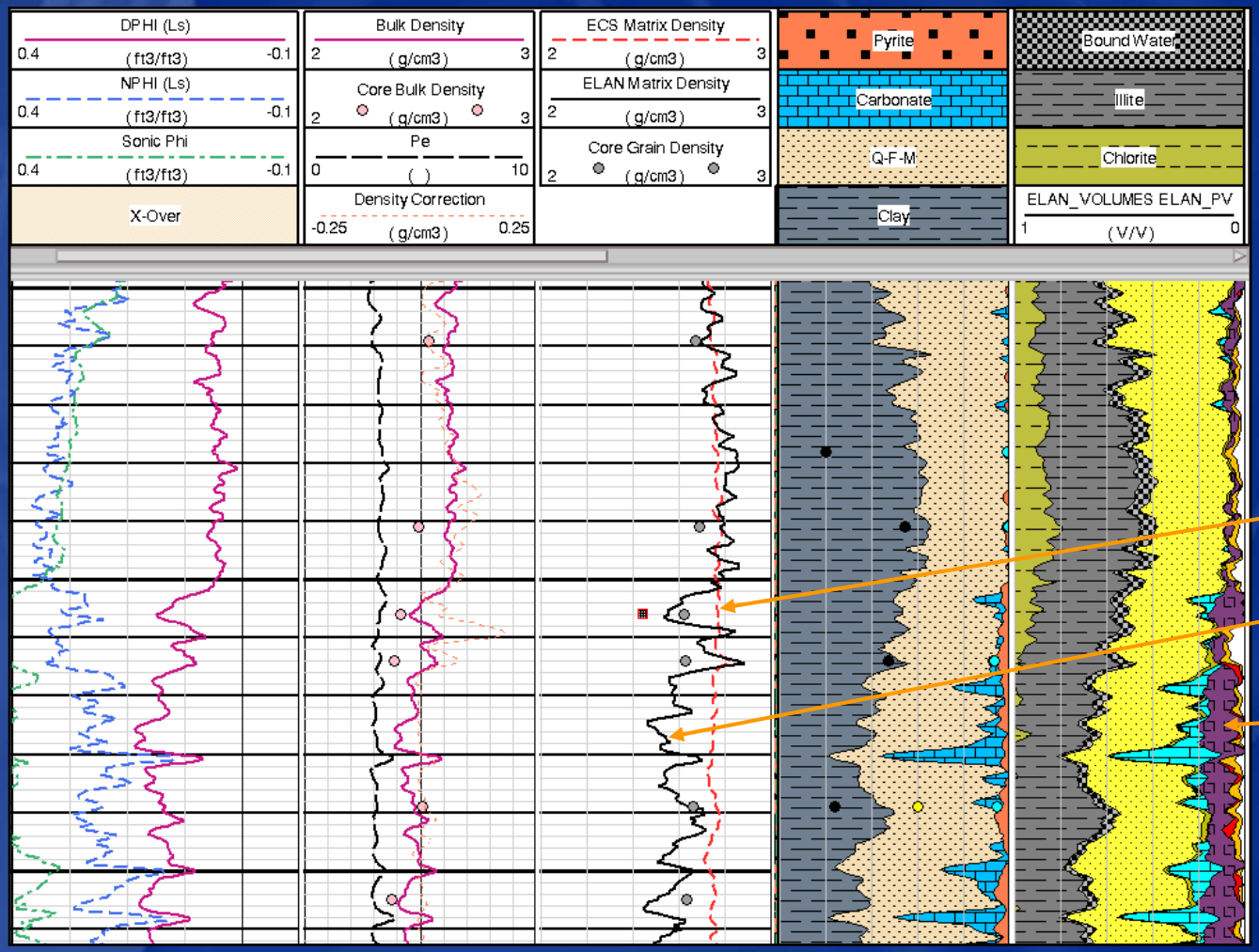
Clay Quantification

- Necessary for shale gas evaluation
  - Kerogen volume
  - S_w
- Geochemical log is key to evaluation
  - Si, Ca, Fe, S, K
  - SpectroLith lithology
  - Independent of measurements affected by kerogen





ELAN to Calculate Kerogen Volume



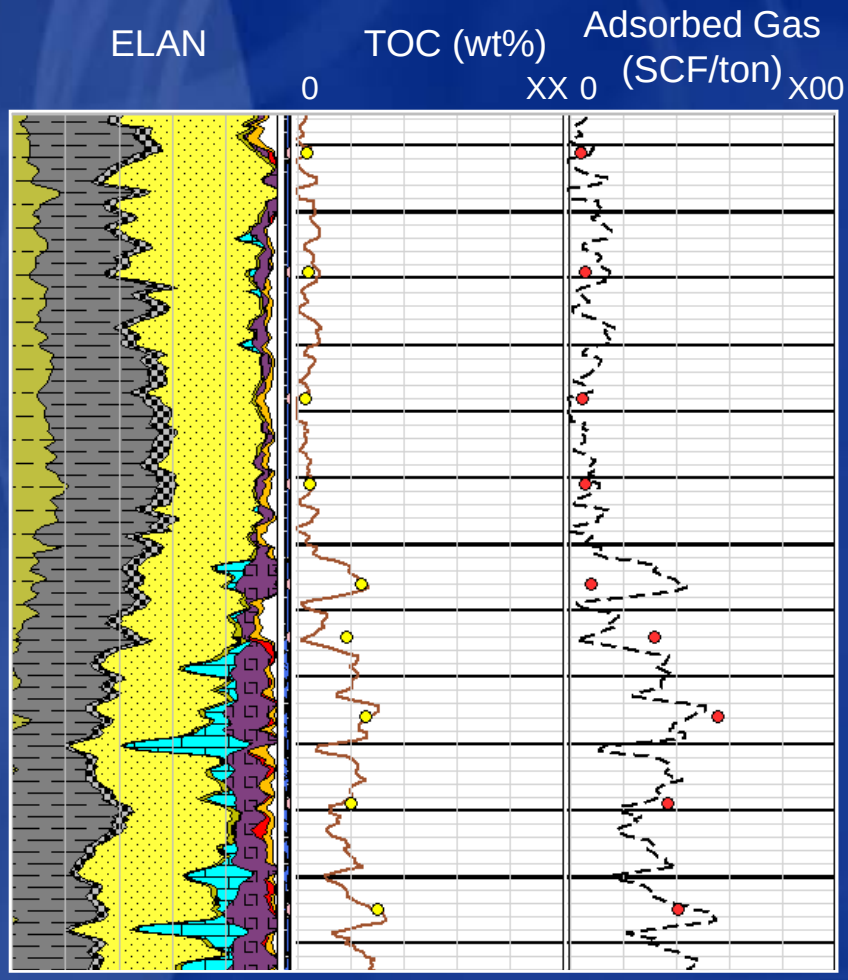
ECS RHOM

ELAN RHOM

Kerogen

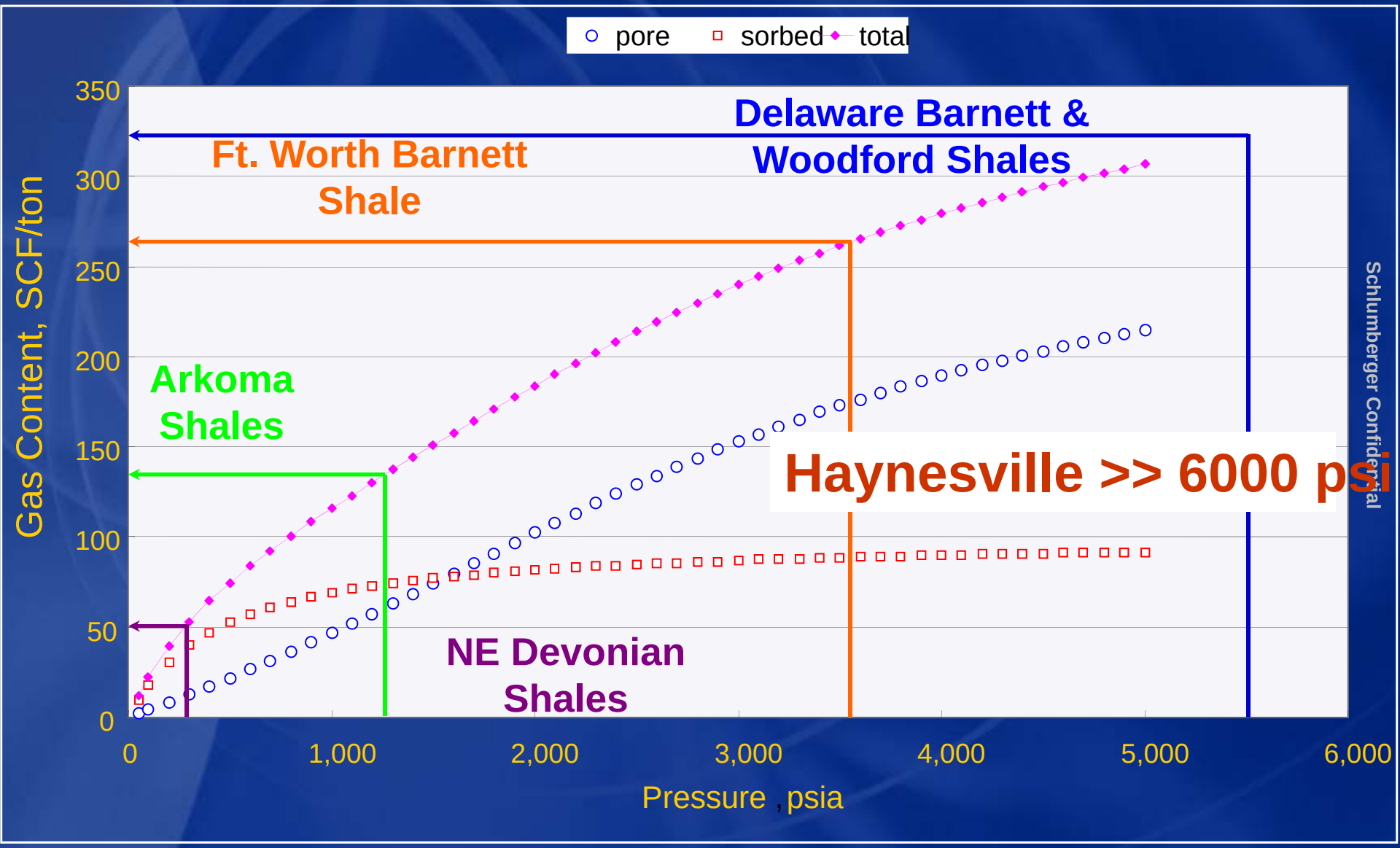
Schlumberger

Adsorbed Gas Log



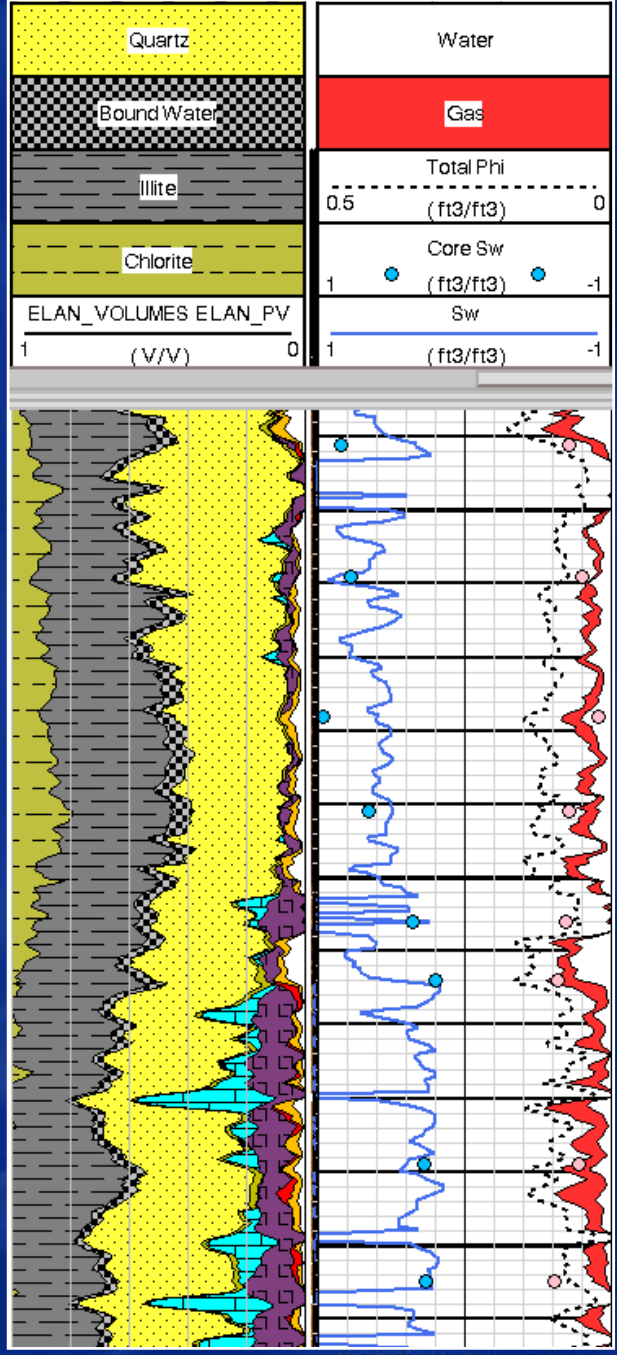
- Kerogen converted to TOC
  - Function of thermal maturity
- Isotherm used to calculate adsorbed gas
- Calculated in SCF/ton (industry standard)

GIP - Importance of Gas Location



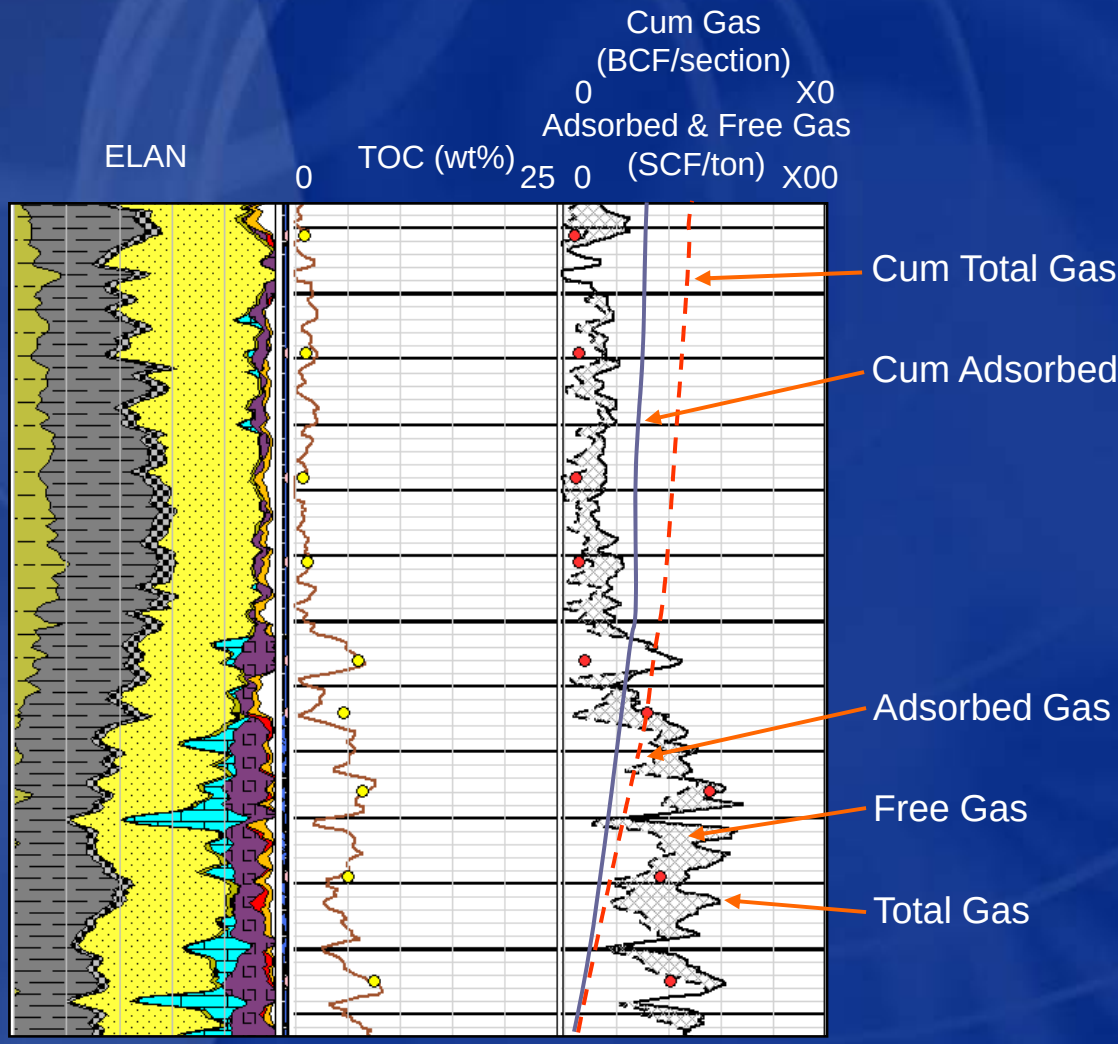
Free Gas Log

- Accurate measure of gas within shale microporosity
  - Effective Phi
  - S_{gas}
- Requires knowledge of
  - Clay content
  - Matrix density
  - Corrected NPHI
  - R_w, R_{bw}



Schlumberger

Total Gas Log

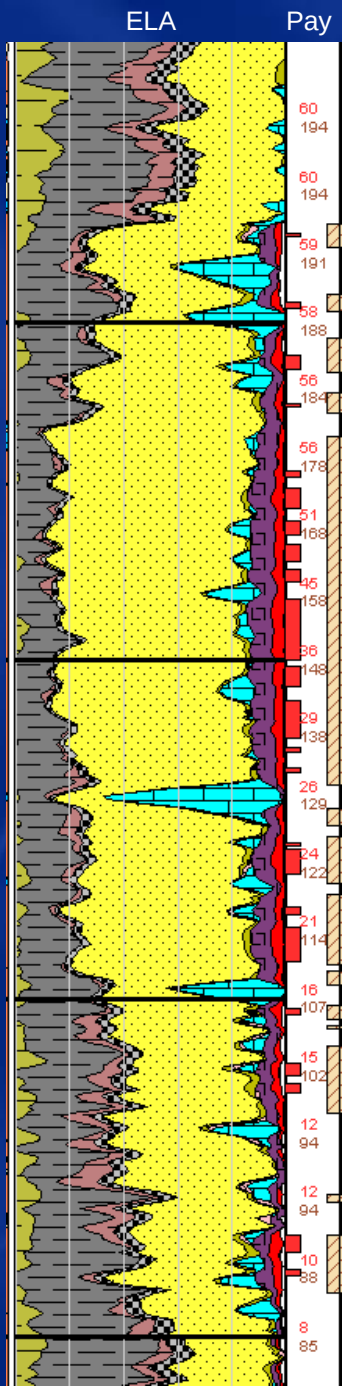


- All gas in SCF/ton
- Solves for cumulative gas (BCF/section)
- Identify and quantify resource not visible with conventional logs

Reservoir and Pay

- Reservoir
  > 2% Gas-filled porosity
- Pay
  > 4 pu effective porosity
  < 45% Sw
  > 2% TOC
  > 100 nD permeability

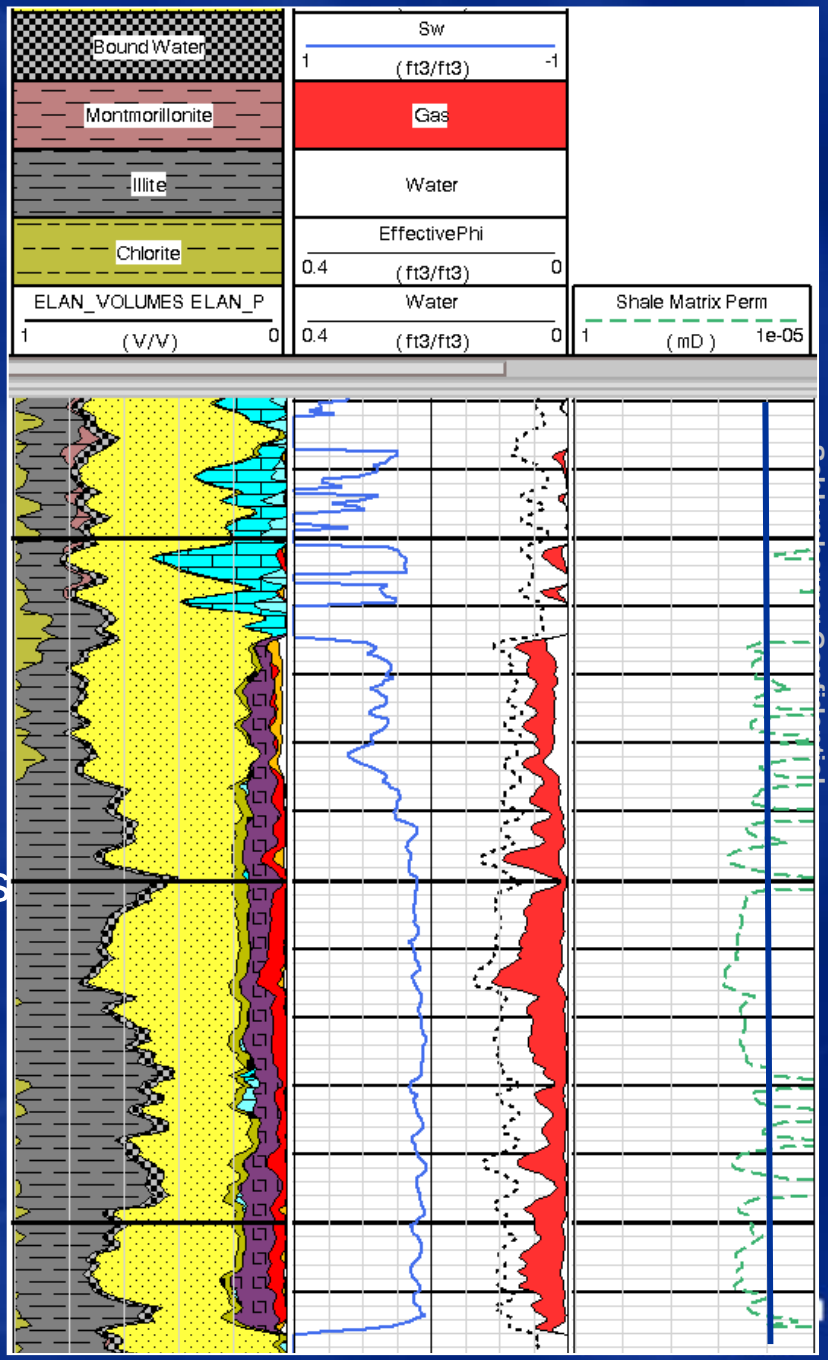
Haynesville—can have outstanding petrophysical properties



Matrix Permeability

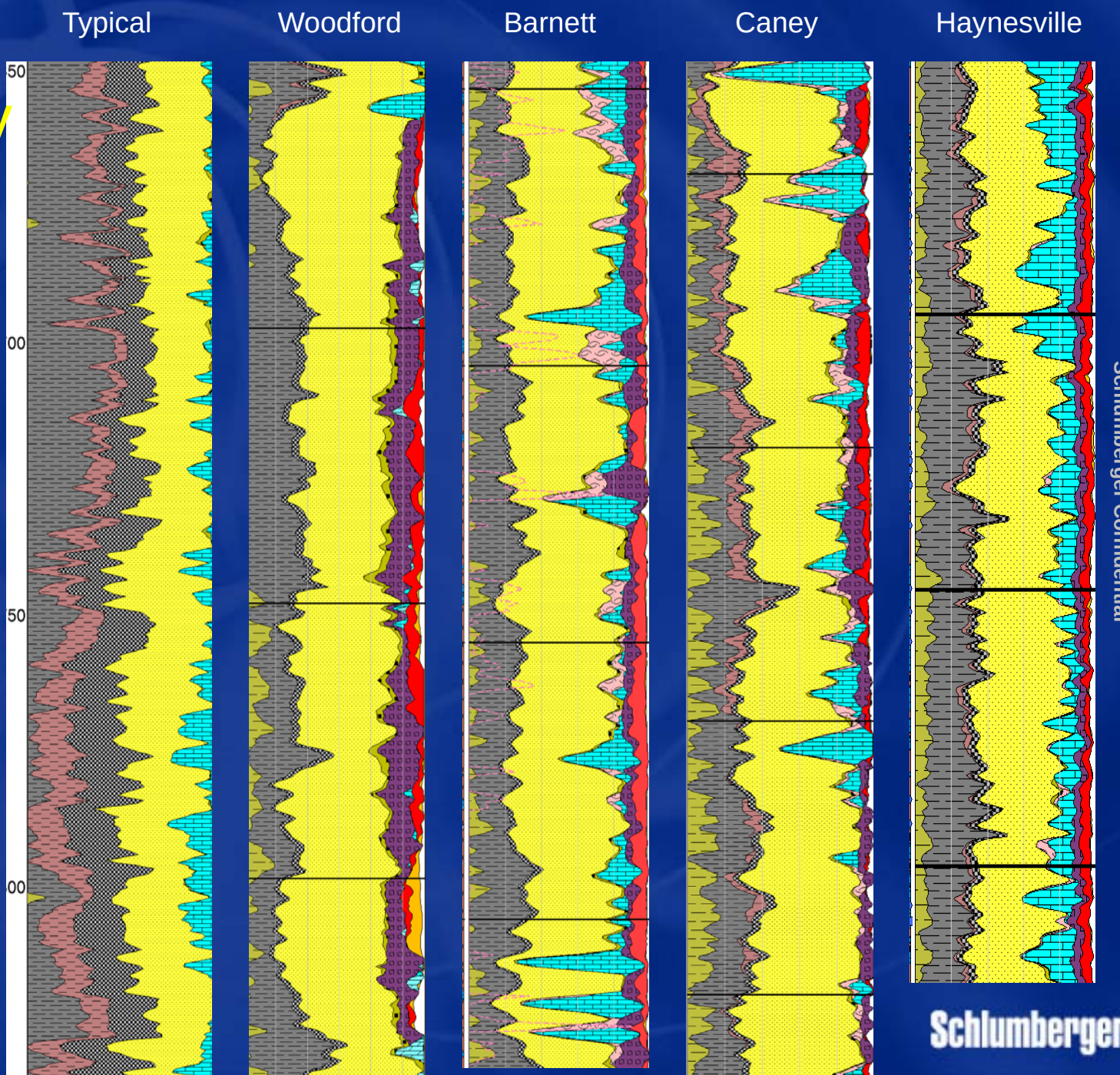
- Range 0.001 mD to 0.0000001 mD
  (1000 nD to 0.1 nD)

- Function of
  - Porosity
  - Gas saturation
  - Oil saturation
  - Mineralogy
- Specialized core preparation and analysis



Shale Mineralogy

- Quartz Rich
- Frequent Carbonate
- Illite Dominant Clay
- Chlorite Common
- Periodic Swelling Clays
- Pyrite Common
- Variable Kerogen



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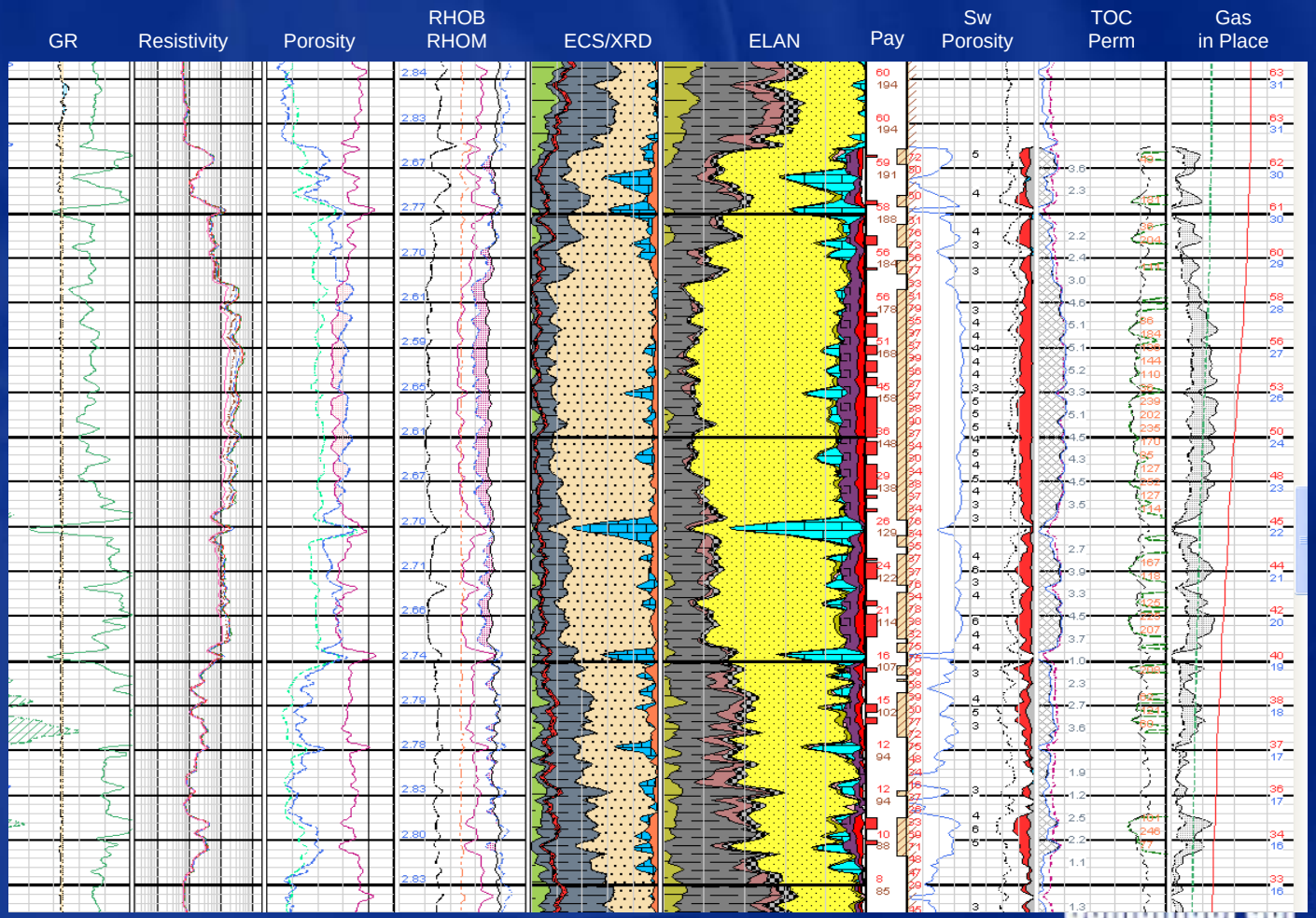
Gas Shale Advisor

- Mineralogy
- Phi, Effective Phi
- S_w
- TOC
- K_{int}
- GIP and Cum GAS
  - SCF and BCF/mi^2
- Inputs for
  - Frac design
  - Production simulator



Recommended Logging Program

- Platform Express and ECS
  - Petrophysical—total and effective porosity, Sw, perm
  - Mineralogic
  - Pay and reservoir ID
  - Resource quantification
- Sonic Scanner
  - Stress orientation
  - Mechanical properties
  - Fracture mapping
- Modular Dynamics Tester (MDT)
  - Frac closure stress
  - Pore pressure and mobility
- Imaging Log (FMI, OBMI, UBI)
  - Natural fracture identification, classification, and orientation
  - Drilling-induced fractures
  - Fault identification and orientation
  - Bed orientation
- Nuclear Magnetic Resonance
  - Oil saturation
- Sidewall Coring Tool

Thank You!