Core Technology for Evaluating the Bakken

Fundamentals for Reservoir Quality Assessment and Completion Analysis

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Topics Covered

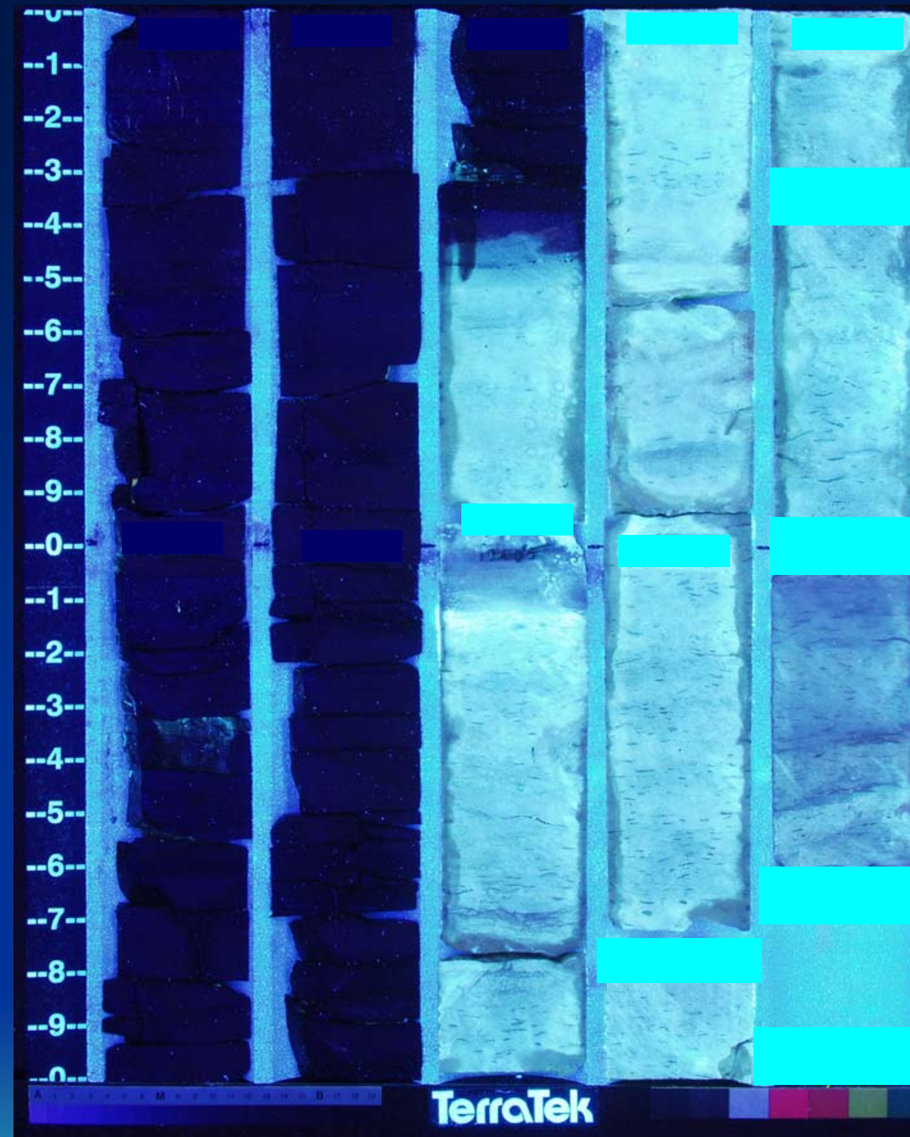
- Core Technology Changes and Why
  - Photos and Petrophysical Data of the Bakken
- Integrated Approach
  - Geochemical Analysis
    - Kerogen Maturity
  - Geological Analysis
    - Geological Profile
  - Petrological Analysis
    - Lithofacies Recognition
    - Clay Quantity, Type and Maturity
    - Pore Geometry and Texture
  - Mechanical Properties
- The Bakken Vision

Background

- *Unlike Conventional Core Analysis whose core analysis techniques are designed to evaluate conventional high perm reservoirs, Unconventional Core Analysis (i.e. TRA$_{TM}$ analysis) is structured at solving the complex issues of measuring many of the necessary parameters to unlock the potential of tight reservoirs.*

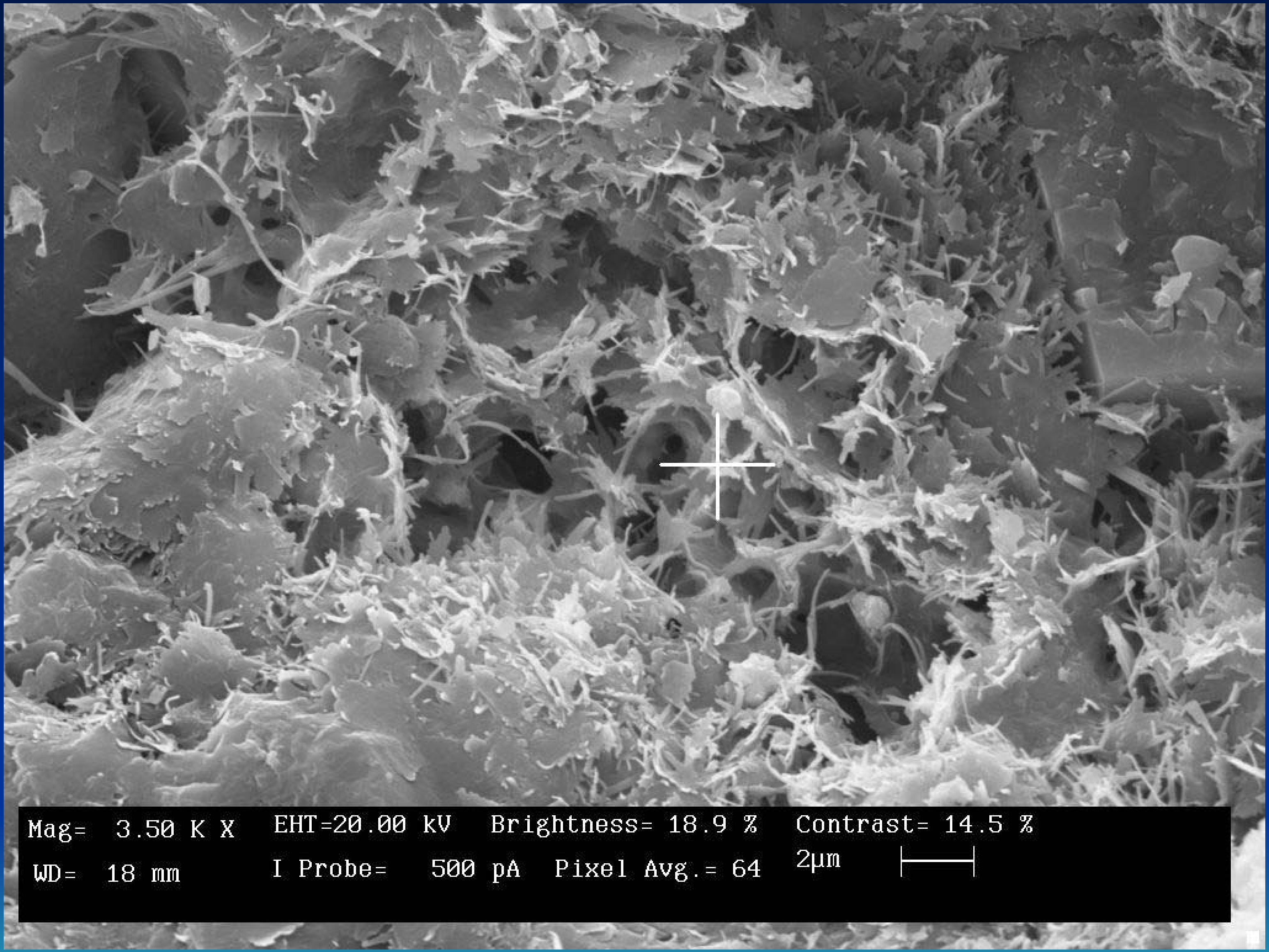
Effects on Tight Reservoirs

- *During Core Retrieval, Gas and Oil which are typically in solution (unless liquids are bound by capillarity as in shales) are expressed through the more permeable intervals (pore pressure is trying to reach equilibrium with the reduced pressure) therefore pore space formerly filled with oil and gas is now filled with expanded gas*
- *If the pore pressure can't reach equilibrium fast enough it can cause stress-release induced microfractures which can greatly alter matrix permeabilities and porosities (a very common effect on tight reservoirs)*
- *Low matrix permeabilities have a profound impact on all petrophysical measurements*
- *The presence of kerogen (organics) has altered the way we measure fluid saturations*
- *The impact of clay type, quantity, and especially maturity has altered the way all petrophysical properties are measured*



Bakken Dolomitic Mudstone to Dolomite

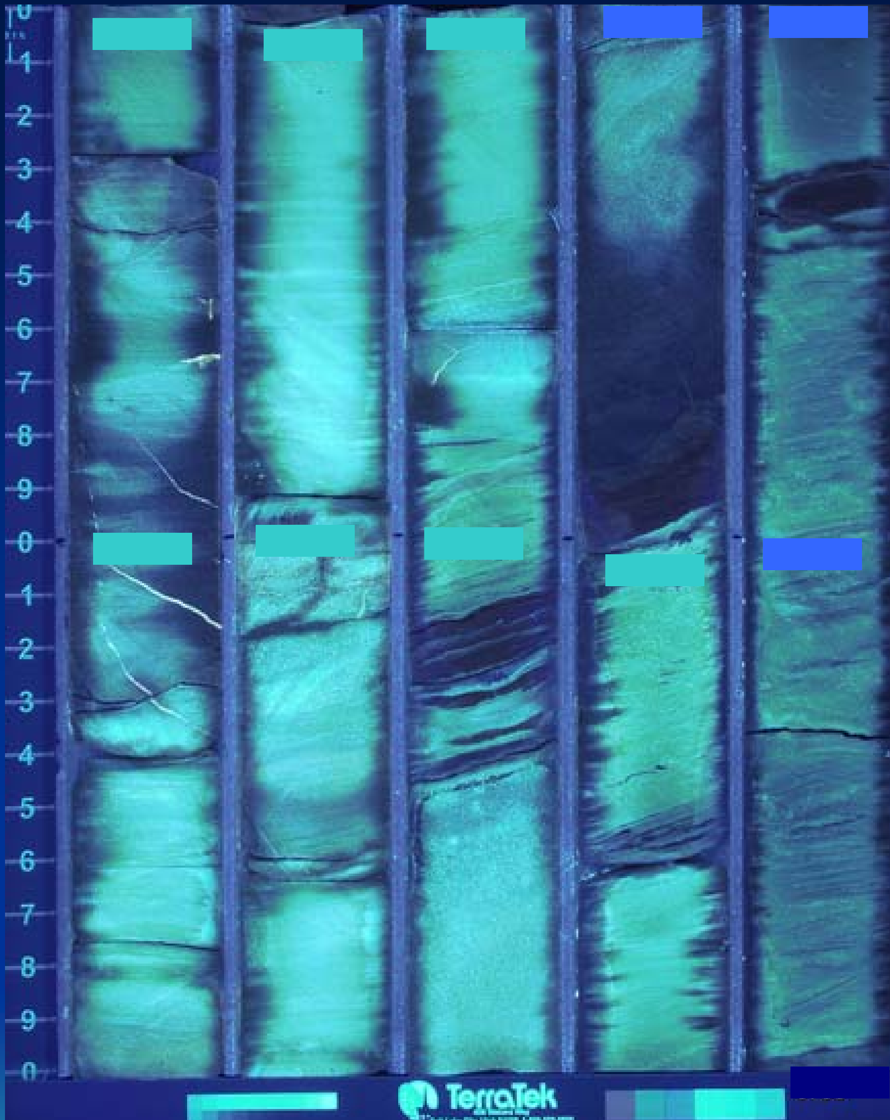

q
q
q
q
Mag= 2.50 K X
EHT=20.00 kV
Brightness= 18.0 %
Contrast= 14.0 %
WD= 25 mm
I Probe= 500 pA
Pixel Avg.= 64
2µm

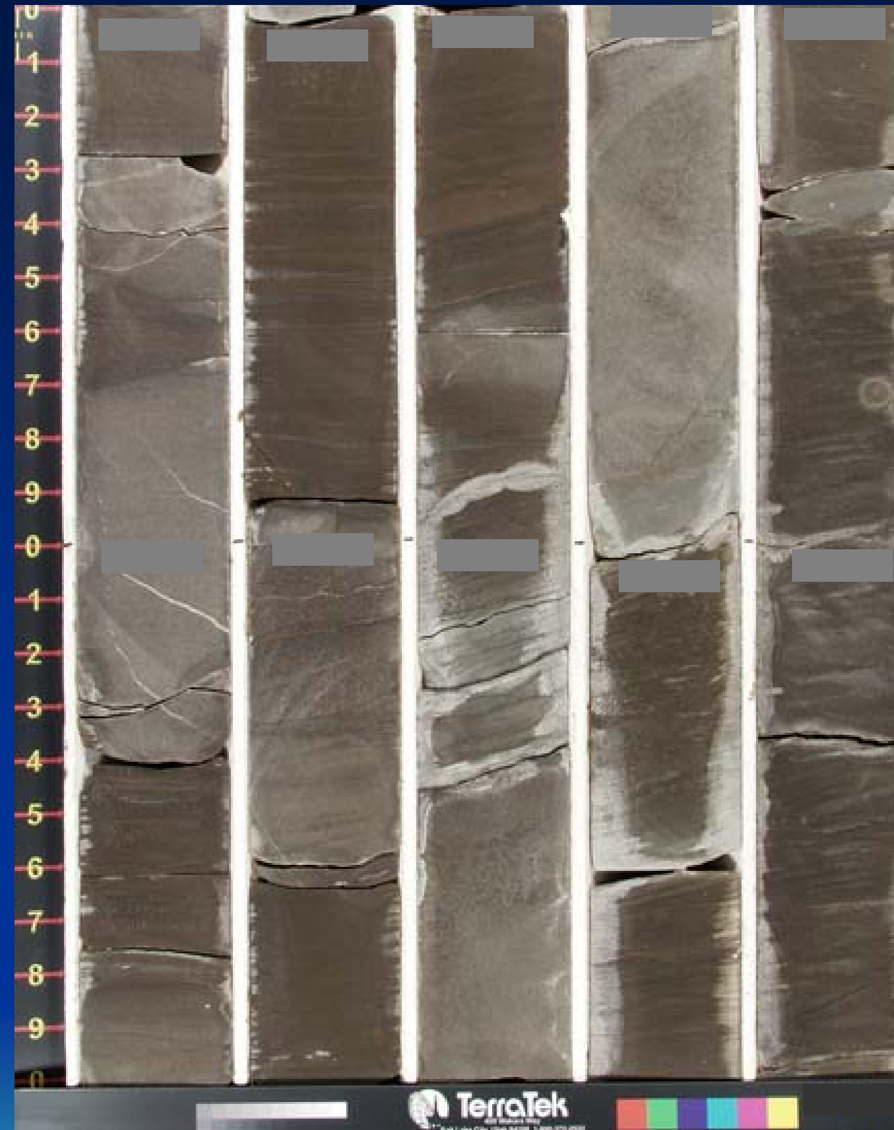

Mag= 3.50 K X
EHT=20.00 kV
Brightness= 18.9 %
Contrast= 14.5 %
WD= 18 mm
I Probe= 500 pA
Pixel Avg.= 64
2µm

Matrix Properties

Average Petrophysical Properties of the Middle Bakken Dolomitic Mudstone to Dolomite Members

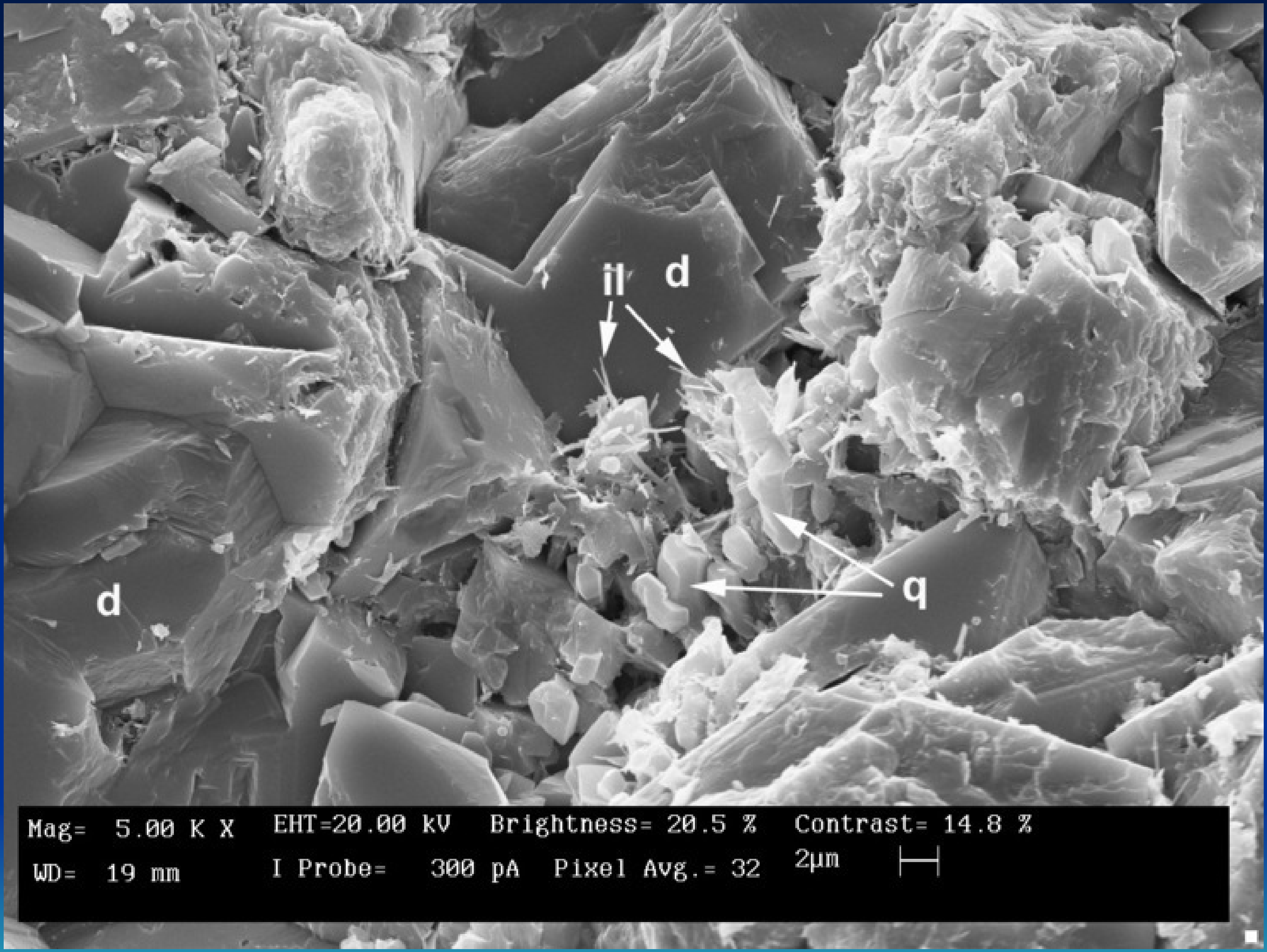
Depth, feet	A-R Bulk Density, gms/cc	A-R Grain Density, gms/cc	Dry Grain Density, gms/cc	Porosity, % of BV	Water Saturation, % of PV	Gas Saturation, % of PV	Mobile Oil Saturation, % of PV	Oil Space-Gas Filled Porosity, % of BV	Bound Hydrocarbon Saturation, % of BV	Bound Clay Water, % of BV	Permeability, md
Average Data											
Varies	2.639	2.754	2.796	6.22	19.95	66.11	13.94	4.19	0.27	1.50	0.000254
Range Data											
Low	2.561	2.725	2.748	2.30	8.56	44.83	7.20	1.50	0.05	0.29	0.000021
High	2.689	2.813	2.844	9.28	44.95	81.84	19.43	6.58	0.62	3.78	0.001



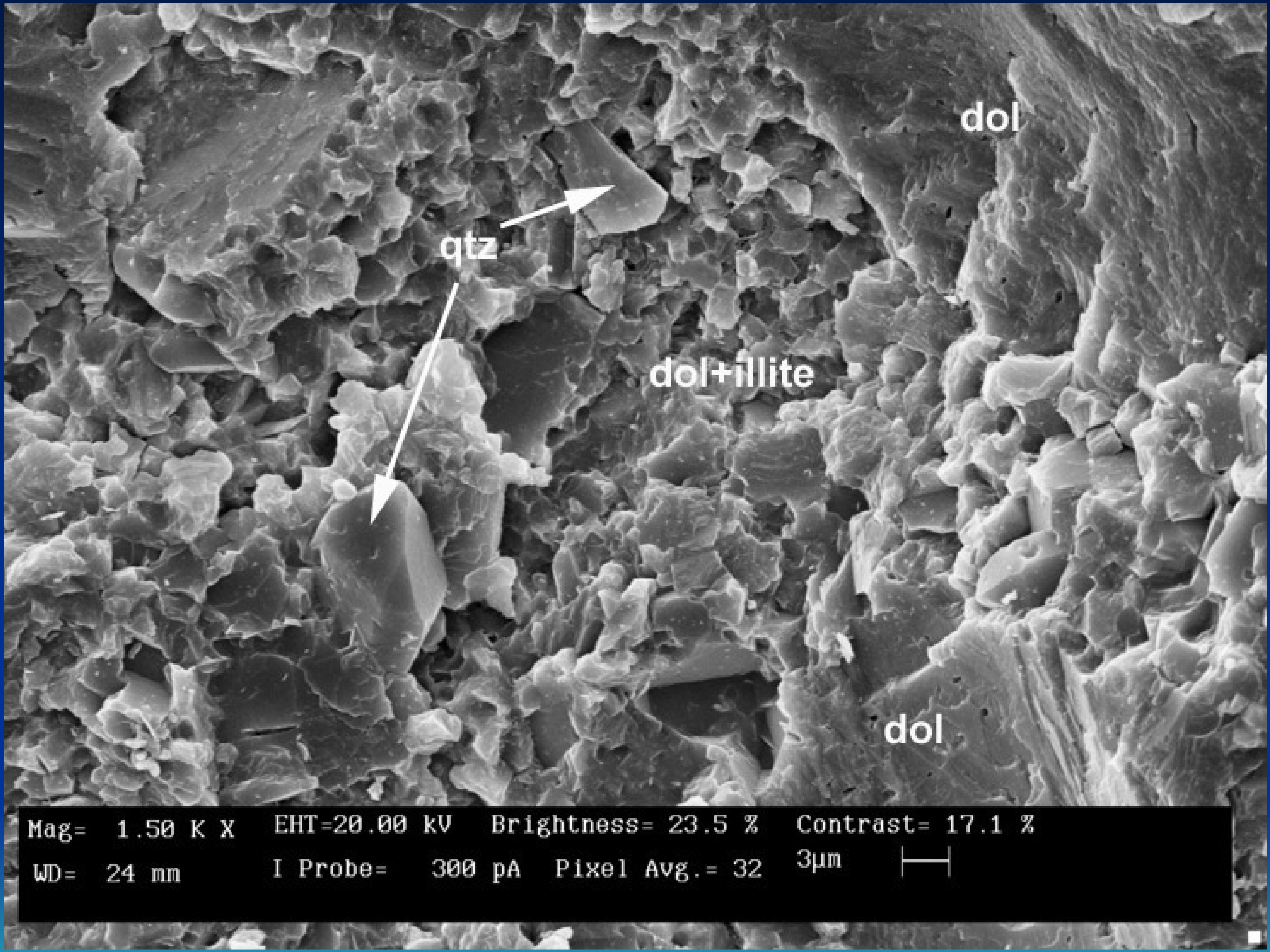


Bakken Silty / Sandy Mudstone to Sandstone


calcite
illite
Mag= 6.00 K X
EHT=20.00 kV
Brightness= 20.2 %
Contrast= 14.8 %
WD= 24 mm
I Probe= 300 pA
Pixel Avg.= 32
3µm



il
d
d
q
Mag= 5.00 K X
EHT=20.00 kV
Brightness= 20.5 %
Contrast= 14.8 %
WD= 19 mm
I Probe= 300 pA
Pixel Avg.= 32
2µm


dol
qtz
dol+illite
dol
Mag= 1.50 K X
EHT=20.00 kV
Brightness= 23.5 %
Contrast= 17.1 %
WD= 24 mm
I Probe= 300 pA
Pixel Avg.= 32
3μm

Matrix Properties

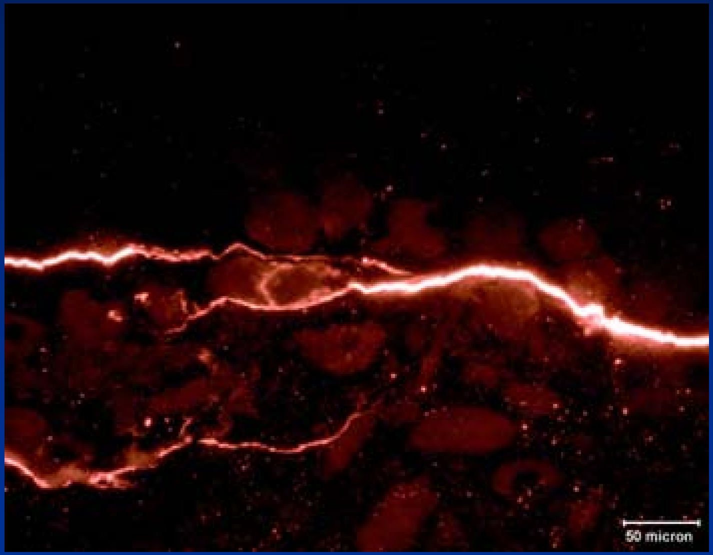
Average Petrophysical Properties of the Middle Bakken Silty / Sandy Mudstone to Sandstone Members

Depth, feet	A-R Bulk Density, gms/cc	A-R Grain Density, gms/cc	Dry Grain Density, gms/cc	Porosity, % of BV	Water Saturation, % of PV	Gas Saturation, % of PV	Mobile Oil Saturation, % of PV	Oil Space-Gas Filled Porosity, % of BV	Bound Hydrocarbon Saturation, % of BV	Bound Clay Water, % of BV	Permeability, md
Average Data											
Varies	2.552	2.698	2.742	7.65	17.74	71.53	10.74	5.40	0.16	1.11	0.0996
Range Data											
Low	2.387	2.637	2.699	3.32	2.47	60.75	1.26	2.88	0.00	0.29	0.000135
High	2.638	2.754	2.780	13.26	30.16	88.89	17.57	10.78	0.53	2.00	1.2917

Bakken Evaluation

- Unlocking the full potential of the Bakken play requires an Integrated Approach of Core Technologies which include:
  - Petrophysical
  - Geochemical
  - Geological
  - Petrological
  - Mechanical

Matrix Permeability and Porosity are altered by:



Coring induced and stress-release microfractures

- *Alter matrix permeability measurements by offering a quick path through the matrix*
- *Create added porosity that is not present at “in situ” conditions*

Specialized techniques are required to correct for both of these effects

Porosity

- *Solving the Issues in measuring Tight Reservoir Porosities- Gas, Oil, Water and Effective*
  - *Reduced permeability effects all saturation and porosity measurements*
  - *Separate measurements are required for Gas, Oil and Water to determine Effective Porosities and saturations*

Permeability

- *Solving the Issues in measuring Tight Reservoir Permeabilities*
  - *Coring Effects to Permeability Measurements*
    - *induced microfractures - mechanical and stress-release*
    - *bedding fractures*
    - *desiccation cracks*
    - *coring fluid damage*
  - *Clay Effects on Tight Reservoir Permeability (Presence of Clay Minerals of varying type, maturity, and location within the matrix and pore systems)*
  - *Fluid Effects (including the effect of oil and condensates) on Tight Reservoir Permeability measurements*
  - *Stress Effects on Tight Reservoir Permeability*

Saturations

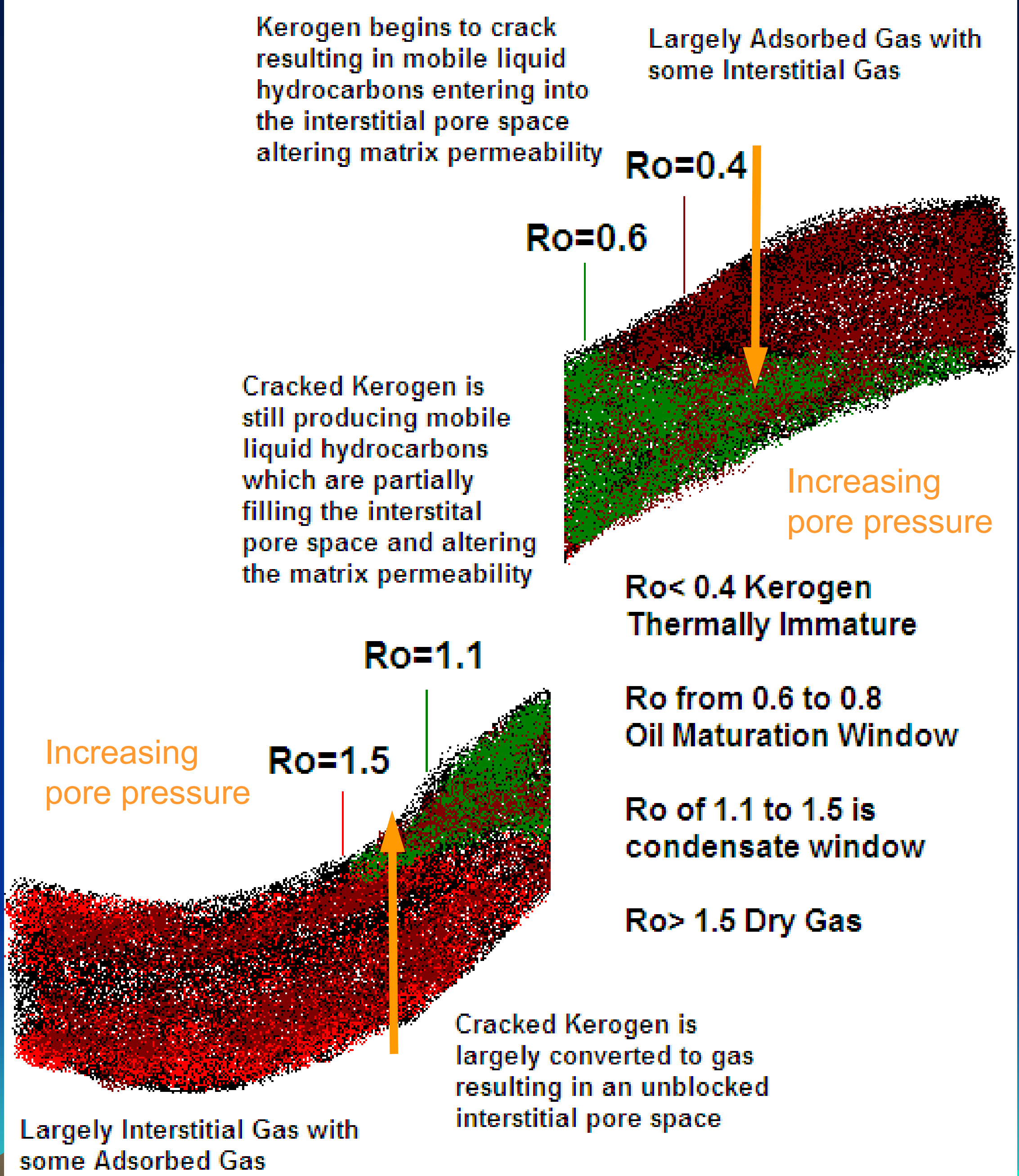
- *Solving the Issues in measuring Fluid Saturations*
  - *Kerogen/Vapor Pressure/and Low Permeability effects on Dean Stark Analysis*
    - *Free Hydrogen- Nitrogen/Argon Blankets*
    - *Vapor Pressure Equilibrium (accounting for volume)*
    - *Low Permeability effects on cleaning (it takes energy)*
  - *Development of Gravimetric Method*
    - *Humidity drying (associated errors)*
  - *Development of Tight Rock saturation Methods*

Confirming Petrophysical Properties Measurements

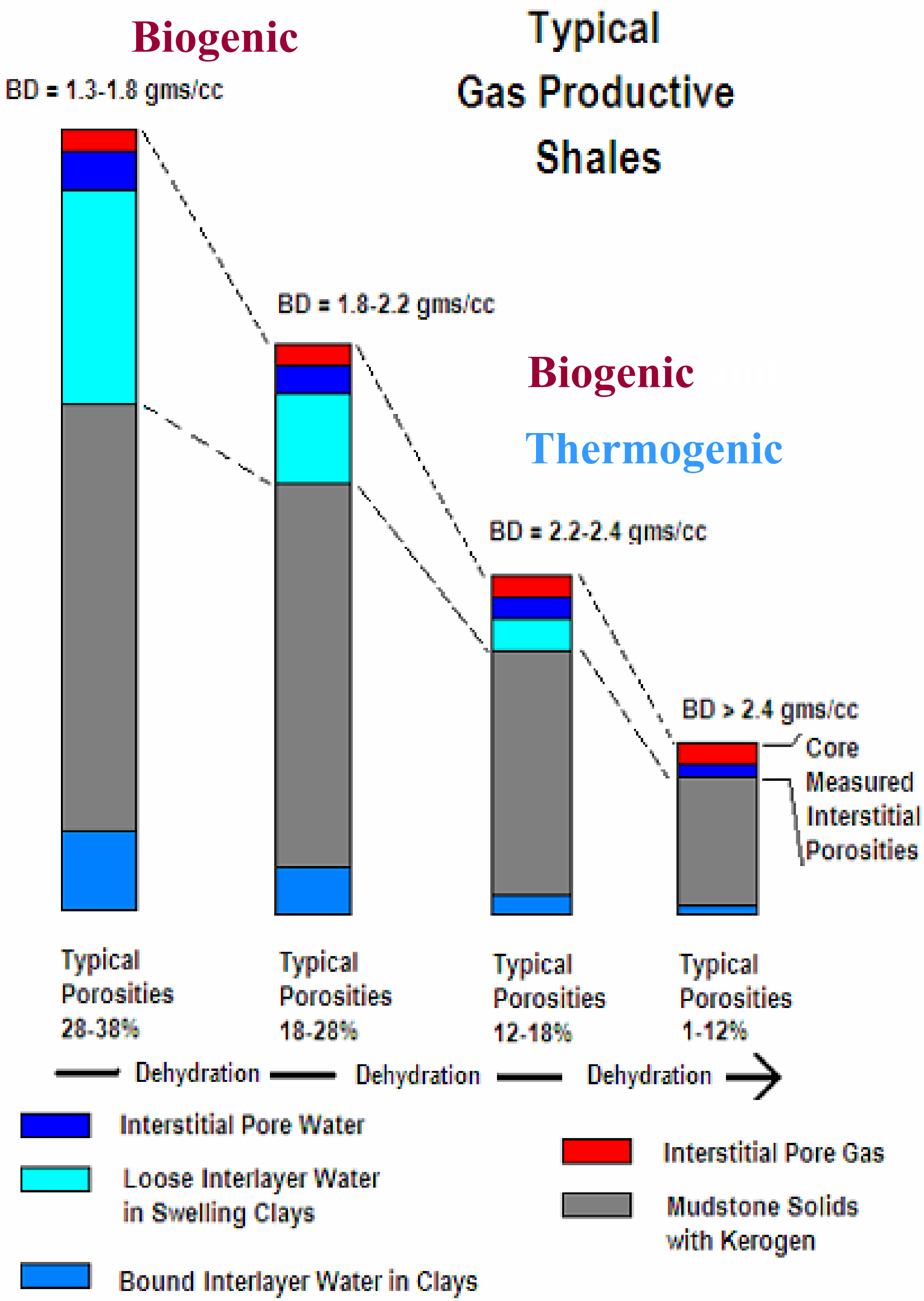
- *Grain Densities should approximate calculated Grain Densities from XRD*
- *Porosities should match porosities measured on cleaned and dried samples (where clays are < 3%)*
- *Fluid saturations should match production results*
- *Permeabilities should match interval K tests on non-fractured intervals with field flow tests*
- *Petrophysical data should be predictable with wireline log data*

Impact of Kerogen Maturity

Type 1: Lacustrine - oil prone source paraffinic
Type 2: Marine - oil prone source planktonic
Type 2S: Marine - oil prone source heavy sulfur (example Monterey)
Type 3: Marine - gas prone source higher plant & woody fiber
Type 4: Residual - dry gas prone source



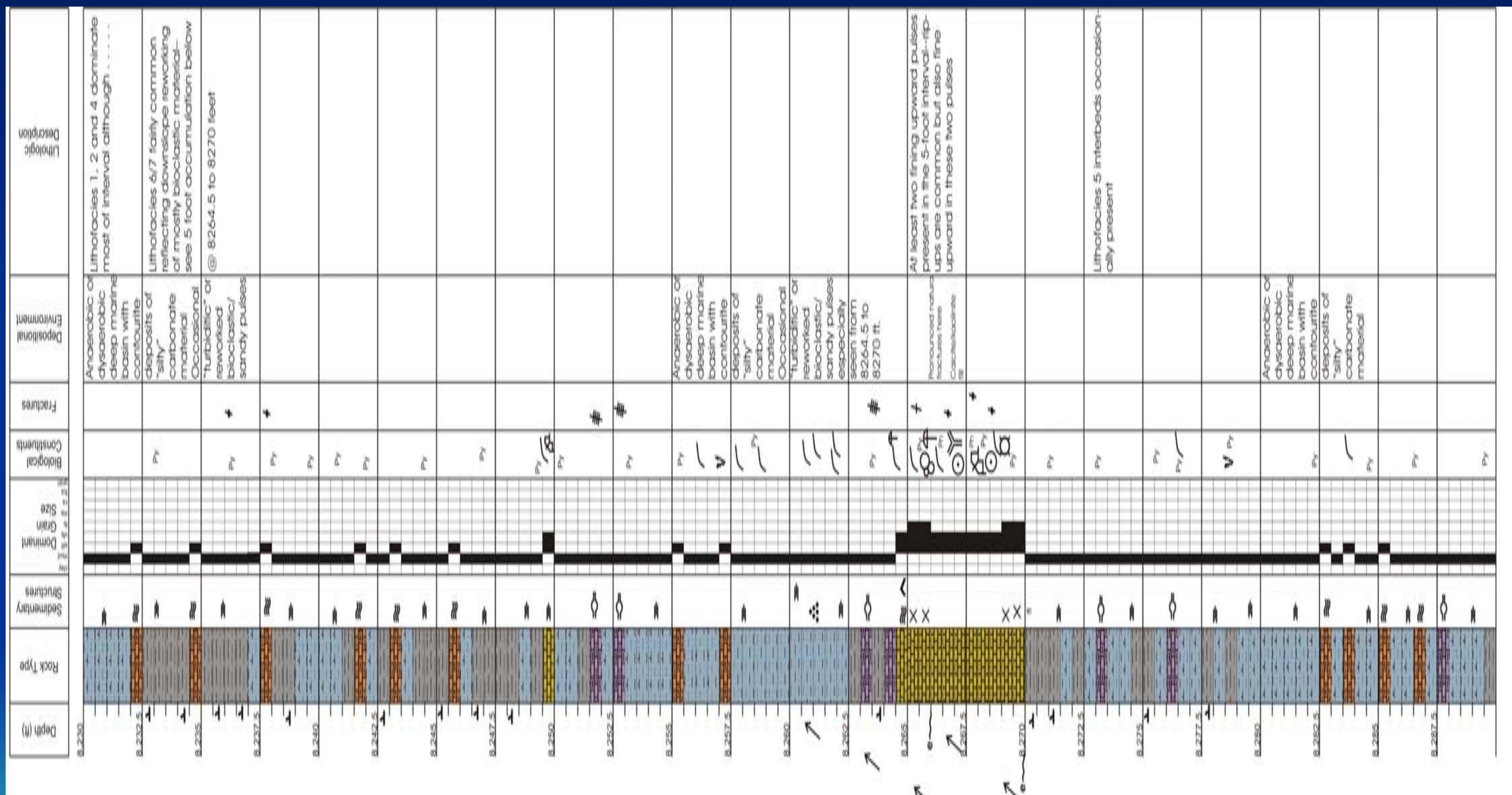
Impact of Clay Maturity



Geological Analysis

- Lithofacies Identification
- Depositional Environments
- Mineralogy
- Diagenetic / Detrital Minerals
- Other Ingredients including fossils
- Photomicrographs of Enlarged Thin Sections
- Natural Fractures and Fracture Fills
- Log Responses to Geology / Minerals

Example Geological Profile



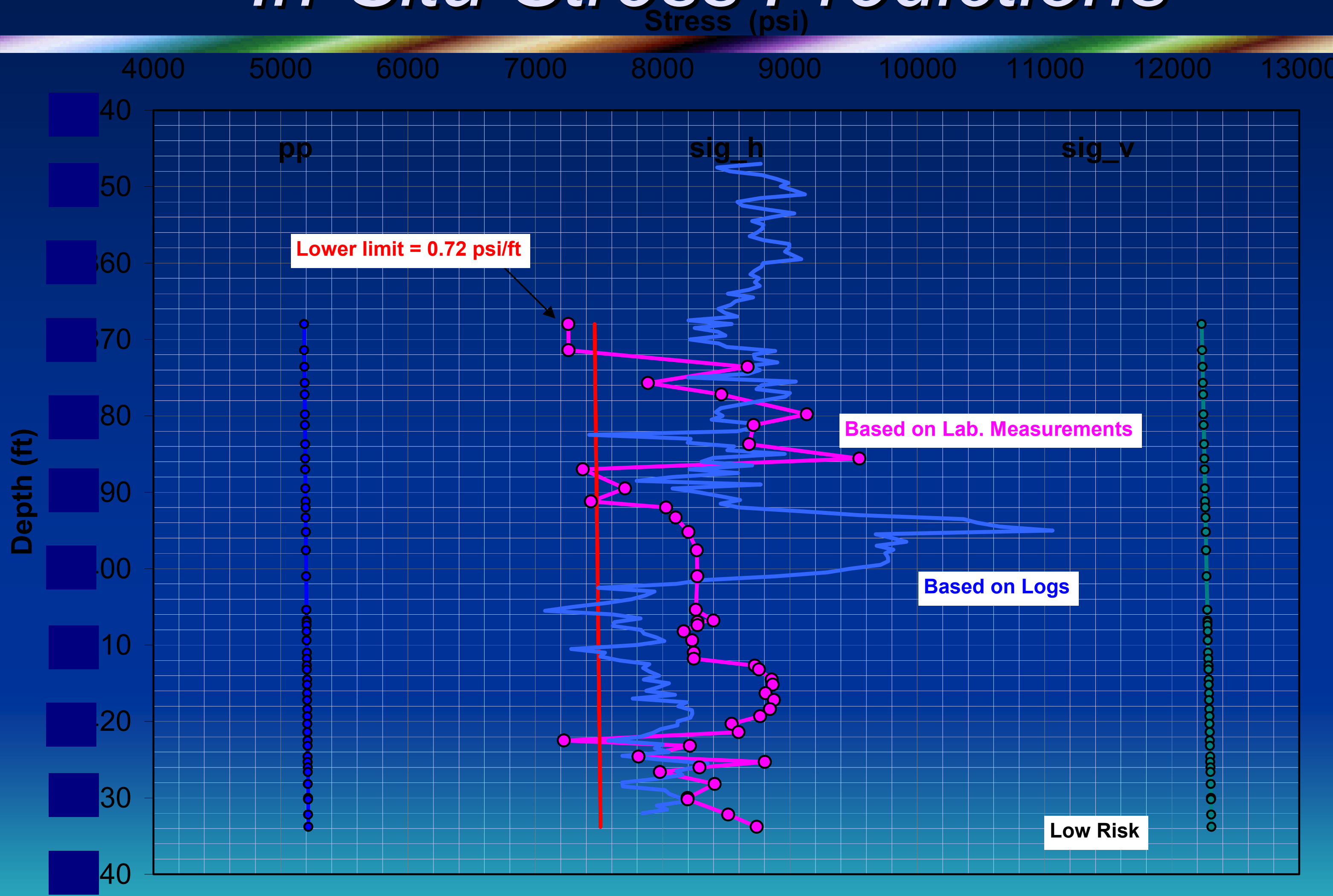
Petrological Analysis

- Lithofacies Recognition
  - Thin Section Descriptions
- Clay Quantity, Type, and Maturity
  - XRD Analysis
  - Bound Clay Water
- Pore Geometry and Texture
  - SEM imaging

Mechanical Properties

- Measuring Heterogeneity
- Fracture Analysis
- Tri-axial Testing
- Predicting Stress Profiles
- Modeling Fracture Containment

The Effect of Heterogeneity on In-Situ Stress Predictions



Capture the Bakken Vision

Bakken Vision

- *The Bakken example may be visionary for Unconventional Oil Plays*
  - *Near conventional (fracturable/brittle) lithofacies within high TOC shales having the right thermal maturity (mid-late-post oil generation) within an interval where the fracture can be contained.*
  - *Lateral Completions (often multiple oriented laterals required)*
  - *Thermal Maturity, Lithofacies, and fracture containment are and will be critical issues to these plays.*
- *New Plays underway*
  - *Barnett – Ft. Worth Basin (3 wells currently producing)*
  - *Dolomitic Mudstone in Canada (untested)*
  - *Barnett – West Texas (untested)*
- *Potential Plays – many (i.e. Lewis, Wolfcamp, the Green River, Antrium, New Albany, Ohio, Devonian…*
- *Old Fractured Oil Shale Plays needing to be revisited – Monterey and Mancos*