PS Visual and Analytical Comparisons of Upper Bakken “Shale” Cores from a West-to-East Transect, McKenzie and McLean Counties, North Dakota*

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*Adapted from core poster presentation given at AAPG Rocky Mountain Section Meeting, Denver, CO, July 20-22, 2014

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Abstract

Data from six lowermost Mississippian (Kinderhookian) upper Bakken “shale“ cores along a 52-mile-long transect in the Williston Basin in North Dakota provide a rich suite of stratigraphic and analytical information for detailed comparisons. Thickness of this silty, organic-rich mudrock varies from 14 to 21 feet with no consistent regional trend evident along the transect. A visual display alone of three slabbed cores reveals some color variations but fails to show the subtle compositional and textural components of this interval. Analytical results from all six cores, however, serve to characterize and contrast these world-class source rocks as they change from peak oil generation to thermally immature. Detrital silt, disseminated throughout the interval, occurs as scattered grains and thin, locally discontinuous laminae that are visible in the slabbed core. These eolian silt grains, along with a variety of pelagic fossil fragments and fecal pellets, settled through the stratified water column and accumulated on a mostly anoxic seafloor, although there were some minor periods of dysoxia indicated by burrowing. Mineral assemblages identified in thin sections and by SEM EDS are surprisingly diverse. X-ray diffraction results show that the major components that are relatively constant along the transect include quartz (30–50%, detrital, biogenic, and authigenic), kerogen (10–20 wt. %, mostly Type II), illite/mica (15–25%), and K-feldspar (4–8%). The constituents that vary the most include dolomite (2–13%, both detrital and authigenic), albite (2–9%), mixed-layer illite/smectite (1–17%, increasing eastward), pyrite (3–14%, all authigenic), and calcite (1–7%, mostly as skeletal fragments). Present-day as well as estimated original TOC values highlight the well-known westward increase in thermal maturity of the Upper Bakken from east to west with a few interesting exceptions close to the Nesson anticline. Corresponding organic pore development is also related to increasing thermal maturity. Elemental data from hand-held X-ray fluorescence show considerable vertical and lateral variability. The resulting chemostratigraphic interpretation of key elements has defined recognizable, geographically continuous sequences that offer new insights into depositional processes and environments.

VISUAL AND ANALYTICAL COMPARISONS OF UPPER AND LOWER BAKKEN "SHALE" & UPPER PRONGHORN "SHALE" CORES ALONG A WEST-TO-EAST TRANSECT, McKENZIE & McLEAN COUNTIES, NORTH DAKOTA

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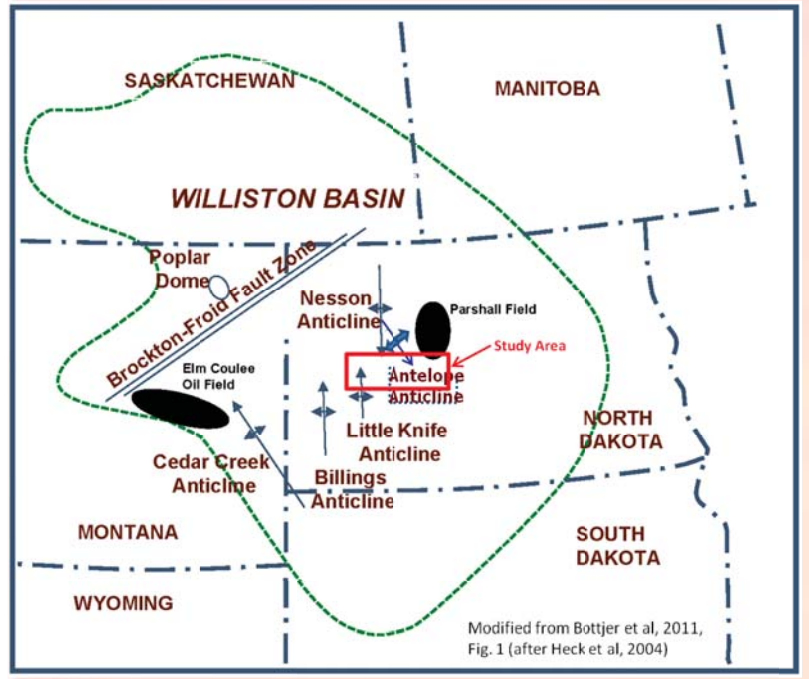
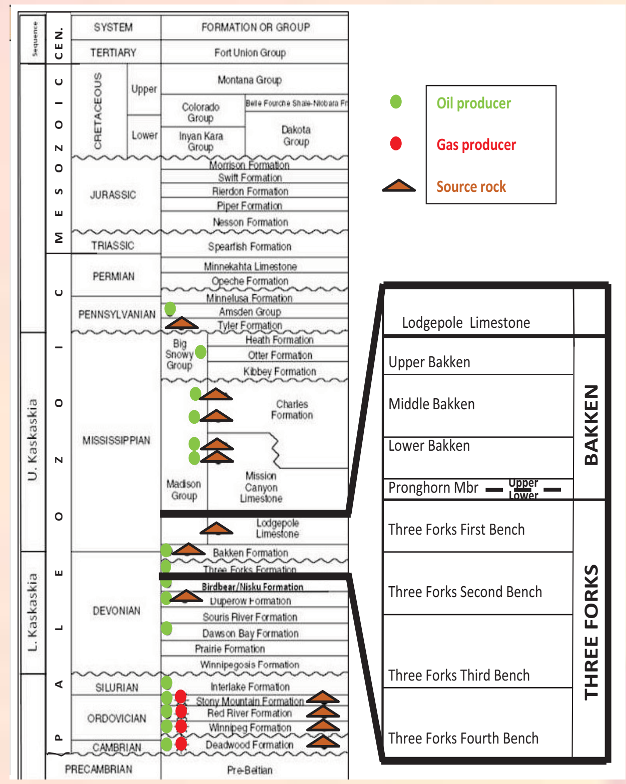
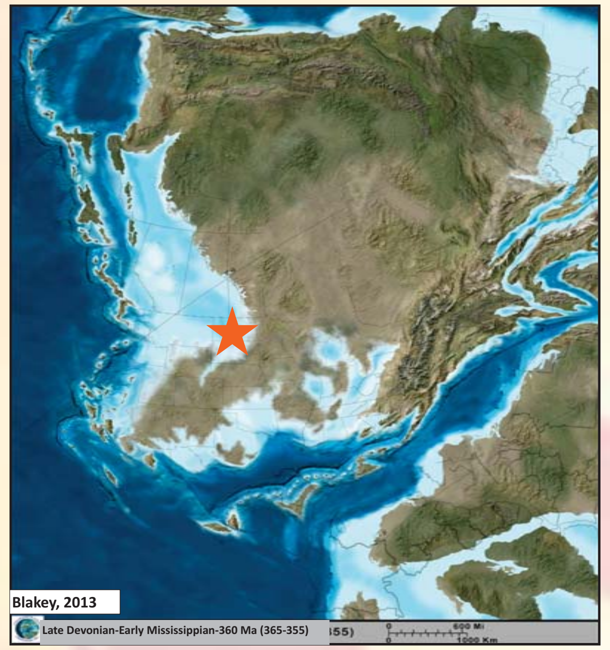


Regional map of the Williston Basin showing major structural features as well as the study area.

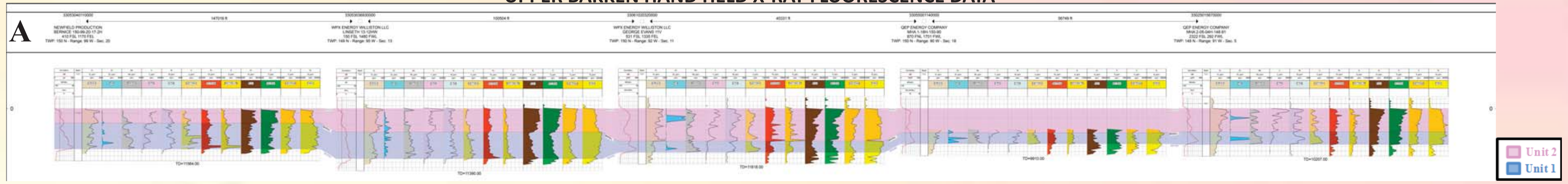


Stratigraphic column for the SE Williston Basin with an expanded section showing the Bakken Petroleum System http://en.wikipedia.org/wiki/File:WillistonStratCol.jpg

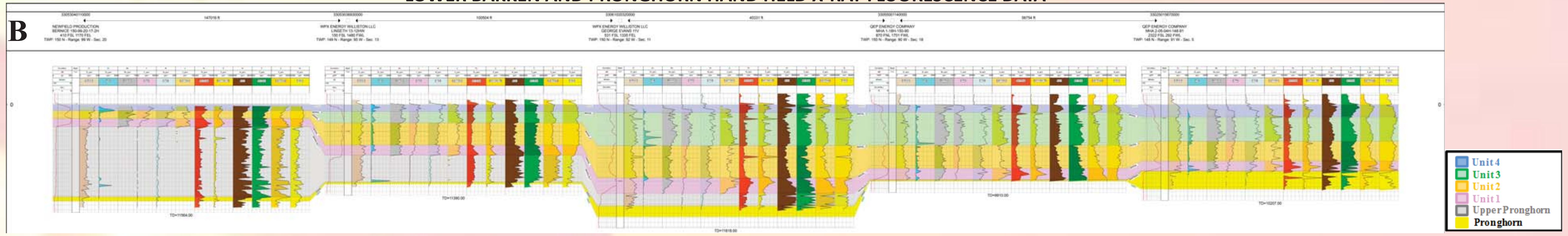


Late Devonian paleogeographic map of North America with relative position of cores shown with the red star. Organic accumulation and preservation in the Bakken may be attributed to anoxic conditions, abundant organic source and productivity, sparcity of diluting inorganic elements, rapid sedimentation and burial rates, and lack of biodegradation in the water column. (Caplan and Bustin, 1996)

UPPER BAKKEN HAND HELD X-RAY FLUORESCENCE DATA

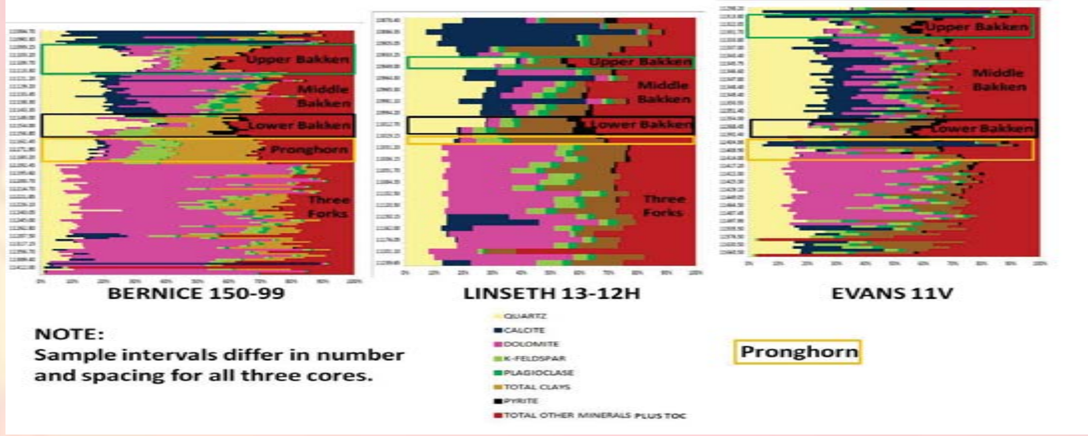


LOWER BAKKEN AND PRONGHORN HAND HELD X-RAY FLUORESCENCE DATA

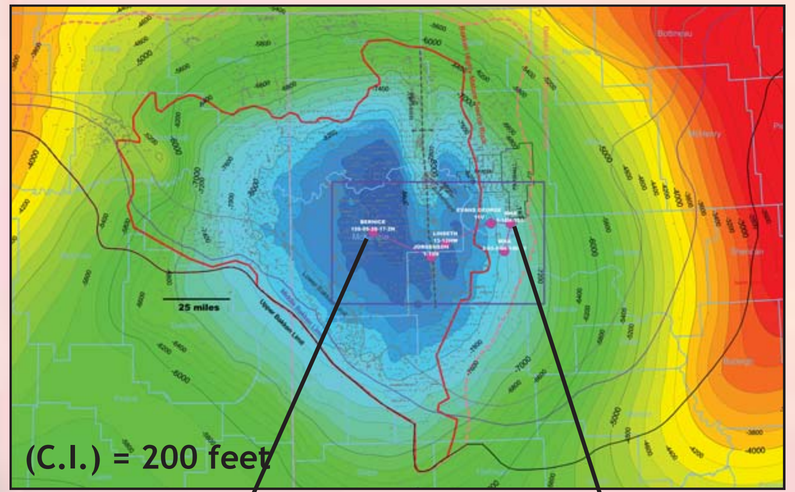


West-to-East cross sections showing the distribution of hand held X-ray fluorescence elemental data for the Upper Bakken (A) and the Lower Bakken and the Pronghorn (B) From left to right, elemental tracks include: Cr (light brown); Zn (teal); Mo (gray); V (pink); Ni (light blue); U (light yellow); Fe (red); S (dark yellow); Al (brown); Ti (green); K (light orange); Si (bright yellow). Sequence correlations are based upon vertical profiles that reflect varying degrees of anoxic, organic, and detrital elements.

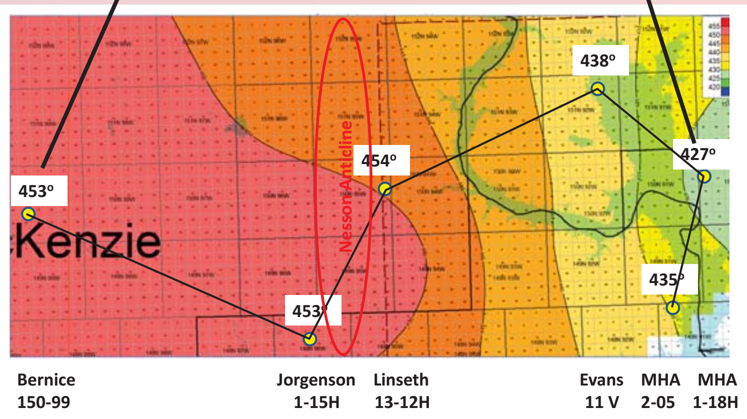
COMPARISON OF VOL % X-RAY DIFFRACTION DATA FROM BAKKEN TO THREE FORKS



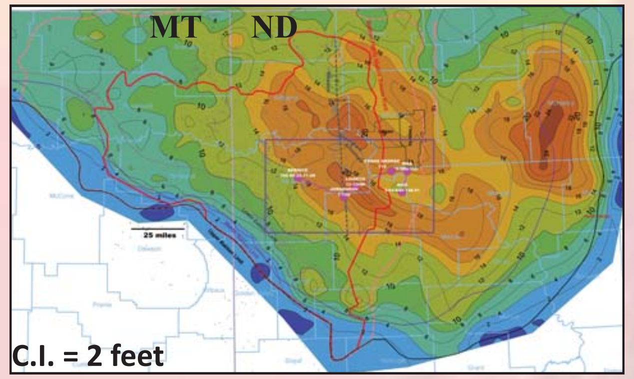
Most of the available XRD data was measured in volume percent shown to the right. In the Upper and Lower Bakken intervals, much of the red "total other minerals" track is composed of organic material which can be computed as weight percent XRD.



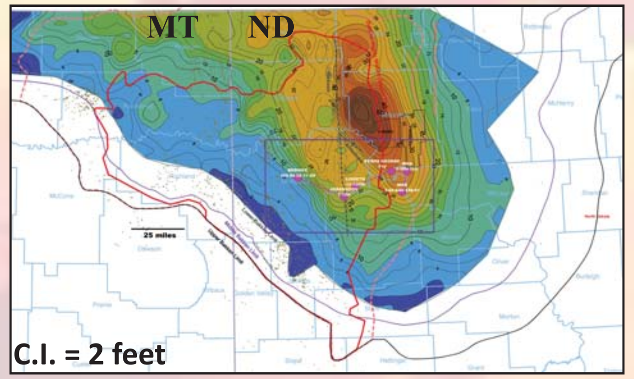
Upper Bakken structure map of N. Dakota and Montana. Study area shown in the rectangle contains the locations of the six cored wells analyzed for this core poster presentation. Three of the cores are displayed in a West-to-East orientation.



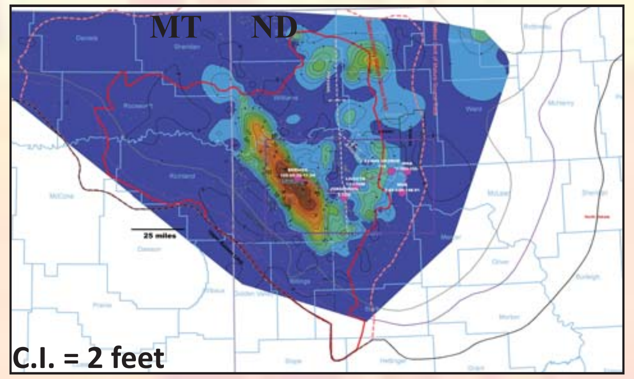
Upper Bakken Tmax map closely mirrors the Upper Bakken structure map above, except where a thermal anomaly appears over the area of the Nesson Anticline (outlined).
Note that maturity increases to the west.



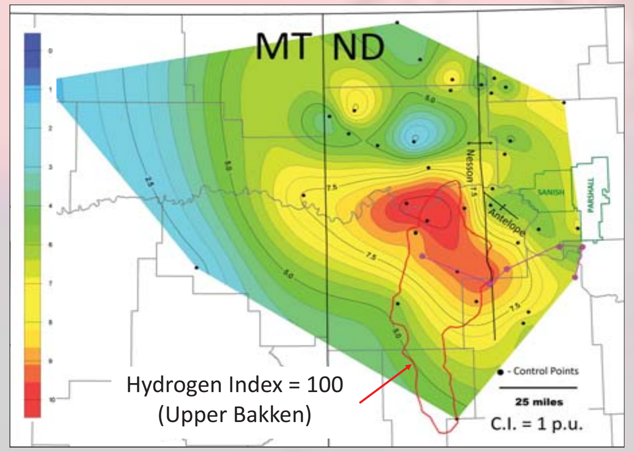
Upper Bakken isochore map



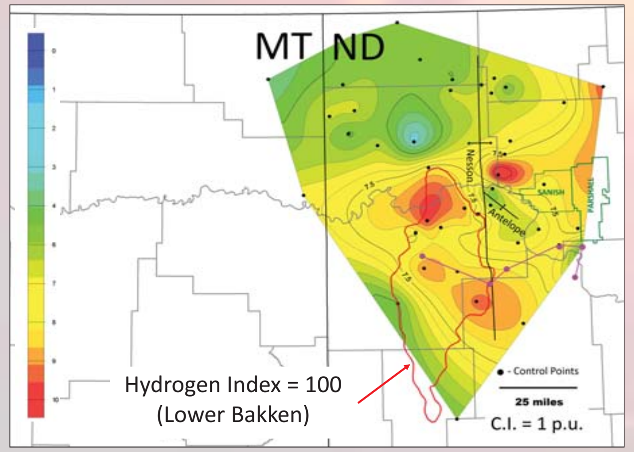
Lower Bakken isochore map



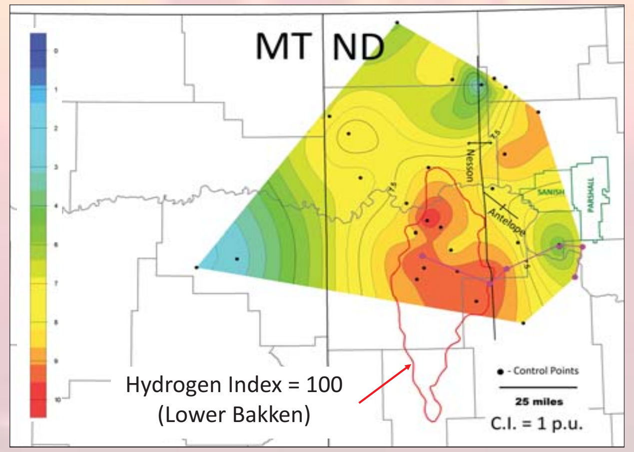
Upper Pronghorn isochore map



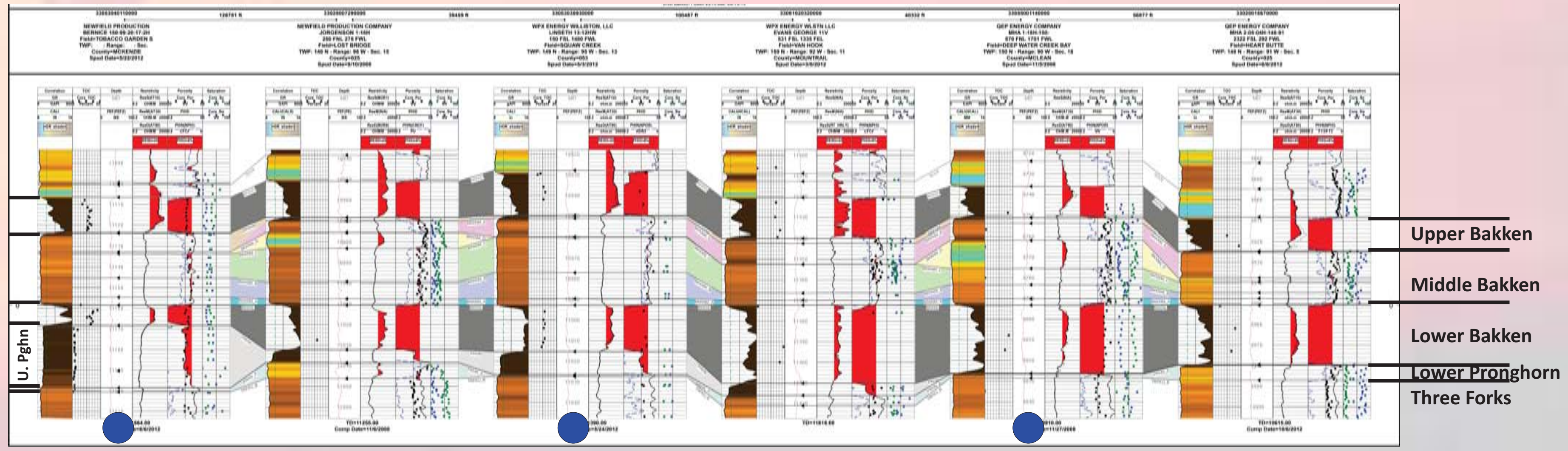
Upper Bakken average porosity from cores. Note general trend of increasing porosity with maturity and development of unconnected nano-pores in organic material in SEM images on poster 2A. Bold red line approximates hydrogen index of 100 from Upper Bakken rock eval data.



Lower Bakken average porosity from cores. Note general trend of increasing porosity with maturity and development of unconnected nano-pores in organic material in SEM images on poster 2B. Bold red line approximates hydrogen index of 100 from Lower Bakken rock eval data.



Upper Pronghorn average porosity from cores. Note general trend of increasing porosity with maturity. Bold red line approximates hydrogen index of 100 from Lower Bakken rock eval data.



West-to-East log cross section of the six cored wells analyzed for this presentation.
Actual cores on display are marked on the section with a blue dot.
Track 1: Shaded gamma ray curve (0 to 800 API scale); Caliper (dashed green on 6 to 16" scale).
Track 2: Core TOC (black dots on 0 to 20% scale).
Track 3: Measured depth (in feet); PEF (dashed pink on 0 to 10 B/E scale).
Track 4: Deep resistivity (black with shaded red >20 ohm-m) on 0.2 to 2000 ohm-m scale.
Track 5: Density porosity (black and shaded red >6% on LS matrix) on 0 to 20% scale;
Core porosity (black dots on 0 to 20% scale); Neutron porosity (blue dashed on 0-20% scale).
Track 6: Core oil saturation (green dots on 0 to 100% scale); Core water saturation (blue dots on 0-100% scale).

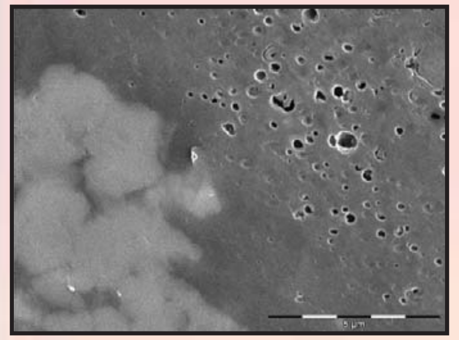
VISUAL AND ANALYTICAL COMPARISON OF UPPER BAKKEN "SHALE" CORES FROM A WEST-TO-EAST TRANSECT, MCKENZIE AND MCLEAN COUNTIES, NORTH DAKOTA

Laura Wray(1), Mark Longman(2), Katie Kocman(2), Laura Mauro Johnson(3), Grant Sha(3), and Simon Cole(1)
(1) WPX Energy (2) Newfield Exploration (3) QEP Resources, Inc.

UPPER BAKKEN UNCONNECTED NANO-POROSITY WITHIN ORGANIC MATTER

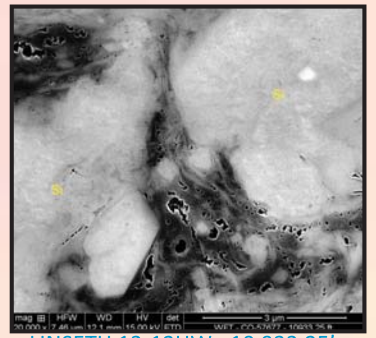
West — East

Average TOC : 10.3%



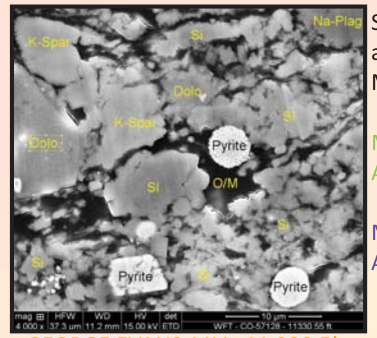
BERNICE 150-99-20-17-2H : 11,109.7'

Average TOC = 17%



LINSETH 13-12HW : 10,933.25'

Average TOC : 10.1%



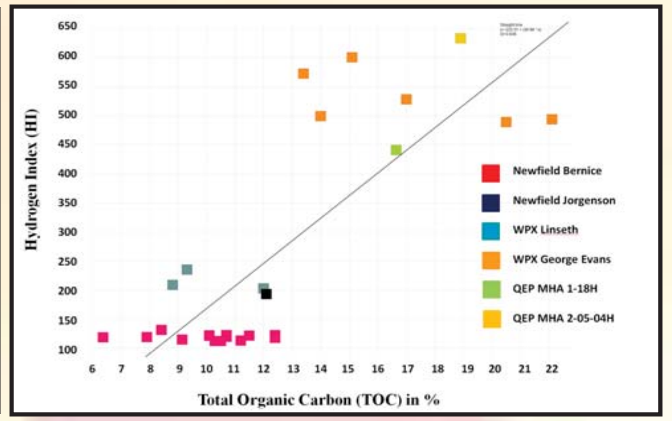
GEORGE EVANS 11V : 11,330.5'

SEM images are not available for the two MHA cores.

MHA 1-18H-150-90 = AVG. TOC = 16.6%

MHA 2-05-04H-148-91 AVG. TOC= 14.6%

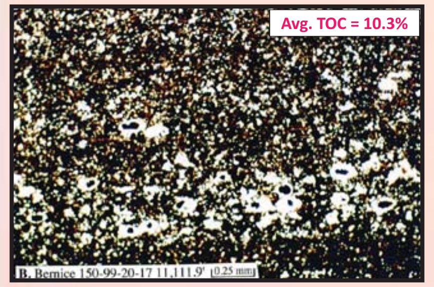
Graph at right illustrates the increase in maturity from east to west as represented by lower HI and TOC Values for higher thermal maturity. Variability in TOC is due to differences in organic facies.



Note: Colors on graph correspond to text colors under images

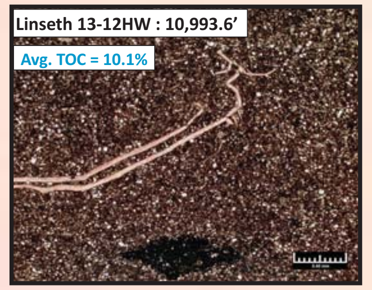
DECREASING MATURITY FROM WEST TO EAST REPRESENTED BY COLOR CHANGE AND INCREASE IN TOC & ILLITE/SMECTITE CONTENT

West — East



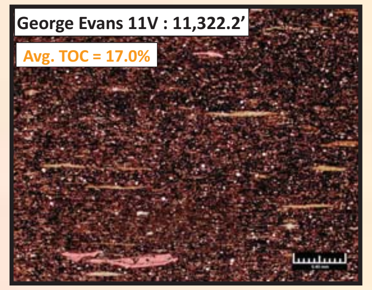
Silty, organic-rich kerogennite with layers of radiolarians.

Quartz = 62%; Clay = 17%; Pyrite = 6%



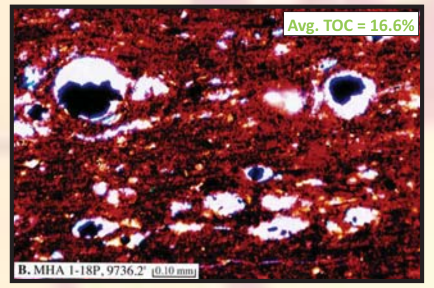
Silty, dolomitic, organic-rich kerogenite with brachiopod shell

Quartz = 26%; Clay = 38%; Pyrite = 2%



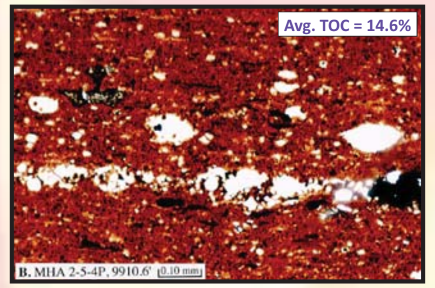
Siliceous, organic-rich kerogenite with bioclasts & pellets

Quartz = 50%; Clay = 14%; Pyrite = 7%



Organic and clay-rich kerogenite with radiolarians

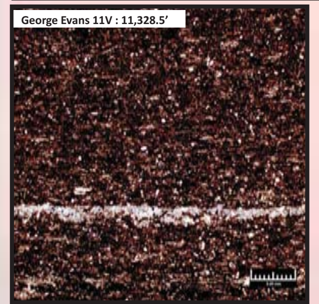
Quartz : 37%; Clay : 36%;Pyrite : 12%



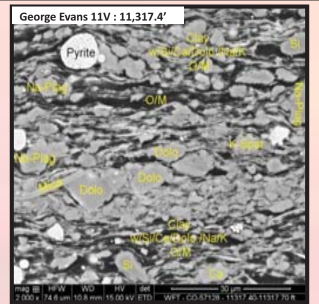
Siliceous, clay-rich kerogenite with radiolarians

Quartz : 40%; Clay : 31%; Pyrite : 14%

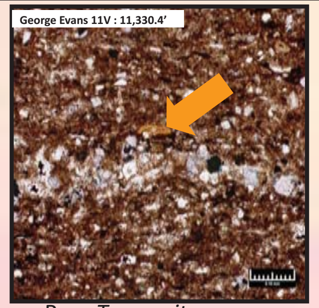
OTHER CHARACTERISTICS OF THE UPPER BAKKEN



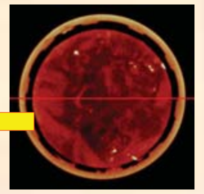
Typical silt lamination



Mineral diversity



Rare *Tasmanites* spore



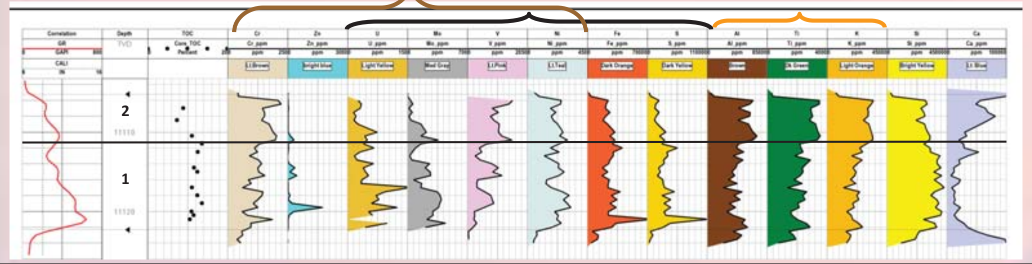
Thin interval of bioturbation at the top of the Upper Bakken.

UPPER BAKKEN ANALYTICAL DATA FROM FIVES CORES ALONG THE WEST TO EAST TRANSECT

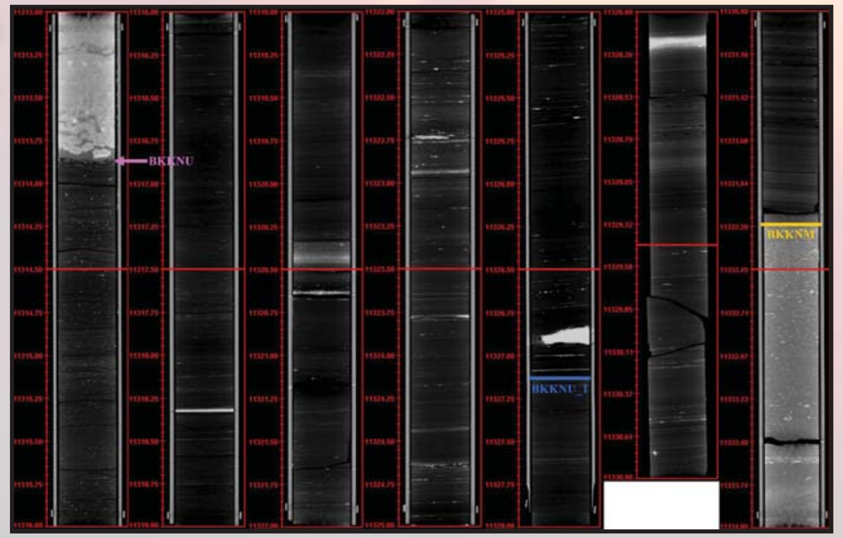
West → East

	Well Name:	Bernice 150-99-20-17-2H	Linseth 13-12HW	George Evans 11V	MHA 1-18H-150-90	MHA 2-05-04H-148-91
	Upper Bakken					
	Top Core Depth	11096.5'	10932'	11313.9'	n/a but @ 9723.7'	9897.9'
	Quartz	48%	48.7%	45.8%	37%	40%
	K-Spar	7%	6.7%	7.3%	4%	7%
	Plagioclase	2%	4.0%	3.3%	9%	4%
	Calcite	4%	6.0%	3.3%	1%	1%
	Dolomite	9%, Fe-Dol: 4	6.7%	5.8%	2%	3%
	Pyrite	3%	3.3%	7.5%	12%	14%
CLAYS	Illite/Smectite	3%	2.7%	1.0%	10%	16%
	Illite/Mica	20%	23.0%	24.0%	25%	15%
	Kaolinite	0%	tr	tr	0%	0%
	Chlorite	3%	0.5%	1.6%	1%	0%
	TOC	10.3%	10.1%	17.0%	16.6%	14.6%
	T Max	455	454	438	427	435
	HI	118	215	531	441	634
	Thickness	17'	21'	18'	14'	15'
	Avg Phi	8.9%	8.7%	6.3%	4.7%	n/a
	Avg Sw	10.5%	n/a	n/a	24.7%	n/a
	Avg So	36.7%	n/a	n/a	67.5%	n/a
	Base Core Depth	11113'	10953'	11332'	9737.7'	9912.4'

HAND-HELD X-RAY FLUORESCENCE ANALYSIS FOR THE UPPER BAKKEN



The X-ray fluorescence profiles to the left show that TOC is associated with organic (nutrient-type) elements such as Cr, Zn, Mo, V, and Ni. High values of Mo, U, Ni, Fe, and S are also indicators of anoxic conditions. The remaining detrital elements decrease at top of Upper Bakken except for Ca which increases. Elemental trends allow for subdivision of the Upper Bakken into two units.



CT scan images of WPX's George Evans 11V showing dominantly horizontal laminations. Dark color = low density; Lighter colors = high density.

UPPER BAKKEN KEY POINTS

- The Upper Bakken is a black, silty, massive, organic-rich mudrock or kerogenite with relatively low clay content (<36%).
- Average values from west-to-east along the transect are: TOC 11-18.5%, Tmax 455-427, thickness 21-14 ft (with variations), porosity 9-6% (highest where most thermally mature), total clay 36-26% (due in part to decreasing TOC to the west).
- Top and base of Upper Bakken are sharp (a few cm or less) and easily picked on gamma-ray and other logs.
- Deposition occurred below storm wavebase under anoxic conditions interrupted by brief periods of dysoxia near the base and top of interval.
- A wide range of detrital minerals (quartz, K-spar, plagioclase, calcite, illite/mica, illite/smectite, kaolinite, and chlorite) and diagenetic minerals (quartz, calcite, dolomite, pyite, and illite) in the silt-sized fraction.
- Detrital silt laminae are sparse, thin, laterally continuous (except where disrupted by compaction fluids), and deposited from eolian dust-storms rather than bottom traction currents.
- Radiolarians, phosphatic fossil fragments, and flattened fecal pellets are locally common but *Tasmanites* spores are rare compared to the Lower Bakken.
- Redox elements (U, Mo, V, Ni) are abundant as is diagenetic pyrite (FeS2) locally.

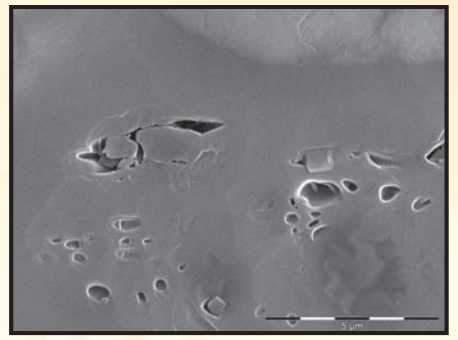
VISUAL AND ANALYTICAL COMPARISON OF LOWER BAKKEN "SHALE" CORES FROM A WEST-TO-EAST TRANSECT, MCKENZIE AND MCLEAN COUNTIES, NORTH DAKOTA

Katie Kocman(1), Mark Longman(1), Laura Mauro Johnson(2), Grant Sha(2), Laura Wray(3), and Simon Cole(3)
(1) QEP Resources, Inc. (2) Newfield Exploration (3) WPX Energy

LOWER BAKKEN UNCONNECTED NANO-POROSITY WITHIN ORGANIC MATTER

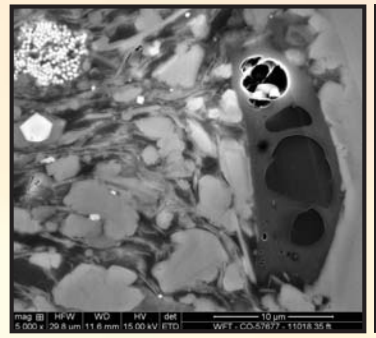
West — East

Average TOC : 11%



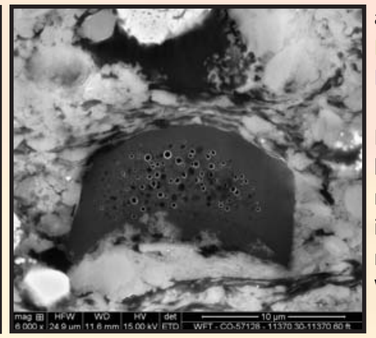
BERNICE 150-99-20-17-2H : 11,153.3'

Average TOC : 10.9%



LINSETH 13-12HW : 11,018.35'

Average TOC : 18.4%

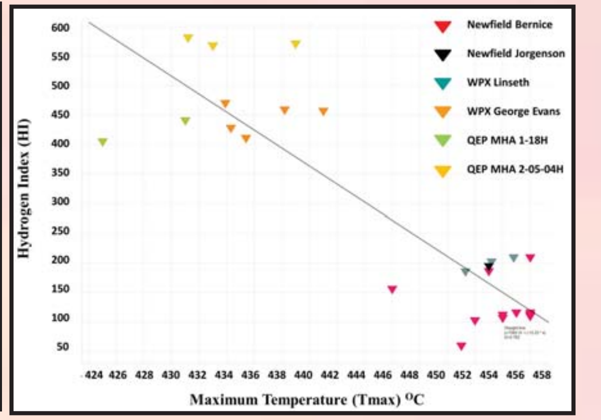


GEORGE EVANS 11V : 11,370.3'

SEM images are not available for :
MHA 1-18H-150-90
MHA –2-05-04H-148-91

Nano-porosity hypothesized to be more abundant with increasing thermal maturity (from East-to-West).

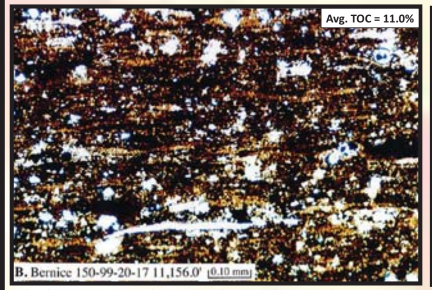
Graph at right illustrates the relationship between Tmax and HI. An inverse relationship is seen between the two, as expected.



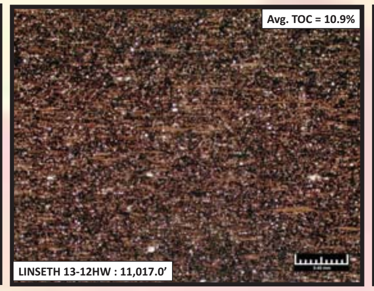
Note: Colors on graph correspond to text colors under images

DECREASING MATURITY FROM WEST TO EAST REPRESENTED BY COLOR CHANGE AND INCREASE IN TOC & ILLITE/SMECTITE CONTENT

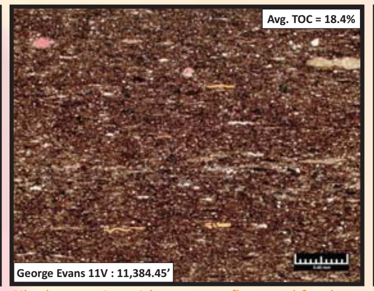
West — East



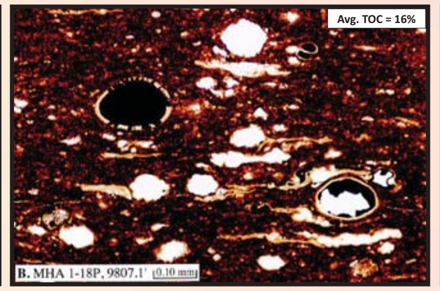
Silty kerogenite with randomly distributed silt grains and flattened fecal pellets. *Tasmanites* not present due to thermal cooking.



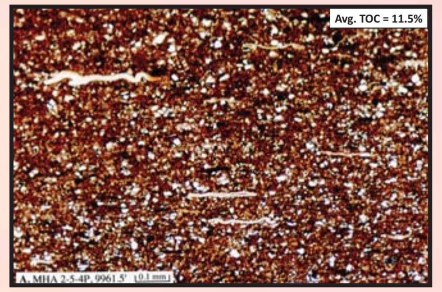
Silty kerogenite with common flattened fecal pellets and randomly distributed silt grains. Grains of dark green possible glauconite are also present. *Tasmanites* not present.



Silty kerogenite with common flattened fecal pellets, *Tasmanites,* and calcitic fossil fragments. As is typical in the Lower Bakken, silt grains are randomly distributed.

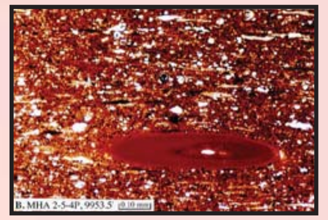


Sample contains common *Tasmanites* and radiolarians. Very early cementation by pyrite filled many of the *Tasmanites* before sediment compaction.



Sample contains common flattened *Tasmanites* and wind-blown quartz and dolomite silt.

BITUMEN?



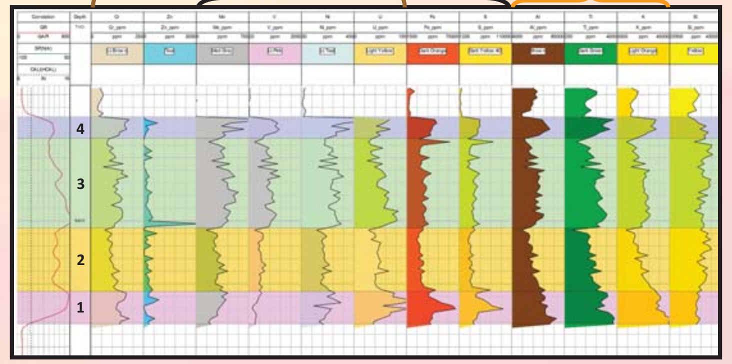
Evidence of possible bitumen in eastern-most cores. This is not present in the western, more thermally mature cores.

LOWER BAKKEN ANALYTICAL DATA FROM FIVE CORES ALONG THE WEST TO EAST TRANSECT

West → East

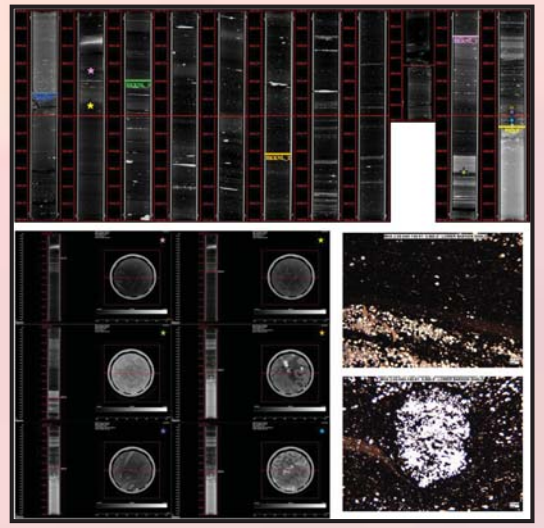
	Well Name:	Bernice 150-99-20-17-2H	Linseth 13-12HW	George Evans 11V	MHA 1-18H-150-90	MHA 2-05-04H-148-91
	Lower Bakken					
	Top Core Depth	11148'	10996.3'	11365.3'	9781'	9937.1'
	Quartz	38%	39.0%	40.5%	44%	34%
	K-Spar	11%	7.3%	7.8%	5%	11%
	Plagioclase	1%	4.0%	5.2%	6%	8%
	Calcite	4%	1.3%	1.6%	0%	6%
	Dolomite	9%, Fe-Dol: 2	6.7%	4.8%	2%	9%
	Pyrite	7%	8.3%	9.2%	6%	3%
CLAYS	Illite/Smectite	5%	2.3%	4.0%	10%	n.a.
	Illite/Mica	24%	28.7%	26.0%	25%	n.a.
	Kaolinite	0%	tr	tr	1%	n.a.
	Chlorite	3%	2.0%	tr	0%	n.a.
	TOC	11.0%	10.9%	18.4%	16.0%	11.5%
	T Max	454	453	437	428	434
	HI	121	197	443	421	572
	Thickness	10'	22'	38'	33'	32'
	Avg Phi	8.2%	7.5%	6.6%	5.5%	n/a
	Avg Sw	17.1%	n/a	35.3%	23.0%	n/a
	Avg So	31.0%	n/a	55.9%	67.0%	n/a
	Base Core Depth	11157.8'	11018'	11403.75'	9813.6'	9968.7'

HAND-HELD XRF DATA : MHA 1-18H-150-90

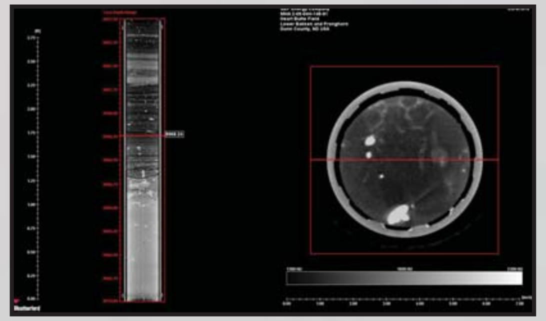


Four units have been identified in the Lower Bakken based on elemental trends and gamma-ray signatures. The term "unit" simply refers to a package of rocks. See correlation of these units across the west to east transect on poster 1.

CT SCANS



CT scan images showing bioturbation in the Lower Bakken. Bioturbated intervals are rare, extremely thin and represent very short periods of dysoxia. Two thin section photo-micrographs also document horizontal burrowing in the lowest part of the Lower Bakken.



CT scan images showing polygonal features, which may be syneresis cracks, are filled with higher density material, possibly calcite.

LOWER BAKKEN KEY POINTS

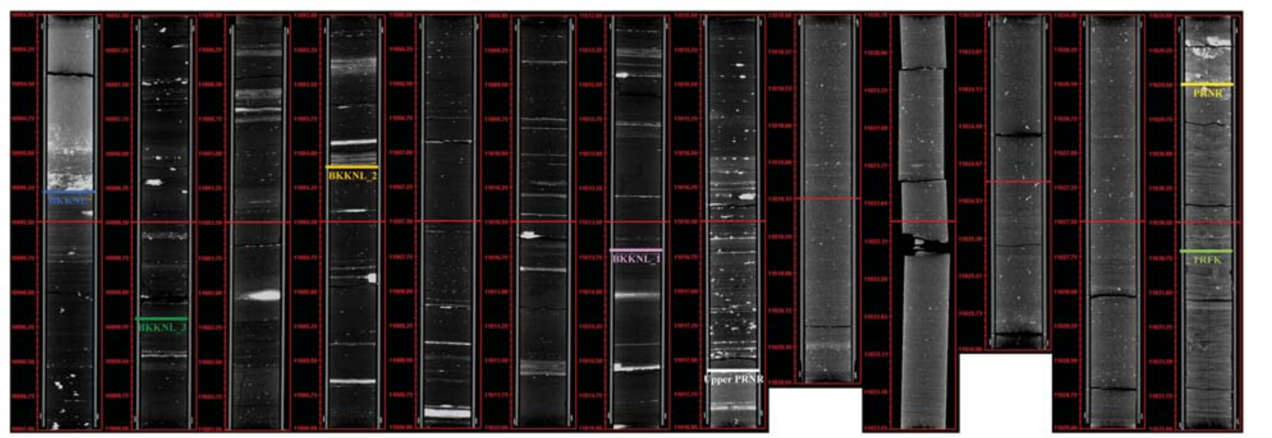
- The Lower Bakken is a black, silty, massive, organic-rich mudrock or kerogenite with relatively low clay content.
- Average values along the west-to-east transect are: TOC 10-17%, Tmax 455-427, thickness 10-33 ft (with variations), porosity 6-9% (highest in most thermally mature area), total clay ~32% throughout.
- The top and base of the lower "shale" are easily picked on gamma-ray and other logs and in core by sharp contacts (<cms), but complicated by local development of underlying upper Pronghorn.
- Deposition occurred below storm wave base under anoxic conditions interrupted by brief periods of dysoxia near the base and top of the interval.
- A wide range of detrital minerals (quartz, K-spar, plagioclase, calcite, illite/mica, illite/smectite, kaolinite, and chlorite) and diagenetic minerals (quartz, calcite, dolomite, pyite, and illite) in the silt-sized fraction.
- Detrital silt laminae are sparse, thin, laterally continuous (except where disrupted by compaction fluids), and deposited from eolian dust-storms rather than bottom traction currents.
- Radiolarians, phosphatic fossil fragments, flattened fecal pellets, and *Tasmanites* are locally common to abundant. Some *Tasmanites* were filled with authigenic minerals (pyrite, calcite, silica) prior to compaction. Tasmanites are "burned out" to the west in areas of higher thermal maturity.
- Redox elements (U, Mo, V, Ni) are abundant as is diagenetic pyrite (FeS2) locally.

Poster 3 of 3: Visual and Analytical Comparisons of Upper Bakken, Lower Bakken, and Upper Pronghorn "Shale" Cores Along a West-to-East Transect, McKenzie and McLean Counties, North Dakota

Laura Mauro Johnson and Grant Sha, Newfield Exploration; Katie Kocman, QEP Resources; Simon Cole and Laura Wray, WPX Energy; and Mark Longman, QEP Resources, Inc.

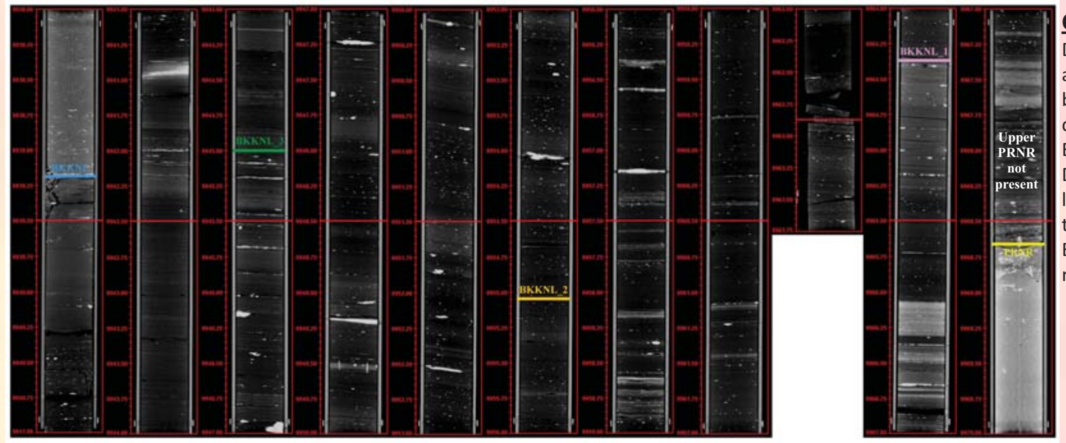
CT Scans of Slabbed Core from 3 Wells in Transect (Linseth, George Evans, MHA 2-05-04H):

Linseth 13-12HW



George Evans 11V

MHA 2-05-04H

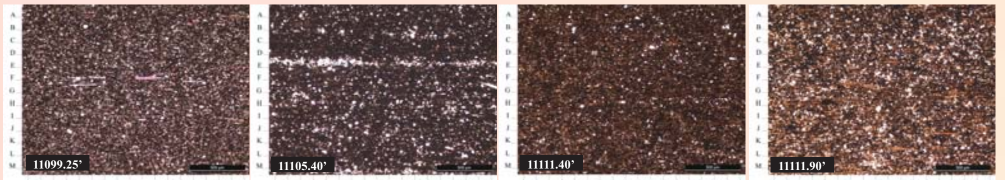


CT Scan Key Points:

Density-based images provide another method to observe bulk composition and textural differences between lower Bakken and upper Pronghorn. Density image laminations likely related to TOC variations. Contact between lower Bakken and upper Pronghorn more apparent.

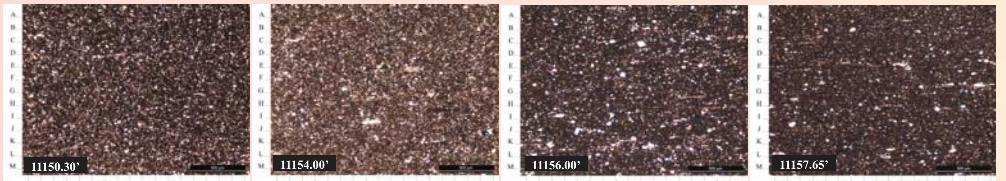
Photomicrographs (Bernice, Linseth, George Evans)

Upper Bakken - Organic-rich silty mudstone



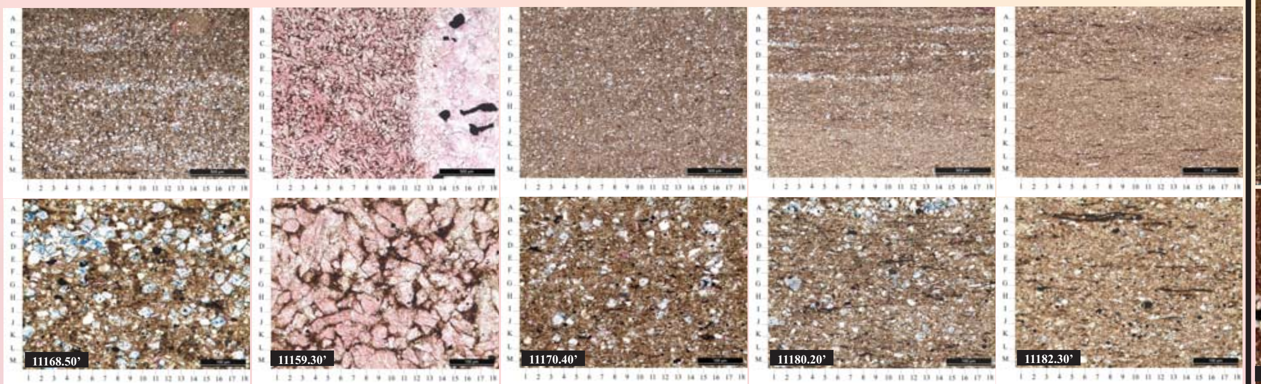
Rare skeletal fragments, randomly distributed quartz and dolomite silt grains, clay and organics (brown and black) | Randomly distributed quartz and dolomite silt grains, rare silt laminae and radiolarians | High organic and clay content, randomly distributed quartz and dolomite silt grains, reddish brown flattened fecal pellets | High organic content, reddish brown flattened fecal pellets, randomly distributed quartz and dolomite silt grains

Lower Bakken - Organic-rich silty mudstone

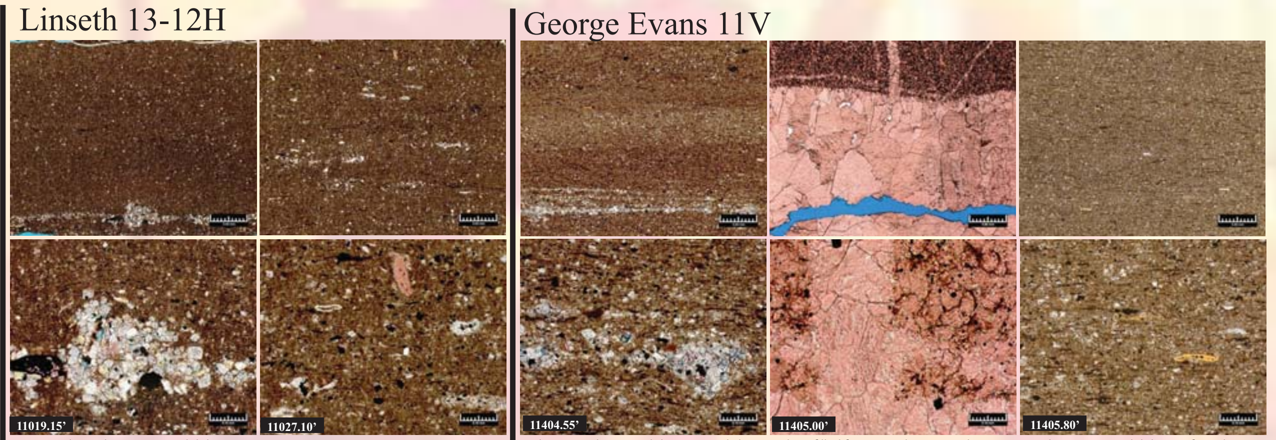


Randomly distributed quartz and dolomite silt grains in clay and organic-rich matrix (brown and black) | Rare skeletal fragments and radiolarians. Flat white grains possibly silicified *Tasmanites*. | High organic content, randomly distributed quartz and dolomite silt grains, reddish brown flattened fecal pellets | High organic and clay content, randomly distributed quartz and dolomite silt grains, reddish brown flattened fecal pellets

Upper Pronghorn – Silty organic mudstone



Dolomite and quartz silt alternating with clay-rich laminae. Scattered calcareous fossil fragments and pyrite | Calcite filled fracture in large pseudospar nodule. Clay matrix between grains. Few remnant calcareous fossil fragments | Randomquartz and dolomite silt grains, calcareous fossil fragments, radiolarians, pyrite and kerogen particles in clay matrix | Dolomite and quartz silt alternating with clay-rich laminae. Flattened black grains may be burned out *Tasmanites*. | Randomly distributed quartz and dolomite silt grains. Flattened black grains filamentous flattened kerogen.

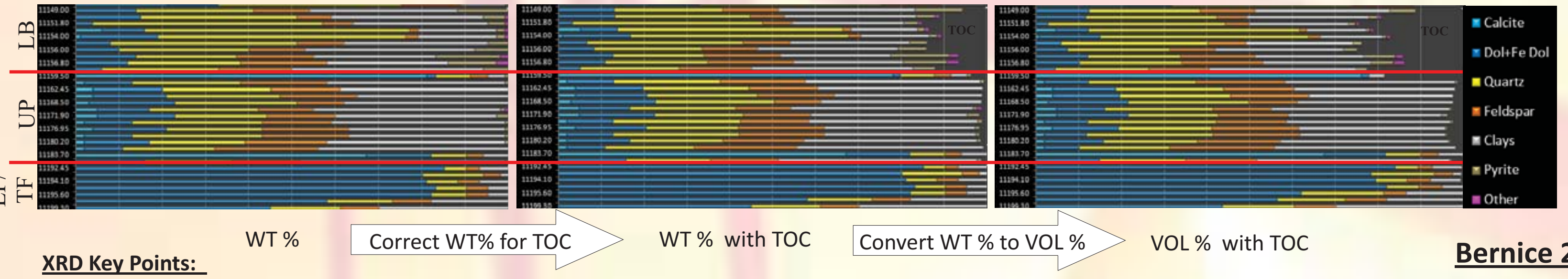


Dominantly random quartz and dolomite silt grains with a single silt laminae. Note mud drape over silt grain cluster | Random quartz and dolomite silt grains, fossil fragments (silicified *tasmanites*), and kerogen particles in clay-rich matrix | Dolomite and quartz silt laminae and clay-rich laminae. Calcareous fossil fragments, flattened kerogen particles and pyrite | Calcite filled fracture in large pseudospar nodule. Clay matrix between grains. Occur within 2 ft of contact with Lower Bakken | Random quartz and dolomite fine silt grains, *tasmanites*, and flattened kerogen particles in clay-rich matrix

Photomicrographs Key Points:

1. Photomicrographs highlight the mineralogical and textural similarities and differences between the upper Bakken, lower Bakken and upper Pronghorn
2. Visually see more silt laminae, calcite fossil fragments, filamentous/flattened kerogen particles as well as lower organic content and randomly distributed quartz in the upper Pronghorn
3. Visually see key similarities randomly distributed silt grains, detrital and biogenic quartz, lack of current transported beds, sparse fossil debris that appears to rafted in rather than transported into the basin
4. Calcite filled fractures within large pseudospar nodules tend to occur within 2 ft of the lower Bakken and upper Pronghorn contact and are documented in two out of the three W-E transect wells with upper Pronghorn
5. Along the W-E transect wells the textural composition and sedimentary structures within the upper Pronghorn are very similar
6. Detailed look at the rock textures in thin section support the interpretation that the upper Pronghorn was deposited in a basinal setting below storm wave base

BERNICE 150-99-17-20-2H XRD Data—Importance of Incorporating TOC and Converting to Volume Percent:



XRD Key Points:

1. XRD data highlights the mineralogical similarities and differences between the lower Bakken and upper Pronghorn in the Bernice 2H where the upper Pronghorn is thickest and most densely sampled along the maturity transect.
2. Weight percent data indicates minor variability in the major mineralogical compositions with slight differences between clay and pyrite content.
3. The correction for TOC and then converting from weight percent to volume percent illustrate more highly variable bulk compositions between the lower Bakken and upper Pronghorn mainly seen in the total clay and organic content

Bernice 2H Geochemistry Data:

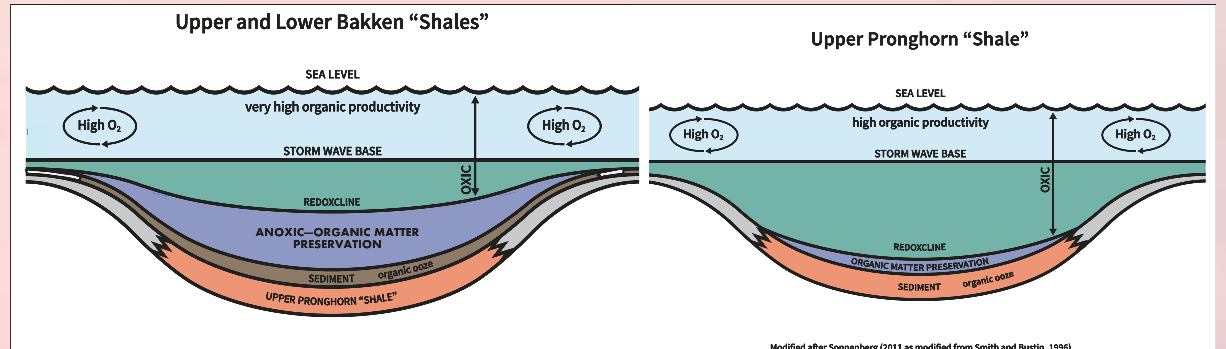
Geochemistry Key Points:

1. Upper plots illustrate the vertical variability of TOC, hydrogen index (HI), and oxygen index (OI) within the upper Bakken, lower Bakken and upper Pronghorn
2. In general, the upper Pronghorn shows lower TOC, lower HI, and higher OI compared to both the upper and lower Bakken. This is likely related to lower organic productivity and more biodegradation in a more oxygenated water column during upper Pronghorn deposition.

Key Poster Points:

1. The upper Pronghorn is classified as a silty organic mudstone
2. To the west the upper Pronghorn has rare thin bioturbated limestone beds near the base of the unit
3. Minor textural differences along the W-E transect. Mineralogical differences include less quartz, feldspar, and clay and more calcite and pyrite to the east in the upper Pronghorn. The unit thins dramatically to the east as well
4. TOC in the upper Pronghorn averages 1-4 wt. %
5. The lower Bakken and upper Pronghorn contact is easily recognizable on e-logs, but visual differences are subtle
6. Key differences between the upper Pronghorn and the lower Bakken include (% based on averages from Bernice):
   - Lower TOC (3% Pronghorn vs 19% lower Bakken), Hydrogen Index (70 vs 121), and Oxygen Index (30 vs 5)
   - More clay (36% vs 25%), feldspar (17% vs 9%), and carbonate (21% vs 9%)
   - Less quartz (23% vs 32%, pyrite 0.4% vs 3%), and apatite (0% vs 1%)
   - Slightly more bioturbation
   - Coarser quartz grains
   - More phosphatic fossil debris including conodonts
   - More common silt laminae
   - Little to no redox sensitive elements (U, Mo, V, Ni, Fe/S)
   - Not as laterally continuous/structurally bound
5. Key similarities between the upper Pronghorn and the lower Bakken include:
   - Randomly distributed silt grains
   - Detrital and biogenic quartz
   - Lack of current transported beds
   - Sparse fossil debris that appears to be rafted versus transported into basin

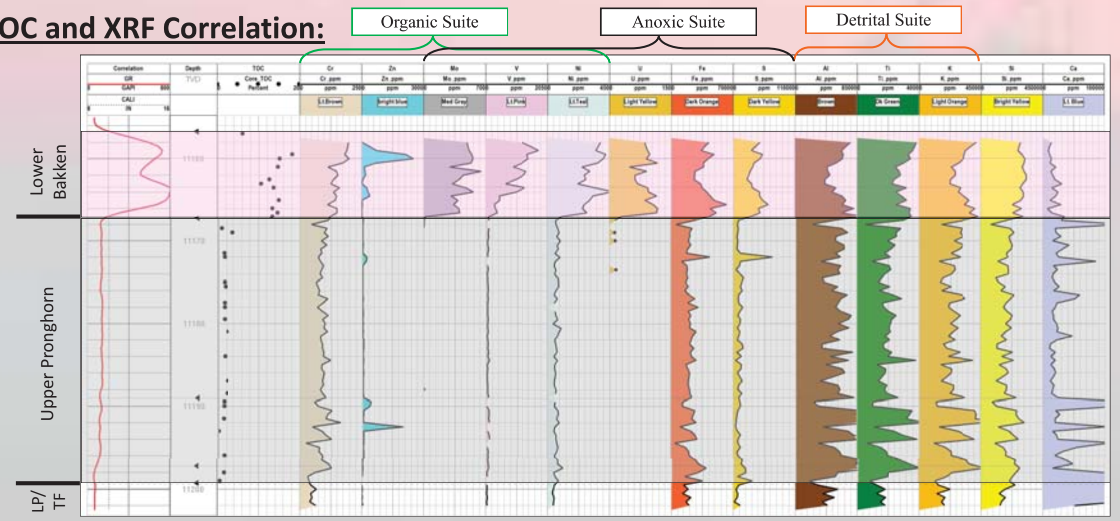
Depositional Models:



Conceptual depositional model for lower and upper Bakken showing thicker anoxic water column and shallower location of redoxcline

Conceptual depositional model for upper Pronghorn thinner anoxic water column and deeper location of redoxcline

Bernice 2H TOC and XRF Correlation:



XRF Key Points:

1. Along the W-E transect overall XRF in the upper Pronghorn has higher K, AL, Ti which is likely related to detrital input.
2. Upper Pronghorn essentially has no Mo, U and very low V, Ni and low S, Fe, Si. This data indicates more organic productivity in the lower Bakken over the upper Pronghorn and a thicker oxygenated water column during upper Pronghorn versus lower Bakken deposition. Increased Zn and other organic material associated elements (Cr, Ni, V, Mo) increase in the lower Bakken shale and often relate to higher organic productivity.
3. A more oxygenated water column during upper Pronghorn deposition is supported by the geochemistry data. The hydrogen index in the upper Pronghorn is lower than the lower Bakken and the oxygen index is higher. The larger oxic section likely affected the preservation and quality of the organic matter and therefore hydrogen richness which is directly related to redox conditions of the preservation environment. Reworking and removing of organic matter under oxic conditions preferentially removes hydrogen thus increasing oxygen in kerogen.
4. More phosphatic fossil debris, including conodonts, was observed by Mark Longman in the upper Pronghorn than the lower Bakken shale which also supports a more oxygenated water column during deposition.

Discussion:

1. The upper Pronghorn was deposited in a basinal setting below storm wave base.
2. The oxic water column during upper Pronghorn deposition was thicker compared to upper and lower Bakken deposition directly affecting organic matter accumulation and preservation
3. As the transgression continued into lower Bakken deposition, the rate of organic input increased and the redoxcline moved shallower which increased the anoxic water column and allowed for more organic matter accumulation and preservation as documented by the higher TOC and enrichment of certain redox sensitive elements (Mo, U, V, Zn, Ni, and S)
4. Lower TOC and hydrogen index and higher oxygen index in the upper Pronghorn supports a thicker oxic water column where increased oxidation and biodegradation of organic matter affected organic matter preservation and quality
5. Vertical variability of geochemical parameters is likely due to redox conditions, clastic input, and organic carbon flux during deposition
6. Although the upper Pronghorn is not as organic-rich as the upper and lower Bakken, it is a source rock and its presence is an important part of the Bakken petroleum system

Acknowledgements:

1. Newfield, QEP, and WPX for permission to collaborate, use data, and displays to present this poster
2. Mark Brooks and Janet Huchteman, WPX Energy, for plots and graphics
3. Core Lab and Geosystems for the FIB-SEM photos and thin-section photomicrographs
4. Jaime Kostelnik, Petrologist with Weatherford Labs in Golden, for photomicrograph and SEM descriptions

References:

Caplan and Bustin, 1996.
Sonnenberg
Smith and Bustin
GRANT WILL FILL THIS OUT…