X-Ray Fluorescence and Rock Hardness Relationships within the Devonian-Mississippian Bakken and Three Forks Formations, Williston Basin, North Dakota*

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Abstract

Detailed investigation of the chemical nature and the hardness of the Devonian-Mississippian Bakken Formation as well as the underlying Devonian Three Forks Formation, Williston Basin of North Dakota, were undertaken to both evaluate the relationships of these rock properties within a stratigraphic and paleontological framework and to assess their utility in correlating intervals within these formations across a broad areal extent. Hand-held X-ray fluorescence (XRF) data and rock hardness analyses were acquired on the same intervals at a high density (generally every 3”) throughout the entire Bakken and into the Three Forks in two widely spaced wells (~30 miles apart) and these data were augmented with XRF data from a third well (~40 miles away). Chemofacies established from the XRF data were primarily defined using calcium, silicon, and aluminum and secondarily by other major elements as well as the trace metals iron and molybdenum. A strong, negative relationship exists between rock hardness results and intervals enriched in aluminum and potassium (associated with clay minerals), resulting in particular hardness zones and chemofacies co-occurring at the same stratigraphic intervals. These intervals also appear to co-occur with distinct lithofacies and biofacies that facilitate the subdivision of the Bakken Formation and the upper Three Forks into at least 9 zones that can be correlated across this transect in the Williston Basin. Of the 9 zones, a total of 7 are apparent in the Bakken, with 2 each in the upper and lower shale members, and 3 in the middle member. The remaining 2 zones were identified in the upper part of the Three Forks. Some facies show minor or significant lateral variations in chemical, faunal, hardness, or sedimentological character whereas others appear continuous across the studied transect. The 9

stratigraphic intervals can be confidently distinguished in the Bakken and the Three Forks by combining different facies/chemofacies characteristics. Because many of these facies also have identifiable well log signatures, the integration of facies evaluations from Bakken/Three Forks cores with XRF and rock hardness data may improve interpretations of log data from locations where core is not readily available, especially as it pertains to predicting rock properties.

Reference Cited

Smith, M.G., and R.M. Bustin, 2000, Late Devonian and Early Mississippian Bakken and Exshaw Black Shale Source Rocks, Western Canada Sedimentary Basin: A Sequence Stratigraphic Interpretation: AAPG Bulletin, v. 84/7, p. 940-960.

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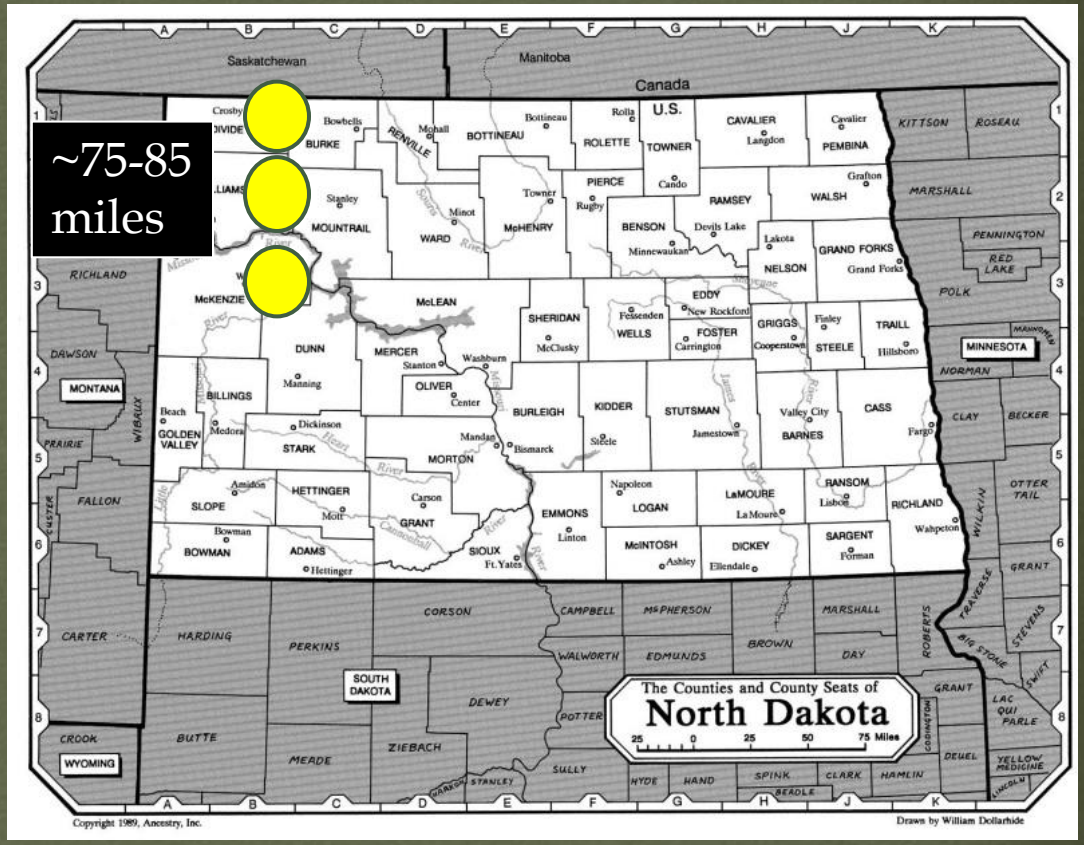
Presentation Outline

- Present XRF results from lowermost Lodgepole, through Bakken and into upper Three Forks
- Present rock hardness (Leeb's) measurements through same interval
- Outline the sedimentological and paleontological framework of the Bakken.
- Integrate data to define stratigraphic horizons based on
  - Lithology
  - Chemostrat
  - Paleontology
  - Rock Hardness

Geologic Setting

3 cored intervals.

Lowermost Lodgepole to the upper Three Forks



Map from Smith and Bustin, 2000

Sampling Procedure

Lowermost Lodgepole to the upper Three Forks

0.3 feet (~3.5 inches) for XRF & hardness

Core	XRF	Leeb's hardness
North	2 inch 1 inch for shales	No data
Middle	0.3 feet	0.3 feet
South	0.3 feet	0.3 feet

XRF Procedure

Settings	Major element instrument	Trace element instrument
kV	15	40
µA	40	13.9
vacuum	yes	no

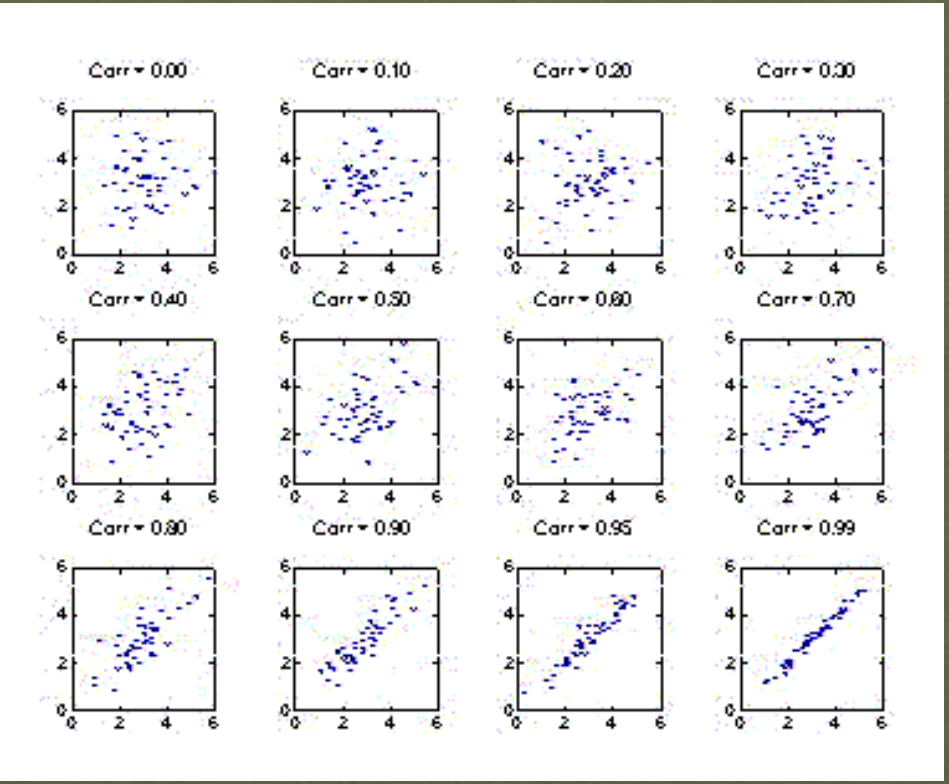
Leeb's Hardness

5 tests per XRF sample

XRF and hardness

Created correlation matrices in excel.

Looking for linear relationships between particular elements and Leeb's hardness.



XRF and hardness

Mean Leeb's hardness and weight % (major elements), ppm (trace elements)

Whole core (middle core) analysis

Al	K	Th	Rb	Ti	Ca	Mn	Ni	Si	Fe
-0.70	-0.70	-0.75	-0.65	-0.62	0.56	0.53	0.54	-0.45	-0.44

PROBLEM: lots of clumping going on here.

XRF and hardness

Upper Bakken

Al	K	Th	Rb	Ti	Ca	Mn	Ni	Si	Fe
-0.80	-0.82	-0.88	-0.87	-0.82	-0.29	0.51	0.54	0.57	-0.19

Middle Bakken

Al	K	Th	Rb	Ti	Ca	Mn	Ni	Si	Fe
-0.51	-0.54	-0.57	-0.53	-0.41	0.44	0.33	-0.47	-0.34	-0.44

Lower Bakken

Al	K	Th	Rb	Ti	Ca	Mn	Ni	Si	Fe
-0.68	-0.68	-0.75	-0.44	-0.72	0.19	0.35	-0.33	0.14	0

Three Forks

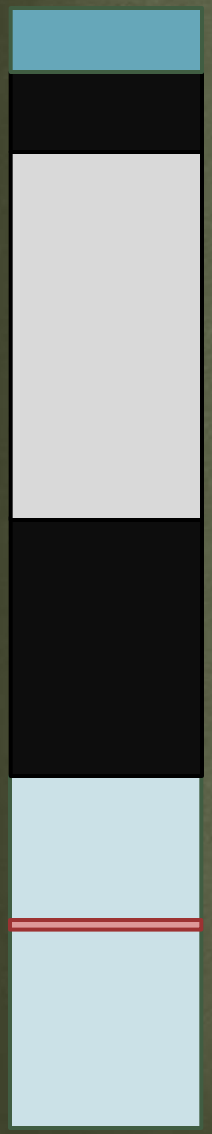
Al	K	Th	Rb	Ti	Ca	Mn	Ni	Si	Fe
-0.63	-0.61	-0.59	-0.57	-0.61	0.49	0.48	-0.37	-0.40	-0.52

XRF and hardness

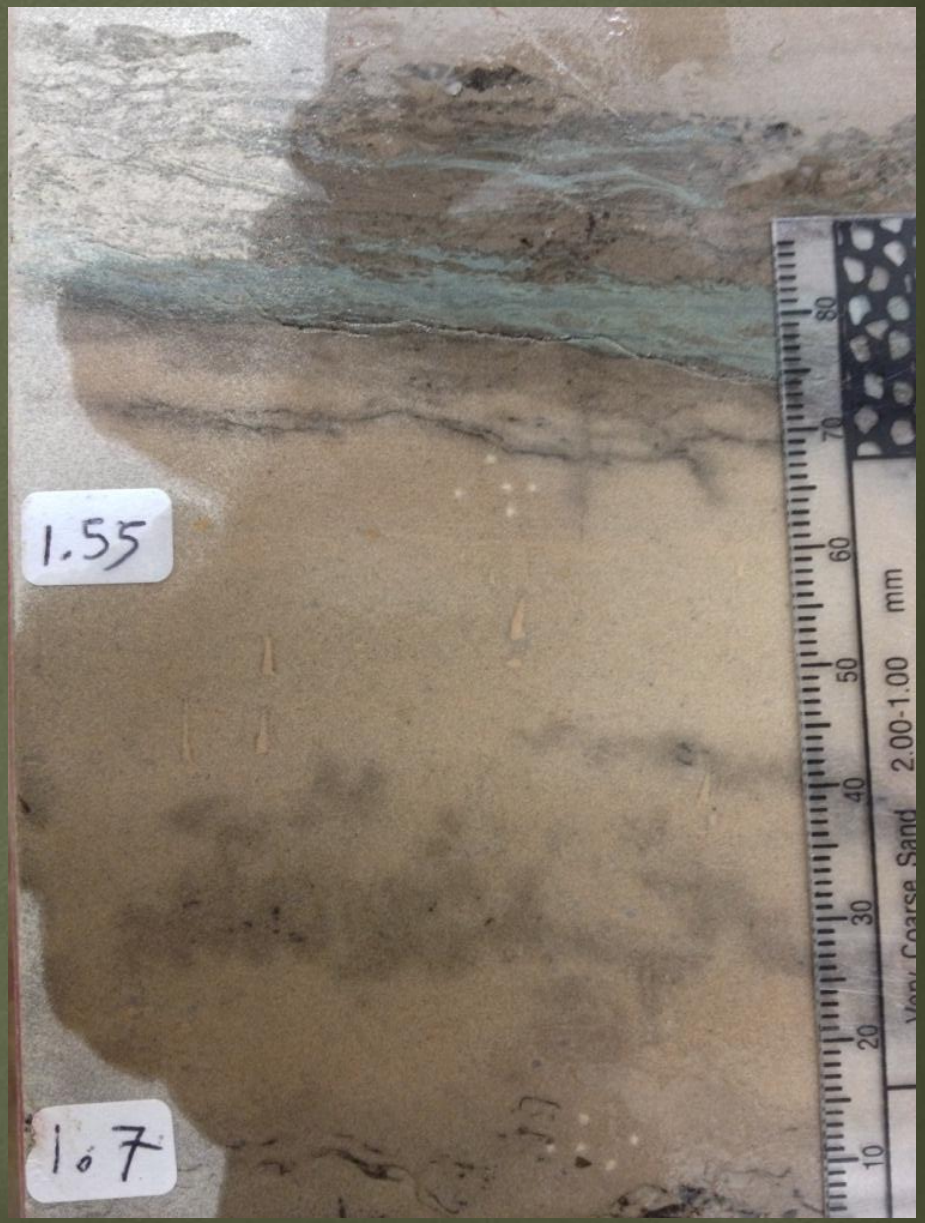
Lower Bakken		Upper Bakken		Middle Bakken	
K:Ti	0.90	K:Ti	0.95	K:Ti	0.96
K:Al	0.93	K:Al	0.94	K:Al	0.97
Pb:Ga	-0.14	Pb:Ga	-0.96	Ca:Al	-0.85
Pb:As	-0.11	Pb:As	0.99	Ca:Si	-0.85
Pb:Co	-0.84	Pb:Co	-0.99	Ca:K	-0.89
				Ca:Ti	-0.84
Ni:Mo	0.86	Ni:Mo	0.74		
				Si:Zr	0.78
Ca:Y	0.15	Ca:Y	0.82	Si:Al	0.84
				Si:K	0.83
Si:Zr	-0.75	Si:Zr	-0.30	Si:Ti	0.78

Stratigraphy

Middle

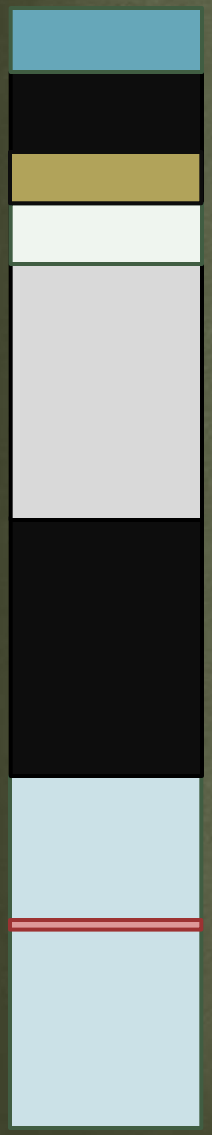


Well sorted, fine sand-silt
"Skolithos"



Stratigraphy

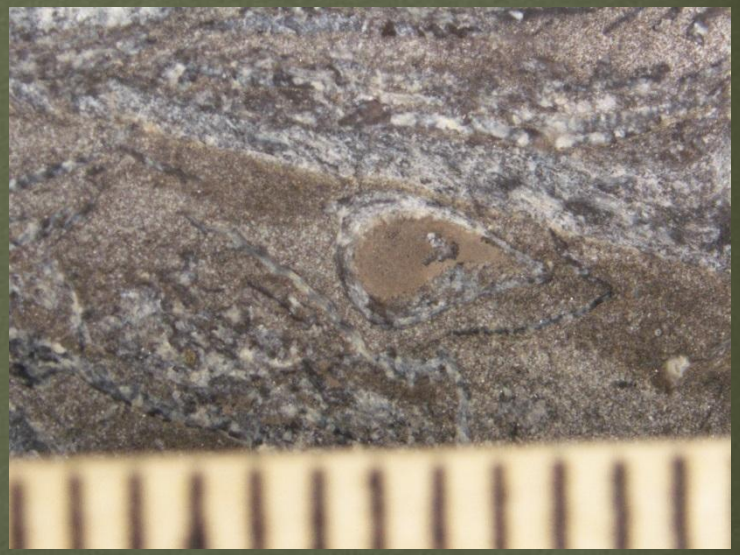
Middle



Variable dipping beds of interbedded fine sands, silts and clays.
Brachiopods near the top

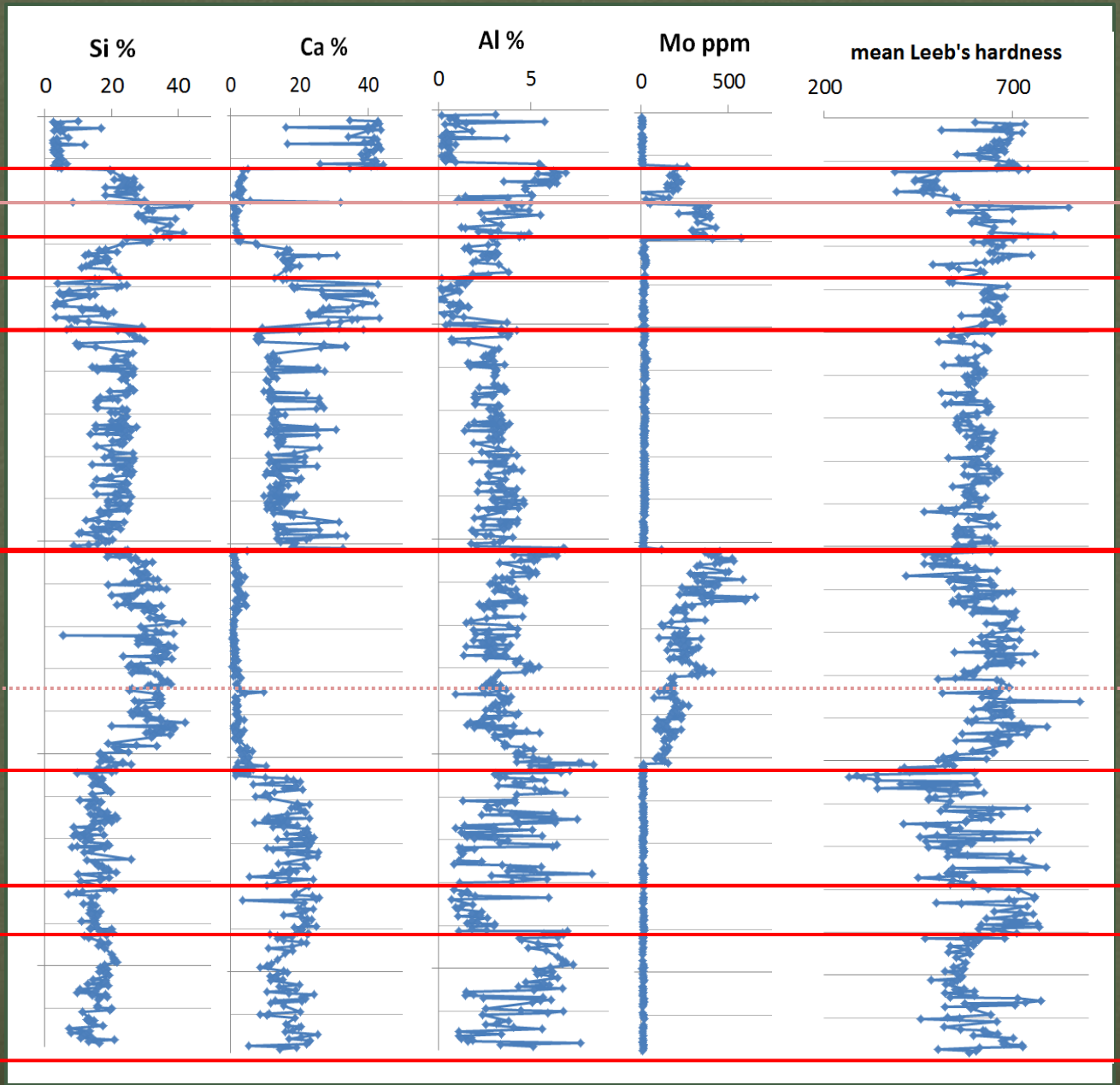
Massive medium-coarse calcareous sands

Horizontal, crenulated silts and muds.
Horizontal grazing traces
Helminthopsis, Cosmorhaphe



Stratigraphy

Middle



L.P.

U.B.

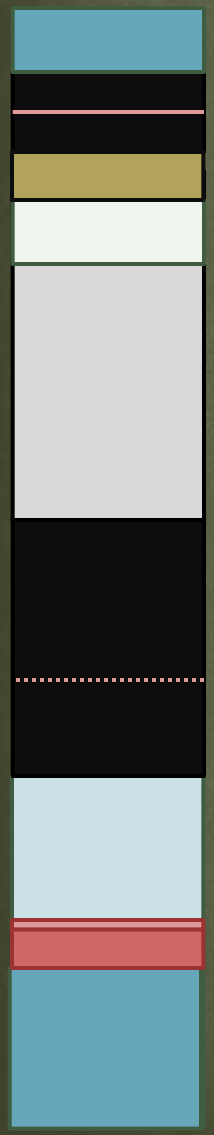
M.B.

L.B.

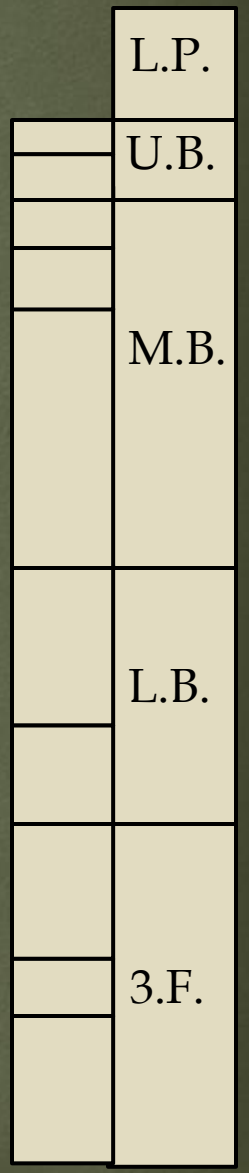
3.F.

Stratigraphy

Middle



Are these “facies”/stratigraphic intervals correlatable?



South

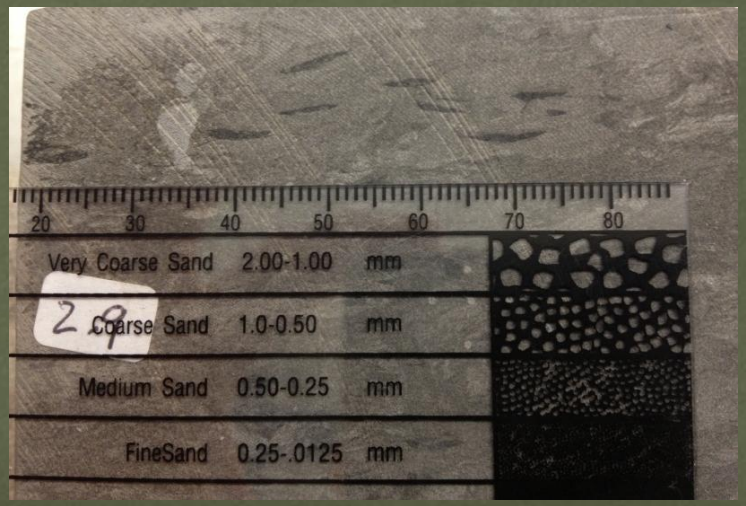
Middle Bakken

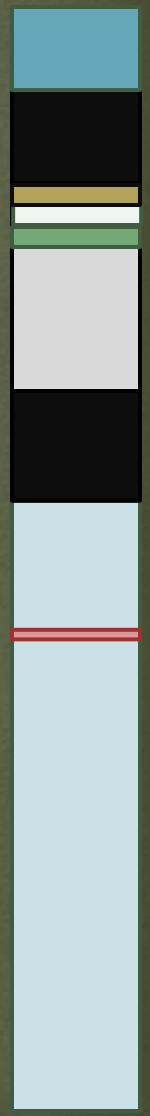
- Silt clay interbeds
- Coarse carbonate sand
- Crenulated lams, fine-grained, irregularly shaped calcareous "patches"

- Bioturbated
  - *Helminthopsis, Cosmorhaphe*
  - Brachiopods
  - Pyritized cephalopods

Three Forks

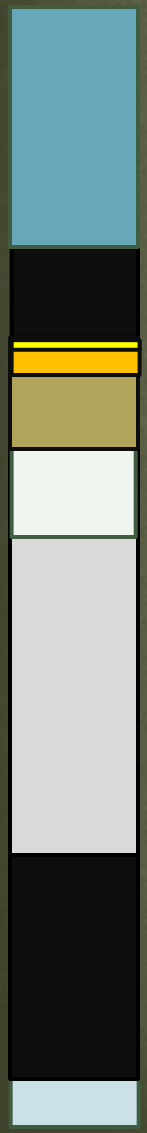
  - *"Skolithos"* marker bed





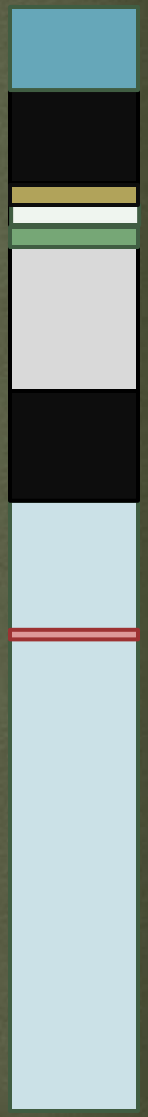
North

South



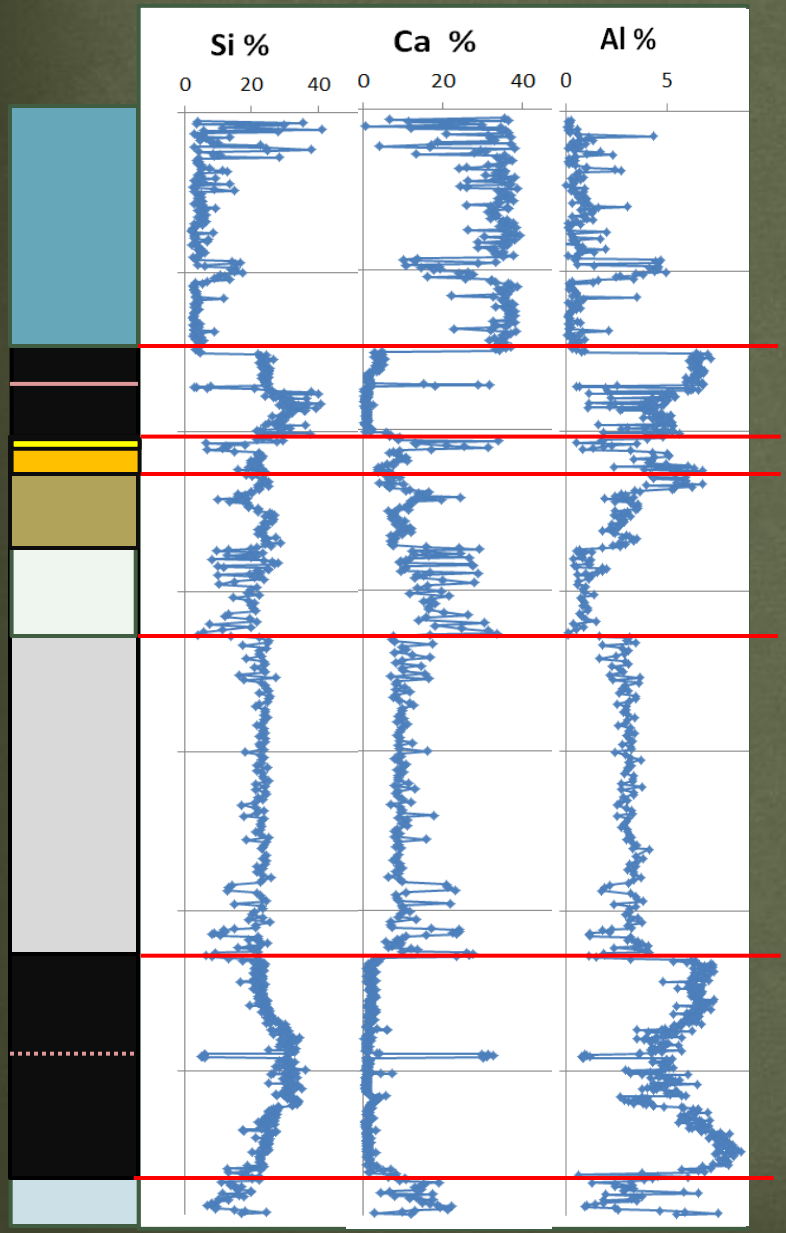
Middle Bakken

- Brachiopod rich (lags?)
- *Planolites* deposit traces
- Silt clay interbeds
- Coarse carbonate sand
- Bioturbated
  - *Helminthopsis, Cosmorhaphe*
  - Brachiopods

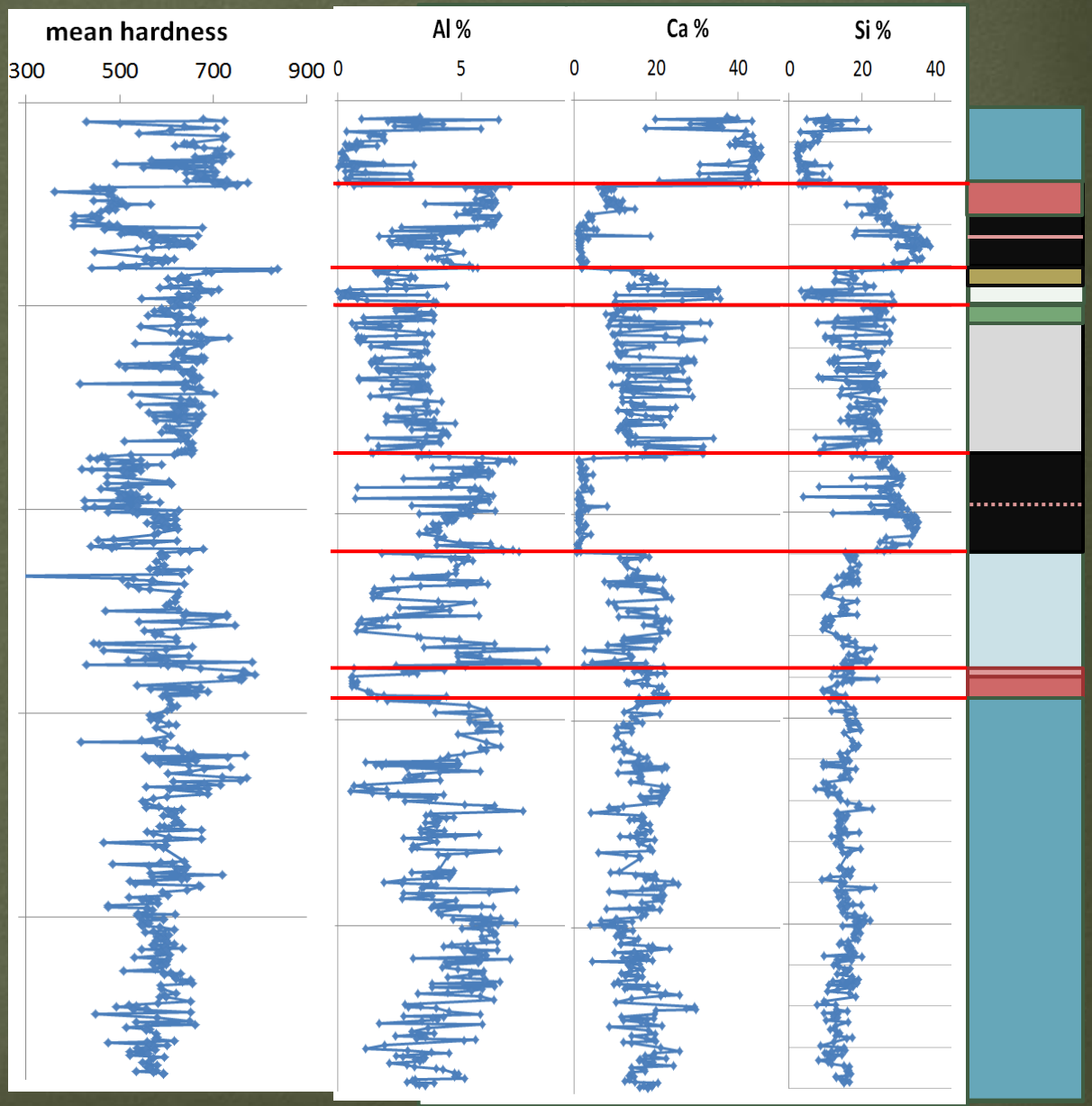


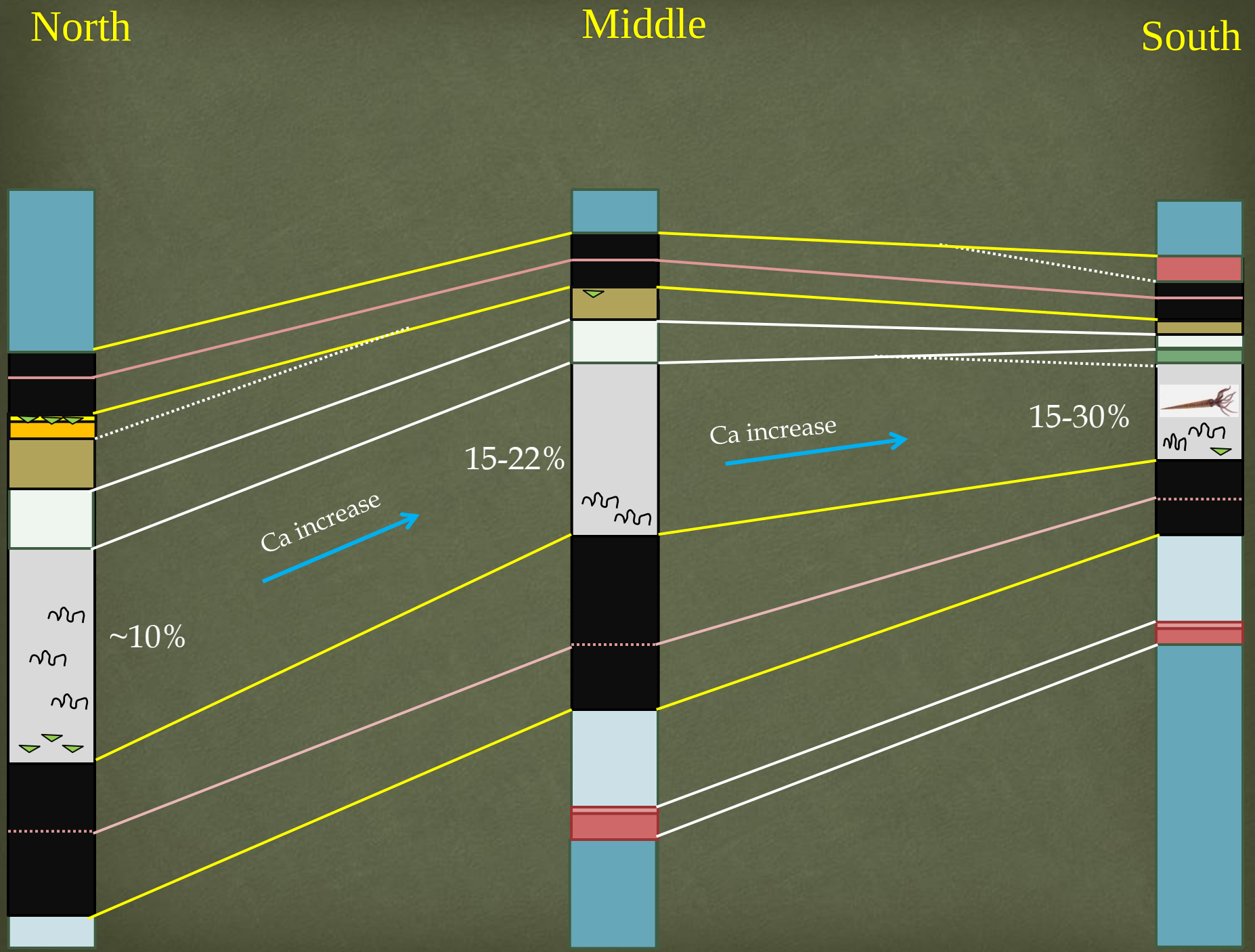
North

South



South




North
Middle
South
~10%
15-22%
15-30%
Ca increase
Ca increase

Conclusions

There are correlatable stratigraphic intervals within the Bakken and upper Three Forks Formations!

-Chemostratigraphic signature (XRF).

-Leeb's hardness values.

-Sedimentary structures and lithology.

-invertebrate faunas and trace fossil assemblages.

Leeb's hardness values are most correlated with aluminum and potassium. It is a negative correlation.

Thank you!

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Thanks for your attention!