[PS]Quantitative Mineralogy and Microfractures in the Middle Bakken Formation, Williston Basin, North Dakota*

Stephen A. Sonnenberg[1], Sarah K. Appleby[2], and J. Rick Sarg[1]

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Abstract

Fractures are considered to play a key role in controlling Bakken petroleum production in the North Dakota part of the Williston Basin. Generally, wells are oriented to intersect the maximum number of fracture swarms, and fracture stimulation is employed resulting in initial producing rates of several hundred to over one thousand barrels per day in some fields.

This study utilizes a new approach to assess the impact of microfractures on fluid flow by integrating mineralogy and fracture analysis using SEM-based quantitative mineralogy on several drill core samples from North Dakota. Due to the high spatial resolution of the analysis (~2 μm) even very small fractures can be detected using this technique. In addition to fracture abundance quantification, fracture size, orientation and mineral associations can also be investigated.

Quantitative mineralogy shows that samples of the Middle Bakken Formation consist of silt-to sand-sized grains of quartz, feldspar (plagioclase and K-feldspar), dolomite and limestone with minor amounts of clays indicative of a marine depositional environment with water depths ranging from shallow (within wave base and tidal influence) to deep neritic. Texturally the samples may be massive, display cross stratified or subparallel bedding and laminated zones.

Preliminary results of quantitative mineralogy microfracture analysis show that microfractures generally are oriented parallel to bedding (i.e., horizontal microfractures), hence along natural planes of weakness. Fracture widths range from 2 μm to 25 μm, and fracture lengths from 6 μm to several 10s of microns. In the studied samples the vast majority (~95%) of horizontal fractures appear to occur within clay-rich horizons. Some areas in the Williston Basin, such as the Parshall Field, are known to contain additional fracture swarms that are

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oriented in a northeastern direction perpendicular to bedding resulting in a well fractured petroleum system. However, at least on a microfracture-scale, similar vertical fractures were not identified in the samples presented here.

This study demonstrates that the analysis of microfractures by quantitative mineralogy, in particular in conjunction with other macro- and mesofracture analyses, has the potential to be a powerful tool in well design and may provide new insights into fracturing behavior and fluid flow in petroleum reservoirs.

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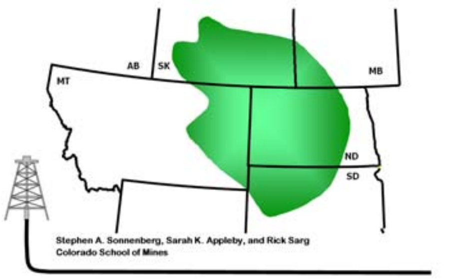
Quantitative Mineralogy and Microfractures in the Middle Bakken Formation, Williston Basin, North Dakota



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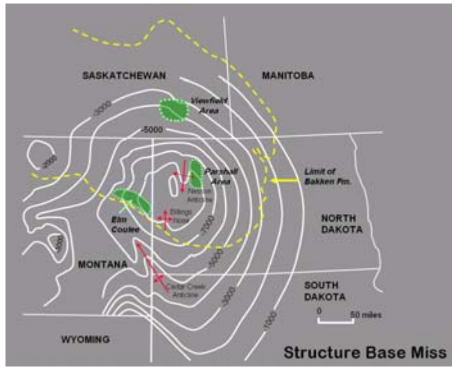
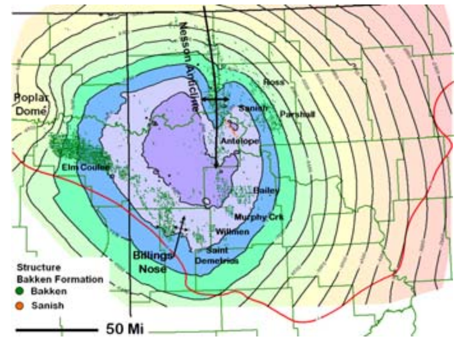
Colorado School of Mines





Upper and Lower Bakken

- Presence of planktonic algal spores (tasmanites), fish remains, cephalopods, ostracodes, conodonts, and inarticulate brachiopods indicates marine environment
- Shale: hard, siliceous, pyritic, fissile, organic rich (average 11.3 wt % organic carbon)
- Upper and lower shales identical in lithology
- High OM indicates anoxic conditions (amorphous-sapropelic OM: probably algal or phytoplankton origin)

Webster, 1984

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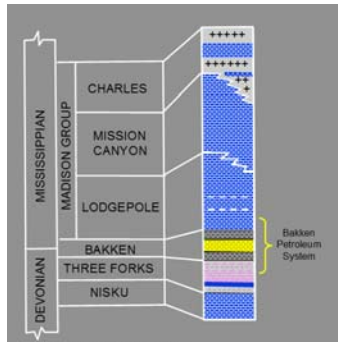
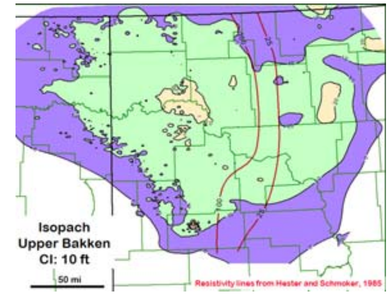


Modified from Webster, 1984

Bakken Formation Basics

- Upper & lower black shales
  - 'World Class' Source Rocks
    - Hard, siliceous, pyritic, fissile, organic rich
    - TOC's as high as 40 wt% (average 11%)
    - High OM indicates anoxic conditions (amorphous-sapropelic OM; probably algal or phytoplankton origin)
    - HC Generation: 10 to 400 B bbl oil
- Middle member (target of horizontal drilling)
  - Dolomitic siltstone to a silty dolomite
  - Low porosity and permeability
- Abnormal pressure and hydrocarbon generation (> 0.5 psi/ft)

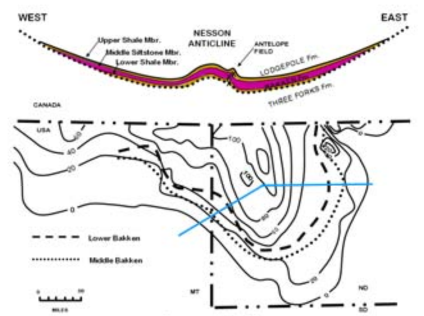
Modified from LeFever, 2005



Colorado School of Mines
Bakken Consortium

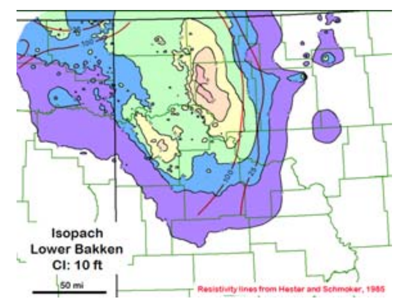
Late Devonian-Early Mississippian black shales (360 Ma)

Blakey, 2007, <http://jan.ucc.nau.edu/~rcb7/namD360.jpg>



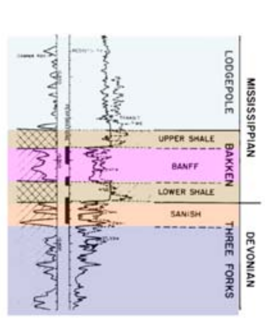
Isopach Bakken

Meissner, 1978 after Sandberg, 1962



Unconventional, Continuous Tight Oil Accumulations

- Pervasive petroleum saturation
- Mature source rocks
- Abnormally pressured
- Generally lacks down-dip water
- Up-dip water saturation
- Low porosity and permeability reservoirs
- Enhanced by fracturing and partings



Smith No. 1-A Weedeman
Sec. 29-153N-94W

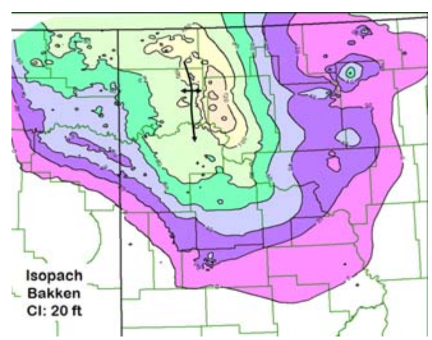
Typical Productive Section

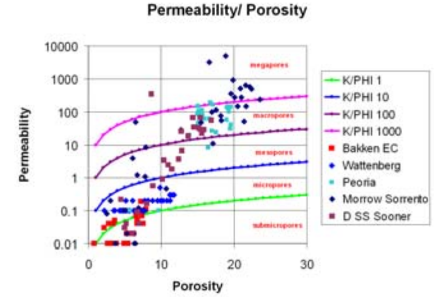
Antelope Field

Banff-
"dolomite, dolomitic siltstone, and minor quantities of shale"

Sanish-
"very dolomitic sandstone"

Murray, 1968

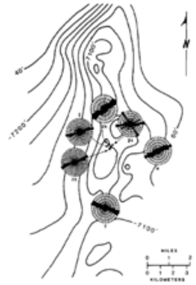




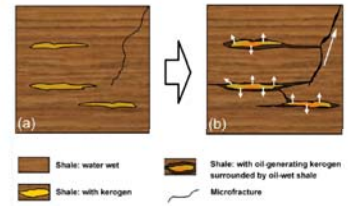
Bakken has low porosity and permeability. Micropores and submicropores are suggested by the plot. Natural fractures are thought to enhance reservoir properties.

Bakken Fractures Working Hypothesis

Vertical fractures, bedding plane partings, and reticulated fractures all play a roll



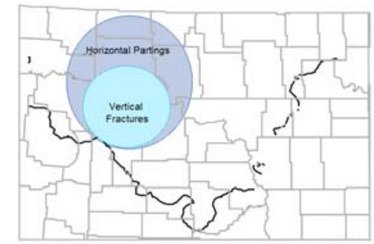
Azimuth of fractures in oriented cores from Mission Canyon Formation in Little Knife Field area (from Narr and Burruss, 1984).



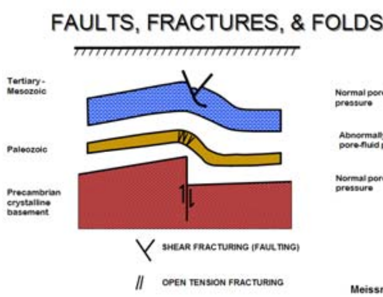
Microfracture-induced hydrocarbon-phase migration during oil generation.
A. Initial stage prior to oil generation, source rock is water-wet.
B. Oil generation has occurred, oil-wet pore network around kerogen.

oil generation → expansion → pressure buildup → microfracturing → hydrocarbon expulsion → pressure release → ....

Bend, 2007

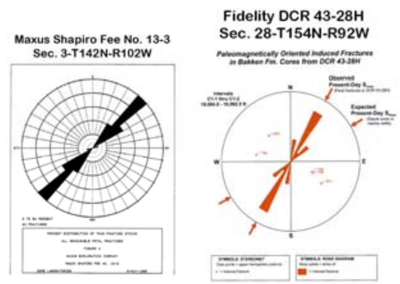


Areas of Fractures in Bakken Formation (modified from LeFever)

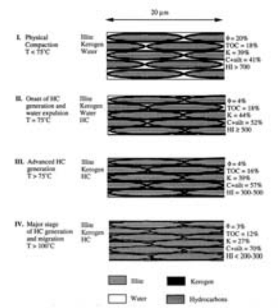


Meissner, 1978

Concept of radius of curvature of a fold and resulting fractures (modified from Murray, 1968 and Meissner, 1978)

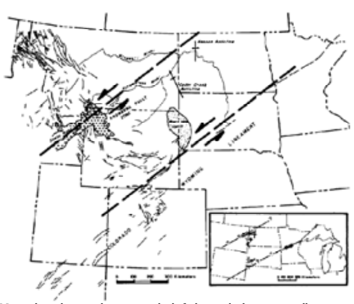


Orientation of petal, induced fractures illustrating Sh maximum direction is northeast.

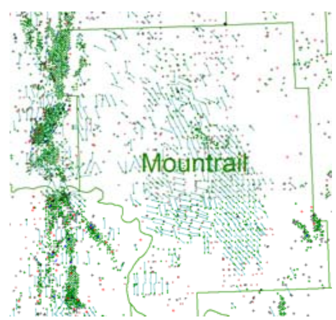


Stages of maturation of kerogen-rich black shales and respective changes in their composition, porosity structure and fluid saturation (Vernik, 1994)

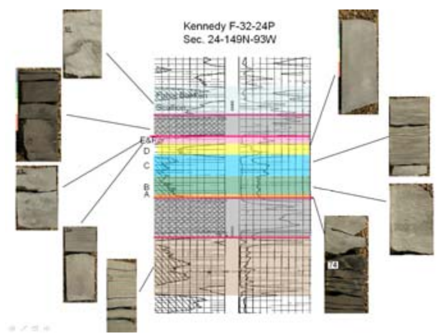
Slabbed sandstone displaying reticulated fracture network on wet surface. Permeable nature and distribution of fractures not apparent when surface dry (Pitman et al., 2001).



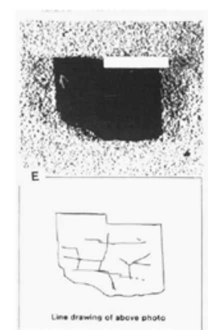
Map showing major tectonic left-lateral shear sets (late Proterozoic) that formed the Central Rocky Mountain province and Williston Basin Block (Gerhard et al., 1990)



Parshall Field, located in Mountrail County, ND. Most horizontal wells drilled in a northwest to west-northwest direction.



Facies found in Bakken and Three Forks formations (facies modified from LeFever, 1991; Canter and Sonnenfeld, 2009).



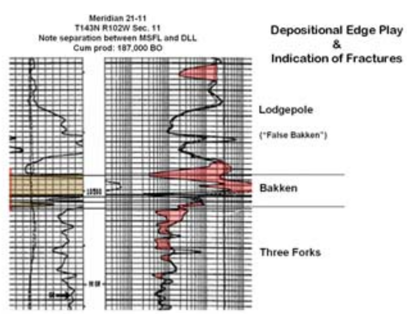
Bakken Microfractures

"microfractures occur in all Bakken units"

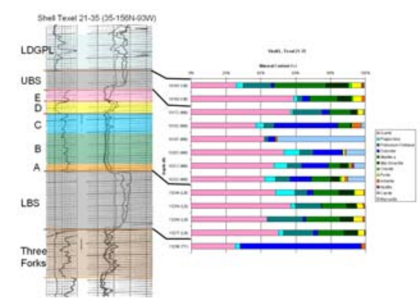
Carlisle et al., 1992

Bakken Fractures

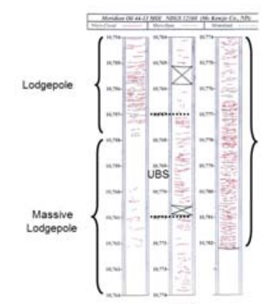
- Tectonic\structural
- Regional Fractures (NE)
- Local structures
- Hydrocarbon generation
- Prairie salt dissolution



Permeability (fracture or matrix or both) indicated on resistivity logs (drilled with salt mud) because of separation of shallow and depth investigation curves

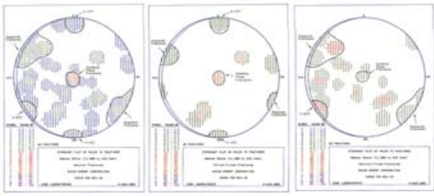


Heterogeneous lithologies in shales and Middle Bakken, horizontal bedding and laminations: planes of weakness.

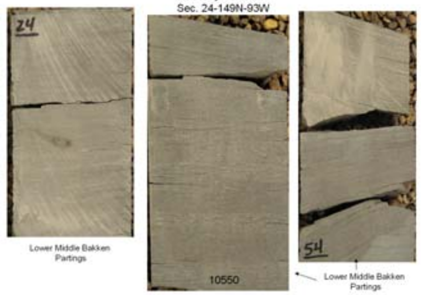


Price, 2000, unpublished

Carus Fee 21
Bakken Shale
Fracture Analysis
Sec. 19-147N-96W

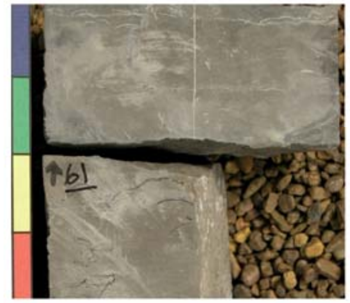


Kennedy F-32-24P
Sec. 24-149N-93W

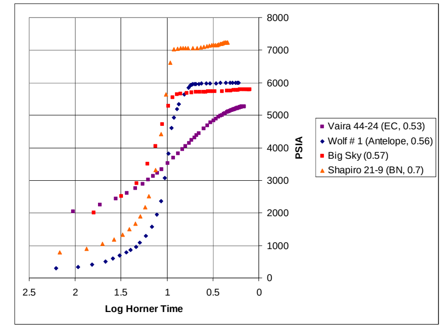


Lower Middle Bakken Partings

Lower Middle Bakken Partings



Peck # 2
27-150N-96W
Middle Bakken
10761



Bakken Fractured reservoirs have unique pressure build-up curves.

Carus Fee
Upper Bakken Shale
11293
NDIC

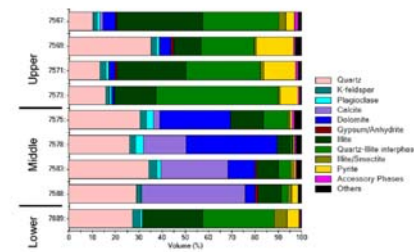
Shell Young Bear 32-4
4-148N-92W
Middle Bakken
10449

"Fluid-release fractures"

Kennedy F-32-24P
Sec. 24-149N-93W

Three Forks
Partings

QEMSCAN ANALYSIS
Waswick # 1
Sec. 2-T153N-R85W



Heterogeneous lithologies in shales and Middle Bakken, horizontal bedding and laminations: planes of weakness.

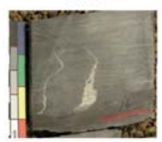
Kennedy F-32-24P
Sec. 24-149N-93W

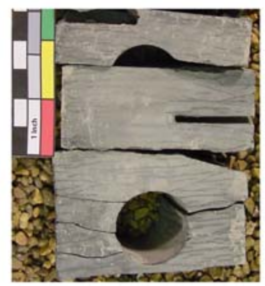
Upper Shale Fractures and Partings

Lower Shale Fractures and Partings

Carus Fee
Sec. 19-T147N-R96W
Middle Bakken
11319

Peck # 2
Sec. 27-T150N-R96W
Middle Bakken
10776





FEDERAL #11-4
SEC 11 T144 N R102 W

10751
Lodgepole

Microfractures in Upper Bakken Shale
From QEMSCAN backscatter image
Waswick 7573

Microfractures filled with gypsum

Backscatter QEMSCAN image of porosity/OM (red)and minerals (gray).

Thompson 5-1
Sec. 5-143N-99W

BWAB Ahel State #36-44H2
SE SE Section 36, T145N, R102W
Horizontal Core cut in 1989

From Sunburst Well Report:
"Horizontal fractures along bedding planes were observed with an abundance of bleeding gas"

Cum Oil 173,455 BO
Cum Gas: 469016 MCF

Summary

- Fractures and partings are common in Bakken
- Vertical and reticulated fractures and bedding-plane partings enhance low reservoir quality
- Bedding-plane partings are inherent weaknesses in rock arising from thin bedding (laminations), fissility and/or lithologic contacts
- Partings may be a consequence of oil generation and overpressuring in the Bakken