PS Petroleum Geology of the Giant Elm Coulee Field, Williston Basin*

Stephen A. Sonnenberg[1]

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*Adapted from poster presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-15, 2010. Please refer to companion articles, "Quantitative Mineralogy and Microfractures in the Middle Bakken Formation, Williston Basin, North Dakota," Search and Discovery Article #40628 (2010), and "Abnormal Pressure Analysis in the Bakken Formation, a Key to Future Discoveries," Search and Discovery Article #40629 (2010). Also, please refer to article with the same title in AAPG Bulletin, 209, v. 93, p. 1127-1153, by the author, with A. Pramudito.

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Abstract

The Elm Coulee Field of the Williston basin is a giant oil discovery in the middle Bakken Formation (Devonian-Mississippian) discovered in 2000. Horizontal drilling began in the field in 2000 and to date over 500 wells have been drilled. The estimated ultimate recovery for the field is over 200 million barrels (31.8 million m3) of oil.

The Bakken in the field area consists of three members: (1) upper shale, (2) middle silty dolostone, (3) lower siltstone. The total Bakken interval ranges in thickness from 10 to 50 ft (3.1 to 15.3 m) over the field area. The upper shale is dark-gray to black, hard, siliceous, slightly calcareous, pyritic, and fissile. The shale consists of dark organic kerogen, minor clay, siltsized quartz, and some calcite and dolomite. The kerogen consists mainly of amorphous material, and the organic material is distributed evenly throughout the shale interval (not concentrated in laminations or lenses). The upper shale ranges in thickness from 6 to 10 ft (1.8 to 3.1 m) over the field area. The middle member consists of a silty dolostone and ranges in thickness from 10 to 40 ft (3.1 to 12.2 m). The lower member in the Elm Coulee field consists of brownish-gray, argillaceous, organic-rich siltstone. Burrowing and brachiopod fragments are common in the lower member. This facies is equivalent to the lower Bakken black shale facies on the northern side of the field and is interpreted to be an up-dip-landward equivalent to the deeper-water, black shale facies. The lower member ranges in thickness from 2 to 6 ft (0.61 to 1.8 m). Based on abundance of fossil content and amount of burrowing, the members of the Bakken are interpreted to have been deposited under aerobic (middle member, common burrows and rare fossils), dsyaerobic (lower member, common fossils, lesser amount of burrows) and anaerobic conditions (upper member, rare fossils and burrows).

The main reservoir in Elm Coulee is the middle member which has low matrix porosity and permeability and is found at depths of 8500 to 10500 ft (2593 to 3203 m). The current field limits cover approximately 450 mi2 (1165 km2). The porosities range from 3 to 9% and

permeabilities average 0.04 md. Overall, reservoir quality improves upward as the middle Bakken has less mudstone matrix. The middle Bakken is interpreted to be a dolomitized carbonate-shoal deposit based on subsurface mapping and dolomite lithology. The main production is interpreted to come from matrix permeability in the field area. Occasional vertical and horizontal fractures are noted in cores. The vertical pay ranges in thickness from 8 to 14 ft (2.4 to 4.3 m). The Bakken is slightly overpressured with a pressure gradient of 0.53 psi/ft (0.02 kpa/m). Horizontal wells are drilled on 640 to 1280 acre (259 to 518.4 ha.) spacing units. Long single laterals, dual laterals, and tri-laterals have all been drilled in the field. The horizontal intervals are sand-gel-water fractured stimulated. Initial production ranges from 200 to 1900 BOPD (31.8 to 302.1 m3 per day). Initial potential rates for vertical wells are generally less than 100 BOPD (15.9 m3 per day). The upper Bakken shale probably also contributes to the overall production in the field. The exact contribution is unknown but estimated to be less than 20% of the total production.

The Elm Coulee field illustrates that the Bakken petroleum system has enormous potential for future oil discoveries in the Williston Basin.

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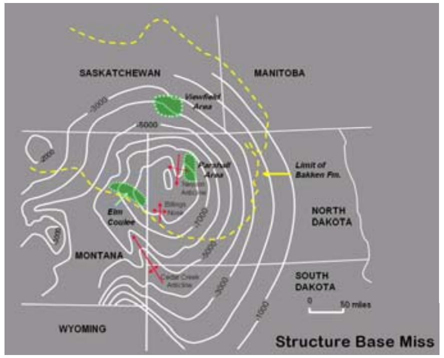
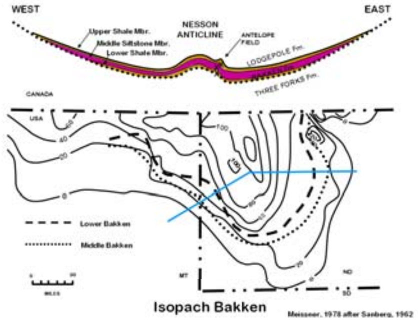


Bakken Formation Basics

- 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



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ABSTRACT

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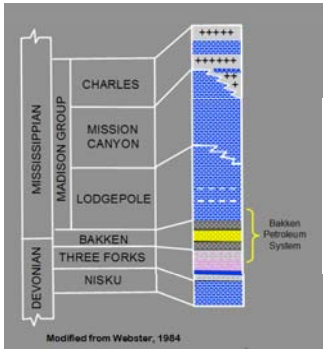
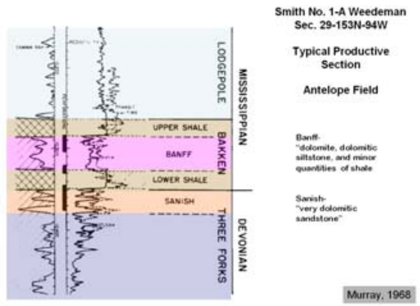
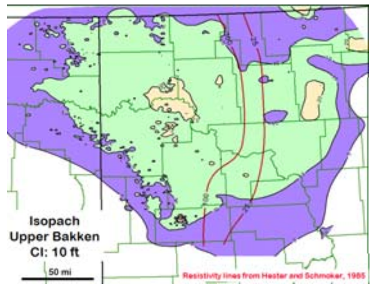
The main reservoir in Elm Coulee is the middle member which has low matrix porosity and permeability and is found at depths of 8500 to 10500 ft (2593 to 3203 m). The current field limits cover approximately 450 mi2 (1165 km2). The porosities range from 3 to 9% and permeabilities average 0.04 md. Overall, reservoir quality improves upward as the middle Bakken has less mudstone matrix. The middle Bakken is interpreted to be a dolomitized carbonate-shoal deposit based on subsurface mapping and dolomite lithology. The main production is interpreted to come from matrix permeability in the field area. Occasional vertical and horizontal fractures are noted in cores. The vertical pay ranges in thickness from 8 to 14 ft (2.4 to 4.3 m). The Bakken is slightly overpressured with a pressure gradient of 0.53 psi/ft (0.02 kpa/m). Horizontal wells are drilled on 640 to 1280 acre (259 to 518.4 ha.) spacing units. Long single laterals, dual laterals, and tri-laterals have all been drilled in the field. The horizontal intervals are sand-gel-water fractured stimulated. Initial production ranges from 200 to 1900 BOPD (31.8 to 302.1 m3 per day). Initial potential rates for vertical wells are generally less than 100 BOPD (15.9 m3 per day). The upper Bakken shale probably also contributes to the overall production in the field. The exact contribution is unknown but estimated to be less than 20% of the total production.

The Elm Coulee field illustrates that the Bakken petroleum system has enormous potential for future oil discoveries in the Williston Basin.





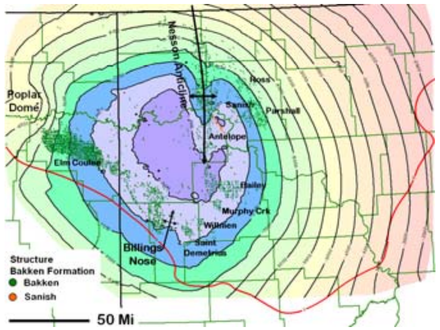


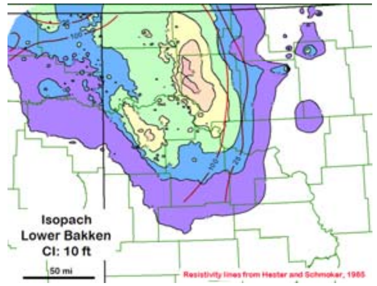
Acknowledgements

- DOE/NETL
- CSM Bakken Consortium Members
  - EOG, Whiting, Enerplus, Marathon, Red Willow, Total, Mike Johnson, Hendricks and Associates, Discovery Group, Samson, Fidelity, Savant, Questar, XTO, Statoil, Husky Energy
- IHS
- MJ Systems, TGS
- NDIC, North Dakota Geological Survey
- EERC, University of North Dakota
- USGS Williston Basin Team

Late Devonian-Early Mississippian black shales (360 Ma)

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

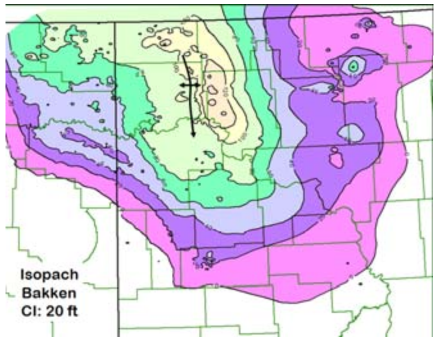




Colorado School of Mines
Bakken Consortium

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



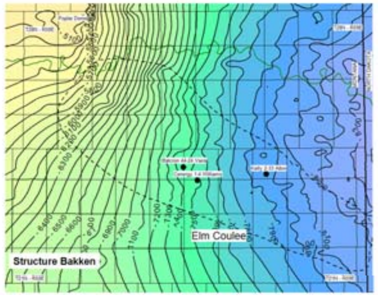
Upper and Lower Bakken

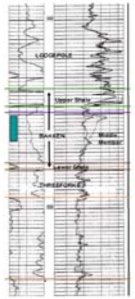
- Presence of planktonic algal spores (tasmanites), fish remains, cephalopods, ostracodes, conodonts, and inarticulate brachiopods indicates marine environment
- Shale: hard, siliceous, pyritic, fissile, organic rich (average 11.3 wt % organic carbon)
- Upper and lower shales identical in lithology
-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

Webster, 1984

Source Rocks

- TOC
- RockEval Pyrolysis (heating to 550°C)
  - S1 (volatile hydrocarbons)
  - S2 (hydrocarbons generated from pyrolysis)
  - S3 (CO_2 generated from kerogen pyrolysis)
  - PI = [S1/(S1+S2)]
  - HI = S2/TOC; OI = S3/TOC
  - Tmax = temperature at which maximum evolution of S2 hydrocarbons occurs
- Well logs
  - Density logs: TOC
  - Resistivity logs: Maturity





Kelly/Prospector (Enerplus Resources) Albin Flb 2-33 Sec. 33-24N-57E

Pfs: 10,451-463
IP: 73 BOPD
Flowed 2,191 barrels oil in the first 30 days beginning March 20, 1996

Treatment:
Water sand frac with 80,260 gallons water & 151,800 lbs sand

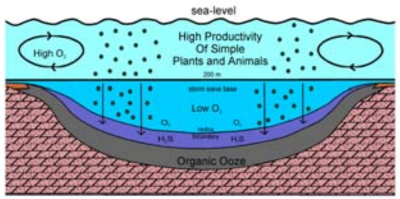
Cum: Cum:
92,119 BO; 56,607 MCFG, 10,674 BW

Middle Bakken Reservoir Data

- Formation type: Fractured Silty Dolomite
- Vertical Depth: 8,500' to 10,500'
- Vertical thickness: 8' to 14'
- Porosity: 8 to 10%
- Permeability: 0.05 md average
- Oil Saturation: 75% average
- Spacing Units: Primarily 640 to 1280 acres
- Stimulation: Gelled water, sand frac
- Initial Production: 200 to 1900 BOPD; 100 to 900 Mcfd
- Oil Gravity: 42° API @ 60°F
- Bottom hole temp: 240°F
- GOR: 500 CFG/Bbl
- Oil in Place (BO/section): 5,000 MBO
- Primary Recovery Factor: 10%
- Primary Oil Recovery: 500 MBO
- Well Cost: ~ $4,500,000

Walker, 2006

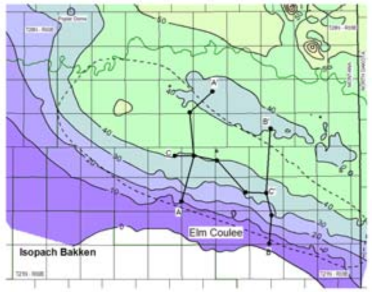
Depositional Setting: Lower and Upper Bakken Black Mudstone



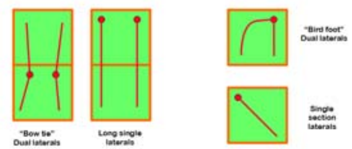
Modified from Smith and Bustin, 1996; Meissner et al., 1984

Bakken Exploration History in US Williston basin.

1953	Discovery of Antelope Field Establishment of production in Bakken and Three Forks
1961	Shell Elkhorn Ranch #41X-5-1 drilled, discovery well for depositional limit play on Billings Nose Established production from upper Bakken shale
Late 1970s	Vertical well drilling upper Bakken shale on Billings Nose
1987	First horizontal well drilled in upper Bakken shale in Billings Nose area
1996	Albin wells completed in middle Bakken "Sleeping Giant" concept developed
2000	First horizontal wells in middle Bakken Elm Coulee Field discovered
2006	Parshall Field discovered



Well Spacing Units & Patterns

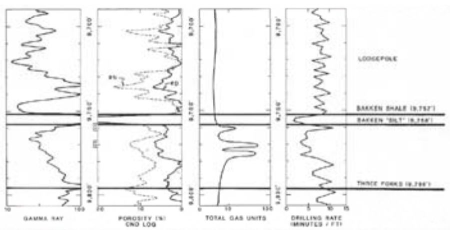


Elm Coulee Data

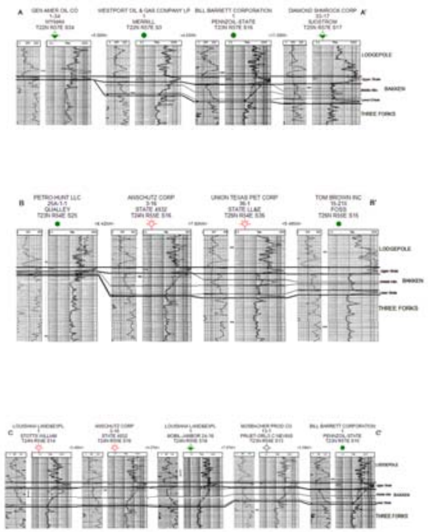
Well Name	Source Bed Potential							Maturity	Hydrocarbon Indicators	
	Depth	TOC	S1	S2	S3	HI	OI	Tmax°C	S1/TOC	PI
Cenergy 1-4 Williams Sec. 4, T23N, R55E	10046	10.6								
Cenergy 1-4 Williams Sec. 4, T23N, R55E	10047	9.29								
Cenergy 1-4 Williams Sec. 4, T23N, R55E	10048	9.44								
Cenergy 1-4 Williams Sec. 4, T23N, R55E	10049	9.32	5.18	44.01		472		443	55.5	0.11
Cenergy 1-4 Williams Sec. 4, T23N, R55E	10050	7.23								
Balcron 44-24 Vaira Sec. 24, T24N, R54E	10001	13.90	5.03	42.7	0.38	307	3	447	36	0.11
Balcron 44-24 Vaira Sec. 24, T24N, R54E	10004	7.49	4.74	19.75	0.26	264	3	443	63	0.19

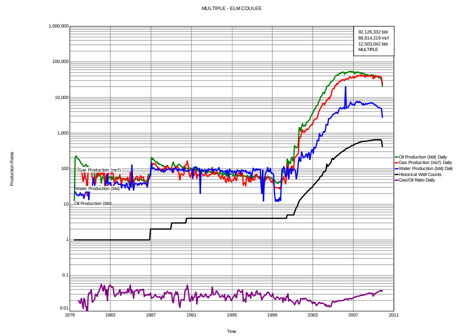
TOC = weight percent organic carbon in rock
S1, S2 = mg hydrocarbon per gram of rock
S3 = mg carbon dioxide per gram of rock
Tmax = °C

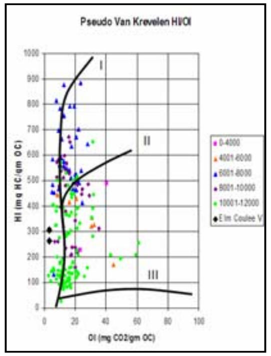
HI = hydrogen index = S2 X 100 / TOC
OI = oxygen index = S3 X 100 / TOC
S1/TOC = normalized oil content = S1 X 100 / TOC
PI = production index = S1 / (S1 + S2)

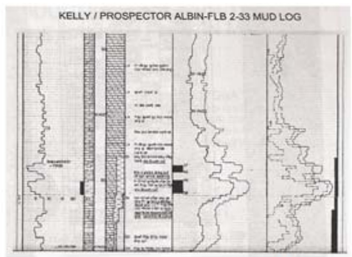


Log suite, BN 9-27, Richland Co., MT (Cramer, 1991)
Note mud log shows in Middle Bakken.

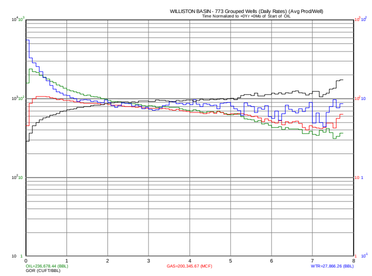


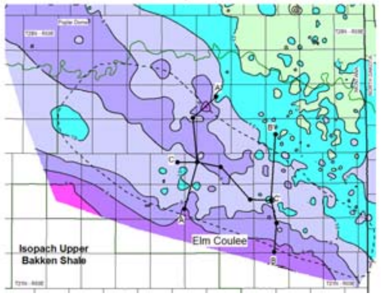


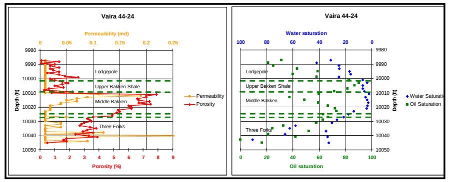




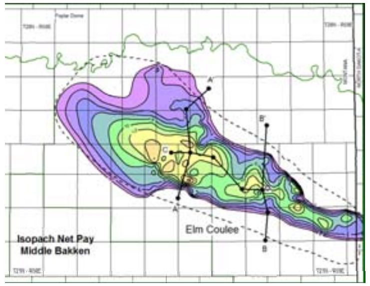
From Findley, 2005







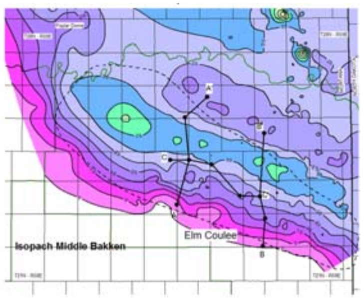
Core permeability, porosity, oil and water saturation, Vaira 44-24, Richland County, MT



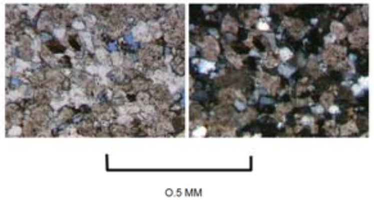
Primary Keys to Success of the Middle Bakken Play

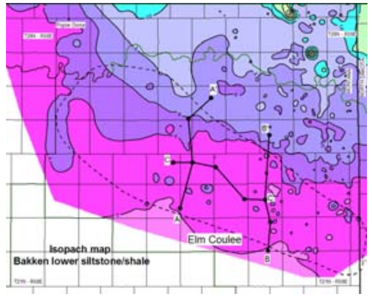
- Horizontal Drilling & Completion of the Well with Fracture Stimulation
- Wells Contain 4,000' to 23,000' of Lateral per Well
- Typical Horizontal Fracture Stimulation ($350,000 to $650,000)
- Per Lateral (in open hole or uncemented pre-perfed liner hole):
  - "Gelled water-sand frac" in several stages
  - Sand concentration from 1 to 4+ pounds of sand per gallon (20-40 mesh sand, to 100 #/ft of hole)
  - Pumped at rate of 70 – 100 BPM, (In 5,000' lateral, Total of ~5,000 bbls gelled water and 400,000# sand)

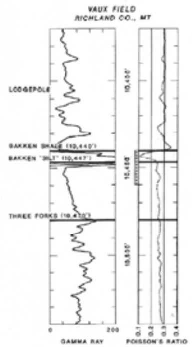
Walker, 2006



Vaira - 10011

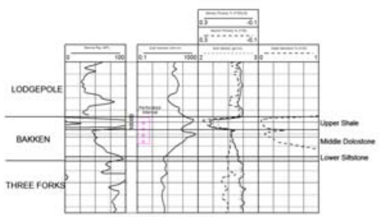




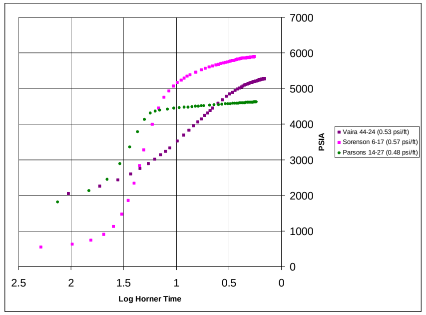


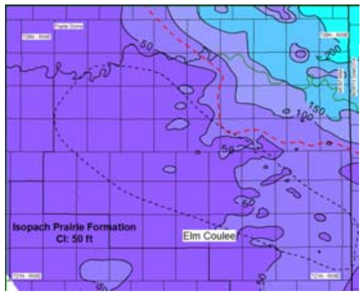
Poisson's ratio vs depth, Sorensen # 8-17 (Cramer, 1991)

Balcron 44-24 Vaira
(Sec. 24-T24N-R54E, Richland County, Montana)



IP: 83 BOPD and 61 MCFD





Elm Coulee Summary

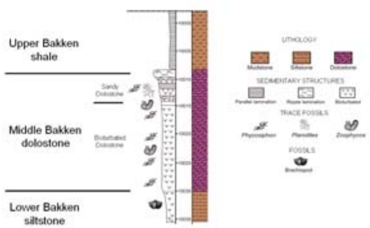
- Production defined to date
- In 6+ years since discovery (to April/09) Cum Oil Production: ~ 80 million Bbls
- Field Daily Rate: ~40,000 BOPD
- Currently 1 Rig
- Covers approximately 450 square miles
- Ultimate Recovery ~ 225 million BO (at 500,000 BO per square mile)
Est. 225 BCFG (average GOR 1,000 over life)

Why does it work?

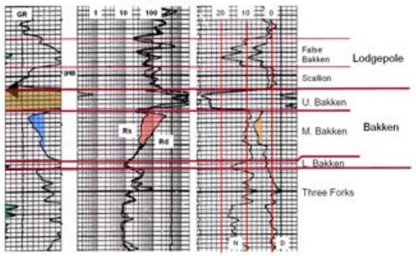
- Well developed wide spread matrix porosity and permeability (not solely dependent on fractures)
- Horizontal drilling very effective in improving deliverability by accessing more reservoir
- Reservoir responds well to gelled water/sand frac stimulation
- Regulatory agency openness to large spacing units has allowed more efficient and effective development

Modified from Walker, 2006

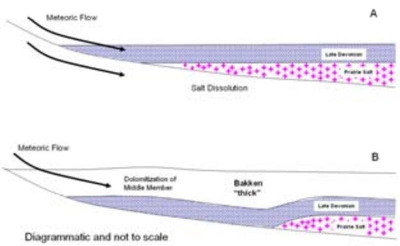
Core description of the Balcron #44-24 Vaira



Bakken Type Log
Richland County, Montana
Sec. 16-T23N-R57E



SAS, 2004



Tight Oil Resource Play

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