[PS]Abnormal Pressure Analysis in the Bakken Formation, Williston Basin, a Key to Future Discoveries

Stephen A. Sonnenberg[1]

Search and Discovery Article #40629 (2010)
Posted December 14, 2010

*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 "Petroleum Geology of the Giant Elm Coulee Field, Williston Basin," Search and Discovery Article #20096 (2010).

[1]Department of Geology, Colorado School of Mines, Golden, CO (ssonnenb@mines.edu)

Abstract

Productive areas in the Bakken Formation in the U.S. part of the Williston Basin are associated with abnormal pressure and mature Bakken source rocks. The cause of the abnormal pressure is related to hydrocarbon generation. Drill stem tests (DST's) are the most abundant and accurate source of subsurface pressures in the Bakken. Pressures recorded on the tests can be interpreted for the original formation pressure, permeability, producibility, flow capacity, transmissibility, well bore damage, barriers near the wellbore, and reservoir size. The type of reservoir fluid present can also be sampled and analyzed.

DST's analyzed for the Bakken help delineate the extent and amount of overpressuring in the Bakken. An analysis of the pressure data also reveals the presence of matrix and/or fracture permeability. Knowledge of the type of permeability present is a key to the development of fields and determining proper well spacing. DST data can also reveal areas of pressure depletion during the course of field development.

Formation damage is a common attribute in the Bakken Formation which results from mud filtrate invasion. Formation damage can result in poor DST fluid recoveries and poor pressure buildup data. Low fluid recovery on DST's is very common in the low permeability Bakken reservoirs. DST's in the Bakken require long final shut-in periods so pressure build-ups can be accurately projected for original formation pressures.

The interpretation of pressure data in the Bakken may aid in the discovery and development of new fields in the basin.

References

Helms, L.D. and. J.A. LeFever, 2005, Middle Bakken play and technical problems and questions, possible solutions: Petroleum Council / North Dakota Geological Survey Geologic Investigation no. 15, 45 p. (PowerPoint presentation) Web accessed October 27, 2010 (https://www.dmr.nd.gov/ndgs/bakken/Papers/2005%20Petroleum%20Council.pdf)

Hester, T.C. and J.W. Schmoker, 1985, Selected physical properties of the Bakken Formation, North Dakota and Montana part of the Williston Basin: U.S. Geological Survey Oil and Gas Investigation Chart OC-126, 1 Sheet

Meissner, F.F., 1978, Patterns of source-rock maturity in non-marine source rocks of some typical western interior basis in non-marine Tertiary and Upper Cretaceous source rocks and the occurrences of oil and gas in the west central US: Rocky Mountain. Association of Geologists Continuing Education Course Notes.

Murray, G.H., 1968, Quantitative fracture study--Sanish pool,McKenzie County, North Dakota: AAPG Bulletin, v. 52, p. 57-65.

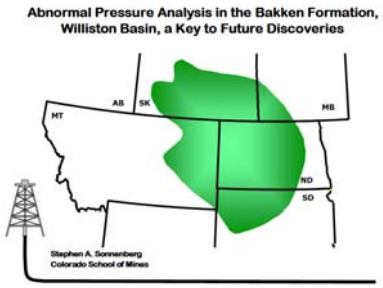
Price, L.C., T. Ging, T. Daws, A. Love, M. Pawlewicz, and D. Anders, 1984, Organic metamorphism in the Mississippian - Devonian Bakken shale, North Dakota portion of the Williston Basin, in J. Woodward, F.F. Meissner, and J.L. Clayton, eds., Hydrocarbon Source Rocks of the Greater Rocky Mountain Region: Rocky Mountain Association of Geologists, Denver, CO, p. 83-134.

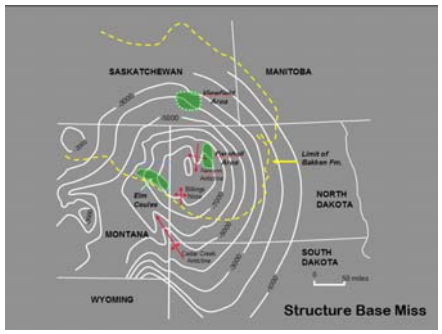
Sandberg, C.A., 1962, Geology of the Williston Basin, North Dakota, Montana and South Dakota with reference to subsurface disposal of radioactive waste: U.S. Atomic Energy Commission, U.S. Geological Survey TEI-809, 148 p.

Webster, R.L., 1984, Petroleum source rocks and stratigraphy of the Bakken Formation in North Dakota, *in* J. Woodward, F.F. Meissner, and J.L. Clayton, eds., Hydrocarbon Source Rocks of the Greater Rocky Mountain Region: Rocky Mountain Association of Geologists, Denver, CO, p. 57-81.

Website

Blakey, R., 2007, Paleogeographic maps, North America, Devonian-Mississippian (260 Ma) Web accessed October 27, 2010 (http://jan.ucc.nau.edu/rcb7/namD360.jpg).

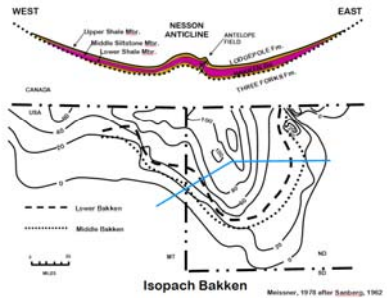




Bakken Formation Basics

- 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



Abnormal Pressure Analysis in the Bakken Formation, Williston Basin, a Key to Future Discoveries

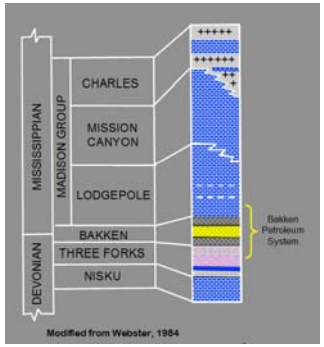
Stephen A. Sonnenberg
Colorado School of Mines

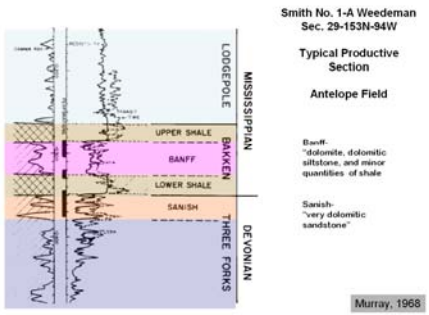
Productive areas in the Bakken Formation in the U.S. part of the Williston Basin are associated with abnormal pressure and mature Bakken source rocks. The cause of the abnormal pressure is related to hydrocarbon generation. Drill stem tests (DST's) are the most abundant and accurate source of subsurface pressures in the Bakken. Pressures recorded on the tests can be interpreted for the original formation pressure, permeability, producibility, flow capacity, transmissibility, well bore damage, barriers near the wellbore, and reservoir size. The type of reservoir fluid present can also be sampled and analyzed.

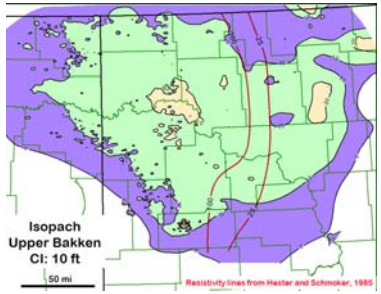
DST's analyzed for the Bakken help delineate the extent and amount of overpressuring in the Bakken. An analysis of the pressure data also reveals the presence of matrix and/or fracture permeability. Knowledge of the type of permeability present is a key to the development of fields and determining proper well spacing. DST data can also reveal areas of pressure depletion during the course of field development.

Formation damage is common attribute in the Bakken formation which results from mud filtrate invasion. Formation damage can result in poor DST fluid recoveries and poor pressure buildup data. Low fluid recovery on DST's is very common in the low permeability Bakken reservoirs. DST's in the Bakken require long final shut-in periods so pressure build-ups can be accurately projected for original formation pressures.

The interpretation of pressure data in the Bakken may aid in the discovery and development of new fields in the basin.





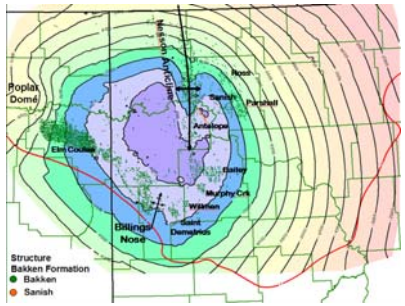


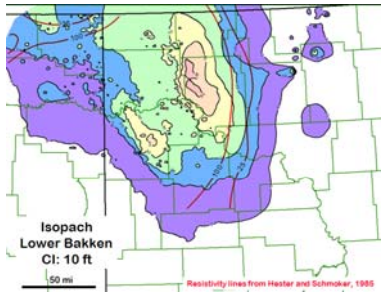
Acknowledgements

- 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>

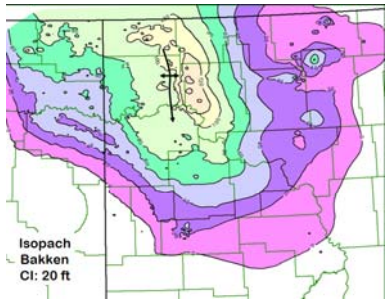




Colorado School of Mines Bakken Consortium

Unconventional, Continuous Tight Oil Accumulations

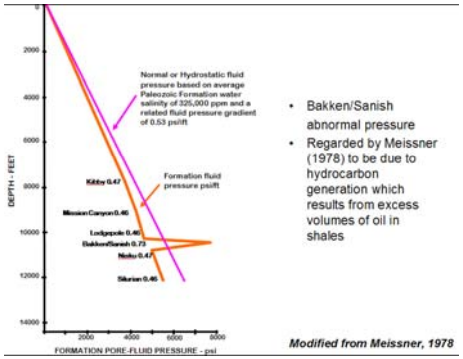
- Pervasive petroleum saturation
- Mature source rocks
- Abnormally pressured
- Generally lacks down-dip water
- Up-dip water saturation
- Low porosity and permeability reservoirs
- Enhanced by fracturing and partings



Upper and Lower Bakken

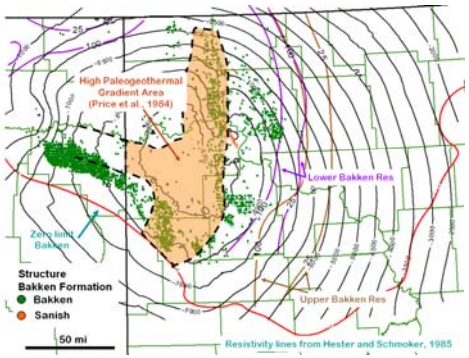
- Presence of planktonic algal spores (tasmanites), fish remains, cephalopods, ostracodes, conodonts, and inarticulate brachiopods indicates marine environment
- Shale: hard, siliceous, pyritic, fissile, organic rich (average 11.3 wt % organic carbon)
- Upper and lower shales identical in lithology
-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

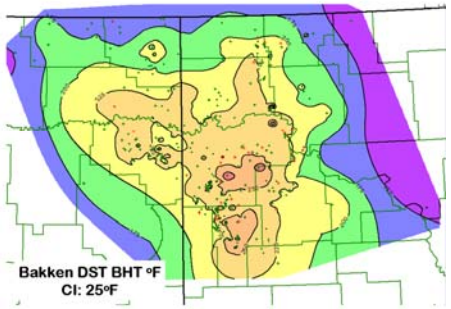
Webster, 1984

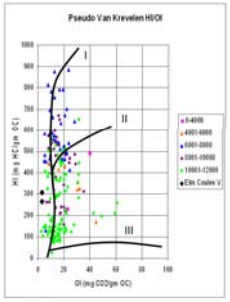


- Bakken/Sanish abnormal pressure
- Regarded by Meissner (1978) to be due to hydrocarbon generation which results from excess volumes of oil in shales

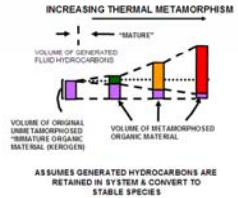
Modified from Meissner, 1978

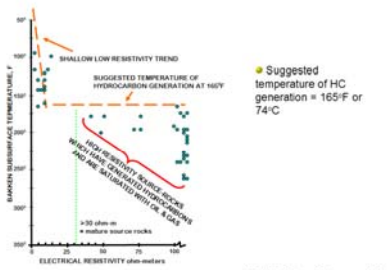






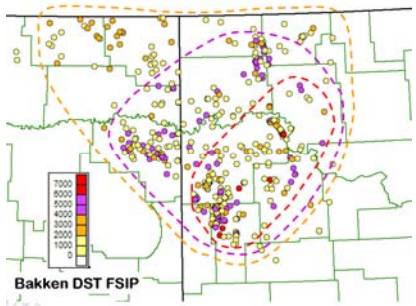
Abnormal Pressure with Hydrocarbon Generation





- Suggested temperature of HC generation = 165°F or 74°C

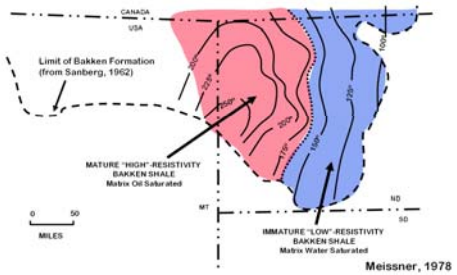
Modified from Meissner, 1978



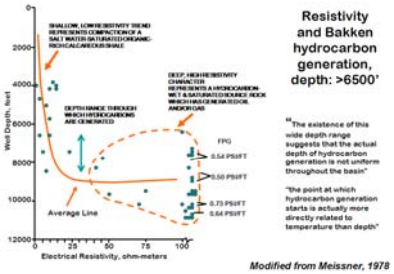
Drill Stem Tests

- Most abundant source of subsurface pressures is the drill-stem test
- Conducted to obtain fluid sample from porous and permeable formations
- Pressures recorded during testing can be interpreted for the original fluid pressure before fluid withdrawal
- Pressure buildup can be interpreted for reservoir permeability and for barriers near the wellbore (structural and stratigraphic)

BAKKEN FORMATION TEMPERATURES & SOURCE ROCK MATURITY



Meissner, 1978

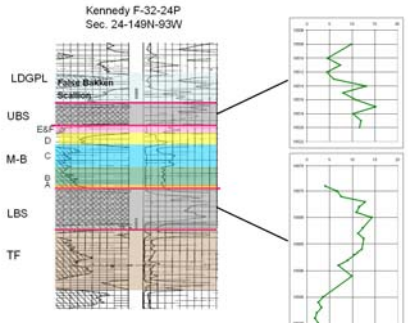


Resistivity and Bakken hydrocarbon generation, depth: >6500'

"The existence of this wide depth range suggests that the actual depth of hydrocarbon generation is not uniform throughout the basin"

"the point at which hydrocarbon generation starts is actually more directly related to temperature than depth"

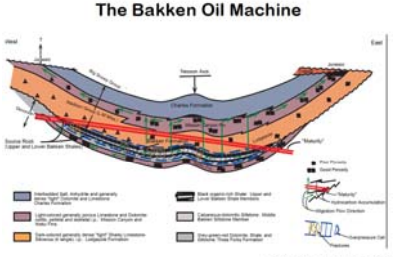
Modified from Meissner, 1978



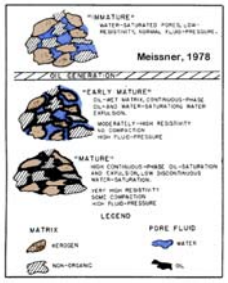
Drill Stem Tests

- An economical technique to help evaluate a well
- Permits the evaluation of:
  - Presence and physical description of reservoir fluids
  - Effective permeability (k in md)
  - Productivity and reservoir pressure
  - Flow capacity and transmissibility
  - Barrier indications
  - Well bore damage
  - Skin
  - Reservoir size

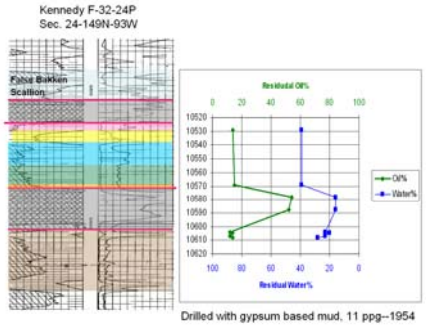
The Bakken Oil Machine



Modified from Meissner, 1978



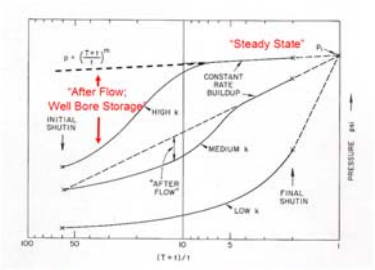
Meissner, 1978



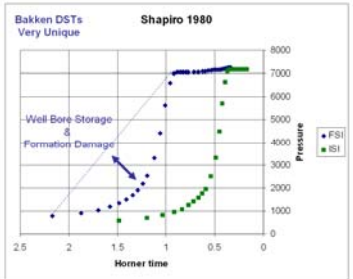
Drilled with gypsum based mud, 11 ppg--1954

Extrapolating Build Up Data

- Buildup data follows an essentially logarithmic path, a graphical (mathematical) procedure was devised to predict what the pressure would have built up to if the shut-in period had been infinitely long
  - Pressure buildup curve samples over convenient number of time intervals
  - Δt (sometimes seen as θ) is defined as the elapsed (or cumulative) time in minutes from the beginning of the shut-in period.
  - Duration of the FLOW period is designated as T
  - The following parameters calculated:
    - $T + \Delta t$ and $(T + \Delta t)/\Delta t$
  - Individual pressure values from the original buildup curve are plotted against the logarithm $(T + \Delta t)/\Delta t$ to linearize the curve (plot either log values on arithmetic paper or use semi-log paper)
  - Straight line portion of resulting points is projected linearly out to the appropriate pressure value corresponding to a limit of zero if the arithmetic plot is utilized or a value of 1 on the logarithmic plot.

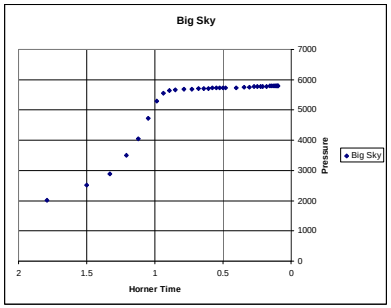


Plots of shutin pressures as a function of log (T+t)/t for high, medium, and low permeability formations and extrapolation of the constant rate of buildup to the original formation pressure (Pi)

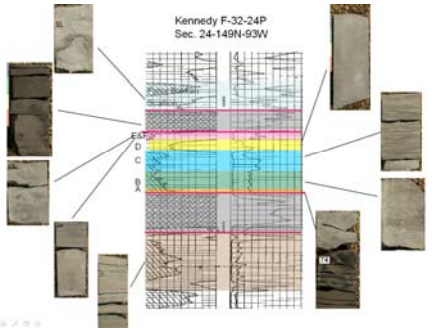


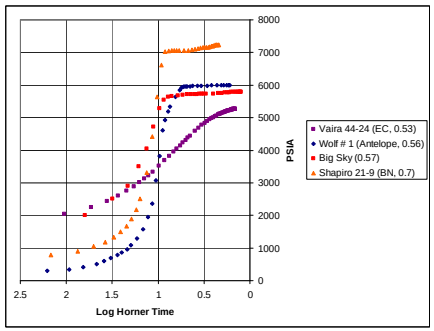
"erratic buildup indicates some type of communication, possibly through a vertical fracture system"

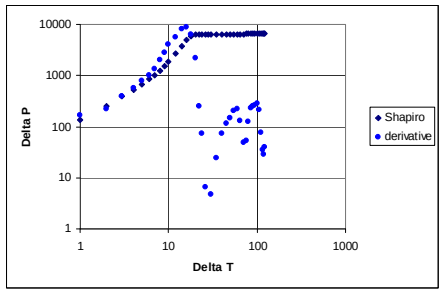
Billings Nose Area



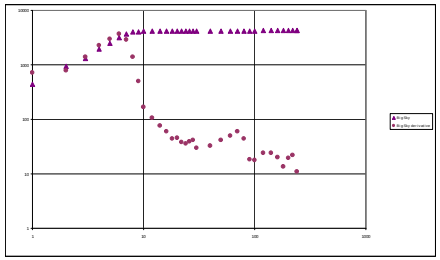
Montana well



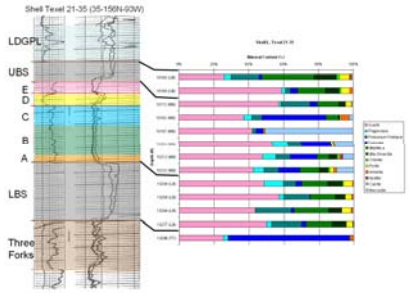


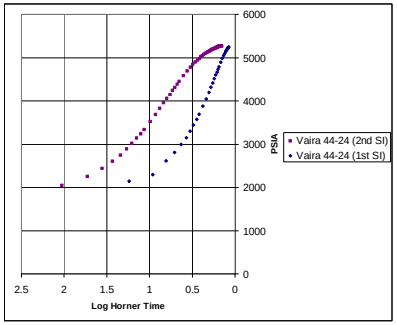


Billings Nose Area

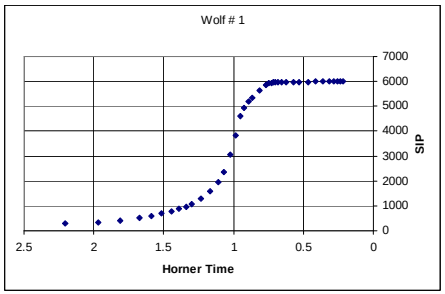


Montana well



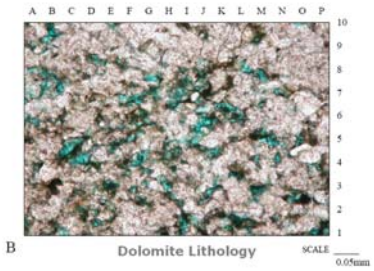


Elm Coulee Area



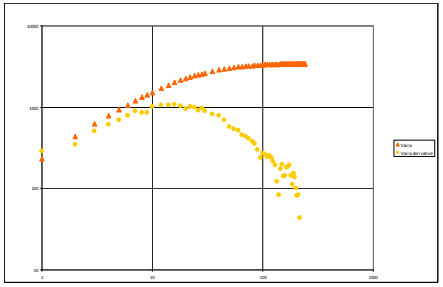
Antelope Field Area

Balcron Oil #44-24 Vaira
SESE 17-24N-54E

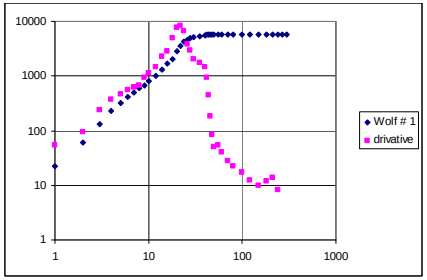


Summary

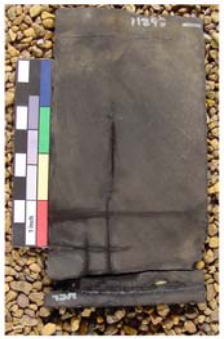
- Bakken contains world class source rocks
- Abnormal pressure in the Bakken Petroleum System is related to hydrocarbon generation
- Overpressuring creates fractures and horizontal partings in low quality reservoirs
- Pressure build-up curves help to identify fracture permeability systems



Elm Coulee Area



Antelope Field Area



Carus Fee
Upper Bakken Shale
11293
NDIC

Tight Oil Resource Play

Bakken Research Consortium
ssonnenb@mines. edu