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A SYNOPTIC OVERVIEW OF THE BAKKEN FORMATION IN PORTIONS OF BILLINGS, GOLDEN VALLEY, AND MCKENZIE COUNTIES, NORTH DAKOTA

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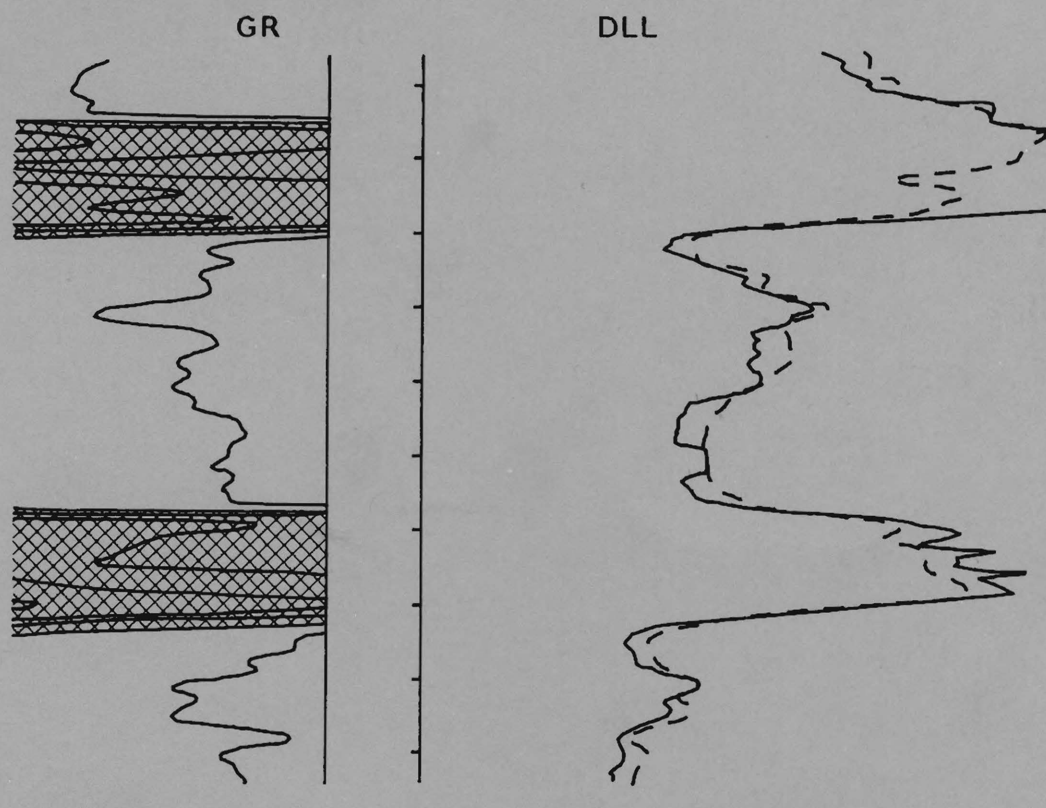

REPORT OF INVESTIGATION 89
North Dakota Geological Survey
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PURPOSE

The following is intended to serve as an introduction to the Bakken Formation in portions of McKenzie, Golden Valley, and Billings Counties, North Dakota. The information herein is a synthesis of information and research published elsewhere.

Exploration activity in the above mentioned portion of North Dakota has recently been focused on the Bakken--specifically, developing Bakken reserves with horizontal drilling. Meridian Oil, Inc., the initial impetus behind the horizontal play, in testimony before the North Dakota Industrial Commission, lists 4 reasons for their industrial drilling program:

1. Increase the probability of success.
2. Increase profit potential (table 1).
3. Increase the effective drainage area and maximize recoverable reserves (fig. 1).
4. Increase productivity by encountering more natural occurring fractures.

INTRODUCTION

The Bakken Formation (Nordquist, 1959) is a relatively thin unit found in the deeper portion of the Williston Basin. In North Dakota it is present in most of the central and western portions of the state. Considered by most to be lower Mississippian or upper Devonian in age, the Bakken is conformably overlain by the Mississippian Lodgepole Formation and underlain (unconformably?) by the Devonian Three Forks Formation.

STRATIGRAPHY

The Bakken Formation is traditionally divided into three informal members (fig. 2): an upper organic-rich black shale; a middle tight siltstone/limestone; and a lower organic-rich black shale. The three members display an overlapping relationship (Webster, 1982, 1984, 1987), each extending farther than the previous (fig. 3). The Bakken Formation attains a maximum thickness of 145 feet in Mountrail County, North Dakota, thinning to a feather edge along its depositional limit (Webster, 1982, 1984, 1987). In the study area (fig. 4) the Bakken is approximately 30 feet thick. The lower shale member is all but absent.

The upper and lower shale members are identical in lithology and are lithologically constant where found. The shales are hard, siliceous in part, pyritic in part, fissile, and organically rich. The middle member varies in lithology, including calcareous siltstones, sandstones, dolomites, or silty limestones.

Various early Mississippian or late Devonian black shale units found throughout North America are considered equivalent or near equivalent to the Bakken Formation. They are known variously as the Exshaw (Canada and Northern Rocky Mountains), the Pilot (Cordilleran Area), the lower Mississippian Shale (Permian Basin), Woodford Shale (Eastern Midcontinent/Southern Appalachian Basin), Antrium Shale (Michigan Basin), and the New Albany Group (Northern Appalachian Basin) (Meissner, 1978).

LOG CHARACTER

On logs the Bakken Formation displays an unmistakable character throughout the basin. The shales exhibit a very high (greater than 200 API) gamma-ray deflection, and are usually off scale. High resistivity readings (greater than 1,000 ohms) are associated with the shales.

Both characters occur because of the high organic content of the shales and a high petroleum content in pore space.

PETROLEUM GEOLOGY

The Bakken is considered to be the primary source rock of the Williston Basin (Murray, 1968; Dow, 1974; Webster, 1982; etc.). Organic carbon measurement of the shales average 11.33 (weight percent of organic carbon) and may reach as high as 20 percent (Webster, 1982, 1984, 1987). Webster states that the onset of hydrocarbon generation occurs at an average depth of 9,000' (fig. 5), at a temperature of approximately 180°F. He further states that oil generation was probably initiated during the late Cretaceous (approximately 80 mya) with initial hydrocarbon expulsion at that time.

The Bakken Formation is currently productive in North Dakota along or adjacent to the Nesson Anticline and in the study area. Vertically drilled Bakken wells generally have low initial potentials (less than 100 BOPD) with very low initial water production. Relatively large volumes of gas can be associated with the low sulphur, high paraffin Bakken oil.

The reservoir properties of the Bakken are generally poor. Core fluid porosities in the study area are most often well below 5 percent and always less than 10 percent. Core permeabilities seldom are greater than 0.2 millidarcies and are often as low as 0.01 millidarcies. Large vertical fractures (macro-fractures) often occur, and where found greatly increase measured permeabilities. A fractured reservoir is considered necessary for production and will be discussed later.

Overpressuring of the Bakken Formation is usually observed in areas when the formation is productive. Meissner attributes such overpressuring to the intense generation of hydrocarbons which result in abnormal fluid volumes in shale pores. A pressure gradient of over 0.6 psi/ft is often associated with the Bakken. A normal pressure gradient in the basin is usually considered to be 0.45 psi/ft.

Two types of fracturing are found in the Bakken shales of the Williston Basin. One is the relatively large vertical fractures, previously noted, and the other is what will be referred to here as micro-fractures (microscopic). The first type of fractures are related to mechanical stress and form as basement block adjustments are made along major linear fault trends. Such fractures contribute to the overall productivity of a well but are probably not essential for production.

Micro-fractures are formed in two ways. Micro-fractures, as with macro-fractures, can result from mechanical stress. More importantly, micro-fractures, may be related to hydrostatic stress, forming as hydrocarbons are generated. These are considered to be the essential type for production. Where micro-fractures occur in the Bakken, production can be established with a successful fracture-stimulation.

COMPLETION TECHNIQUES: VERTICAL WELLS

It is necessary to fracture-stimulate the Bakken for maximum production rates. Although variations exist, a proven successful Bakken fracture procedure is given as follows:

1. Swab the hole clean.
2. Perforate the entire Bakken

section and the lower 5+ feet of the Lodgepole with a gun capable of removing hydrostatic head, which reduces skin damage.
3. Produce the formation for a short time (two weeks?).
4. Fracture, using 20/40 mesh sand as propant followed by 65,000# sintered bauxite injected with 1,200 barrels of gelled Bakken oil at 10,000 psi.

Water and acid should be avoided in completion. Unpublished, proprietary SEM analysis of the shale indicate the presence of water and acid-sensitive clays. A low water loss mud should be considered when drilling the formation.

DRILLING AND COMPLETION OF HORIZONTAL WELLS

To date (3/88), 7 horizontal wells have been completed in the Bakken Formation.

The first horizontal Bakken well in North Dakota was drilled by Meridian Oil, Inc. The 33-11 MOI Elkhorn is located in the NW¼SE¼sec 11, T143N, R102W. The well initially cored a vertical section of the Bakken from 10,401 to 10,411'. A cement plug was set uphole and kickoff initiated at 9,782' MD. True horizontal drilling was attained at 10,737' MD. The resulting radius of curvature was approximately 630'. Total length of the horizontal portion was 2,603'.

Drilling time to total depth was 58 days. Some hole problems were encountered drilling the vertical section which necessitated extra trips, particularly during logging and coring operations. The first attempt to kickoff was not successful, resulting in 4½ extra days of rig time. The second attempt required 16 days from kickoff to true horizontal and 11 days to drill the horizontal section. Total depth was reached at 13,340' MD at which time the drill string became stuck in the hole. From drilling reports, this was the second case of stuck pipe encountered after kicking-off. An inverted-oil-emulsion (trade name "Carbo Fast Invert") was used as the drilling fluid.

The completed perforated intervals in the 33-11 MOI are 11,799-11,885', 12,160-12,246', 12,480-12,838', and 12,915-13,097', totalling 702'. The initial flowing rate 258 BOPD, 299 MCF gas, and 0 water. Choke size was 12/64" and the flowing tubing pressure was 750 psig. The average flowing rate in the first 15 months of production was 292 BOPD. The production essentially has remained constant over the life of the well.

Conoco's only attempt to horizontally drill a Bakken test was located less than 5 miles south of the initial Meridian test. The Federal 12-1 (SW¼SW¼sec 12, T143N, R102W) lost a portion of the drill string in the initial horizontal section. A sidetrack was able to regain 400' of lost horizontal hole. Completed horizontal section totalled approximately 1,100'; this was reduced from the original 2,058' of horizontal hole.

Most completion details are being kept very confidential. None of the wells to date report any stimulation treatments. It appears from the completion reports that all wells subsequent to the 33-11 MOI are completed across the entire horizontal section with pre-perforated casing and no cement. Conoco's 12-1 Federal and Meridian's 43-36H State have been put on pump. The remaining wells continue flowing.

The 33-11 MOI and subsequent horizontal wells drilled and producing, are listed on table 2. Production data and drilling statistics are given for each well. The last column is the maximum vertical deviation measured along the entire length of horizontal section.

EXPLORATION CONCEPTS

Regionally, several exploration tools may be useful in searching for areas of potential Bakken production. Historically, one should be interested in defining areas in which the Bakken is overpressured. If one assumes that the overpressuring occurs in areas of intense hydrocarbon generation and is due to abnormal fluid volumes in shale pores, and that the majority of that fluid is oil, resistivity mapping from downhole, wireline sources may be useful. Similarly, mapping DST shut-in pressures would be effective. In areas that are actively generating hydrocarbons, mapping bottom-hole temperatures may be useful, with 'hot spots' defining areas of interest.

Once a regional 'play' has been outlined, more conventional mapping techniques may be utilized to define local areas of interest. Structure mapping may be a valuable tool in defining drill sites that would have a higher chance of intersecting a macro-fracture system. On large, broad, structural features a flank position may be chosen as the optimum drill site; whereas, on a small, sharp, structural feature, a terminal location may be optimum (Murray, 1968; Meissner, 1978).

ACKNOWLEDGMENTS

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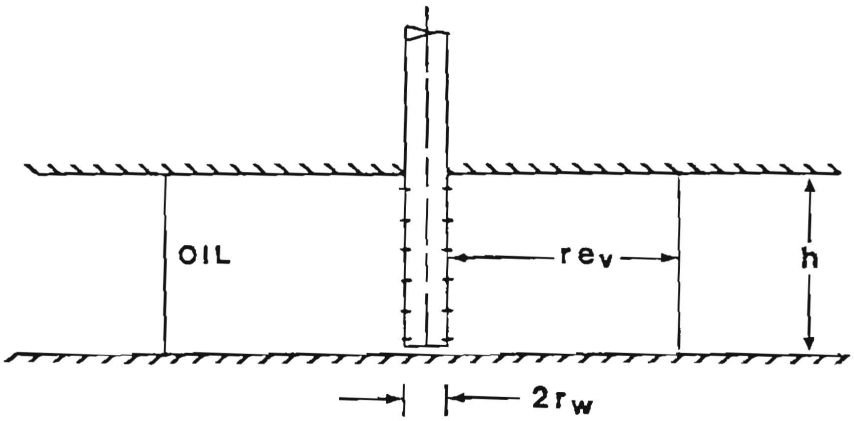
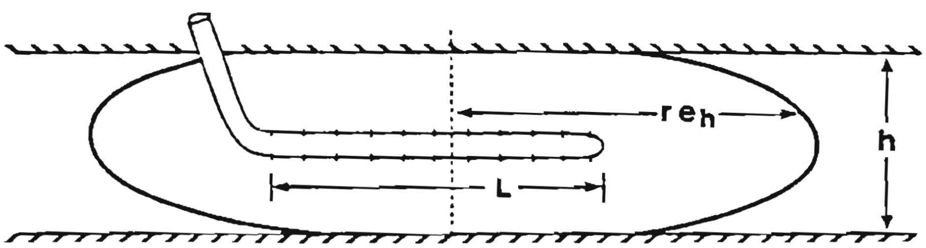


$$Q = \frac{ckh(\Delta p)}{u\ B\ \ln\left(\frac{re}{rw}\right)}$$



$$Q = \frac{c\,k\,h\Delta p/uB}{\ln\left[a+\sqrt{a^2-(L/2)^2}\right] + \frac{h}{L}\ln\left[\frac{(h/2)^2}{hrw/2}\right]}$$

where

$$a = 0.5L\left[0.5+\sqrt{0.25+(2re_h/L)^4}\right]^{0.5}$$

Figure 1. Comparison of vertical and horizontal well drainage volume schematic (Meridian Oil, Inc., North Dakota Industrial Commission Case #4606).

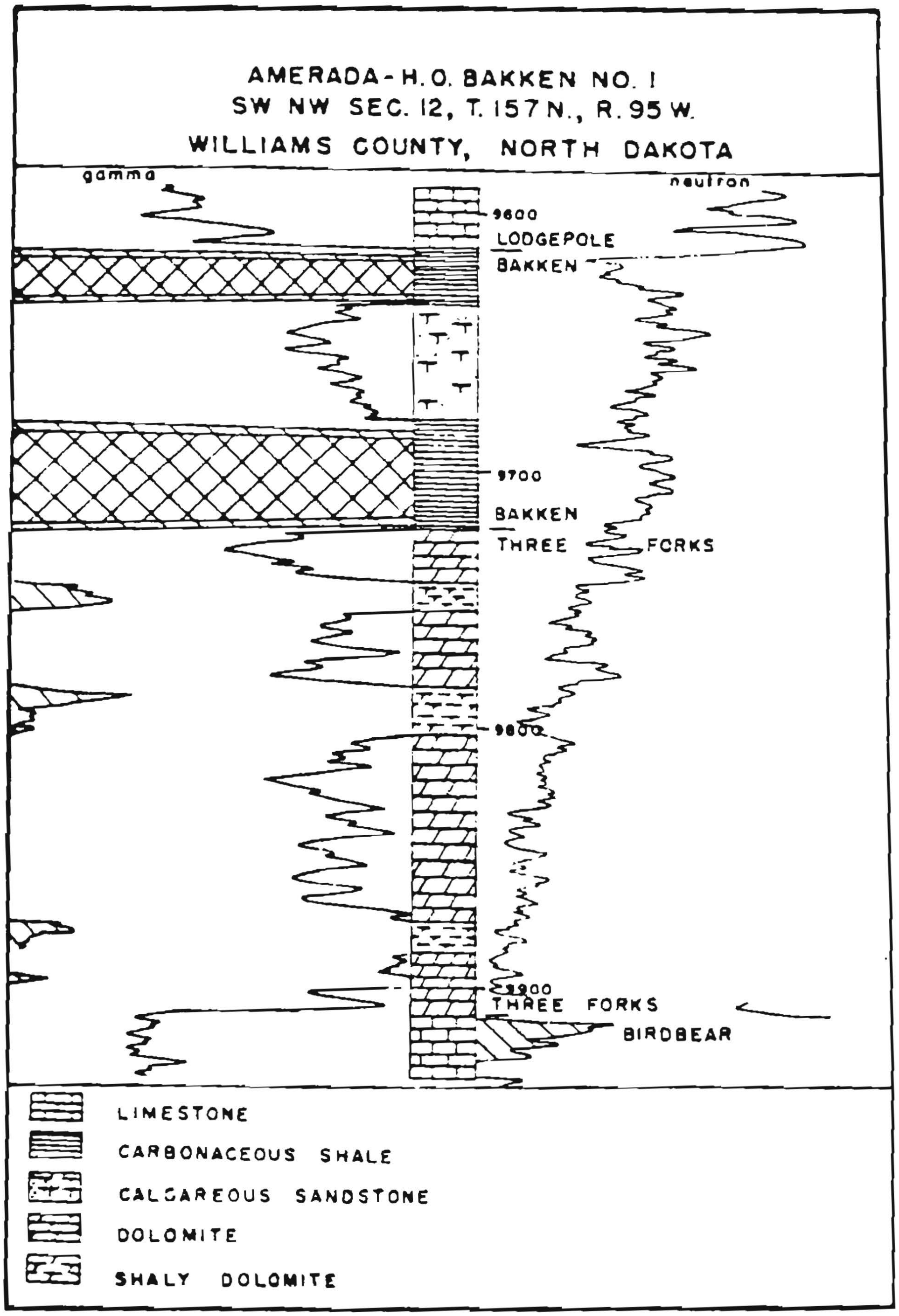


Figure 2. Type section of the Bakken Formation in the Amerada Petroleum Corporation - H.O. Bakken No. 1 well (NDGS no. 32). Taken from Webster, 1982.

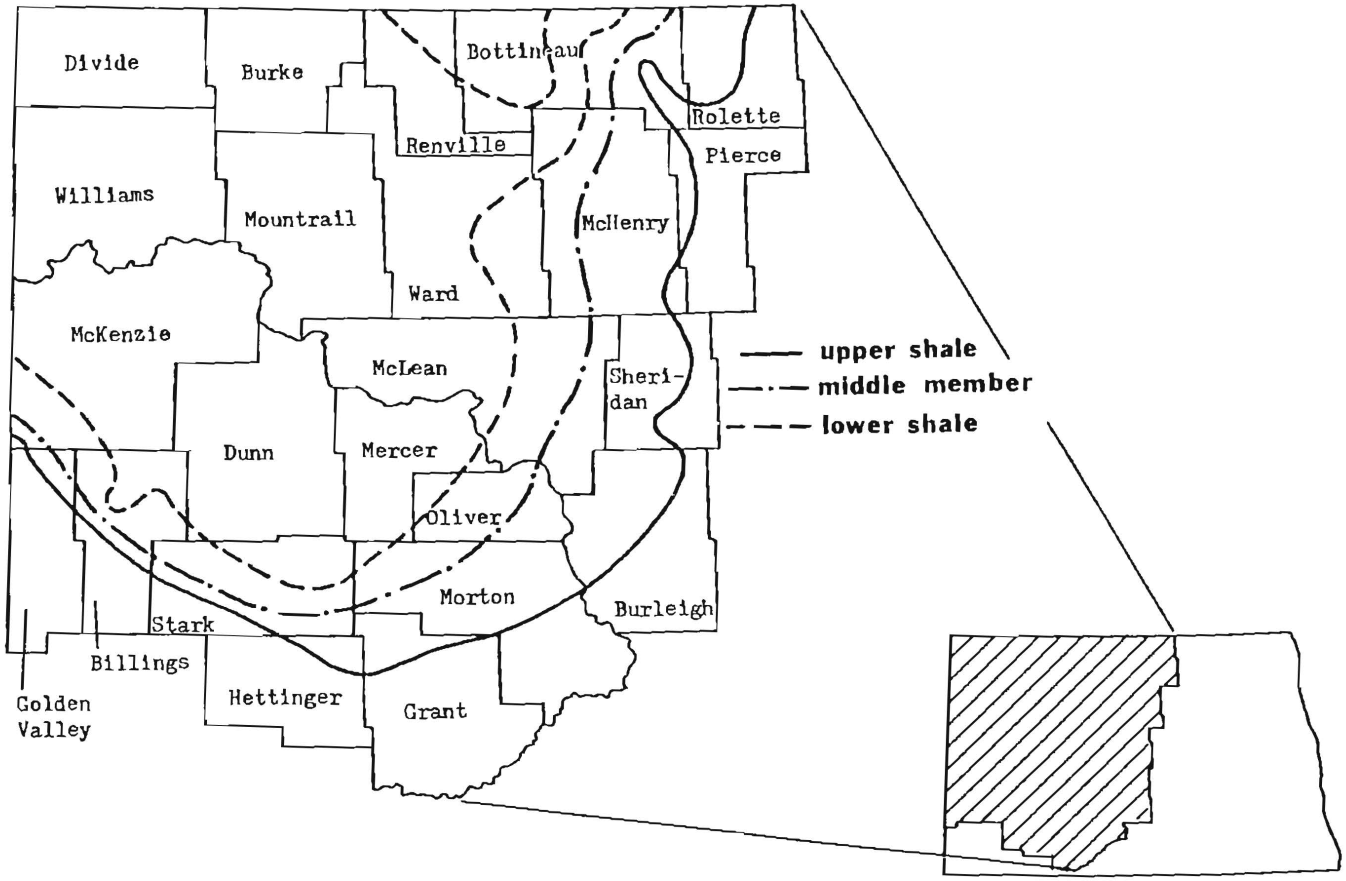


Figure 3. Approximate subsurface limits of the three members of the Bakken Formation. Taken from Webster, 1982.

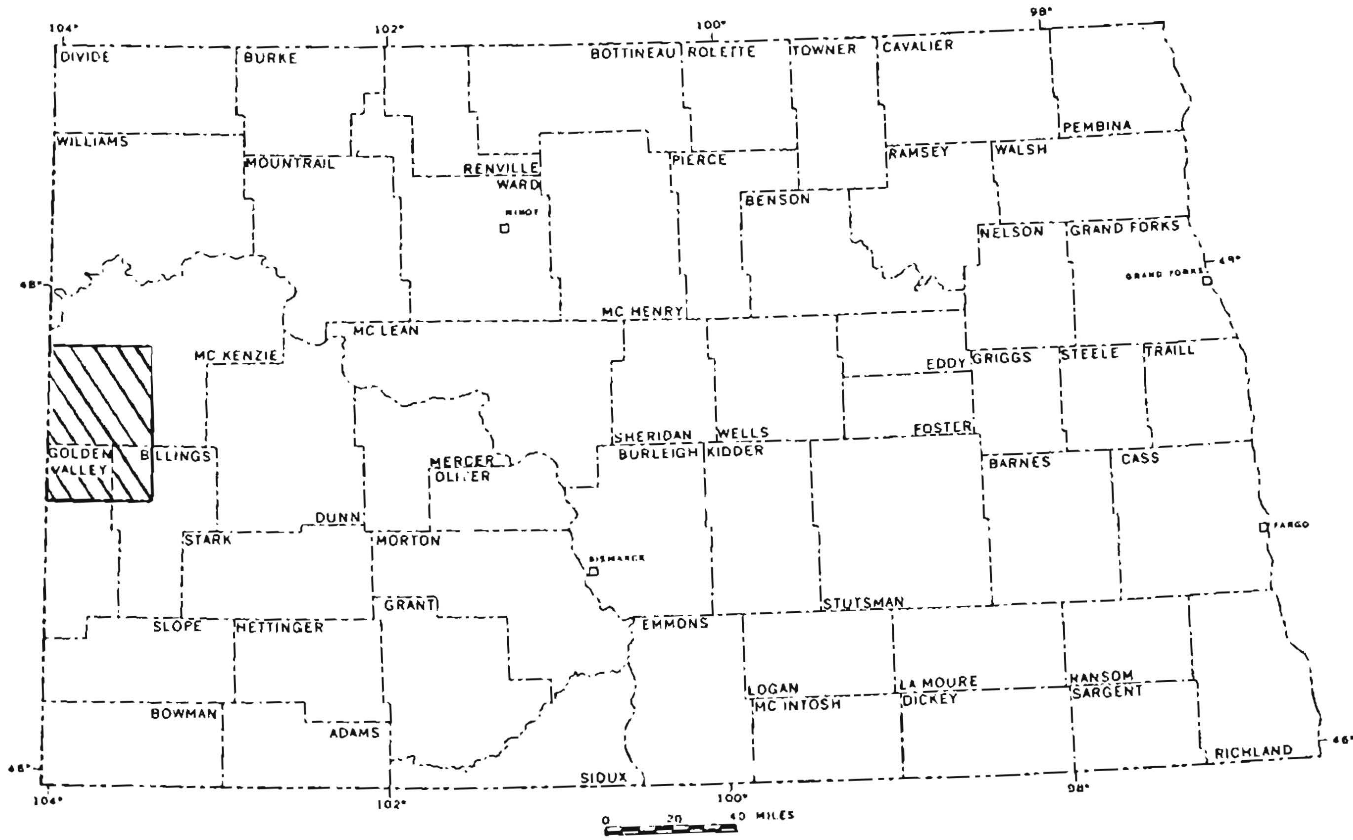


Figure 4. Study area.

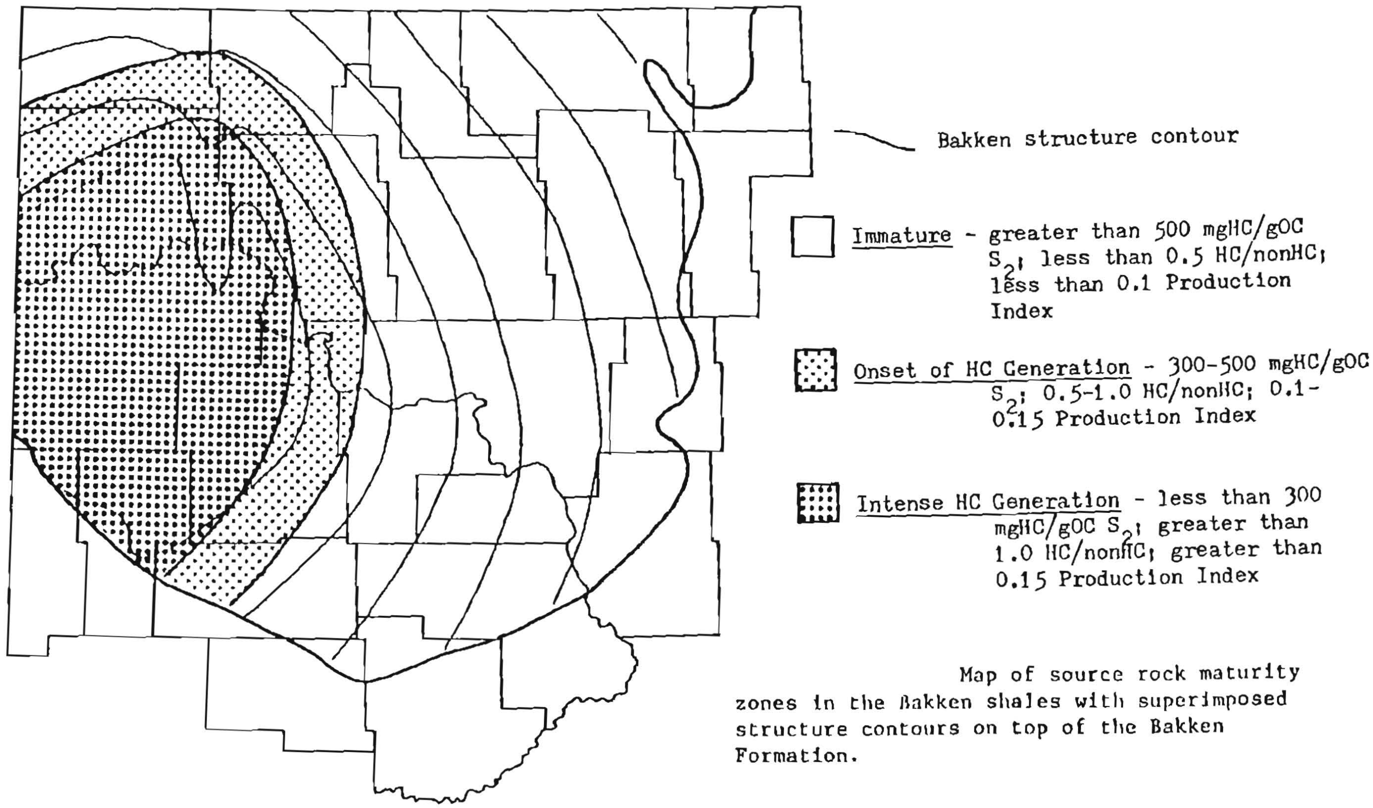


Figure 5. Map of source rock maturity zones in the Bakken shales with superimposed structure contours on top of the Bakken Formation. Taken from Webster, 1982.

TABLE 1. Comparison of Vertical and Horizontal Well Economics (Meridian Oil, Inc., North Dakota Industrial Commission Case #4606)

ELKHORN RANCH FIELD

BAKKEN ECONOMICS

A. Vertical Well

Monthly Expenses	$ 4,000
Dry-hole Cost	$ 419,000
Total Completed Well Cost	$ 832,000
Tangible Cost	$ 221,000
Intangible Cost	$ 385,000
Initial Production	120 BOPD, 96 MCFD
Reserves	184 MBO, 148 MMCF
AFIT ROR	49.6%
Profit (Discounted @ 12% AFIT)	$ 522,000
Payout	1.9 years

B. Horizontal Well

Monthly Expenses	$ 4,000
Dry-hole Cost	$ 971,000
Total Completed Well Cost	$1, 520,000
Tangible Cost	$1, 135,000
Intangible Cost	$ 611,000
Initial Production	480 BOPD, 384 MCFD
Reserves	364 MBO, 291 MMCF
AFIT ROR	112%
Profit (Discounted @ 12% AFIT)	$1, 527,000
Payout	1.0 years

TABLE 2. Available Horizontal Hole Completion Information

Well	Completion Date	Producing Interval(s) (MD)	Initial Production	Current (cumulative) Production 12/88	Total Horizontal Section	Radius	Vert. Dev.
33-11 MOI Federal NWSE 11-143-102 Meridian Oil, Inc.	12-4-87	11799-11885' 12160-12246' 12480-12838' 12915-13087'	258 BOPD 0 BWPD 299 MCF/day 12/64" choke 750# FTP	297 BOPD 1 BWPD (109680 BO) (258 BW) Flowing	2603'	630'	8'
34-29 MOI SWSE 29-143-101 Meridian Oil, Inc.	8-24-88	10849-12093'	356 BOPD 0 BWPD gas flared 18/64" choke 520# FTP	205 BOPD 1 BWPD (28736 BO) (37 BW) Flowing	1267'	586'	10'
12-1 Federal SWSW 12-143-102 Conoco, Inc.	5-24-88	10514-11846'	61 BOPD 0 BWPD 35 MCF/day 10/64" choke 200# FTP	32 BOPD 0 BWPD (8744 BO) (0 BW) Pump	1100'	516'	19'
33-19 MOI NWSE 19-145-103 Meridian Oil, Inc.	6-7-88	11200-12712'	443 BOPD 0 BWPD 172 MCF/day 24/64" choke 205# FTP	271 BOPD 5 BWPD (63477 BO) (37 BW) Flowing	1512'	806'	10'
43-36H State NESE 36-147-103 Meridian Oil, Inc.	9-25-88	11178-14548'	253 BOPD 0 BWPD 209 MCF/day 20/64" choke 150# FTP	169 BOPD 2 BWPD (13090 BO) (60 BW) Pump	3292'	525'	36'
44-23H MOI SESE 23-143-102 Meridian Oil, Inc.	Not Available	Not Available	Not Available	87 BOPD 0 BWPD (5320 BO) (49 BW)	Not Available	Not Available	Not Available
32-33H MOI SWNE 33-147-102 Meridian Oil, Inc.	Not Available	Not Available	Not Available	111 BOPD 0 BWPD (3061 BO) (4 BW)	Not Available	Not Available	Not Available

TABLE 3. Horizontal Hole Spacing Hearings Through March, 1989.

DATE	CASE#	COMPANY	LOCATION	FIELD
May 11, 1987	4322	Meridian Oil Company	11-143-102	Elk Ranch
September 30, 1987	4382	Conoco	12-143-102	Elk Ranch
	4382	Conoco	13-143-102	Elk Ranch
August 27, 1987	4392	Meridian Oil Company	27-146-101	Flat Top Butte
August 27, 1987	4393	Meridian Oil Company	27-143-102	Roosevelt
August 27, 1987	4394	Meridian Oil Company	3-143-102	Elk Ranch
November 2, 1987	4410	Meridian Oil Company	27-146-101	Flat Top Butte
November 17, 1987	4417	Meridian Oil Company	1-146-103	Pierre Creek
	4417	Meridian Oil Company	7-146-102	Pierre Creek
	4417	Meridian Oil Company	30-147-103	Pierre Creek
November 17, 1987	4418	Meridian Oil Company	35-143-102	Roosevelt
July 27, 1988	4553	Meridian Oil Company	33-145-101	Devils Pass
July 27, 1988	4554	Meridian Oil Company	33-147-102	Hay Draw
July 27, 1988	4555	Meridian Oil Company	33-146-101	Flat Top Butte
July 27, 1988	4556	Meridian Oil Company	23-143-102	Elk Ranch
July 27, 1988	4557	Meridian Oil Company	35-146-104	Bicentennial
August 31, 1988	4576	Meridian Oil Company	7-145-102	Wildcat
October 26, 1988	4606	Meridian Oil Company	11-146-103	Poker Jim
October 26, 1988	4607	Meridian Oil Company	33-143-102	Roosevelt
October 26, 1988	4608	Meridian Oil Company	25-143-102	Elk Ranch
October 26, 1988	4609	Meridian Oil Company	17-145-103	Bicentennial
October 26, 1988	4609	Meridian Oil Company	29-145-103	Bicentennial
November 16, 1988	4615	Meridian Oil Company	23-145-103	Wildcat
November 16, 1988	4616	Meridian Oil Company	3-144-103	Wildcat
November 16, 1988	4617	Meridian Oil Company	25-147-103	Pierre Creek
November 16, 1988	4618	Meridian Oil Company	21-146-101	Flat Top Butte

HORIZONTAL SPACING HEARINGS (Cont.)

DATE	CASE#	COMPANY	LOCATION	FIELD
November 16, 1988	4619	Meridian Oil Company	33-143-101	Elk Ranch
January 25, 1989	4643	Meridian Oil Company	35-144-102	Elk Ranch
January 25, 1989	4644	Meridian Oil Company	21-143-102	Roosevelt
January 25, 1989	4646	Meridian Oil Company	7-143-100	Wildcat?
February 22, 1989	4660	BWAB	21-147-103	Wildcat?
February 22, 1989	4661	BWAB	36-144-103	Wildcat?
February 22, 1989	4662	BWAB	36-145-102	Buckhorn
February 22, 1989	4663	BWAB	24-144-103	Wildcat
February 22, 1989	4664	BWAB	8-144-103	Bicentennial
February 22, 1989	4665	Meridian Oil Company	17-144-102	Wildcat
February 22, 1989	4666	Meridian Oil Company	19-144-103	Bicentennial
March 24, 1989	4687	Meridian Oil Company	27-145-101	Rough Rider