### PSRe-Evaluating Petroleum Potential of Birdbear Formation in McKenzie County, Williston Basin North Dakota\*

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### **Abstract**

The Birdbear Formation in the Williston Basin is a carbonate-evaporite sequence that extends across western North Dakota, eastern Montana, southern Manitoba, and southwestern Saskatchewan. This study evaluates role of diagenesis on porosity and permeability, as compared to the depositional patterns/facie of the Birdbear Formation in McKenzie County North Dakota, to re-evaluate its petroleum potential. This study looks at: 1) core and thin section examination; 2) performed geochemical analysis (TOC Rock-Eval program pyrolysis); 3) wireline log correlations of the formation; and 4) nuclear magnetic resonance (NMR) spectroscopy measurements was used to determine the role of deposition and diagenesis on porosity types, lateral and vertical distribution of reservoir porosity, lateral and vertical distribution of prospective source beds and anhydrite seals.

The Birdbear has two distinct units; 1) a lower carbonate dolomite-limestone (boundstone to wackestone) unit, with abundant organic material that is being evaluated as potential source material for hydrocarbon production using TOC Rock Eval Pyrolysis; and 2) an upper anhydrite-carbonate (packstone) unit that has the ability to entrap migrating fluids within the study area. Rocks in the upper section of the lower carbonate unit were exposed to high diagenetic alteration that enhanced permeability and porosity types that includes, intra-crystalline, inter-granular, solution enhanced, and moldic vuggy porosities. These were confirmed by NMR spectroscopy analysis from marked producible fluids indications and porosity maps across McKenzie County (center of the Williston basin).

The rocks in the formation showed marked selective or partial dolomitization, micritization and dissolution of calcite cement from inclusion of brines, creating excellent reservoir rock qualities of porosity and permeability (15-20%  $\Phi$ , 20-85 md perm). Hydrocarbon production in the Birdbear Formation has been documented to be from restricted intervals of varying lithological thickness up to a feet, from two distinct dolomitized zones. TOC Rock-Eval program pyrolysis data indicate fair to good distribution of prospective source beds (1-2% TOC) that are thermally mature and within oil generating window. This indicates the Birdbear Formation may be a self-sourced hydrocarbon system within the Williston Basin.

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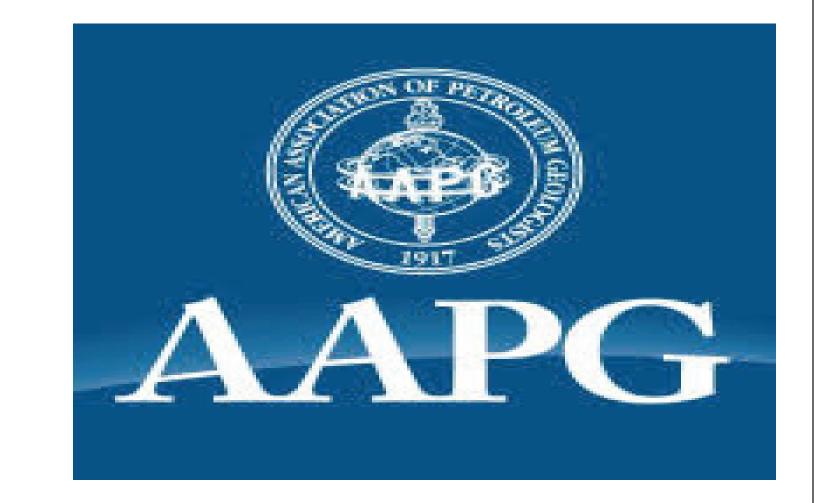


# RE-EVALUATING PETROLEUM POTENTIAL OF BIRDBEAR FORMATION IN MCKENZIE COUNTY,

# WILLINSTON BASIN NORTH DAKOTA

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### Abstract

The Birdbear Formation in the Williston Basin is a carbonate-evaporite sequence that extends across western North Dakota, eastern Montana, southern Manitoba and southwestern Saskatchewan. This study evalu-Birdbear Formation in McKenzie County North Dakota, to re-evaluate its petroleum potential. This study looks at: 1) core and thin section examination; 2) performed geochemical analysis (TOC Rock-Eval program

The Birdbear has two distinct units; 1) a lower carbonate dolomite-limestone (boundstone to wackestone) unit, with abundant organic material that is being evaluated as potential source material for hydrocarbon production using TOC Rock Eval Pyrolysis; and 2) an upper anhydrite-carbonate (packstone) unit that has the ability to entrap migrating fluids within the study area. Rocks in the upper section of the lower carbonate unit were exposed to high diagenetic alteration that enhanced permeability and porosity types that includes, intra-crystalline, inter-granular, solution enhanced and moldic vuggy porosities. These were confirmed by NMR spectroscopy analysis from marked producible fluids indications and porosity maps across McKenzie County (center of the Williston basin).

The rocks in the formation showed marked selective or partial dolomitization, micritization and dissolution of calcite cement from inclusion of brines, creating excellent reservoir rock qualities of porosity and permeability (15-20% Φ, 20-85 md perm). Hydrocarbon production in the Birdbear Formation has been documented to be from restricted intervals of varying lithological thickness up to a feet, from two distinct dolomitized zones. TOC Rock-Eval program pyrolysis data indicate fair to good distribution of prospective source beds (1-2% TOC) that are thermally mature and within oil generating window. This indicates the Birdbear Formation may be a self-sourced hydrocarbon system within the Williston Basin.

# Purpose of Research

- Identify and describe sedimentary facies of the Birdbear Formation, and determine its lateral extent.
- Identify, evaluate type and map Birdbear Formation source beds.
- Determine the relationship between diagenesis, porosity and permeability of the rock units of the Bird-

Determine the stratigraphic and geographic extent of active source beds. Further correlate identified facie in relation to porosity zones and intervals.

To measure total organic carbon (TOC) present, and determine level of thermal maturation of source beds, generation of hydrocarbon; and evaluate potential reservoir quality related to production trends.

# Map of Study Area

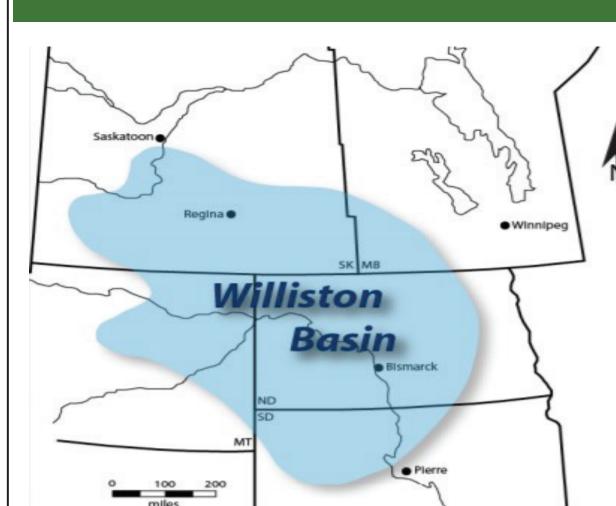


Figure 1. Extent of the Williston Basin in North America

Figure 2. Map of McKenzie County showing distribution of Birdbear wells

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# Introduction

The Williston Basin is an intra-cratonic sedimentary basin in the heart of North America that covers several thousand square miles across parts of North Dakota, South Dakota, Montana, Manitoba and Saskatchewan. ates role of diagenesis on porosity and permeability, as compared to the depositional patterns/facie of the The rock unit's range from marine, shallow marine, non-marine, sabkha conditions and fluvial deposits that were laid down from various land modifying events over several millions of years.

pyrolysis); 3) wireline log correlations of the formation; and 4) nuclear magnetic resonance (NMR) spectros- In North Dakota, the Birdbear Formation is one of the producing units in the Williston Basin that has not copy measurements was used to determine the role of deposition and diagenesis on porosity types, lateral been extensively studied, but may have great potential for hydrocarbon production because of its unique and vertical distribution of reservoir porosity, lateral and vertical distribution of prospective source beds and lithology (deposited in late Devonian regressive phase, (Halabura, 1982), thickness, porosity and permeability, extent and distribution of lithofacies. To better understand the Birdbear Formation and re-evaluate its petroleum potential in the Williston Basin, this study was aimed to recognize and identify the distribution of sedimentary facies within the study area, evaluate source-bed potentials and its mappable producing thickness, determine if facies are thermally matured, type of kerogen present and if within oil generating window, interpret facies changes from diagenetic activity in relation to porosity types and permeability trends and the general over view of its reservoir characteristics.

> Thirteen cores were examined for petro-physical and thin section analysis to evaluate distinct depositional facies related to environment of deposition, its changes, distribution and extent, degree of burial and diagenetic alterations of potential reservoir evaluation. Core plugs were soaked in distilled water for two weeks to saturate pores and then placed in an NMR spectroscopy machine. Samples runs were from four hours to twelve hours to evaluate the size distribution of pores within limestone and dolomite facies of the Birdbear Formation. Over 1100 compensated neutron density logs tops were picked for facies mapping and correlation, and additional 150 logs were digitized to determine porosity zones and hydrocarbon producing inter-

> Rock-Eval pyrolysis of eight pulverized samples of weight (65 to 80 mg), were placed in crucibles on a source rock analyzer (SRA) analysis machine and were gradually heated under inert atmosphere to determine crackable hydrocarbons (TOC) from source beds of the Birdbear with a steady and gradual heating increase from 300 to 650oC. This study covers McKenzie County in northwestern North Dakota from available data of producing Birdbear wells and extends a little into the Williams County for a better understanding of potential hydrocarbon production play system.

Estimate the density of source beds using Compensated Neutron Density (CND) logs.

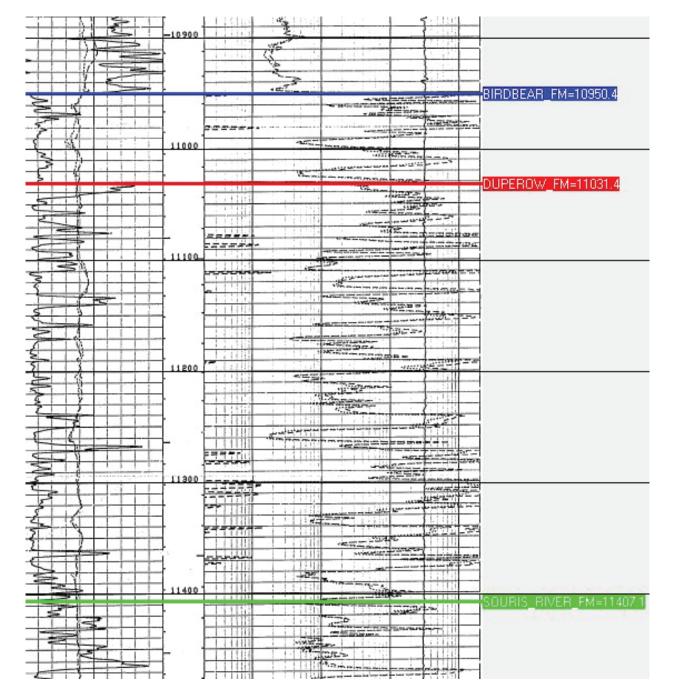


Figure 3. Wireline log from Compensated Neutron Density showing the Birdbear Formation.

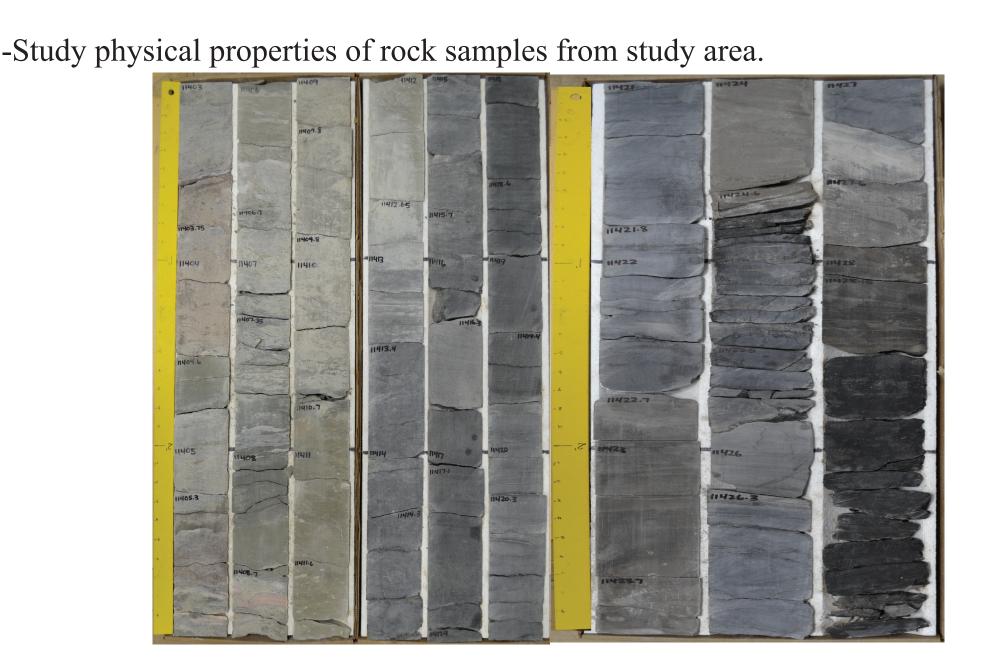
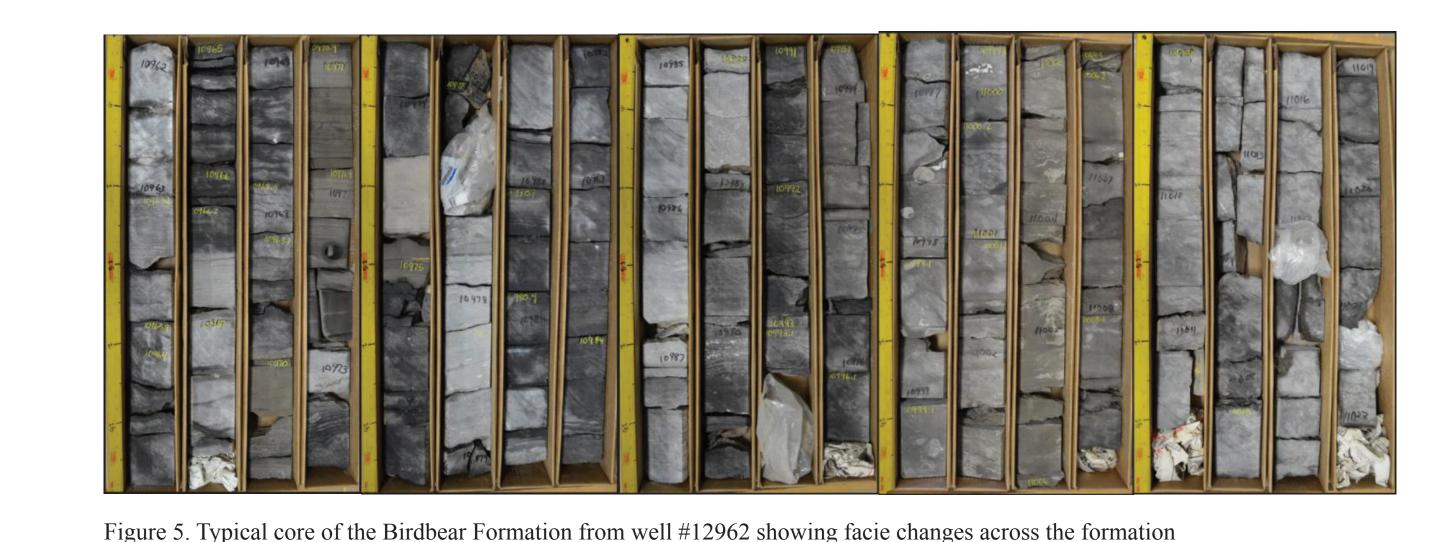
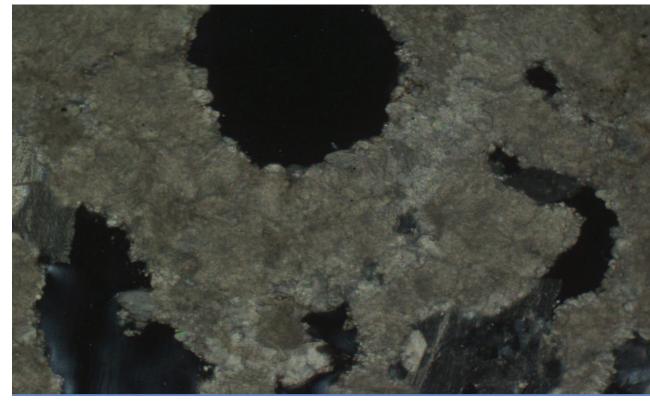


Figure 4. Typical core of the Birdbear Formation from well #21786 showing facie changes across the formation.



-Evaluate porosity level and type from thin section analysis.



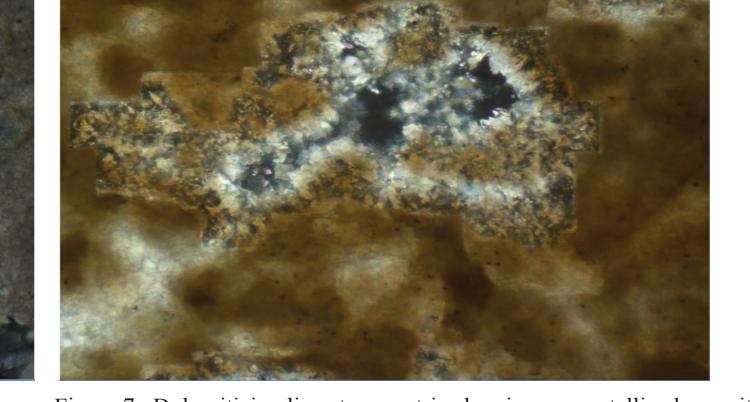
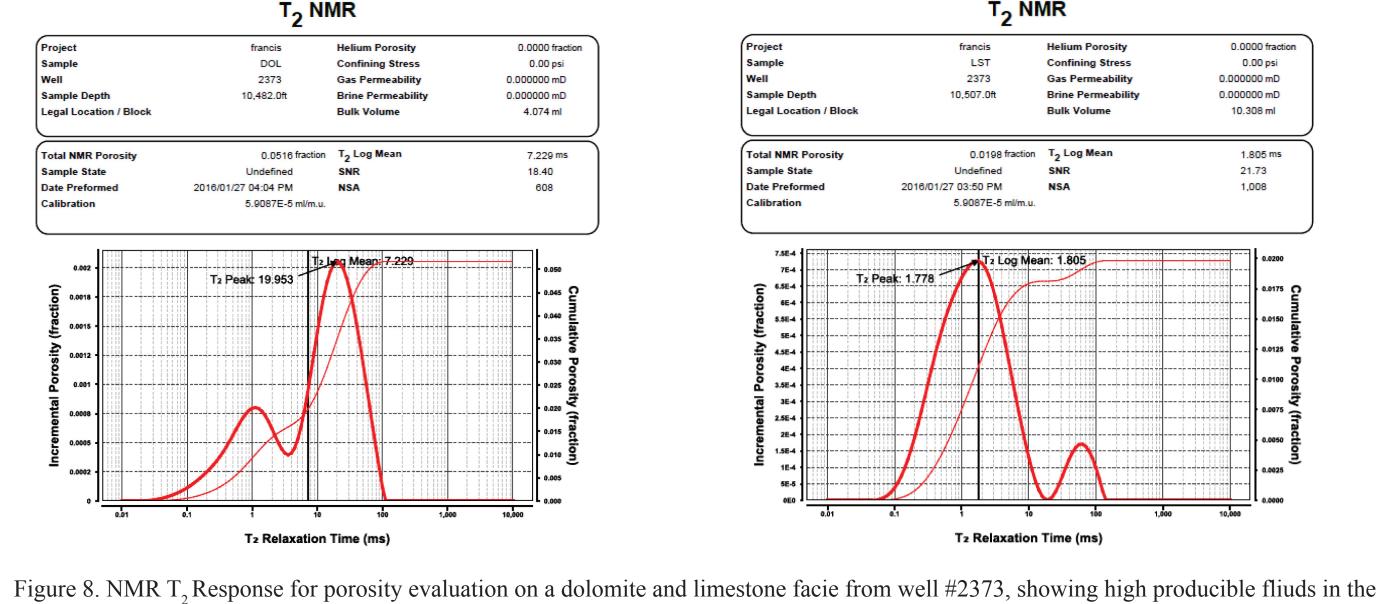


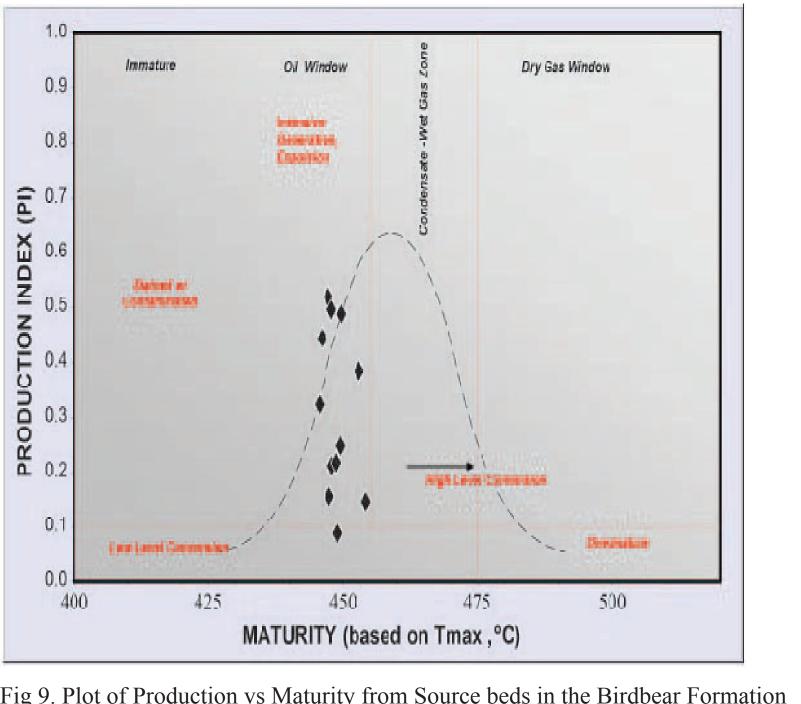
Figure 7. Dolomitizing limestone matrix showing re-crystallized porosity, Figure 6. Limestone matrix showing evidence of vuggy porosity, characteristics of the lower carbonate unit. characteristics of the lower carbonate unit.

-Estimate percentage porosity from NMR spectroscopy.

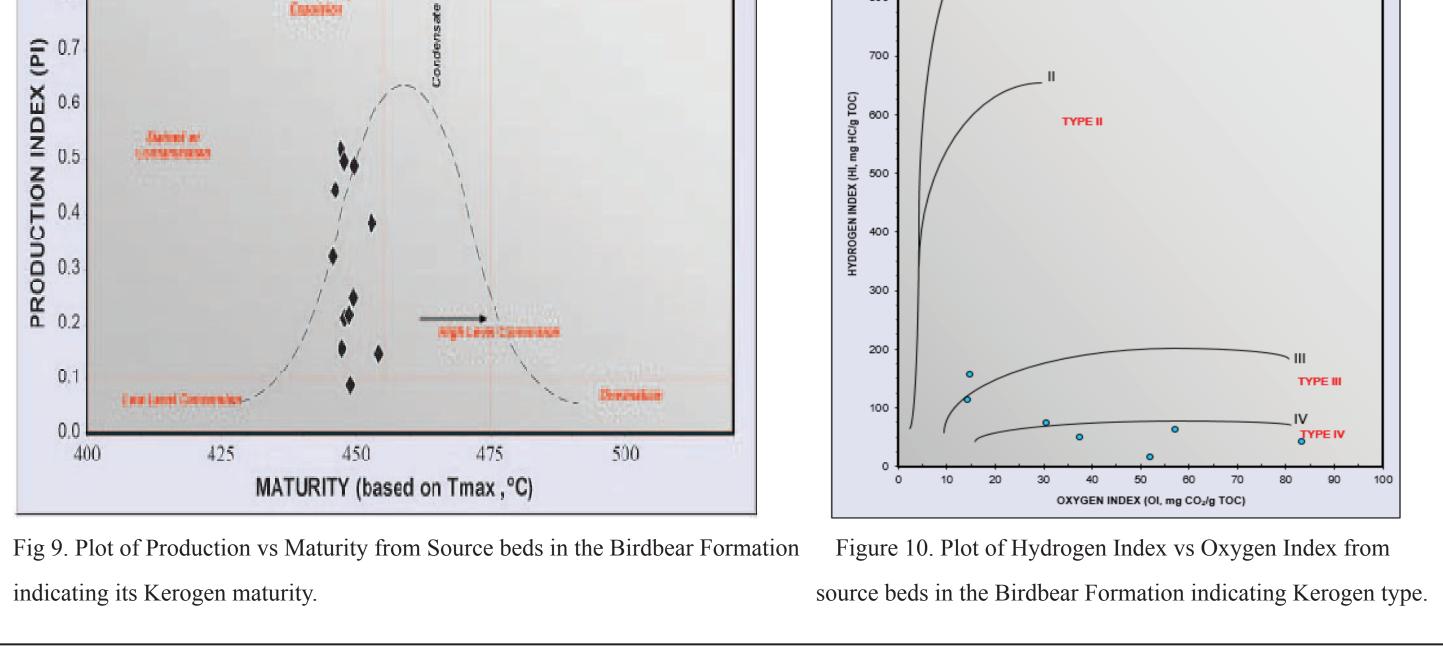


dolomite facie as against more clay bound fluids in limestone facie.

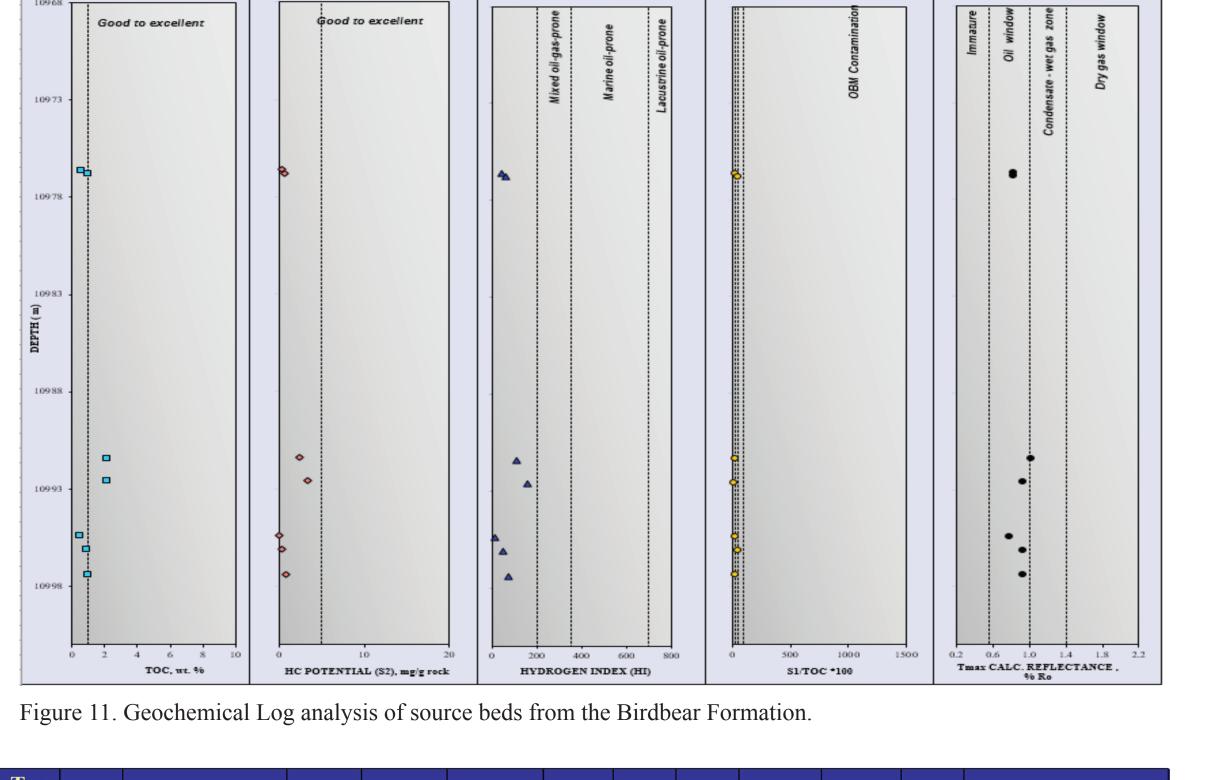
### -Evaluate source beds and TOC (crackable hydrocarbon) by programmed pyrolysis (SRA).



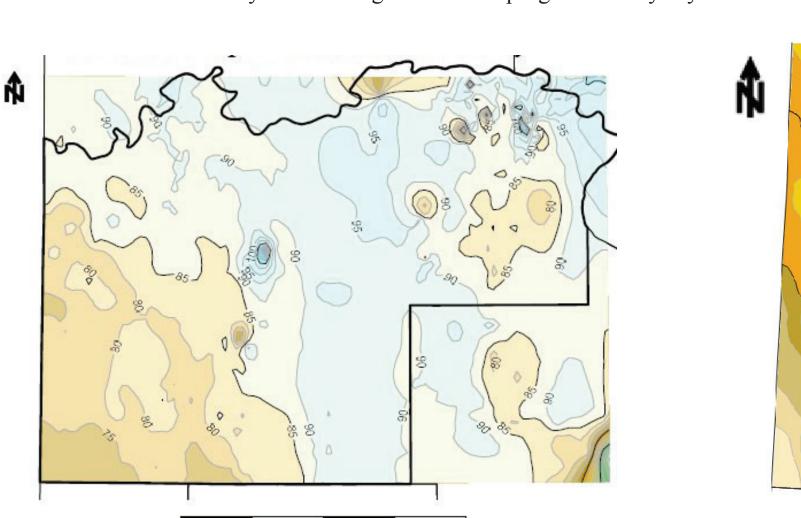
indicating its Kerogen maturity.



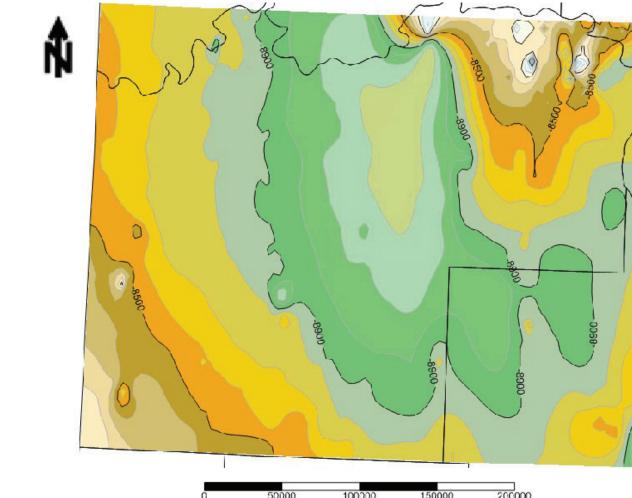
# Results NDGS 5742 Table 1. Summary of core analysis from NMR Sprectroscopy of 13 wells used for porosity determination



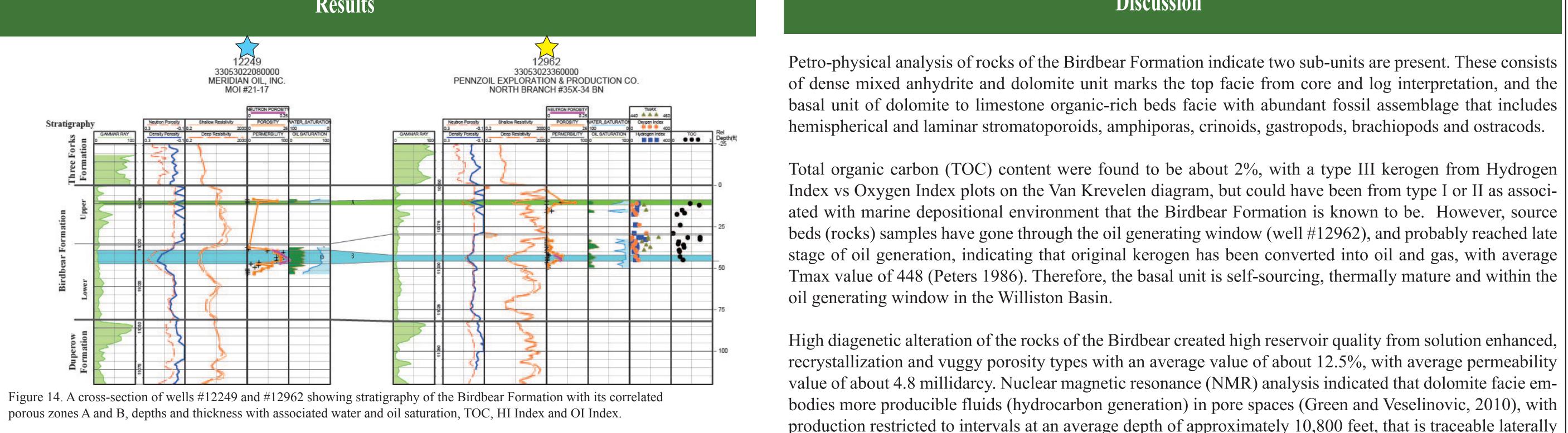
epth ()	SRA TOC	$\mathbf{S}_1$	$S_2$	S <sub>3</sub>	Tmax (°C)	Calc. % Ro	HI	OI	S2/S3	\$1/TOC *100	PI	Lab ID
10971	1.39	3.38	1.16	0.97	310		83	70	1.2	243	0.74	12962-10971
10972	2.05	0.28	1.52	0.47	447	0.89	74	23	3.2	14	0.16	12962-10972
10975	0.80	0.15	0.56	0.27	448	0.90	70	34	2.1	19	0.21	12962-10975
10977	0.54	0.14	0.23	0.45	443	0.82	43	83	0.5	26	0.38	12962-10976.6
10977	0.98	0.47	0.61	0.56	443	0.82	62	57	1.1	48	0.44	12962-10976.8
10977	0.28	0.07	0.14	0.24	435	0.68	50	86	0.6	25	0.33	12962-10977.3
10978	0.43	0.08	0.17	0.28	438	0.72	40	65	0.6	19	0.32	12962-10977.5
10984	0.67	0.59	0.39	0.62	295		58	93	0.6	88	0.60	12962-10984
10989	0.16	0.03	0.07	0.26	427	0.53	44	163	0.3	19	0.30	12962-10989
10991	0.56	0.20	0.32	0.25	453	0.99	57	45	1.3	36	0.38	12962-10991.2
10991	2.10	0.41	2.39	0.30	454	1.02	114	14	8.0	20	0.15	12962-10991.4
10992	1.21	0.30	1.08	0.31	449	0.92	89	26	3.5	25	0.22	12962-10991.5
10992	0.42	0.11	0.23	0.19	446	0.86	55	45	1.2	26	0.32	12962-10992
10993	2.10	0.32	3.29	0.31	449	0.92	157	15	10.6	15	0.09	12962-10992.6
10993	0.44	0.12	0.17	0.24	429	0.57	39	55	0.7	27	0.41	12962-10993
10994	0.56	0.20	0.25	0.34	446	0.87	45	61	0.7	36	0.44	12962-10994
10995	0.52	0.09	0.08	0.27	441	0.78	15	52	0.3	17	0.53	12962-10995.5
10996	0.91	0.63	0.64	0.34	448	0.90	70	37	1.9	69	0.50	12962-10996
10996	0.88	0.41	0.43	0.33	450	0.94	49	38	1.3	47	0.49	12962-10996.1
10997	0.95	0.23	0.70	0.29	450	0.93	74	31	2.4	24	0.25	12962-10997.4
10999	0.59	0.40	0.37	0.35	447	0.89	63	59	1.1	68	0.52	12962-10999.1
11000	0.62	0.22	0.26	0.40	442	0.79	42	65	0.7	35	0.46	12962-11000
11003	0.66	0.70	0.48	0.39	429	0.56	73	59	1.2	106	0.59	12962-11003
11005	0.87	1.03	0.50	0.73	422	0.43	57	84	0.7	118	0.67	12962-11005

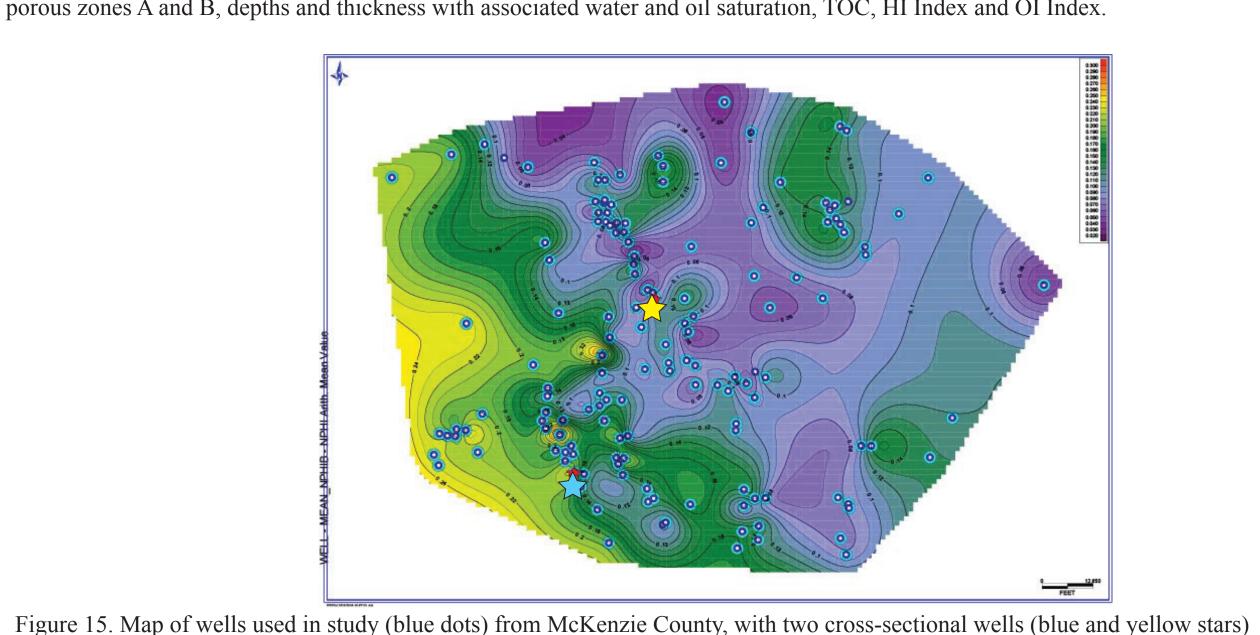


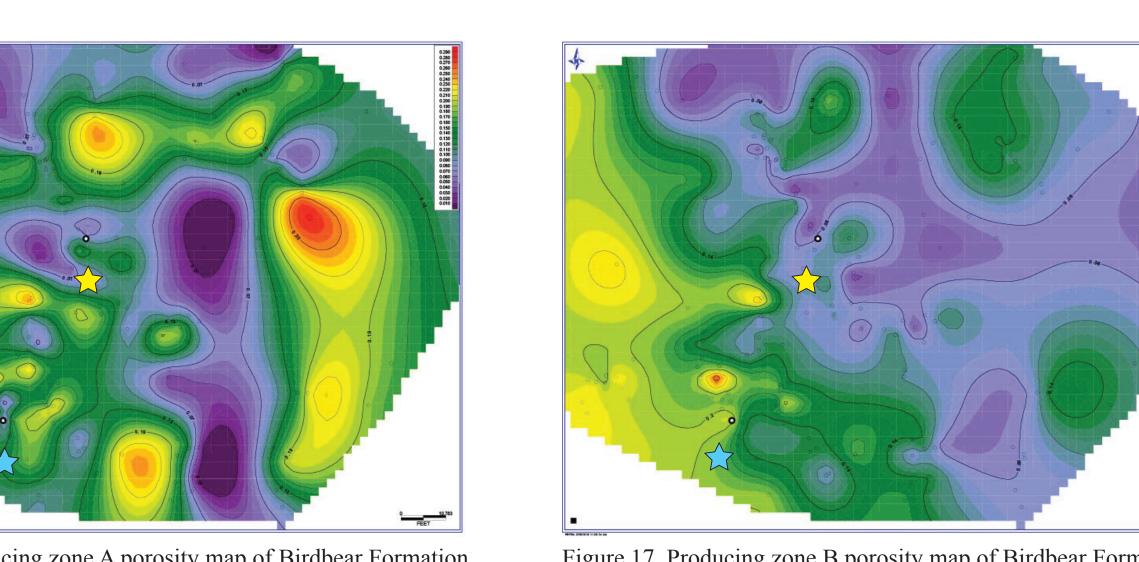
Contour interval = 5ft Figure 12. Isopach Map of Birdbear Formation showing thickness across study area, as thickness increases centrally and in the northeast portion.



Contour Interval = 100ft Figure 13. Contour Map of Birdbear Formation showing topographic feartures of the formation across McKenzie County.





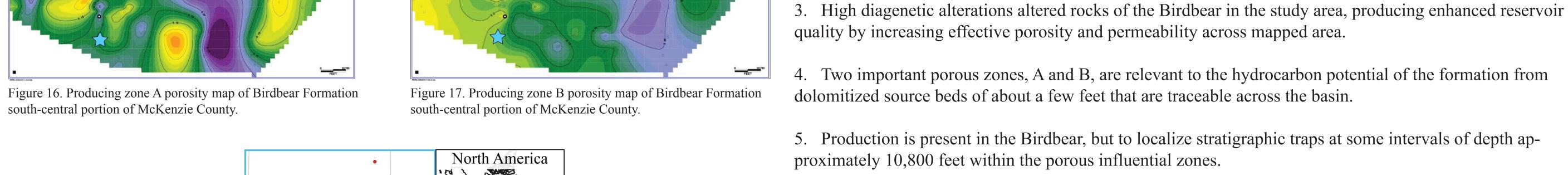


- 200,000-500,000

- 100,000-200,000

- 10,000-50,000

Figure 18. Cumulative production map of Birdbear Formation across Mckenzie and Willams Counties.



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type I or II kerogen.

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Klienberg, R. L., W. E. Kenyon, P. P. Miltra, 1994, Mechanism of NMR relaxation of fluids in rock, Journal of magnetic Reso-

and continuously across the Williston Basin. Limestone facie holds more capillary fluids (formation water)

An Isopach map of the Birdbear Formation with a maximum thickness of a 100 feet, indicate that sedimenta-

tion thickens in the center and northeastern sections of McKenzie County. This further corresponds with po-

rosity map of the B porosity zone, synonymous with high hydrocarbon production from a potential hydrocar-

bon play system. Interpretation from the Birdbear contour map shows that hydrocarbon potential is further

enhanced by both the Beaver Creek and Nesson anticlines, providing structural, stratigraphic and combined

trap reservoirs in the south-central and northeastern portions of the Williston Basin. However hydrocarbon

production in the Birdbear over the last decade is estimated to be over 500 (Barrel of Oil Equivalent)

(LeFever Julie, 2009), this could further be increased from more dedicated studies and high technological ad-

Conclusion

1. The Birdbear Formation has a distinct anhydrite, dolomite and limestone lithology that is easily identifi-

. Sediments of the Birdbear are thermally mature and may be self-sourcing hydrocarbon formation with

good (TOC) content that indicated hydrocarbon generation from a type III kerogen, but could probably be a

associated with hydrocarbon migration in the formation.

Halabura, S., 1982, Depositional environments of Upper Devonian Birdbear Formation, Saskatchewan: North Dakota Geological Survey & Saskatchewan Geological Society – Fourth International Symposium, p. 113–124. Martiniuk, C. D., H. R. Young, and J. A. LeFever, 2010, Lithofacies and Petroleum Potential of the Birdbear Formation (Upper