

# **PS Pore Characterization of Bakken Shales (Mississippian-Devonian) in the Williston Basin\***

**Chioma Onwumelu<sup>1</sup> and Stephan Nordeng<sup>1</sup>**

Search and Discovery Article #11242 (2019)\*\*

Posted August 19, 2019

\*Adapted from poster presentation given at AAPG 2019 Annual Convention & Exhibition, San Antonio, Texas, May 19-22, 2019

\*\*Datapages © 2019. Serial rights given by author. For all other rights contact author directly. DOI:10.1306/11242Onwumelu2019

<sup>1</sup>University of North Dakota, Grand Forks, ND, United States ([chioma.onwumelu@und.edu](mailto:chioma.onwumelu@und.edu))

## **Abstract**

Oil and gas production from the unconventional resources has increased over the last decade. Despite the significant production from the middle siliciclastic/carbonate member of the Bakken Formation in the Williston Basin, little or none has been produced from the upper and lower shales. Understanding the pore geometry and structures as it relates to porosity in organic material is essential. Thus, it is important to develop an approach to characterize the pores within the shale to better understand how oil is expelled from these shales. We propose to test the idea that Nuclear Magnetic resonance (NMR) transverse relaxation time (T<sub>2</sub>) reflect the development of porosity in organic material in shales. Five wells from North Dakota and one well each from Montana, Saskatchewan and Manitoba will be utilized for this study. Preliminary result of NMR on samples from North Dakota shows that the pores within Bakken Shales are predominantly micropores with thermally matured samples having the least percentage. The objective of this study is to use the NMR T<sub>2</sub> to determine how the porosity of NMR is evident in organic pores and link its porosity to porosity seen in the Field Emission Scanning Electron Microscope (FE-SEM) on ion milled samples to understand the nanometer and micrometer scale pore properties and pore geometry. I expect that with maturation, pores within the kerogen macerals will change in size, frequency and shape. Linking the NMR pore and FE-SEM pores will provide an understanding of the pore properties and geometry which is important in evaluating and developing of Bakken shales, thus maximize production.

## **References Cited**

- Brownstein, K.R., & Tarr, C.E. (1979). Importance of classical diffusion in NMR studies of water in biological cells. *Physical review A*, 19(6), 2446.
- Clarkson, C.R., Solano, N., Bustin, R.M., Bustin, A.M.M., Chalmers, G.R.L., He, L., and Blach, T.P. (2013). Pore structure characterization of North American shale gas reservoirs using USANS/SANS, gas adsorption, and mercury intrusion. *Fuel*, 103, 606-616.
- Grunewald, E., and Knight, R. (2009). A laboratory study of NMR relaxation times and pore coupling in heterogeneous media. *Geophysics*, 74(6), E215-E221.

- Green, D.P., and Veselinovic, D. (2010). Analysis of unconventional reservoirs using new and existing NMR Methods. GeoCanada, Calgary, Canada.
- Jin, H., and Sonnenberg, S. A. (2014). Characterization for source-rock potential of the Bakken Shales in the Williston basin, North Dakota and South Montana. In AAPG Annual Convention and Exhibition (p. 37). Pittsburgh, PA: American Association of Petroleum Geologists.
- LeFever, J.A., Martiniuk, C.D., Dancsok, E.F., and Mahnic, P.A. (1991). Petroleum potential of the middle member, Bakken Formation, Williston Basin. Williston Basin Symposium.
- Loucks, R.G., Reed, R.M., Ruppel, S.C., and Hammes, U. (2012). Spectrum of pore types and networks in mudrocks and a descriptive classification for matrix-related mudrock pores. AAPG Bulletin, 96(6), 1071-1098.
- Peters, K.E., and Cassa, M.R. (1994). Applied source rock geochemistry: Chapter 5: Part II. Essential elements.
- Ross, D.J., and Bustin, R.M. (2009). The importance of shale composition and pore structure upon gas storage potential of shale gas reservoirs. Marine and Petroleum Geology, 26(6), 916-927.
- Sandberg, C.A., and Hammond, C.R. (1958). Devonian system in Williston Basin and central Montana. AAPG Bulletin, 42(10), 2293-2334.
- Smith, M.G., and Bustin, R.M. (1995). Sedimentology of the Late Devonian and Early Mississippian Bakken Formation, Williston Basin. Williston Basin Symposium.
- Thrasher, L.C. (1985). Macrofossils and biostratigraphy of the Bakken Formation (Devonian and Mississippian) in western North Dakota.
- Webster, R.L. (1984). Petroleum source rocks and stratigraphy of Bakken Formation in North Dakota. AAPG Bulletin, 68(7), 953-953.
- Wignall, P.B. (1991). Model for transgressive black shales? Geology, 19(2), 167-170.
- Wignall, P.B., and Maynard, J.R. (1993). The sequence stratigraphy of transgressive black shales. AAPG Stud. Geol, 37, 35-47.
- Xu, J., and Sonnenberg, S.A. (2017, September). An SEM Study of Porosity in the Organic-rich Lower Bakken Member and Pronghorn Member, Bakken Formation, Williston Basin. In Unconventional Resources Technology Conference, Austin, Texas, 24-26 July 2017 (pp. 3213-3225). Society of Exploration Geophysicists, American Association of Petroleum Geologists, Society of Petroleum Engineers.

Chioma J. Onwumelu (chioma.onwumelu@und.edu) and Stephan H. Nordeng (Stephan.nordeng@und.edu)

Harold Hamm School of Geology and Geological Engineering, University of North Dakota

## Abstract

Oil and gas production from the unconventional resources has increased over the last decade. Despite the significant production from the middle siliciclastic/carbonate member of the Bakken Formation in the Williston Basin, little has been produced from the upper and lower shales. Understanding the pore geometry and structures as it relates to porosity in organic material is essential. Thus it is important to develop an approach to characterize the pores within the shale to better understand how oil is expelled from these shales. Five wells from North Dakota were utilized for this study. The objective of this study is to use NMR T<sub>2</sub> to determine how the porosity of NMR is evident in organic pores and link its porosity to porosity seen in the scanning electron microscope (SEM) on ion milled samples to understand the nanometer and micrometer scale pore properties and pore geometry. Results shows that with maturation, pores within the kerogen marcelar changed in size, frequency and shape. Linking the NMR pore and SEM pores provided an understanding of the pore properties and geometry which is important in evaluating and developing of Bakken Shales, thus maximize production.

## Geologic Context and Sample Information

- 10 samples from 5 wells in the North Dakota portion of the Williston Basin
- 5 samples from Lower Bakken Shale
- 5 samples from Upper Bakken Shale

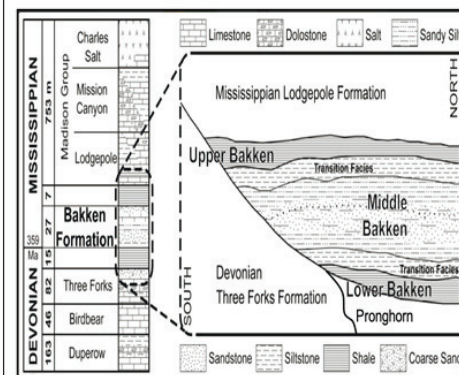


Figure 1: Stratigraphic column of North Dakota showing the location of Bakken Formation

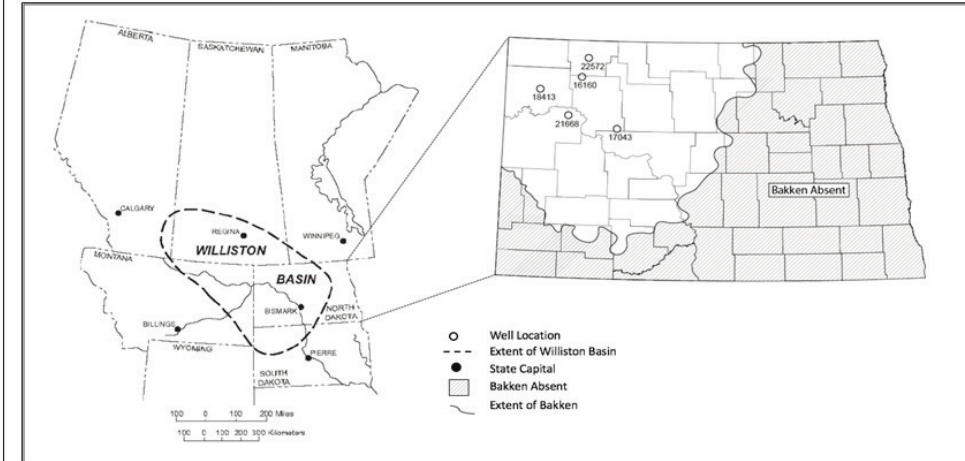


Figure 2: Map of the study area

NDIC File No	Well Name	API Number
17043	St Andes	33061006530000
16160		33061004980000
21668	Überwachen	33053038190000
22572		33013016670000
18413	Heidi	33105017560000

Five wells from North Dakota were used in this study. These wells were picked because of the availability of cores for petrographic studies.

## Methods

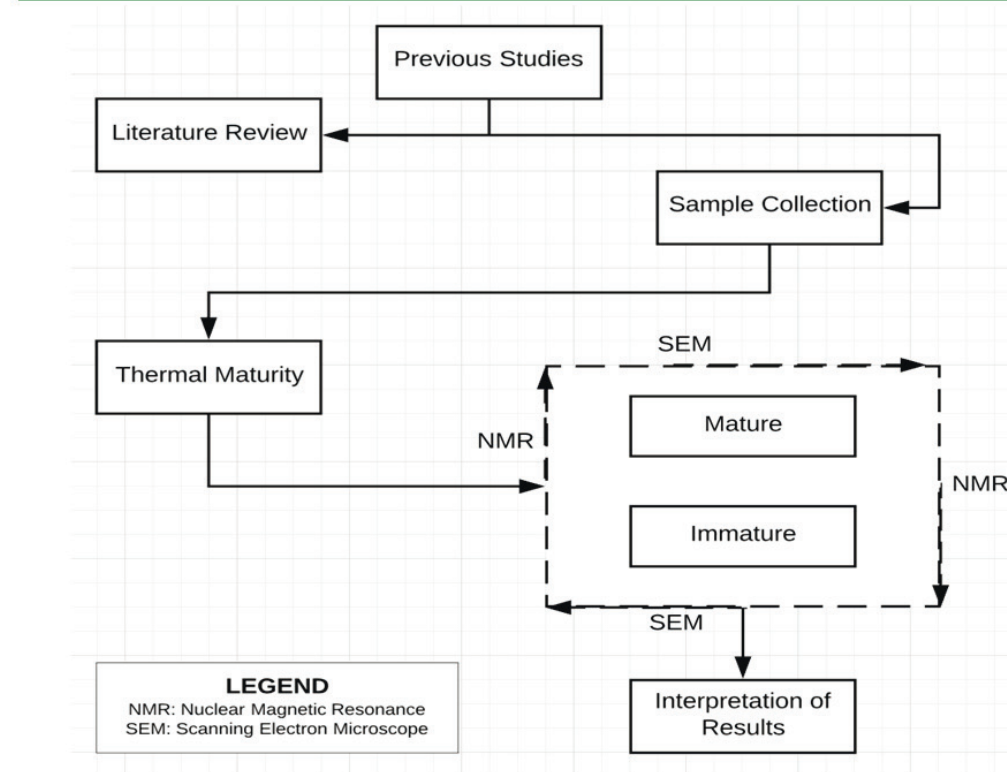


Figure 3: Flow chart of research methodology

## Organic Geochemistry

NDIC File No	API Number	S1 (mg HC/g rock)	S2 (mg HC/g rock)	Tmax (°C)	S3 (mg CO <sub>2</sub> /g rock)	TOC (wt.%)	HI (mg HC/g C)	OI (mg CO <sub>2</sub> /g C)	PI	Calc. %Ro	Maturity
17043	33061006530000	5.75	99.63	424.39	0.94	15.75	621.97	6.17	0.05	0.5	Immature
16160	33061004980000	7.43	47.38	441.49	0.42	12.00	391.42	3.60	0.15	0.8	Peak mature
21668	33053038190000	9.45	16.82	449.21	0.45	11.43	146.04	4.20	0.36	1.0	Late mature
22572	33013016670000	6.91	89.58	435.78	0.38	15.59	566.00	2.51	0.08	0.7	Peak mature
18413	33105017560000	5.32	44.28	442.99	0.23	12.31	358.92	1.88	0.11	0.8	Peak mature

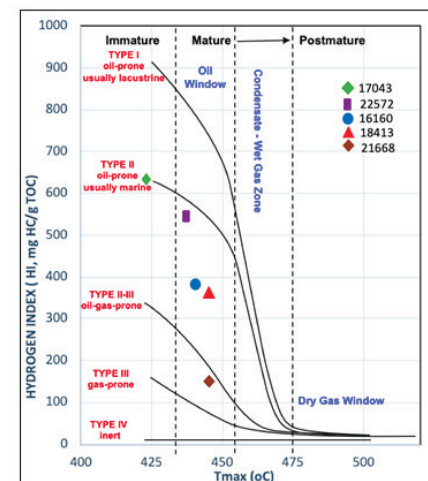


Figure 4: Plot of HI vs Tmax showing maturity

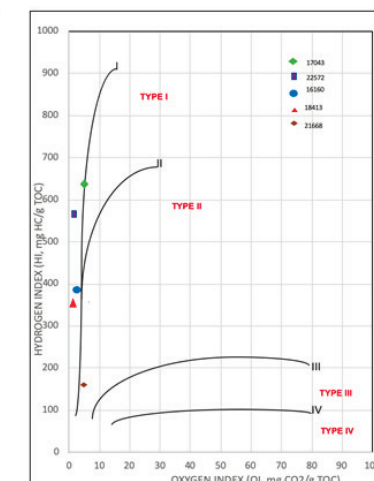


Figure 5: Plot of HI vs OI showing type of organic matter

## SEM Imaging Analyses

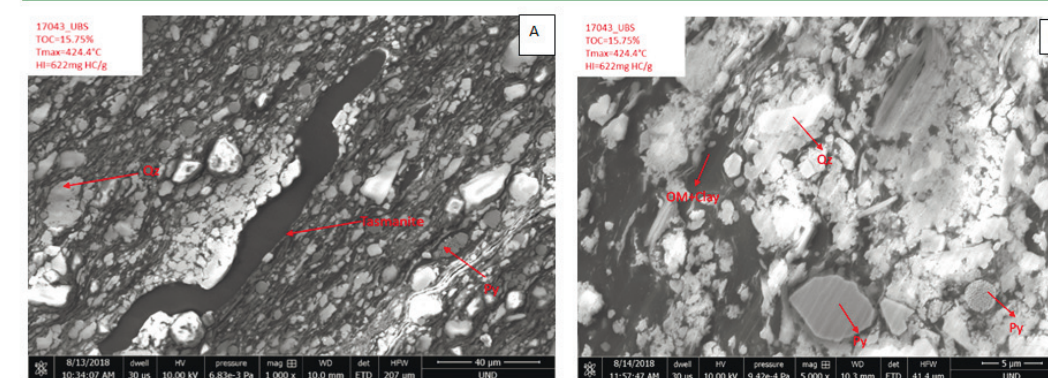


Figure 6: Pore network of immature Bakken Shale (A) Presence of Tasmanites cyst. (B) Organic matter + clay, pyrite nodules.

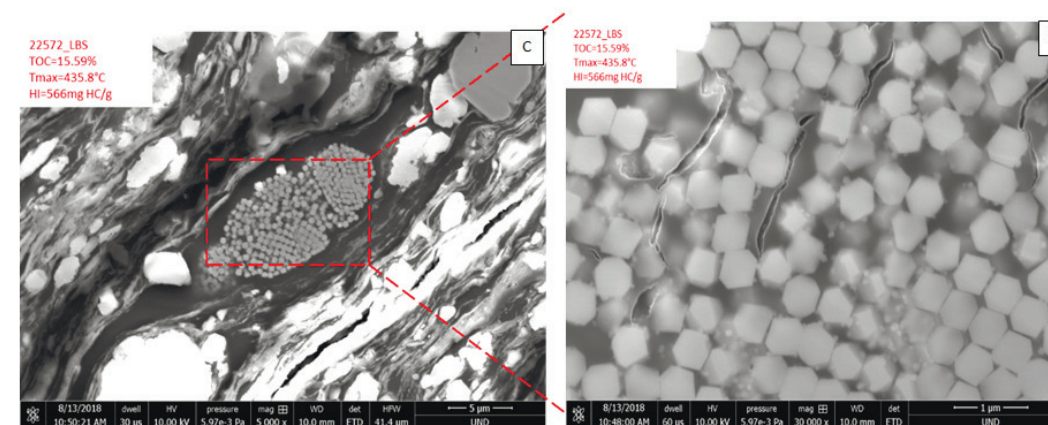


Figure 7: Pore network of mature Bakken Shale (C) Pyrite crystals within organo-clay matrix. (D) Close-up image of the pyrite crystals showing fractures.

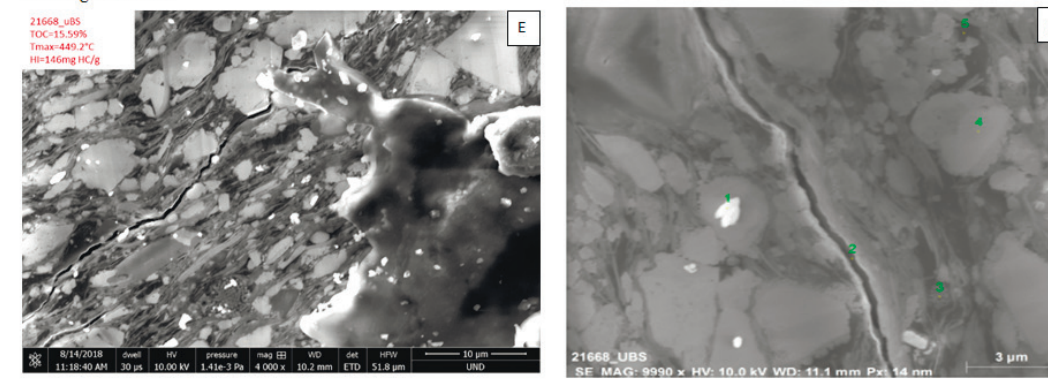


Figure 8: Pore network of mature Bakken Shale (E) Possible artificial shrinkage fracture. (F) Close-up image of (E).

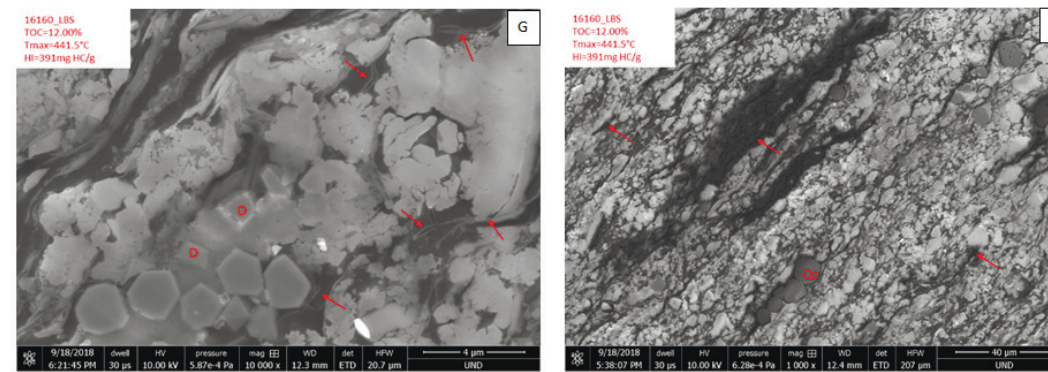


Figure 9: Pore network of mature Bakken Shale (G) Microfractures and dolomite grains. (H) Abundant calcite cement and quartz grains. Note the dolomite grains. Py-pyrite, Qz-quartz, D-dolomite, K-spar-K-feldspar.

## NMR Interpretation

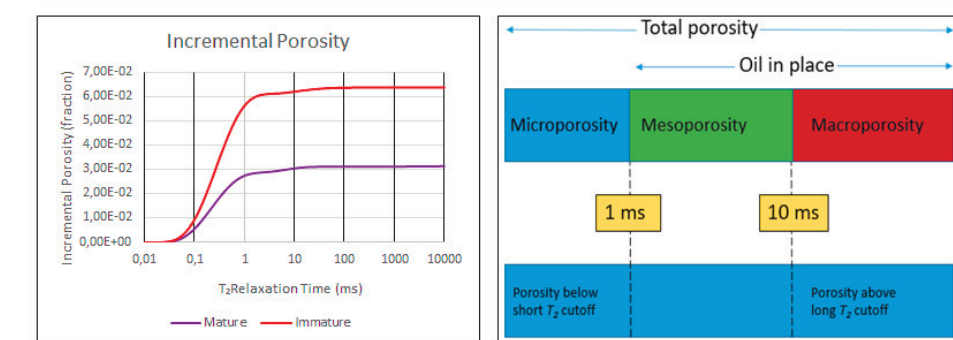


Figure 10: Incremental Porosity of mature and immature well showing the difference in porosity

Figure 11: NMR porosity partitioning based on T<sub>2</sub> cutoffs. Adapted from Green and Veselinovic (2010)

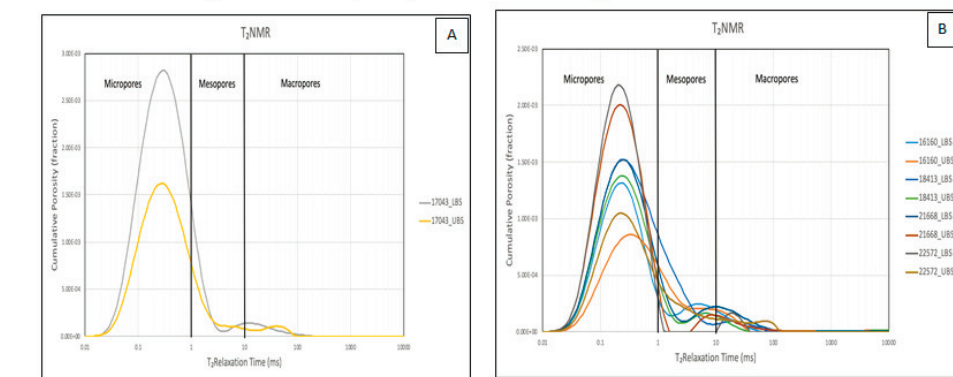


Figure 12: T<sub>2</sub> cutoff for all the study wells (A) immature well (B) matured wells

## Conclusions

- The study wells ranged from thermally immature to over-mature with Tmax ranging from 424.39 °C and 442.99 °C. TOC content ranged from 11.43 to 15.75 (wt%) showing they are very good source rocks.
- Three different types of organic matter pores were seen on the SEM images (mineral matrix pores, organic matter pores and fracture pores).
- NMR results shows that Bakken source rocks are comprised of mainly nanometer to micrometer pore sizes. Although there is difference in the size of mature (total porosity 0.0413) and immature samples (total porosity 0.0638), they were all within the porosity below short T<sub>2</sub> cutoff (1ms).
- Both the SEM and NMR porosity show that porosity decreases with increased maturity which is related to burial and overburden. Low maturity source has high porosity because pores are filled with conductive water and became more matured as high conductive water are replaced with non-conductive hydrocarbon.

## Acknowledgement

The authors thank the staff of Wilson Laird Core Library at the University of North Dakota for the provision of cores and Energy and Environmental Research Center (EERC) for opportunity to use their equipment.