Helium Trends in North Dakota

Timothy O. Nesheim and Ned W. Kruger

GEOLOGIC INVESTIGATION NO. 223
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources
2019

TABLE OF CONTENTS

INTRODUCTION 1

Helium in the Williston Basin 1

Relationship to Nitrogen 1

METHODS 1

RESULTS AND INTERPRETATION 3

DISCUSSION 7

CONCLUSIONS 8

ACKNOWLEDGEMENTS 8

REFERENCES 9-10

TABLES

Table 1. U.S. Bureau of Land Management (2019) data (modified) of gas analyses from 65 samples collected from wells in North Dakota, including helium, nitrogen, methane, and carbon dioxide 2

FIGURES

Figure 1. North Dakota state map with county boundaries (grey lines) and helium gas concentrations by stratigraphic unit 3

Figure 2. Helium versus nitrogen plot for North Dakota gas analyses color coated by geologic age/formation. 4

Figure 3. Helium versus nitrogen plot for the Devonian (Winnipegosis and Duperow Formations) Silurian (Interlake Formation), and Ordovician Red River Formation gas analysis samples of North Dakota. 4

Figure 4. Nitrogen gas analyses for the Ordovician Red River Formation 5

Figure 5. Gas to oil ratios (GOR) of Red River C and D interval production plotted with nitrogen gas concentrations 5

Figure 6. Hydrocarbon, nitrogen, and CO2 concentrations for the Black Island and Deadwood Formations 6

Figure 7. Precambrian basement terrane map for the Williston Basin. 7

Figure 8. Stratigraphic column of the Paleozoic-Mesozoic section of North Dakota's Williston Basin. 8

Figure 9. Regional map showing the extent of the Williston Basin and Prairie evaporite in relations to state and provincial borders 8

Figure 10. Wireline logs with perforation and production information for Amerada Hess's Pederson #14-2. 9

INTRODUCTION

In May of 2018, the element helium was included in a list of 35 minerals or mineral groups, published in the Federal Register, which the United States Department of Interior designated as "critical minerals". A critical mineral is defined as (i) a non-fuel mineral or mineral material essential to the economic and national security of the United States, (ii) the supply chain of which is vulnerable to disruption, and (iii) that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for our economy or our national security. This designation prioritizes the need to find new domestic and foreign supply sources of helium to avert future supply shortages, as have been experienced on and off over the past fourteen years.

Its unique properties are what makes helium critical to various processes and industries. Helium has the lowest boiling point of all elements and will remain a liquid at absolute zero under normal pressure. This makes it ideal for cryogenic applications, which account for its greatest use. Helium is used to create very low temperatures which are necessary for magnetic resonance imaging (MRI) machines, semiconductor processing, and both large-scale research (such as the Large Hadron Collider at CERN) and small-scale scientific research. It is light weight, non-toxic, and both chemically and radiologically inert which makes it a less hazardous alternative to hydrogen as a lifting gas, and also well-suited for use as an effective shielding gas in welding, in pressurizing and purging rocket tanks, in complex fabrication processes, and for leak detection.

Helium is generated by the radioactive decay of uranium and thorium. It is estimated that approximately 3,000 metric tons of helium are generated each year within the lithosphere (Cook, 1957), where it migrates along faults and fractures and can accumulate along with natural gas in subsurface traps. It was first found in concentrated amounts in the natural gas produced by wells in areas of the midcontinental United States in the early 1900s.

The strategical importance of helium to the United States was first acted upon during World War I, at which time finding a domestic source of supply was assigned to the U.S. Bureau of Mines. Later, the Helium Act of 1925 authorized the federal government to acquire lands with potential for helium gas production and established the National Helium Reserve within a vast underground reservoir (Bush Dome) near Amarillo, Texas. In 1960, the Helium Act Amendments provided for the build-up of the National Helium Reserve at Bush Dome, the infrastructure of the associated Cliffside storage facility, and provisions for the Bureau of Mines to construct 425 miles (684 km) of pipeline from Kansas to the Cliffside facility, connecting the National Helium Reserve to plants which could separate helium from natural gas (National Resource Council, 2000).

Following a period of price and supply stability, the Helium Privatization Act of 1996 sought to gradually liquidate the federal government's stake in the National Helium Reserve (National Resource Council, 2000). As this proceeded, and as new uses for helium increased the demand for it, price and supply instability once again arose, despite further legislative initiatives to bring them to heal.

The United States is the world's leading producer of helium with fourteen extraction plants in operation in the states of Arizona, Colorado, Kansas, Oklahoma, Texas, and Utah. These plants extracted an estimated 64 billion cubic feet (1.8 billion cubic meters) of helium from natural gas in 2018 (Peterson, 2019). Much of this production came from the Panhandle-Hugoton field which stretches from southwestern Kansas across the panhandles of Oklahoma and Texas (Brown, 2019). Recently, the United States' share of world production has been declining, as areas of current U.S. production deplete and more production is brought online from outside the United States.

Helium in the Williston Basin

An indication of helium potential in the Canadian portion of the Williston Basin was first discovered in southwestern Saskatchewan in 1952, with production occuring from four wells during the years of 1963 to 1977. Production resumed in the region in 2014. Recent reporting of gas analysis from wells in southwestern Saskatchewan suggests the Deadwood Formation and other lower Paleozic formations tend to have the highest helium concentrations (Yurkowski, 2016).

Relationship to Nitrogen

Natural gases with high concentrations of helium appear to also be associated with high concentrations of nitrogen. A U.S. Bureau of Mines study of 10,074 gas samples representing 6,445 reservoirs from 35 states (Tongish, 1980) found that the samples with the highest helium concentrations came from reservoirs which contained high concentrations of nitrogen.

METHODS

A total of 65 gas analyses (Table 1), which included helium and nitrogen concentrations, were compiled from the United States Bureau of Land Management (USBLM) database (USBLM, 2019) and reviewed for helium-nitrogen concentration by geologic unit. Nitrogen and helium concentrations from the BLM database were plotted and compared by stratigraphic unit to evaluate

Table 1. U.S. Bureau of Land Management (2019) data of gas analyses from 65 samples collected from wells in North Dakota, including helium, nitrogen, methane, and carbon dioxide. When italicized, formation names were added based on perforation data from North Dakota Oil & Gas Division website. Asterisk(*) indicates where BLM data was modified from Devonian & Silurian age to Silurian age based on production data at the time of sampling.

NDIC#	API#	ORIGINAL WELL NAME	ORIGINAL OPERATOR	COUNTY	LATITUDE	LONGITUDE	FIELD	FORMATION	AGE	HELIUM %	NITROGEN %	MENTHANE %	CARBON DIOXIDE %
12363	33105013400000	PEDERSON NO. 14-22	AMERADA HESS CORP.	WILLIAMS	48.425	-102.921	TIOGA	DEADWOOD	CAMB	0.46	70.31	24.83	2.86
5161	33013007220000	HOLTE-BANK OF ND NO. 1	NORTH AMERICAN ROYALTIES INC.	BURKE	48.733	-102.931	STONEVIEW	WINNIPEG-RED RIVER	ORDO	0.37	46.8	43.1	0.8
1231	33105004950000	IVERSON NELSON UNIT NO. 1	AMERADA PETROLEUM CORP.	WILLIAMS	48.280	-102.984	BEAVER LODGE	WINNIPEG	ORDO	0.2	12.8	78.6	2.9
6436	33075007440000	DUERRE NO. 43-5	SHELL OIL CO.	RENVILLE	48.971	-101.982	NEWPORTE	DEADWOOD	CAMB	0.17	74.4	15.7	0.6
6296	33075007180000	LARSON NO. 23X-9	SHELL OIL CO.	RENVILLE	48.957	-101.969	NEWPORTE	DEADWOOD	CAMB	0.17	67	20.3	0.1
13405	33053023970000	BRENNA-LACEY NO. 1-32	AMERADA HESS CORP.	MCKENZIE	40.019	-102.776	ANTELOPE	WINNIPEG, CAMB-DEADWOOD	ORDO	0.17	11.65	79.9	5.46
1231	33105004950000	IVERSON NELSON UNIT NO. 1	AMERADA PETROLEUM CORP.	WILLIAMS	48.280	-102.984	BEAVER LODGE	RED RIVER	ORDO	0.13	6.4	78.7	1.9
3268	33007000540000	SCORIA UNIT NO. 8	AMERADA PETROLEUM CORP.	BILLINGS	46.866	-103.413	SCORIA	RED RIVER	ORDO	0.1	0.5	77	1
3398	33105006370000	BLSU D-408	AMERADA PETROLEUM CORP.	WILLIAMS	48.280	-102.985	BEAVER LODGE	*INTERLAKE*	SILU	0.09	5.3	80.6	0.5
9056	33089002560000	OGRE NO. 1-24-1C	GULF OIL EXPL. & PROD. CO.	STARK	46.842	-102.361	RICHARDTON	WINNIPEG	ORDO	0.09	2.1	90.7	1.1
9913	33023002330000	GIN-HAN PARTNERSHIP NO. 1	TEXACO INC.	DIVIDE	48.961	-103.231	PAULSON	RED RIVER	ORDO	0.08	4.8	70.5	0.5
6466	33075007500000	MOTT NO. 32-3	SHELL OIL CO.	RENVILLE	48.977	-101.939	NEWPORTE	DEADWOOD	CAMB	0.07	45.3	28.4	0.7
25	33105000040000	C. IVERSON NO. 1	AMERADA PETROLEUM CORP.	WILLIAMS	48.271	-102.955	BEAVER LODGE	INTERLAKE	SILU*	0.07	5.6	79.4	0
9393	33053014960000	CHARLSON DEEP UNIT NO. 2	TEXACO INC.	MCKENZIE	48.108	-102.885	CHARLSON	RED RIVER	ORDO	0.07	2.7	73.5	1.5
343	33053000150000	GOV'T DOROUGH NO. 1	TEXACO INC.	MCKENZIE	48.083	-102.928	CHARLSON	MINNELUSA	PENN	0.06	98	0.4	1.5
2764	33053004730000	K. S. HALVERSON NO. 1	SKELLY OIL CO.	MCKENZIE	47.965	-102.938	CLEAR CREEK	MINNELUSA	PENN	0.06	96	0.5	3
2764	33053004730000	K. S. HALVERSON NO. 1	SKELLY OIL CO.	MCKENZIE	47.965	-102.938	CLEAR CREEK	MINNELUSA	PENN	0.06	95.8	0.4	3.7
2086	33009003710000	ROLLIN STAIRS TR-2 NO. 4	AMERADA PETROLEUM CORP.	BOTTINEAU	48.757	-100.876	NEWBURG	CHARLES	MISS	0.06	17.6	27.6	0
453	33105002440001	T. LALIM NO. 4	AMERADA PETROLEUM CORP.	WILLIAMS	48.472	-102.921	TIOGA	AMSDEN	PENN	0.05	97.6	1	1.2
5679	33029000150000	HUBER NO. 1	KELSCH & DONLIN	EMMONS	46.369	-99.956	NOT GIVEN	MUDDY	CRET	0.05	13.4	85.2	0.7
10002	33011000010000	F. W. BURNETT NO. 38	MONTANA-DAKOTA UTILITIES CO.	BOWMAN	46.118	-104.042	CEDAR CREEK	EAGLE	CRET	0.05	3.2	96.3	0
7587	33053010610000	SILURIAN UNIT 5 NO. 1X	TEXACO INC.	MCKENZIE	48.115	-102.890	CHARLSON	INTERLAKE	SILU	0.05	3	75.4	0.6
6697	33007002860000	KESSEL NO. 1	AMOCO PRODUCTION CO.	BILLINGS	47.214	-103.225	WHITETAIL	RED RIVER	ORDO	0.05	0.9	84.3	1.1
2361	33009004670000	ARNOLD NERMYR A. NO. 2	AMERADA PETROLEUM CORP.	BOTTINEAU	48.776	-100.936	NEWBURG	SPEARFISH	TRIA	0.04	26	11.8	0
5680	33029000160000	LOEB NO. 1	KELSCH & DONLIN	EMMONS	46.354	-100.093	NOT GIVEN	MUDDY	CRET	0.04	12.2	86.4	0.5
12562	33053022600000	BUFFALO WALLOW NO. 41-7	CONOCO, INC.	MCKENZIE	47.658	-103.464	BUFFALO WALLOW	RED RIVER A & B	ORDO	0.04	3.5	81.6	1.3
12589	33053022670000	MCKEEN NO. 30-23	AMERADA HESS CORP.	MCKENZIE	48.043	-102.821	ANTELOPE DEEP	RED RIVER	ORDO	0.04	3.1	80.6	0.7
9806	33053016030000	FEDERAL STORM NO. 13-6	ADOBE OIL & GAS CORP.	MCKENZIE	47.405	-103.352	BIECEGAL CREEK	RED RIVER	ORDO	0.04	1.1	77.7	1.6
11466	33105011840000	ROGERS NO. 15-1	COLUMBIA GAS DEVELOPMENT CORP.	WILLIAMS	47.995	-103.982	NOT GIVEN	RED RIVER	ORDO	0.04	1	60	0.6
7466	33007004880000	F.F. VOLENSKY NO. 34-1	MOSBACHER PRODUCTION CO.	BILLINGS	46.990	-103.093	UNNAMED	RED RIVER	ORDO	0.04	0.9	76.3	0.9
8491	33025002110000	BULLINGER NO. 1-30	VANDERBILT RESOURCES CORP.	DUNN	47.087	-102.898	RUSSIAN CREEK	RED RIVER	ORDO	0.04	0.6	84.2	0.8
11198	33053019590000	OSCAR JONSRUD NO. 1	TEXACO INC.	MCKENZIE	47.932	-102.997	EDGE	INTERLAKE	SILU	0.03	5.6	71.3	1.3
3356	33013005260000	H. HERMANSON B NO. 1	PAN AMERICAN PETROLEUM CORP.	BURKE	48.860	-102.576	BLACK SLOUGH	RIVAL	MISS	0.03	3.2	65.9	2.4
9462	33025003190000	KNUTSON-WERRE 34 NO. 1	MESA PETROLEUM CO.	DUNN	47.598	-102.906	BEAR CREEK	RED RIVER	ORDO	0.03	0.9	74.4	0.9
8910	33105009570000	T. P. SLETTE NCT NO. 1	TEXACO INC.	WILLIAMS	48.080	-103.493	WILLOW CREEK	RED RIVER	ORDO	0.03	0.7	72.3	0.6
11980	33053021560000	L.M. STENEHJEM NO. 2	TEXACO INC.	MCKENZIE	47.916	-103.462	POE	RED RIVER	ORDO	0.03	0.6	81.6	0.8
7879	33053011430000	STATE-ROGNESS 41-22 NO. 1	CHAMPLIN PETROLEUM CO.	MCKENZIE	47.716	-103.457	ELLSWORTH	RED RIVER	ORDO	0.03	0.5	73	1.3
6493	33053007570000	PETERSON NO. 1-10	ALPAR RESOURCES INC.	MCKENZIE	47.742	-103.328	CHERRY CREEK	RED RIVER	ORDO	0.03	0.4	83	1.5
10280	33053017160000	SOVIG NO. 44-31	NATIONAL OIL CO.	MCKENZIE	47.850	-103.521	SPRING CREEK	RED RIVER	ORDO	0.03	0.4	74.6	0.9
7997	33053011700000	MORK NO. 1	AMOCO PRODUCTION CO.	MCKENZIE	47.738	-103.382	CHERRY CREEK	RED RIVER	ORDO	0.03	0.2	75.7	1.4
3323	33053005150000	ANTELOPE UNIT E NO. 1	AMERADA PETROLEUM CORP.	MCKENZIE	48.036	-102.805	ANTELOPE	INTERLAKE	SILU	0.02	5	56.7	0.7
9635	33053015510000	EIDE NO. 35-11	PLACID OIL CO.	MCKENZIE	47.680	-103.317	JUNIPER	RED RIVER	ORDO	0.02	2.6	74.1	1.2
1326	33053001920001	MILDRED BANCROFT NO. 1	AMERADA PETROLEUM CORP.	MCKENZIE	48.009	-102.763	ANTELOPE	SANISH	DEVO	0.02	1.9	70.3	0.7
9998	33053016430000	IVERSON NO. A-1	SUN EXPLORATION & PRODUCTION CO.	MCKENZIE	47.933	-103.794	ELK	MISSION CANYON	MISS	0.02	1.6	63.6	1.1
204	33105001210000	A. M. PETERSON NO. 1	AMERADA PETROLEUM CORP.	WILLIAMS	48.329	-102.934	BEAVER LODGE	MADISON	MISS	0.02	1.2	61.7	1.8
1816	33053003310000	SIGNALNESS NO. 1	CALVERT DRILLING CO.	MCKENZIE	47.842	-102.938	NOT GIVEN	MADISON	MISS	0.02	0.9	65.3	2.9
9388	33053014950000	ROY MOEN NO. 1	MOBIL OIL CORP.	MCKENZIE	47.774	-103.451	TIMBER CREEK	RED RIVER	ORDO	0.02	0.5	92.6	0.2
7873	33053011400000	FELLANO NO. A-1	TEXACO INC.	MCKENZIE	47.806	-103.340	TOBACCO GARDEN	RED RIVER	ORDO	0.02	0.5	80.8	1
8737	33053013580000	BURNING-MINE BUTTE NO. 4-33	ABRAXAS PETROLEUM CORP.	MCKENZIE	47.579	-103.681	BURNING MINE	RED RIVER B	ORDO	0.02	0	69.9	0.6
1255	33053001600000	E. BRENNA TR-1 NO. 1	AMERADA PETROLEUM CORP.	MCKENZIE	48.012	-102.787	ANTELOPE	MADISON	MISS	0.01	2.2	54	2.5
291	33007000010000	HERMAN MAY NO. 1	AMERADA PETROLEUM CORP.	BILLINGS	46.874	-103.302	WILDCAT	MADISON	MISS	0.01	1.3	48.4	1.9
1664	33013001020000	C. S. STAALESON NO. 1	PAN AMERICAN PETROLEUM CORP.	BURKE	48.888	-102.516	LIGNITE	MIDALE	MISS	0.01	1.3	46.6	0.5
25	33105000040000	CLARENCE IVERSON NO. 1	AMERADA PETROLEUM CORP.	WILLIAMS	48.271	-102.955	BEAVER LODGE	*DUPEROW*	DEVO	0.01	1.3	70	0.6
8155	33007006310000	F-6-144-101 NO. 2	SUPRON ENERGY CORP.	BILLINGS	47.326	-103.536	ROUGH RIDER	DUPEROW	DEVO	0.01	0.9	64.3	0.7
8499	33025002120000	SKACHENKO NO. A-1	AMOCO PRODUCTION CO.	DUNN	47.439	-102.830	JIM CREEK	DUPEROW	DEVO	0.01	0.8	55.7	0.5
7268	33007004170000	FED. NO. 8-24	KOCH EXPLORATION CO.	BILLINGS	47.105	-103.415	BIG STICK W	FRYBURG	MISS	0.01	0.7	45.6	4
7652	33007005430001	FEDERAL NO. 34-4	DIAMOND SHAMROCK EXPL. CO.	BILLINGS	47.140	-103.613	ROOSEVELT	DUPEROW	DEVO	0.01	0.6	56.5	0.5
10110	33053016660000	CROWFLY NO. 17-10	GETTY OIL CO.	MCKENZIE	47.985	-103.761	MARLEY	INTERLAKE	SILU	0.01	0.3	62.1	0.5
3468	33105006430000	BLDU NO. I-315	AMERADA PETROLEUM CORP.	WILLIAMS	48.328	-102.935	BEAVER LODGE	*DUPEROW*	DEVO	0.01	0.1	58.7	0.3
11198	33053019590001	OSCAR JONSRUD NO. 1	TEXACO INC.	MCKENZIE	47.932	-102.997	EDGE	DUPEROW	DEVO	0.01	0	62	0.8
9057	33053014280001	RIGGS NO. 10-31	TEXACO INC.	MCKENZIE	47.852	-102.884	BLUE BUTTES	STONEWALL	ORDO	0.01	0	70.9	0.9
8296	33105009000001	TEMPLE NO. 30-16	GETTY OIL CO.	WILLIAMS	48.390	-103.128	RAY	RED RIVER	ORDO	0.01	0	47.36	0.87
7505	33007005000000	FED. NO. 1-28	PATRICK PETROLEUM CO.	BILLINGS	47.087	-103.352	TREE TOP	MISSION CANYON	MISS	<0.01	1	46.1	2.3
3246	33053005130000	ANTELOPE UNIT C NO. 1	AMERADA PETROLEUM CORP.	MCKENZIE	48.021	-102.793	ANTELOPE	*BIRD BEAR/DUPEROW*	DEVO	<0.01	0.9	69.6	0.9
9748	33025003490000	FREDERICK SKACHENKO NO. A-1	AMOCO PRODUCTION CO.	DUNN	47.257	-103.008	LITTLE KNIFE	MISSION CANYON	MISS	<0.01	0.3	27.8	2.9

any potential nitrogen-helium correlations. An additional 123 gas analyses (109 Red River Formation and 14 Winnipeg/Deadwood), which included nitrogen concentrations but not helium, were compiled from the North Dakota Dept. of Mineral Resources Oil and Gas Division (OGD) gas analysis database, individual well files, and oil and gas hearing exhibits (OGD, 2019). Using both the BLM and composite OGD data, nitrogen gas concentrations were mapped and examined by formation for the stratigraphic units that displayed positive nitrogen-helium correlations and notable elevated nitrogen-helium concentrations.

RESULTS AND INTERPRETATIONS

Only three of the 65 total gas analyses from the BLM database did not contain measurable helium concentrations (<0.01%), two of which were from the Mississippian Mission Canyon Formation and the other was from an unspecified Devonian formation. Of the remaining 62 samples with measurable helium concentrations (≥0.01), 54 samples contained between 0.01% and 0.09% while the remaining eight contained 0.10% to 0.46% (Table. 1). All of the samples with higher concentrations (≥0.10% He) were from the deeper and older formations (Cambrian-Ordovician) and primarily positioned along either the Nesson-Antelope anticline trend or the Newporte Structure (Fig. 1).

Examining nitrogen versus helium concentrations in the BLM data, at least two distinct positive nitrogen-helium trends can be delineated. A moderate increase in helium appears to coincide with higher nitrogen concentrations within a few Deadwood gas samples from the Newporte structure area (Figs. 1 and 2). A more substantial increase in helium coincides with increased nitrogen with the deeper, Cambrian-Ordovician rock units along the Nesson and Antelope anticlines (Figs. 1 and 2). Even within some of the other deeper reservoirs within the Silurian and Devonian rock units, which have lower nitrogen and helium concentrations, there appears to be a subtle positive nitrogen-helium correlation as well (Fig. 3). The shallower, Pennsylvanian (Amsden and Broom Creek Formations) gas samples, however, all contained very high nitrogen (>95%) but with relatively low helium (0.06%). Therefore, positive nitrogen-helium correlations within the Williston Basin of North Dakota may be a function of both location and stratigraphic position.

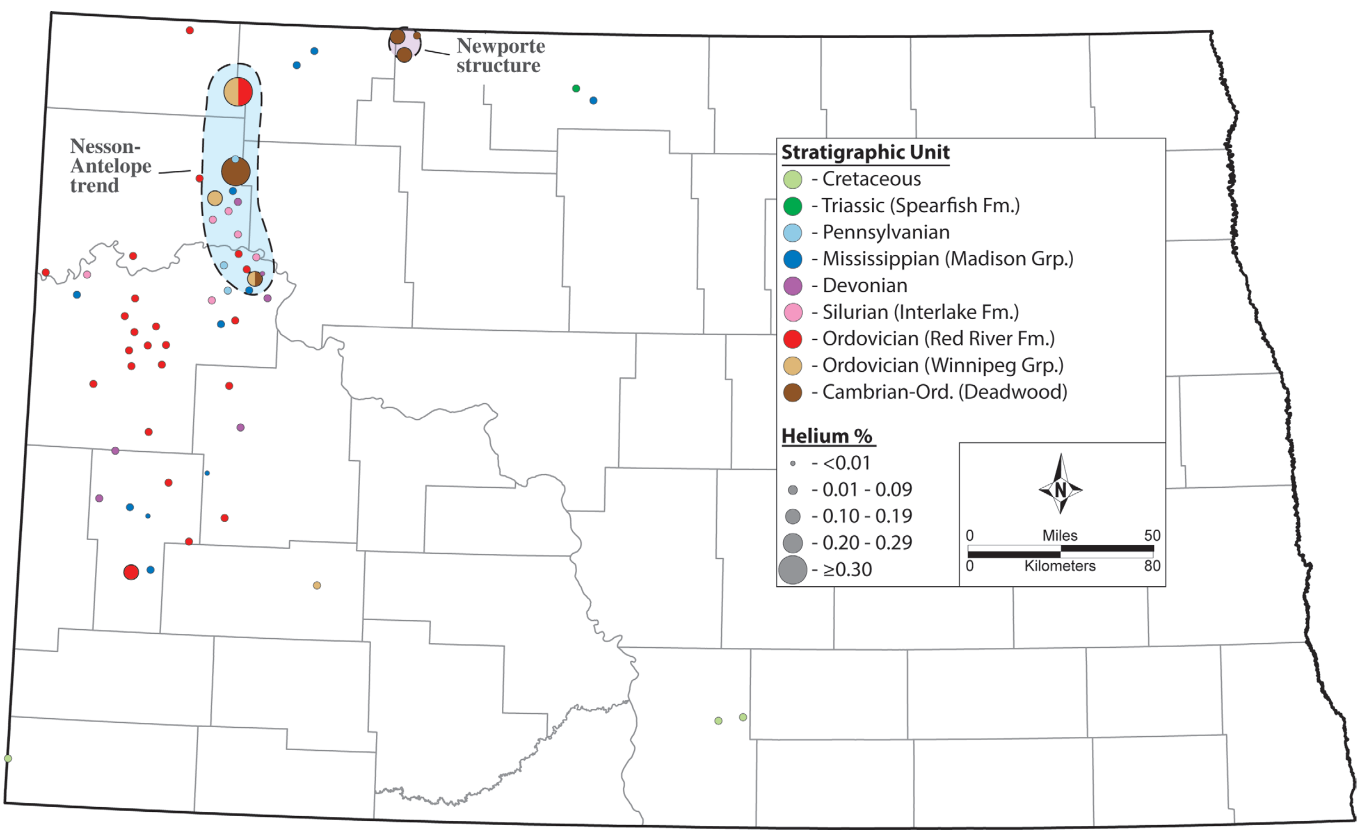

Figure 1. North Dakota state map with county boundaries (grey lines) and helium gas concentrations by stratigraphic unit. Data from the BLM gas analysis database.

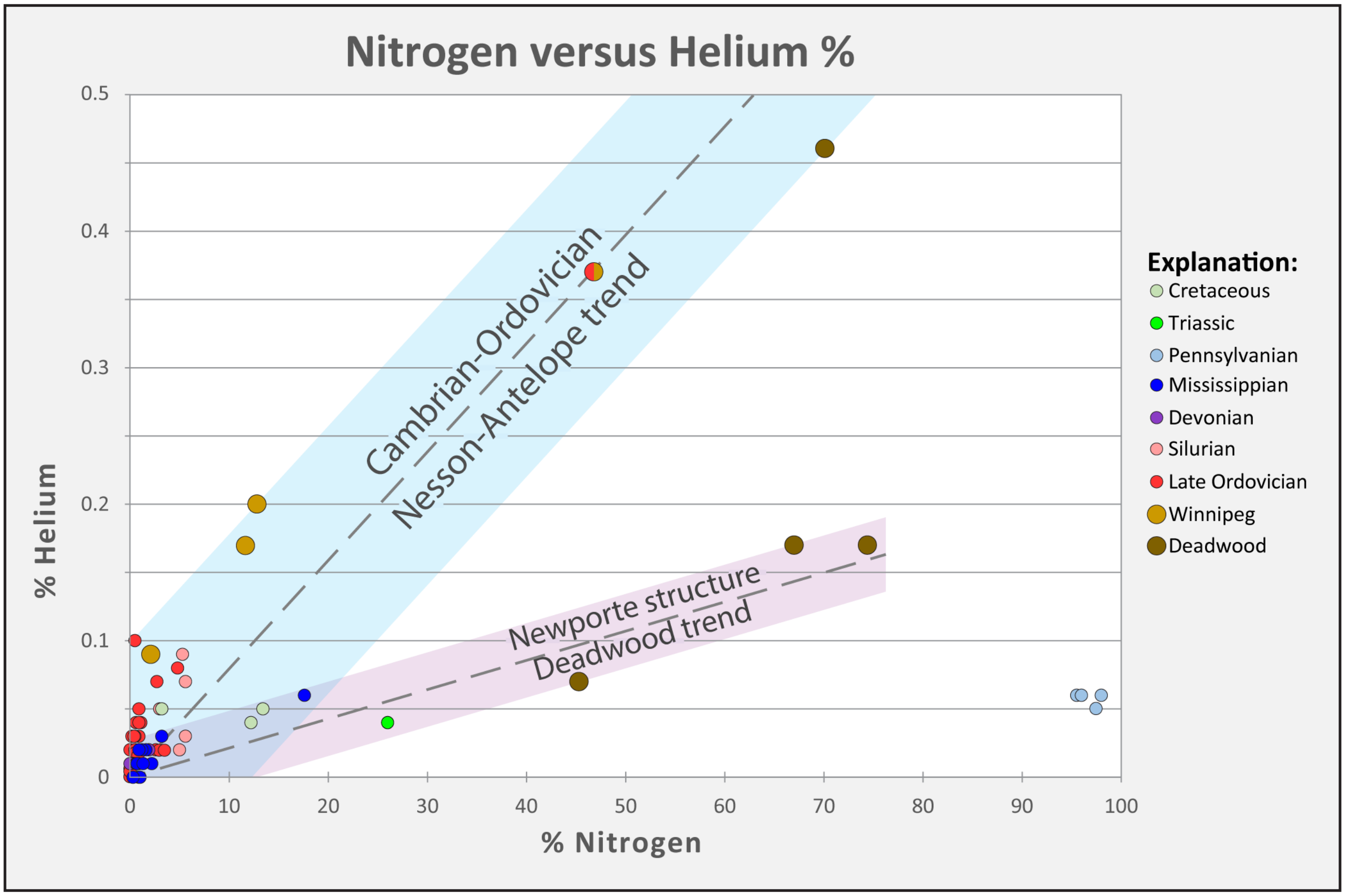

Figure 2. Helium versus nitrogen plot for North Dakota gas analyses color coated by geologic age/formation. Data from the BLM gas analysis database.

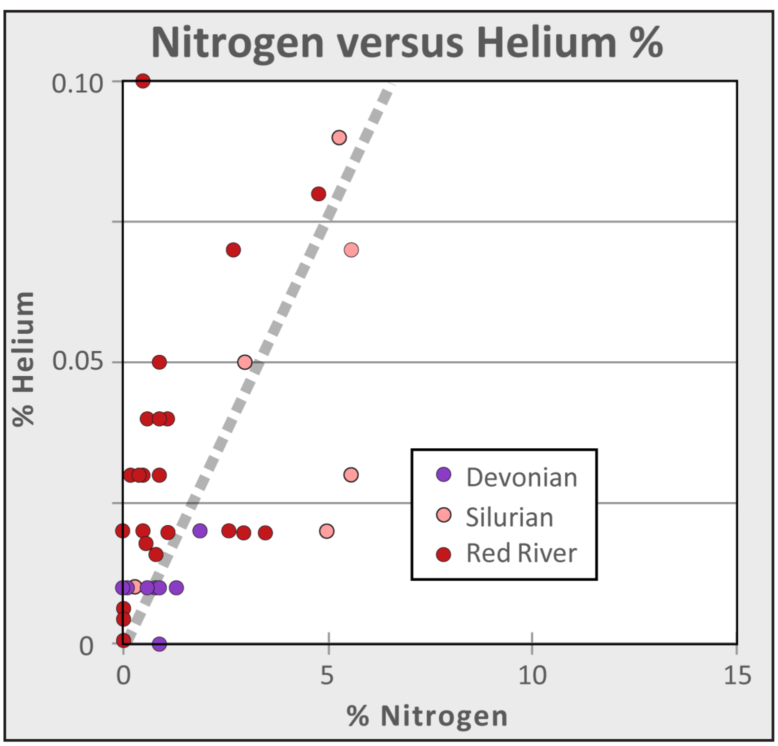

Figure 3. Helium versus nitrogen plot for the Devonian (Winnipegosis and Duperow Formations) Silurian (Interlake Formation), and Ordovician (Red River Formation) gas analysis samples of North Dakota. Data from the BLM gas analysis database.

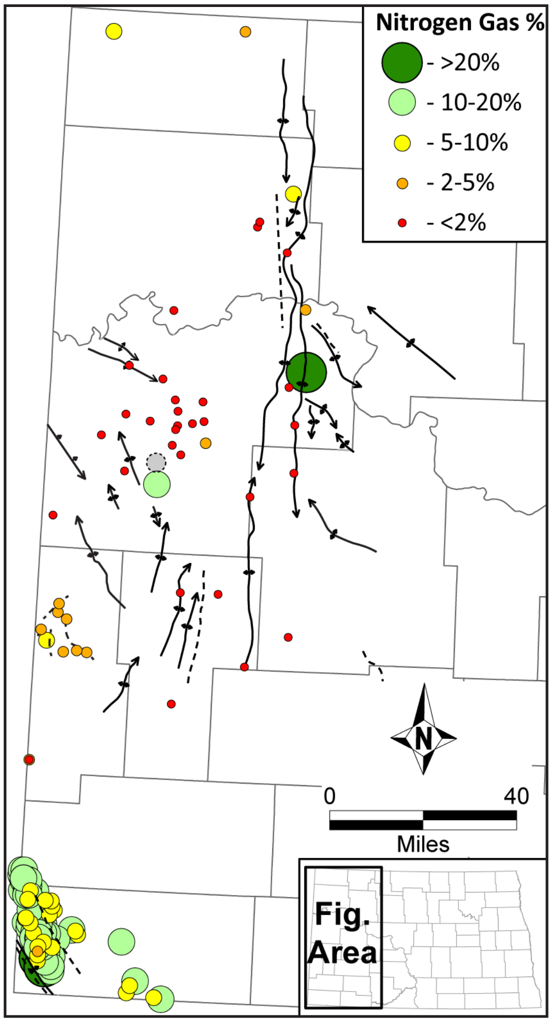

Figure 4. Nitrogen gas analyses for the Ordovician Red River Formation. Anticlines and monocline are shown by the solid black lines, and faults are shown as dashed black lines. Data compiled from the ND Dept.of Mineral Resources Oil and Gas Division database (2019).

Elevated nitrogen concentrations within Red River Formation reservoir gases is especially high along the Cedar Creek anticline* (Fig. 4). While this may be of some interest regarding helium potential, the Cedar Creek anticline is positioned where Red River reservoirs tend to have low gas to oil ratios (GOR) and therefore potentially lower gas flow rates (Fig. 5). Away from the Cedar Creek anticline area, nitrogen concentrations in Red River gases overall decrease towards basin center (Fig. 4) as the GOR of Red River reservoirs generally increase (Fig. 5). The decrease in nitrogen concentrations toward basin center may therefore be a function of dilution by increased hydrocarbon gas volumes. However, a few notable nitrogen concentration increases do occur along the Nesson anticline as well as towards the west-southwest (Fig. 4). These higher nitrogen concentrations may be of interest if they correlate with increased helium as they overlap with where the Red River reservoirs have higher GOR's and potentially higher gas flow rates.

*Atmospheric air has been injected within select Red River fields for enhanced oil recovery efforts proximal to the Cedar Creek anticline. Gas analyses potentially effected by atmospheric air injection were removed from our database.

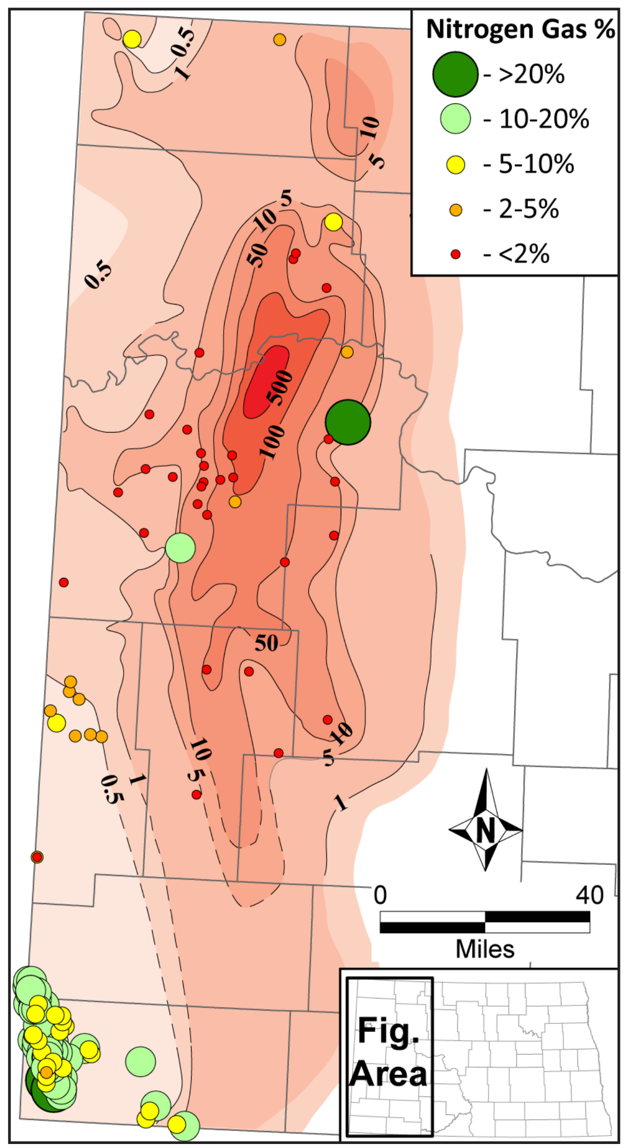

Figure 5. Gas to oil ratios (GOR) of Red River C and D interval production plotted with nitrogen gas concentrations (nitrogen gas includes composite of Red River A-D intervals). The C and D interval GOR contours are from Nesheim (2017).

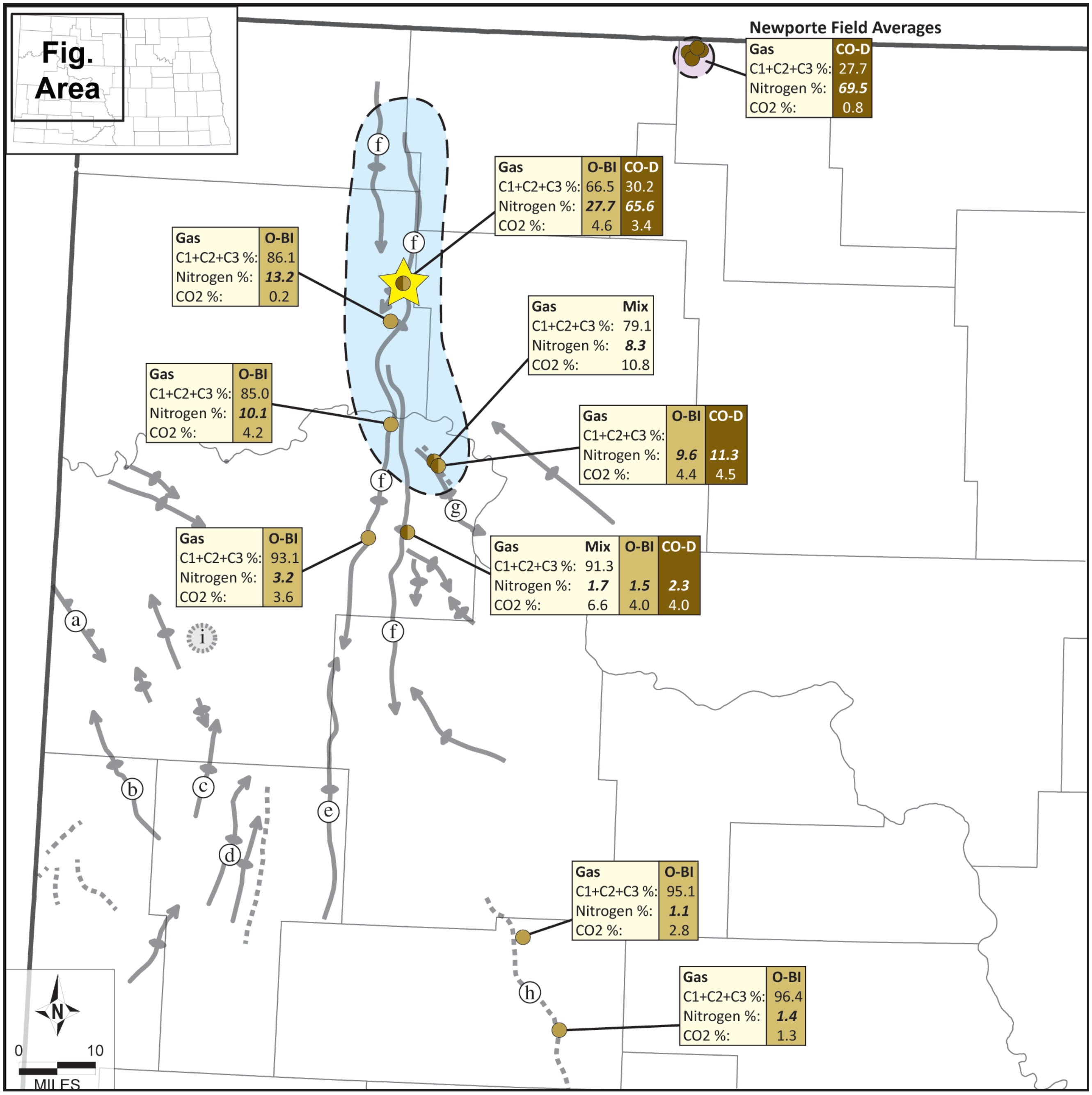

Figure 6. Hydrocarbon, nitrogen, and CO2 concentrations for the Black Island and Deadwood Formations. Data compiled from the NDIC Oil and Gas Division database (2019). Modified from Nesheim (2012). a = Mondak monocline; b = Beaver Creek anticline; c = Rough Rider anticline; d = Billings Nose anticline; e = Little Knife anticline; f = Nesson anticline; g = Antelope anticline; h = Heart River fault; i = Red Wing Creek structure

Overall, Black Island (Winnipeg Group) and Deadwood Formation gases along the southern portions of the Nesson anticline and the Heart River fault appear to contain low concentrations of nitrogen and therefore, likely low concentrations of helium (Fig. 6). However, along the central to northern portions of the Nesson anticline, as well as within the Newporte structure, nitrogen concentrations of tested gases from both formations increase with a general northwards trend (Fig. 6). The higher nitrogen in the Black Island and the Deadwood along the central to northern portions of both the Nesson and Antelope anticlines, as well as the Newporte structure, overlap with the higher Cambrian-Ordovician helium concentrations from the BLM database (Fig. 1). More than a dozen wells have commercially produced hydrocarbon gas from the Winnipeg-Deadwood along the Nesson and Antelope anticlines with average flow rates greater than 2,000 MCF per day and cumulative production of several BCF per well (Nesheim, 2012).

DISCUSSION

One model proposed by Yurkowski (2016) for the occurrences of helium within the Williston Basin consists of the following three components: 1) helium generation through the radioactive decay of uranium and thorium in Precambrian granitic rocks, 2) migration along fracture and/or fault systems, and 3) entrapment along structural highs. The Williston Basin is underlain by varying types of igneous and metamorphic basement rocks, which range from mafic to felsic in composition (Sims et al., 1991). The Nesson anticline is positioned both proximal and parallel to a previously delineated Precambrian basement terrane boundary (Fig. 7). A basement-rooted fault, previously mapped by Gerhard et al. (1987), occurs along the western margins of the Nesson anticline (Fig. 6) which approximately coincides with the basement terrane boundary. Similarly, another basement fault occurs along the northeastern margins of the Antelope anticline (Fig. 6) (Murray, 1968). Each of these previously mapped faults may form migration pathways for helium from the Precambrian basement rocks into the overlying sedimentary formations. Lastly, both the Nesson and Antelope structures are anticlines and therefore structural highs that could potentially trap and accumulate helium. The Newporte structure, meanwhile, has been interpreted as an astrobleme (meteorite impact structure) that disrupted Precambrian bedrock (migration pathways) and resulted in the development of semi-spherical, concentric ridges in the deeper sedimentary formations (structural highs = trapping) (Forsman et al., 1996). The elevated helium concentrations along the Nesson-Antelope trend and the Newporte structure may therefore fit with the previously proposed model by Yurkowski (2016) for basement-derived helium accumulations.

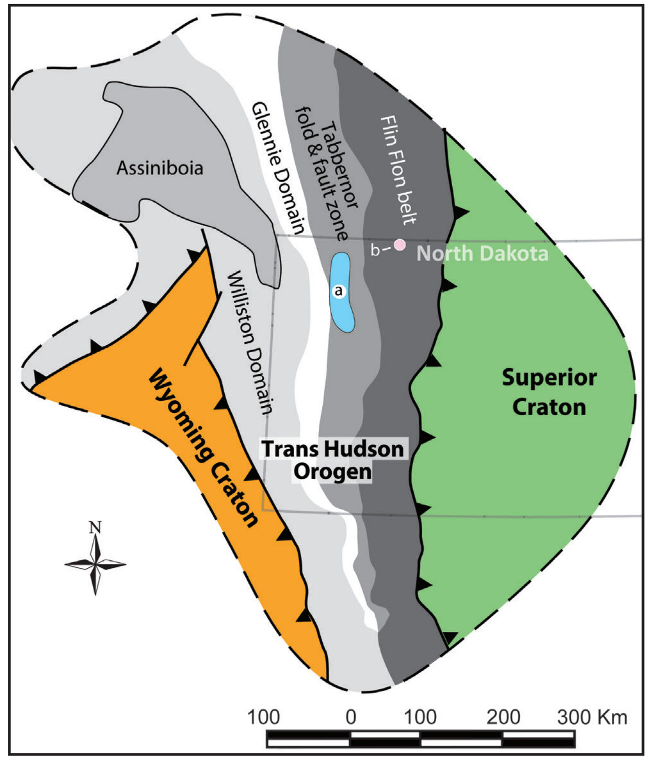

Figure 7. Precambrian basement terrane map for the Williston Basin. The outline of North Dakota is shown as a light grey line. Modified from Bader (2019). a = Nesson-Antelope trend; b = Newporte structure (as shown on Figures 1 and 6)

Regionally extensive evaporite beds may form seals to accumulate the upward migration of basement-originated helium within North Dakota. Lower Permian evaporites are reported to provide vertical fault seals for helium accumulations within the Permian Basin of New Mexico (Broadhead, 2005). The highest helium concentrations are found primarily within the Ordovician Red River and Black Island Formations, and/or the Cambrian/Ordovician Deadwood Formation (Table 1). Above those units are numerous, thin (10's ft. thick or less) but regionally extensive dense evaporite (anhydrite) beds found throughout Late Ordovician-Early Silurian rock units, including: the upper Red River, Stony Mountain, Stonewall, and lower Interlake Formations (Fuller, 1961; Kendall, 1976; Nesheim, 2014; Husinec, 2016) (Fig. 8). Stratigraphically higher in the section, the Devonian Prairie Formation is comprised primarily of salt (low density evaporite) that is regionally extensive and is 100's of feet thick (Figs. 8 and 9). Where present, Prairie salts may be an upward seal for basement-originated helium. All of the highest helium concentrations (≥0.10%) are found in formations below the Prairie Formation, and also primarily below the thin, regionally extensive Late Ordovician-Early Silurian anhydrite beds.

Substantial amounts of helium may have unknowingly been produced already from at least one well in North Dakota. Amerada Hess's Pederson #14-22, the northernmost well tested along the Nesson anticline, had a nitrogen measurement of 27.7% of the total gas in the Black Island Formation. The Black Island went on to produce over 8 BCF of gas (Fig. 10). In addition, the upper Deadwood was perforated, flow tested, and yielded 1,300 MCF gas per day with 65.6% nitrogen (Fig. 10). Even though the Deadwood perforations were not commercially produced, the BLM database reports a Deadwood gas analysis from the Pederson #14-22 (renamed to Astrid Ongstad 14-22) that contained 70.3% nitrogen and 0.46% helium (Table 1). A total gas flow rate of 1,300 MCF per day with 0.46% helium would yield approximately 6 MCF per day of helium gas. In addition, the commercially produced Black Island perforations also likely contained some amount of helium based upon the 27.7% nitrogen concentration and the apparent nitrogen-helium correlation along the Cambrian-Ordovician section of the Nesson-Antelope anticlines (Figs. 1 and 2). Applying the nitrogen-helium plot in Figure 2, the 27.7% nitrogen value correlates with 0.2% helium. Assuming this helium value, the 8.1 BCF of Black Island gas cumulatively produced from the Pederson #14-22 would have contained ~16,000 MCF of helium, which is worth $3.4 million at a recent helium price of ~$210/MCF (Peterson, 2019).

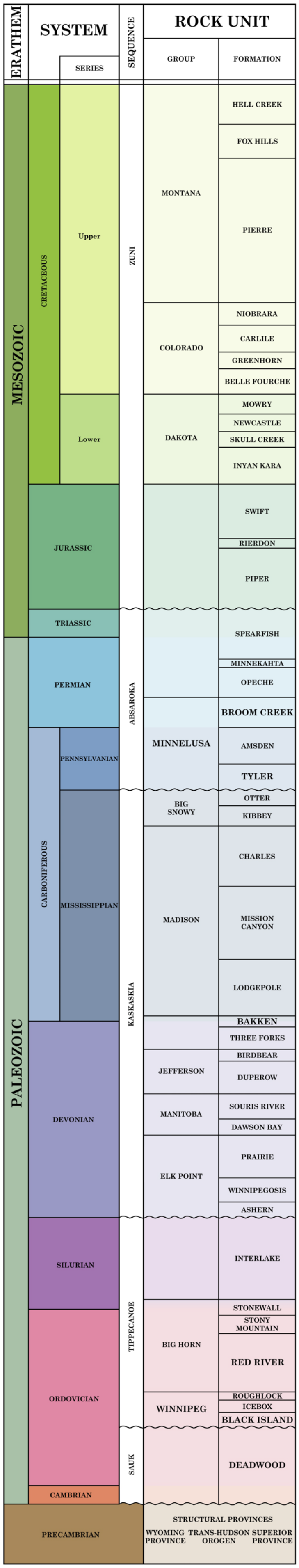

Figure 8. Stratigraphic column of the Paleozoic-Mesozoic section of North Dakota's Williston Basin which includes the stratigraphic units of the BLM database gas analyses. Modified from Murphy et al. (2009).

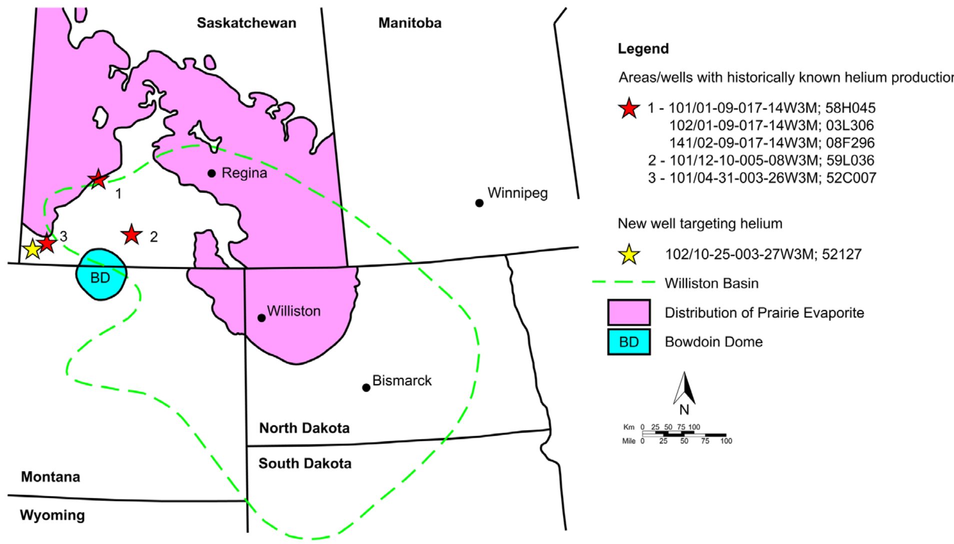

Figure 9. Regional map showing the extent of the Williston Basin and Prairie evaporite in relations to state and provincial borders as well as commercial helium production wells in southwestern Saskatchewan. Modified from Yurkowski (2016).

CONCLUSIONS

- Trace amounts of helium appear to be present in the majority of oil and gas productive reservoirs within North Dakota.
- The highest helium concentrations are found within the older, deeper Cambrian-Ordovician rock units.
- Positive nitrogen-helium correlations occur within the Cambrian and Ordovician formations and possibly in the overlying Silurian and Devonian rock units as well.
- Elevated nitrogen and helium concentrations occur within Cambrian and Ordovician formations most commonly along the Nesson and Antelope anticlines, as well as the Deadwood Formation (Cambrian) within the Newporte structure area.
- Late Ordovician-Early Silurian anhydrite beds and/or the salt-dominated Prairie Formation may form the upper seal for basement-originated helium gas migration.

ACKNOWLEDGEMENTS
Thanks to David Driskill with the United States Bureau of Land Managment for assisting with data sharing and other information.

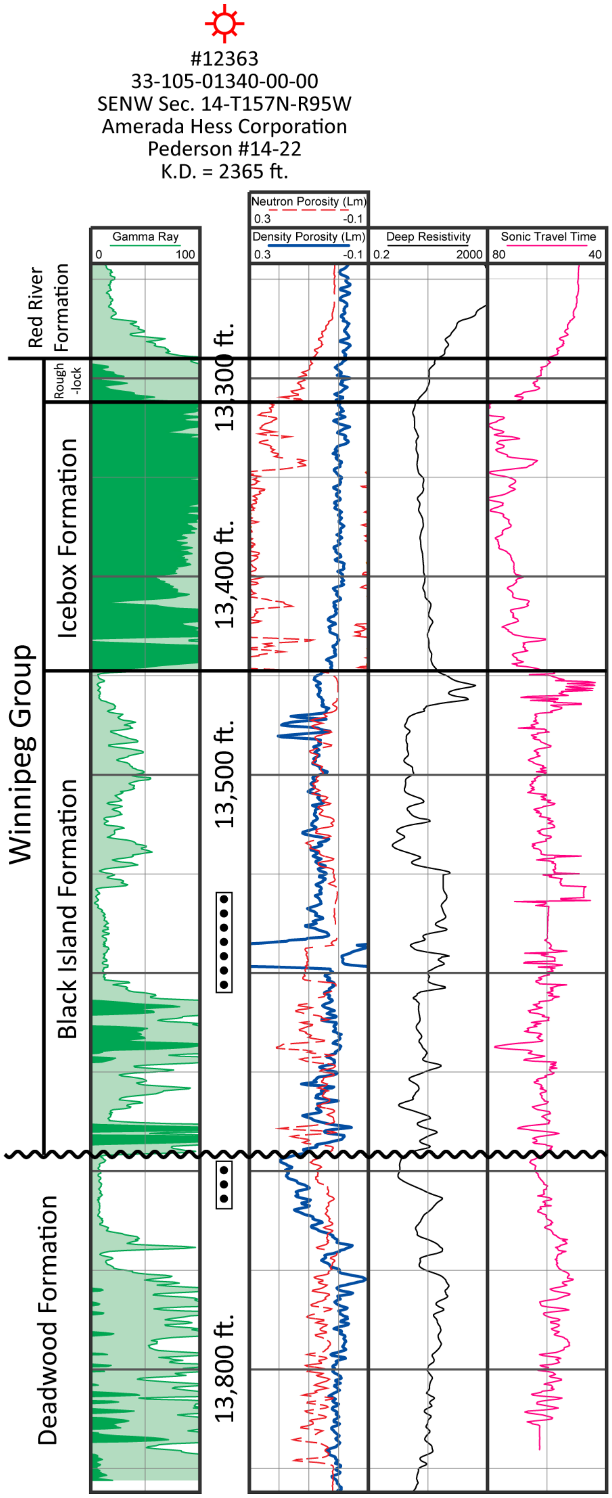

Figure 10. Wireline logs with perforation and production information for Amerada Hess's Pederson #14-22. Note: the Pederson #14-22 was renamed the Astrid Ongstad 14-22. The Pederson #14-22 well location is depicted as a yellow star on the Figure 6 map.

Winnipeg Gas Analysis

Methane:	62.37 %
Nitrogen:	27.72 %
Carbon Dioxide:	4.61 %
Ethane:	3.25 %
Propane:	0.81 %

Winnipeg Oil Analysis

Specific Gravity:	0.7587 @60/60F
API Gravity:	55.0 @60F
Pour Point:	7 F
Viscosity:	1.38 Kinematic; Centistokes@ 100F
Paraffin:	3.1 wt. %

Cumulative Black Island Production (13,560-13,609 ft.)

Oil:	3,240 BBLS
Gas:	8,135,823 MCF
Water:	28,763 BBLS

Deadwood Gas Analysis

Methane:	28.89 %
Nitrogen:	65.60 %
Carbon Dioxide:	3.35 %
Ethane:	1.09 %
Propane:	0.20 %

Deadwood Oil Analysis

Specific Gravity:	0.7941 @60/60F
API Gravity:	46.7 @60F
Pour Point:	-17 F
Viscosity:	15.81 Kinematic; Centistokes@ 100F
Paraffin:	0.54 wt. %

Initial Production Deadwood Formation (13690-13720 ft.)

Oil:	3 BBLS
Gas:	1,300 MCF
Water:	14 BBLS

REFERENCES

Bader, J.W., 2019, An ancient Everest: Precambrian basement terranes of the Williston Basin: North Dakota Department of Mineral Resources, Geo News, vol. 46, no. 1, p. 30-34.

Broadhead, R.F., 2005, Helium in New Mexico-geologic distribution, resource demand, and exploration possibilities: New Mexico Geology, vol. 27, no. 4, p. 93-101.

Brown, A., 2019, Origin of helium and nitrogen in the Panhandle-Hugoton field of Texas, Oklahoma, and Kansas, United States: AAPG Bulletin, v. 103, no. 2, pp. 369-403.

Cook, M.A., 1957, Where is the Earth's Radiogenic Helium?: Nature. 179 (4552), 213.
Forsman, N.F., Gerlach, T.R., and Anderson, N.L., 1996, Impact Origin of the Newporte structure, Williston Basin, North Dakota: AAPG Bulletin, vol. 80, no. 5, p. 721-730.
Fuller, J. G. C. M., 1961, Ordovician and contiguous formations in North Dakota, South Dakota, Montana, and adjoining areas of Canada and United States: AAPG Bulletin, vol. 45, no. 8, p. 1334-1363.
Gerhard, L.C., Anderson, S.B. and LeFever, J.A. 1987. Structural history of the Nesson Anticline, North Dakota. In: Peterson, J.A., Kent, D.M., Anderson. S.B., Piladzke, R.H. and Longman, M. W. (eds.) Williston Basin: anatomy of a cratonic oil province, Rocky Mountains Association of Geologists, p. 337-354.
Husinec, A., 2016, Sequence stratigraphy of the Red River Formation, Williston Basin, USA: Stratigraphic signature of the Ordovician Katian greenhouse to icehouse transition: Marine and Petroleum Geology, vol. 77, p. 487-506.
Kendall, A. C., 1976, The Ordovician carbonate succession (Big Horn Group) of southeastern Saskatchewan: Department of Mineral Resources, Saskatchewan Geological Survey Report 180, 185 p.
Murphy, E.C., Nordeng, S.H., Junker, B.J., and Hoganson, J.W., 2009, North Dakota Stratigraphic Column: North Dakota Geological Survey Miscellaneous Series No. 91.
Murray, G. H., 1968, Quantitative fracture study-Sanish Pool, McKenzie County, North Dakota, American Association of Petroleum Geologists Bulletin v. 52, P. 57-65.
National Research Council, 2000, The Impact of Selling the Federal Helium Reserve. Washington, DC: The National Academies Press.
North Dakota Dept. of Mineral Resources Oil and Gas Division (OGD), 2019.
Nesheim, T.O., 2012, Review of Ordovician Black Island Formation (Winnipeg Group) Oil and Gas Production: North Dakota Geological Survey, Geologic Investigations No. 161.
Nesheim, T.O., 2014, Preliminary Examination of Source Beds within the Stonewall Formation (Ordovician-Silurian), Western North Dakota: North Dakota Geological Survey, Geologic Investigations No. 181, 20p.
Nesheim, T.O., 2017, Stratigraphic Correlation and Thermal Maturity of Kukersite Petroleum Source Beds within the Ordovician Red River Formation: North Dakota Geological Survey, Report of Investigations No. 118, 48 p., 1 pl.
Nesheim, T.O., 2019, Review of Production, Completions, and Future Potential of the lower Tyler Formation – Central Williston Basin, North Dakota: North Dakota Geological Survey, Geologic Investigations No. 222.
Peterson, J.B., 2019, Mineral Commodity Summaries – Helium 2019: United States Geological Survey, p. 76-77.
Sim, P.K., Peterman, Z.E., Hildenbrand, T.G., and Mahan, S., 1991, Precambrian Basement Map of the Trans-hudson Orogen and adjacent terranes, northern Great Plains, U.S.A.: USGS Miscellaneous Investigations Series Map, I-2214.
Tongish, C.A., 1980, Helium-Its Relationship to Geologic Systems and Its Occurrence With the Natural Gases, Nitrogen, Carbon Dioxide, and Argon; United States, Bureau of Mines, Report of Investigations 8444, 176p.
United States Bureau of Land Management, Amarillo Field Office, Analyses of Natural Gases, 1917-October 2008 (Raw Data Only) (on CD-ROM, received Aug. 9, 2019).
Yurkowski, M.M., 2016, Helium in southwestern Saskatchewan: accumulation and geological setting; Saskatchewan Ministry of the Economy, Saskatchewan Geological Survey, Open File Report 2016-1, 20p.