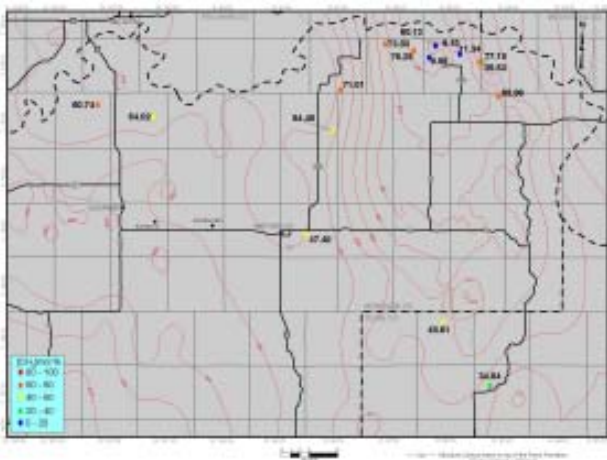
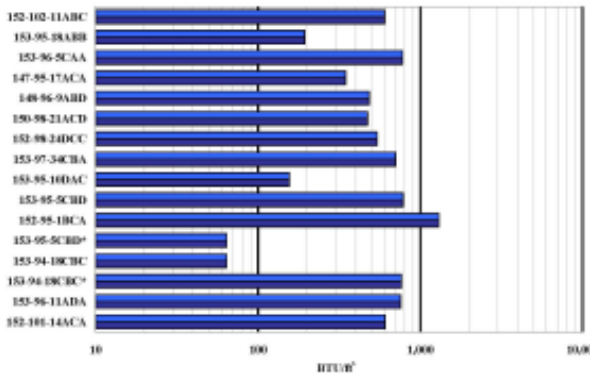
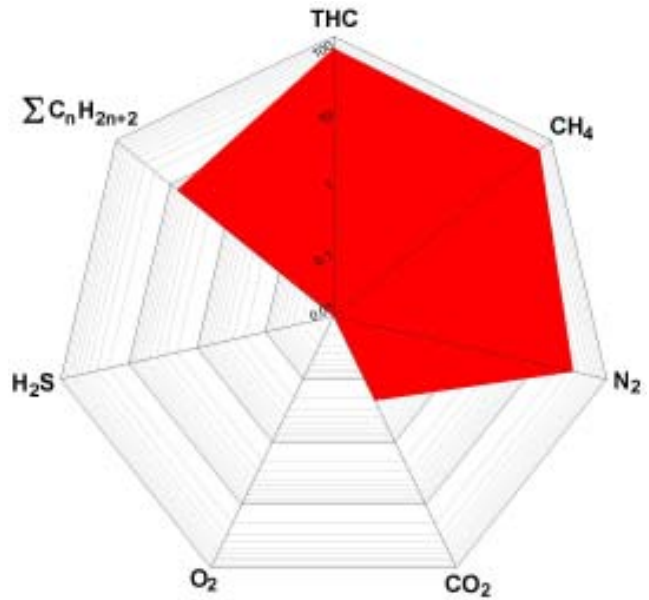


North Dakota Geological Survey



# Historic Shallow Natural Gas Occurrences in Cretaceous and Tertiary Aquifers in West-Central North Dakota



**GEOLOGIC INVESTIGATION NO. 58**  
**NORTH DAKOTA GEOLOGICAL SURVEY**  
 Edward C. Murphy, State Geologist  
 Lynn D. Helms, Director Dept. of Mineral Resources  
 2008

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**Geological Investigation No. 58  
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On the cover (photographs):

Upper left - Cretaceous Fox Hills – Hell Creek aquifer sediments (prominently displayed in the foreground) outcropping along Little Beaver Creek in western Bowman County south of Marmath, North Dakota. Gray to light brown, massive and cross-bedded sandstones of the Colgate member of the Fox Hills Formation overlain at this location by channel scour flaggy sandstones of the Hell Creek Formation. (Photo by NDGS)

Lower right - Well 152-102-11ABC (Stock well included in this study) located in northeastern Elk Township in northwestern McKenzie County in west-central North Dakota. Artesian wells like this one, completed in the Fox Hills – Hell Creek Aquifer, have been used for farm and ranch water supply for decades. (Photo by NDSWC)

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## Abstract

Shallow natural gas has been documented in several wells in west-central North Dakota in McKenzie and northwestern Dunn Counties with wells screened in Cretaceous and Tertiary age Aquifers: Fox Hills – Hell Creek, Ludlow/Cannonball, and Tongue River (Bullion Creek), which commonly flow under artesian (flowing-head) conditions that have been decreasing over time in western North Dakota. Gas samples were collected from 14 wells during hydrologic monitoring in the 1980s with samples analyzed for C<sub>1</sub> through C<sub>6</sub> hydrocarbons using gas chromatography/mass spectrometry (GC/MS) along with analyses for nitrogen, oxygen, and carbon dioxide. Calculated total hydrocarbon content in gases (mol%) ranged 90.34% from a minimum of 6.43% in well 153-95-5CBD to a maximum of 96.77% in well 152-95-1BCA with an average of 51.87%. Methane ranged 70.75 % from a minimum of 6.43% in well 153-95-5CBD to a maximum of 77.18% in well 153-94-18CBC with an average of 48.77%. Nitrogen concentrations ranged 90.34 % from a minimum of 3.21% in well 152-95-1BCA to a maximum of 93.55% in well 153-95-5CBD with an average of 47.46%. Oxygen was detected in three wells, likely the result of atmospheric contamination, ranging 0.39% from a minimum of 0.45% in well 153-95-18ABB to 0.84% in well 153-96-5CAA. Carbon dioxide was reported in 12 of the 14 wells sampled with concentrations being below the highest value detected of 1.22% in well 153-96-5CAA ranging 1.20% from a low of 0.02% in wells 152-951BCA and 153-95-5CBD to 1.22% in well 153-96-5CAA with an average carbon dioxide concentration of 0.62%. Hydrogen sulfide was not detected in any well supporting the presumption that fluid and gas origins are likely to be from within the hydrogeologic unit sampled or from deeper formations above the Madison Group. BGIs suggest that nine of the wells contained gases of a biogenic origin, likely late generation. DGIs ranging from 0.63 to 1.00 suggest that three wells contain wet gases, one contains both dry and wet gas, while the remaining ten wells contain dry gas. Wells with wet gas are located above the longitudinal axis of the Nesson Anticline. The three wells with low BGI and DGI are located on structure, where the possibility of vertical migration along faults and fractures may occur, most likely coincident with the underlying Keene and Charlson oil fields. It has been further suggested that deeper ground-water sources such as the Minnelusa Formation, may be the gas source. Gas composition data from two wells tested in the Minnelusa Formation reported total hydrocarbon concentrations of 1.90 to 49.90%. The data compare somewhat favorably to wells in the Cretaceous and Tertiary aquifers. Well 9280 compares most favorably across all major gas components. Well 9107 has a gas composition profile less similar to gases from the Cretaceous and Tertiary aquifers, except for the presence of nitrogen. Nitrogen concentrations are relatively consistent between the Minnelusa Formation wells tested and gases collected from Cretaceous and Tertiary aquifers, which tend to decrease in concentration off structure, suggesting a portion of the gases present are sourced in the underlying Minnelusa or deeper formations. Further evaluation of gas composition and isotopic data from other underlying units is needed.

## **Acknowledgements**

The author would first like to recognize and thank Mr. Alan Wanek; ground-water hydrologist with the North Dakota State Water Commission, for the time spent in the field at the wellhead, collecting the individual gas samples described in this report, and for providing access to the laboratory analytical reports and supporting hydrologic data required to complete this investigative work.

## **Author's Note**

The intent of this investigation was to assemble, present, compare, and discuss the analytical results of shallow gas sampling conducted on wells completed in Cretaceous and Tertiary aquifers in west-central North Dakota by the NDSWC in the 1980s. The information contained herein has been assembled from best available sources. Well construction information was less complete and should be considered with caution. It is further intended that this investigation will enhance our understanding of the nature and character of natural gas found in the shallow subsurface of North Dakota and will lead to further discussion and investigation of shallow natural gas generation, migration, and accumulation throughout the state.

## **BACKGROUND**

### **Introduction**

Shallow natural gas has been documented in several wells in west-central North Dakota in McKenzie and northwestern Dunn Counties. These wells are screened in Cretaceous and Tertiary age Aquifers and commonly flow under artesian (flowing-head) conditions (Figure 1). These wells were installed for the purposes of water supply (industrial, stock, and domestic) and have been selectively monitored over the last thirty years. Individual gas composition analyses were collected directly from the wellheads of 14 individual wells during monitoring of pressure heads during the 1980s (Table 1). The results of analytical testing of collected gases and their associated potential implications for natural gas sourcing are described and discussed in this report.

### **Fox Hills – Hell Creek Aquifer**

The Fox Hills – Hell Creek Aquifer is a confined aquifer consisting of the entire Fox Hills Formation and lower portions of the Hell Creek Formation that are in hydraulic connection with the underlying Fox Hills sediments. Sediments of the Fox Hills and lower Hell Creek aquifer generally consist of fine- to medium- grained sandstones, siltstones, and claystones (with occasional detrital lignites) that were deposited in shallow marine (Fox Hills) and terrestrial (lower Hell Creek) environments around 65 million years ago during the late Cretaceous. The aquifer is present in the shallow subsurface and is continuous across approximately 60% of the state from west to east. The aquifer can be found at depths ranging from as shallow as 20 feet, in the extreme southwestern (e.g. Bowman and Slope Counties) and easternmost (e.g. Pierce, Kidder, Emmons Counties) portions of the state, to as deep as 2000 feet in northwestern Billings County. The aquifer is found in all western counties from the Montana border in the west, reaching east into the shallow subsurface of Rolette, Pierce, Benson, Wells, Kidder, Stutsman, Logan, and McIntosh Counties, where the Hell Creek and Fox Hills Formations subcrop below glacial drift (i.e. Coleharbor Formation). In McKenzie County the aquifer can be found at depths from 1,100 to 1,800 feet and is deepest in the central portions of the county. The aquifer is found at relatively shallow depths: above the Nesson Anticline in the northwest, near the Missouri River Valley and Lake Sakakawea in the north, and in the extreme southwest (Croft a&b, 1985, Honeyman, 2007). Ten of the 14 wells described herein are thought to be completed within the Fox Hills – Hell Creek Aquifer.



**Table 1. Date of Natural Gas Sample Collection from Selected Wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.**

Well ID	Sample No.	Date of Sample Collection/Analysis <sup>1</sup>
152-102-11ABC	G-83-5839	12/14/83
153-95-18ABB	G-83-5837	12/13/83
153-96-5CAA	G-83-5838	12/15/83
147-95-17ACA	G-84-2401	04/24/84
148-96-9ABD	G-84-2398	04/24/84
150-98-21ACD	G-84-2399	04/25/84
152-98-24CCC	G-84-2402	04/25/84
153-97-34CBA	G-84-2400	04/25/84
153-95-10DAC	G-84-4138	07/24/84
153-95-5CBD	G-87-1293 <sup>1</sup>	07/27/87
152-95-1BCA	G-87-1684	08/10/87
153-95-5CBD*	G-87-1413 <sup>1</sup>	08/17/87
153-94-18CBC	G-87-1597 <sup>1</sup>	09/14/87
153-94-18CBC*	G-87-2026	11/02/87
153-96-11ADA	G-87-1598 <sup>1</sup>	09/14/87
152-101-14ACA	G-89-1295	06/15/89

<sup>1</sup>Date of sample analysis. All other dates are dates of sample collection.

\*Two samples collected at well location.

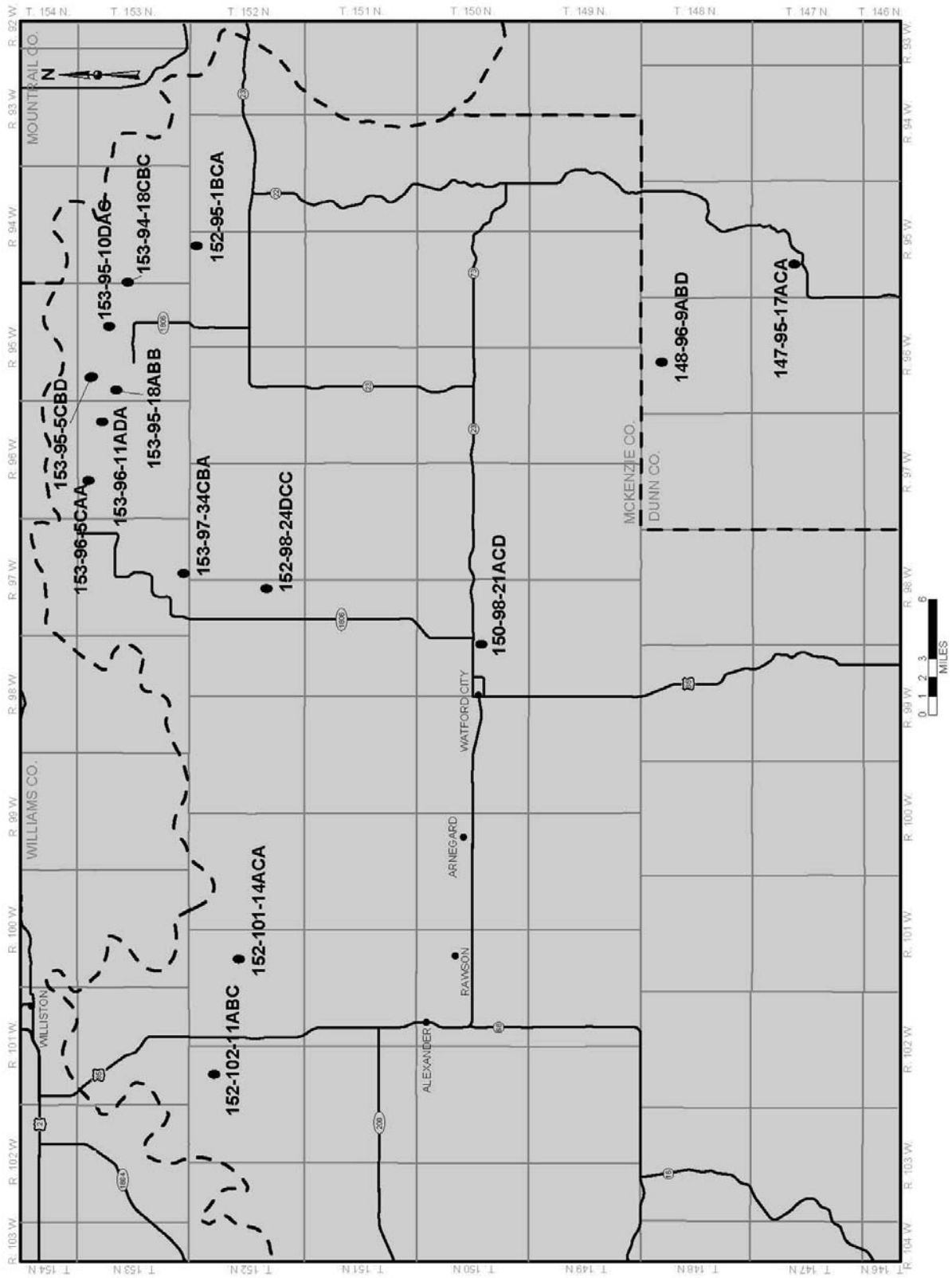


Figure 1. Locations of selected flowing-head wells in Cretaceous and Tertiary aquifers in west-central North Dakota sampled for shallow gas in the 1980's.

## **Ludlow/Cannonball Aquifer**

The Ludlow/Cannonball Aquifer is generally found at depths of around 500 ft bls and is present in the subsurface across the entire study area in McKenzie and northwestern Dunn County. The aquifer consists of terrestrially deposited fine- to medium grained sandstones, claystone, and lignites and is separated from the overlying Tongue River (Bullion Creek) Aquifer by around 75 feet of claystone (Cannonball member equivalent?). The head in the aquifer has previously been characterized as generally being lower than the underlying Fox Hills – Hell Creek Aquifer which supports the supposition that flow is from the Fox Hills – Hell Creek Aquifer into the Ludlow/Cannonball Aquifer (Thorstenson, et.al., 1979, Croft, 1985). Two of the 14 wells described in this report (153-94-18CBC and 152-101-14ACA) are thought to have been completed within the aquifer.

## **Tongue River (Bullion Creek) Aquifer**

The Tongue River (Bullion Creek) Aquifer is present in the subsurface across the entire study area. The aquifer occurs at depths ranging from 140 to 500 ft bls. The Aquifer materials consists of fine- to medium-grained sandstones, siltstones, claystones, and lignites that were deposited as distributary channel and delta-plain deposits (Croft, 1985). Recharge is dominantly from surface sources. Two of the 14 wells described in this report (153-95-18ABB and 153-95-10DAC) are thought to have been completed within the aquifer.

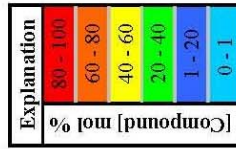
## **Gas Composition Analysis**

Gas samples were collected at the wellhead using field headspace sampling methods. Samples were submitted to local laboratories for gas composition analysis via gas chromatography/mass spectrometry (GC/MS) analysis. Analyses were available for 14 flowing-head wells in the study area. Two wells (153-95-5CBD & 153-94-18CBC) were sampled on two occasions. Gas constituents reported include nitrogen, methane, carbon dioxide, oxygen, hydrogen sulfide, ethane, propane, butanes, pentanes, and hexanes+. A calculation of gross BTU per cubic foot (BTU/ft<sup>3</sup>) on each analysis was completed. Methane (CH<sub>4</sub>) and Nitrogen (N<sub>2</sub>) were detected in all wells. Oxygen (O<sub>2</sub>) was detected in three of the wells. Carbon Dioxide (CO<sub>2</sub>) was detected in 12 of the 14 wells sampled. Ethane (C<sub>2</sub>H<sub>6</sub>) was detected in six of the wells, Propane (C<sub>3</sub>H<sub>8</sub>) was detected in five of the wells, n- and isobutane (n- and i-C<sub>4</sub>H<sub>10</sub>), n- and isopentane (n- and i-C<sub>5</sub>H<sub>12</sub>), and Hexane (C<sub>6</sub>H<sub>14</sub>+) were detected in two wells. Hydrogen Sulfide (H<sub>2</sub>S) was not found in any of the wells sampled (Table 2).

Table 2. Summary of compounds detected in gas samples collected from selected wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.

Well ID	O <sub>2</sub>	N <sub>2</sub>	CH <sub>4</sub>	CO <sub>2</sub>	C <sub>2</sub> H <sub>6</sub>	H <sub>2</sub> S	C <sub>3</sub> H <sub>8</sub>	i-C <sub>4</sub> H <sub>10</sub>	n-C <sub>4</sub> H <sub>10</sub>	i-C <sub>5</sub> H <sub>12</sub>	n-C <sub>5</sub> H <sub>12</sub>	C <sub>6</sub> H <sub>14</sub>
152-102-11ABC												
153-95-18ABB												
153-96-5CAA												
147-95-17ACA												
148-96-9ABD												
150-98-21ACD												
152-98-24CCC												
153-97-34CBA												
153-95-10DAC												
153-95-5CBD												
152-95-1BCA												
153-95-5CBD*												
153-94-18CBC												
153-94-18CBC*												
153-96-11ADA												
152-101-14ACA												

\*Second sample at well location.



**Table 3. Summary of Well Construction Information from Selected Wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.**

Well ID	Total Well Depth (ft)	Depths of Screened/Open Intervals (ft bbls)	Land Surface Elevation <sup>1</sup> at Well Location (ft amsl)	Elevations of Screened Intervals (ft amsl)	Aquifer Monitored	Lithology across Screened Interval
152-102-11ABC*	1,600	1,600	2,073	473	Fox Hills – Hell Creek	Likely Colgate/Timber Lake mbrs.
153-95-18ABB	1,380	1,085 - 1,127	2,260	1,175 – 1,133	Fox Hills – Hell Creek	Sand.
153-96-5CAA	1,290	1,272 - 1,290	1,912	640 - 622	Fox Hills – Hell Creek	Sandy Clay, Sand, and Clay.
147-95-17ACA*	1,570	1,570	2,079	509	Fox Hills – Hell Creek	N/A
148-96-9ABD*	1,500	1,460 - 1,465	1,978	523 - 518	Fox Hills – Hell Creek	N/A
150-98-21ACD	1,810	1,730 - 1,810	2,125	395 - 315	Fox Hills – Hell Creek	Coal and Sand.
152-98-24CCC	1,730	1,680 - 1,730	2,000	320 - 270	Fox Hills – Hell Creek	Sand.
153-97-34CBA*	1,660	1,600 - 1,660	2,021	421 - 361	Fox Hills – Hell Creek	Clay, Sand, and Shale.
153-95-10DAC*	770	640 - 770	2,301	1,661 – 1,531	Tongue River (Bullion Creek)	Sand, Coal, Clay.
153-95-5CBD*	492	355 - 492	1,970	1,615 – 1,478	Tongue River (Bullion Creek)	Sandy Shale, Sandstone.
152-95-1BCA*	730	645 - 730	2,162	1,517 – 1,432	Fox Hills – Hell Creek	Sand.
153-94-18CBC	960	876 - 906	2,190	1,314 – 1,284	Cannonball-Ludlow	Siltstone and very fine grained, silty, clayey, Sandstone, very fine grained, clay, greenish.
153-96-11ADA	1,520	1,289 - 1,370	2,340	1,051 - 970	Fox Hills – Hell Creek	N/A
152-101-14ACA	1,000	945 - 969	1,940	995 - 971	Bullion Creek/Ludlow	N/A

N/A = Well construction/lithologic information not available.

\*Well construction information estimated from available well depth information.

<sup>1</sup>Land surface elevations determined from 1:24,000 topographic maps where elevation data was not reported.

ft bbls = feet below land surface.

ft amsl = elevation in feet above mean sea level.

## INDIVIDUAL WELL SUMMARIES

Available well information for each of the wells sampled is summarized below, on an individual well basis, in chronologic order of gas sample collection occurrence. All gas constituent concentrations are reported in mol %. Well construction information was compiled from available drilling records (e.g. well depth, screened intervals, aquifers monitored, etc.) are summarized in Table 3.

### 152-102-11ABC

Well 152-102-11ABC is located in northeastern Elk Township in northwestern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer in the early 1980s to a depth of approximately 1,600 feet. The well has been used as a water supply well for livestock. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on December 14, 1983 by the NDSWC. The sample (G-83-5839) was subject to laboratory gas composition analysis the following day on December 15, 1983. Total hydrocarbon concentration [THC] was calculated at 60.74% [THC], with reported values of 60.74% [CH<sub>4</sub>], 37.59% [N<sub>2</sub>], and 1.07% [CO<sub>2</sub>] (Figure 2). Calculated gross BTU content equals 605 BTU/ft<sup>3</sup> (saturated) and 615 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7233 (where air = 1.000).

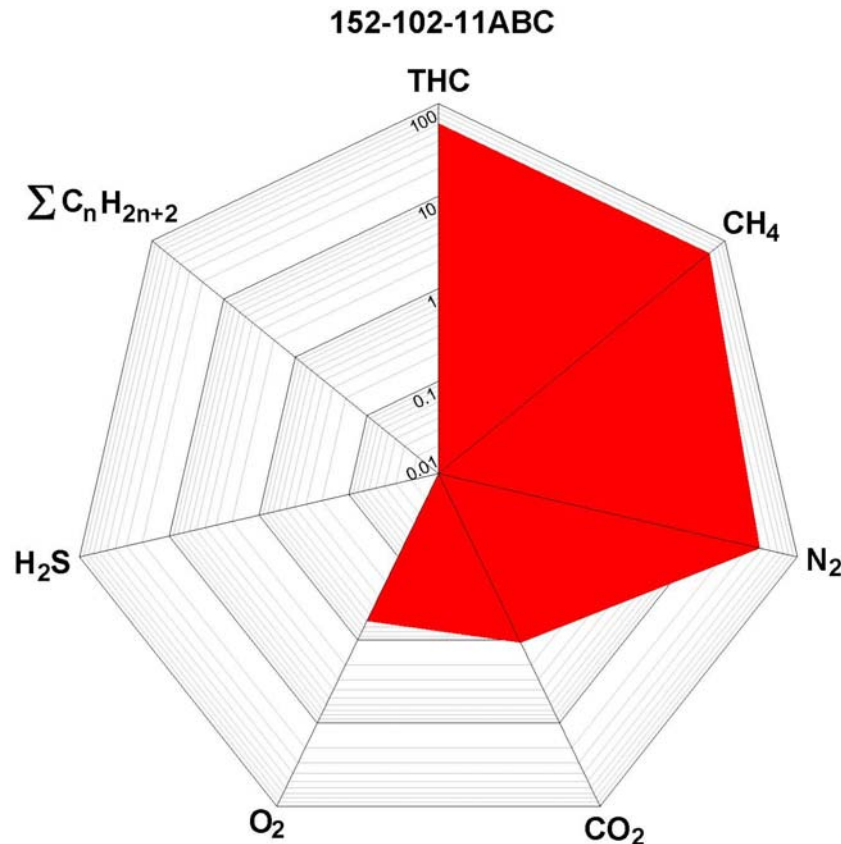


Figure 2. Radar diagram of gas constituents found in well 152-102-11ABC. Scale is logarithmic in mol %.

## 153-95-18ABB

Well 153-95-18ABB is located in western Elm Tree Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on January 5, 1982 to a depth of approximately 1,380 ft. The well has been used as an industrial water supply well and is screened within the aquifer over a 42 ft interval from 1,085 ft to 1,127 ft below land surface (bls). Land surface elevation at the well location is 2,260 ft above mean sea level (amsl) which results in the screened interval being at an altitude of 1,175 to 1,133 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on December 13, 1983 by the NDSWC. The sample (G-83-5837) was subject to laboratory gas composition analysis on December 15, 1983. Gas composition was calculated at 15.24% [THC], with reported values of 9.56% [CH<sub>4</sub>], 83.15% [N<sub>2</sub>], 1.16% [CO<sub>2</sub>], and 5.66% [C<sub>2</sub>H<sub>6</sub>], and 0.02% [C<sub>3</sub>H<sub>8</sub>] (Figure 3). Calculated gross BTU content equals 194 BTU/ft<sup>3</sup> (saturated) and 198 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.9388.

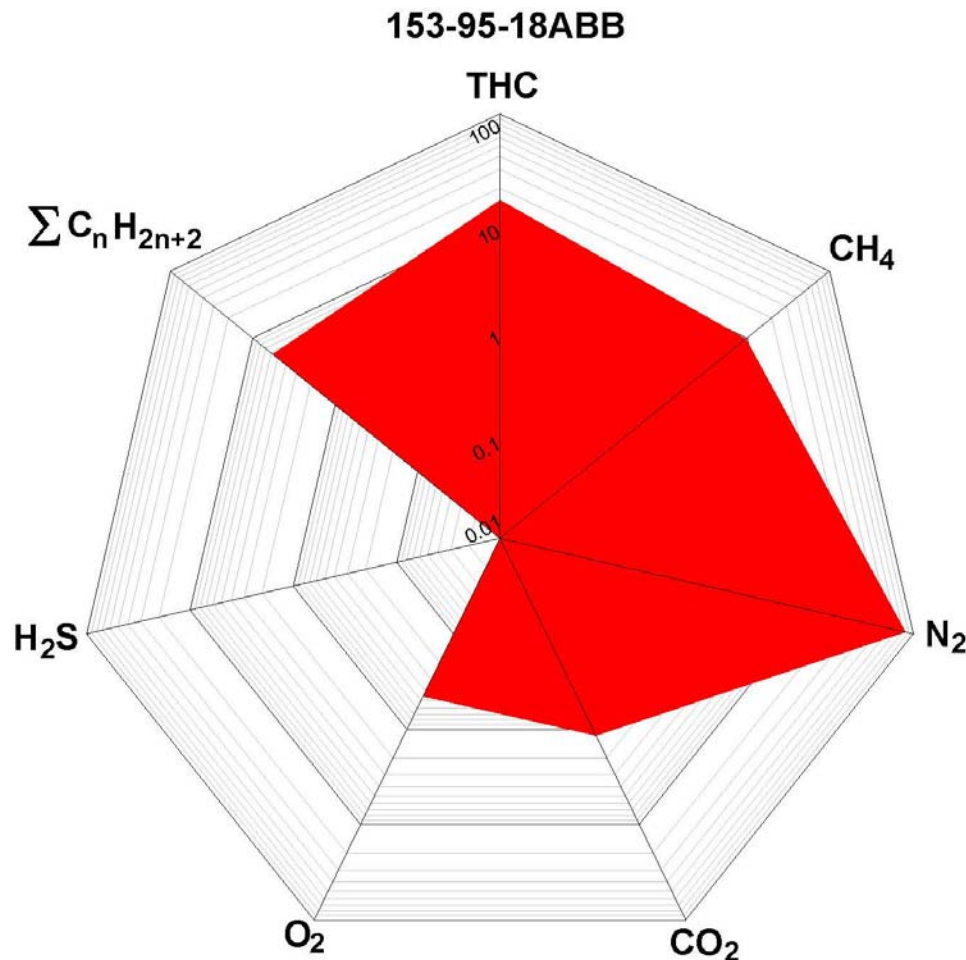


Figure 3. Radar diagram of gas constituents found in well 153-95-18ABB. Scale is logarithmic in mol %.

## 153-96-5CAA

Well 153-96-5CAA is located in northwestern Frish Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on November 20<sup>th</sup>, 1976 to a depth of approximately 1,290 ft. The well has been used as a livestock water supply well and is screened within the aquifer over an 18 ft interval from 1,272 ft to 1,290 ft bls. Land surface elevation at the well location is 1,912 ft amsl which results in the screened interval altitude of 640 to 622 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on December 12, 1983 by the NDSWC. The sample (G-83-5838) was subject to laboratory gas composition analysis on December 15, 1983. Gas composition was calculated at 77.47% [THC], with reported values of 73.83% [CH<sub>4</sub>], 20.46% [N<sub>2</sub>], 1.22% [CO<sub>2</sub>], and 3.64% [C<sub>2</sub>H<sub>6</sub>]. The presence of oxygen was reported in this sample at 0.84% [O<sub>2</sub>] (Figure 4). Calculated gross BTU content equals 799 BTU/ft<sup>3</sup> (saturated) and 813 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.6733.

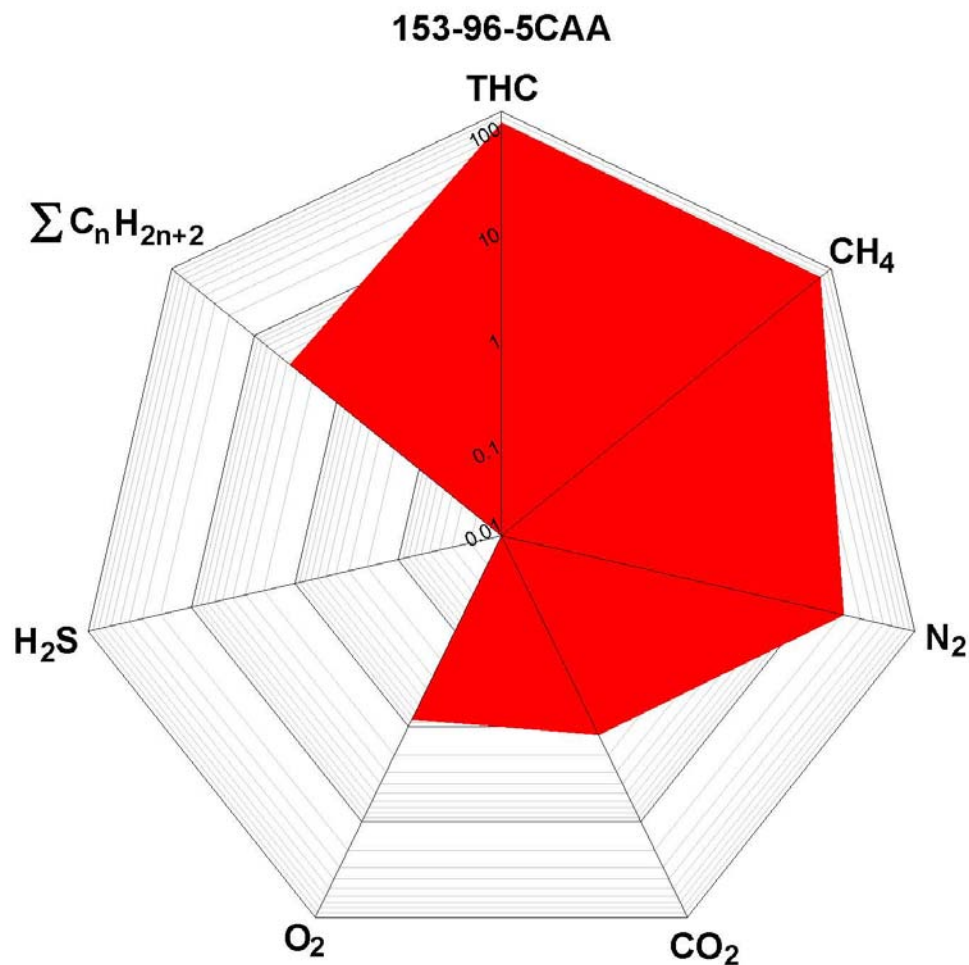


Figure 4. Radar diagram of gas constituents found in well 153-96-5DAA. Scale is logarithmic in mol %.



## 147-95-17ACA

Well 147-95-17ACA is located in northwestern Dunn County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer to a depth of approximately 1,570 ft. The well has been used as a livestock water supply well. The well was sampled for gas content on April 24, 1984 by the NDSWC. The sample (G-84-2401) was subject to laboratory gas composition analysis on May 4, 1984. Gas composition was calculated at 34.84% [THC], with reported values of 34.84% [CH<sub>4</sub>], 64.29% [N<sub>2</sub>], and 0.87% [CO<sub>2</sub>] (Figure 5). Calculated gross BTU content equals 347 BTU/ft<sup>3</sup> (saturated) and 353 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.8281.

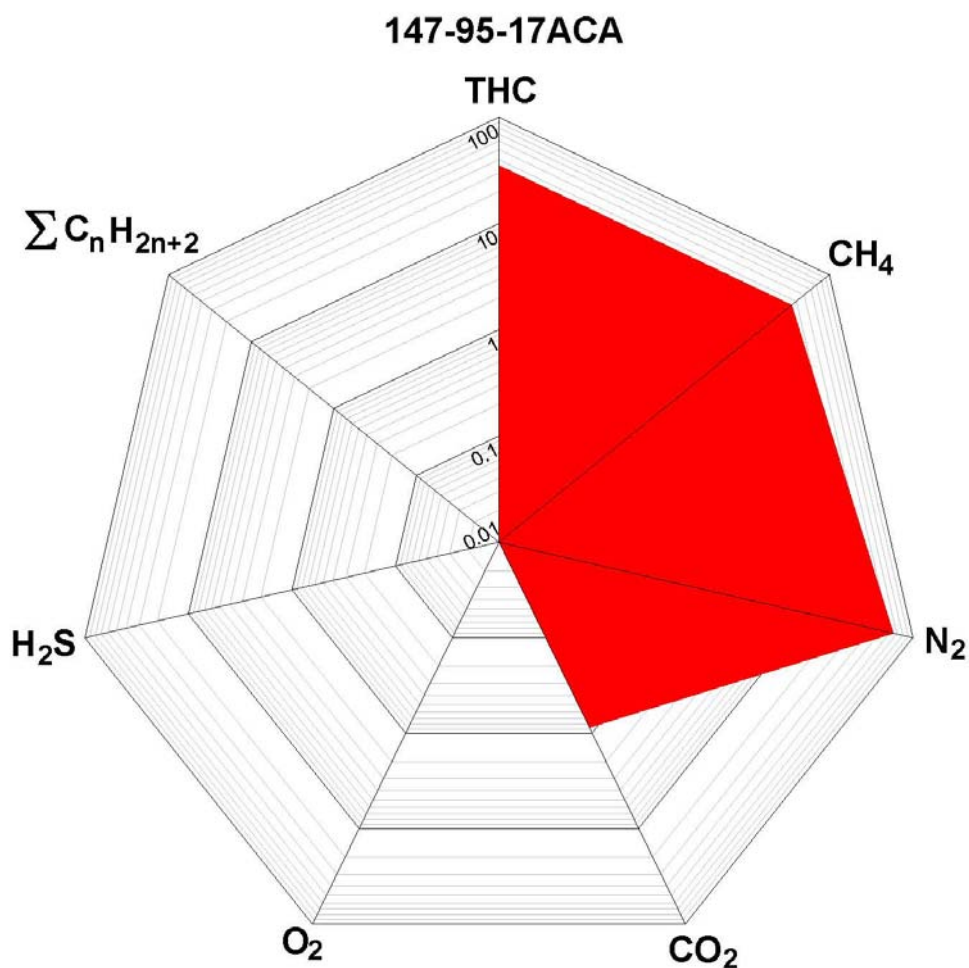


Figure 5. Radar diagram of gas constituents found in well 147-95-17ACA. Scale is logarithmic in mol %.

## 148-96-9ABD

Well 148-96-9ABD is located in northwestern Dunn County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer to a depth of approximately 1,500 ft. The well has been used as a livestock water supply well and is screened within the aquifer over a five-foot interval from 1,460 ft to 1,465 ft bls. Land surface elevation is 1,978 ft amsl which results in the screened interval being at an altitude of 523 to 518 feet amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on April 24, 1984 by the NDSWC. The sample (G-84-2398) was subject to laboratory gas composition analysis on April 26, 1984. Gas composition (mol %) was calculated at 48.61% [THC], with reported values of 48.61% [CH<sub>4</sub>], and 51.39% [N<sub>2</sub>] (Figure 6). Calculated gross BTU content equals 484 BTU/ft<sup>3</sup> (saturated) and 492 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7666.

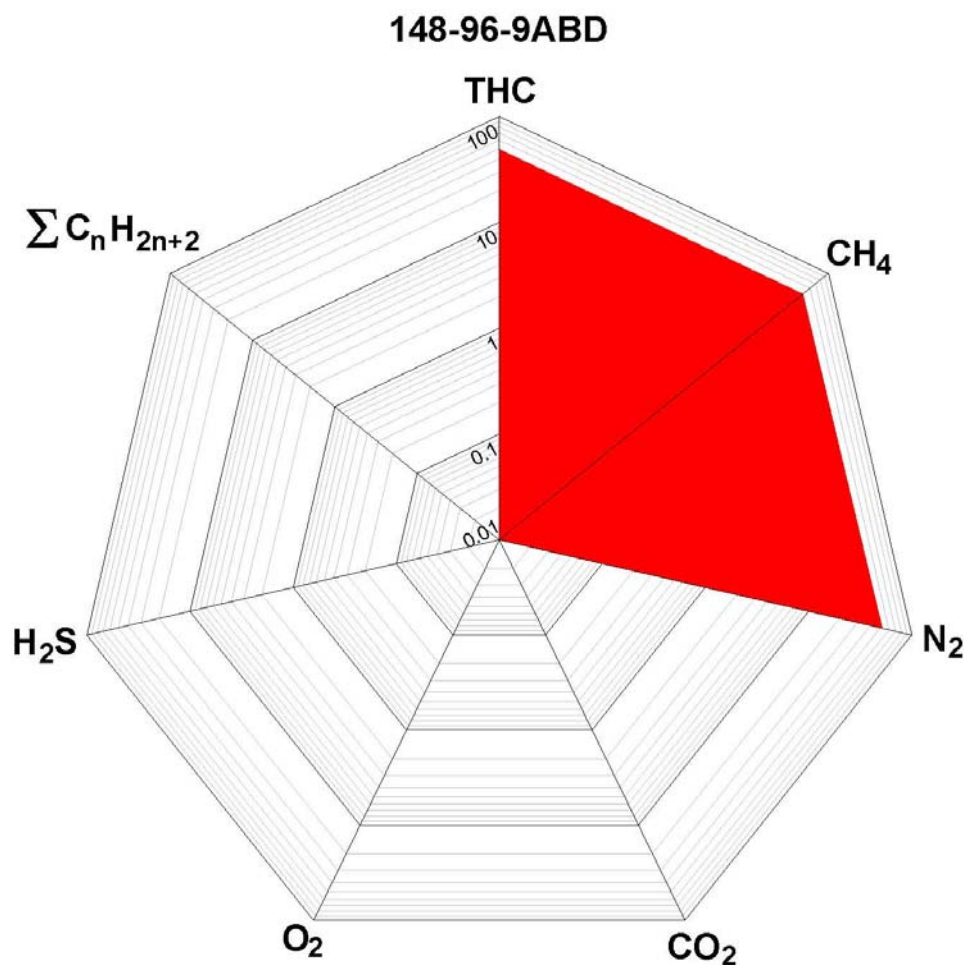


Figure 6. Radar diagram of gas constituents found in well 148-96-9ABD. Scale is logarithmic in mol %.

## 150-98-21ACD

Well 150-98-21ACD is located in western Schafer Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on August 4, 1980 to a depth of approximately 1,810 ft below land surface (bls). The well has been used as a domestic water supply well and is screened within the aquifer over an 80 ft interval from 1,730 to 1,810 ft bls. Land surface elevation at the well location is 2,125 ft amsl which results in the screened interval being at an altitude of 395 to 315 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on April 25, 1984 by the NDSWC. The sample (G-84-2399) was subject to laboratory gas composition analysis on May 4, 1984. Gas composition was calculated at 47.40% [THC], with reported values of 47.40% [CH<sub>4</sub>] and 52.60% [N<sub>2</sub>] (Figure 7). Calculated gross BTU content equals 472 BTU/ft<sup>3</sup> (saturated) and 480 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7716.

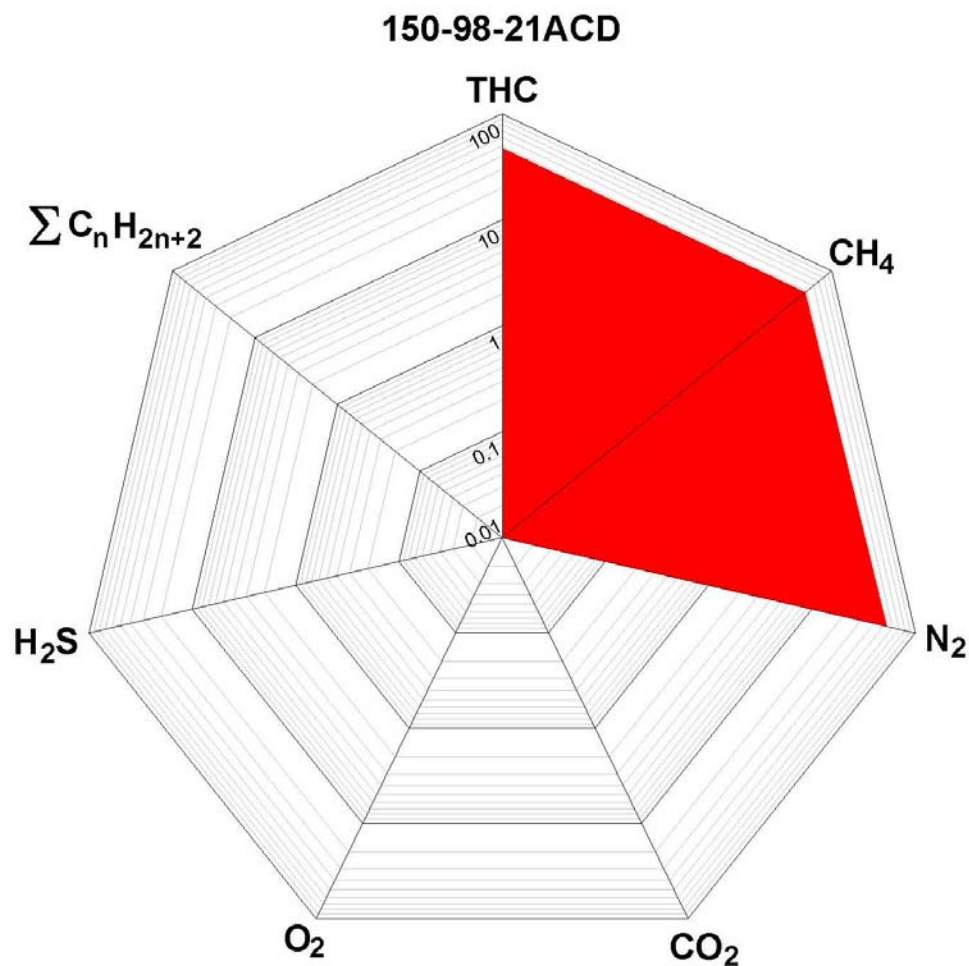


Figure 7. Radar diagram of gas constituents found in well 150-98-21ACD. Scale is logarithmic in mol %.

## 152-98-24CCC

Well 152-98-24CCC is located in eastern Twin Valley Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on June 21, 1975 to a depth of approximately 1,730 ft bls. The well has been used as a livestock water supply well and is screened within the aquifer over an 50 foot interval from 1,680 to 1,730 ft bls. Land surface elevation at the well location is 2,000 ft amsl which results in the screened interval being at an altitude of 320 to 270 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on April 25, 1984 by the NDSWC. The sample (G-84-2402) was subject to laboratory gas composition analysis on May 4, 1984. Gas composition was calculated at 54.48% [THC], with reported values of 54.48% [CH<sub>4</sub>] and 44.85% [N<sub>2</sub>], and 0.67% [CO<sub>2</sub>] (Figure 8). Calculated gross BTU content equals 542 BTU/ft<sup>3</sup> (saturated) and 552 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7461.

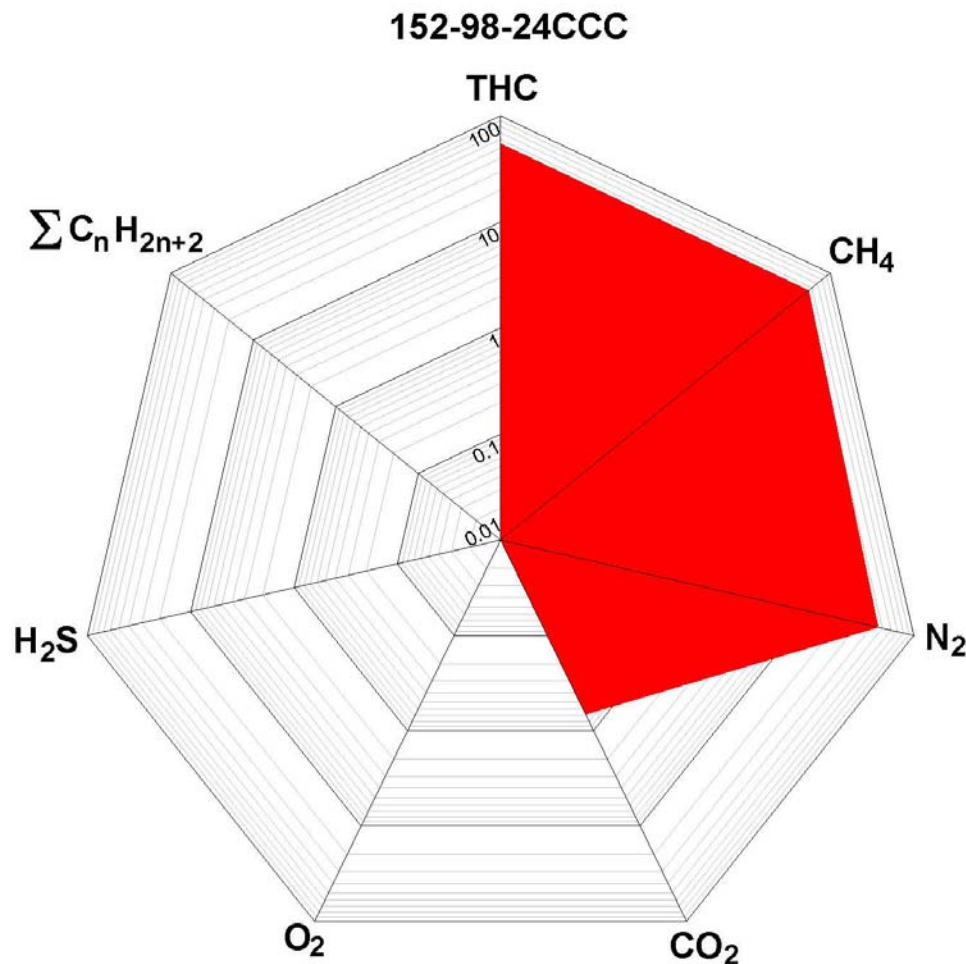


Figure 8. Radar diagram of gas constituents found in well 152-98-24CCC. Scale is logarithmic in mol %.

## 153-97-34CBA

Well 153-97-34CBA is located in southeastern Twin Valley Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on July 27, 1974 to a depth of approximately 1,660 ft. The well has been used as a livestock water supply well and is screened within the aquifer over a 60 foot interval from 1,600 ft to 1,660 ft bls. Land surface elevation at the well location is 2,021 ft amsl which results in the screened interval being at an altitude of 421 to 361 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on April 25, 1984 by the NDSWC. The sample (G-84-2400) was subject to laboratory gas composition analysis on May 4, 1984. Gas composition was calculated at 71.01% [THC], with reported values of 71.01% [CH<sub>4</sub>], 28.21% [N<sub>2</sub>], 0.78% [CO<sub>2</sub>] (Figure 9). Calculated gross BTU content equals 707 BTU/ft<sup>3</sup> (saturated) and 720 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.6786.

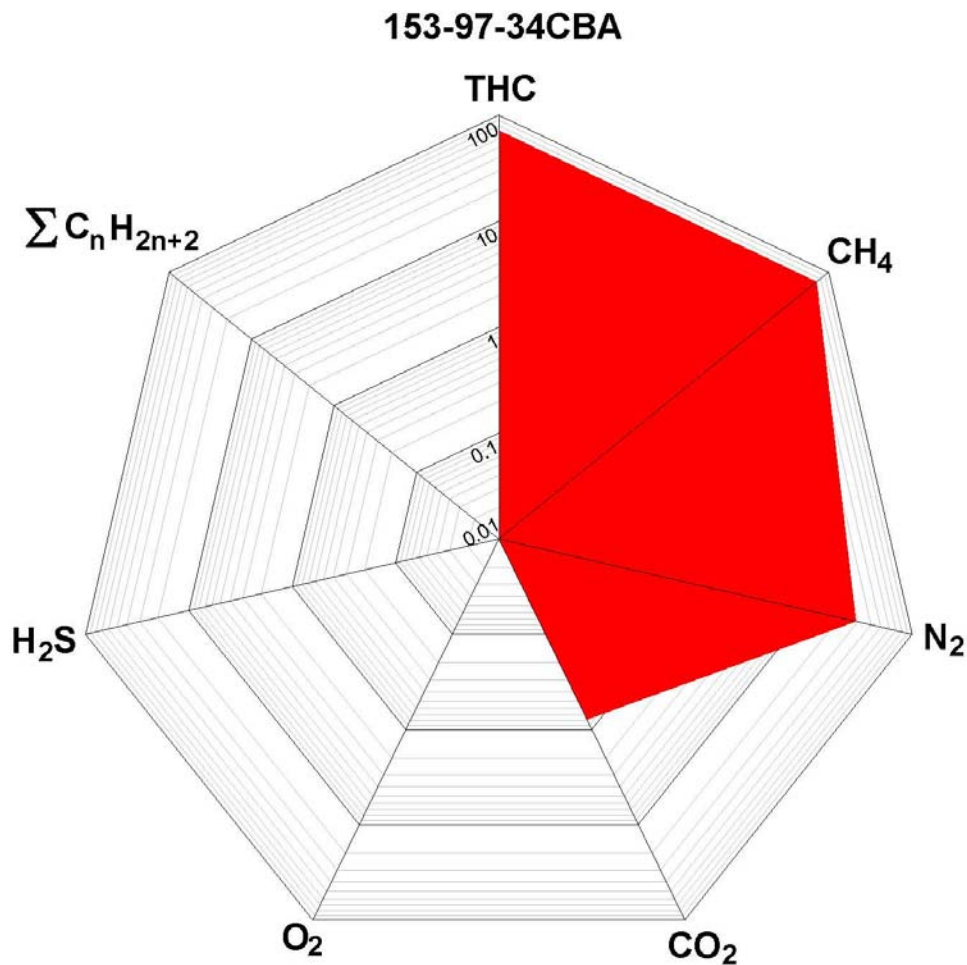


Figure 9. Radar diagram of gas constituents found in well 153-97-34CBA. Scale is logarithmic in mol %.



## 153-95-10DAC

Well 153-95-10DAC is located in northeastern Elm Tree Township in northeastern McKenzie County (Figure 1). The well was drilled into Tongue River (Bullion Creek) Aquifer to a depth of approximately 770 ft bls. The well was pressured (150 psi) as it was completed and developed. The well was sampled for gas content on July 24, 1984 by the NDSWC. The well was screened across a 130 ft interval from 640 to 770 ft bls. Land surface elevation at the well is 2,301 ft amsl which resulted in the screened interval being at an altitude of 1,661 to 1,531 ft amsl. The well was abandoned shortly after drilling and was plugged with a considerable amount of cement (Wanek, 2007). The sample (G-84-4138) was subject to laboratory gas composition analysis on August 9, 1984. Gas composition was calculated at 13.80% [THC], with reported values of 11.34% [CH<sub>4</sub>], 85.42% [N<sub>2</sub>], 0.77% [CO<sub>2</sub>], and 2.45% [C<sub>2</sub>H<sub>6</sub>], and 0.01% [C<sub>3</sub>H<sub>8</sub>] (Figure 10). Calculated gross BTU content equals 156 BTU/ft<sup>3</sup> (saturated) and 159 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.9265.

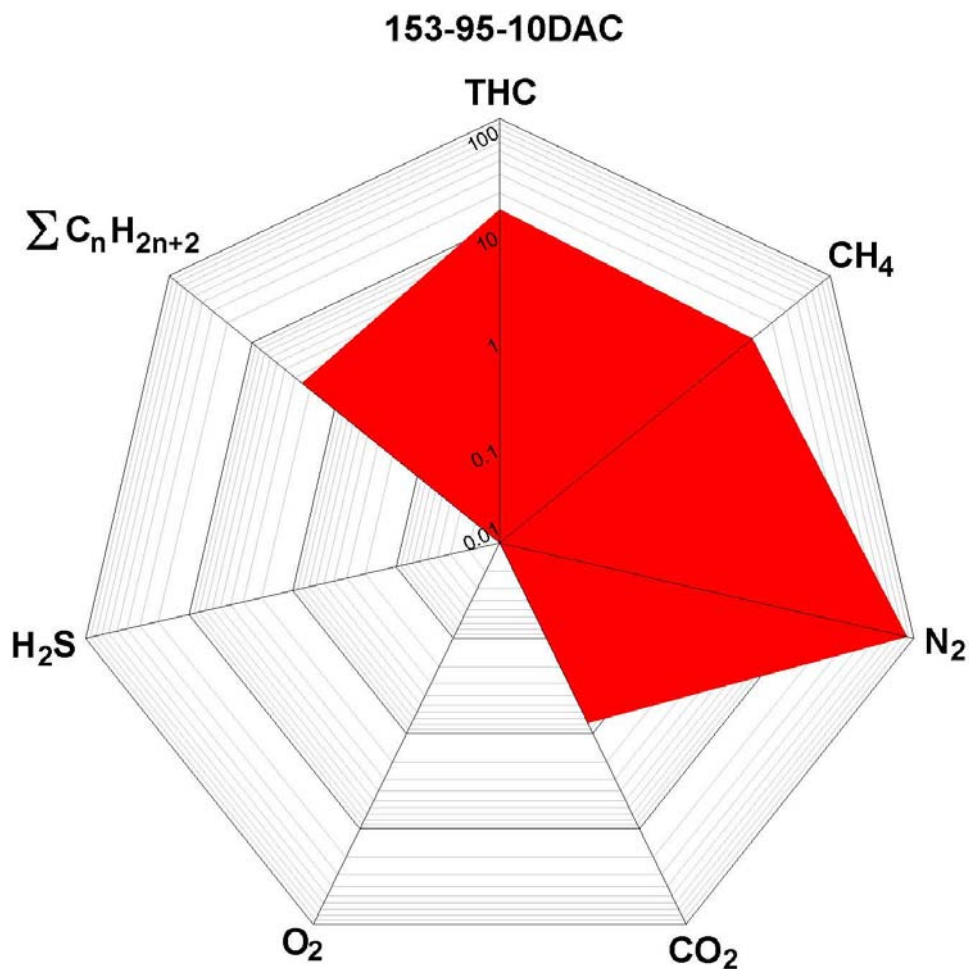


Figure 10. Radar diagram of gas constituents found in well 153-95-10DAC. Scale is logarithmic in mol %.

## 153-95-5CBD

Well 153-95-5CBD is located in northwestern Elm Tree Township in northeastern McKenzie County (Figure 1). The well was drilled into the Tongue River (Bullion Creek) Aquifer on July 23, 1987 to a depth of approximately 492 ft, probably around 900 feet above the underlying Fox Hills – Hell Creek Aquifer. The well has been used as an industrial water supply well and is screened within the aquifer over a 137 ft interval (53 ft slotted) from 355 ft to 492 ft bls. Land surface elevation at the well location is 1,970 ft amsl which results in the screened interval being at an altitude of 1,615 ft to 1,478 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled twice for gas content by the NDSWC. Sample G-87-1293 was analyzed on July 27<sup>th</sup>, 1987. Sample G-87-1413 was analyzed on August 17, 1987. Gas composition for sample G-87-1293 was calculated at 67.61% [THC], with reported values of 60.13% [CH<sub>4</sub>], 32.17% [N<sub>2</sub>], 0.22% [CO<sub>2</sub>], 2.77% [C<sub>2</sub>H<sub>6</sub>], 2.54% [C<sub>3</sub>H<sub>8</sub>], 0.43% [i-C<sub>4</sub>H<sub>10</sub>], 0.97% [n-C<sub>4</sub>H<sub>10</sub>], 0.28% [i-C<sub>5</sub>H<sub>12</sub>], 0.33% [n-C<sub>5</sub>H<sub>12</sub>], and 0.16 [C<sub>6</sub>H<sub>14</sub>+] (Figure 11) which is probably representative of “typical gas storage conditions” (Wanek, 2007). Calculated gross BTU equals 785 BTU/ft<sup>3</sup> (saturated) and 798 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is reported at 0.764.

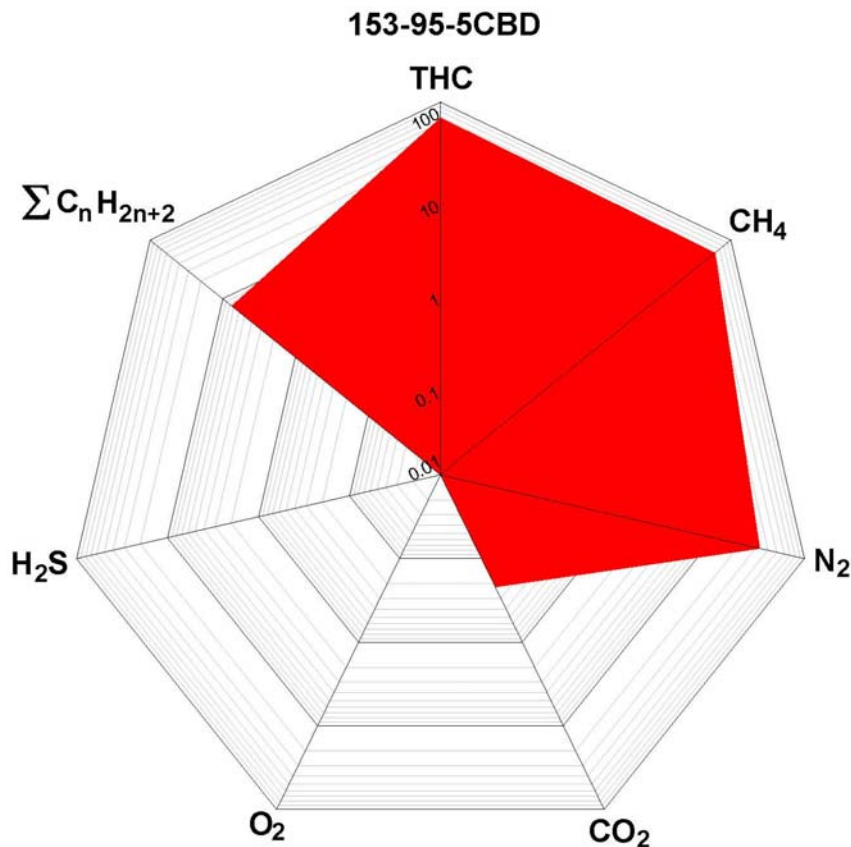


Figure 11. Radar diagram of gas constituents found in well 153-95-5CBD. Scale is logarithmic in mol %.

Gas composition for sample G-87-1413 was calculated at 6.43% [THC], with reported values of 6.43% [CH<sub>4</sub>], and 0.02% [CO<sub>2</sub>] (Figure 12) which seems to be more suggestive of a migrated source due to the elevated N<sub>2</sub>. Calculated gross BTU content equals 64 BTU/ft<sup>3</sup> (saturated) and 65 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.9400.

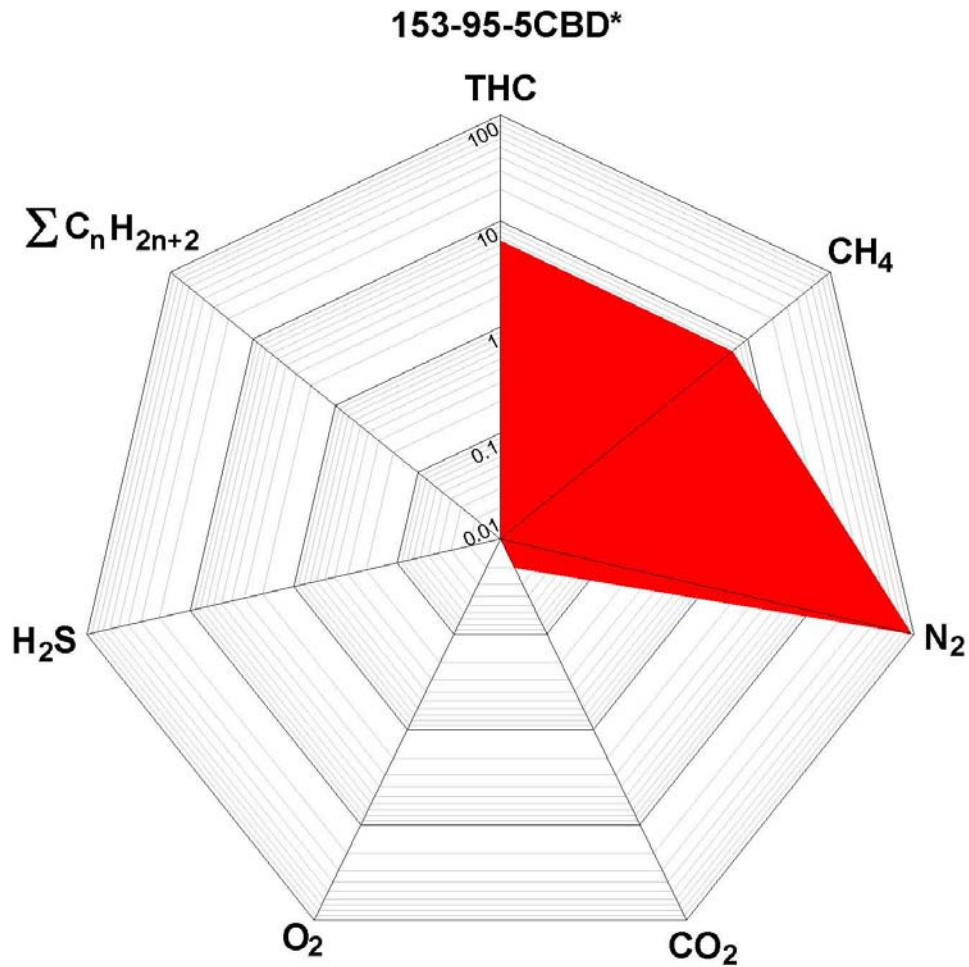


Figure 12. Radar diagram of gas constituents found in well 153-95-5CBD. \*Second sample from well. Scale is logarithmic in mol %.



## 152-95-1BCA

Well 152-95-1BCA is located in northeastern Hawkeye Valley Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on January 20, 1988 to a depth of 730 ft. The well was used as a test hole by Amerada Hess and was screened within the aquifer over an 81 ft interval from 645 ft to 730 ft bls. Land surface elevation at the well location is 2,162 ft amsl which results in the screened interval being at an altitude of 1,517 to 1,432 ft amsl. The well was an artesian and was sampled for gas content on August 10, 1987 by the NDSWC. The sample (G-87-1684) was subject to laboratory gas composition analysis on August 13, 1987. Gas composition (mol %) was calculated at 96.77% [THC], with reported values of 68.96% [CH<sub>4</sub>], 3.21% [N<sub>2</sub>], 0.02% [CO<sub>2</sub>], 16.18% [C<sub>2</sub>H<sub>6</sub>], 7.54% [C<sub>3</sub>H<sub>8</sub>], 0.88% [i-C<sub>4</sub>H<sub>10</sub>], 2.04% [n-C<sub>4</sub>H<sub>10</sub>], 0.40% [i-C<sub>5</sub>H<sub>12</sub>], 0.45% [n-C<sub>5</sub>H<sub>12</sub>], and 0.32 [C<sub>6</sub>H<sub>14</sub>+] (Figure 13). Calculated gross BTU content equals 1,302 BTU/ft<sup>3</sup> (saturated) and 1,325 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7883.

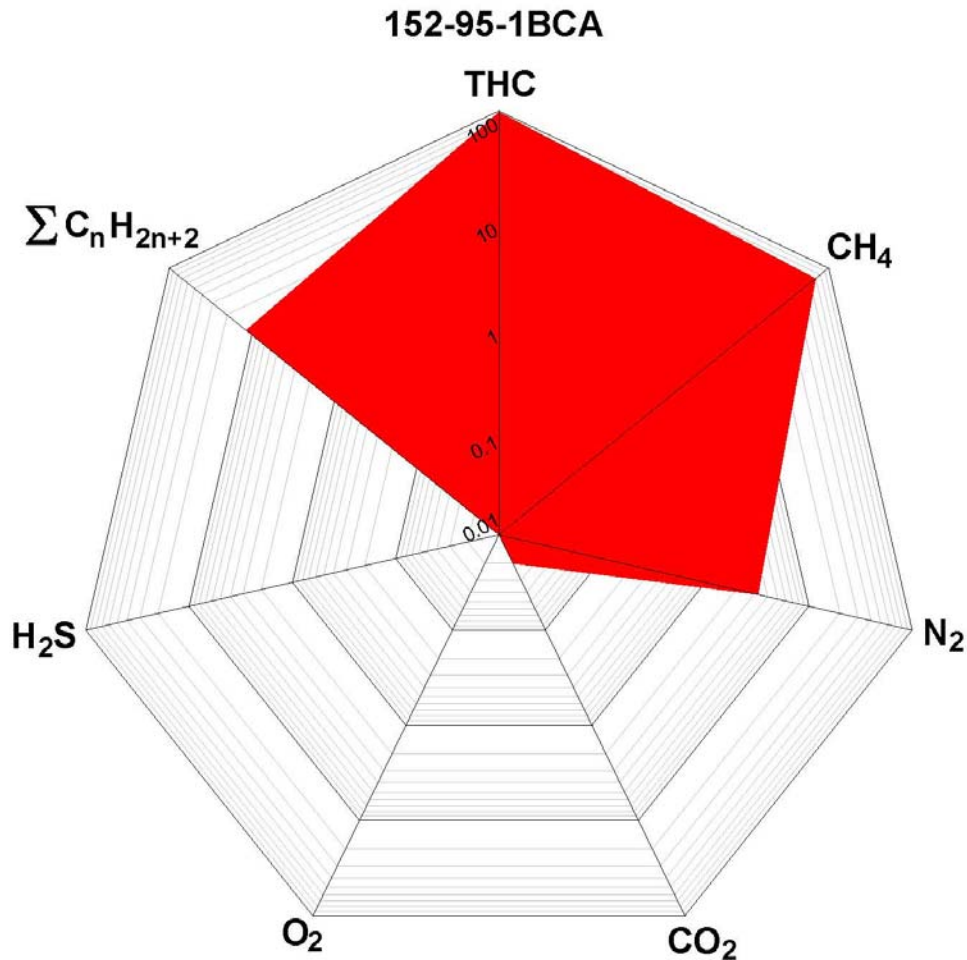


Figure 13. Radar diagram of gas constituents found in well 152-95-1BCA. Scale is logarithmic in mol %.

## 153-94-18CBC

Well 153-94-18CBC is located in eastern Riverview Township in northeastern McKenzie County (Figure 1). The well was drilled into a shallow sand (likely Cannonball/Ludlow) aquifer interval, known to occur along the Nesson anticline, on June 4, 1987 to a depth of approximately 960 ft, around 500 feet above the Fox Hills – Hell Creek Aquifer. This interval is believed to have some horizontal extent, and as a result, is used as a local fresh water source. The well has been used as an observation well and is screened within the aquifer over a 30 ft interval from 876 ft to 906 ft bls. Land surface elevation at the well location is 2,190 ft amsl which results in the screened interval being at an altitude of 1,314 to 1,284 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled twice for gas content by the NDSWC. Sample G-87-1597 was collected on September 10, 1987 and analyzed on September 14, 1987. Gas composition was calculated at 25.53% [THC], with reported values of 25.53% [CH<sub>4</sub>], 74.40% [N<sub>2</sub>], and 0.07% [CO<sub>2</sub>] (Figure 14). Calculated gross BTU content equals 253 BTU/ft<sup>3</sup> (saturated) and 258 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is reported at 0.8620.

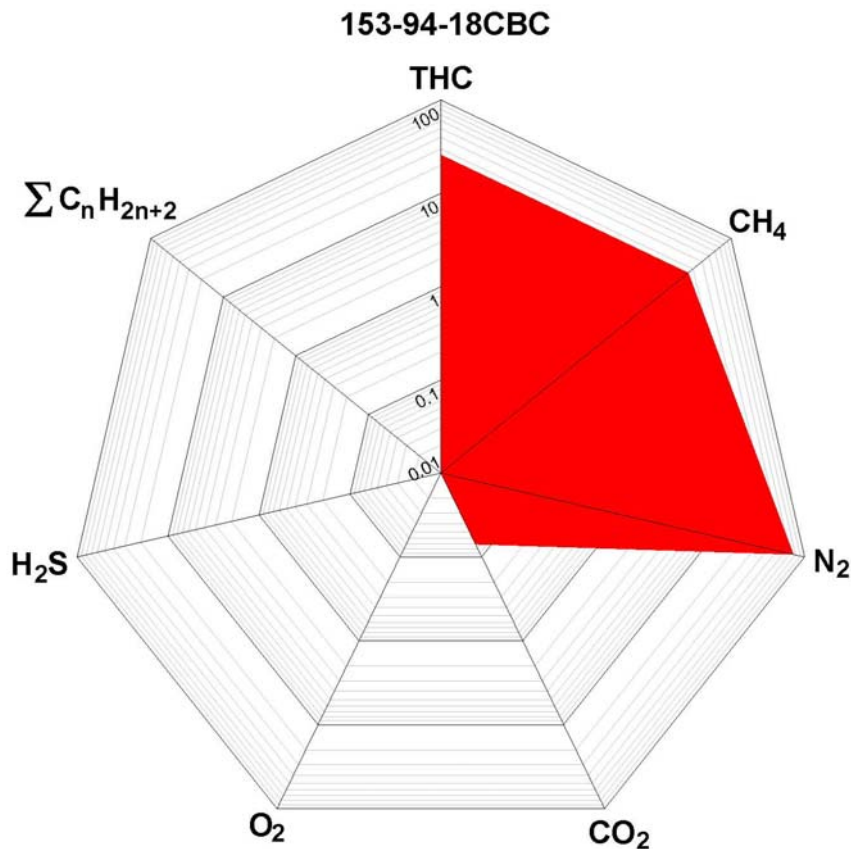
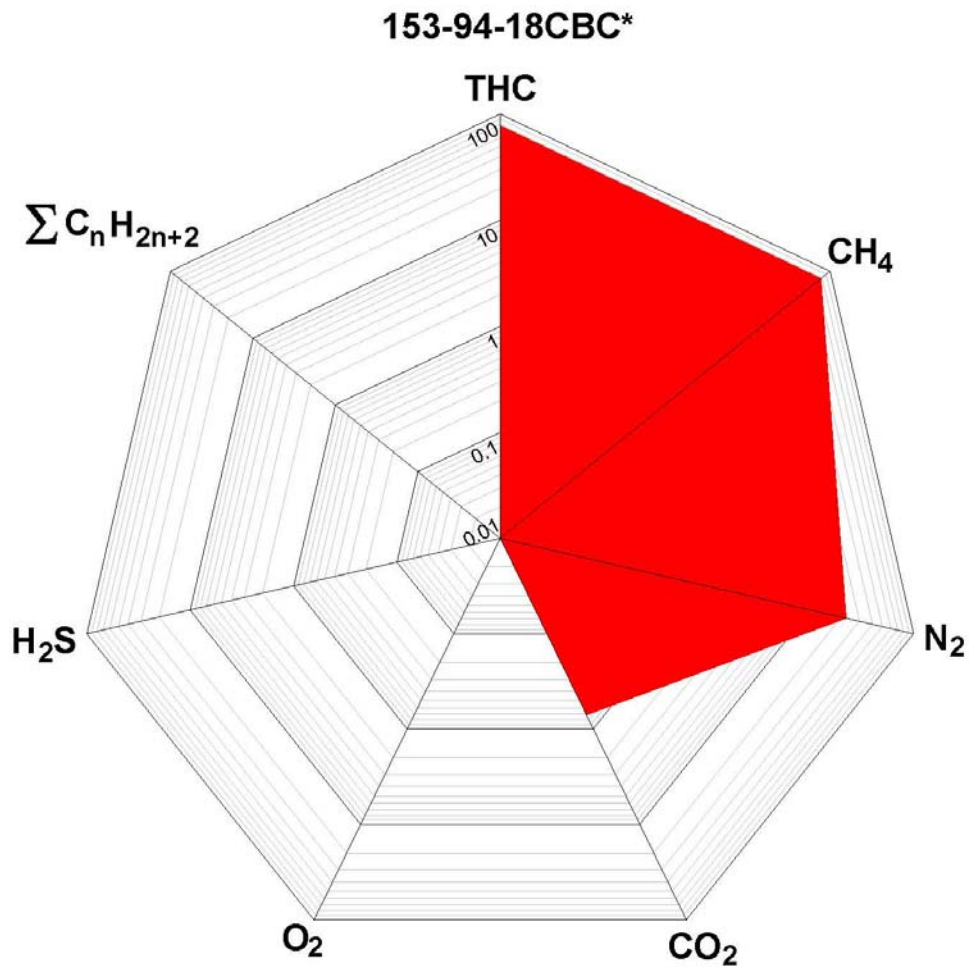


Figure 14. Radar diagram of gas constituents found in well 153-94-18CBC. Scale is logarithmic in mol %.

Sample G-87-2026 was collected on November 2, 1987 and analyzed on November 6, 2007. Gas composition was calculated at 77.18% [THC], with reported values of 77.18% [CH<sub>4</sub>], 22.11% [N<sub>2</sub>] and 0.71% [CO<sub>2</sub>] (Figure 15). Calculated gross BTU content equals 767 BTU/ft<sup>3</sup> (saturated) and 779 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.6530.



**Figure 15. Radar diagram of gas constituents found in well 153-94-18CBC.**  
 \* Second sample collected from well. Scale is logarithmic in mol %.

## 153-96-11ADA

Well 153-96-11ADA is located in northeastern Frish Township in northeastern McKenzie County (Figure 1). The well was drilled into the Fox Hills – Hell Creek Aquifer on June 17, 1987 to a depth of 1,520 ft. The well has been used as an observation well and is screened within the aquifer over an 81 ft interval from 1,289 ft to 1,370 ft bls. Land surface elevation at the well location is 2,340 ft amsl which results in the screened interval being at an altitude of 1,051 to 970 ft amsl. The well is artesian with an overall *decreasing* head over time (NDSWC, 2007). The well was sampled for gas content on September 9, 1987 by the NDSWC. The sample (G-87-1598) was subject to laboratory gas composition analysis on September 14, 1987. Gas composition (mol %) was calculated at 76.25% [THC], with reported values of 76.25% [CH<sub>4</sub>], 23.26% [N<sub>2</sub>], and 0.49% [CO<sub>2</sub>] (Figure 16). Calculated gross BTU content equals 758 BTU/ft<sup>3</sup> (saturated) and 770 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.6550.

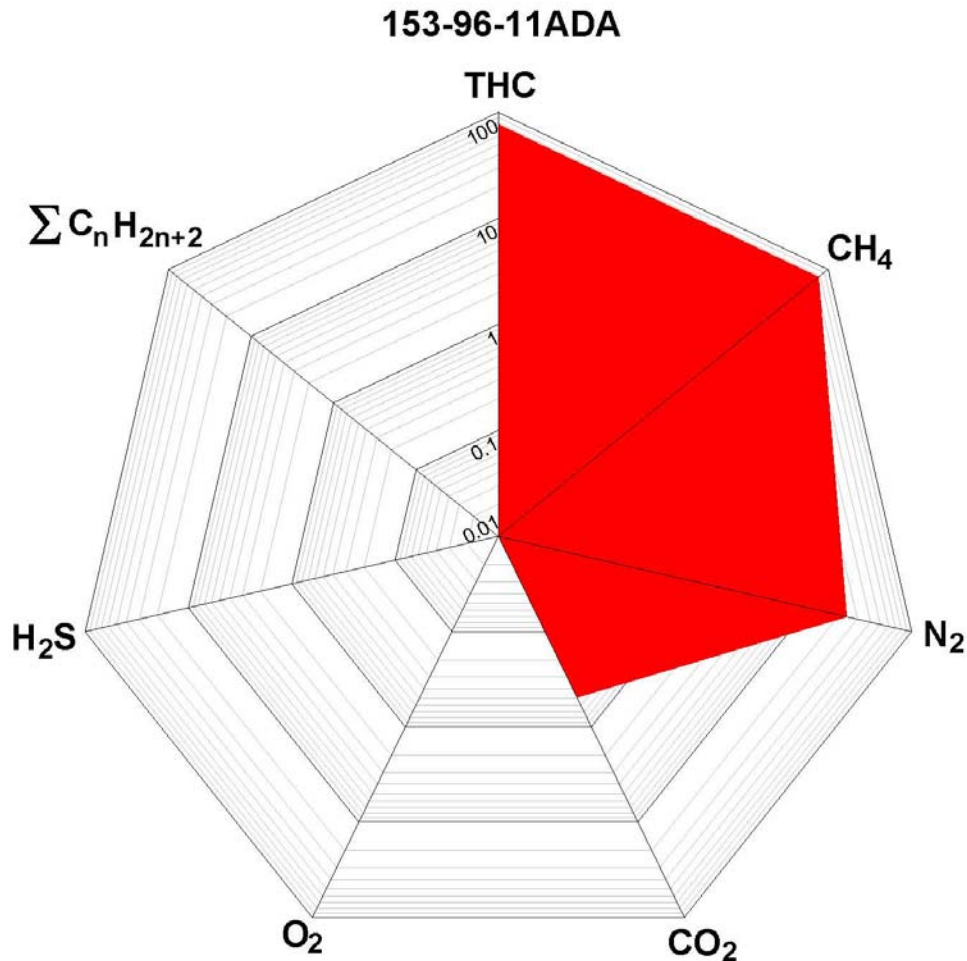


Figure 16. Radar diagram of gas constituents found in well 153-96-11ADA. Scale is logarithmic in mol %.

## 152-101-14ACA

Well 152-101-14ACA is located in eastern Poe Township in northwestern McKenzie County (Figure 1). The well was likely drilled into the Tongue River (Bullion Creek) or Ludlow Aquifer on November 6, 1981 to a depth of approximately 1,000 ft. The well was located in a topographically low location and was installed as a part of NDSWC ground-water studies in McKenzie county. The well was used as an observation well and was screened over a 24 ft interval from 945 ft to 969 ft bls. Land surface elevation at the well location was 1,940 ft amsl which resulted in the screened interval being at an altitude of 995 to 971 ft amsl. The well was an artesian, with an overall *decreasing* head over time (NDSWC, 2007). The well was left in place for a local cattleman's stock use until the well developed holes in the casing and was plugged (Wanek, 2007). The well was sampled for gas content by the NDSWC in June of 1989. The sample (G-89-1295) was subject to laboratory gas composition analysis on June 15, 1989. Gas composition was calculated at 56.63% [THC], with reported values of 54.02% [CH<sub>4</sub>], 42.70% [N<sub>2</sub>], 0.67% [CO<sub>2</sub>], 0.94% [C<sub>2</sub>H<sub>6</sub>], 0.69% [C<sub>3</sub>H<sub>8</sub>], 0.05% [i-C<sub>4</sub>H<sub>10</sub>], 0.30% [n- C<sub>4</sub>H<sub>10</sub>], 0.13% [i-C<sub>5</sub>H<sub>12</sub>], 0.19% [n-C<sub>5</sub>H<sub>12</sub>], and 0.31 [C<sub>6</sub>H<sub>14</sub>]. Due to sample volume, oxygen content was not able to be determined. As a result, it was reported as included in the reported value of [N<sub>2</sub>] (Figure 17). Calculated gross BTU content equals 608 BTU/ft<sup>3</sup> (saturated) and 618 BTU/ft<sup>3</sup> (dry) as determined at conditions of 14.73 psi and 60 °F. Calculated gas specific gravity is 0.7670.

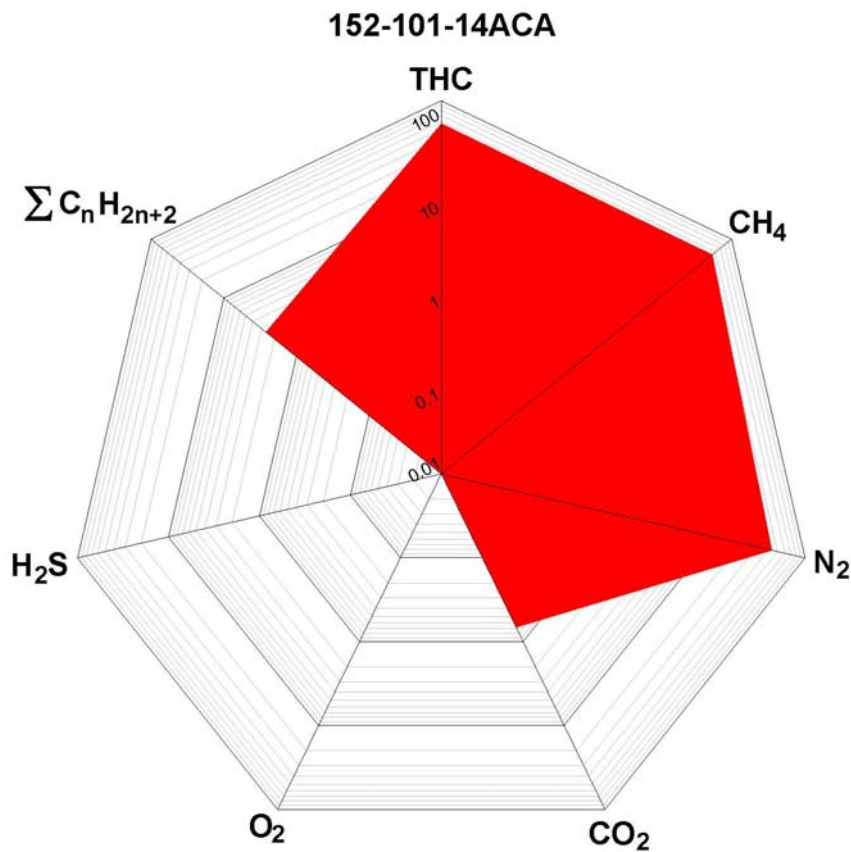


Figure 17. Radar diagram of gas constituents found in well 152-101-14ACA. Scale is logarithmic in mol %.



## COMPARISON OF GAS CONSTITUENTS

### Total Hydrocarbons (THC)

Total hydrocarbons concentrations [THC] were calculated from the individual gas composition data reported and summarized for the organic compounds detected in the 14 wells sampled. THC ranged 70.75 % from a minimum of 6.43% in well 153-95-5C to a maximum of 77.18% in well 153-94-18CBC (Figure 18). The average concentration, calculated from the results of the wells sampled, is 51.87% [THC] (Table 4). THC concentrations appear to be higher in wells in the northeastern part of McKenzie County that are located above the Nesson Anticline. A subtle north to south gradient can be interpreted as one moves further away from the subsurface expression of the anticline to the south and west (Figure 19). This was also observed in the field during well monitoring and gas sampling by NDSWC personnel. More specifically, that apparent gas contents appeared to increase as one got closer to the Nesson anticline (Plate 1).

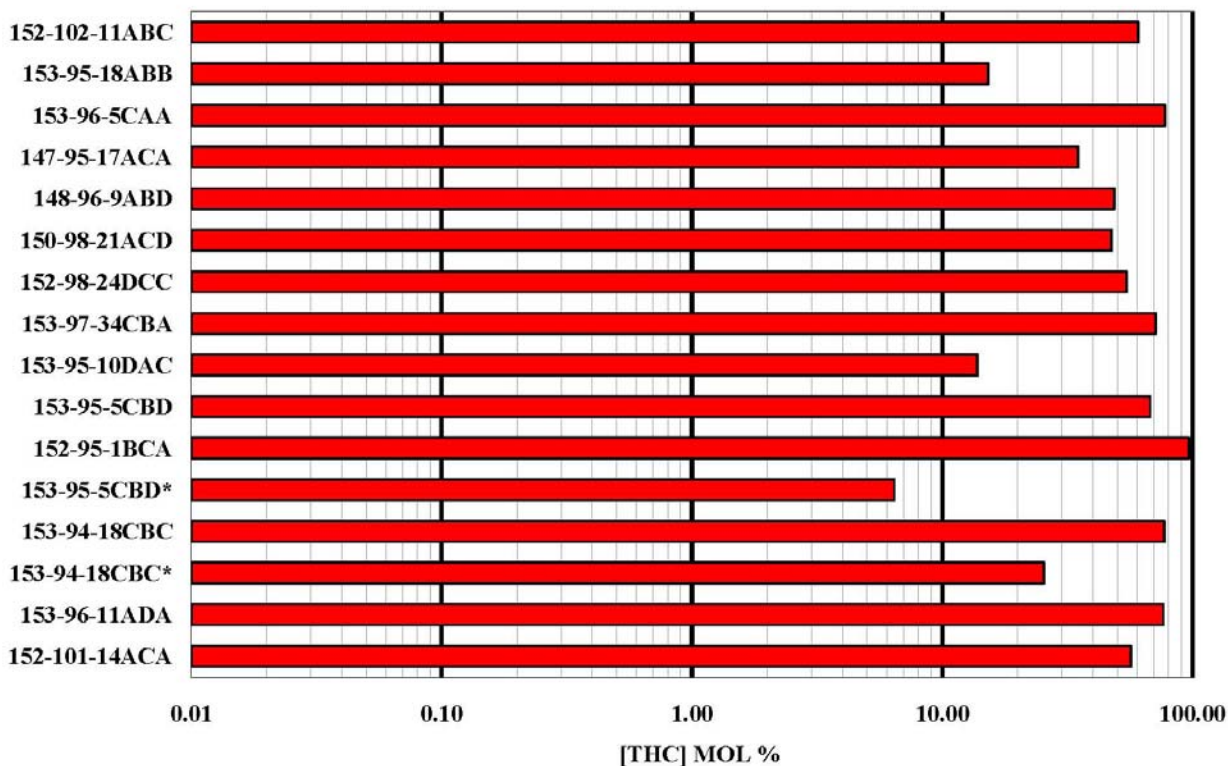


Figure 18. Bar graph depicting the numerical values and relative relationships of total hydrocarbons [THC] detected from gasses collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates.

Table 4. Gas constituent concentrations<sup>1</sup> detected in gases collected from wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota

Well ID	[THC]	[CH <sub>4</sub> ]	[N <sub>2</sub> ]	[O <sub>2</sub> ]	[CO <sub>2</sub> ]	[C <sub>2</sub> H <sub>6</sub> ]	[H <sub>2</sub> S]	[C <sub>3</sub> H <sub>8</sub> ]	[i-C <sub>4</sub> H <sub>10</sub> ]	[n-C <sub>4</sub> H <sub>10</sub> ]	[i-C <sub>5</sub> H <sub>12</sub> ]	[n-C <sub>5</sub> H <sub>12</sub> ]	[C <sub>6</sub> H <sub>14</sub> + <sup>2</sup> ]	BTU Sat. (ft <sup>3</sup> )	BTU Dry (ft <sup>3</sup> )	<sup>2</sup> Specific Gravity
152-102-11ABC	60.74	60.74	37.59	0.59	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	605	615	0.7233
153-95-18ABB	15.24	9.56	83.15	0.45	1.16	5.66	0.00	0.02	0.00	0.00	0.00	0.00	0.00	194	198	0.9388
153-96-5CAA	77.47	73.83	20.46	0.84	1.22	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	799	813	0.6733
147-95-17ACA	34.84	34.84	64.29	0.00	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	347	353	0.8281
148-96-9ABD	48.61	48.61	51.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	484	492	0.7666
150-98-21ACD	47.40	47.40	52.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	472	480	0.7716
152-98-24CCC	54.48	54.48	44.85	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	542	552	0.7461
153-97-34CBA	71.01	71.01	28.21	0.00	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	707	720	0.6786
153-95-10DAC	13.80	11.34	85.42	0.00	0.77	2.45	0.00	0.01	0.00	0.00	0.00	0.00	0.00	156	159	0.9265
153-95-5CBD	67.61	60.13	32.17	0.00	0.22	2.77	0.00	2.54	0.43	0.97	0.28	0.33	0.16	785	798	0.7640
152-95-1BCA	96.77	68.96	3.21	0.00	0.02	16.18	0.00	7.54	0.88	2.04	0.40	0.45	0.32	1,302	1,325	0.7883
153-95-5CBD*	6.43	6.43	93.55	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64	65	0.9400
153-94-18CBC	25.53	25.53	74.40	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	253	258	0.8620
153-94-18CBC*	77.18	77.18	22.11	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	767	779	0.6530
153-96-11ADA	76.25	76.25	23.26	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	758	770	0.6550
152-101-14ACA	56.63	54.02	42.70	0.00	0.67	0.94	0.00	0.69	0.05	0.30	0.13	0.19	0.31	608	618	0.7670
Statistical Summary																
Range	90.34	70.75	90.34	0.39	1.20	15.24	--	7.53	0.83	1.74	0.27	0.26	0.16	1,238	1,260	0.2870
Minimum	6.43	6.43	3.21	0.45	0.02	0.94	--	0.01	0.05	0.30	0.13	0.19	0.16	64	65	0.6530
Average	51.87	48.77	47.46	0.63	0.62	5.27	--	2.16	0.45	1.10	0.27	0.32	0.26	540	550	0.7801
Median	55.56	54.25	43.78	0.59	0.69	3.20	--	0.69	--	--	--	--	--	574	584	0.7668
Maximum	96.77	77.18	93.55	0.84	1.22	16.18	--	7.54	0.88	2.04	0.40	0.45	0.32	1,302	1,325	0.9400

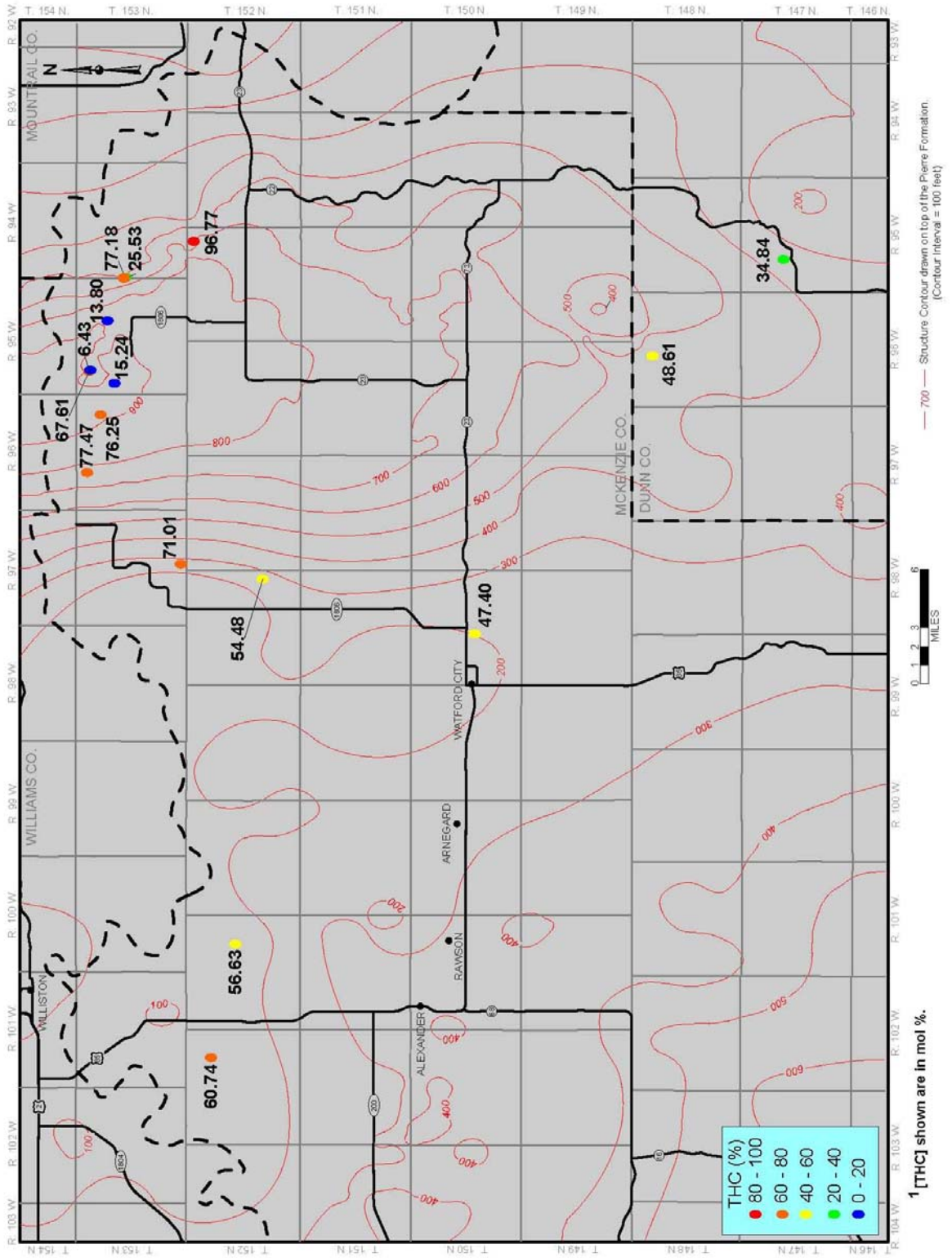
<sup>1</sup>[Compound] in mol %.

<sup>2</sup>Air = 1.0000

\* Second sample collected on separate date.

-- Value not determined.

Figure 19. Calculated total hydrocarbon concentrations [THC]<sup>1</sup> from gases collected from wells in Cretaceous and Tertiary aquifers in McKenzie County, North Dakota





## Methane (CH<sub>4</sub>)

Methane was detected in all 14 of the wells sampled. Methane concentrations in these wells ranged across 70.75 % from a minimum of 6.43% in well 153-95-5C to a maximum of 77.18% in well 153-94-18CBC (Figure 20). The average concentration, calculated from the results of the wells sampled, is 48.77% (Table 4). Methane concentrations are similar in their distribution to [THC] and appear to be higher in wells in the northeastern part of McKenzie County that are located above the Nesson Anticline. A subtle north to south gradient can be interpreted as one moves further away from the subsurface expression of the anticline to the south and west (Figure 21).

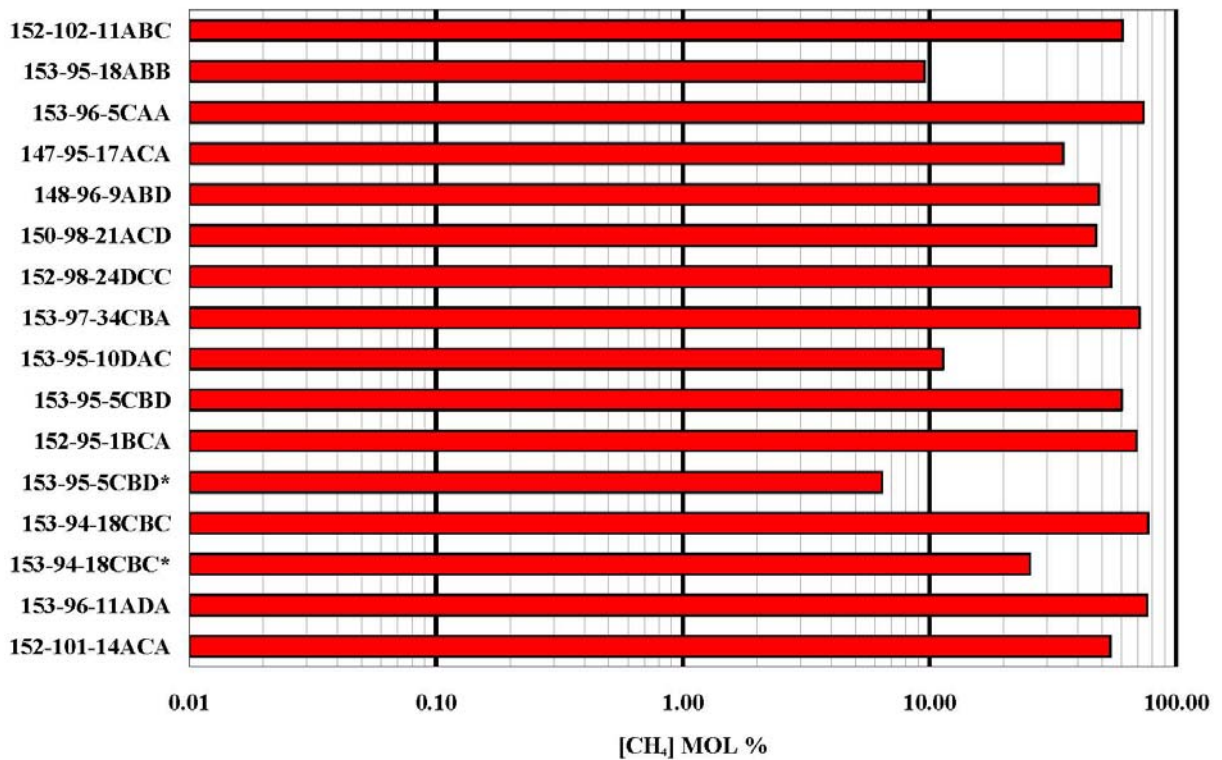
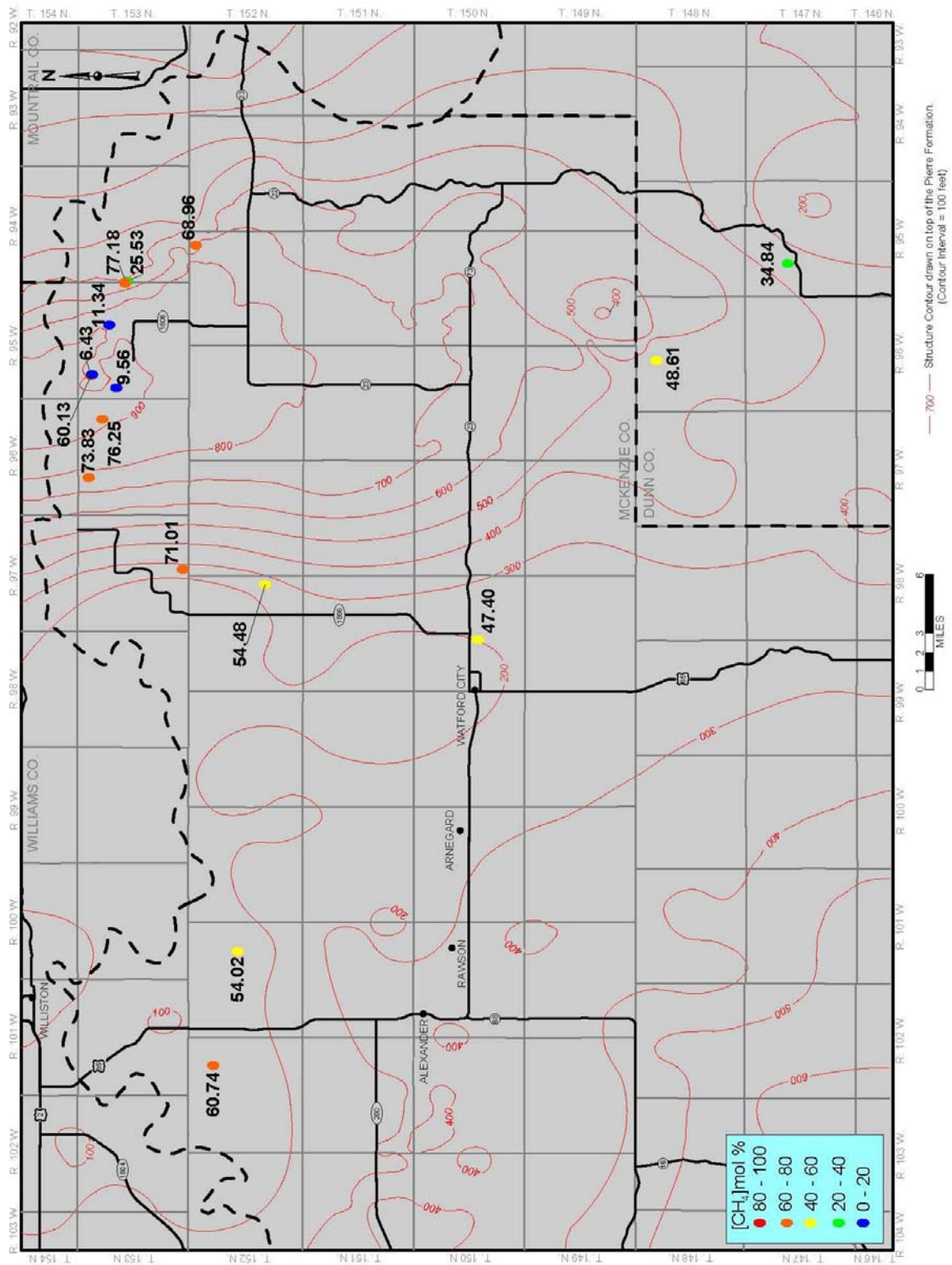


Figure 20. Bar graph depicting the numerical values and relative relationships of methane (CH<sub>4</sub>) detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples from well collected from wells on separate dates.

Figure 21. Methane concentrations detected in gases collected from selected wells in Cretaceous Aquifers in west-central North Dakota.



## Nitrogen (N<sub>2</sub>)

Nitrogen was also detected in all 14 of the wells sampled (Figure 22). Nitrogen concentrations in these wells ranged 90.34 % from a minimum of 3.21% in well 152-95-1BCA to a maximum of 93.55% in well 153-95-5CBD. The average concentration, calculated from the results from all of the wells, is 47.46% (Table 4). Nitrogen concentrations appear to be highest in the wells located in the northeastern part of McKenzie County. Four wells have nitrogen concentrations above 70%: 153-95-5CBD at 93.55%, 153-95-10DAC at 85.42, 153-95-18ABB at 83.15, and 153-94-18CBD\* at 74.40%. In contrast to [THC] and [CH<sub>4</sub>], a subtle north to south increasing nitrogen concentration gradient can be seen (Figure 22) as one moves away from the subsurface expression of the anticline to the southern end of the county. It is also apparent that the four wells with nitrogen contents above 70% are all in close proximity to one another (i.e. all nearest neighbors) and are all located along the central structural high of the Nesson Anticline.

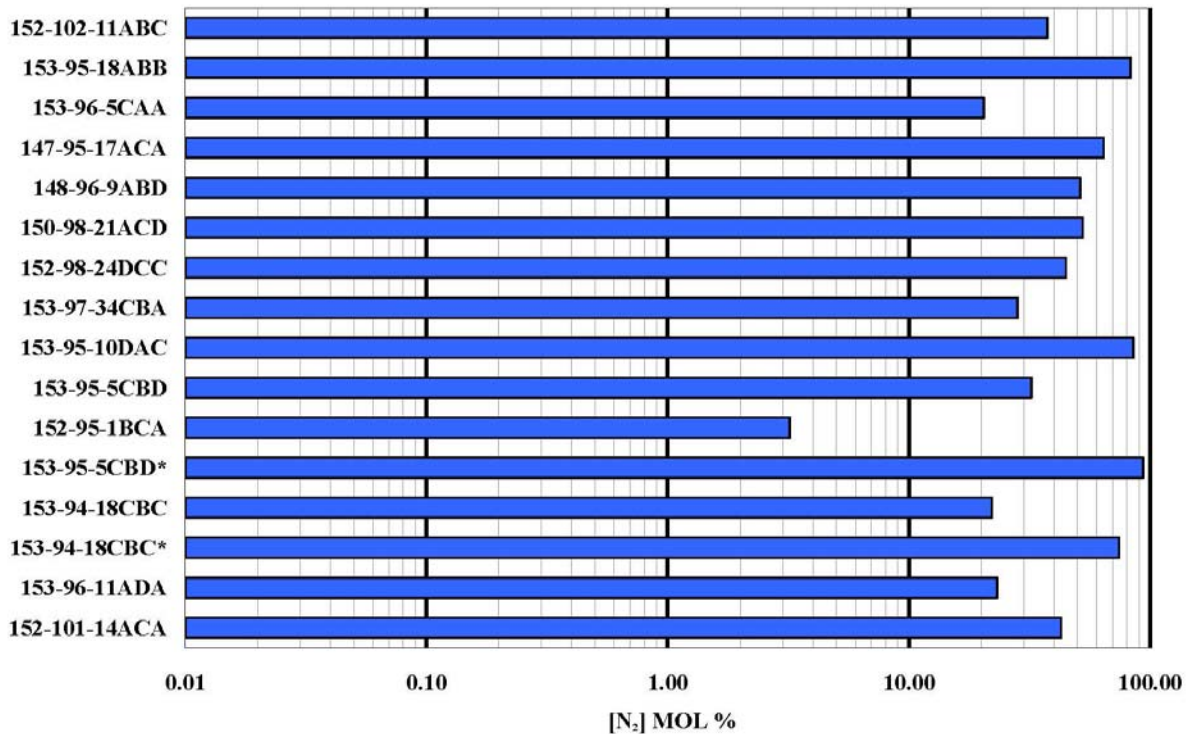
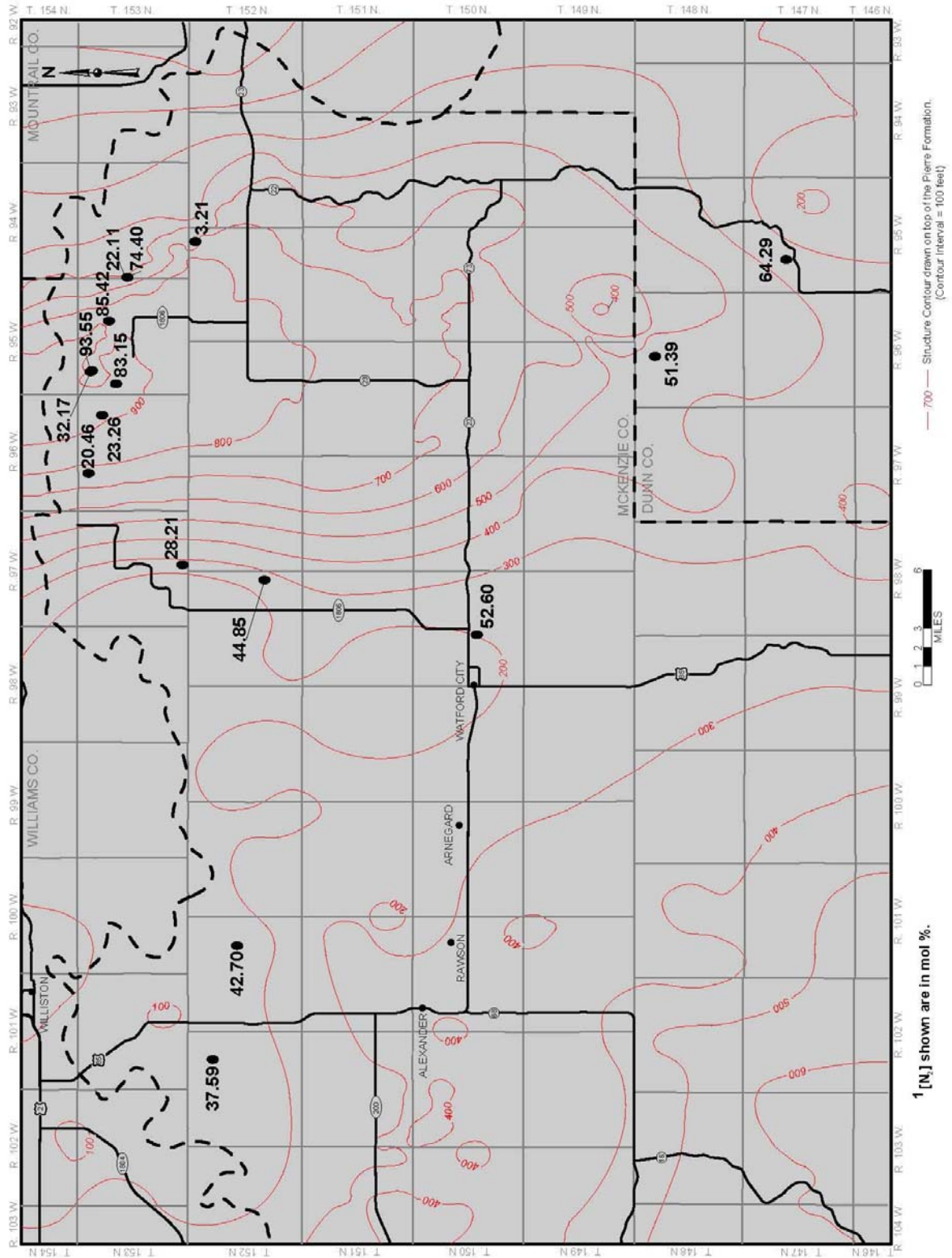


Figure 22. Bar graph depicting the numerical values and relative relationships of nitrogen [N<sub>2</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates.

Figure 23. Nitrogen concentrations detected in gases collected from selected wells in Cretaceous and Tertiary Aquifers in west-central North Dakota.



1 [N<sub>2</sub>] shown are in mol %.



## Oxygen (O<sub>2</sub>)

Oxygen was detected and reported in three of the wells sampled and ranged 0.39% from a minimum of 0.45% in well 153-95-18ABB to 0.84% in well 153-96-5CAA (Table 4 & Figure 24). Oxygen detected in these amounts are commonly indicative of atmospheric contamination of the sample.

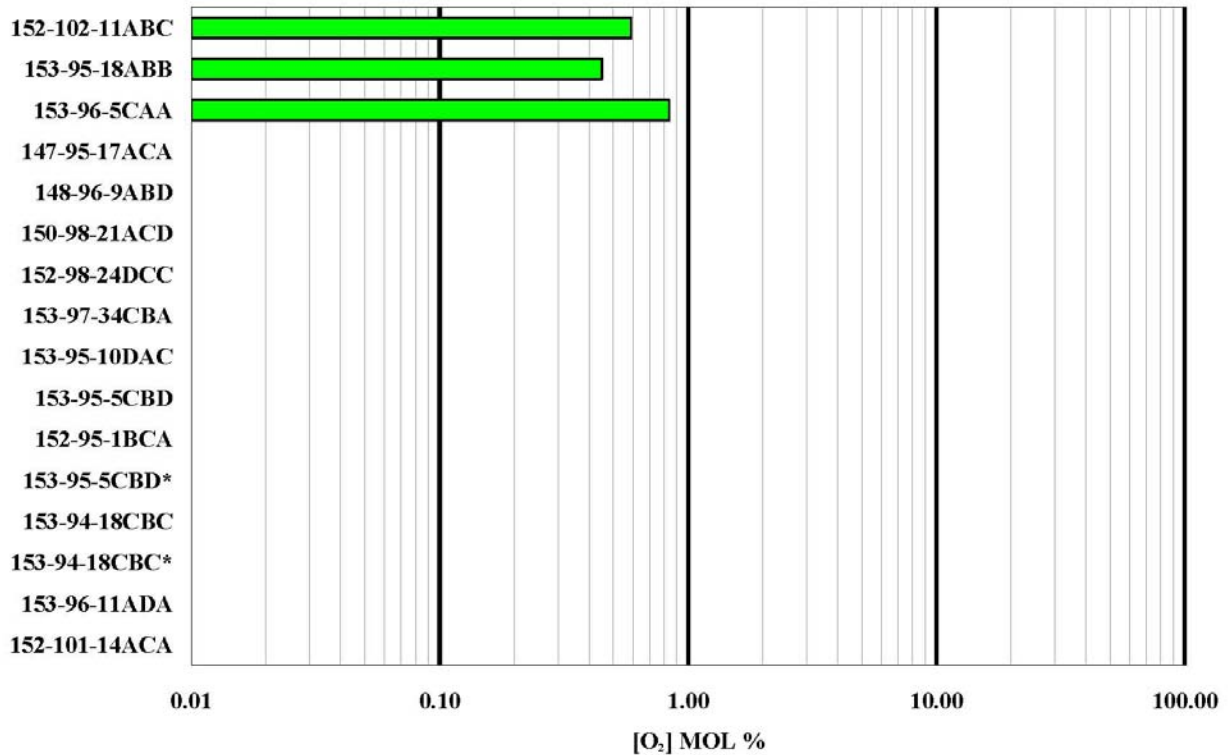


Figure 24. Bar graph depicting the numerical values and relative relationships of oxygen [O<sub>2</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. Wells with analyses of 0.0 mol % O<sub>2</sub> detected are depicted without a bar.

## Carbon Dioxide (CO<sub>2</sub>)

Carbon dioxide was reported in 12 of the 14 wells sampled. Carbon dioxide concentrations detected were all below the highest value detected of 1.22% in well 153-96-5DAA (Figure 25). Carbon dioxide concentrations ranged 1.20% from a low of 0.02% in wells 148-96-9ABD and 150-98-21ACD to 1.22% in well 153-96-5DAA. The average carbon dioxide concentration, calculated from the results from all of the wells where carbon dioxide was detected, is 0.62% (Table 4). Carbon dioxide concentrations are relatively randomly distributed throughout the county. Three wells have carbon dioxide concentrations greater than 1.00%: 153-96-5DAA at 1.22%, 153-95-18ABB at 1.16%, and 152-102-11ABC at 1.07% (Figure 26). The reported carbon dioxide concentrations that are above 1.00% may have been influenced by atmospheric contamination, as each of the wells reported also have oxygen concentrations reported in the analyses.

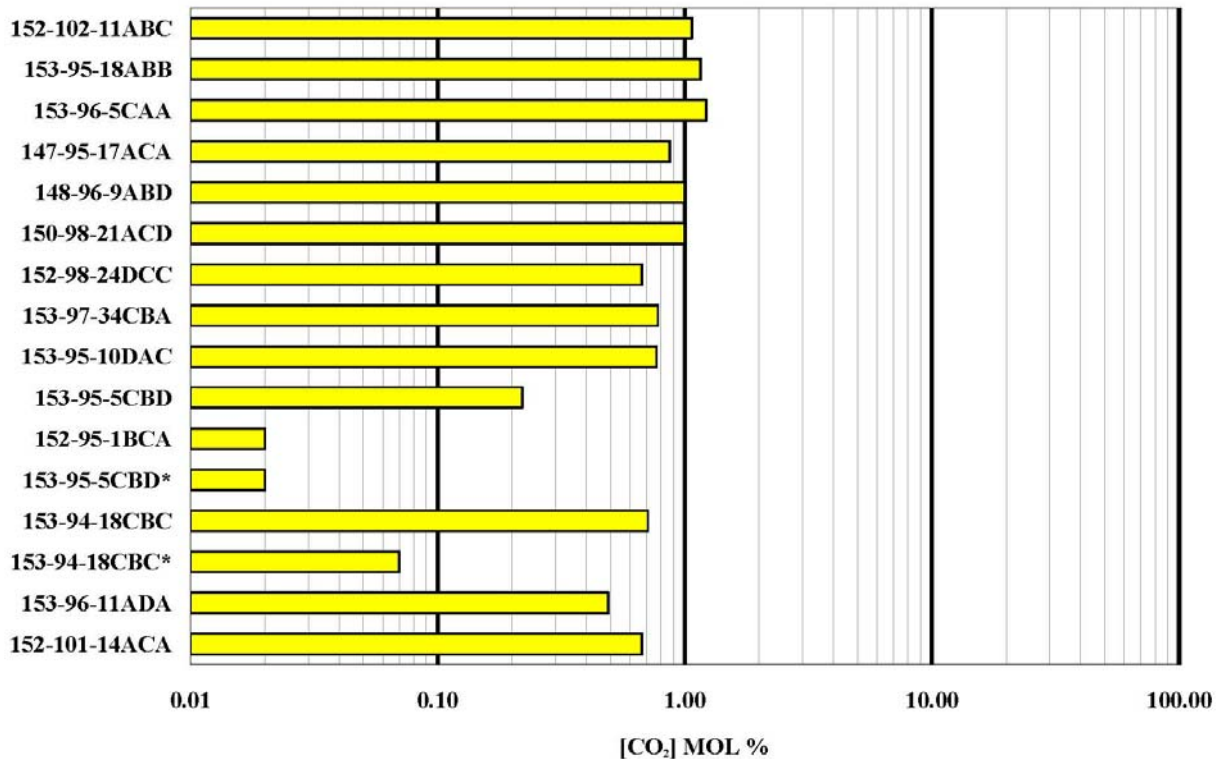
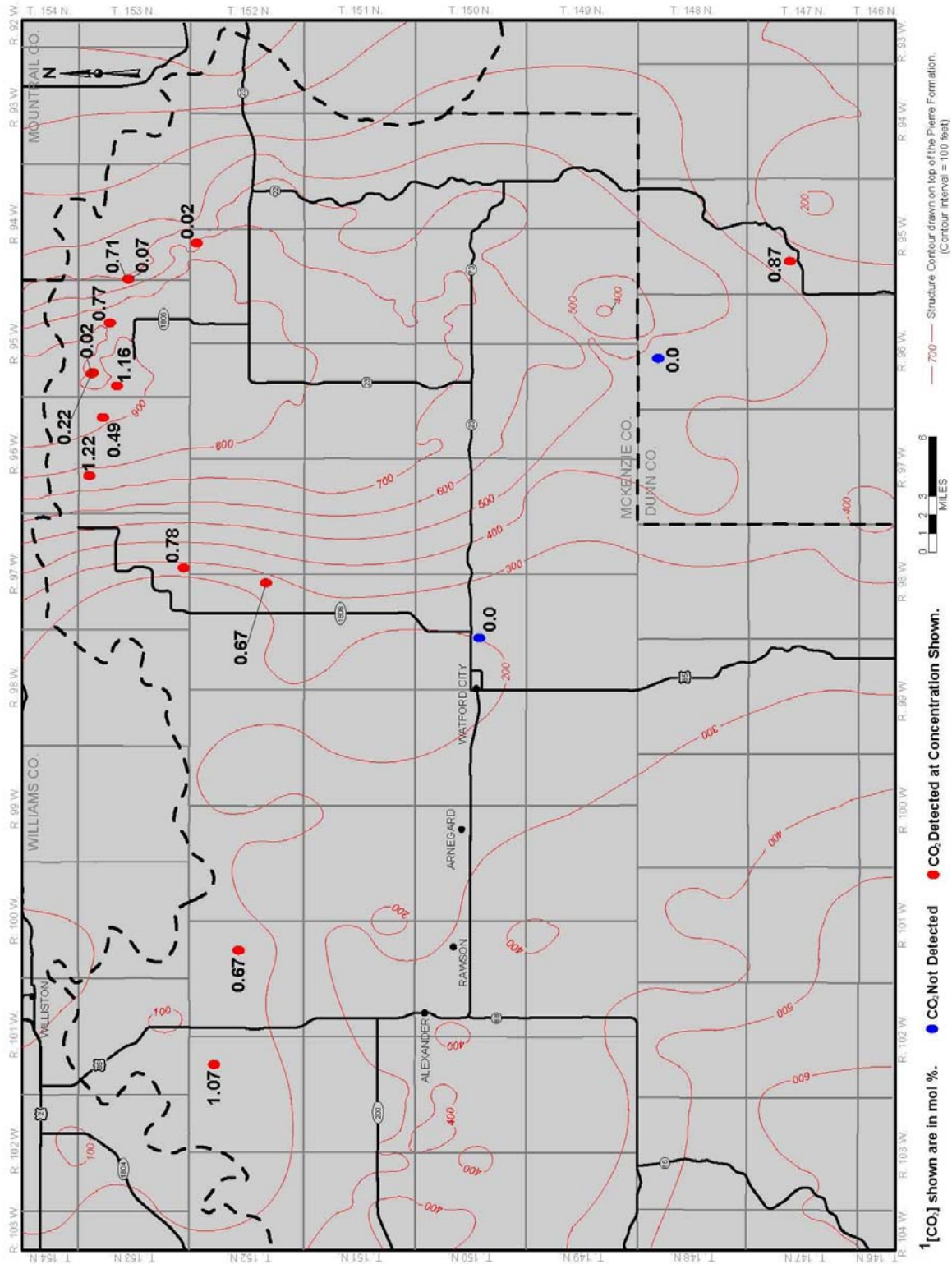


Figure 25. Bar graph depicting the numerical values and relative relationships of carbon dioxide [CO<sub>2</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from well on separate dates.

Figure 26. Carbon Dioxide concentrations detected in gases collected from selected wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.



## Hydrogen Sulfide (H<sub>2</sub>S)

Hydrogen sulfide was not detected in any of the samples collected and analyzed. Hydrogen sulfide is generally associated with produced fluids from Mississippian age carbonates (e.g. Madison Limestone). The lack of detected H<sub>2</sub>S in the samples collected and analyzed adds to the presumption that fluid and gas origins are likely to be from within the hydrogeologic unit sampled or from other underlying units.

## Ethane (C<sub>2</sub>H<sub>6</sub>)

Ethane was detected in six of the 14 wells sampled (Figure 27). Ethane concentrations ranged 15.24% from a low of 0.94% in well 152-101-14ACA to a high of 16.18% in well 152-95-1BCA. The average concentration, calculated from the results from all of the wells where ethane was detected, is 5.27% (Table 4). Ethane concentrations are dominantly detected in wells in the northeastern corner the county above the Nesson Anticline. Ethane was reported in only one other well (152-101-14ACA) located away from the anticline in the northwestern portion of the county (Figure 28).

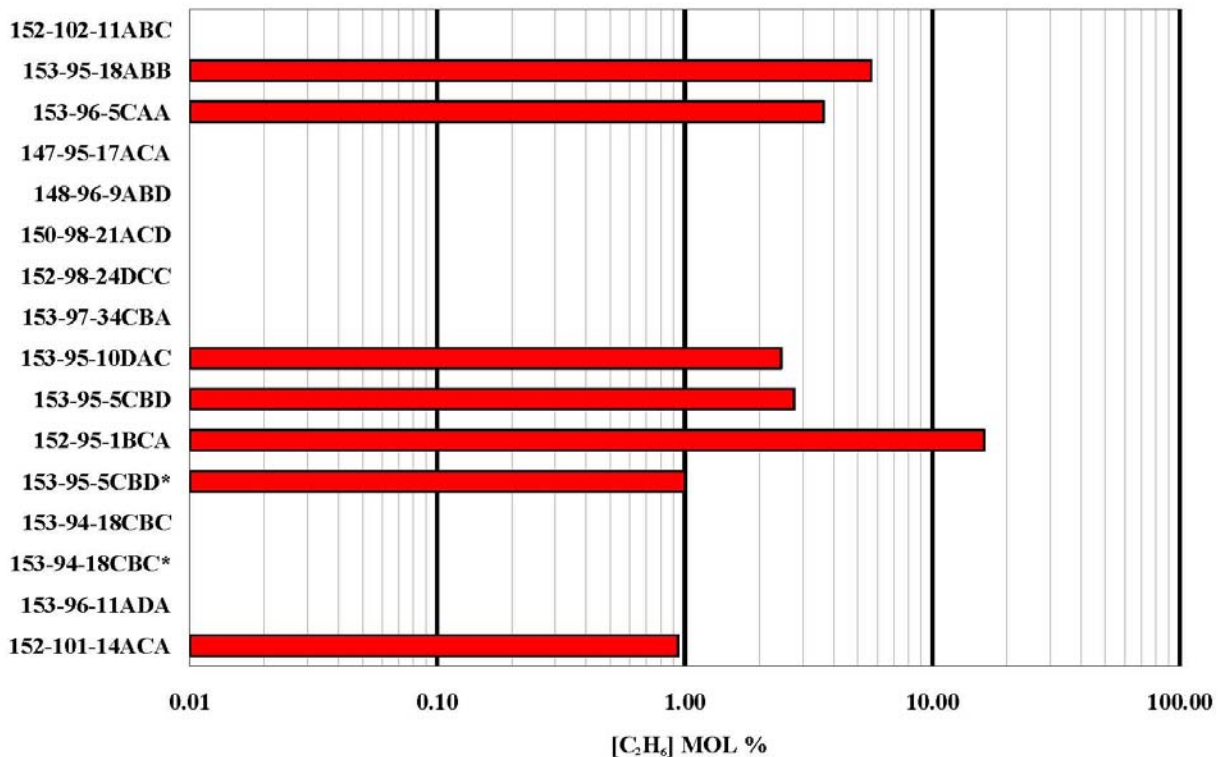
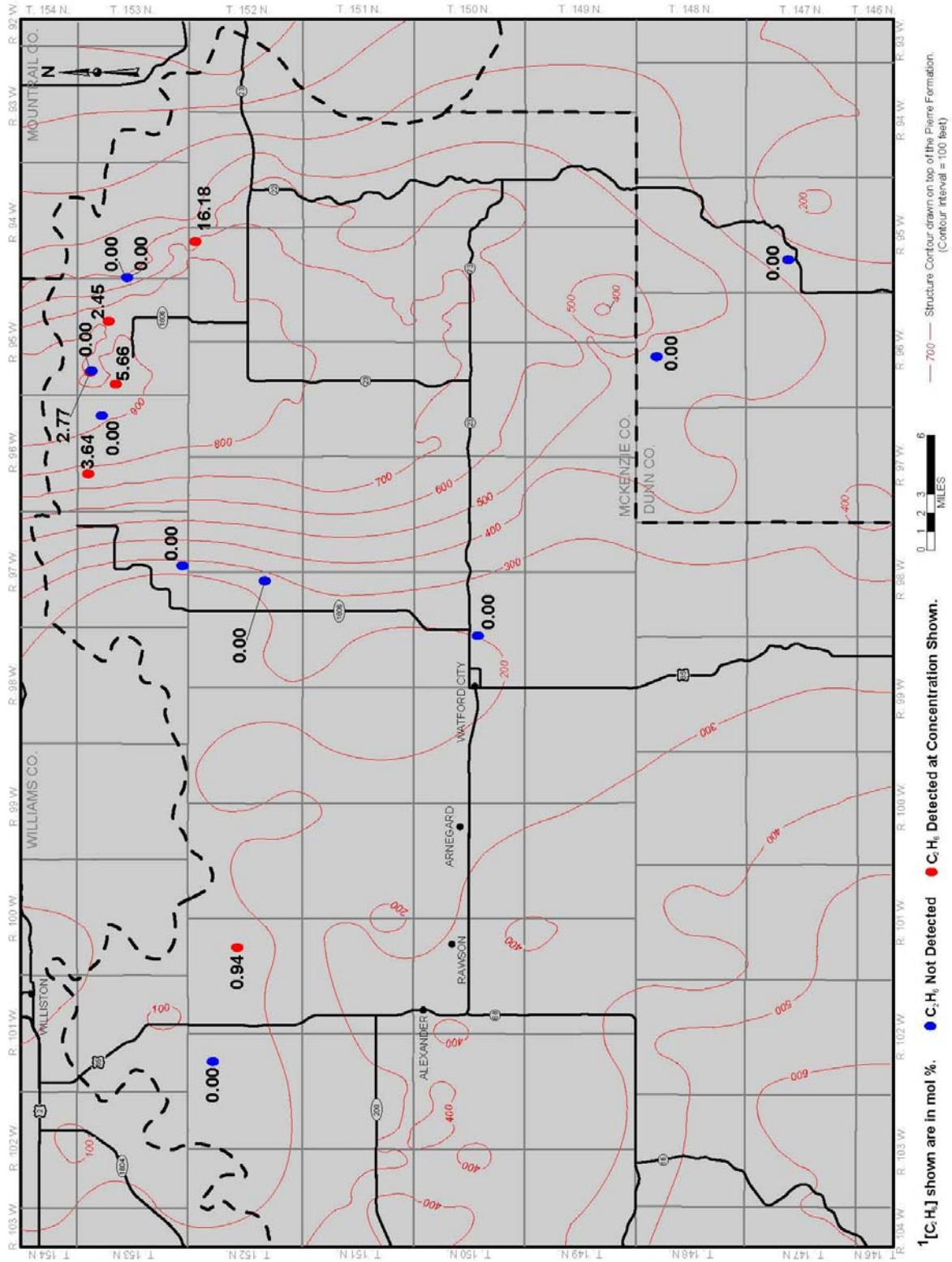


Figure 27. Bar graph depicting the numerical values and relative relationships of ethane [C<sub>2</sub>H<sub>6</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % C<sub>2</sub>H<sub>6</sub> detected are depicted without a bar.



Figure 28. Ethane<sup>1</sup> concentrations detected in gases collected from selected wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.



## Propane (C<sub>3</sub>H<sub>8</sub>)

Propane was detected in five of the 14 wells sampled and ranged 7.53% from a low of 0.01% in well 153-95-10DAC to 7.54% in well 152-95-1BCA (Figure 29). The average propane concentration from these wells is 2.16% (Table 4). Propane is commonly found in most natural gases and can also be found in gases of biogenic origin (Ridgley, 1998). Propane concentrations were found in only one well (152-101-14ACA) located away from the Nesson Anticline. The remaining three wells where propane was found are located above the central structural high areas of the anticline (Plate 1).

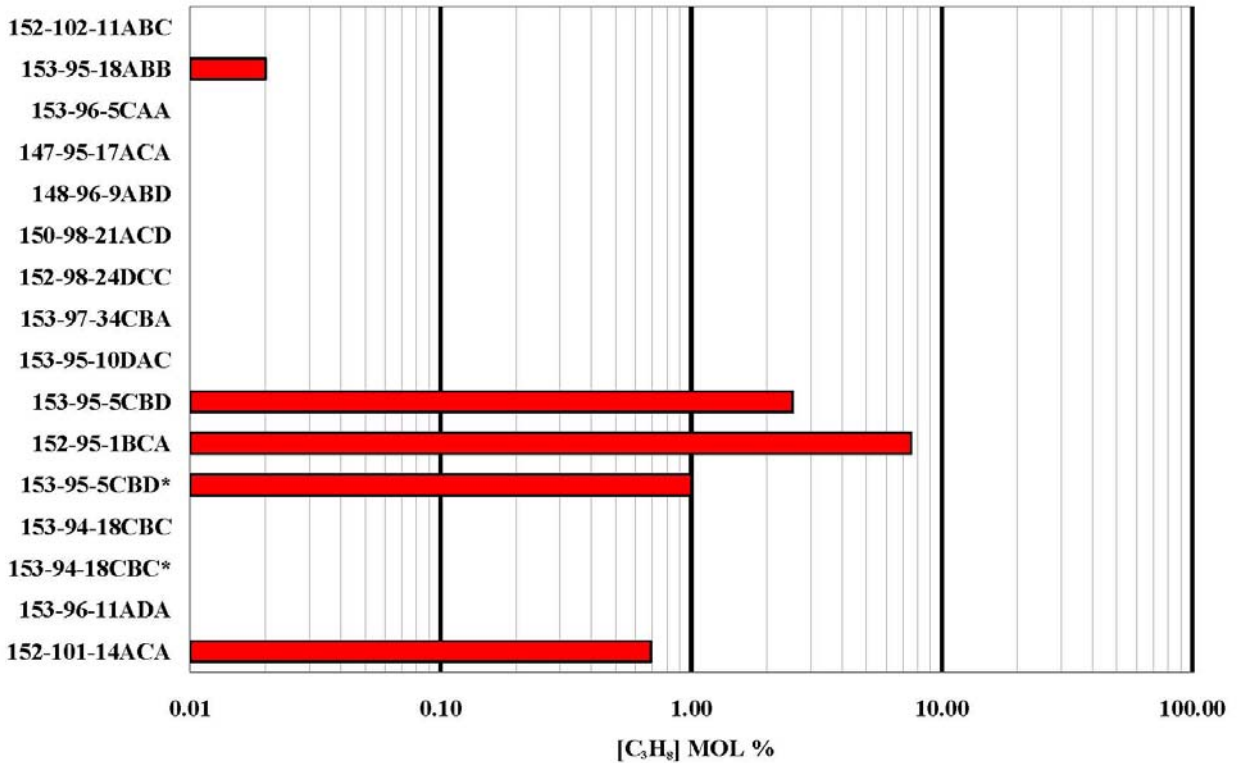


Figure 29. Bar graph depicting the numerical values and relative relationships of propane [C<sub>3</sub>H<sub>8</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % C<sub>3</sub>H<sub>8</sub> detected are depicted without a bar.

## Butanes (n- & i-C<sub>4</sub>H<sub>10</sub>)

n-Butane (n-C<sub>4</sub>H<sub>10</sub>) and iso-butane (i-C<sub>4</sub>H<sub>10</sub>) were detected in three of the 14 wells sampled (Figures 30 & 31). When butanes were detected, both compounds were reported. Well 153-95-5CBD had butane concentrations of 0.97% (n-C<sub>4</sub>H<sub>10</sub>) and 0.43% (i-C<sub>4</sub>H<sub>10</sub>). Well 152-101-14ACA had butane concentrations of 0.30% (n-C<sub>4</sub>H<sub>10</sub>) and 0.05% (i-C<sub>4</sub>H<sub>10</sub>). Well 152-95-1BCA had butane concentrations of 2.04 % (n-C<sub>4</sub>H<sub>10</sub>) and 0.88% (i-C<sub>4</sub>H<sub>10</sub>) (Table 4). Wells 153-95-5CBD and 152-95-1BCA are located above the Nesson Anticline. Well 152-101-14ACA is located approximately 30 miles west of the anticline (Plate 1).

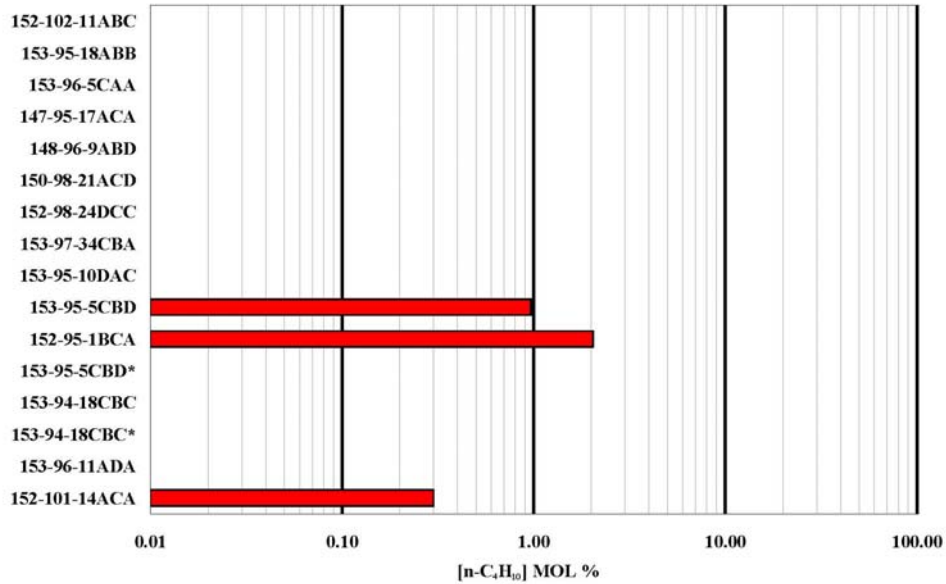


Figure 30. Bar graph depicting the numerical values and relative relationships of n-butane [n-C<sub>4</sub>H<sub>10</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary Aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % n-C<sub>4</sub>H<sub>10</sub> detected are depicted without a bar.

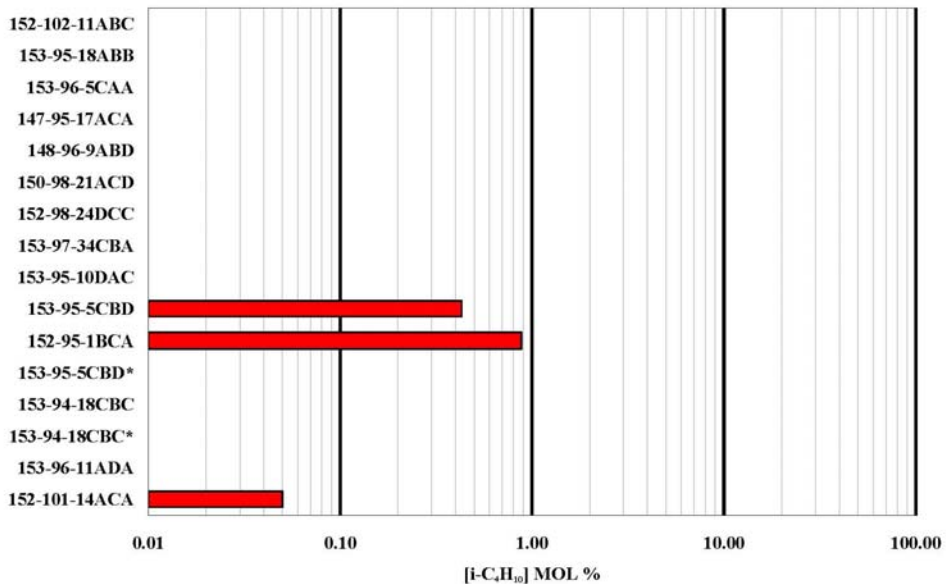


Figure 31. Bar graph depicting the numerical values and relative relationships of isobutane [i-C<sub>4</sub>H<sub>10</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % i-C<sub>4</sub>H<sub>10</sub> detected are depicted without a bar.

## Pentanes (n- & i-C<sub>5</sub>H<sub>12</sub>)

n-Pentane (n-C<sub>5</sub>H<sub>12</sub>) and Iso-Pentane (i-C<sub>5</sub>H<sub>12</sub>) were detected in three of the 14 wells sampled (Figures 32 & 33). When pentanes were detected, both compounds were reported. Well 153-95-5CBD had pentane concentrations of 0.33% (n-C<sub>5</sub>H<sub>12</sub>) and 0.28% (i-C<sub>5</sub>H<sub>12</sub>). Well 152-101-14ACA had pentane concentrations of 0.19% (n-C<sub>5</sub>H<sub>12</sub>) and 0.13% (i-C<sub>5</sub>H<sub>12</sub>). Well 152-95-1BCA had pentane concentrations of 0.45% (n-C<sub>5</sub>H<sub>12</sub>) and 0.40% (i-C<sub>5</sub>H<sub>12</sub>) (Table 4). Well 153-95-5CBD and 152-95-1BCA are located above the Nesson Anticline. Well 152-101-14ACA is located approximately 30 miles west of the anticline (Plate 1).

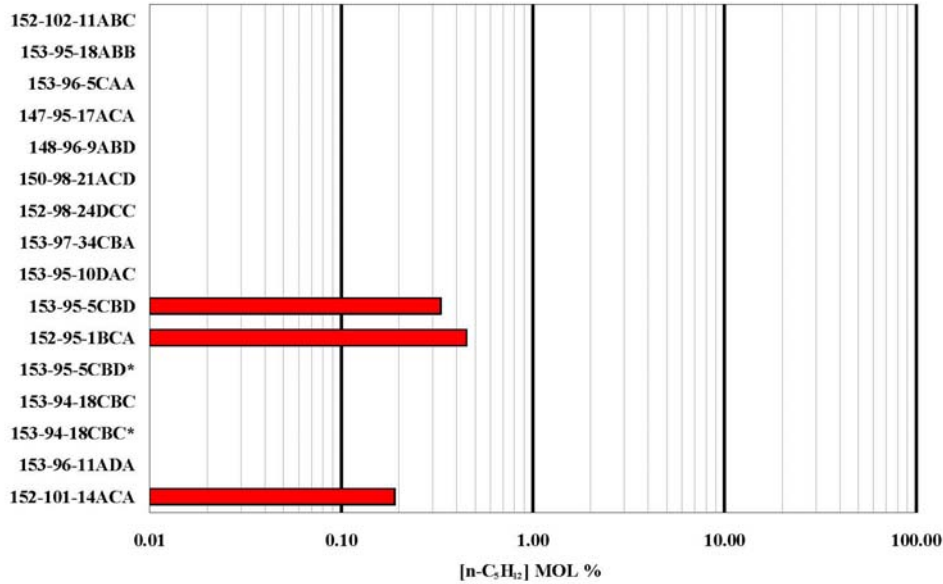


Figure 32. Bar graph depicting the numerical values and relative relationships of n-pentane [n-C<sub>5</sub>H<sub>12</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % n-C<sub>5</sub>H<sub>12</sub> detected are depicted without a bar.

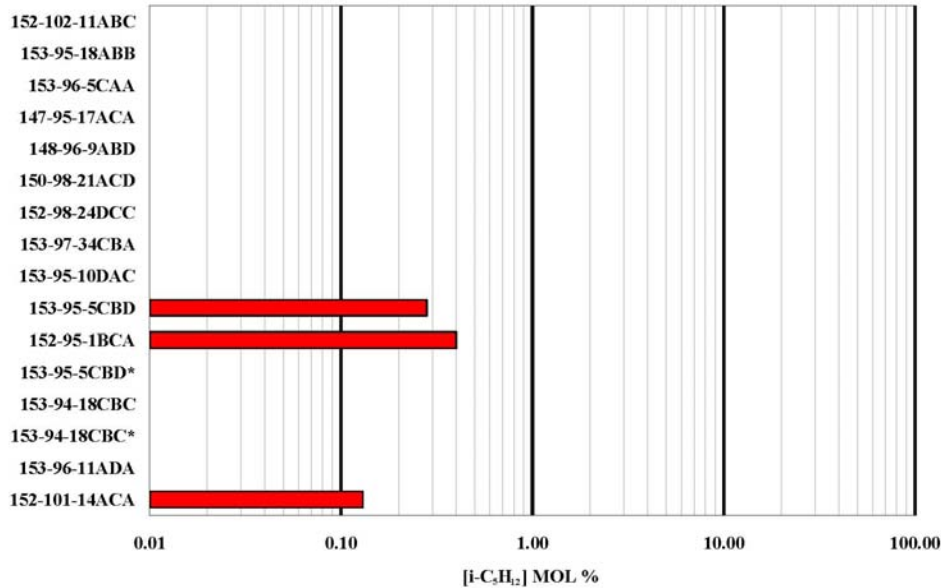


Figure 33. Bar graph depicting the numerical values and relative relationships of isopentane [i-C<sub>5</sub>H<sub>12</sub>] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol % i-C<sub>5</sub>H<sub>12</sub> detected are depicted without a bar.

### Hexanes+ ( $C_6H_{14+}$ )

Hexanes, along with any other detectable hydrocarbons greater than  $C_6$ , were also found in only three of the wells in McKenzie County (Figure 34). Similar to the butanes and pentanes, hexane concentrations were found in wells 153-95-5CBD at 0.16%, 152-101-14ACA at 0.31%, and 152-95-1BCA at 0.32% (Table 4). Well 153-95-5CBD and 152-95-1BCA are located above the Nesson Anticline. Well 152-101-14ACA is located approximately 30 miles west of the anticline (Plate 1).

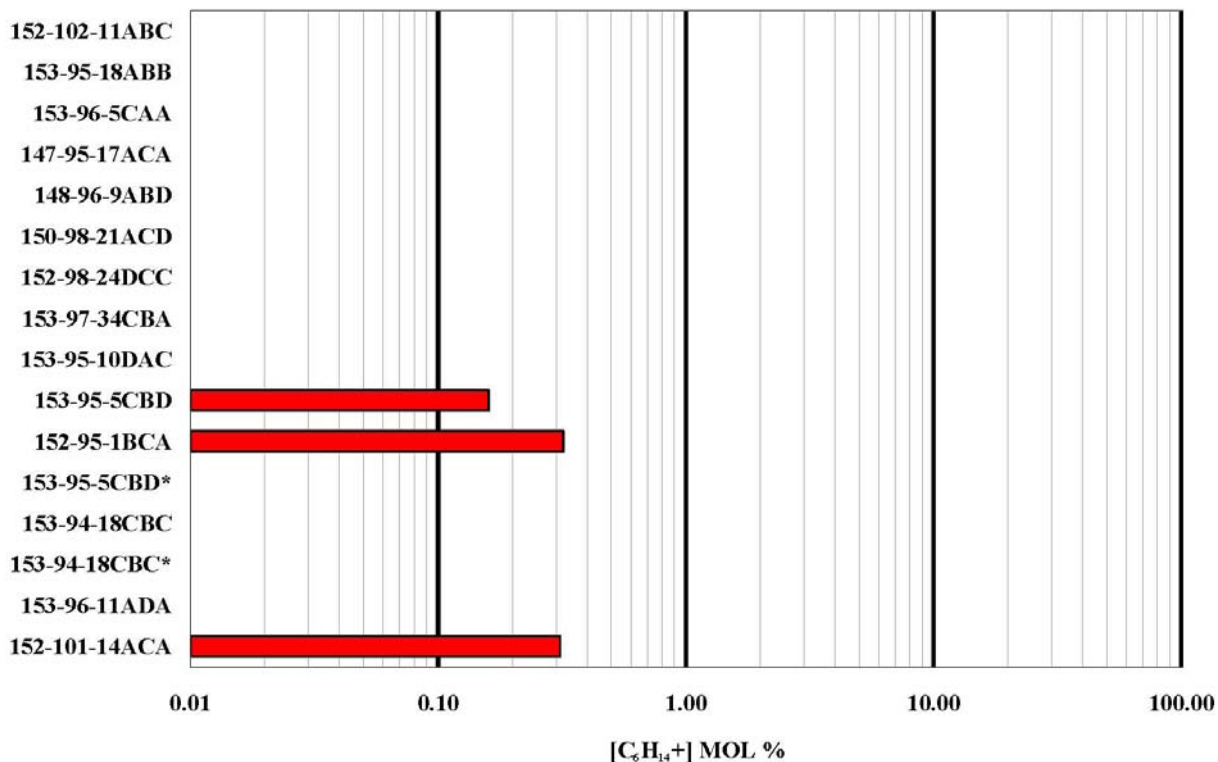


Figure 34. Bar graph depicting the numerical values and relative relationships of hexane [ $C_6H_{14+}$ ] detected from gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. Wells with analyses of 0.0 mol %  $C_6H_{14+}$  detected are depicted without a bar.

## Gross BTU/Cubic Foot

Saturated BTU content ranged 1,238 BTU/ft<sup>3</sup> from 64 BTU/ft<sup>3</sup> in well 153-95-5CBD to 1,302 BTU/ft<sup>3</sup> in well 152-95-1BCA (Figure 35). The average saturated BTU content is 540 BTU/ft<sup>3</sup>. Dry BTU content ranged 1,260 BTU/ft<sup>3</sup> from 65 BTU/ft<sup>3</sup> in well 153-95-5CBD to 1,325 BTU/ft<sup>3</sup> in well 152-95-1BCA. The average dry BTU content is 550 BTU/ft<sup>3</sup> (Table 4). BTU content generally increases from the south to the north, as well locations get closer to the Nesson Anticline, and appears to be highest in wells that are located above the anticline (Figure 36).

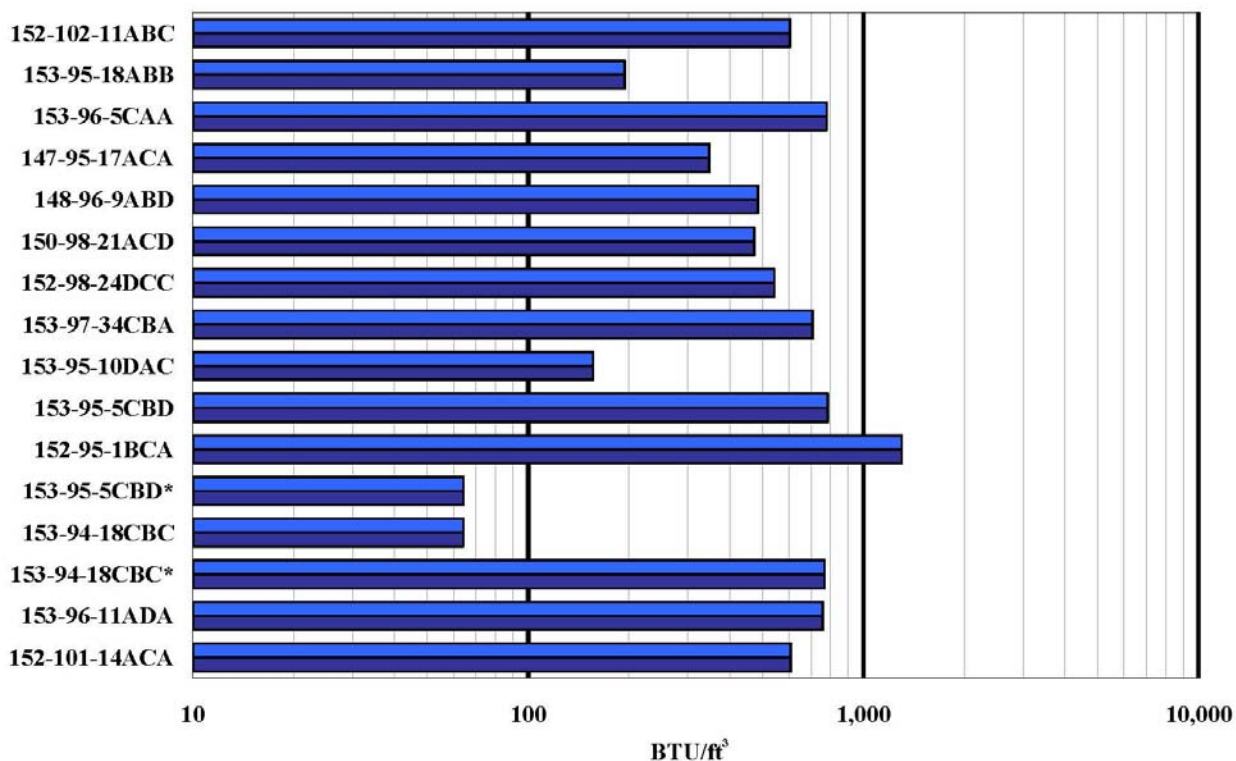
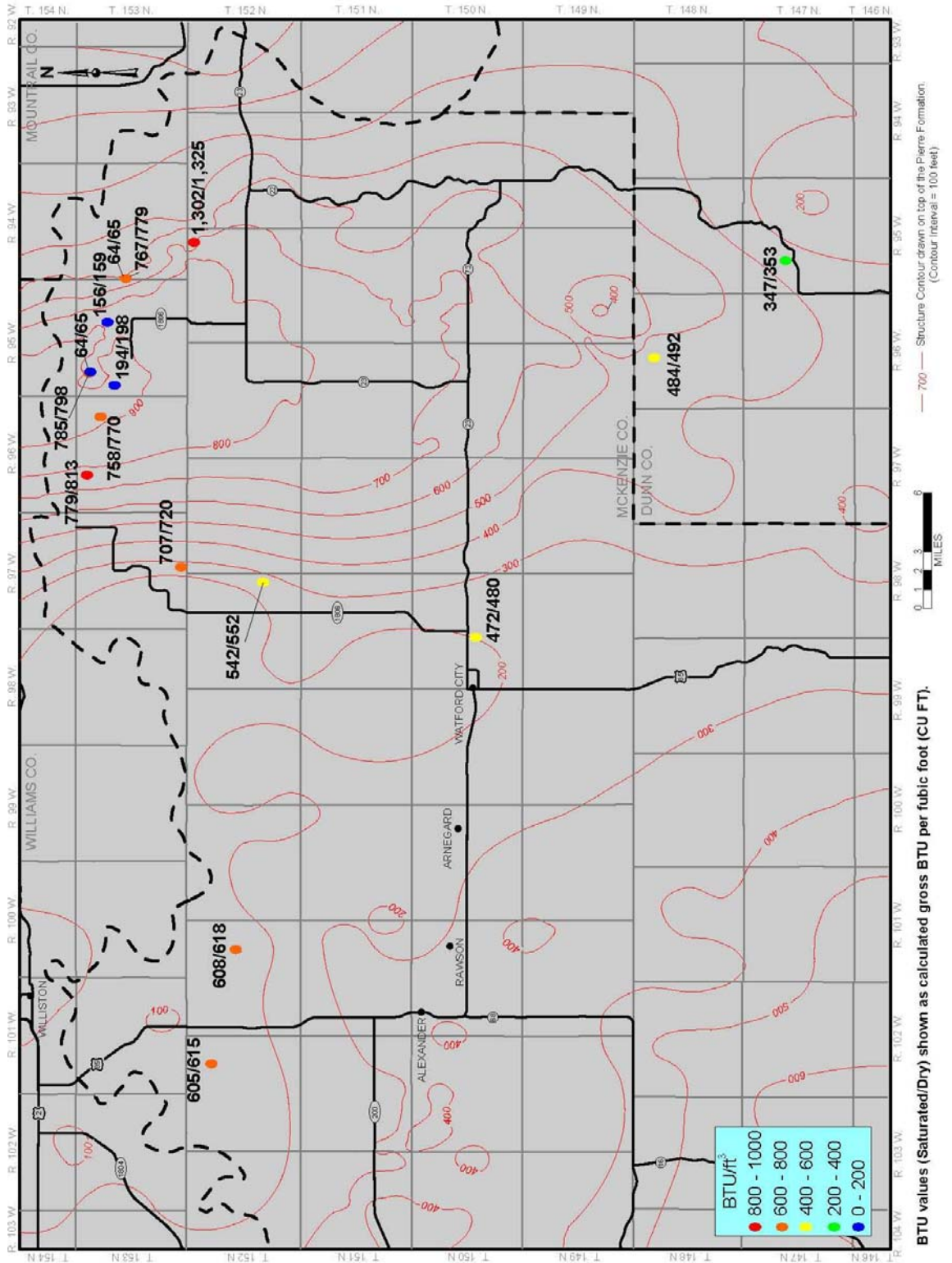


Figure 35. Bar graph depicting the numerical values and relative relationships of BTU values (saturated & dry) determined on gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples were collected from wells on separate dates. (Saturated = dark blue, Dry = light blue).



Figure 36. BTU content of shallow gas collected from wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota



## Specific Gravity (SG)

Calculated gas specific gravity (SG) was determined on all 16 samples collected (Table 4). SG ranged 0.2870 from a low of 0.6530 in well 153-94-18CBC to a high of 0.9400 in well 153-95-5CBD (Figure 37). Natural gas SG typically falls within the range of 0.6 to 0.7. SG values of natural gases generally increase with increasing amounts of hydrocarbon compounds detected beyond methane (i.e. C<sub>2</sub>, C<sub>3</sub>, etc.).

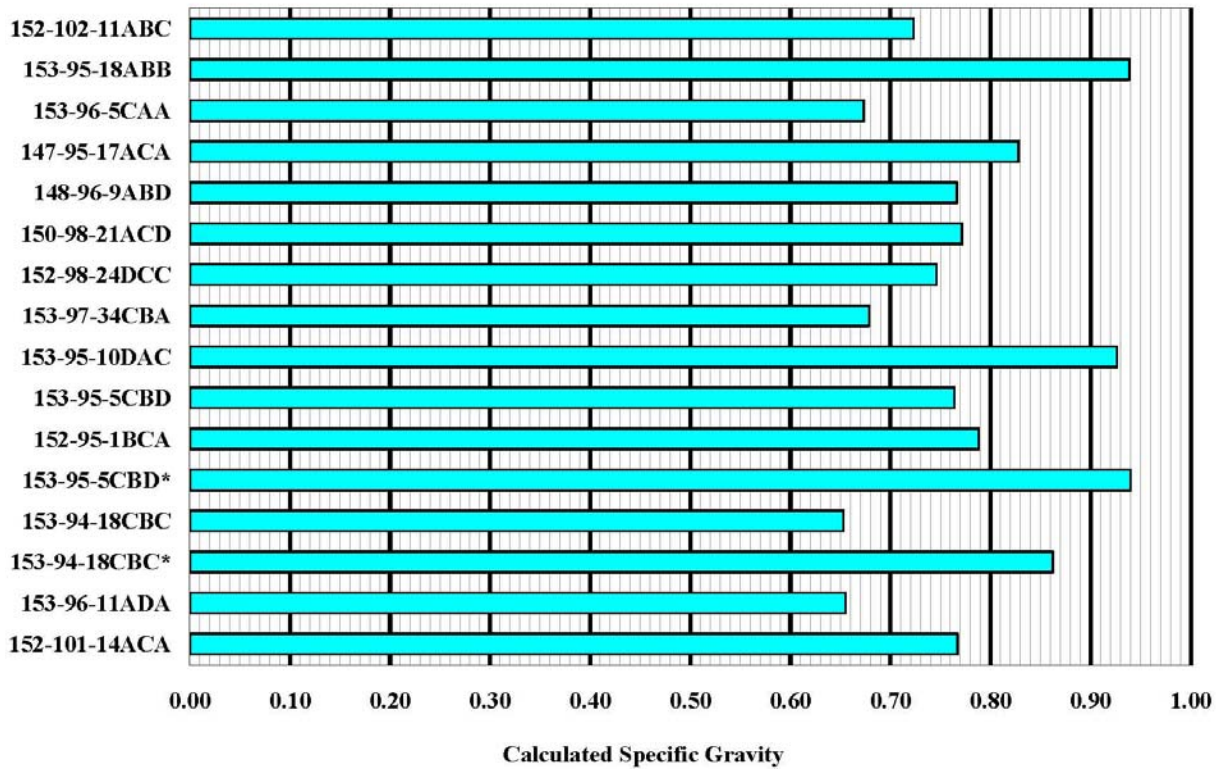


Figure 37. Bar graph depicting the numerical values and relative relationships of specific gravities determined on gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. (Air = 1.00).



## GAS GENERATION INDICATORS

### Biogenic Gas Index (BGI)

One method to interpret the origin of natural gas from analytical gas composition data is by determining the Biogenic Gas Index (BGI). The BGI is defined as the ratio of the concentration of methane divided by the summation of the remaining hydrocarbons reported within an analysis (expressed in mol %) that range from methane (C<sub>1</sub>), ethane (C<sub>2</sub>), propane (C<sub>3</sub>), butane (C<sub>4</sub>), and pentane (C<sub>5</sub>). The BGI is calculated using the following equation introduced by Rice and Claypool (1981):

$$\text{BGI} = [(C_1)/\Sigma (C_1+C_2+C_3+C_4+C_5)]$$

Where:            BGI = Biogenic Gas Index  
                      C<sub>1</sub> = Methane (CH<sub>4</sub>)  
                      C<sub>2</sub> = Ethane (C<sub>2</sub>H<sub>6</sub>)  
                      C<sub>3</sub> = Propane (C<sub>3</sub>H<sub>8</sub>)  
                      C<sub>4</sub> = n- & isobutane (C<sub>4</sub>H<sub>10</sub>)  
                      C<sub>5</sub> = n- & isopentane (C<sub>5</sub>H<sub>12</sub>)  
                      Σ = Summation

The BGI equation was applied to the gas analyses compiled and resulted in calculated biogenic gas indices ranging from 0.63 to 1 (Table 5). Gases whose calculated values are above a BGI of 0.98 (Figure 38) are considered to be of biogenic origin (Rice and Claypool, 1981). The range of results suggests that ten of the wells, located generally away from the subsurface expression of the Nesson Anticline, contained gases of a biogenic origin, likely to be of later generation biogenic character. Four of the five wells with BGI indices lower than 0.98 (i.e. 153-95-18ABB, 153-95-10DAC, 153-95-5CBD, and 152-95-1BCA) are located above the longitudinal axis of the Nesson Anticline (Figure 39). The two samples collected from well 153-95-5CBD show both a thermogenic (0.89) and a biogenic (1.00) value. This suggests variability in gas composition which may be suggestive of comingled gases with varying sourcing.

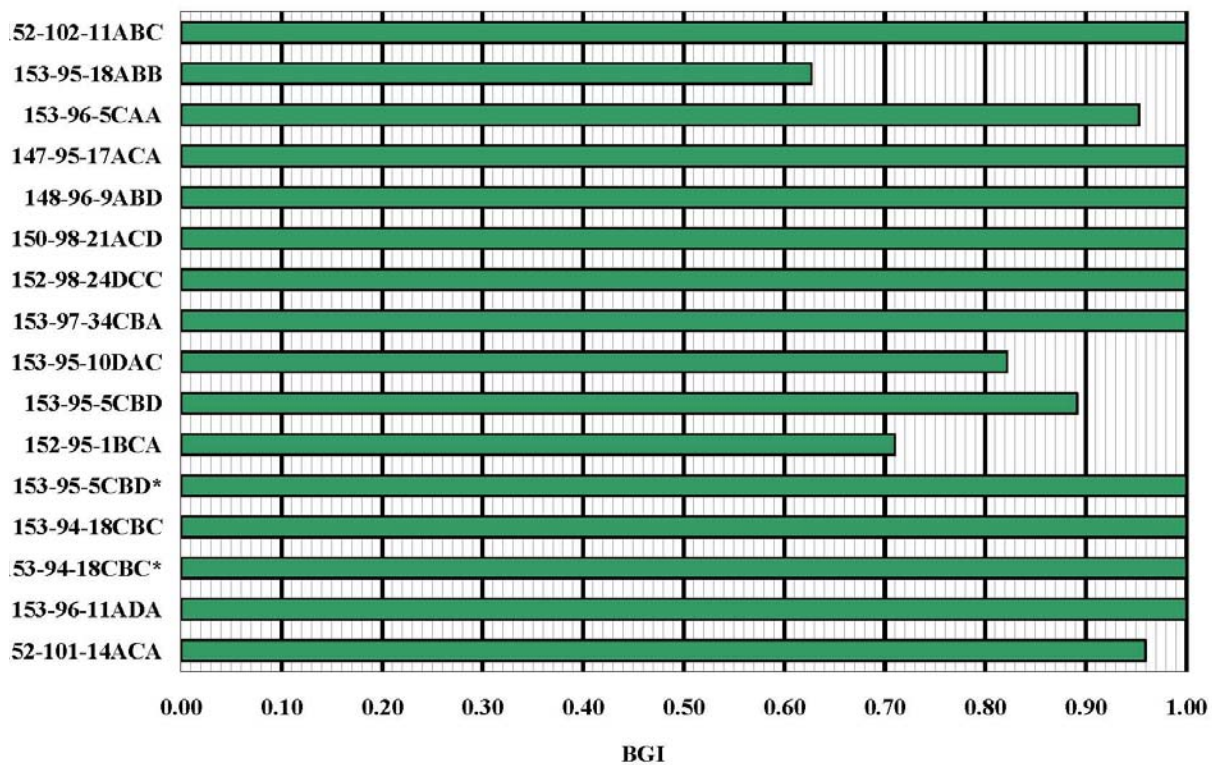


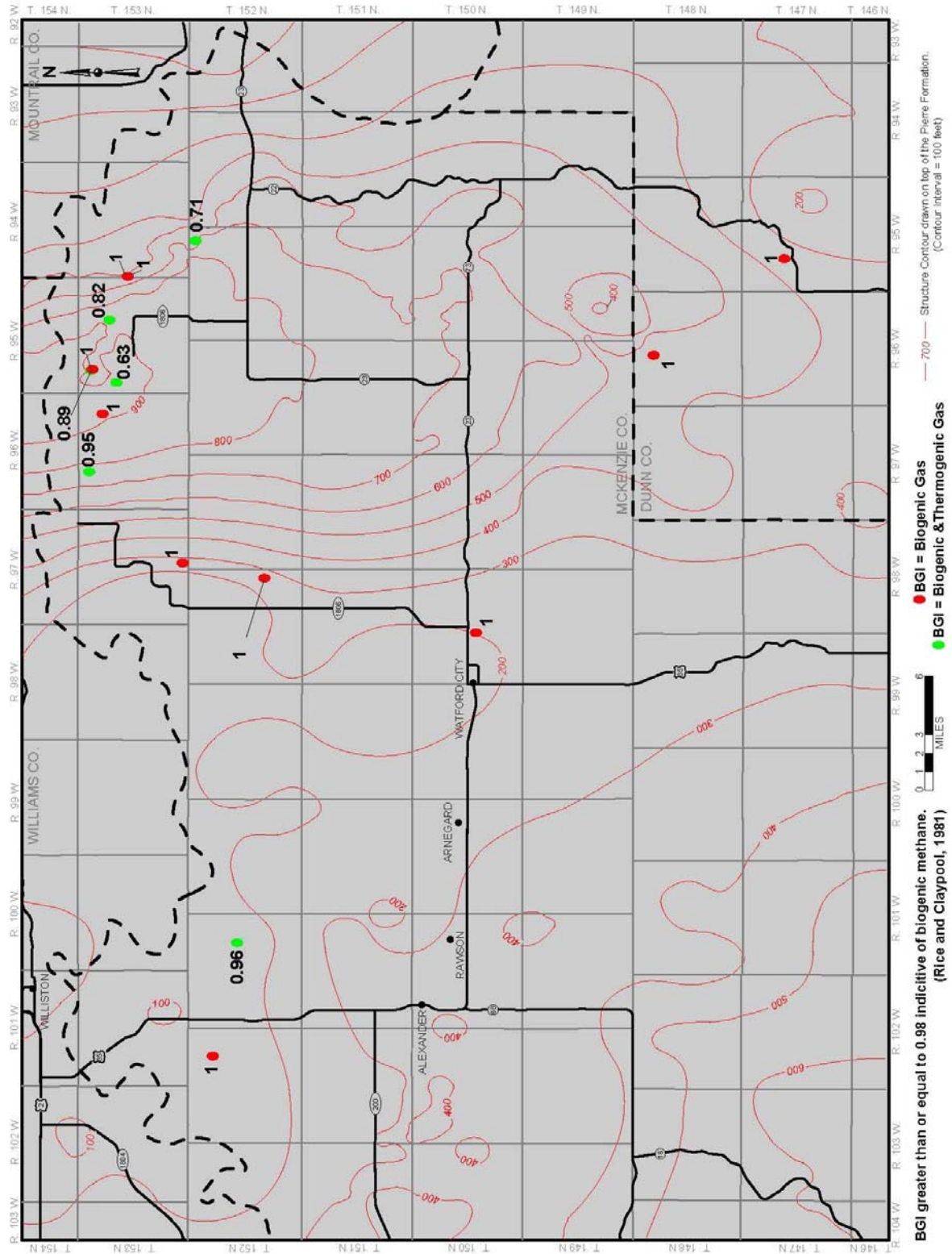
Figure 38. Bar graph depicting the numerical values and relative relationships of biogenic gas indices (BGI) determined on gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. BGI indices  $\geq 0.98$  are suggestive of biogenic origin (Rice and Claypool, 1981).

**Table 5. Summary of Calculated Biogenic and Dry Gas Indices**

<b>Well ID</b>	<b>BGI</b>	<b>Gas Origin</b>	<b>DGI</b>	<b>Gas Classification</b>
152-102-11ABC	1.00	Biogenic	1.00	Dry
153-95-18ABB	0.63	Thermogenic	0.63	Wet
153-96-5CAA	0.95	Marginal Biogenic	0.95	Dry
147-95-17ACA	1.00	Biogenic	1.00	Dry
148-96-9ABD	1.00	Biogenic	1.00	Dry
150-98-21ACD	1.00	Biogenic	1.00	Dry
152-98-24CCC	1.00	Biogenic	1.00	Dry
153-97-34CBA	1.00	Biogenic	1.00	Dry
153-95-10DAC	0.82	Thermogenic	0.82	Wet
153-95-5CBD	0.89	Thermogenic	0.89	Wet
152-95-1BCA	0.71	Thermogenic	0.71	Wet
153-95-5CBD*	1.00	Biogenic	1.00	Dry
153-94-18CBC	1.00	Biogenic	1.00	Dry
153-94-18CBC*	1.00	Biogenic	1.00	Dry
153-96-11ADA	1.00	Biogenic	1.00	Dry
152-101-14ACA	0.96	Marginal Biogenic	0.95	Dry

\*Additional sample collected from well on separate date.

Figure 39. Calculated biogenic gas indices from wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota



## Dry Gas Index (DGI)

One additional method to support the interpretation of the origin of natural gas from analytical gas composition data is by determining the Dry Gas Index (DGI). The DGI is defined as the ratio of the concentration of methane divided by the summation of the remaining hydrocarbons reported within an analysis (expressed in mol%) that range from methane (C<sub>1</sub>), ethane (C<sub>2</sub>), propane (C<sub>3</sub>), butane (C<sub>4</sub>), pentane (C<sub>5</sub>), hexane (C<sub>6</sub>), and heptane (C<sub>7</sub>). The DGI is calculated, using the an equation similar in form to the equation used to calculate the BGI, also introduced by Rice and Claypool (1981):

$$\text{DGI} = [(C_1)/\Sigma (C_1+C_2+C_3+C_4+C_5+C_6+C_7)]$$

Where:           DGI = Dry Gas Index  
                  C<sub>1</sub> = Methane (CH<sub>4</sub>)  
                  C<sub>2</sub> = Ethane (C<sub>2</sub>H<sub>6</sub>)  
                  C<sub>3</sub> = Propane (C<sub>3</sub>H<sub>8</sub>)  
                  C<sub>4</sub> = n- & isobutane (C<sub>4</sub>H<sub>10</sub>)  
                  C<sub>5</sub> – n- & isopentane (C<sub>5</sub>H<sub>12</sub>)  
                  Σ = Summation

The result of this calculation is a determination of the “wetness” of the gas. The DGI equation was applied to the gas analyses compiled and resulted in calculated dry gas indices ranging from 0.63 to 1 (Table 5). Gases whose calculated values are above a DGI of 0.95 (Figure 40) are considered to be “dry” and below a DGI of 0.95 are considered to be “wet” (Rice and Claypool, 1981). The range of results calculated here suggests that three of the wells contained wet gases, one contained both dry and wet gasses (i.e. 153-95-5CBD) while the remaining 9 wells may be considered to be dry gases. Three of the four wells with DGI indices lower than 0.95 and therefore are considered to be “wet” (i.e. 153-95-18ABB, 153-95-10DAC, and 153-95-5CBD) are located above the longitudinal axis of the Nesson Anticline (Figure 41).

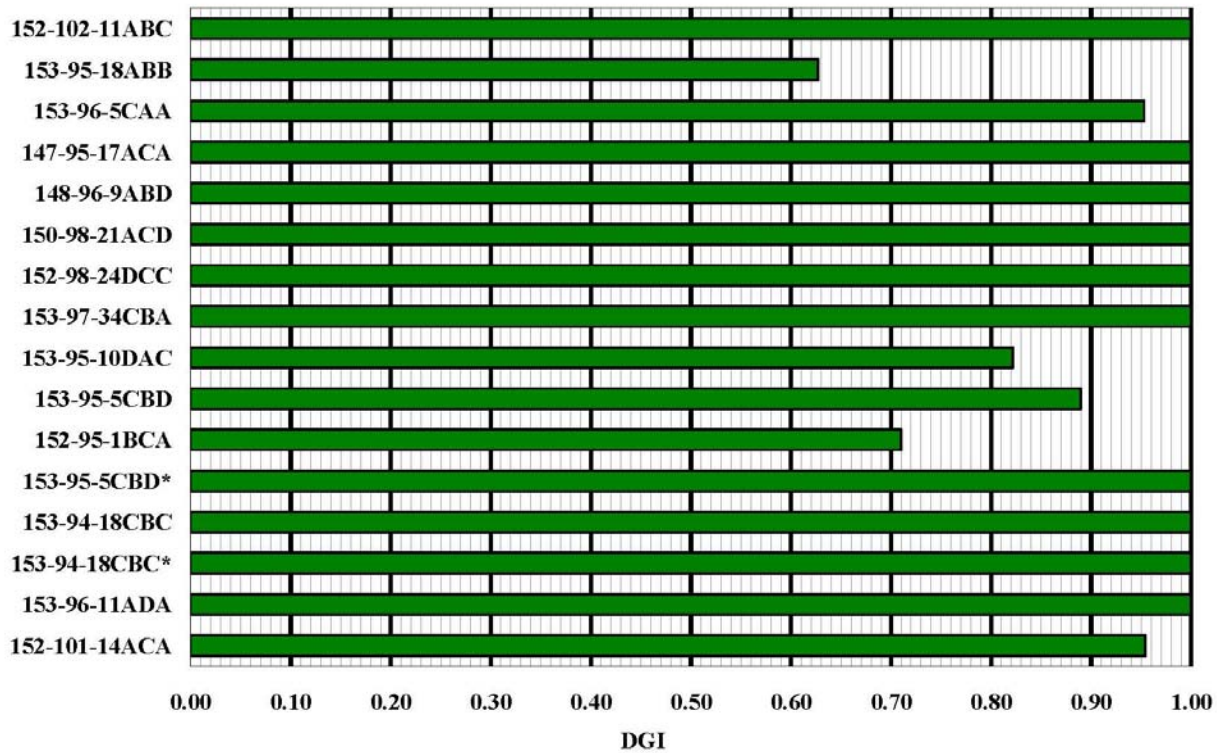
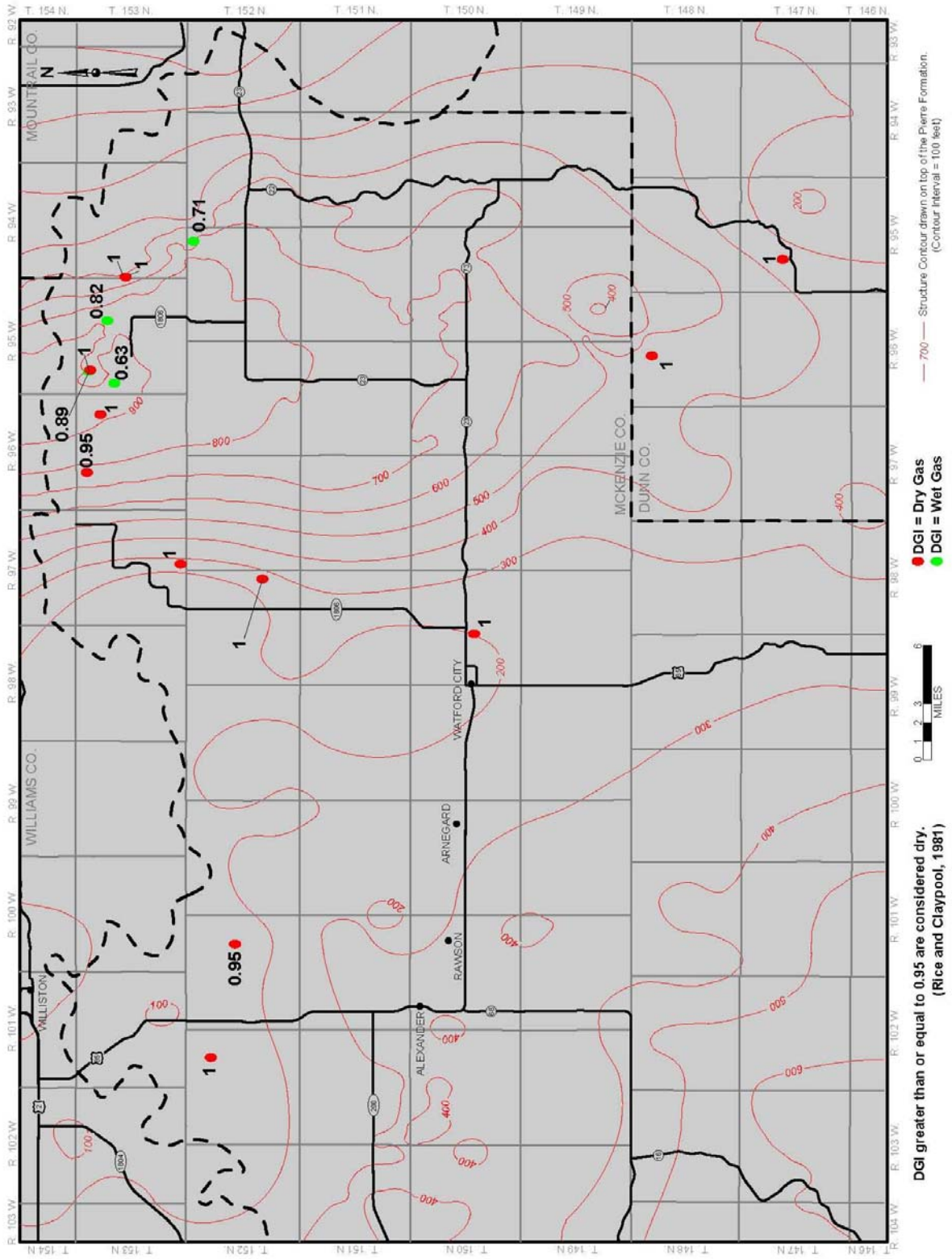


Figure 40. Bar graph depicting the numerical values and relative relationships of dry gas indices (DGI) determined on gases collected from individual wells in Cretaceous and Tertiary aquifers. \*Additional samples collected from wells on separate dates. DGI indices  $\geq$  to 0.95 are considered to be dry,  $<$  0.95 are considered to be wet (Rice and Claypool, 1981).



Figure 41. Calculated dry gas indices (DGI) from selected wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota.





## DISCUSSION

Methane concentrations are well dispersed across a relatively large concentration range from around 6% to 76% [CH<sub>4</sub>]. When plotted graphically (Figure 42) these concentrations all fall well within a BGI window. This supports the notion that the majority of the gases sampled are of biogenic origin, most likely to be early generation as evidenced by reported carbon dioxide values less than 1% (Shurr, 2007), and are likely to be either self-sourced or sourced from deeper formations. The three wells with low BGI's and DGI's are located on structure where the possibility of vertical migration along faults and fractures (LeFever, et al 1987) may occur, most likely coincident with the underlying Keene and Charlson oil fields (Wanek, 2007).

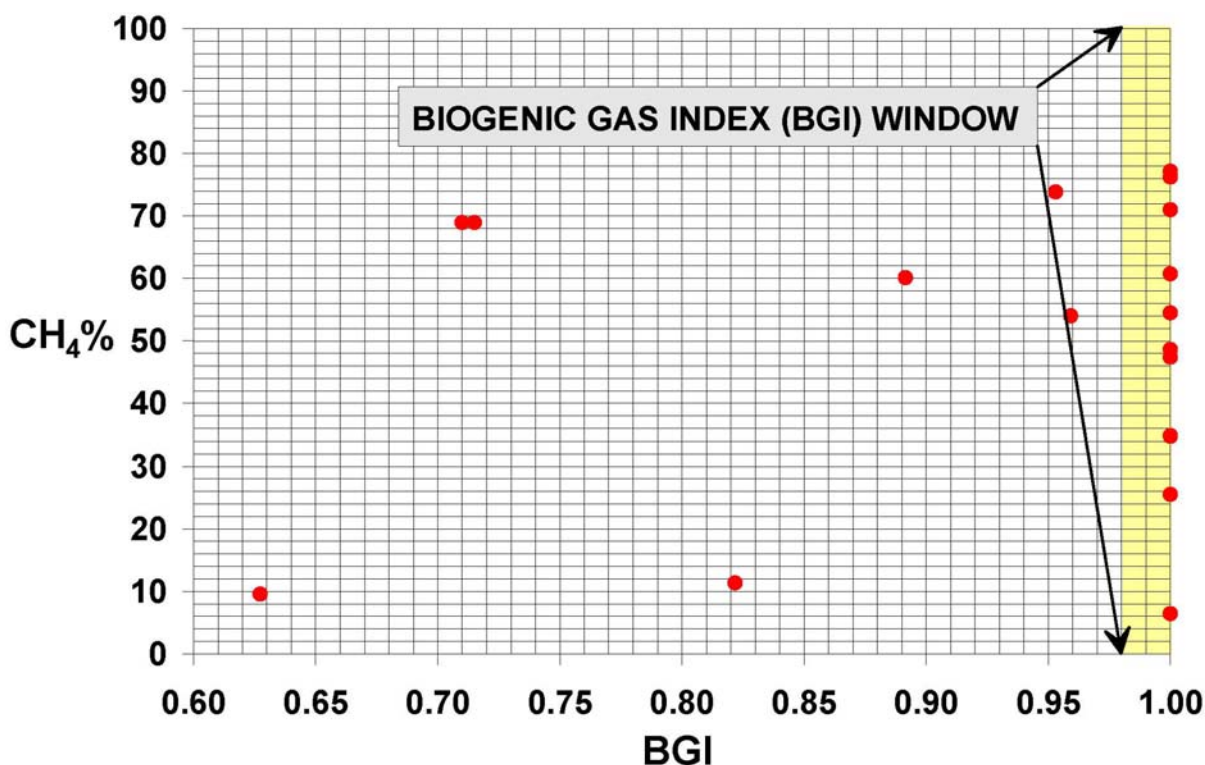


Figure 42. Plot of BGI versus methane concentrations (mol %) from gases collected from selected wells in the Cretaceous and Tertiary Aquifers in West-Central North Dakota. BGI index window greater than or equal 0.98 captures several values across a wide range of methane concentrations.

Previous workers have also suggested that deeper ground-water sources, such as the Minnelusa Formation, may be a source for gas generation and migration (Wanek, 2007). In order to expand on this, gas composition data from two wells tested in the Minnelusa Formation (Figure 43) were extracted from the recently completed EERC/PCOR database (EERC, 2008). Well 9107 and 9280, reported respectively, total hydrocarbon concentrations of 1.90 to 49.90 %, methane concentrations of 1.87 to 33.57%, nitrogen concentrations of 98.09 and 48.92%, carbon dioxide concentrations of 0.00 and 0.18%, and remaining alkanes (C<sub>2</sub>-C<sub>6</sub>+) of 0.03 and 16.33% (Table 6). No hydrogen sulfide was reported from these wells, which is also consistent with gas composition data from the overlying Cretaceous and Tertiary aquifers.

Table 6. Gas constituent concentrations<sup>1</sup> detected in wells tested in the Minnelusa Formation in West-Central North Dakota

Well ID	[THC]	[CH <sub>4</sub> ]	[N <sub>2</sub> ]	[O <sub>2</sub> ]	[CO <sub>2</sub> ]	[C <sub>2</sub> H <sub>6</sub> ]	[H <sub>2</sub> S]	[C <sub>3</sub> H <sub>8</sub> ]	[i-C <sub>4</sub> H <sub>10</sub> ]	[n-C <sub>4</sub> H <sub>10</sub> ]	[i-C <sub>5</sub> H <sub>12</sub> ]	[n-C <sub>5</sub> H <sub>12</sub> ]	[C <sub>6</sub> H <sub>14</sub> ]	<sup>2</sup> Specific Gravity	BTU (Saturated)	BTU (Dry)
9107	1.90	1.87	98.09	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.959	19	20
9280	49.90	33.57	48.92	0.00	1.18	5.36	0.00	3.78	1.67	1.93	0.68	0.66	2.05	0.963	792	804

<sup>1</sup>[Compound] in mol %.

<sup>2</sup>Air = 1.0000

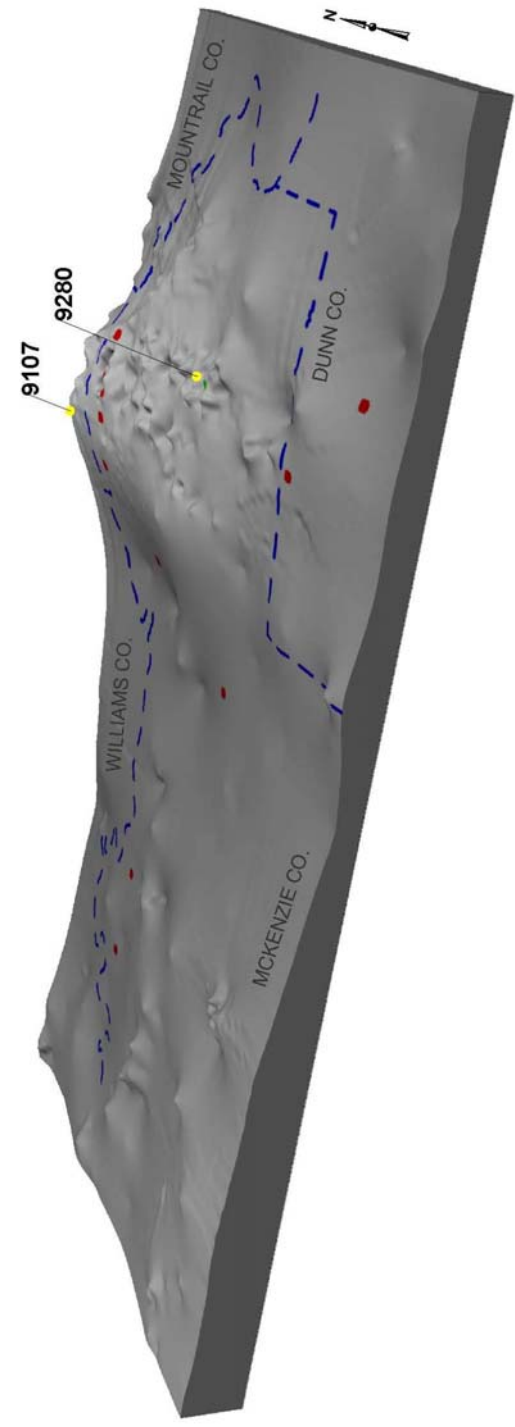


Figure 43. 3D perspective view from the southeast to the northwest across the subsurface topography of the Cretaceous Pierre Formation in west-central North Dakota. Southern nose of the Nesson Anticline is expressed in the northeast portion of this study area. The location of Minnelusa Formation wells are shown in yellow. Locations of Cretaceous and Tertiary wells are shown in Red. The border of McKenzie county is shown with the dashed blue line. VE = 2X.

The data compare favorably from a qualitative gross gas composition viewpoint. Further, of the two Minnelusa Formation wells tested, Well 9280 – which is located in the southeastern portion of the study area and at the southern end of the Nesson Anticline, compare most favorably across all major gas components. Well 9107 – which is located in the northeastern portion of the study area, has a gas composition profile that is much less similar than gases from the Cretaceous and Tertiary aquifers, except for the presence of nitrogen. Nitrogen concentrations are relatively consistent between the Minnelusa Formation wells tested and the gases collected from the Cretaceous and Tertiary aquifers. Nitrogen concentrations do tend to decrease off structure (Figure 44). These relationships would seem to suggest that at a minimum, a portion of the gases that are present in the Cretaceous and Tertiary aquifers are being sourced in the underlying Minnelusa or perhaps deeper formations. Further evaluation of available gas composition and isotope data from other underlying units (e.g. the Spearfish, Bakken, Madison, and Winnepeg) is recommended in order to gain a better understanding of the relationships between shallow and deep gas sourcing and accumulation.

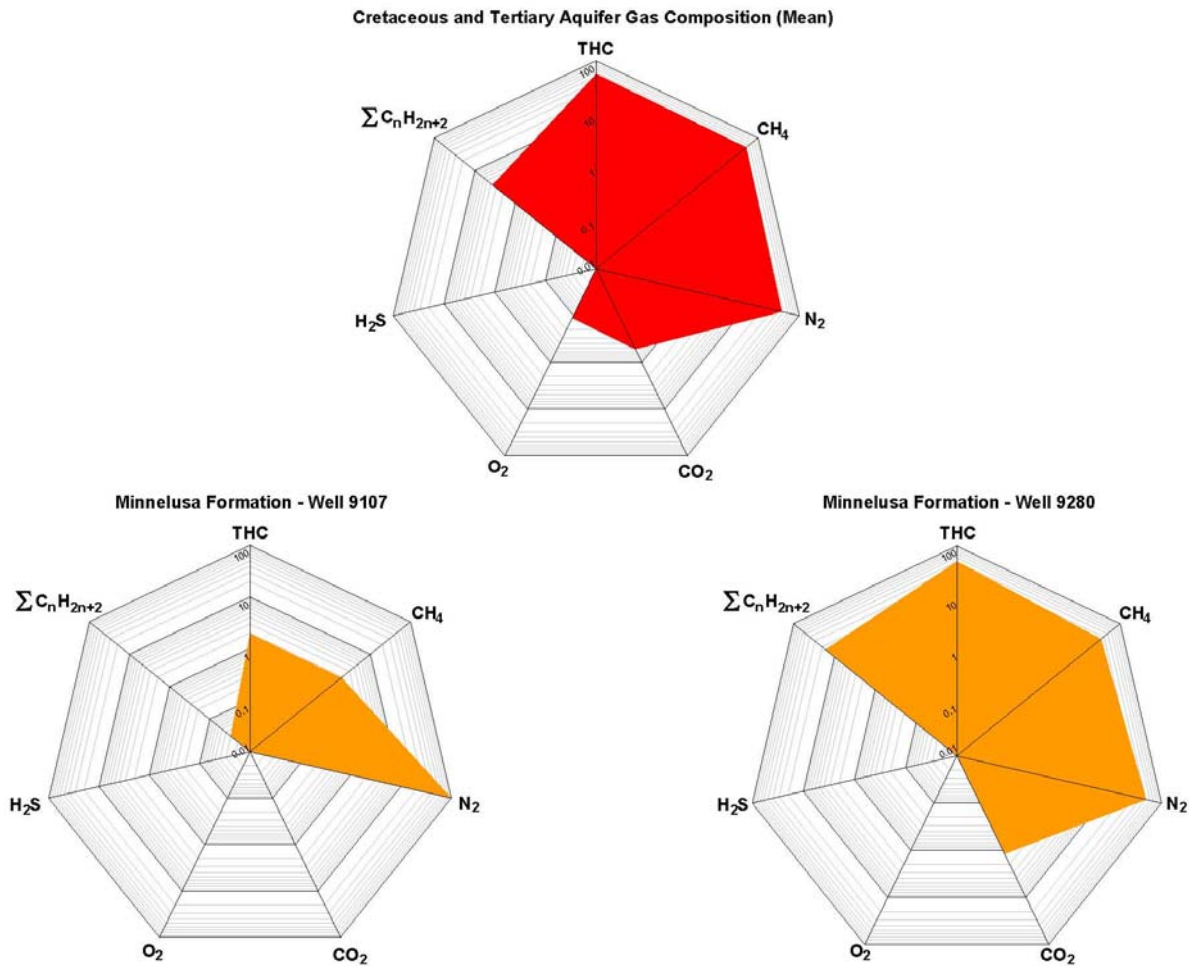


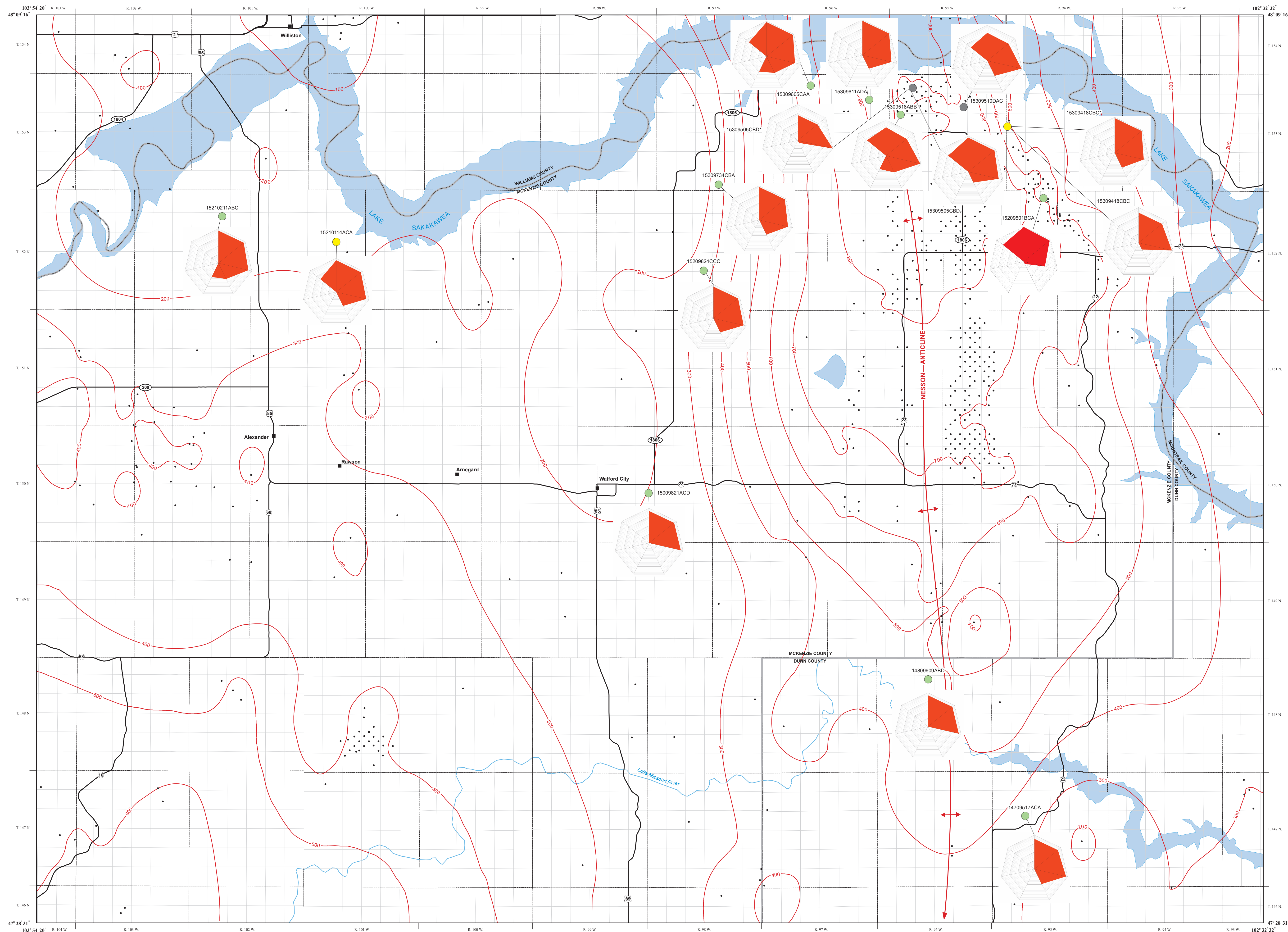
Figure 44. Radar diagrams of gas constituents in wells tested in the Minnelusa Formation compared with overall gas constituent composition from wells in Cretaceous and Tertiary aquifers in west-central North Dakota.

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# Plate 1 - Composition of Shallow Gas from Wells in Cretaceous and Tertiary Aquifers in West-Central North Dakota



## Discussion

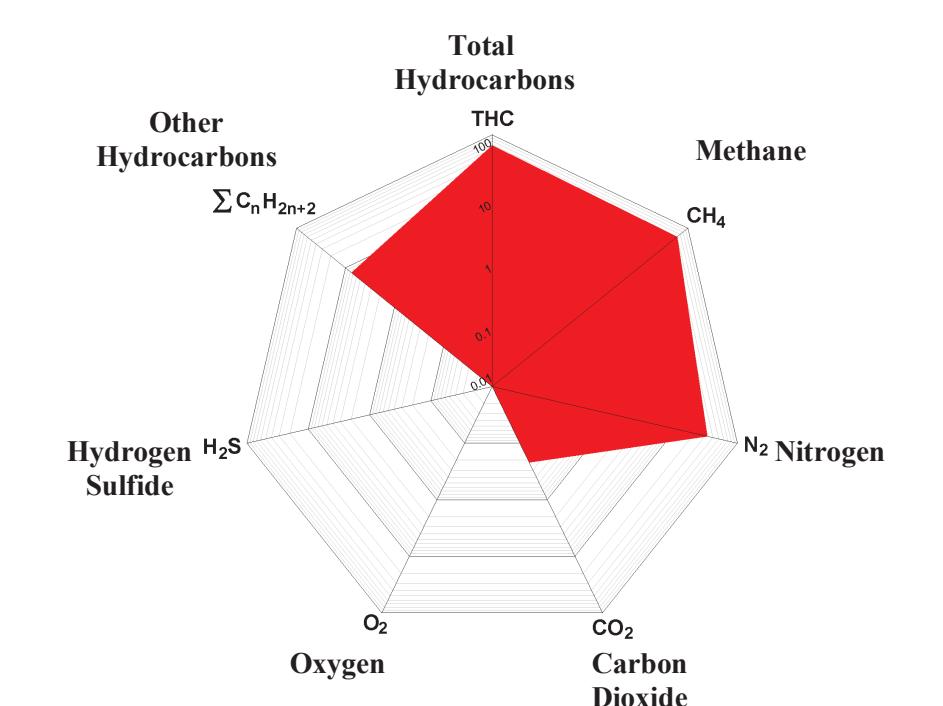
Historical shallow gas composition analyses, obtained from flowing-head wells in the Fox Hills - Hell Creek, Cannonball/Ludlow, and Bullion Creek Aquifers in West-Central North Dakota, are shown on this plate. Gas constituent concentrations, obtained from available analytical reports, are presented. All sampling and analysis was completed in the 1980's by N.D. State Water Commission hydrologists. The analyses shown are temporally variable and range from as early as 1983 to as late as 1989. Gas composition constituents include: Total Hydrocarbons (THC), Methane (CH<sub>4</sub>), Nitrogen (N<sub>2</sub>), Carbon Dioxide (CO<sub>2</sub>), Oxygen (O<sub>2</sub>), Hydrogen Sulfide (H<sub>2</sub>S), and the sum of all remaining reported hydrocarbons (ΣC<sub>n</sub>H<sub>2n+2</sub>), including: ethane, propane, n- and i-butane, n- and i-pentane, and hexanes+. Results are presented as radar diagrams shown adjacent to the wells tested. An interpretation of the subsurface topography of the Pierre Formation, which directly underlies the Fox Hills - Hell Creek Aquifer, was drawn from available Pierre Formation stratigraphic tops and is shown with a 100 foot contour interval. Pierre Formation stratigraphic tops data was extracted from databases of the N.D. Oil & Gas Division and N.D. Geological Survey.

## Explanation

### Geologic Symbols

- 15309510DAC Well ID Number
- Well - Tongue River (Bullion Creek) Aquifer
- 15309418CBC Well ID Number
- Well - Cannonball/Ludlow Aquifer
- 15309611ADA Well ID Number
- Well - Fox Hills/Hell Creek Aquifer
- \* Additional sample collected from well.

### Observation Well Radar Diagram<sup>1</sup>



<sup>1</sup>Scale is logarithmic.

- ↕ Approximate location of anticlinal axis.
- Structure Top of Pierre Formation  
Contour interval equals 100-ft.
- Control Points for Structure

### Other Features

- Water
- River
- County Boundary
- Township Boundary
- Section Lines
- Town
- Federal Highway
- State Highway

