North Dakota Geological Survey
Geologic Investigation No. 116

Evidence for Potential CH_4 Sourcing and Methanogenesis in Late Cretaceous Shales along the Eastern Flank of the Williston Basin in North Dakota

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Abstract

Methane (CH_4) is frequently found to occur in ground-water wells within shallow aquifers above Cretaceous marine shales of the Dakota, Colorado, and Montana Groups on the eastern flank of the Williston Basin in North Dakota. Shallow gas flame-ionization detector (FID) field screening has revealed 144 CH_4 occurrences in ground-water wells, completed in aquifers with reservoir-style architecture, along the eastern flank (east of 100° west longitude) of the Williston Basin in North Dakota. CH_4 is found predominantly in wells completed in shallow bedrock and surficial aquifers above subcrops of shales belonging to the Late Cretaceous Skull Creek-Mowry-Bell Fourche (undifferentiated), Greenhorn, Carlile, Niobrara, and Pierre Formations. Methane concentration [CH_4], from FID field screening values, ranges from 0.1 to 6,087 parts-per-million (ppm), with a mean of 121 ppm (as CH_4 in air). Overall, the areal CH_4 occurrence density is 0.29 per township (36 mi). The presence of CH_4 in shallow ground-water systems above Cretaceous shales suggests potential sourcing from these units. Preliminary analysis of [CH_4] as a shallow natural gas exploration indicator in southeastern North Dakota shows that the mean [CH_4] is highest in wells above the Niobrara Formation (182 ppm), followed by the Pierre Formation (120 ppm), the Skull Creek-Mowry-Belle Fourche (94 ppm), the Greenhorn Formation (69 ppm), and the Carlile Formation (46 ppm), which, assuming vertical migration, suggests a higher degree of methanogenesis within the Niobrara Formation.

Table 1. CH_4 Occurrences in Ground-Water Wells above Cretaceous Shale Units[1] - Williston Basin Eastern Flank[2]

Stratigraphic Unit (in depositional sequence)	n	CH_4 Occurrence (ppm as CH_4 in air) Range	Mean	Min	Max
Pierre Formation	239	6086.9	120	0.1	6087
Niobrara Formation	72	3711.8	182	0.2	3712
Carlile Formation	39	635.6	46	0.4	636
Greenhorn Formation	12	575.1	69	0.9	576
Belle Fourche, Mowry, Skull Creek (undiff.)	21	1074.5	94	0.5	1075

[1] Cretaceous marine shale formations subcropping below completed well locations independent of depth.

[2] East of 100 deg. west longitude.

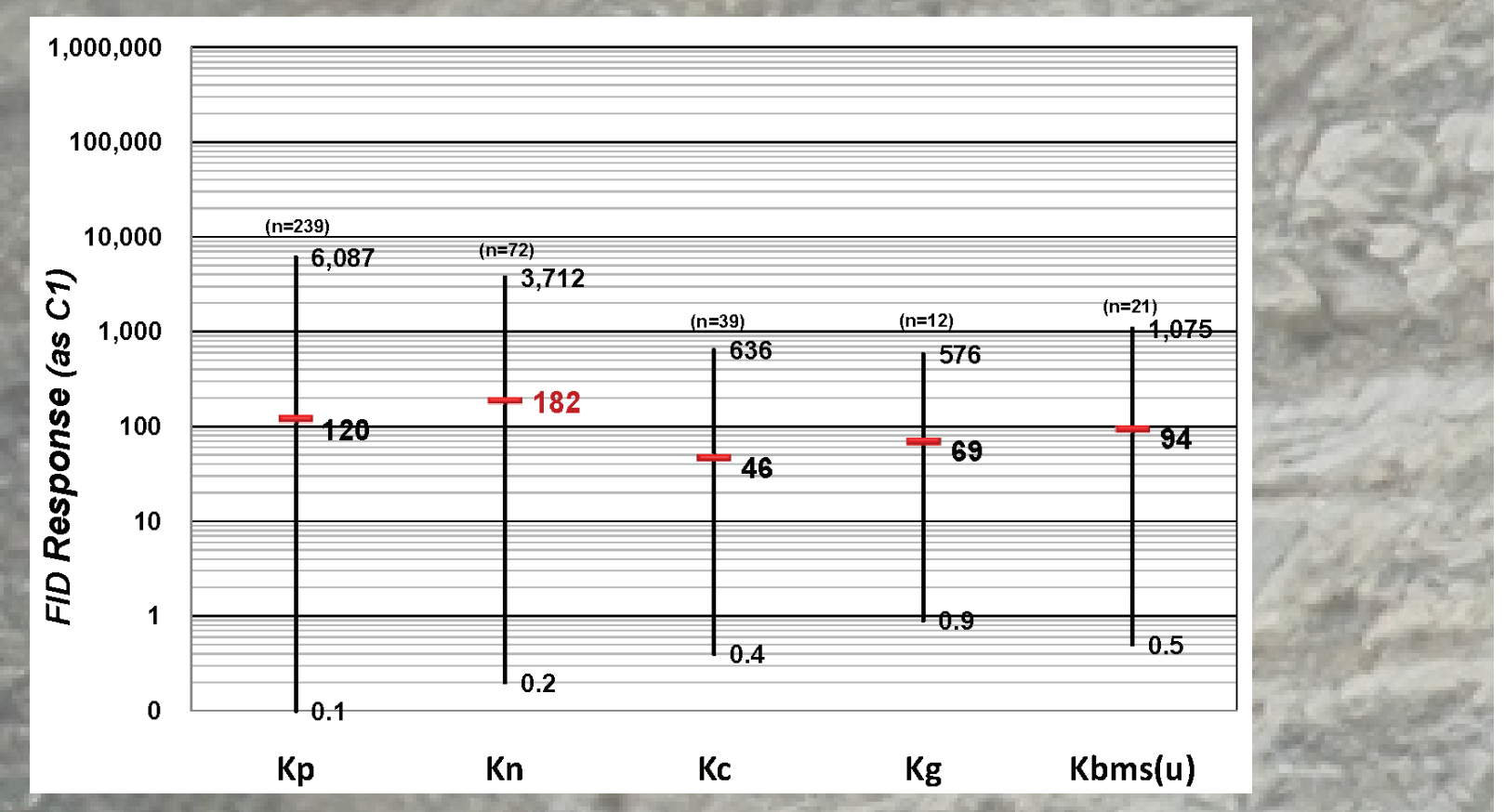
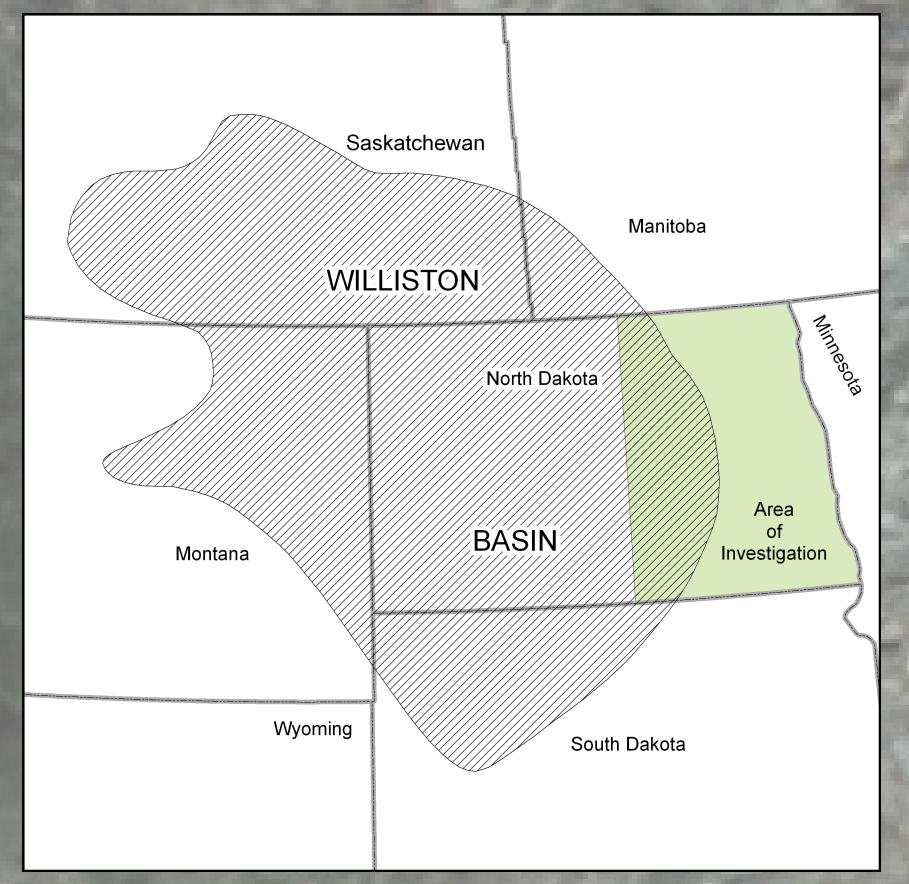


Figure 1. Ranges (black bars) and numerical means (red markers) of FID instrument responses (as C1 in air) collected from ground-water wells along the eastern flank (east of 100° west longitude) of the Williston Basin in North Dakota. Data is compiled into groups of wells that lie above particular Cretaceous age bedrock stratigraphic units (Kp = Pierre Formation, Kn = Niobrara Formation, Kc = Carlile Formation, Kg = Greenhorn Formation, and Kbms (u) = the Belle Fourche, Mowry, and Skull Creek Formations).



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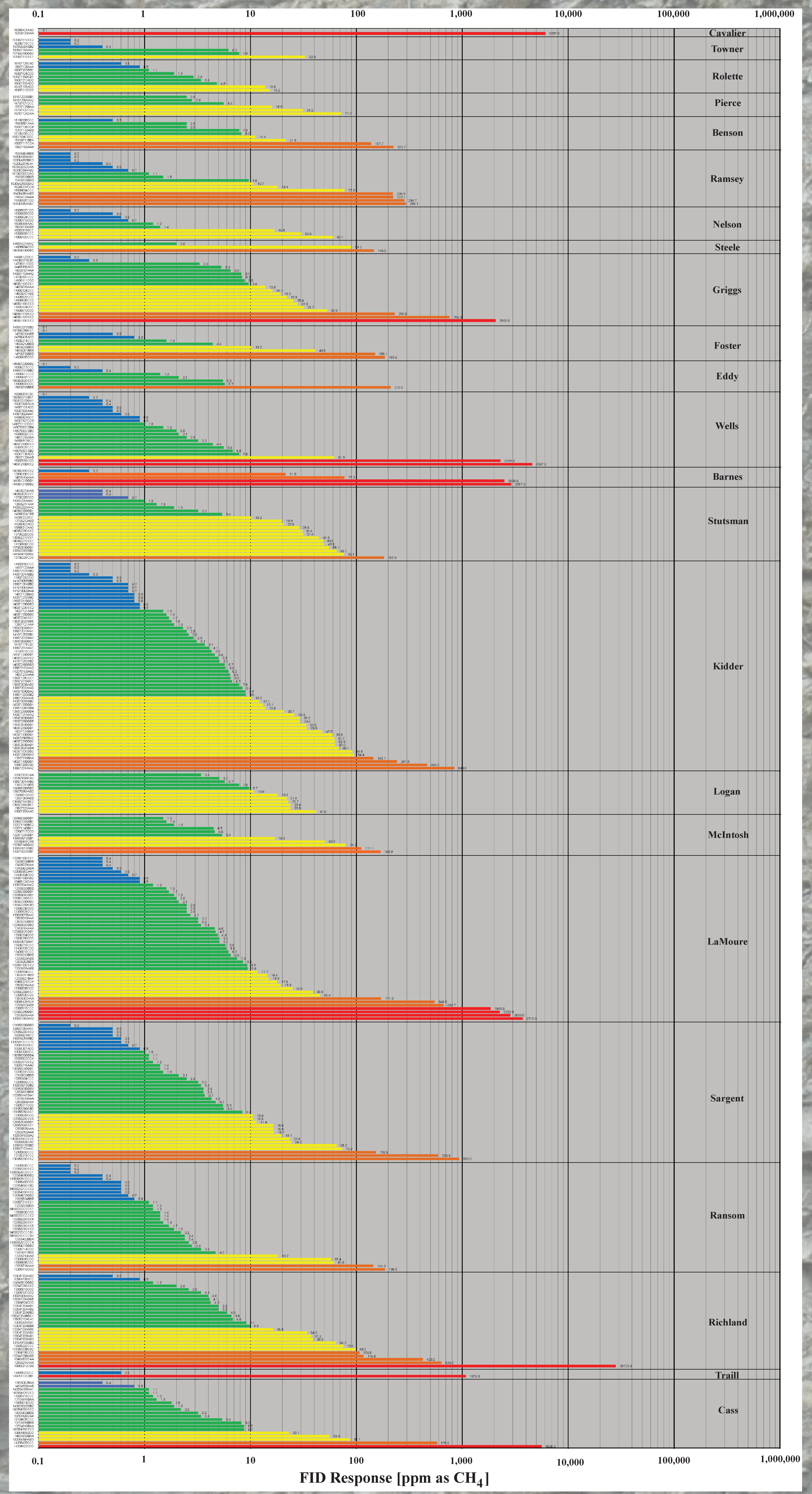


Figure 6. Comparison of shallow gas occurrences for wells field screened above the eastern flank of the Williston Basin in North Dakota from 2006-2009. Data is grouped geographically by county generally from north to south and shown from top to bottom. Data within each county grouping is sorted by [CH_4] in ascending order (i.e. lowest to highest). Bars are color coded with increasing values changing from cooler to warmer colors based on the order of magnitude of FID instrument response: blue = 0 to 1 ppm, green = 1 to 10 ppm, yellow = 10 to 100 ppm, orange = 100 to 1,000 ppm, red = 1,000 to 10,000 ppm, and purple = 10,000 to 1,000,000 ppm. Monitoring well identification numbers are displayed at the right of each respective bar. Well identification format is in ND State Water Commission database format as Township, Range, Section and 1/4, 1/4, 1/4 (e.g. 01ABC) sections. Nested wells are commonly listed with an appended 1, 2, 3 etc., attached to the well identification (e.g. 01ABC2).

Wells Field Screened

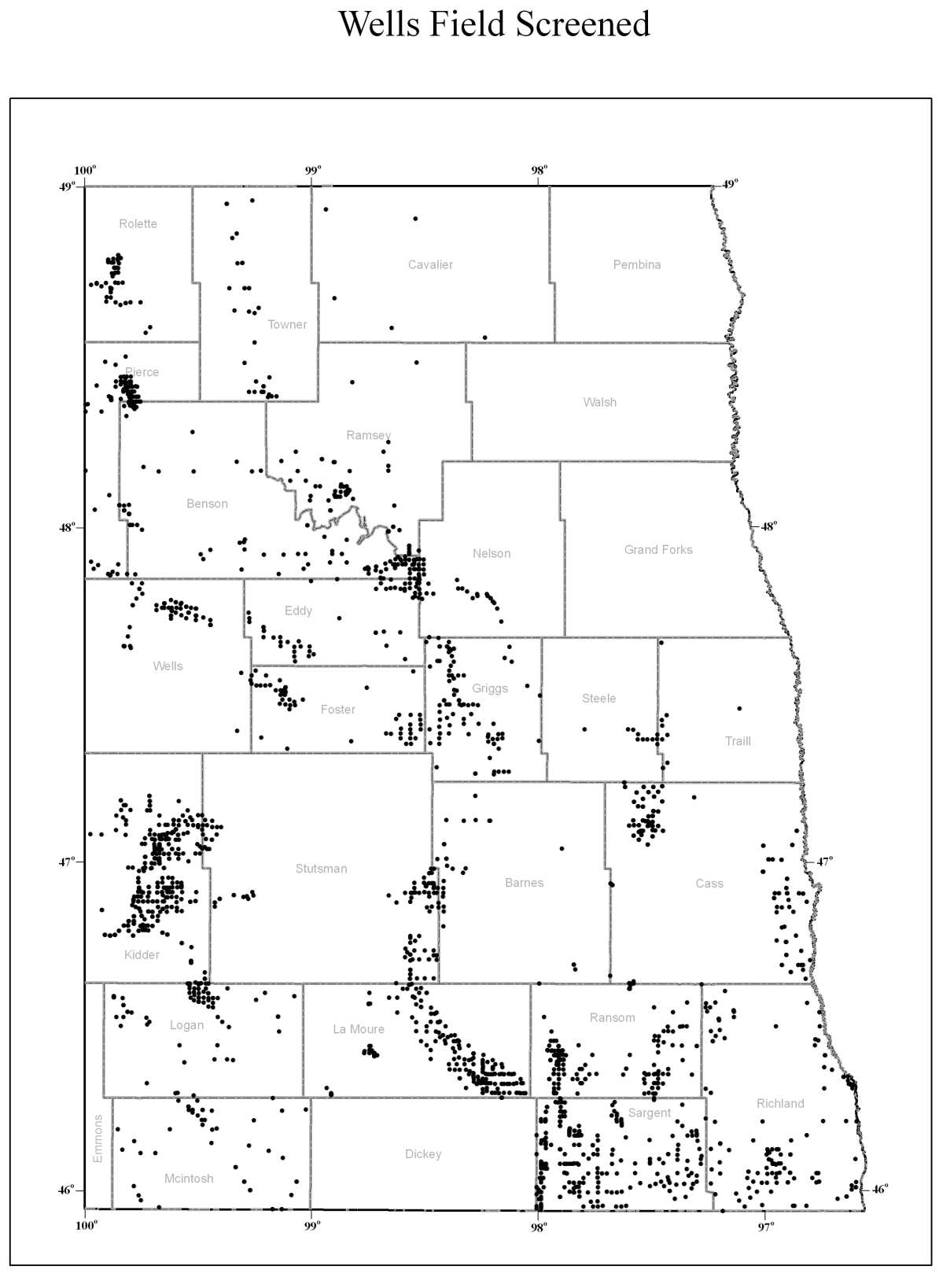


Figure 2a. Locations of all wells field screened (black dots) for the presence of methane in ground-water wells along the eastern flank (east of 100° west longitude) of the Williston Basin in North Dakota.

Scale 1:1,500,000
Miles 0 20 40 60 80
Kilometers 0 20 40 60 80

Wells Field Screened with CH4 Shows

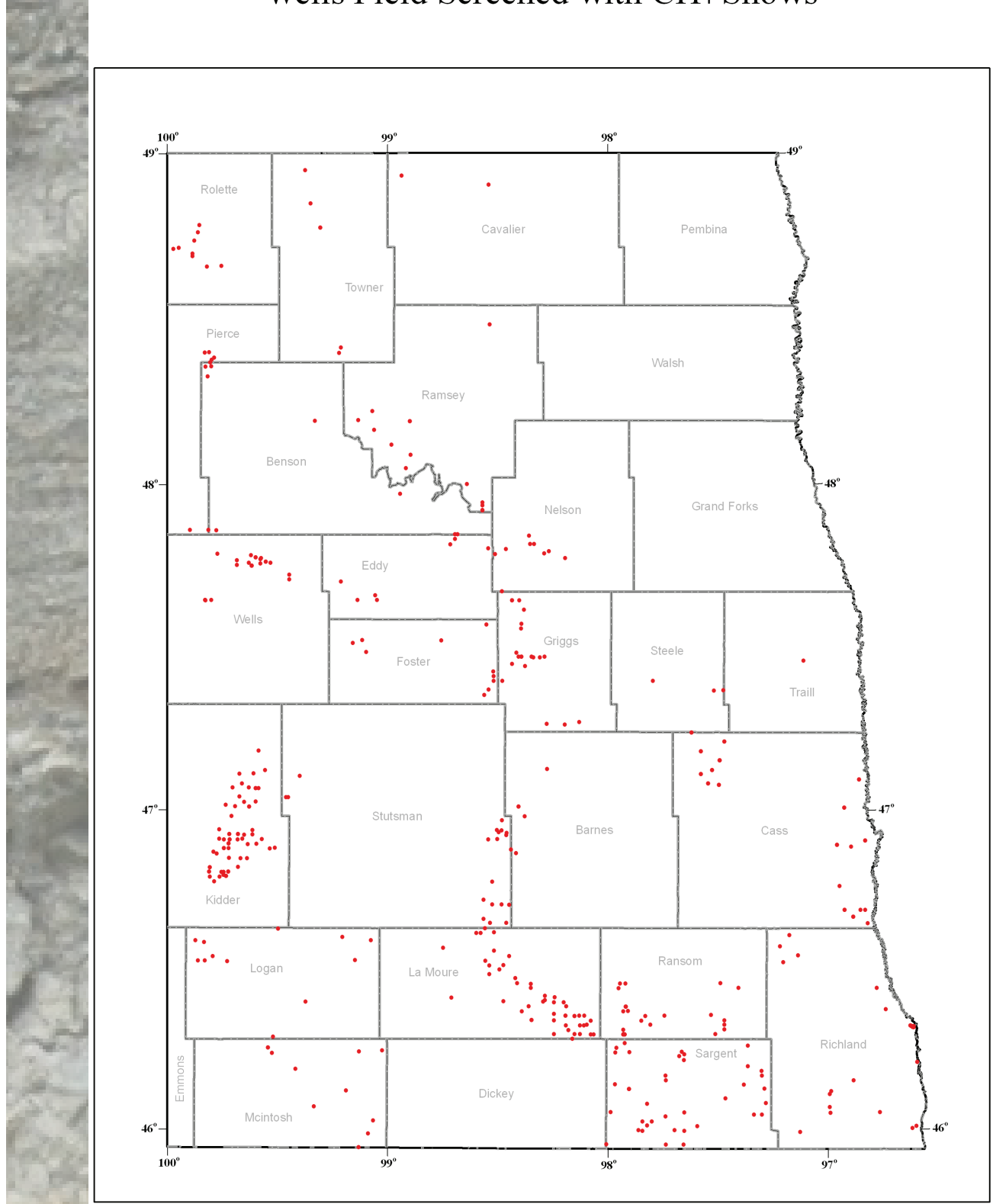


Figure 2b. Locations of wells where methane was detected (red dots) by FID field screening.

Scale 1:1,500,000
Miles 0 20 40 60 80
Kilometers 0 20 40 60 80

CH4 Shows as per FID Response Class

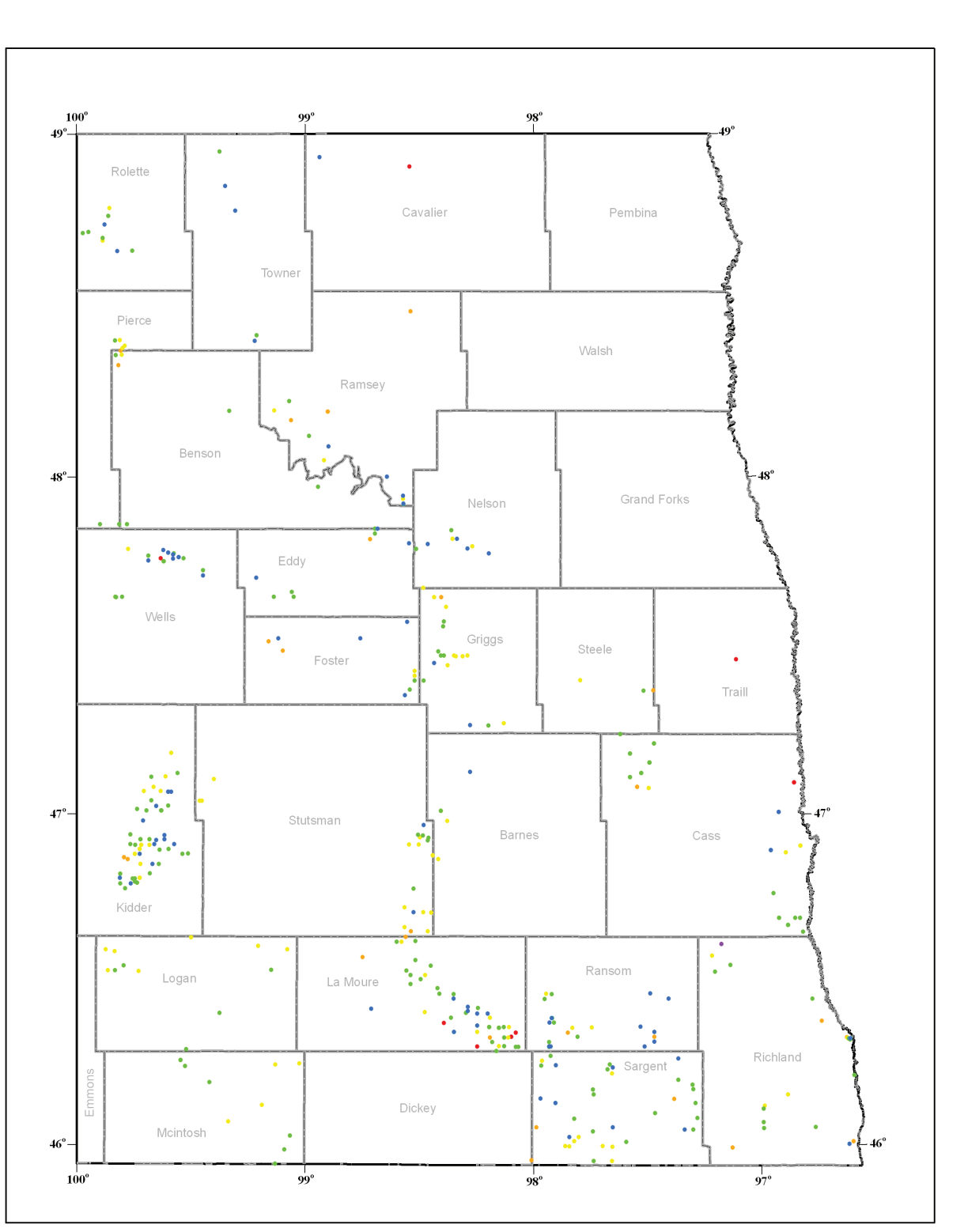


Figure 2c. Locations of wells field screened where methane was detected, grouped into six C1 concentration intervals (ppm as C1 in air) of: 0 – 1 ppm (blue), 1 – 10 ppm (green), 10 – 100 ppm (yellow), 100 – 1,000 ppm (orange), 1,000 – 10,000 ppm (red), and 10,000 – 100,000 ppm (purple).

Scale 1:1,500,000
Miles 0 20 40 60 80
Kilometers 0 20 40 60 80

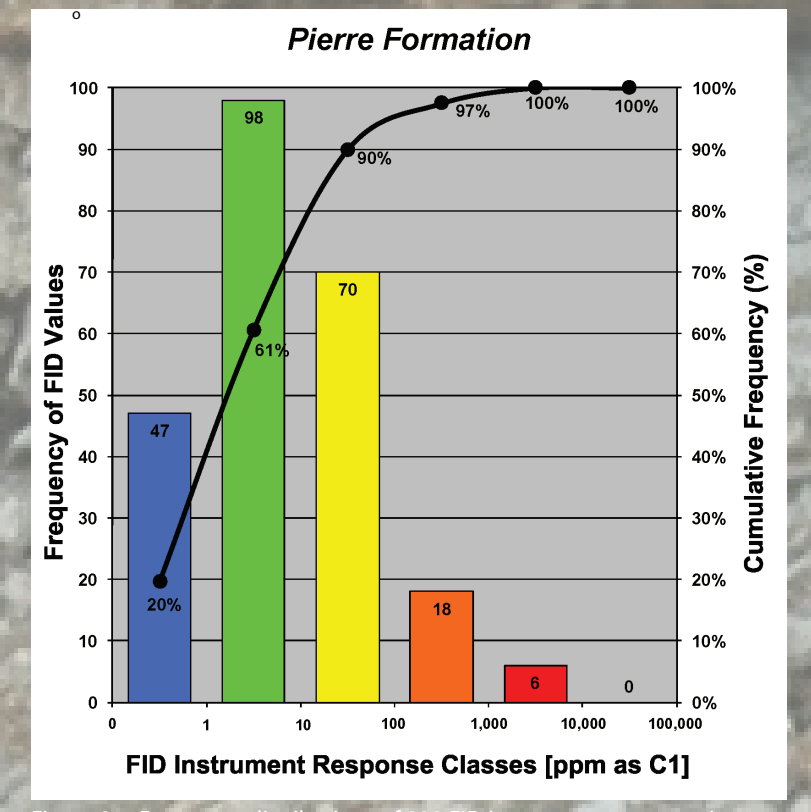


Figure 3a. Frequency distributions of 239 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above the Cretaceous Pierre Formation. The 1 – 10 ppm interval contains the majority (61%) of C1 detections. The cumulative percentage trend through the data is shown by the curved black line with 90% of the detected C1 occurrences falling below 100 ppm.

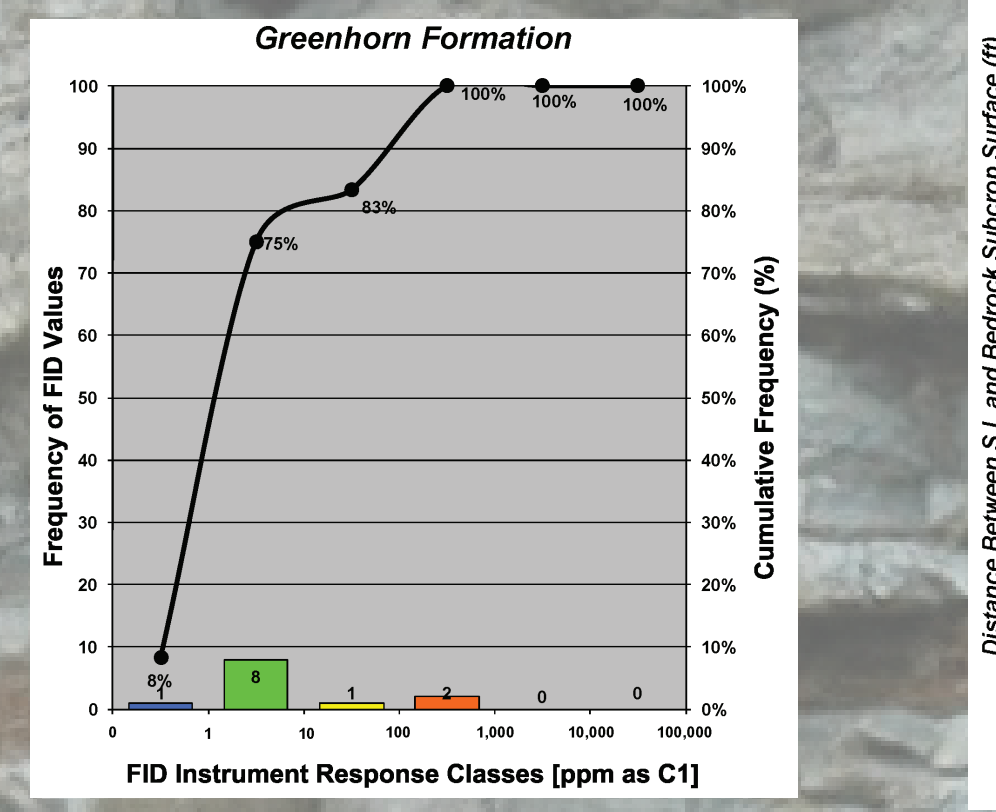


Figure 3d. Frequency distributions of 12 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above the Cretaceous Greenhorn Formation. The 1 – 10 ppm interval contains the majority (75%) of C1 detections. The cumulative percentage trend through the data is shown by the curved black line with 83% of the detected C1 occurrences falling below 100 ppm.

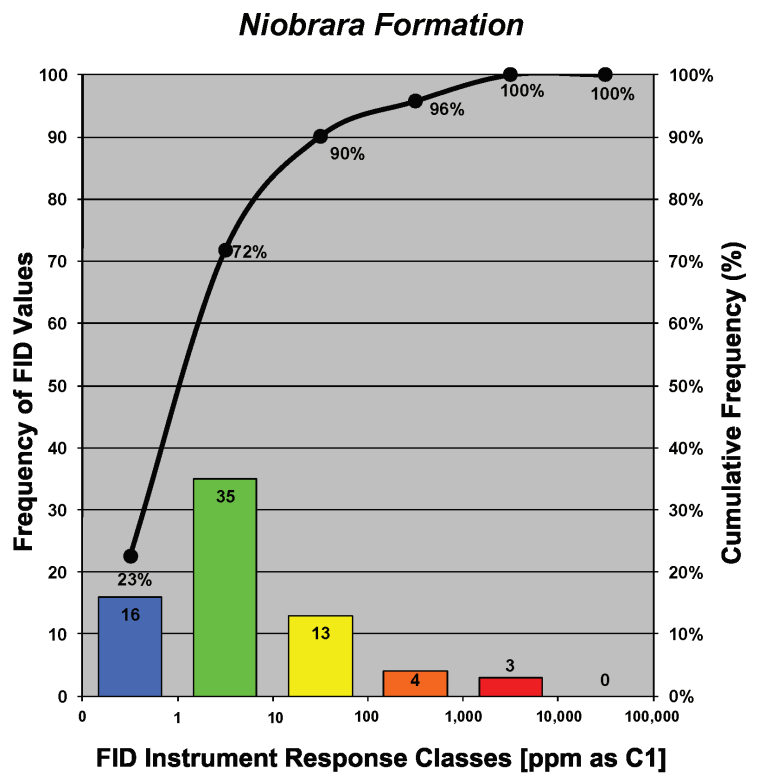


Figure 3b. Frequency distributions of 72 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above the Cretaceous Niobrara Formation. The 1 – 10 ppm interval contains the majority (72%) of C1 detections. The cumulative percentage trend through the data is shown by the curved black line with 90% of the detected C1 occurrences falling below 100 ppm.

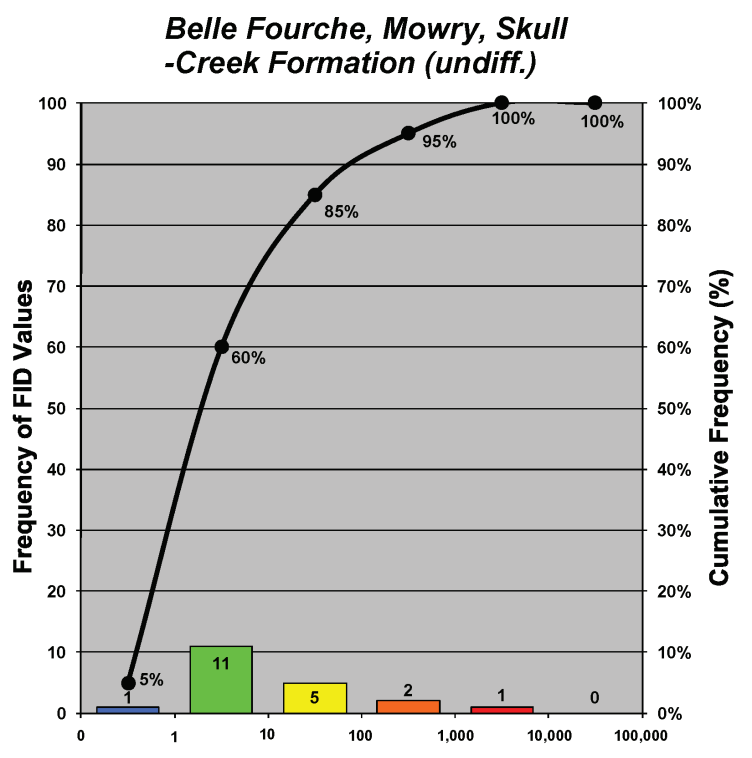


Figure 3e. Frequency distributions of 21 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above the Cretaceous Mowry\Belle Fourche\Skull Creek (undifferentiated) Formations. The 1 – 10 ppm interval contains the majority (60%) of C1 detections. The cumulative percentage trend through the data is shown by the curved black line with 85% of the detected C1 occurrences falling below 100 ppm.

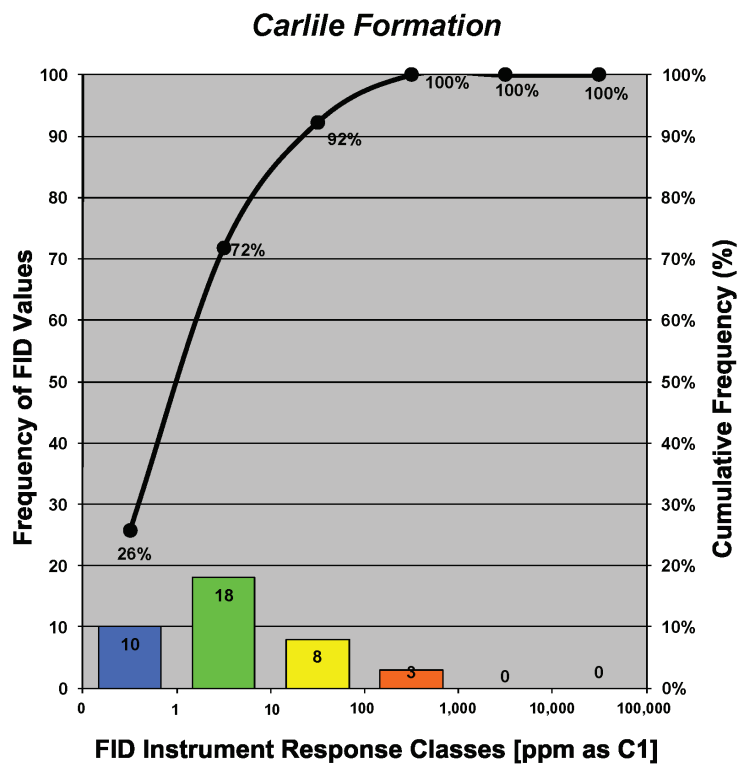


Figure 3c. Frequency distributions of 39 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above the Cretaceous Carlile Formation. The 1 – 10 ppm interval contains the majority (72%) of C1 detections. The cumulative percentage trend through the data is shown by the curved black line with 92% of the detected C1 occurrences falling below 100 ppm.

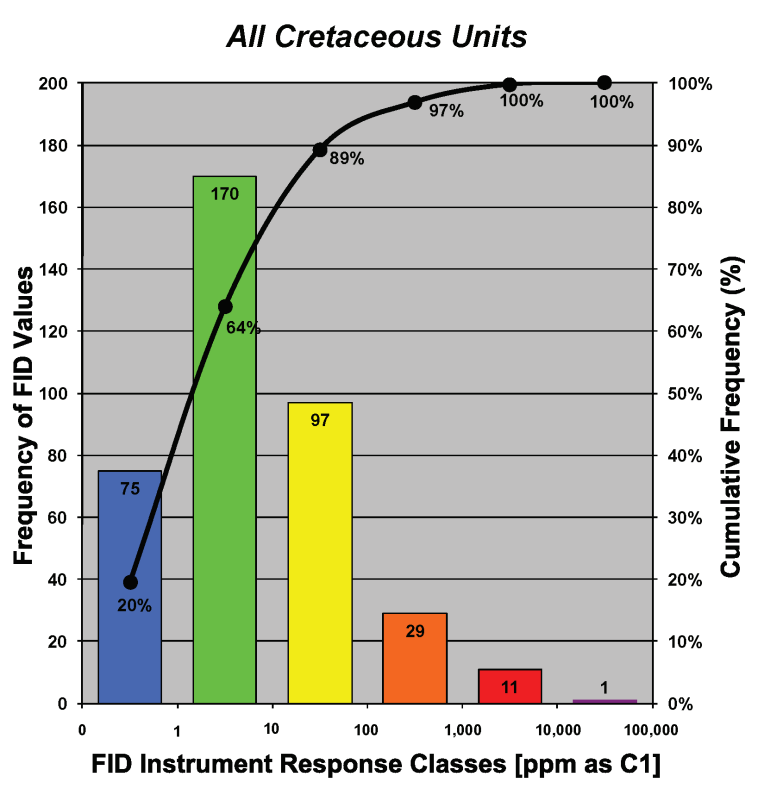


Figure 3f. Frequency distributions of 383 FID instrument responses in ppm (as C1 in air) described within six logarithmic concentration intervals from zero to 100,000 ppm from ground-water wells completed above Cretaceous stratigraphic units. The 1 – 10 ppm interval contains the majority (44%) of C1 detections. Only one value was reported that was greater than 10,000 ppm, which is likely an outlier. The cumulative percentage trend through the data is shown by the curved black line. Nearly 90% of the detected C1 occurrences fall below 100 ppm.

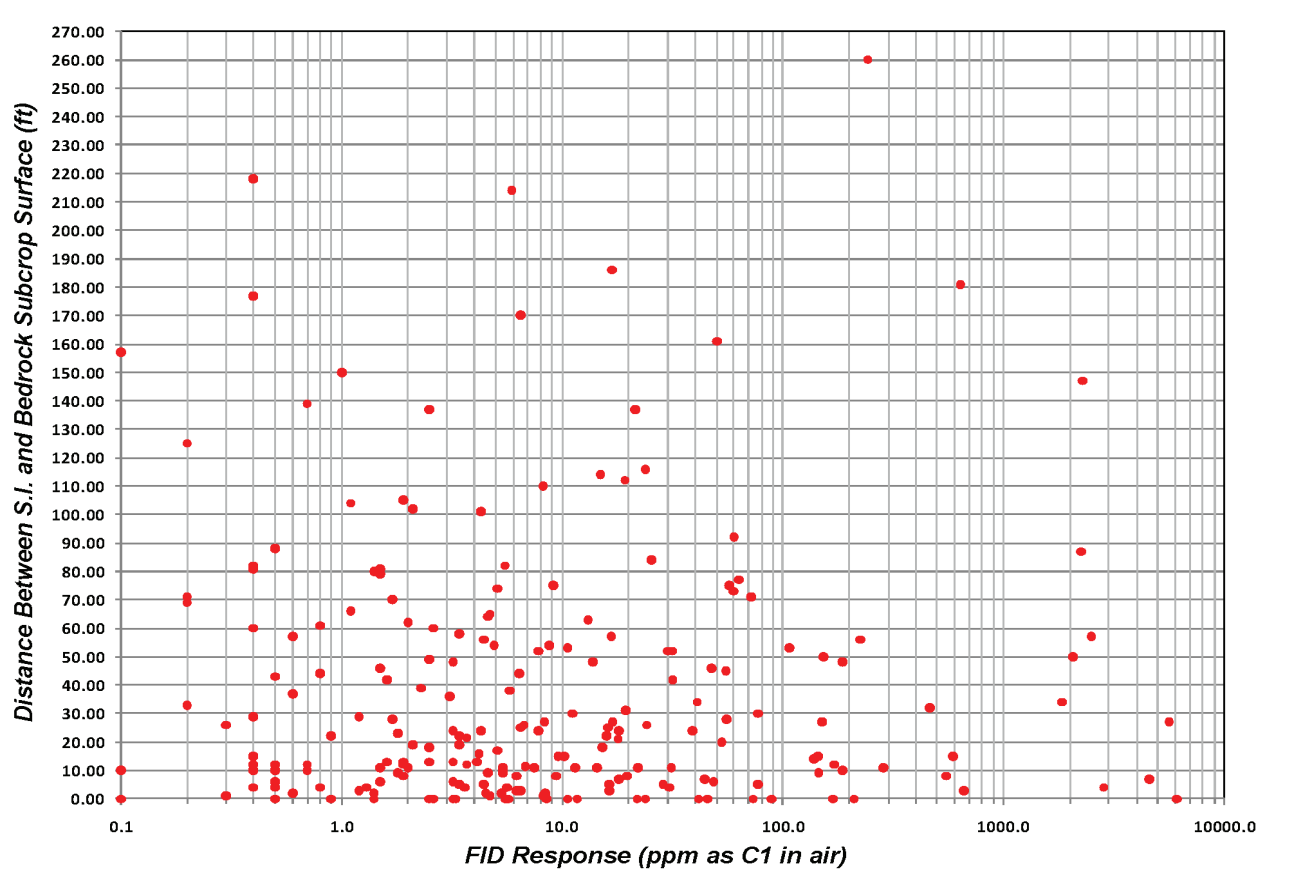


Figure 5a. Detected methane concentrations (ppm as C1 in air) plotted versus separation distance between well completion depth and depth of Cretaceous bedrock subcrop (ft) suggesting that the smaller the distance between the depth of well completion and the bedrock subcrop, the greater the number of methane occurrences are detected.

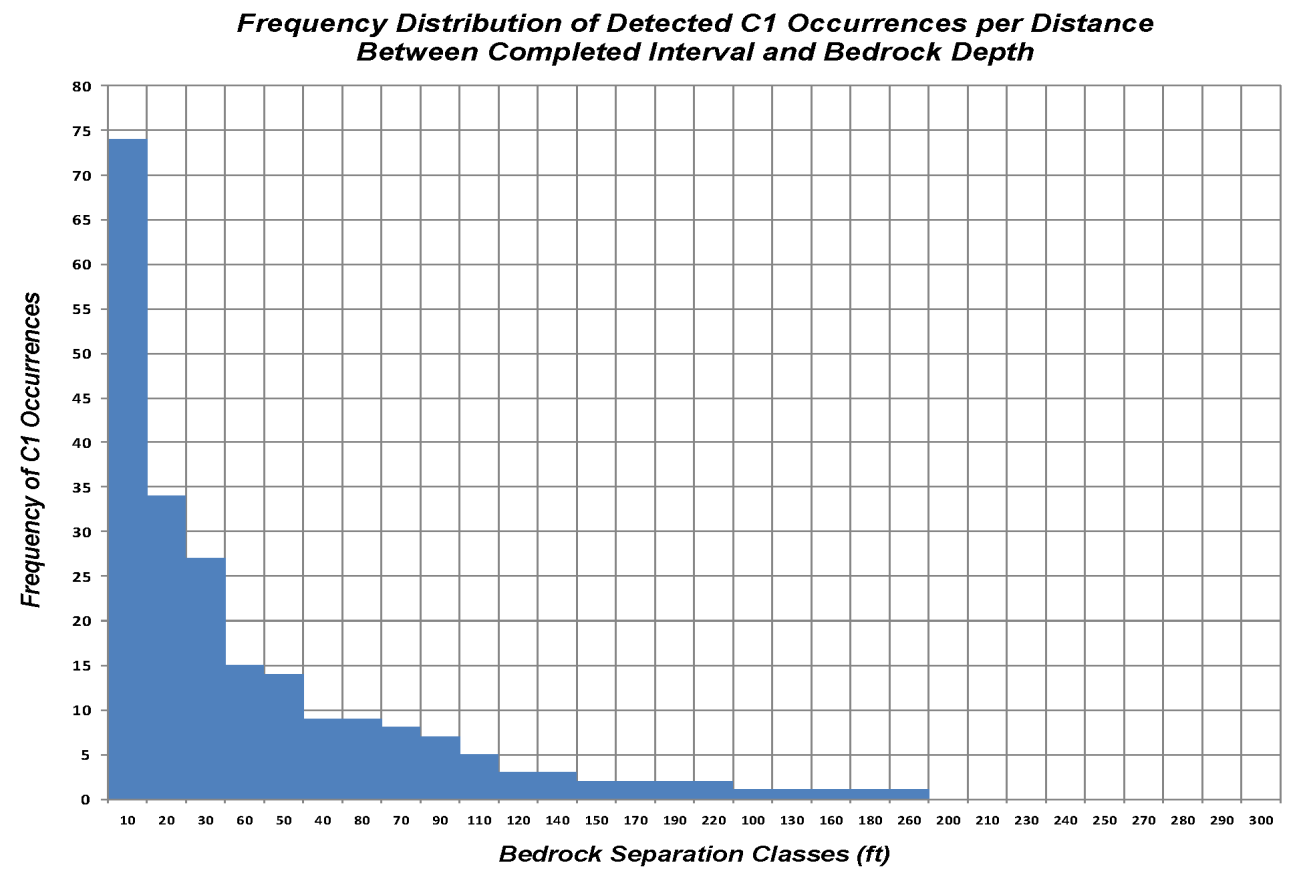


Figure 5b. Frequency distribution of detected methane concentrations (ppm as C1 in air) as per bedrock separation classes further illustrating evidence of potential methane sourcing from the Cretaceous subcrop. The greater the distance between the well completed depth and bedrock subcrop the lower the number of methane occurrences detected.

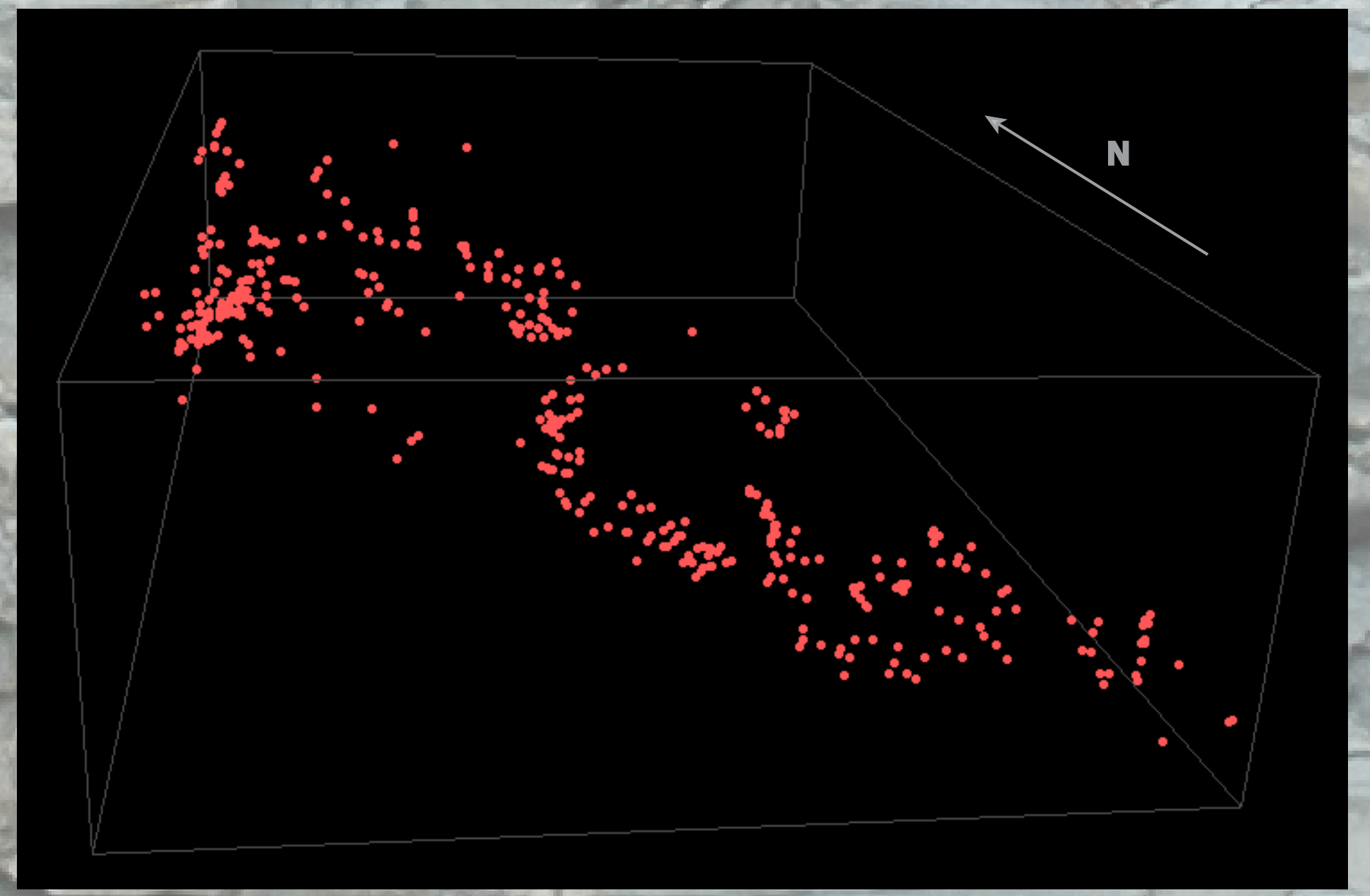


Figure 8. 3D scatter plot model of CH_4 occurrences along the eastern flank of the Williston Basin in North Dakota (view from south to north). Detected [CH_4] are shown at ground-water well completion elevations, generally decreasing in elevation from the northwest to the southeast. Data distribution is controlled by existing well locations and screened intervals.

BEDROCK

PALEOCENE
- Tc CANNONBALL FORMATION

UPPER CRETACEOUS
- Kh HELL CREEK FORMATION
- Kf FOX HILLS FORMATION
- Kp PIERRE FORMATION
- Kn NIOBRARA FORMATION
- Kc CARLILE FORMATION
- Kg GREENHORN FORMATION

LOWER TO UPPER CRETACEOUS
- Kbs BELLE FOURCHE-MOWRY-SKULL CREEK FORMATIONS

LOWER CRETACEOUS
- Ki INYAN KARA FORMATION

JURASSIC
- Ju UNDIFFERENTIATED SEDIMENTS

ORDOVICIAN
- Or RED RIVER FORMATION-WINNIPEG GROUP

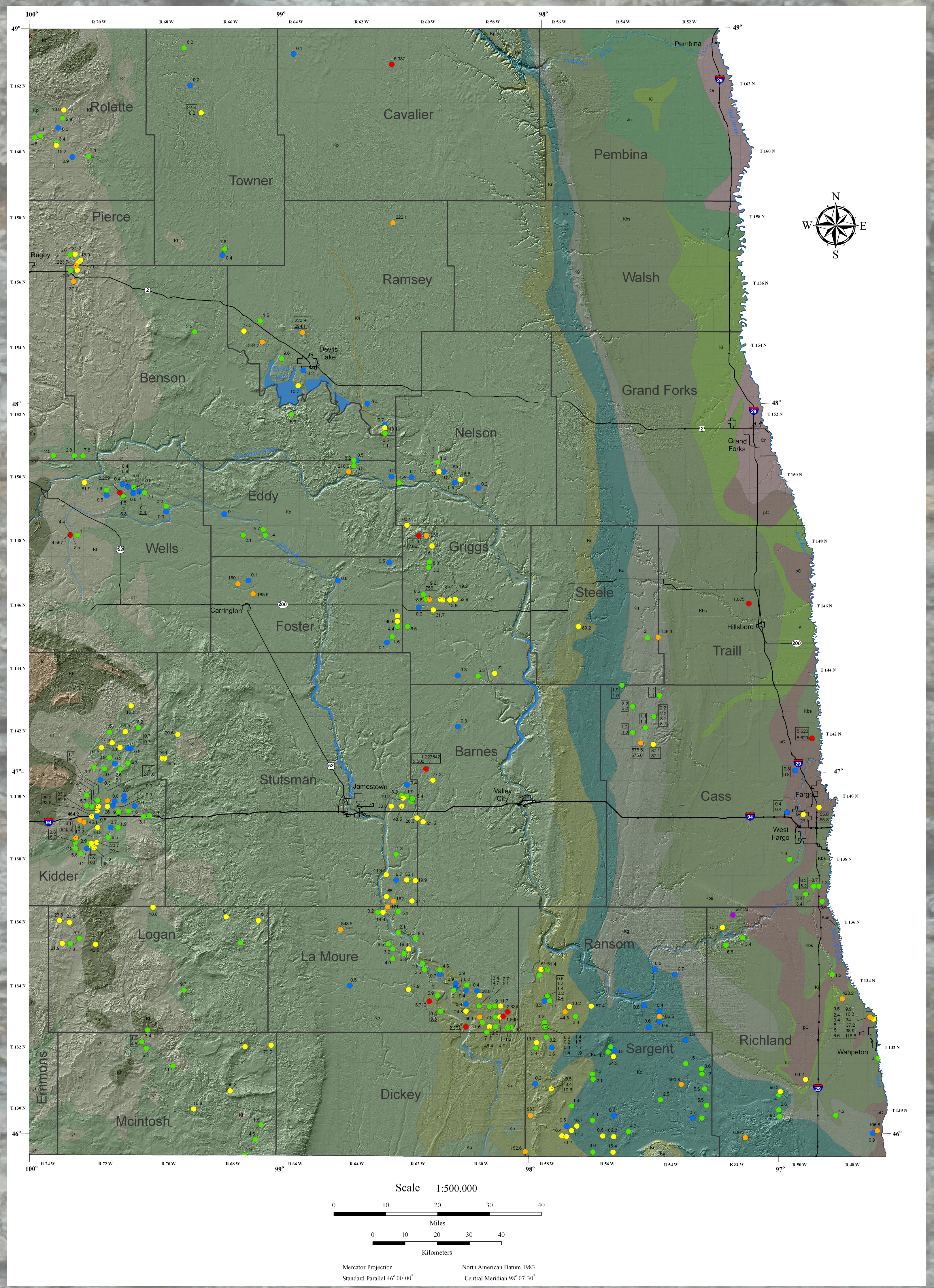
PRECAMBRIAN
- pC PRECAMBRIAN ROCKS

FID [CH_4]

- ● > 10,000 ppm
- ● 1,000 - 9,999 ppm
- ● 100 - 999 ppm
- ● 10 - 99 ppm
- ● 1 - 9 ppm
- ● 0.1 - 0.9 ppm

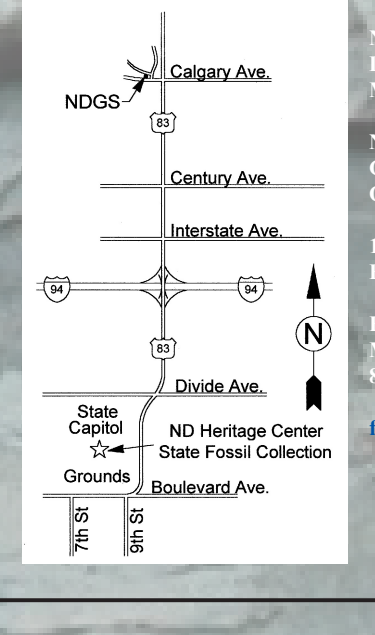
Misc Symbols

- Water
- Selected Major Rivers
- County Boundaries
- Township Boundaries
- City Boundaries
- Interstate Highway
- US Highway
- State Highway



Scale 1:500,000
Miles 0 10 20 30 40
Kilometers 0 10 20 30 40
Mercator Projection
Standard Parallel 46° 00' 00"
North American Datum 1983
Central Meridian 98° 07' 30"

Figure 7. Shaded-relief surface map of eastern North Dakota with subcropping bedrock geologic units underlain. Locations of ground-water wells field screened with a potential shallow gas show as CH_4 are shown. Well location symbols are color-coded indicating the range of flame-ionization detector (FID) instrument response recorded within the well at the groundwater/atmospheric interface (GWI). Well locations are color coded from cooler to warmer colors based on the increasing order of magnitude of FID instrument response (ppm as CH_4 in air).



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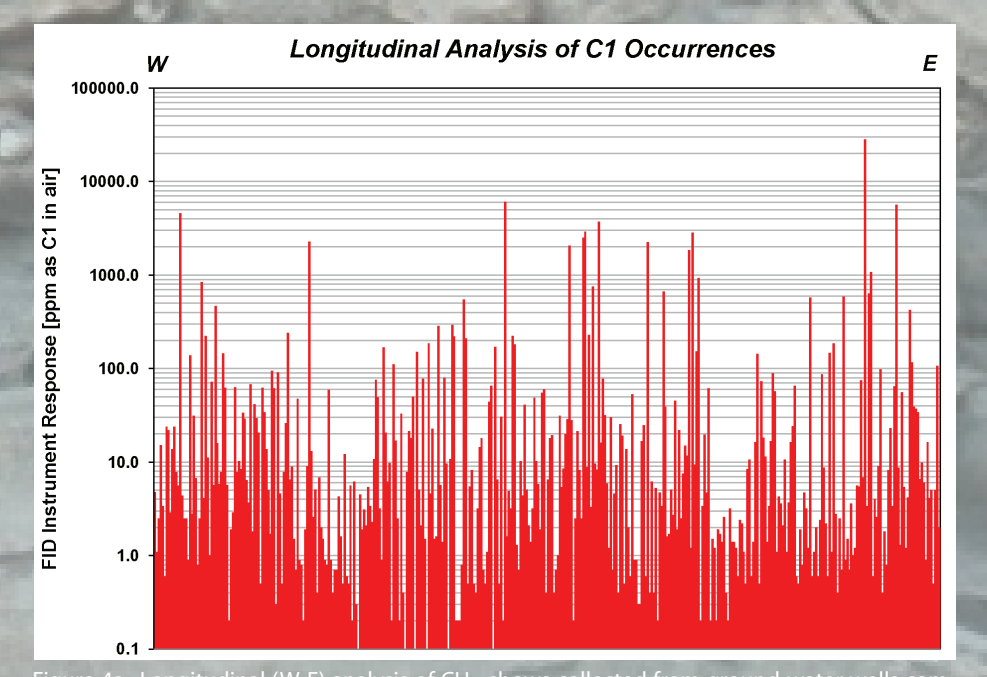

Figure 4a. Longitudinal (W-E) analysis of CH_4 shows collected from ground-water wells completed above Cretaceous stratigraphic units along the eastern flank of the Williston Basin. Greater amounts of CH_4 occurrence appear to found in the western quarter and eastern half of the study area.

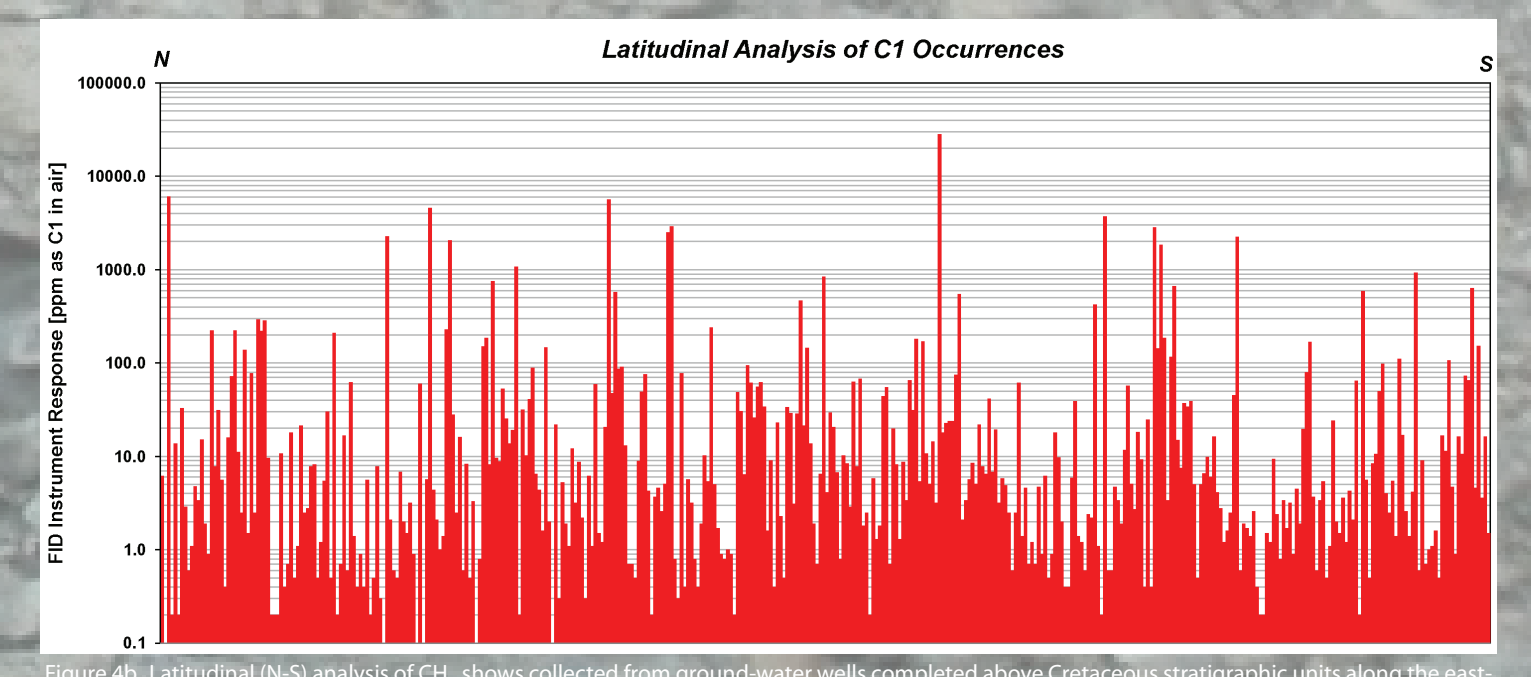

Figure 4b. Latitudinal (N-S) analysis of CH_4 shows collected from ground-water wells completed above Cretaceous stratigraphic units along the eastern flank of the Williston Basin. Greater amounts of CH_4 occurrence appear to found in the southern two-thirds of the study area.