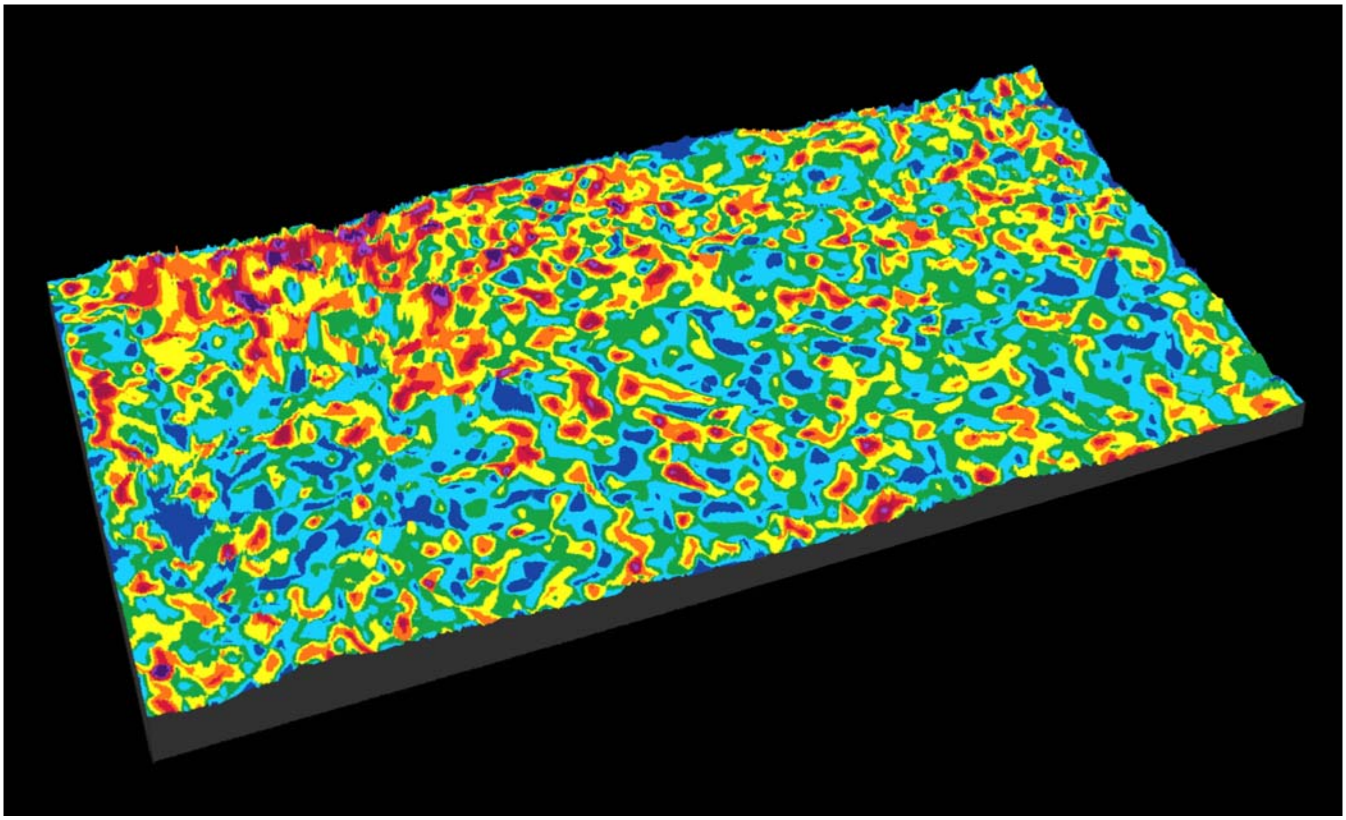
LINEAMENT MAPPING AND ANALYSIS IN THE SOUTHERN WILLISTON BASIN IN SOUTHWESTERN NORTH DAKOTA

By

Fred J. Anderson



GEOLOGIC INVESTIGATIONS NO. 129
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
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On the cover: Three-dimensional perspective view from the southwest towards the northeast across the Dickinson 1:250K sheet map area displaying the lineament density map created from this investigation overlain onto a digital elevation model of the land surface.

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Abstract

A lineament mapping and analysis investigation of a 7,110 square mile area, located in the southern portion of the Williston Basin in southwestern North Dakota, was conducted at a scale of 1:250,000 to potentially identify and characterize surficial lineaments and relate these features to areas of current and historical oil and gas exploration and production and to support future petroleum geologic investigations seeking to identify surface expression of deeper buried subsurface folds, faults, and stratigraphic structures that may influence the generation, migration, accumulation, and production of petroleum hydrocarbons. Lineaments were identified and mapped by successive visual and manual inspection at various scales, ranging from 1:24,000 to 1:1,000,000, from four sources: previous studies (historical lineaments), digital shaded relief data, aerial imagery, and LANDSAT-7 ETM+ data and imagery. Lineaments were mapped and characterized based on data source and further combined into a single compilation for overall characterization and analysis. The lineaments identified and analyzed in this investigation are the interpreted lineament features derived from the various imagery and mapping data sources and were not field verified. Dominant lineament trends were found in orthogonal NE to SW and NW to SE orientations, generally consistent with previous lineament studies in the region and currently accepted knowledge of regional tectonic stress regimes and fracture development in the southern portion of the Williston Basin. The distributions of lineament line lengths follow generally lognormal relationships within each data source and in compilation. Qualitative spatial relationships between mapped lineaments and areas of current oil and gas production and development, were examined by visual comparison of mapped lineament intersection, lineament density via domain mapping, degree of lineament interconnectivity, the evaluation of preferred lineament directional trends, and overall lineament density. Evaluation of these relationships revealed several areas of generally higher lineament density in the north-northwestern and southwestern portions of the map area that correspond with areas of current oil and gas production and field development and known anticlinal (i.e., Cedar Creek and Billings) structures. Areas with a high degree of overall lineament density and low degree of oil and gas exploration and development in the central and east-central portions of the map area were identified that may be favorable for future potential exploration. Further, producing wells appear to be located in areas of greater lineament development where non-producing wells appear common in areas of lesser lineament development.

Acknowledgements

The author would like to acknowledge the work of Mr. Elroy Kadrmas, GIS Specialist at the NDGS, for his contributions to cartographic design and overall support for spatial analysis and map production. In addition, Ms. Shannon Heinle for her work in the compilation of previous lineament studies in the Williston Basin, while a graduate student at the University of North Dakota. Comments and criticisms which also improved this work were also provided by Mr. Ed Murphy, N.D. State Geologist, and NDGS subsurface and petroleum geologists Dr. Stephan Nordeng and Julie LeFever.

Author’s Note

The intent of this investigation was to combine information contained in previous lineament studies, with a larger scale contemporary lineament mapping investigation, in order to identify and evaluate relationships between mapped lineaments and current oil and gas production and development trends, and to support the identification of the surface expression of subsurface geologic structures influencing the accumulation of petroleum hydrocarbons. In order to maintain objectivity during the mapping of lineaments, the evaluation of the relationships between currently producing wells and current oil and gas field development and exploration trends were not conducted until after lineament mapping was completed.

BACKGROUND

Introduction

Lineaments have been defined as extended mappable linear or curvilinear features of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures, or faults in the subsurface (Sabins, 2000). These features are mappable at various scales, from local to continental, and can be utilized in minerals, oil and gas, and groundwater exploration studies. The NDGS recently completed a lineament mapping and analysis investigation of the area within the Dickinson 1:250k map sheet located in the southern Williston Basin in southwestern-most North Dakota. This investigation was conducted in order to potentially identify any linear or linear-like surface features that may be linked to deeper, buried basinal and stratigraphic structures that may have an influence on the generation, migration, accumulation, and production of petroleum hydrocarbons. Lineaments mapped and analyzed in this study are the interpreted lineament features derived from the various imagery and mapping data sources and were not field verified.

Description of the Study Area

The area within the Dickinson 1:250k map sheet is a modified 1:250,000 scale (1^o x 2^o) quadrangle covering an approximate 7,110 square mile area from 45^o, 56’, 50” to 47^o, 00’, 00” N. Latitude and 102^o, 00’, 00” to 104^o, 02’, 50” W. Longitude. This 1:250K quadrangle study area was extended into the Miles City, Lemmon, and Ekalaka 1:250K sheets to the North Dakota – Montana and North Dakota – South Dakota borders for completeness and includes all of the land areas within Adams, Bowman, Hettinger, and Slope Counties, along with the southern portion of Billings and Golden Valley Counties and the easternmost portions of Morton and Grant County. Some of the larger oil fields found in the north-central portion of the sheet include the Fryburg, Green River, and Dickinson fields. The Cedar Creek and Little Missouri gas fields occur within the sheet in the southwestern corner in southwestern Bowman County (Figure 1). The Daglum SE, New England SW and East and West Rainy Butte quadrangles are the four 1:24,000 scale (7.5’ series) quadrangles that are located at the center of the study area.

Previous Lineament Studies Conducted at Various Scales

Several continental to regional scale lineament studies have been completed by several authors over the last four decades at regional to continental scales (Figure 2) and include the works of: Penner and Cosford (2006), Kreis and Kent (2000), Freisatz (1995), Gibson (1995), Inden and Burke (1995), Shurr (1995), Brown and Brown, (1987), Downey, et. al. (1987), Gerhard, et. al. (1987), Mollard (1987), Oglesby (1987), Peterson and MacCray (1987), Anna (1986), Maughan and Perry (1986), Hayes (1984), Hindman (1984), Cooley (1983), Haman (1975), Kent (1974), Thomas (1974), and Erickson (1970), (Plate I).

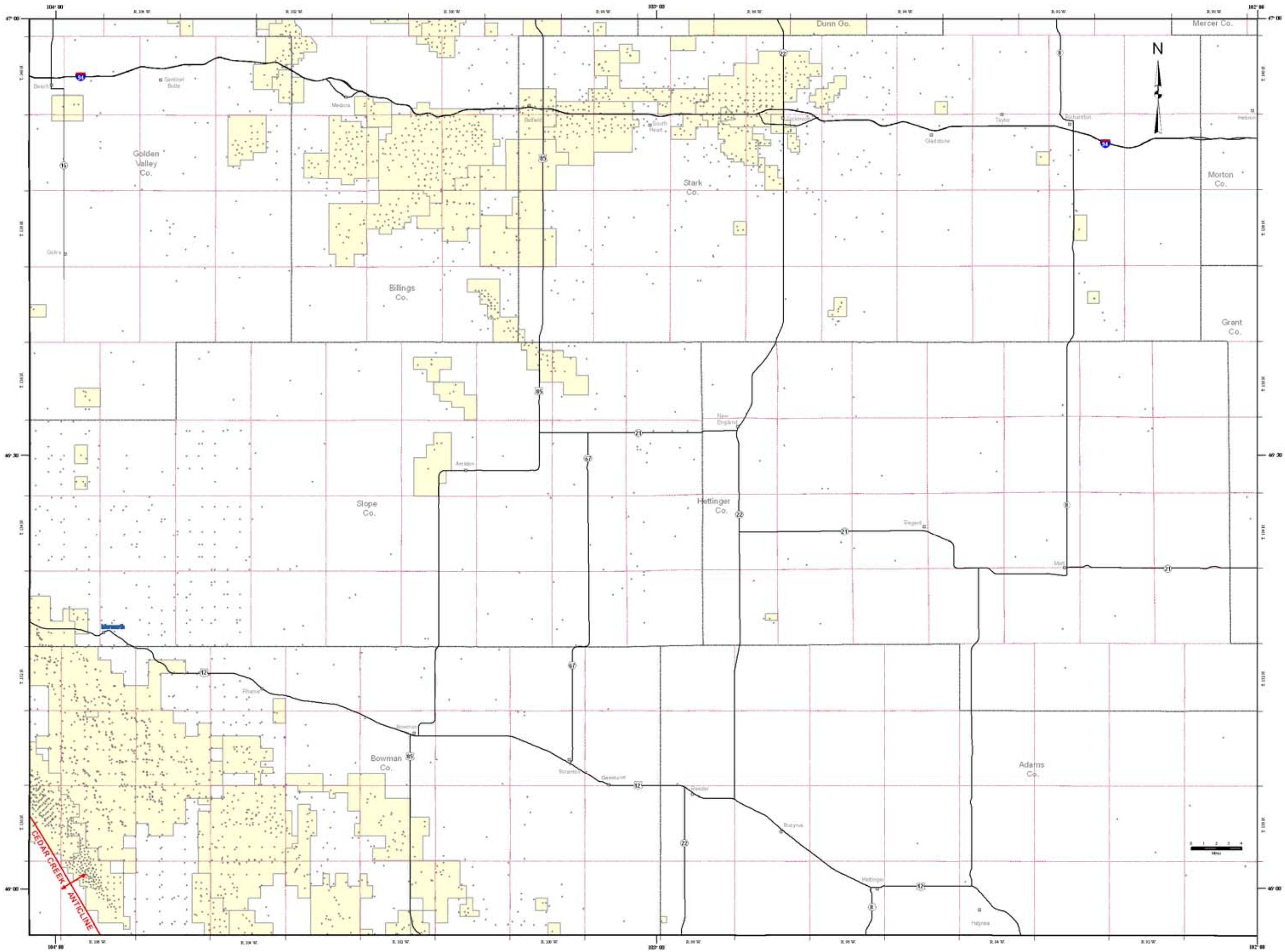


Figure 1. Area of investigation in the Dickinson 1:250k map sheet located in the southern Williston Basin in southwestern North Dakota. Locations of oil and gas fields are shown in yellow. Locations of oil and gas wells are shown in gray.

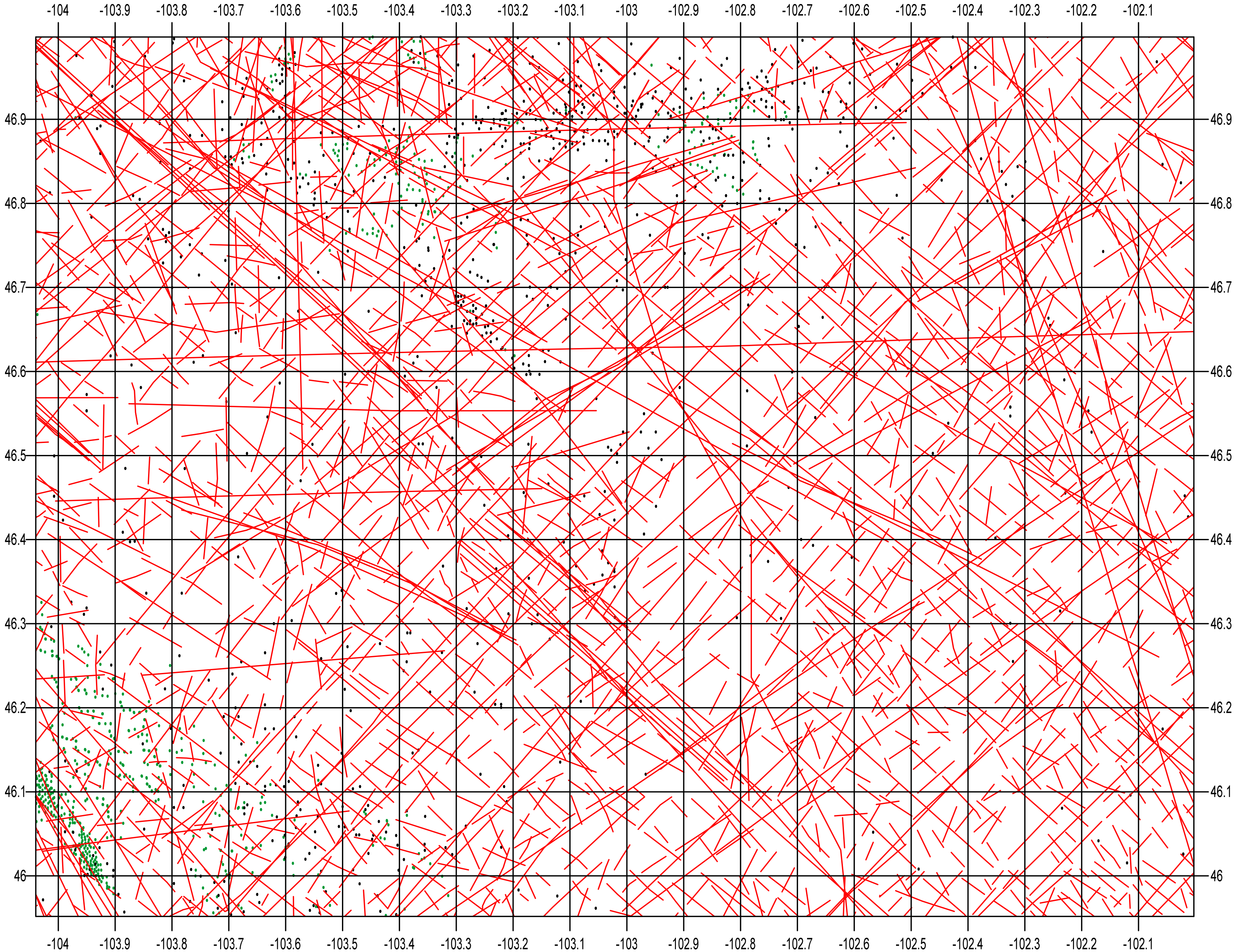


Figure 2. Historical (i.e., previously published) lineaments mapped in the Dickinson 1:250k sheet. Locations of currently producing oil and gas wells (green) and non-producing wells (black) are shown.

LINEAMENT MAPPING AND ANALYSIS METHODOLOGY

Description of Data and Imagery Sources

Lineaments in the Dickinson 1:250k map sheet were identified, and progressively derived from four primary data and imagery sources (Table 1): lineaments mapped from previous studies, lineaments mapped from digital shaded relief data, lineaments mapped from aerial imagery, and lineaments mapped from LANDSAT data and imagery. Images and data from the ambient thermal band (band 6) of the LANDSAT data suite, along with ASTER data, as a replacement, were also considered as a part of this investigation. However, limited availability of data covering the study area negated their use.

Table 1. Summary of Data and Imagery Sources used for Lineament Mapping

Data Type	Original Data Creation/Acquisition	Description/Author	Data Source Location (URL address)
Historical Lineaments	1970 - 2006	Compiled from Various Published Sources	https://www.dmr.nd.gov/ndgs//
Shaded-Relief Data	1997	USGS National Elevation Dataset (NED)	http://ned.usgs.gov/
Aerial Imagery	Summer, 2009	National Agricultural Imagery Program (NAIP)	http://165.221.201.14/NAIP.html
Satellite Imagery Data	Summer, 2000	LANDSAT-7 ETM+	http://eros.usgs.gov/products/satellite/landsat7.php

Historical Lineaments

Lineaments published in previous studies and determined to be present, as mapped in the Dickinson sheet (Figure 2), were digitally extracted from their original published sources (Heinle, 2007) as is, compiled, and merged into a single "historical" lineament coverage for the Dickinson 1:250k map sheet area (Plate I).

Shaded Relief Data

Lineaments were also mapped and digitized (Figure 3) from a digital, shaded-relief image created from 1997 USGS National Elevation Dataset (NED) data set, with a vertical exaggeration of 9X (Plate II).

National Agricultural Imaging Program (NAIP) Imagery

Imagery data sources were also utilized for lineament mapping in this investigation. Lineaments were interpreted from digital aerial imagery and digitized from a digital aerial image mosaic of the study area (Figure 4), compiled as is from 2009 USDA National Agricultural Image Program (NAIP) imagery (Plate III).

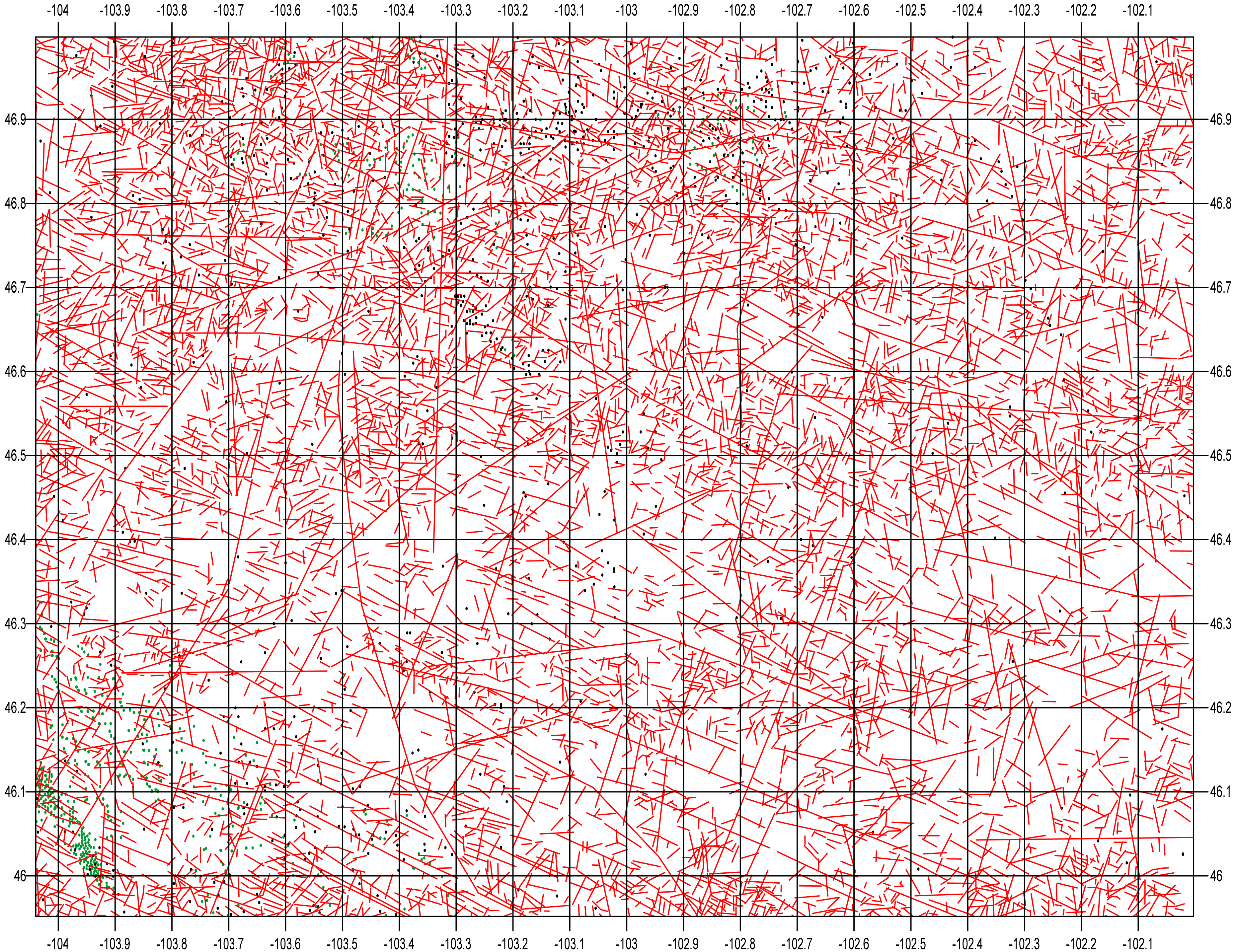


Figure 3. Lineaments mapped from USGS NED shaded relief data in the Dickinson 1:250k sheet. Locations of currently producing oil and gas wells (green) and non-producing wells (black) are shown.

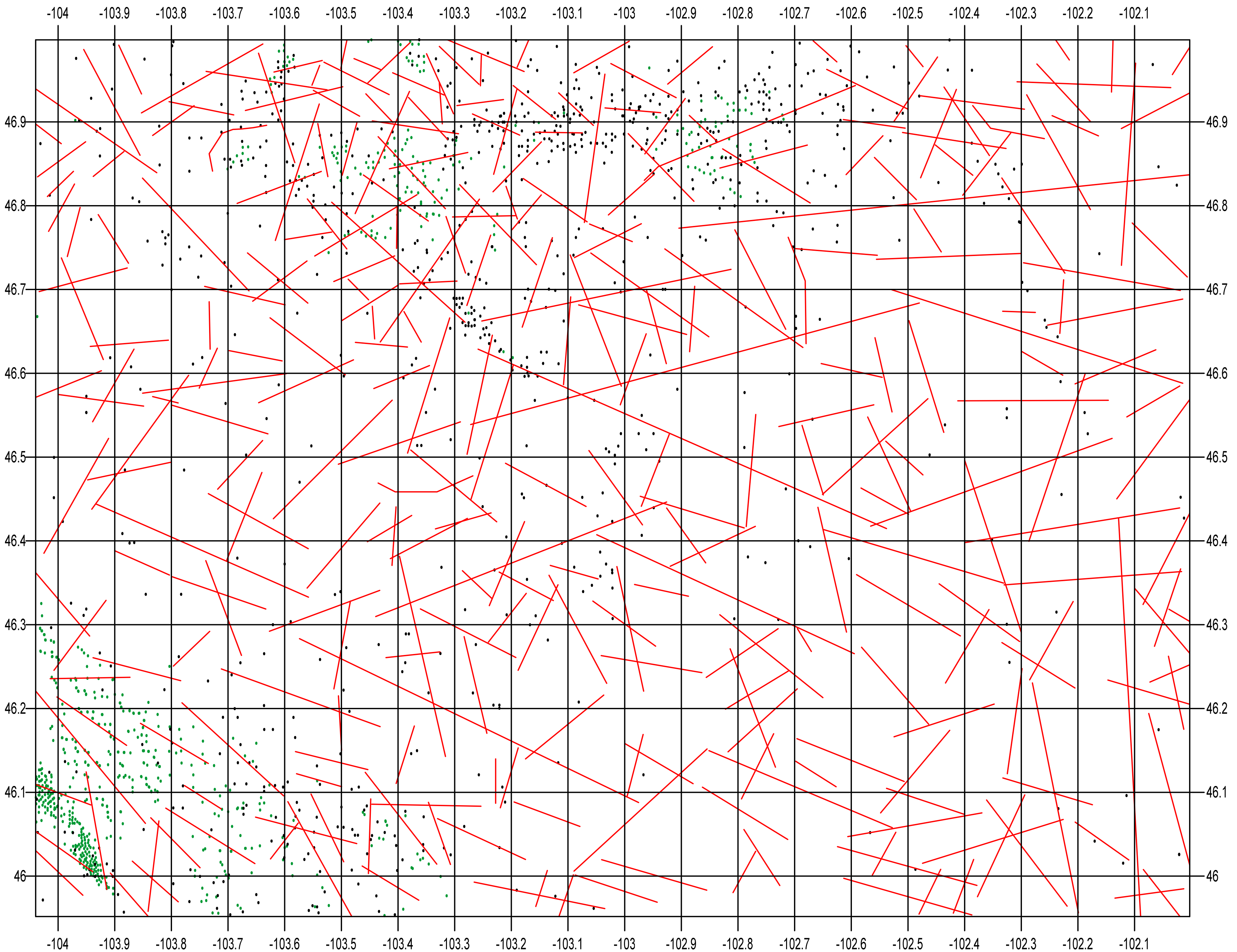


Figure 4. Lineaments mapped from 2009 USDA NAIP aerial imagery in the Dickinson 1:250k sheet. Locations of currently producing oil and gas wells (green) and non-producing wells (black) are shown.

LANDSAT-7 Enhanced Thematic Mapper (ETM) Imagery

In addition to the traditional data and image mapping sources, lineaments were also digitally mapped and digitized from a digital image mosaic compiled from 2000 LANDSAT-7 Enhanced Thematic Mapper Plus (ETM+) data (Figure 5). This digital image mosaic was created from four available scenes in a blue, green, red (BGR) false color combination of spectral bands 2, 4, and 7 for enhanced visual lineament mapping and analysis (Plate IV).

Merged (Compiled) Lineaments

All lineaments mapped from previously described data sources in this investigation, were combined into a single compilation (Figure 6) for a comprehensive characterization and analysis (Plate V).

Lineament Mapping and Analysis Methodology

Lineament identification and mapping was conducted by successive visual and manual inspection of each of the data and imagery layers at various scales (most commonly 1:24,000, 1:100,000, 1:250,000 and 1:1,000,000). Lineaments were identified and manually digitized on screen using the drawing and mapping tools in Surfer v. 9.0 and exported to ArcGIS for final digitizing, georeferencing, and ESRI shape file (.shp) creation. All lineaments mapped are presented at a scale of 1:250,000 in Plates I-V. Individual lineament orientations were analyzed for directional trends in RockWorks using the rose diagrams tool in the utilities module. Full rose diagrams were created from the lineaments mapped from each data source (i.e., LANDSAT, shaded relief, etc.) and presented as directional trends on 10^{o} orientation intervals (Figure 7). Individual lineament line lengths were also statistically analyzed and plotted on frequency distributions of lineament length per lineament length class for each of the data sources (Figure 8) that best characterized the data. The qualitative relationships between mapped lineaments and current oil and gas production from wells in the Dickinson sheet was also explored by comparing the spatial relationships of mapped lineament intersections (Plate I-Figure 4), lineament density via domain mapping (Plate II-Figure 4), degree of lineament interconnectivity (Plate III-Figure 4), evaluation of “preferred” lineament directional trends (Plate IV-Figure 4), and overall lineament density (Plate V-Figure 4). The locations of currently producing and non-producing oil and gas wells were also included in each of these qualitative comparisons in order to identify any observable potential spatial relationships.

Lineament Density Mapping

Compiled lineaments (Figure 6, Plate V) were merged into a 1 mile (5,280-ft) by 1 mile grid that corresponds to the actual Public Land Survey System (PLSS) sections found within the area of investigation. Lineament densities were calculated for each section or “cell” using the total lineament(s) lengths contained within each unit section.

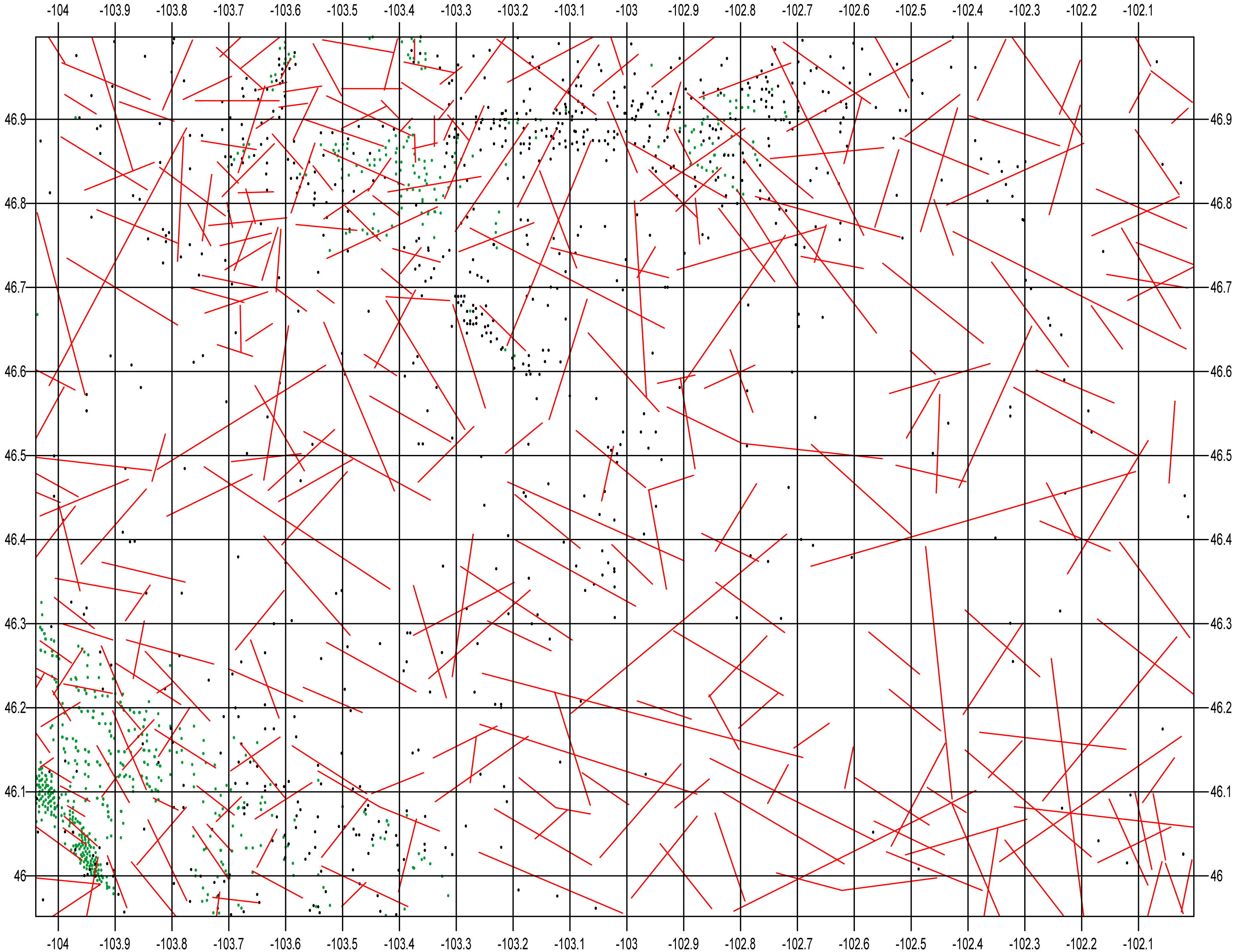


Figure 5. Lineaments mapped from 2000 LANDSAT-7 ETM+ data (bands 2,4, and 7) in the Dickinson 1:250k sheet. Locations of currently producing oil and gas wells (green) and non-producing wells (black) are shown.

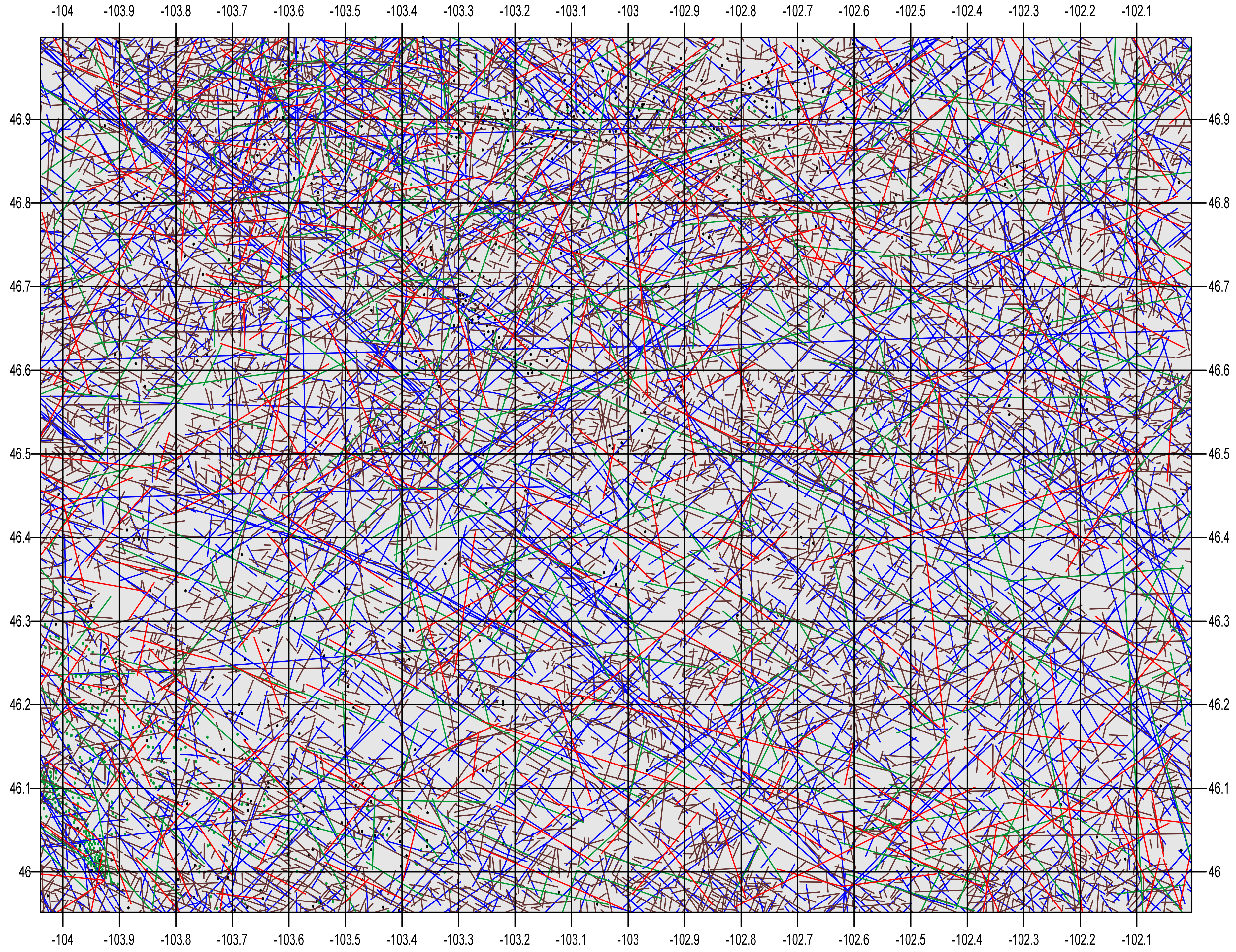


Figure 6. Compilation of lineaments mapped in the Dickinson 1:250k sheet. Historical lineaments (blue), lineaments mapped for shaded relief data (brown), NAIP imagery (green), and LANDSAT-7 ETM+ data (red). Locations of currently producing oil and gas wells (green) and non-producing wells (black) are shown.

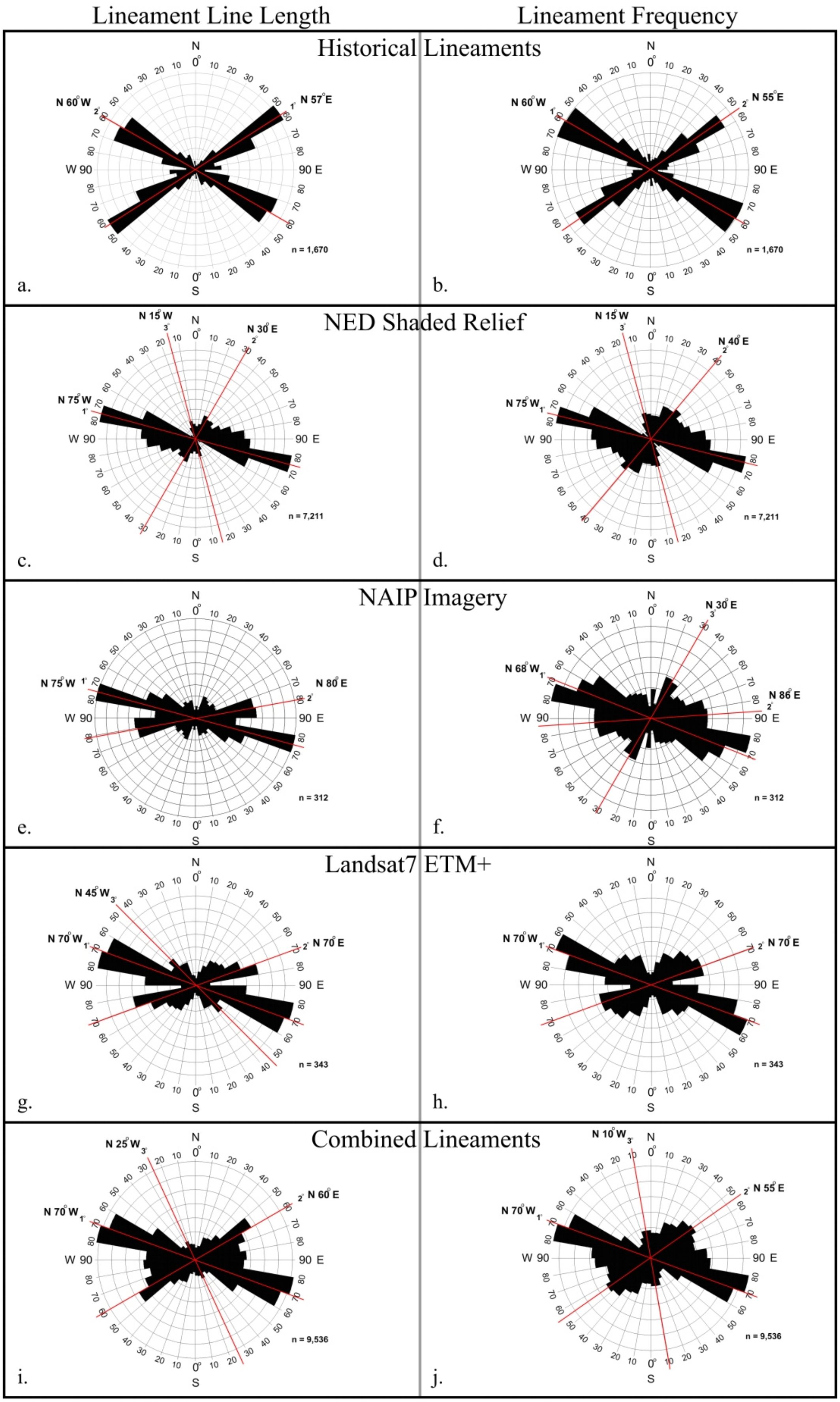
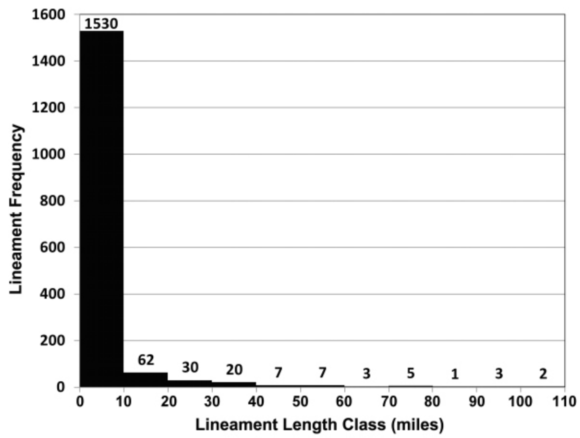
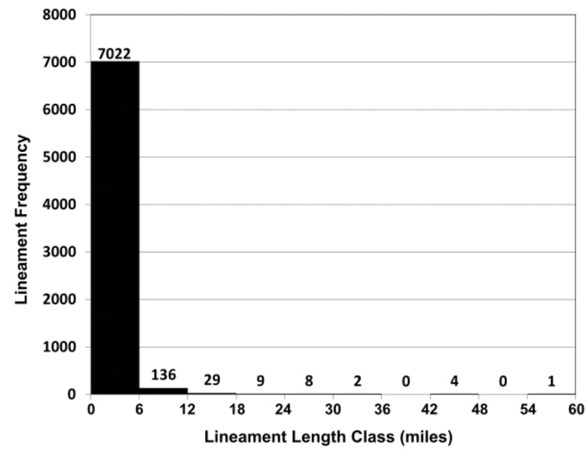


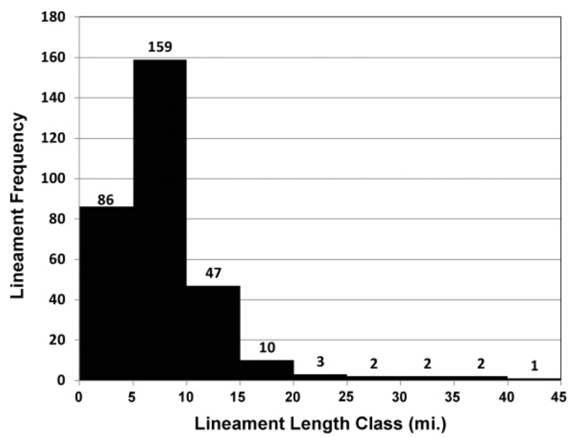
Figure 7. Summary of rose diagrams depicting dominant lineament orientation trends in each set of mapped lineaments, based on data/image source (a.- h.). Strike trends of compiled lineaments (i. & j.) show trends extracted from all mapped lineaments combined.



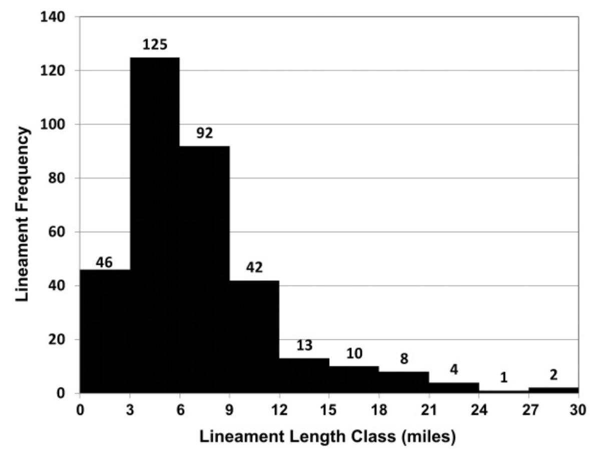
a. **Distribution of lineaments mapped from historical data.**



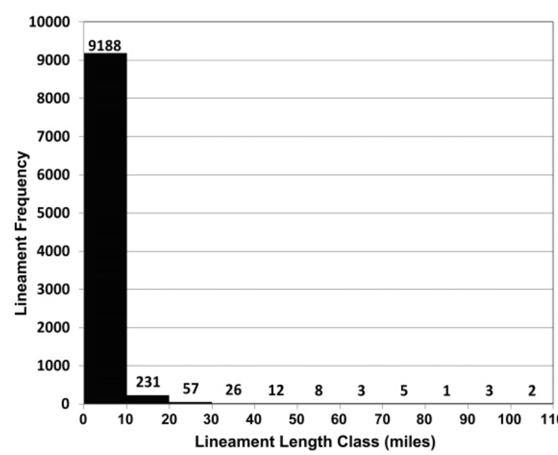
b. **Distribution of lineaments mapped from shaded relief data.**



c. **Distribution of lineaments mapped from NAIP imagery.**



d. **Distribution of lineaments mapped from Landsat imagery.**



e. **Distribution of lineaments mapped from combined data.**

Figure 8. Frequency distributions of mapped lineaments per data and image source. All of the lineament sets mapped follow generally lognormal distributions.

Nodes were determined at the center points of each of the sections in ArcGIS for extraction of geographic coordinates and data file assignment of corresponding lineament density values.

The resulting X,Y,Z data file was taken in to Surfer v. 9.0 for density mapping and contouring (Figure 9) using an ordinary kriging interpolation algorithm. The interpolated density contours were exported from Surfer as shape files (.shp, etc.) and imported back into ArcGIS for final compilation of spatially correct projected mapping (Plate VI). The resulting density map shows several areas of generally higher lineament density in the northwestern portions of the map area that generally correspond to areas of current oil and gas production and field development. Density mapping also shows some areas with a high degree of overall lineament density and low degree of oil and gas exploration and development as evidenced by sparse drilling in these areas (Figure 10). These areas may be favorable for future potential exploration throughout the Dickinson sheet.

RESULTS AND CONCLUSIONS

Lineament Orientations

Lineament orientations based on the contributions of lineament line length and frequency components to the orientation trends (Figure 7) are dominantly found in orthogonal NE to SW and NW to SE orientations (Table 2) consistent with previous lineament studies in the region and currently accepted knowledge of regional tectonic stress regimes and fracture development in the Williston Basin of North Dakota (Besler, 2008).

Table 2. Lineament Orientation Trends Determined within Individual Data Sources

Data Type	No. of Trends	Orientation Description			Basic Relationship
		1°	2°	3°	
Historical Lineaments	2	N 55° E	N 60° W	--	1° and 2° trends approximately Orthogonal.
NED Shaded-Relief Data	3	N 75° W	N 35° E	N 15° W	1° and 2° trends approximately Orthogonal, 3° trend Intermediate between 1° and 2° trend.
2003 NAIPAerial Imagery	3	N 70° W	N 80° E	N 30° E	1° and 2° trends Conjugate, 3° trend Intermediate between 1° and 2° trend and Orthogonal to the 1° trend.
2002 LANDSAT-7 ETM+ Satellite Imagery Data	3	N 70° W	N 70° E	N 45° W	1°, 2°, and 3° trends Conjugate.
Combined\Merged Lineaments	3	N 70° W	N 60° E	N 10 - 25° W	1° and 2° trends Conjugate. 3° trend Intermediate between 1° and 2° trend and approximately Orthogonal to the 2° trend.

[1]Trends determined and summarized from lineament length and frequency based methods.

A primary (1°) trend of N 55° E along with an approximately orthogonal secondary (2°) trend of N 60° W were identified (Figure 7a & b) within the historical lineaments mapped (Plate I-Figure 2) and are consistent with most continental to regional scale lineament mapping studies completed over the last 40 years.

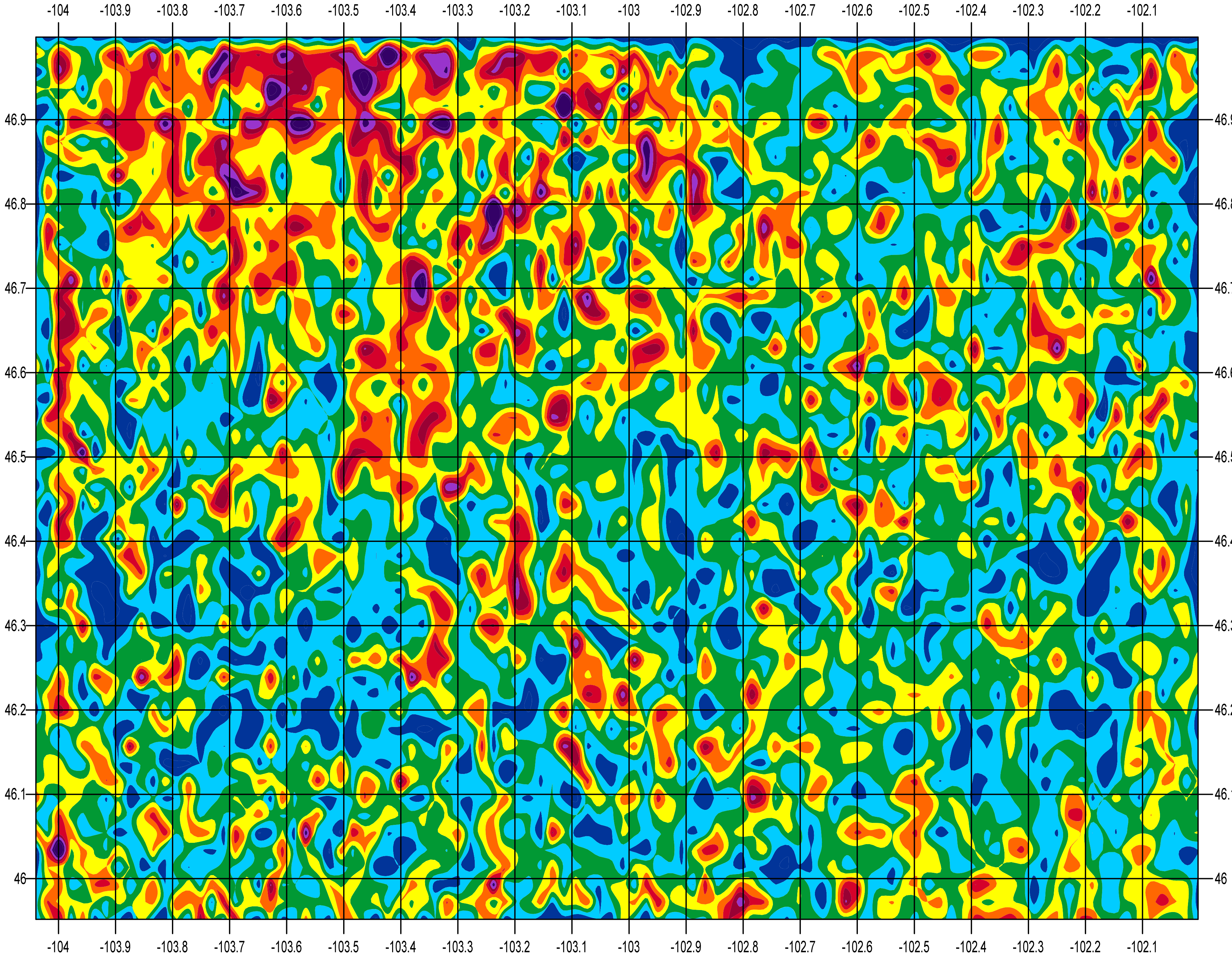


Figure 9. Lineament density map of the Dickinson 1:250k sheet located in the southern Williston Basin in southwestern North Dakota. Increasing lineament density per unit area (i.e., total length of lineaments per square mile) is depicted across nine intervals: 0-10,000 feet (dark blue), 10,000-15,000 feet (pale blue), 15,000-20,000 (green), 20,000-25,000 (yellow), 25,000-30,000 (orange), 30,000-35,000 (red), 35,000 -40,000 (dark red), 40,000-45,000 (purple), and 45,000-50,000+ (dark purple).

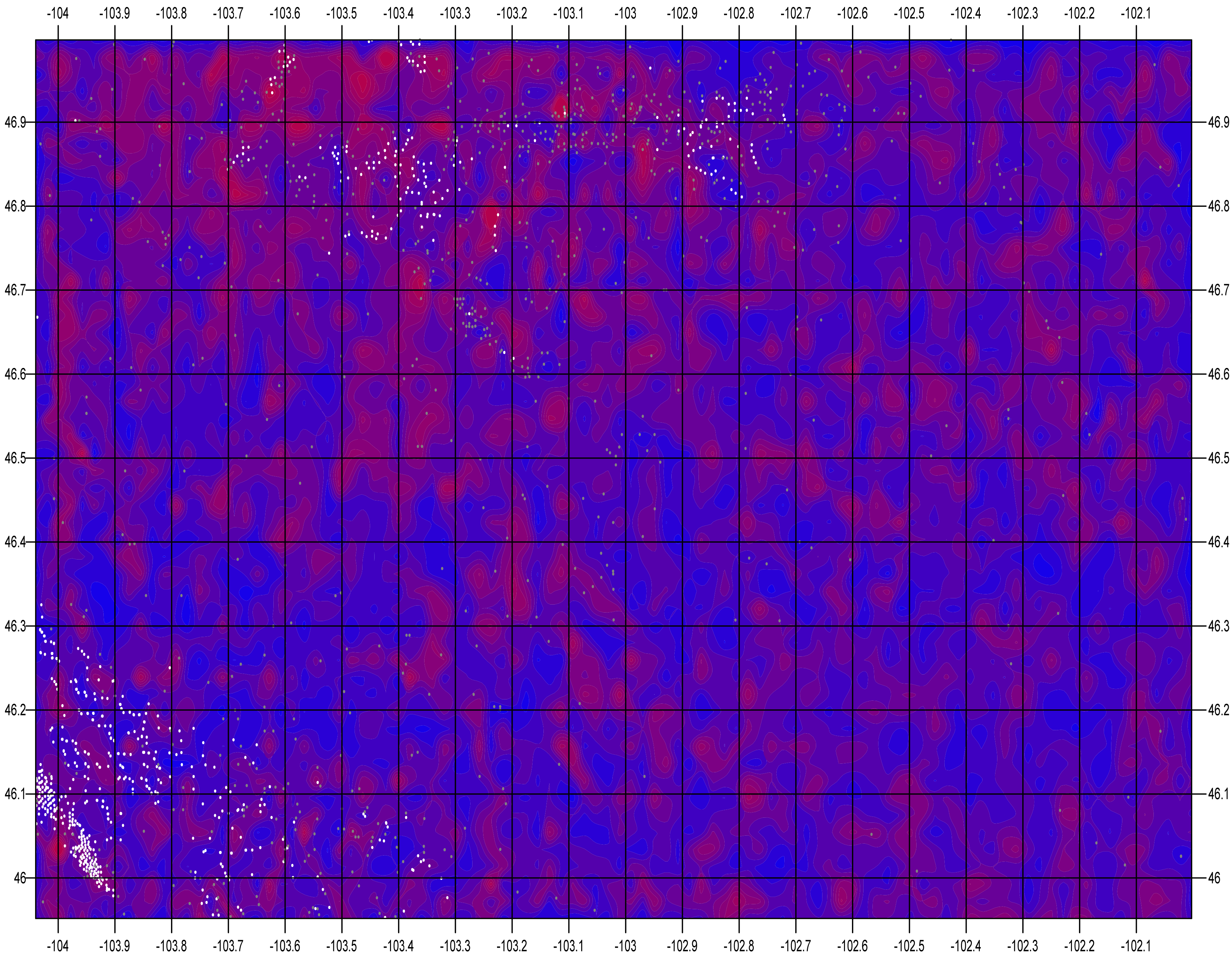


Figure 10. Lineament density map of the Dickinson 1:250k sheet located in the southern Williston Basin in southwestern North Dakota. Areas of lineament density are shown as warmer (reds) colors. Areas of lower lineament density are shown as cooler (blues) colors. The locations of currently producing wells (white) and non-producing wells (gray) are shown.

These orientations are heavily influenced numerically by the inclusion of the LANDSAT lineaments mapped by Cooley (1983) which contained a strong NW-NE orthogonal trend as well as a relatively high number of smaller length lineaments. Removing the Cooley (1983) data from the analysis, in this instance, would not likely reorient the dominant trends.

Within the shaded relief data it was possible to interpret three directional trends within the lineaments mapped (Figure 7c & d). A 1^o trend of N 75^o W along with an approximately orthogonal 2^o trend of N 35^o E was found, in addition to a tertiary 3^o trend of N 15^o W intermediate between the 1^o and 2^o trend (Plate II-Figure 2).

Since it has been found that is possible to map a greater amount of lineaments from shaded relief data and imagery (Penner and Cosford, 2006), due to the high resolution of surface features and geomorphological influence inherent in the data, it is not surprising that additional trends are revealed and may be indicative of surficial geomorphological influence related to exposed bedrock weathering and drainage development.

Lineaments mapped from the 2003 NAIP aerial imagery also exhibited three directional trends (Figure 7e & f). A 1^o trend of N 70^o W along with a conjugate 2^o trend of N 80^o E was found, in addition to a 3^o trend of N 30^o E intermediate between the 1^o and 2^o trends (Plate III-Figure 2) and orthogonal to the 1^o trend. Lineament mapping from this image and data source was found to continue to be somewhat difficult as land use in the region results in less natural tonal contrast and variation across relatively larger land areas, which has an overall homogenization effect on individual pixel contrast (Plate III-Figure 1).

Mapping of lineaments from LANDSAT derived satellite imagery afforded a different look at the aerial image data and also revealed three dominant orientation trends within the lineaments mapped (Figure 7g & h). A 1^o trend of N 70^o W along with a conjugate 2^o trend of N 70^o E and a conjugate 3^o trend of N 45^o W was revealed (Plate IV-Figure 2). The somewhat less prominent 3^o trends are visible as somewhat subdued trends within the lineament trends mapped from the NAIP Imagery. It is likely that the 2-4-7 (BGR) band combination simply accentuated the tonal contrasts associated with these lineaments, which permitted a more discernable tonal expression (Plate IV-Figure 1).

Combining all of the lineament directional data into one set and analyzing it for orientation trends resulted in the identification of three dominant orientations (Figure 7i & j). A 1^o trend of N 70^o W along with a slightly closed orthogonal 2^o trend of N 60^o E was found, in addition to a 3^o NW trend ranging between N 10^o W to N 25^o W (Plate V-Figure 2). It is apparent that the 1^o and 2^o orientation trends within the historical lineaments data set are strengthened by additional lineament mapping from other data and imagery sources. The 3^o trend within the combined lineaments data set (Plate V-Figure 2) is reinforced from the 3^o trend identified from the lineaments mapped from LANDSAT (Plate IV-Figure 2) imagery.

Distribution of Lineament Lengths

The descriptions of lineament line lengths mapped (Table 3) are consistent with statistically valid distributions commonly found in lineament mapping studies and generally follow log-normal type distributions (Figure 8).

Table 3. Characteristics of Lineaments Mapped in the Dickinson 1:250k sheet.

Data Type	No.	Lineament Length Characteristics (miles)				Lineament Density (Lpsm/Lpst)
		Min	Max	Mean	1 Std. Dev.	
Historical Lineaments	1,670	0.0065	106.94	5.32	9.79	0.24/8.5
NED Shaded-Relief Data	7,211	0.156	59.39	1.52	2.28	1/36
2009 NAIP Aerial Imagery	312	1.75	43.03	8.1	5.45	0.04/1.6
2000 LANDSAT-7 ETM+ Satellite Imagery Data	343	0.94	28.35	7.1	4.54	0.05/1.7
Merged\Combined Lineaments	9,536	0.0065	106.94	2.6	5.13	1.3/48

(Lpsm/Lpst): Lineaments per square mile/Lineaments per standard township (36 mi^2).

A total of 1,670 lineaments were mapped in the Dickinson 1:250k sheet as compiled from previous works (Figure 2). Lineament line lengths tend to follow a lognormal distribution (Figure 8a) with the majority of lineaments falling within the 0 to 10 mi. lineament length class. Minimum lineament line length was 0.0065 miles (mi.) with a maximum length of 106.94 mi. The mean lineament line length was 5.32 mi. with a standard deviation of 9.79 mi. Lineament density across the entire 1:250k map sheet area of investigation was 0.24 lineaments per square mile (Lpsm) which translates to approximately 8.5 lineaments per township (i.e. 36 square miles).

A total of 7,211 lineaments were mapped in the Dickinson 1:250k sheet as mapped from shaded relief data (Figure 3). Lineament line lengths in this data set also tend to follow a lognormal distribution (Figure 8b) with the majority of lineaments falling within the 0 to 6 mi. lineament length class. Minimum lineament length was 0.15 mi. with a maximum length of 59.39 mi. The mean lineament line length was 1.52 mi. with a standard deviation of 2.28 mi. Lineament density across the entire 1:250k area was one Lpsm which translates to approximately 36 lineaments per township (Lpst).

A total of 312 lineaments were mapped in the Dickinson 1:250k sheet as mapped from NAIP aerial imagery (Figure 4). Lineament line lengths in this data set also tend to follow a lognormal distribution (Figure 8c) with the majority of lineament line lengths falling within the 5 to 10 mi. lineament length class. Minimum lineament line length was 1.75 mi. with a maximum length of 43.03 mi. The mean lineament line length was 8.1 mi. with a standard deviation of 5.45 mi. Lineament density across the entire 1:250k area was 0.04 Lpsm which translates to approximately 1.6 Lpst.

A total of 343 lineaments were mapped in the Parshall Area as mapped from LANDSAT-7 ETM+ data and imagery (Figure 5). Lineament line lengths in this data set also follow a lognormal distribution (Figure 8d) with the majority of lineament line lengths also falling within the 3 to 6 mi. lineament length class. Minimum lineament line length was 0.94 mi. with a maximum length of 28.35 mi. The mean lineament line length was 7.1 mi. with a standard deviation of 4.54 mi. Lineament density across the entire 1:250k map sheet was 0.05 Lpsm which translates to approximately 1.7 Lpst. The data characteristics of lineaments mapped from both the NAIP and LANDSAT data are similar and suggest a scale effect for the identification of lineaments mapped at the 1:250,000 scale.

A total of 9,536 lineaments were mapped in the Dickinson 1:250k sheet as compiled from all data and imagery sources (Figure 6) used. Lineament line lengths continue to follow a lognormal distribution (Figure 8e) with the majority of lineament line lengths falling well within the 0 to 10 mi. lineament length class. Minimum lineament line length was 0.0065 mi., with a maximum length of 106.94 mi. The mean lineament line length was 2.6 mi. with a standard deviation of 5.13 mi. Lineament density across the entire 1:250K area was 1.3 Lpsm which translates to approximately 48 Lpst.

Lineament Density Mapping

Lineament densities were calculated for each square mile within the area of investigation as the sum of the lineament line lengths occurring within each unit grid cell (i.e., $\Sigma L_1 + L_2 + L_3 ....$). Each unit cell was assigned a nodal value at the cell center in true geographic coordinates. The data was interpolated using an ordinary kriging algorithm and contoured over nine lineament density classes (Figure 9). The resulting lineament density map shows increased lineament density dominantly in the northwest and northeast with lessening lineament density moving towards the south and west.

The total area covered by the Dickinson 1:250k map sheet area is 7,110 square miles. Of this total, the largest Lineament Density Area (LDA) is the Class-VII LDA which is dispersed throughout the map area (Table 4). The Class-VI to Class-I LDAs are highly visually correlative to currently producing oil and gas wells. The Class-VII to Class-IX LDAs are conversely highly visually correlative to non-producers (Plate VI).

Table 4. Map Surface Area and Representative Covered by Lineament Density Class

Lineament Density Class	Lineament Density Range (Lpsm)	Map Area Covered (mi^2)
Class-I	8.5 – 9.5	21
Class-II	7.6 – 8.5	35
Class-III	6.6 – 7.6	110
Class-IV	5.7 – 6.6	305
Class-V	4.7 – 5.7	804
Class-VI	3.8 – 4.7	191
Class-VII	2.8 – 3.8	2,083
Class-VIII	1.9 – 2.8	1,677
Class-IX	0 – 1.9	584
		Total = 7,110

(Lpsm): Total of all lineament lengths (mi) per square mile (mi).

Overlaying the interpolated lineament density map with current producing and non-producing oil and gas wells in the area (Figure 10) shows a fair qualitative correlation between areas of producing wells and areas of high lineament density, particularly in the northwestern and southwestern portions of the map area. A less apparent qualitative visual correlation is observable in the eastern most third of the map area with areas containing producing wells and relatively higher lineament density. It does become more visually apparent, as one moves southward towards the central portions of the map area, that the distribution of non-producing wells tend to be located in areas of relatively low lineament density.

DISCUSSION

Consistent with previous lineaments studies in the region (e.g., Penner and Cosford, 2006) it was found that it was possible to map a considerably greater number of lineaments from shaded relief data than other data sources due to the resolution and refinement of detail at mappable scales. Conversely, unique lineament expression was found within each data source used in mapping which added to the complexity of the overall mapped interpretation and enhanced the comprehensive nature of the data coverage. Generally and qualitatively, it appears that wells that have produced oil and gas appear to be located in areas of greater lineament density (Figure 11), a higher amount of lineament intersection, and in areas of greater degrees of lineament connectivity, and within mappable lineament density domains of greater lineament density per unit area. Non-producing wells were commonly found to be located in areas of lesser lineament development. Further quantitative investigation into this relationship is planned.

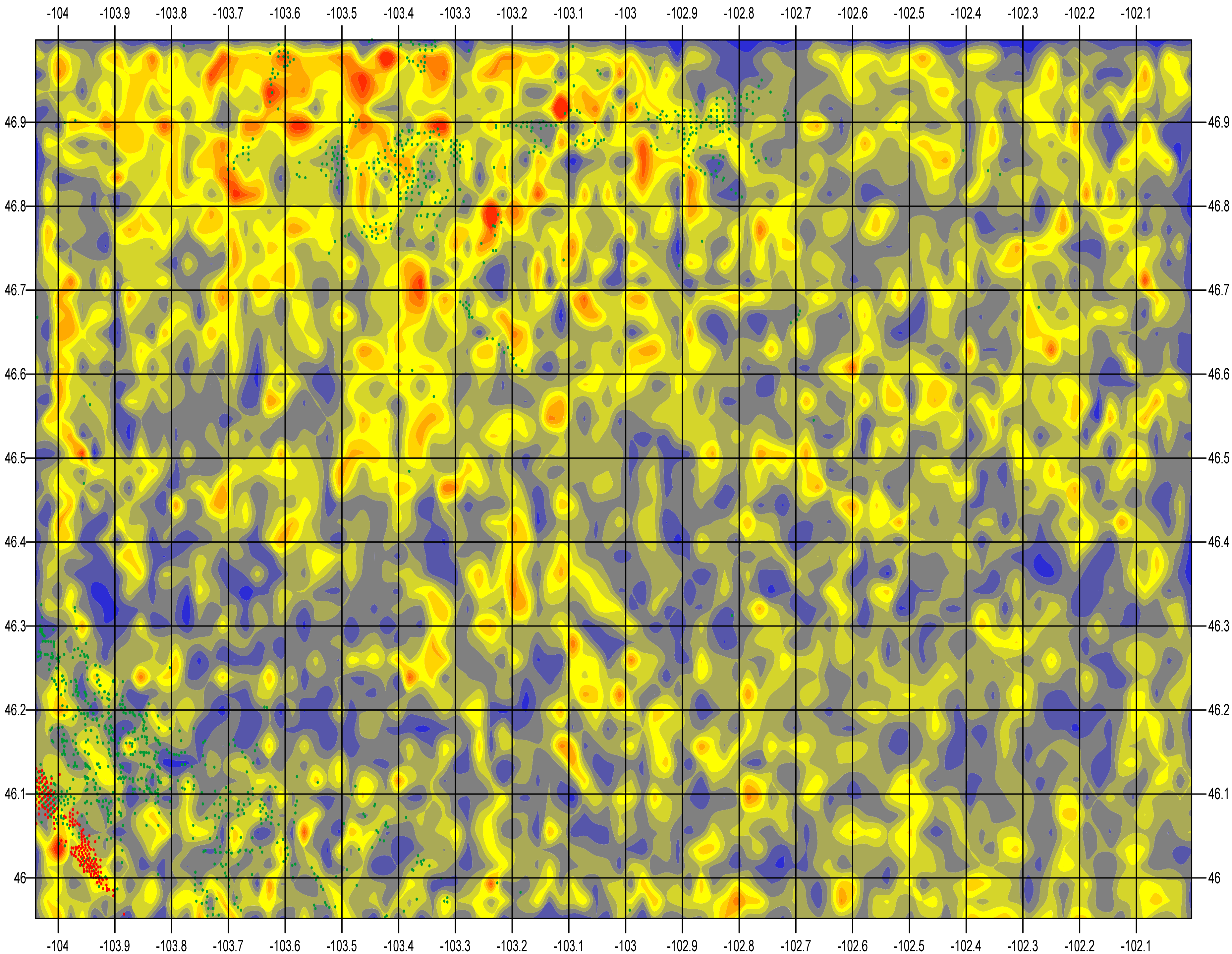


Figure 11. Lineament density map of the Dickinson 1:250k sheet located in the southern Williston Basin in southwestern North Dakota. Areas of higher lineament density are shown as warmer (reds) colors. Areas of lower lineament density are shown as cooler (blues) colors. The locations of all (historic and current) oil and gas (green) and gas (red) producing wells are shown.

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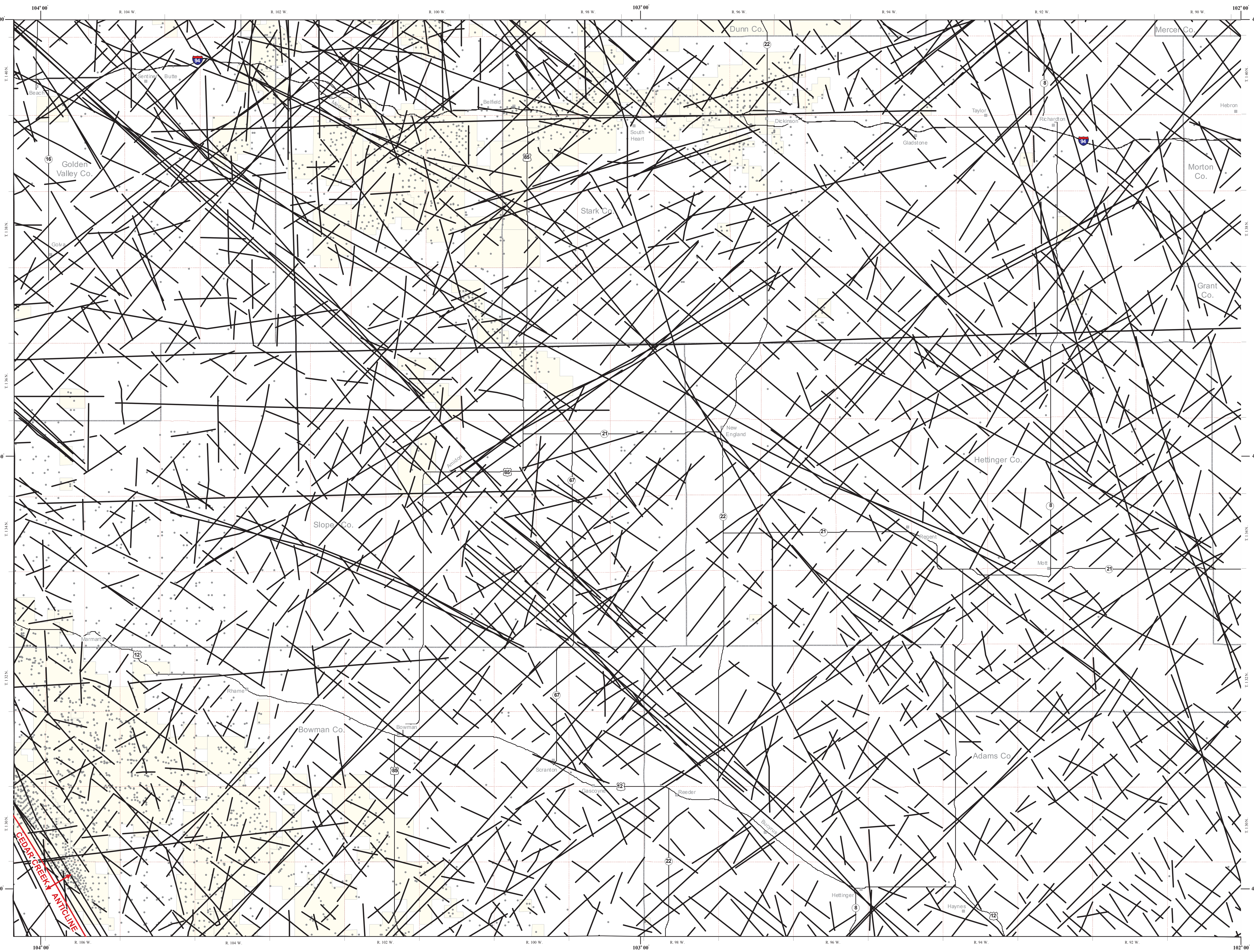
North Dakota Geological Survey
Geologic Investigations No. 129 - Plate I

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE I - HISTORICAL LINEAMENTS MAPPED IN THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

2010



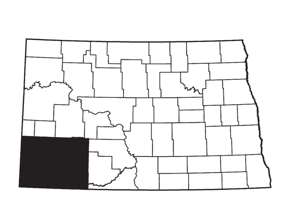
Scale 1:250,000

0 5 10 15 20
Miles

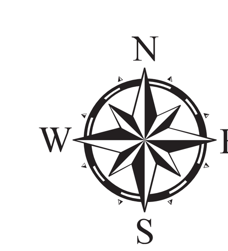
0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 46° 00' 00"

1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota



HISTORICAL LINEAMENTS IN THE DICKINSON 1:250K SHEET COMPILED AND MERGED FROM PREVIOUS STUDIES

This map presents the results of a segment of a contemporary lineament mapping investigation for the Dickinson 250k sheet. The Dickinson 250k sheet is located in the southwestern portion of the Williston Basin. Lineaments mapped from previous studies (i.e., historical lineaments) by several authors over the last four decades, include: Freisatz, 1995, Gibson, 1995, Shurr, 1995, Brown and Brown, 1987, Downey, et. al., 1987, Gerhard, et. al., 1987, Mollard, 1987, Oglesby, 1987, Peterson and MacCray, 1987, Anna, 1986, Maughan and Perry, 1986, Hayes, 1984, Hindman, 1984, Cooley, 1983, Kent, 1974, Thomas, 1974, and Erickson, 1970, (Figure 1). These lineaments were digitally extracted from a compilation of original published sources (Heinle, 2007), compiled, and merged into a single historical lineament coverage for the Dickinson 250k sheet (Figure 1). Previously mapped lineament centerline traces are presented here at a scale of 1:250,000, independent of their original mapped scales. Lineament directional analysis of the strike of 1,670 individual lineaments in this compilation reveals two distinct trends; a primary(1°) orientation of N 60° W (S 60° E) and a secondary (2°) orientation of N 55° E (S 55° W) (Figure 2). The distribution of lineament length follows a general log-normal distribution with the majority of lineaments (92%) falling within the zero to one mile lineament length range. Over 98% of the lineaments mapped were less than 40 miles in length (Figure 3). The overall density of lineaments within the sheet (i.e. lineaments mapped per unit area) is 0.24 lineaments per square mile, approximately 8.5 lineaments per township. Lineament density is generally greater in the north-central and southwestern (coincident with the relative location of the north-eastern limb of the Cedar Creek Anticline) portions of the study area, but overall is relatively uniform in character, particularly for shorter lineaments. This may be partially attributed to scale factors, as most of these lineaments were originally mapped at much smaller scales (e.g., 1:1,000,000 or greater). On this map, several of the lineaments are coincident with areas of current oil and gas field development and current exploration and production trends, particularly in northwest-central Stark County, near Belfield and Medora. Lineaments mapped are likely influenced by subsurface geological (i.e., basement faulting) and surface geomorphological conditions (e.g., degree and extent of weathering). Lineament intersections are also shown (Figure 4) as a variation of lineament density and are generally coincident with currently producing and developing oil and gas fields and areas where exploratory oil and gas drilling has been completed (e.g., along the northeastern limb of the Cedar Creek Anticline). Areas with a higher relative lineament intersection density, and a corresponding small drilling exploration footprint, include area within the entire central portion of the sheet. Several of the smaller fields in the north-central portion of the sheet are somewhat surrounded by paths of lineament intersections, which may provide a hint to deeper structure. Several lineaments have been mapped coincident with and adjacent to the strike of the Cedar Creek Anticline.

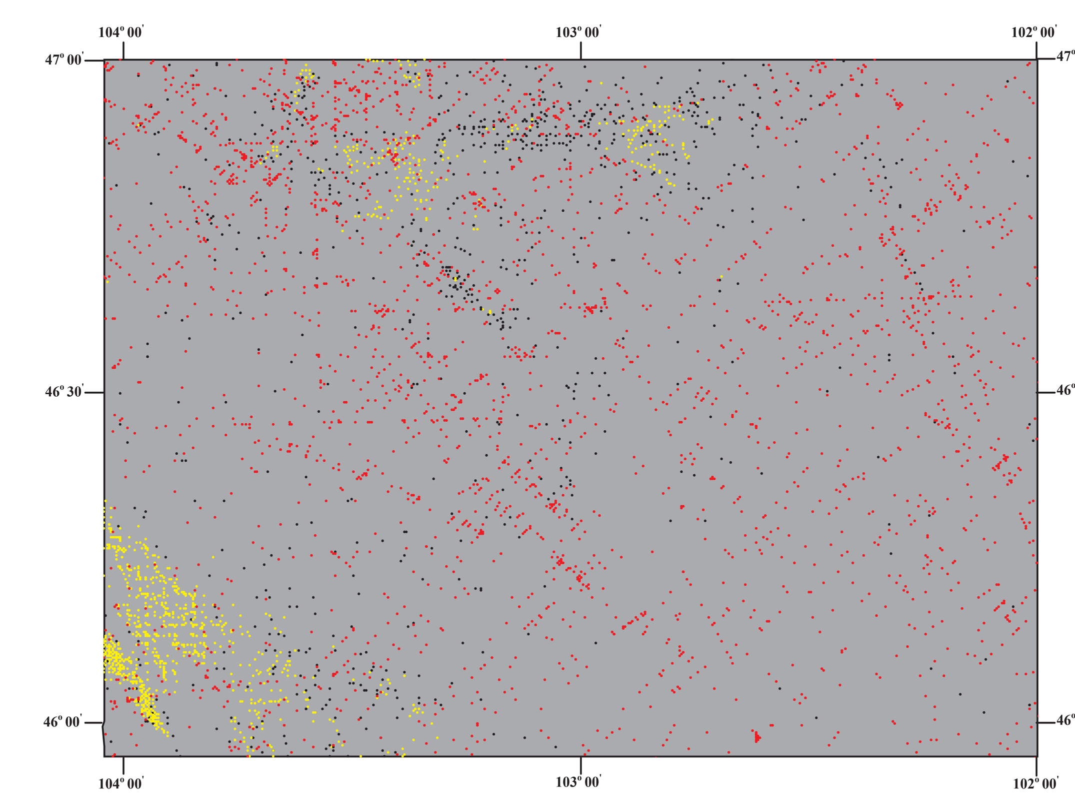


Figure 4. Map of lineament intersections (shown in red) overlain with currently producing wells (shown in yellow) and dry holes (shown in black) displaying the relationship between areas where lineament intersections are prevalent or lacking and areas of current production and field development.

EXPLANATION

Geologic Features

- Lineaments
- Drill Hole
- Oil & Gas Fields
- Cedar Creek Anticline

Other Features

- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

The Dickinson 250k sheet was extended into the Miles City 250k sheet to the North Dakota/Montana border and into the Lemmon 250k sheet to the North Dakota/South Dakota border.

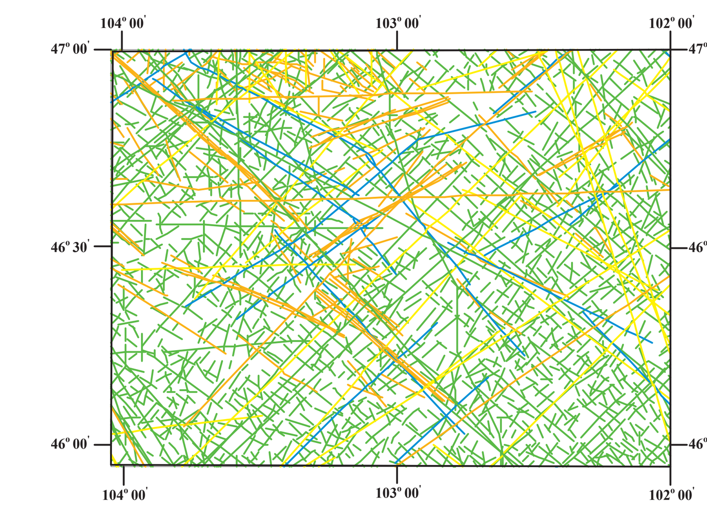
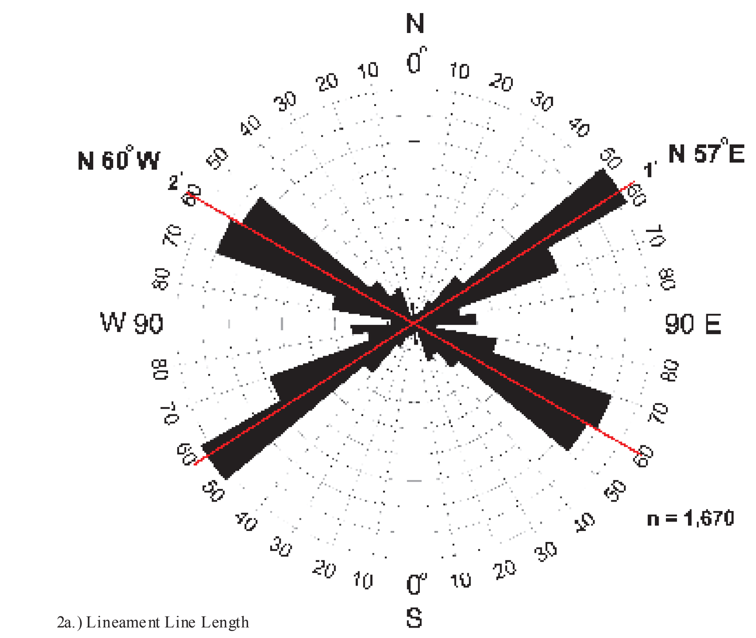
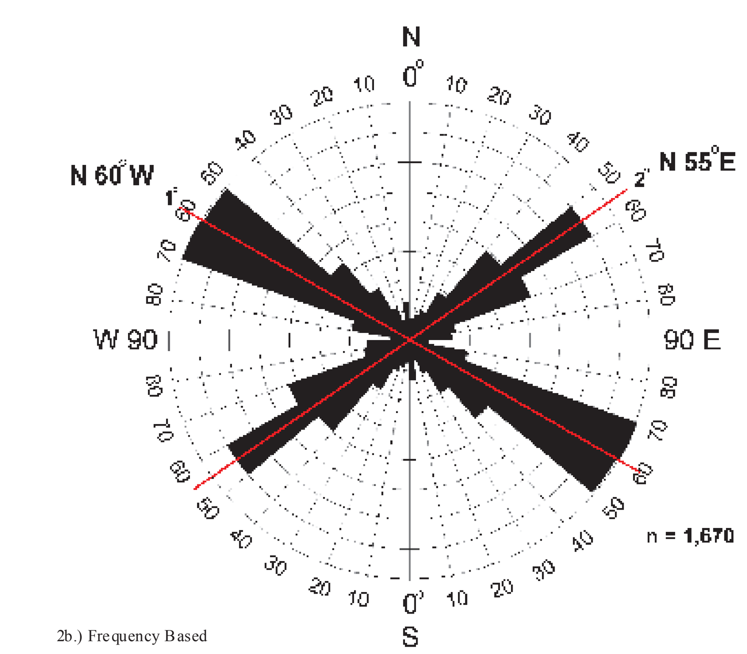


Figure 1. Index map of historical (i.e. previously published) lineaments, grouped by color by the decade in which they were mapped, in the Dickinson 1:250k sheet in the southwestern portion of the Williston Basin in southwestern North Dakota. Lineaments by Freisatz, 1995, Gibson, 1995, and Shurr, 1995, in orange, Brown and Brown, 1987, Downey, et. al., 1987, Gerhard, et. al., 1987, Mollard, 1987, Oglesby, 1987, and Peterson and MacCray, 1987 in yellow, Anna, 1986, Maughan and Perry, 1986, Hayes, 1984, Hindman, 1984, and Cooley, 1983 in green, and Kent, 1974, Thomas, 1974, and Erickson, 1970 in blue.



2a.) Lineament Line Length



2b.) Frequency Based

Figure 2. Rose diagrams of 1,670 individual lineament orientations mapped from previous lineament studies in the Dickinson 1:250k sheet located in the southwestern portion of the Willison Basin in Southwestern North Dakota. The two dominant orientations (1° and 2°), are N 60° W (S 60° E), and N 55° E (S 55° W) based on orientational analysis of lineament line length (2a) and lineament frequency (2b).

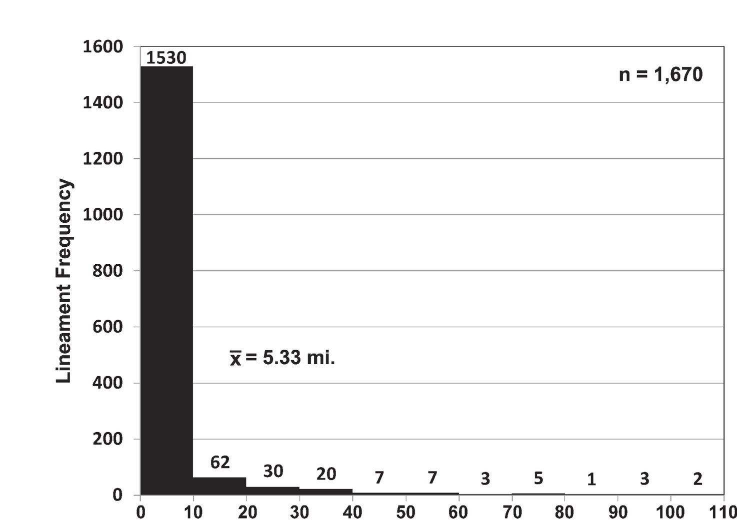


Figure 3. Frequency distribution of 1,670 individual lineament lengths from previously mapped lineaments in the Dickinson 1:250k sheet located in the southwestern portion of the Williston Basin in southwestern North Dakota. Lineament distributions are shown for eleven lineament length classes from zero to 110 miles in 10 mile intervals or classes. This distribution is heavily influenced by the inclusion of the Cooley (1983) LANDSAT derived lineaments as a part of this compilation, as the majority of lineaments mapped were less than 20 miles in length.

Cartographic Compilation: Elroy L. Kadrmas

North Dakota Geological Survey
Geologic Investigations No. 129 - Plate II

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE II - LINEAMENTS MAPPED FROM SHADED RELIEF DATA IN THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

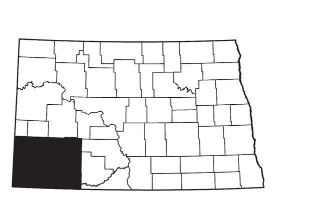
2011

Scale 1:250,000

0 5 10 15 20 Miles

0 5 10 15 20 Kilometers

Mercator Projection
Standard parallel 46° 00' 00"
1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota

Cartographic Compilation: Elroy L. Kadrmas

LINEAMENTS IN THE DICKINSON SHEET DERIVED FROM SHADED RELIEF MAP INTERPRETATION

This map presents the results and discussion of a segment of a contemporary lineament analysis of the Dickinson 1:250k map sheet in southwestern North Dakota. The Dickinson 1:250k map area is located in the southern portion of the Williston Basin and is centered in the southwest corner of the state. Lineaments were mapped and digitized from a digital, shaded-relief image, constructed from a from USGS National Elevation Data (NED) set with a vertical exaggeration of 9X (Figure 1). Mapping of lineaments was conducted digitally by successive visual and manual inspection at various scales (most commonly 1:24,000, 1:100,000, 1:250,000, and 1:1,000,000). Lineaments mapped are presented here at a scale of 1:250,000. Lineament orientation analysis of 7,211 individual lineaments reveal three distinct orientation trends (Figures 2a. and b.). A primary (1°) trend of N 75° W (S 75° E), a secondary (2°) trend of N 35° E (S 35° W), and a tertiary (3°) trend of N 15° W (S 15° E). The distribution of lineament lengths follows a general log-normal distribution with the majority of lineaments (97%) falling within the 0-6 mile lineament length size interval (Figure 3). The density of lineaments (i.e. lineaments mapped per unit area) is generally greater in the western portion of the map area with a overall lineament density of one lineament per square mile (36 lineaments per township). In this map, the general distribution of lineaments can be grouped into 14 areas of six similar individual relative lineament density classes. These lineament density areas (LDAs) exhibit similar lineament character (i.e. lineament density, length, degree of connectivity) and are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree of surficial weathering and exposed bedrock units). Lineament density is observed to be greatest in the northwestern (LDAs I, II, and III) and southern (LDAs I and III) portions of the map area and is generally coincident with known geologic structure (i.e. the Cedar Creek Anticline and southern end of the Billings Anticline), current oil and gas field development, and current exploration and production trends. LDA-IV is located in the northeastern portion of the map area where limited oil and gas drilling and field development has occurred. LDAs-I, II, and III, contain areas of significant oil and gas field development. LDAs-V, and VI are located in the center of the map area. Overall, lineament density appears greater in areas of currently producing wells and relatively lower in areas of limited or no production.

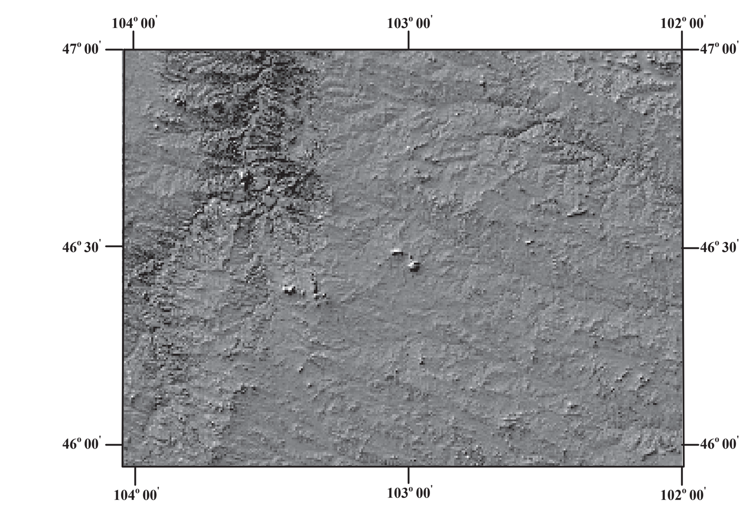
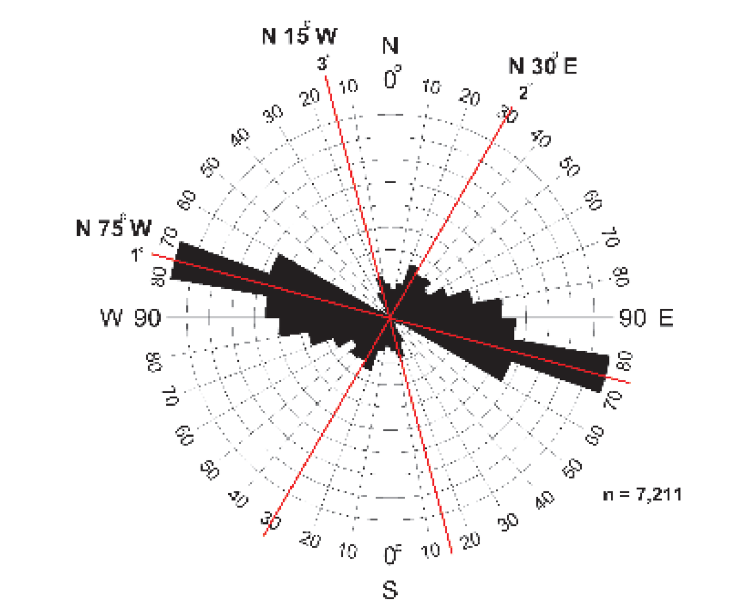
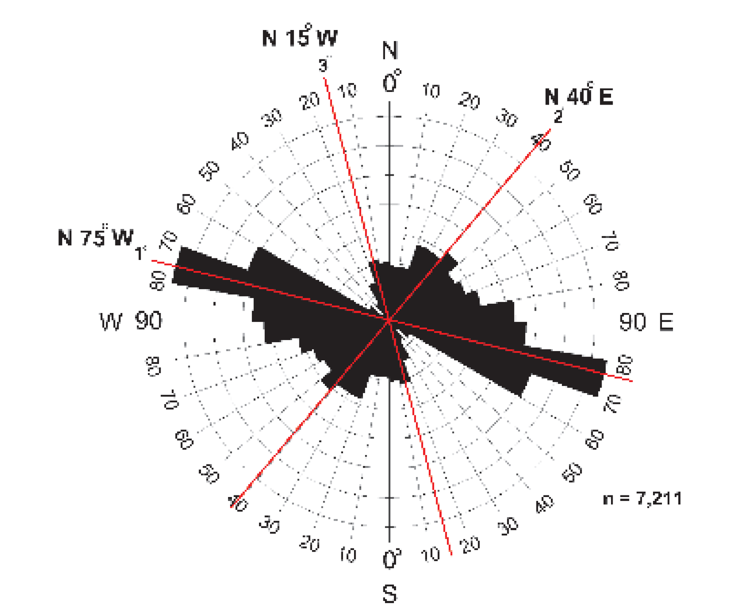


Figure 1. Index map of USGS NED shaded relief data for the Dickinson 1:250k sheet located in the southern portion of the Williston Basin in southwestern North Dakota.



2a.) Lineament Line Length



2b.) Frequency Based

Figure 2. Rose diagrams of 7,211 individual lineament orientations mapped from shaded relief data in the Dickinson 1:250k sheet located in the southern portion of the Willison Basin in Southwestern North Dakota. The three dominant orientations (1°, 2°, and 3°) are N 75° W (S 75° E), N 35° E (S 35° W), and N 15° W (S 15° E), based on directional analysis of lineament line length (2a) and lineament frequency (2b).

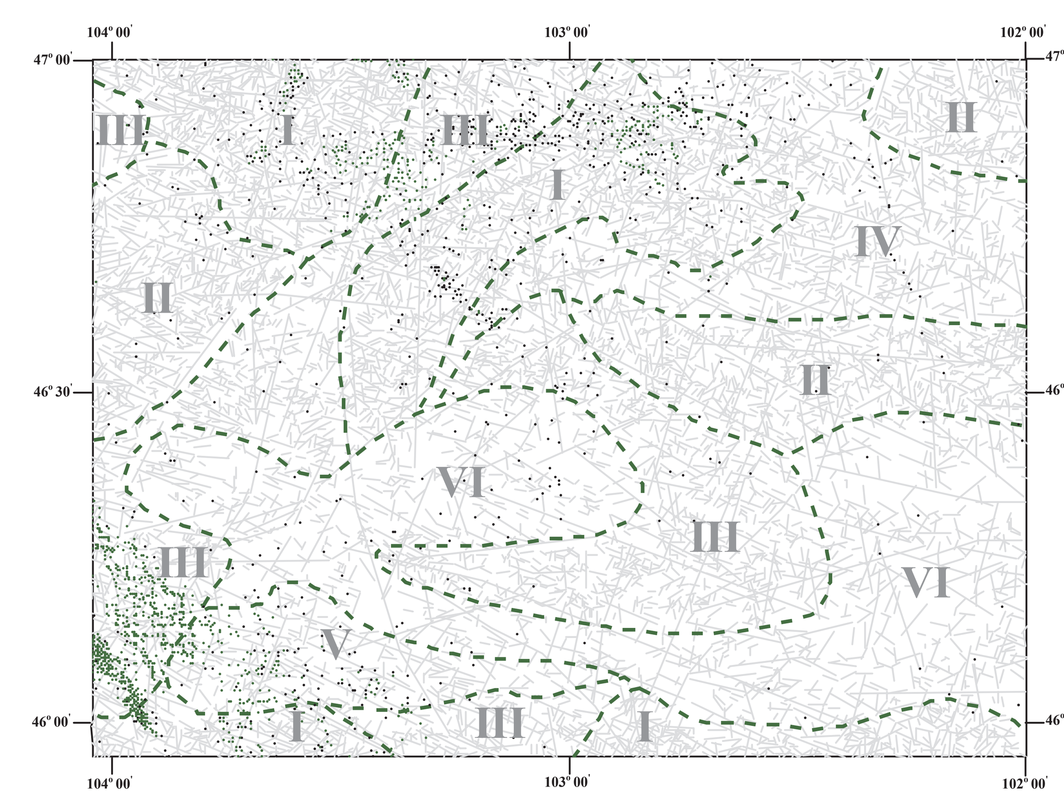


Figure 4. Diagram of Lineament Domain Areas (LDAs I-VI) mapped in order of decreasing relative lineament densities (i.e. lineaments per unit area). Mapped LDAs generally encompass areas coincident with areas of current production and non-production. Currently producing wells (green) and dry holes (black) are shown. LDA boundaries are approximately delineated by the dashed green line.

EXPLANATION

Geologic Features

- Lineaments
- Drill Hole
- Oil & Gas Fields
- Cedar Creek Anticline

Other Features

- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

The Dickinson 250k sheet was extended into the Miles City, Lemmon and Ekalaka 250k sheets to the North Dakota/Montana and North Dakota/South Dakota borders.

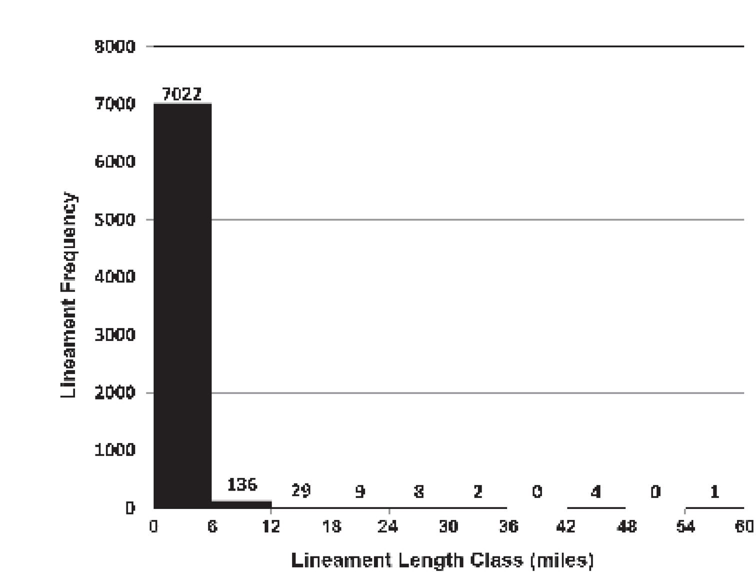


Figure 3. Frequency distribution of 7,211 individual lineament lengths from lineaments mapped from shaded relief data in the Dickinson 1:250k sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Lineament distributions are shown for ten lineament length classes from zero to 60 miles in 6 mile intervals or classes.

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE III - LINEAMENTS MAPPED FROM NAIP IMAGERY IN THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

2011

LINEAMENTS IN THE DICKINSON 1:250K SHEET DERIVED FROM AERIAL IMAGE MAP INTERPRETATION

This map presents the results and discussion of a segment of a contemporary lineament mapping and analysis study in the Dickinson 250k sheet. The Dickinson 1:250k map sheet area is located at the southern edge of the Williston Basin in North Dakota in the southwest corner of the state. Lineaments were digitally mapped and digitized from a digital aerial image mosaic of the study area, compiled from 2009 USDA National Agricultural Image Program (NAIP) imagery (Figure 1). Lineament mapping was conducted by successive visual and manual inspection at various scales (most commonly 1:24,000, 1:100,000, 1:250,000, and 1:1,000,000). Lineaments mapped are presented here at a scale of 1:250,000. Directional analysis of the length (Figure 2) and frequency (Figure 3) of the orientation (i.e. strike) of 312 individual lineaments reveals three distinct orientations. A primary (1^{o}) trend of N 70^{o} W (S 70^{o} E), a secondary (2^{o}) trend of N 80^{o} E (S 80^{o} W), and a tertiary (3^{o}) trend of N 30^{o} E (S 30^{o} W). The distribution of lineament lengths follows a general log-normal distribution with the majority of lineaments (51%) falling within the five to ten mile lineament length range. Overall, 97% of the lineaments mapped were less than 20 miles in length (Figure 3). The overall density of lineaments within the study area (i.e. lineaments mapped per unit area) is 0.043 lineaments per square mile (approximately 1.6 lineaments per township). Lineament density is generally greater in the northwestern portion of the map area but overall is relatively uniform in character. This may be attributed partially to the existence of large tracts of agricultural land where image tonal contrasts are reduced. On this map, several of the lineaments, particularly in the northwest portion of the map area are coincident with areas of current oil and gas field development and current exploration and production trends near and west of Dickinson, particularly in southern Billings and Western Stark Counties in the vicinity of the Fryburg, Bell, and Green River oil field areas. Lineaments mapped are likely influenced by subsurface geological features and surface geomorphological conditions. Lineaments are generally coincident with currently producing and developing oil and gas fields and areas where exploratory oil and gas drilling has been completed (e.g., along the trend of the Cedar Creek Anticline). Areas with a higher relative lineament density, and a corresponding small drilling exploration footprint, include areas in Hettinger, Adams, and central Slope Counties. Several of the smaller fields in the north-central and northeastern portion of the map area are somewhat bound by commonly two or more mapped lineaments which may provide a hint to subsurface structure. The Little Missouri River is the major surface water feature found in the western third of the map area.The Heart and Cannonball Rivers, along with Lake Tschida, are present in the eastern portion of the map area. These features are not displayed on the 1:250,000 scale lineament map shown at left.

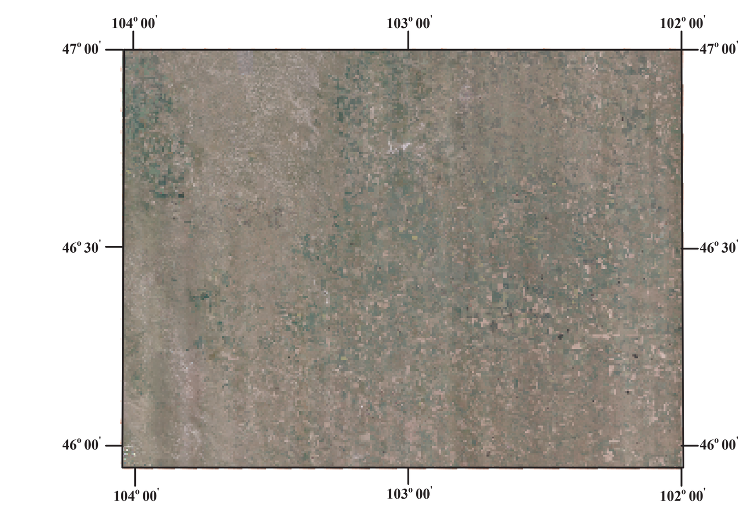
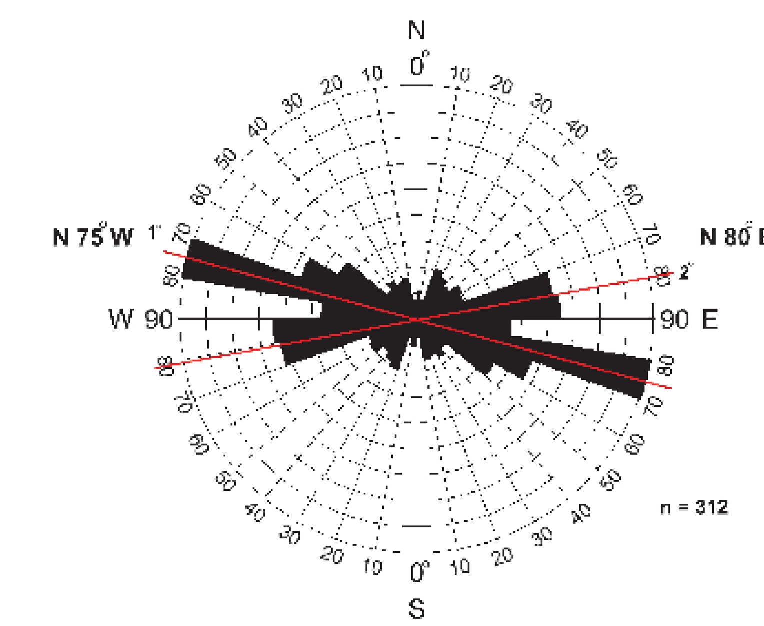
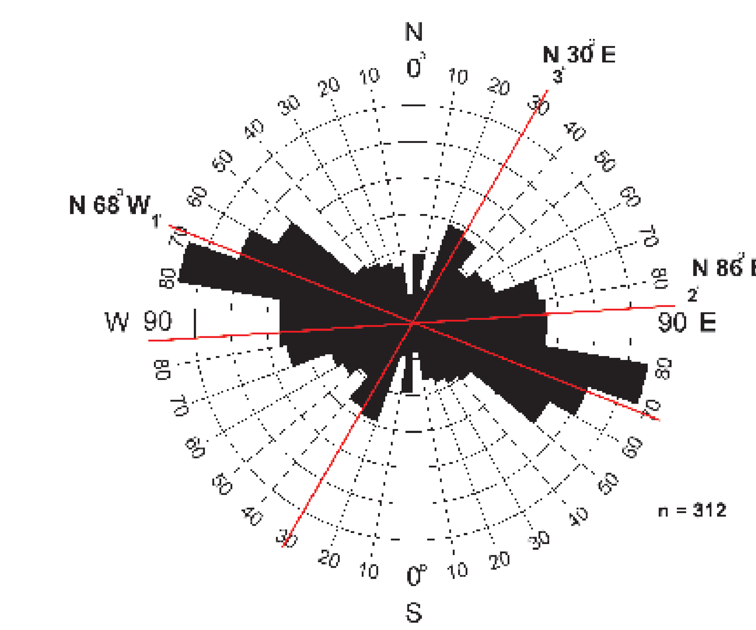


Figure 1. Map of 2009 NAIP aerial imagery used for lineament mapping in the Dickinson 1:250k sheet in the southwestern portion of the Williston Basin in southwestern North Dakota.



2a.) Lineament Line Length



2b.) Frequency Based

Figure 2. Rose diagrams of 312 individual lineament orientations mapped from 2009 NAIP imagery in the Dickinson 1:250k sheet located in the southern portion of the Willison Basin in Southwestern North Dakota. The two dominant orientations (1^{o} and 2^{o}), are about N 70^{o} W (S 70^{o} E), and N 80^{o} E (S 80^{o} W) based on orientational analysis of lineament line length (2a) and lineament frequency (2b).

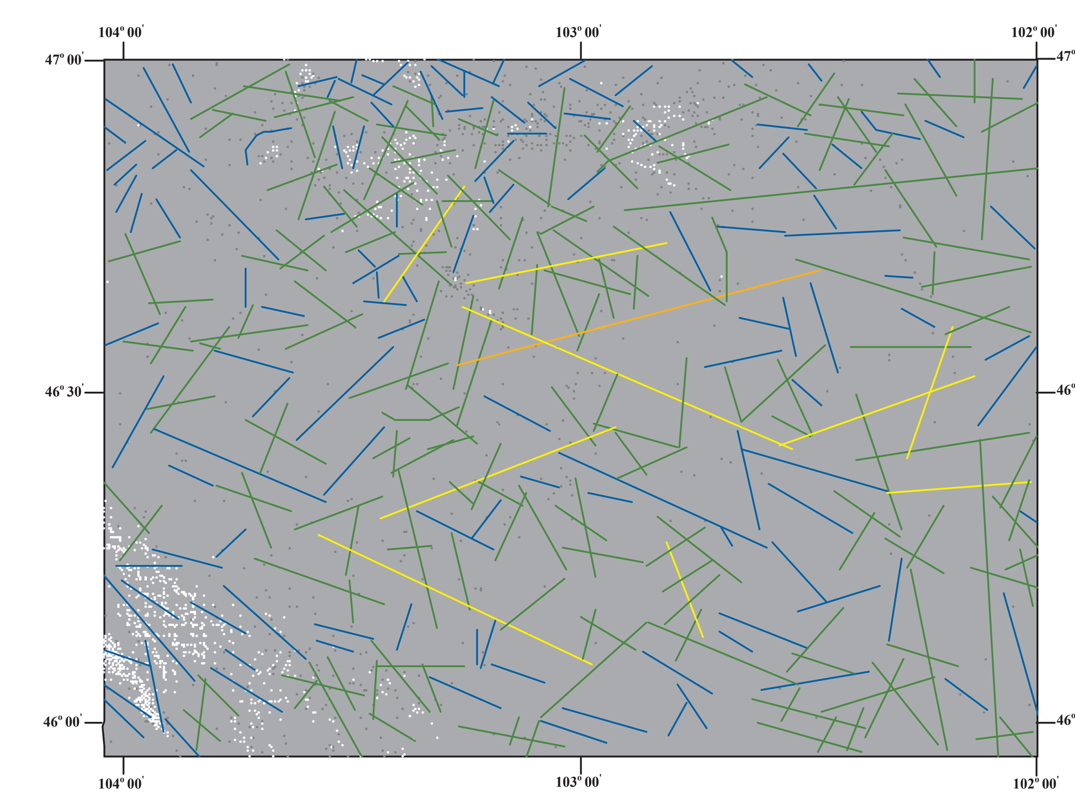


Figure 4. Lineament intersection map displaying lineaments in six classes of lineament intersection. Discontinuous lineaments (i.e. lineaments that do not meet or intersect another lineament along the path of the lineament) are shown in blue, lineaments with intersections of 1 - 3 intersections per lineament path are shown in green, 4 - 6 yellow, and 7 - 9 orange. Producing wells (shown in white) display linear trends siimilar to mapped lineament orientations. The distribution of the dry holes (shown in gray) tend to be in areas where no mapped lineaments occur.

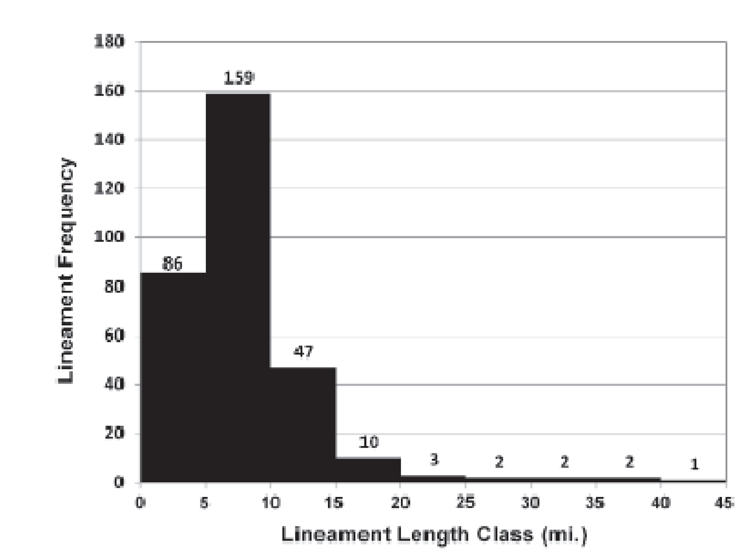


Figure 3. Frequency distribution of 312 individual lineament lengths from lineaments from 2009 NAIP imagery mapped in the Dickinson 1:250k sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Lineament distributions are shown for nine lineament length classes from zero to 45 miles in 5 mile intervals or classes.

EXPLANATION

Geologic Features

- Lineaments
- Drill Hole
- Oil & Gas Fields
- Cedar Creek Anticline

Other Features

- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

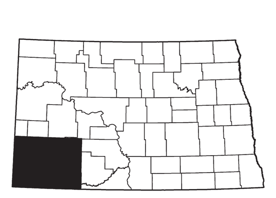
The Dickinson 250k sheet was extended into the Miles City, Lemmon and Ekalaka 250k sheets to the North Dakota/Montana and North Dakota/South Dakota borders.

Scale 1:250,000

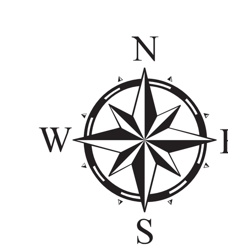
0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 46° 00' 00"
1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota



Cartographic Compilation: Elroy L. Kadrmas

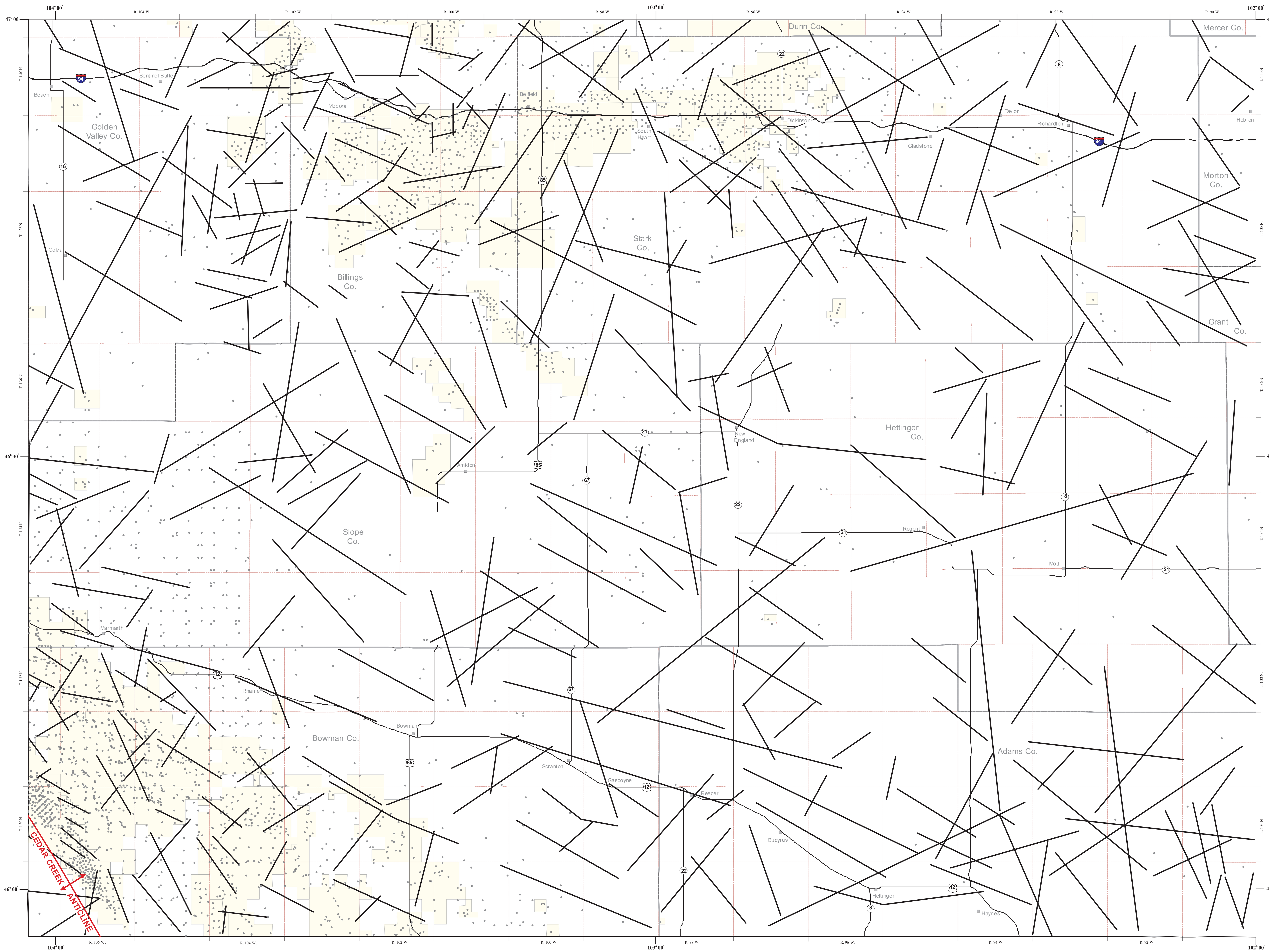
North Dakota Geological Survey
Geologic Investigations No. 129 - Plate IV

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE IV - LINEAMENTS MAPPED FROM LANDSAT DATA IN THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

2011

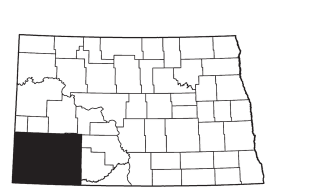


Scale 1:250,000

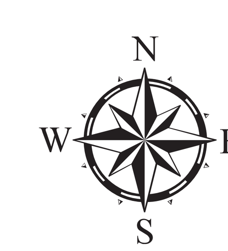
0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 46° 00' 00"
1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota



LINEAMENTS IN THE DICKINSON SHEET DERIVED FROM LANDSAT 7-ETM IMAGE MAP INTERPRETATION

This map presents the results and discussion of a segment of a contemporary lineament mapping and analysis study of the Dickinson 1:250k map sheet in southwestern North Dakota. The Dickinson 1:250k map area is located in the southern portion of the Williston Basin and is centered in the southwest corner of the state. Lineaments were digitally mapped and digitized from a digital image mosaic of the study area, compliled from 2000 LANDSAT 7 Enhanced Thematic Mapper (ETM) data. A digital image mosaic was created from four available scenes in a blue, green, red (BGR) false color combination of spectral bands 2, 4, and 7 for analysis (Figure 1). Lineament mapping was conducted by successive visual and manual inspection at various scales (most commonly 1:24,000, 1:100,000, 1:250,000, and 1:1,000,000). Lineaments mapped are presented here at a scale of 1:250,000. Lineament orientation analysis of 343 individual lineaments reveal three distinct orientation trends (Figures 2a. and b.). A primary (1°) orientation of N 70° W (S 70° E), a secondary (2°) orientation of N 70° E (S 70° W), and a tertiary (3°) orientation of N 45° W (S 45° E). The distribution of lineament lengths follows a general log-normal distribution with the majority of lineaments (63%) falling within the three to nine mile lineament length range. Overall, 89% of the lineaments mapped were less than 12 miles in length (Figure 3). The overall density of lineaments within the study area (i.e. lineaments mapped per unit area) is 0.05 lineaments per square mile (approximately 1.7 lineaments per township). Lineament density is generally greater in the north and southwestern portions of the study area (coincident with local structure) but overall is relatively uniform in character. This may attributed partially to the existence of large tracts of agricultural land (i.e., cultivated crops) where image tonal constrasts are reduced. On this map, several of the lineaments are coincident with areas of current oil and gas field development and current exploration and production trends. Lineaments mapped are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e. degree of surficial weathering and exposed bedrock units). Lineaments are generally coincident with currently producing and developing oil and gas fields and areas where exploratory oil and gas drilling has been completed (e.g., in the area of the Cedar Creek Anticline). Lineament density appears to be generally greater in areas of currently producing wells and less in areas of non-producing wells. Horizontal drilling and production trends have suggested more successful preferential horizontal leg completions along a NW trend from collar. Visual analysis of lineaments mapped perpendicular to sub-perpendicular of this trend suggest a relatively higher amount of lineament frequency (i.e., lineaments encountered per path) normal to the preferred NW trend (Figure 4). The Little Missouri River is the major surface water feature found in the western third of the map area. The Heart and Cannonball Rivers, along with Lake Tschida, are present in the eastern portion of the map area. These features are not displayed on the 1:250,000 scale lineament map shown at the left.

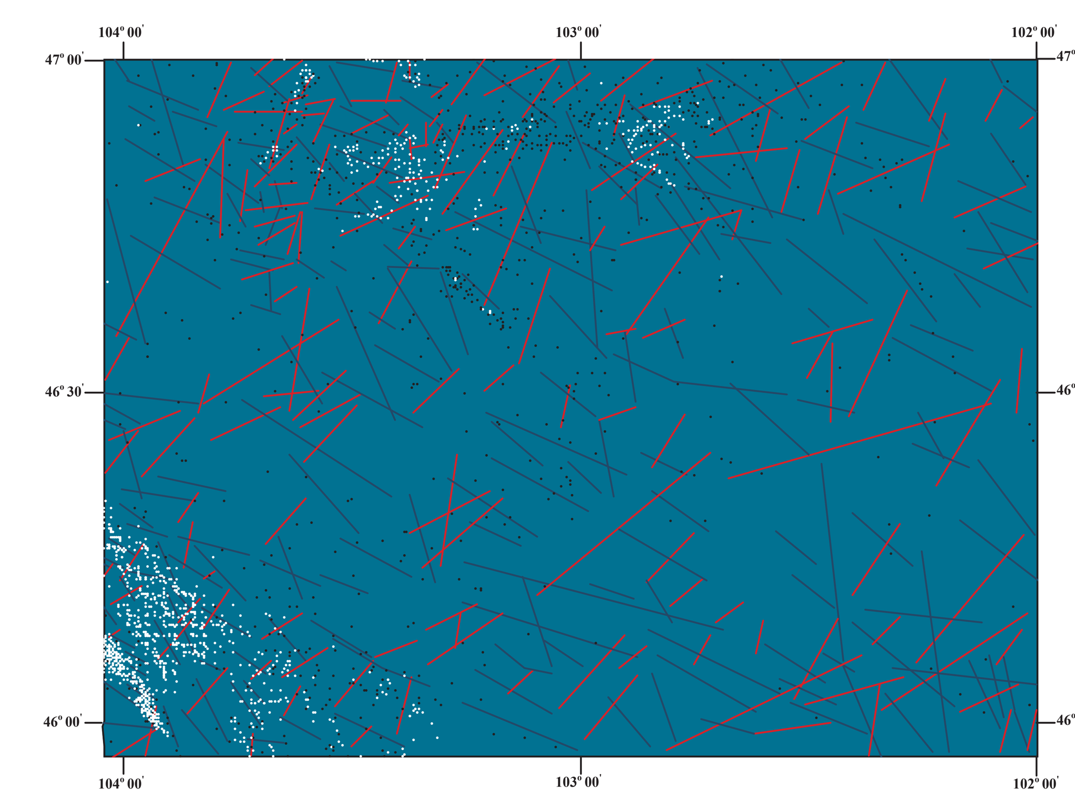


Figure 4. Lineament map displaying lineaments in two classes of lineament orientation. Lineaments oriented along a N-NE or S-SW orientation are showin in red, lineaments oriented along a N-NW or S-SE orientation are shown in blue. Producing wells (shown in white) tend to be located near areas of relatively higher lineament density. The distribution of dry holes (shown in black) tend to be in areas where lineament density is relatively low.

EXPLANATION

Geologic Features		Other Features	
	Lineaments		Towns
	Drill Hole		Township Boundaries
	Oil & Gas Fields		County Boundaries
	Cedar Creek Anticline		State and US Highways

The Dickinson 250k sheet was extended into the Miles City, Lemmon and Ekalaka 250k sheets to the North Dakota/Montana and North Dakota/South Dakota borders.

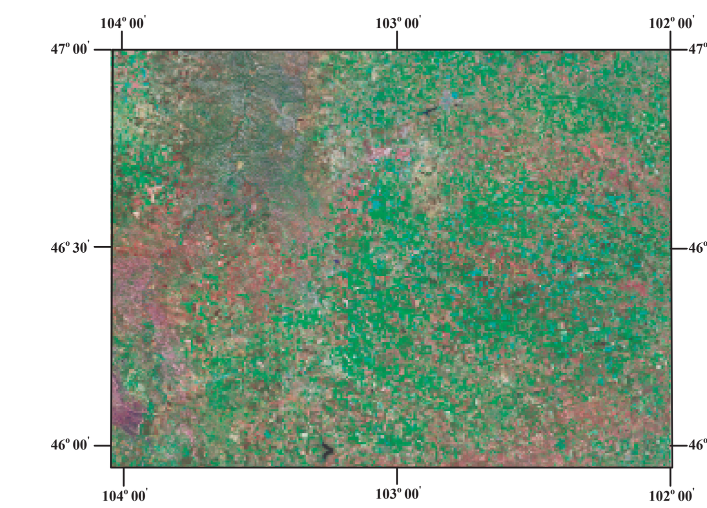
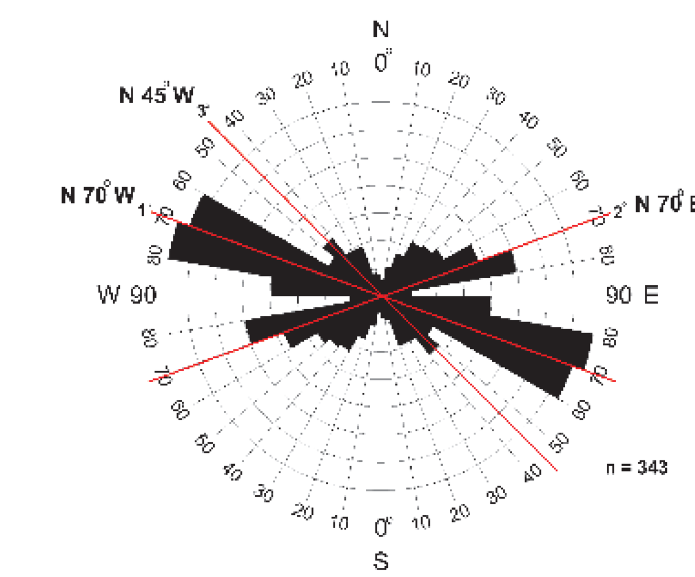
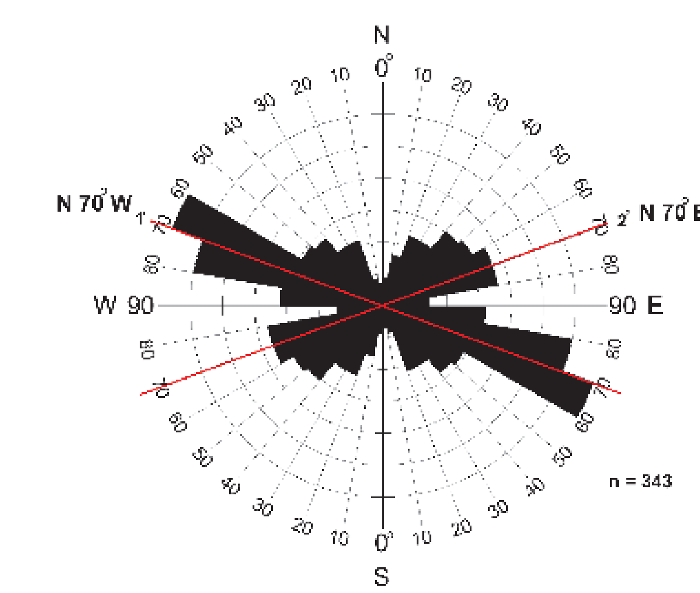


Figure 1. Map of 2000 LANDSAT 7-ETM false color (2-4-7) imagery used for lineament mapping in the Dickinson 1:250k sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Agricultural land use can again be seen as the patchwork pattern (green) throughout the central and eastern two-thirds of the study area.



2a.) Lineament Line Length



2b.) Frequency Based

Figure 2. Rose diagrams of 343 individual lineament orientations mapped from 2000 LANDSAT 7-ETM imagery in the Dickinson 1:250k map sheet in the southern portion of the Willison Basin in southwestern North Dakota. There are three dominant orientations (1°, 2°, and 3°) of N 70° W (S 70° E), N 70° E (S 70° W), and N 45° W (S 45° E) based on directional analysis of lineament line length (2a) and lineament frequency (2b).

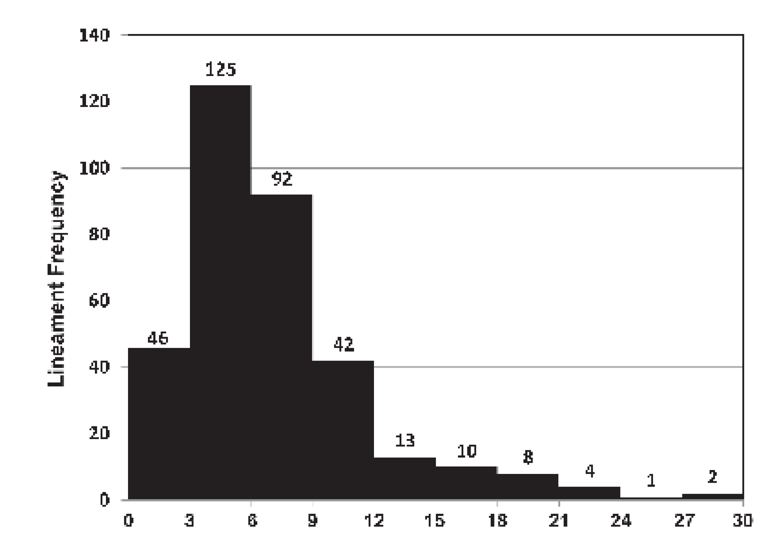


Figure 3. Frequency distribution of 343 individual lineament lengths (distance in miles) mapped from 2000 LANDSAT 7-ETM false color (2-4-7) imagery of the Dickinson 1:250k map sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Lineament distributions are shown for ten lineament length classes from zero to 30 miles in three mile intervals or classes.

Cartographic Compilation: Elroy L. Kadrmas

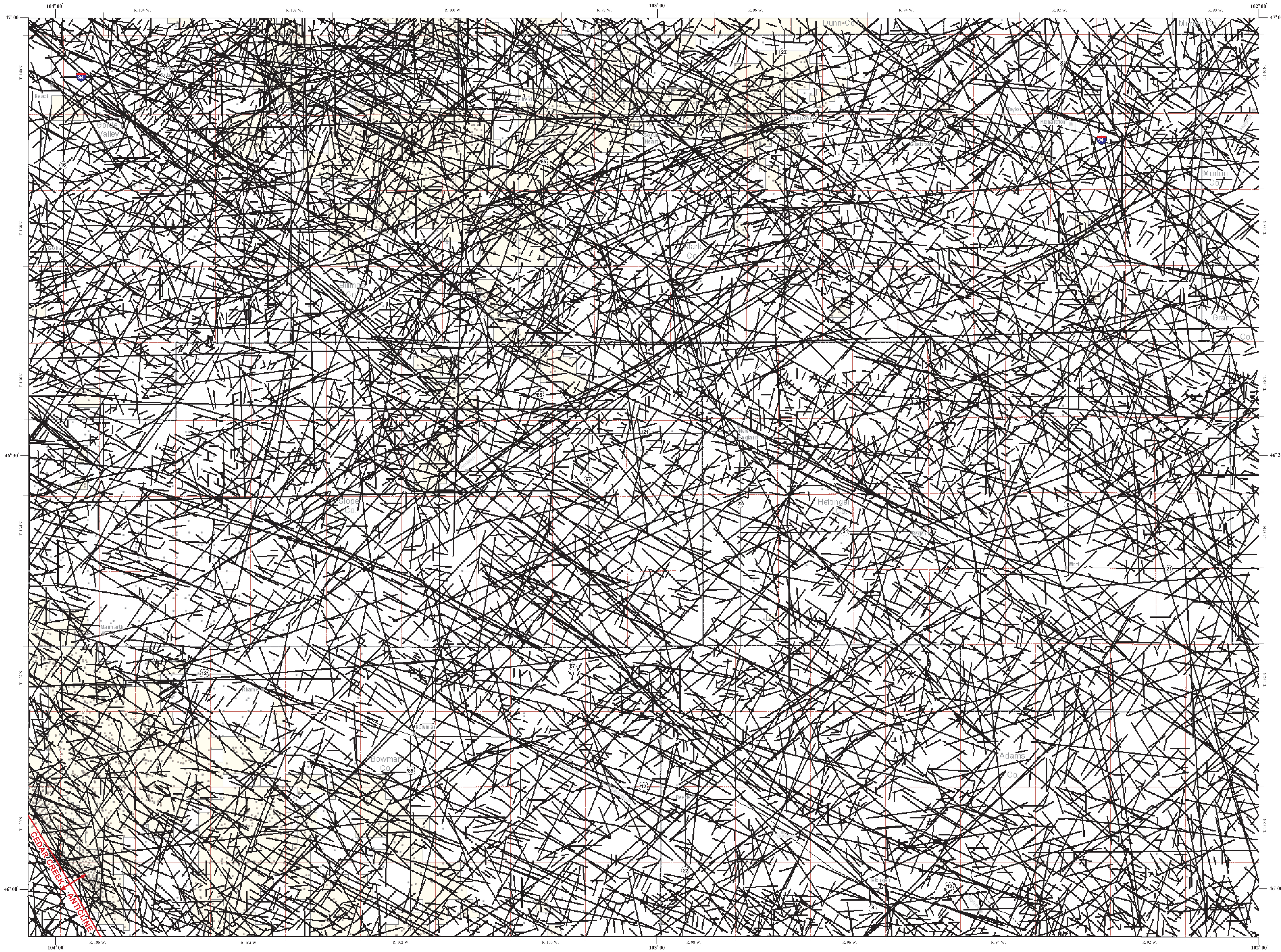
North Dakota Geological Survey
Geologic Investigations No. 129 - Plate V

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE V - COMPILED LINEAMENTS MAPPED IN THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

2011

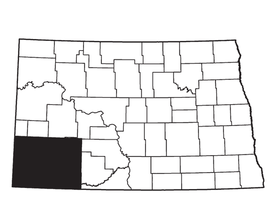


Scale 1:250,000

0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 46° 00' 00"
1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota

Cartographic Compilation: Elroy L. Kadrmas

COMPILED LINEAMENTS IN THE DICKINSON SHEET

This map presents the results and discussion of a segment of a contemporary lineament analysis study of the Dickinson 1:250k map sheet in southwestern North Dakota. The Dickinson 1:250k map area is located in the southern portion of the Williston Basin and is centered in the southwest corner of the state. Lineaments were compilied from Plates I - IV for this map (Figure 1). Lineaments compiled are presented here a scale of 1:250,000. Lineament orientation analysis of 9,536 mapped lineaments reveal three dominant orientation trends (Figures 2a. and b.). A primary (1°) orientation of N 70° W (S 70° E), a secondary (2°) orientation of N 55° E (S 55° W), and a tertiary (3°) trend ranging between a 15° interval from N 10° W (S 10° E) to N 25° W (S 25° E). The distribution of lineament length follows a sharp log-normal distribution with the majority of lineaments (96%) falling within the 0-10 mile lineament length size range (Figure 3). The density of lineaments (i.e. lineaments mapped per unit area) is generally greater in the northwestern and southwestern portions of the map area with an overall linement density of 1.3 lineaments per square mile (~48 lineaments per township). In this map, the general distribution of lineaments is likely influenced by subsurface geological and surface geomorphological conditions. Lineament density is observed to be greatest and generally coincident with known geologic structure (e.g. the Cedar Creek Anticline), current oil and gas field development, and current exploration and production trends. Overall, lineament density appears to be greater in areas of currently producing wells and relatively lower in areas of limited or no production.

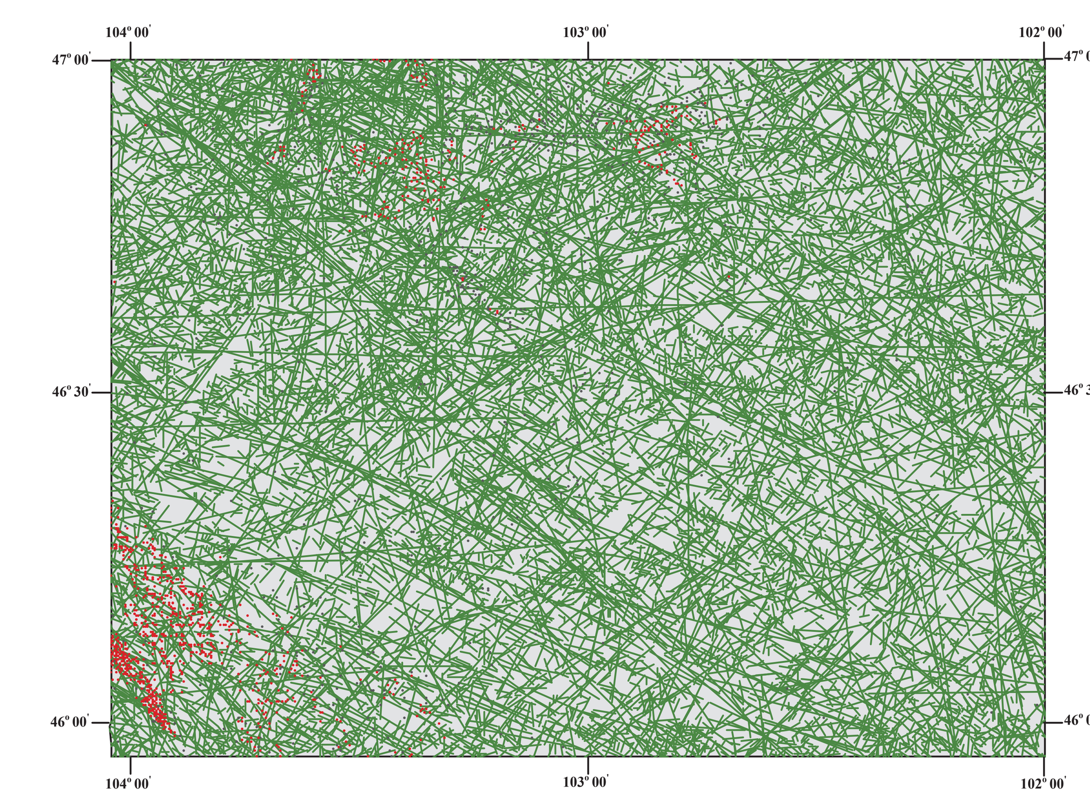


Figure 4. Map of compiled lineaments (green) with currently producing wells (red) and non-producing wells (dark gray) displaying the general relationships between overall lineament trends and densities and oil and gas production and development in the Dickinson 1:250k Sheet.

EXPLANATION

Geologic Features

- Lineaments
- Drill Hole
- Oil & Gas Fields
- Cedar Creek Anticline

Other Features

- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

The Dickinson 250k sheet was extended into the Miles City, Lemmon and Ekalaka 250k sheets to the North Dakota/Montana and North Dakota/South Dakota borders.

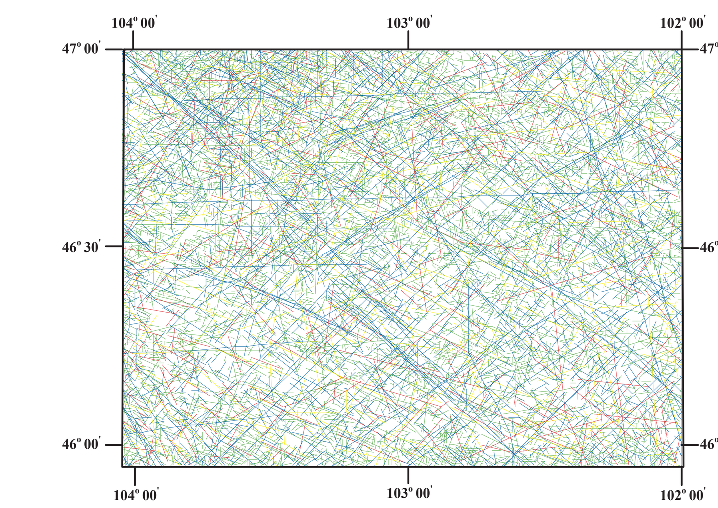
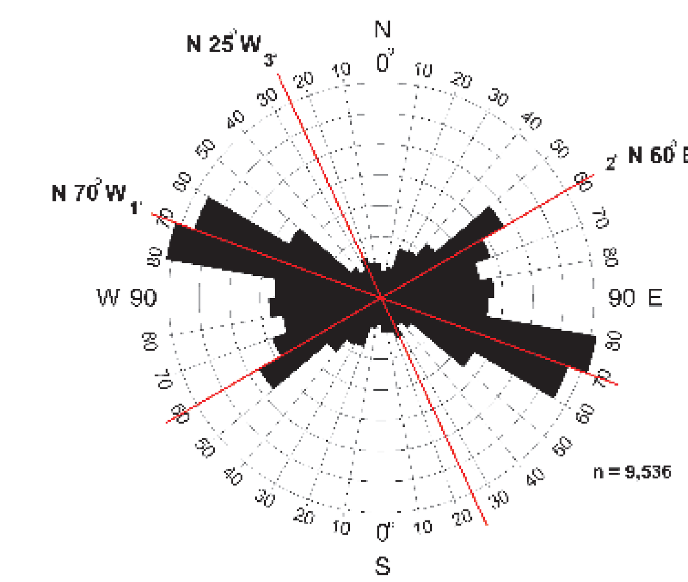
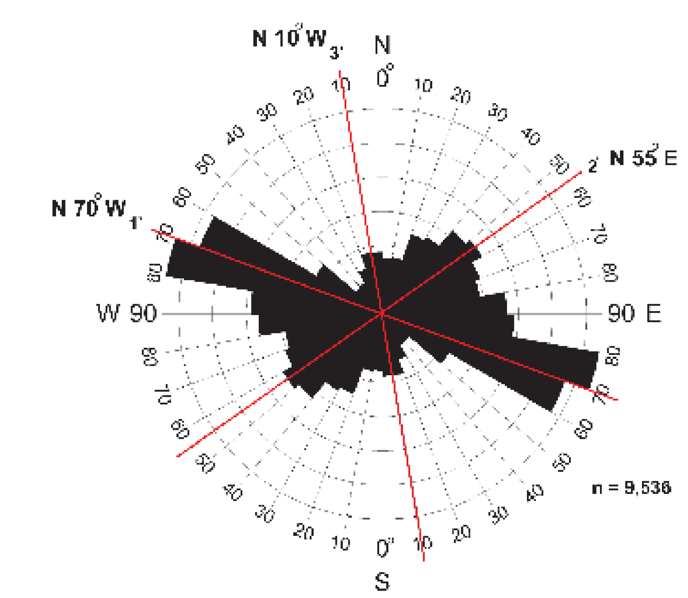


Figure 1. Index map of compiled lineaments in the Dickinson 1:250k map sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Historical or lineaments compiled from previous studies, are shown in blue. Lineaments mapped from shaded relief data are shown in green. Lineaments mapped from aerial imagery are shown in yellow. Lineaments mapped from LANDSAT imagery are shown in red.



2a.) Lineament Line Length



2b.) Frequency Based

Figure 2. Rose diagrams of 9,536 individual lineament orientations compiled from all lineaments mapped in the the Dickinson 1:250k sheet located in the southern portion of the Willison Basin in southwestern North Dakota, analyzed for trends in strike orientation by lineament length (2a) and frequency based (2b) methods. There are three dominant orientation trends (1°, 2°, and 3°) displayed within the data of N 70° W (S 70° E), N 55° E (S 55° W), and a third, less pronounced trend ranging between a 15° interval from N 10° W (S 10° E), to N 25° W (S 25° E).

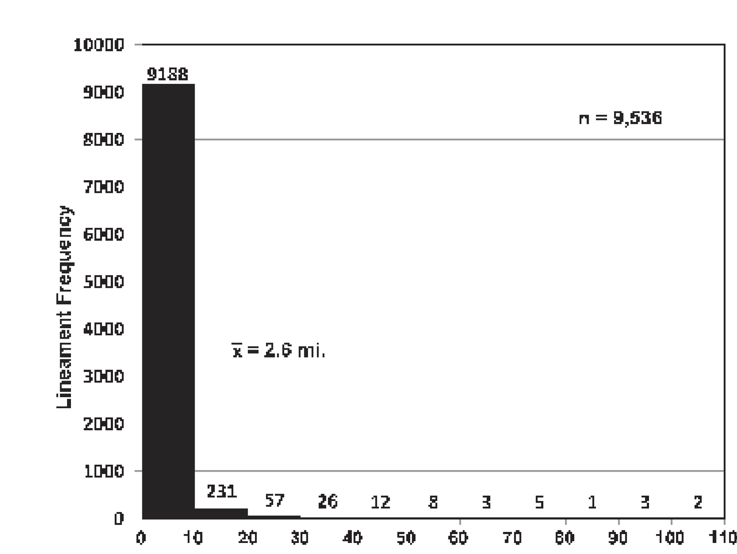


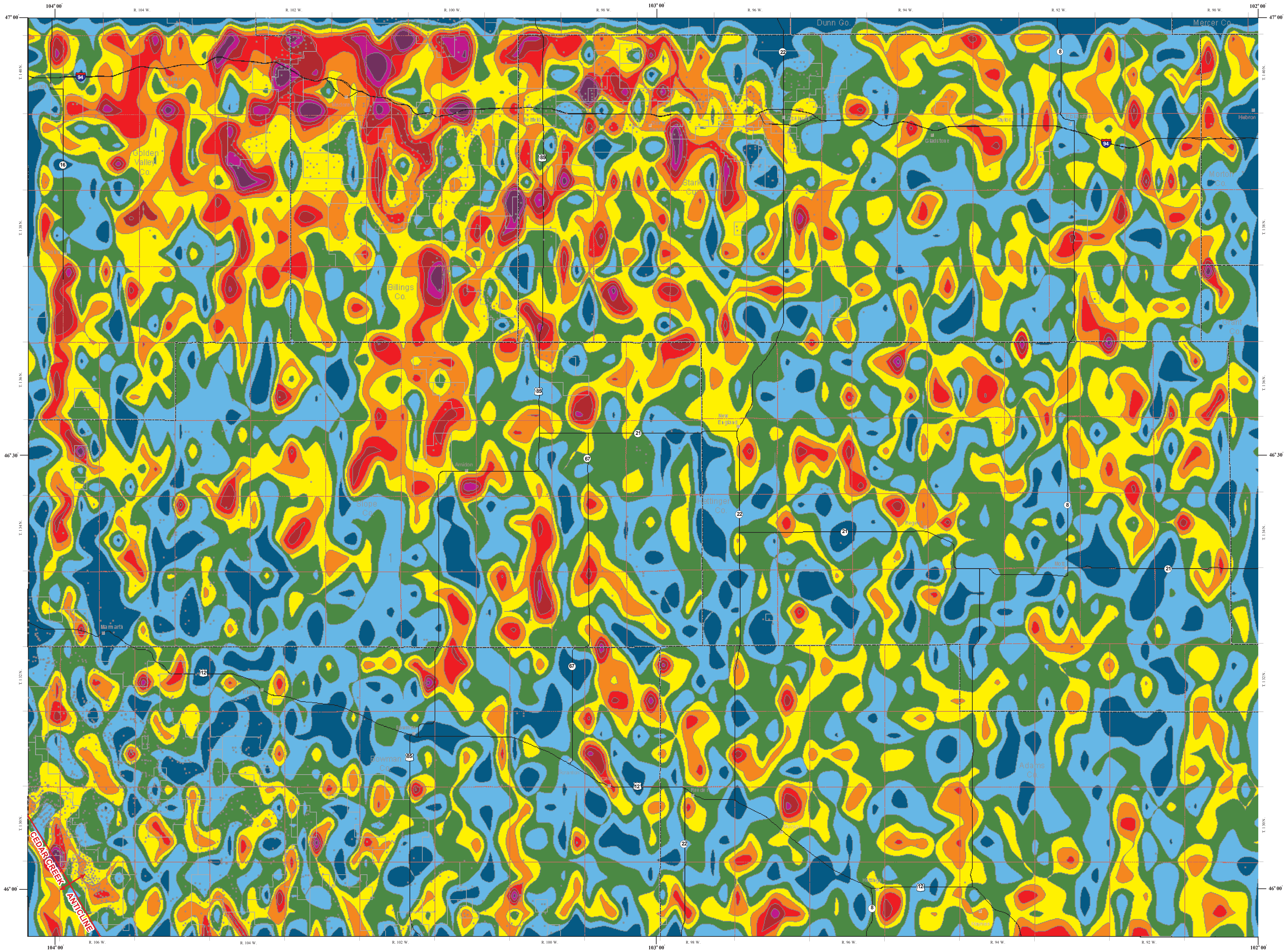
Figure 3. Frequency distribution of 9,536 individual lineament lengths (distance in miles) compiled from lineaments mapped in the Dickinson 1:250k map sheet located in the southern portion of the Williston Basin in southwestern North Dakota. Lineament distributions are shown for 11 lineament length classes from zero to 110 miles in 10 mile intervals. This distribution is heavily influenced by lineaments less than 10 miles in length that are commonly associated with drainage network development in exposed Cenozoic bedrock sediments common throughout the map area.

Edward C. Murphy, State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

PLATE VI - LINEAMENT DENSITY MAP OF THE DICKINSON 250K SHEET, NORTH DAKOTA

Fred J. Anderson

2011



LINEAMENT DENSITY MAPPING IN THE DICKINSON SHEET

This map presents the results and discussion of a segment of a contemporary lineament analysis of the Dickinson 1:250k sheet located in southwestern North Dakota. The Dickinson sheet is located in the southern portion of the Williston Basin centered in the southwest corner of North Dakota. The density of lineaments for this map was determined from the compliled lineaments extracted from Plate V. Lineament density was calculated across the map area by automated analysis of all lineament lengths found to occur within a 1 mile x 1 mile grid cell coincident with actual Public Land Survey System (PLSS) sections. Cellular lineament density values (i.e., total lineament line length per unit cell) were assigned to nodal values for the centers of each of the grid cells (sections). The resulting x,y,z data file was contoured across the determined data range in 5,000-ft intervals from 0 to >50,000-ft. Lineament density classes are depicted on this map as ranging from areas of lower lineament density, shown as cooler colors, to areas of higher lineament density, shown as warmer colors. This map shows areas of higher lineament density in the northwestern portion of the map area, consistent with subsurface structural development and geomorphological influence from enhanced drainage development on exposed Cenozoic sedimentary bedrock. Areas of lower lineament density are found in the central portions of the map area. Overall, lineament density appears to be greatest and coincident with areas where producing oil and gas wells and fields are commonly located, and lower in areas where non-producing wells have been drilled (Figure 1). This suggests a relationship between overall production and areas of relatively higher lineament density.

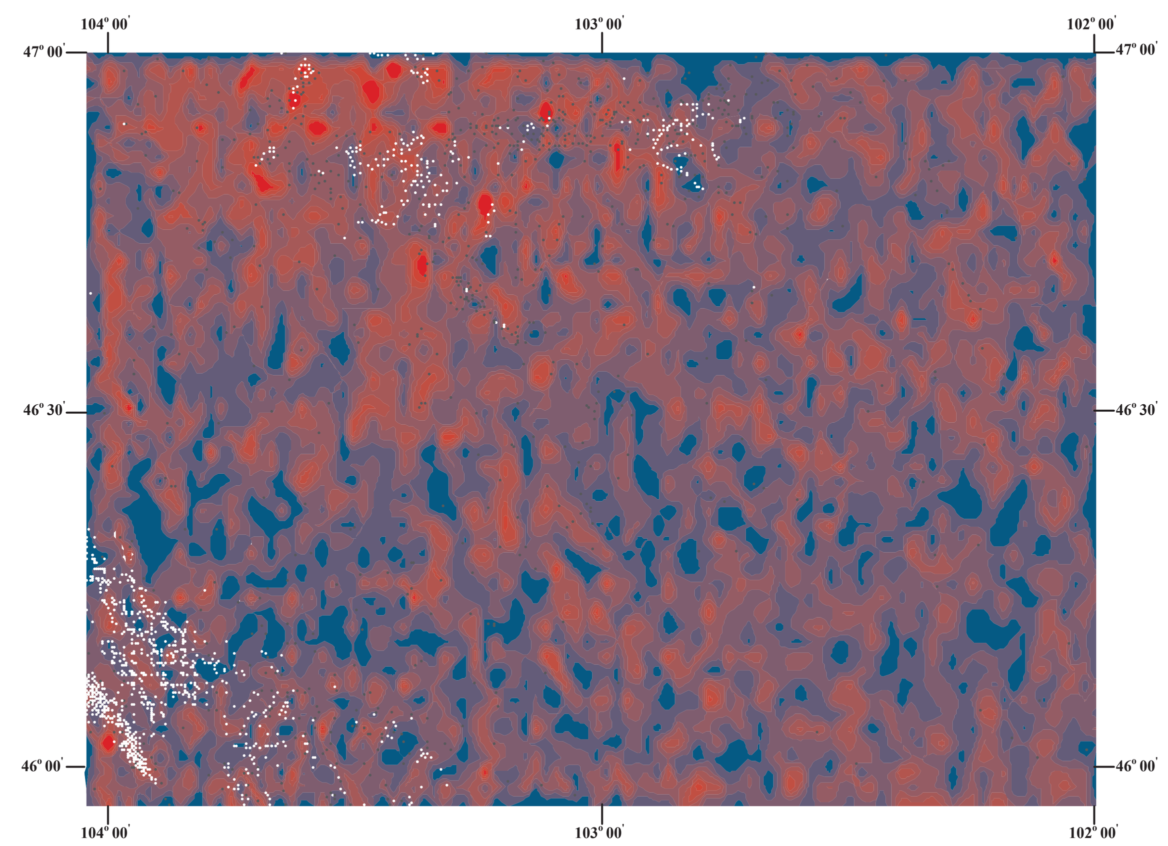


Figure 4. Lineament density map displaying lineament density with currently producing (white) and non-producing (dark gray) in the Dickinson 1:250k Sheet. Producing wells tend to be located near areas of relatively higher lineament density (shown in red). The distribution of dry holes or non-producing wells tend to be in areas where lineament density is relatively low (shown in blue).

Lineament Density (ft/mi^2)

- > 50,000
- 40,000 - 50,000
- 35,000 - 40,000
- 30,000 - 35,000
- 25,000 - 30,000
- 20,000 - 25,000
- 15,000 - 20,000
- 10,000 - 15,000
- 0 - 10,000

EXPLANATION

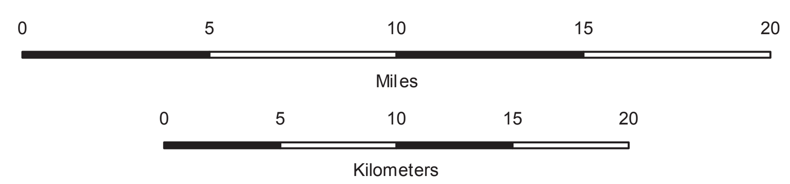
Geologic Features

- Drill Hole
- Oil & Gas Fields
- Cedar Creek Anticline

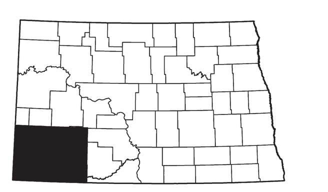
Other Features

- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

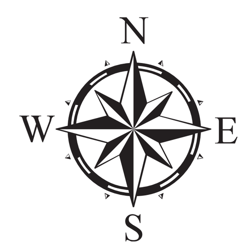
Scale 1:250,000



Mercator Projection
Standard parallel 46° 00' 00"
1927 North American Datum
Central meridian 103° 00' 00"



Dickinson 250K Sheet, North Dakota



The Dickinson 250k sheet was extended into the Miles City, Lemmon and Ekalaka 250k sheets to the North Dakota/Montana and North Dakota/South Dakota borders.

Cartographic Compilation: Elroy L. Kadrmas