# LINEAMENT MAPPING AND ANALYSIS IN THE NORTHEASTERN WILLISTON BASIN OF NORTH DAKOTA

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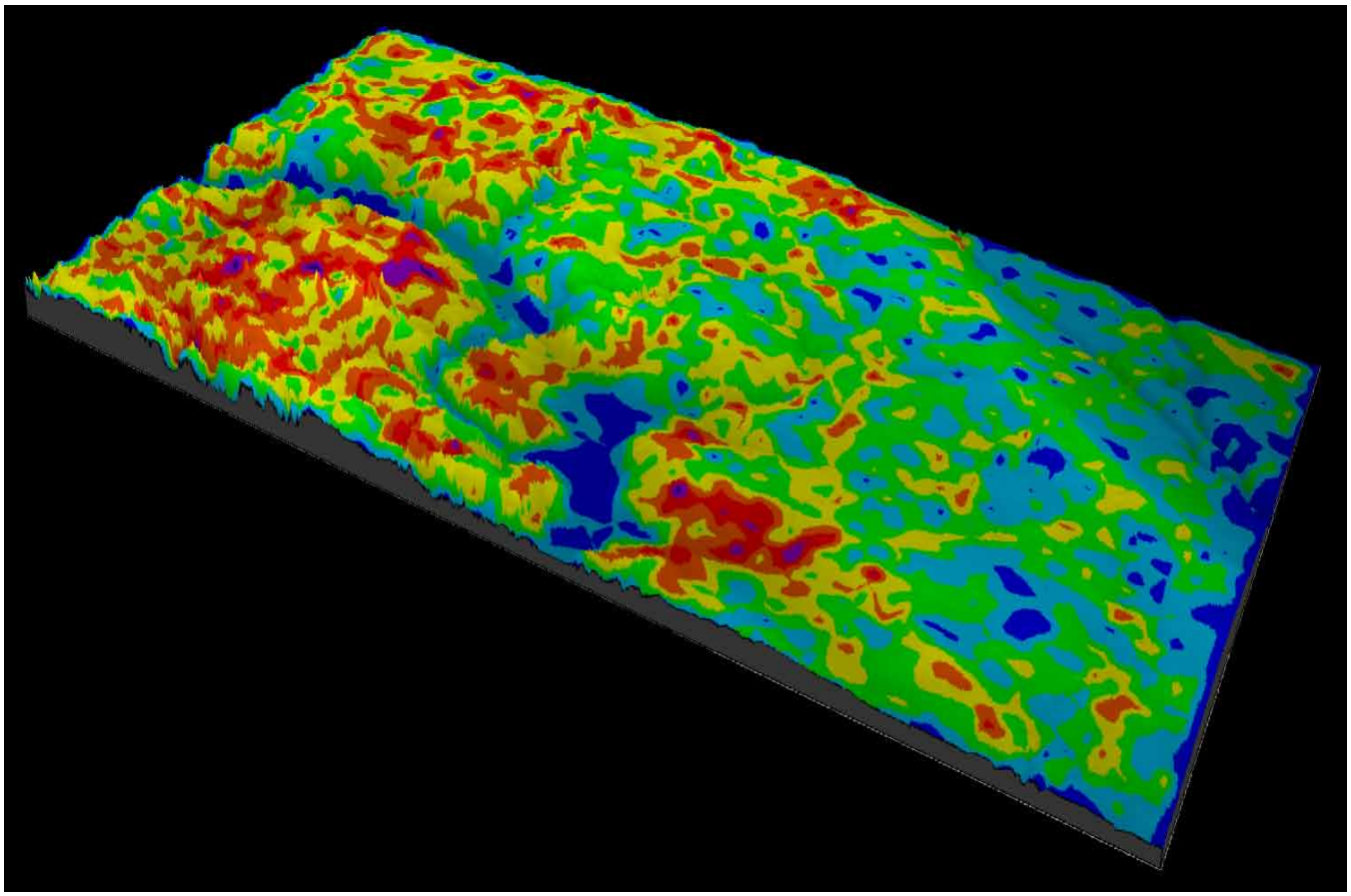
Fred J. Anderson



**GEOLOGIC INVESTIGATIONS NO. 70**
**NORTH DAKOTA GEOLOGICAL SURVEY**
**Edward C. Murphy, State Geologist**
**Lynn D. Helms, Director Dept. of Mineral Resources**
**2008**

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Fred J. Anderson

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**On the cover: Three-dimensional perspective view from the southeast towards the northwest across the Parshall Area showing 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 6,393 square mile area, centered around Mountrail County in the northeastern portion of the Williston Basin of 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, digital shaded relief data, aerial imagery, and LANDSAT-7 ETM+ data and imagery. Lineaments were 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 northeastern 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 western (coincident with the subsurface expression of the Nesson Anticline) and southeastern portions of the map area that correspond with areas of current oil and gas production and field development. Areas with a high degree of overall lineament density and low degree of oil and gas exploration and development in the north and south 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, Mr. Bruce Juenker, petroleum geologist with the N.D. Oil and Gas Division 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 the 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.

## 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 around Parshall, North Dakota in the northeastern portion of the Williston Basin. 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 are not field verified.

### Description of the Study Area

The Parshall study area was predefined as a custom 1:250,000 scale ($1^o$ x $2^o$) quadrangle covering an approximate 6,393 square mile area from $47^o$, 37', 30" to $48^o$, 37', 30" N. Lat and $103^o$, 22', 30" to $101^o$, 22', 30" W Long. This 1:250K quadrangle study area was centered on the Parshall and Sanish Oil Fields in the northeastern portion of the Williston Basin in northwestern North Dakota located between the towns of Stanley and Parshall (Figure 1). The Belden, Belden SE, Belden SW, and Sikes Dam 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).

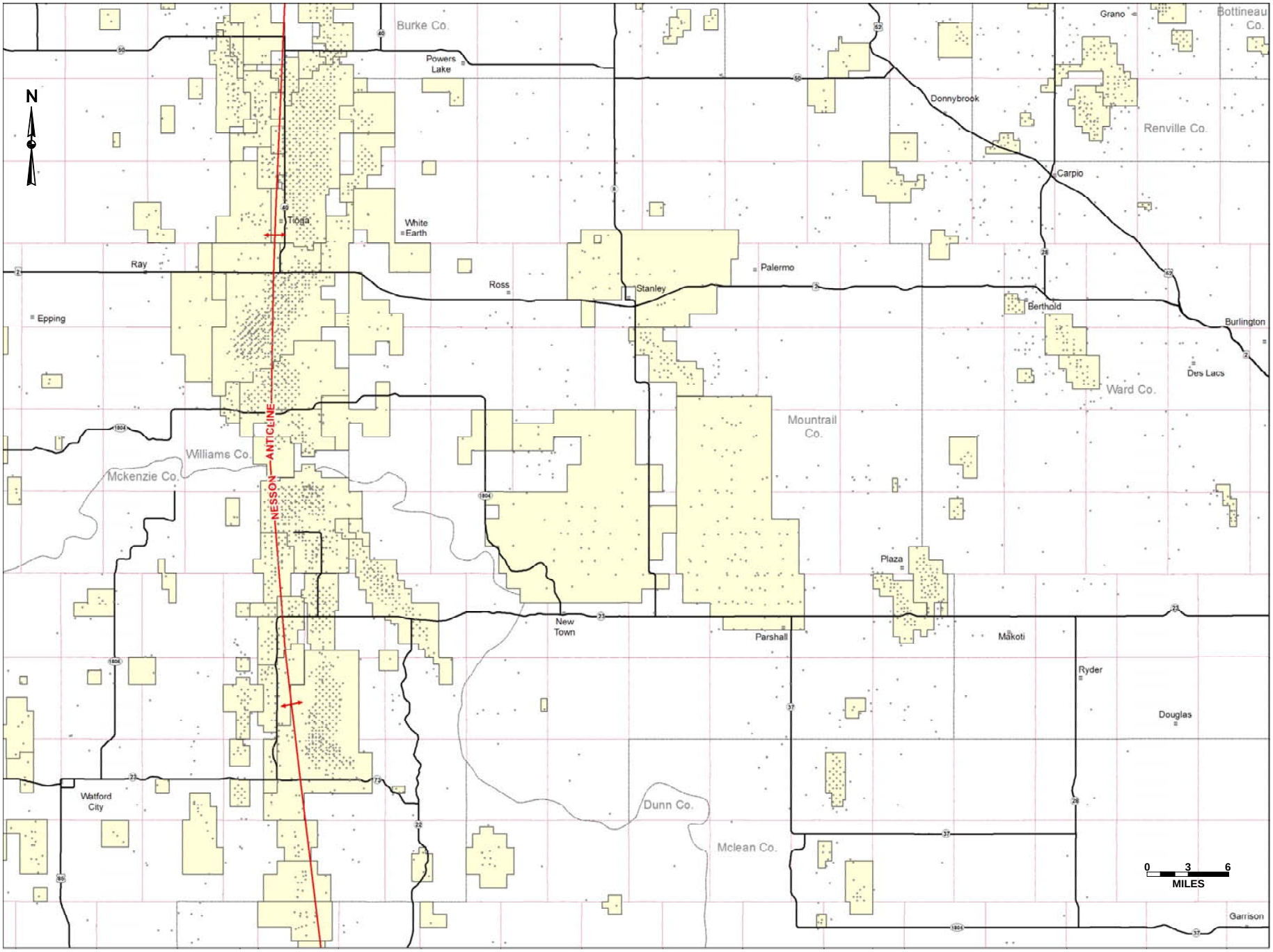



**Figure 1. Area of investigation in the Parshall Area in the northeastern portion of the Williston Basin in northwestern North Dakota. Locations of oil and gas fields are shown in yellow. Locations of oil and gas wells are shown in gray.**

## LINEAMENT MAPPING AND ANALYSIS METHODOLOGY

### Description of Data and Imagery Sources

Lineaments in the Parshall area 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 | Data Origination | 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, 2003 | National Agricultural Imagery Program (NAIP) | http://165.221.201.14/NAIP.html |
| Satellite Imagery Data | Summer, 2002 | 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 Parshall area (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 Parshall study 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 2003 USGS National Agricultural Image Program (NAIP) imagery (Plate III).

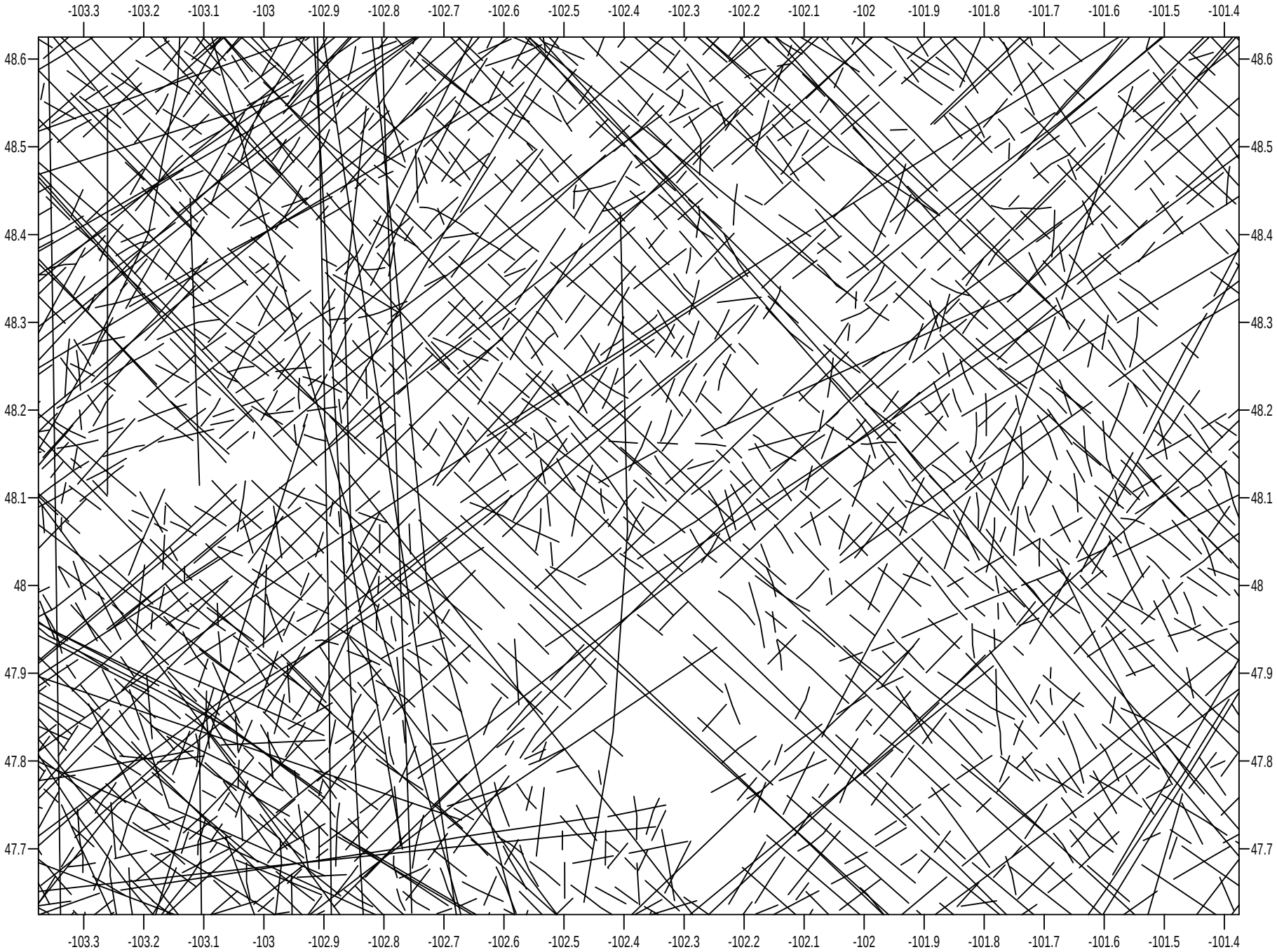



**Figure 2. Historical Lineaments (i.e., previously published) in the Parshall area.**

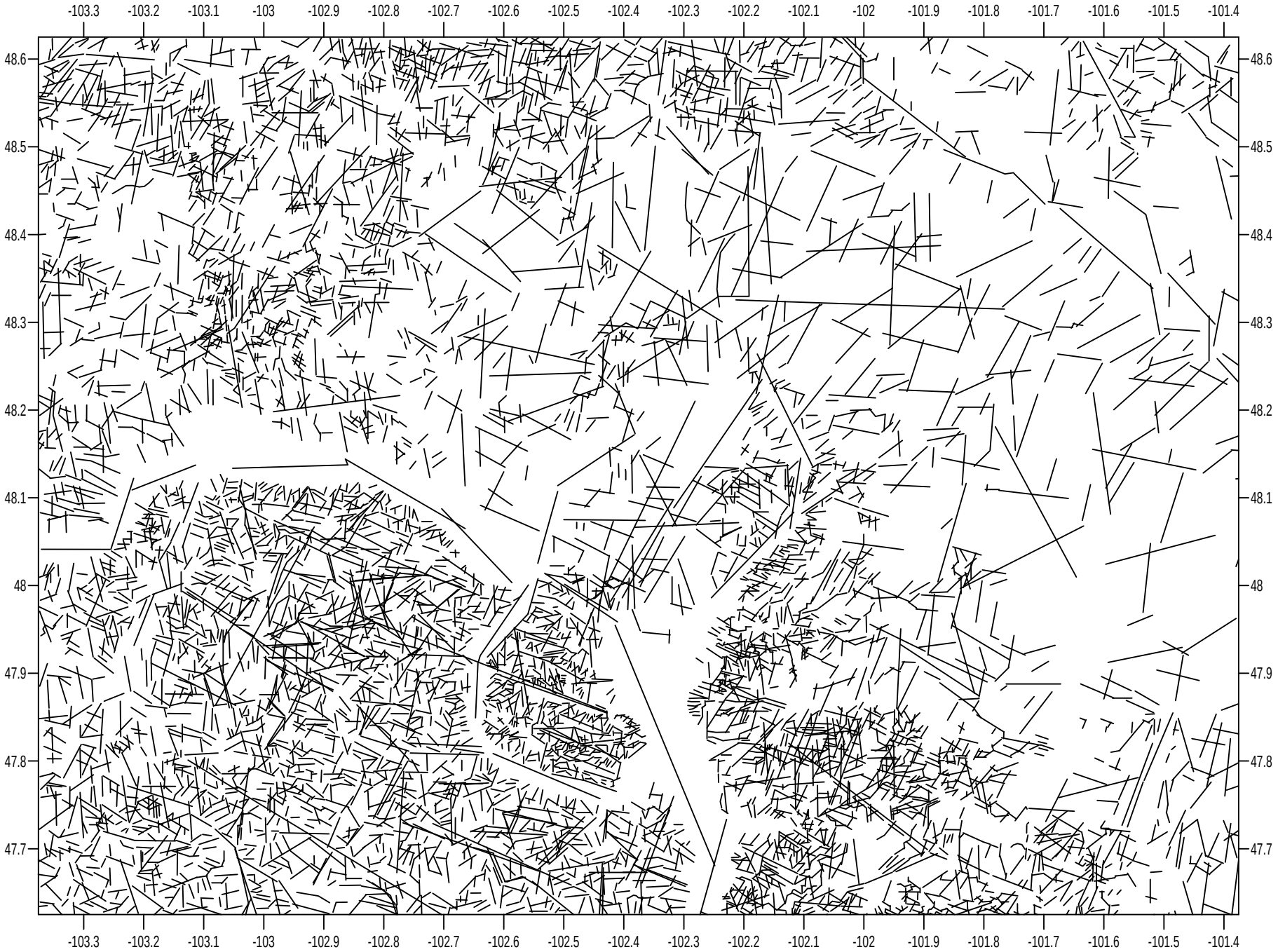



**Figure 3. Lineaments mapped from 1997 USGS NED shaded relief data for the Parshall area.**

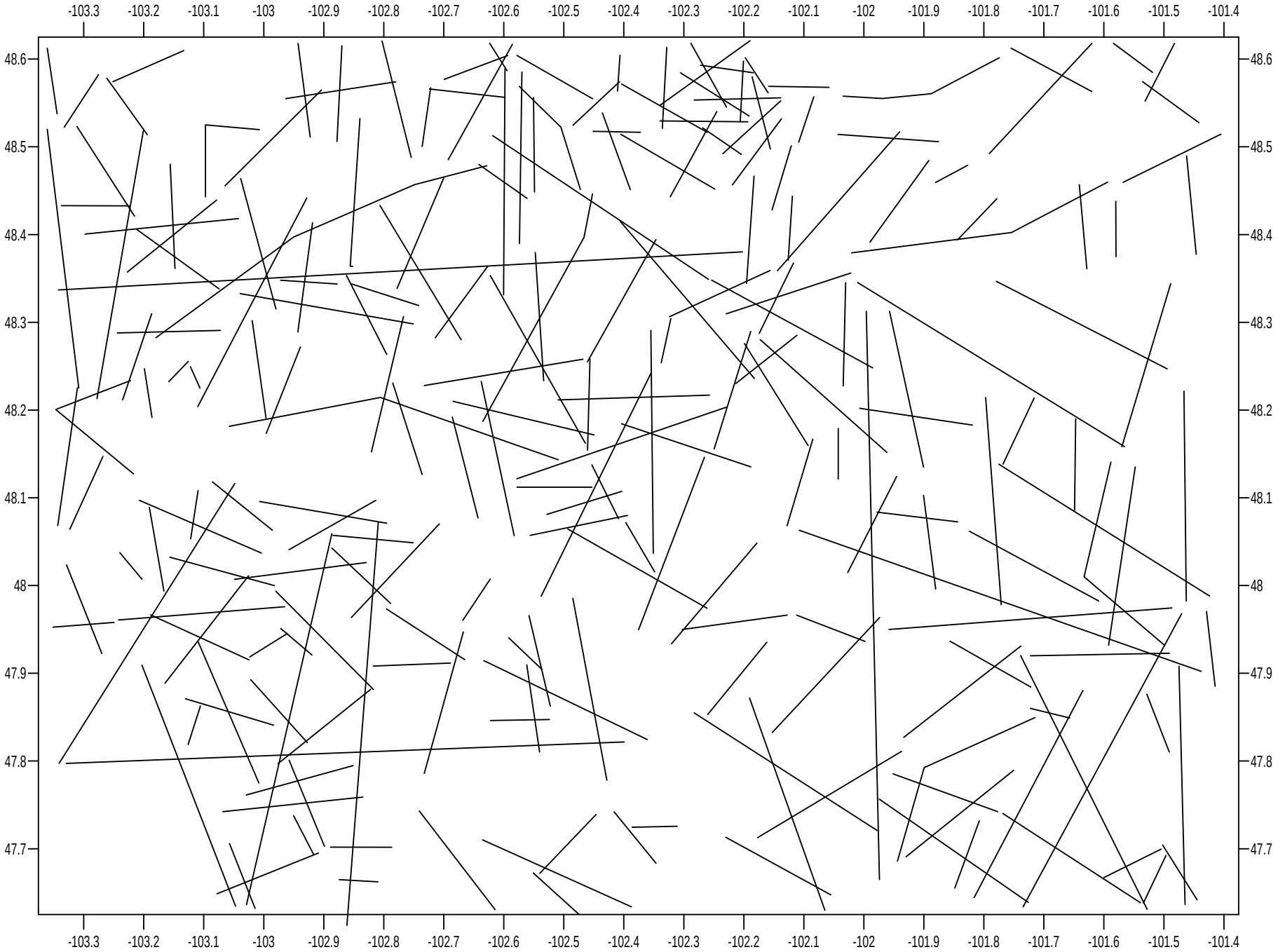



**Figure 4. Lineaments mapped from 2003 NAIP Imagery for the Parshall area.**

## 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 2002 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 Lineaments

All of the lineaments mapped from the 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. 8.0 and exported to ArcGIS for final digitizing and georeferencing. 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 PETRA v.3.1.9.8 using the Lineament Analysis and Rose Diagrams tool in the PETRA Map 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 relationships between mapped lineaments and current oil and gas production in the Parshall area 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. Nodes were determined at the center points of each of the sections in ArcGIS for

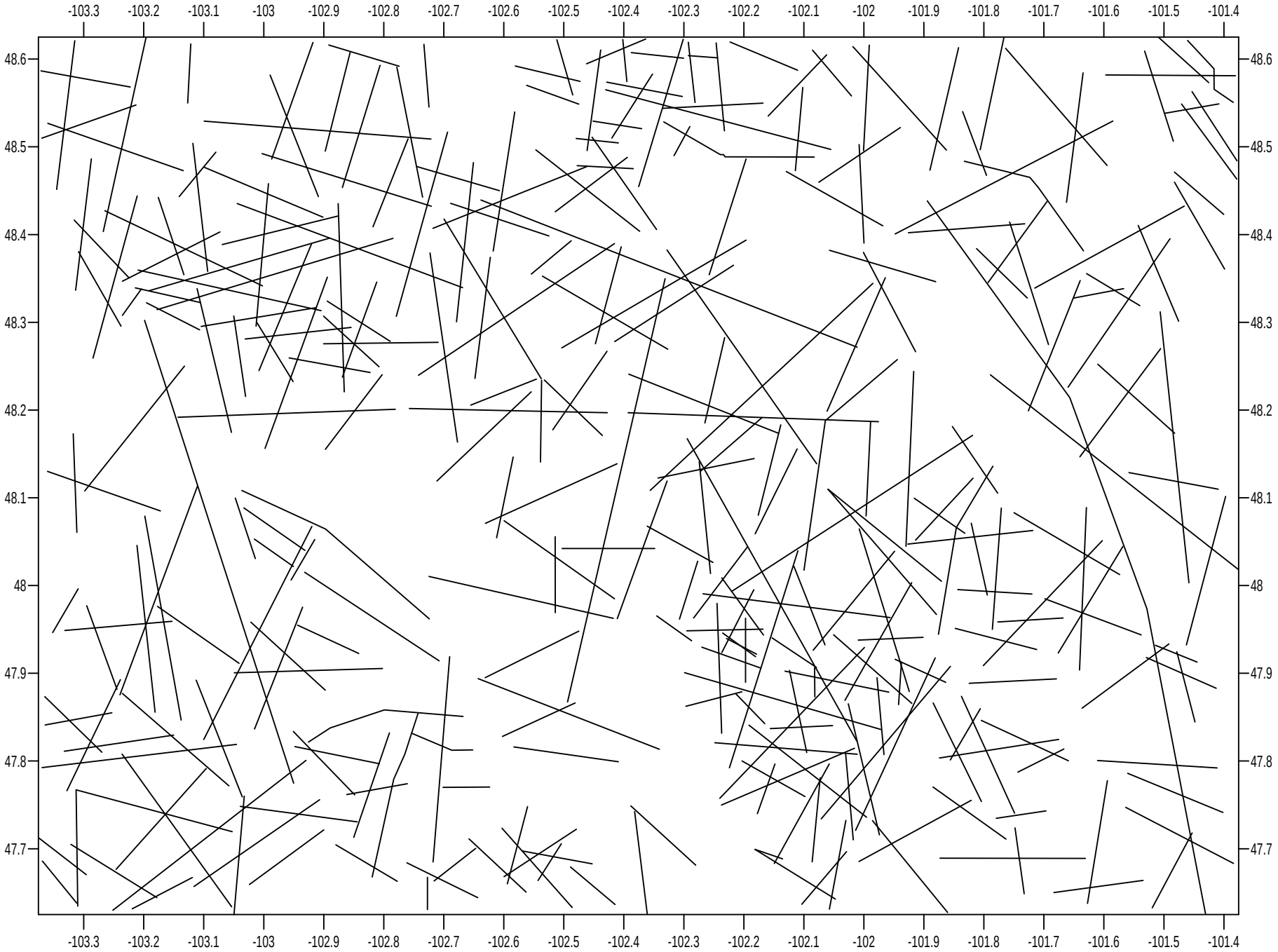



**Figure 5. Lineaments mapped from LANDSAT-7 ETM+ data (bands 2, 4, and 7) for the Parshall area.**

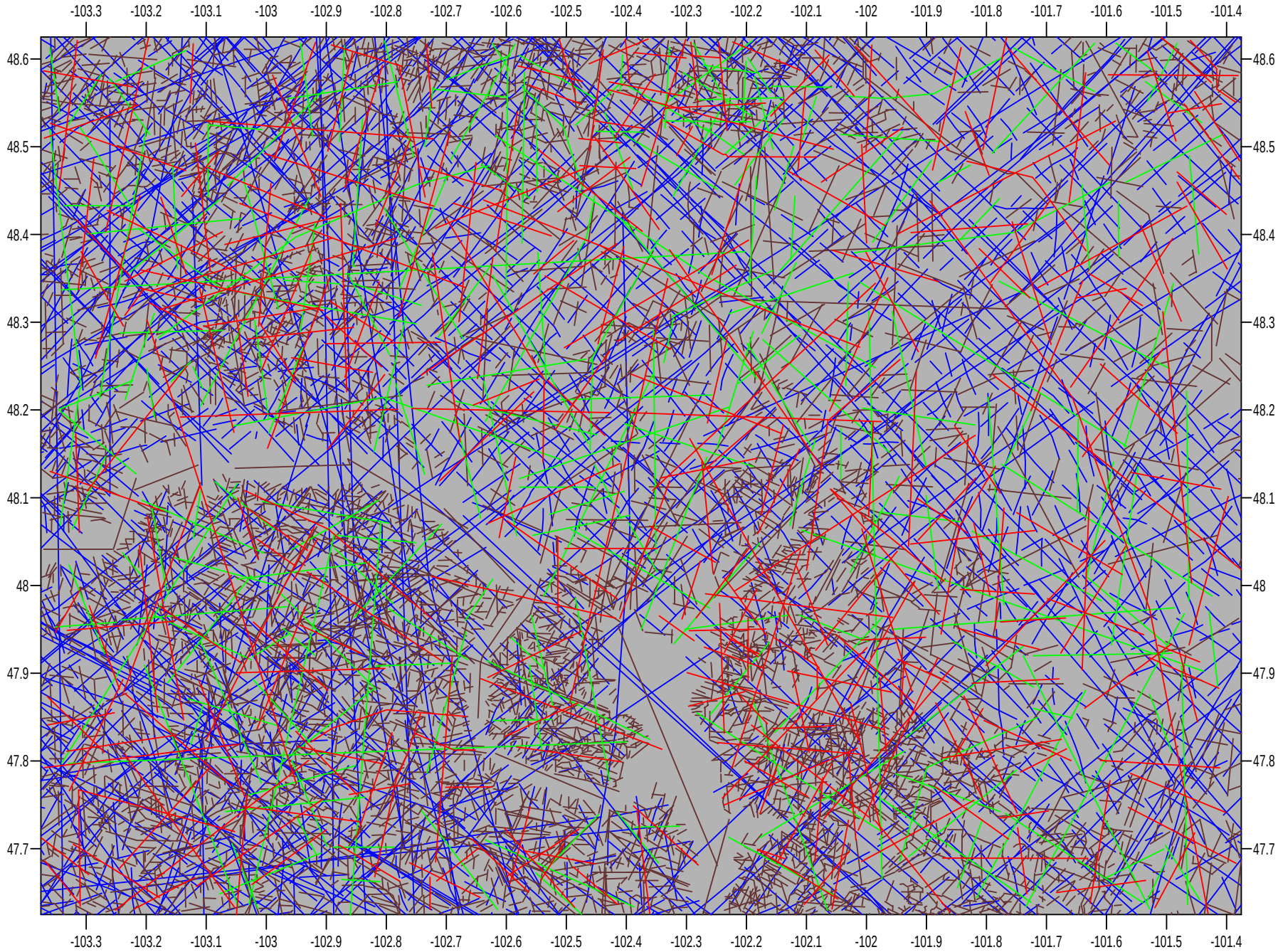
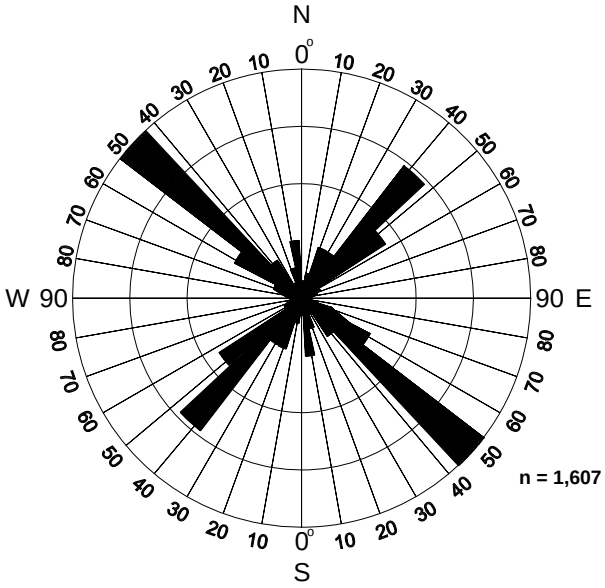
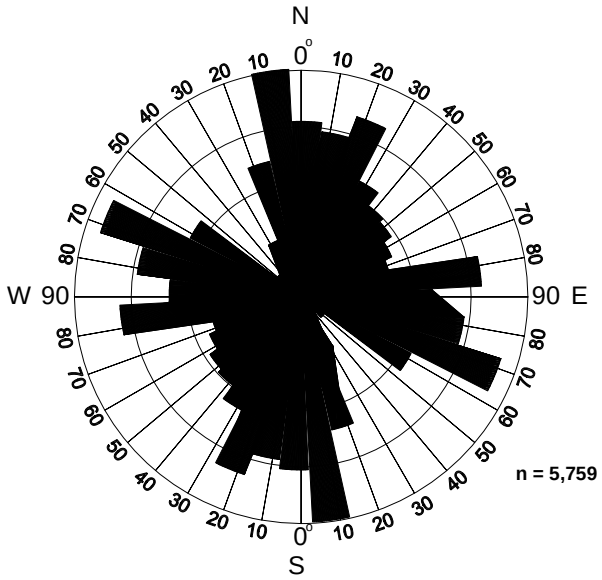


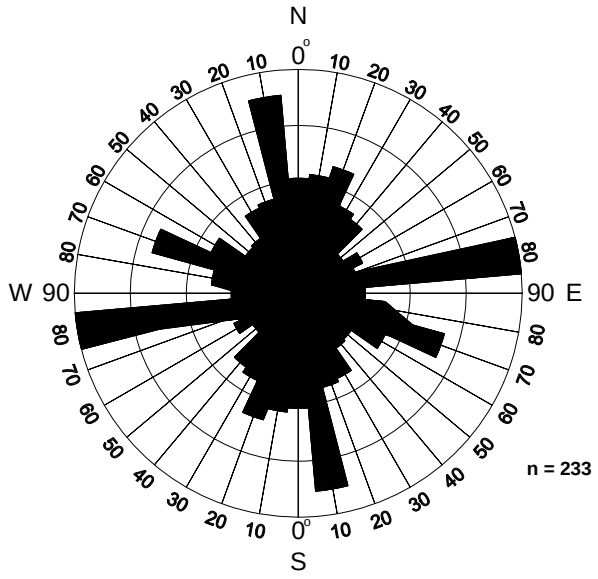

**Figure 6. Compilation of all lineaments mapped in the Parshall area. Historical lineaments (blue), lineaments mapped from shaded relief data (brown), NAIP Imagery (green), and LANDSAT-7 ETM+ data (red) are shown.**



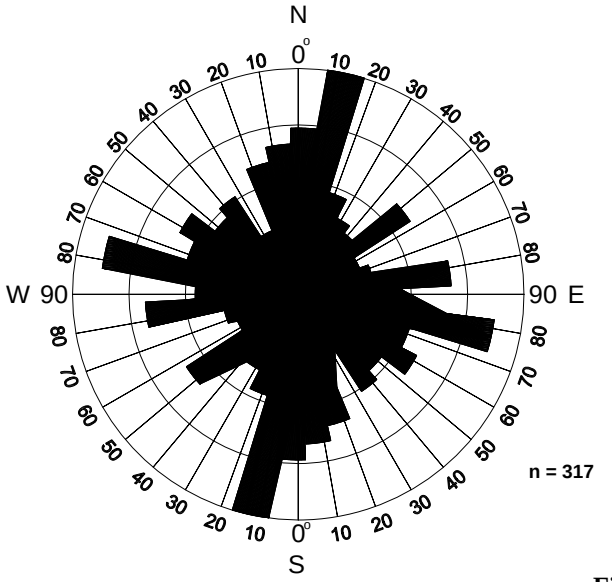

**Historical Lineaments**



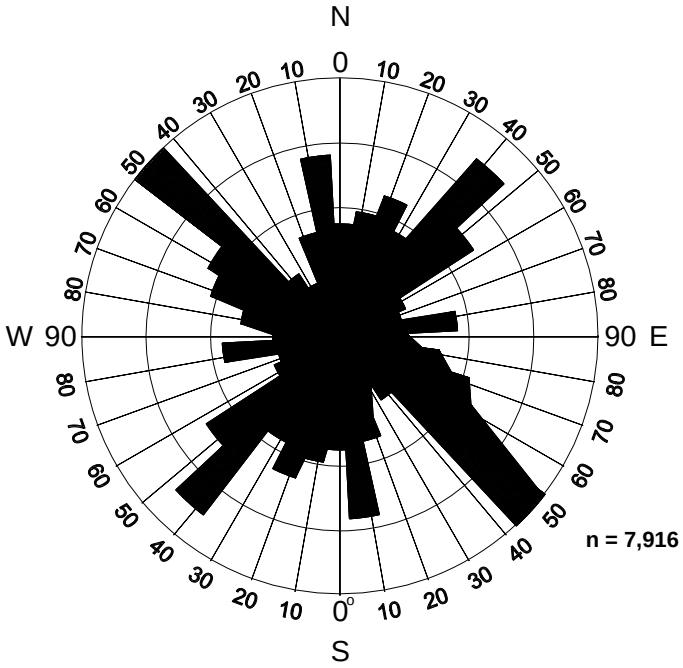

**Shaded Relief Lineaments**




**Aerial Imagery Lineaments**

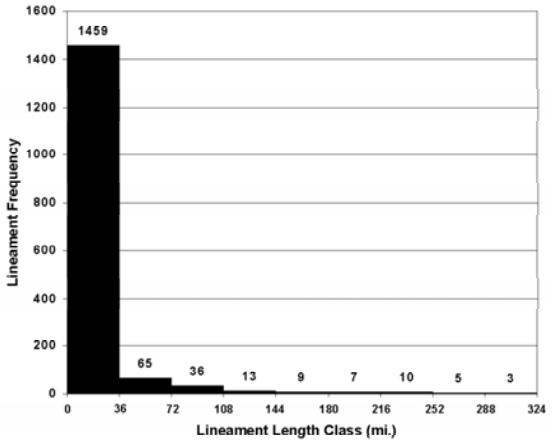



**LANDSAT-7 ETM+ Lineaments**

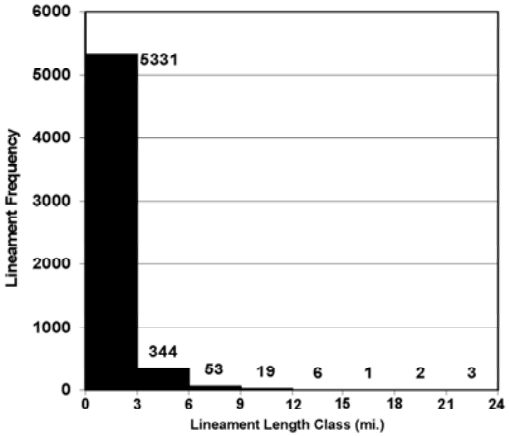



**Merged Lineaments**

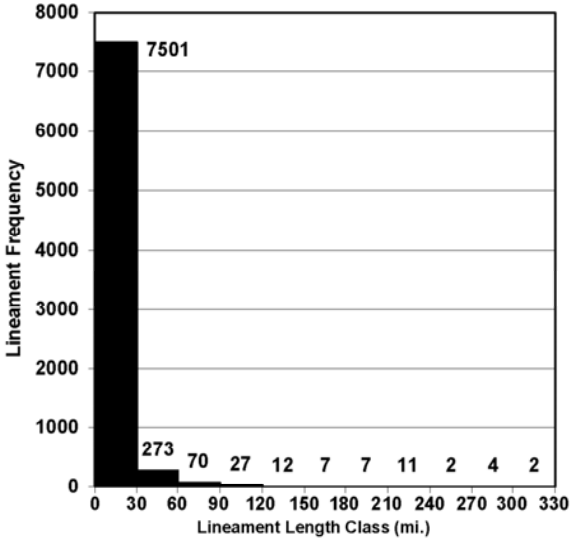
**Figure 7. Summary of mapped lineamnet orientation trends. Individual rose diagrams shown for each set of lineaments mapped from each individual data or image source. The merged lineaments rose diagram shows the dominant trends within all of theavailable data.**



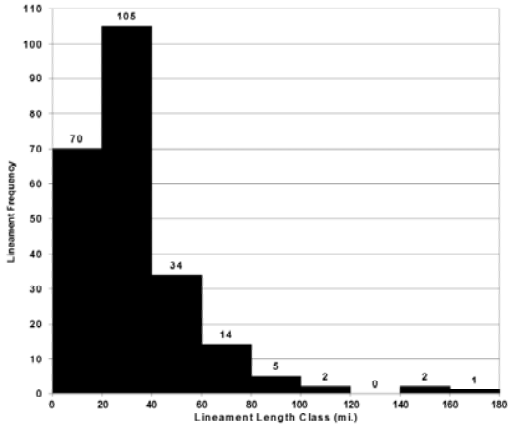

**Historical Lineaments**



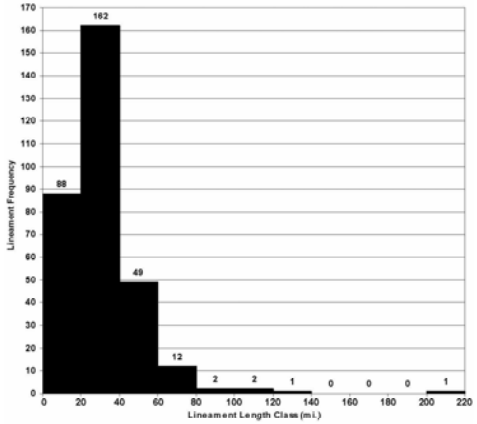

**Shaded Relief Lineaments**




**Merged Lineaments**




**Aerial Imagery Lineaments**




**LANDSAT-7 ETM+ Lineaments**

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

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. 8.0 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 into ArcGIS for final spatially correct projected mapping (Plate VI). The resulting density map shows several areas of generally higher lineament density in the western (coincident with the subsurface expression of the Nesson Anticline) portions of the map area that correspond with 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 in the Parshall area.

## RESULTS AND CONCLUSIONS

### Lineament Orientations

Lineament orientations (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$^o$ | 2$^o$ | 3$^o$ | 4$^o$ | |
| Historical Lineaments | 2 | N 45$^o$ W | N 42$^o$ E | -- | -- | 1$^o$ and 2$^o$ trends approximately Orthogonal. |
| 1997 NED Shaded-Relief Data | 4 | N 8$^o$ W | N 68$^o$ W | N 82$^o$ E | N 22$^o$ E | 1$^o$ and 2$^o$ trends Conjugate, 3$^o$ and 4$^o$ trends Conjugate. 1$^o$ and 3$^o$ trends Orthogonal, 2$^o$ and 4$^o$ trends Orthogonal. |
| 2003 NAIPAerial Imagery | 3 | N 80$^o$ E | N 10$^o$ W | N 70$^o$ W | N 20$^o$ E | 1$^o$ and 2$^o$ trends Orthogonal, 3$^o$ and 4$^o$ trends Orthogonal. |
| 2002 LANDSAT-7 ETM+ Satellite Data | 4 | N 12$^o$ E | N 77$^o$ W | -- | -- | 1$^o$ and 2$^o$ trends Orthogonal. |
| Merged Lineaments | 2 | N 47$^o$ W | N 42$^o$ E | N 7$^o$ W | N 22$^o$ E | 1$^o$ and 2$^o$ trends closed Orthogonal, 3$^o$ and 4$^o$ trends Conjugate. |

A primary (1$^o$) trend of N 45$^o$ W along with an orthogonal secondary (2$^o$) trend of N 42$^o$ E were identified 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.

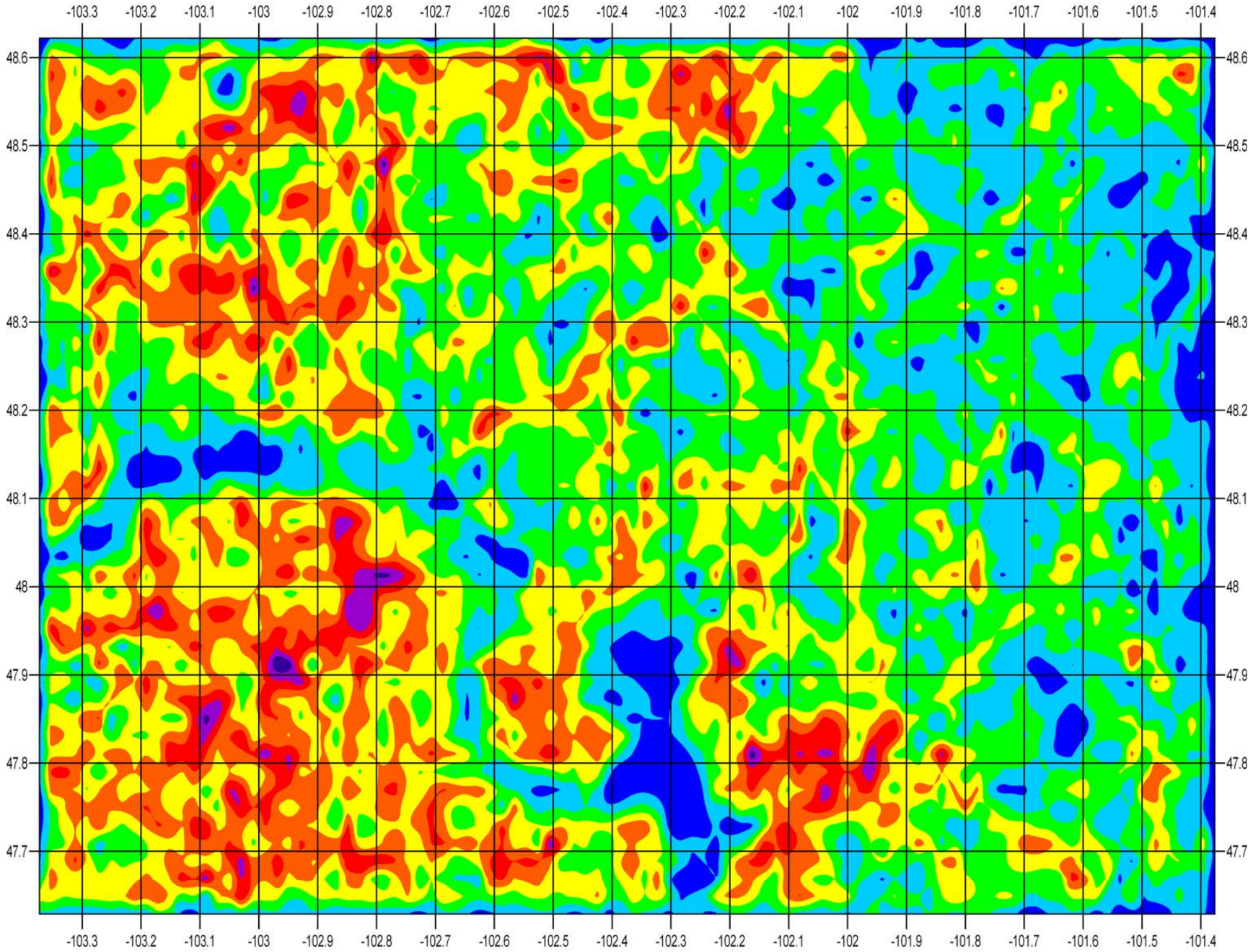



**Figure 9. Lineament density map of the Parshall Area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Intervals of increasing lineament density per unit area (i.e., total length of lineaments per square mile) are depicted across eight equal 2,000 foot intervals. 0-2,000-feet (dark blue), 2,000-4,000-feet (blue), 4,000-6,000-feet (green), 6,000-8,000 feet (yellow), 8,000-10,000 feet (orange), 10,000-12,000 feet (red), 12,000-14,000 feet (purple), and 14,000+ (dark purple).**

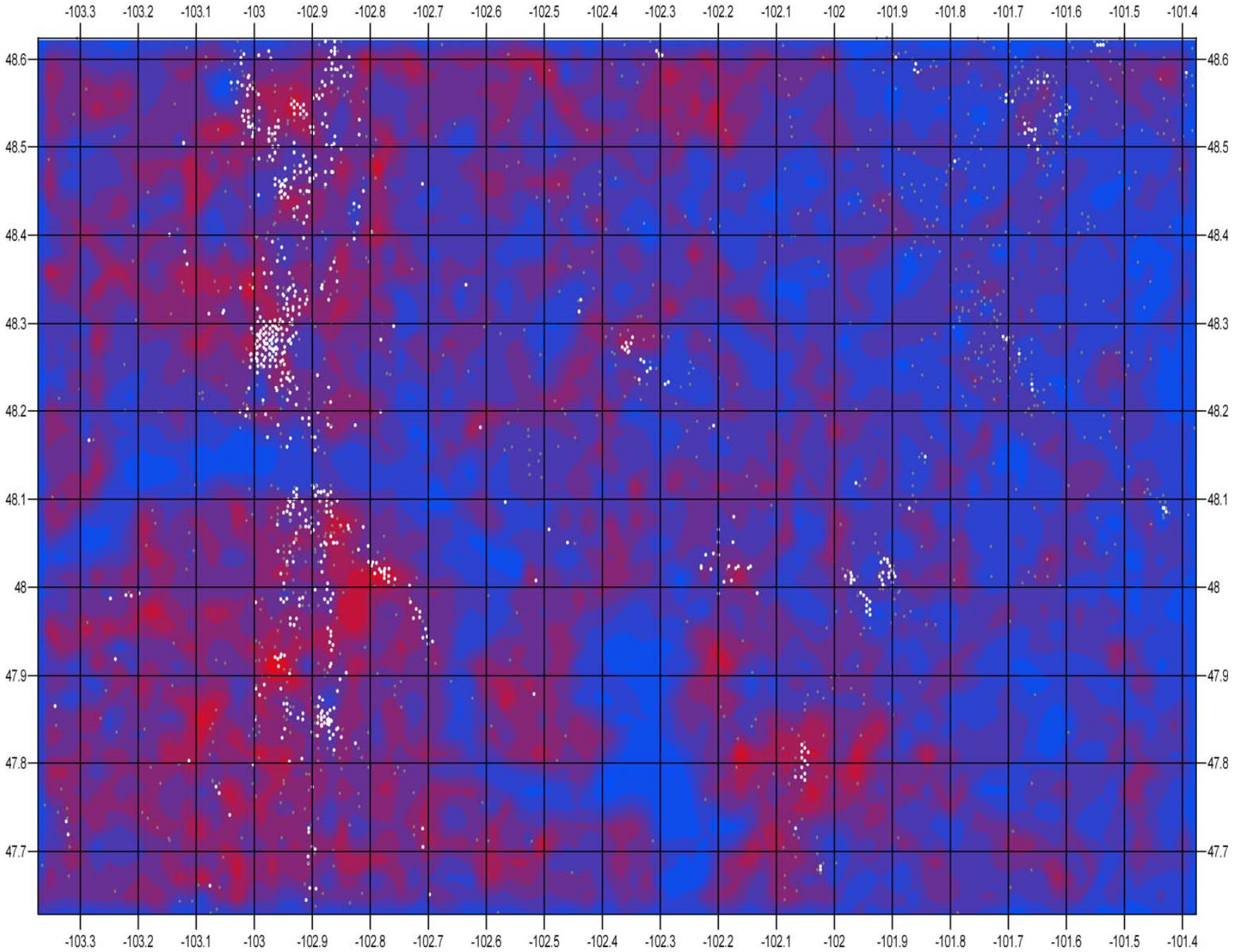



**Figure 10. Lineament density map of the Parshall Area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Areas of greater lineament density are shown as warmer (reds) colors. Areas of lower lineament density are shown as cooler (blues) colors. The locations of 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 would likely reorient the dominant trends towards a stronger N-S component.

Within the shaded relief data it was possible to interpret as many as four directional trends within the lineaments mapped (Figure 7) and possibly a fifth. A $1^{o}$ trend of N $8^{o}$ W along with a conjugate $2^{o}$ trend of N $68^{o}$ W was found, in addition to a tertiary $3^{o}$ trend of N $82^{o}$ E and conjugate quaternary ($4^{o}$) trend of N $22^{o}$ E (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 Pleistocene glaciation in the region.

Lineaments mapped from the 2003 NAIP aerial imagery exhibited as many as four directional trends (Figure 7) and possibly a fifth. A $1^{o}$ trend of N $80^{o}$ E along with an orthogonal $2^{o}$ trend of N $10^{o}$ W was found, in addition to a $3^{o}$ trend of N $70^{o}$ W and orthogonal $4^{o}$ trend of N $20^{o}$ E (Plate III-Figure 2). Lineament mapping from this image and data source was found to be the most difficult as agricultural land use in the region results in less natural tonal contrast and variation with an overall homogenization effect of individual pixel contrast (Plate III-Figure 1).

Mapping of lineaments from satellite imagery afforded a different look at the aerial image data and revealed two dominant orientation trends within the lineaments mapped (Figure 7). A $1^{o}$ trend of N $12^{o}$ E along with a slightly open orthogonal $2^{o}$ trend of N $77^{o}$ W was revealed (Plate IV-Figure 2). These 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 four and possibly five dominant orientations (Figure 7). A $1^{o}$ trend of N $47^{o}$ W along with a slightly closed orthogonal $2^{o}$ trend of N $42^{o}$ E was found, in addition to a $3^{o}$ trend of N $7^{o}$ W with a $4^{o}$ conjugate trend of N $22^{o}$ E (Plate V-Figure 2). It is apparent that the $1^{o}$ and $2^{o}$ orientation trends within the historical lineaments data set were strengthened by additional lineament mapping from other data and imagery sources. The $3^{o}$ and $4^{o}$ trends within the merged lineaments data set (Plate V-Figure 2) are reinforced from the $1^{o}$ and $3^{o}$ trends from the mapped shaded-relief lineaments (Plate II-Figure 2).

## 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 Parshall Area, North Dakota**

| Data Type | No. | Lineament Length Characteristics (mi.) | | | | Lineament Density (Lpsm/Lpst) |
|---|---|---|---|---|---|---|
| | | Min | Max | Mean | 1 Std. Dev. | |
| Historical Lineaments | 1,607 | 0.12 | 323.55 | 19.54 | 34.73 | 0.25/9.02 |
| NED Shaded-Relief Data | 5,759 | 0.015 | 23.99 | 1.40 | 1.42 | 0.9/32.35 |
| 2003 NAIPAerial Imagery | 233 | 5.98 | 172.42 | 32.91 | 23.31 | 0.04/1.31 |
| 2002 LANDSAT-7 ETM+ Satellite Data | 317 | 7.35 | 200.8 | 30.84 | 19.14 | 0.05/1.78 |
| Merged Lineaments | 7,916 | 0.015 | 323.55 | 7.19 | 19.34 | 1.24/44.47 |

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

A total of 1,607 lineaments were mapped in the Parshall Area as compiled from previous works (Figure 2). Lineament line lengths tend to follow a lognormal distribution (Figure 8) with the majority of lineaments falling within the 0 to 36 mi. lineament length class. Minimum lineament line length was 0.12 miles (mi.) with a maximum length of 323.55 mi. The mean lineament line length was 19.54 mi. with a standard deviation of 34.73 mi. Lineament density across the entire 1:250K area of investigation was 0.25 lineaments per square mile (Lpsm) which translates to approximately nine lineaments per township (i.e. 36 square miles).

A total of 5,759 lineaments were mapped in the Parshall Area as mapped from shaded relief data (Figure 3). Lineament line lengths in this data set also tend to follow a lognormal distribution (Figure 8) with the majority of lineaments falling within the 0 to 3 mi. lineament length class. Minimum lineament length was 0.15 mi. with a maximum length of 23.99 mi. The mean lineament line length was 1.4 mi. with a standard deviation of 1.42 mi. Lineament density across the entire 1:250K area was 0.9 Lpsm which translates to approximately 32 lineaments per township (Lpst).

A total of 233 lineaments were mapped in the Parshall Area as mapped from NAIP aerial imagery (Figure 4). Lineament line lengths in this data set also tend to follow a lognormal distribution (Figure 8) with the majority of lineament line lengths falling within the 20 to 40 mi. lineament length class. Minimum lineament line length was 5.98 mi. with a maximum length of 172.42 mi. The mean lineament line length was 32.91 mi. with a standard deviation of 23.31 mi. Lineament density across the entire 1:250K area was 0.04 Lpsm which translates to approximately 1.3 Lpst.

A total of 317 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 8) with the majority of lineament line lengths also falling within the 20 to 40 mi. lineament length class. Minimum lineament line length was 7.35 mi. with a maximum length of 200.8 mi. The mean lineament line length was 30.84 mi. with a standard deviation of 19.14 mi. Lineament density across the entire 1:250K area was 0.05 Lpsm which translates to approximately 1.8 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 at the 1:250,000 scale.

A total of 7,916 lineaments were mapped in the Parshall Area as compiled from all data and imagery sources (Figure 6). Lineament line lengths continue to follow a lognormal distribution (Figure 8) with the majority of lineament line lengths falling within the 0 to 30 mi. lineament length class. Minimum lineament line length was 0.015 mi., as reported from the NAIP imagery lineament data, with a maximum length of 323.55 mi., as reported from the historical lineaments data, The mean lineament line length was 7.19 mi. with a standard deviation of 19.34 mi. Lineament density across the entire 1:250K area was 1.24 Lpsm which translates to approximately 44.5 Lpst.

**Lineament Density Mapping**

Lineament densities were calculated for each square mile within the area of investigation as the sum of all 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 eight lineament density classes (Figure 9). The resulting lineament density map can be partitioned from west to east into three separate areas of successively decreasing lineament density. The western one-third from about -102.65 W. long. to the western edge of the map area is the area where lineament densities are greatest and are coincident with the subsurface expression of the Nesson Anticline. The central portion of the map area from around -102.65 to -101.85 W. long. has several areas of increased lineament density such as in the southern and northernmost portions. A rough lattice like pattern begins to appear in this region which is likely coincident with basement "block-type" features. The eastern one third of the map area from around -101.85 W. long. to the eastern edge of the map area has the lowest overall lineament density, but the latticework pattern of NW and NE trending lineaments remains visible.

The total area covered by the custom 1:250,000 scale Parshall Area Quadrangle is 6,393 square miles. Of this total, the largest Lineament Density Area (LDA) is the Class-VI LDA which is dispersed throughout the western two-thirds of the map area (Table 4). The Class-IV to Class-I LDAs are highly visually correlative to currently producing oil and gas wells. The Class-VI to Class-VIII LDAs are conversely highly visually correlative to non-producers (Plate VI).

**Table 4. Map Surface Area Covered by Lineament Density Class**

| Lineament Density Class | Lineament Density Range (Lpsm) | Map Area Covered ($mi^2$) |
|---|---|---|
| **Class-I** | 2.7 – 3.4 | 3 |
| **Class-II** | 2.3 – 2.7 | 37 |
| **Class-III** | 1.9 – 2.3 | 231 |
| **Class-IV** | 1.5 – 1.9 | 874 |
| **Class-V** | 1.1 – 1.5 | 1,613 |
| **Class-VI** | 0.8 – 1.1 | 1,960 |
| **Class-VII** | 0.4 – 0.8 | 1,353 |
| **Class-VIII** | 0.0 – 0.4 | 323 |
| Total Map Area | | 6,394 |

(Lpsm): Total of all lineament lengths 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 good qualitative correlation between areas of producing wells and areas of high lineament density, particularly in the western and central 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 eastward in the map area that the distribution of non-producing wells tend to be located in areas of relatively low lineament density. This may be attributed to surficial geomorphological effects, resulting from Pleistocene glaciation in the area (Clayton, 1972), which may tend to mask or subdue overall lineament expression at the surface.

## 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 producing wells appear to be located in areas of greater lineament density, a higher amount of lineament intersection, 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.

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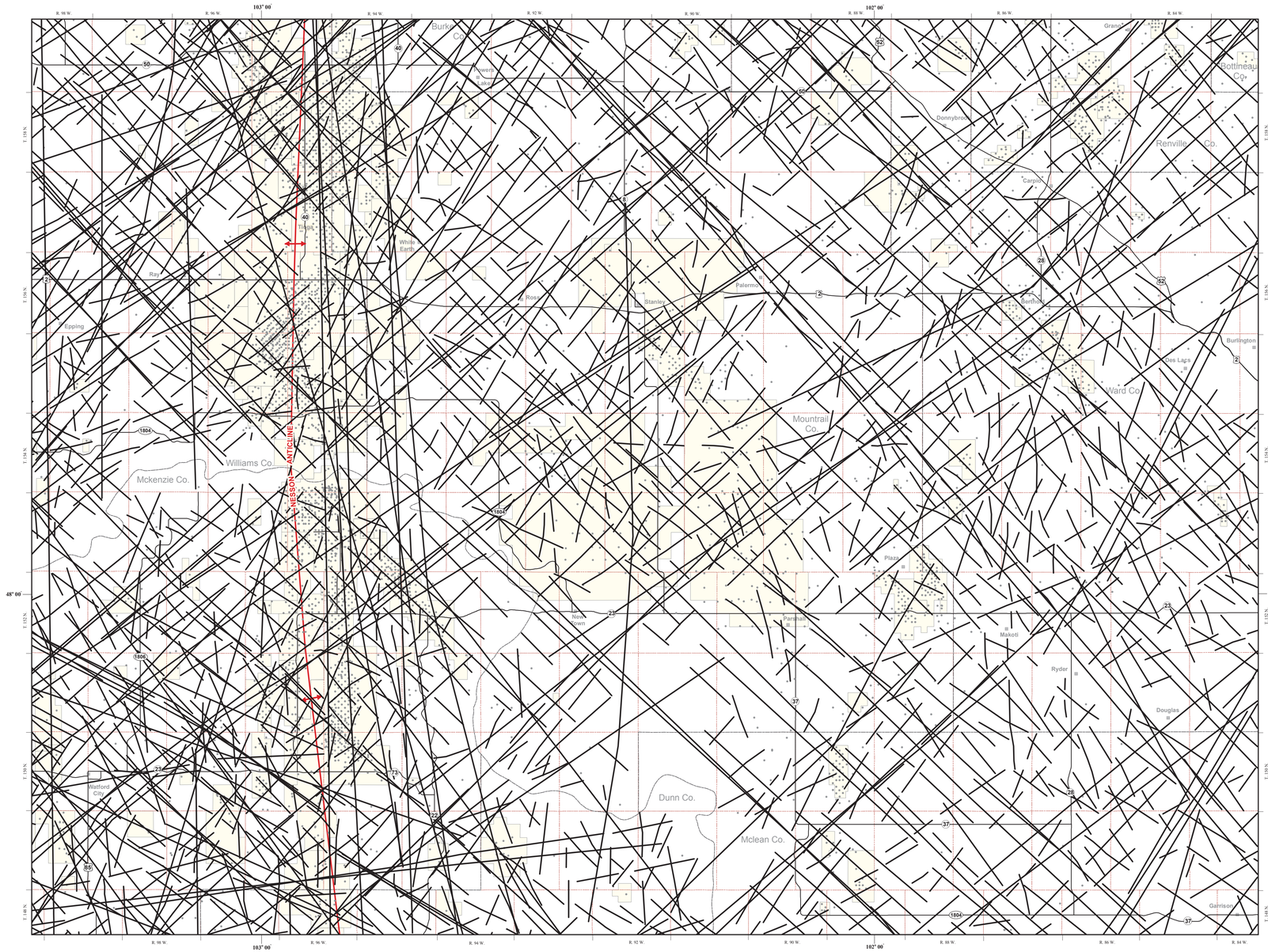
North Dakota Geological Survey
Geologic Investigations No. 70 - Plate I

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

# PLATE I - HISTORICAL LINEAMENTS MAPPED IN THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**




## HISTORICAL LINEAMENTS IN THE PARSHALL AREA COMPILED AND MERGED FROM PREVIOUS STUDIES

This map presents the results and discussion of a segment of a contemporary lineament mapping and analysis study of the Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. Historical lineaments mapped during previous studies by several authors over the last four decades, include: 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, Kent, 1974, Thomas, 1974, and Erickson, 1970, (Figure 1). These lineaments were digitally extracted from their original published sources (Heinle, 2007), compiled, and merged into a single historical lineament coverage for the Parshall study area (Figure 1). Previously mapped lineament centerline traces are presented here at a scale of 1:250,000, independent of their original mapped scales. Lineament analysis of 1,608 individual lineaments in this compilation reveals two distinct lineament orientation trends (Figure 2). A primary ($1^o$) orientation of N 42° E (S 42° W), and a secondary ($2^o$) orientation of N 42° E (S 42° W) (Figure 2.) The distribution of lineament length follows a general log-normal distribution with the majority of lineaments (91%) falling within the zero to 36 mile (six standard townships) lineament length range. Overall, over 97% of the lineaments mapped were less than 144 miles in length (Figure 3). The overall density of lineaments within the study area (i.e., lineaments mapped per unit area) is 0.25 lineaments per square mile (approximately nine lineaments per township). Lineament density is generally greater in the eastern and western (coincident with the relative location of the Nesson Antilcline) portions of the study area, but overall is relatively uniform in character. This may be attributed partially to the various scales that these lineaments were originally mapped at which were generally of much smaller scale (i.e. 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 central Mountrail County south of Stanley in the Sanish and Parshall field areas. Lineaments mapped are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree and extent of glaciation). Lineament intersections are depicted as a variation of lineament density (Figure 4) 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 area of the Nesson Anticline). Areas with a higher relative lineament intersection density, and a corresponding small drilling exploration footprint, include area south west of the southern nose of the Nesson Anticline near Watford City, ND in the southwestern corner of the map area and within the entire central portion of the map area. Several of the smaller fields in the eastern portion of the map area are somewhat surrounded by paths of lineament intersections which may provide a hint to deeper structure. Lake Sakakawea is the major surface water feature found in the southwest portion of the study area. The Souris and Des Lacs Rivers are present in the far northeastern corner of the study area. These features are not displayed on the 1:250,000 scale lineament map shown at left.

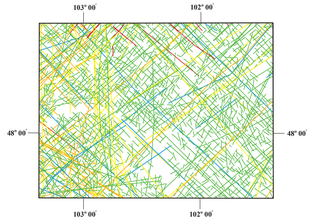



Figure 1. Index map of historical (i.e. previously published) lineaments, grouped by color by the decade in which they were mapped, in the Parshall study area in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineaments by Penner and Cosford, 2006, and Kreis and Kent, 2000 are shown in red, Freisatz, 1995, Gibson, 1995, Inden and Burke, 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 Haman, 1975, Kent, 1974, Thomas, 1974, and Erickson, 1970 in blue.

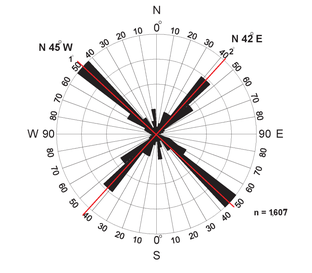



Figure 2. Rose diagram of 1,607 individual lineament orientations mapped from previous lineament studies in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. There are two dominant orientations ($1^o$ and $2^o$), displayed within the data of N 45° W (S 45° E), and N 42° E (S 42° W).

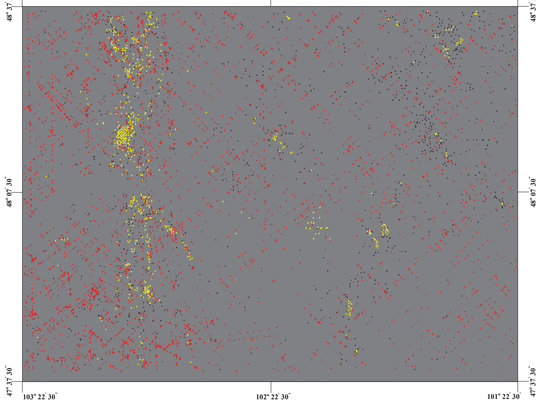



Figure 4. Map of lineament intersections (shown in red) overlain with currently producing wells (shown in yellow) and dry holes (shown in black) displaying the relationship between areas where lineament intersections are prevalent or lacking and areas of current production and field development.

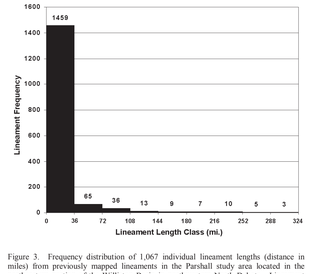
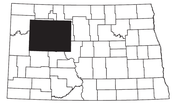



Figure 3. Frequency distribution of 1,067 individual lineament lengths (distance in miles) from previously mapped lineaments in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineament distributions are shown for nine lineament length classes from zero to 324 miles in 36 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 30 miles in length.



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 47° 22' 30"

1927 North American Datum
Central meridian 102° 07' 30"

**EXPLANATION**

**Geologic Features**

- Lineaments
- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

**Other Features**

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

N W E S

Department of Mineral Resources

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

# PLATE II - LINEAMENTS MAPPED FROM SHADED RELIEF DATA IN THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**


## LINEAMENTS IN THE PARSHALL AREA DERIVED FROM SHADED RELIEF MAP INTERPRETATION

This map presents the results and discussion of a segment of a contemporary lineament analysis of the Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. Lineaments were mapped and digitized from a digital, shaded-relief image, of USGS National Elevation Data (NED), set with a vertical exaggeration of 9X (Figure 1). Mapping of lineaments 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 5,759 individual lineaments reveals four distinct orientation trends (Figure 2). A primary (1°) trend of N 8° W (S 8° E), a secondary (2°) trend of N 68° W (S 68° E), a tertiary (3°) trend of N 82° E (S 82° W), and a quaternary (4°) trend of N 22° E (S 22° W). The distribution of lineament length follows a log-normal distribution with the majority of lineaments (93%) falling within the 0-3 mile lineament length size range (Figure 3). The density of lineaments (i.e. lineaments mapped per unit area) is generally greater in the western and southeastern portions of the map area with an overall lineament density of 0.9 lineaments per square mile (~32 lineaments per township). In this map, the general distribution of lineaments can be grouped into eight areas of seven similar individual lineament density classes (in decreasing order of lineament density from I to VII). These lineament density areas (LDAs) exhibit similar lineament character (i.e., lineament density, length, degree of connectivity) are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree of glaciation). Lineament density is observed to be greatest in the western (LDAs I & II) and southeastern (LDA-III) portion of the map area and is generally coincident with known geologic structure (i.e. the Nesson 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. LDAs-I & II contain areas of significant oil and gas field development associated with southern portion of the Nesson Anticline. LDA-V is located in the center of the map area. LDAs-VI and VII are located in the north and eastern portions of the map area coincident where a limited amount of oil and gas field development has occurred. Overall lineament density appears to be greater in areas of currently producing wells and relatively lower in areas of limited or no production.

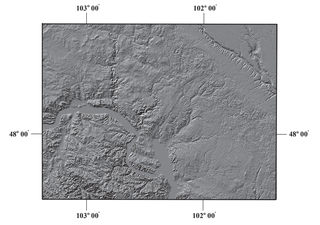



Figure 1. Index map of USGS NED shaded relief data for the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota.

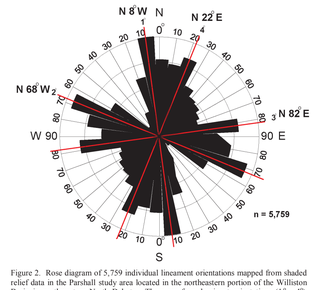



Figure 2. Rose diagram of 5,759 individual lineament orientations mapped from shaded relief data in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. There are four dominant orientations (1° - 4°), displayed within the data of N 8° W (S 8° E), N 68° W (S 68° E), N 82° E (S 82° W), and N 22° E (S 22° W).

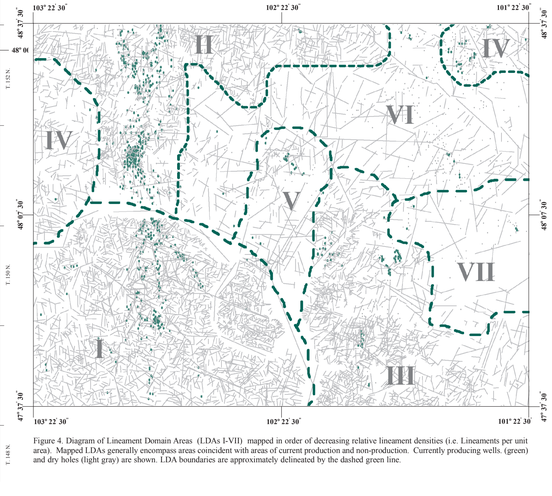



Figure 4. Diagram of Lineament Domain Areas (LDAs I-VII) mapped in order of decreasing relative lineament densities (i.e. Lineaments per unit area). Mapped LDAs generally encompass areas coincident with areas of current production and non-production. Currently producing wells. (green) and dry holes (light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

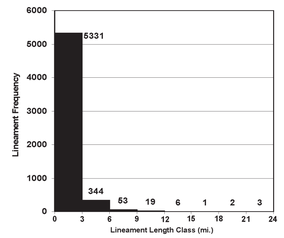
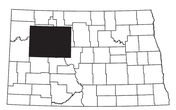



Figure 3. Frequency distribution of 5,759 individual lineament lengths (distance in miles) from lineaments mapped from shaded relief data in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineament distributions are shown for eight lineament length classes from zero to 24 miles in 3 mile intervals or classes. This distribution is heavily influenced by lineaments less than 3 miles in length that are commonly associated with drainage network development in exposed Cenozoic sediments in the southern portions of the map area.



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 47° 22' 30"

1927 North American Datum
Central meridian 102° 07' 30"

**EXPLANATION**

**Geologic Features**

- Lineaments
- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

**Other Features**

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

N W E S

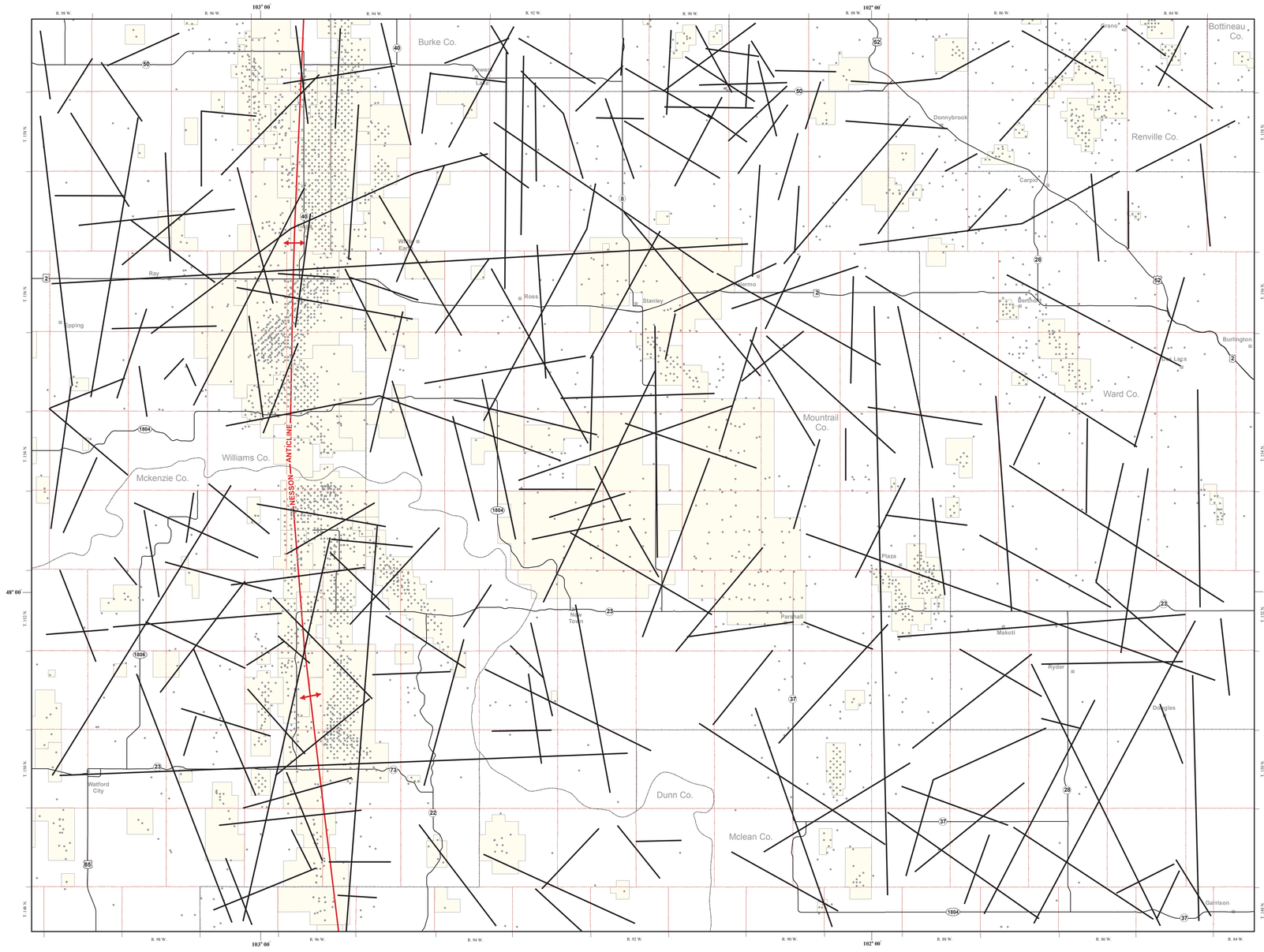
Department of Mineral Resources

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

# PLATE III - LINEAMENTS MAPPED FROM NAIP IMAGERY IN THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**




## LINEAMENTS IN THE PARSHALL AREA DERIVED FROM AERIAL IMAGE MAP INTERPRETATION

This map presents the results and discussion of a segment of a contemporary lineament mapping and analysis study of the Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. Lineaments were digitally mapped and digitized from a digital aerial image mosaic of the study area, compiled from 2003 USGS 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. Lineament analysis of 233 individual lineaments reveals four distinct orientations (Figure 2). A primary (1°) orientation of N 80° E (S 80° W), a secondary (2°) orientation of N 10° W (S 10° E), a tertiary (3°) orientation of N 70° W (S 70° E) and a quaternary (4°) orientation of N 20° E (S 20° W). The distribution of lineament length follows a general log-normal distribution with the majority of lineaments (45%) falling within the 20 to 40 mile lineament length range. Overall, nearly 90% of the lineaments mapped were less than 80 miles in length (Figure 3). The overall density of lineaments within the study area (i.e., lineaments mapped per unit area) is 0.036 lineaments per square mile (approximately 1.3 lineaments per township). Lineament density is generally greater in the northern and eastern 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 contrasts 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, particularly in central Mountrail County south of Stanley in the Sanish and Parshall field areas. Lineaments mapped are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree and extent of glaciation). 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 area of the Nesson Anticline). Areas with a higher relative lineament density, and a corresponding small drilling exploration footprint, include area south of Ryder, ND in the southwestern corner of the map area and area north of Stanley in the north-central portion of the map area. Several of the smaller fields in the eastern portion of the map area are somewhat bound by commonly two or more mapped lineaments which may provide a hint to deeper structure. Lake Sakakawea is the major surface water feature found in the southwest portion of the study area. The Souris and Des Lacs Rivers are present in the far northeastern corner of the study area. These features are not displayed on the 1:250,000 scale lineament map shown at left.

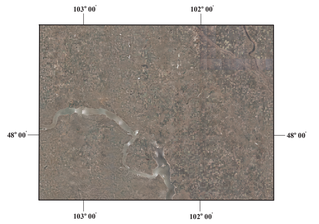



Figure 1. Map of 2003 NAIP aerial imagery used for lineament mapping in the Parshall study area in the northeastern portion of the Williston Basin in northwestern North Dakota. Agricultural land use can be seen as the patchwork pattern throughout the northeastern two-thirds of the study area.

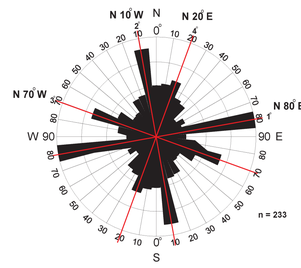



Figure 2. Rose diagram of 233 individual lineament orientations mapped from 2003 NAIP aerial imagery of the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. There are four dominant orientations (1°, 2°, 3°, and 4°) displayed within the data of N 80° E (S 80° W), N 10° W (S 10° E), N 70° W (S 70° E), and N 20° E (S 20° W).

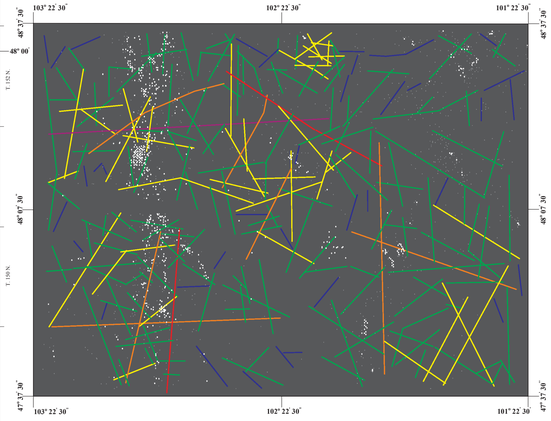



Figure 4. Lineament intersection map displaying lineaments in six classes of lineament intersection. Discontinuous lineaments (i.e. lineaments that do not meet or intersect another lineament along the path of the lineament) are shown in blue, lineaments with intersections of 1 - 3 intersections per lineament path are shown in green, 4 - 6 yellow, 7 - 9 orange, 10 - 12 red, and lineaments with 13 intersections or more are shown in purple. Producing wells (shown in white) display linear trends similar to mapped lineament orientations. The distribution of dry holes (shown in gray) tend to be in areas where no mapped lineaments occur.

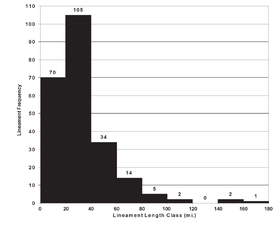
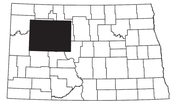



Figure 3. Frequency distribution of 233 individual lineament lengths (distance in miles) mapped from 2003 NAIP aerial imagery of the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineament distributions are shown for nine lineament length classes from zero to 180 miles in 20 mile intervals or classes.



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20
Miles
0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 47° 22' 30"
1927 North American Datum
Central meridian 102° 07' 30"

**EXPLANATION**

**Geologic Features**
- Lineaments
- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

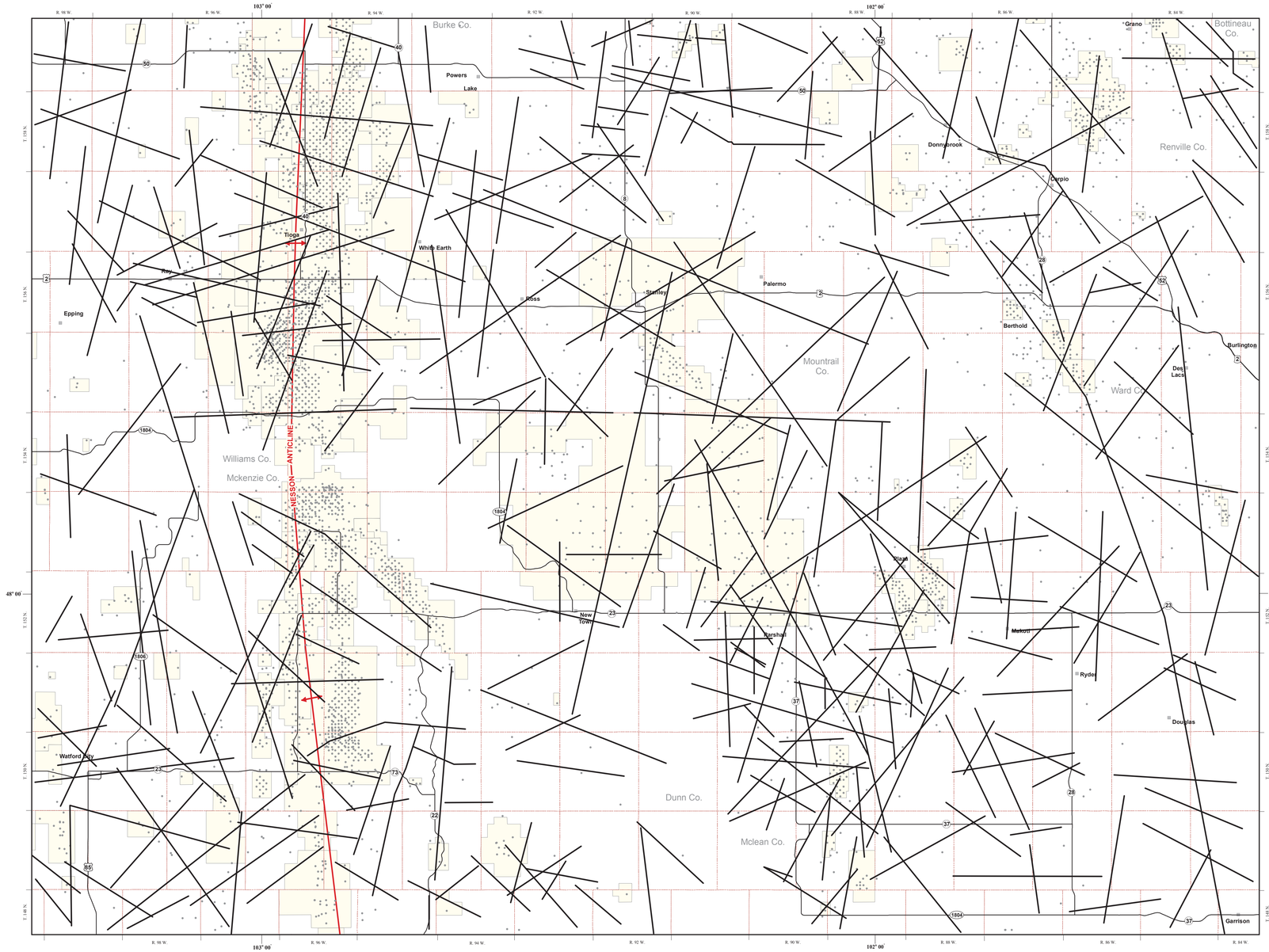
**Other Features**
- Towns
- Township Boundaries
- County Boundaries
- State and US Highways

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

# PLATE IV - LINEAMENTS MAPPED FROM LANDSAT DATA IN THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**




## LINEAMENTS IN THE PARSHALL AREA 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 Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. Lineaments were digitally mapped and digitized from a digital image mosaic of the study area, compiled from 2002 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 analysis of 317 individual lineaments reveals two distinct orientations (Figure 2). A primary ($1^o$) orientation of N $12^o$ E (S $12^o$ W), and a secondary ($2^o$) orientation of N $77^o$ W (S $77^o$ E). The distribution of lineament length follows a general log-normal distribution with the majority of lineaments (51%) falling within the 20 to 40 mile lineament length range. Overall, 94% of the lineaments mapped were less than 60 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 1.8 lineaments per township). Lineament density is generally greater in the southeastern and eastern 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 contrasts 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, particularly in central Mountrail County south of Stanley in the Sanish and Parshall field areas. Lineaments mapped are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree and extent of glaciation). 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 area of the Nesson Anticline). Lineament density appears to be generally greater in areas of currently producing wells and less in areas of non-producing wells. Current horizontal drilling and production trends suggest more successful preferential horizontal leg completions along a NW trend from surface locations. 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). Lake Sakakawea is the major surface water feature found in the southwest portion of the study area. The Souris and Des Lacs Rivers are present in the far northeastern corner of the study area. These features are not displayed on the 1:250,000 scale lineament map shown at left.

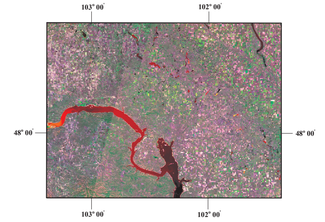



Figure 1. Map of 2002 LANDSAT 7 ETM false color (2-4-7) imagery used for lineament mapping in the Parshall study area in the northeastern portion of the Williston Basin in northwestern North Dakota. Agricultural land use can again be seen as the patchwork pattern (green) throughout the central and eastern two-thirds of the study area similar to the NAIP imagery.

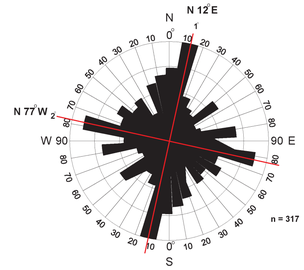



Figure 2. Rose diagram of 317 individual lineament orientations mapped from 2002 LANDSAT 7-ETM imagery of the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. There are two dominant orientations ($1^o$, and $2^o$) displayed within the data of N $12^o$ E (S $12^o$ W), and N $77^o$ W (S $77^o$ E).

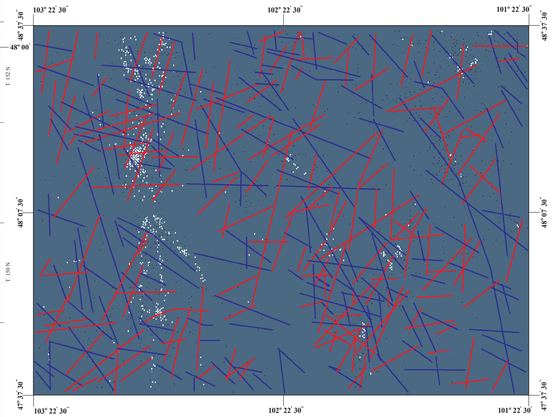



Figure 4. Lineament map displaying lineaments in two classes of lineament orientation. Lineaments oriented along a N-NE or S-SW orientation are shown in red, lineaments oriented along a N-NW or S-SE orientation are shown in blue. Producing wells (shown in white) tend to be located near areas of relatively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

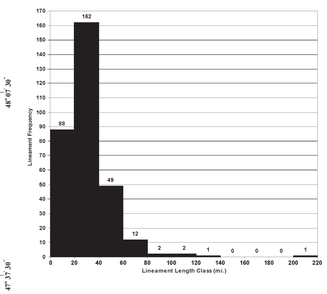
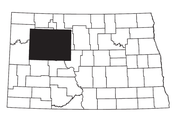



Figure 3. Frequency distribution of 317 individual lineament lengths (distance in miles) mapped from 2002 LANDSAT 7 ETM false color (2-4-7) imagery of the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineament distributions are shown for eleven lineament length classes from zero to 220 miles in 20 mile intervals or classes.



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 47° 22' 30"

1927 North American Datum
Central meridian 102° 07' 30"

## EXPLANATION

**Geologic Features**

- Lineaments
- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

**Other Features**

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

N W E S

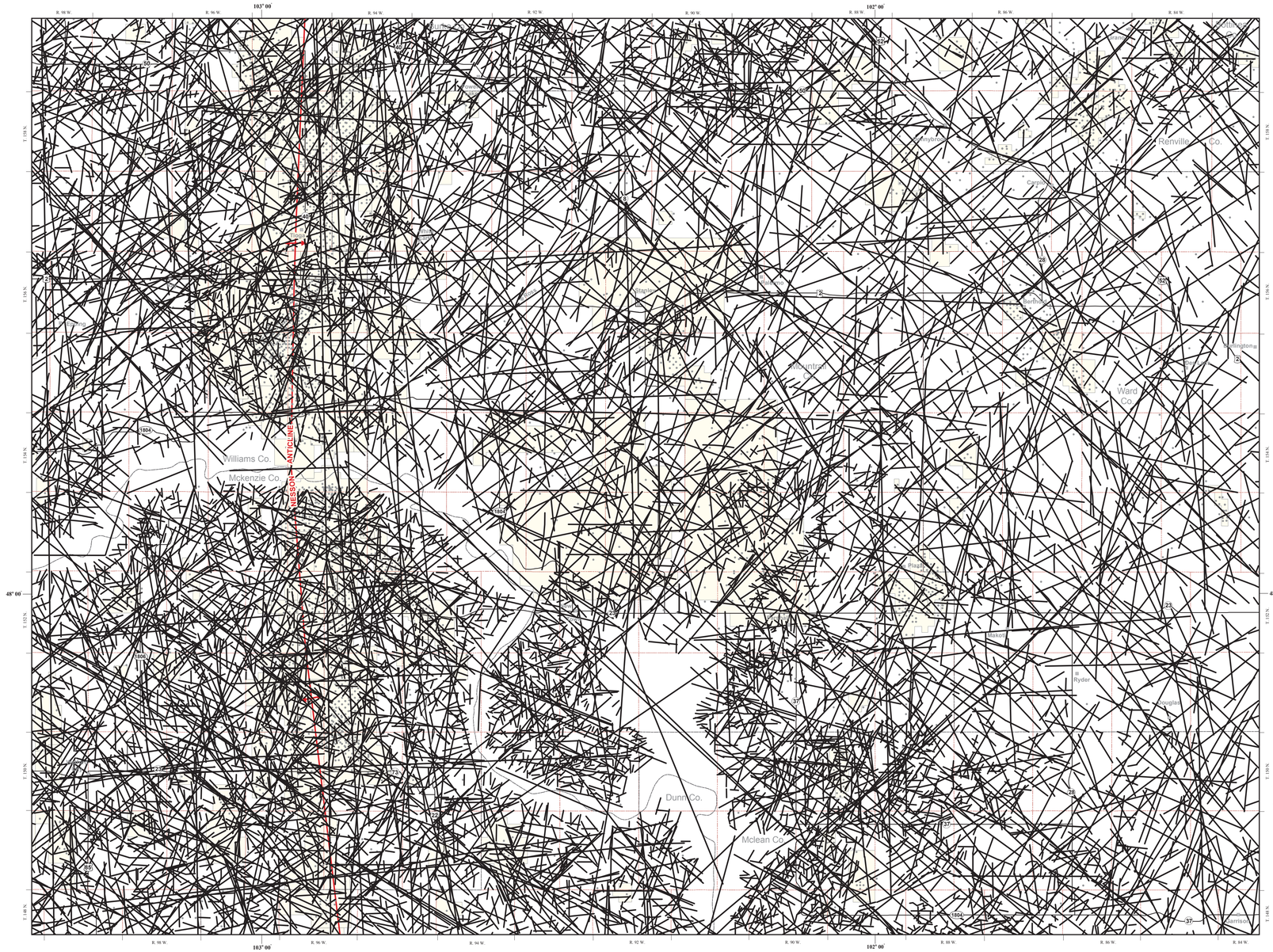
NORTH DAKOTA
Department of Mineral Resources

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

# PLATE V - COMPILED LINEAMENTS MAPPED IN THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**




## COMPILED LINEAMENTS IN THE PARSHALL AREA

This map presents the results and discussion of a segment of a contemporary lineament analysis of the Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. Lineaments were compiled from Plates I – IV for this map (Figure 1). Lineaments compiled are presented here at a scale of 1:250,000. Lineament orientation analysis of all 7,916 individual lineaments reveals four dominant orientation trends (Figure 2). A primary (1°) trend of N 47° W (S 47° E), a secondary (2°) trend of N 42° E (S 42° W), a tertiary (3°) trend of N 7° W (S 7° E), and a quaternary (4°) trend of N 22° E (S 22° W). The distribution of lineament length follows a sharp log-normal distribution with the majority of lineaments (95%) falling within the 0-30 mile lineament length size range (Figure 3). The density of lineaments (i.e. lineaments mapped per unit area) is generally greater in the western, north-central, and southeastern portions of the map area with an overall lineament density of 1.2 lineaments per square mile (~44 lineaments per township). In this map, the general distribution of lineaments are likely influenced by subsurface geological (e.g., basement faulting) and surface geomorphological conditions (i.e., degree of glaciation). Lineament density is observed to be greatest and generally coincident with known geologic structure (i.e. the Nesson 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. Lake Sakakawea is the major surface water feature found in the southwest portion of the study area. The Souris and Des Lacs Rivers are present in the far northeastern corner of the study area. These features are not displayed on the 1:250,000 scale lineament map shown at left.

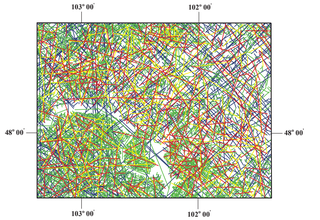



Figure 1. Index map of compiled lineaments in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Historical or lineaments compiled from previous studies are shown in blue. Lineaments mapped from shaded relief data are shown in green. Lineaments mapped from aerial imagery are shown in yellow. Lineaments mapped from recent LANDSAT data are shown in red.

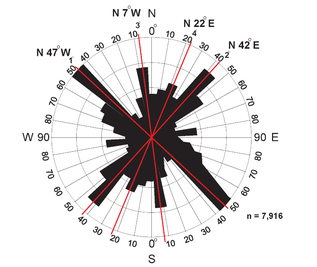



Figure 2. Rose diagram of 7,916 individual lineament orientations compiled from all lineaments mapped in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. There are four dominant orientations (1°, 2°, 3°, and 4°), displayed within the data of N 47° W (S 47° E), N 42° E (S 42° W), N 7° W (S 7° E), and N 22° E (S 22° W).

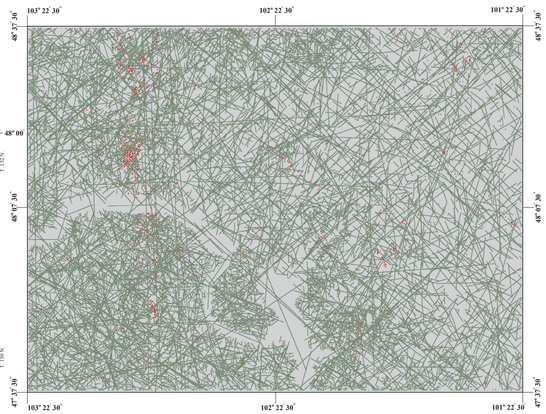



Figure 4. Map of compiled lineaments (green) with currently producing wells (red) and non-producing wells (dark gray) displaying the general relationships between overall lineament trends and densities and oil and gas production and development in the Parshall area.

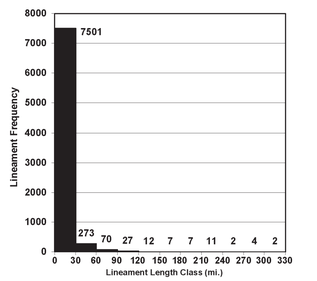
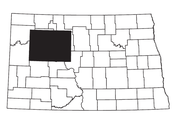



Figure 3. Frequency distribution of 7,916 individual lineament lengths (distance in miles) compiled from lineaments mapped in the Parshall study area located in the northeastern portion of the Williston Basin in northwestern North Dakota. Lineament distributions are shown for 11 lineament length classes from zero to 330 miles in 30 mile intervals or classes. This distribution is heavily influenced by lineaments less than 30 miles in length that are commonly associated with drainage network development in exposed Cenozoic sediments in the southern portions of the map area.

NORTH DAKOTA GEOLOGICAL SURVEY 1895



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20
Miles

0 5 10 15 20
Kilometers

Mercator Projection
Standard parallel 47° 22' 30"

1927 North American Datum
Central meridian 102° 07' 30"

**EXPLANATION**

**Geologic Features**

- Lineaments
- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

**Other Features**

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

N W E S

NORTH DAKOTA D M R 1885 Department of Mineral Resources

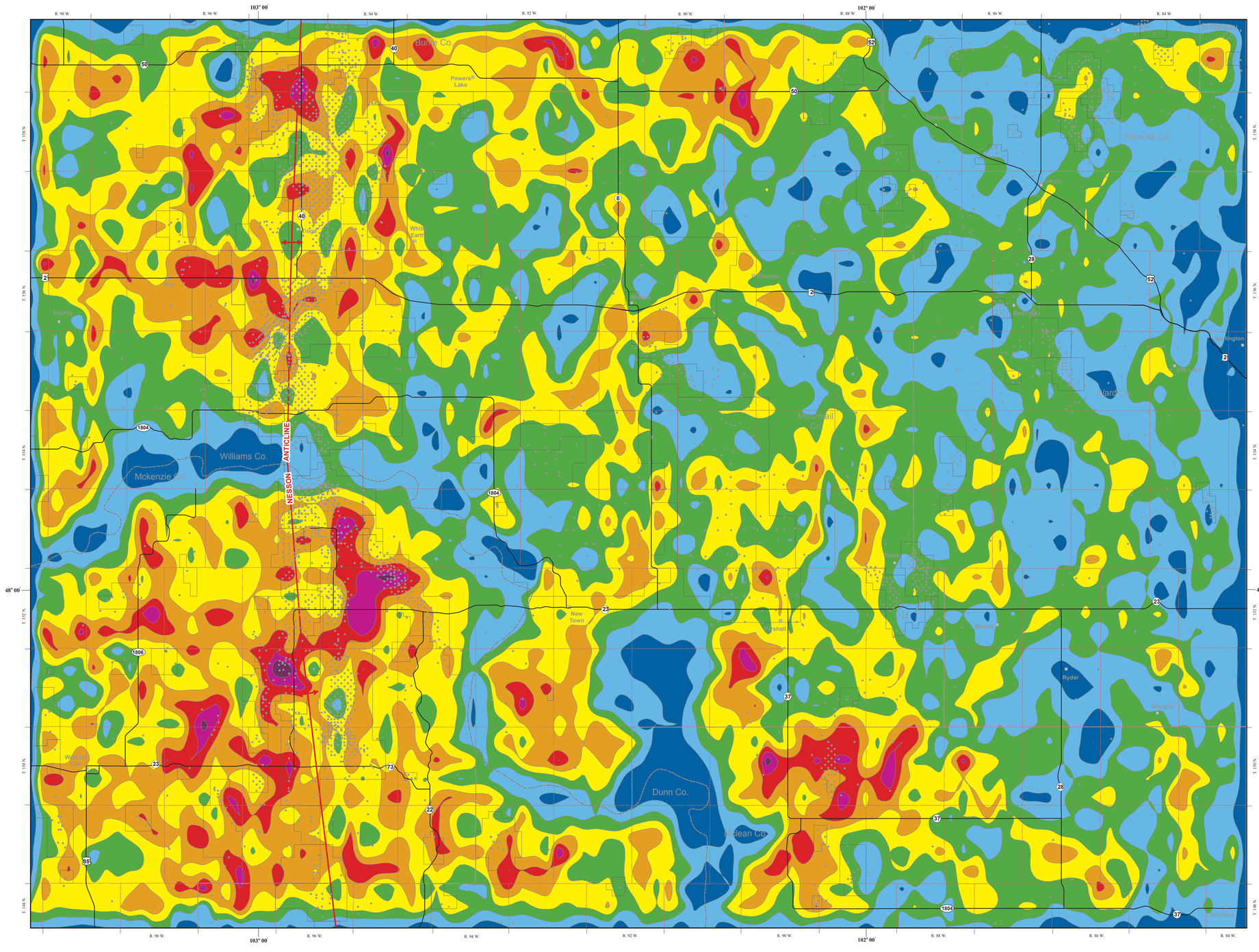
North Dakota Geological Survey
Geologic Investigations No. 70 - Plate VI

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

# PLATE VI - LINEAMENT DENSITY MAP OF THE PARSHALL AREA, NORTH DAKOTA

**Fred J. Anderson**

**2008**




## LINEAMENT DENSITY MAPPING IN THE PARSHALL AREA

This map presents the results and discussion of a segment of a contemporary lineament analysis of the Parshall Area. The Parshall area is located in the northeastern portion of the Williston Basin and is centered around the Mountrail County area in northwestern North Dakota. The density of lineaments was determined from the compiled lineaments extracted from Plate V for this map. Lineament density was calculated across the map area by automated analysis of the sum 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. The resulting x,y,z data file was contoured across the determined data range in 2,000-ft intervals from 0 to 18,000-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 coolers. This map shows area of higher lineament density in the western portion of the map area, consistent with major subsurface structural development and lessened geomorphological influence from Pleistocene glaciation. Areas of lower lineament density are found in the eastern and northeastern portions of the map area. Overall, lineament density appears to be greatest in areas where producing oil and gas wells are commonly located, and lower in areas where non-producing wells have been drilled (Figure 1). This suggests a relationship between producing areas and areas of relatively higher lineament density.

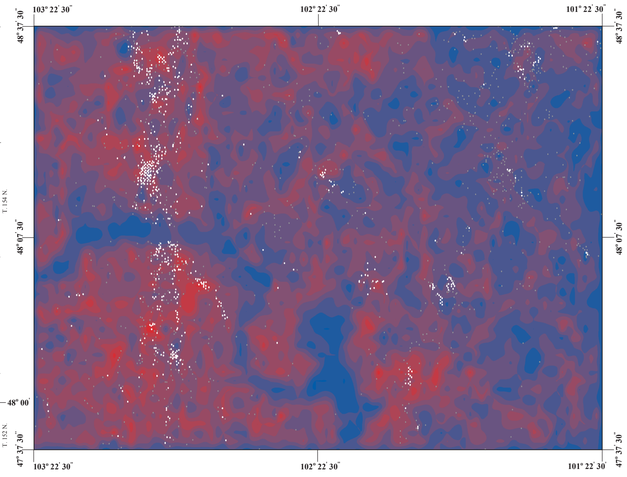



Figure 1. Lineament density map displaying lineament density with currently producing (white) and non-producing (gray) wells in Parshall area. Producing wells tend to be located near areas of relatively higher lineament density (shown in red). The distribution of dry holes or non-producing wells tend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

**Lineament Density (ft/mi$^2$)**

- 14,000 - 18,000
- 12,000 - 14,000
- 10,000 - 12,000
- 8,000 - 10,000
- 6,000 - 8,000
- 4,000 - 6,000
- 2,000 - 4,000
- 0 - 2,000

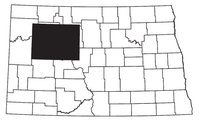
**EXPLANATION**

**Geologic Features**

- Drill Hole
- Nesson Anticline
- Oil & Gas Fields

**Other Features**

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



The map area is a constructed 250k sheet. Belden, Belden SE, Belden SW, and Sikes Dam are the four center 24k quadrangles.

Scale 1:250,000

0 5 10 15 20 Miles

0 5 10 15 20 Kilometers

Mercator Projection
Standard parallel 47° 22' 30"

1927 North American Datum
Central meridian 102° 07' 30"

N W E S