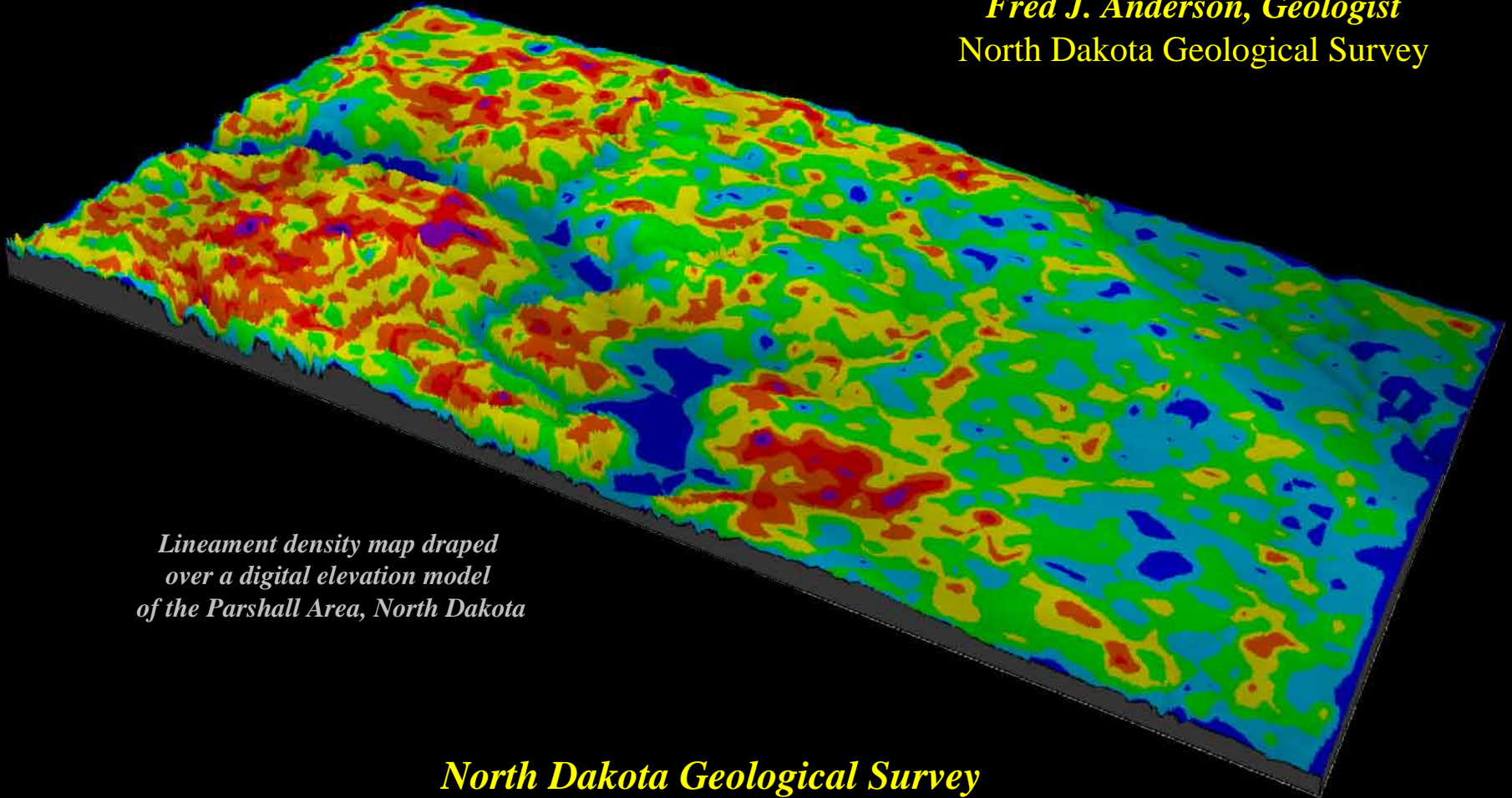




# *Lineament Mapping and Analysis in the Northeastern Williston Basin: Exploration and Production Trends in the Parshall Area, North Dakota*

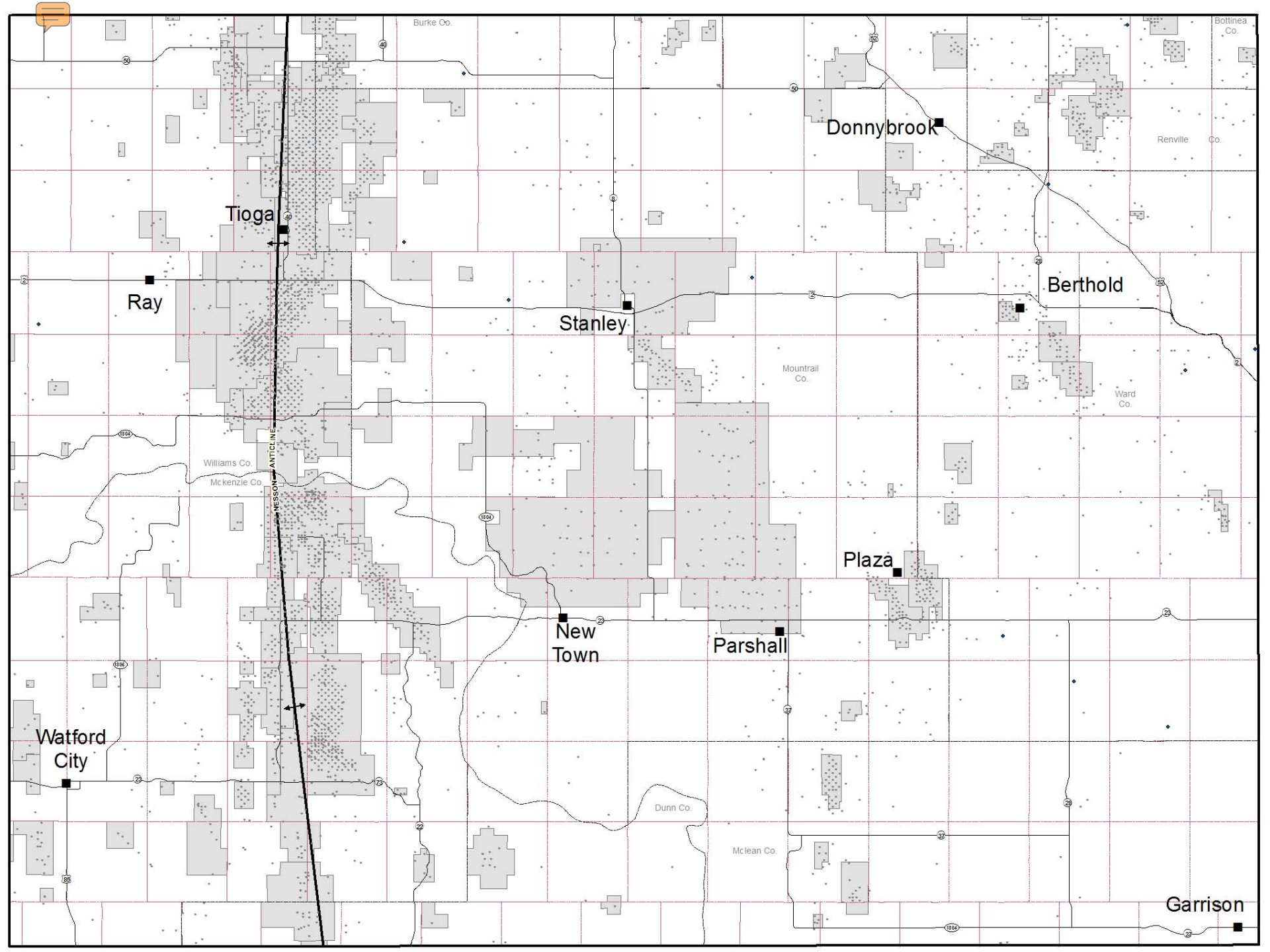


*Fred J. Anderson, Geologist  
North Dakota Geological Survey*

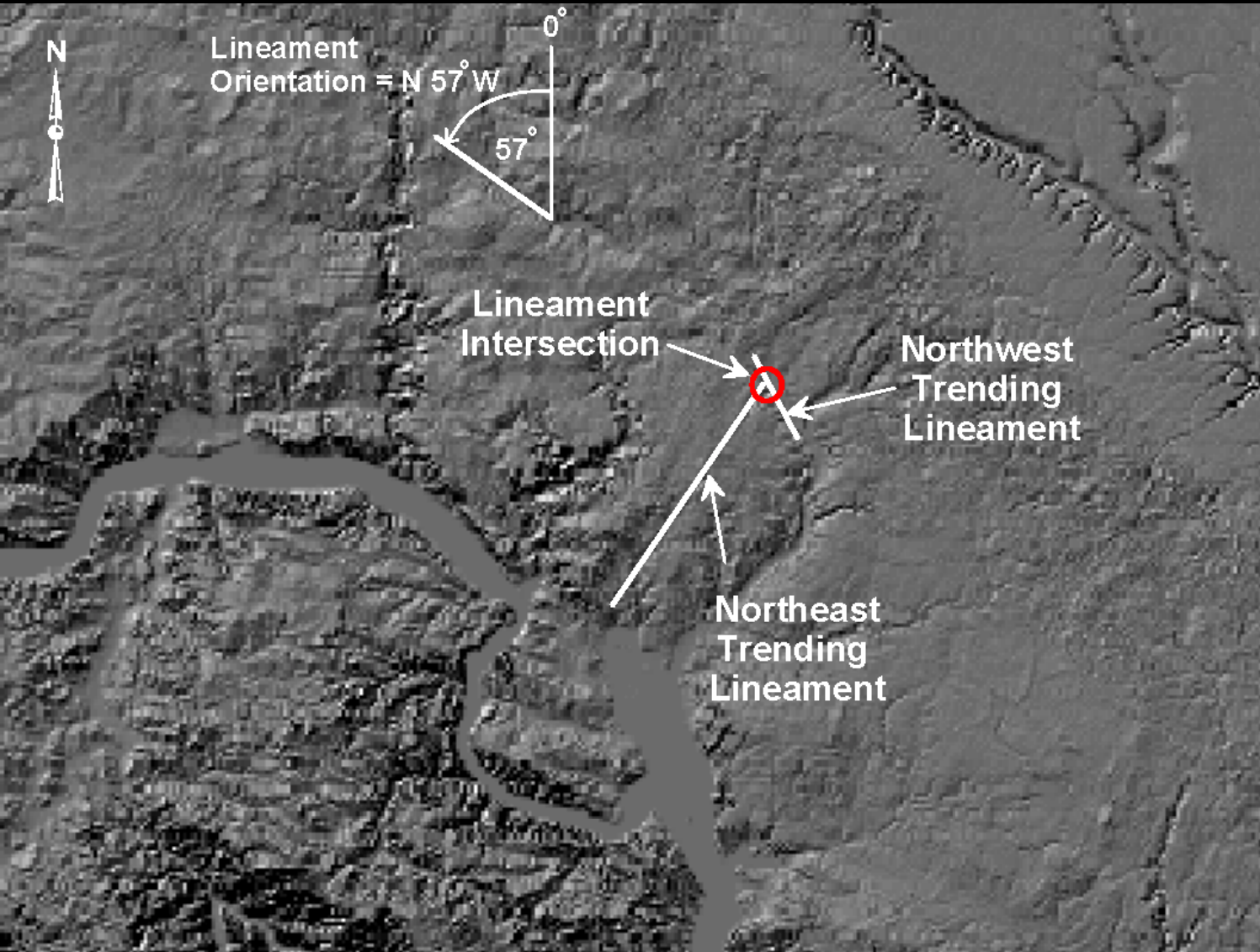


*Lineament density map draped  
over a digital elevation model  
of the Parshall Area, North Dakota*

*North Dakota Geological Survey  
Geologic Investigations No. 80*

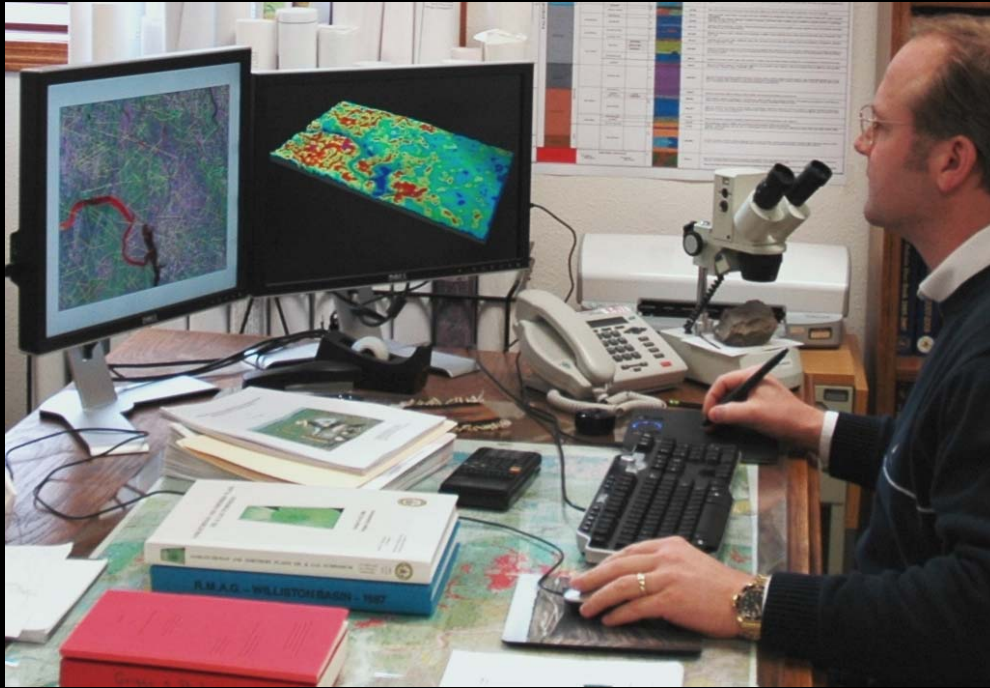


# Definition & Description of Lineaments



***Lineament:*** An extended mappable linear or curvilinear feature 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).

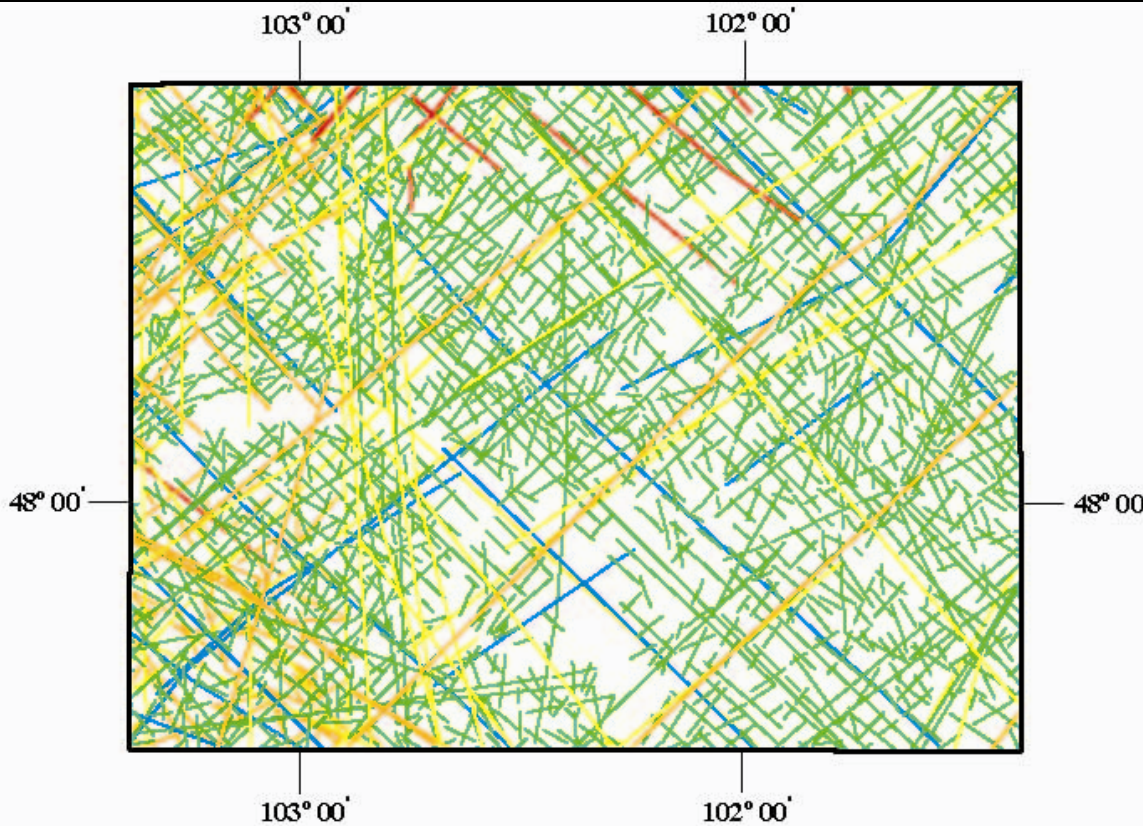
# Lineament Mapping



*NDGS Geologist Fred J. Anderson reviewing lineament mapping work completed on LANDSAT 7 (ETM+) Imagery.*

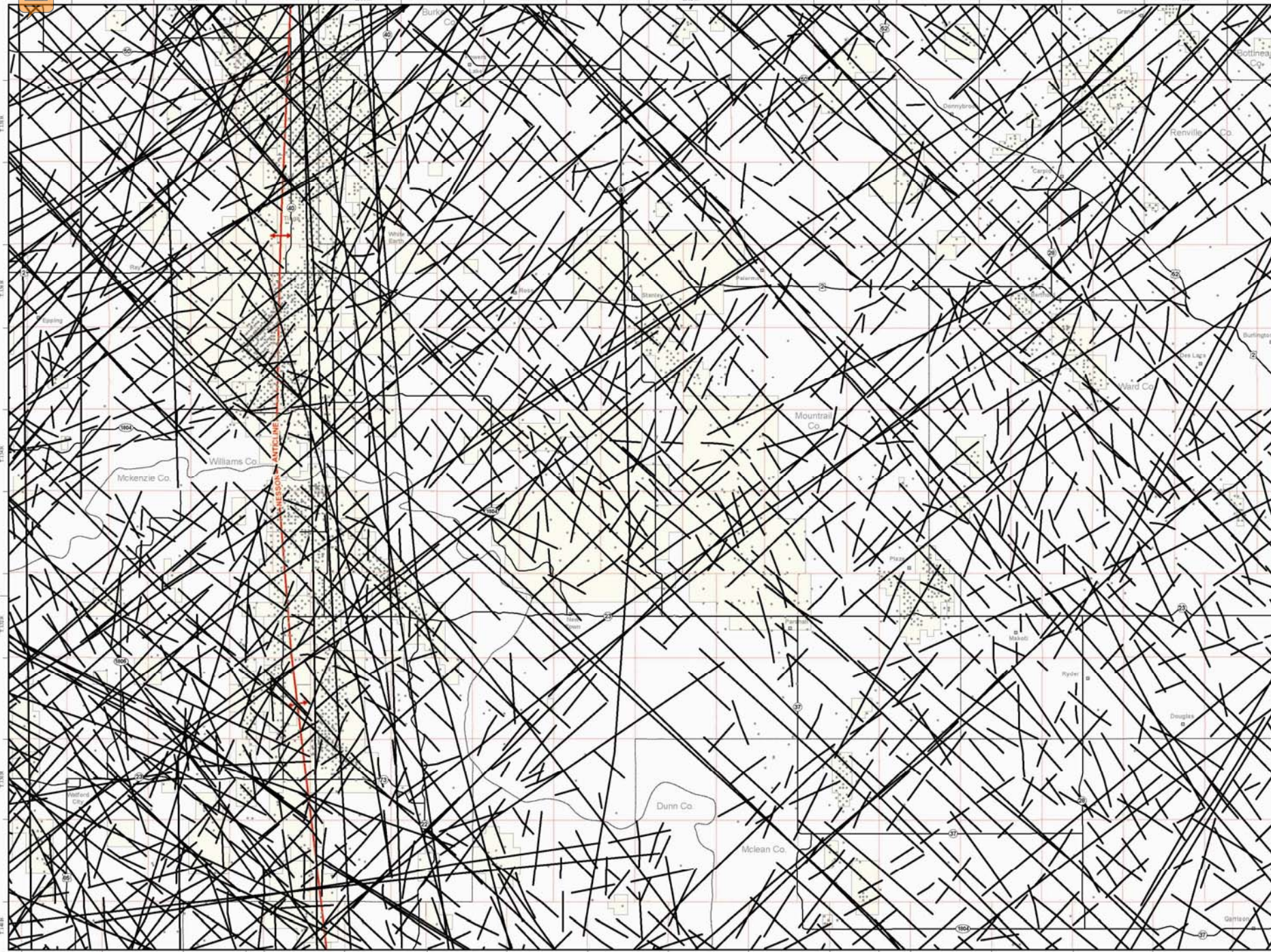
- Visual/Manual Desktop Methods
- Various Scales\*
  - 1:24K,
  - 1:100K,
  - 1:250K,
  - 1:500K,
  - 1:1,000,000
- ArcGIS for .tiff georeferencing.

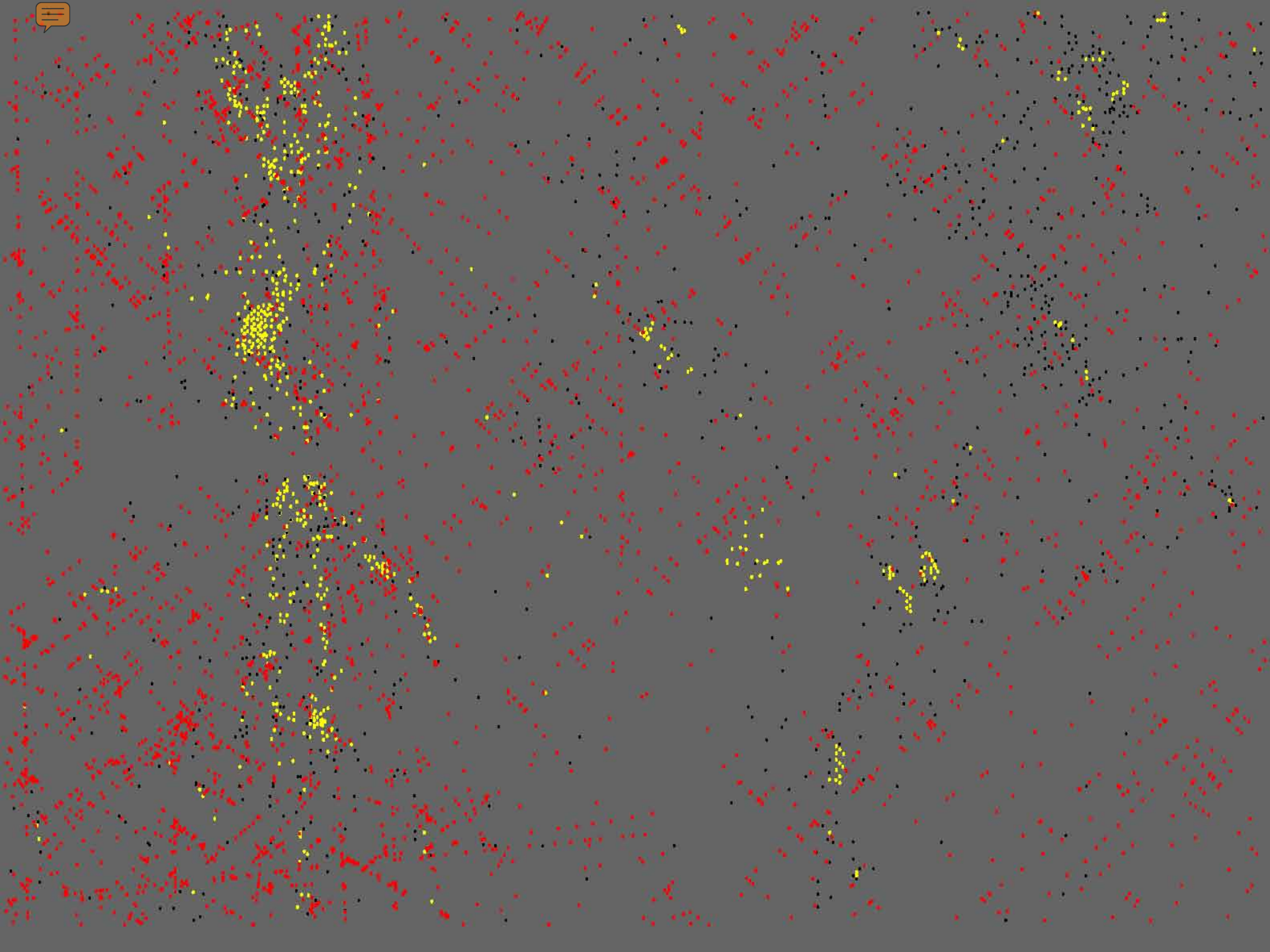
# Historical (Previously Published) Lineaments



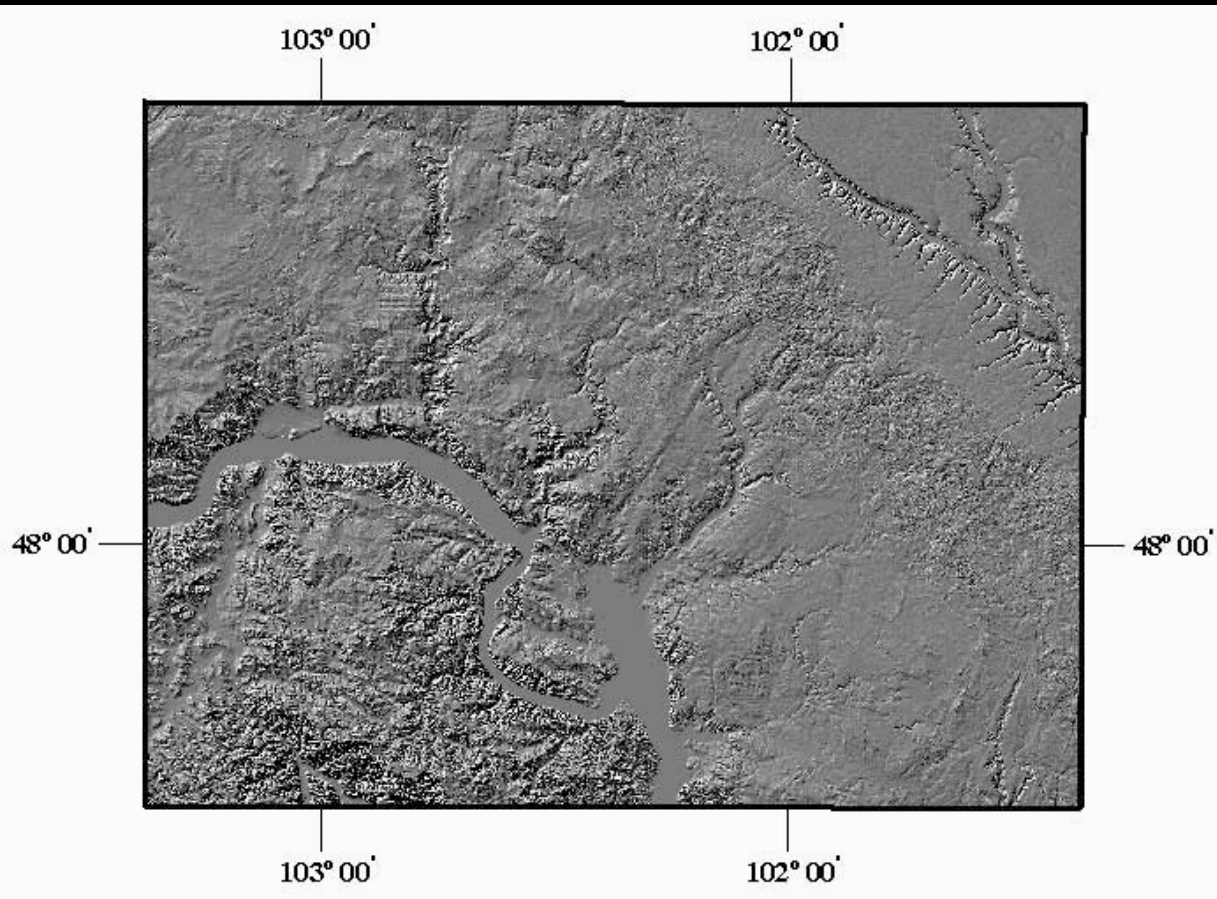
- 1,608 Lineaments Mapped
- $D_L = 0.25 \text{ L/mi}^2$
- Heavily Influenced by the Cooley (1983) data
- Coarse NW-NE Orthogonal Fabric is Readily Discernable

2000's (Red): 2006, Penner and Cosford, Kreis and Kent, 2000.  
1990's (Orange): 1995, Friesatz; Gibson; Inden and Burke; Shurr.  
1980's (Yellow): 1987, Brown and Brown; Downey, et.al.;  
Gerhard, et.al.; Mollard; Oglesby; Peterson and MacCray.  
1980's (Green): 1986, Anna; Maughan and Perry; 1984, Hayes;  
Hindman; 1983, Cooley.  
1970's (Blue): 1975, Haman; 1974, Kent; Thomas; 1970, Erickson.



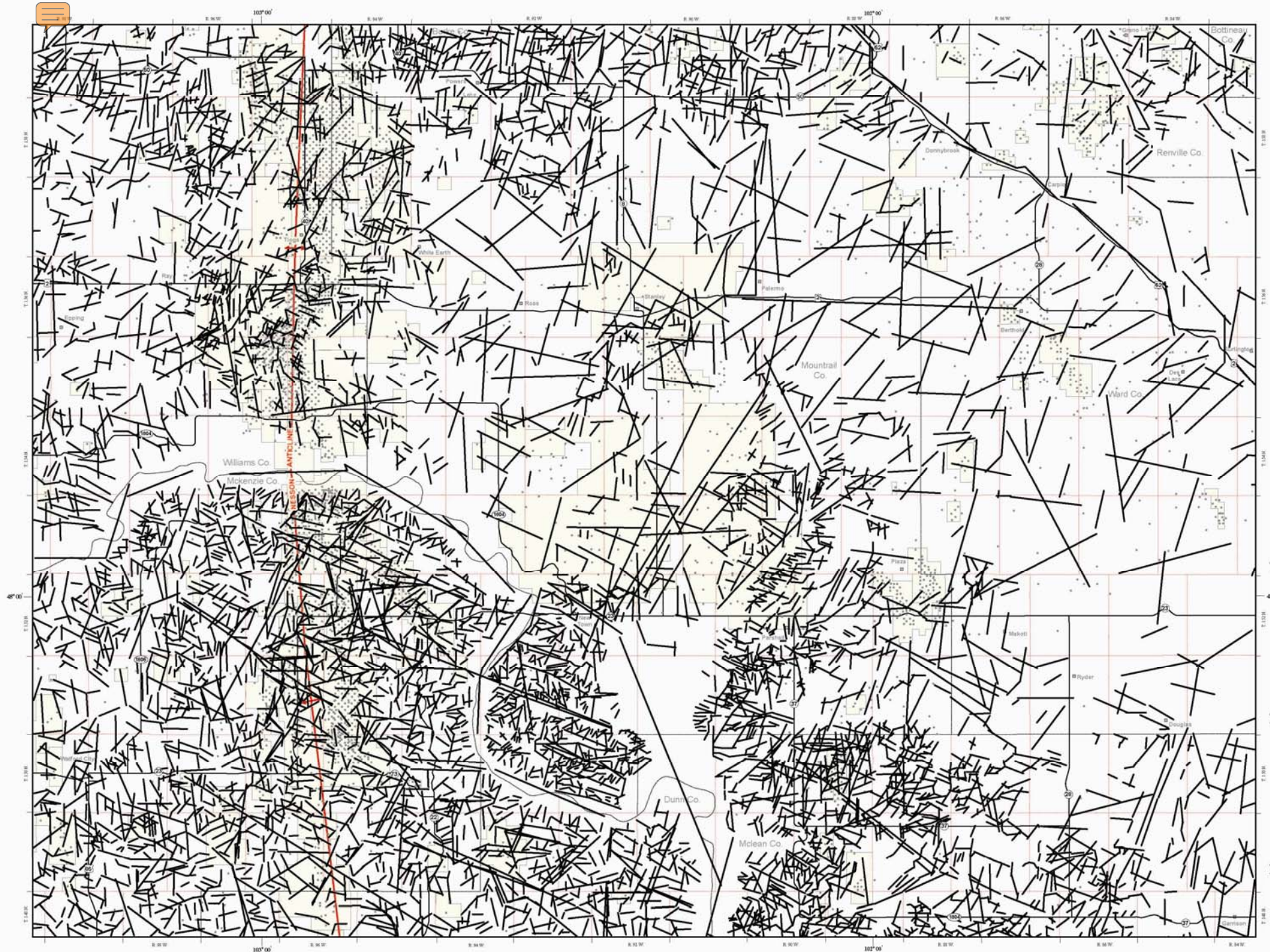


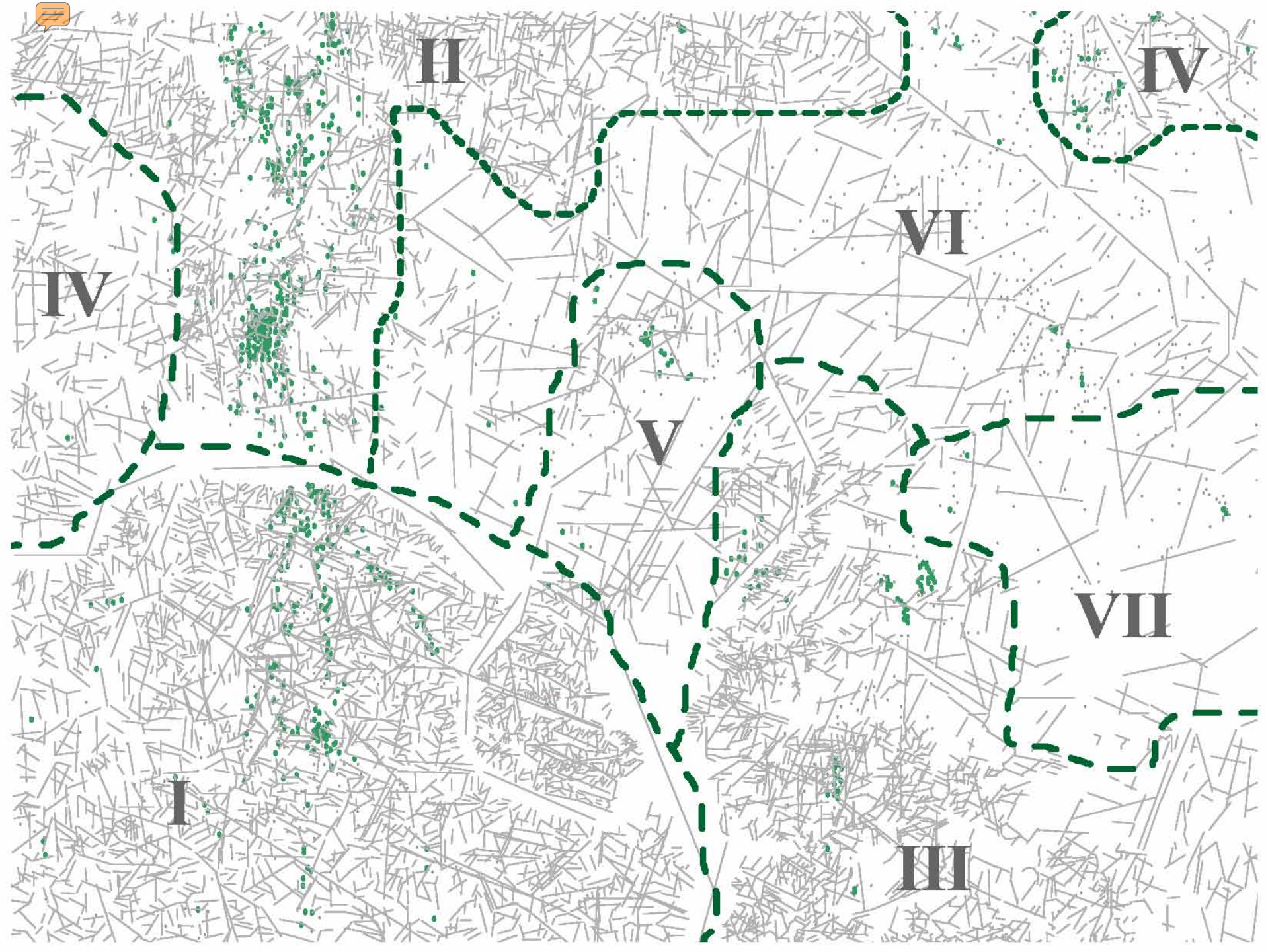
# NED Shaded Relief Data



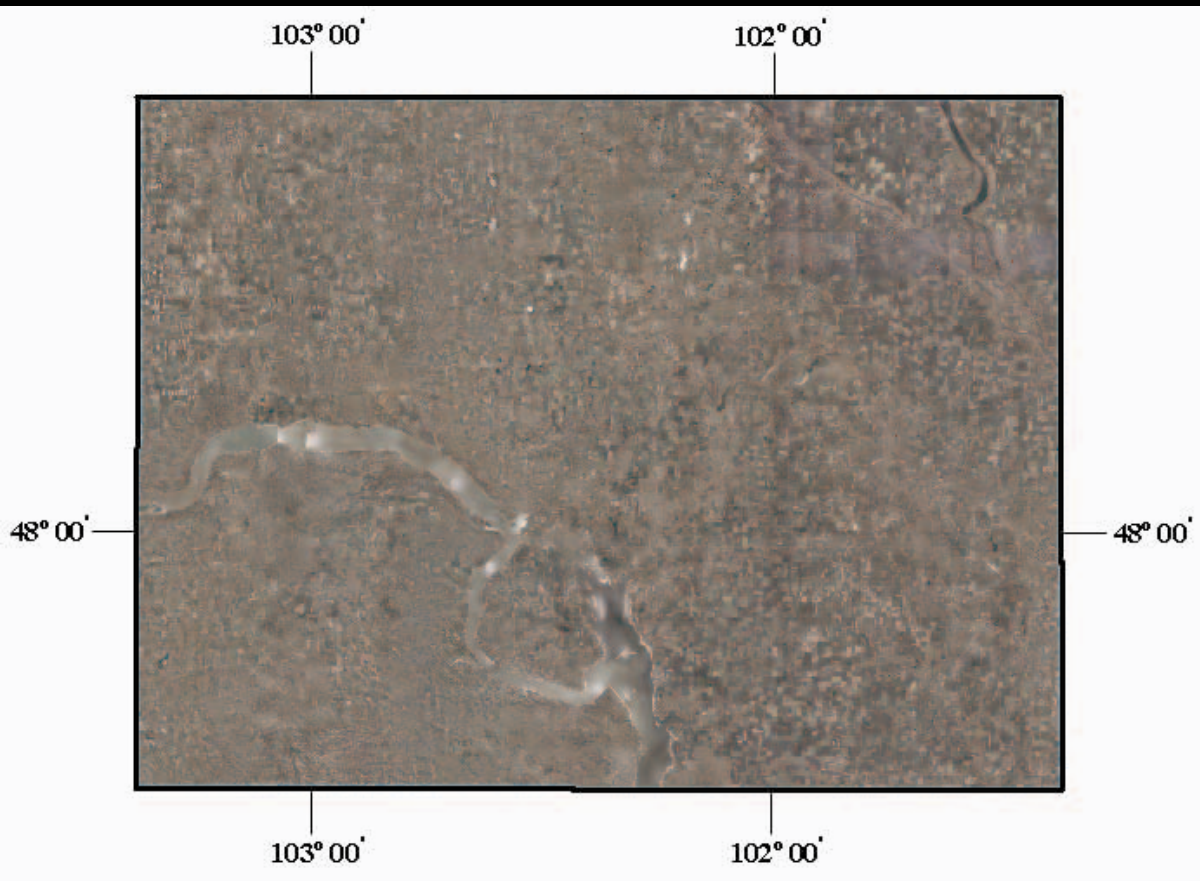
- USGS 1997 Nat. Elev. Dataset
- Interpreted at a VE = 9X
- Image Color Enhanced
- 5,759 Lineaments Mapped
- $D_L = 0.9 \text{ L/mi}^2$



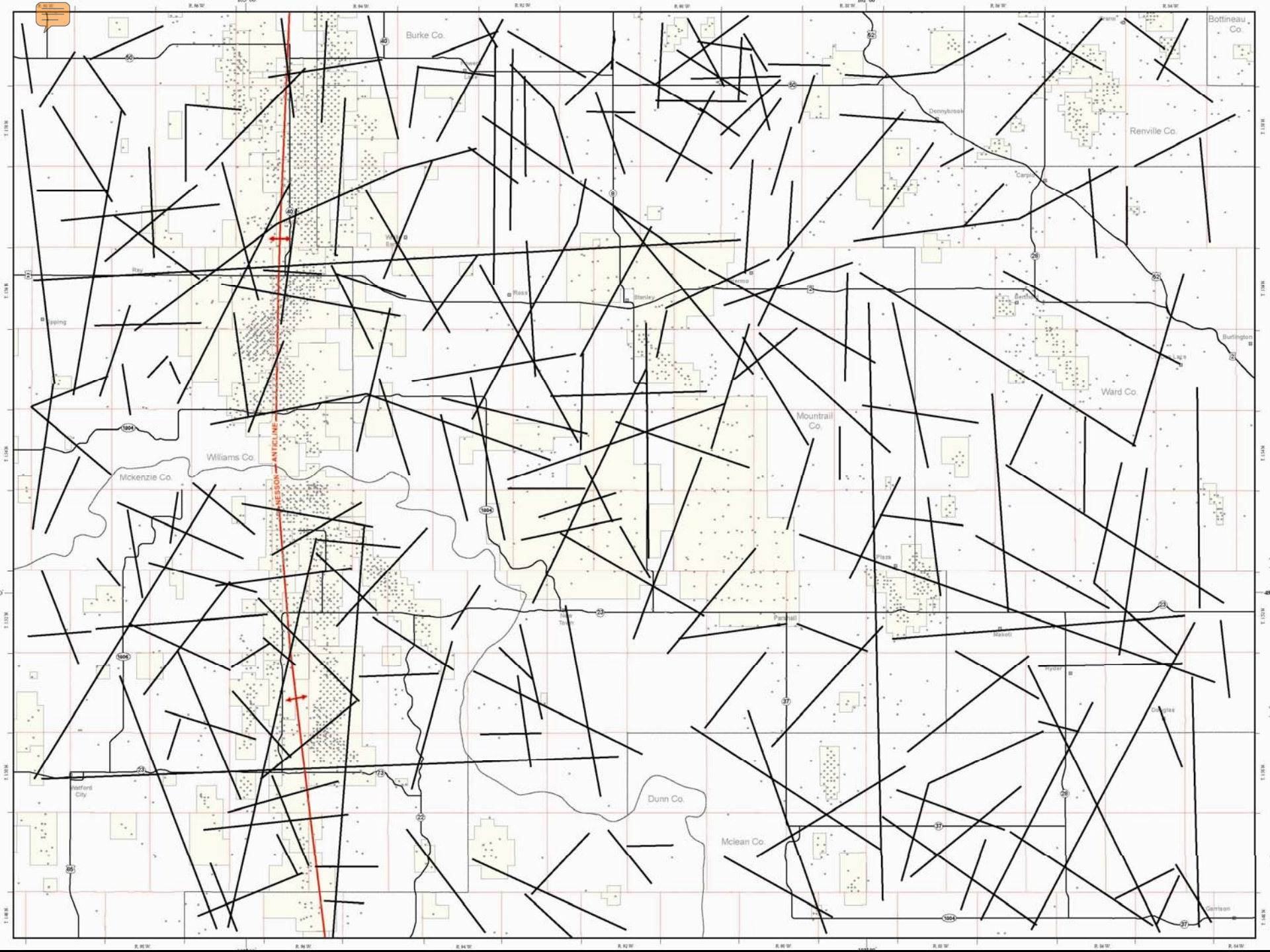


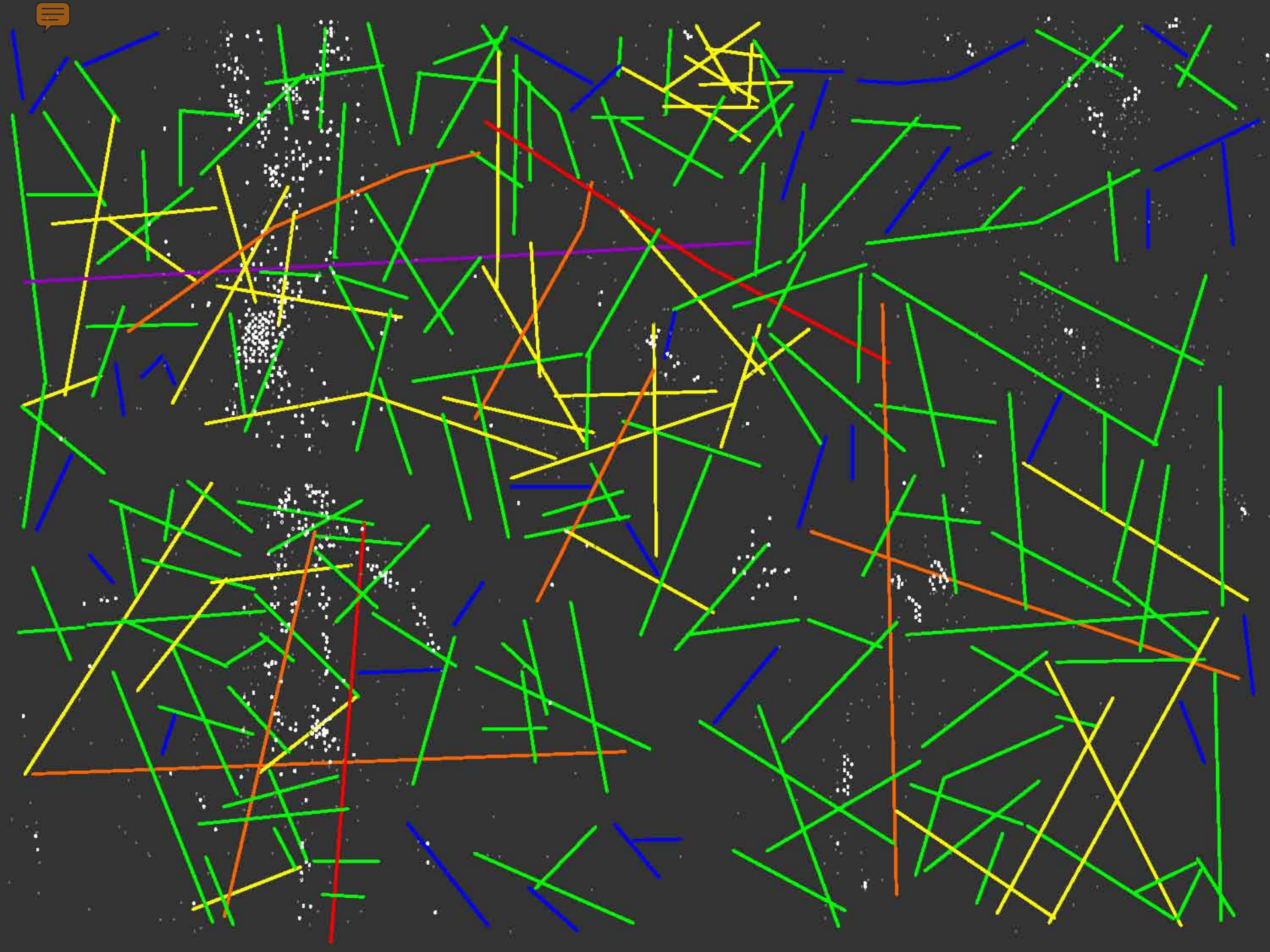


# USDA NAIP Imagery



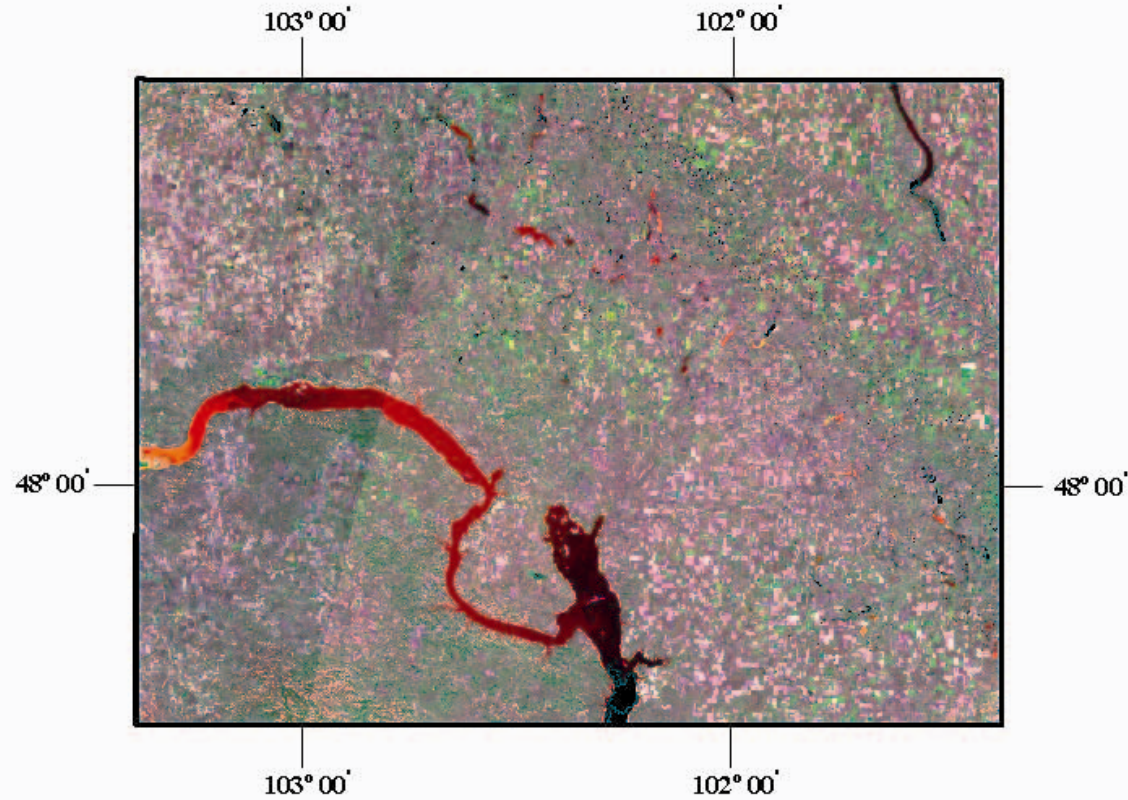
- 2003 USDA National Agricultural Imaging Program (NAIP)
- Aerial Image Mosaic
- 233 Lineaments Mapped
- $D_L = 0.036 \text{ L/mi}^2$

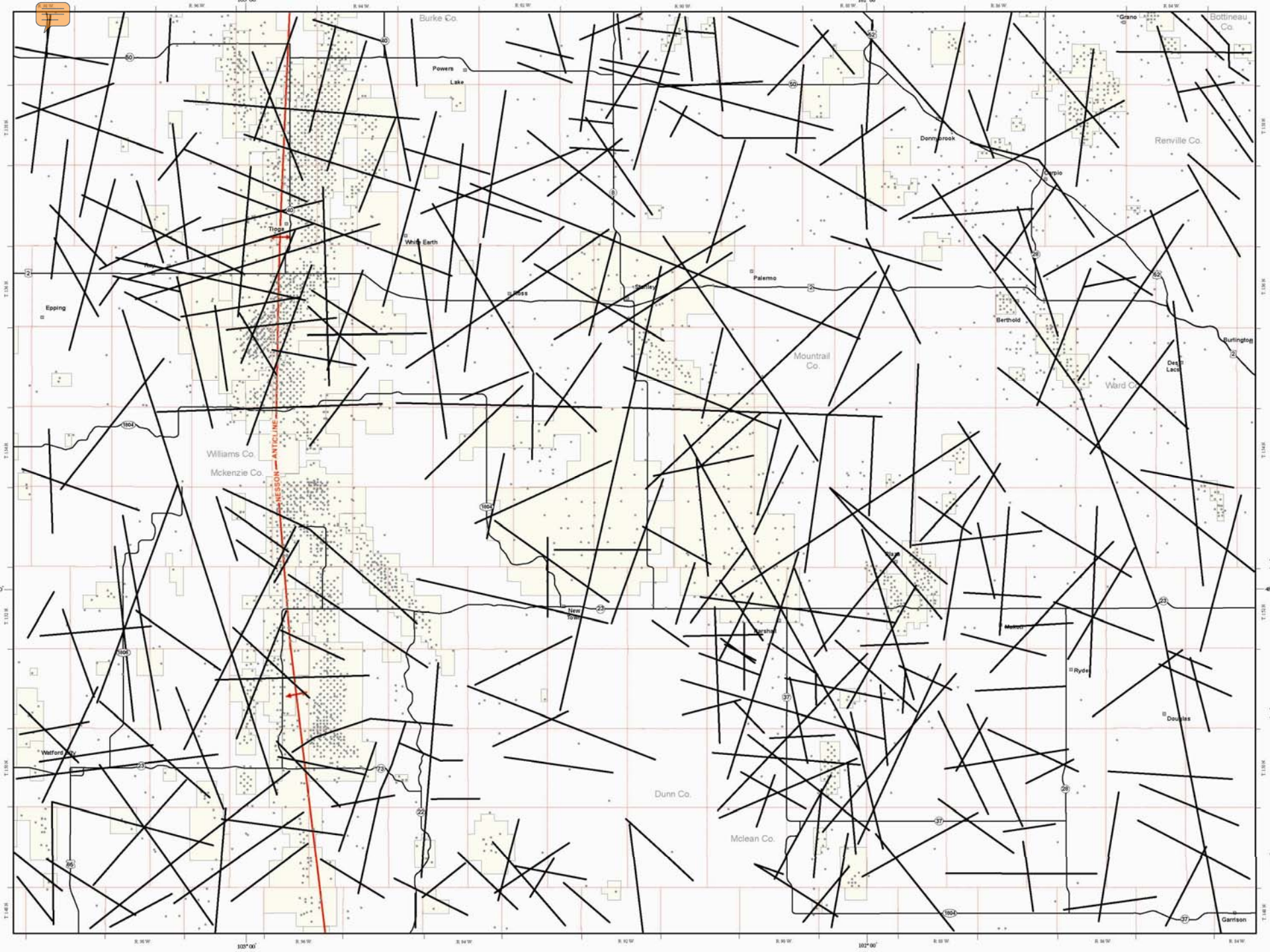


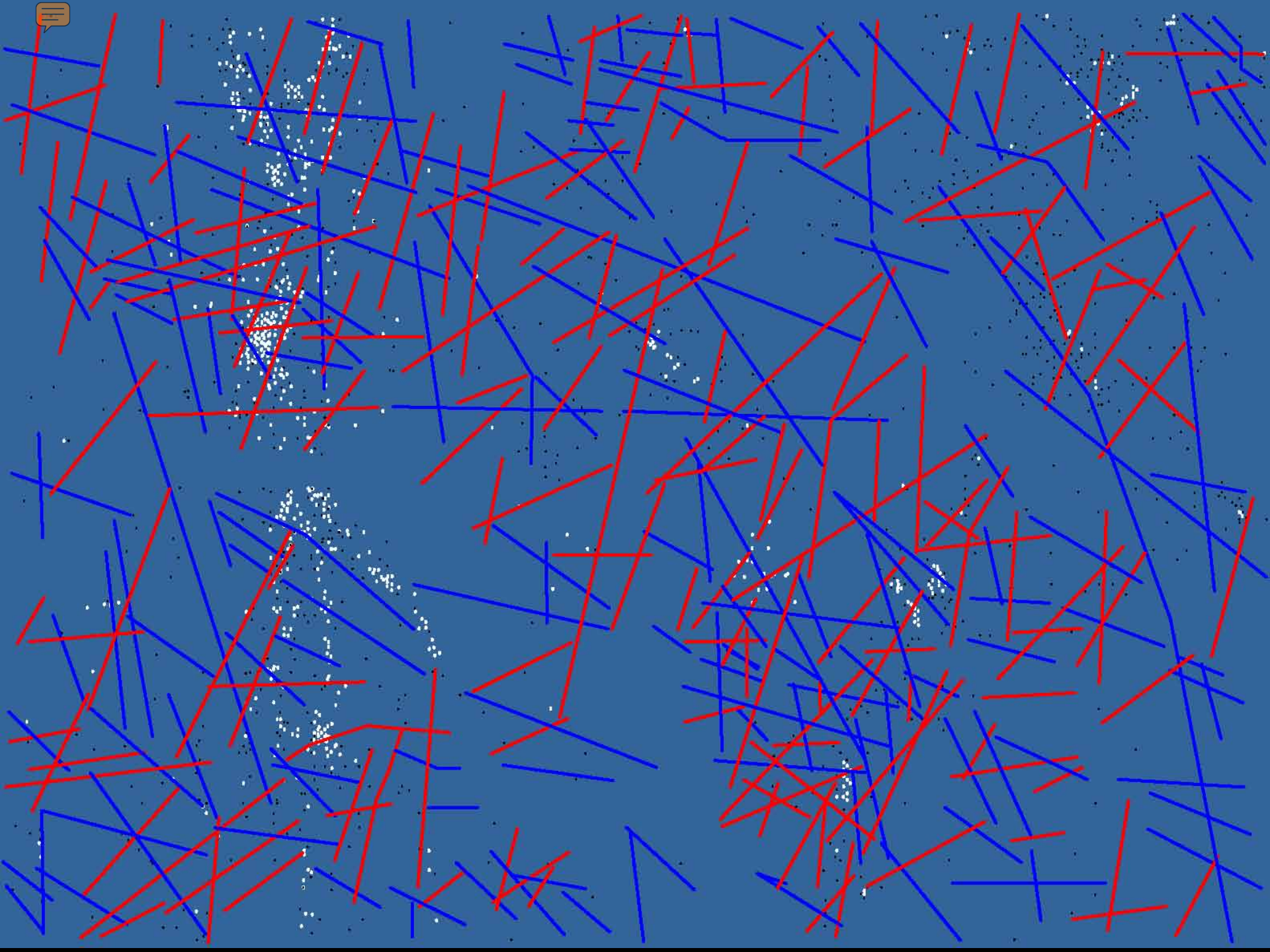


# LANDSAT 7 ETM+

- 2002 LANDSAT-7 (ETM+)
- Digital Image Mosaic of 4 Scenes
- Bands 2,4,7 – (BGR) Processed
- 317 Lineaments Mapped
- $D_L = 0.05 \text{ L/mi}^2$





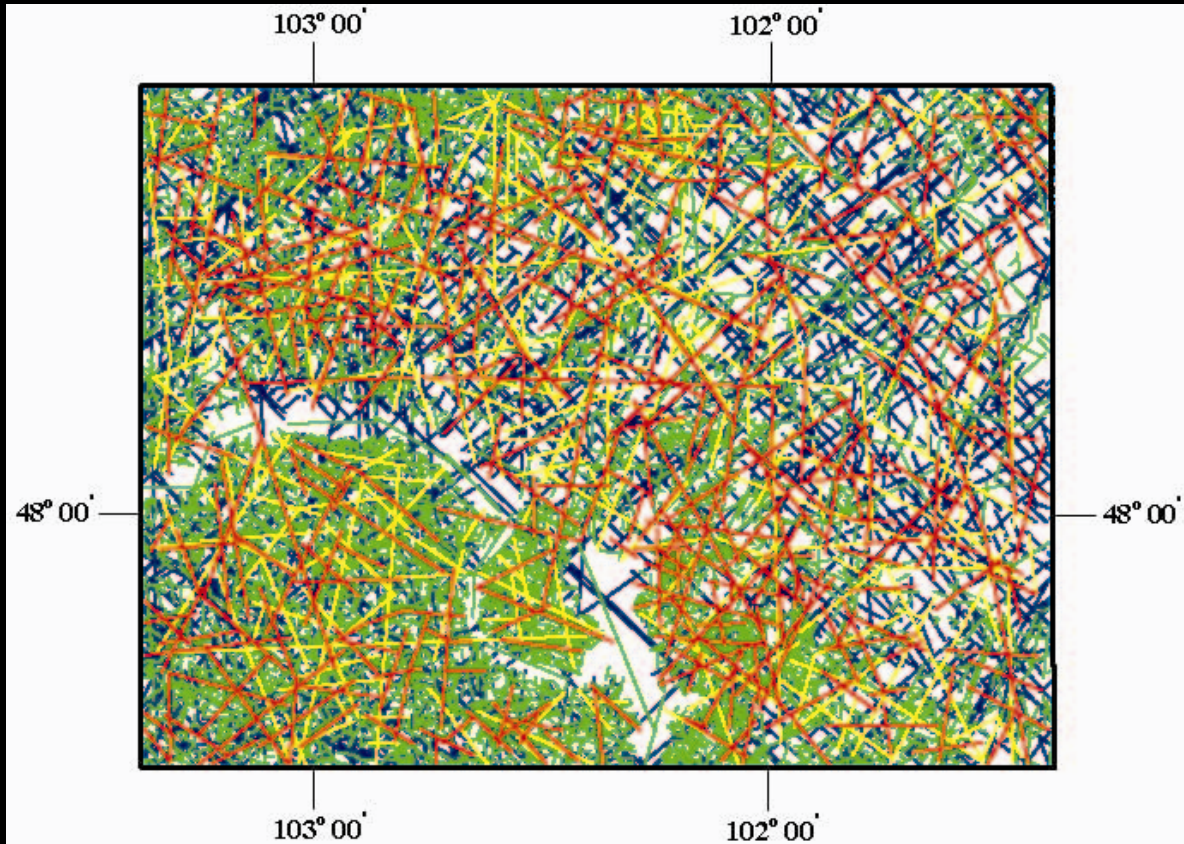


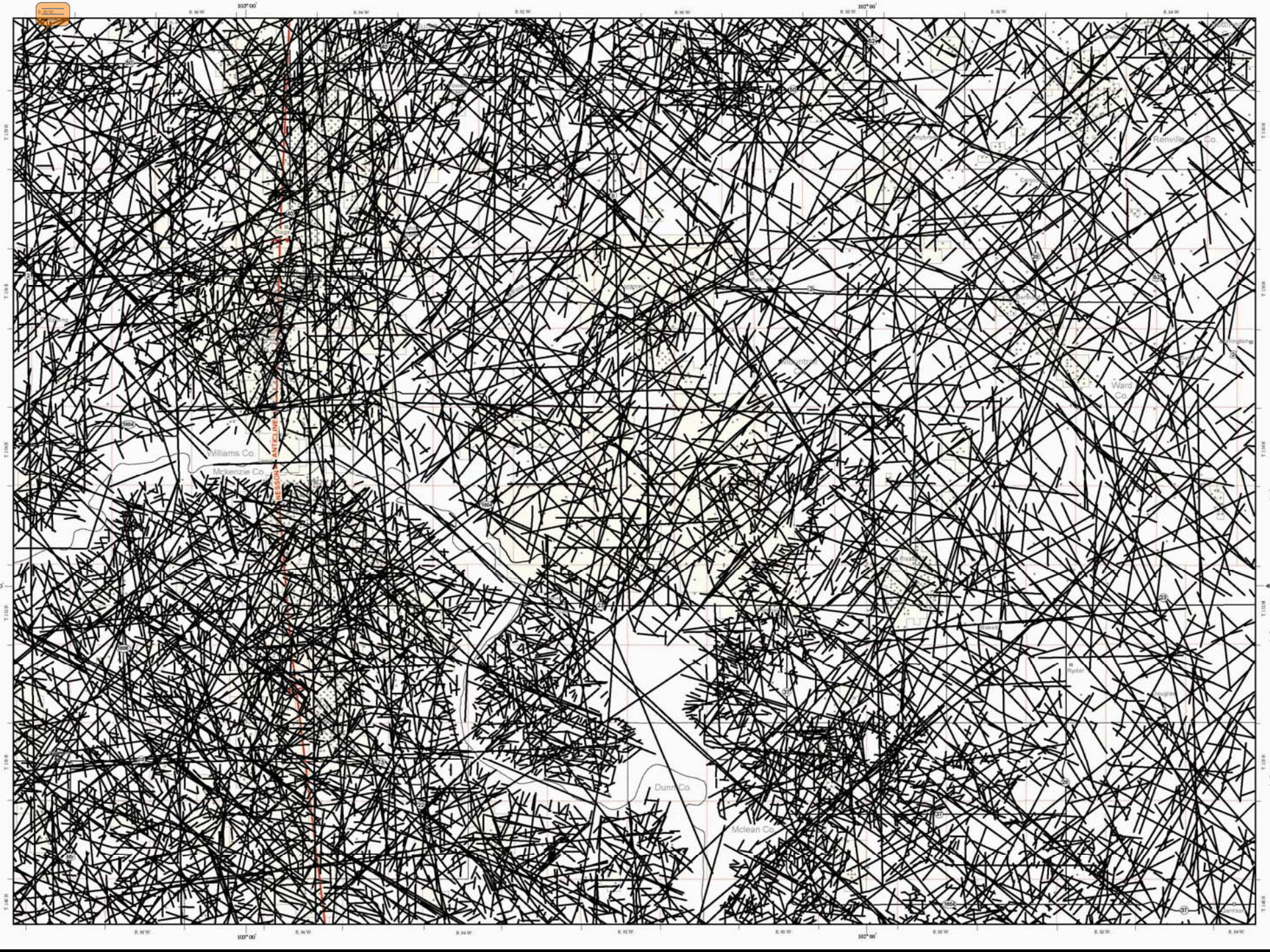


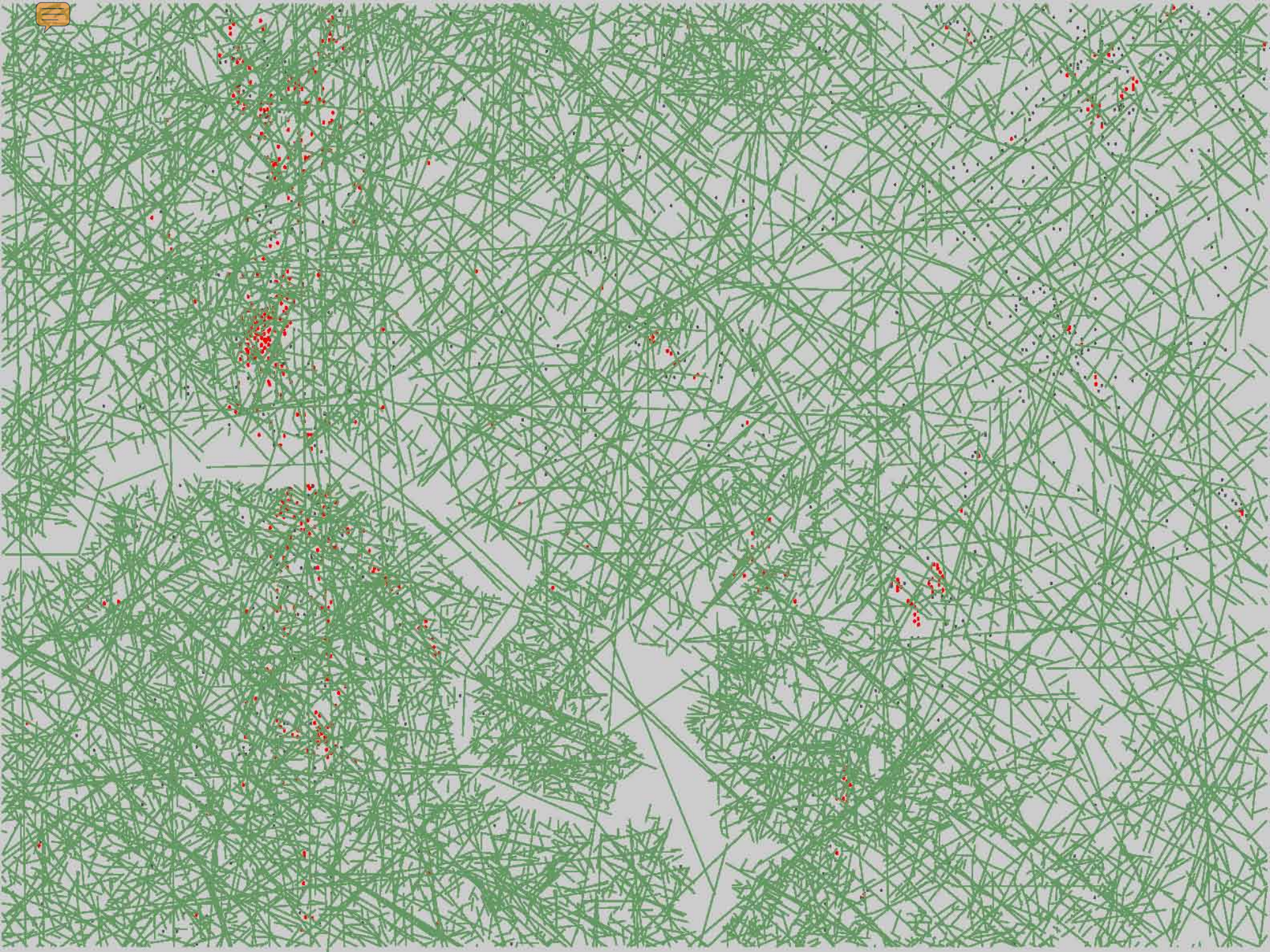


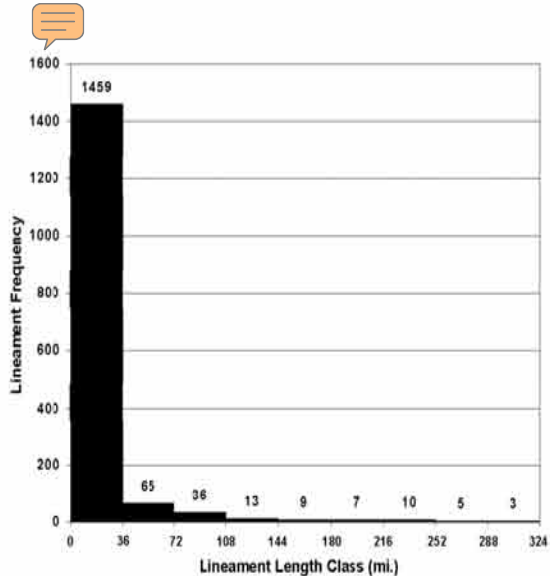
# Merged Lineaments

- All lineaments combined
- 7,916 combined lineaments
- $D_L = 1.2 \text{ L/mi}^2$

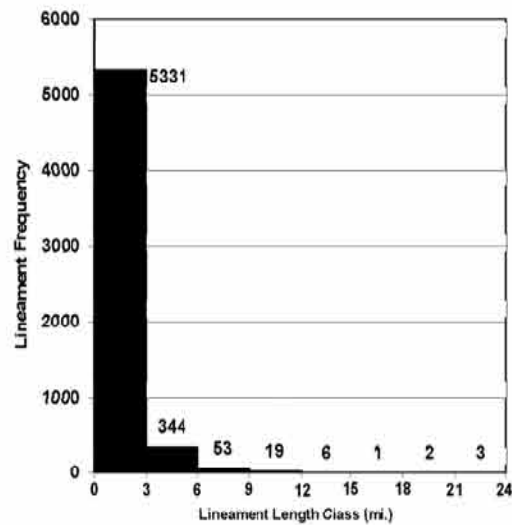




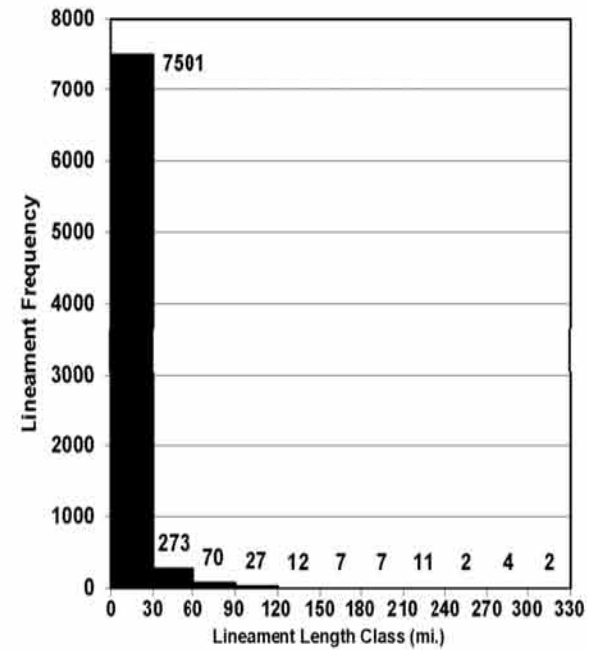




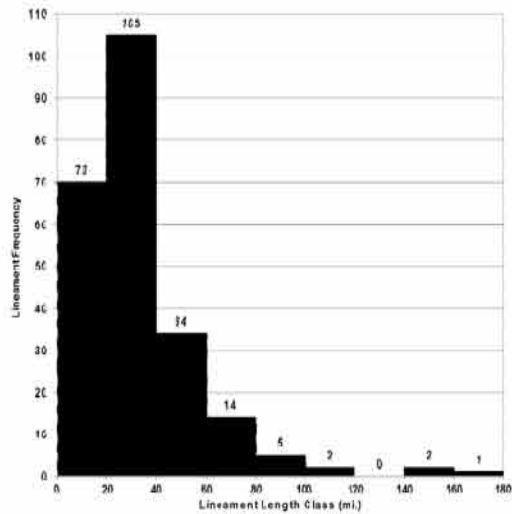
**Historical Lineaments**



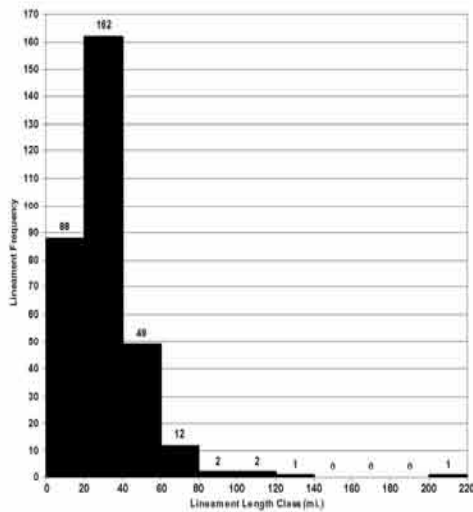
**Shaded Relief Lineaments**



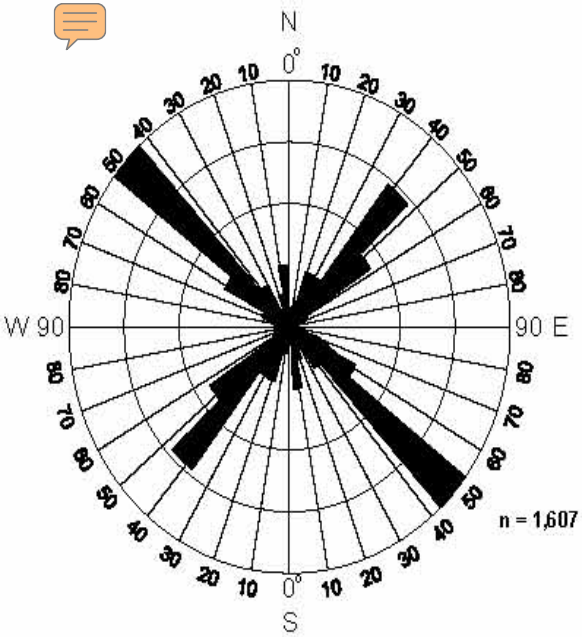
**Merged Lineaments**



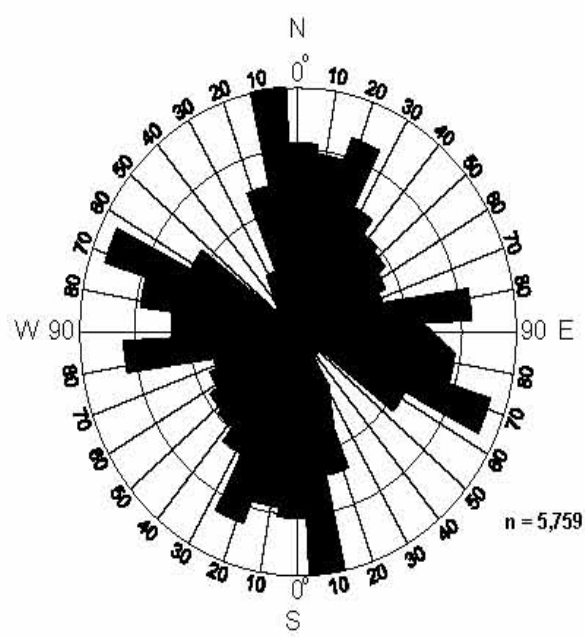
**Aerial Imagery Lineaments**



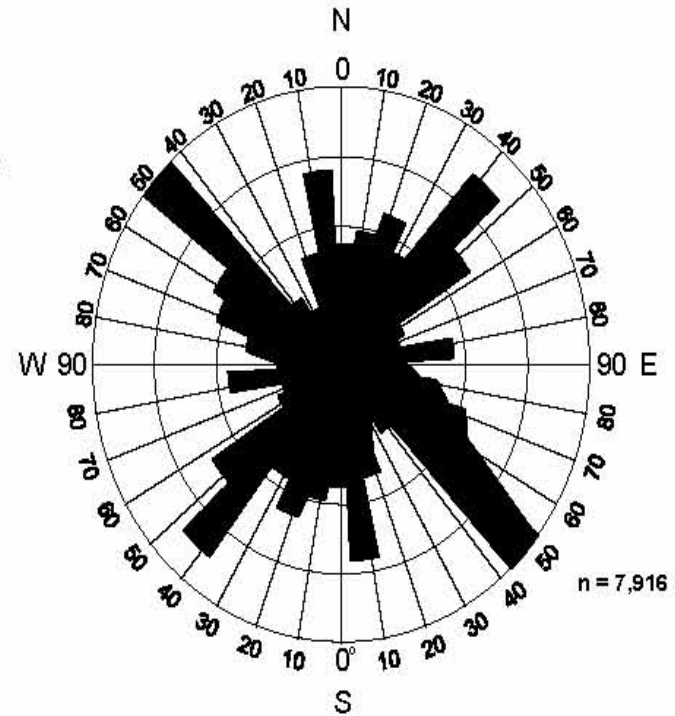
**LANDSAT-7 ETM+ Lineaments**



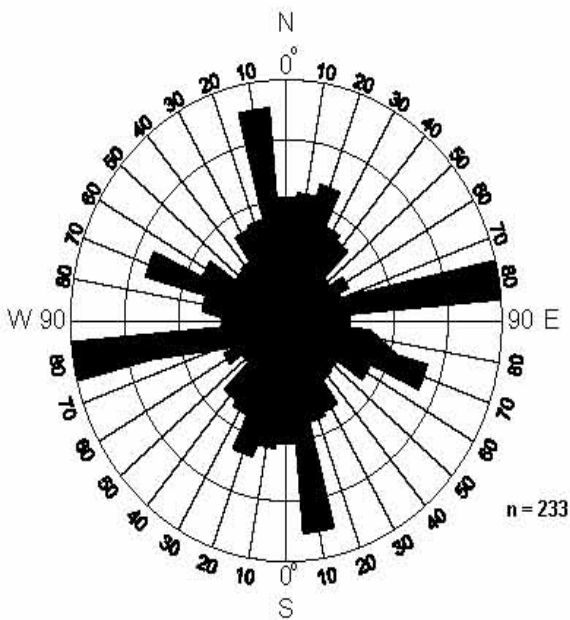
**Historical Lineaments**



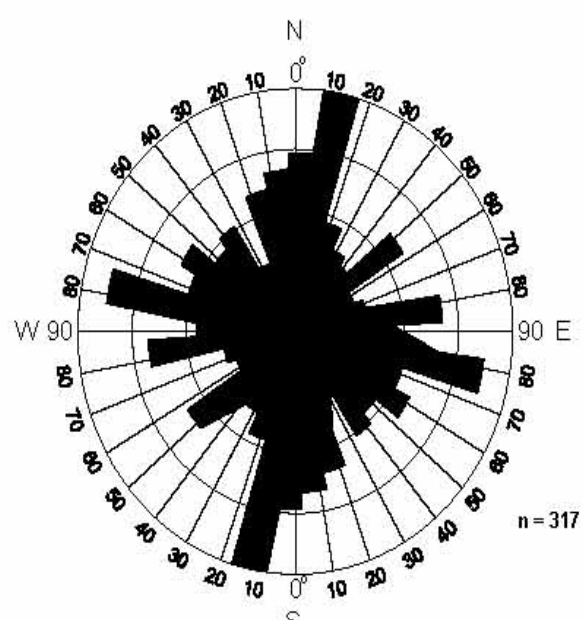
**Shaded Relief Lineaments**



**Merged Lineaments**



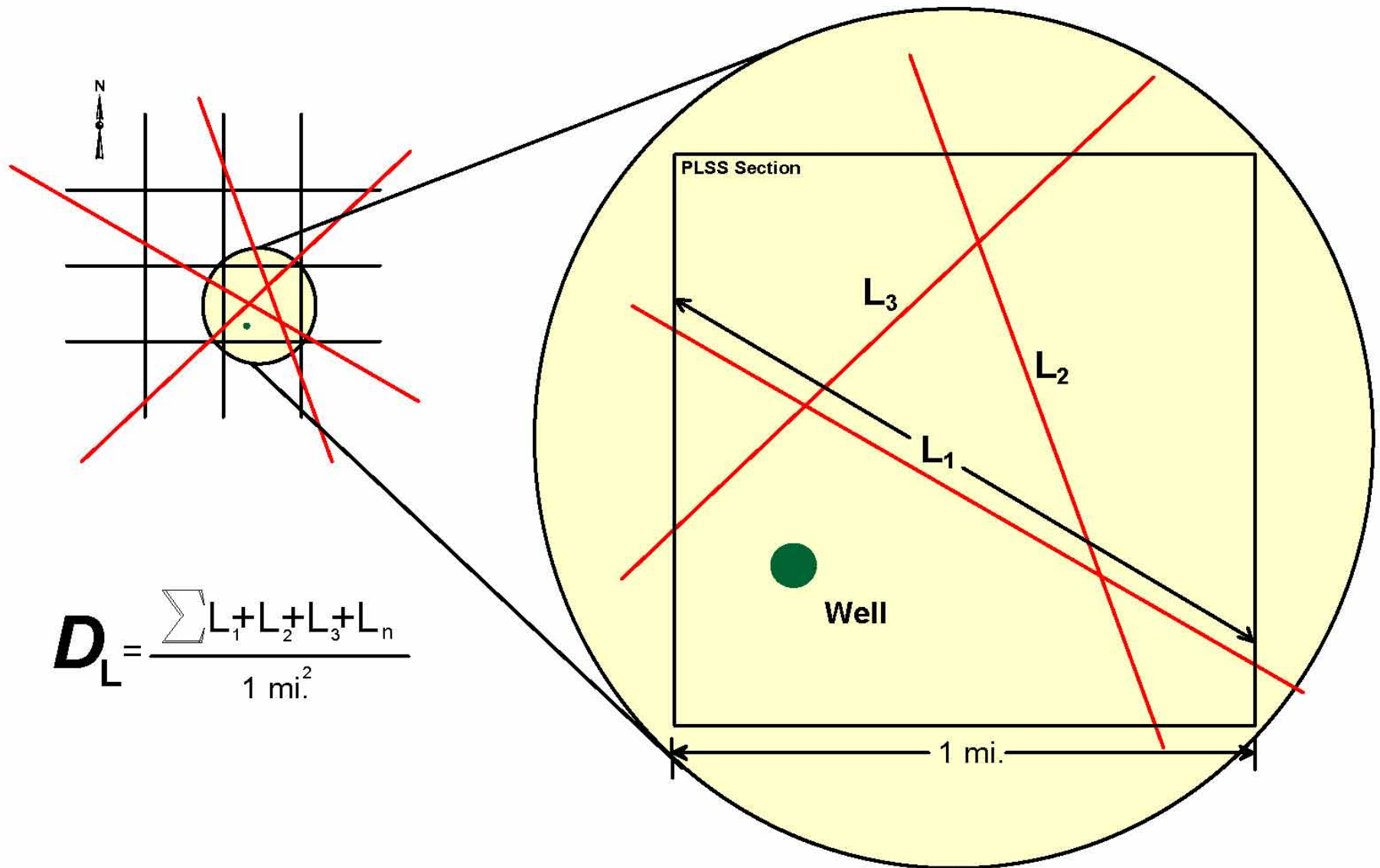
**Aerial Imagery Lineaments**



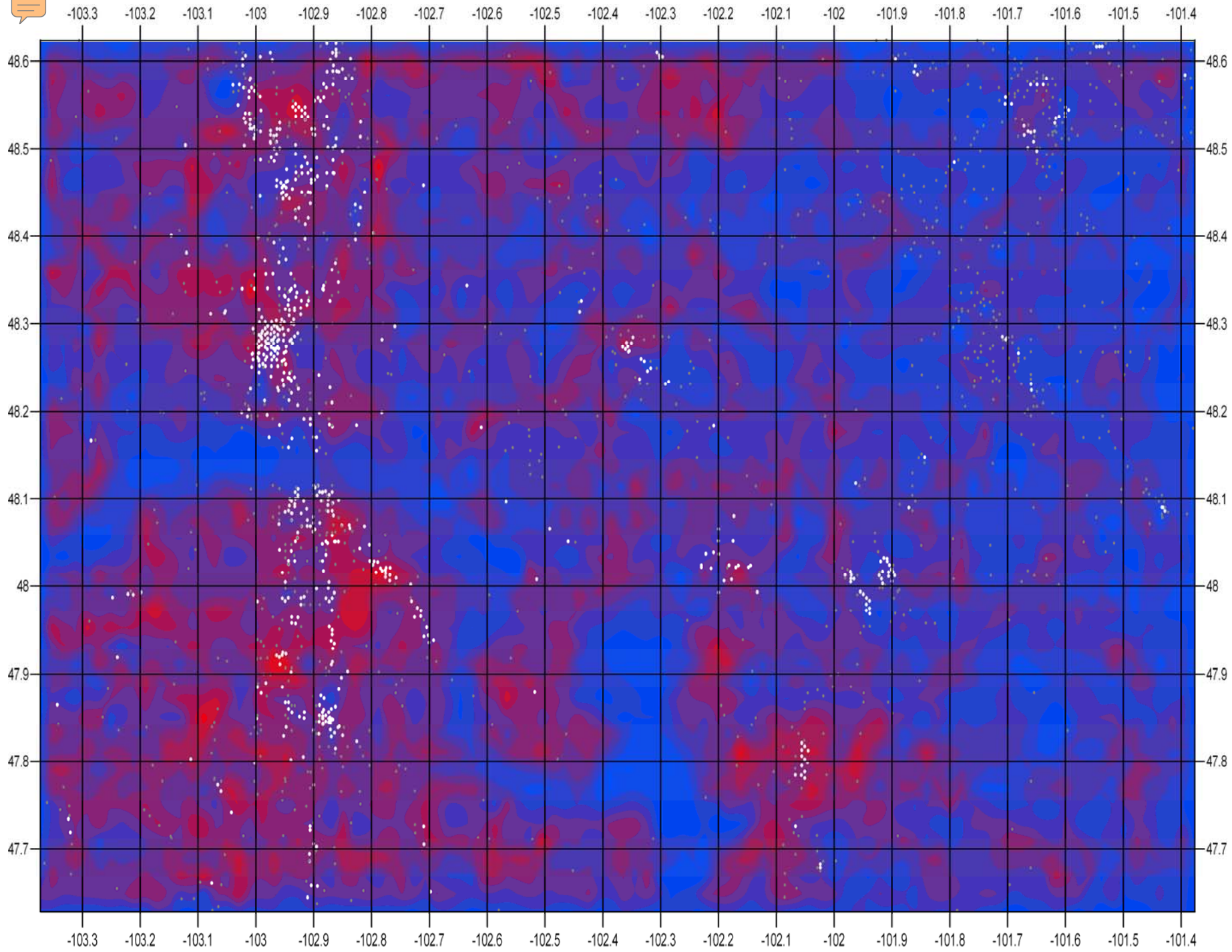
**LANDSAT-7 ETM+ Lineaments**

# Cell based Determination of Lineament Density:

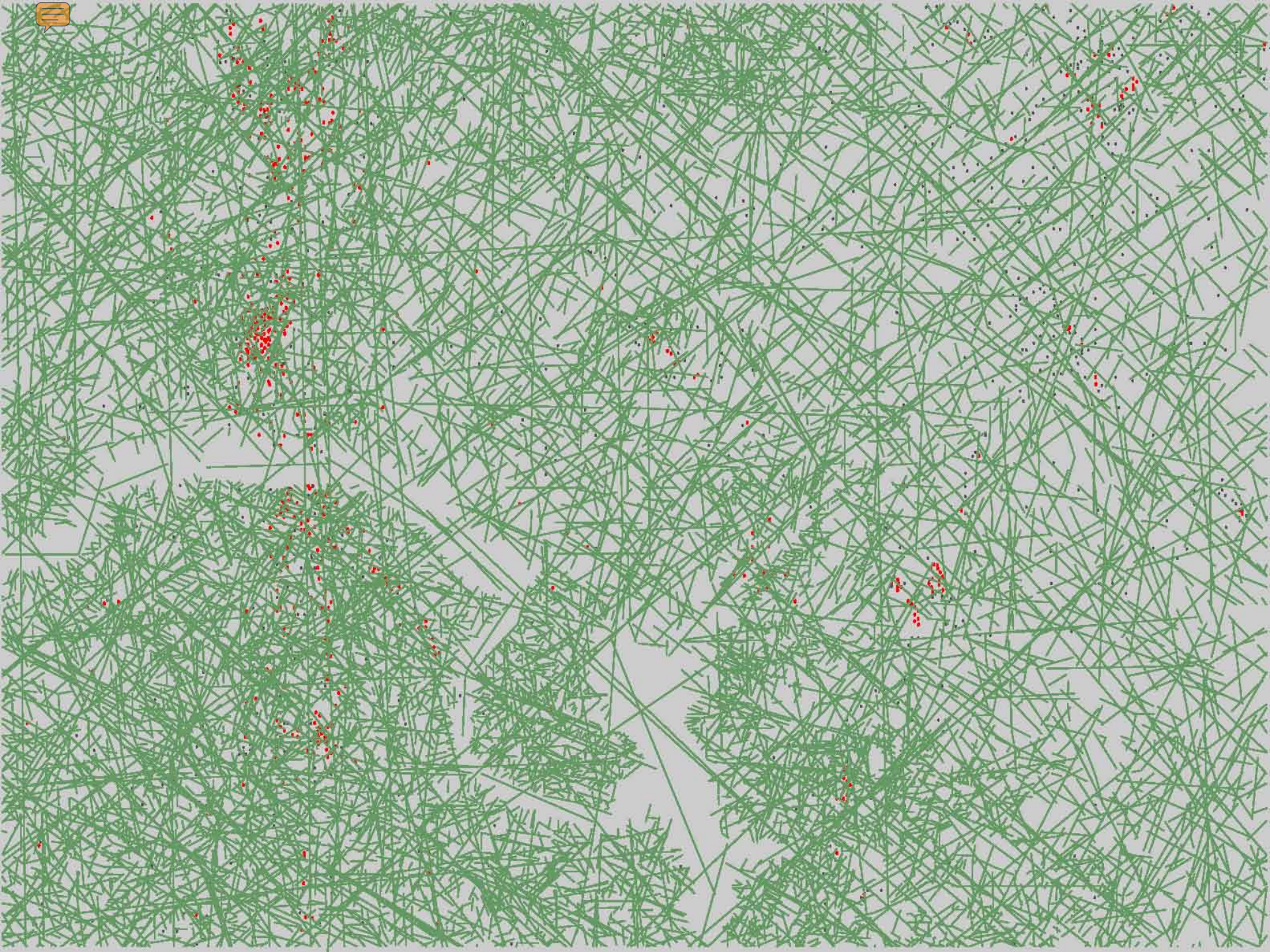
Lineament density (D) calculated as the total amount of lineament length per unit section (i.e. one square mile).





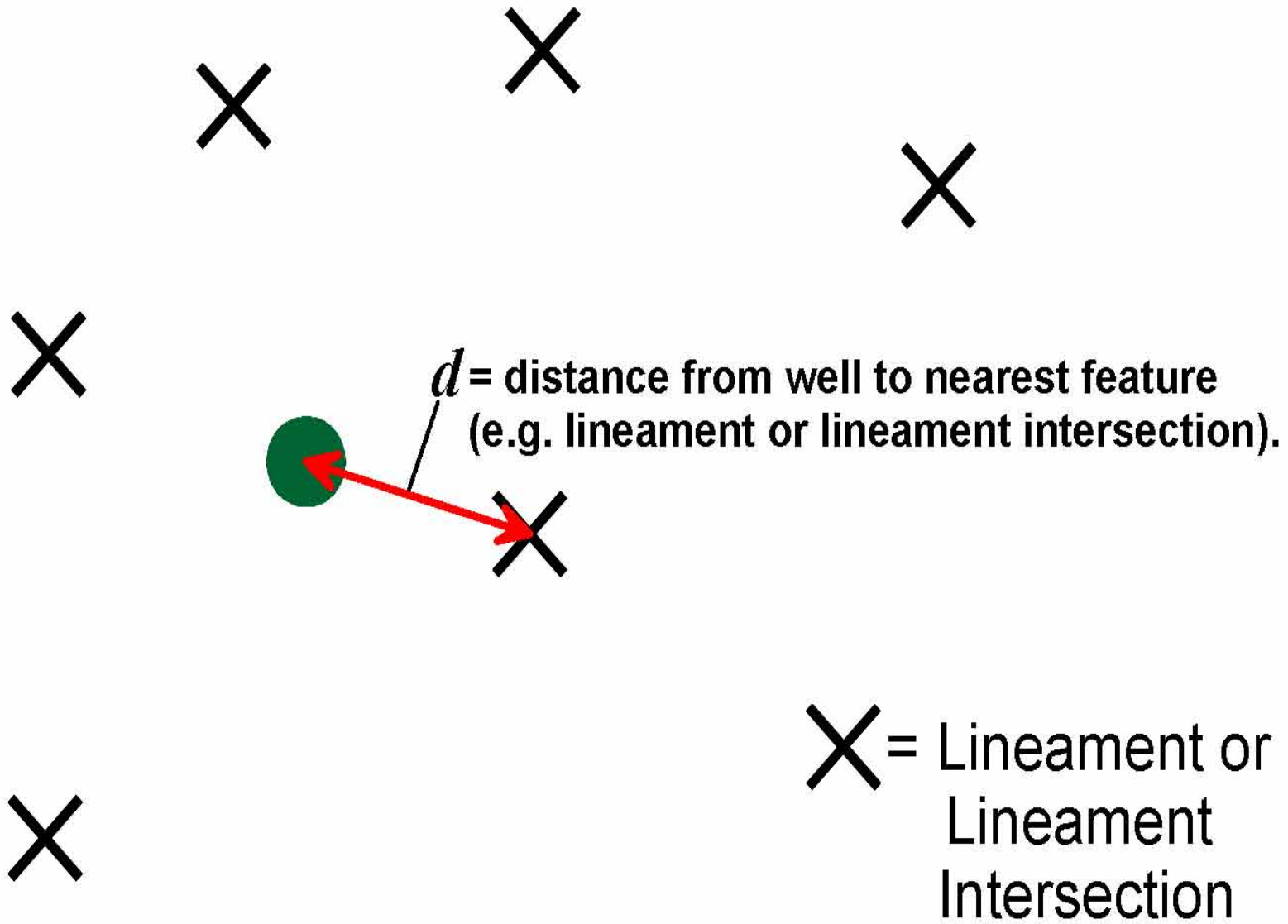






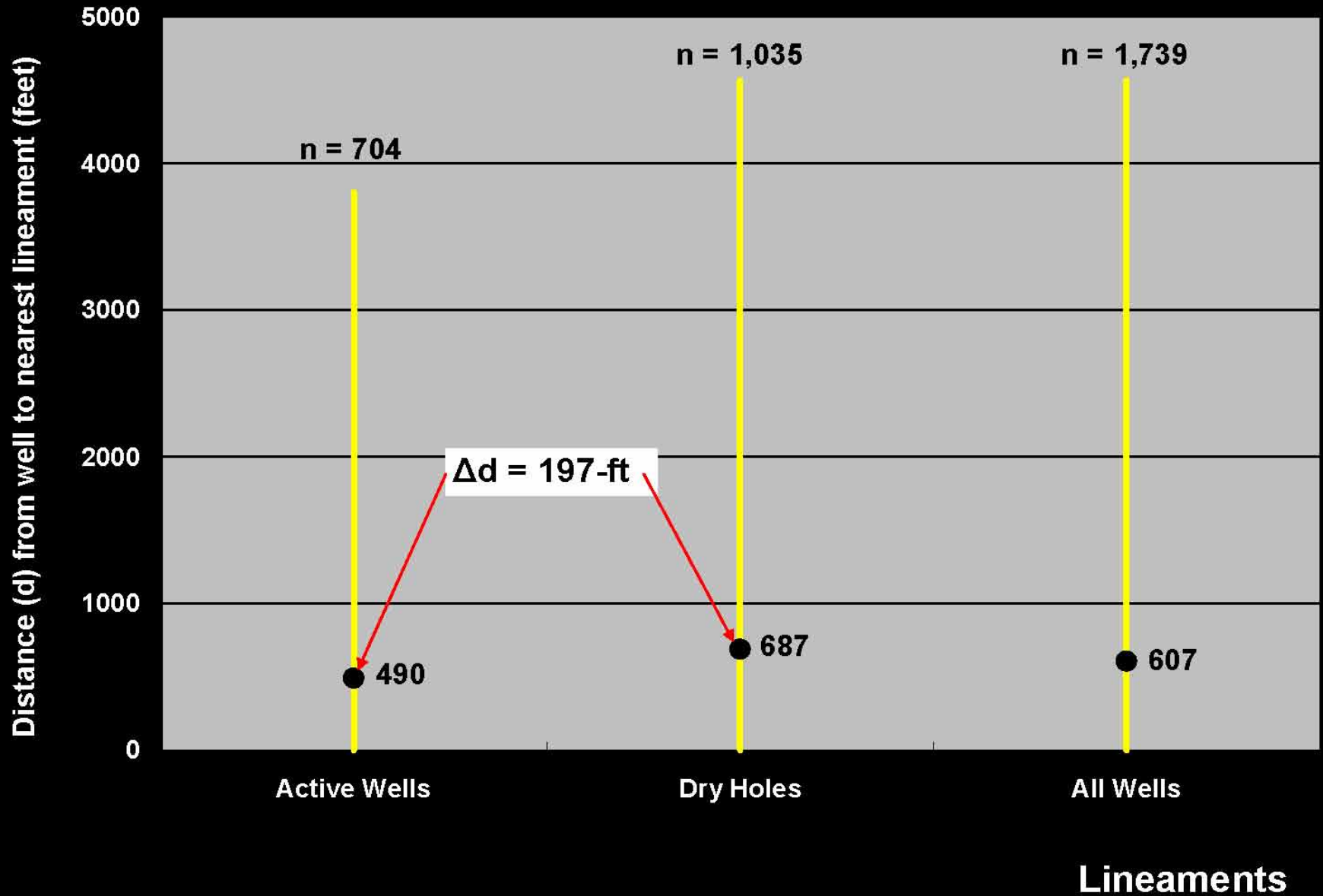


**ArcGIS Near Analysis:** Selects the nearest feature from one set of data to the other (i.e. layers, points, lines, etc.)





# Near Analysis of Wells in the Parshall 1:250K Study Area



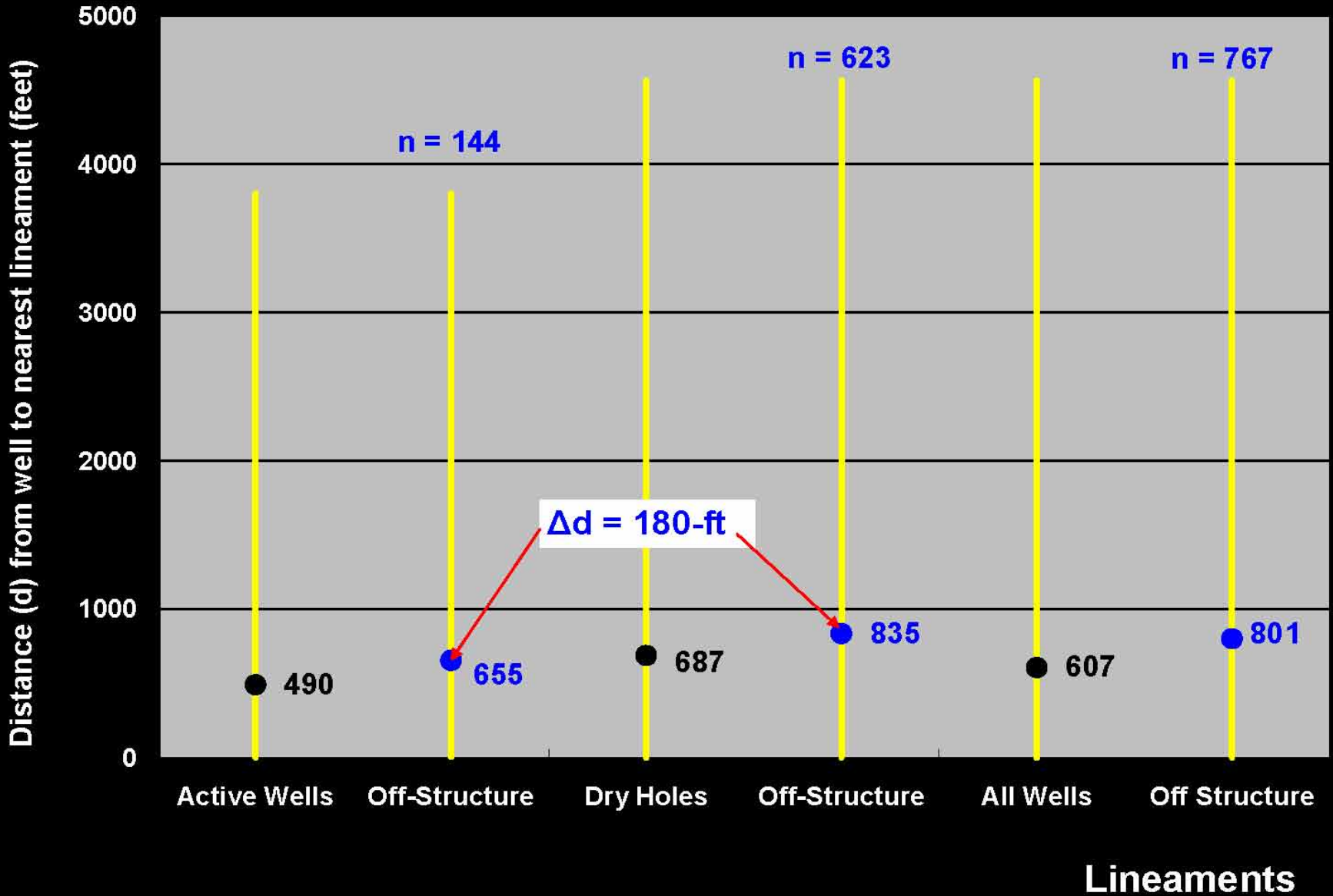


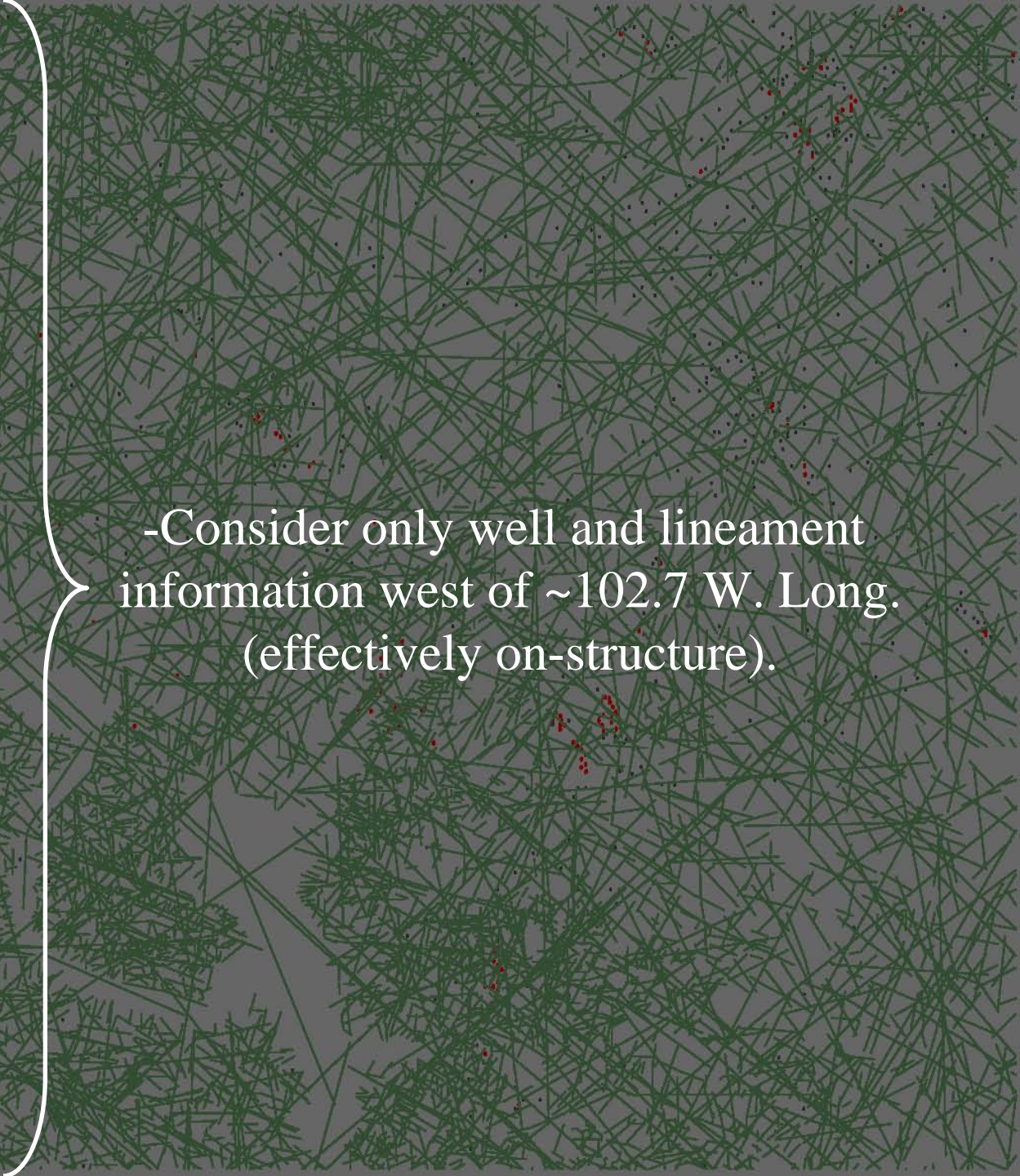
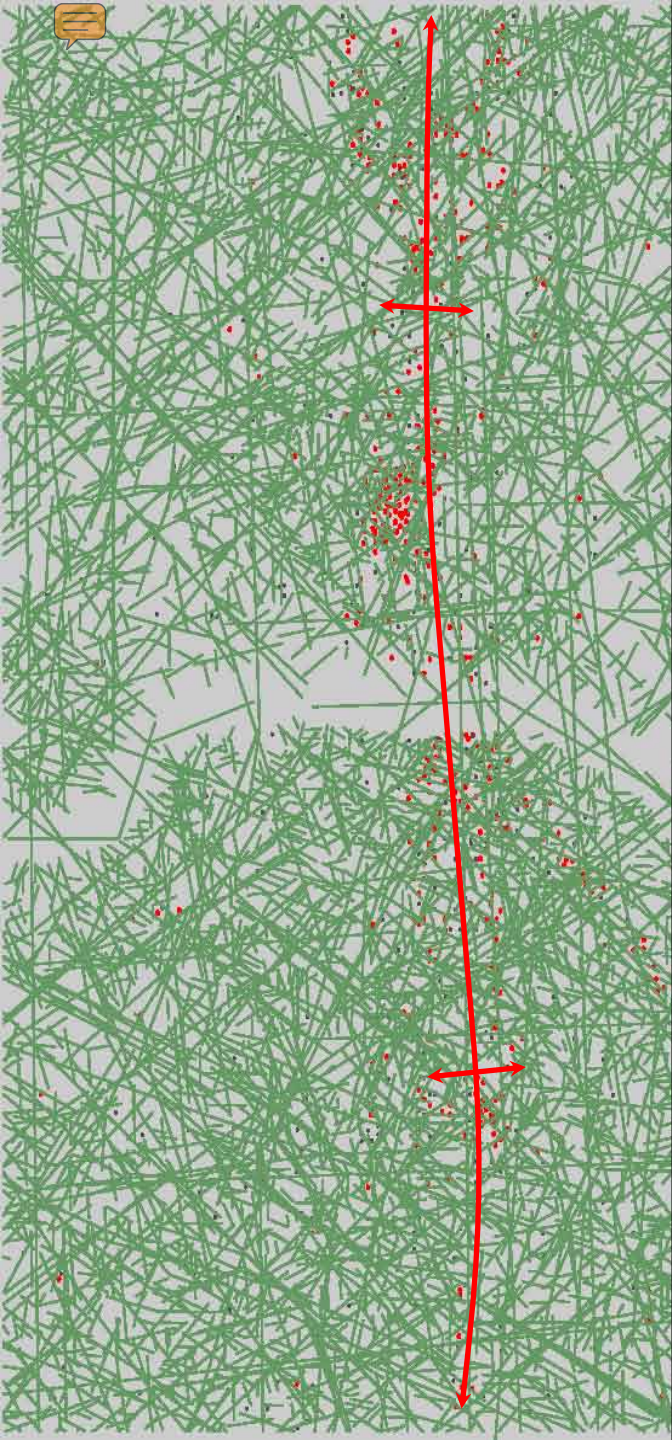
-Consider only well  
and lineament  
information east of  
~102.7 W. Long.  
(effectively off-  
structure).





# Near Analysis of Wells in the Parshall 1:250K Study Area

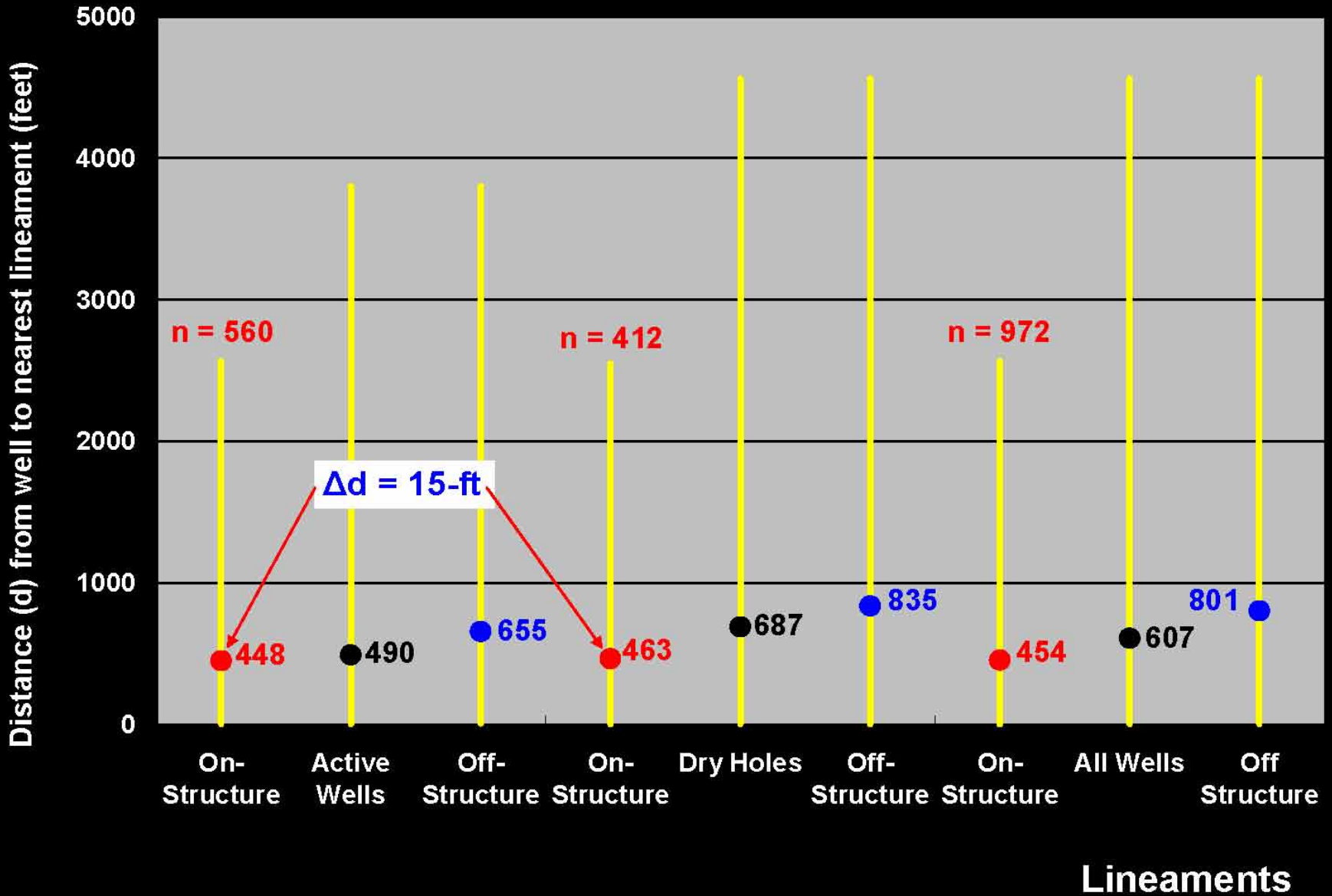




-Consider only well and lineament information west of  $\sim 102.7$  W. Long. (effectively on-structure).



# Near Analysis of Wells in the Parshall 1:250K Study Area





## Well to Lineament Near Analysis Statistical Summary<sup>1</sup>

<b>Well Description</b>	<b>Mean</b>	<b>Range</b>	<b>Standard Deviation</b>	<b>Number of Wells</b>
<b>All Wells</b>	<b>607</b>	<b>0.6 – 4,563</b>	<b>589</b>	<b>1,739</b>
<b>All Wells - On Structure</b>	<b>454</b>	<b>0.6 – 2,565</b>	<b>392</b>	<b>972</b>
<b>All Wells - Off Structure</b>	<b>801</b>	<b>0.6 – 4,563</b>	<b>725</b>	<b>767</b>
<b>Producing Wells</b>	<b>490</b>	<b>0.6 – 3,802</b>	<b>444</b>	<b>704</b>
<b>Producing Wells - On Structure</b>	<b>448</b>	<b>0.6 – 2,565</b>	<b>376</b>	<b>560</b>
<b>Producing Wells - Off Structure</b>	<b>655</b>	<b>5.2 – 3,802</b>	<b>619</b>	<b>144</b>
<b>Dry Wells – All</b>	<b>687</b>	<b>0.6 – 4,563</b>	<b>659</b>	<b>1,035</b>
<b>Dry Wells - On Structure</b>	<b>463</b>	<b>1.6 – 2,548</b>	<b>413</b>	<b>412</b>
<b>Dry Wells - Off Structure</b>	<b>835</b>	<b>0.6 – 4,563</b>	<b>744</b>	<b>623</b>

<sup>1</sup>All results reported in feet.





## Well to Lineament Near Analysis Statistical Summary<sup>1</sup>

Well Description	Mean	Range	Standard Deviation	Number of Wells
All Wells	185	0.2 – 1,391	180	1,739
All Wells - On Structure	138	0.2 – 782	119	972
All Wells - Off Structure	244	0.2 – 1,391	221	767
Producing Wells	149	0.2 – 1,159	135	704
Producing Wells - On Structure	137	0.2 – 782	115	560
Producing Wells - Off Structure	200	1.6 - 1,159	189	144
Dry Wells – All	209	0.2 – 1,391	201	1,035
Dry Wells - On Structure	141	0.5 – 777	126	412
Dry Wells - Off Structure	255	0.2 – 1,391	227	623

<sup>1</sup>Results reported in meters.

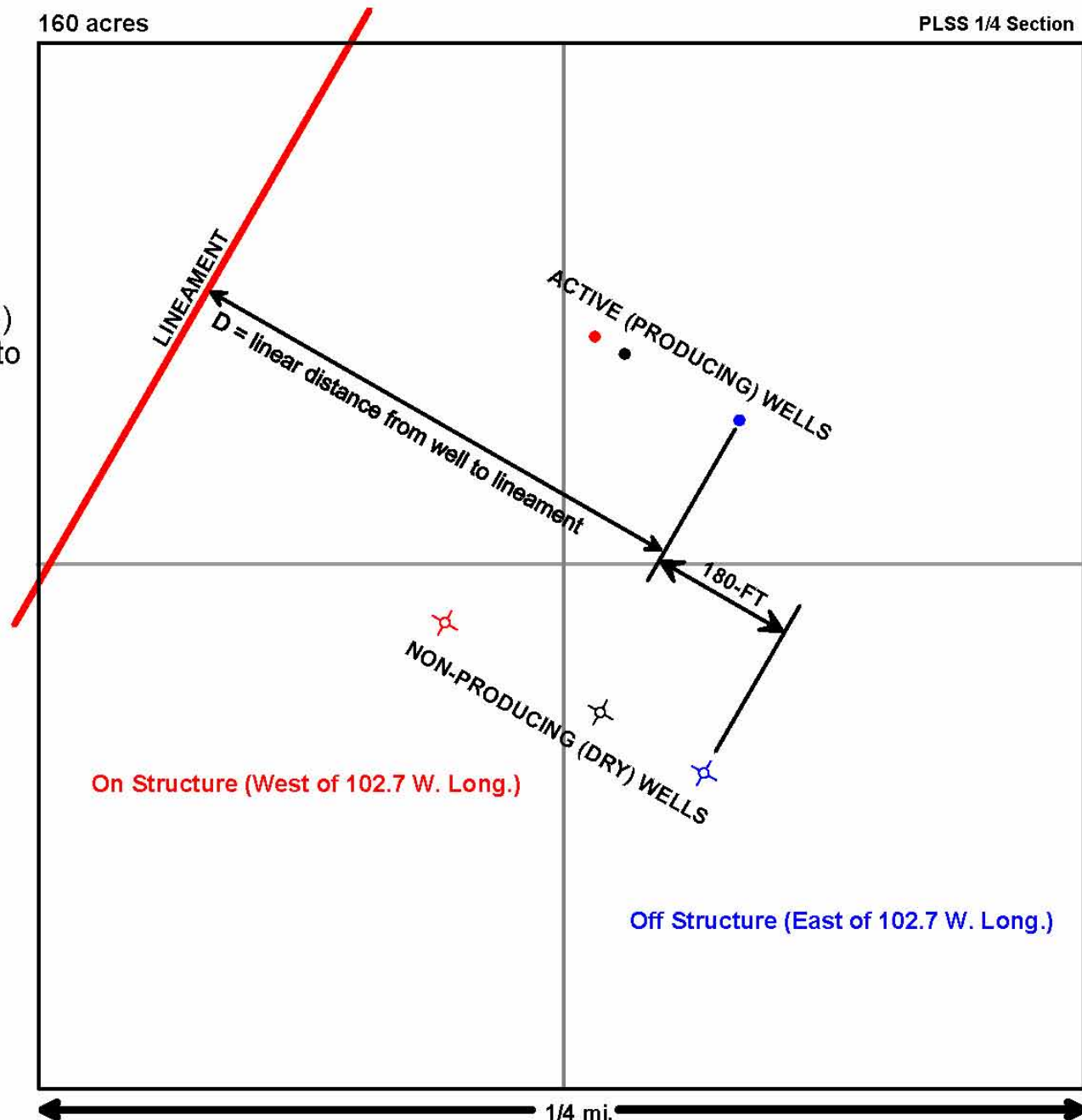
# Proximity of Wells to Lineaments

160 acres

PLSS 1/4 Section



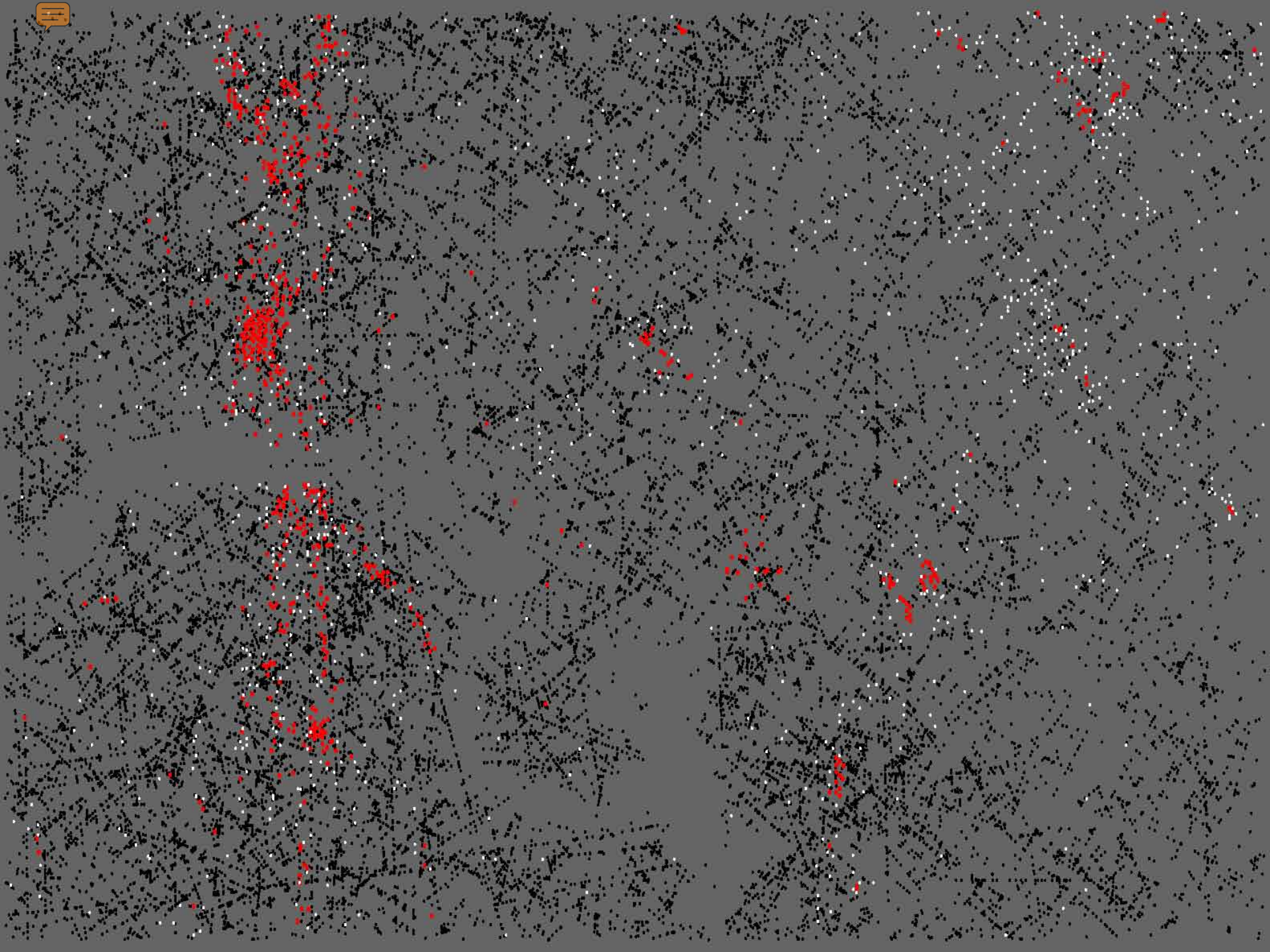
- Producing wells (on average) are located relatively closer to lineaments than dry wells.



On Structure (West of 102.7 W. Long.)

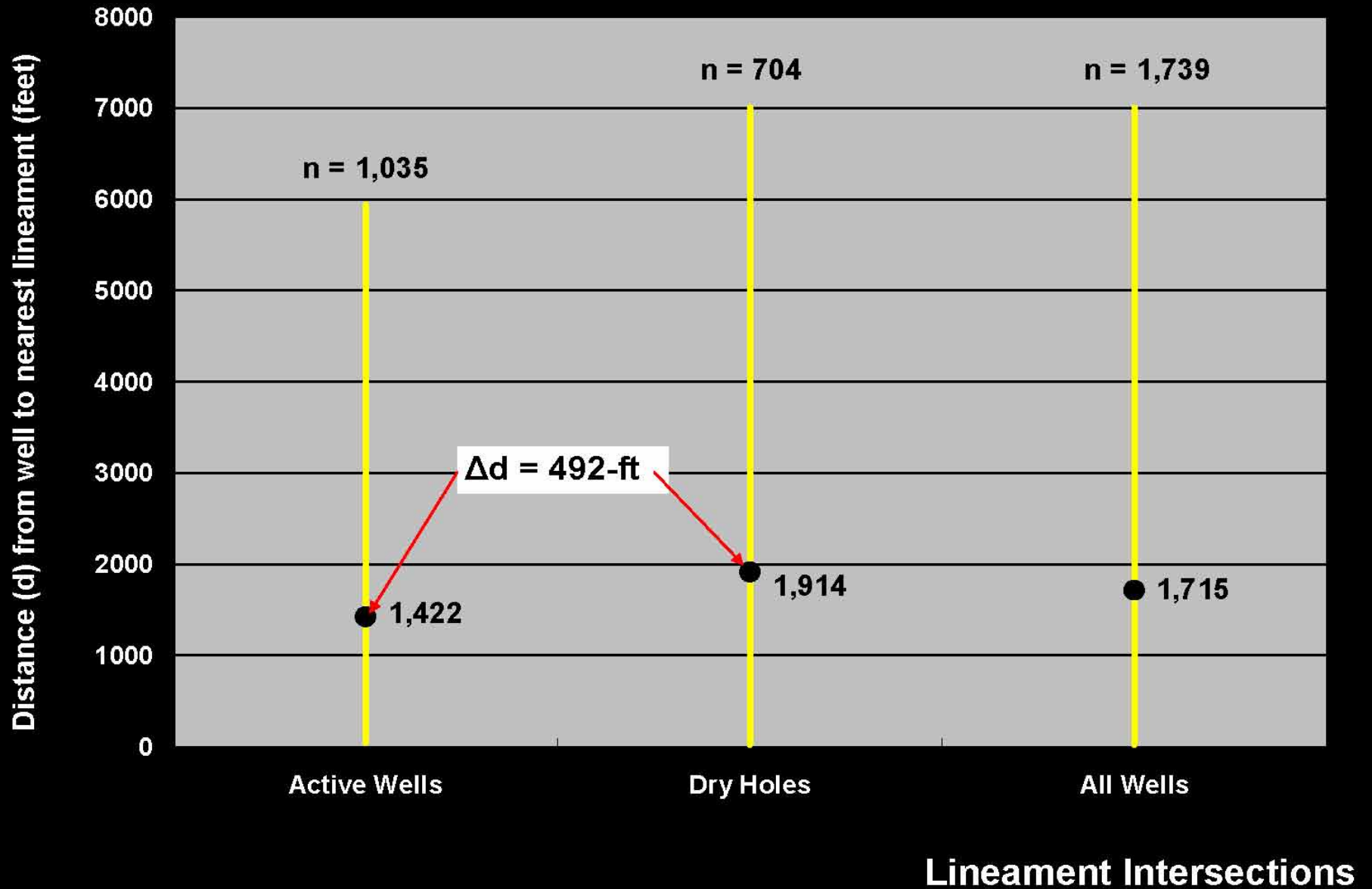
Off Structure (East of 102.7 W. Long.)

1/4 mi.



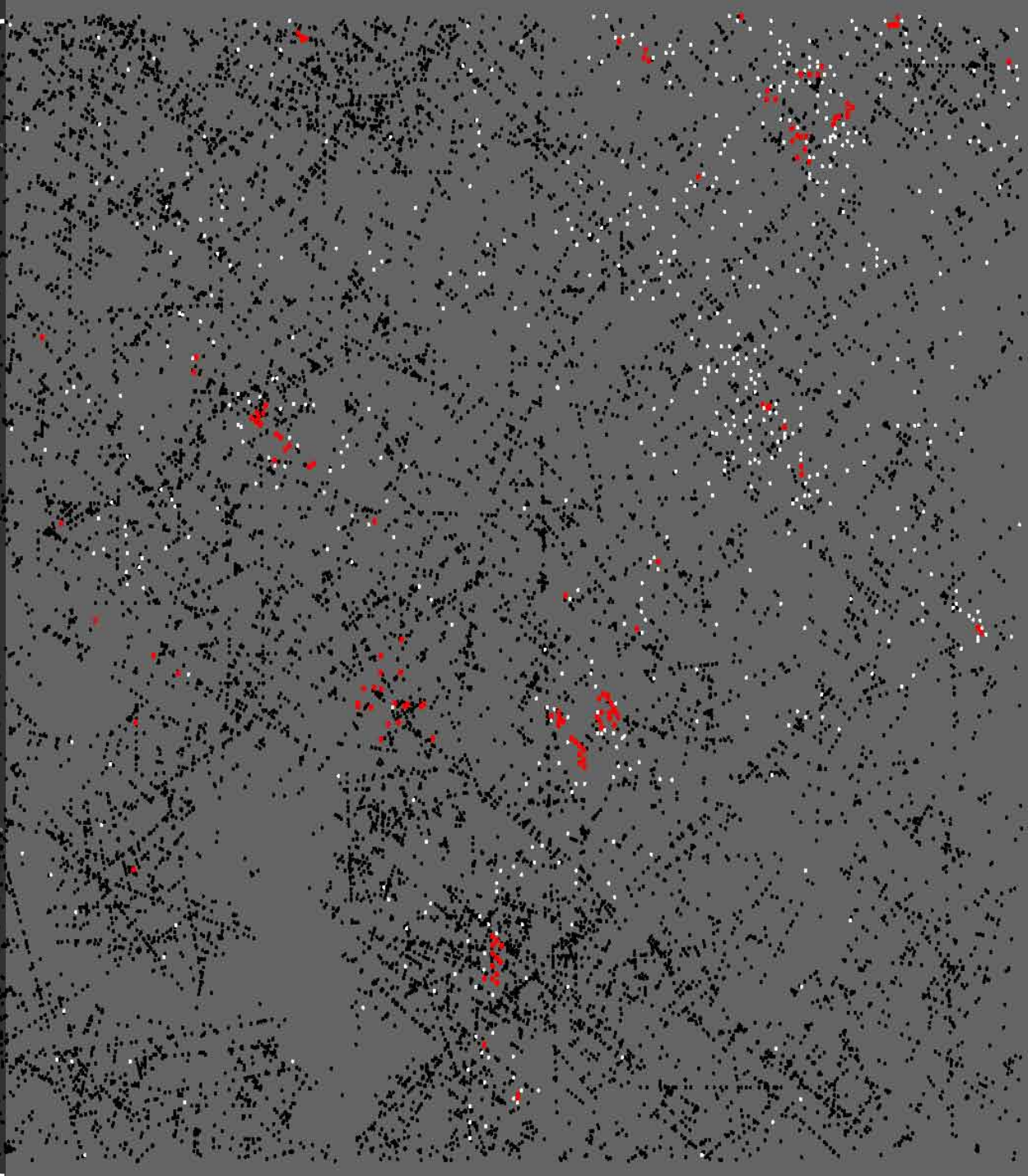


# Near Analysis of Wells in the Parshall 1:250K Study Area





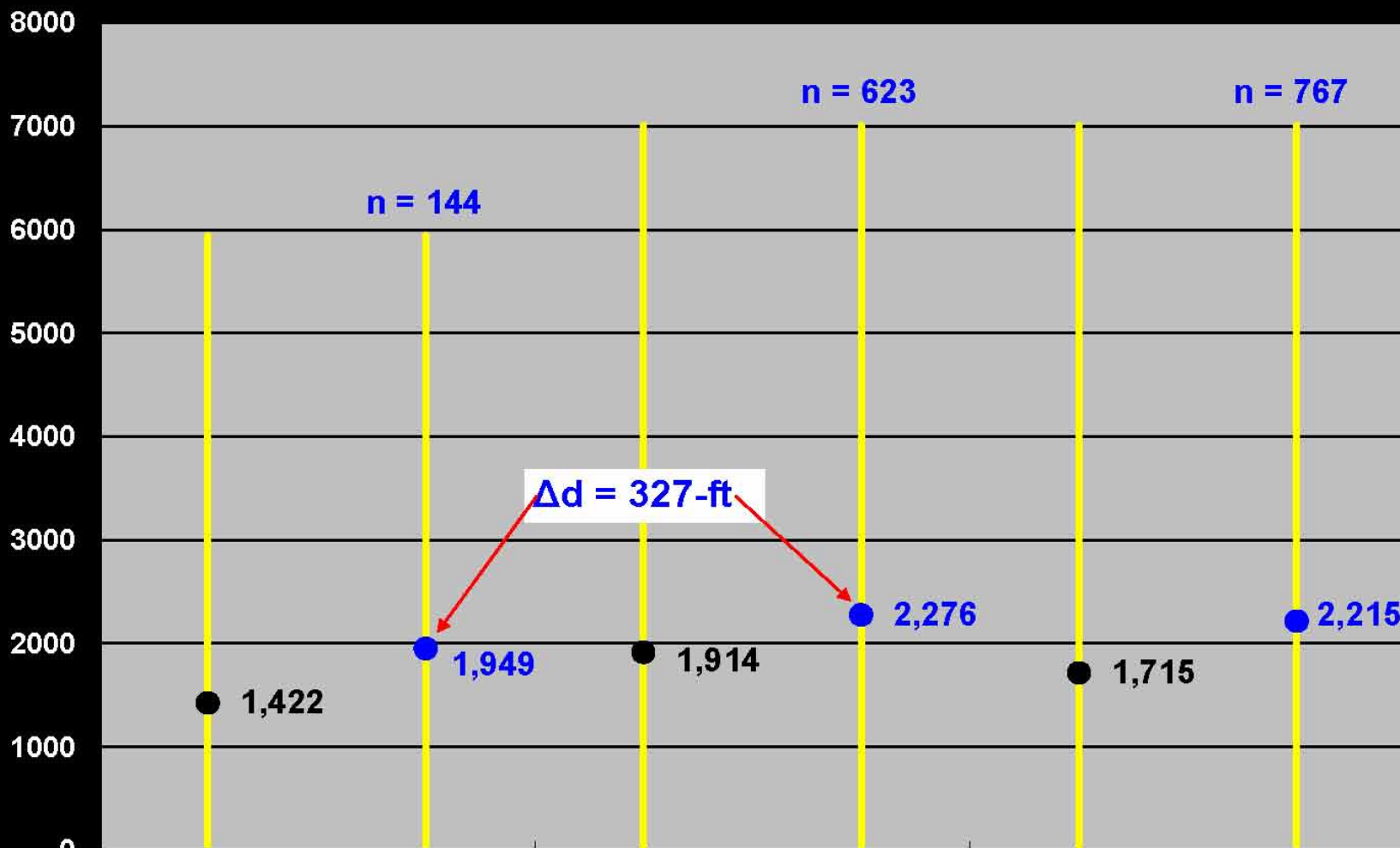
-Consider only well  
and lineament  
information east of  
~102.7 W. Long.  
(effectively off-  
structure).





# Near Analysis of Wells in the Parshall Area 1:250K Study Area

Distance (d) from well to nearest lineament intersection (feet)



$\Delta d = 327\text{-ft}$

Lineament Intersections



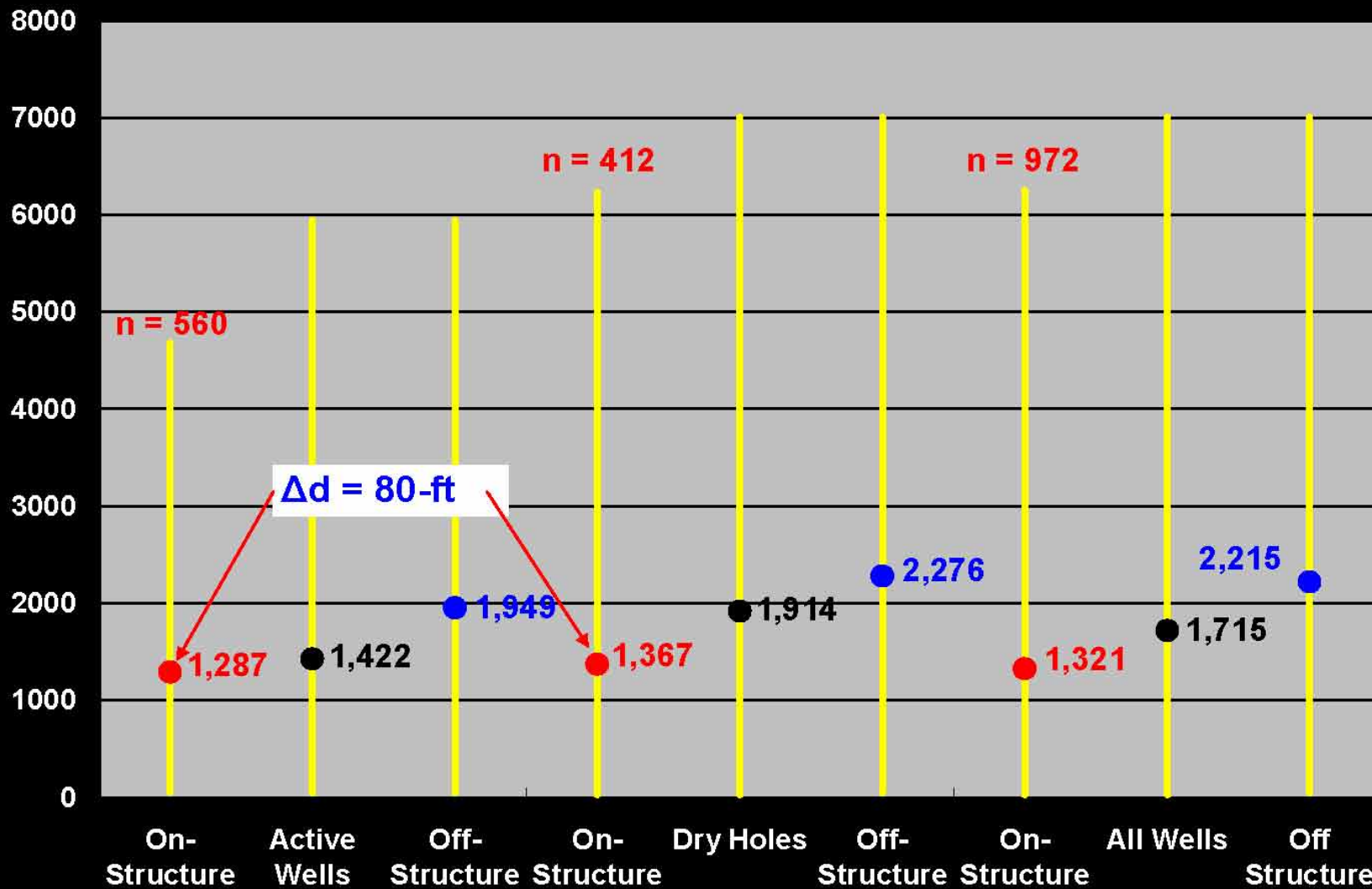
NESSON ANTICLINE

-Consider only well and lineament information west of ~102.7 W. Long. (effectively on-structure).



# Near Analysis of Wells in the Parshall Area 1:250K Study Area

Distance (d) from well to nearest lineament intersection (feet)



$\Delta d = 80\text{-ft}$

Lineament Intersections

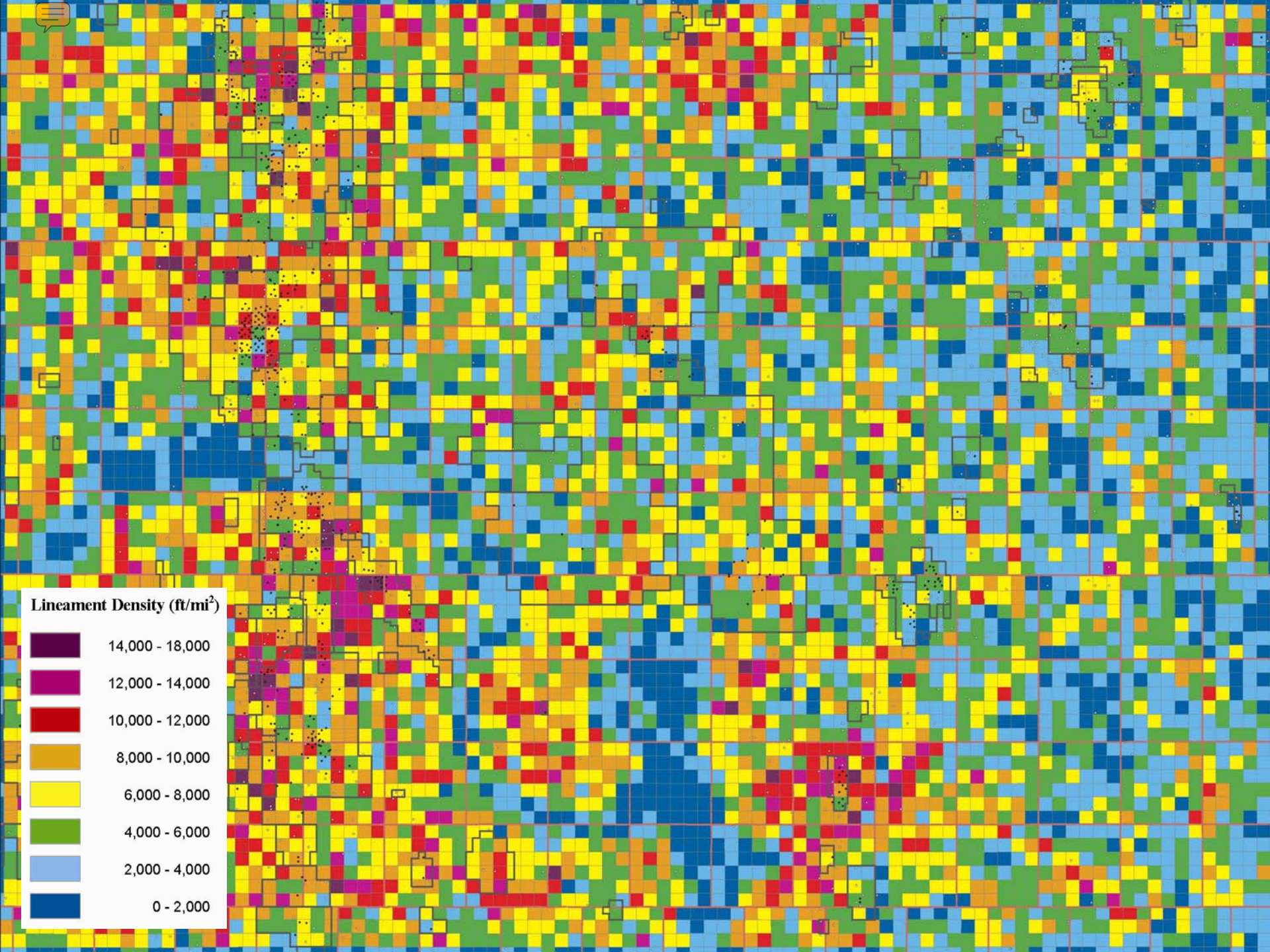




## Well to Lineament Intersection Near Analysis Statistical Summary<sup>1</sup>

<b>Well Description</b>	<b>Mean</b>	<b>Range</b>	<b>Standard Deviation</b>	<b>Number of Wells</b>
<b>All Wells</b>	<b>1,715</b>	<b>22 – 7,006</b>	<b>1,178</b>	<b>1,739</b>
<b>All Wells - On Structure</b>	<b>1,320</b>	<b>22 – 6,252</b>	<b>838</b>	<b>972</b>
<b>All Wells - Off Structure</b>	<b>2,215</b>	<b>38 – 7,006</b>	<b>1,346</b>	<b>767</b>
<b>Producing Wells</b>	<b>1,422</b>	<b>41 – 5,945</b>	<b>899</b>	<b>704</b>
<b>Producing Wells - On Structure</b>	<b>1,287</b>	<b>46 – 4,678</b>	<b>771</b>	<b>560</b>
<b>Producing Wells - Off Structure</b>	<b>1,949</b>	<b>41 – 5,945</b>	<b>1,139</b>	<b>144</b>
<b>Dry Wells – All</b>	<b>1,914</b>	<b>22 – 7,006</b>	<b>1,298</b>	<b>1,035</b>
<b>Dry Wells - On Structure</b>	<b>1,367</b>	<b>22 – 6,252</b>	<b>920</b>	<b>412</b>
<b>Dry Wells - Off Structure</b>	<b>2,276</b>	<b>38 – 7,006</b>	<b>1,382</b>	<b>623</b>

<sup>1</sup>All results reported in feet.



**Lincament Density (ft/mi<sup>2</sup>)**

- 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

# Well Distributions per Lineament Class

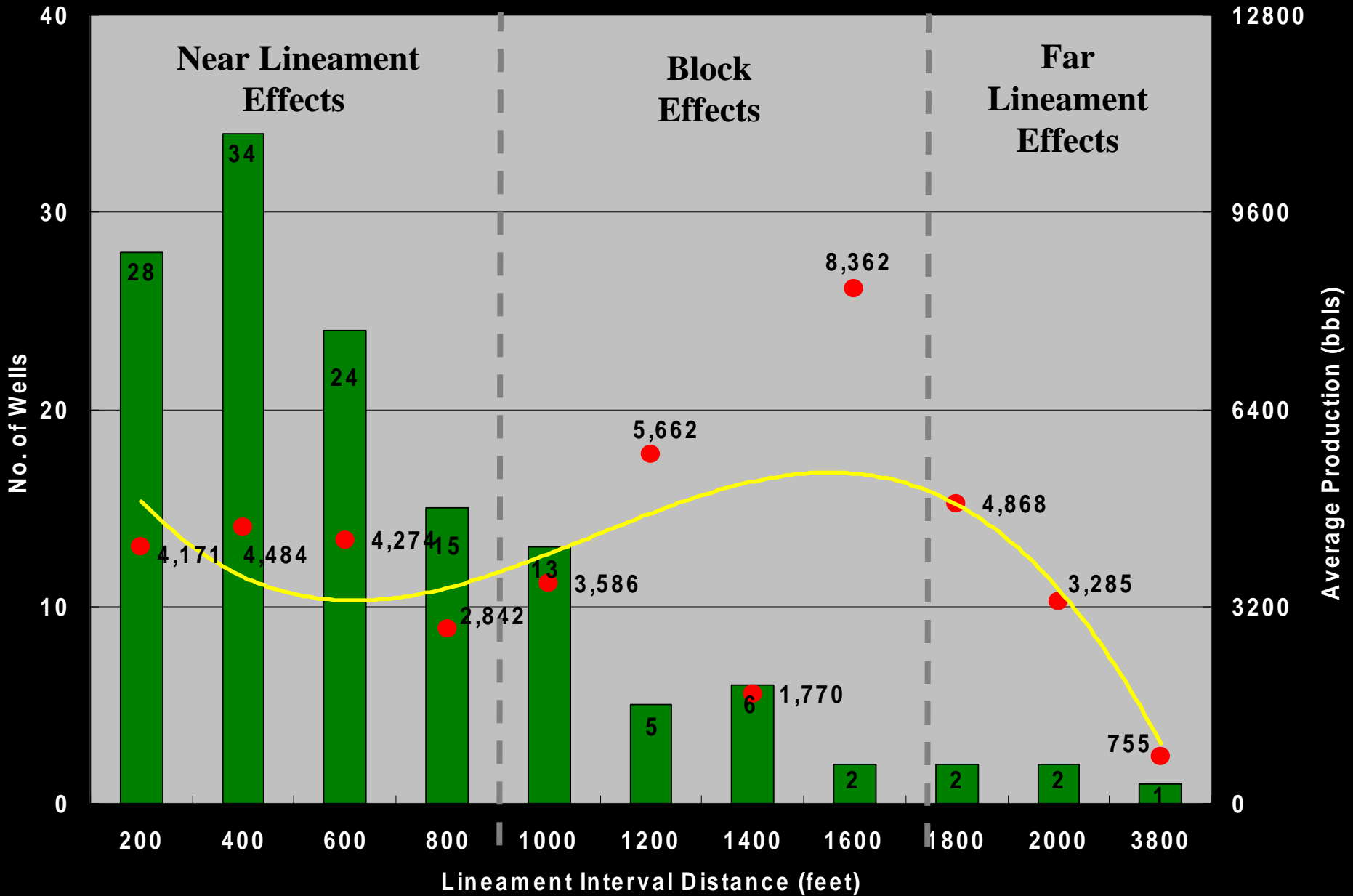
Lineament Class	Averaged Monthly Production <sup>1</sup> (bbls)	Averaged Production Sum (bbls)	No. Producing Wells	No. Non-Producing Wells	Total No. of Wells
I	4,451	80,109	18	17	35
II	2,415	91,754	38	32	70
III	2,838	255,462	90	77	167
IV	2,893	451,304	156	167	323
V	2,731	491,494	180	186	366
VI	2,837	431,157	52	258	410
VII	2,640	145,201	55	200	255
VIII	2,731	40,966	15	98	113
	<b>Totals</b>	<b>1,987,447</b>	<b>704</b>	<b>1,035</b>	<b>1,739</b>

<sup>1</sup>Averaged monthly production calculated from the first 12 months of well production divided by the *total* number of wells drilled within each lineament density class.





# Lineament Proximity and Bakken Well Production in the Parshall 1:250K Area



Block

Lineament Zone

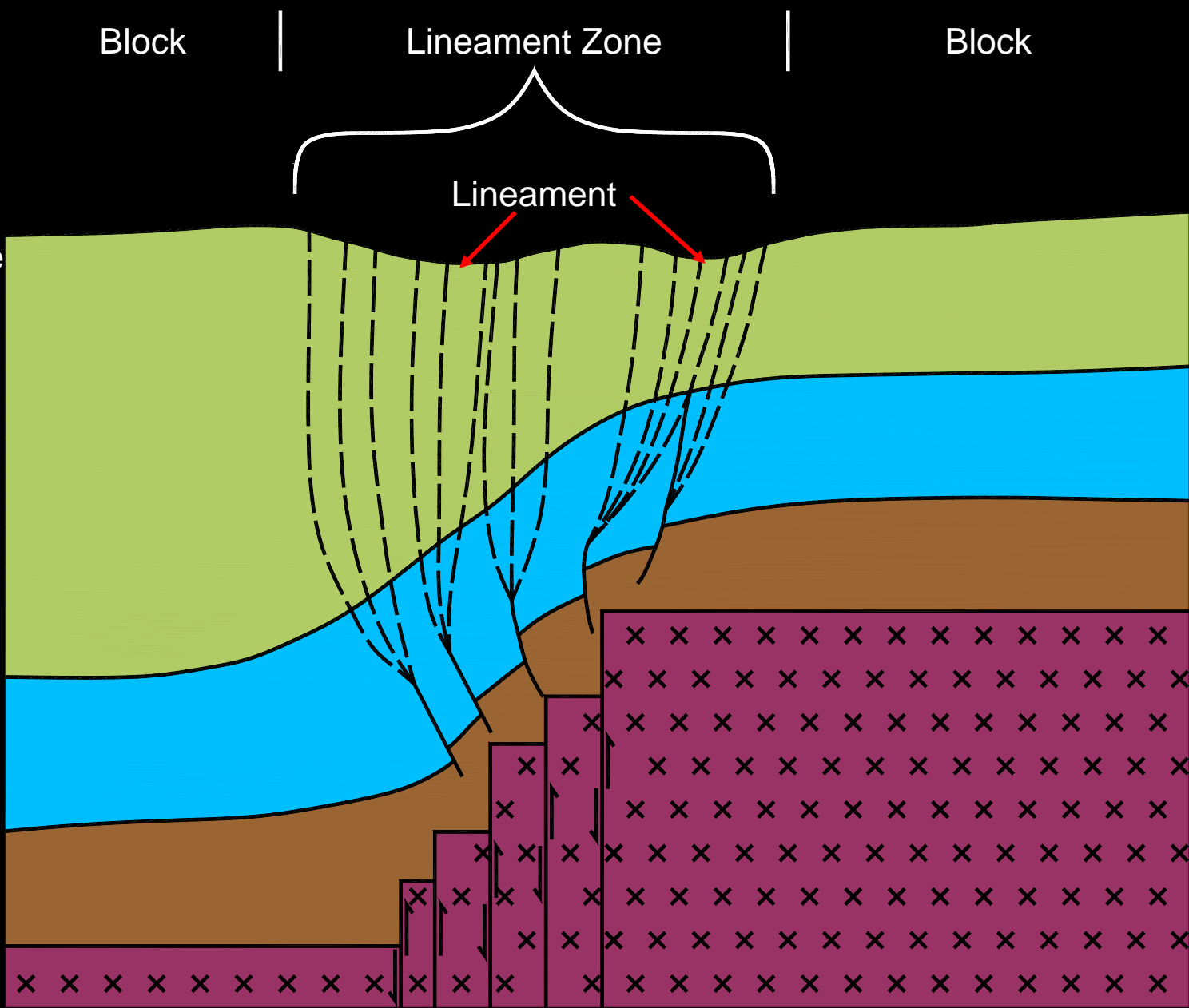
Block

Earth Surface

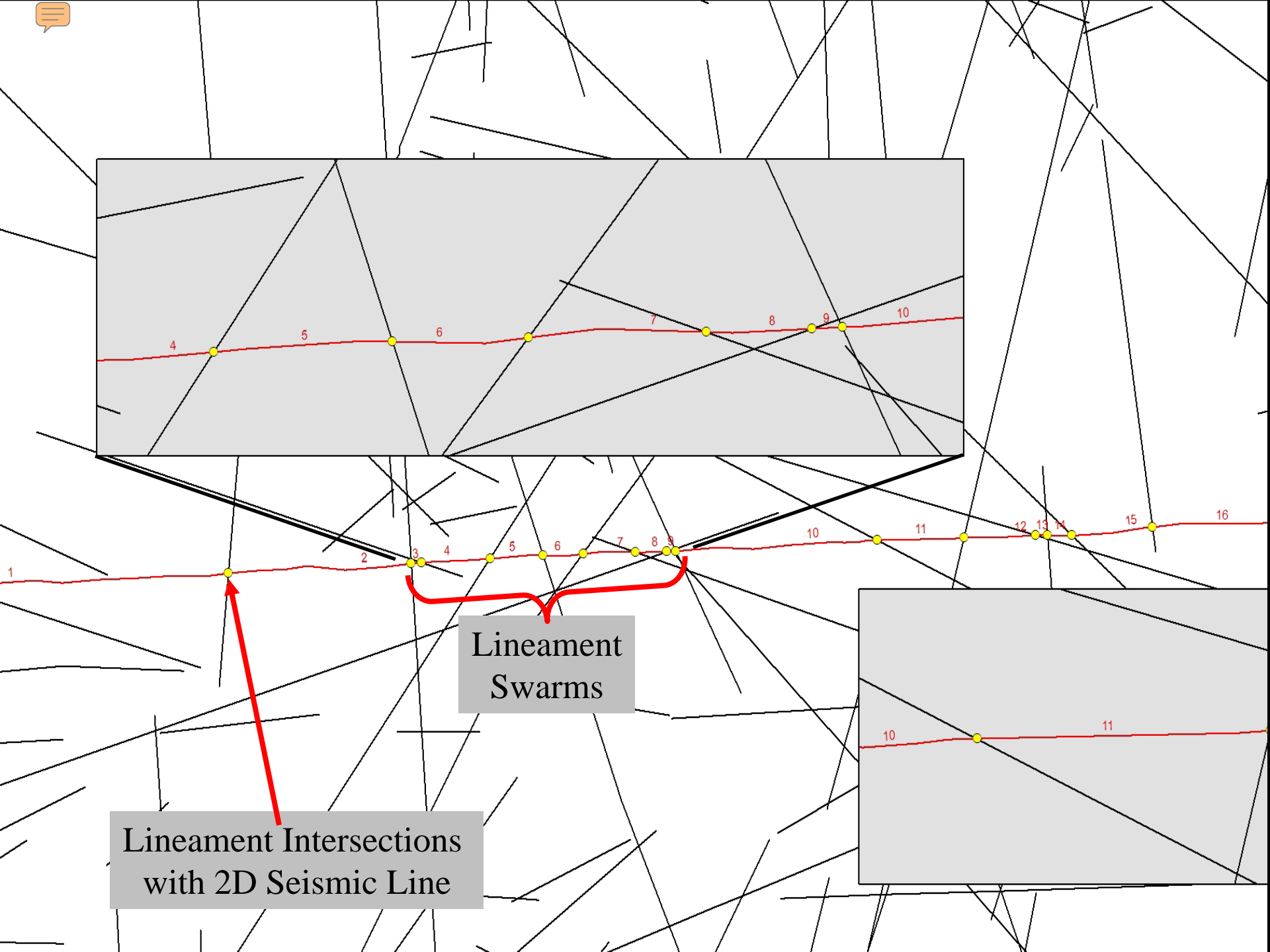
Lineament

Mesozoic Units

Paleozoic Units

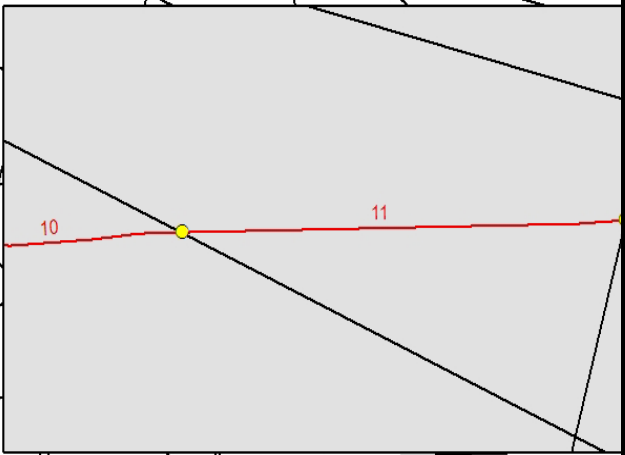


Modified from Shurr (1982)



Lineament Swarms

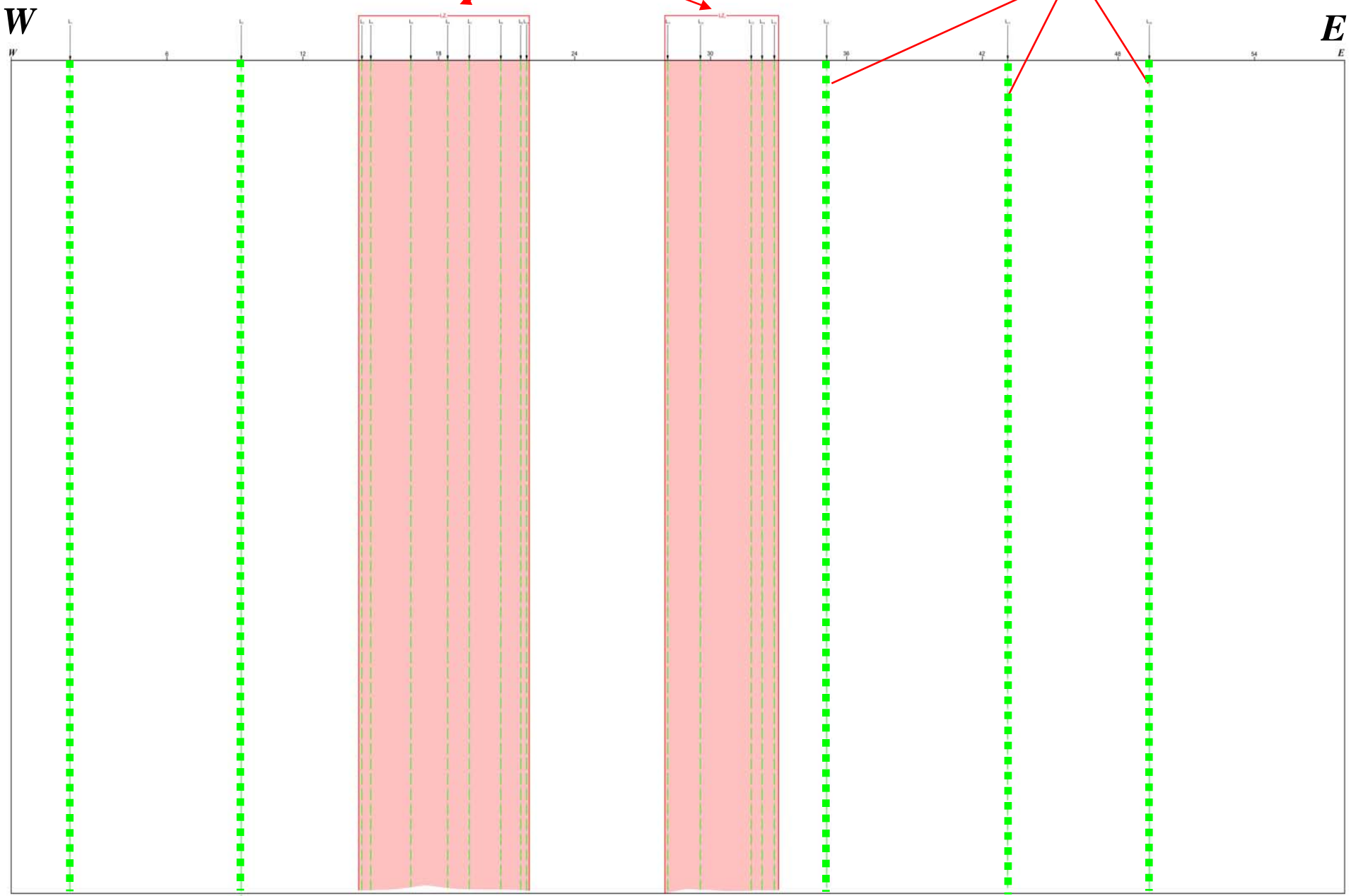
Lineament Intersections with 2D Seismic Line





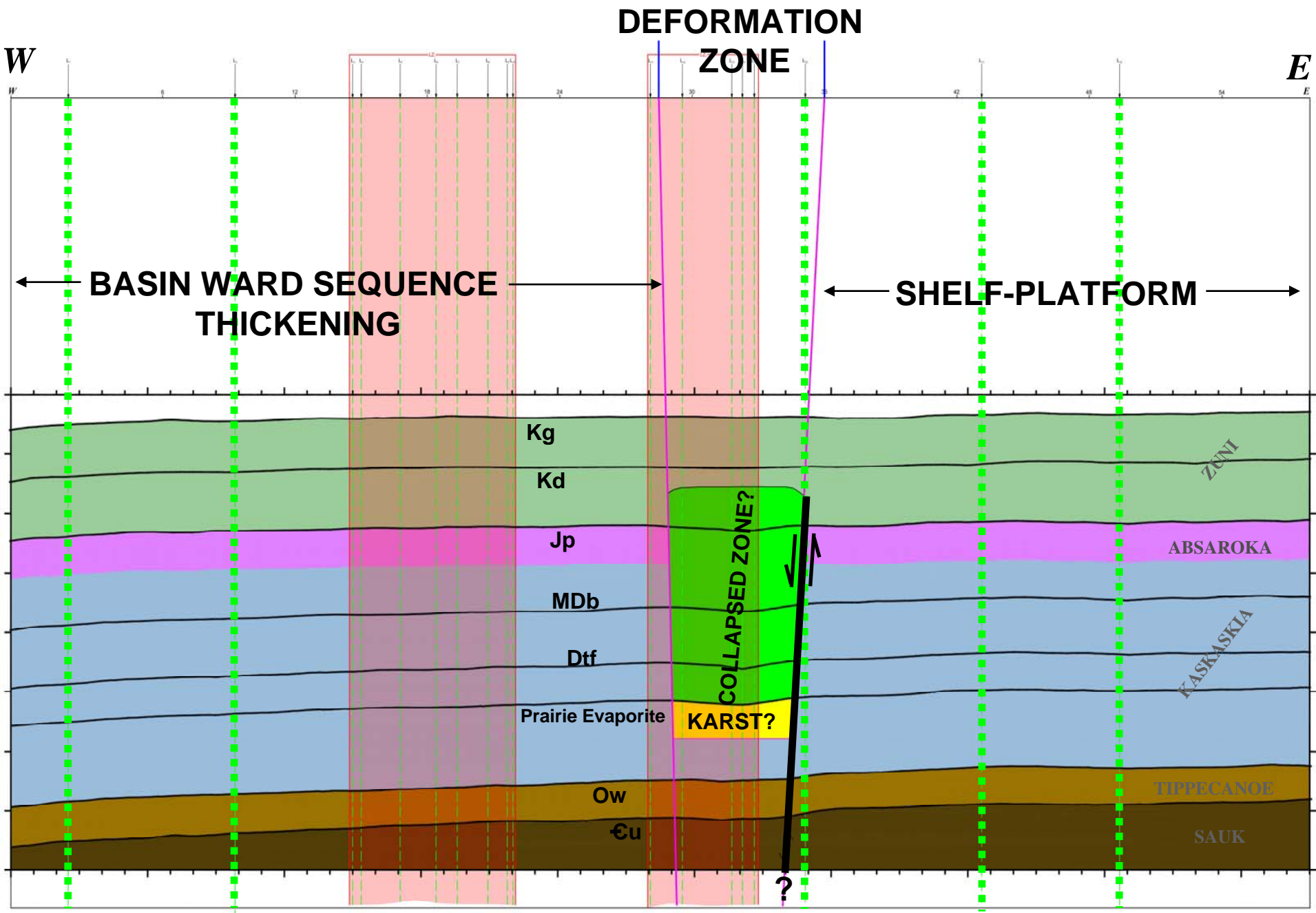
# LINEAMENT ZONES

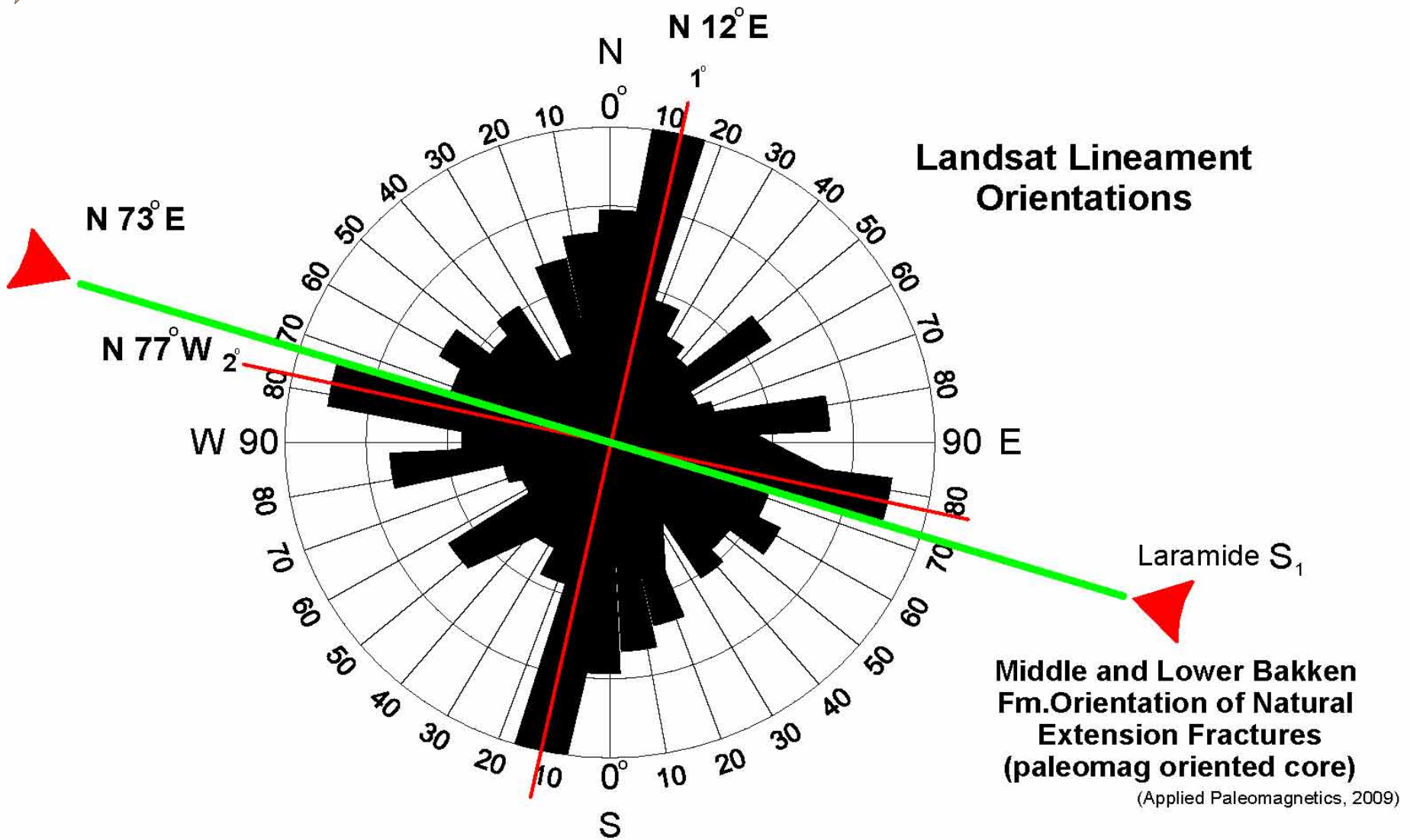
# LINEAMENTS





(modified from Johnson, 2009)





***Relatively good agreement between lineament trends identified from LANDSAT-7 ETM+ imagery (red) and recent paleomagnetically oriented core fracture studies on the Bakken Formation (green).***

# *Conclusions*

- **Producing wells tend to be located relatively closer to lineaments than do dry wells.**
- **The exploration and production trend in the Parshall Area, particularly off structure (i.e. east of the Nesson Anticline), has generally been into areas of lesser lineament development.**
- **Wells drilled in areas of greater lineament development have been shown to be generally more successful, with relatively higher overall averaged production and success rates. Wells drilled in areas of lesser lineament development appear to result in more dry holes.**

# ***Conclusions (contd.)***

- **Averaged production from wells producing from the Bakken Formation appear to follow a variable, decreasing-increasing-decreasing, trend as the distance between the well and lineament(s) increases, which may be suggestive of; near-lineament, bound reservoir, and far-lineament effects, sequentially.**
- **Mapped lineament trends W/NW (N.75°W.) and E/SE (S.75°E.) appear generally consistent with recent industry interpreted fracture trends in Bakken core, particularly for lineament trends identified from LANDSAT-7 ETM+ imagery, suggesting that regional scale lineament development is consistent with reservoir scale natural fractures.**
- **Surface lineaments can be tied to high-angle faulting, through 2D seismic interpretation, originating in the Precambrian basement and propagating into overlying Phanerozoic sedimentary strata creating effective reservoir boundaries.**



# *Acknowledgements*

- *Elroy Kadrmas (GIS) – N.D. Geological Survey*
- *Lynn Helms – Director – N.D. Department of Mineral Resources*
  - *Ed Murphy – State Geologist – N.D. Geological Survey*
  - *Julie LeFever, Petroleum Geologist – N.D. Geological Survey*
- *Dr. Stephan Nordeng – Subsurface Geologist – N.D. Geological Survey*
- *Bruce Juenker – Petroleum Geologist – N.D. Oil & Gas Division*
  - *Bruce Hicks – Assistant Director – N.D. Oil & Gas Division*
    - *Eric Johnson – Johnson Geophysical*

# ***NORTH DAKOTA GEOLOGICAL SURVEY***

**North Dakota Department of Mineral Resources  
and Geological Survey Division Main Offices**

<http://www.dmr.nd.gov/ndgs>



**Office Hours: Monday - Friday, 8am-12pm and 1pm - 5pm**

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## **The Wilson M. Laird Core & Sample Library**



**P.O. Box 8156 University Station  
Grand Forks, ND 58202**  
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## **North Dakota Geological Survey Paleontology Lab**



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