North Dakota Geological Survey
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ANALYSIS OF LINEAMENTS AND HORIZONTAL WELLS IN THE PARSHALL AREA, NORTH DAKOTA

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2012

HORIZONTAL WELL-LINEAMENT INTERSECTION PRODUCTION DISTRIBUTION

Figure 1. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 1 (>1,000 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to nine intersections per well with an average of 3.0. The majority of wells in this category (92%) have six or less lineament intersections per horizontal well. Just under half (48%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 63.

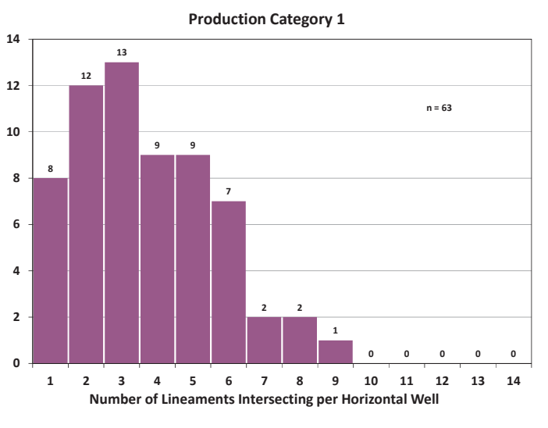


Figure 2. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 2 (500 - 1000 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to 12 intersections per well with an average of 3.6. The majority of wells in this category (92%) have seven or less lineament intersections per horizontal well. Just over half (55%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 549.

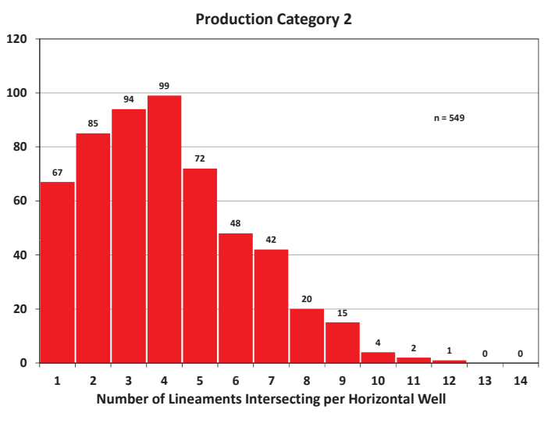


Figure 3. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 3 (250 - 500 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to 13 intersections per well with an average of 3.5. The majority of wells in this category (80%) have five or less lineament intersections per horizontal well. Just under half (49%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 769.

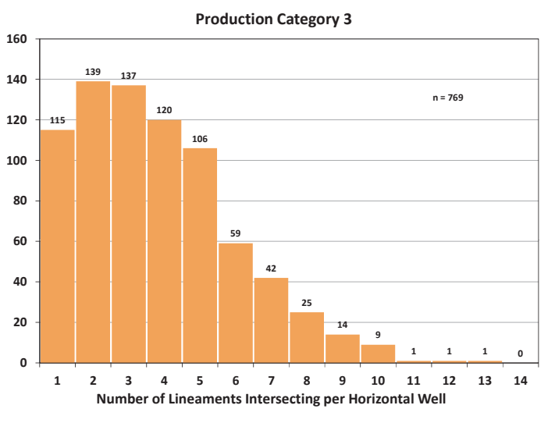


Figure 4. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 4 (125 - 250 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to 11 intersections per well with an average of 3.8. The majority of wells in this category (94%) have seven or less lineament intersections per horizontal well. Less than half (42%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 381.

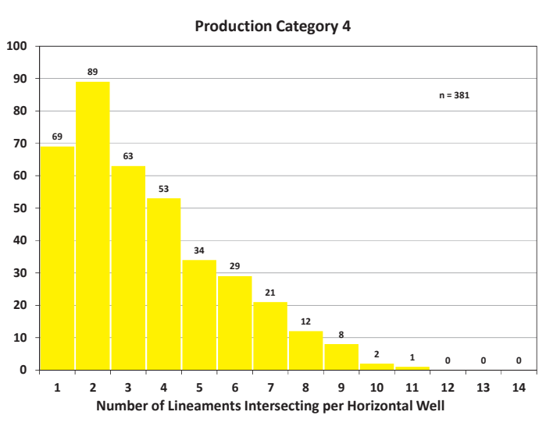


Figure 5. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 5 (50 - 125 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to 11 intersections per well with an average of 4.0. The majority of wells in this category (91%) have six or less lineament intersections per horizontal well. Less than half (46%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 149.

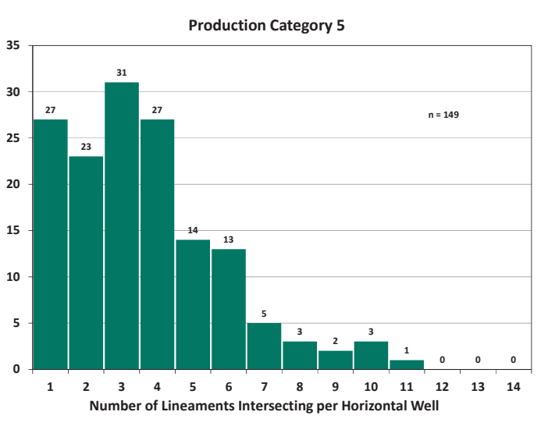
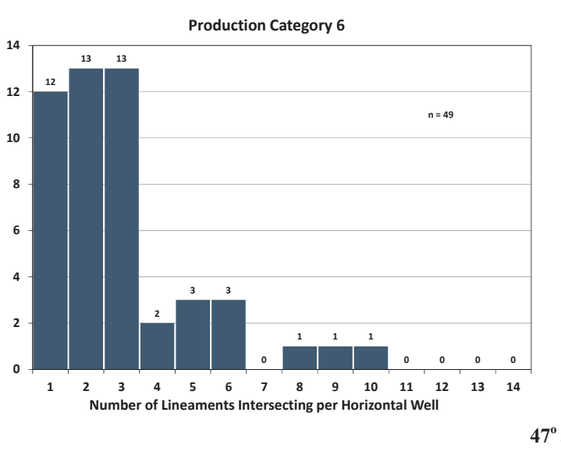
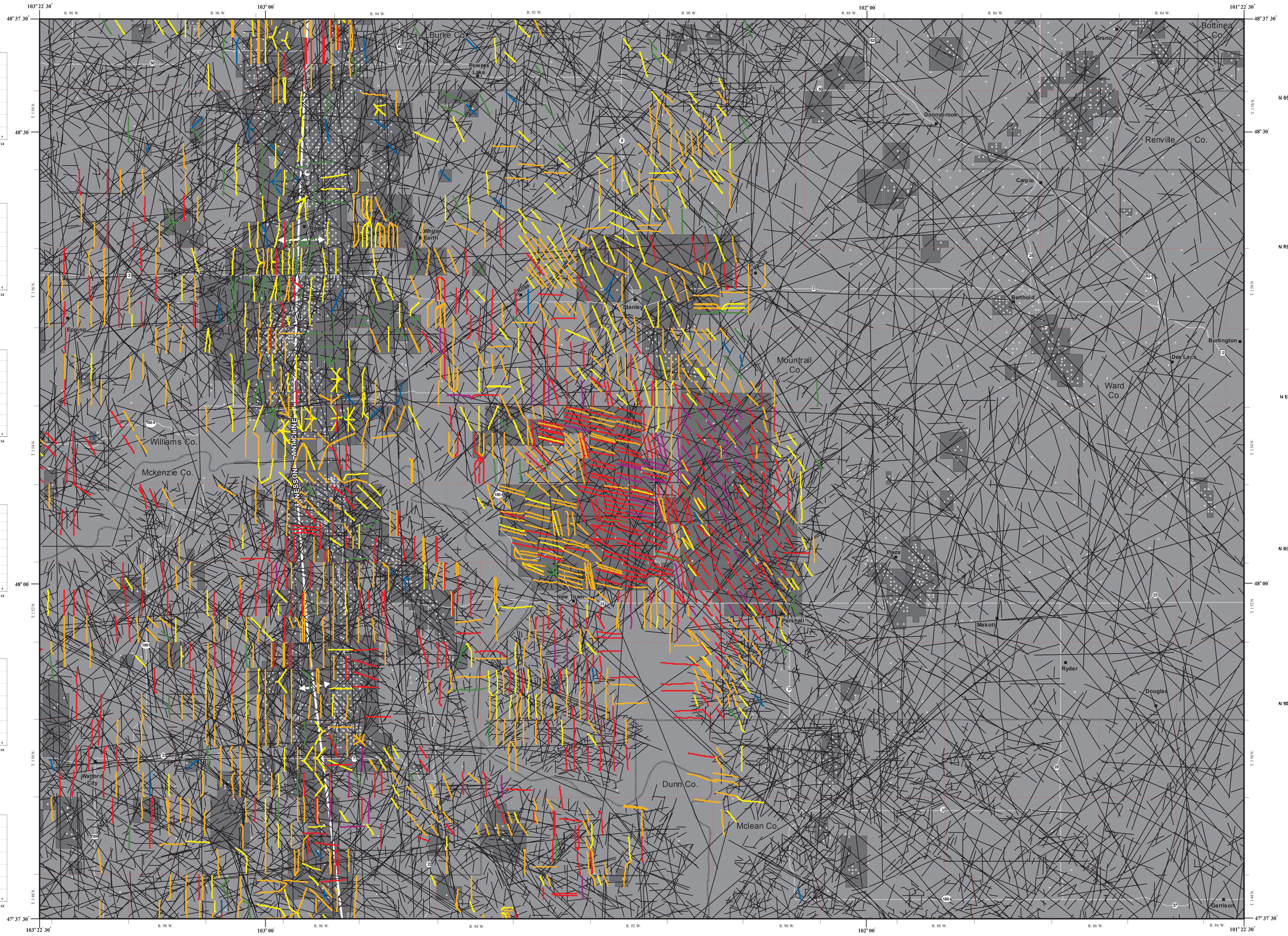


Figure 6. Frequency distribution of the number of horizontal wells with lineament intersections in Production Category 6 (0 - 50 bopd) in the Parshall area. Wells in this production catergory have lineament intersections ranging from one to 10 intersections per well with an average of 3.7. The majority of wells in this category (78%) have six or less lineament intersections per horizontal well. Just over one-fifth (22%) of the wells in this category have more than three lineament intersections per well. The total number of wells in this production catergory with intersecting lineaments is 49.





HORIZONTAL WELL ORIENTATION TRENDS

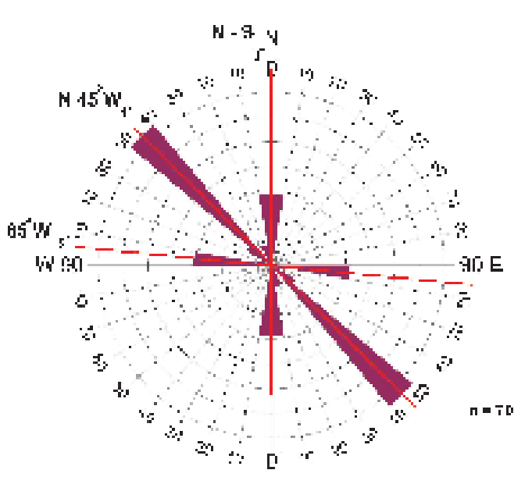


Figure 7. Rose diagram of the orientation trends (strike) of 70 horizontal well laterals from Production Catergory 1 (>1,000 bopd) in the Parshall area.Three trends were observed. A primary (1°) trend of N 45 W, a conjugate secondary (2°) trend of N 85° W, and conjugate tertiary (3°) N-S trend. The secondary and tertiary trends are approximately orthogonal with respect to one another.

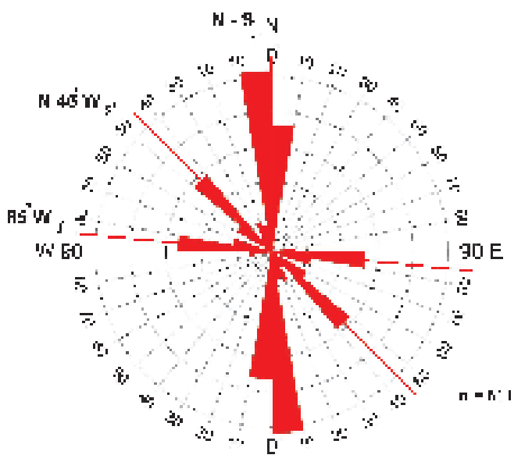


Figure 8. Rose diagram of the orientation trends (strike) of 611 horizontal well laterals from Production Catergory 2 (500 - 1,000 bopd) in the Parshall area.Three trends were observed. A primary (1°) N-S trend a conjugate secondary (2°) trend of N 45° W, and an approximately orthogonal tertiary (3°) trend of N 85° W. The secondary and tertiary trends are conjugate with respect to one another.

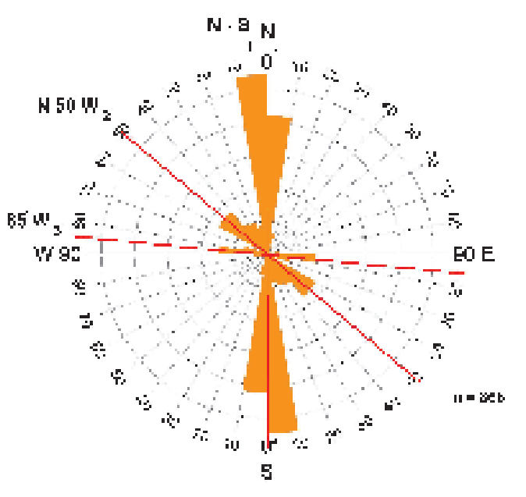


Figure 9. Rose diagram of the orientation trends (strike) of 866 horizontal well laterals from Production Catergory 3 (250 - 500 bopd) in the Parshall area.Three trends were observed. A primary (1°) N-S trend, a conjugate secondary (2°) trend of N 50° W, and an approximately orthogonal tertiary (3°) trend of N 85° W. The secondary and tertiary trends are conjugate with respect to one another.

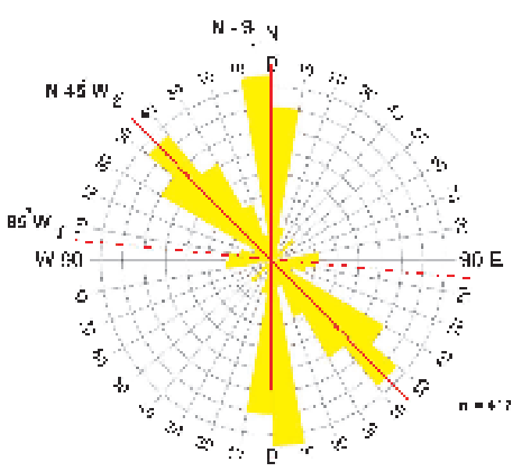


Figure 10. Rose diagram of the orientation trends (strike) of 417 horizontal well laterals from Production Catergory 4 (125 - 250 bopd) in the Parshall area. Two dominant trends and one less prominent trend were observed. A primary (1°) N-S trend and a conjugate secondary (2°) trend of N 45° W, along with an approximately orthogonal tertiary (3°) trend of N 85° W. The secondary and tertiary trends are conjugate with respect to one another.

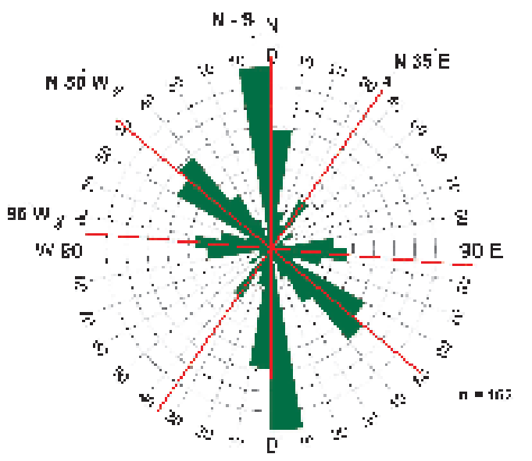


Figure 11. Rose diagram of the orientation trends (strike) of 162 horizontal well laterals from Production Catergory 5 (50 - 125 bopd) in the Parshall area.Three trends were observed. A primary (1°) approximately N-S trend, a conjugate secondary (2°) trend of N 50° W, along with an approximately orthogonal tertiary (3°) trend of N 85° W. The secondary and tertiary trends are conjugate with respect to one another.

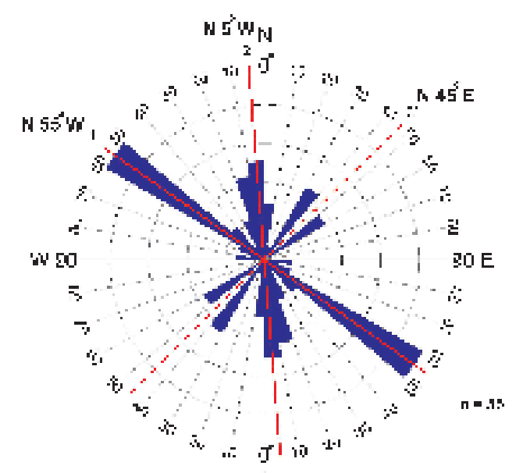


Figure 12. Rose diagram of the orientation trends (strike) of 55 horizontal well laterals from Production Catergory 6 (0 - 50 bopd) in the Parshall area. Three trends were observed. A primary (1°) trend of N 55° W, a conjugate secondary (2°) trend of N 5° W, along with an approximately orthogonal tertiary (3°) trend of N 45° E. The secondary and tertiary trends are conjugate with respect to one another.

Production Category	Number of Wells (n)	Number of Lineaments Intersecting Per Horizontal Well													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	63	8	12	13	9	9	7	2	2	1	0	0	0	0	0
2	549	67	85	94	99	72	48	42	20	15	4	2	1	0	0
3	769	115	139	137	120	106	59	42	25	14	9	1	1	1	0
4	381	69	89	63	53	34	29	21	17	8	2	1	0	0	0
5	149	27	23	31	27	14	13	5	3	2	3	1	0	0	0
6	49	12	13	13	2	3	3	0	1	1	1	0	0	0	0
Totals	1960	298	361	351	310	238	159	112	68	41	19	5	2	1	0

Table 1. Number of lineaments intersecting horizontal wells per production category in the Parshall area.

DISCUSSION

The relationship between the occurrence of lineaments and the drilling, completion, and production trends of horizontal wells found in the northeastern Willison Basin in the Parshall area was explored in this investigation. The locations of mapped lineaments (Anderson, 2008) and horizontal wells drilled in the Parshall area (NDGS, 2012), are presented on this map at a scale of 1:250,000. The horizontal well laterals shown on this map are categorized by averaged first 60 to 90 day oil production values and range from: >1,000 barrels of oil per day (bopd) - Production Category 1 (shown in purple), 500 to 1,000 bopd - Production Category 2 (shown in red), 250 to 500 bopd - Production Category 3 (shown in orange), 125 to 250 bopd - Production Category 4 (shown in yellow), 50 to 125 bopd. Production Category 5 (shown in green), and <50 bopd - Production Category 6 (shown in blue). For each production category the frequency distribution of horizontal wells with intersecting lineaments was calculated by determining the number of lineaments that intersect the path of the completed horizontal well, grouped on average first 60 to 90 day production values per well (Table 1). The resulting frequency distributions of the number of horizontal wells within classes of successively increasing amounts of lineament intersection are shown for each production category (Figures 1 - 7). The analysis of the directional trends of the horizontal wells was also completed by production category and are shown in the accompanying rose diagrams (Figures 8 - 12) with identified trends per production category (Table 2). Further analysis of horizontal wells grouped by production category within four selected directional groups: N - S (N 30° W to N 30° E), NW - SE (N 30° W to N 70° W), W - E (S 70° W to N 70° W), and NE - SW (N 30° E to N 70° E), was also completed (Table 3). Distributions per orientation (strike) group are shown in the included bow-tie diagrams (Figure 13 - 16). The overall distribution of horizontal well lateral lengths in the Parshall area was determined to be bimodal with lengths converging around values of approximately one and two miles (Figure 17). Further analysis of the relationship of lineament density, horizontal well completion directional trend, and production was perfomed on wells within Production Category 1 (>1,000 bopd) revealing two distinct groups of wells, one with a strong relationship between lineament density and production per well in wells (Group A) completed in the NW - SE direction (Figure18) and a second group with a poor relationship between lineament density, production, and completion direction (Group B). The Group A wells cluster in the Parshall Field area (Figure 19). From this analysis it was determined that within the higher production categories (i.e. Production Categories 1 - 3) a greater number of wells with higher amounts of lineament intersection were found than within lower production categories (i.e. Production Categories 4 - 6). Additionally, wells with laterals completed along N - S orientations are more numerous and have more wells in the higher production categories than wells completed in other orientations. Further, horizontal wells with lateral lengths around a mile in length or less and with lineament intersections of 5 or less are shown as being most productive (Figure 20). Longer laterals, even with increasing lineament intersection, at least initially do not appear to be better producers. It should be noted that a key element - the number of hydraulic fracturing stages per individual well - was not included in this evaluation based on limited data availability. It is readily apparent that the dominant directional trends of horizontal wells within the Parshall area occur within a northwesterly orientation (Table 4).

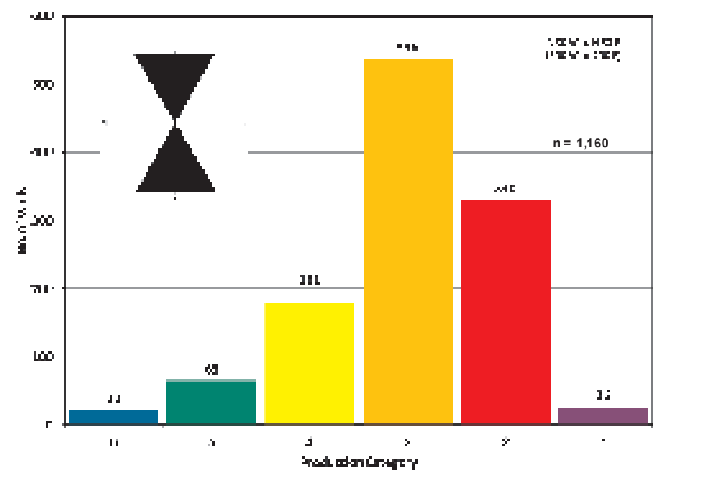


Figure 13. N-S Bow-tie diagram and respective frequency distribution of the number of horizontal well laterals within each horizontal well production category found within the N 30° E to N 30° W orientation (strike) group. The number of wells (536) in Production Category 3 (250 - 500) bopd) was the highest within this orientation group. The N-S orientation group contains the highest number of overall producing wells (1,160) in the Parshall area.

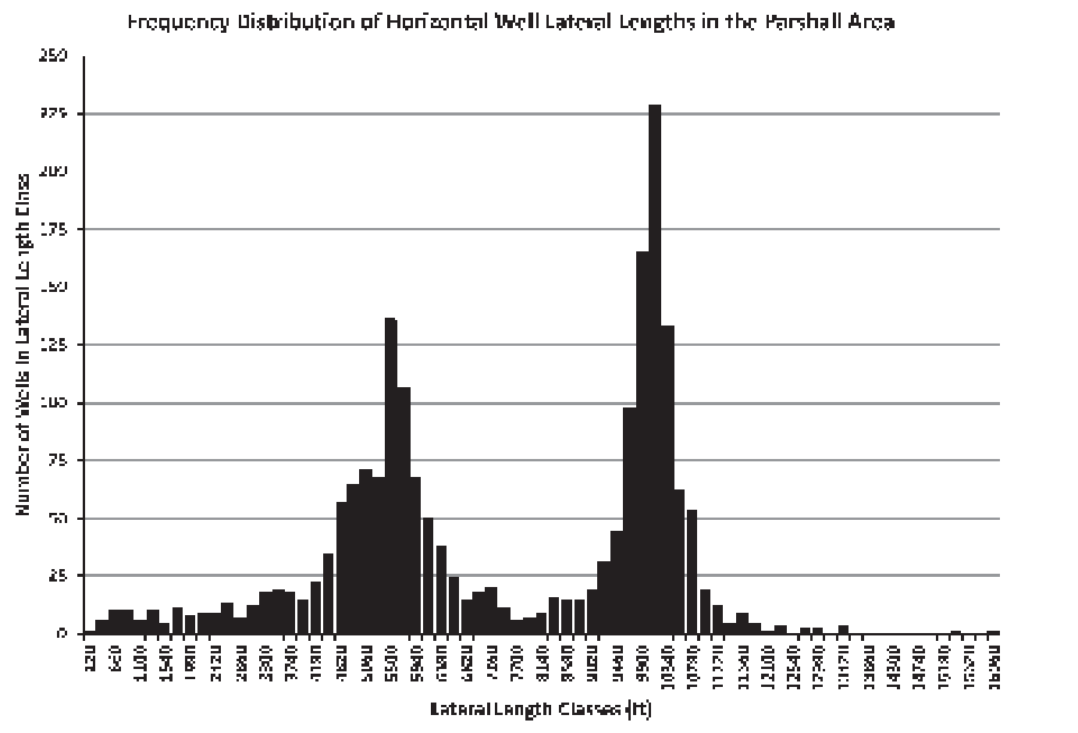


Figure 17. Frequency distribution of the lengths (ft) of 1,950 horizontal well laterals drilled in the Parshall area in 220 ft classes depicting the bimodal distribution of horizontal well lateral lengths found. The two dominant horizontal well lateral lengths that occur in the Parshall area gather around the one mile (~5,280 ft) and two mile (~10,560 ft) lengths.

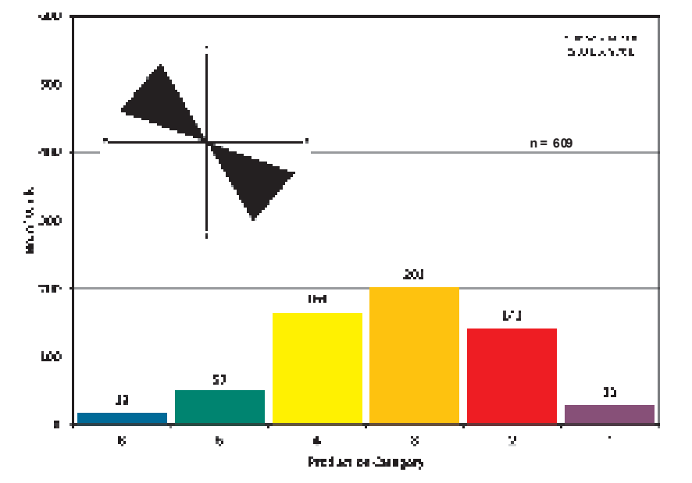


Figure 14. NW-SE Bow-tie diagram and respective frequency distribution of the number of horizontal well laterals within each horizontal well production category found within the N 30° W to N 70° W orientation (strike) group. The number of wells (203) in Production Category 3 (250 - 500) bopd) was the highest within this orientation group. The NW-SE orientation group contains the second highest number of overall producing wells (609) in the Parshall area.

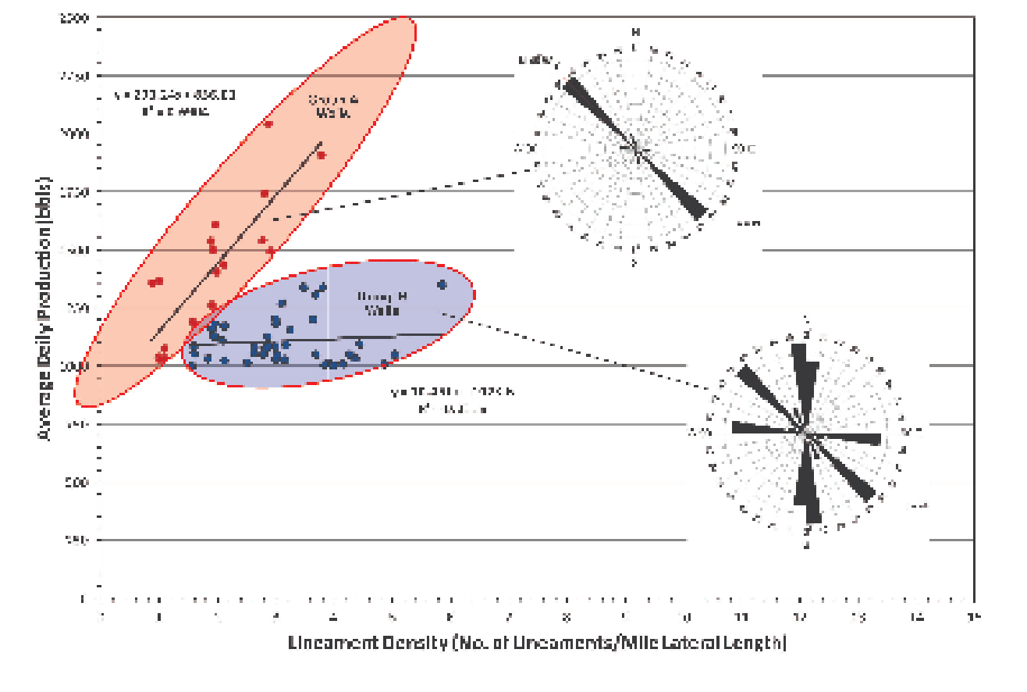


Figure 18. Relationships of lineament density (i.e. number of lineaments intersecting per mile of horizontal well lateral length) versus selected average daily production (first 60 to 90 days) from wells in Production Category 1 (>1,000 bopd) in the Parshall area. Two groups of wells can be identified: Group A wells (n = 19) and Group B wells (n = 44). Group A wells display a strong linear relationship between lineament density (all below four lineaments per mile) and average daily production which also fall within a very defined horizontal well orientation trend of N 45° W. The Group B wells have somewhat higher amounts of lineament density, ranging from one to six, but with lower, more consistent average daily production values that display a poor linear relationship between lineament density and production. Subsequently, the Group B wells can be found to be grouped about into three or more different orientation trends.

Production Category	Horizontal Well Orientation (Strike) Group				Number of Wells (n)
	N 30° W - N 30° E	N 30° W - N 70° W	N 70° W - S 70° E	N 30° E - N 70° E	
1	26	30	14	0	70
2	330	143	136	2	611
3	536	203	116	11	866
4	181	164	52	20	417
5	65	50	32	15	162
6	22	19	3	11	55
Totals	1,160	609	353	59	2,181

Table 3. Number of horizontal wells within selected orientation (strike) group per production category in the Parshall area.

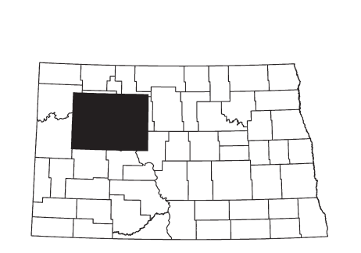
Scale 1:250,000
0 3 6 9 12
Miles
0 3 6 9 12
Kilometers

Mercator Projection
Standard parallel 47°22'30"

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

Production Category	Approximate Horizontal Lateral Trend			
	N - S	N 45° W	N 85° W	N 45° E
🟪 1	Secondary (2°) Trend	Primary (1°) Trend	Tertiary (3°) Trend	No Trend Observed
🟥 2	Primary (1°) Trend	Secondary (2°) Trend	Tertiary (3°) Trend	No Trend Observed
🟧 3	Primary (1°) Trend	Secondary (2°) Trend	Tertiary (3°) Trend	No Trend Observed
🟨 4	Primary (1°) Trend	Secondary (2°) Trend	Tertiary (3°) Trend	No Trend Observed
🟩 5	Primary (1°) Trend	Secondary (2°) Trend	Tertiary (3°) Trend	Quaternary (4°) Trend
🟦 6	Secondary (2°) Trend	Primary (1°) Trend	No Trend Observed	Tertiary (3°) Trend

Table 4. Summary of horizontal directional trends per production category in the Parshall Area.



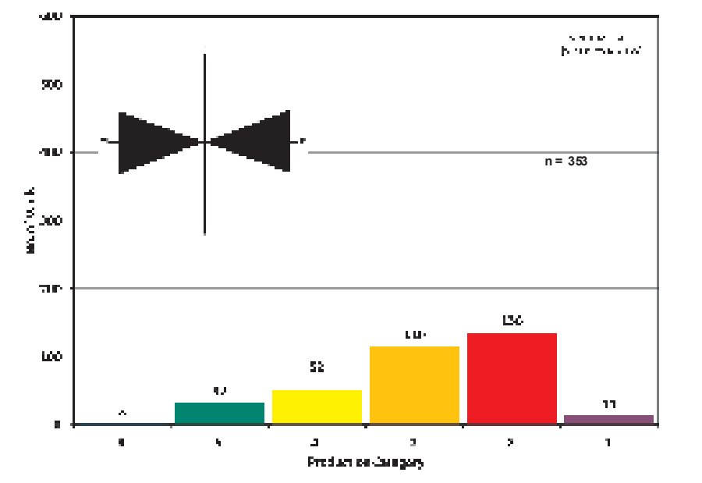


Figure 15. E-W Bow-tie diagram and respective frequency distribution of the number of horizontal well laterals within each horizontal well production category found within the S 70° W to N 70° W orientation (strike) group. The number of wells (136) in Production Category 2 (500 - 1,000) bopd) was the highest within this orientation group. The E-W orientation group contains the third highest number of overall producing wells (353) in the Parshall area.

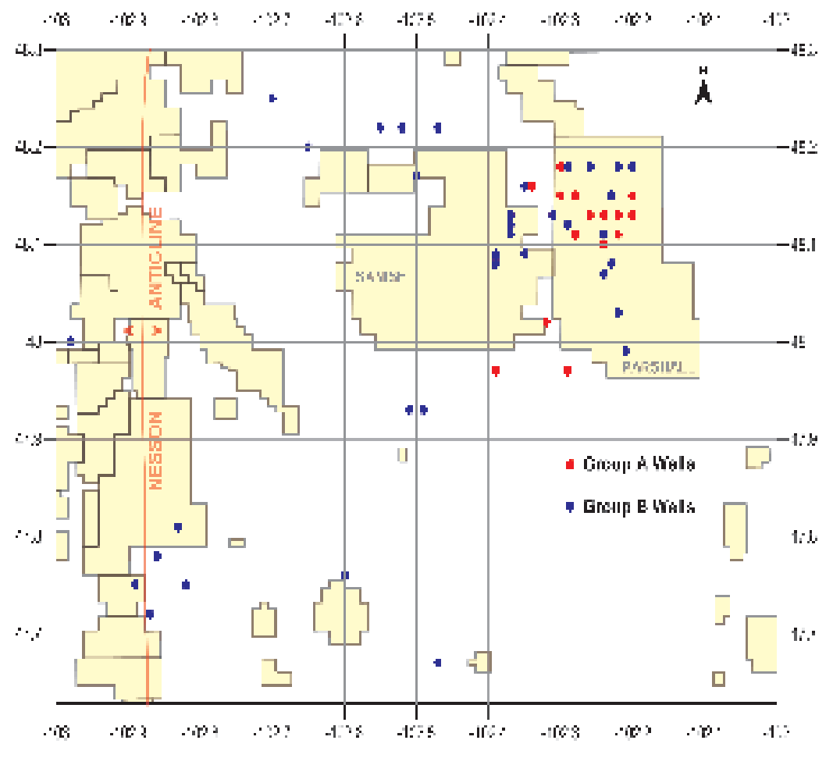


Figure 19. Locations of Group A Wells (red dots) and Group B Wells (blue dots) in the Parshall area. Group A Wells are found dominantly in the Parshall Field area. Group B Wells are found in the Parshall Field and other surrounding areas. Field boundaries contemporaneous with initial lineament mapping in the area (ca 2008) are shaded in yellow.

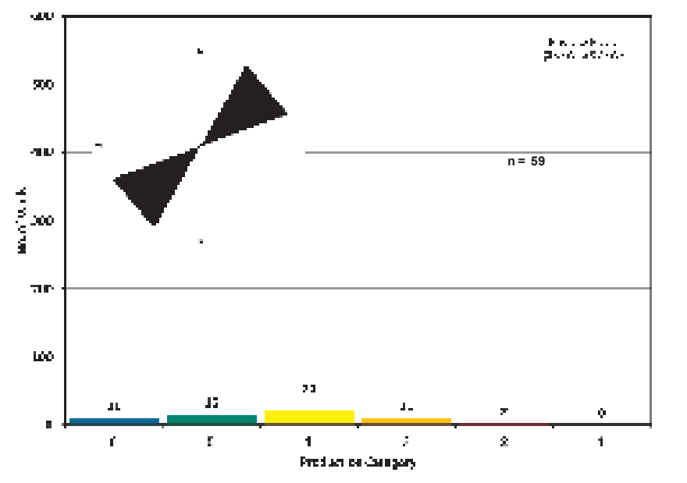


Figure 16. NE-SW Bow-tie diagram and respective frequency distribution of the number of horizontal well laterals within each horizontal well production category found within the N 30° E to N 70° E orientation (strike) group. The number of wells (20) in Production Category 4 (125 - 250) bopd) was the highest within this orientation group. The NE-SW orientation group contains the lowest number of overall producing wells (59) in the Parshall area.

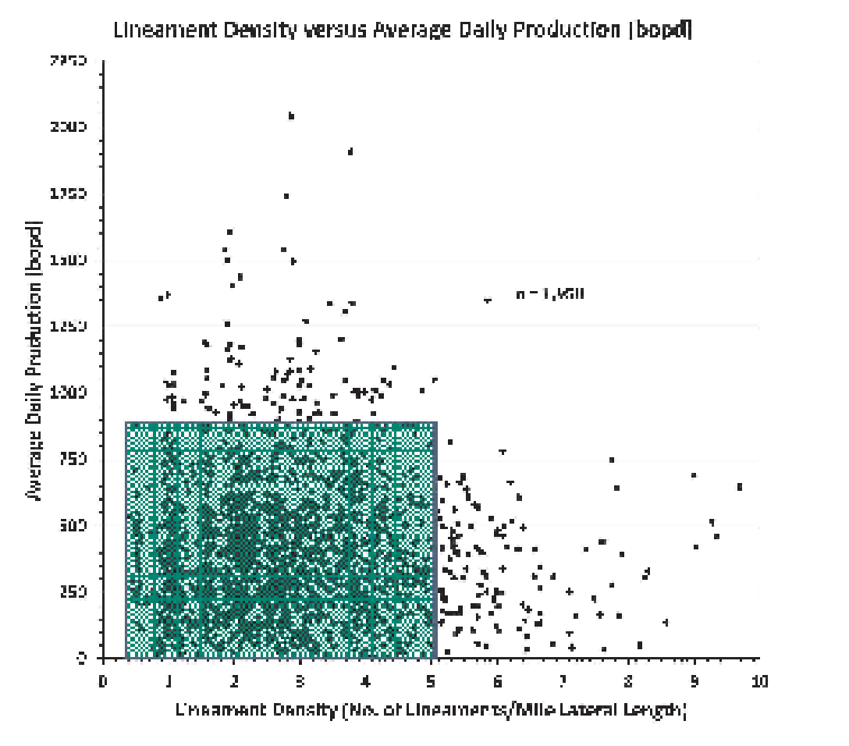


Figure 20. Lineament density as the number of lineaments intersecting a horizontal well per mile of well lateral length plotted against average daily production (first 60-90 days). Generally, there is little correlation between values. However data density falls within an area bounded on lineament density from approximately 0.35 to 5.0 lineaments per mile and average daily production from around zero to 900 bopd.

Production Category	Horizontal Well Orientation (Bearing) Trends				Number of Wells (n)
	Primary (1°)	Secondary (2°)	Tertiary (3°)	Quaternary (4°)	
1	315°	0°	275°	--	70
2	0°	315°	275°	--	611
3	0°	310°	275°	--	866
4	0°	315°	275°	--	417
5	0°	310°	275°	35°	162
6	305°	355°	45°	--	55

Table 2. Horizontal well orientation trends per production category in the Parshall area (Bearing notation).

REFERENCES

Anderson, F.J., 2008, Lineament Mapping and Analysis in the Northeastern Williston Basin of North Dakota, North Dakota Geological Survey, Geologic Investigations No. 70, 26 p.

NDGS, 2012, First 60 - 90 Day Average Bakken Horizontal Production by Well, North Dakota Geological Survey, Geologic Investigations No. 149, 1:350,000 scale map.

HORIZONTAL WELL PRODUCTION CATEGORY (bopd)

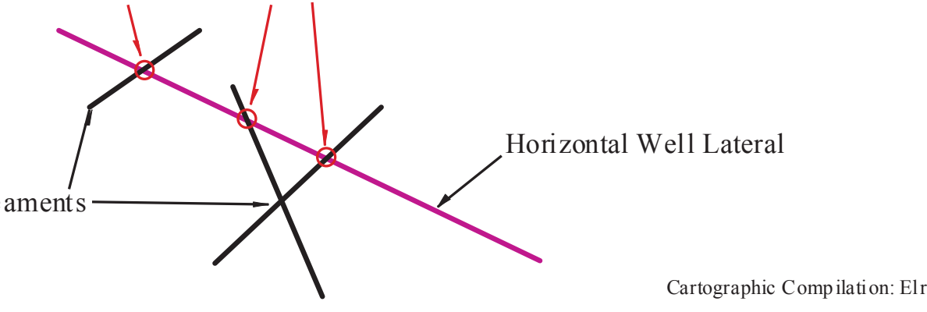
Production Category 1	> 1000 bopd	Production Category 4	125 - 250 bopd
Production Category 2	500 - 1000 bopd	Production Category 5	50 - 125 bopd
Production Category 3	250 - 500 bopd	Production Category 6	< 50 bopd

bopd = average daily production (first 60-90 days)

EXPLANATION

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

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



Cartographic Compilation: Elroy L. Kadrmas