Identifying Oil Exploration Leads Using Integrated Remote Sensing and Seismic Data Analysis, Lake Sakakawea, Fort Berthold Indian Reservation, Williston Basin

Performed by:
Advanced Resources International
Houston, TX

with

Bureau of Indian Affairs
Lakewood, CO

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Advanced Resources International

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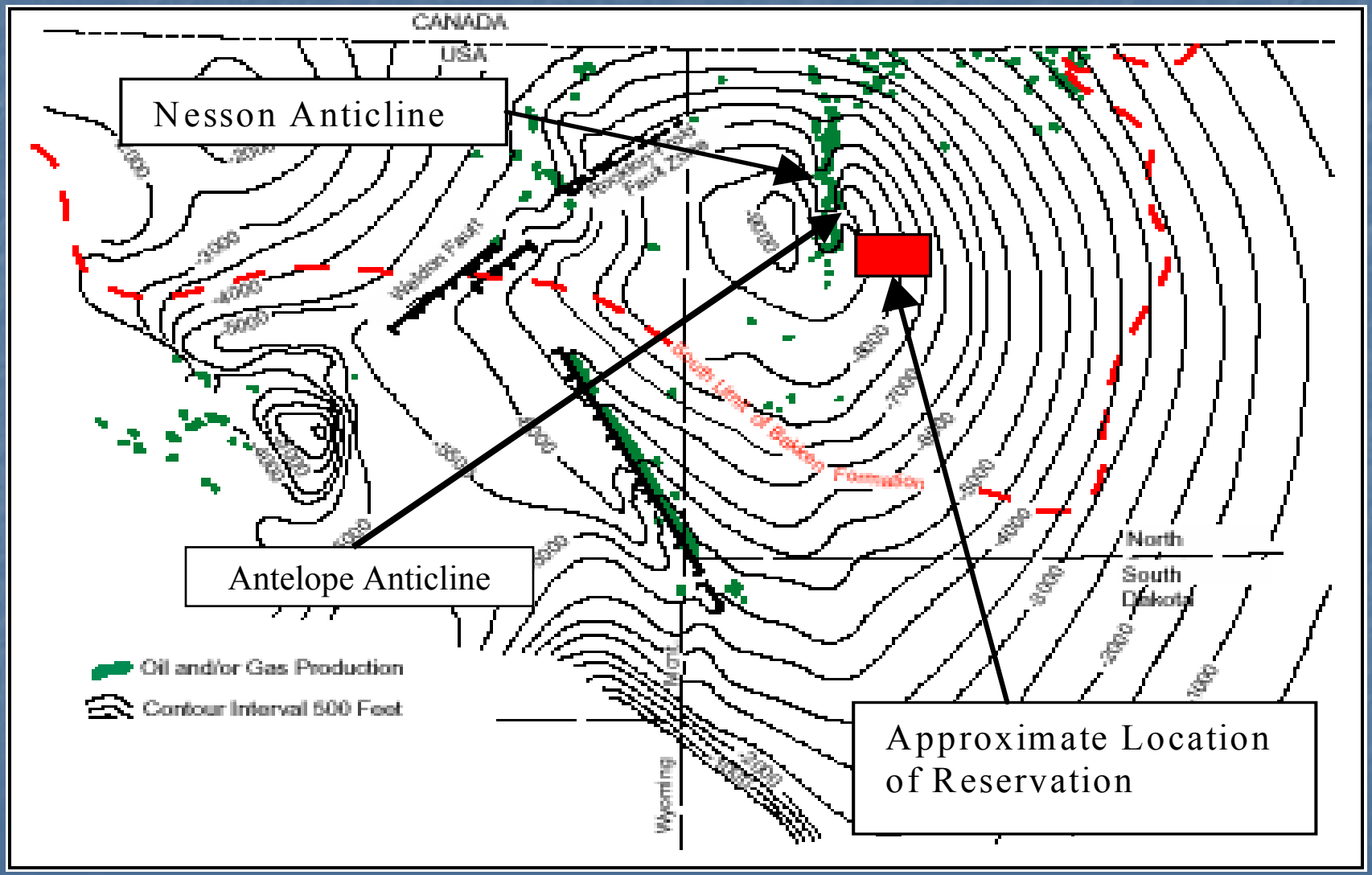
Outline

- Introduction and Background
- Technical Approach
- Regional Geology
- Remote Sensing
- Intermediate-Resolution Aeromag
- Seismic
- Identification of Lead Areas
- Statistical Well Performance
- Economics
- Conclusions and Recommendations
- References

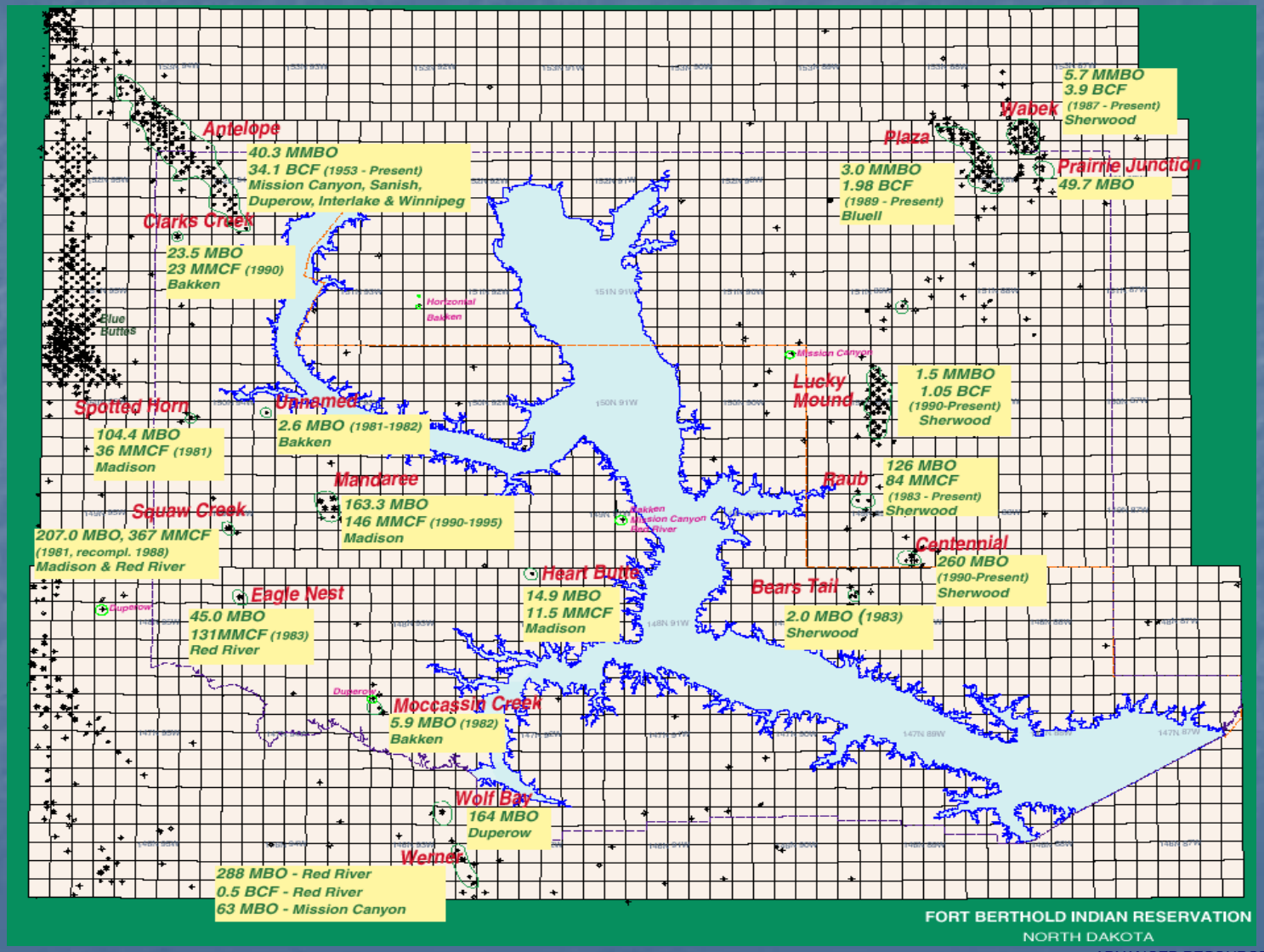
Project Genesis

- DOE solicitation for projects to develop oil reserves on non-allotted Native American Lands.
- ARI's desire to demonstrate its remote sensing exploration technology in oil shale reservoirs (e.g., Mancos, Bakken, etc.).
- Three Affiliated Tribes favorable location in the Williston Basin and availability of large tract of (150,000 acres) unleased non-allotted Tribal Lands.

Location of Fort Berthold Indian Reservation



Oil & Gas Fields on Reservation

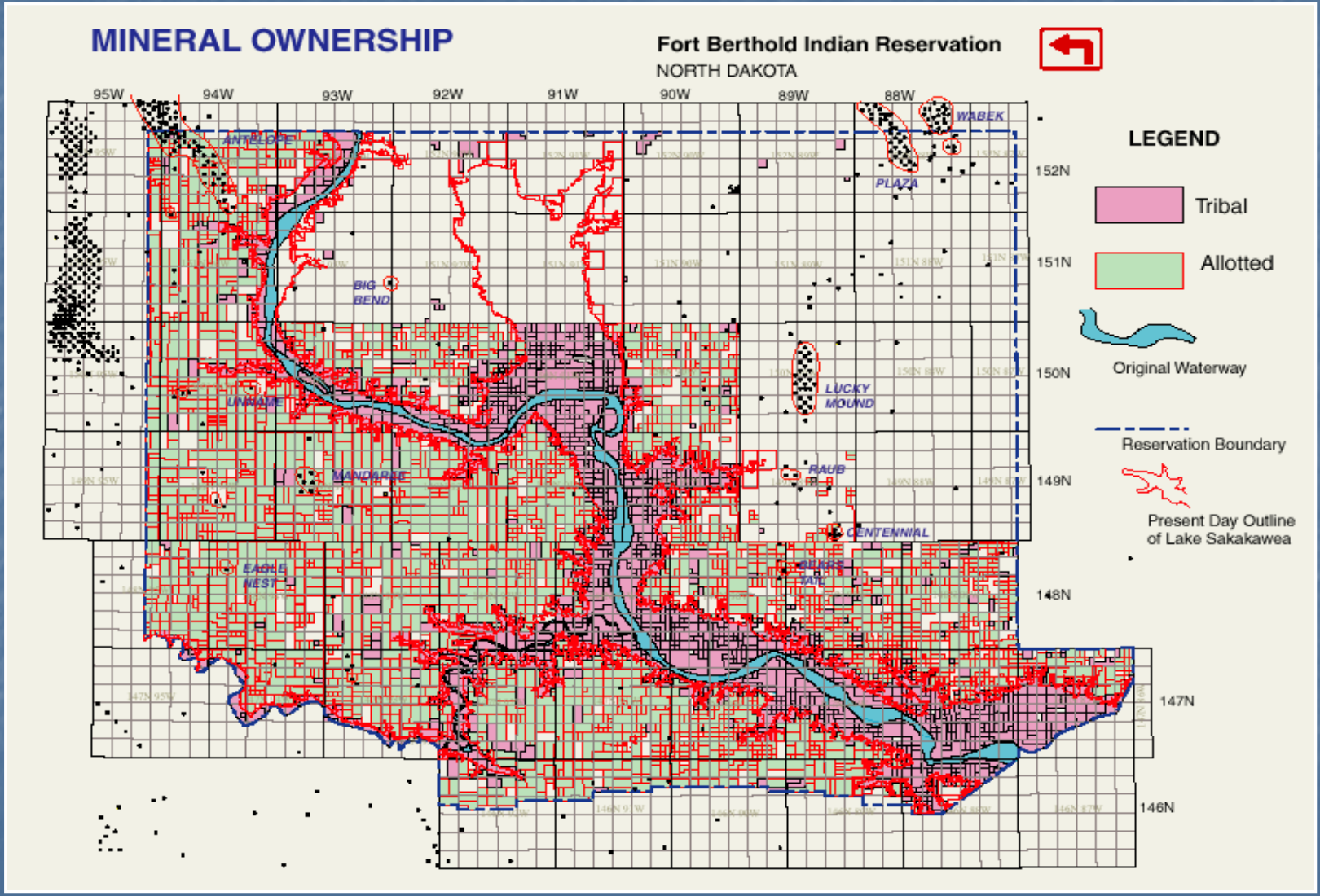


Historical Exploration Results

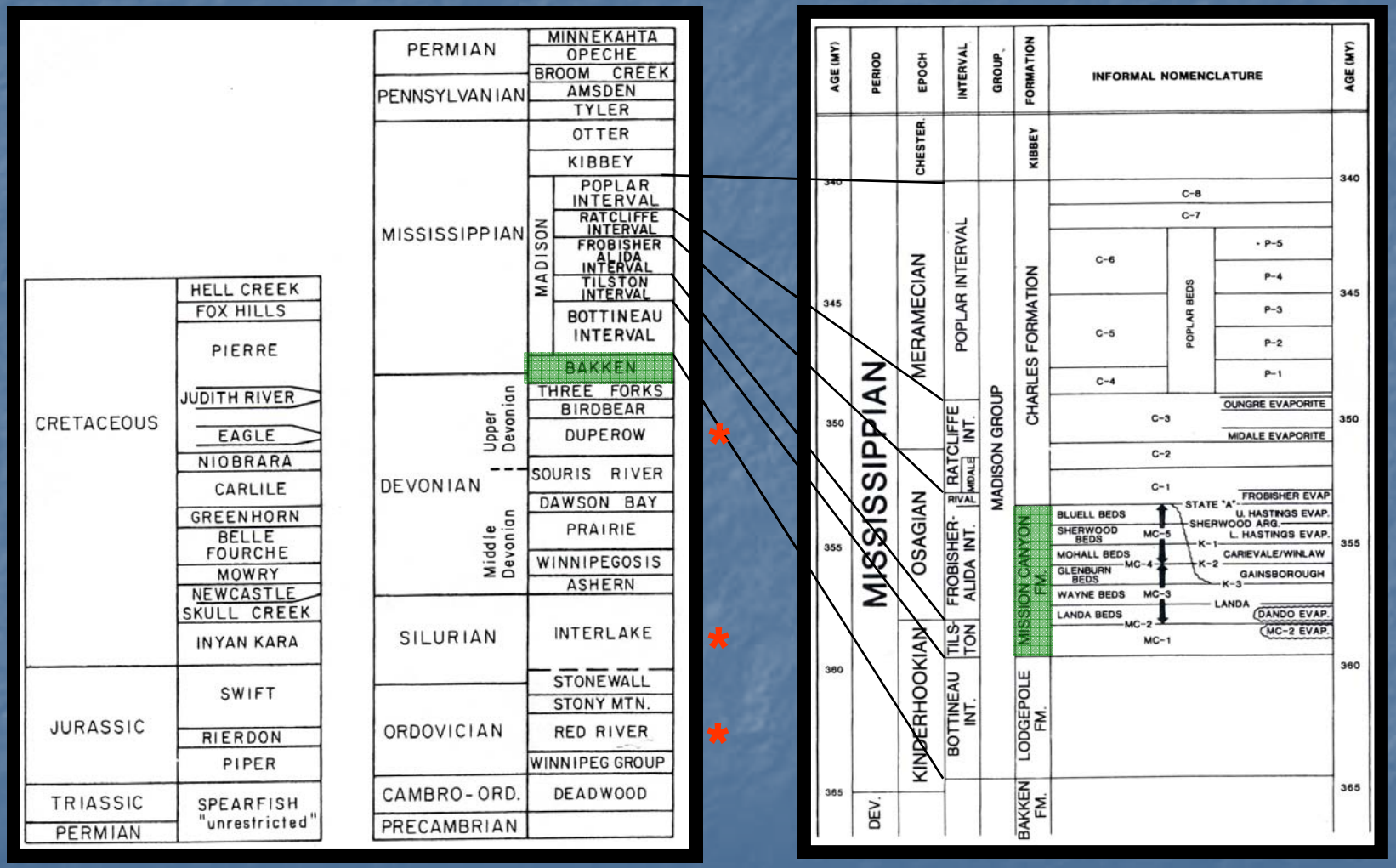
- 592 oil and gas tests, resulting in -
- 392 producing wells, for a -
- Success rate of 69%.
- Yet, only 2% of reservation currently leased.

Ownership Makeup –

(150,000 Acres of Unleased Non-Allotted Tribal Lands Available Under Lake Sakakawea)



Stratigraphic Column



* "Secondary" productive intervals

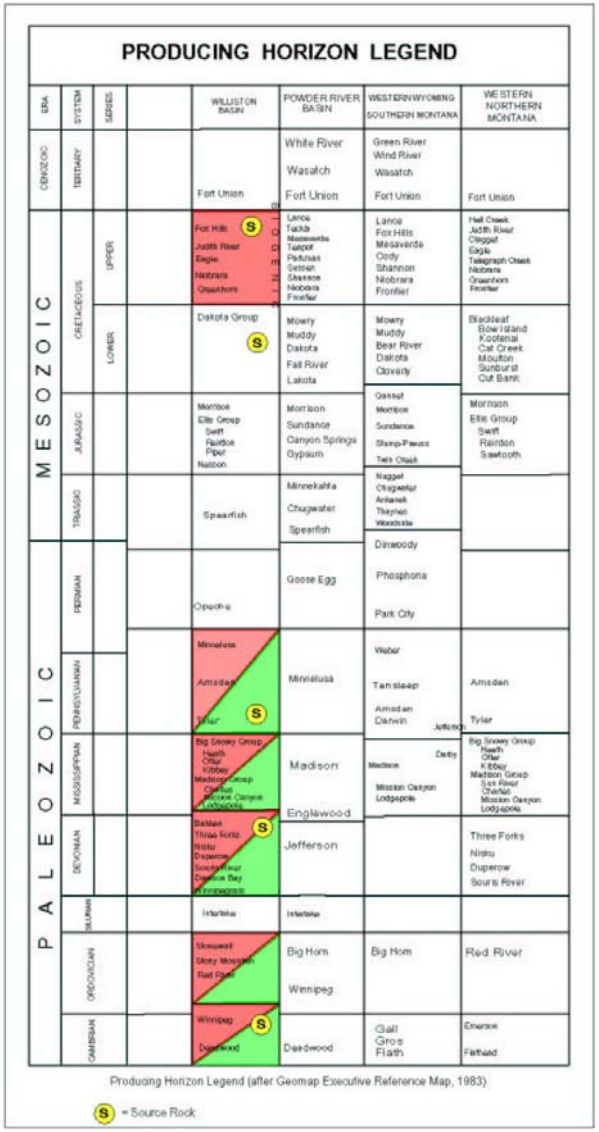
Most Significant Undiscovered Oil Resources in Williston Basin [1]

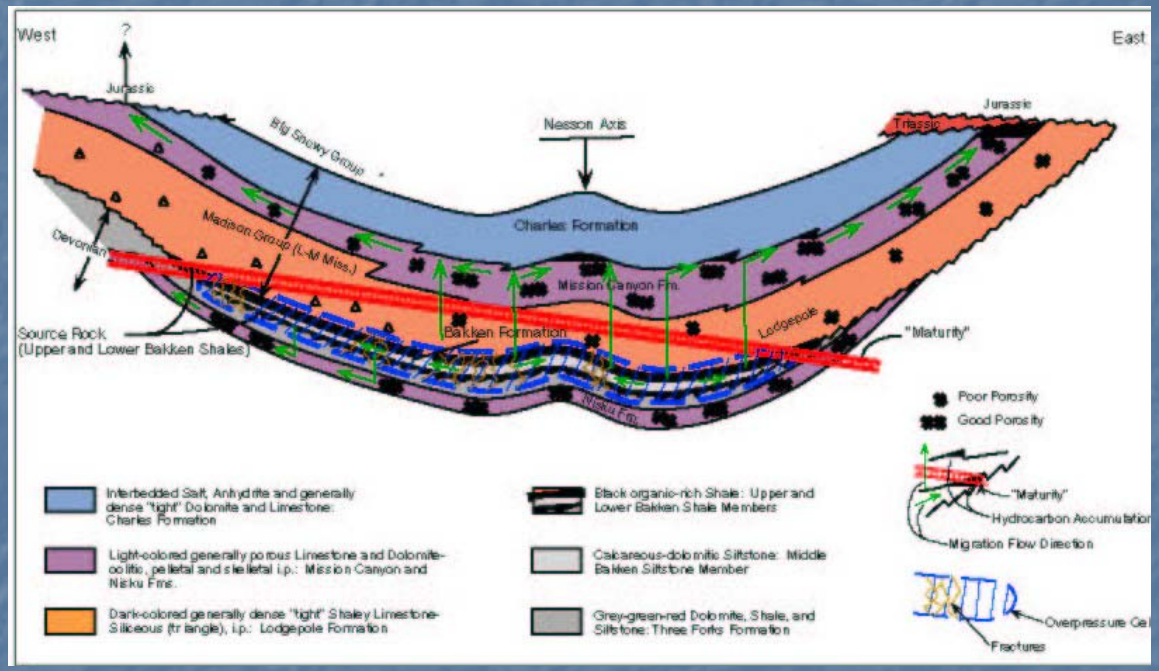
Play	USGS Code	Assigned Success Rate	Total Recoverable Resource (MMBO)
Madison	3101	-----	169*
Bakken Fairway	3110	0.70	73
Bakken Intermediate	3111	0.20	70
Bakken Outl ying	3112	0.10	8
TOTAL			320

* 32 undiscovered fields with an average EUR of 5.3 MMBO each

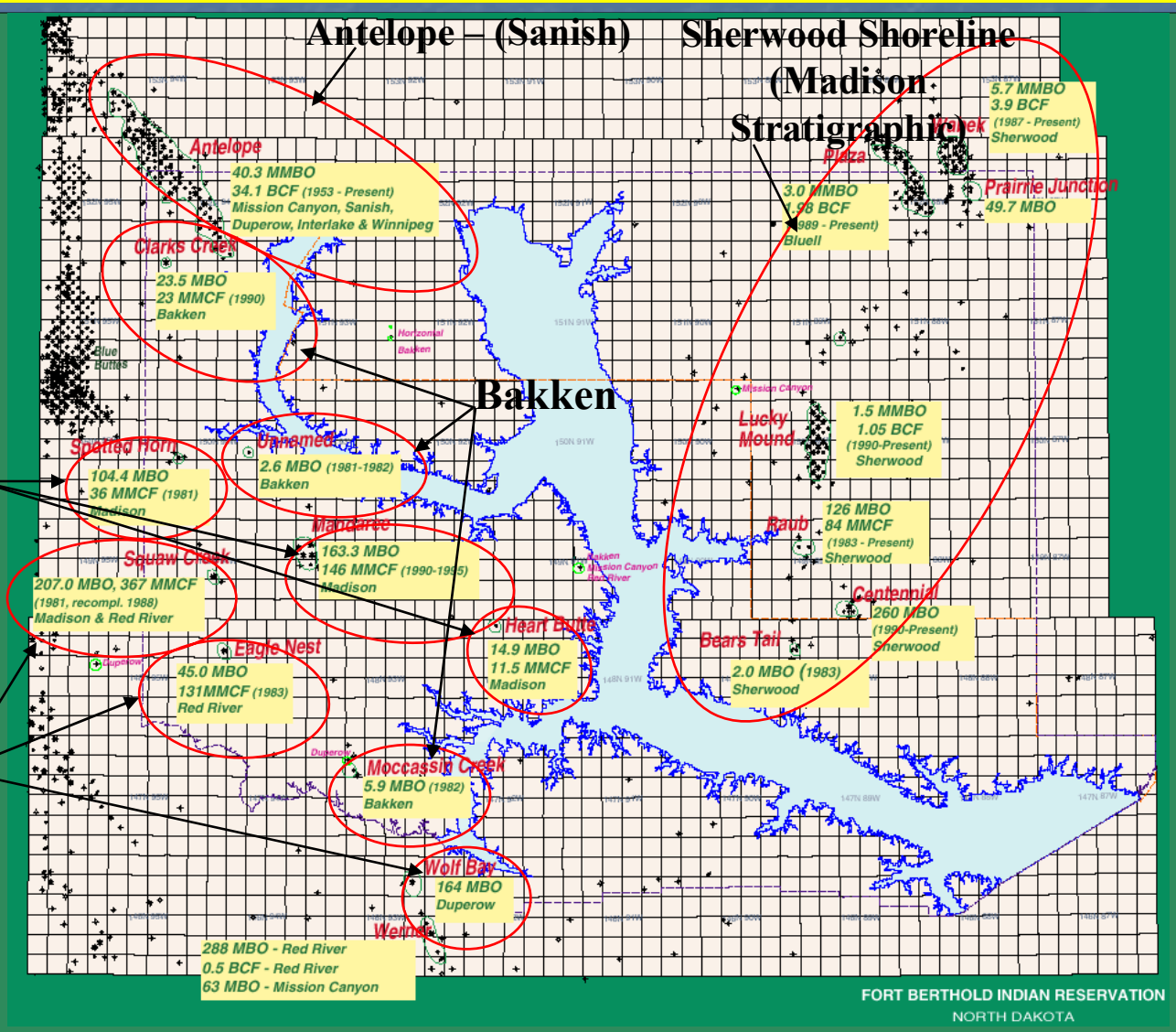
[1] From 1995 USGS National Oil & Gas Reserve Assessment.

Oil Generation and Migration in the Williston Basin

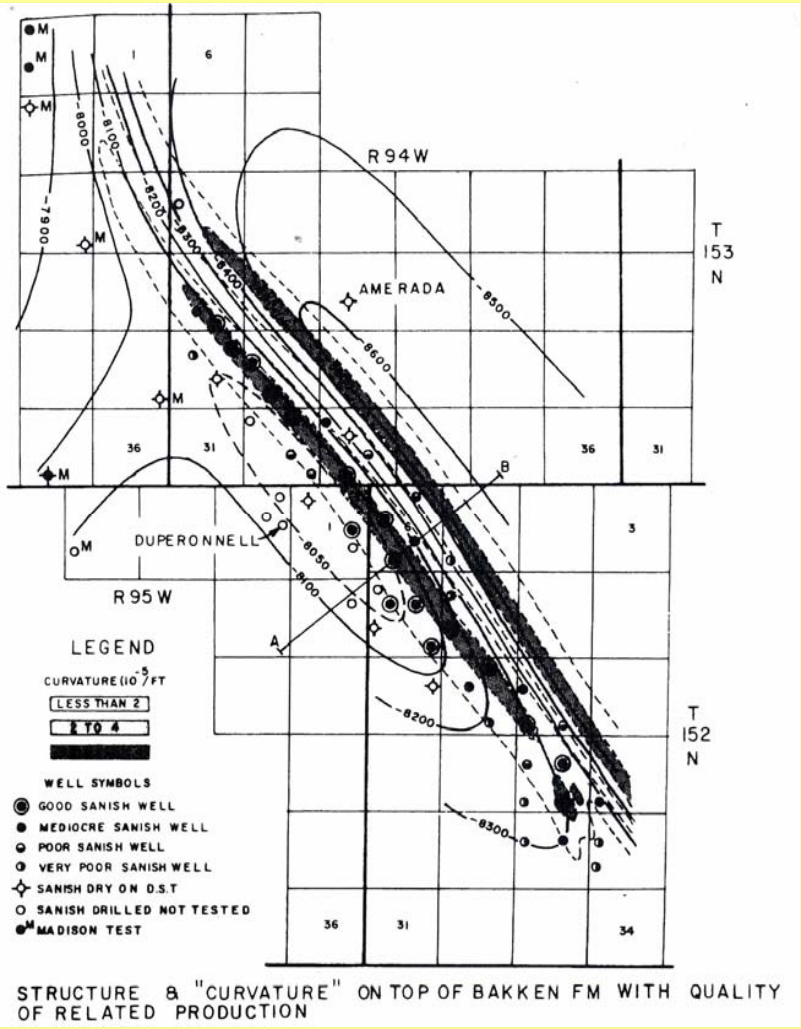




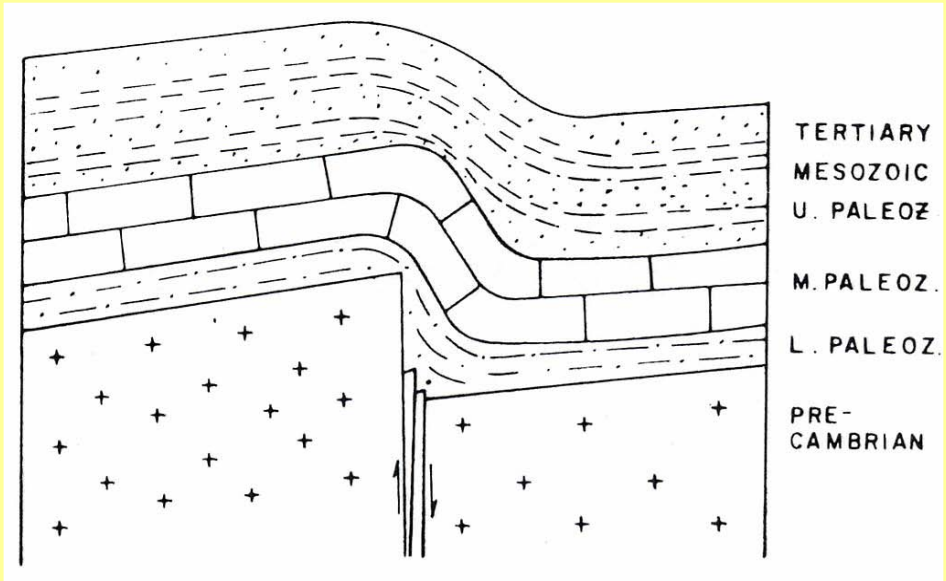
Play "Types" on the Reservation



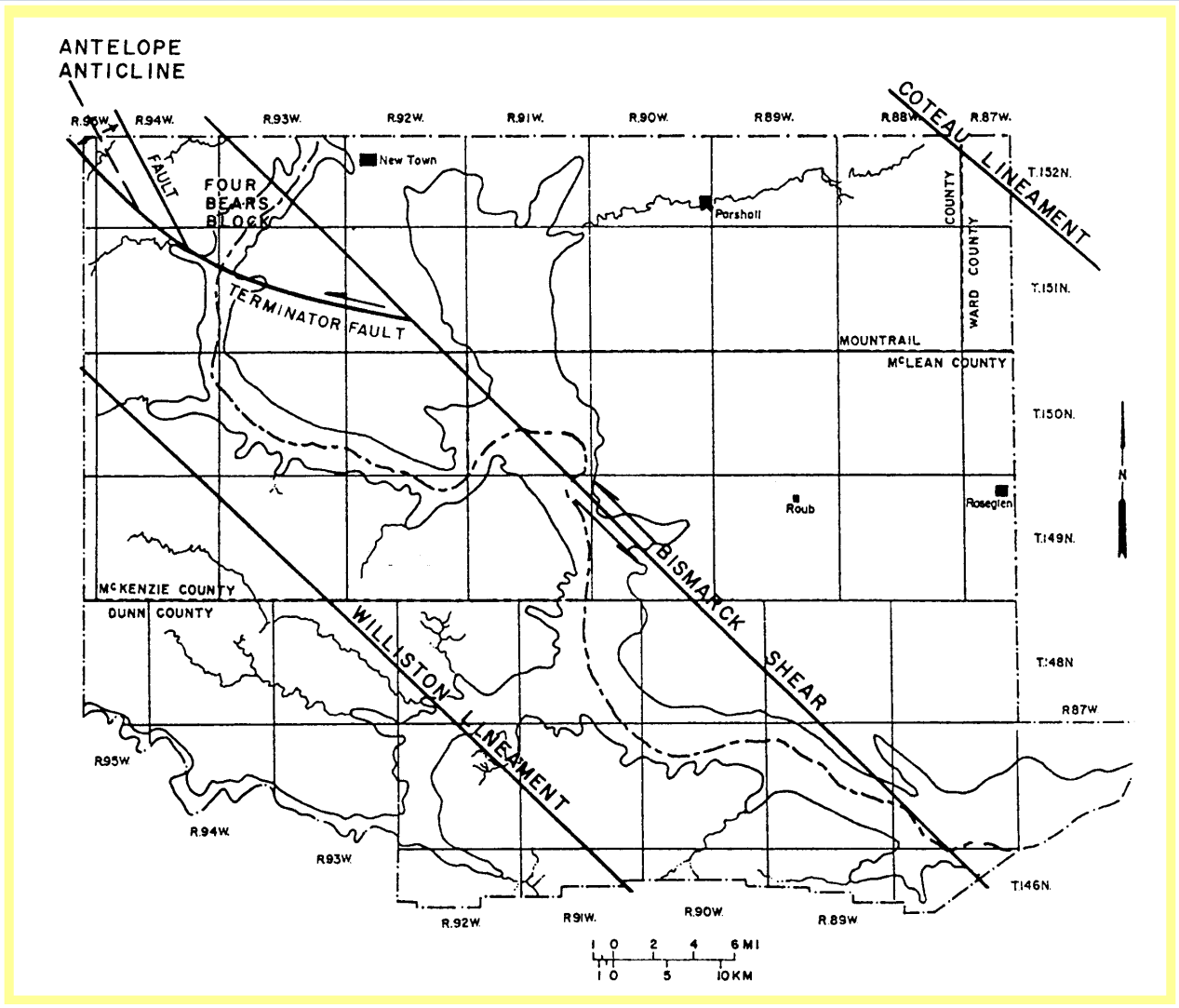
Structural Framework of Antelope Field



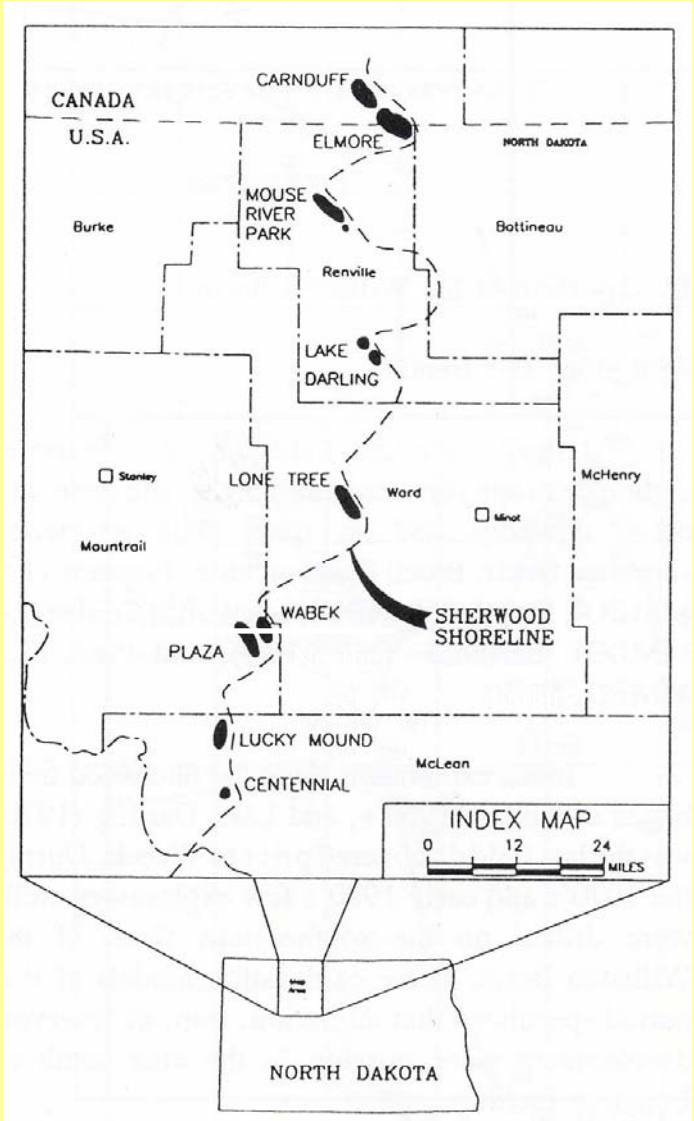
CUM Prod = 40.3 MMBO

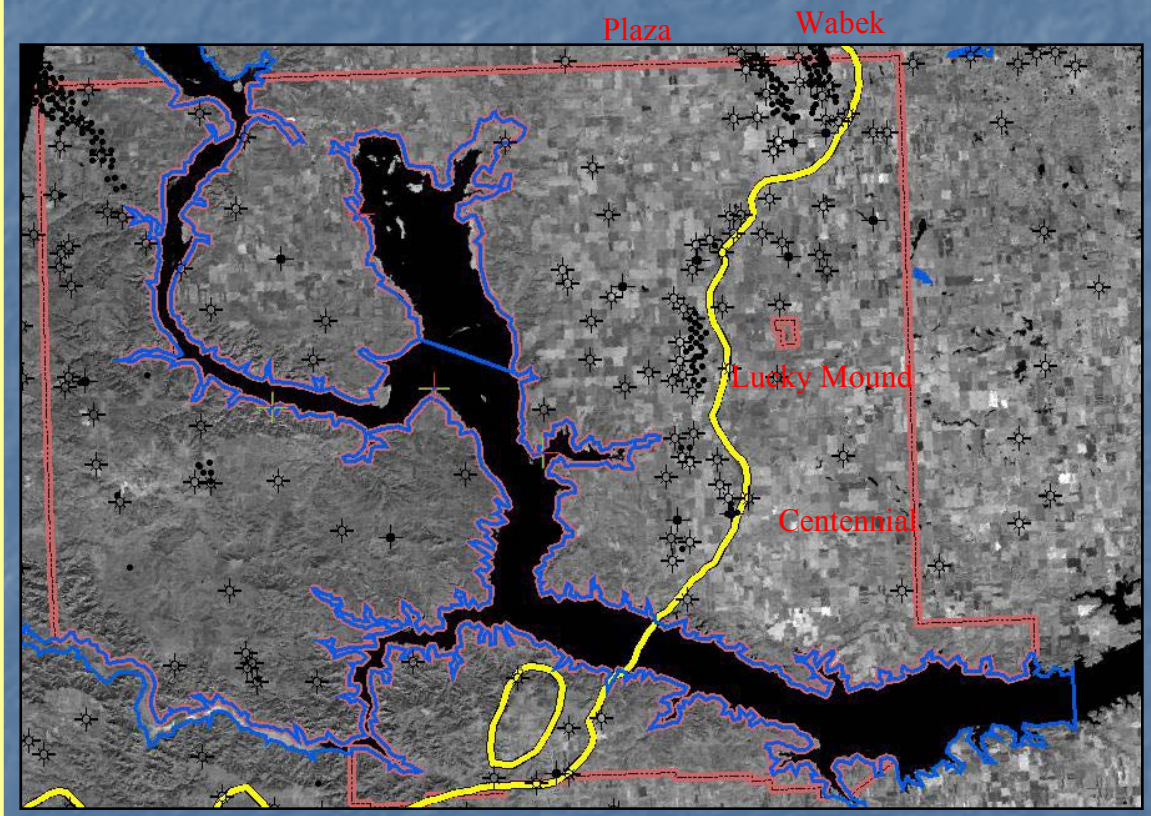


Extension of Prominent (Antelope) Structural Features onto Reservation



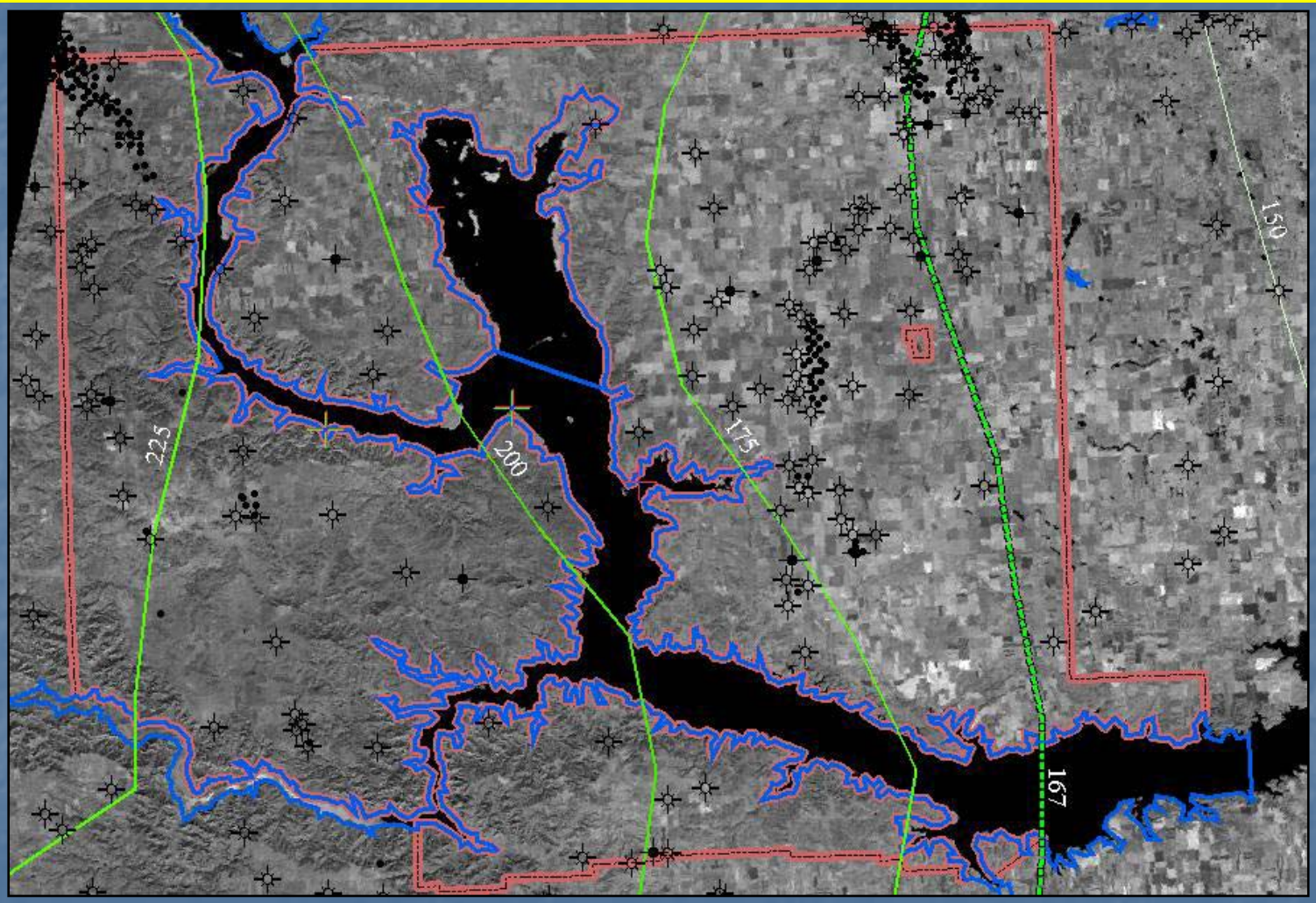
Extension of Sherwood Shoreline onto Reservation





Bakken Maturity Window

(resistivity, ohm-m)



Bakken shale resistivity is a common measure of maturity. Greater than 167 ohm-m is considered mature and oil saturated.

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Project Objectives

- Evaluate the exploration potential under Lake Sakakawea via integrated remote sensing:
  - Satellite Imagery
  - Potential Fields (aeromag, gravity)
  - Intermediate Resolution Aeromag
- Supplement the approach with traditional geologic study and existing (offshore) seismic.
- Identify specific lead areas.
- Develop scoping reserve and F&D costs.
- Disseminate the project results to industry, including potential development partners.

Work Plan

Task 1: Data Collection

New:

- LandSat imagery.
- Low-resolution potential fields (gravity/aeromag) data.
- Intermediate resolution aeromag.
- 200 line-miles of 2-D seismic over lake (out of 500 line-miles available).
- Well logs (about 50).
- Production/well data (100-200 wells).

Existing:

- 123 line-miles of onshore seismic
- Miscellaneous well and log data

} Held by BIA

Work Plan (continued)

Task 2: Geophysical & Geologic Analysis

- Lineament study using LandSat imagery; integrate potential fields data.
- Full interpretation of intermediate resolution aeromag.
- Re-process offshore seismic data.
- Integrate well logs & onshore seismic (geologic study).

Task 4: Identify Leads

- Integrate G&G studies
- Select leads

Work Plan (continued)

Task 3: Production Data Analysis

- Estimate EUR's for Madison & Bakken wells.
- Develop distributions of well performance.

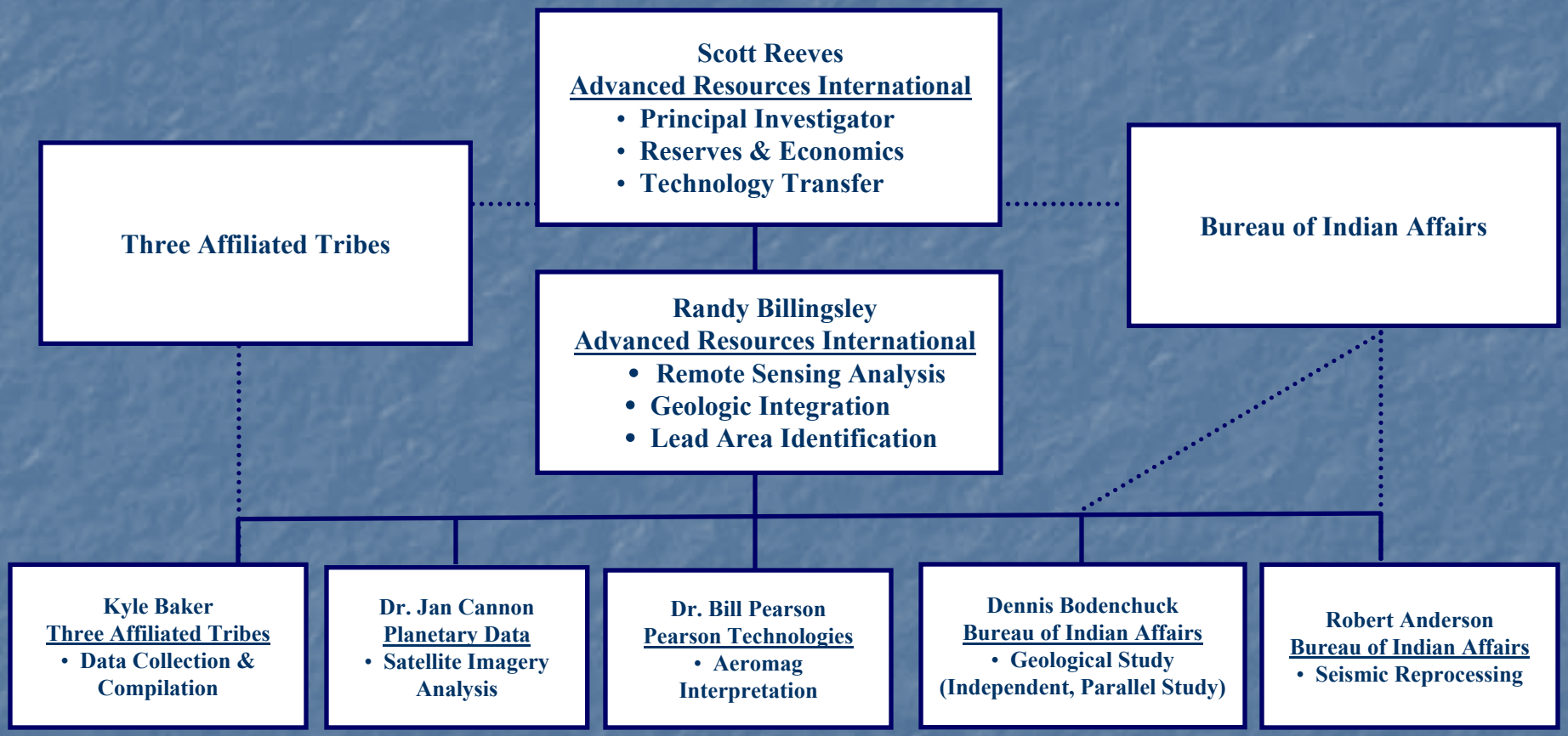
Task 5: Pro-Forma Reserves & Economics

- Estimate reserves via analogy/statistics.
- Compute F & D costs.

Task 6: Technology Transfer

- Prepare final report and presentation (put on CD).
- Publish article in industry trade journal.
- Show at 2004 NAPE conference.

Project Organization



Project Schedule

	D O E FY 2003				D O E FY 2004	
	CY 2002	CY 2003				CY 2004
	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr
Task 1 Data Collection						
Task 2 G & G						
Task 3 Prod Data						
Task 4 Leads						
Task 5 R & E						
Task 6 Tech Trans						Final Report/NAPE

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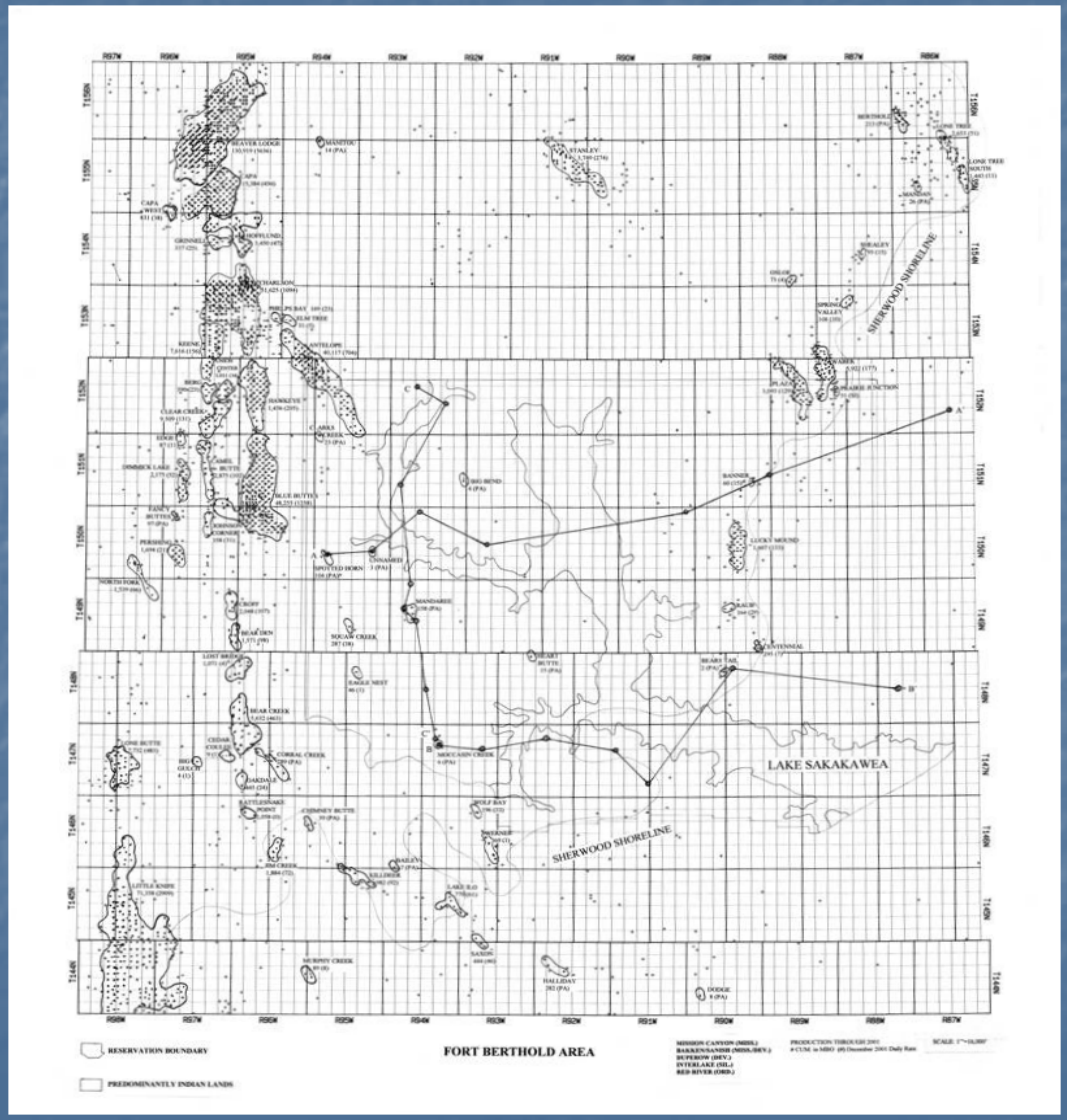
Objective

- Review literature and production data to generate an evaluation scheme
  - Determine play types
  - Geologic characteristics
  - Key indicators
- Apply evaluation scheme on and around reservation, using cross-sections and structure contour maps on relevant horizons.

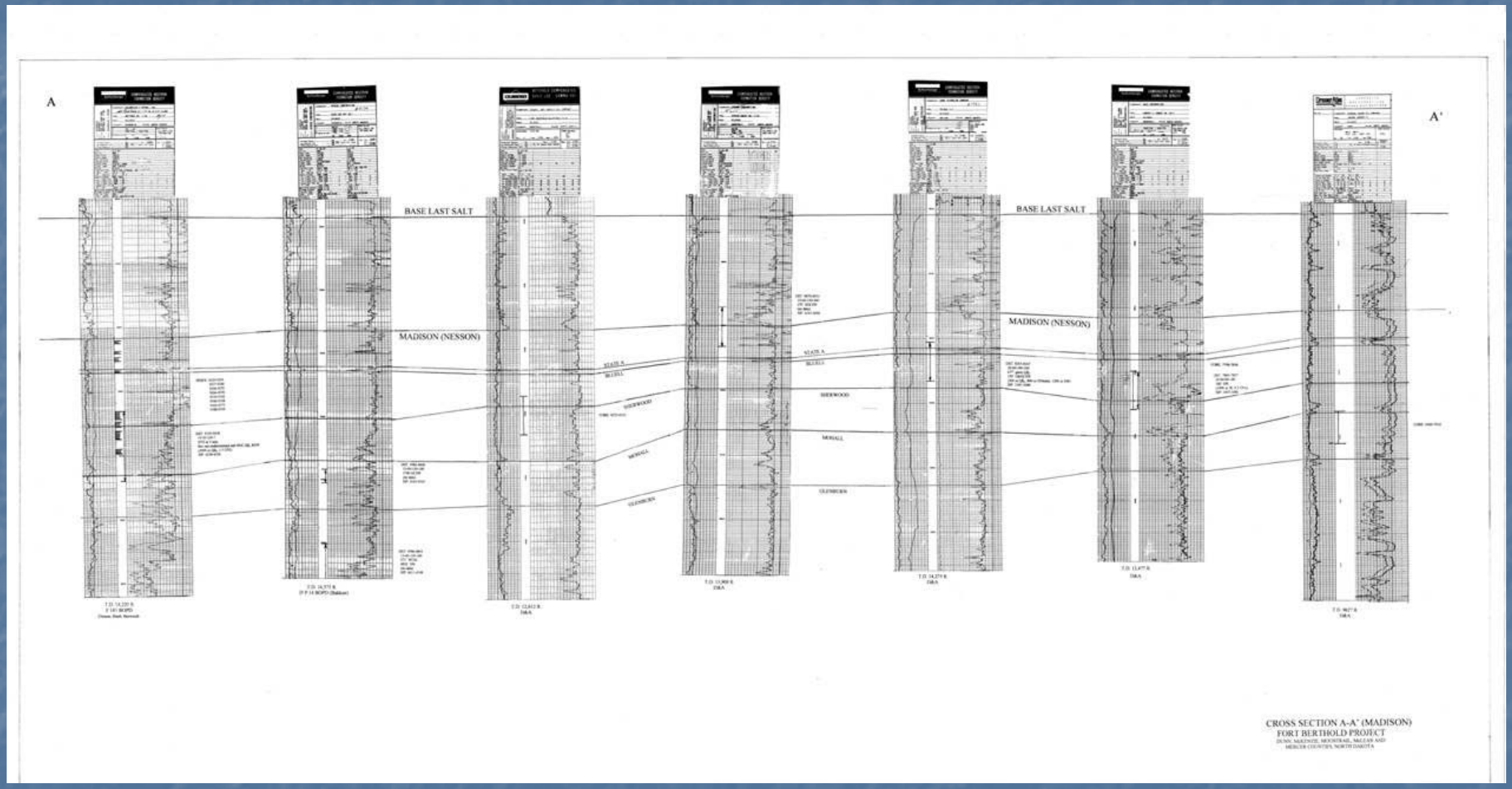
Fort Berthold and the Williston Basin

- The Williston Basin is an oil rich, epicontinental basin developed on the pre-Cambrian craton.
  - Effective oil source beds are present in the Ordovician Winipeg and Mississippian Bakken Formations as well as other less widespread intervals
  - Paleozoic reservoirs are dominantly carbonates trapped in structural and stratigraphic traps
- Fort Berthold Reservation is located along the northeast flank of the basin where the Mississippian Bakken is mature, oil saturated and productive trends surround the reservation

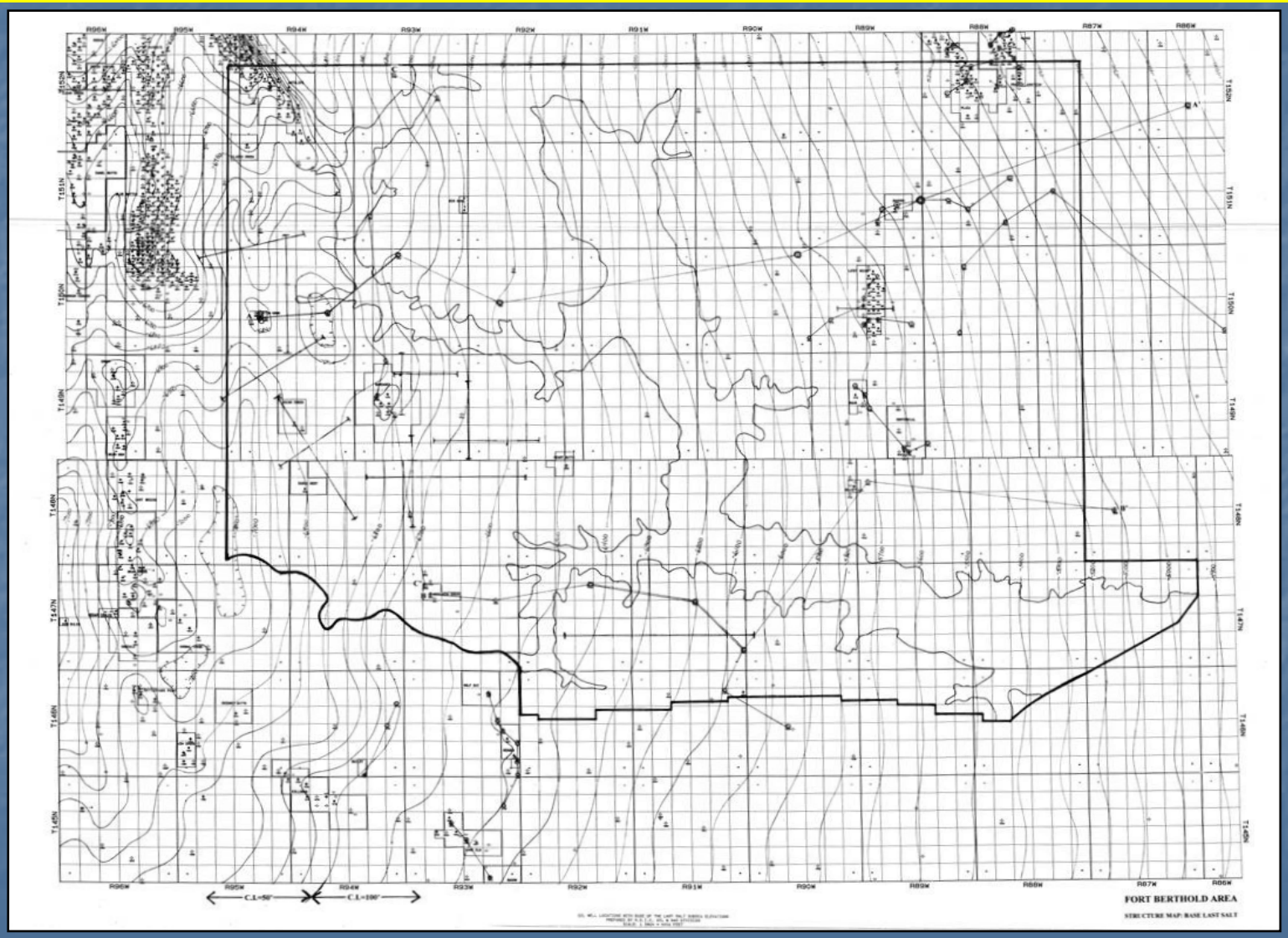
Reservation Area Base Map



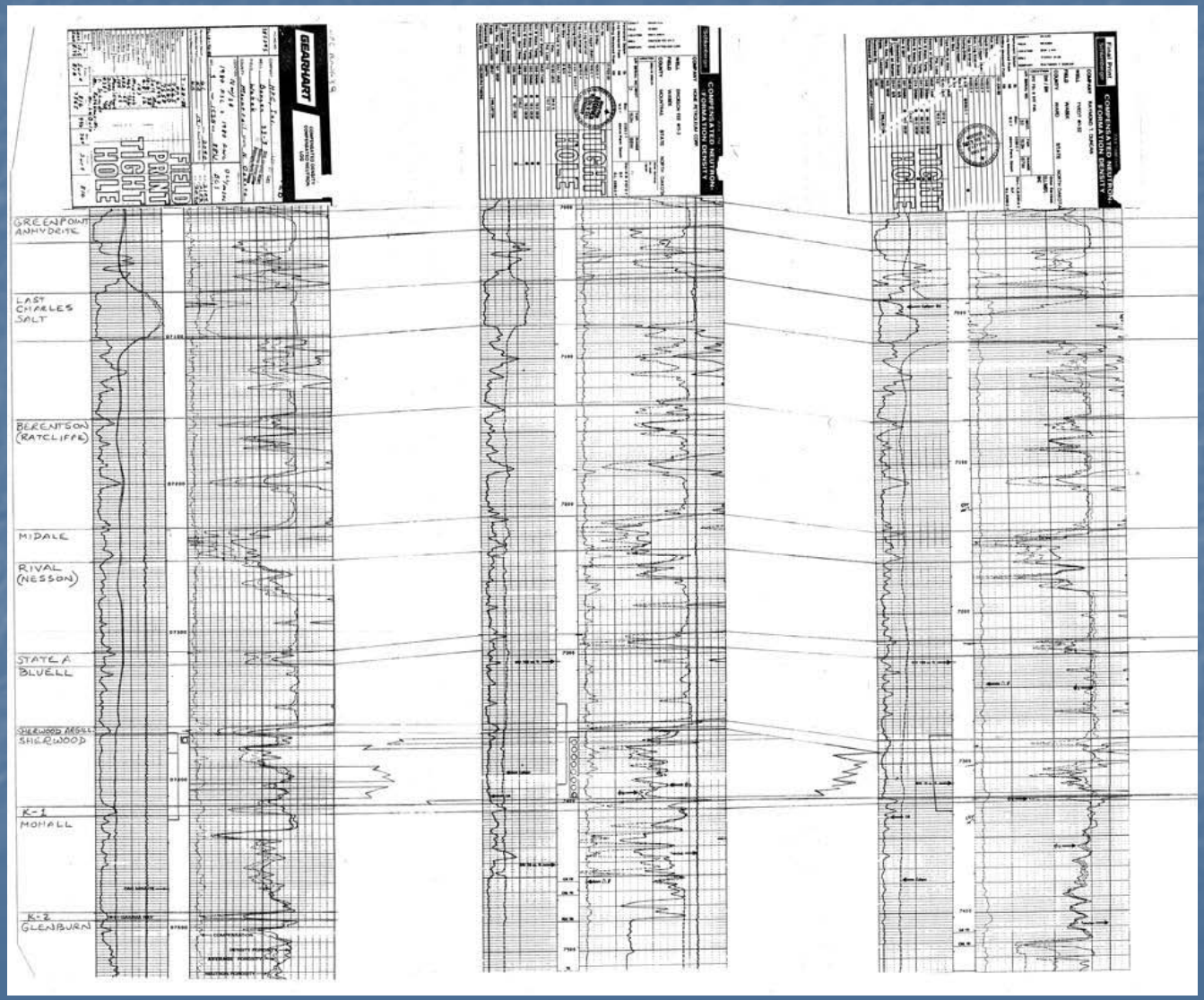
Regional Cross-Section A-A'; Madison



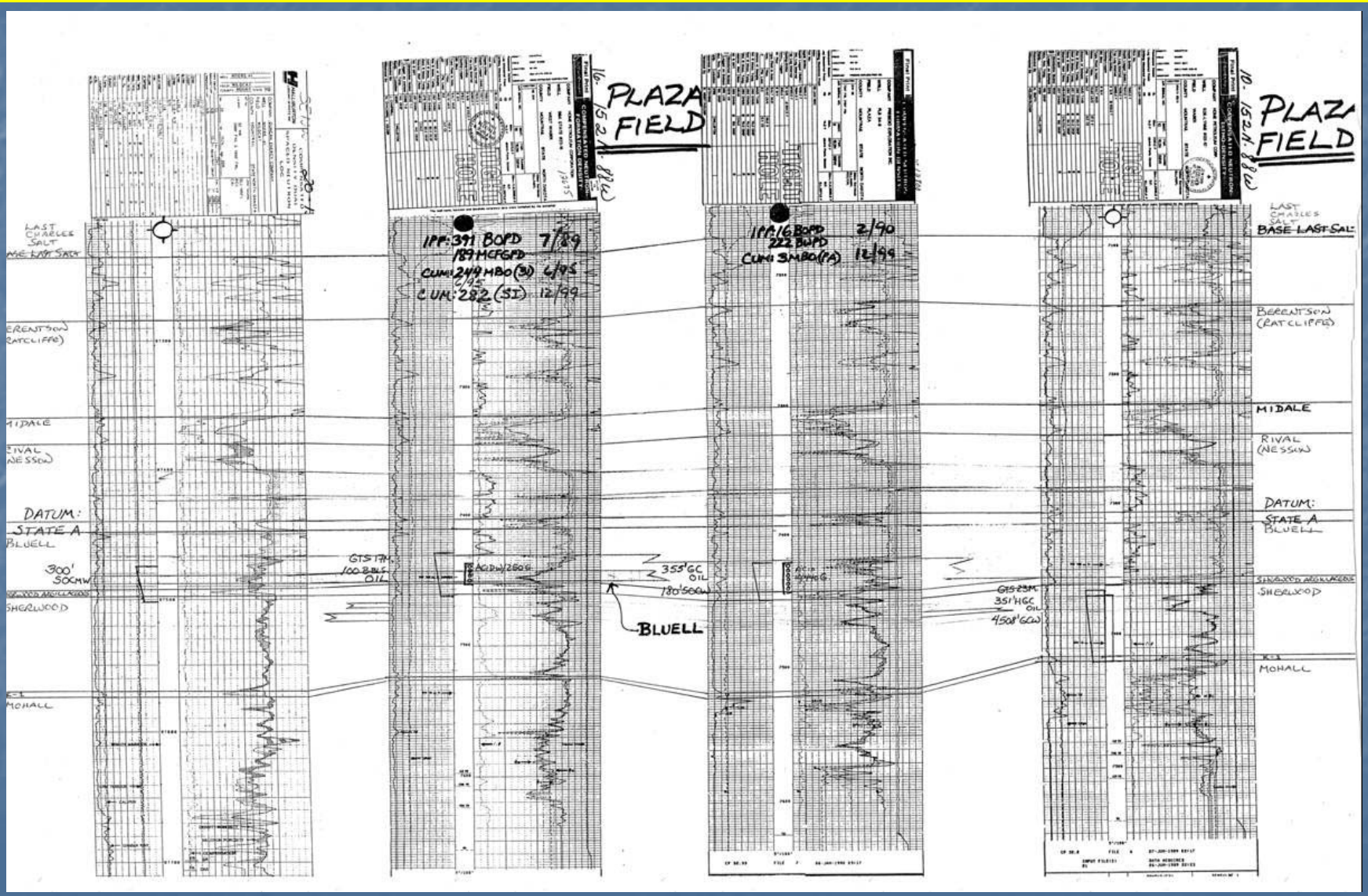
Structure Map - Base Last Salt



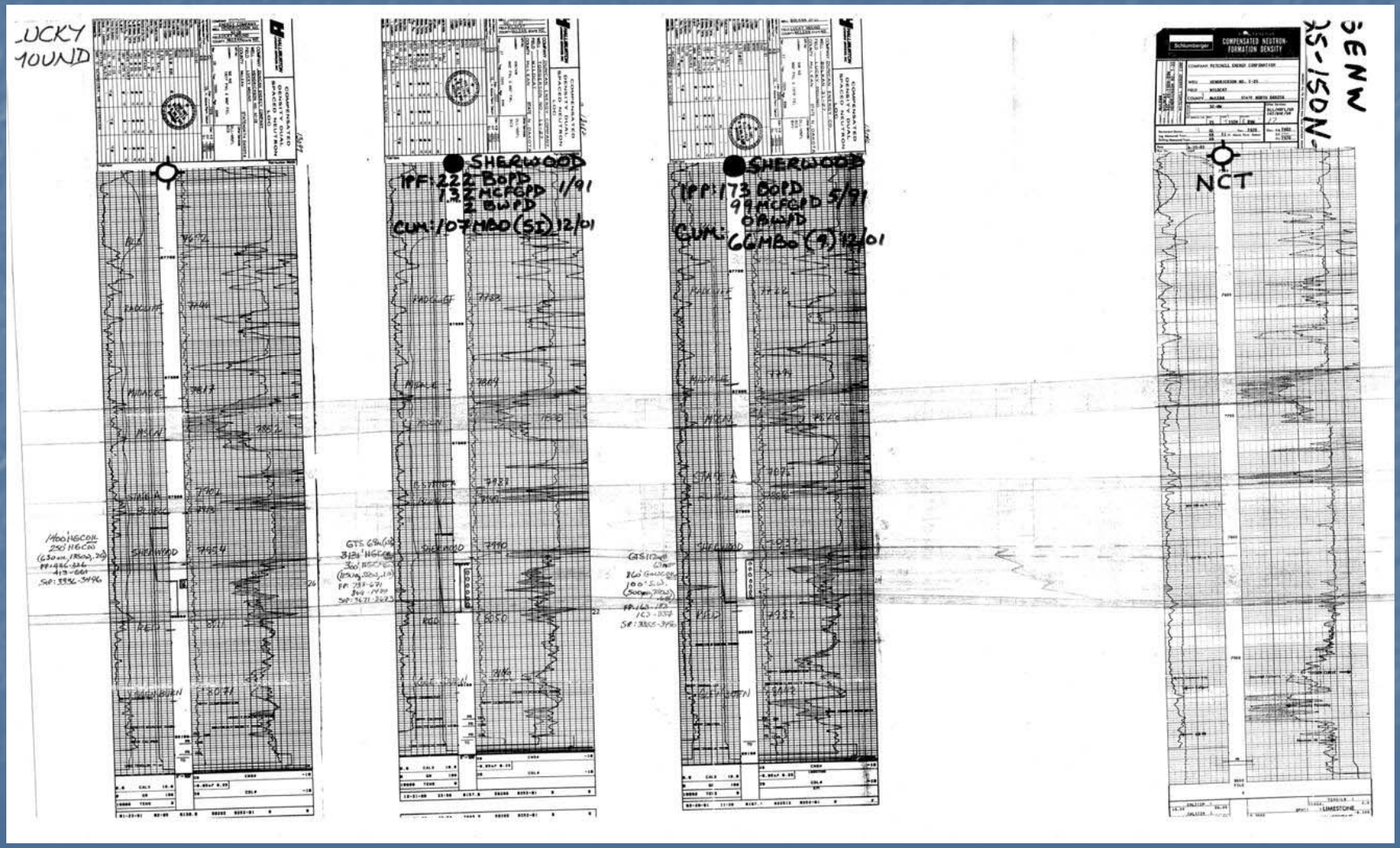
Wabek Field Cross-Section



Plaza Field Cross-Section



Lucky Mound Field Cross-Section



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Objectives

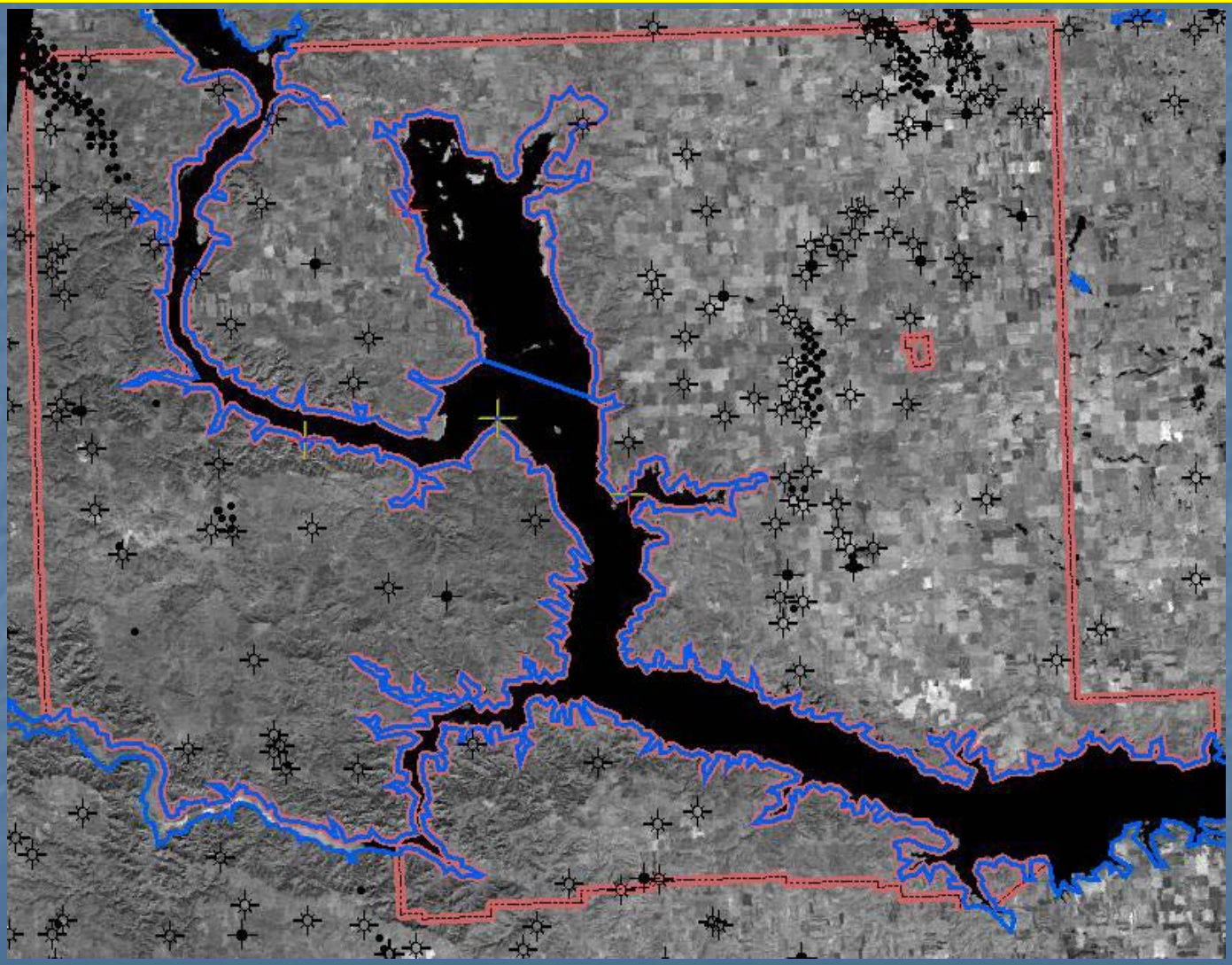
- Utilize satellite (LandSat) imagery, gravity and aeromag to identify major structural features that extend beneath Lake Sakakawea.

Two LandSat Images Acquired

Remote Sensing Imagery Interpretation

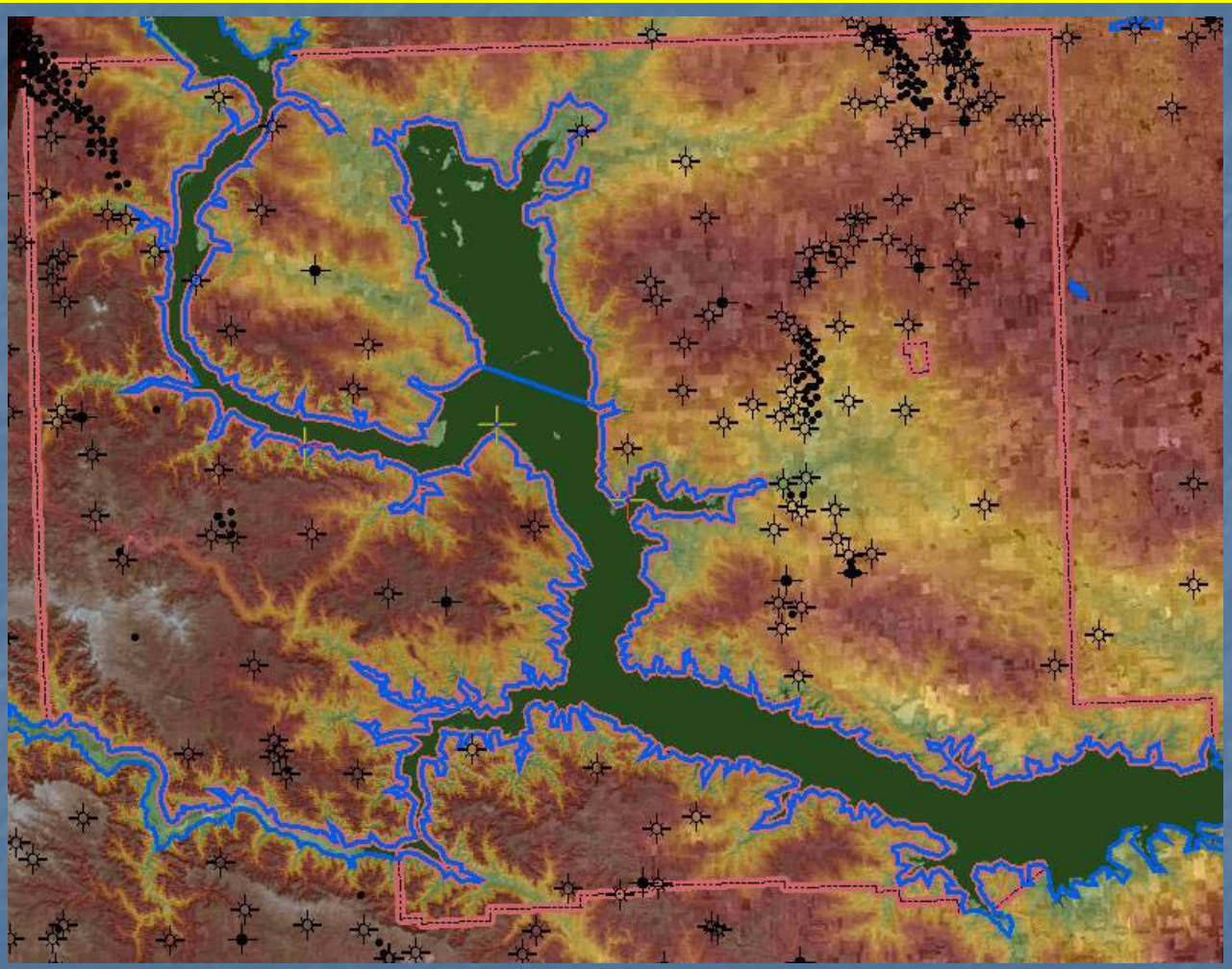
- Two images acquired, merged and georectified to provide coverage beyond bounds of reservation area
- National Elevation Dataset (NED) windowed and combined with Landsat ETM7+ imagery to provide elevation control
- Bands 3, 4, 5 interpreted with and without elevation data
- Interpretation directed towards fault influence of surface geomorphology

Band 4 Image



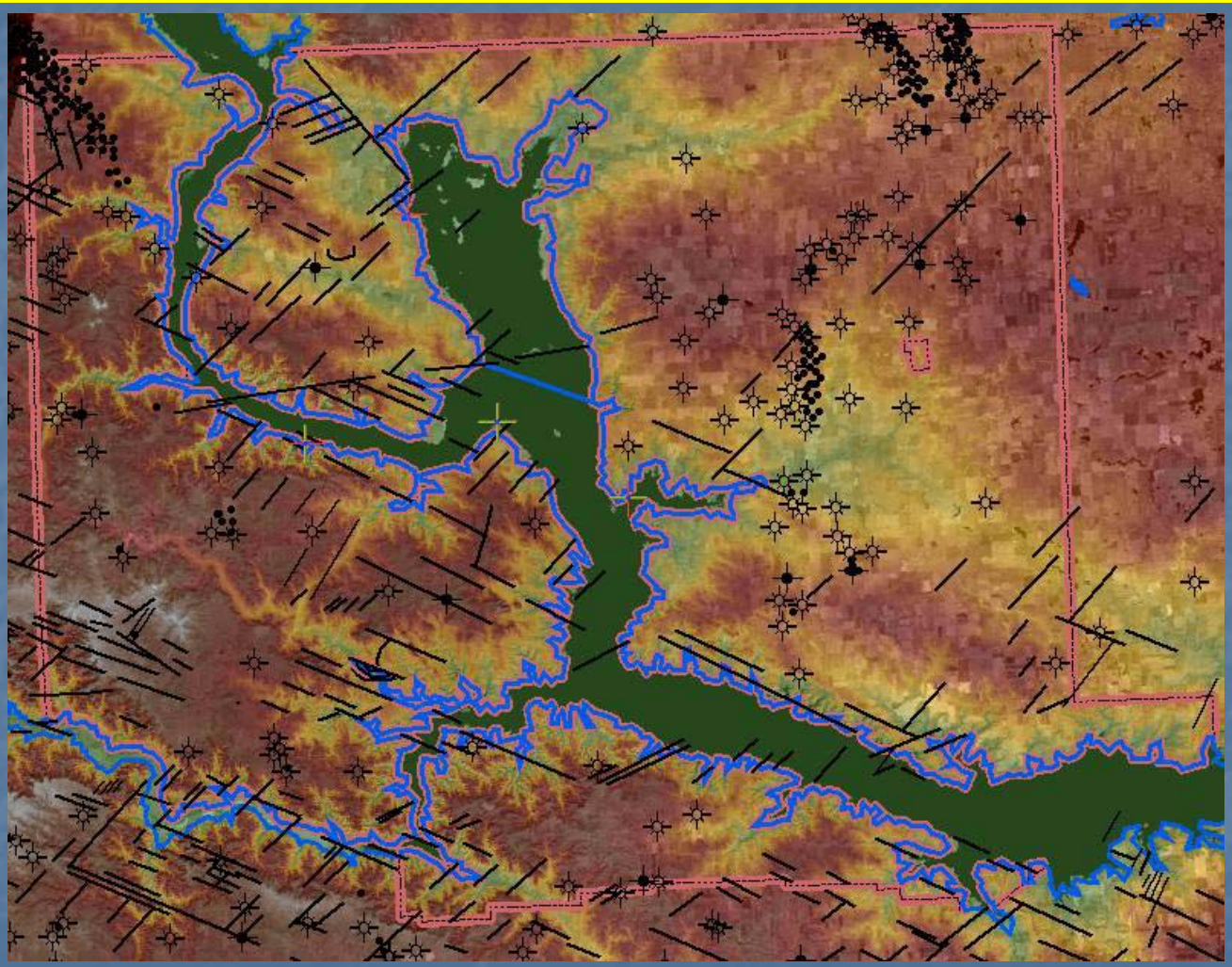
Band 4 Image of low relief terrain on Reservation around Lake Sakakawea.

Band 4 with DEM



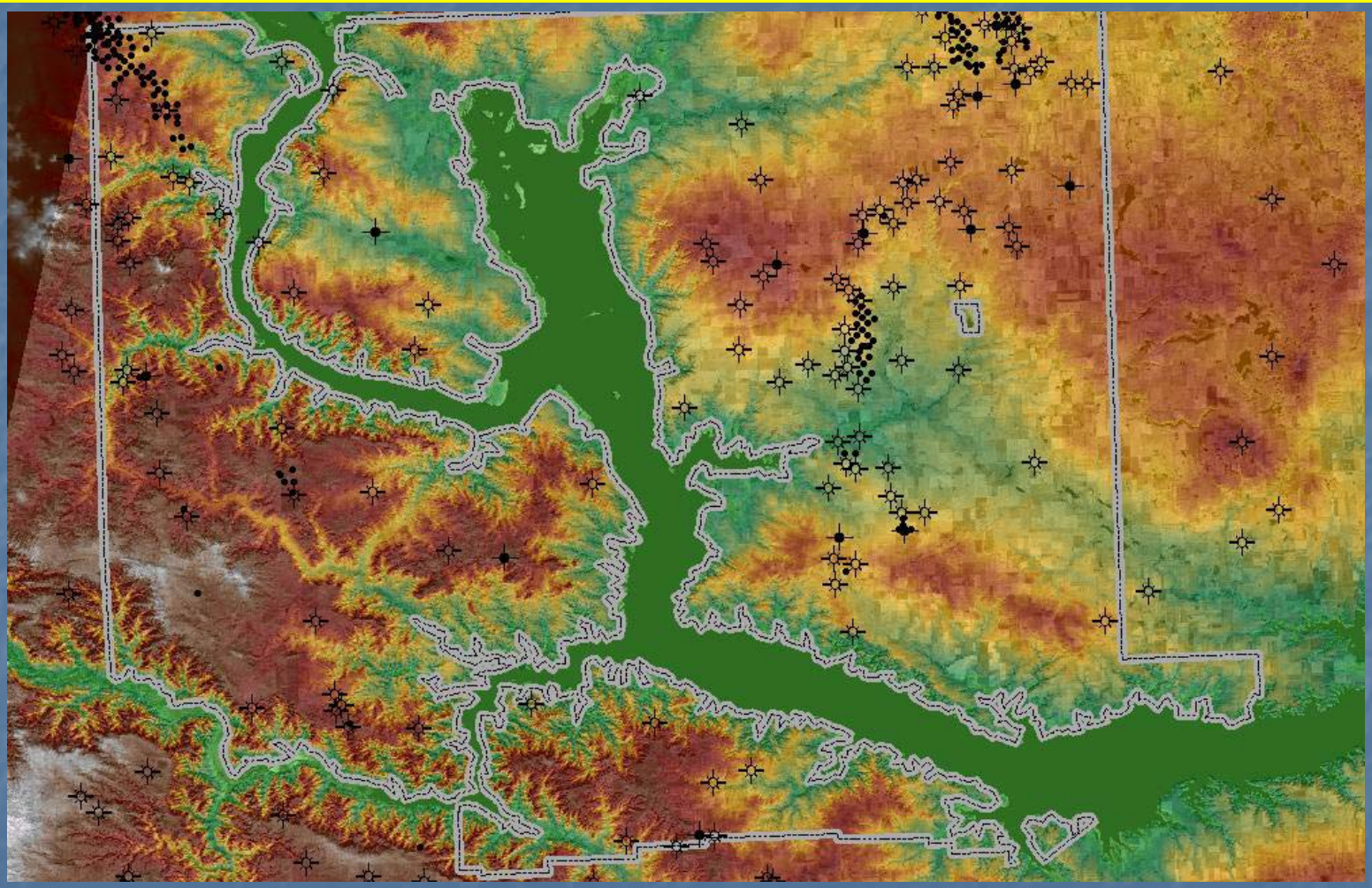
Overlaying Band 4 Image on Digital Elevation Model (DEM) improves interpretation in low relief areas.

Band 4 on DEM w/ Linears



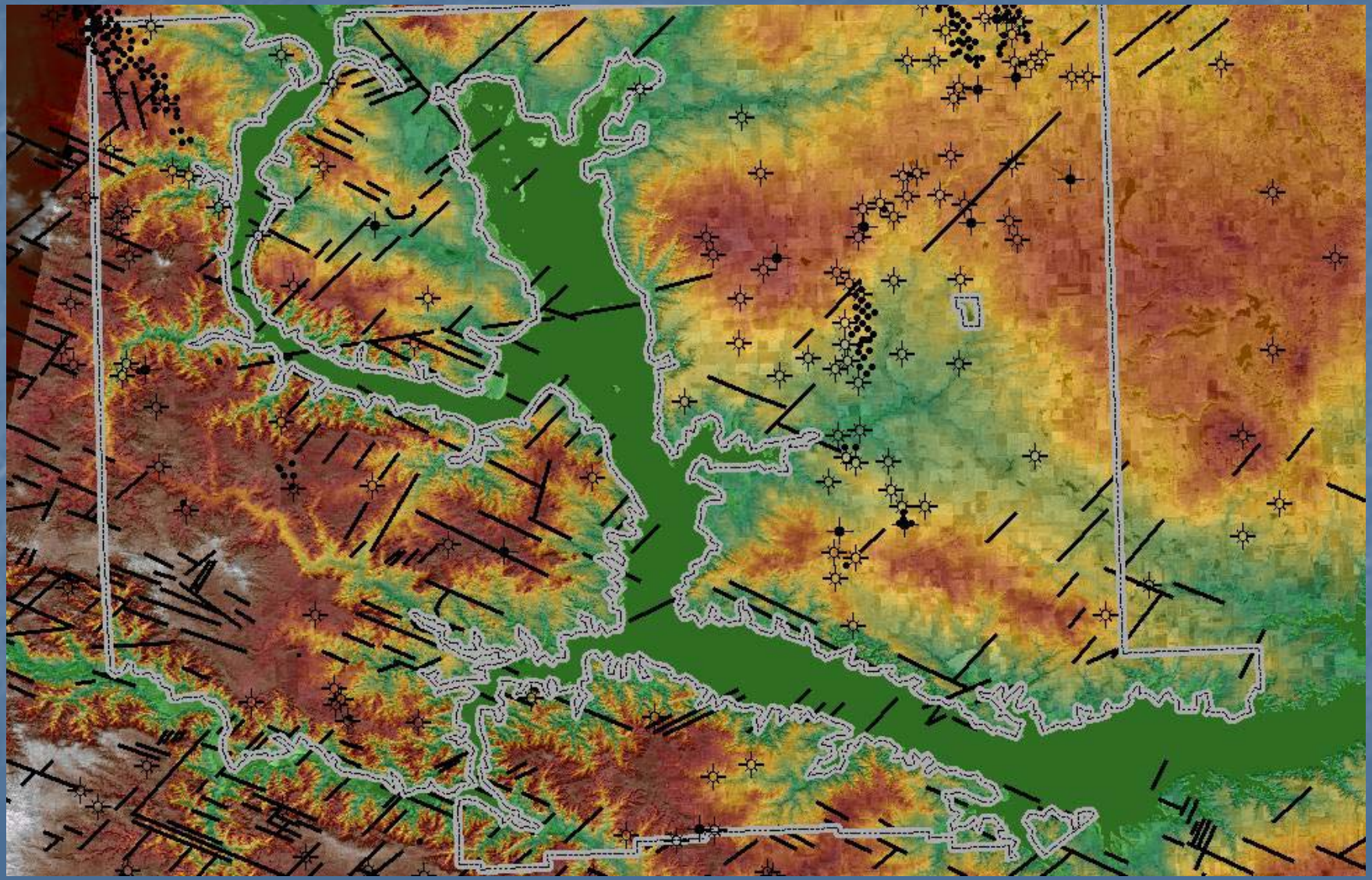
Lineament density is significantly higher towards SW. Area to NE is heavily covered in glacial till.

Band 5 Image

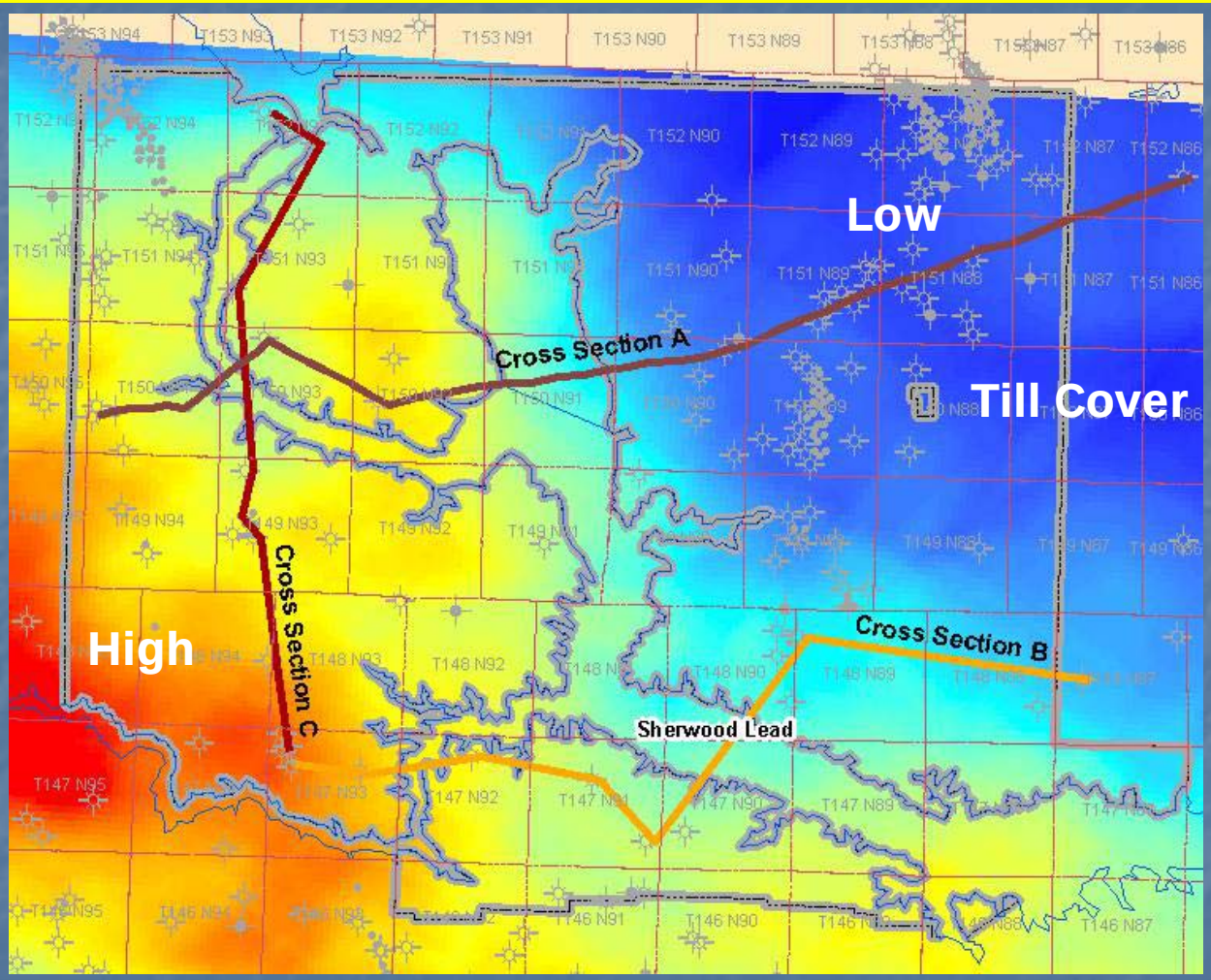


Different IR bands highlight subtle differences in vegetation and geology. The best interpretation incorporates multiple bands.

Band 5 Image with Linears



Lineament Density



Lineament density maps are commonly calculated from compiled lineament interpretations. This map clearly differentiates the till covered area (Low density).

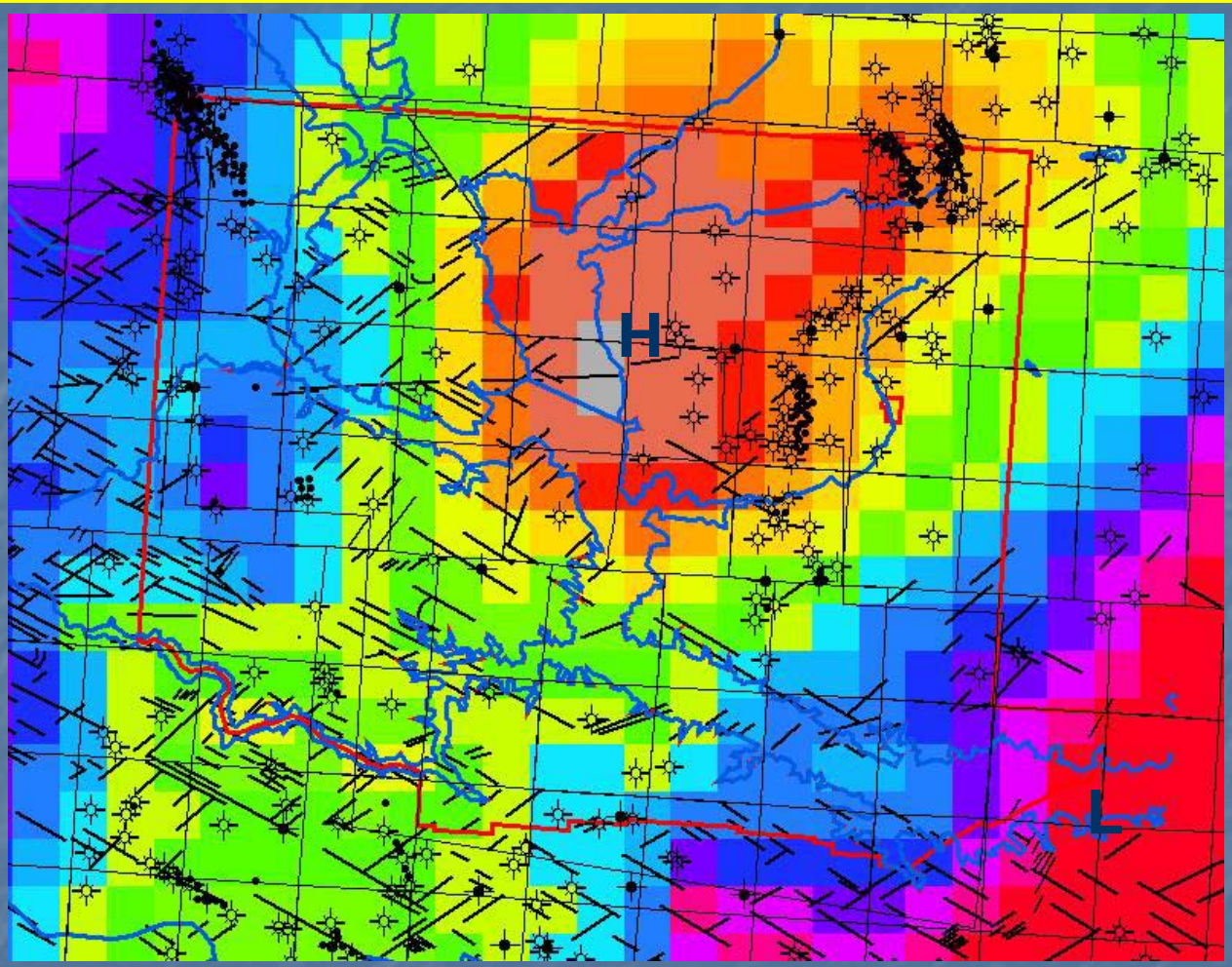
Results

- Northeastern portion of reservation heavily glaciated, reducing numbers of lineaments observed
- Two dominant directions of linears observed
  - ESE lineaments strongly influence Lake geometry
  - NNE present but less well developed
- The lineaments most likely represent the surface traces of fracture zones that create linear trends of weak, easily eroded rock

Regional Potential Fields

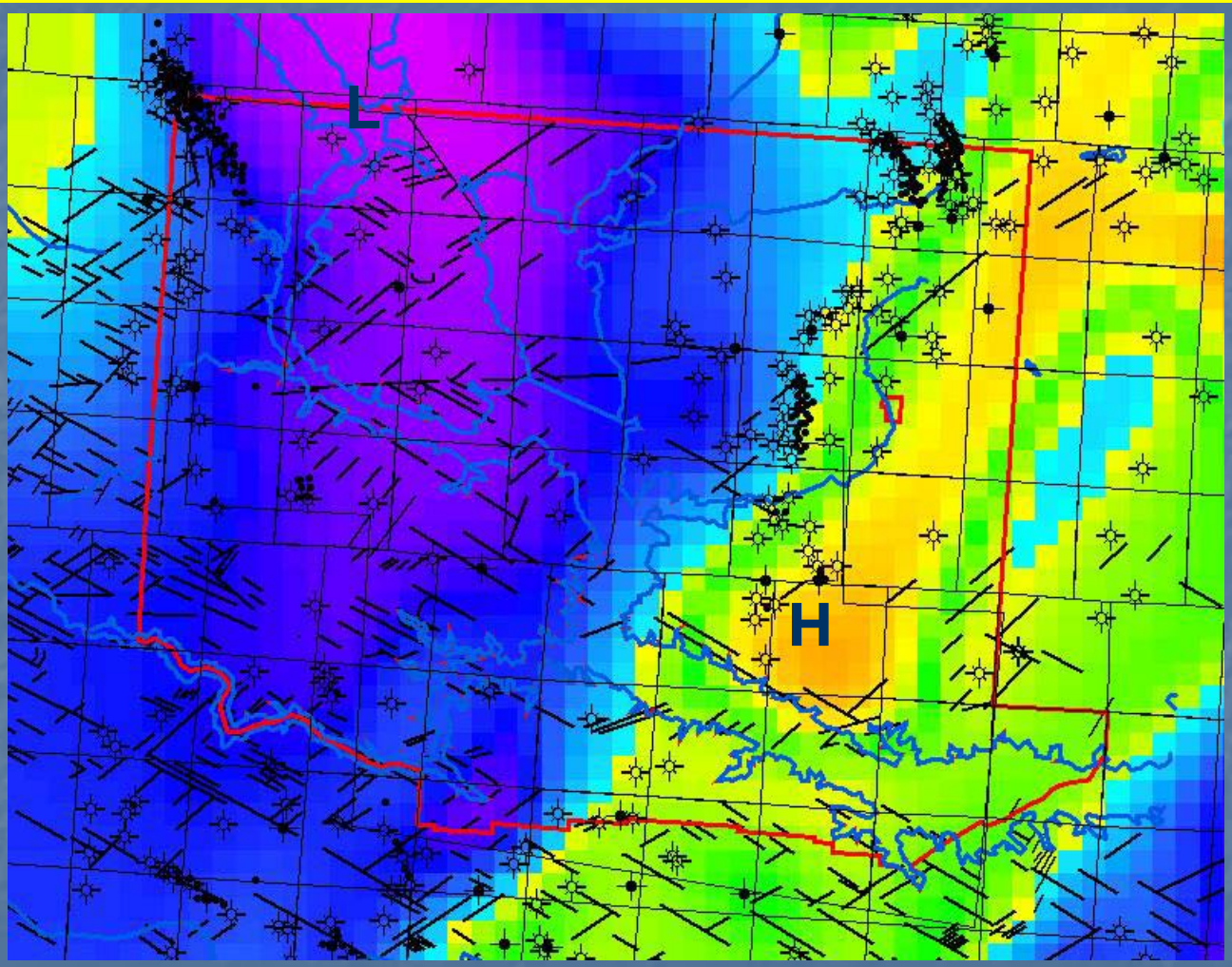
- Reviewed and mapped the regional scale national isostatic gravity and aeromag grids
  - Both data sets gridded on 5 km intervals
  - Provide low resolution image of regional deep (crustal) structural fabric
- Integrated lineament analysis with regional grids
  - Good correspondence between datasets
    - Lineament trends appear to bound the highs and lows with evidence of truncation at intersections

Isostatic Gravity Image



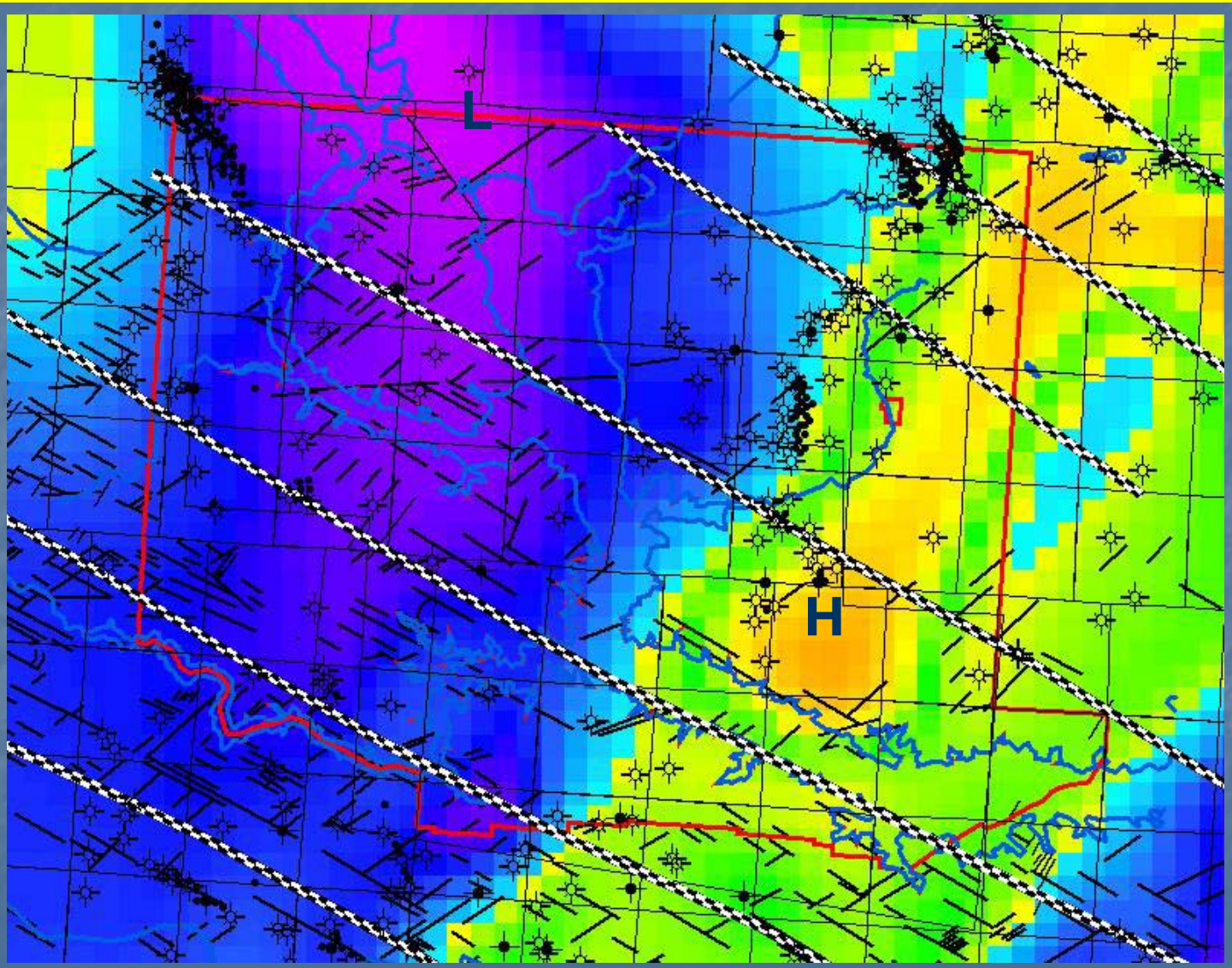
The gravity map shows a broad NE trending high segmented along its length. The Landsat lineaments tend to define the edges of the basement blocks.

Regional Aeromag Image

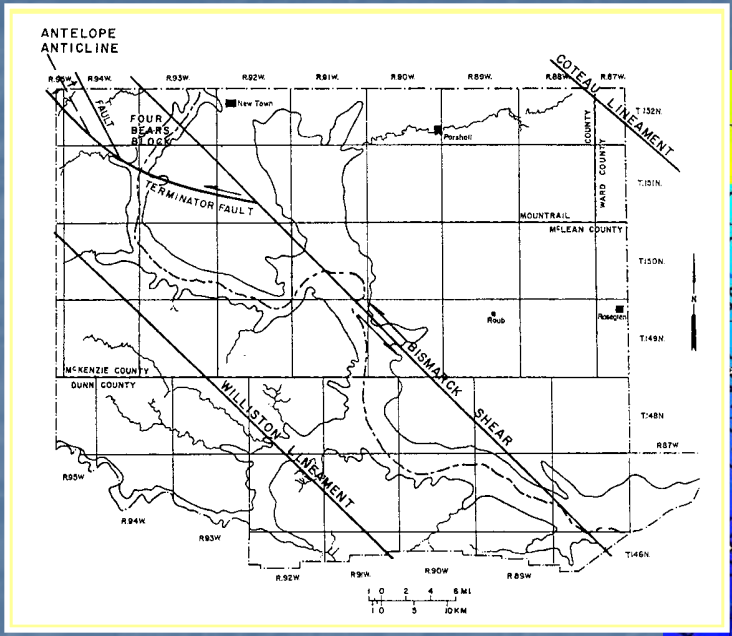


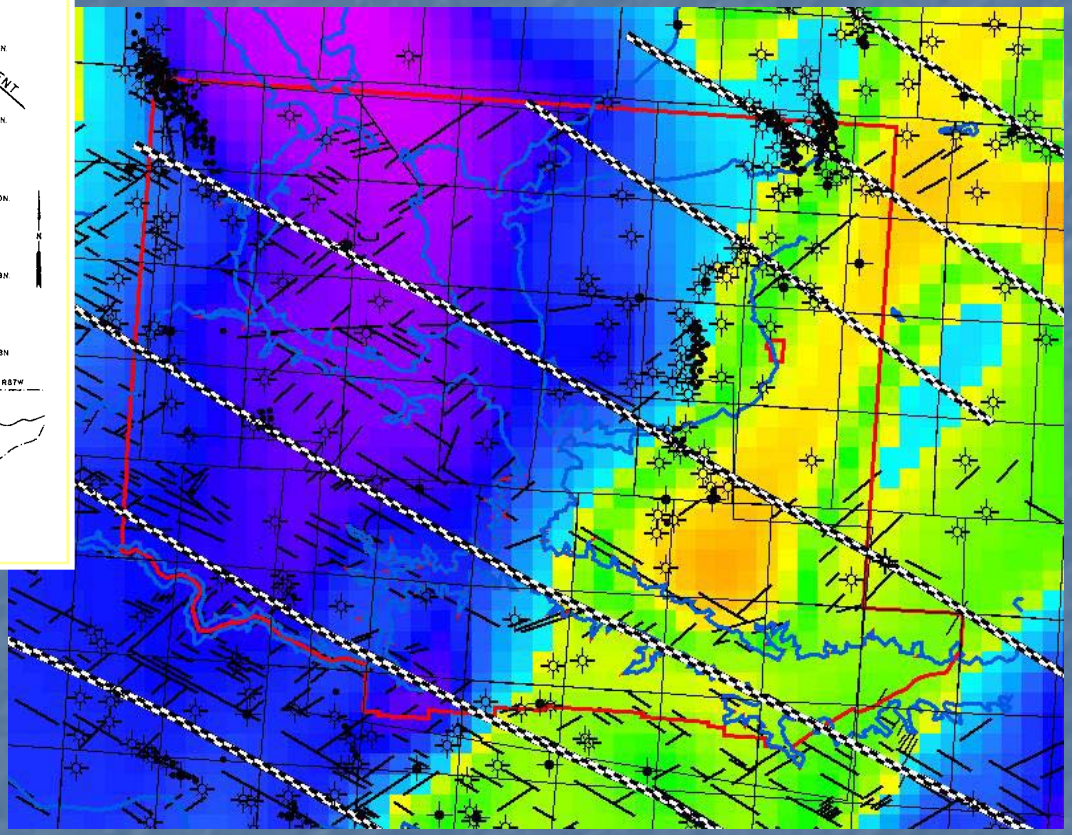
The regional aeromag shows similar but not coincident trends. The gravity high overlies the aeromag low.

Regional Aeromag Lineaments



Regional Tectonic Trends





The aeromag trend appears to be segmented in seven places vs the three described earlier.

Regional Potential Fields Conclusions

- Remote sensing and the regional gravity and mag data sets support 4 additional basement shear zones in addition to the three previously described. The Williston, Bismark and Coteau fault zones are observable in the data.
  - Net effect is to change orientation of trends more to the WNW-ESE
  - Antelope Field lies near termination of unnamed shear zone
  - Central portion of the Lake and Reservation lies in area of interaction between right stepping left lateral deep-seated shear zones

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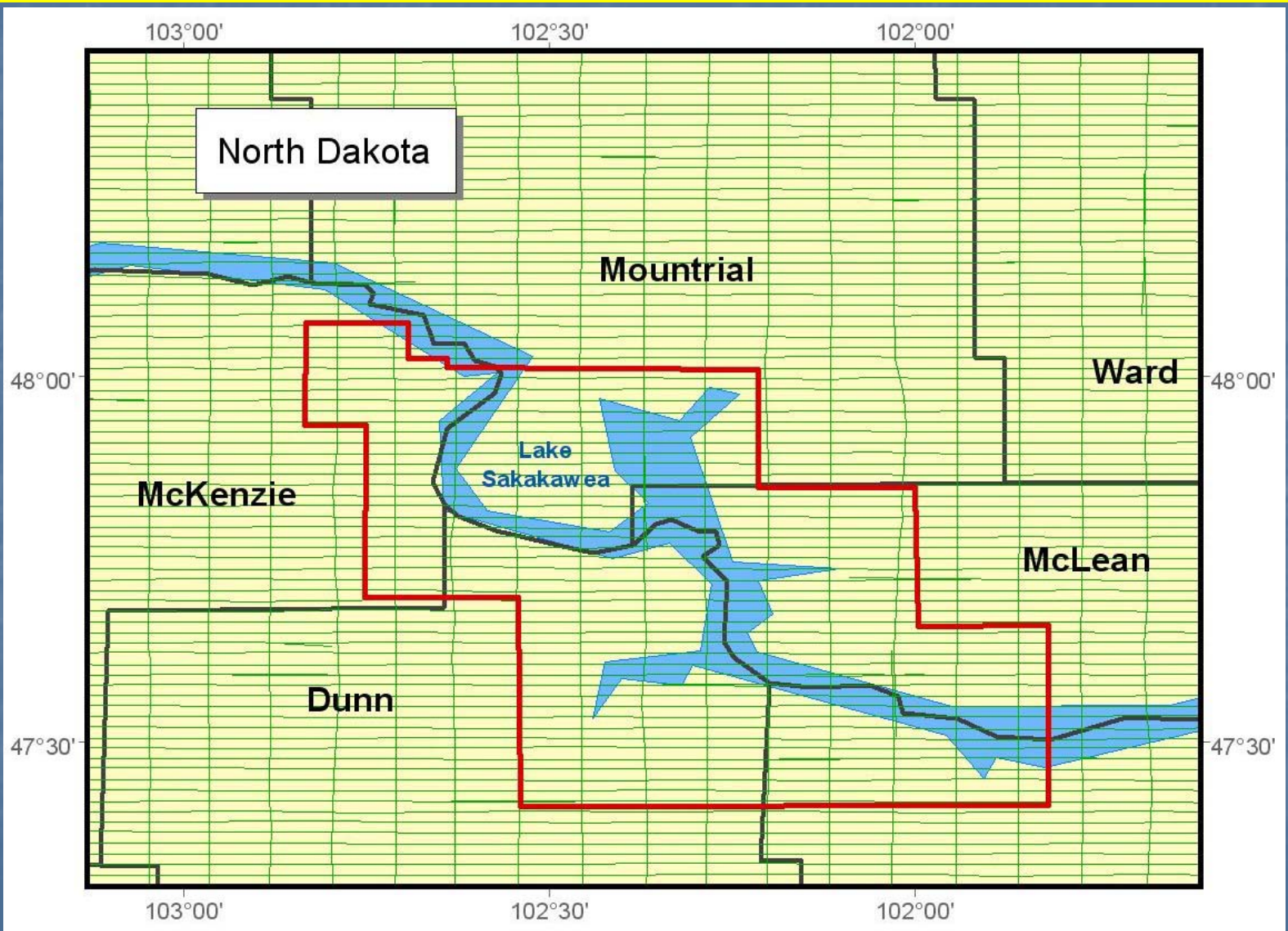
Objective

- Provide laterally extensive 2D (horizontal) to integrate with and extrapolate 2D (vertical) seismic.

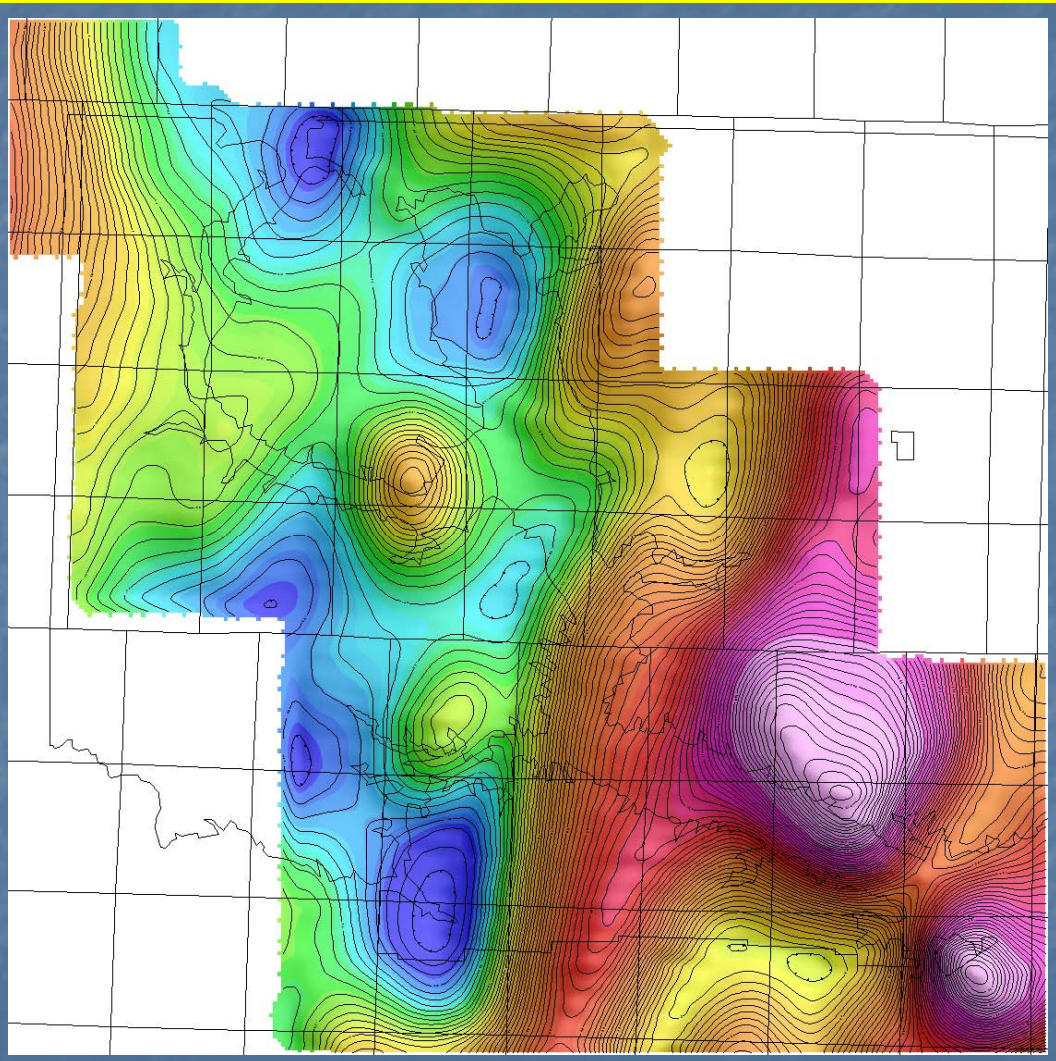
Intermediate Resolution Survey

- Acquired over central portion of lake for prospect generation in conjunction with original 2D seismic
  - Part of an existing survey
  - Windowed to area of interest and processed for interpretation and modeling
    - Derivatives
    - SunMag
    - Modeled to map depth to pC basement

Aeromag Survey Outline

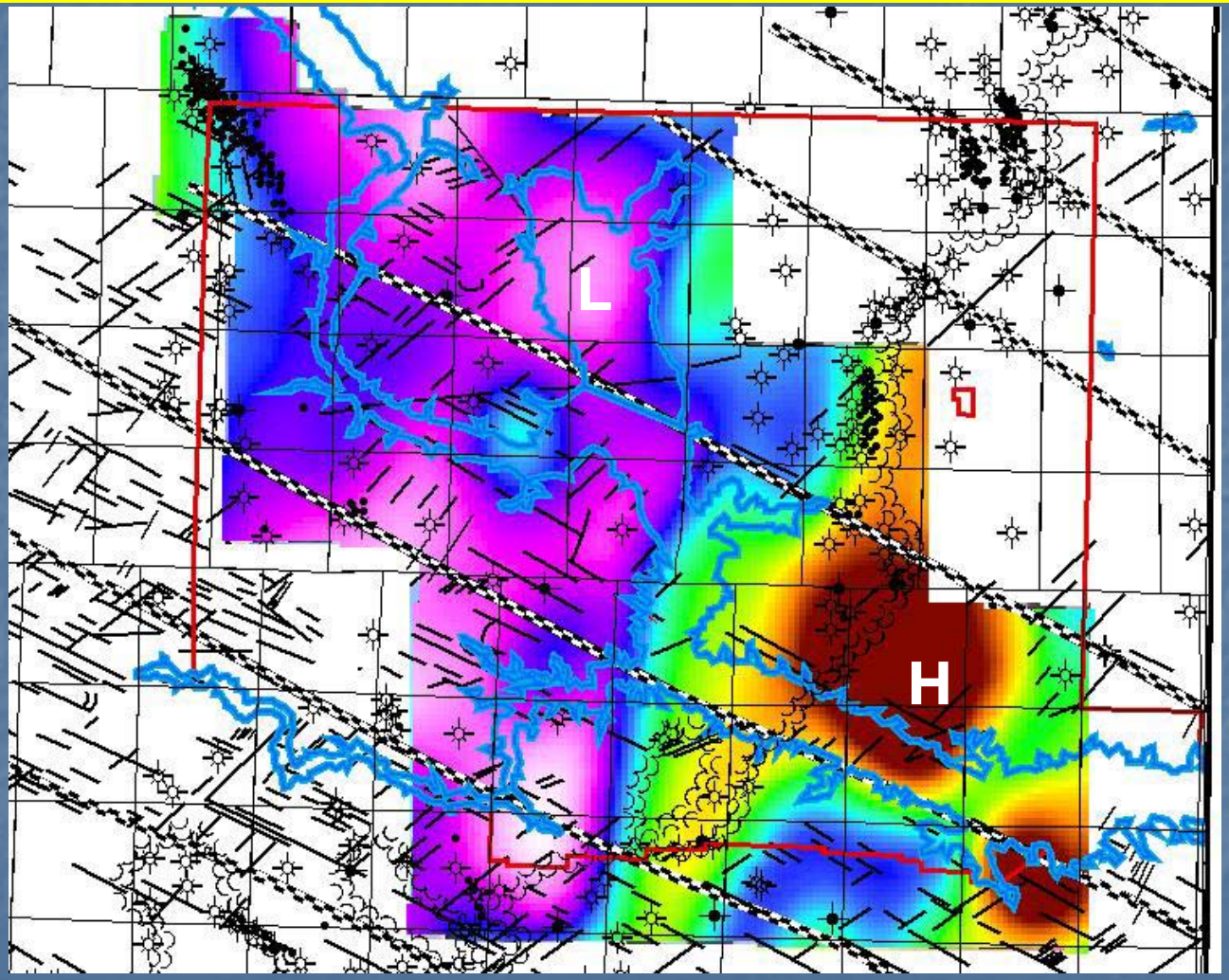


Total Magnetic Intensity



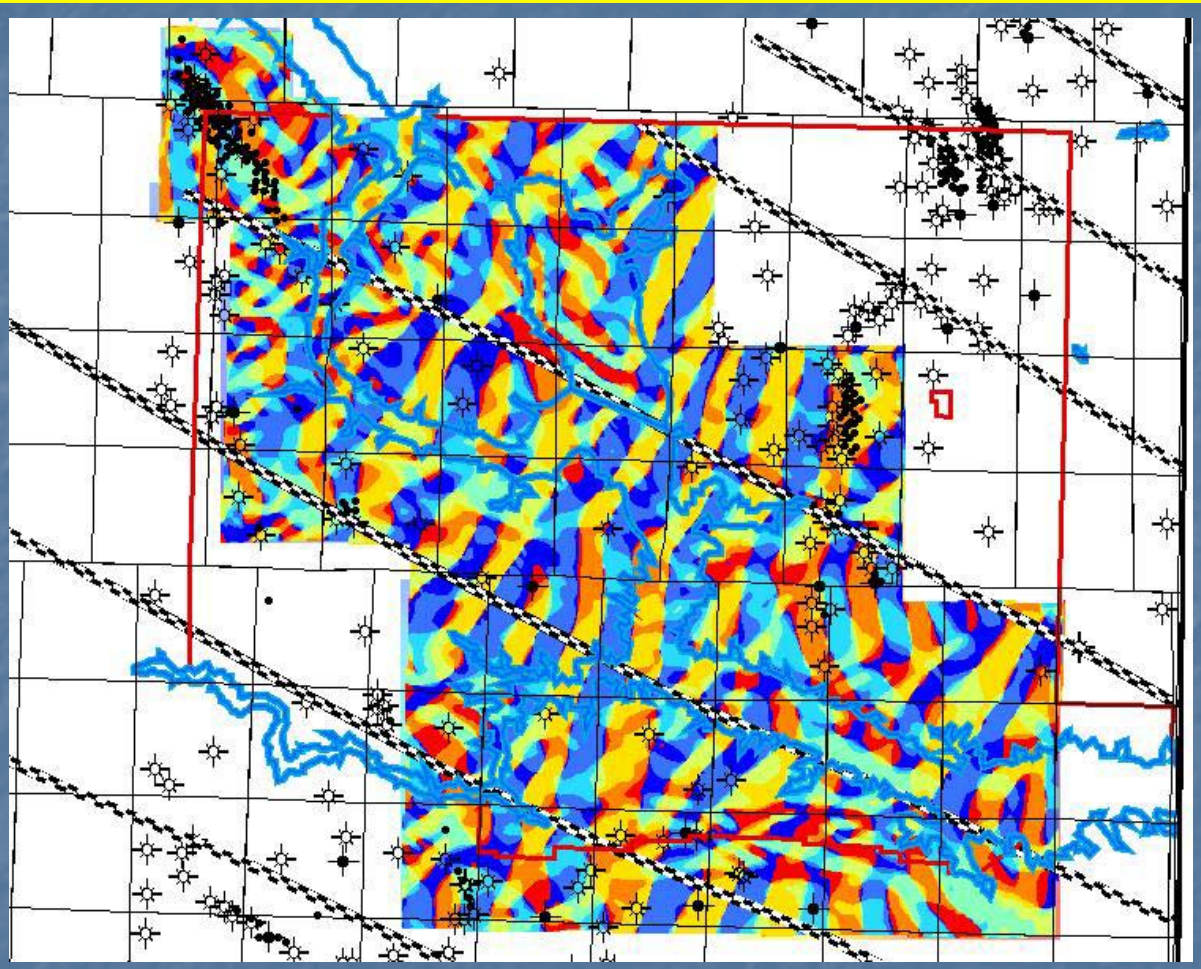
Raw aeromag map with only basic corrections or processing.

Aeromag Total Intensity



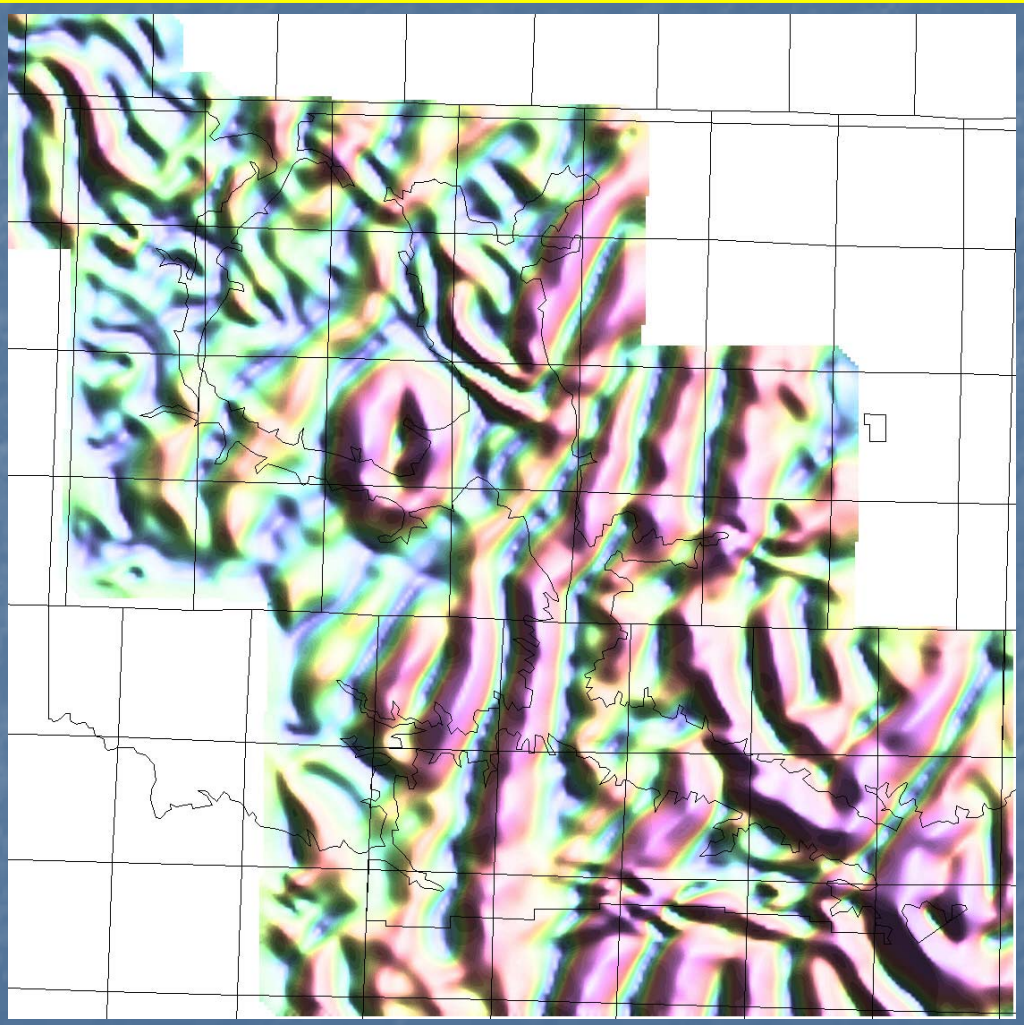
Similar but higher frequency segmentation is observable in the intermediate aeromag data.

Detail Aeromag SunMag



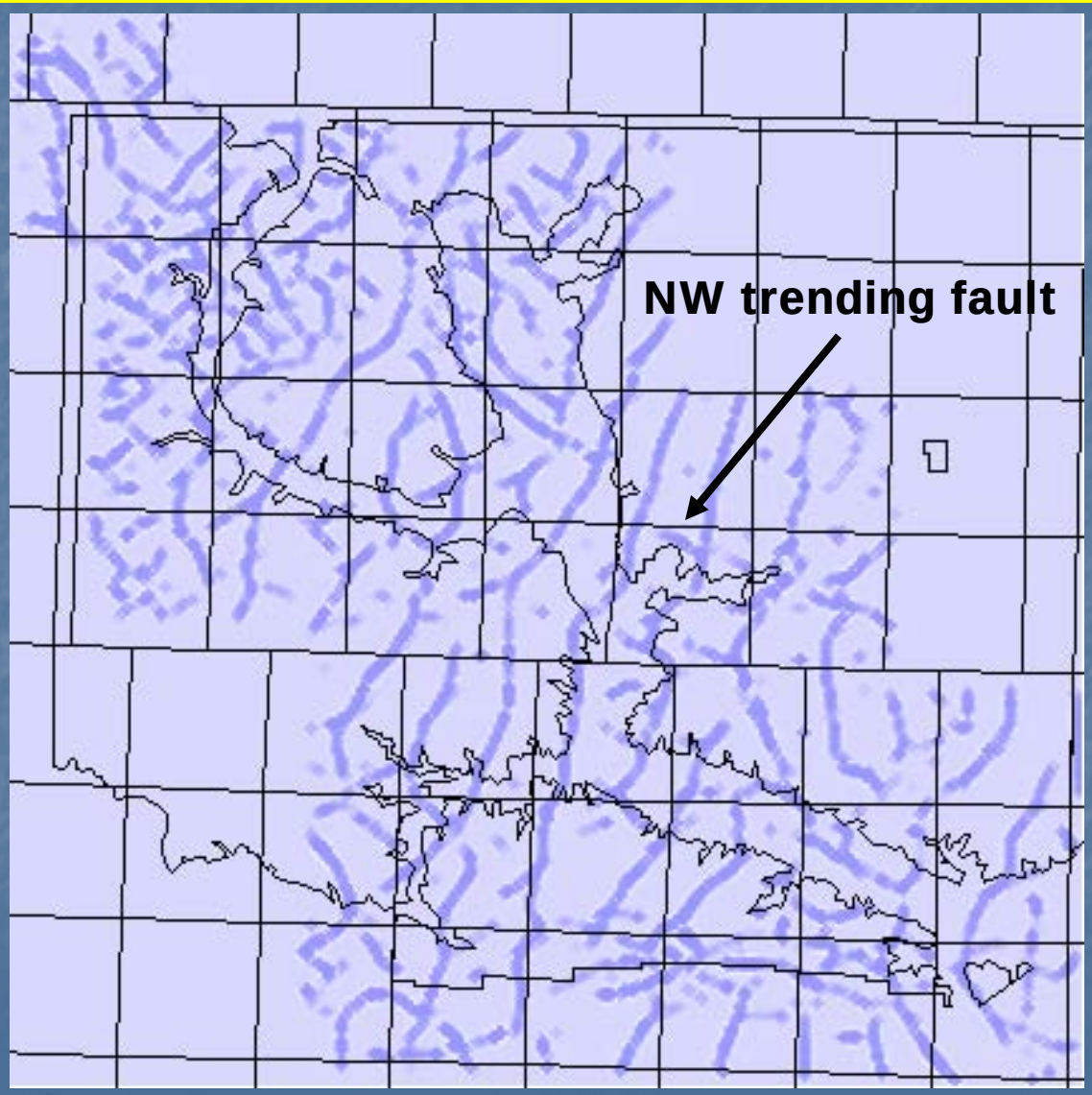
The gradient azimuth plot of the intermediate aeromag data shows the breaks identified in the regional data as well as others.

Horizontal Gradient-NE Sun



Shaded relief gradient maps also provide a graphical representation of discontinuities (faults) in the aeromag data.

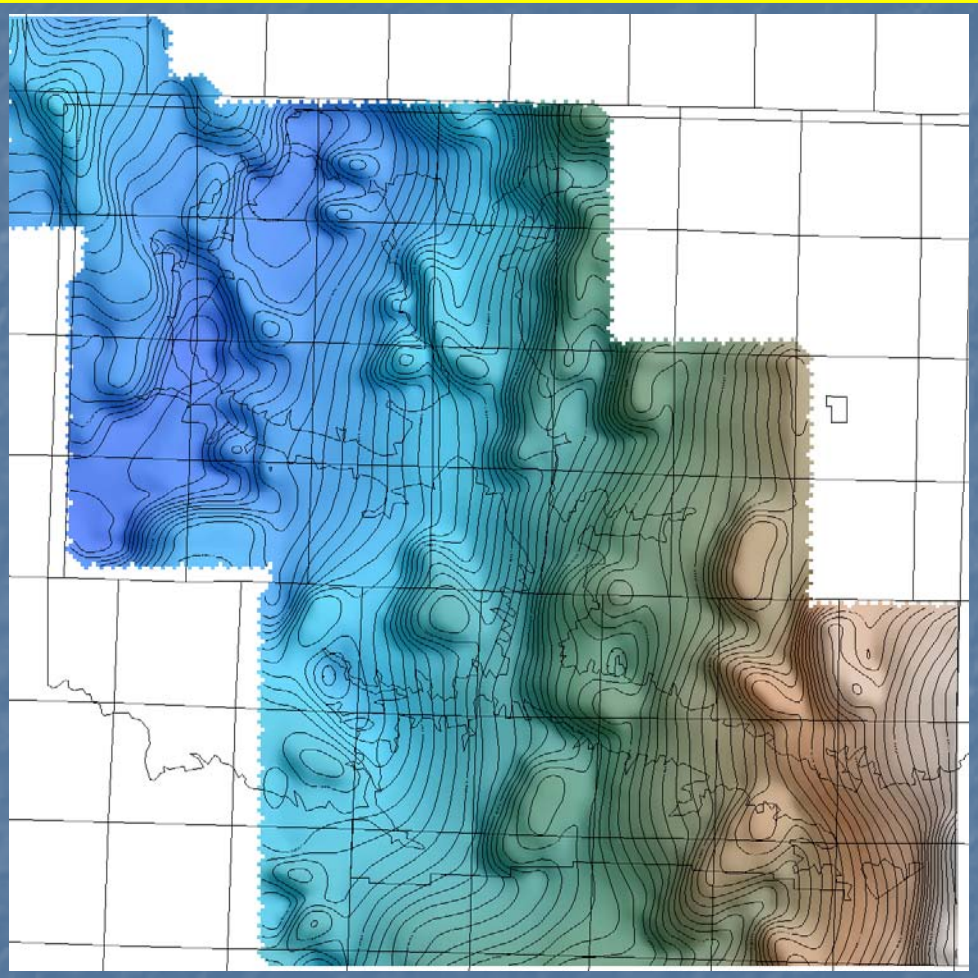
Autofault RTP Magnetics



Aeromag Modeling

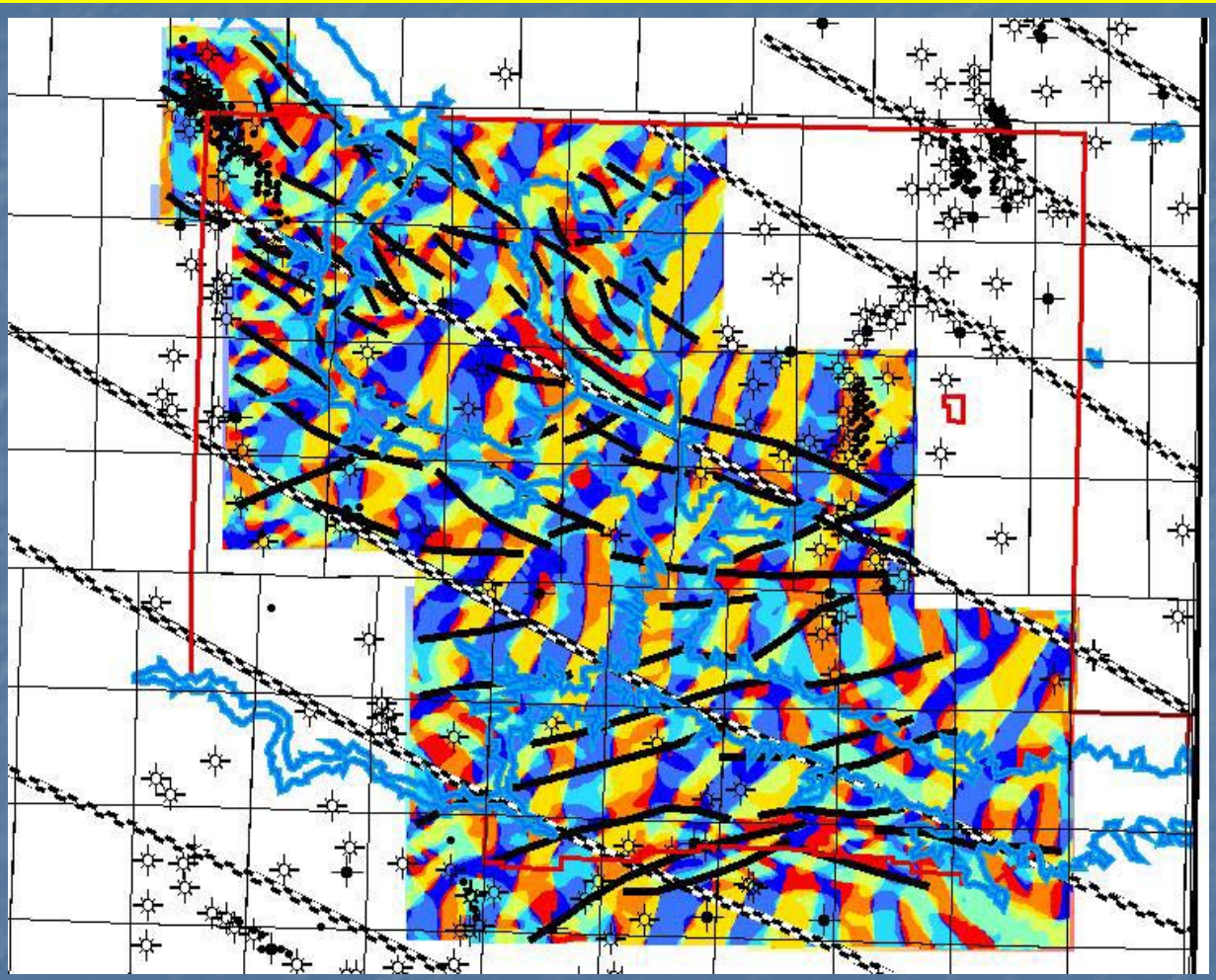
- Determined strong NNE striping due to lateral magnetic changes in basement
  - Influence of lateral changes could be filtered out to make pC structure map
  - Disruption of stripes indicated shear faulting

Interpreted Basement Structure



Sparse pC penetrations were used to invert the aeromag data and create a pseudo basement depth map.

Detail Sunmag w/ Faulting



The shorter faults identifiable in the intermediate resolution aeromag form in groups along or stretch between the deeper, regional shears.

Intermediate Resolution Aeromag Conclusions

- Intermediate resolution aeromag inverted to generate a good pC "basement" map
  - provides lateral information away from lake
- Intermediate resolution aeromag is consistent with regional data but contains more high frequency information about sediments
  - SunMag and derivative products support identification of fault zones closer to reservoir horizons

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Objective

- Provide “direct” indicators of structure and potential leads under Lake Sakakawea.

2D Seismic

- Limited 2D seismic available on lake from previous exploration efforts
  - Difficult acquisition conditions
    - Variable water depth
    - Onshore, offshore and transition zone data
    - Irregular glacial deposits severely complicate statics
- 200 line-miles purchased (500 available), re-processed and interpreted for study (managed by BIA)
- Time structure maps made for Mission Canyon, Winipeg, and Greenhorn
- Isochron map made for Bakken-Winipeg interval

Seismic Base Map

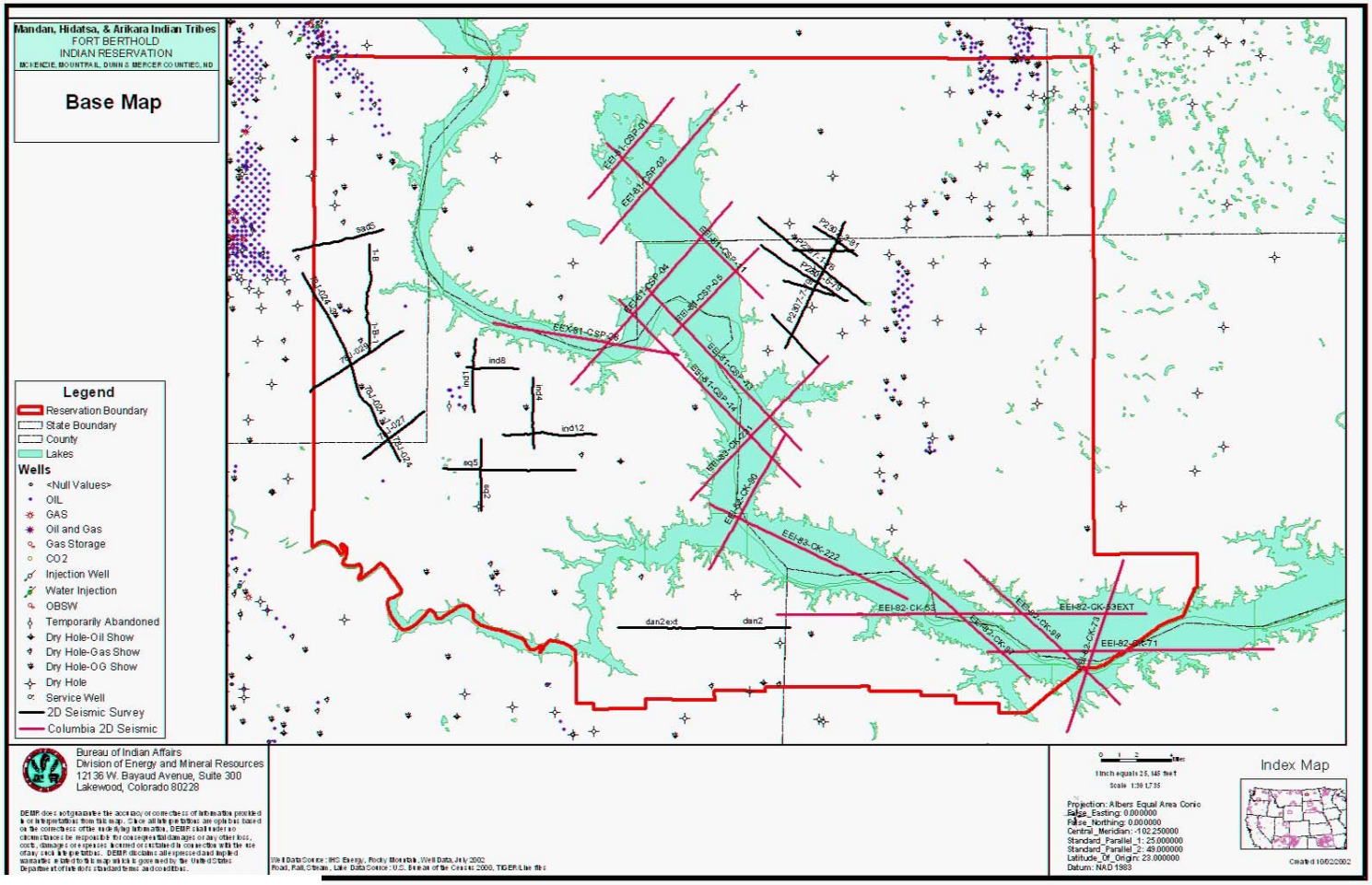
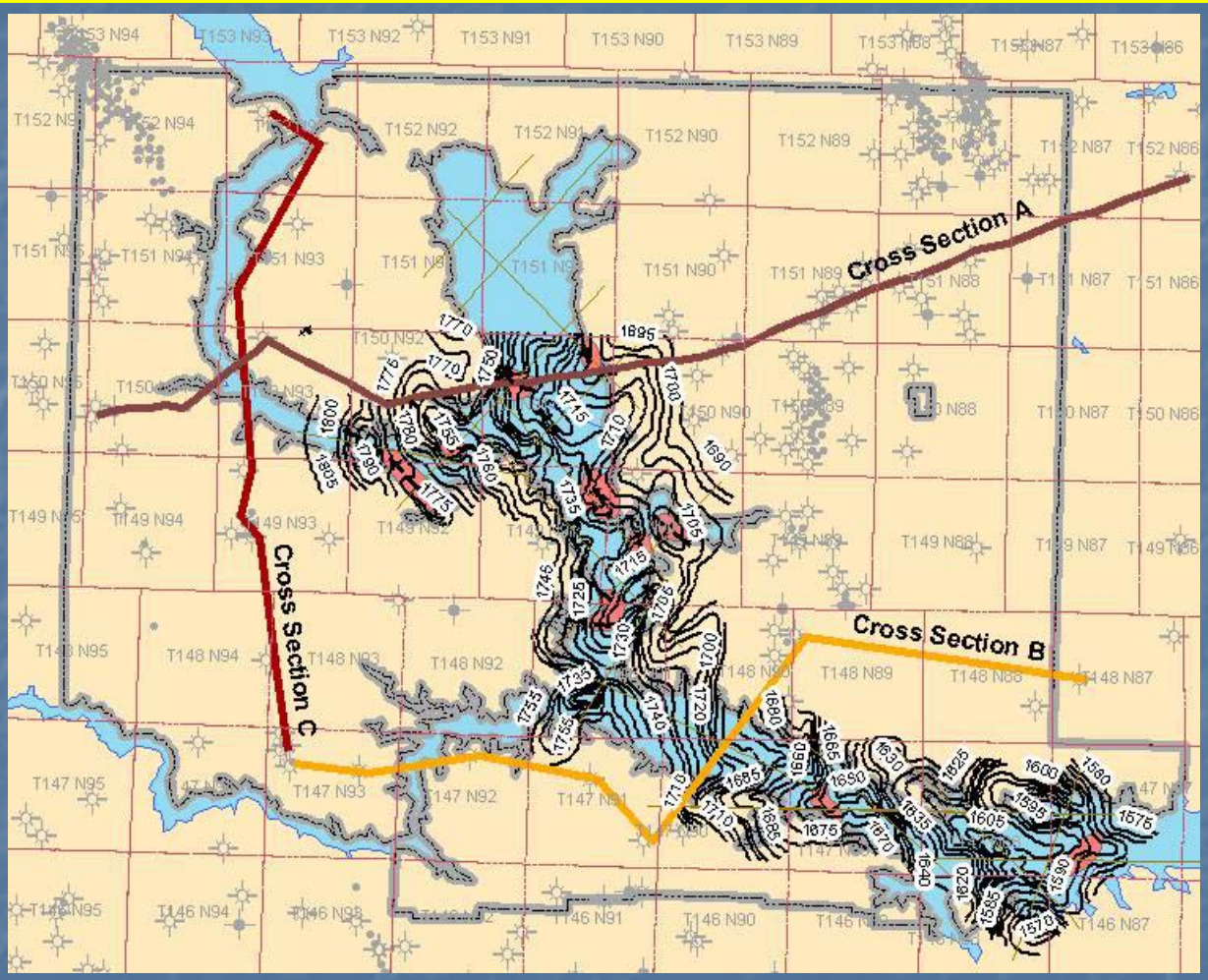


Figure MAP-1

Reprocessing Difficulties Encountered

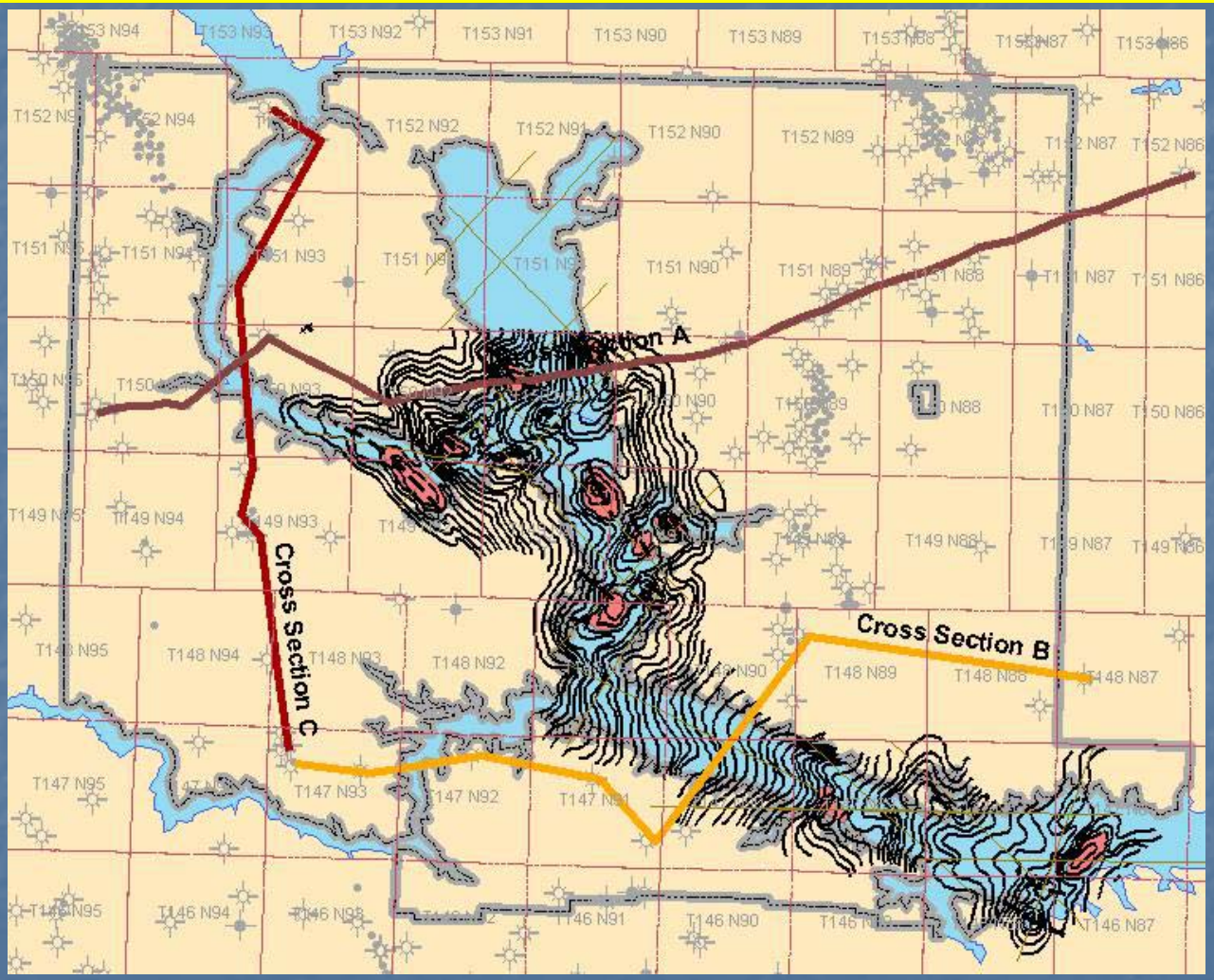
- Sporadic availability of field notes
- Irregular distribution of till across area
- Many data peculiarities result from difficult acquisition conditions
  - Variable water depth
  - Transition zones
  - Different sources
- Many from original crews have retired with resulting loss of "know how"

Mmc Depth Time



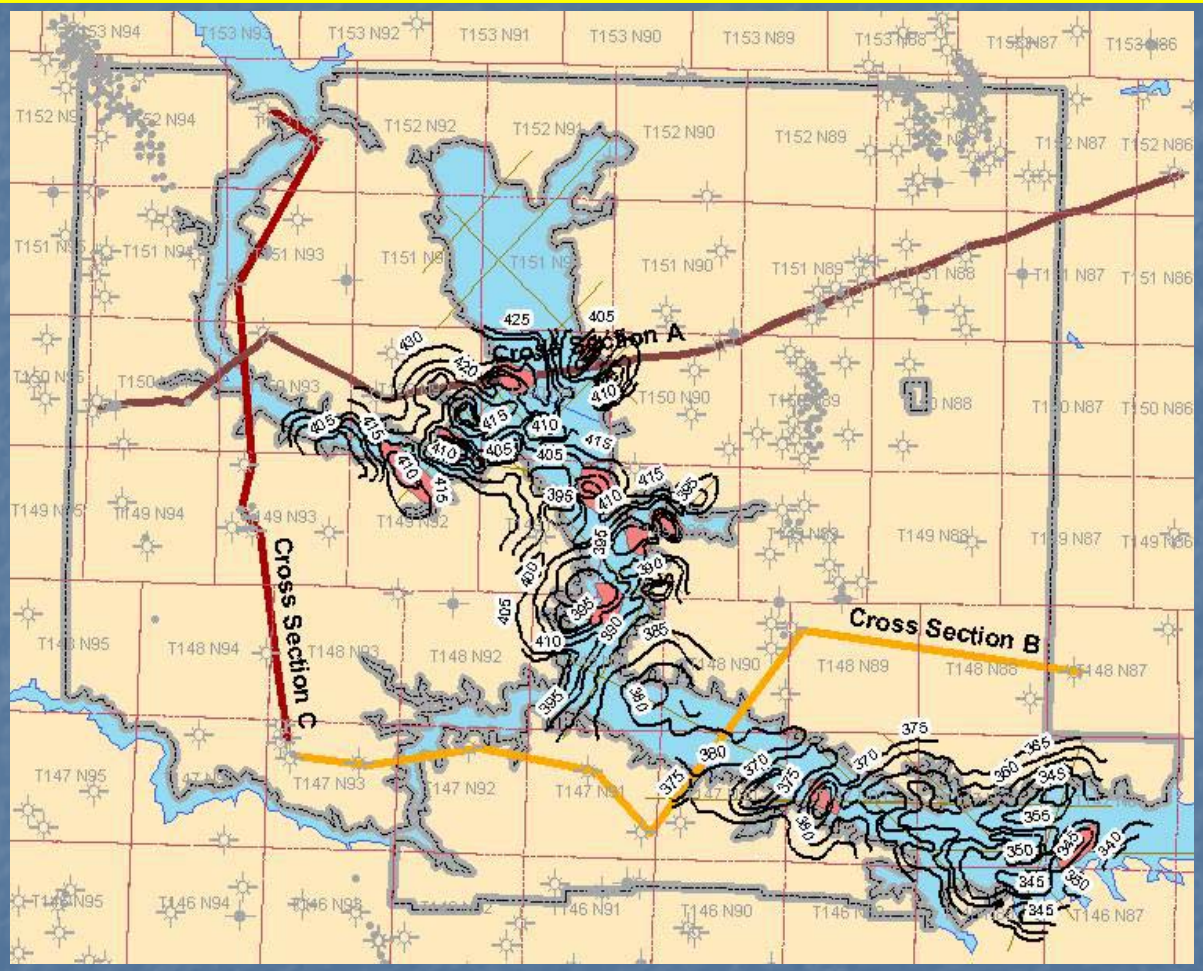
Mission Canyon Time Structure map shows many simple, low relief anomalies. Sparse data often means only one line crosses any given anomaly.

Ow Depth Time



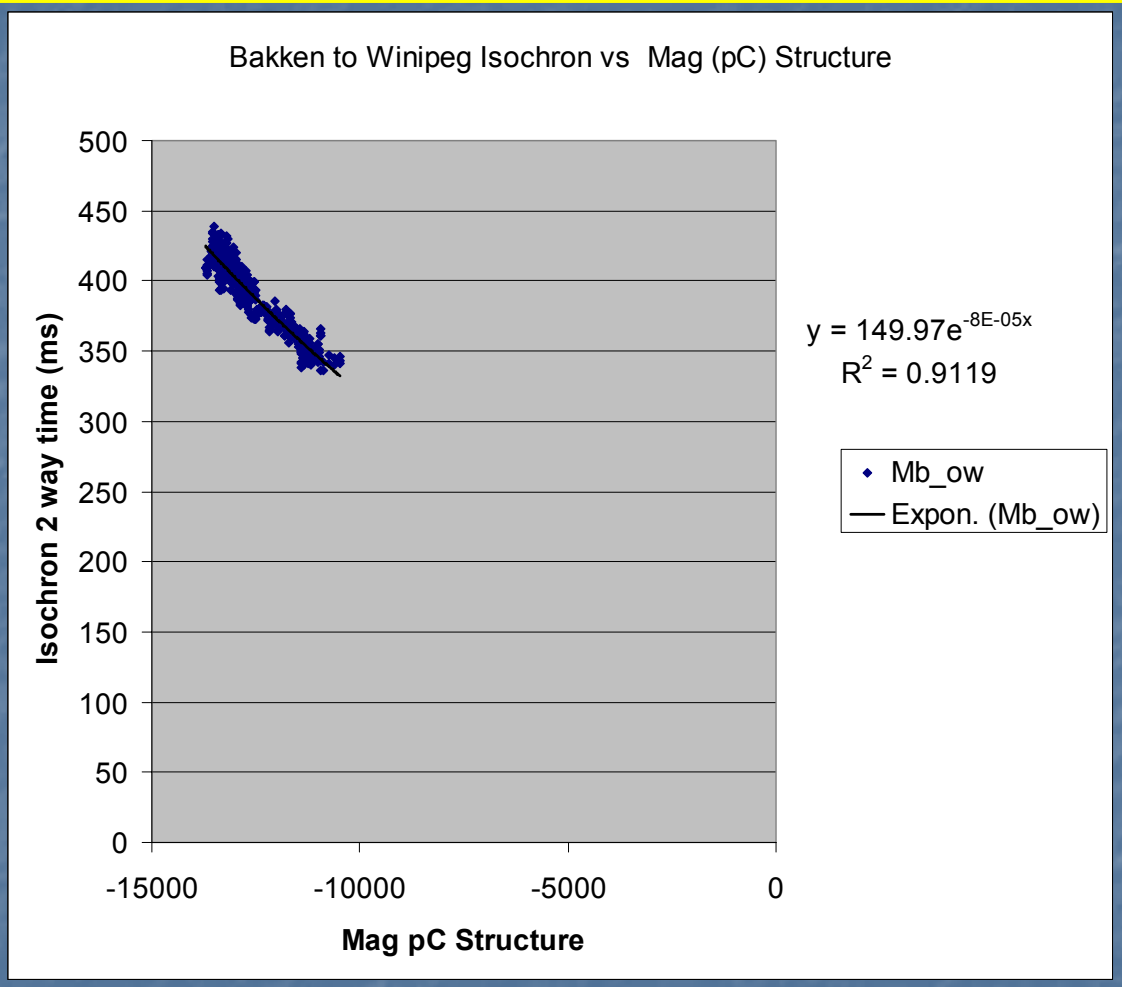
The Ordovician Winipeg was the deepest horizon mapped and also showed several low relief structures.

Mb-Ow Isochron



The Bakken to Winipeg isochron is an important map for identifying low relief paleo structures which are the most objective for stratigraphic traps in this area.

Mb-Ow Isochron to pC Structure Correlation



The Bakken to Winipeg isochron was found to correlate very well to the pC depth map. The relationship was used to calculate a pseudo "isochron" from the aeromag.

Correlation of Seismic to Detail Mag

- Seismic times were digitized and mapped against the inverted pC structure map
  - Values at the shot points were extracted and correlated against the inverted basement structure map.
  - Correlations show the impact of variable statics
  - An extremely good correlation was found between the Mb-Ow isochron and the structure map
  - The correlation was used to generate a "calculated" isochron for the area useful for validating the size and distribution of seismic thins

General Conclusions Based on Seismic

- The existing 2D seismic data over the lake is difficult to reprocess but useable, especially when combined with other data
- Calibration can be achieved between the seismic and inverted aeromag depth maps to image subtle paleohighs through the area

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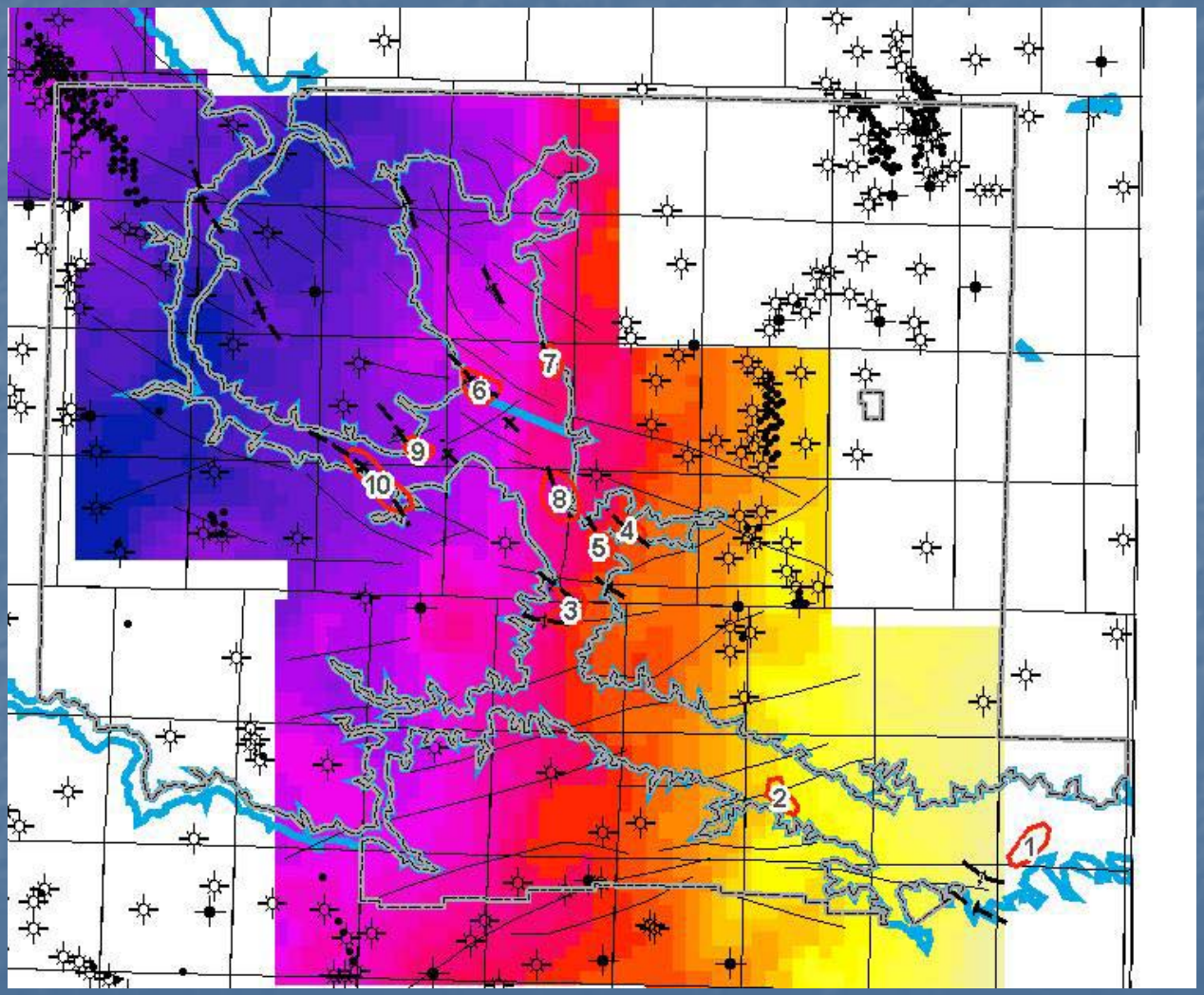
Objective

- Identify specific leads under Lake Sakakawea based on integration of:
  - Remote sensing
  - Intermediate resolution aeromag
  - Seismic

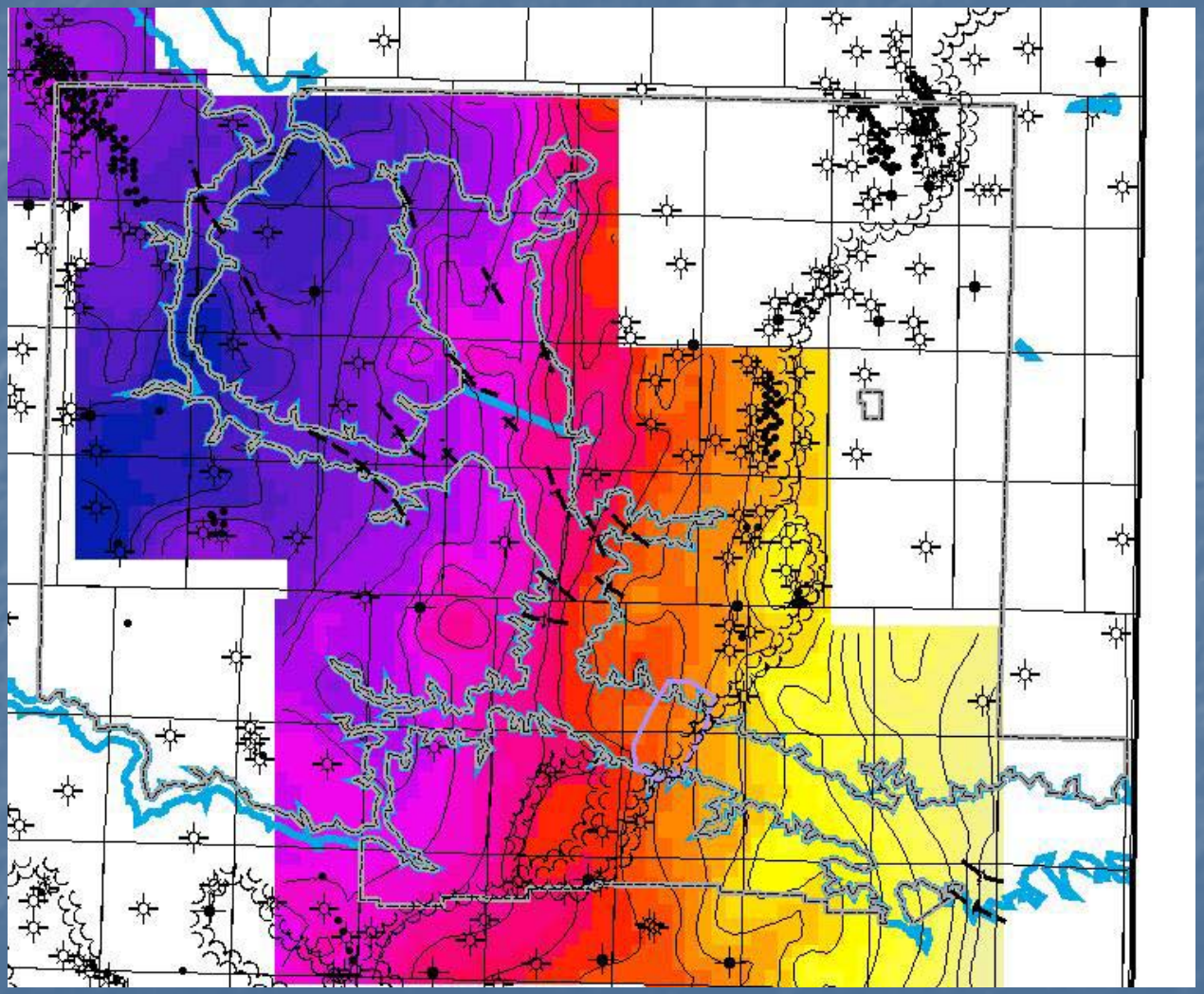
Lead Generation

- Accumulations in areas east of Antelope tend to be combination structural/stratigraphic in nature where traps are formed on and around subtle paleohighs.
  - Primary targets are paleohighs
    - Primary map is the Bakken to Winipeg isochron where thinning represents long lived paleo highs
  - Sherwood shoreline fields form in onlap setting along west dipping transgressive surface

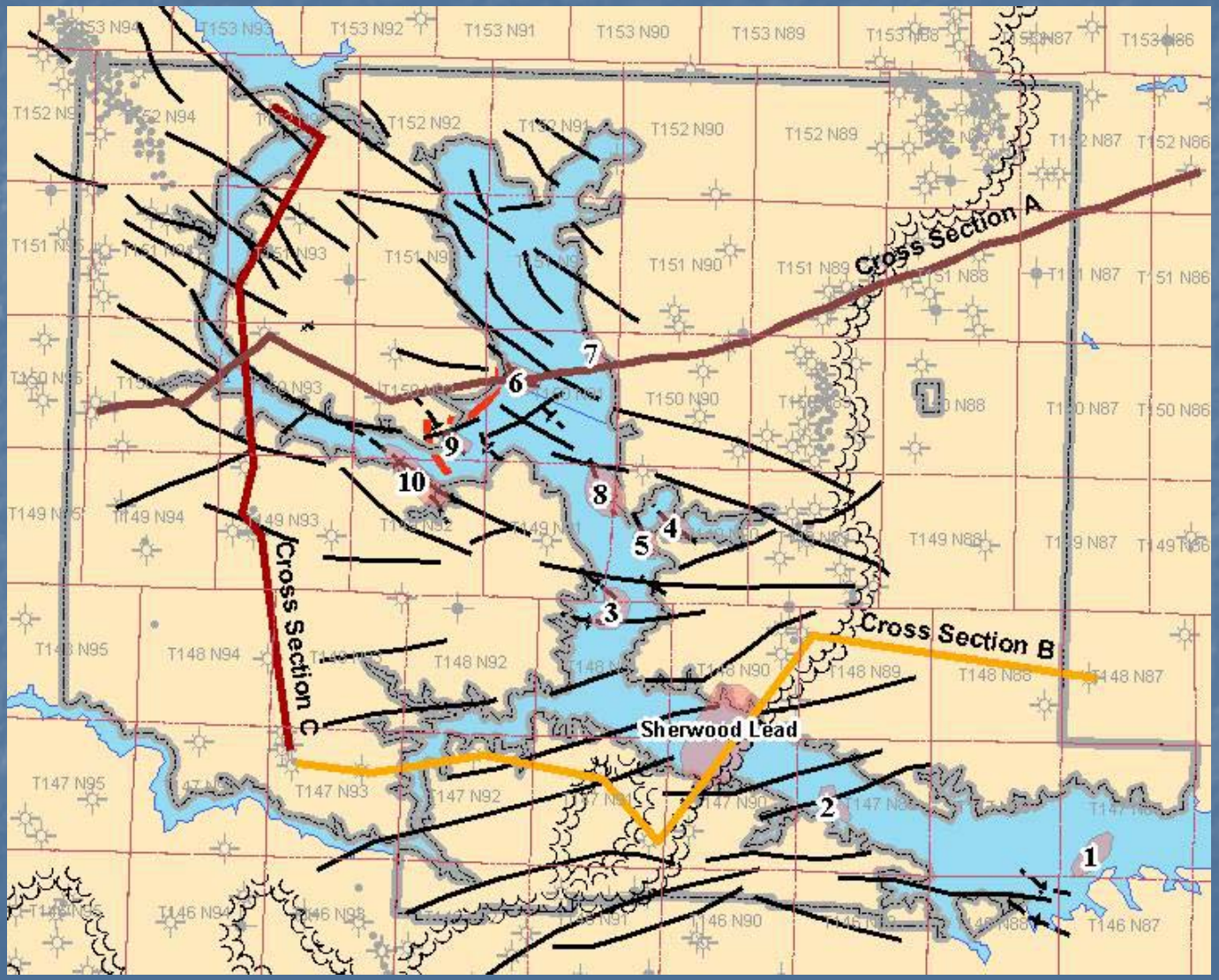
Seismic Leads on Calculated Isochron



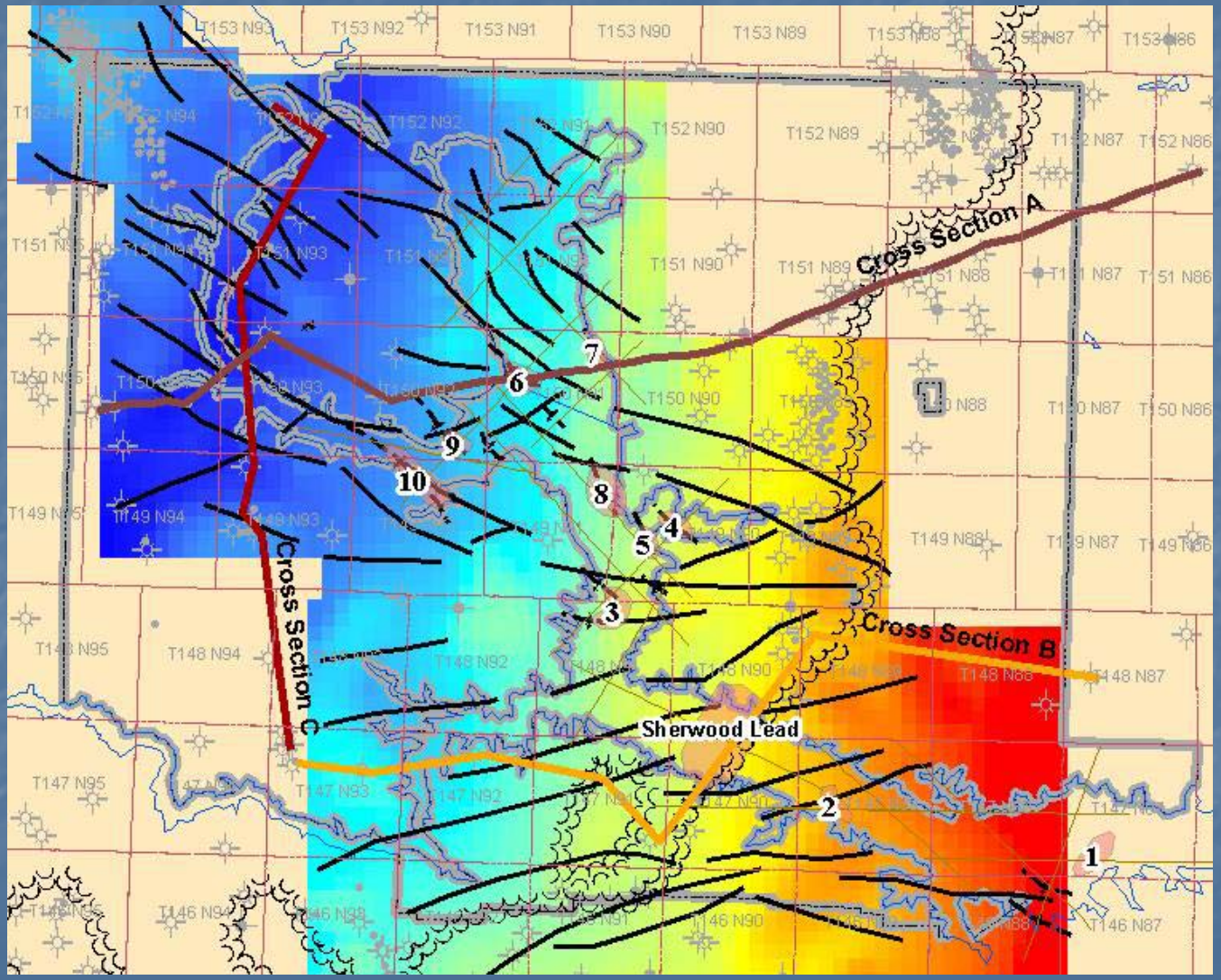
Sherwood Lead on Calculated Isochron



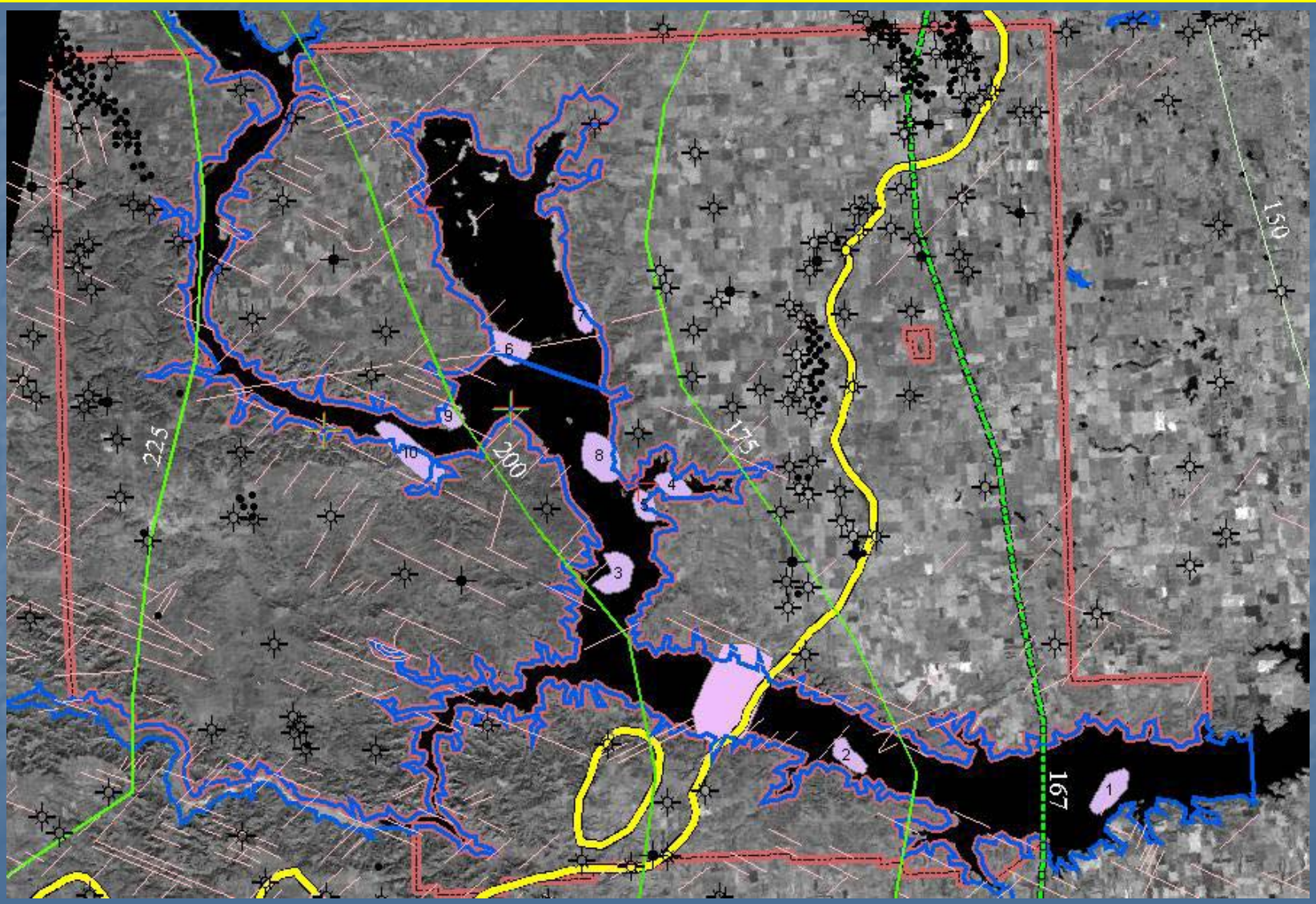
Leads


Cross Section A
Cross Section B
Cross Section C
Sherwood Lead
1
2
3
4
5
6
7
8
9
10
T153 N92
T153 N91
T153 N90
T153 N89
T152 N92
T152 N90
T152 N89
T151 N90
T151 N89
T150 N90
T149 N94
T149 N93
T148 N94
T148 N92
T148 N89
T148 N87
T147 N95
T147 N93
T147 N92
T146 N87

Leads on pC Depth



Lead Map



Conclusions Based on Integrated Evaluation

- The Lands beneath Lake Sakakawea were evaluated using a diverse suite of tools with coverage from regional to prospect scale.
  - Setting a regional framework increases the effectiveness of limited seismic and well control
    - 4 additional basement shear trends were identified which contribute to forming prospects in the area
  - 10 subtle paleohigh leads with seismic and potential fields support were identified beneath the lake on Tribal acreage
  - 1 large stratigraphic lead supported by regional structural trends was identified beneath the lake

Summary of Leads

Lead (from E to W)	Play Type	Size (acres)
1	structural	1,295
2	structural	842
3	structural	1,386
4	structural	823
5	structural	758
6	structural	1,202
7	structural	674
8	structural	1,941
9	structural	628
10	structural	2,308
Sherwood	stratigraphic	7,177

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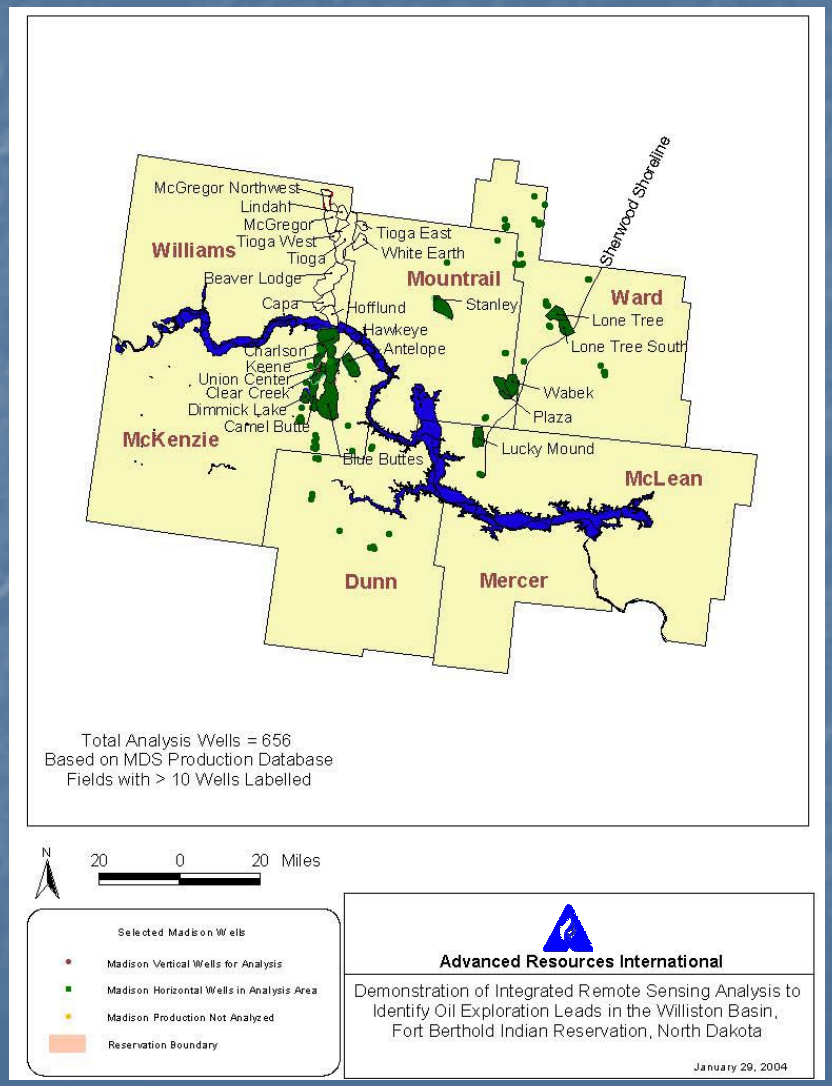
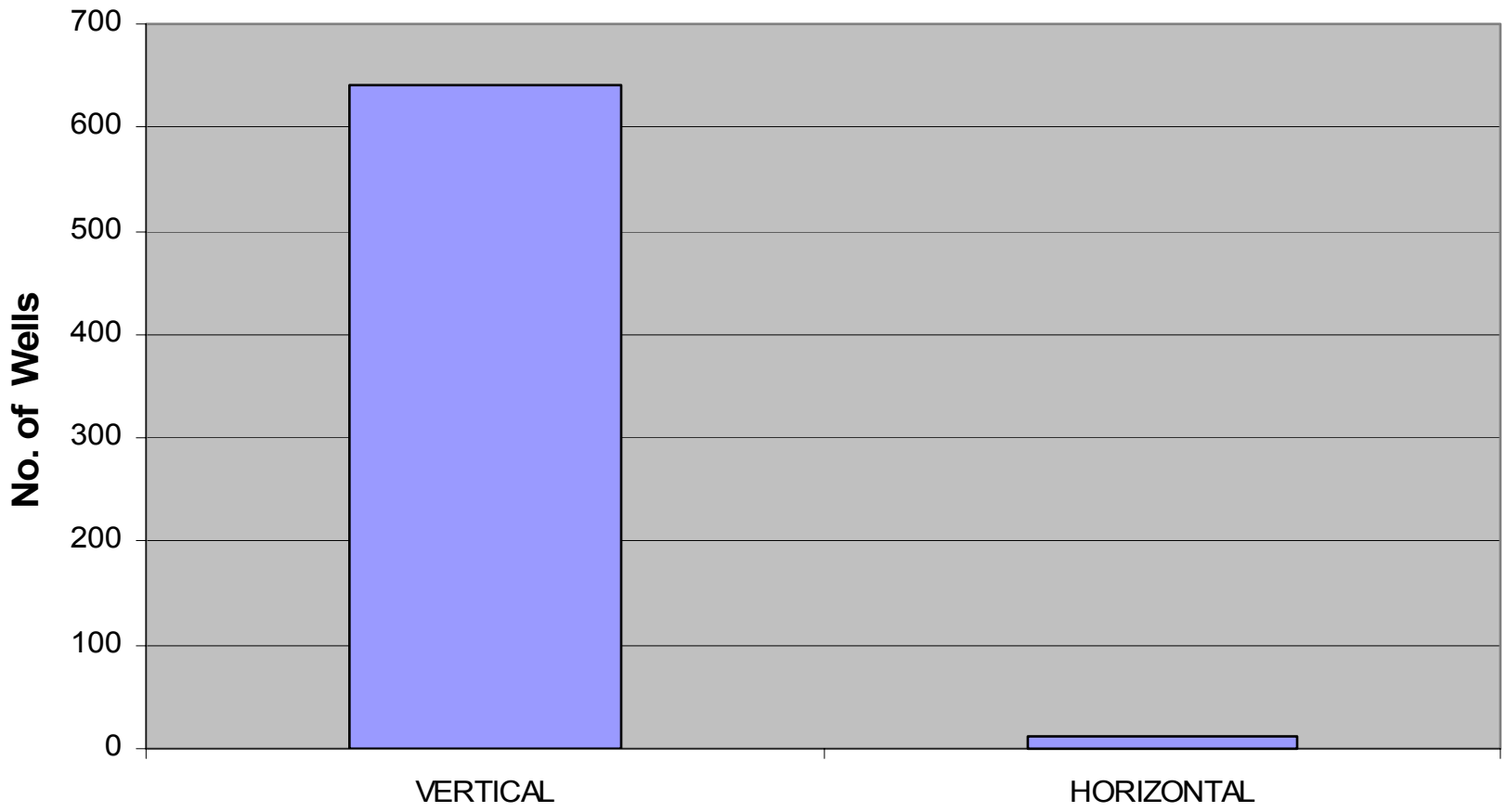
Madison Wells Dataset

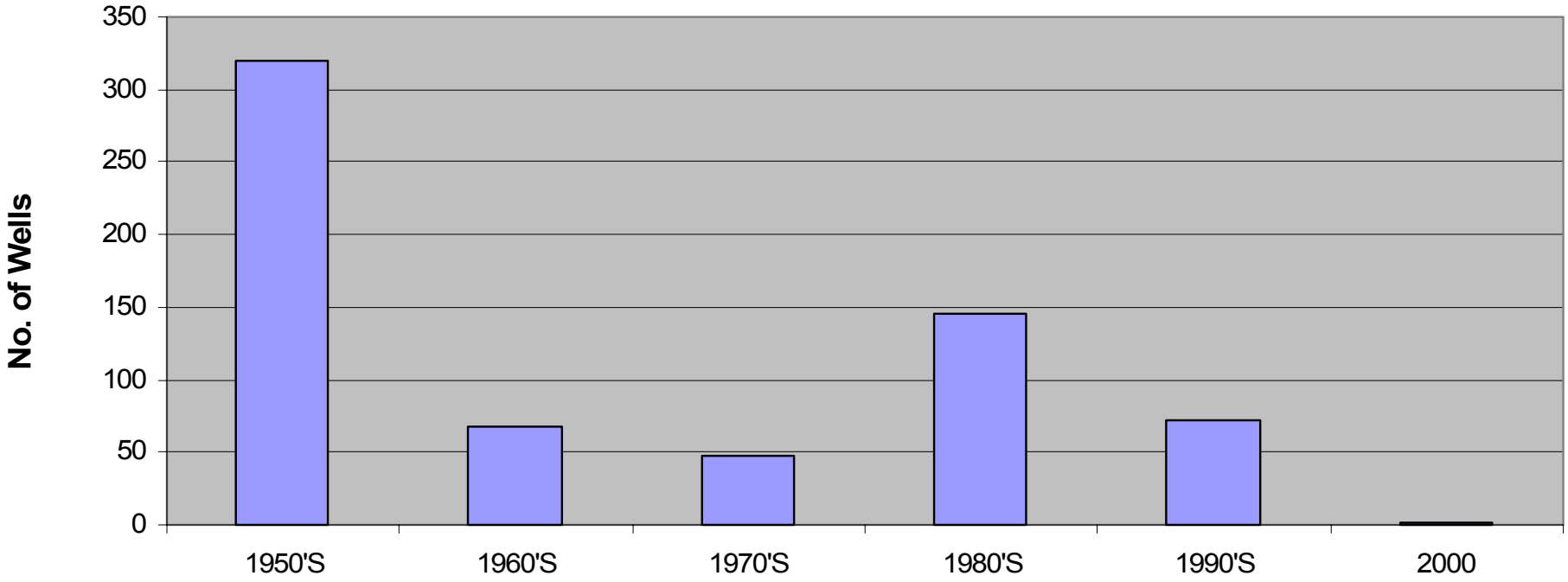


- 656 total wells
- Source: Minerals Diversified Services

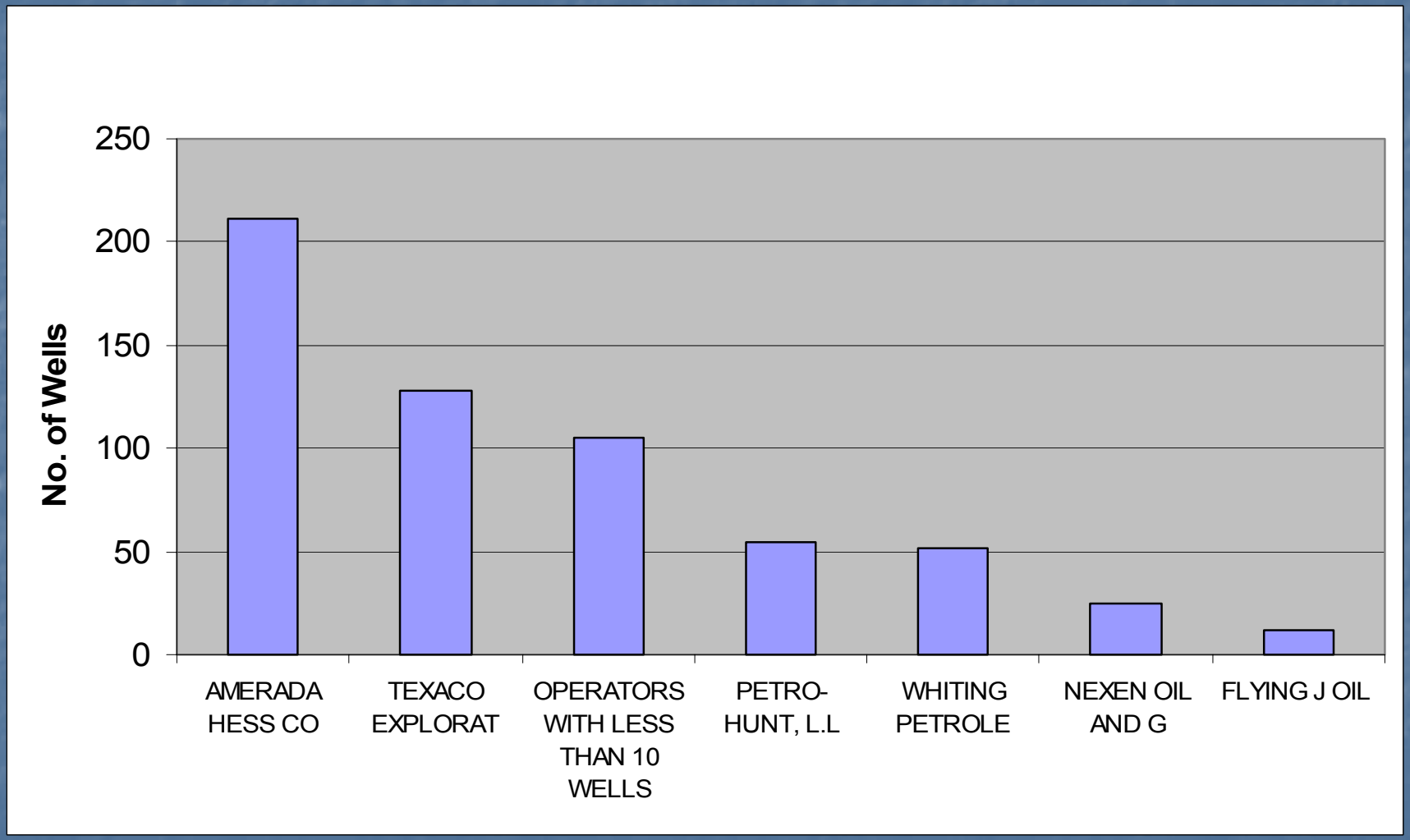
Vertical vs. Horizontal Wells



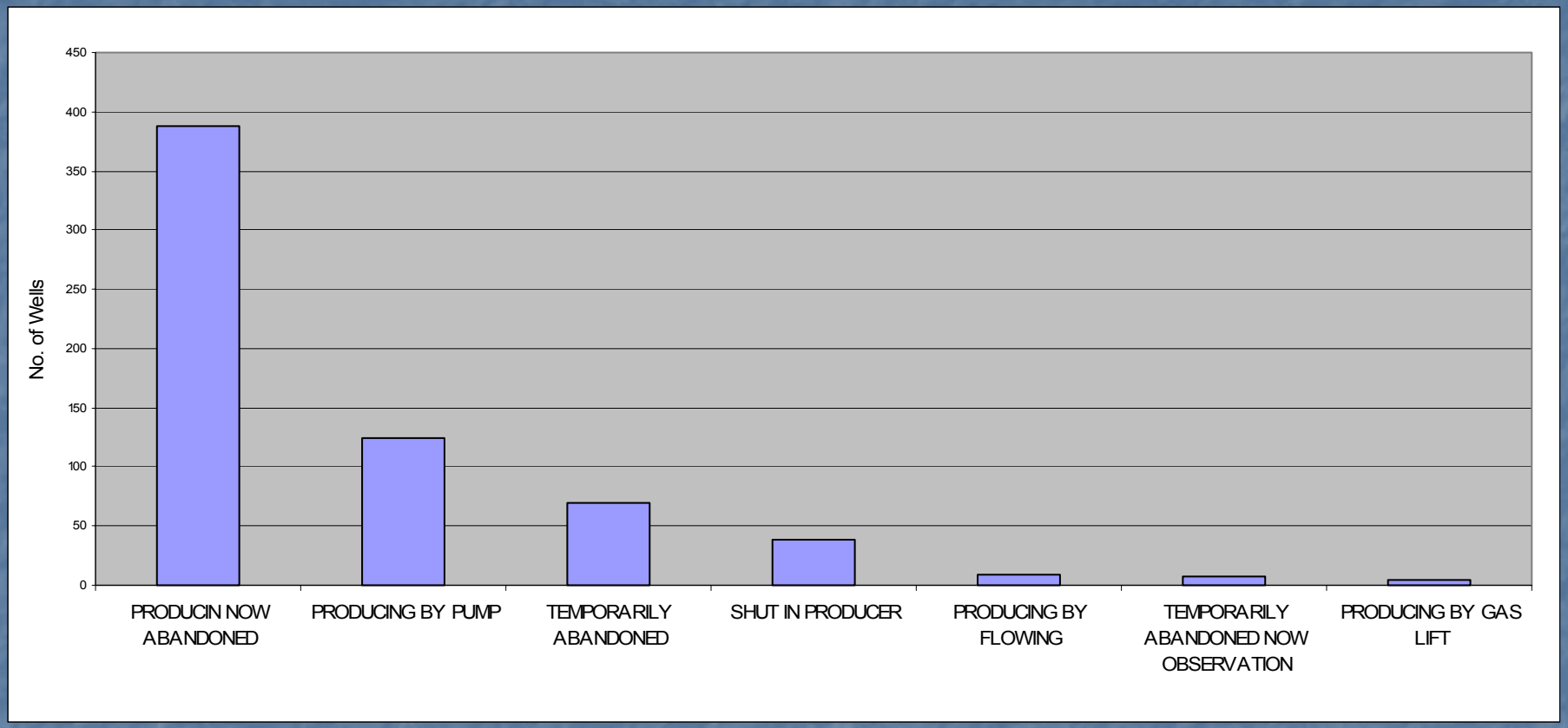
Completion Year



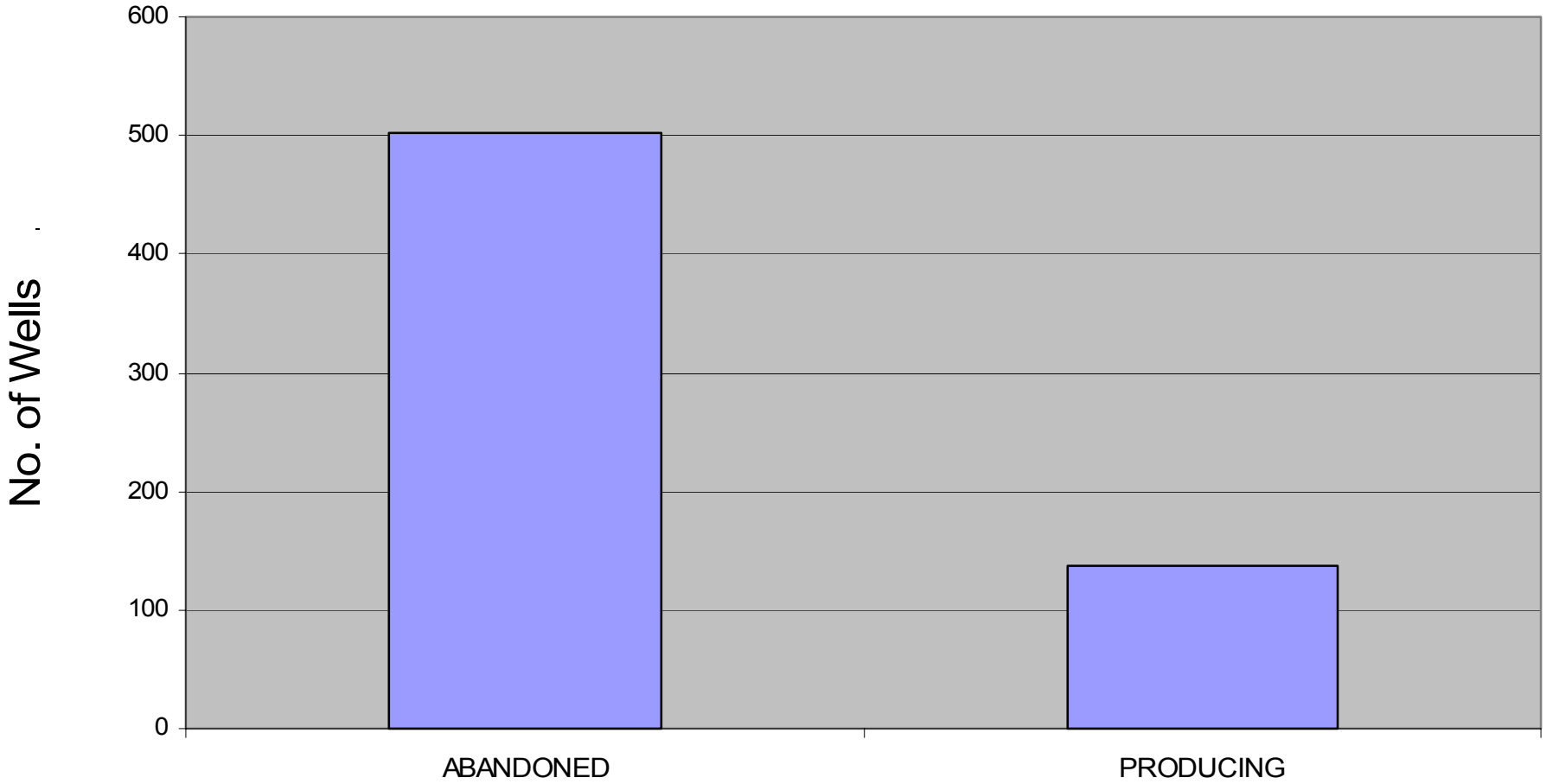
Operator


No. of Wells
250
200
150
100
50
0
AMERADA HESS CO
TEXACO EXPLORAT
OPERATORS WITH LESS THAN 10 WELLS
PETRO-HUNT, L.L
WHITING PETROLE
NEXEN OIL AND G
FLYING J OIL

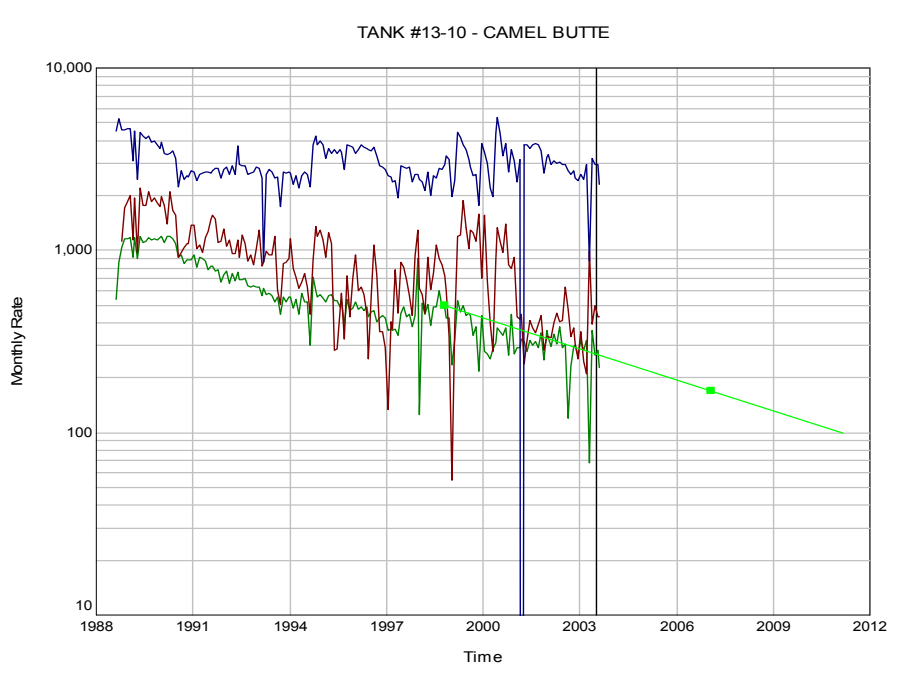
Detailed Well Status

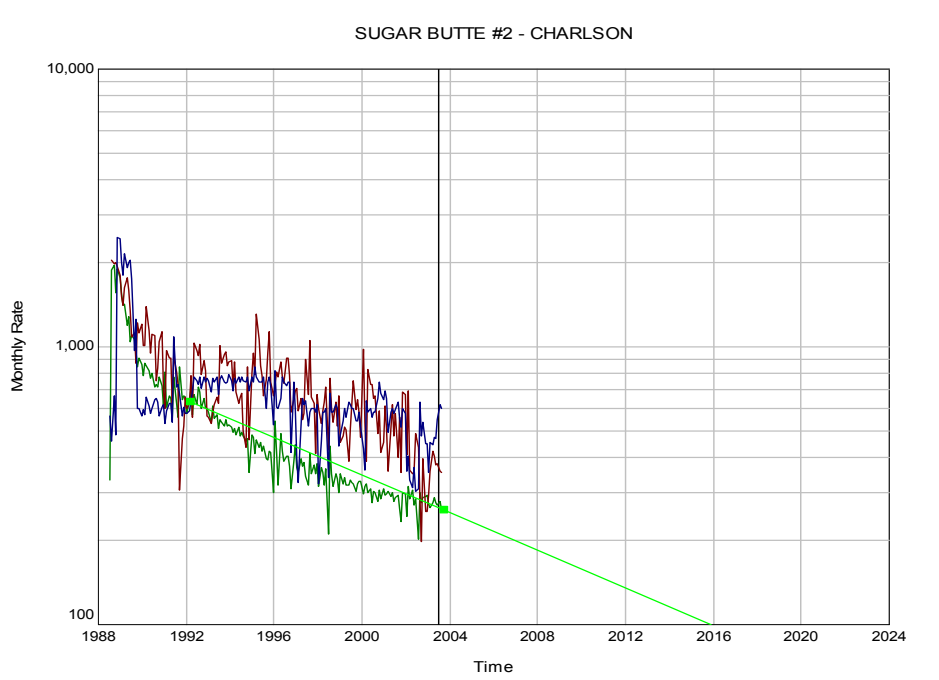


Consolidated Well

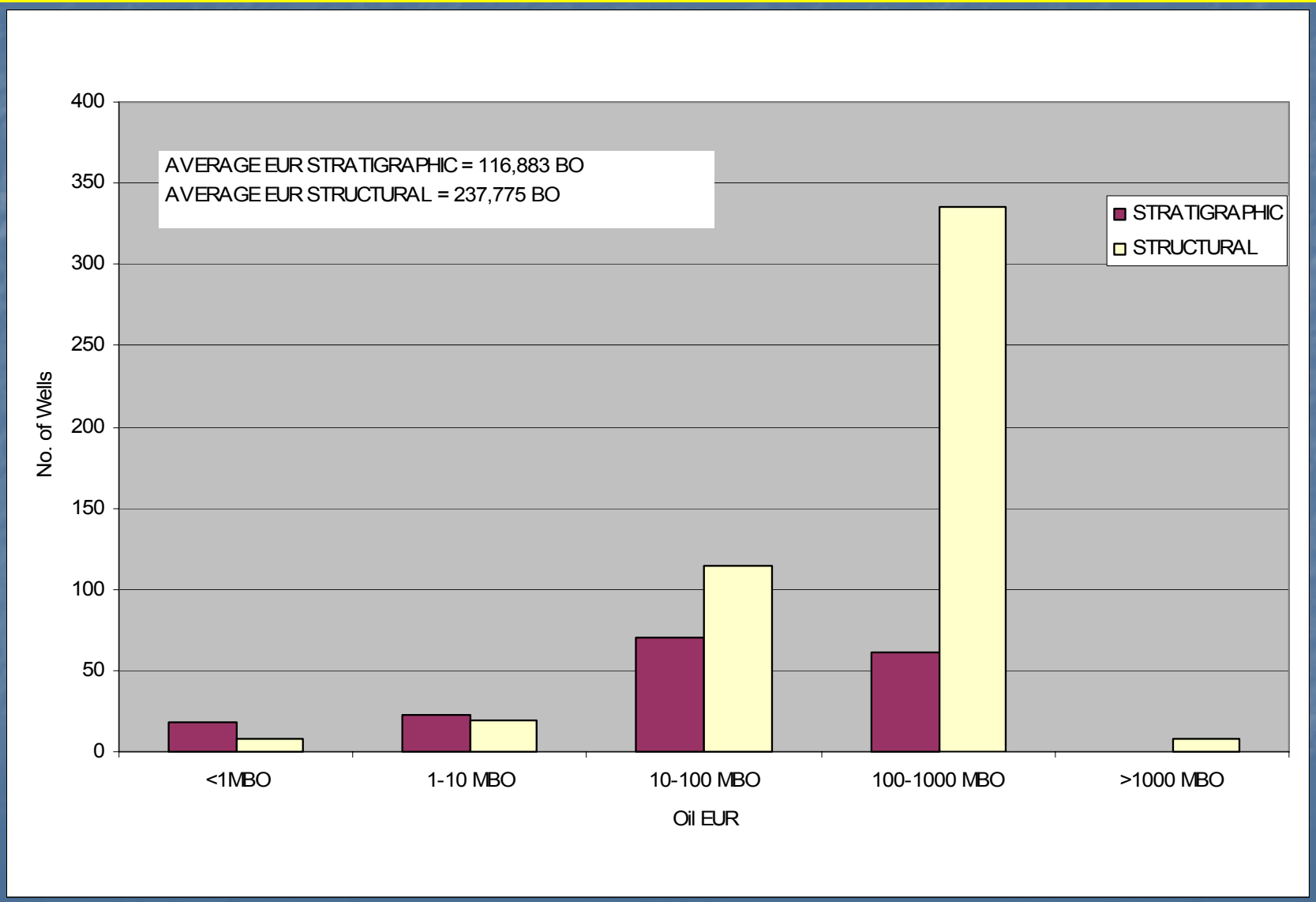


Estimation of EUR for Active Wells

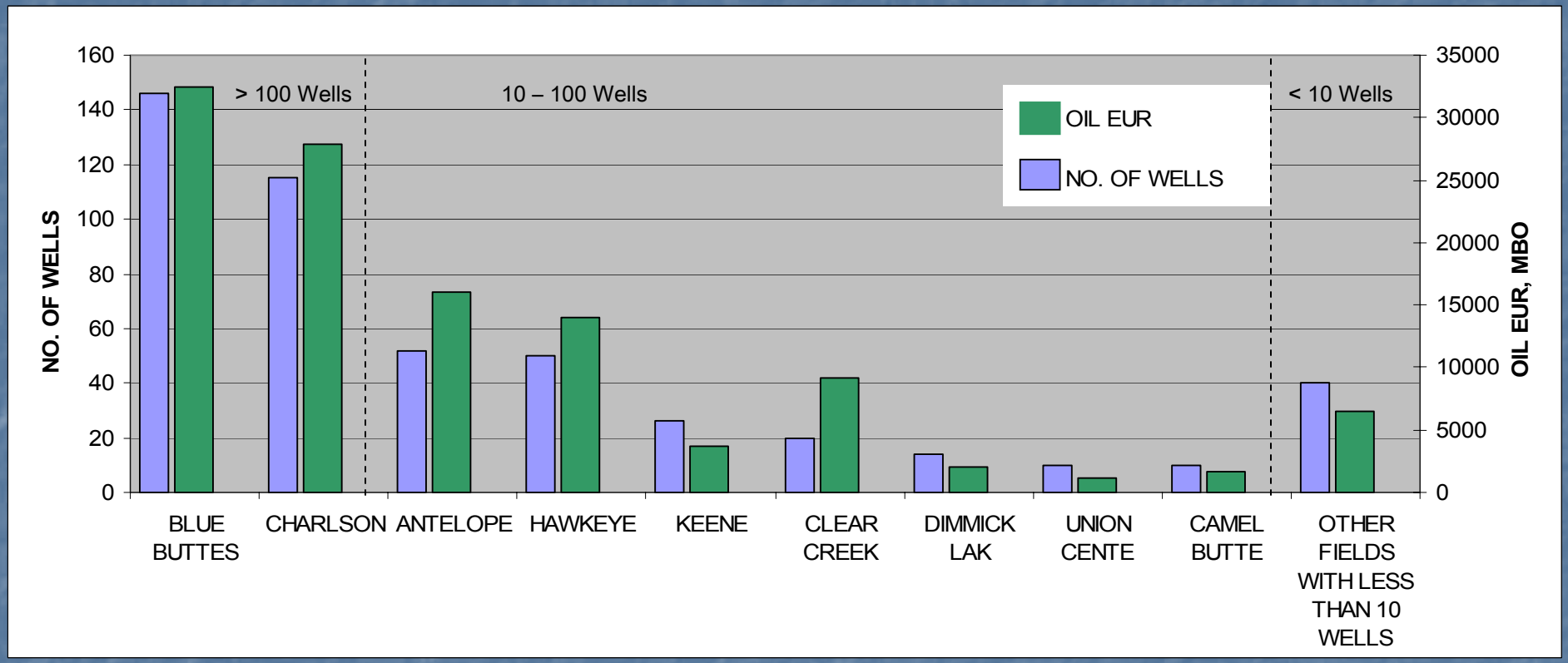




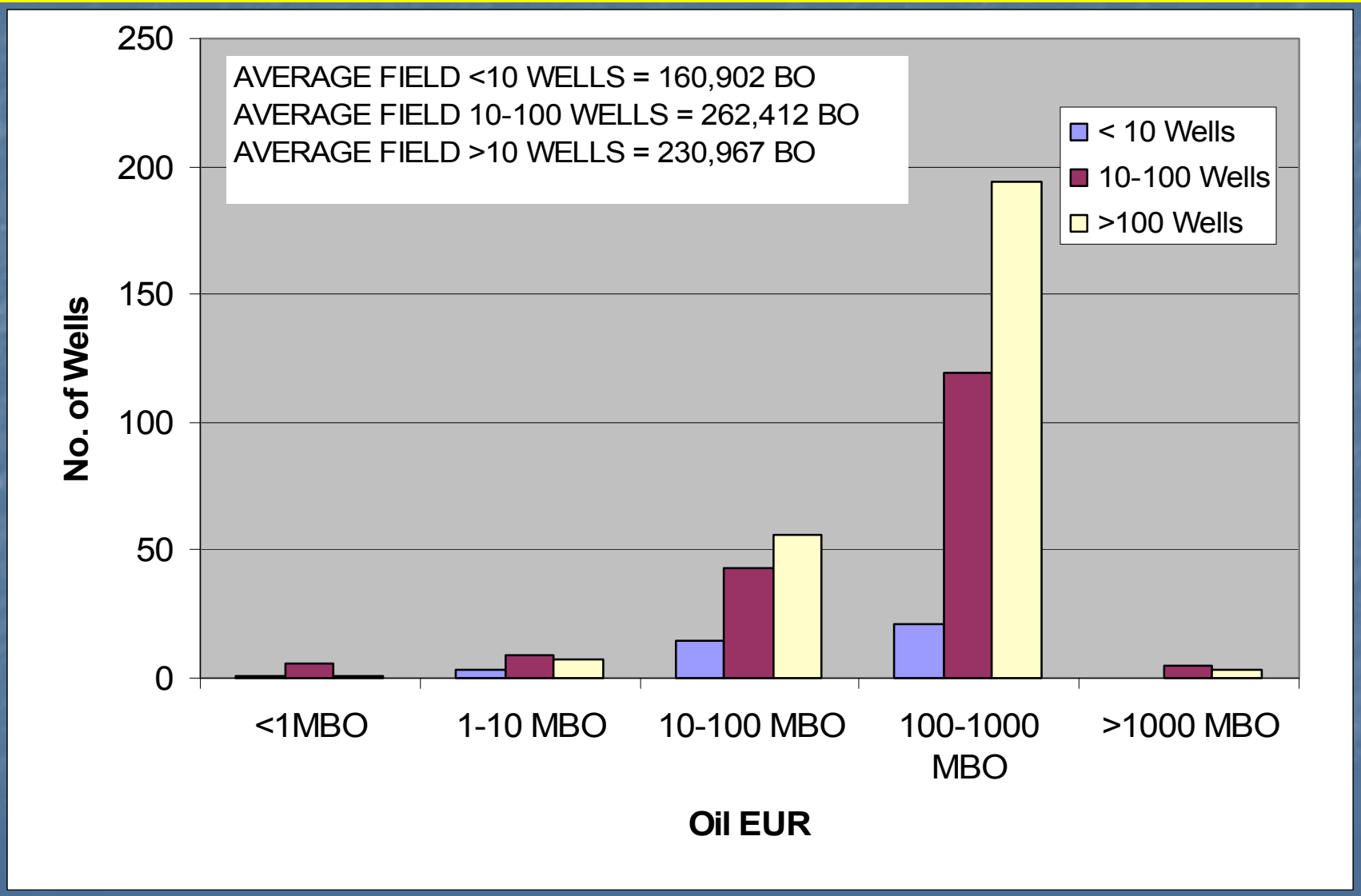
Average Well Recovery by Play



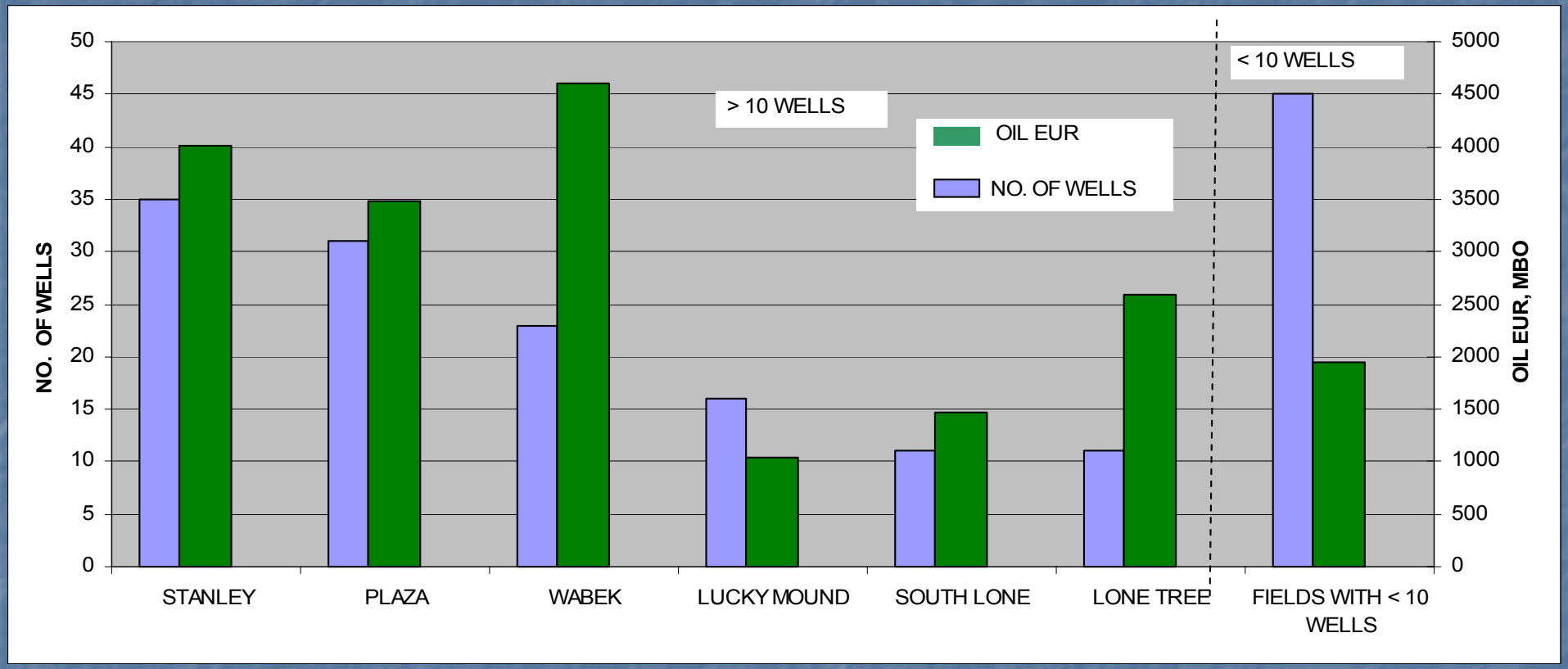
Field Size Distribution – Structural Play



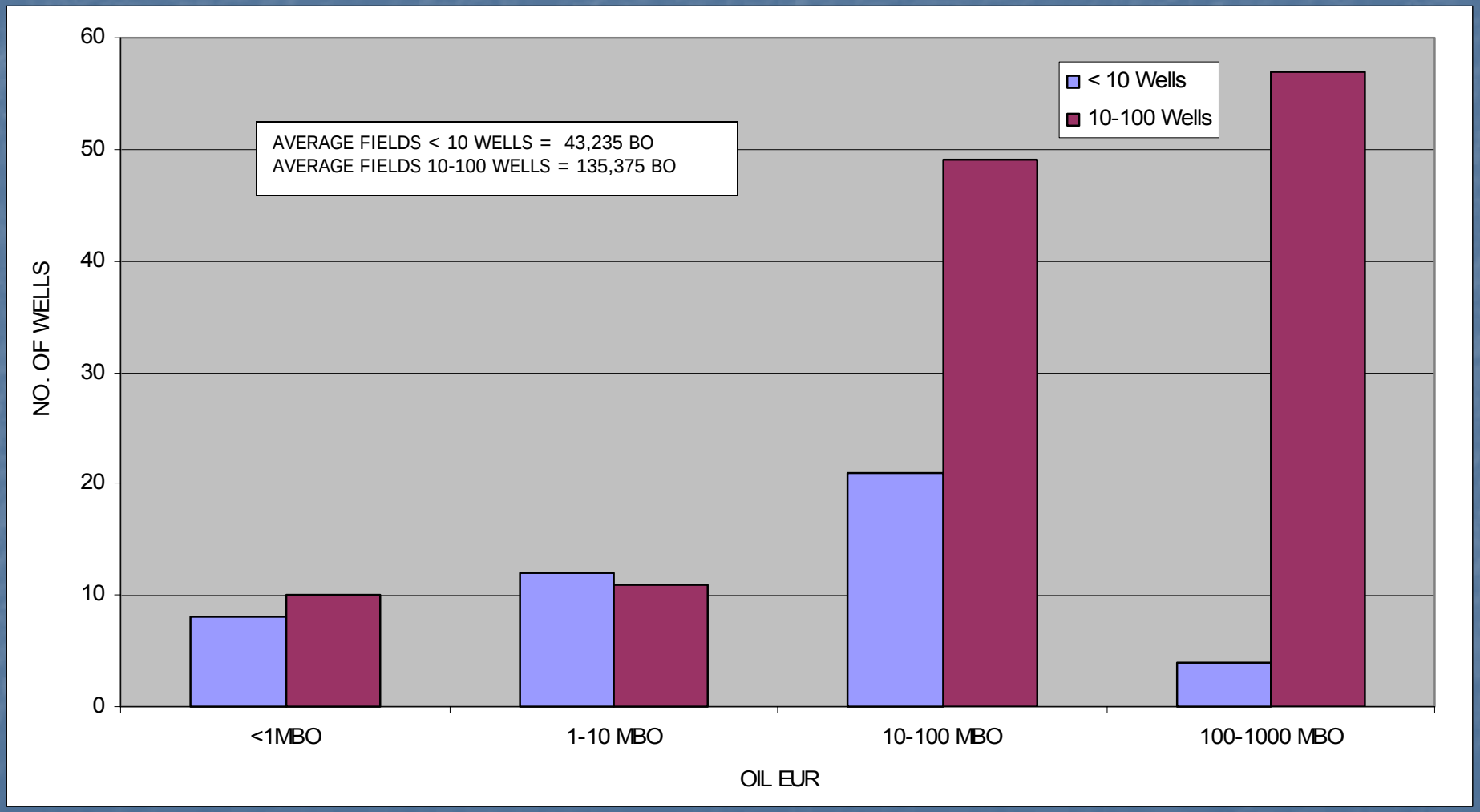
Recovery by Field Size – Structural Play



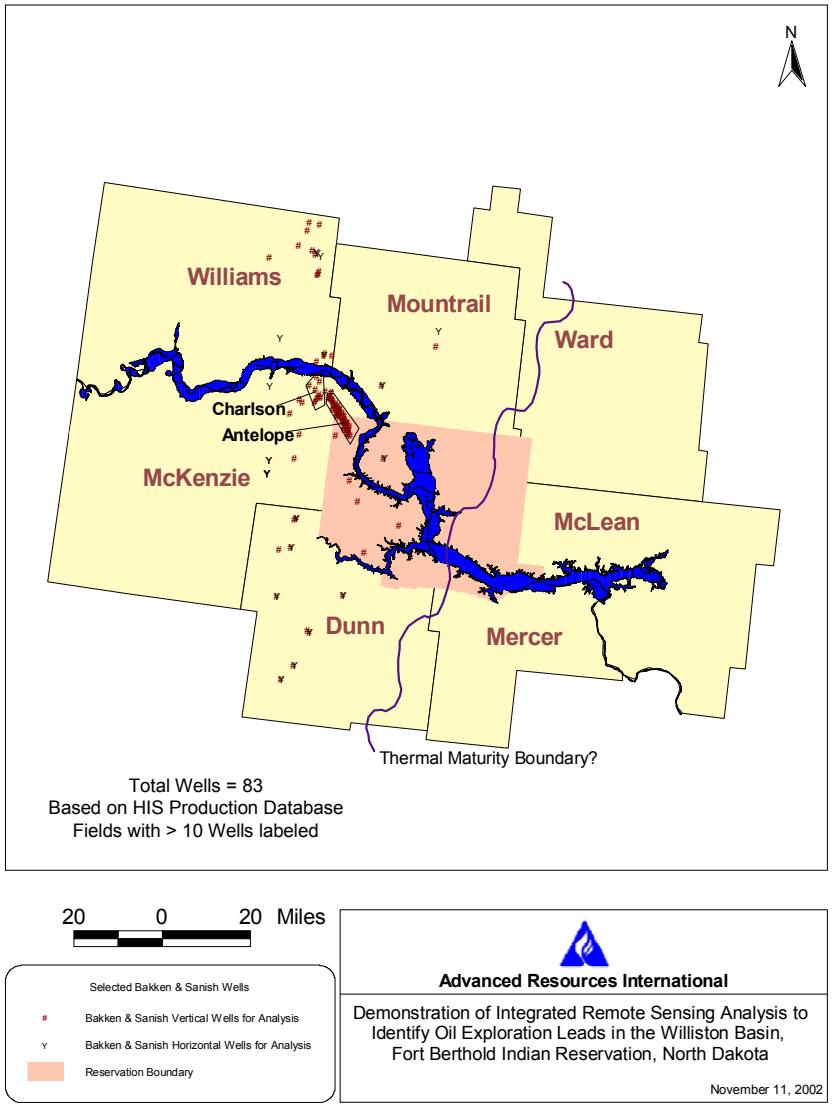
Field Size Distribution – Stratigraphic Play



Recovery by Field Size–Stratigraphic Play

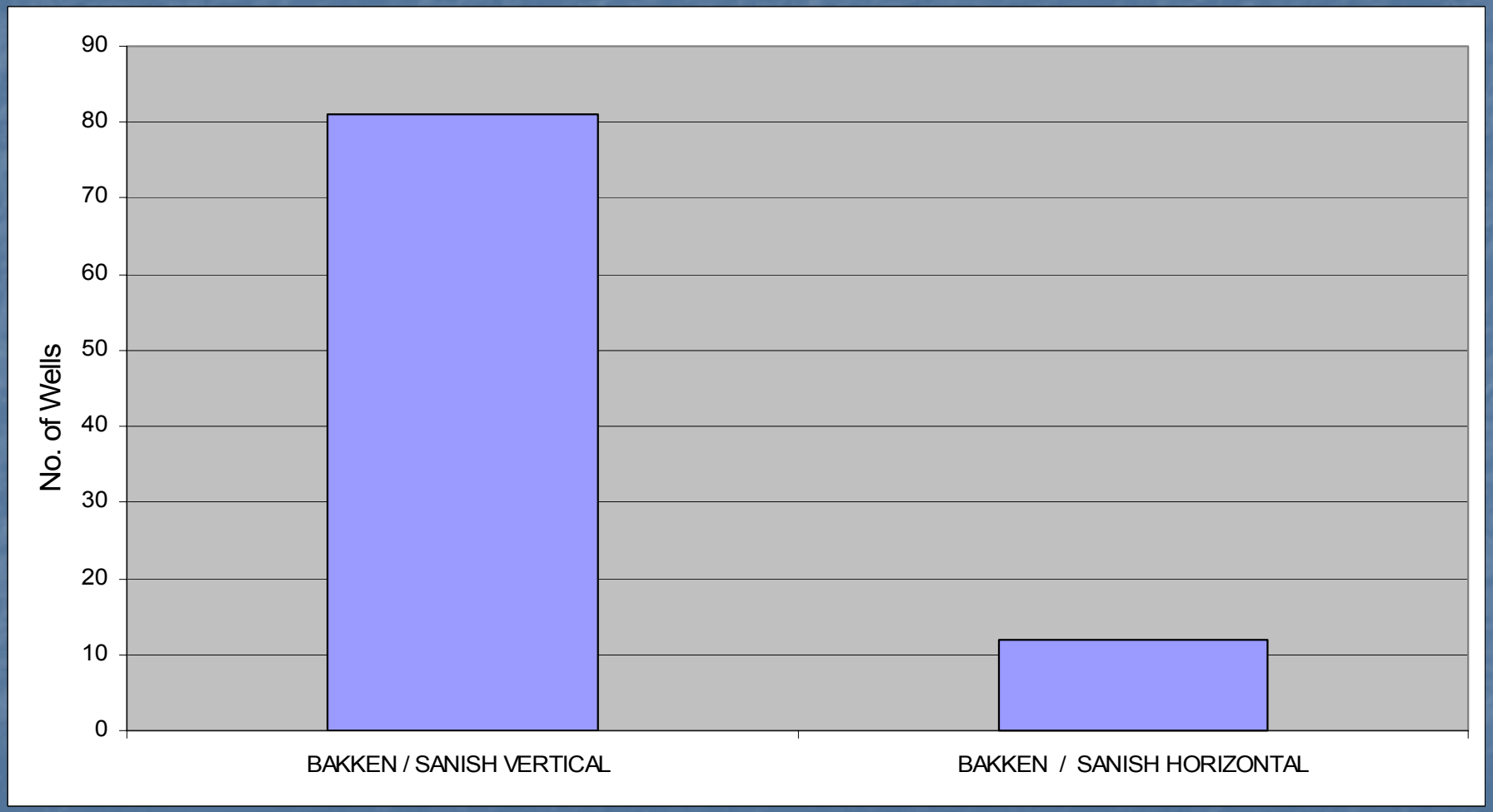


Bakken/Sanish Wells Dataset

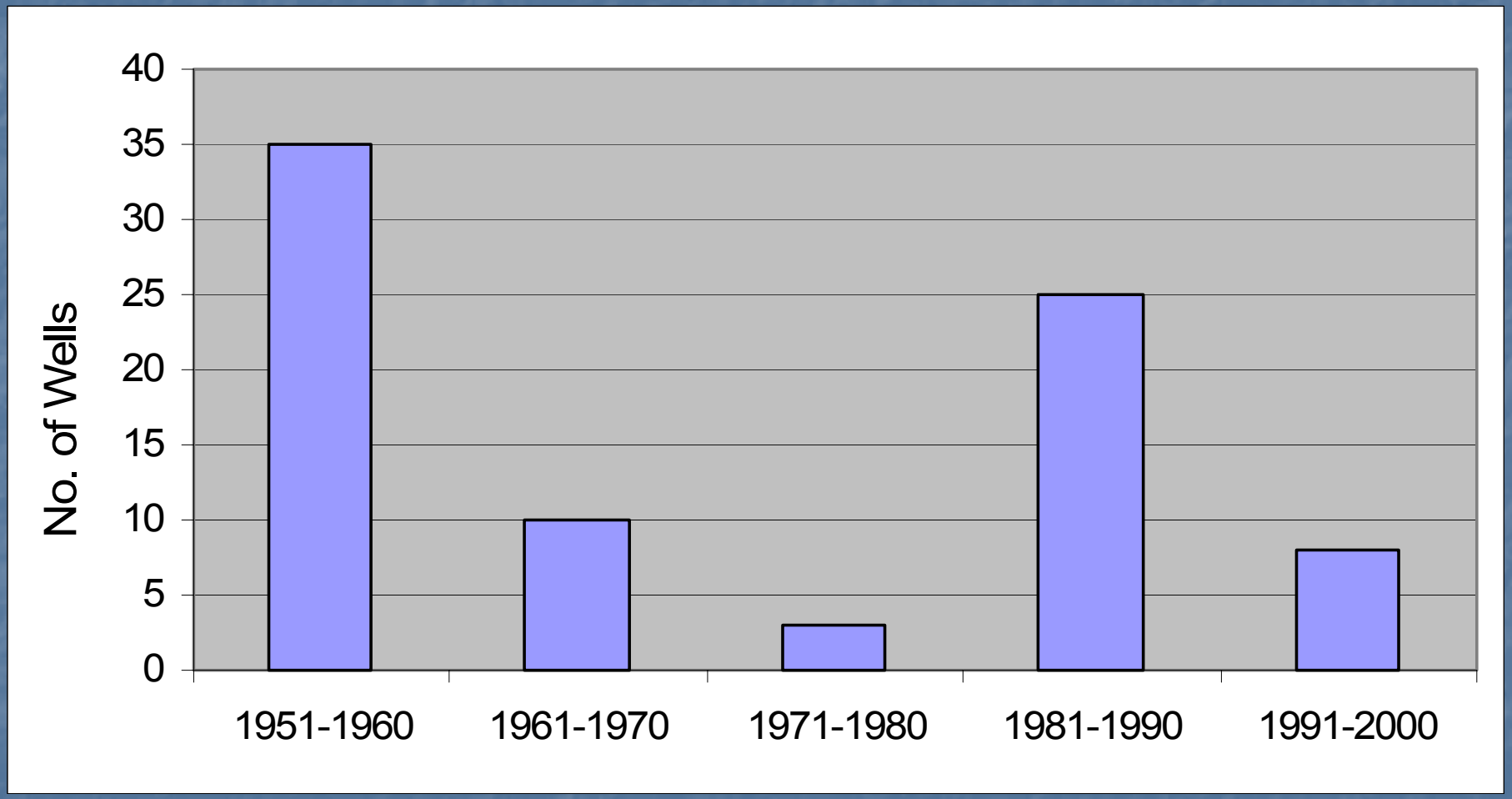


- 83 total wells
- Source: Minerals Diversified Services

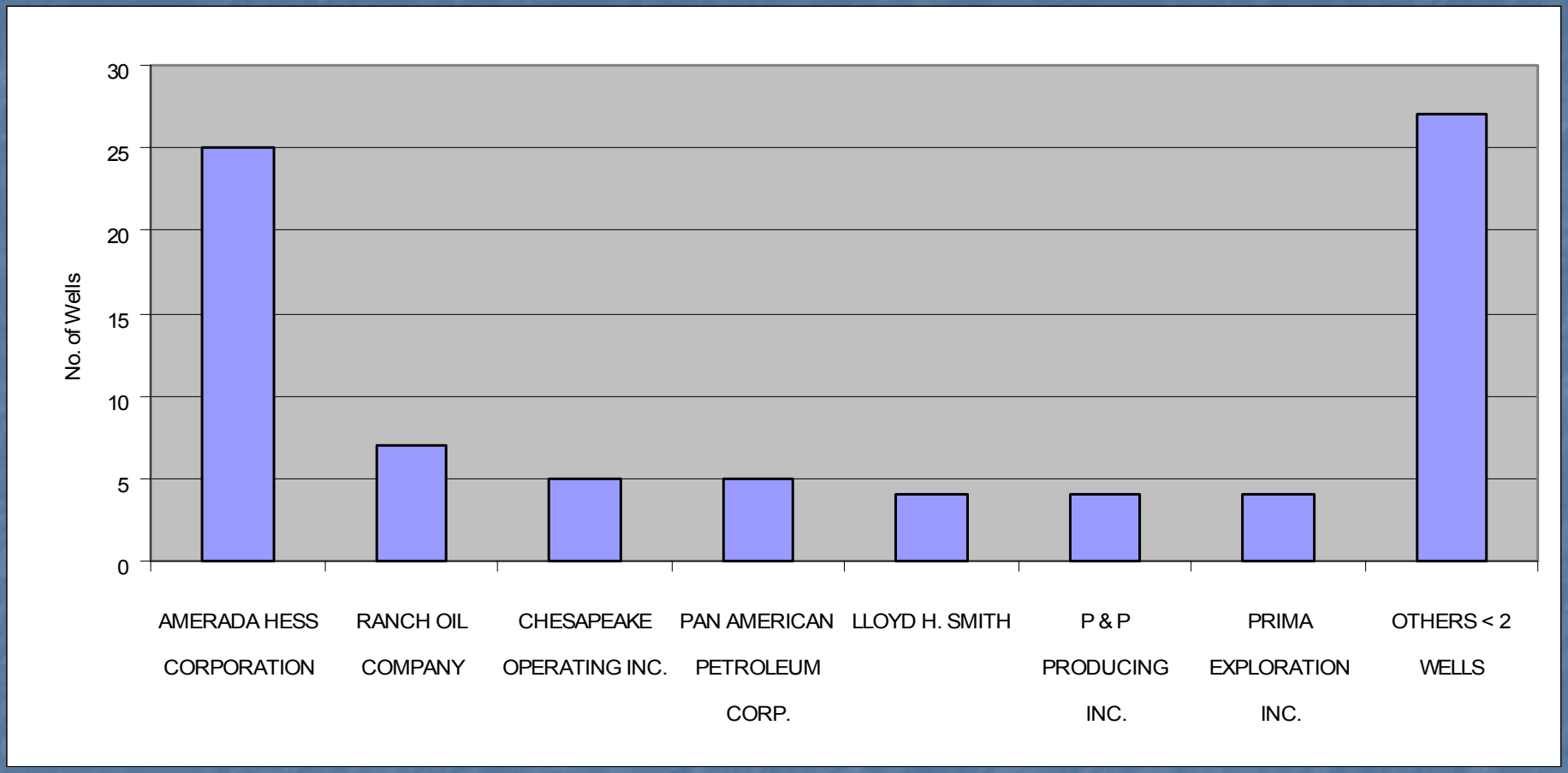
Vertical vs. Horizontal Wells



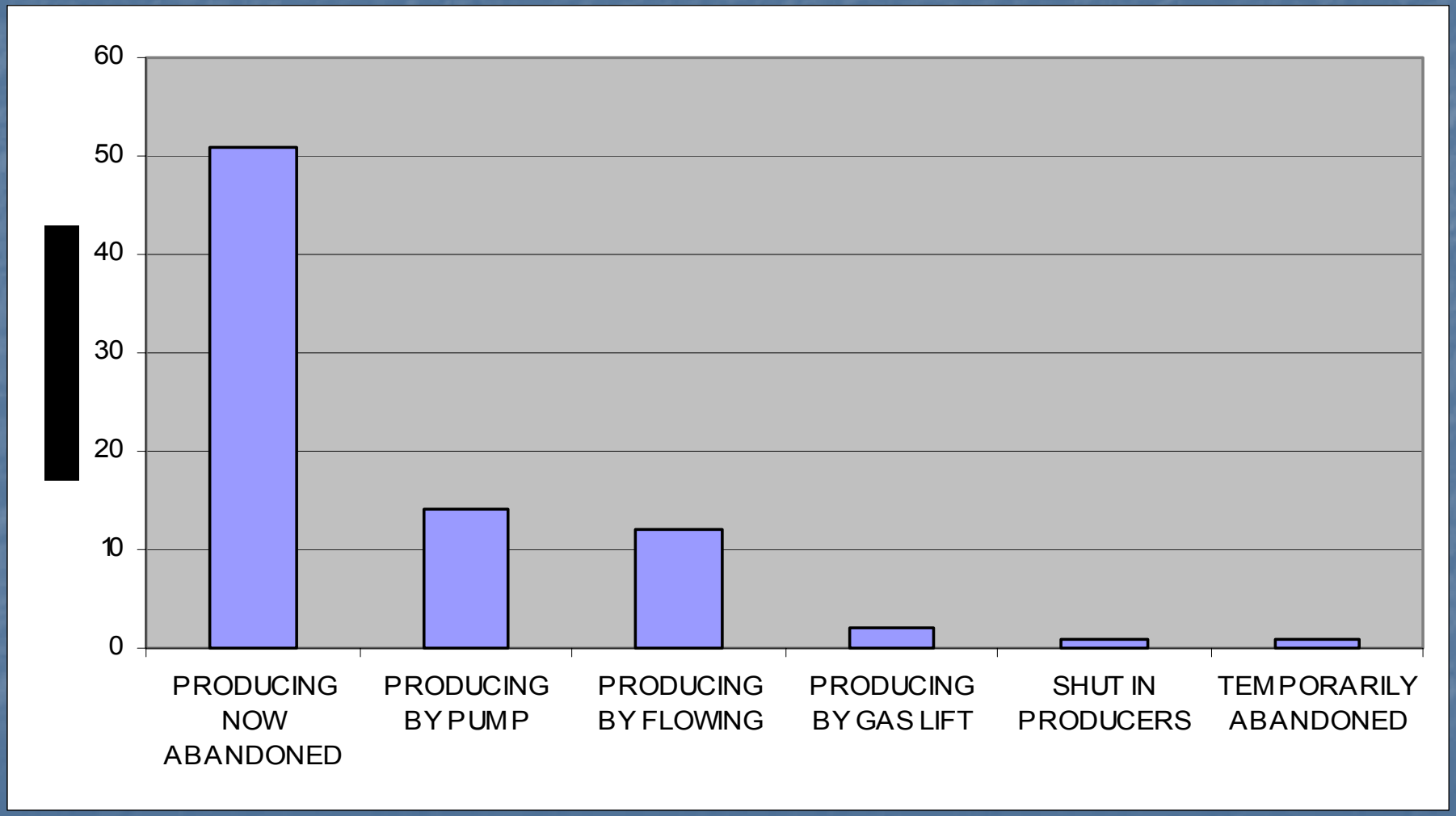
Completion Year



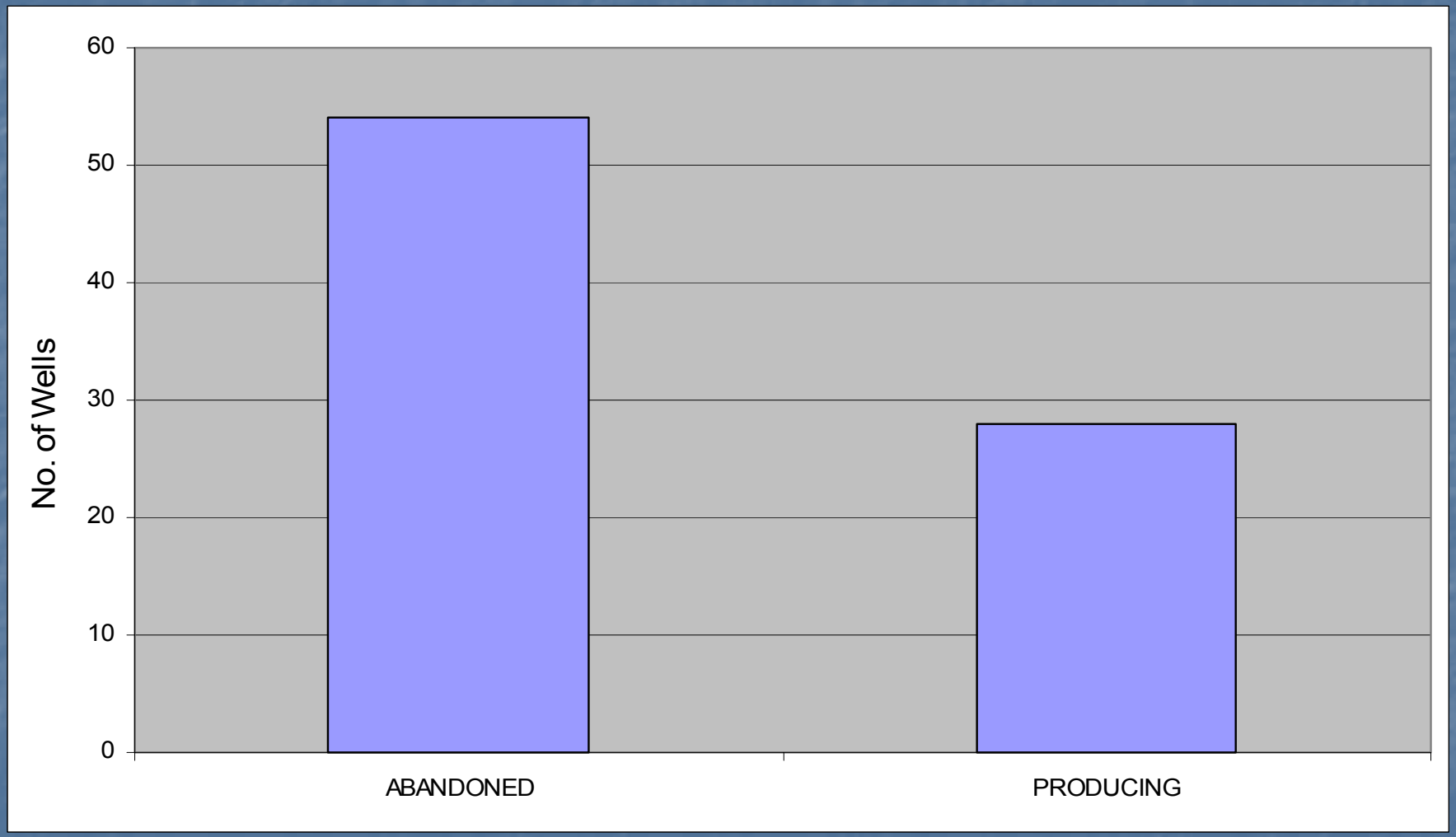
Operator


No. of Wells
30
25
20
15
10
5
0
AMERADA HESS CORPORATION
RANCH OIL COMPANY
CHESAPEAKE OPERATING INC.
PAN AMERICAN PETROLEUM CORP.
LLOYD H. SMITH
P & P PRODUCING INC.
PRIMA EXPLORATION INC.
OTHERS < 2 WELLS

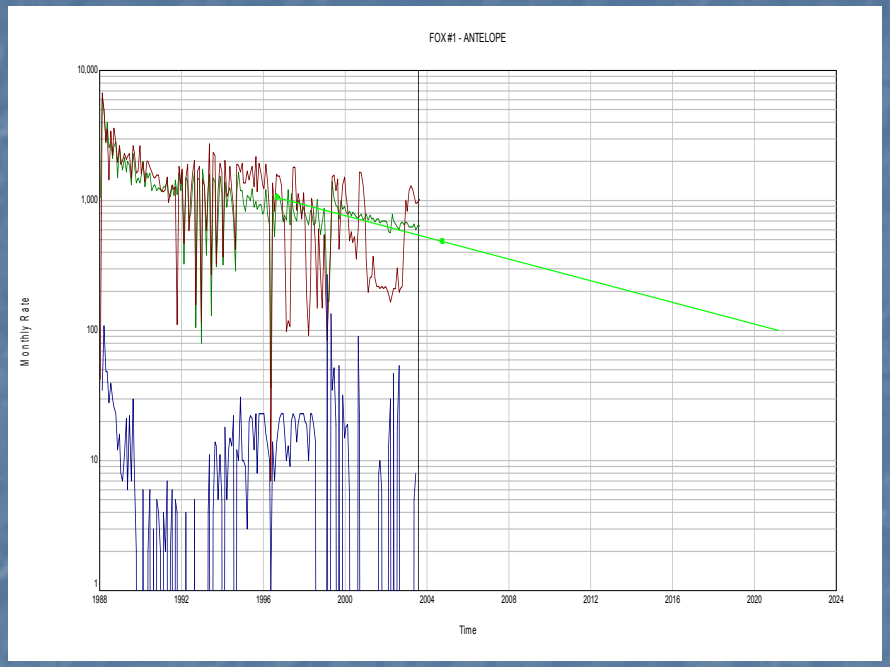
Detailed Well Status

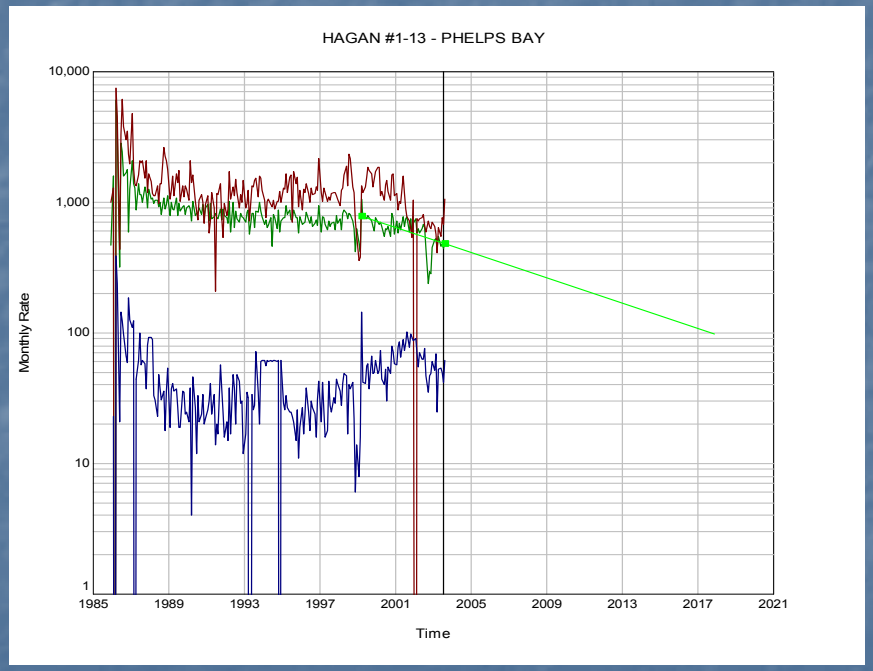


Consolidated Well Status

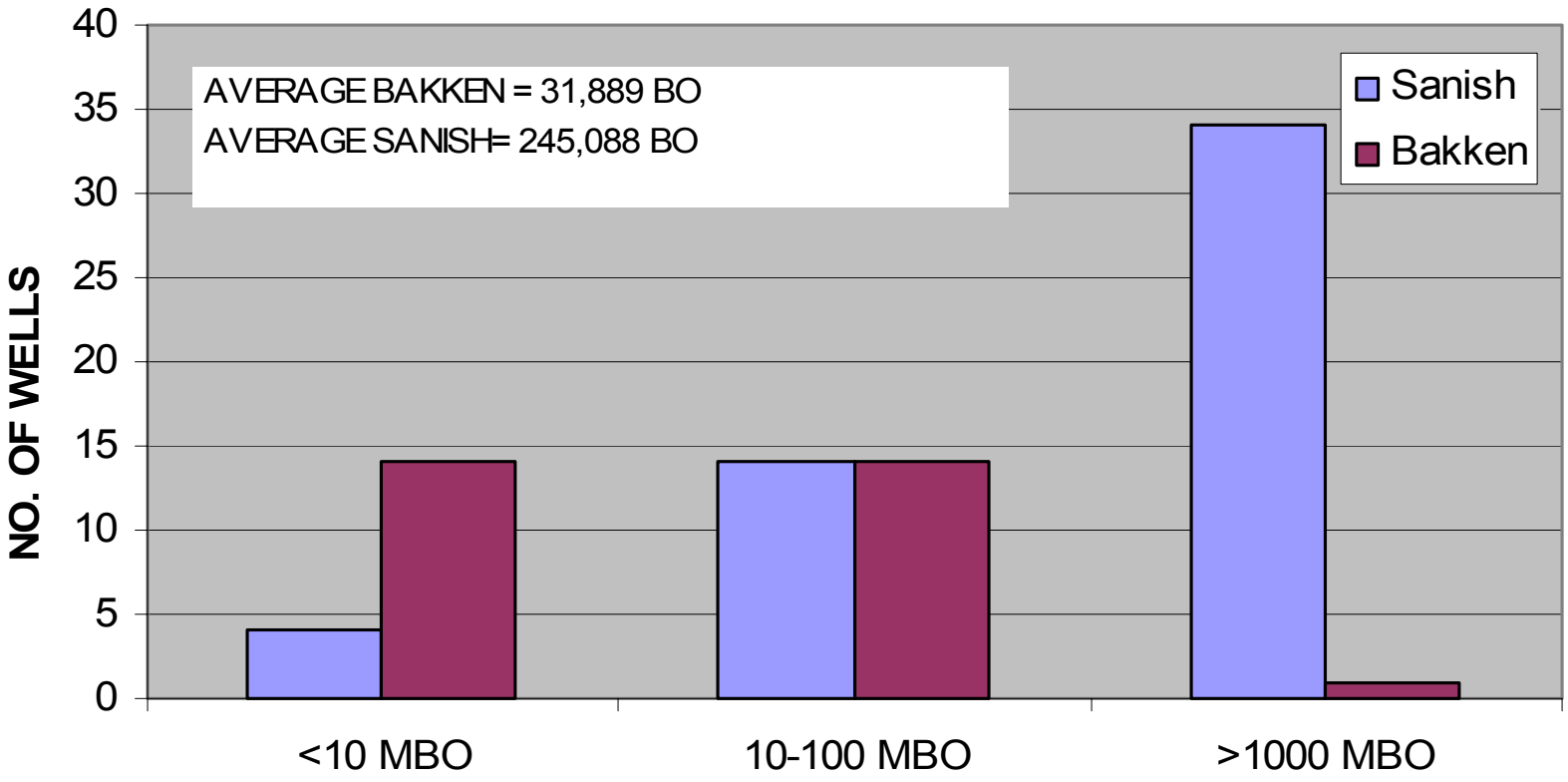


Estimation of EUR for Active Wells

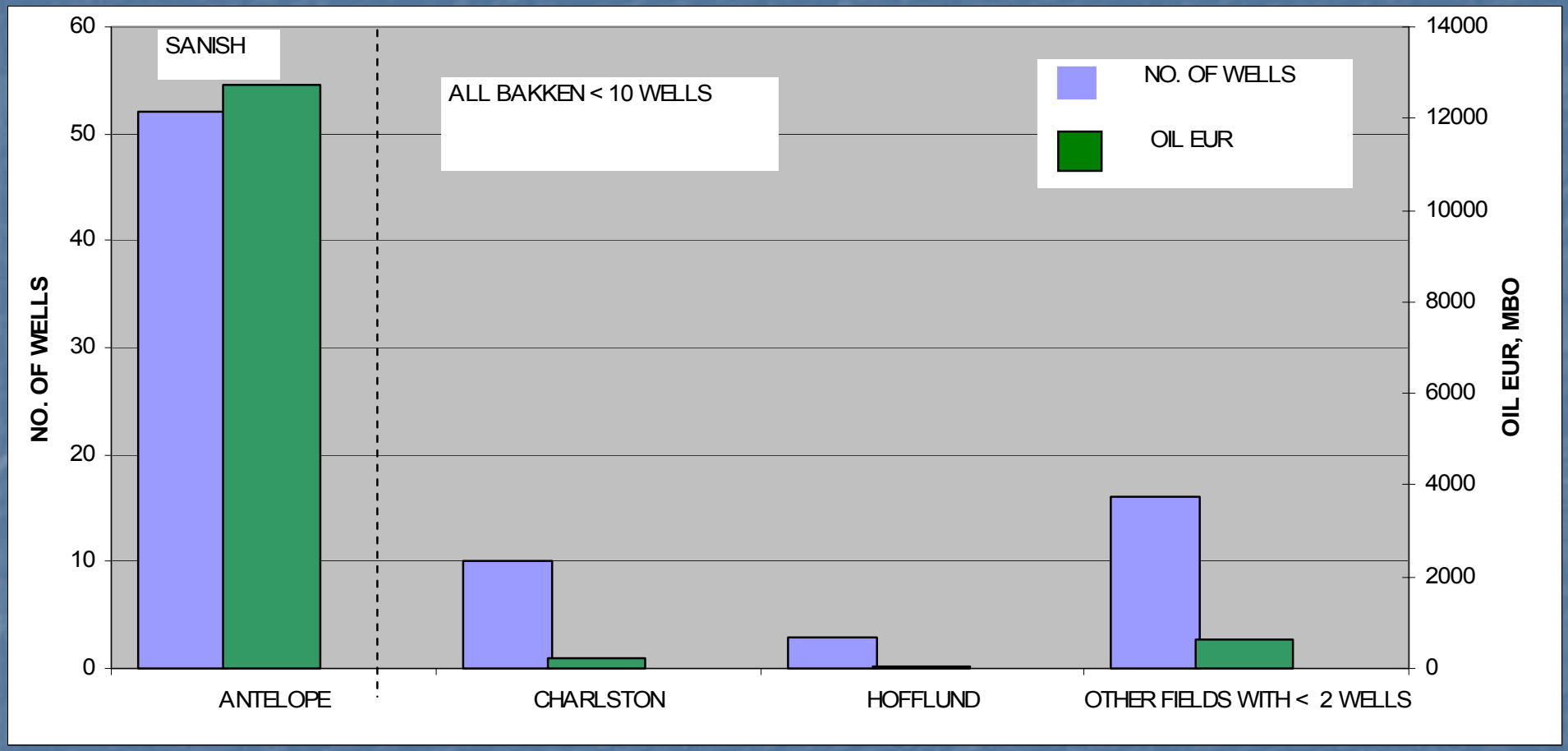




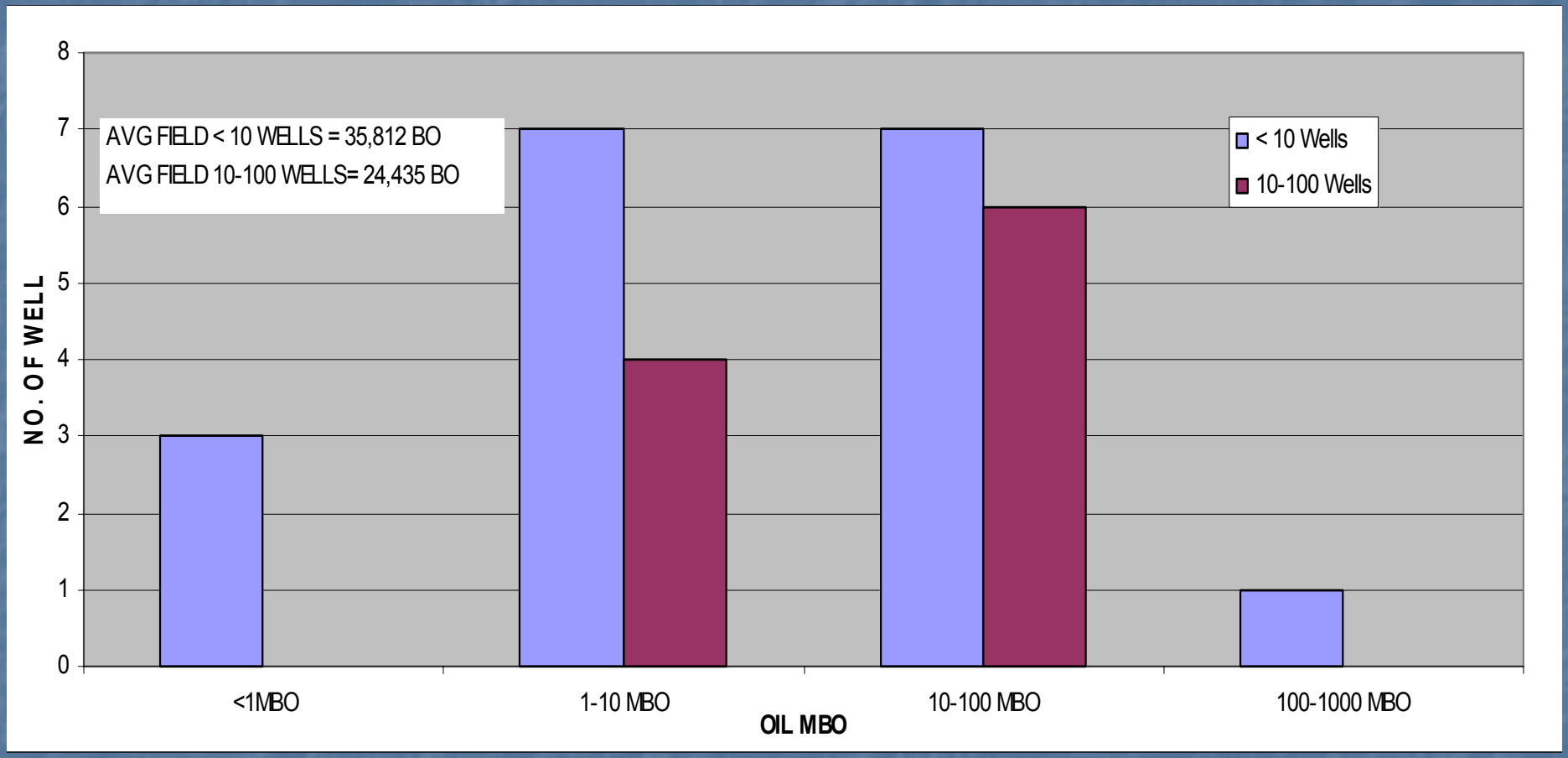
Average Well Recovery by Play



Field Size Distribution



Recovery by Field Size (Bakken)

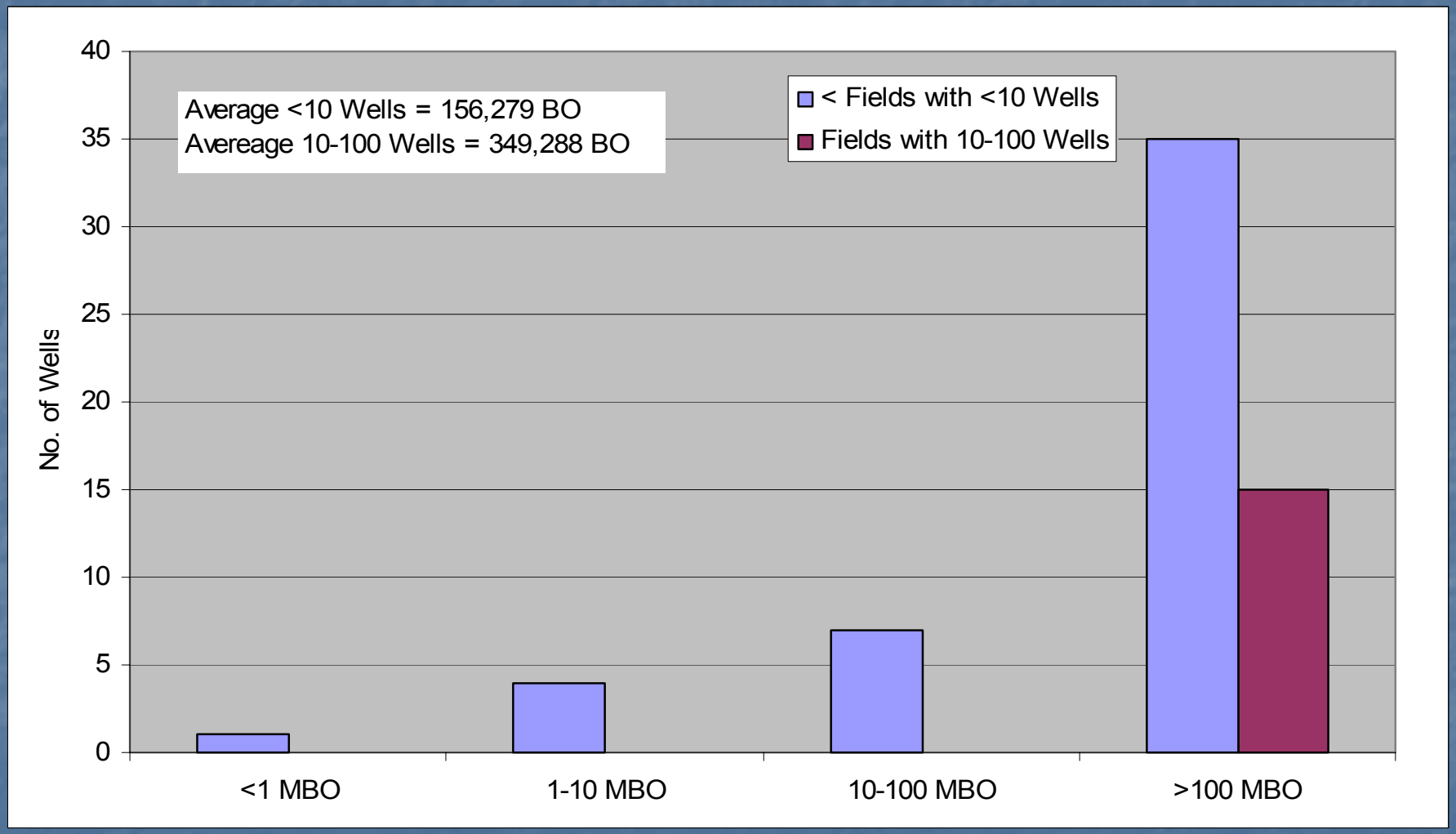


Other Plays Evaluated

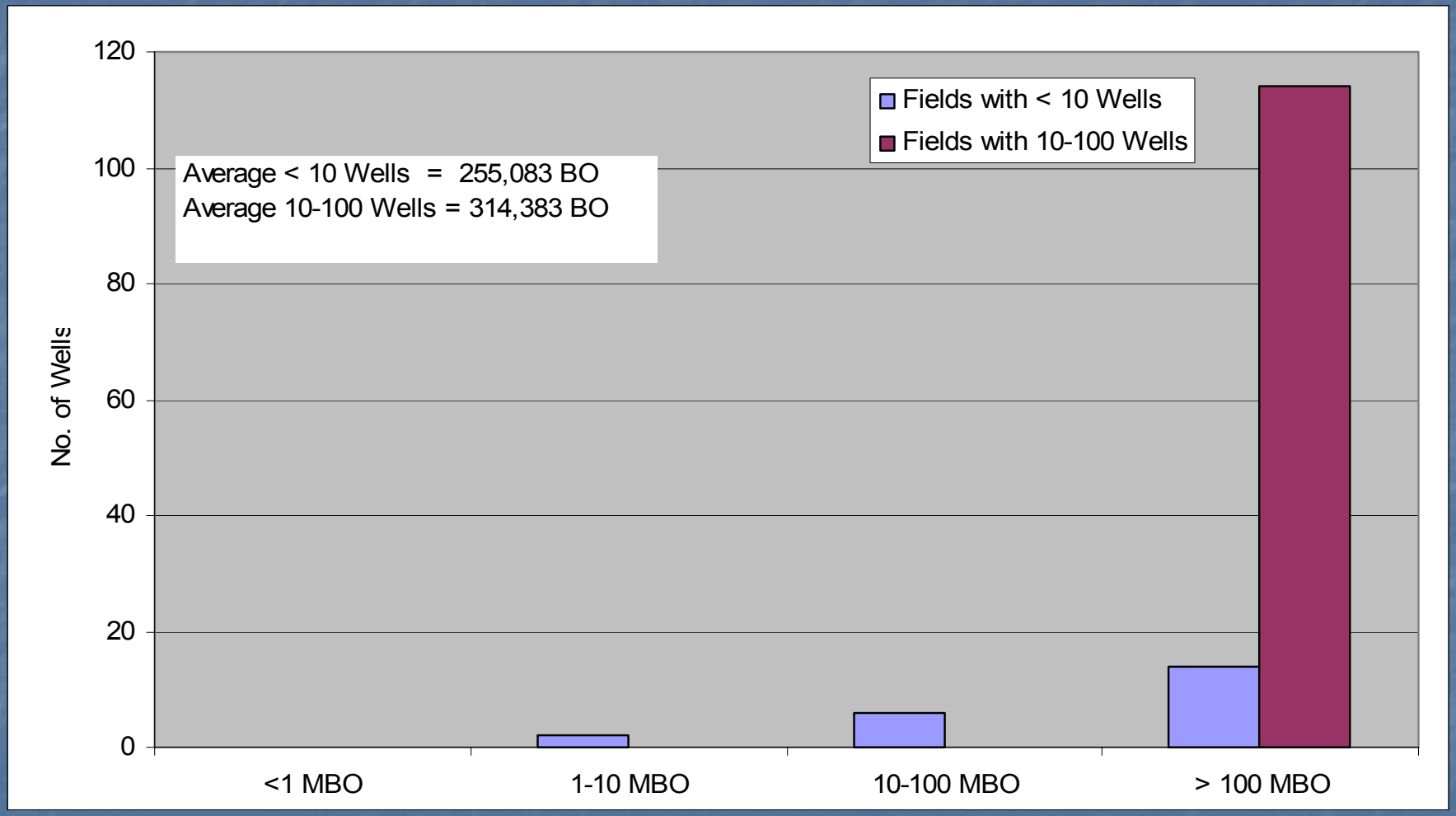
- Duperow
  - 62 Wells
    - 15 Active
    - 47 Inactive
- Silurian/Interlake
  - 136 Wells
    - 37 Active
    - 99 Inactive
- Source: IHS Energy

Below Bakken

Recovery by Field Size - Duperow



Recovery by Field Size–Silurian/Interlake



Summary of Well Performance Data

	Summary of Well Performance Data		
	Recovery, MBO (STD)		
	< 10 Wells	10 - 100 Wells	> 100 Wells
	Average	Average	Average
Madison Structural	161	262	231
Madison Stratigraphic	43	135	n/a
Sanish (i.e., Antelope)	n/a	245	n/a
Bakken	35	24	n/a
Duperow	156	349	n/a
Silurian/Interlake	255	314	n/a

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Oil Recovery Assumptions

- Assign highest probability of oil production to Madison, with lower probabilities to secondary objectives*:

Horizon	Probability	Recovery	
		< 10 Wells (MBO)	10-100 Wells (MBO)
Madison	55%	161	262
Bakken	15%	35	24
Duperow	15%	156	349
Silurian/Interlake	15%	255	314
Total	100%	155	247

- Assign highest probability of oil occurrence to westernmost leads near mature source rock:
  - 200 – 225 = 100%
  - 175 – 200 = 90%
  - 167 – 175 = 80%
  - < 167 = 70%

* Note: 1. No Sanish/Antelope style plays included.
2. Sherwood shoreline play 100% Madison stratigraphic.

Oil Recovery Assumptions (continued)

- Apply exploration and development risk as cited by Tribes [41]:

	Structural	Stratigraphic
Exploration	40%	25%*
Development	80%	75%

- Adjust recovery factors to account for switch from 80-acre vertical wells to 320-acre extended-reach/horizontal wells:
  - Multiply oil recoveries by 75%.

* reduced from 35%

Expected Lead Recoveries

Lead	Type	Area (acres)	80-acre Wells	Average Recovery (MBO/well)	Unadjusted Field Recovery (MBO)	Oil Occurrence Risk	Exploration Risk	Development Risk	Spacing Adjustment	Expected Recovery (MBO)
1	structural	1,295	16	247	4,001	70%	40%	80%	75%	672
2	structural	842	11	247	2,603	90%	40%	80%	75%	562
3	structural	1,386	17	247	4,282	90%	40%	80%	75%	925
4	structural	823	10	247	2,542	90%	40%	80%	75%	549
5	structural	758	9	155	1,473	90%	40%	80%	75%	318
6	structural	1,202	15	247	3,713	90%	40%	80%	75%	802
7	structural	674	8	155	1,310	90%	40%	80%	75%	283
8	structural	1,941	24	247	5,997	90%	40%	80%	75%	1,295
9	structural	628	8	155	1,219	100%	40%	80%	75%	293
10	structural	2,308	29	247	7,131	100%	40%	80%	75%	1,711
Sherwood	stratigraphic	7,177	90	135	12,111	90%	25%	75%	75%	1,533

Economic Assumptions

- Geophysical Costs [41]: $25,000/mi^2 (3D acquisition, processing, permits, damages, etc.)
- Well Costs (vertical) [41].

	Structural (12,500 ft)	Stratigraphic (8,000 ft)
Dry Hole	$ 1,000,000	$450,000
Completion	$350,000	$250,000

Economic Assumptions (continued)

- Extended-reach/horizontal cost premium:
  - 20% per ¼ mile from shore
- Account for fewer (320-acre) wells, but include dry-hole costs.

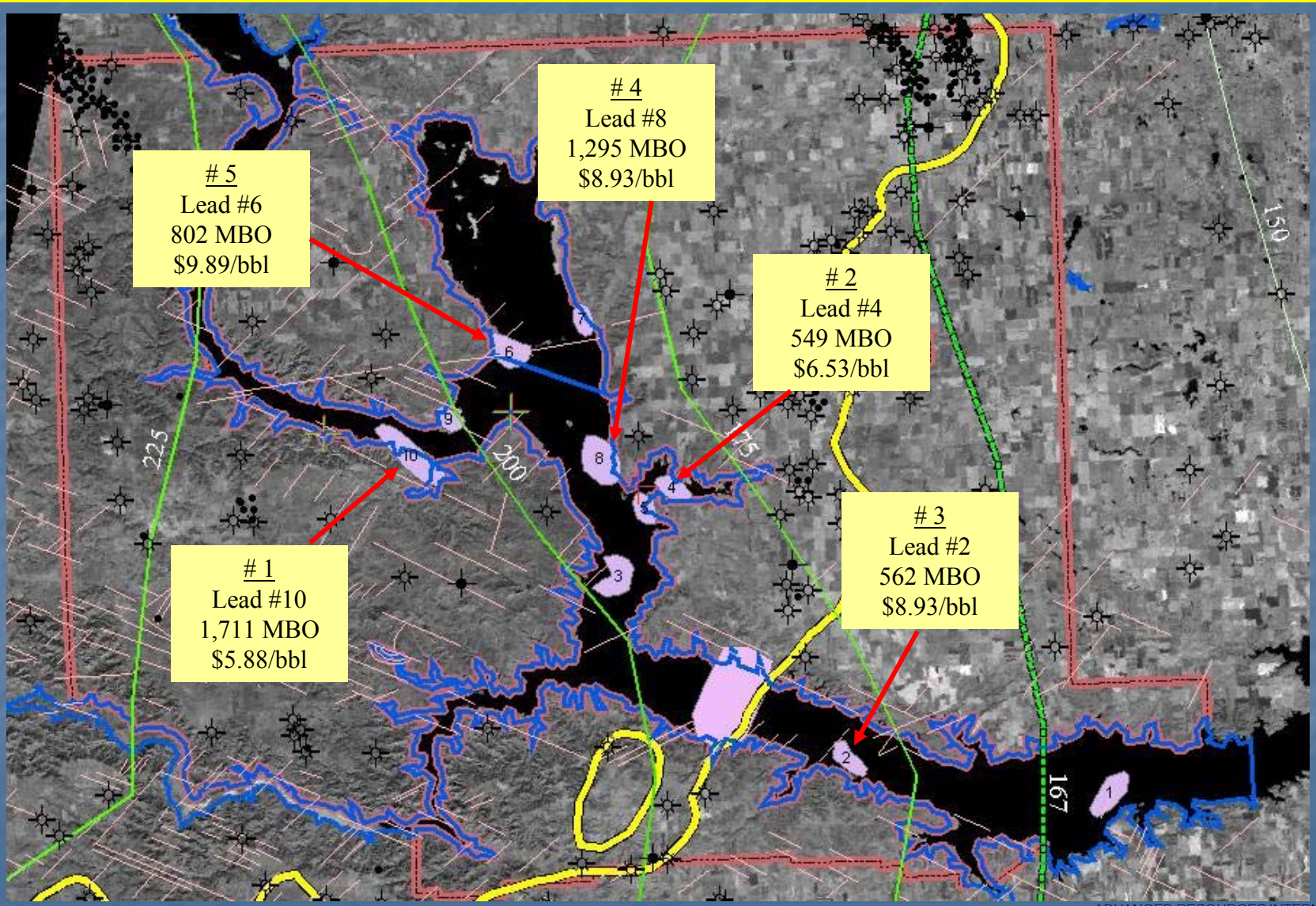
Finding and Development Costs

Lead	Geophysical Cost ($/sq-mi)	Geophysical Cost ($)	Vertical Well Cost: Dry Hole ($)	Vertical Well Cost: Completion ($)	Average Distance from Shore (mi)	Cost Premium (%)	No. 320-acre Wells: Dry	No. 320-acre Wells: Successful	Well Costs ($)	Total F&D Costs ($)	Total F&D Costs ($/bbl)
1	$ 25,000	$ 50,588	$ 1,000,000	$ 350,000	1.1	88%	1	3	$ 9,738,761	$ 9,789,348	$ 14.56
2	$ 25,000	$ 32,908	$ 1,000,000	$ 350,000	0.1	48%	1	2	$ 4,987,202	$ 5,020,110	$ 8.93
3	$ 25,000	$ 54,136	$ 1,000,000	$ 350,000	1.4	112%	1	3	$ 11,752,321	$ 11,806,457	$ 12.77
4	$ 25,000	$ 32,136	$ 1,000,000	$ 350,000	0.1	8%	1	2	$ 3,554,000	$ 3,586,136	$ 6.53
5	$ 25,000	$ 29,621	$ 1,000,000	$ 350,000	0.1	8%	0	2	$ 3,275,891	$ 3,305,512	$ 10.39
6	$ 25,000	$ 46,947	$ 1,000,000	$ 350,000	0.8	64%	1	3	$ 7,884,065	$ 7,931,012	$ 9.89
7	$ 25,000	$ 26,335	$ 1,000,000	$ 350,000	0.1	8%	0	2	$ 2,912,472	$ 2,938,807	$ 10.39
8	$ 25,000	$ 75,828	$ 1,000,000	$ 350,000	0.6	48%	1	5	$ 11,491,842	$ 11,567,670	$ 8.93
9	$ 25,000	$ 24,515	$ 1,000,000	$ 350,000	0.6	48%	0	2	$ 3,715,267	$ 3,739,782	$ 12.78
10	$ 25,000	$ 90,160	$ 1,000,000	$ 350,000	0.1	8%	1	6	$ 9,970,992	$ 10,061,153	$ 5.88
Sherwood	$ 25,000	$ 280,351	$ 450,000	$ 250,000	0.8	64%	6	17	$ 23,448,527	$ 23,728,877	$ 15.48

Lead Rankings
(by F&D Costs)

Rank	Lead	Expected Recovery (MBO)	F&D Costs ($/ bbl)
1	10	1,711	$5.88
2	4	549	$6.53
3	2	562	$8.93
4	8	1,295	$8.93
5	6	802	$9.89
6	5	318	$10.39
7	7	283	$10.39
8	3	925	$12.77
9	9	293	$12.78
10	1	672	$14.56
11	Sherwood	1,533	$15.48
	Totals	8,944	$10.45

Top 5 Leads


4
Lead #8
1,295 MBO
$8.93/bbl
5
Lead #6
802 MBO
$9.89/bbl
2
Lead #4
549 MBO
$6.53/bbl
3
Lead #2
562 MBO
$8.93/bbl
1
Lead #10
1,711 MBO
$5.88/bbl
225
200
175
150
167
1
2
3
4
5
6
7
8
9
10

Outline

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- Seismic
- Identification of Lead Areas
- Statistical Well Performance
- Economics
- Conclusions and Recommendations
- References

Conclusions

- Fort Berthold Indian Reservation is in favorably located within the Williston Basin, with good exploration success. An excellent opportunity exists to capture a 150,000 acre contiguous block on the reservation under Lake Sakakawea.
- An integrated geology, remote sensing, potential fields and seismic study provided on improved understanding of the structural setting and hydrocarbon potential under the lake. That potential has been determined to be very promising.
- Eleven leads have been identified based on that study. Expected lead recoveries range from ~300 to ~1700 MBO (8900 MBO in total), with F&D costs of ~$6/bbl, to ~$15/bbl.

Recommendations

- To further define prospects, the following technical recommendations are made:
  - Acquire and reprocess balance of seismic over lake (~300 line-miles).
  - Acquire and interpret high-resolution aeromag survey.
  - Integrate with existing study.
  - Evaluate need for 3D seismic for further prospect definition and/or drill well.

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