

# Polygonal Faults, Niobrara Formation, Denver Basin\*

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## Abstract

Polygonal fault systems (PFS) are observed in two distinct Cretaceous levels in the Denver Basin. One level extends from the lower Pierre Shale Formation through the Niobrara Formation into the Greenhorn Formation, and the other is located just beneath the Hygiene Sandstone Member of the Pierre Shale. These two faulted intervals are separated by a relatively undeformed interval. PFS are layer-bounded normal fault systems. The PFS have throws of 30 to 150 feet and fault planes dip 30 to 70 degrees. The faults aggregate into polygons or partial polygons in map or plan view. Five separate 3D seismic surveys illustrate the widespread distribution of PFS across the Denver Basin. These surveys illustrate the following: regional presence of PFS; PFS form early as evidenced by growth strata; PFS are slightly listric.

The faults in the PFS generally are intersected by antithetic faults. These fault pairs create complex horst and graben systems in the Niobrara Formation. These surveys also illustrate that other structure styles cause faults in the Niobrara (e.g. basement faults, compaction features, etc.). Other published 3D surveys support the PFS model when reinterpreted. Fracture intensity increases dramatically close to fault systems. Thus PFS are important contributors to production sweet spots in the Niobrara.

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# Polygonal Faults, Niobrara Formation, Denver Basin

Stephen A. Sonnenberg

David Underwood

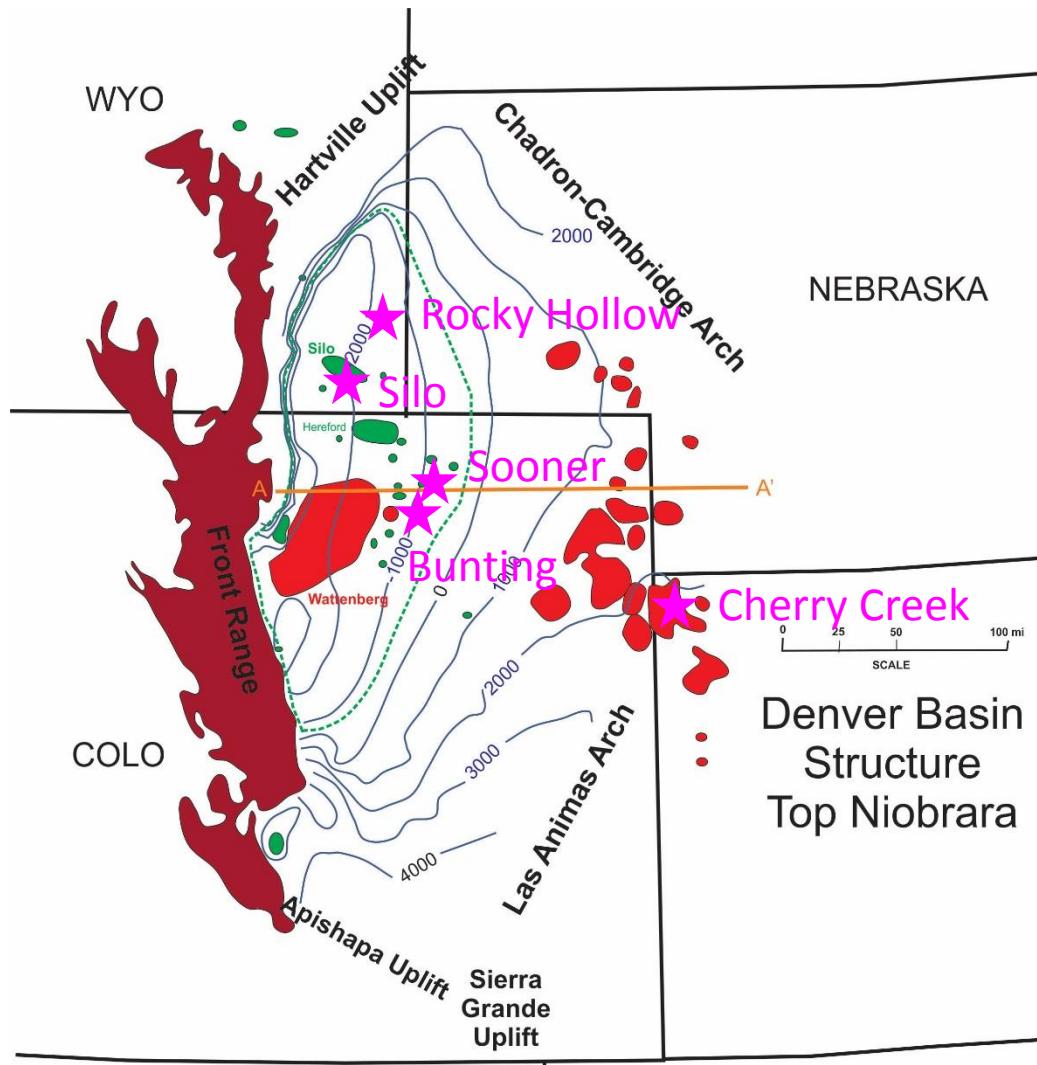
Melanie D. Peterson

Elena Finley

Nicholas Kernan

Alby Harris

# Examples of Polygonal Systems Denver Basin



Period	Formation	Source Rock (SR)	Typical Depth	Potential Pays	PFS ZONES	
Upper Cretaceous	Pierre					
		PIERRE SHALE				
		HYGIENE SS Mbr.	3100'	*		
		..... PIERRE "J" .....	4800'			
	SR	PIERRE SHALE				
		Sharon Springs Member				
		NIOBRARA "A"	5850'	*		
	SR	NIOBRARA "B"		*		
		NIOBRARA "C"		*		
		FT HAYS LIMESTONE		*		
SR	CODELL SAND	6150'	*			
	CARLILE SHALE		*			
	BRIDGE CREEK LS		*			
SR	HARTLAND SHALE	6220'	*			
	LINCOLN LS		*			
	GRANEROS SHALE		*			
SR	J <sub>3</sub> SAND	6580'	*			
	J <sub>3</sub> SAND	6660'	*			
	DAKOTA SAND		*			
Lower Cretaceous						
Dakota SS						

# Niobrara Faults

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- Basement Involved
  - Basement faults (including wrench)
  - Basin flexural extension
- Detached faults (highly debated)
  - Salt dissolution related
  - Permian or Cretaceous sandstone buildups (compaction)
  - Slump features
  - Deeper wrench related
  - Listric faults
  - Polygonal faults

A

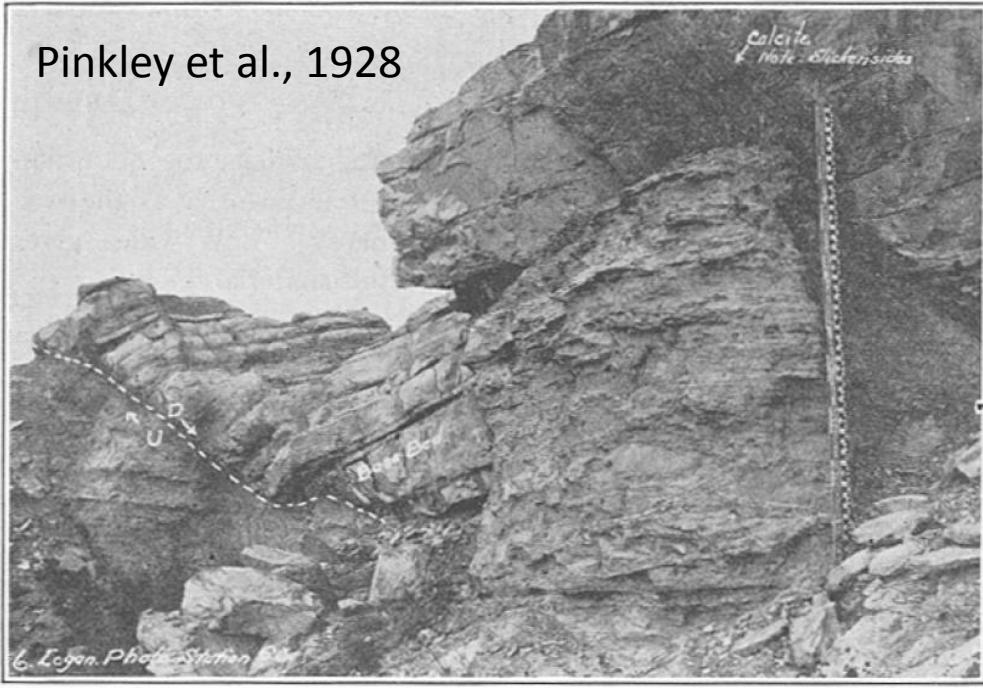
Johnson, 1958

Sec. 11-T14S-R32W

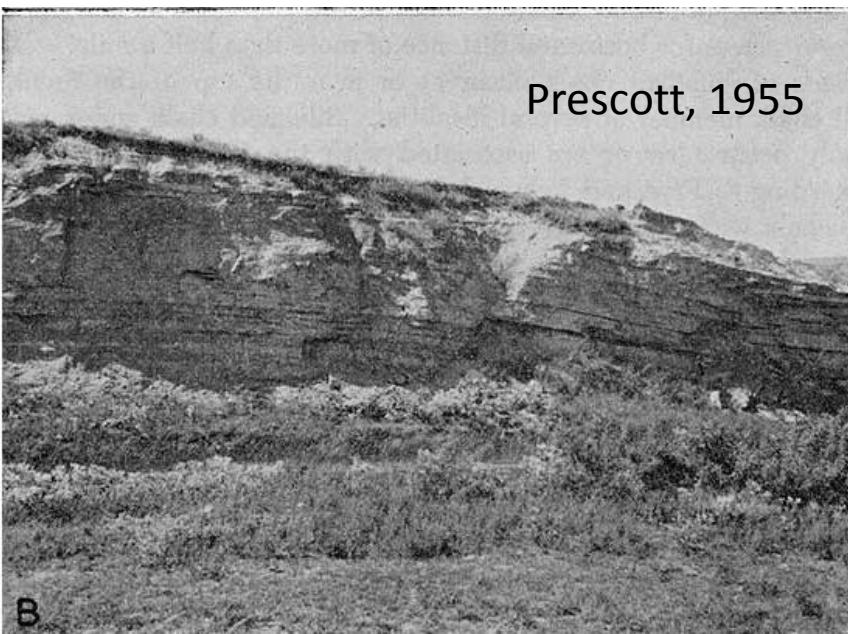


Pinkley et al., 1928

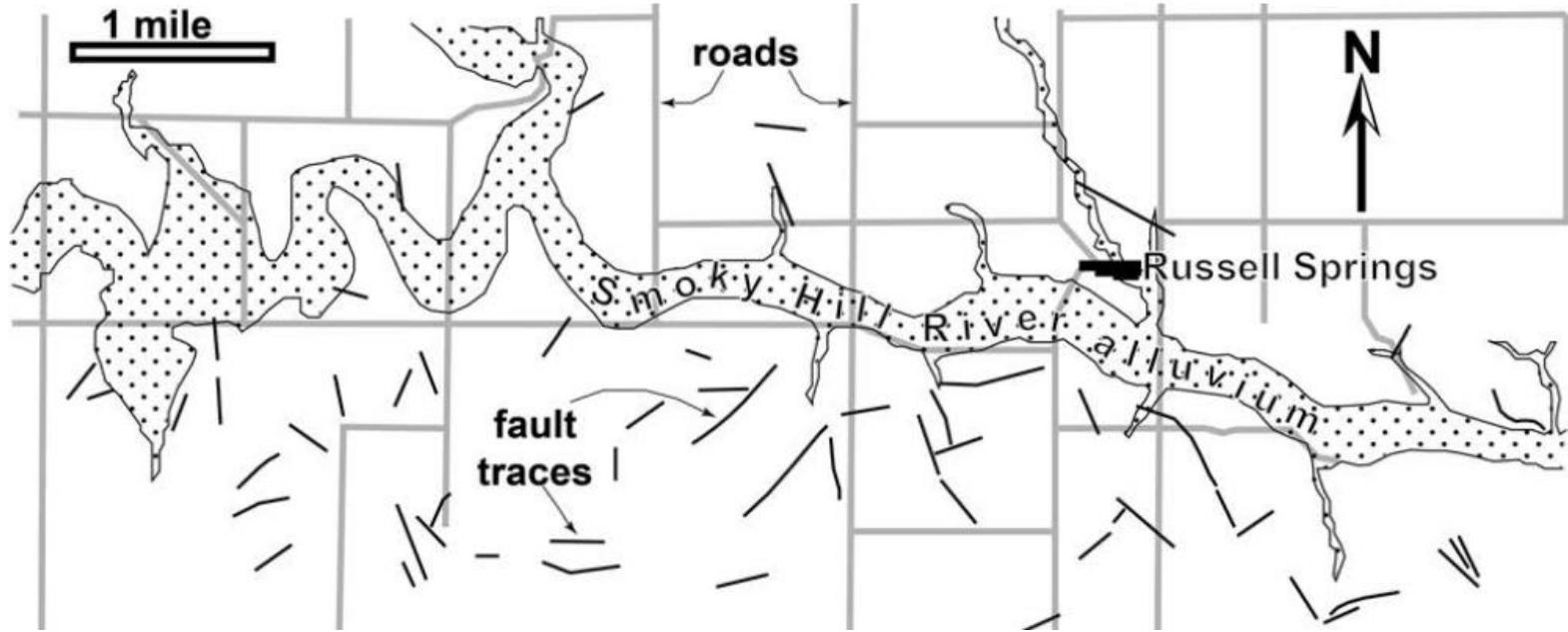
Calcite  
& Wate-Eichersides



Prescott, 1955



B

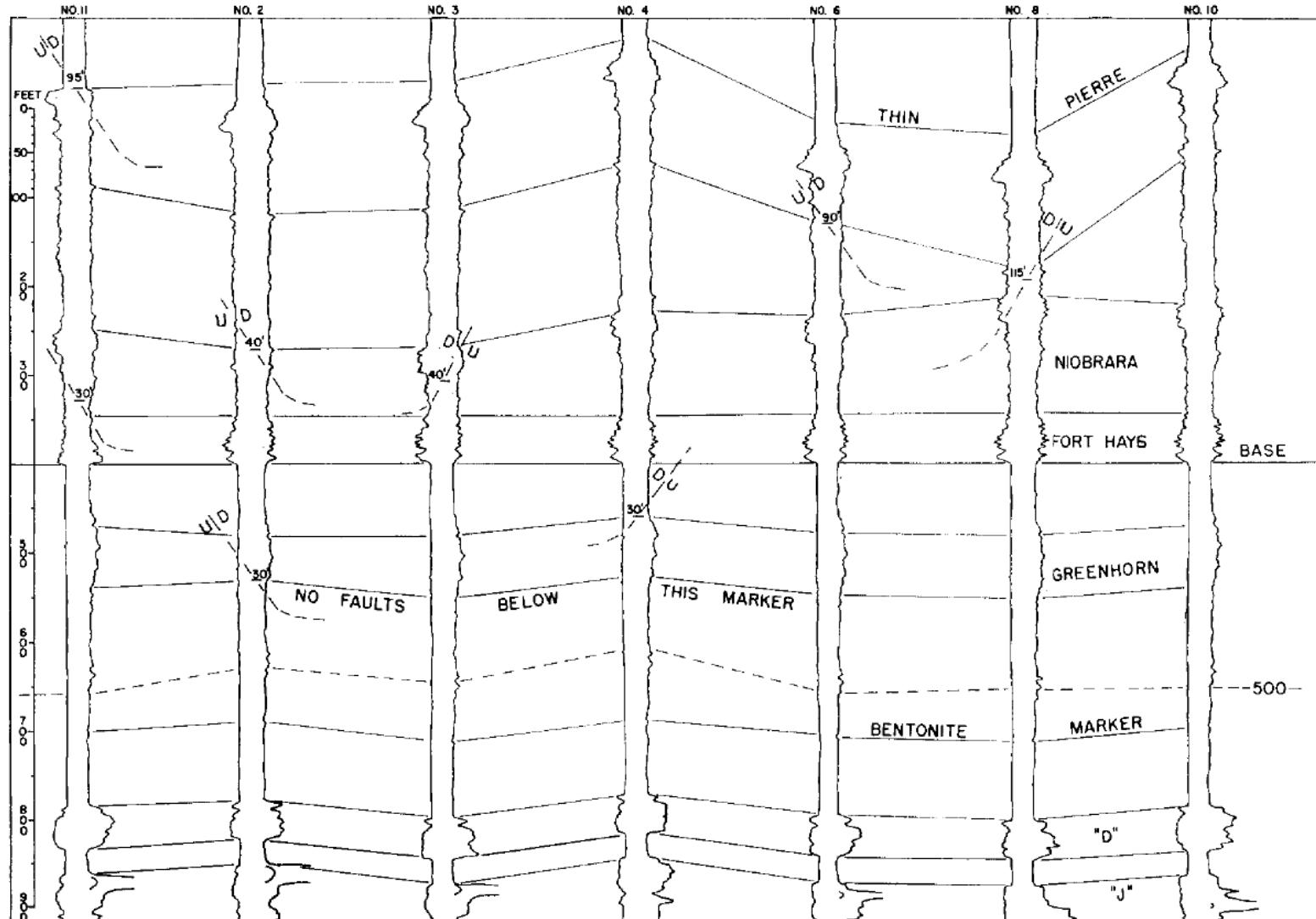


Fault tracing of part of KGS Bulletin 129 map of Logan County (Carlton Johnson, 1954)

# Origin of Niobrara Detached Faults

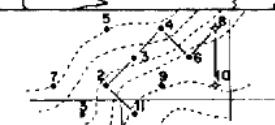
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- Twenhofel (1925): "origin of the faults and locally steep dips in the Niobrara outcrops in western Kansas to slumping of these rocks over the 200 feet of clay beds in the Carlile shale."
- Johnson (1954): No dominant trend of faults was observed. They are generally short; the longest fault trace was less than 3.5 miles long and even that may be a series of shorter en echelon faults.
- Fentress (1955): Slump faults
- Davis (1985): Listric Faults
- Sonnenberg and Underwood (2012, 13): Polygonal Fault Systems



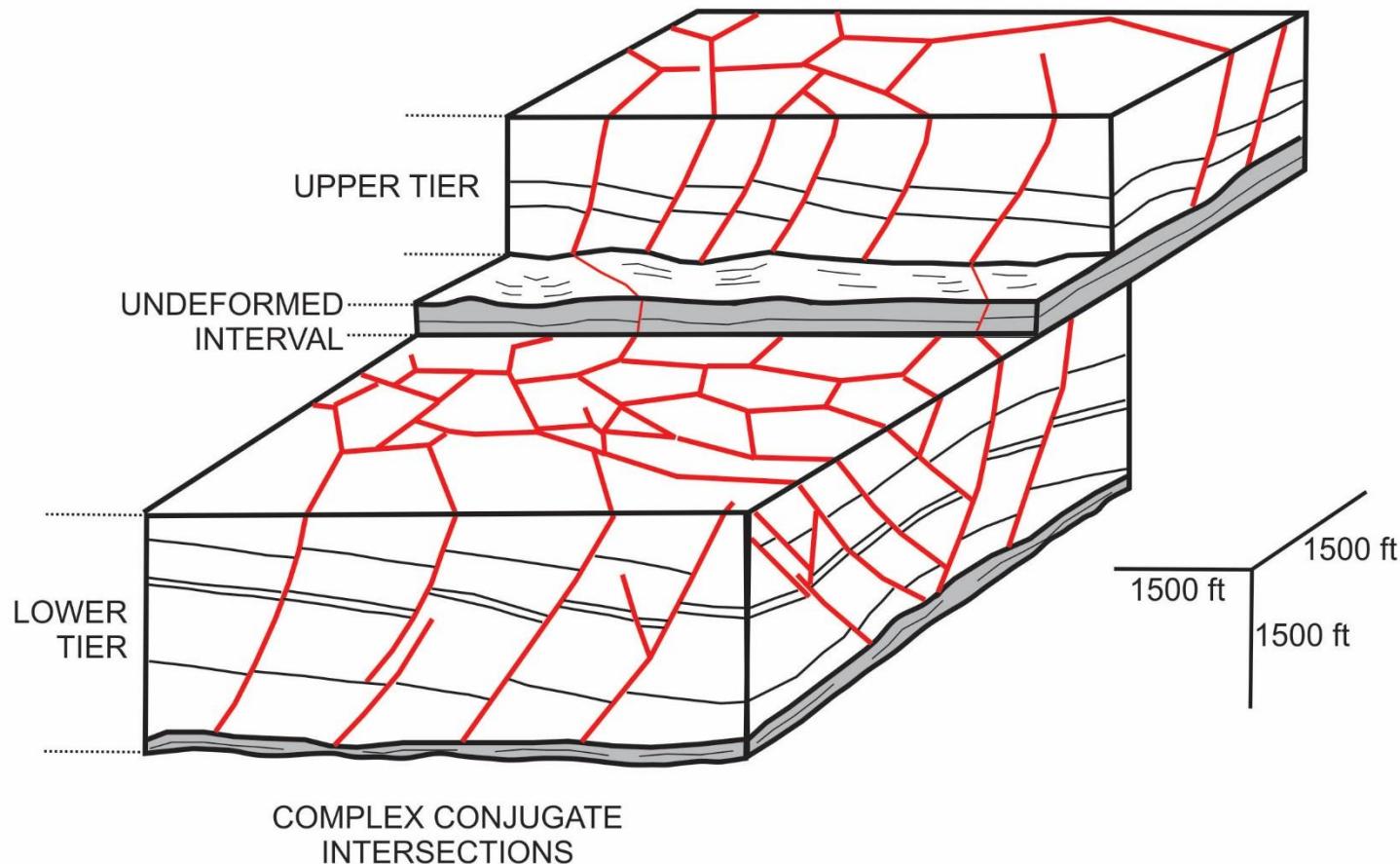
LION OIL CO.  
FLESSNER LEASE  
SEC. 19 & 30 T.I.S.-R.56 W.

POSSIBLE FAULT PATTERN "J" POOL



STRUCTURE ON BENTONITE

Fentress, 1955



Sonnenberg and Underwood, 2013; modified from Cartwright, 1996

# Polygonal Fault Systems (PFS)

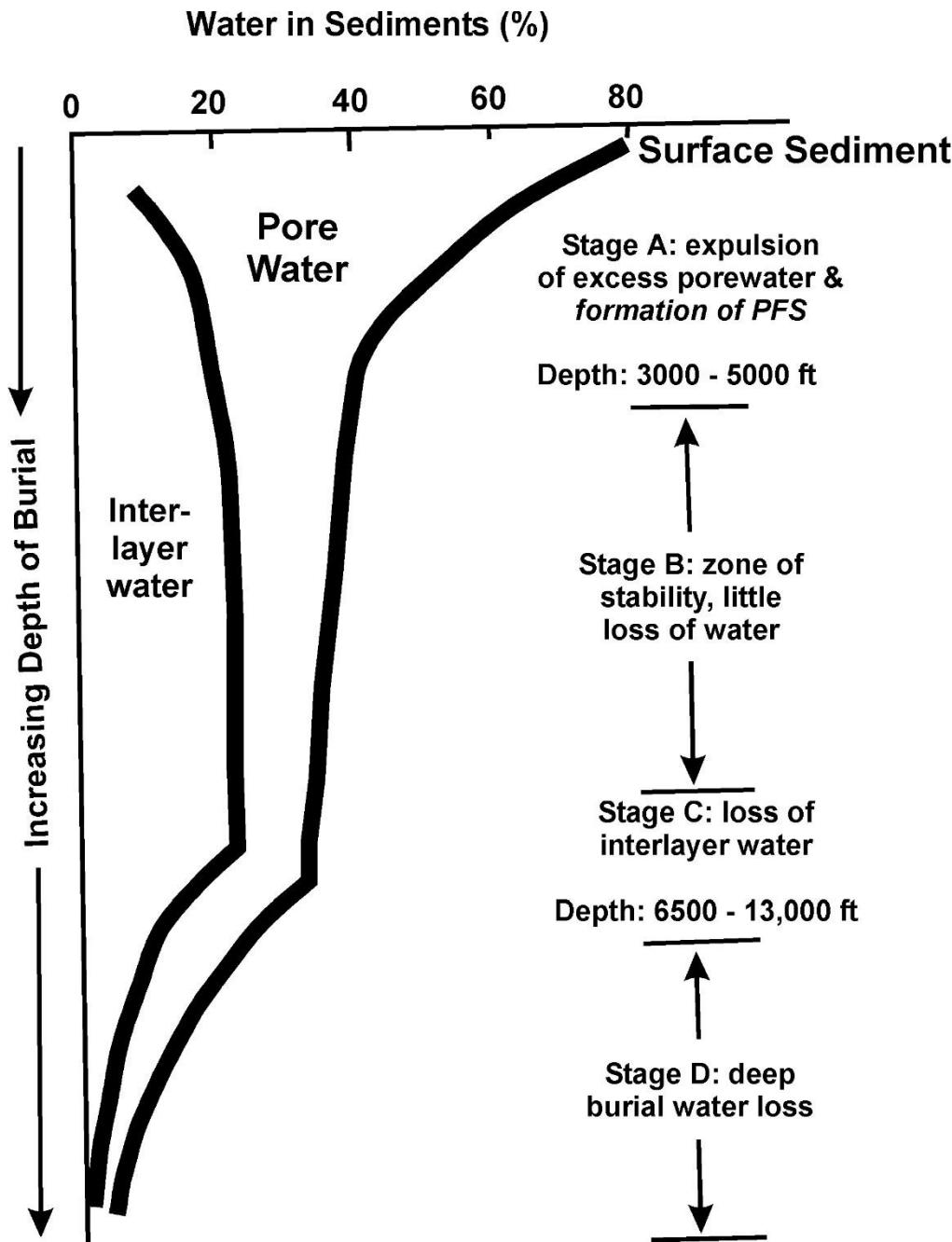
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- Layer-bounded fault systems
- Small extension faults
  - 10-50 m throw
  - Faults dip 30 to 70°
    - Compactional flattening with depth
- Random oriented fault patterns

# PFS

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- Form early in burial history
- Pervasively deformed fine-grained sediments
  - claystones and biogenic mudstones: carbonate and biosiliceous
  - Hemipelagics
- Shear fractures and normal faults aggregate into networks which are polygonal planforms
- Non-tectonic in origin
- Recognized in over 100 basins



Modified from Burst, 1965

# Polygonal Fault Examples, Denver Basin

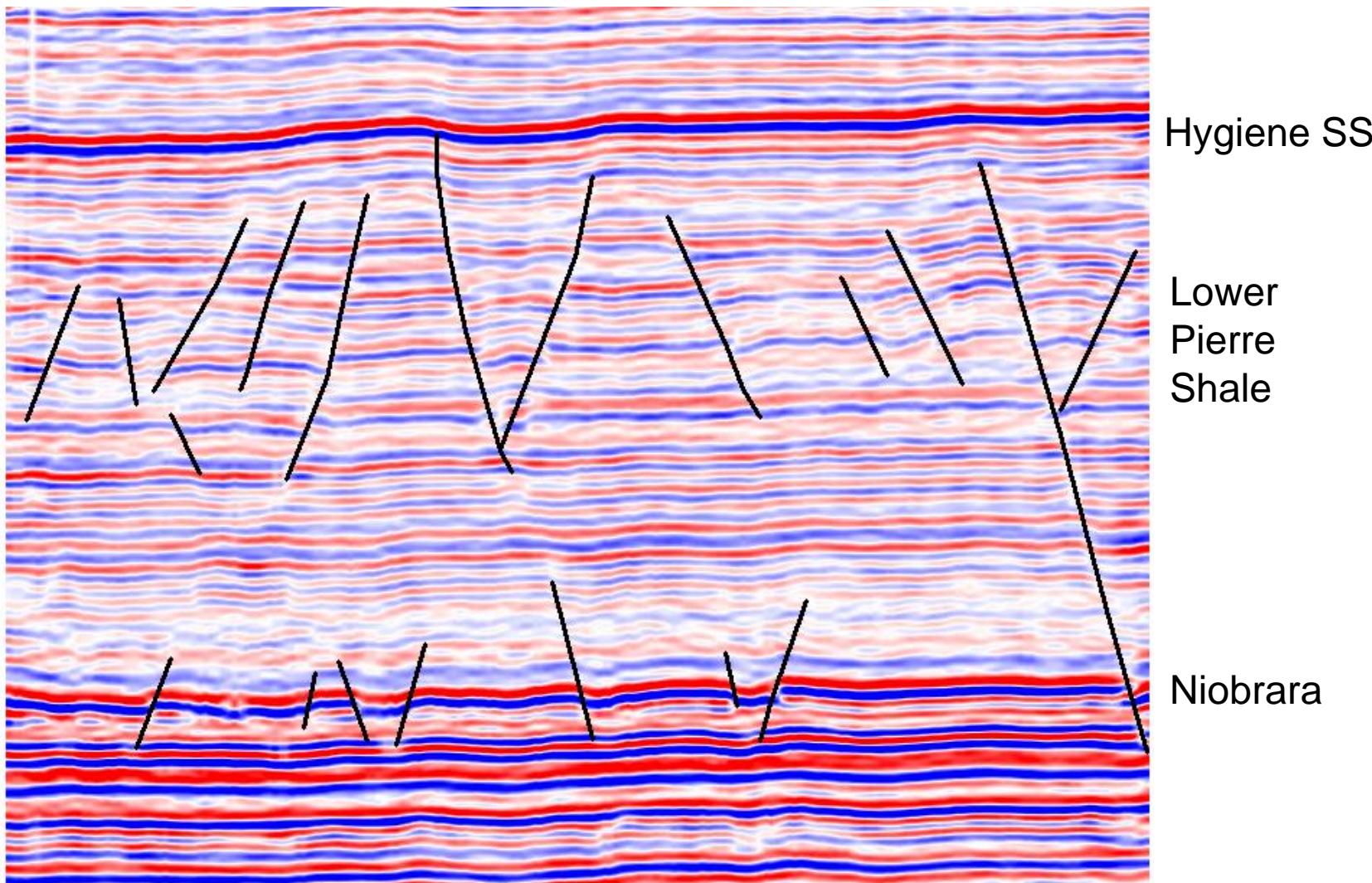
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- **Bunting Survey, Colorado (Underwood, 2013)**
- **Sooner Field (DOE survey)**
- **Rocky Hollow Survey, Wyoming (Kernan, 2014)**
- **Cherry Creek Survey, Kansas (Peterson, 2012)**
- Silo Survey, Wyoming (Finley, 2014)
- Kansas: Monument Rock (Alby Harris, 2014)

# North Bunting 3-D

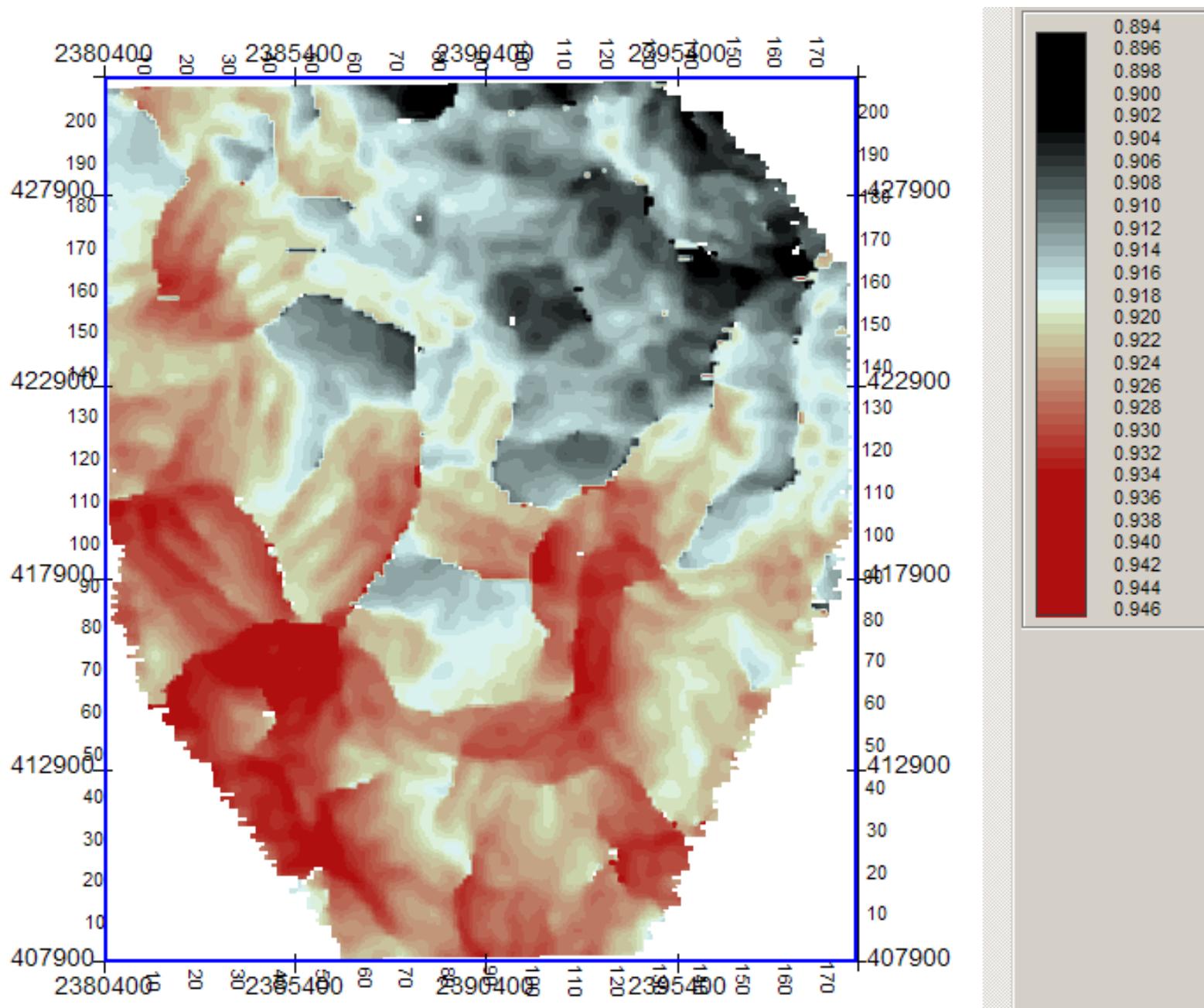
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- T6N-R60W
- 16 square miles
- Acquired 1998
- Data provided by Enerplus

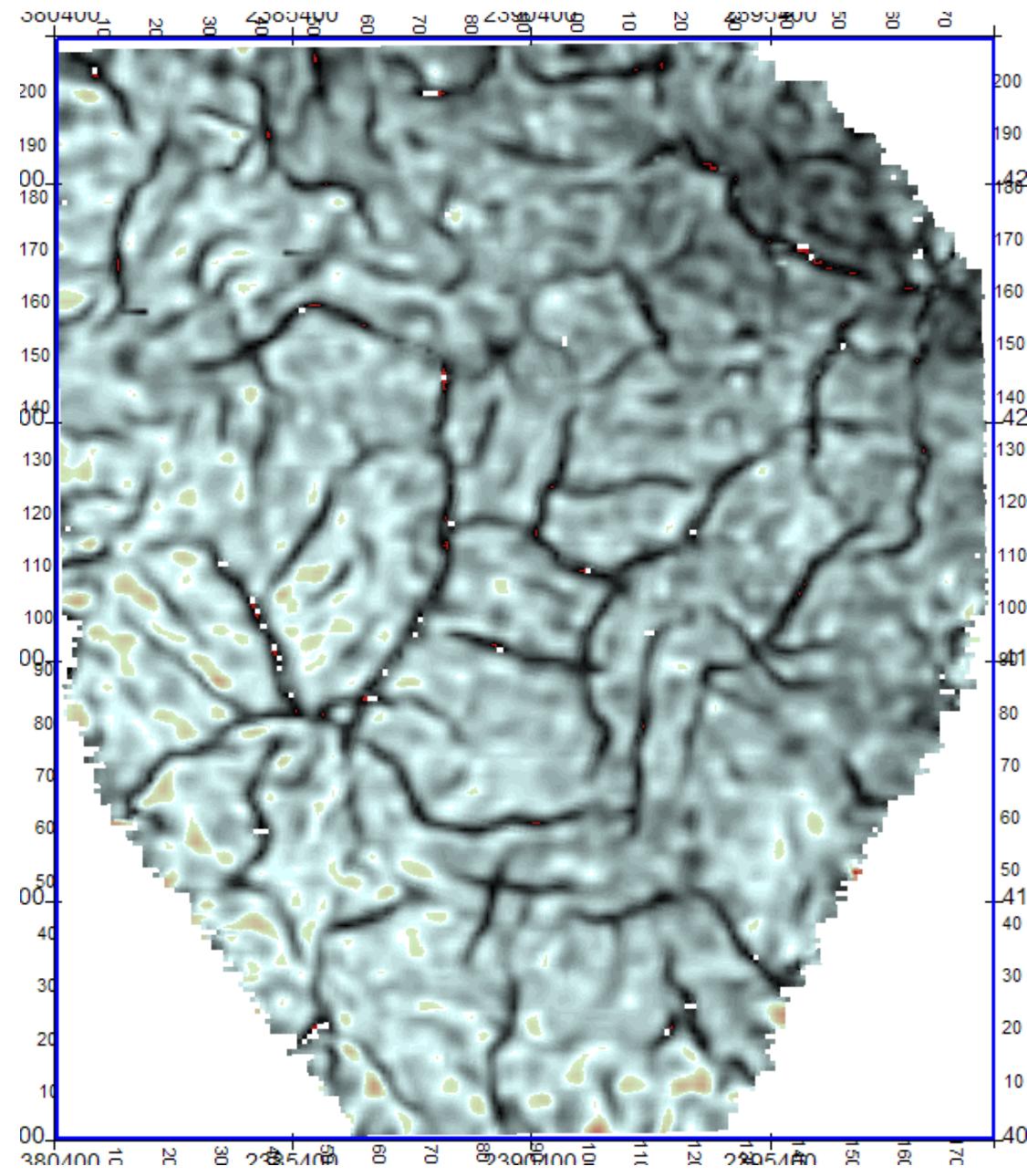


Data courtesy of Enerplus

# Lower Pierre Time Structure

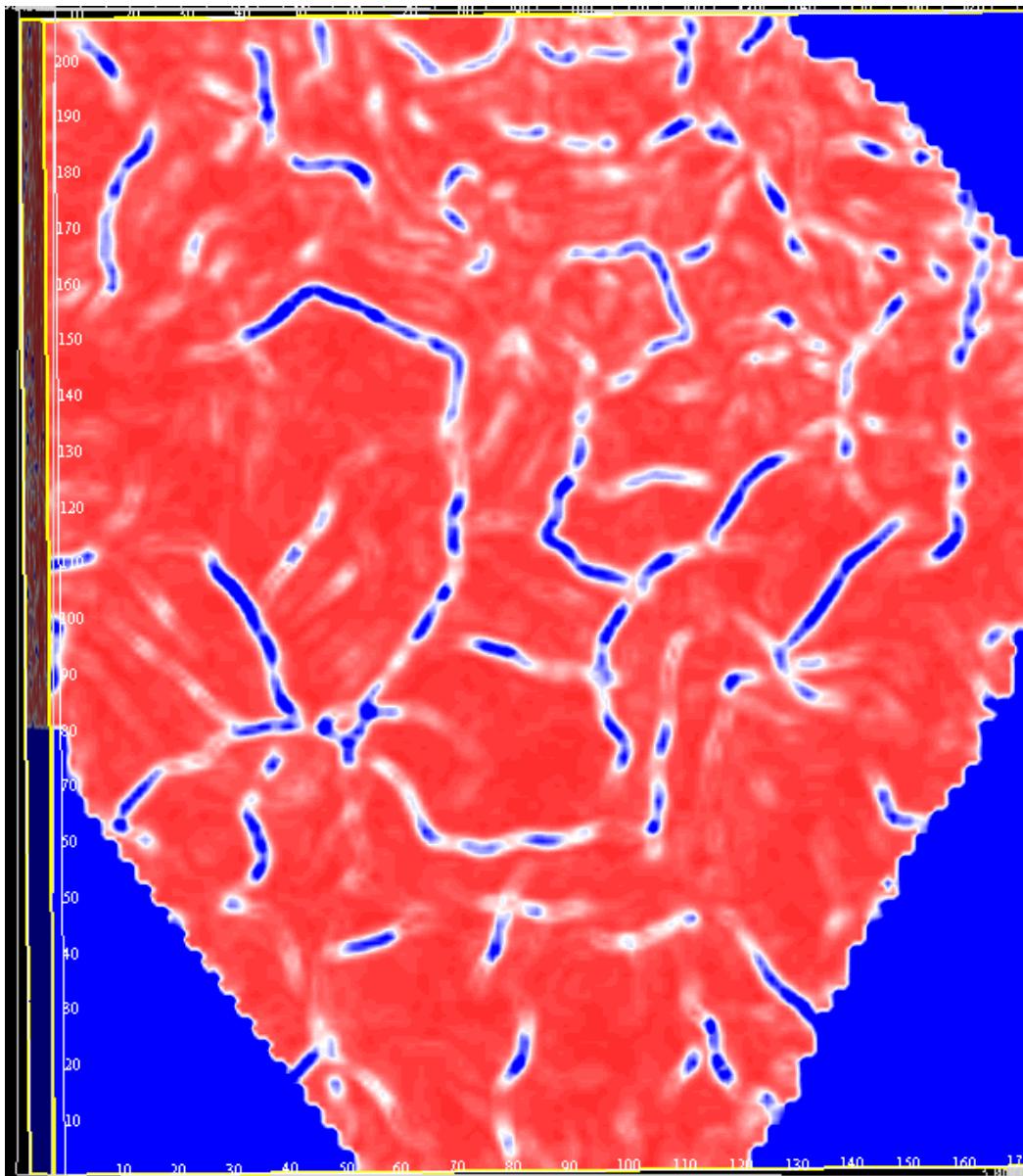


Amplitude ~ 0.93



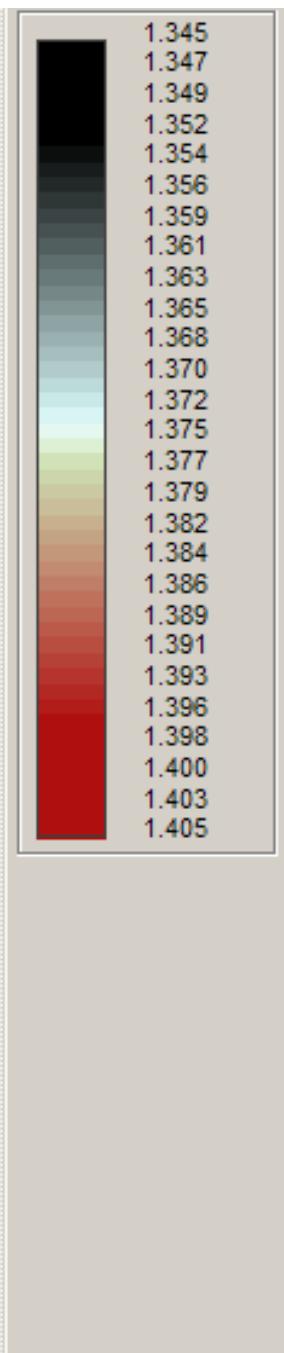
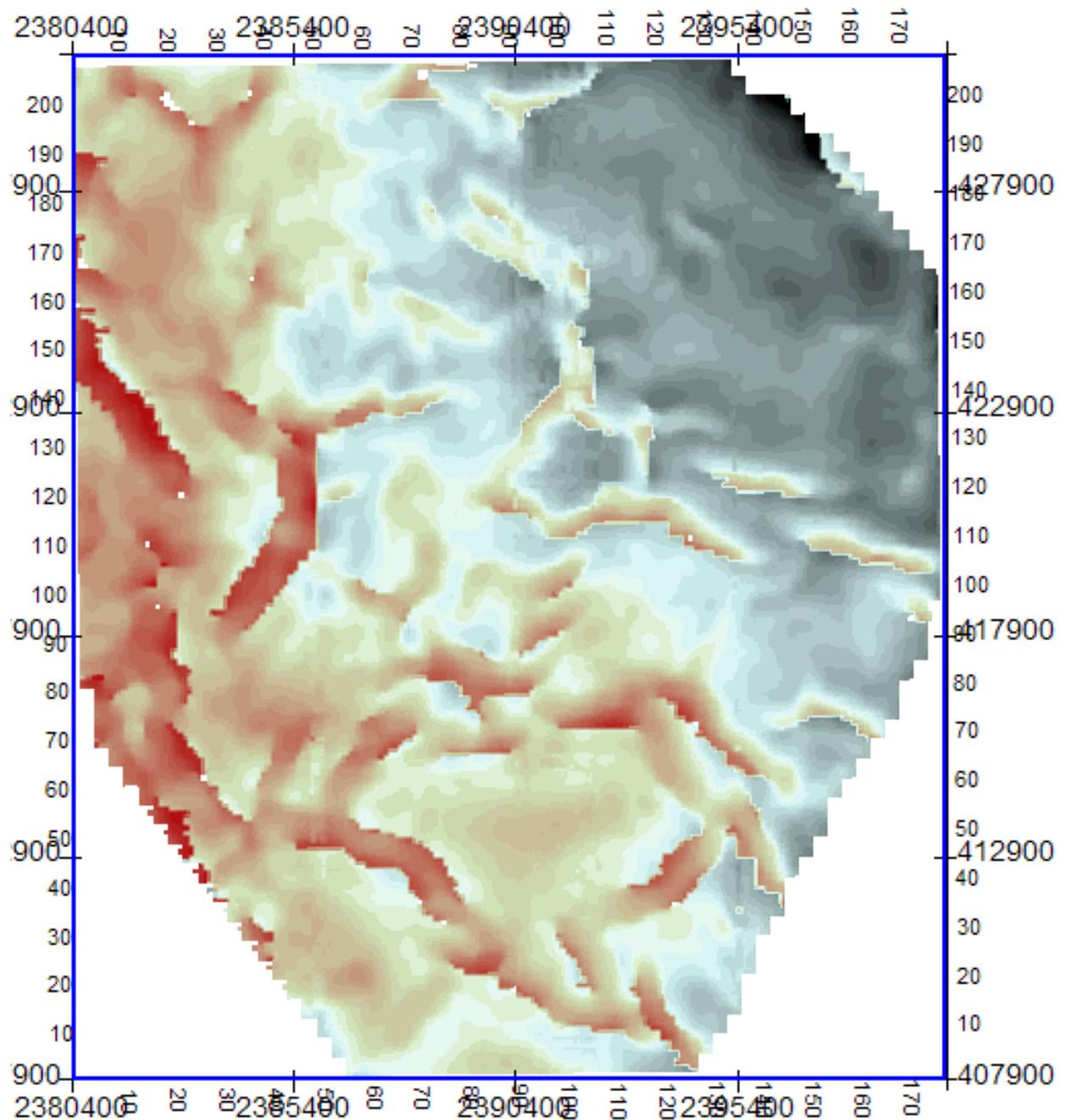
Data courtesy  
of Enerplus

Similarity 0.93

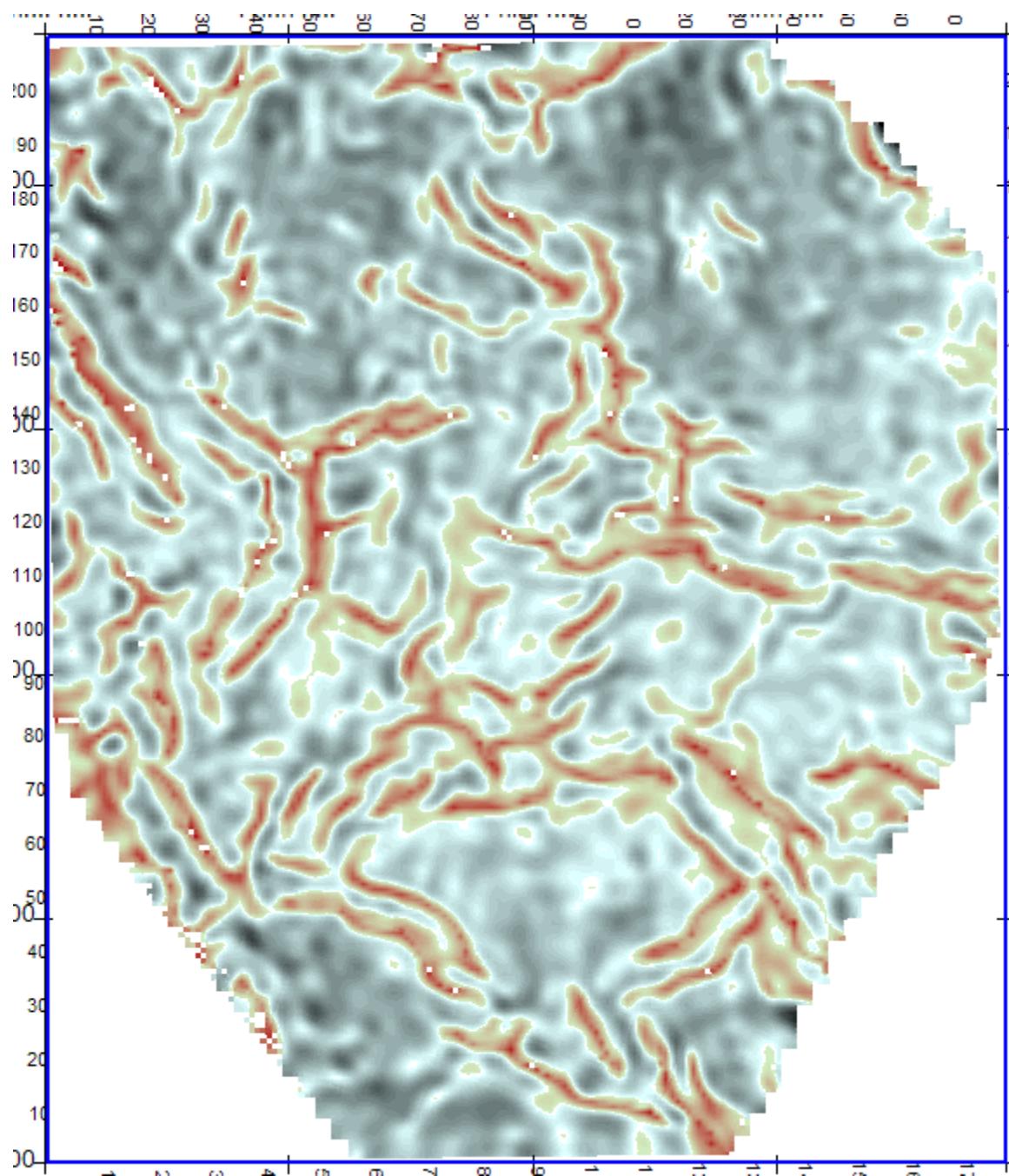


Data courtesy  
of Enerplus

# Niobrara Time Structure

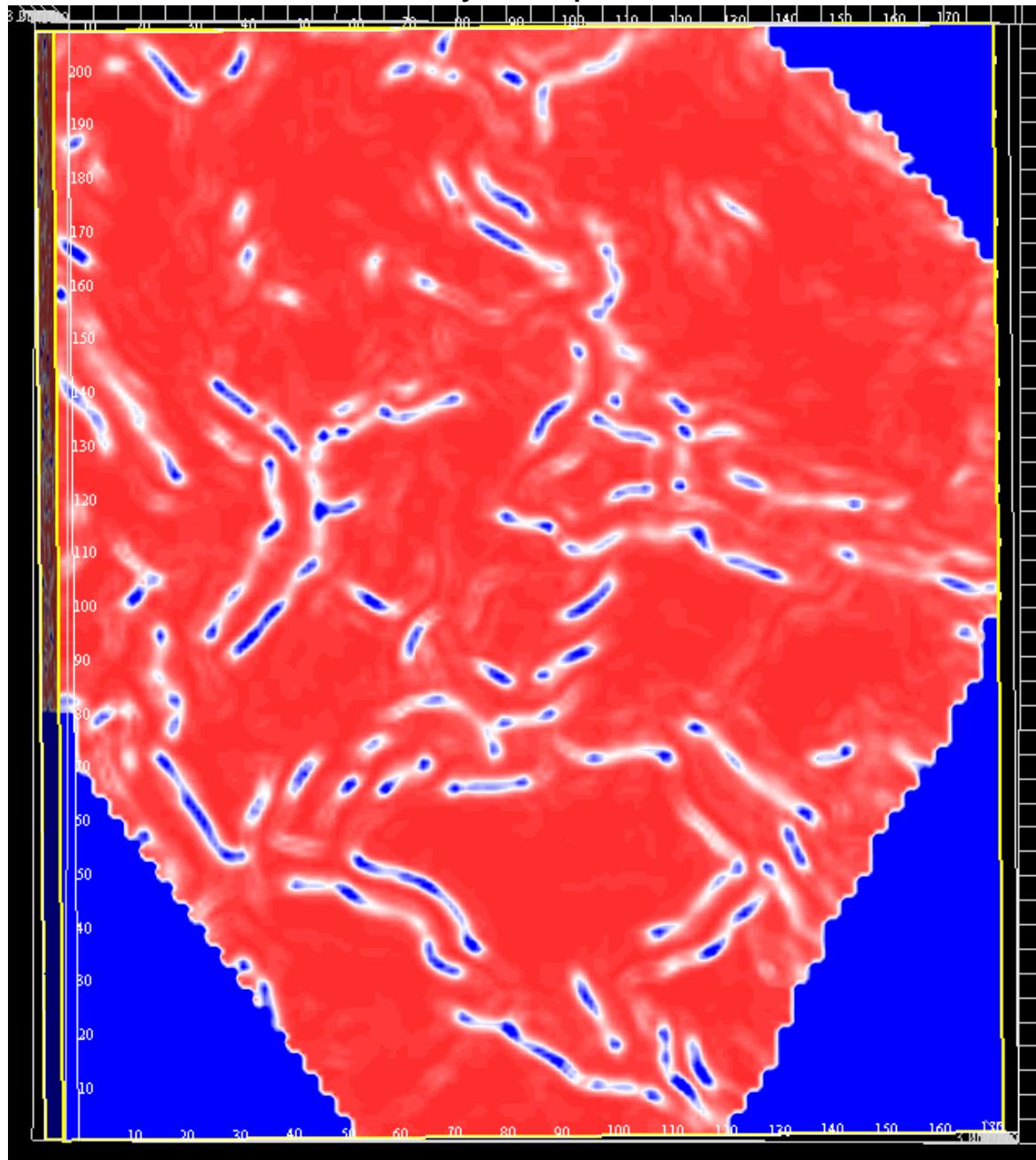


Amplitude ~1.39 Top Niobrara



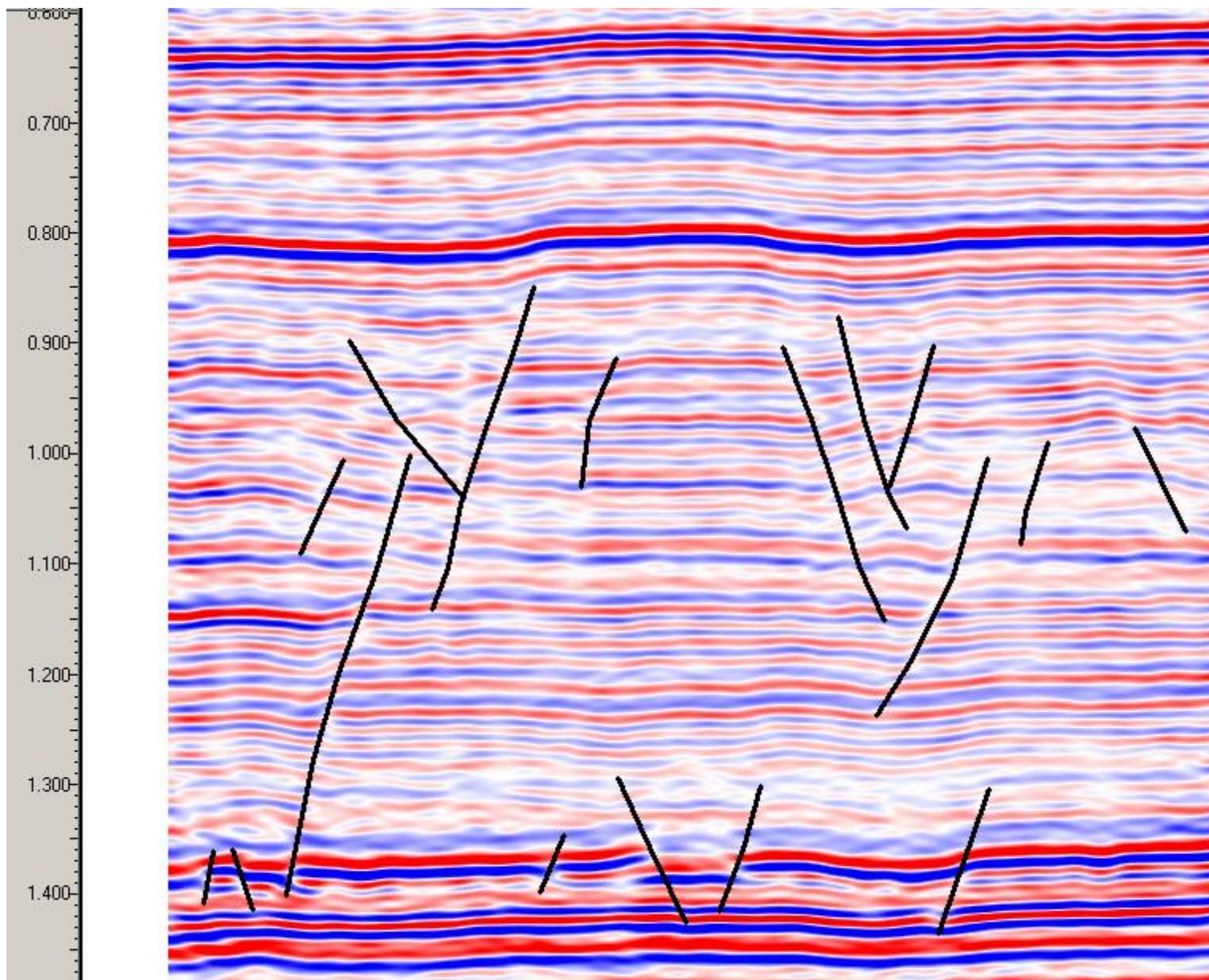
Data courtesy  
of Enerplus

## Similarity – Top Niobrara



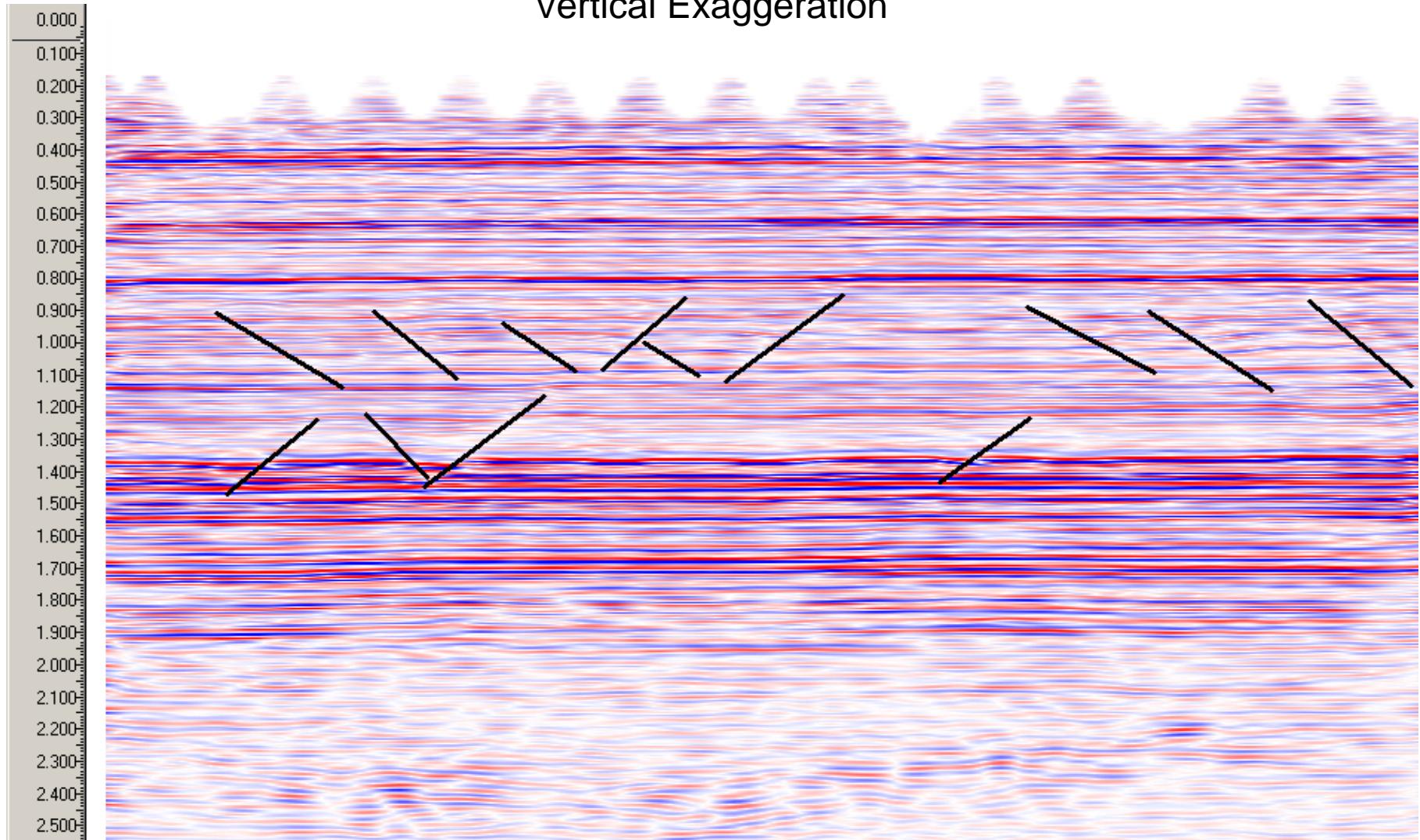
Data courtesy  
of Enerplus

# Timing

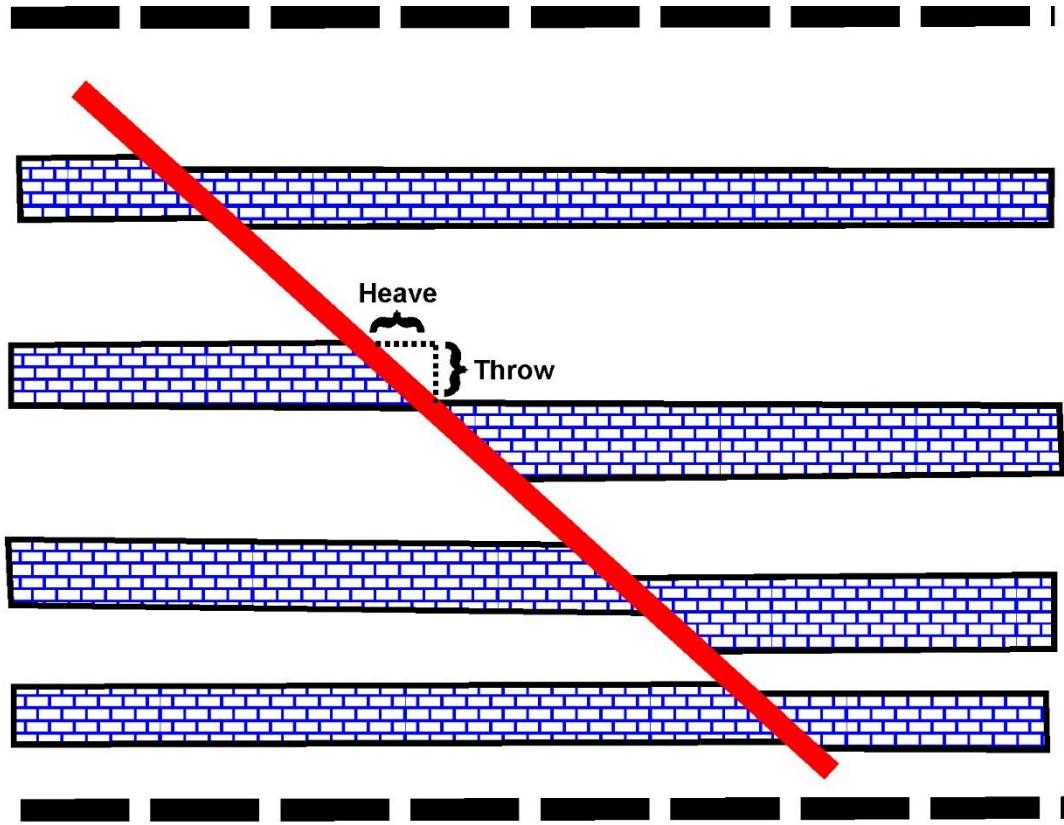
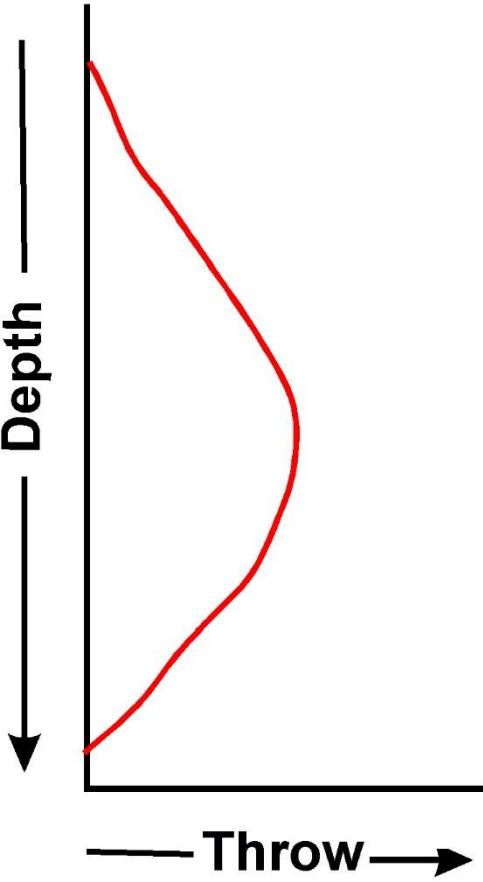


Data courtesy of Enerplus

## Vertical Exaggeration

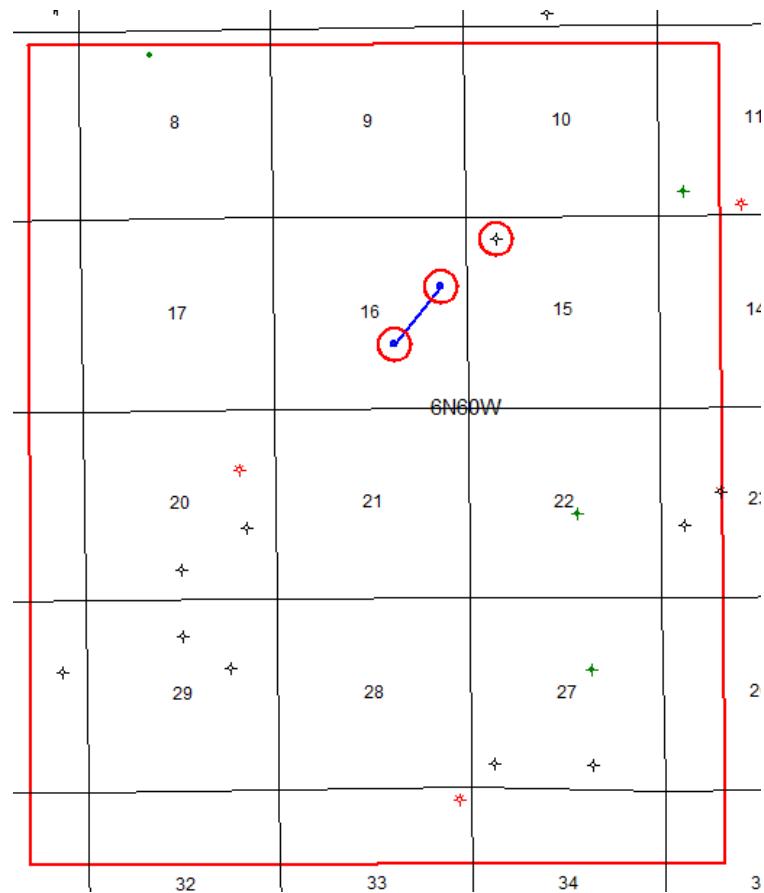
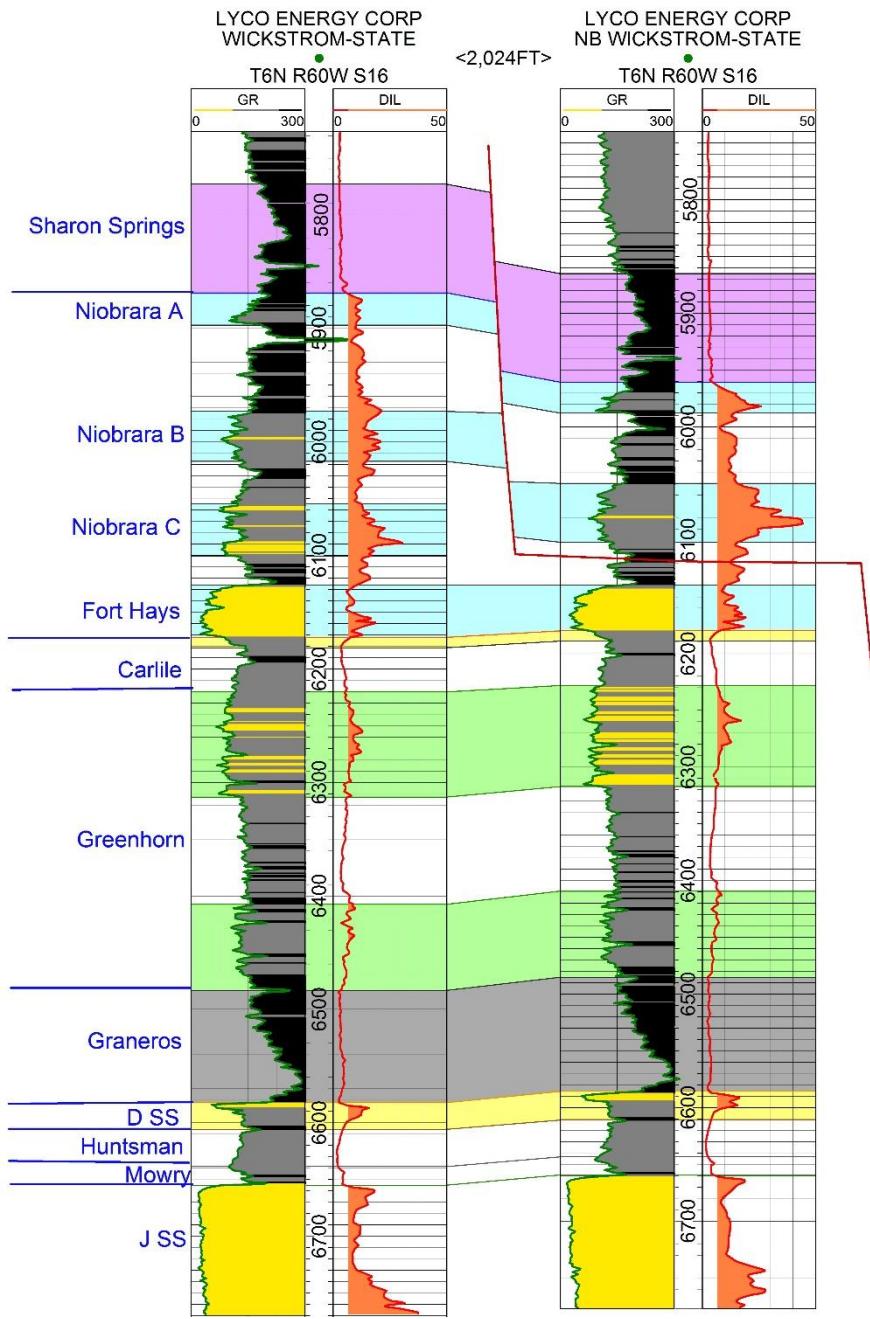


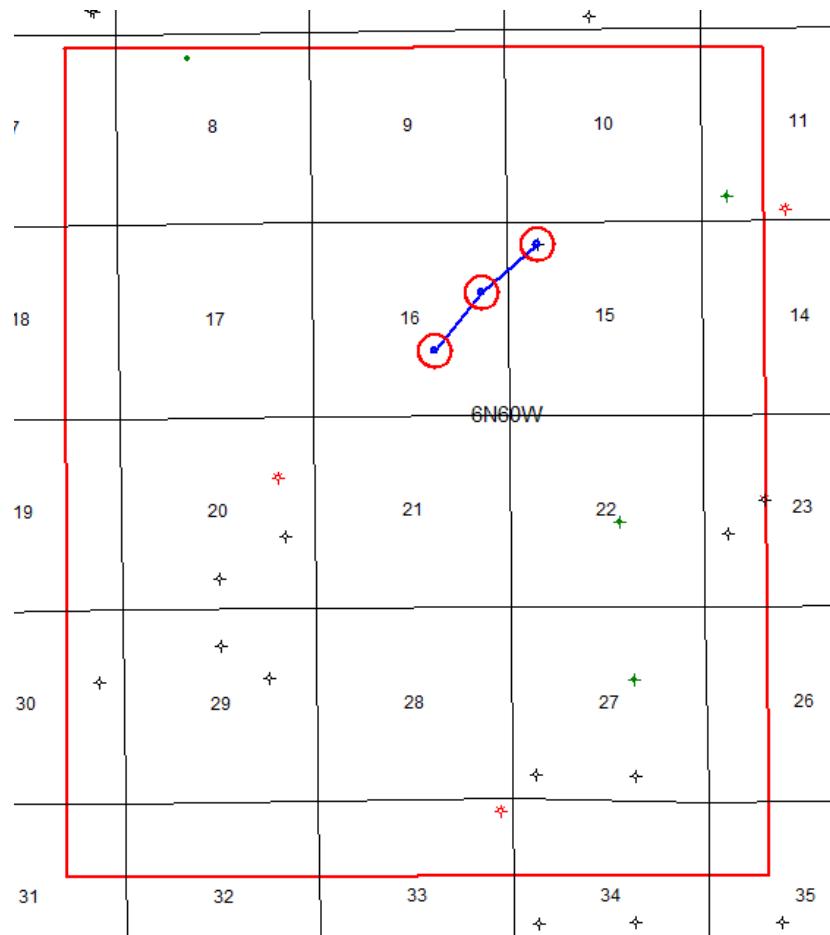
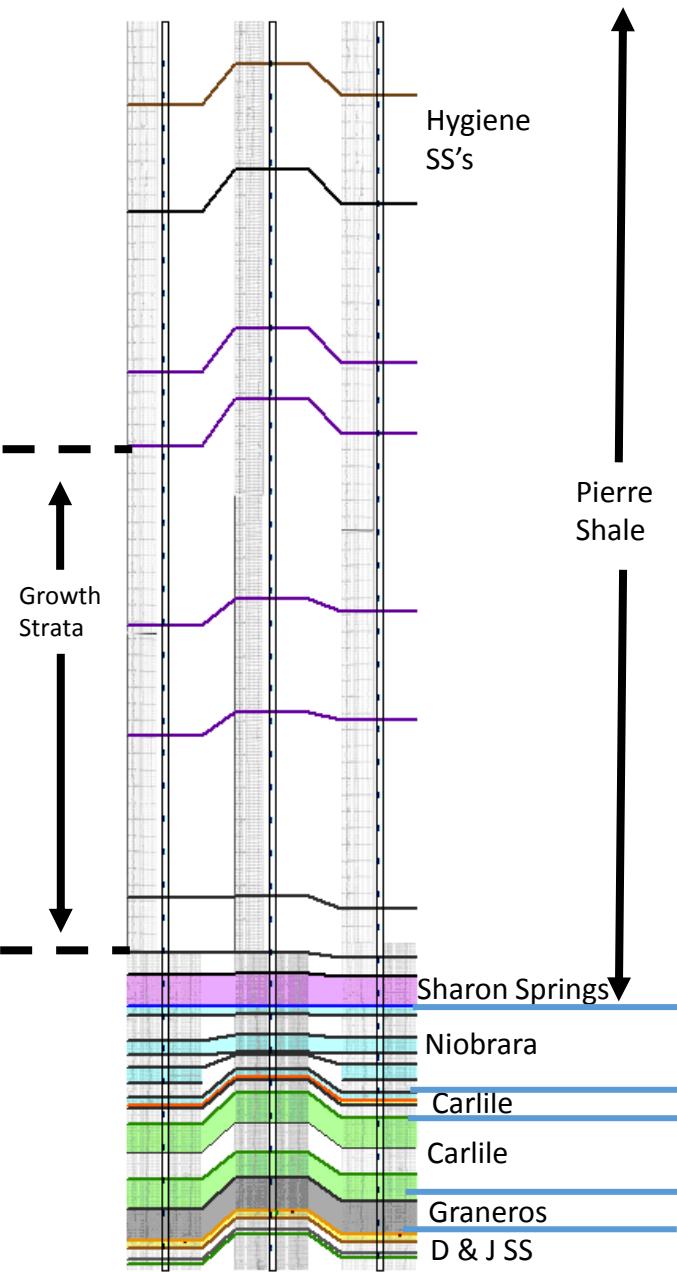
Approximately 1:1



# Fault Throw

(Vertical Separation)

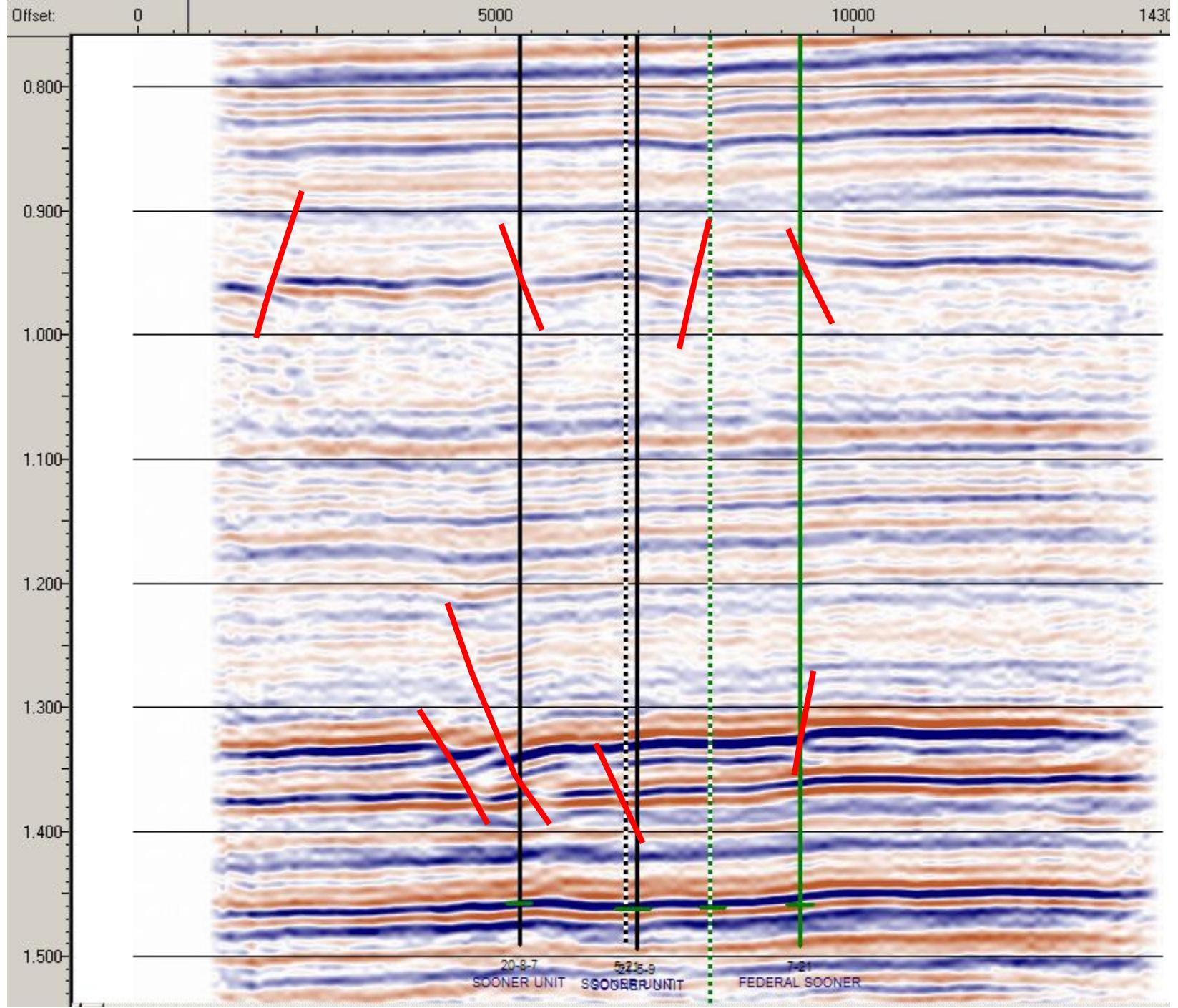




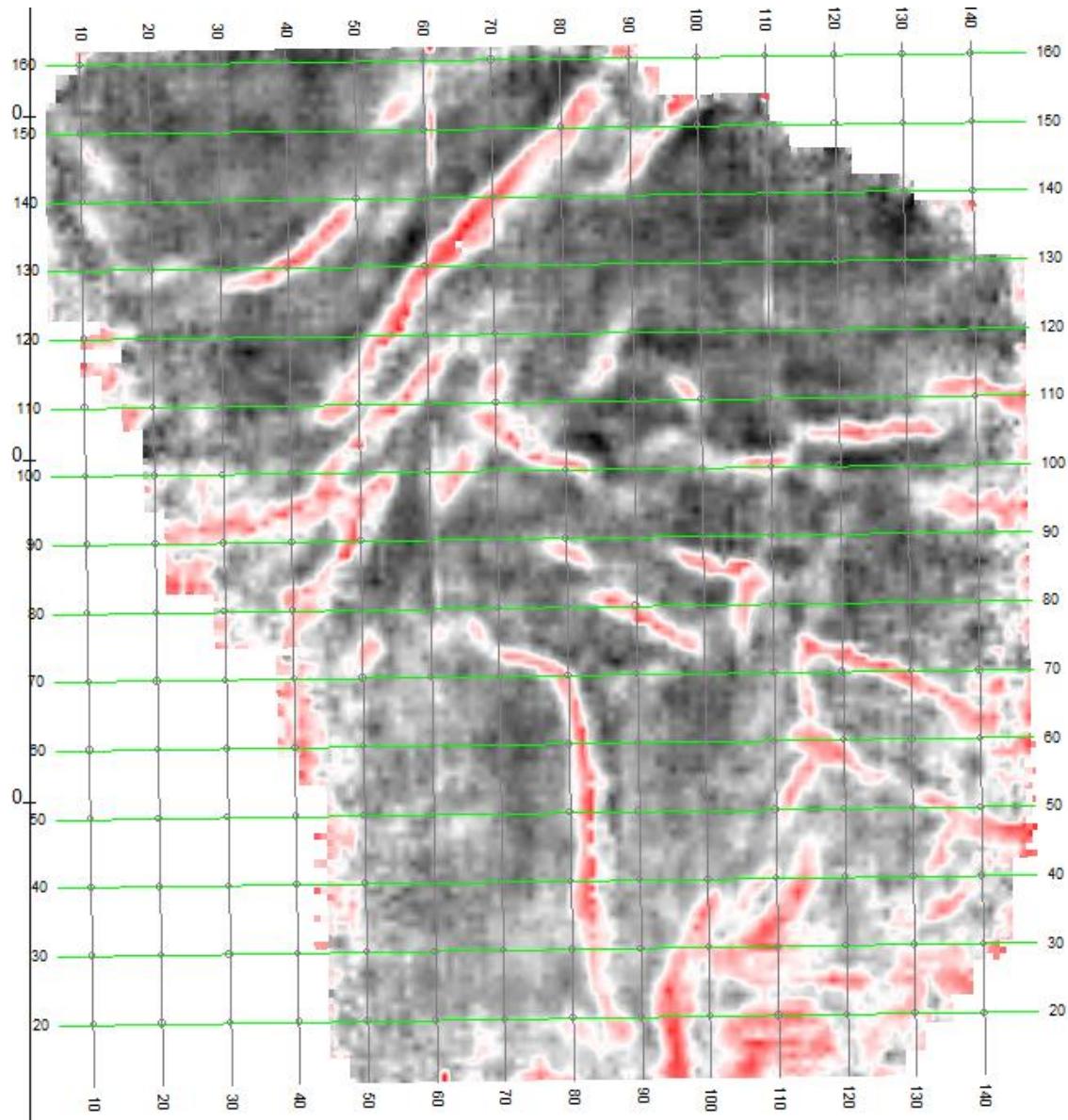
# Sooner Field

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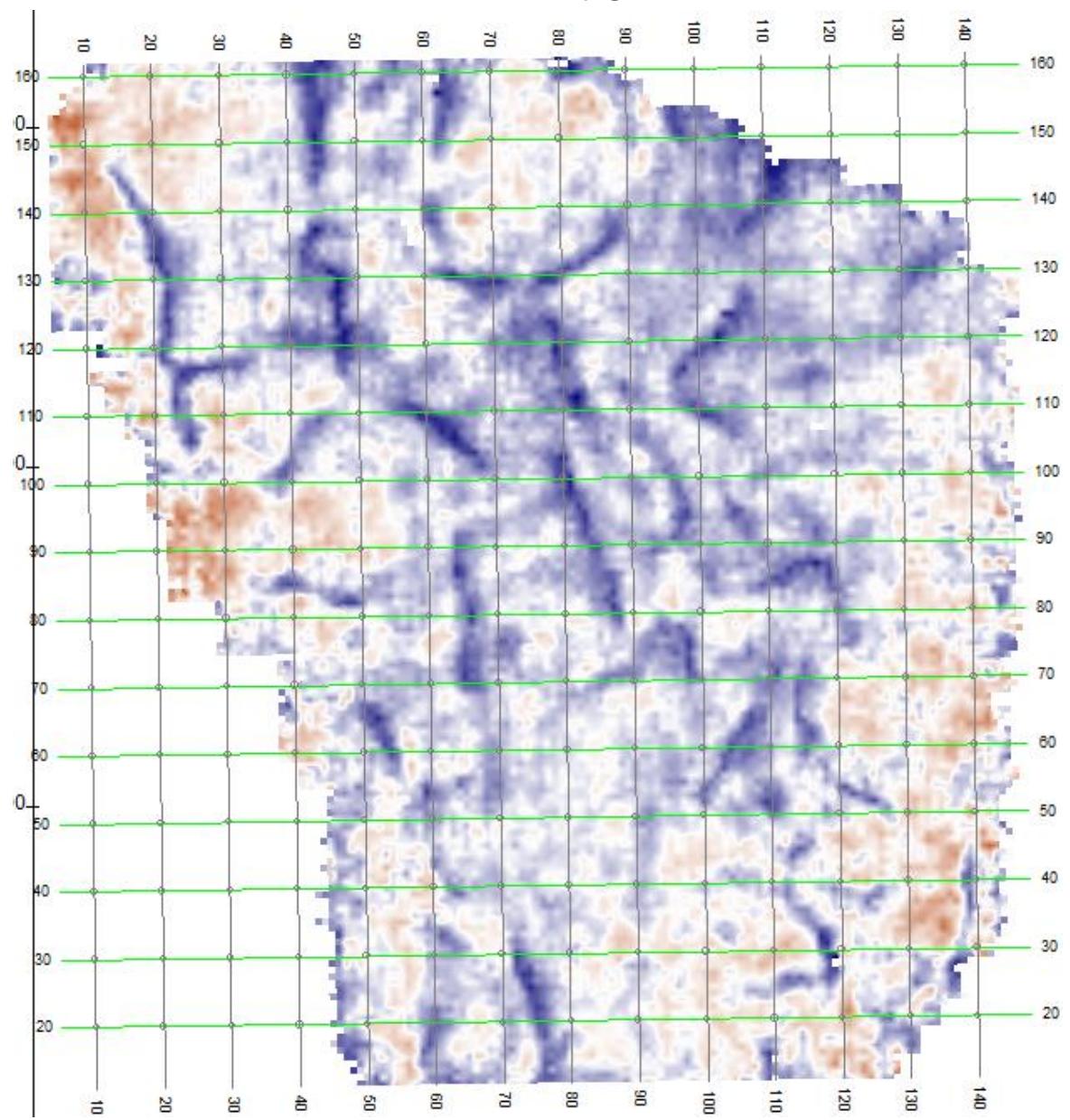
- 7.7 square miles
- 1992
- DOE sponsored seismic

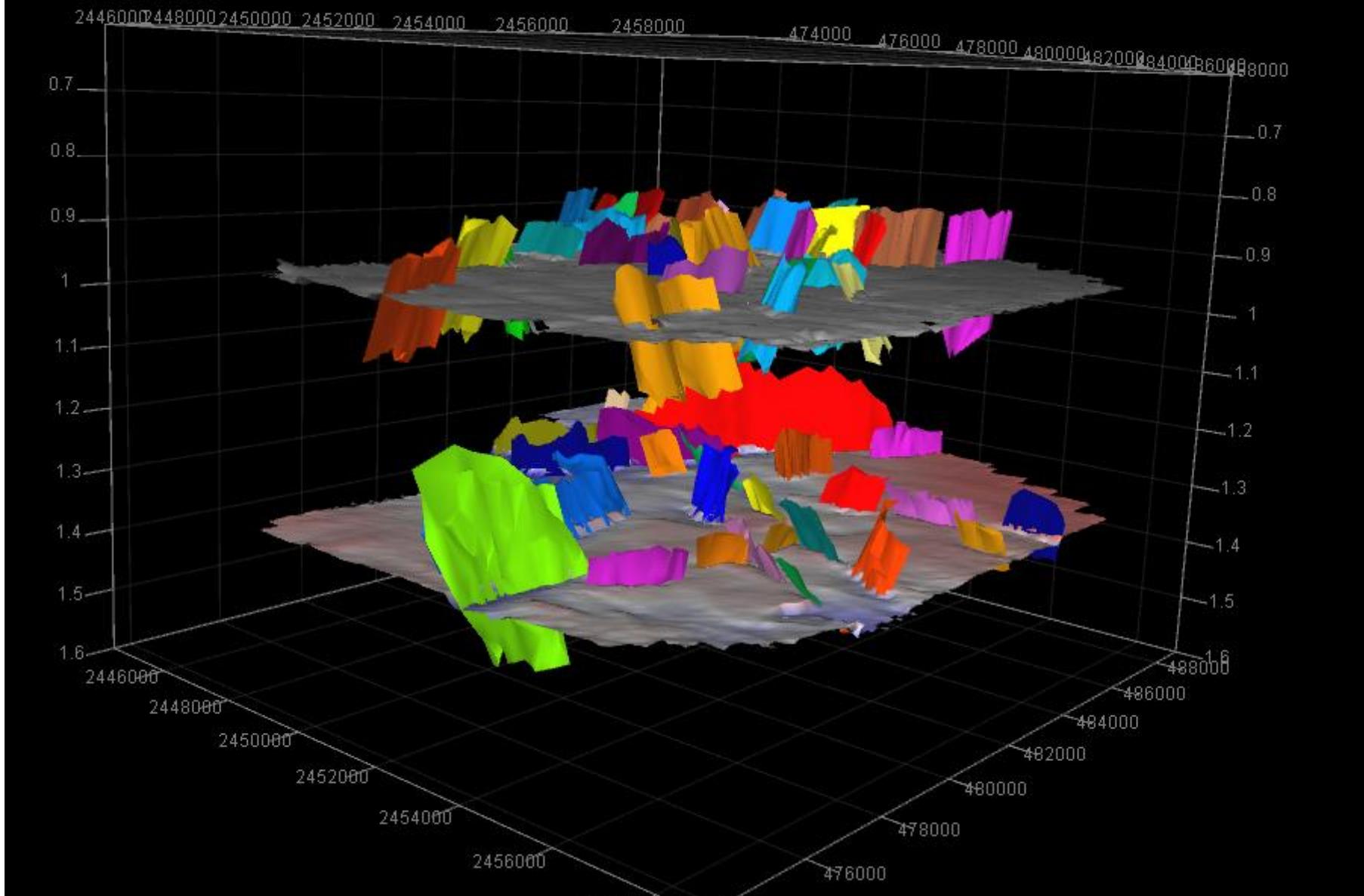


# Amplitude Niobrara



## Amplitude Lower Hygiene (~0.96)





VuPak, Hygiene & Niobrara Faults

Two tiers of normal faults

Dip of fault planes  $\sim 45^\circ$

## PETROLEUM ENERGY CO

JET

M

PETROLEUM ENERGY CO

DIXON

N

PETROLEUM ENERGY CO

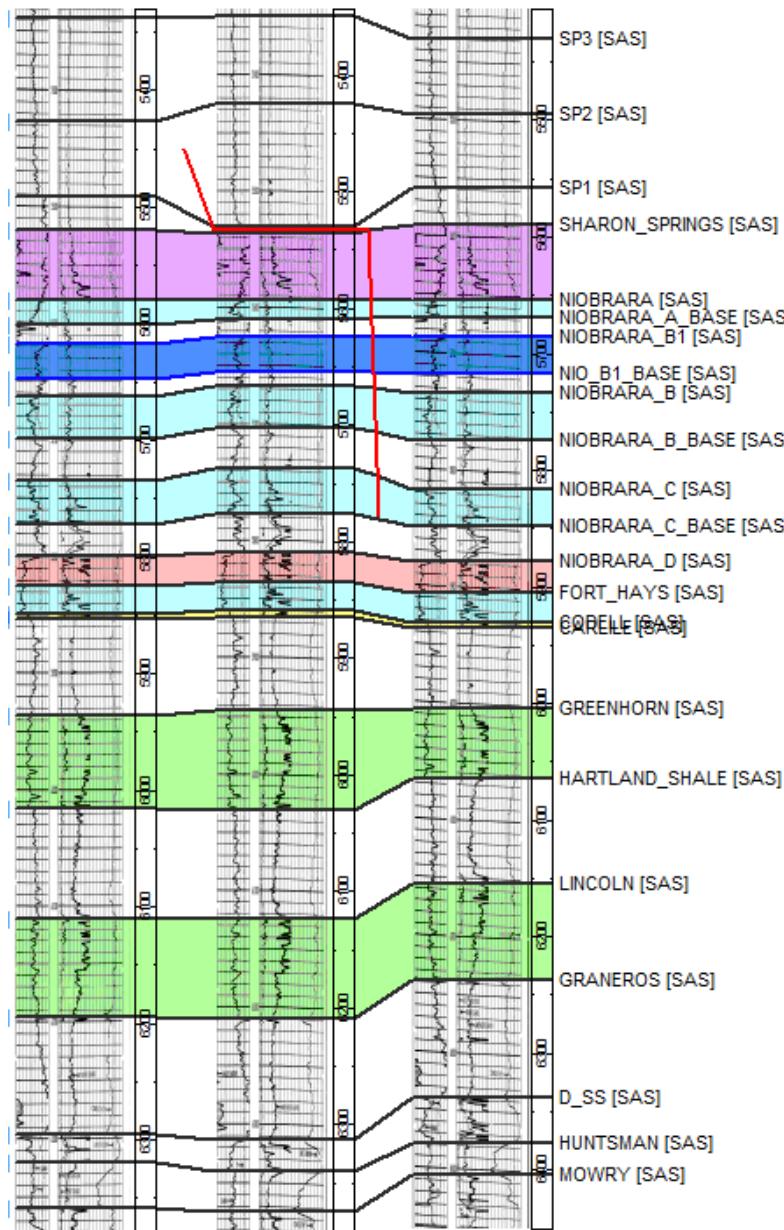
DIXON

OA

T8N R58W S28

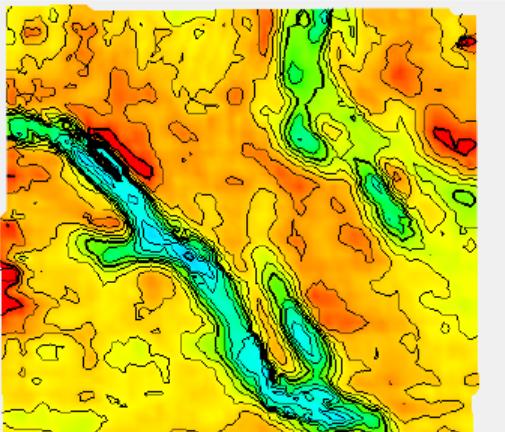
T8N R58W S28

T8N R58W S28



# Rocky Hollow Survey

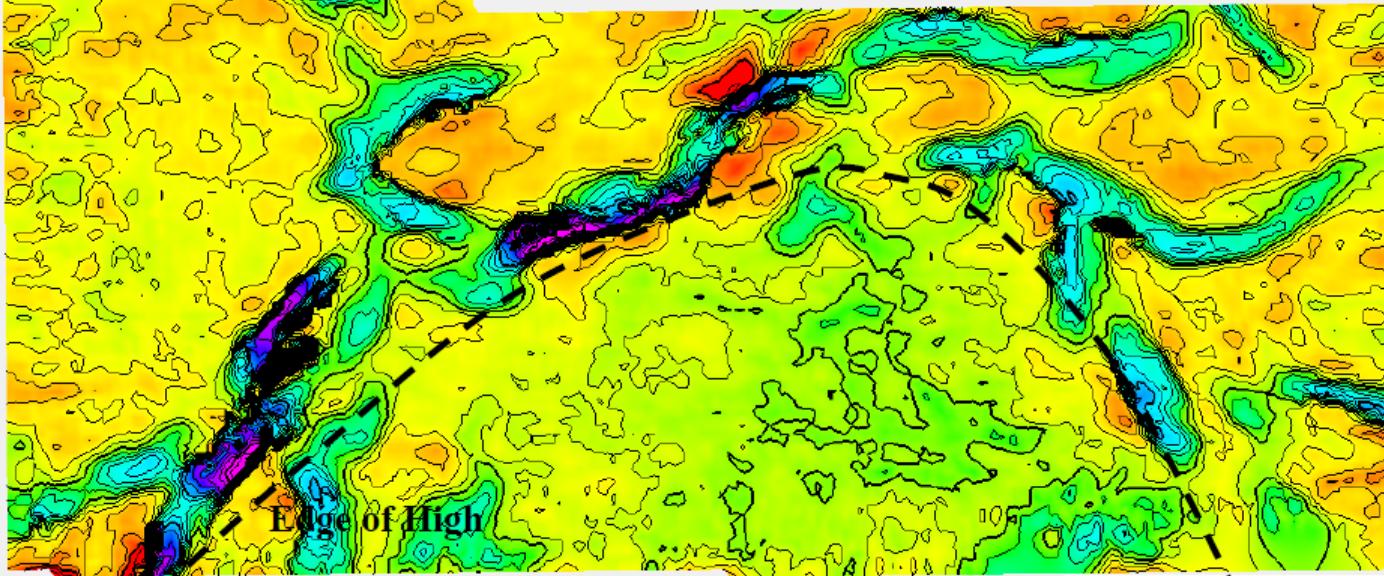
- Fidelity Exploration proprietary survey (2009)
- 10 square mile survey
- Two wells drilled 2011



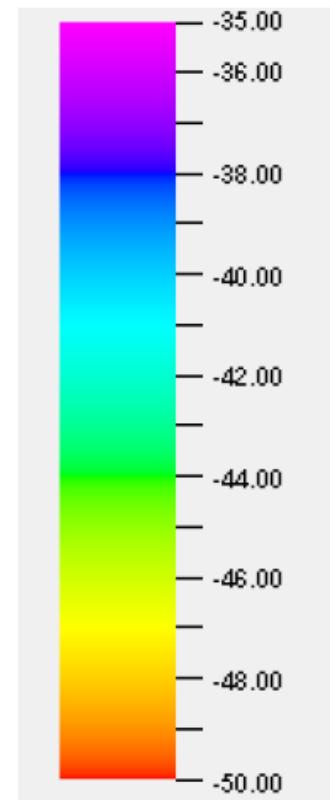
Niobrara Formation Isochron



1 Mile



Thickness time (ms)

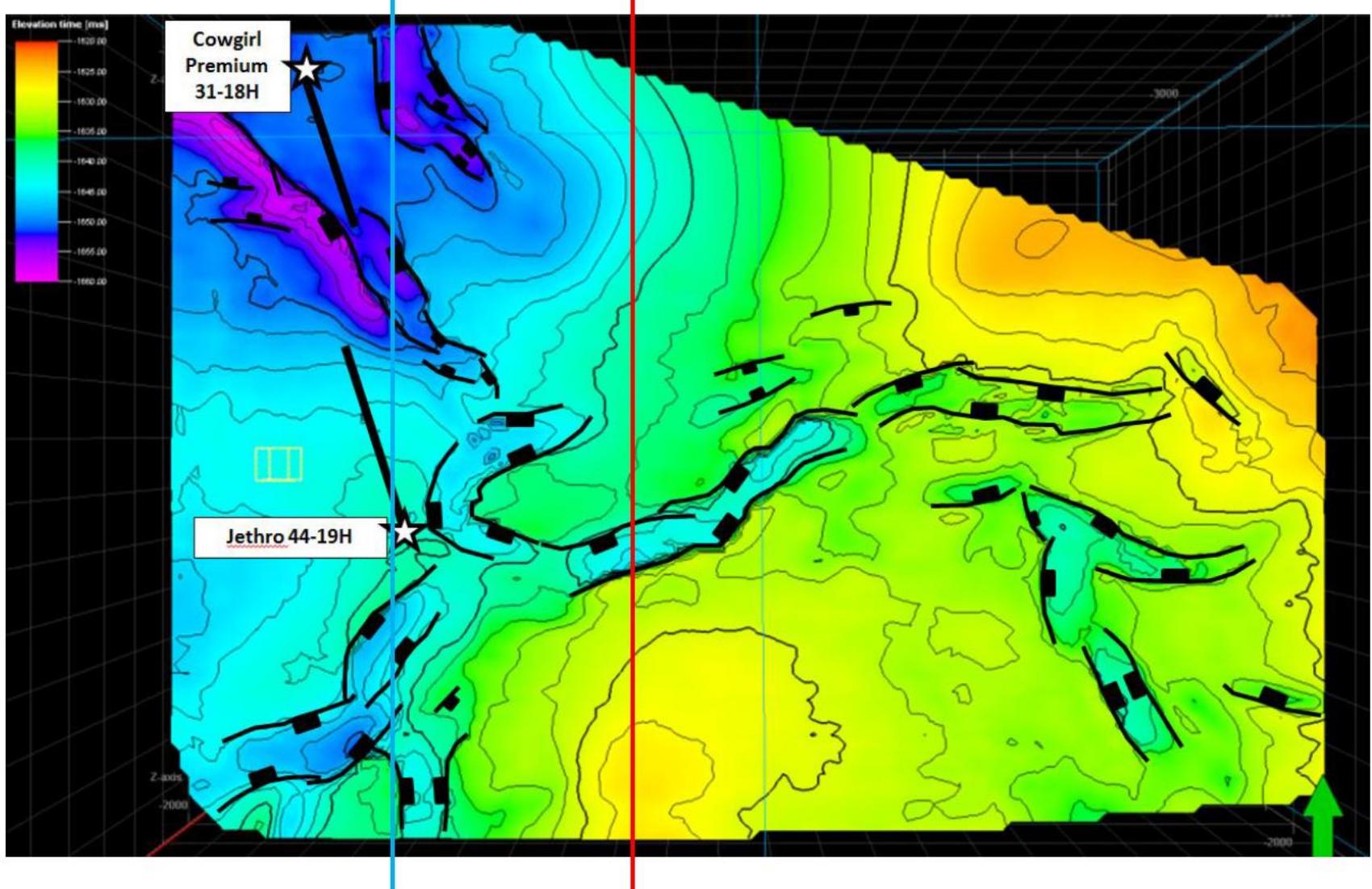


Isochron Niobrara Formation

Thinning indicates normal faults.

CI: 1 milliseconds (cool colors thins, warm colors thick)

Kernan, 2014

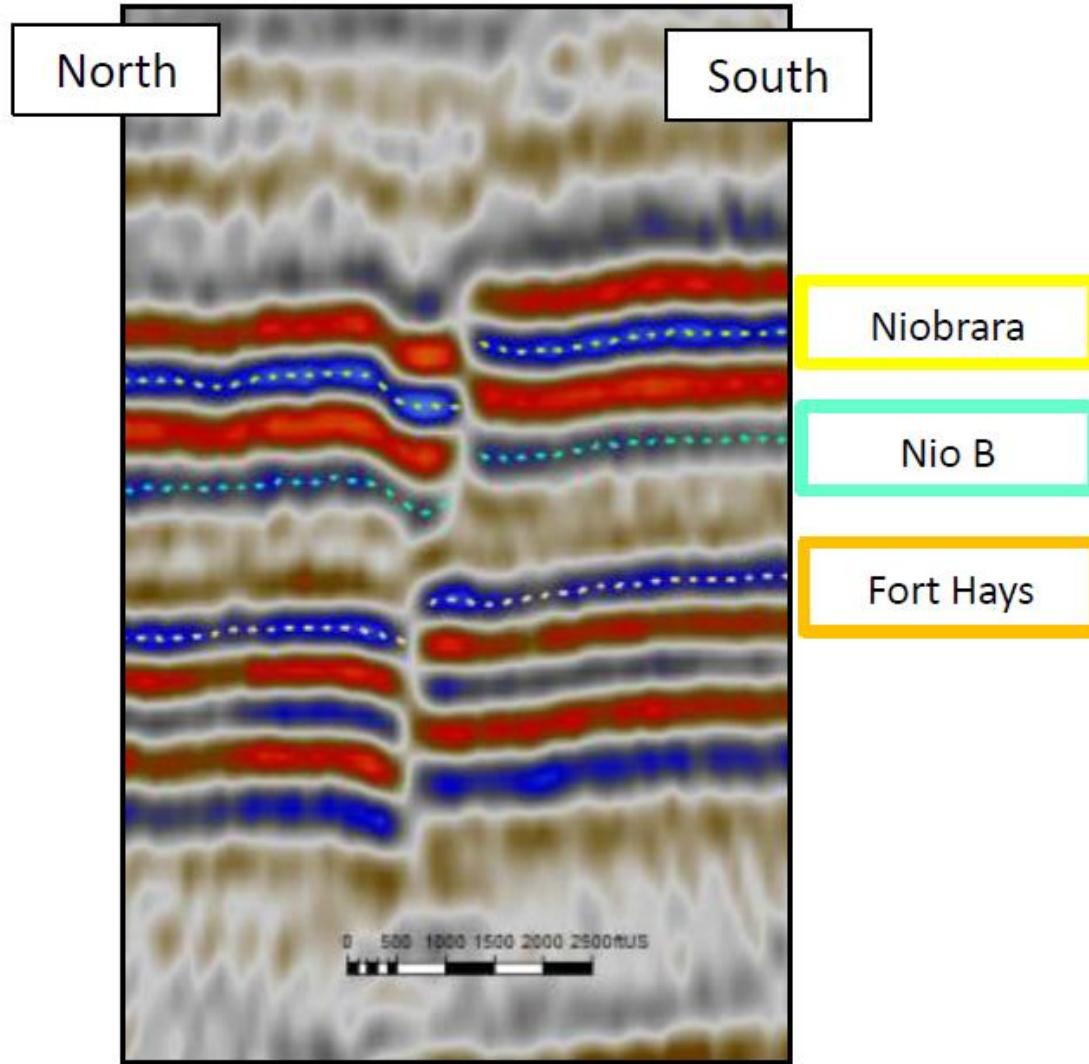


Niobrara time-structure.

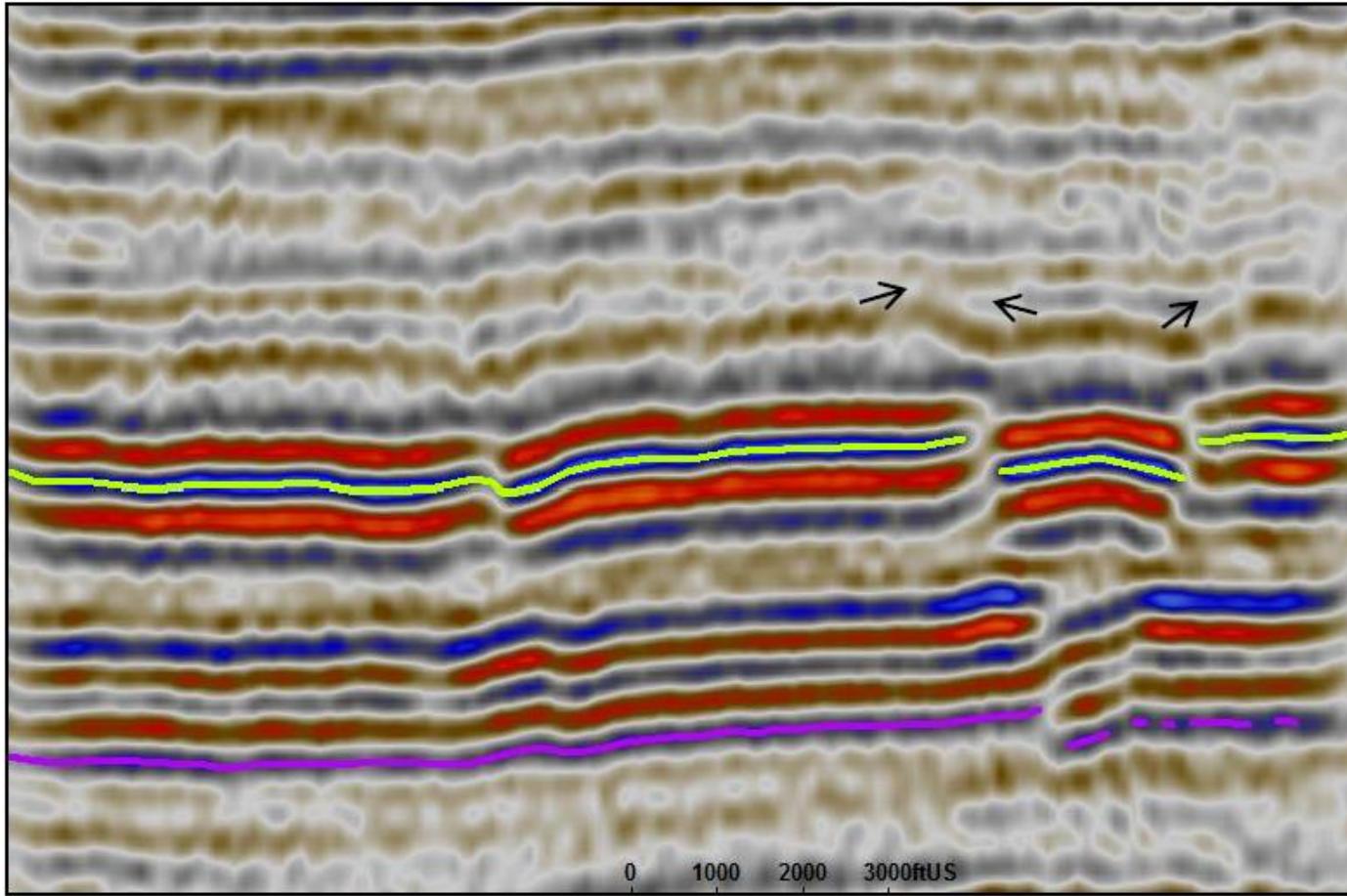
CI: 2 milliseconds

X-line 94 red; x-line 41 blue

Kernan, 2014



X-line 94.  
10X vertical exaggeration.



X-line 41,  
Vertical exaggeration 7:1  
Onlap of strata onto fault scarps

Niobrara

Greenhorn

# Cherry Creek Survey

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- Noble proprietary survey (Peterson thesis)
- 15 square mile survey
- Acquired in 2007

X/Y:  
Feet

2980520

2985800

2991080

2996360

3001640

3006920

3012200

3017480

178640

1231

1241

1201

1161

1121

1081

1041

1001

173360

1241

1201

1161

1121

1081

1041

1001

1241

1001



4840

4860

4880

4900

4920

4940

4960

4980

5000

5020

5040

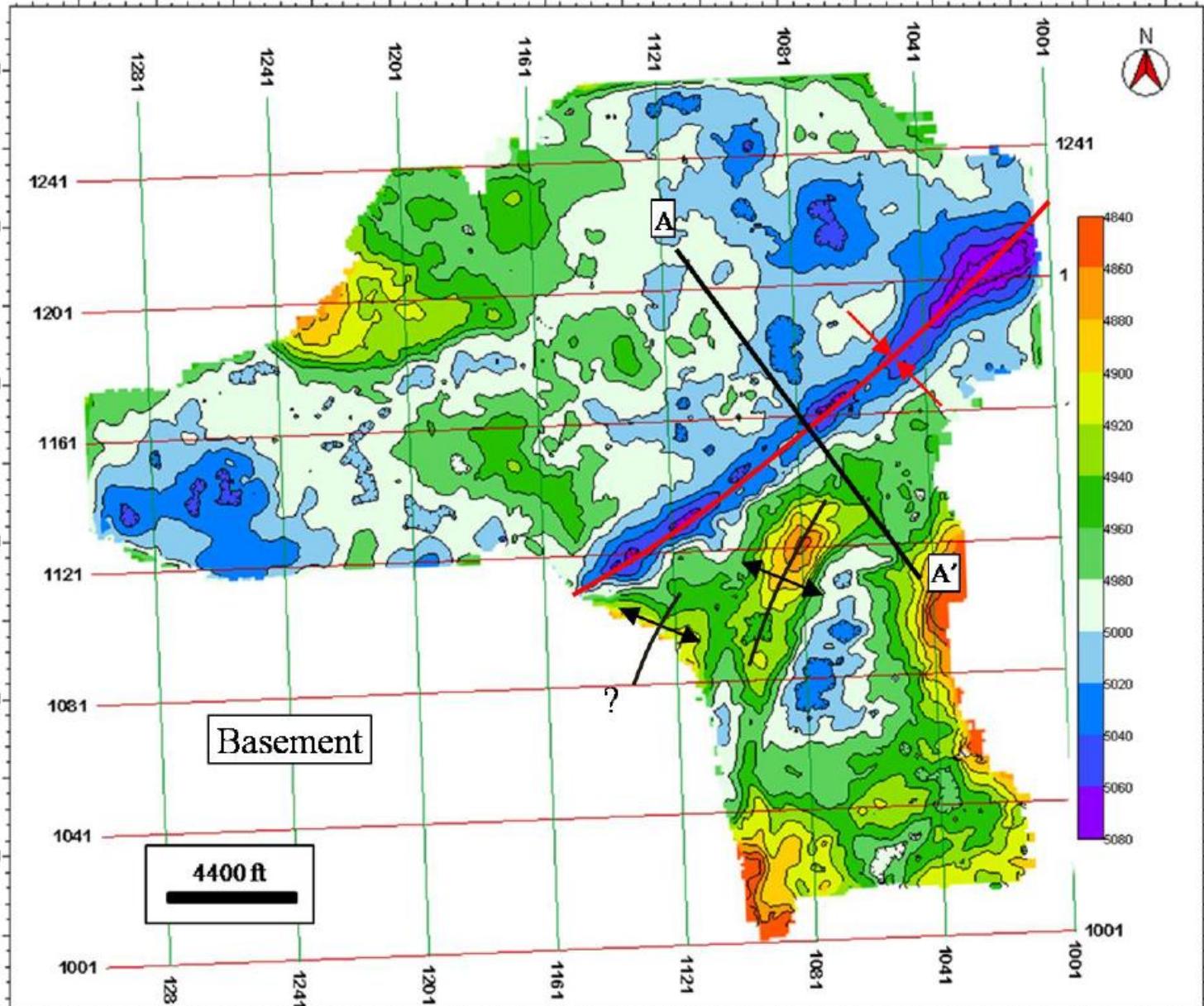
5060

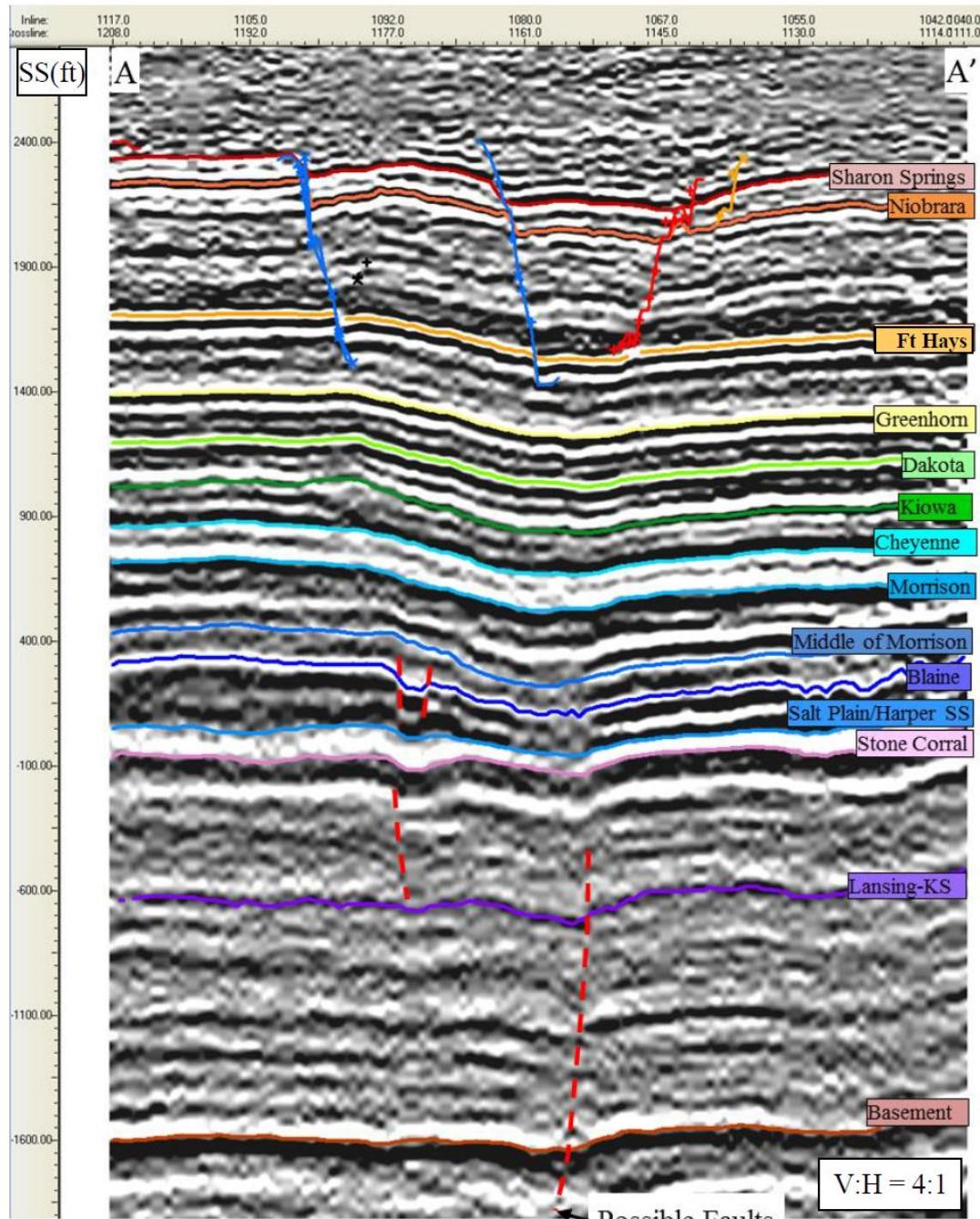
5080

1001

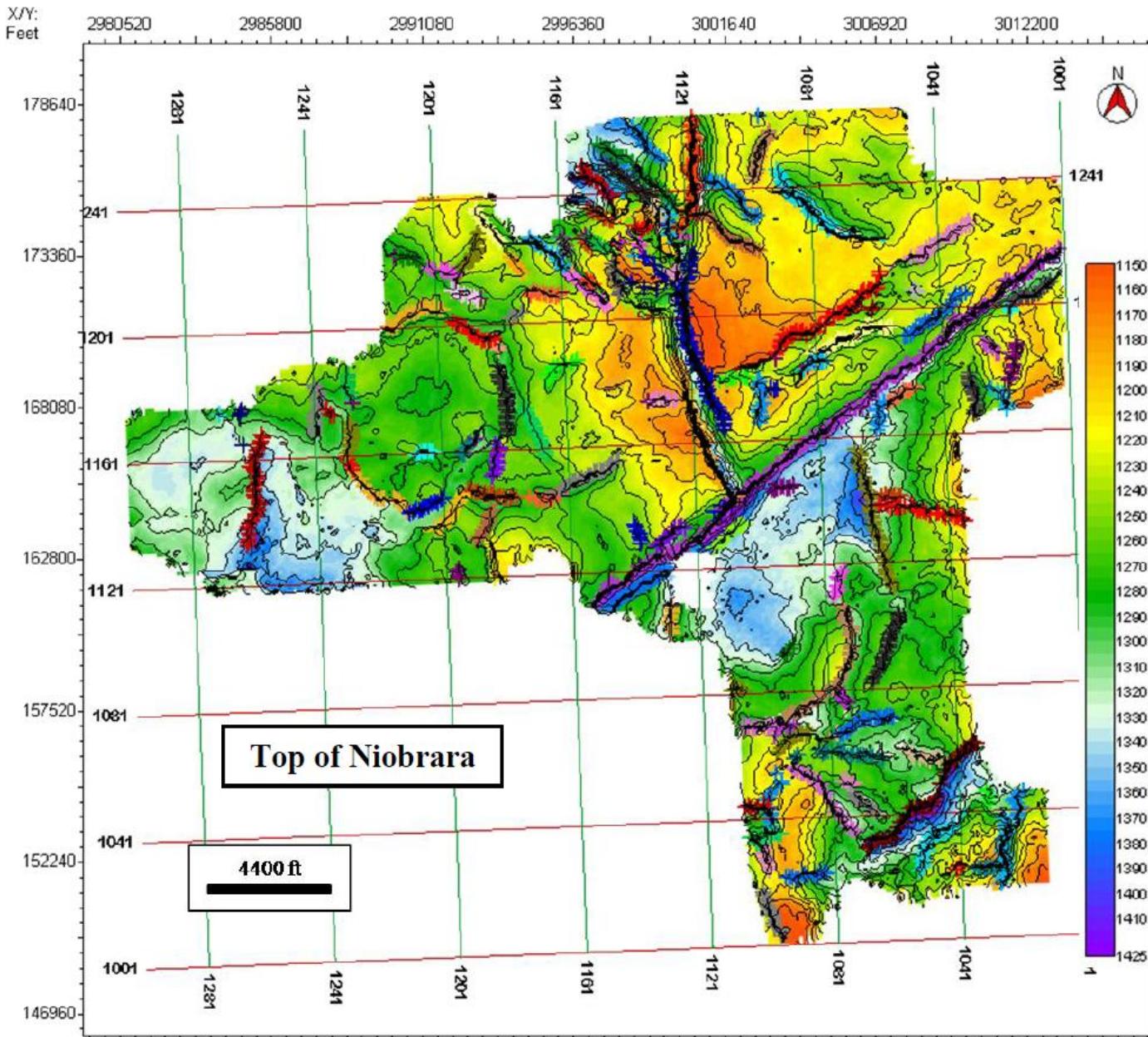
  
Basement

4400 ft

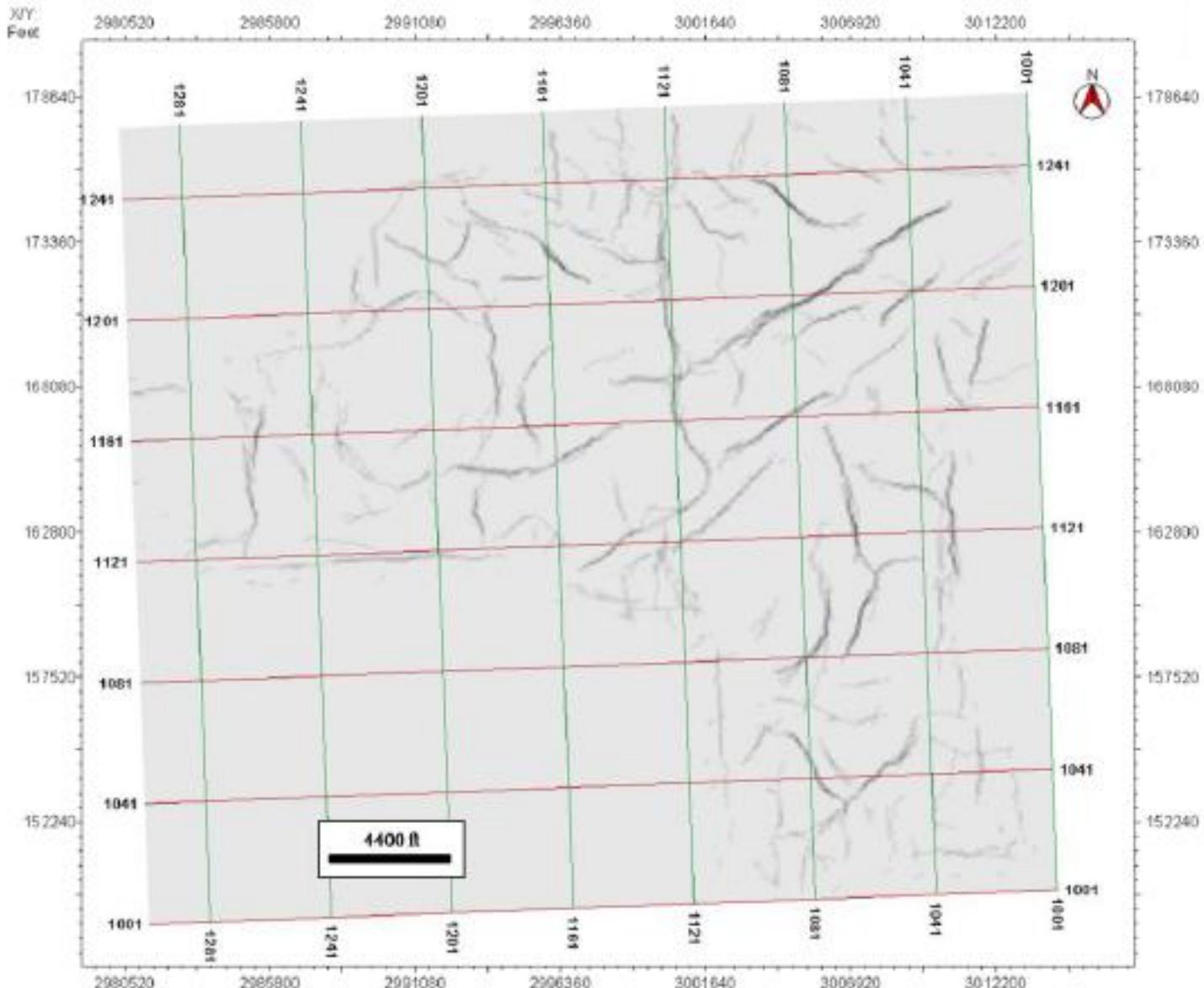
  
Structure Basement Level, CI = 20 ft (Peterson, 2013)



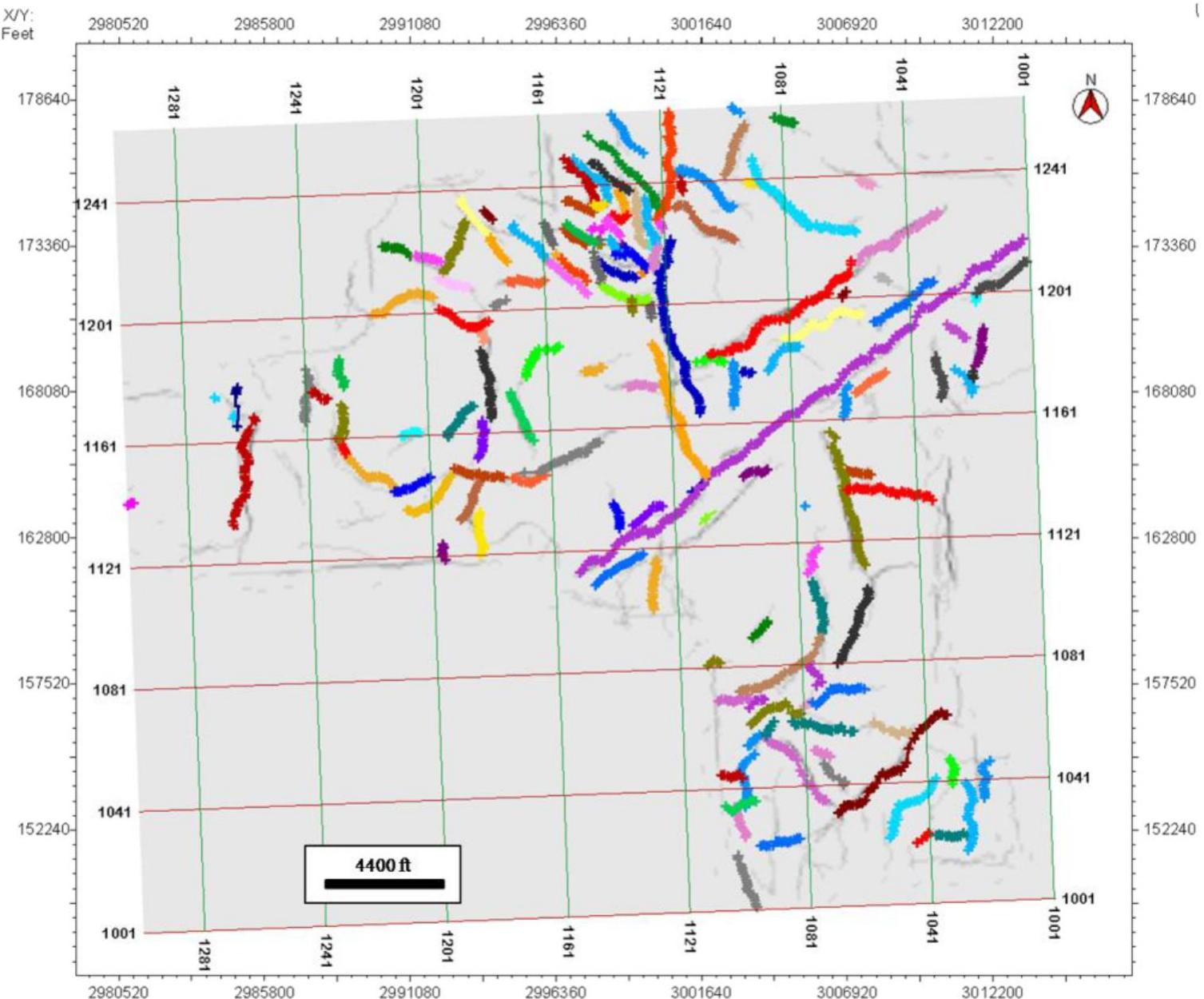
Seismic cross-section A-A' (Peterson, 2013)



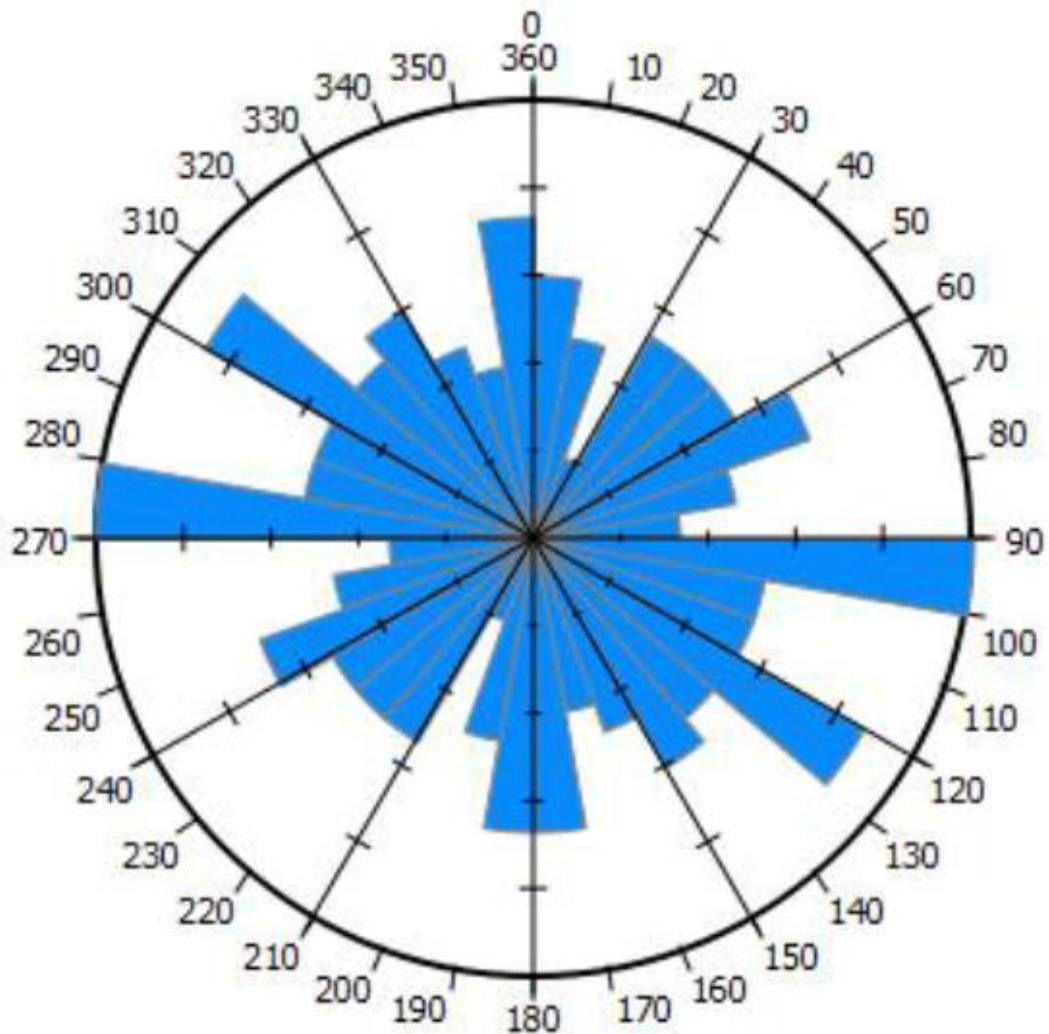
Structure Niobrara Formation (Peterson, 2013)



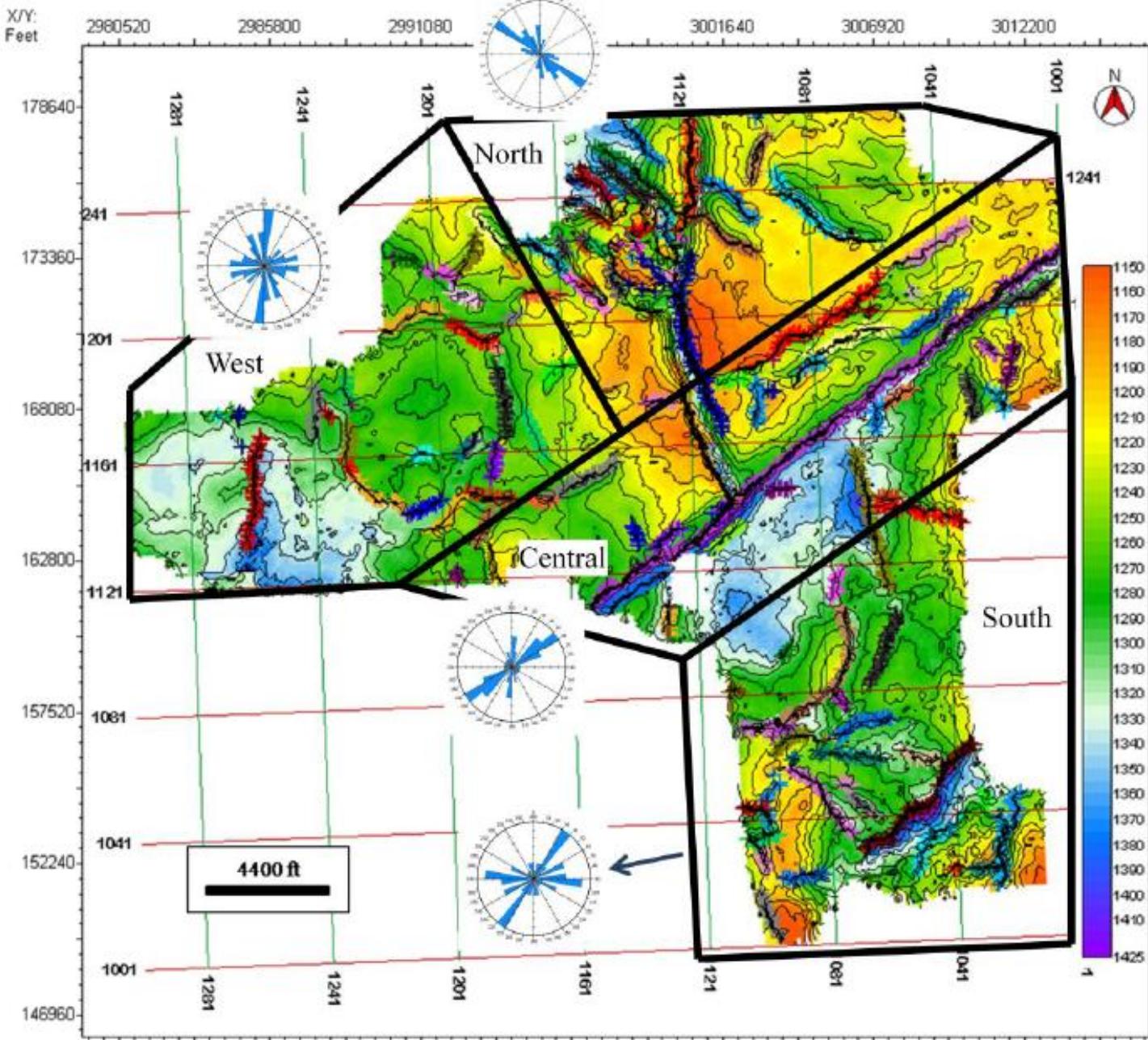
## Ant-tracking depth slice 1240 ft below surface (Peterson, 2013)



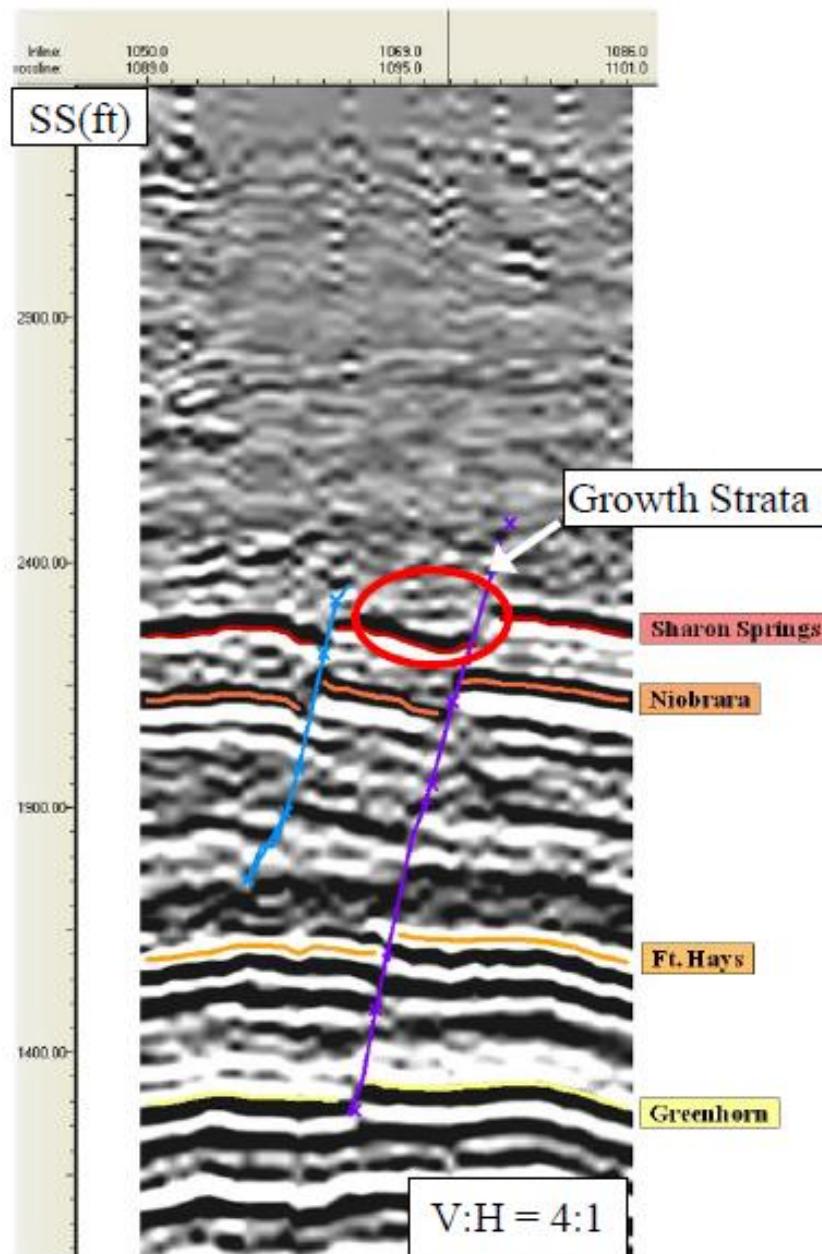
## Ant-tracking and mapped faults (Peterson, 2013)



Rose diagram plot of faults within Cherry Creek study area (Peterson, 2013)

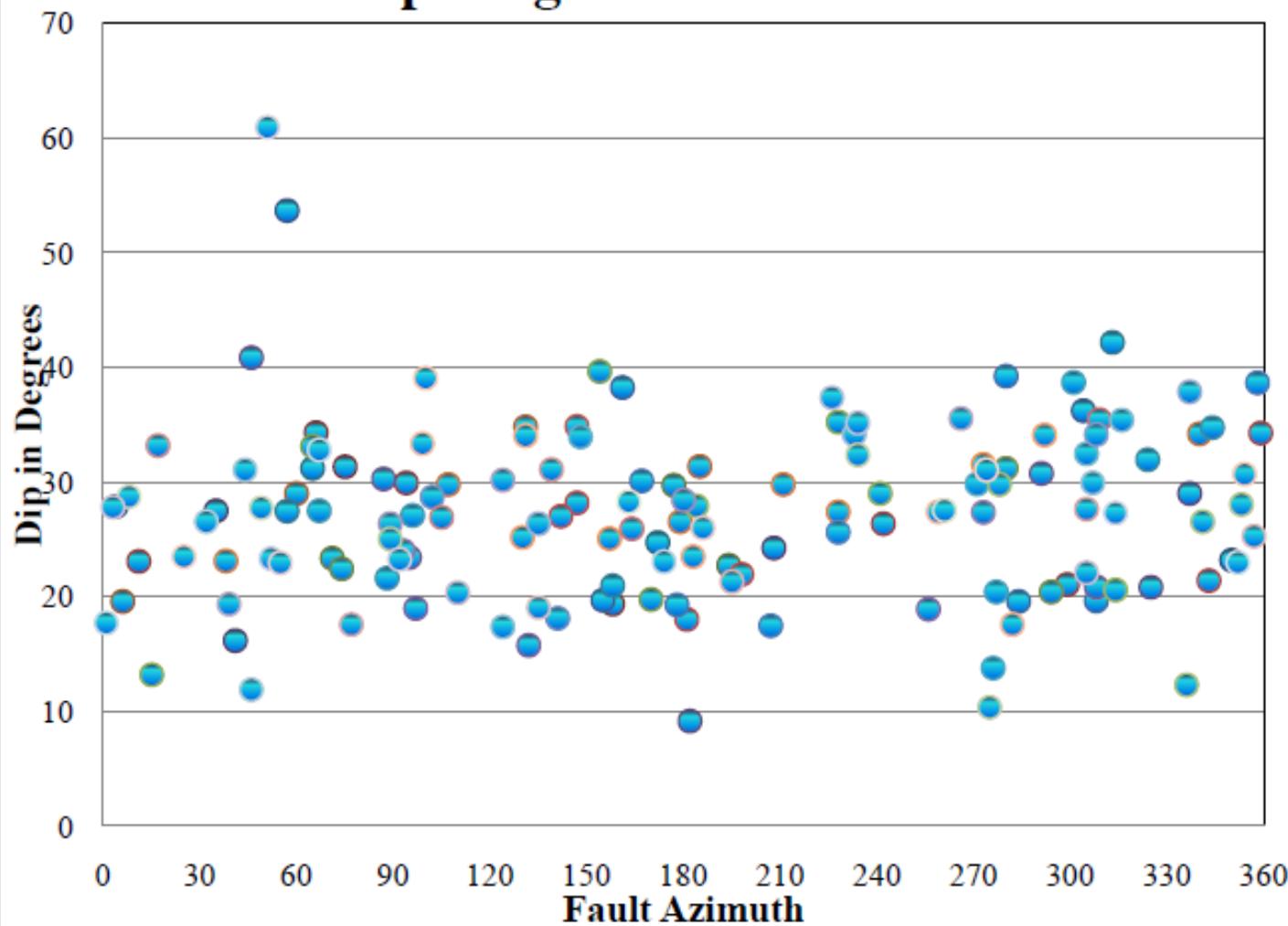


Niobrara Faults and Rose diagram plots (Peterson, 2013)



Growth strata (Peterson, 2013)

## Dip Magnitude vs. Fault Azimuth

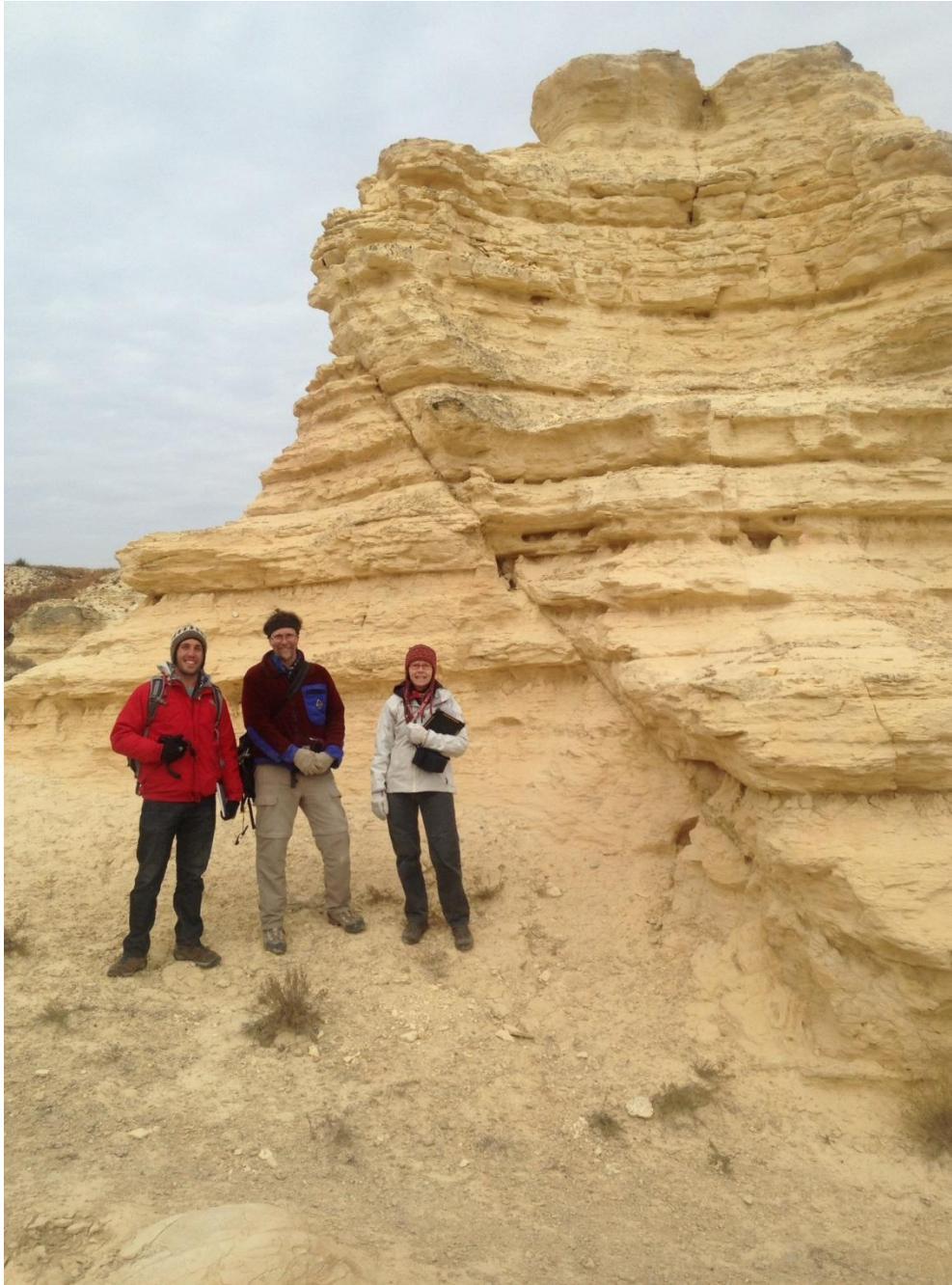


Dip values versus azimuths (Peterson, 2012)

# Summary

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- Two layer bounded polygonal fault systems are recognized in Denver Basin
  - 1) Below Hygiene Sandstones
  - 2) Niobrara Formation
- PFS common in fine grained systems (shales and chalks)
- Most faults low angle, slightly listric (?)
- Basement faults still important
- Permian salt dissolution creates faults
- Compactional features over D SS or Permian Sandstone buildups



Castle Rock  
C Chalk Outcrops:

Nico Kernan  
Dr. Harmon Maher  
(Univ. of Nebraska)  
Dr. Barbara Tewksbury  
(Hamilton)

Photo by Steve Sonnenberg