Petroleum Geology of Silo Field, Wyoming*

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Abstract

The Silo Field is located in the northern part of the Denver basin. Production is from the fractured Niobrara Formation at depths ranging from 7600 to 8500 ft. (2318 to 2593 m). Cumulative production from 40 vertical and 68 horizontal wells at Silo is in excess of 10.4 million barrels of oil and 8.9 billion cubic feet gas. Recent drilling success with horizontal wells and multistage-fracture stimulation suggests much greater future production. Initial potentials from the new horizontal wells range from 500 to 2000 bbl of oil/day.

The dominant lithologies of the Niobrara are limestones (chalks) and interbedded calcareous and organic-rich shales. Niobrara thickness ranges from 280 to 300 ft. (85 to 92 m). Four limestone intervals, averaging 30 ft. (9.2 m), and three intervening shale intervals (averaging 47 ft or 14.3 m) occur regionally and are easily recognized on geophysical logs. The lower limestone is named the Fort Hays, and the overlying units are grouped together as the Smoky Hill member. Limestone beds in the Smoky Hill are informally named the A, B, and C intervals in increasing depth order. The fractures are concentrated in the more brittle limestones. The main production is from the middle limestones (B interval) of the Smoky Hill. Shows and production also come from the A, C, and Fort Hays chalk intervals in older vertical wells; this suggests they may be future targets of horizontal drilling. The current target of horizontal drilling is the B chalk interval. The intervening shales have high organic matter content and served as source beds and seals.

Open fracture systems are essential to Niobrara production because little matrix porosity exists in the limestones. Open fractures in the field are very consistent and are oriented N25-40W. The consistent orientation of fractures suggests that this is the orientation of the maximum horizontal stress. Open fractures may be created by: (1) solution of Permian evaporites; (2) folding over basement fault systems; (3) regional horizontal stress field; (4) hydrocarbon pore pressure; (5) differential compaction over paleotopographic highs; (6) movement on wrench faults; (7) compaction and dewatering of the chalks; and (7) other uncertain causes. Additional data are needed to resolve the origin of the fractures.

High resistivities are observed in limestone beds at Silo. These resistivity anomalies appear to be related to the presence of a large hydrocarbon accumulation delineated by isoresistivity mapping.

Factors present at Silo will serve as a model for future Niobrara production in the Rocky Mountain region. These factors include (1) mature source rocks interbedded with brittle limestone; (2) open fractures to form the reservoir; (3) resistivity anomalies indicating accumulation; and (4) technology to efficiently produce the reservoir.

Selected References

Saint, R.E.., and M.J. Campbell, 1991, New Understanding of Niobrara Reservoir Characteristics Based on Horizaontal Drilling in Silo Field, Southeastern Wyoming: AAPG Bulletin, v. 75/6, p. 1123.

Davis, T.L., and C. Lewis, 1990, Reservoir Characterization by 3-D, 3-C Seismic Imaging, Silo Field, Wyoming: Leading Edge, v. 9/11, p. 22-25.

Du Rouchet, J., 1981, Stress fields, a key to oil migration: AAPG Bulletin, v. 65/1, p. 74-85.

Lockridge, J.P., and P.A. Scholle, 1978, Niobrara Gas in Eastern Colorado and Northwestern Kansas: RMAG, Energy Resources of the Denver Basin, p. 35-49.

Lorenz, J.C., L.W. Teufel, and N.R. Warpinski, 1991, Regional Fractures I: A Mechanism for the formation of Regional Fractures at Depth in Flat-Lying Reservoirs (1): AAPG Bulletin, v. 75-11, p. 1714-1737.

Lorenz, J.C., and S.J. Finley, 1991, Regional Fractures II: Fracturing of Mesaverde Reservoirs in the Piceance Basin, Colorado (1): AAPG Bulletin, v. 75/11, p. 1738-1757.

Meissner, F.F., 1978, Petroleum Geology of the Bakken formation Williston Basin, North Dakota and Montana: Montana Geological Society, Twenty-fourth Annual Conference, Williston Basin Sympoisum: The Economic Geology of Williston Basin, p. 207-227.

Sonnenberg, S.A., and R.J. Weimer, 1991, Silo Field, Laramie County, Wyoming: A Guide for Future Fractured Niobrara Production: AAPG Search and Discovery Article #91010. Website accessed 1 September 2011. http://www.searchanddiscovery.com/abstracts/html/1991/rms/abstracts/1141.htm

Sonnenberg, S.A., and R.J. Weimer, 1993, Oil production from Niobrara Formation, Silo field, Wyoming – Fracturing associated with a possible wrench fault system(?): The Mountain Geologist, v. 30/2, p. 39-54.

Svoboda, J.O., 1995, Is Permian Salt dissolution the Primary Mechanism for Fracture Genesis at Silo Field, Wyoming?: RMAG, High-Definition Seismic Guidebook, p. 79-85.

Thomas, G.E., 1992, Effects of differential compaction fracturing shown in four reservoirs: Oil and Gas Journal, Feb. 3, p. 54-57.

Vincelette, R.R., and N.H. Foster, 1992, Fractured Niobrara of Northwestern Colorado: RMAG, Geological Studies Relevant to Horizontal Drilling: Examples from Western North America, p. 227-242.

Petroleum Geology
of
Silo Field

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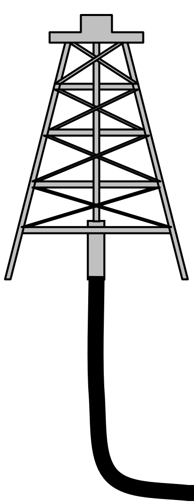
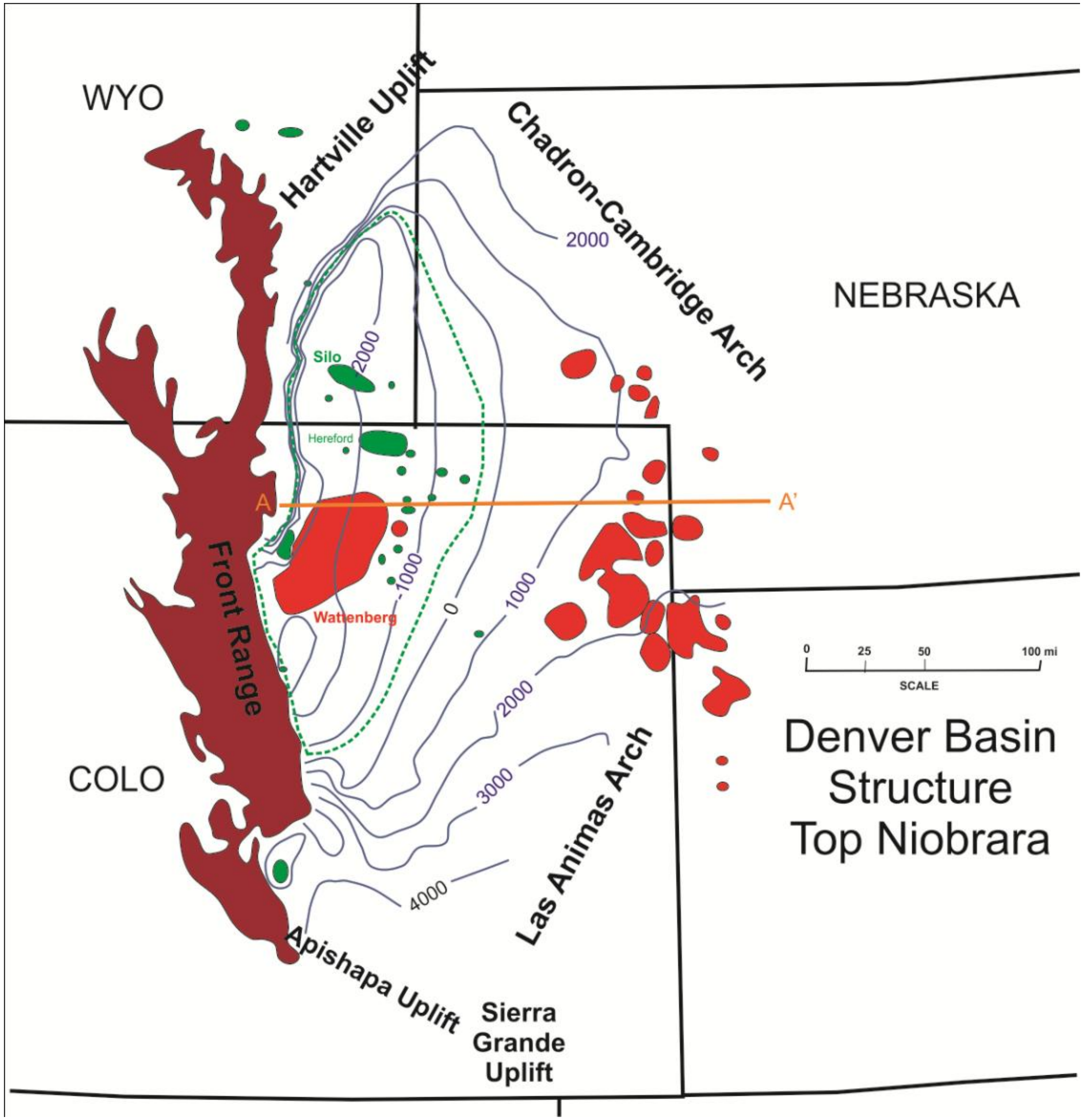
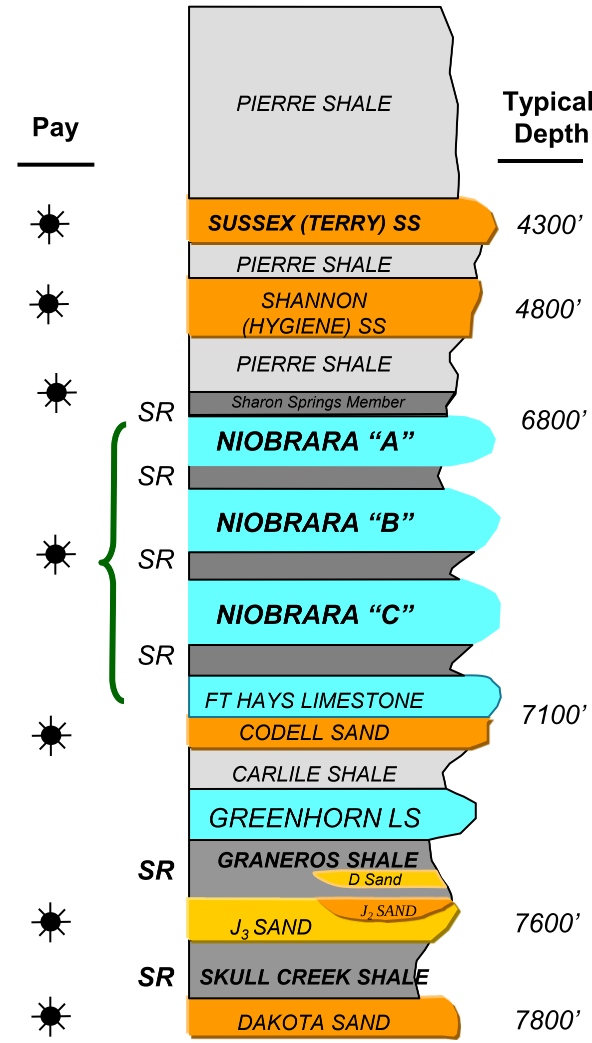
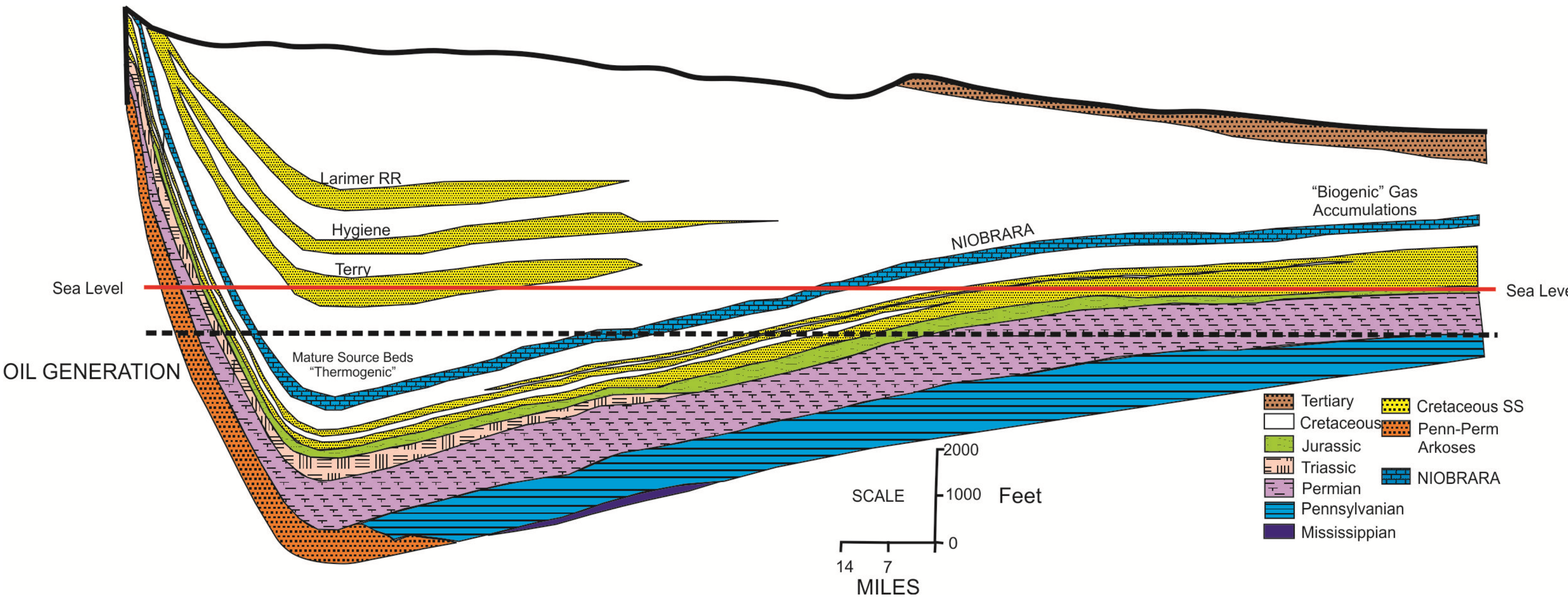
Colorado School of Mines



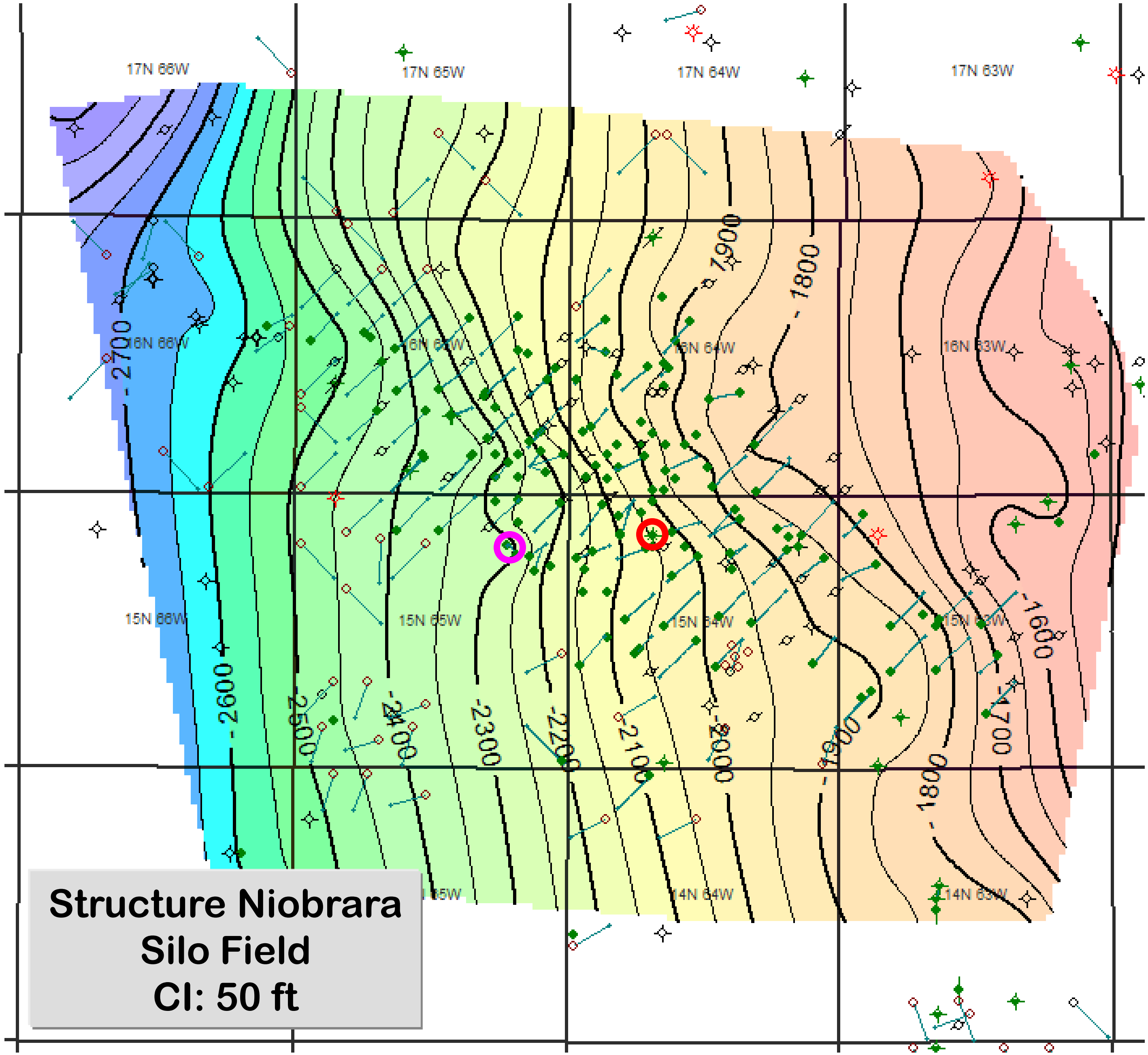
Niobrara Petroleum System - Denver Basin
Shallow Biogenic Gas
Deep Thermogenic Oil and Gas







Larimer RR
Hygiene
Terry
"Biogenic" Gas
Accumulations
NIOBRARA
Sea Level
Sea Level
OIL GENERATION
Mature Source Beds
"Thermogenic"
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Cretaceous SS
Penn-Perm
Arkoses
NIOBRARA
SCALE
2000
1000
0
Feet
14
7
MILES



SILO FIELD

Niobrara Fm.

Discovery:

1981
Amoco Champlin 300 1
SE SE Sec 5, T15N, R64W
Ft Hays completion
78 BOPD

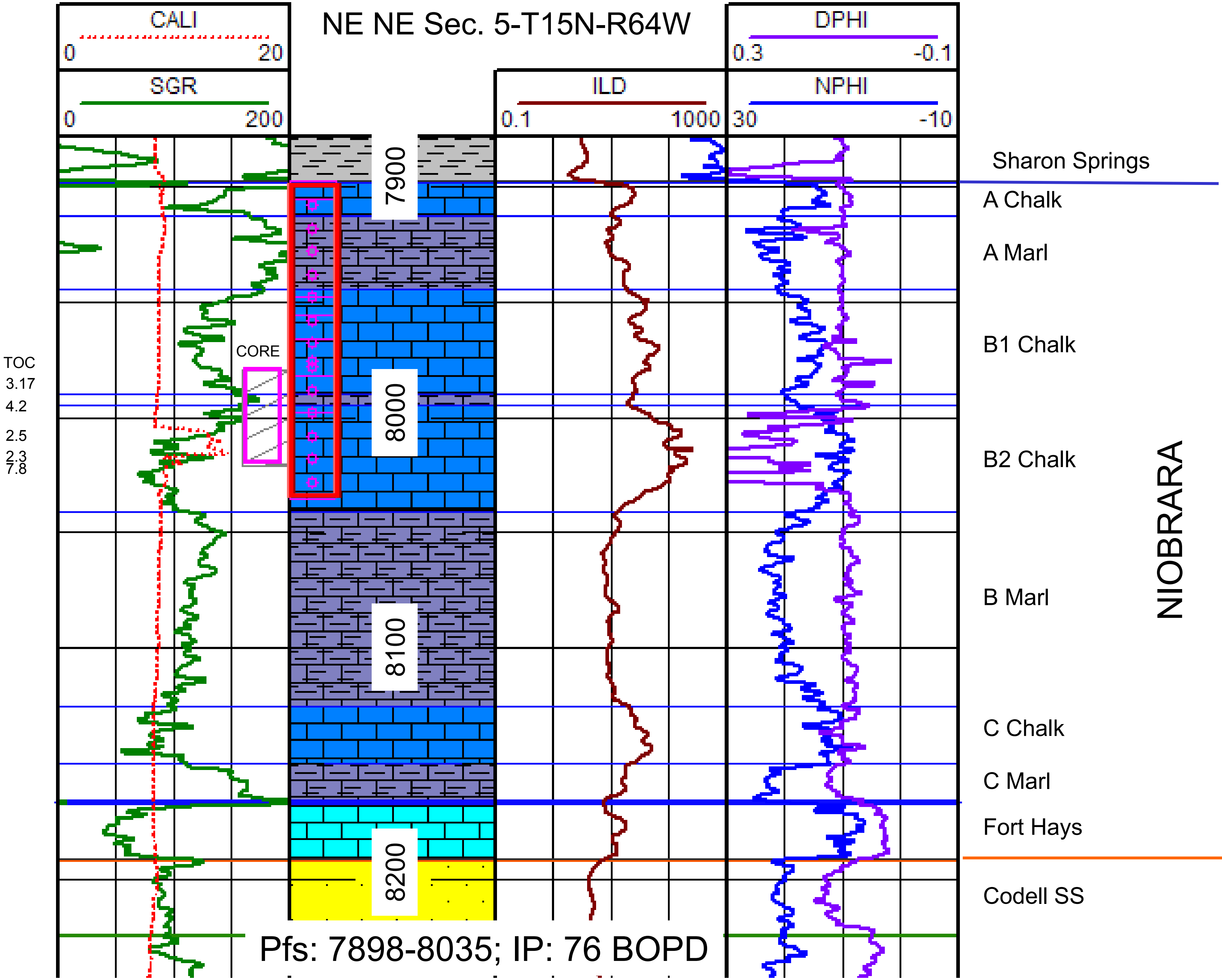
1990
First horizontal:
Warren # 1
Sec. 11, T15N, R65W
600 BOPD

Vertical Depths:
7100 to 8800 ft

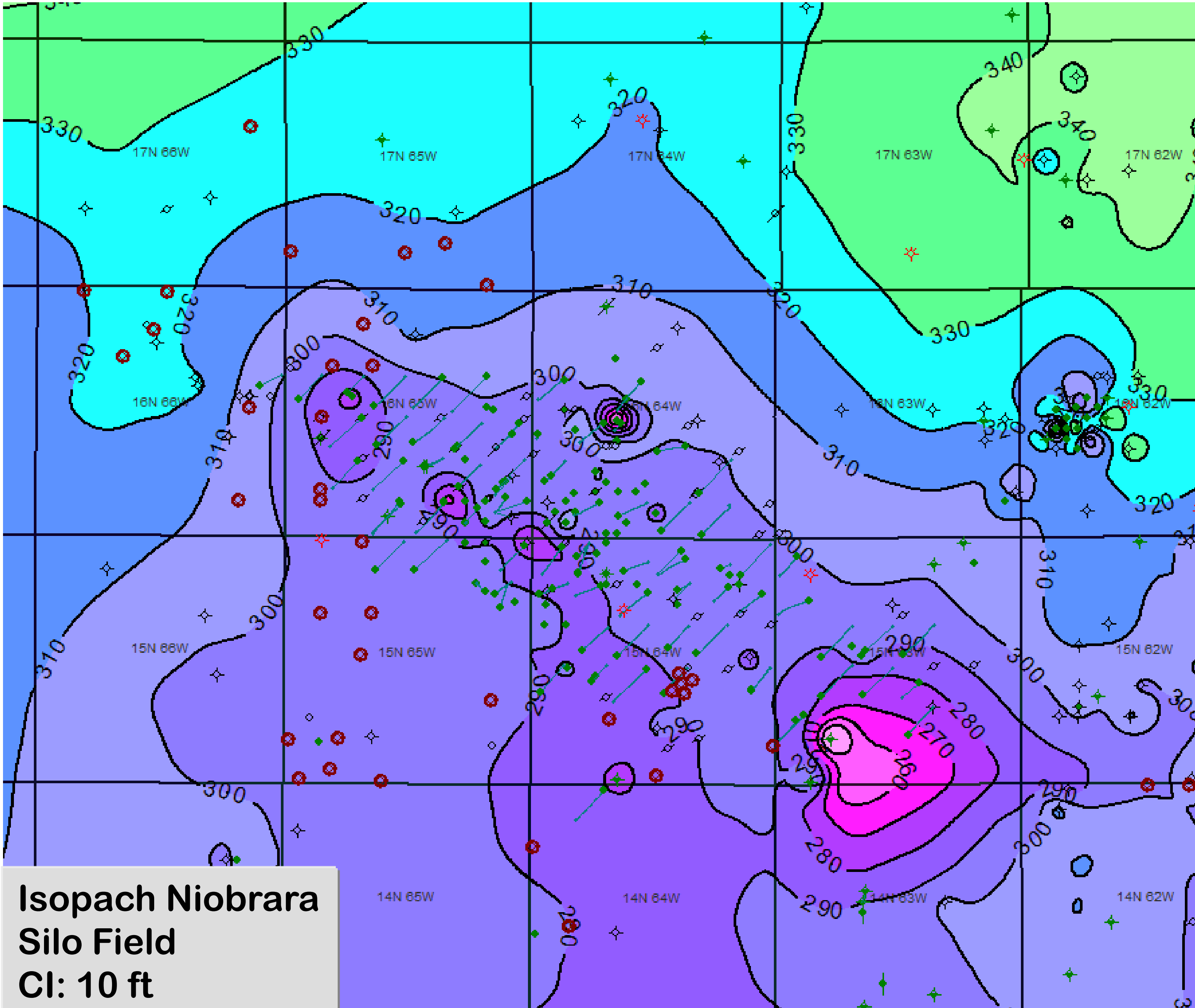
Cum Prod:
10.4 MMBO
8.9 BCFG
6.3 MMBW

Lee 41-5

NE NE Sec. 5-T15N-R64W



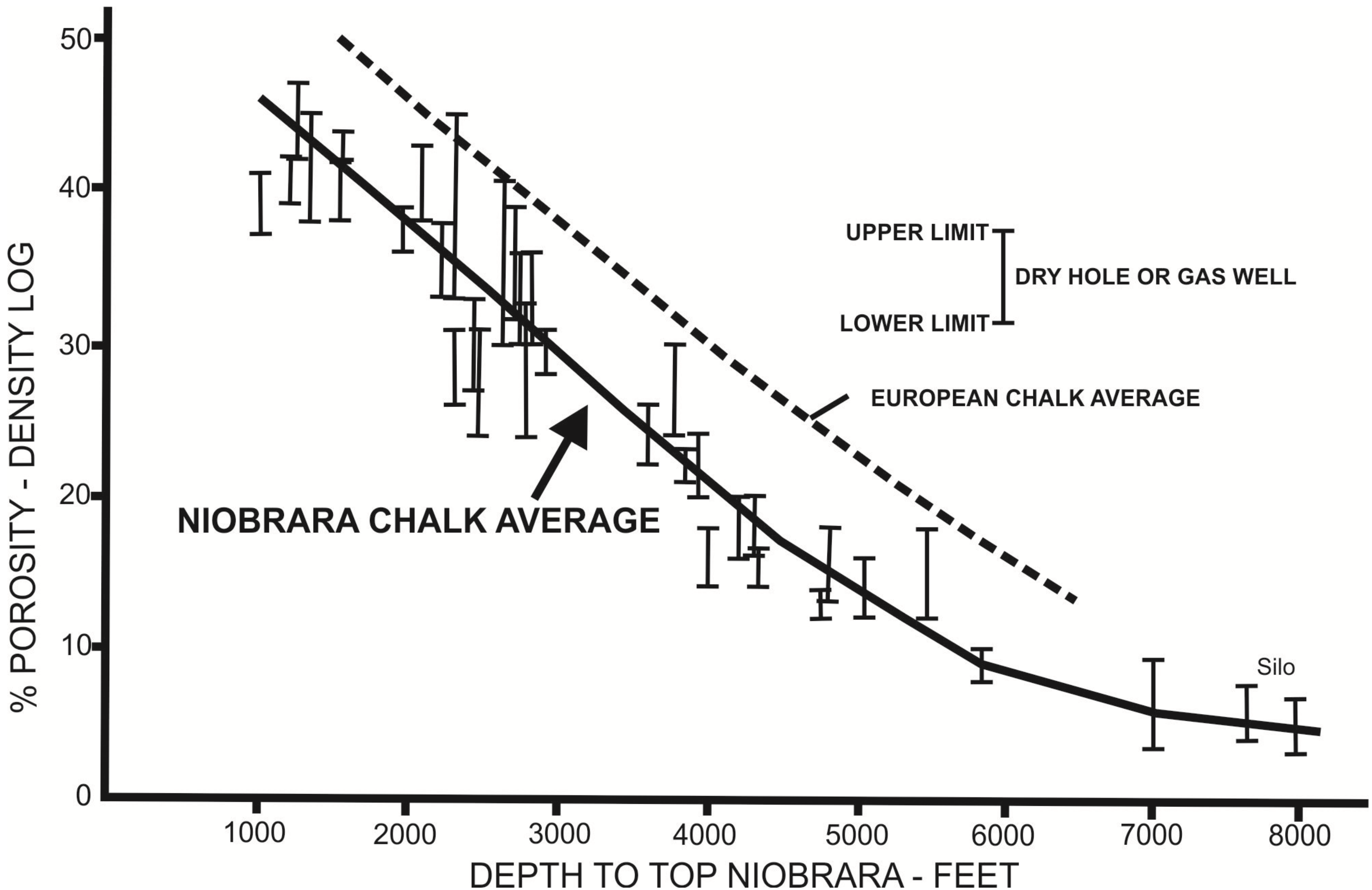
Pfs: 7898-8035; IP: 76 BOPD



Isopach Niobrara
Silo Field
CI: 10 ft

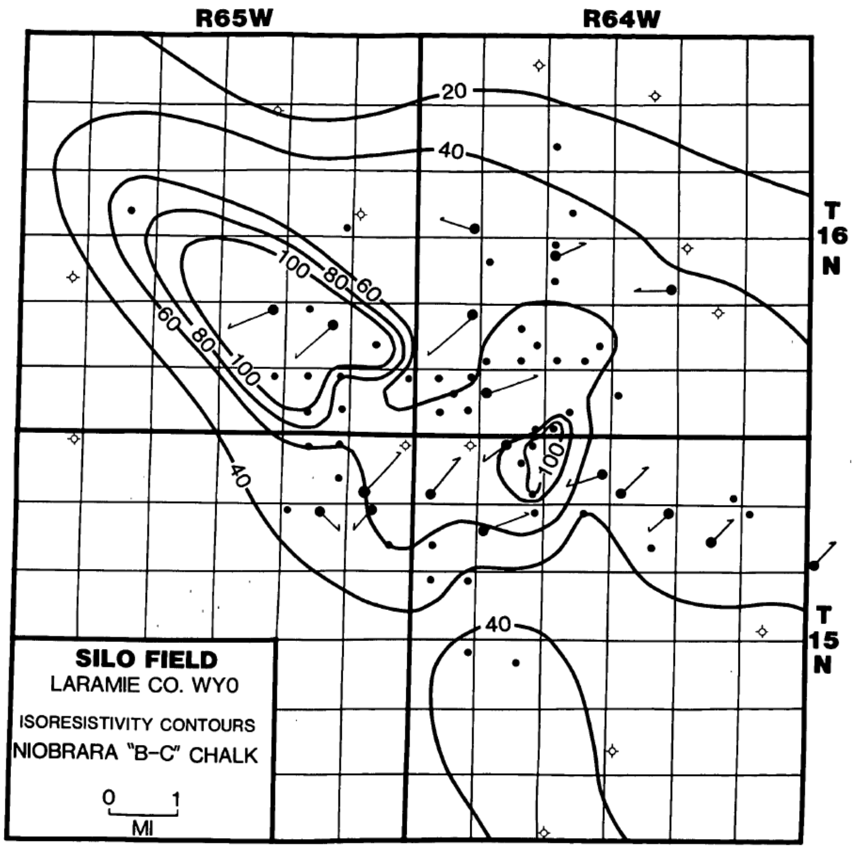
Reservoir Properties

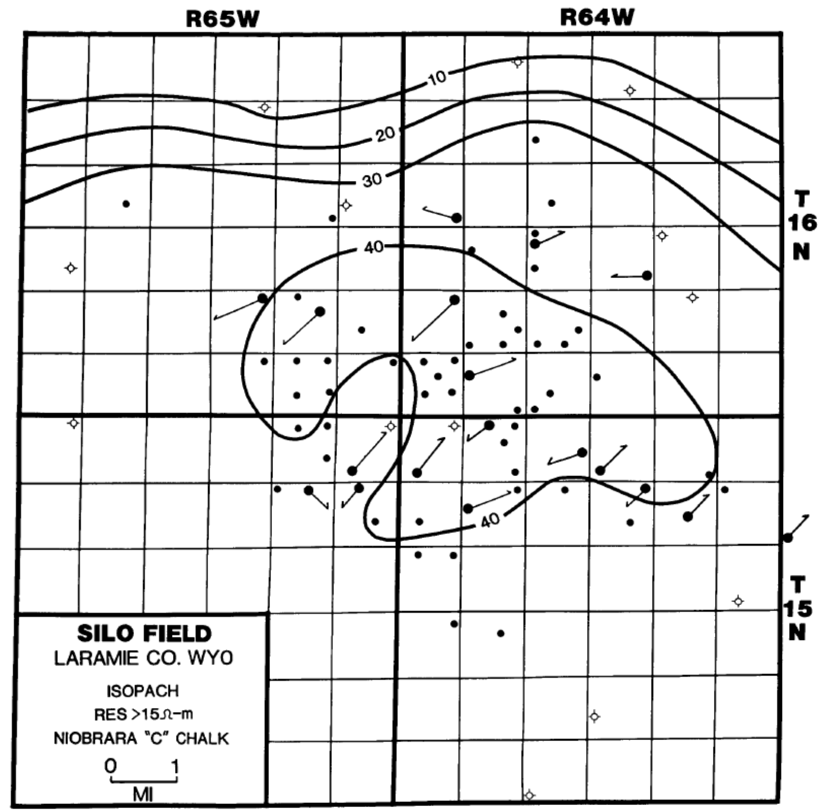
- Porosity: < 8%
- Permeability: < 0.1 md
- Pay: 30 – 60 ft
- GOR: 1030 cu ft per barrel
- Oil gravity: 35^{o} API



Modified from Lockridge and Scholle, 1978

Resistivity Mapping and Accumulation



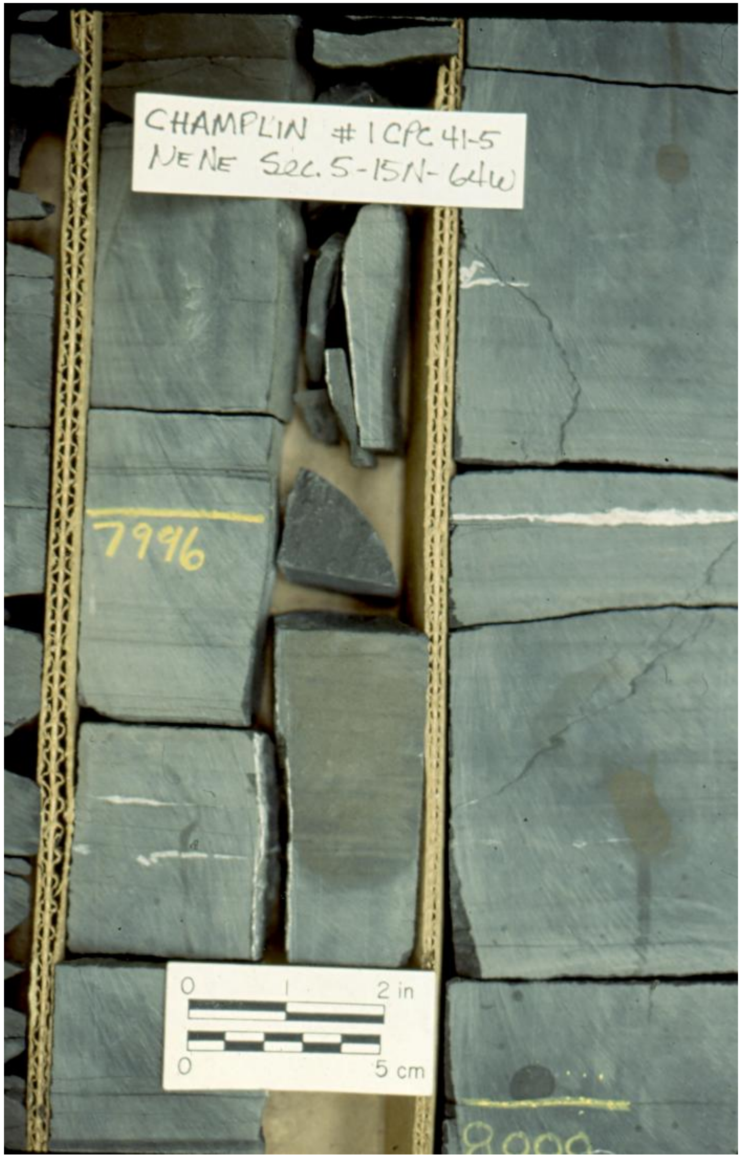


Sonnenberg and Weimer, 1991

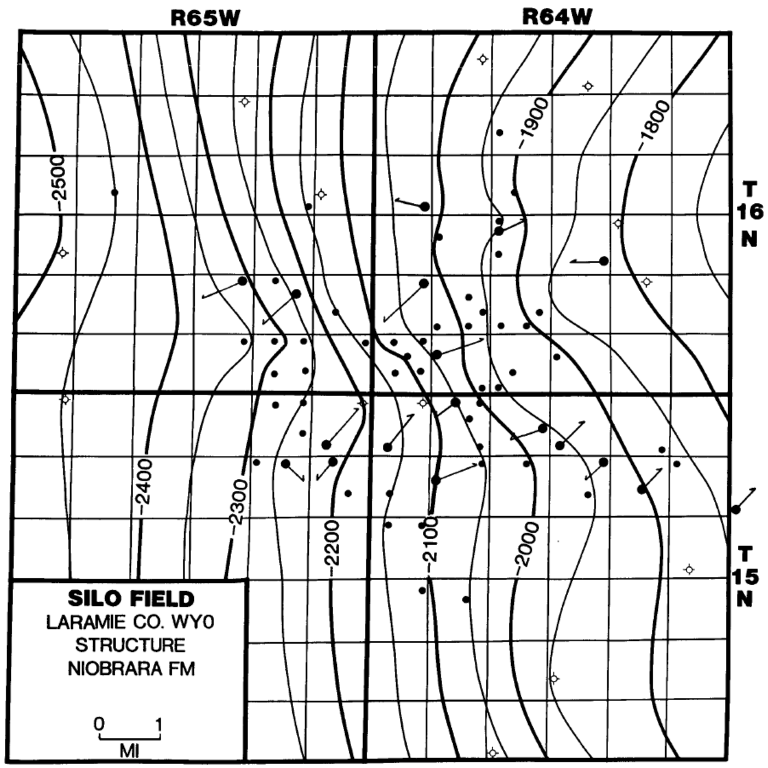
Fractures

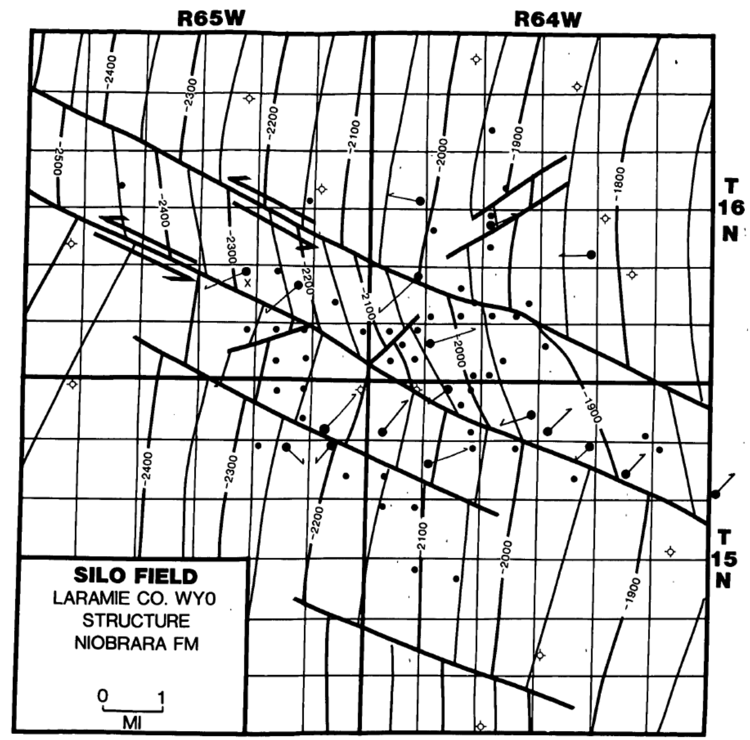
- Differential compaction over paleotectonic high (Thomas, 1992)
- Folding over basement faults (Davis and Lewis, 1990)
- Wrench faults (Sonnenberg and Weimer, 1991; Svoboda, 1995)
- Permian salt dissolution (Campbell and Saint, 1991)
- Regional fracture system (Lorenz et al., 1991)
- Pore pressure fractures (Meissner, 1978)
- Compaction & dewatering (Brown, 2004)
- Neogene extension (Vincelette and Foster, 1992)

Vertical Stylolites and Fractures



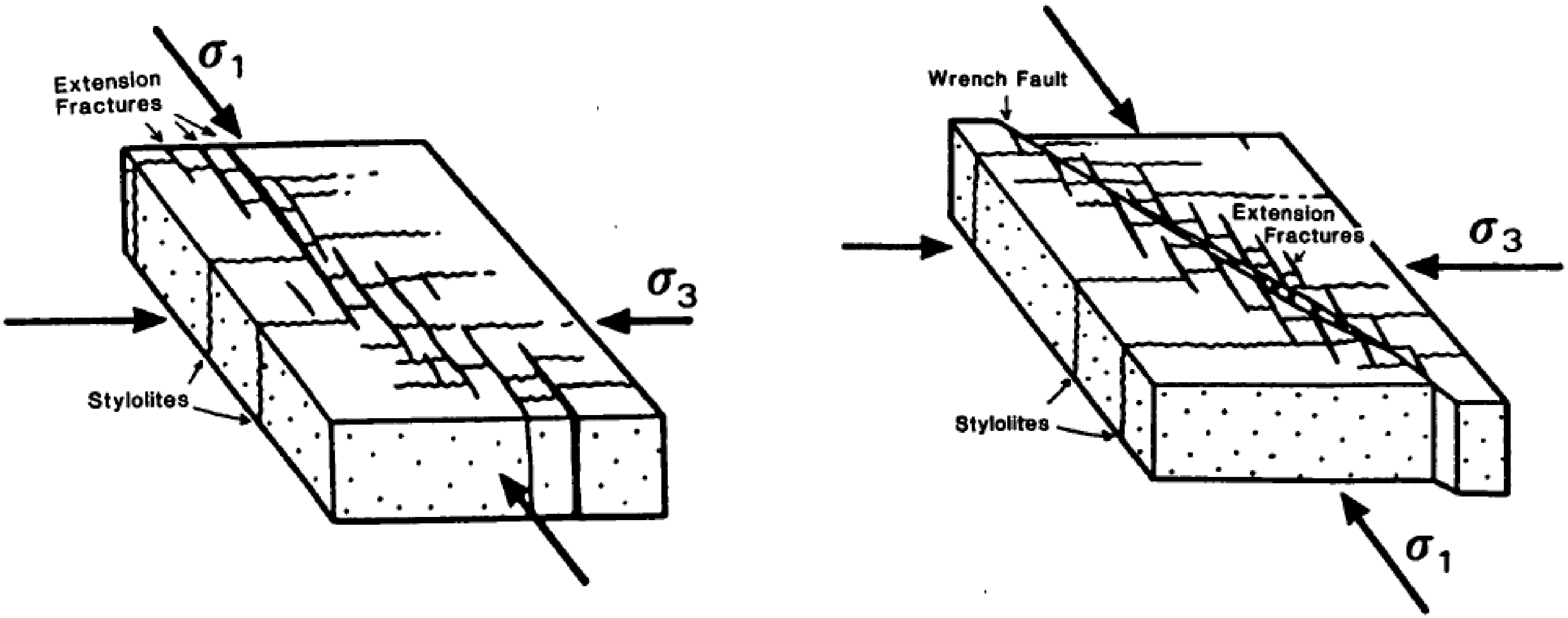
Structure Top Niobrara



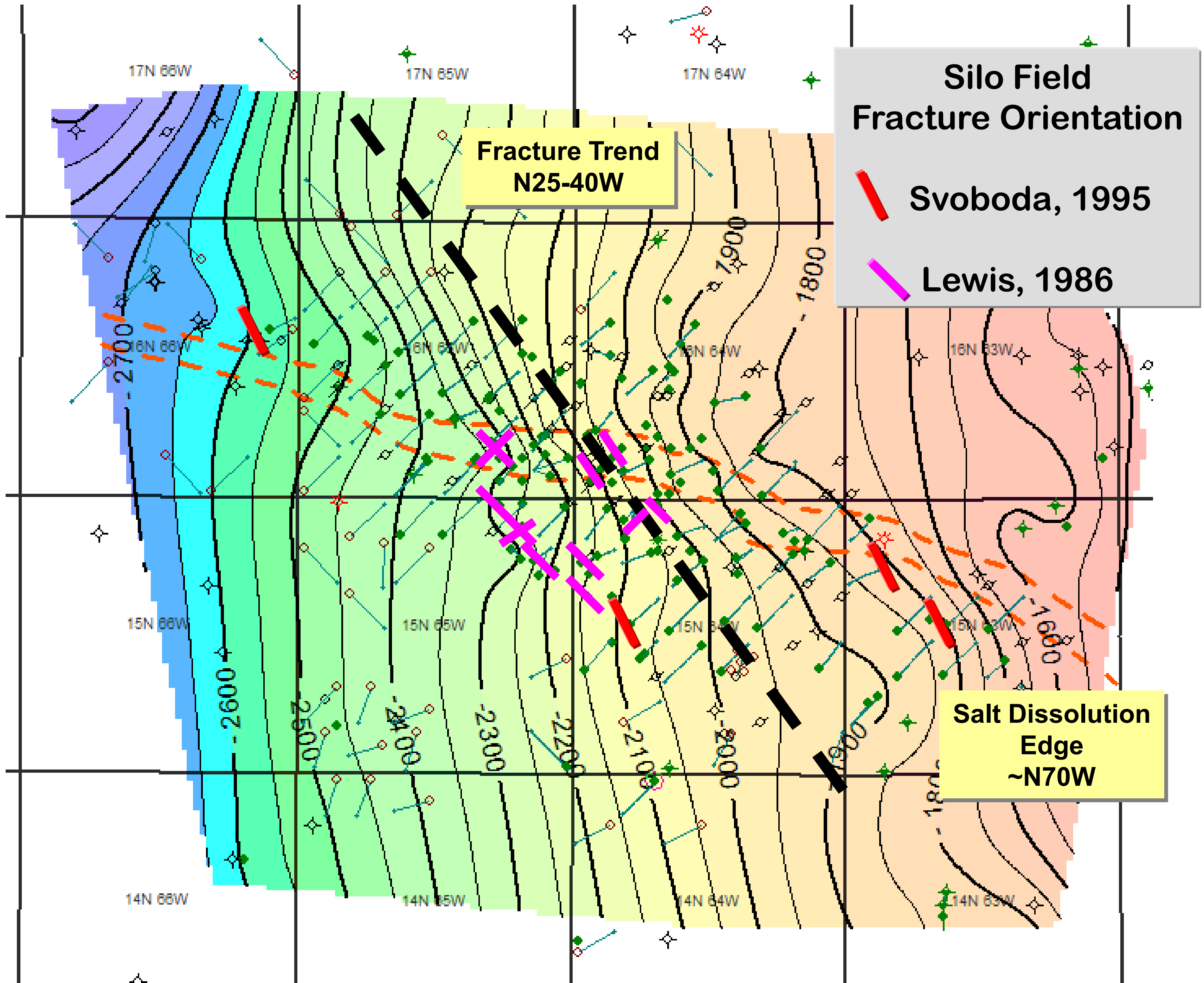


Sonnenberg and Weimer, 1993

Extension Fractures and Wrench Faults

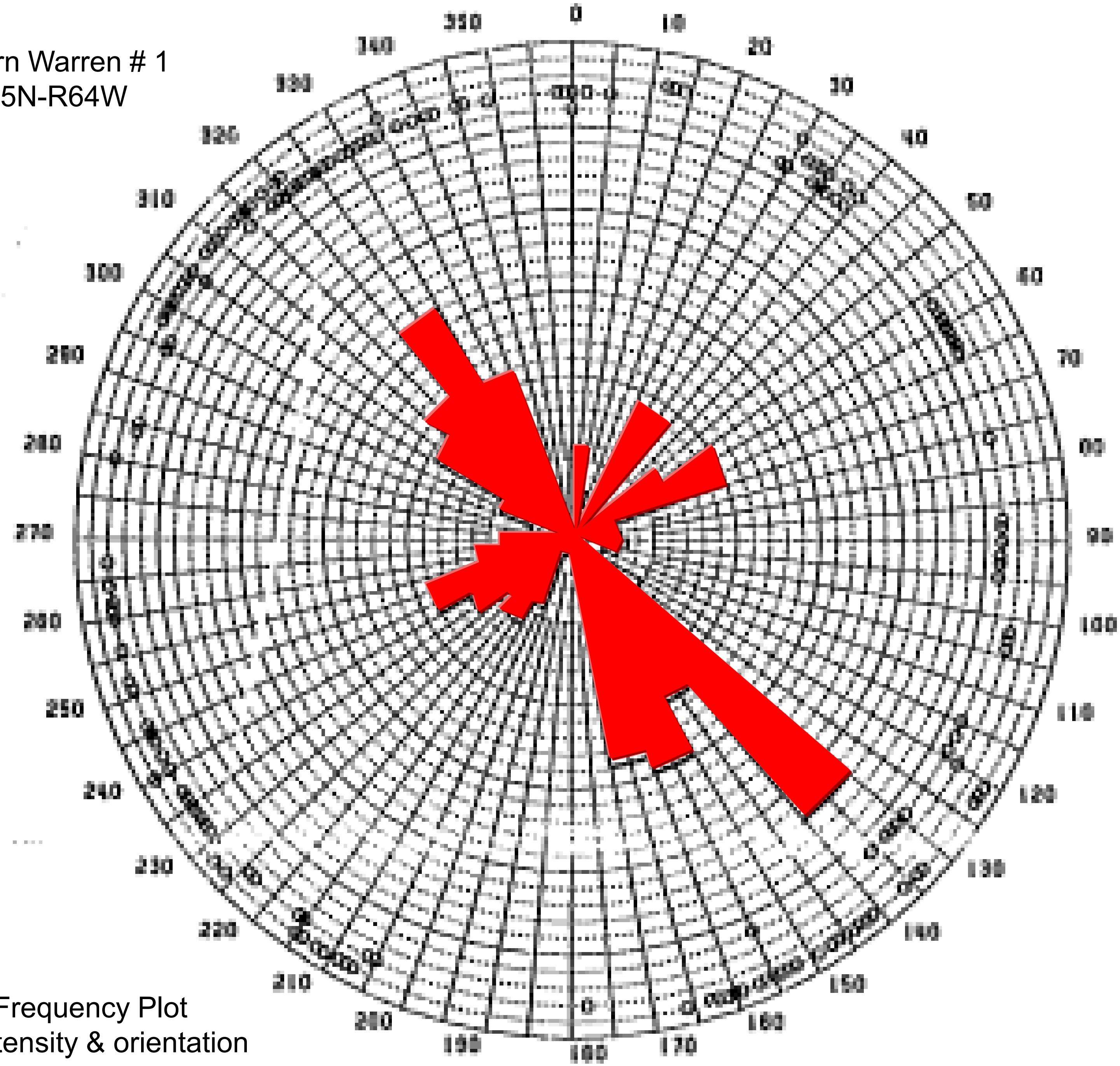


Sonnenberg and Weimer, 1993 after du Rouchet, 1981



Silo Field
Fracture Orientation
Svoboda, 1995
Lewis, 1986
Fracture Trend
N25-40W
Salt Dissolution
Edge
~N70W
17N 66W
17N 65W
17N 64W
16N 66W
16N 65W
16N 64W
16N 63W
15N 66W
15N 65W
15N 64W
15N 63W
14N 66W
14N 65W
14N 64W
14N 63W
-2700
-2600
-2500
-2400
-2300
-2200
-2100
-2000
-1900
-1800
-1600

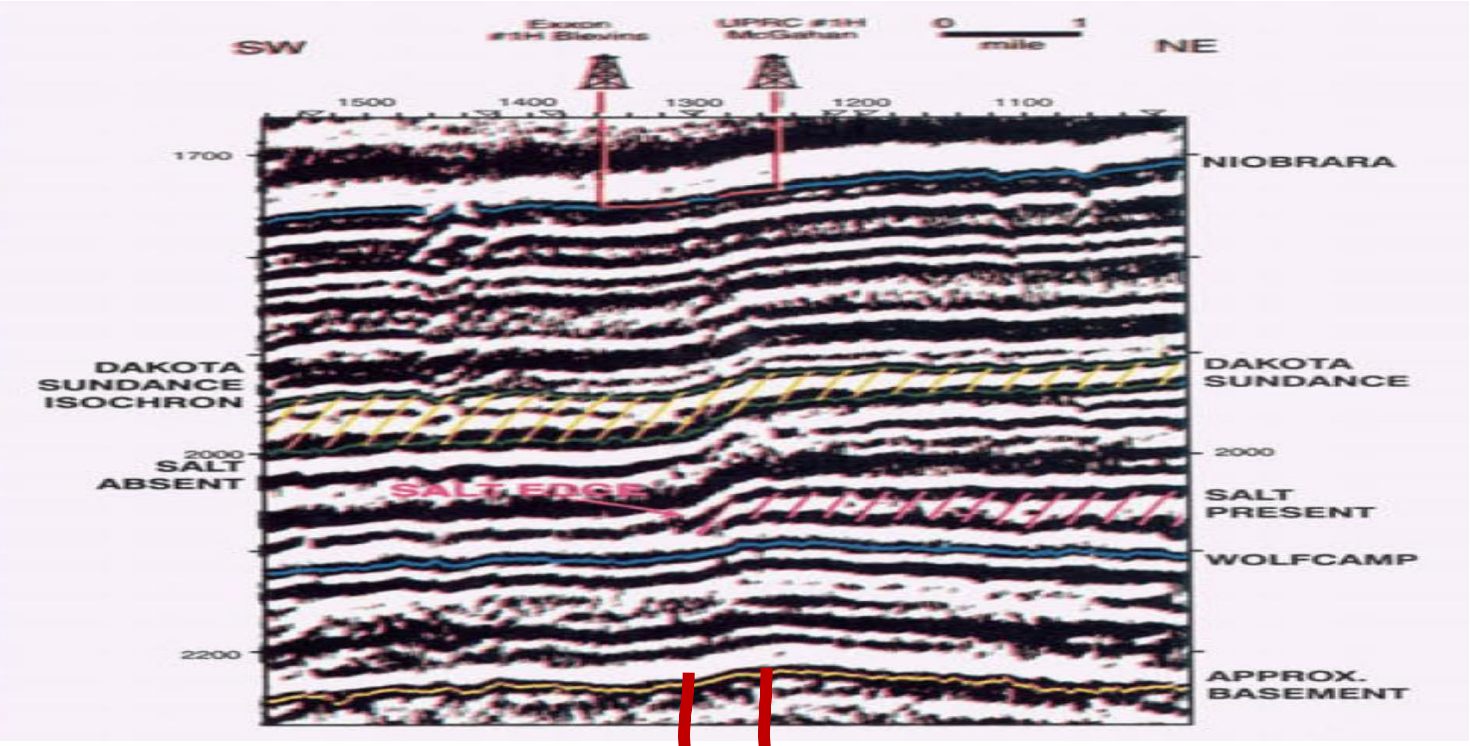
Great Western Warren # 1
Sec. 7-T15N-R64W



Polar Frequency Plot
Fracture intensity & orientation

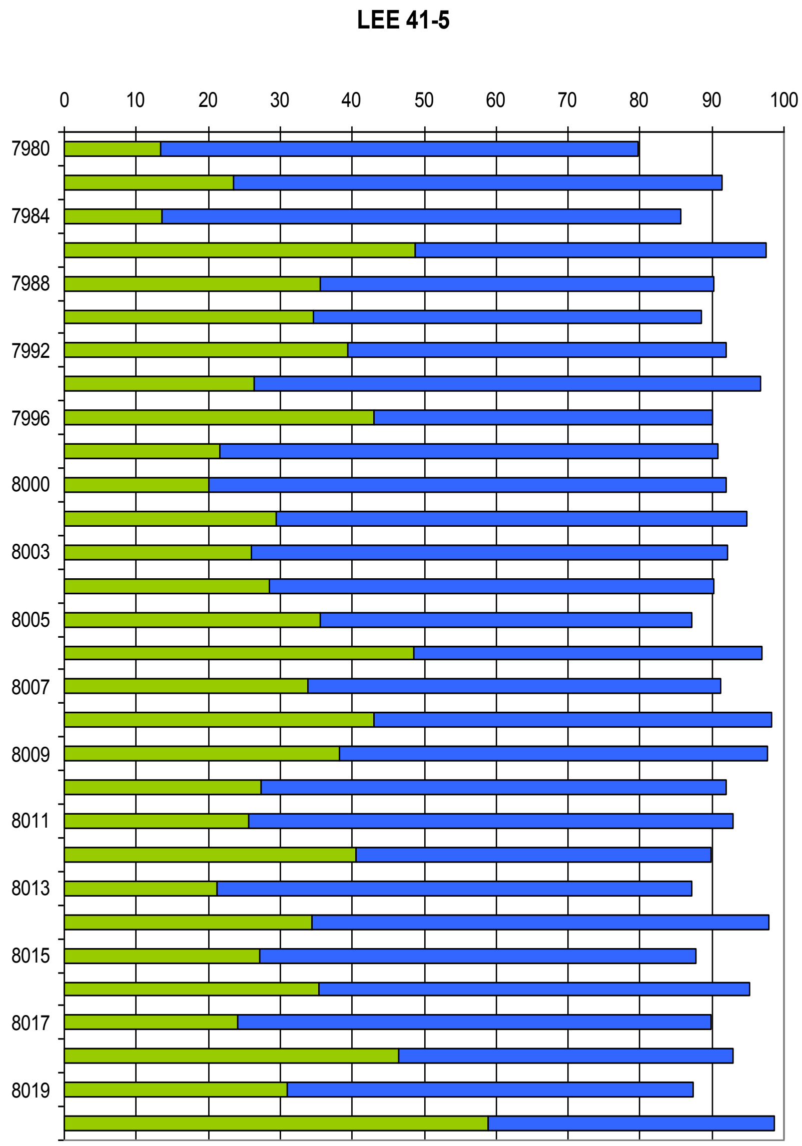
Silo Fractures

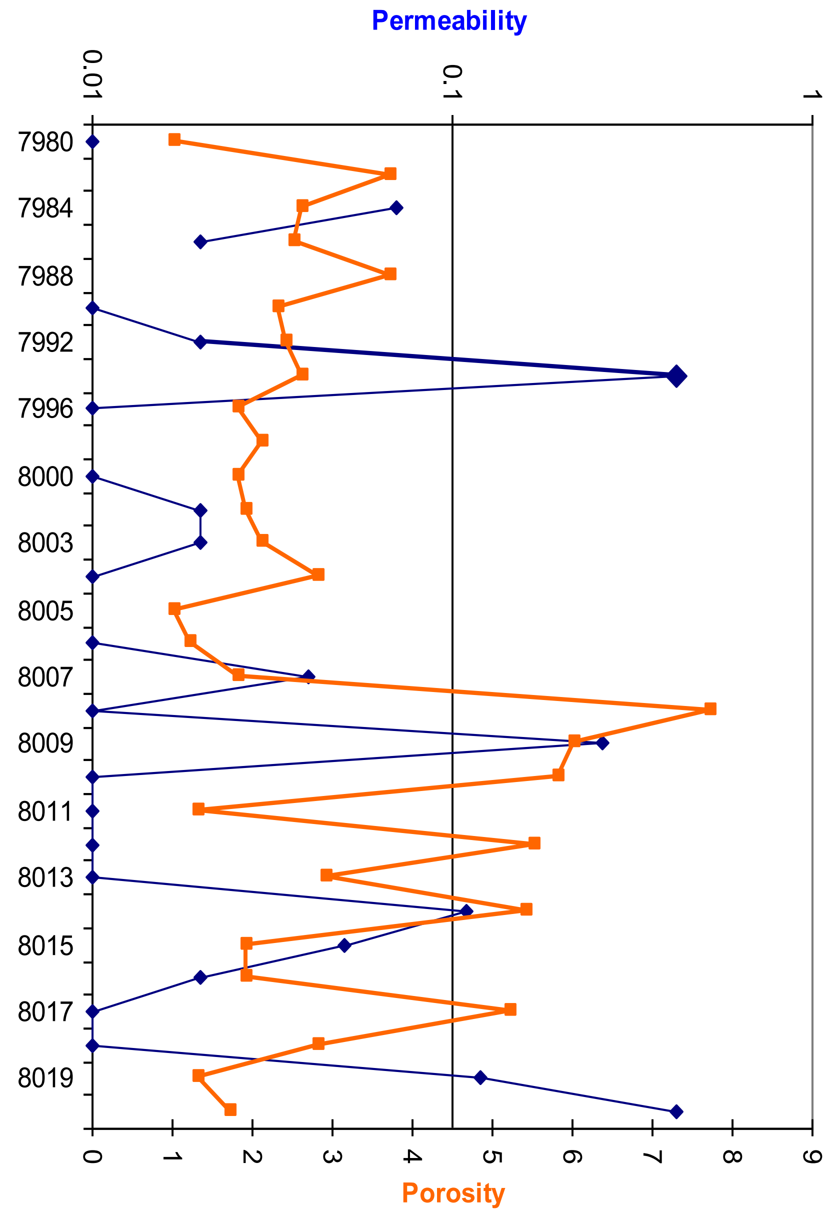
- Structural monocline
- Basement faults control Permian salt dissolution
- Some wrench movement on faults



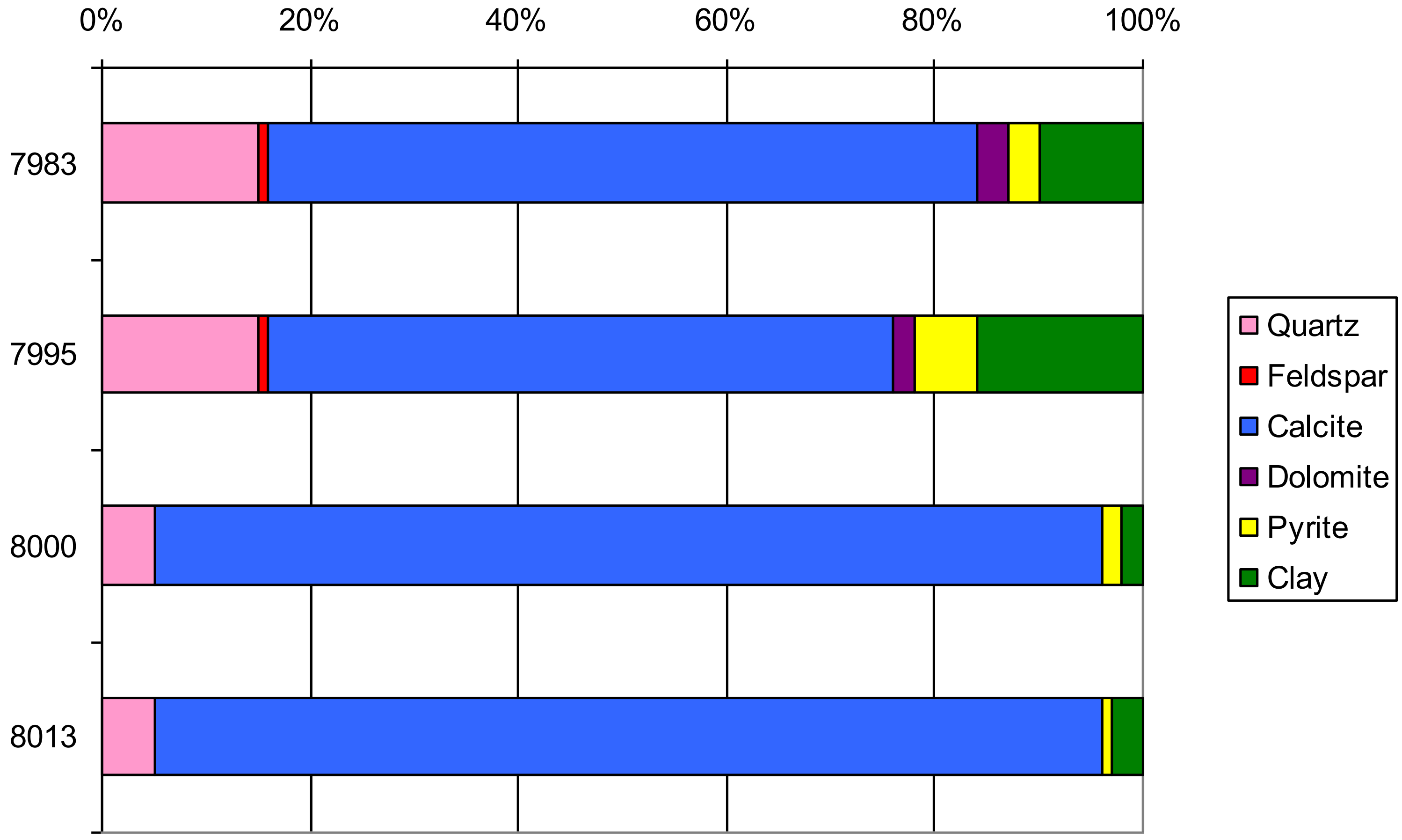
Modified from Svoboda, 1995

Lee 41-5
Sec. 5-T15N-R64W





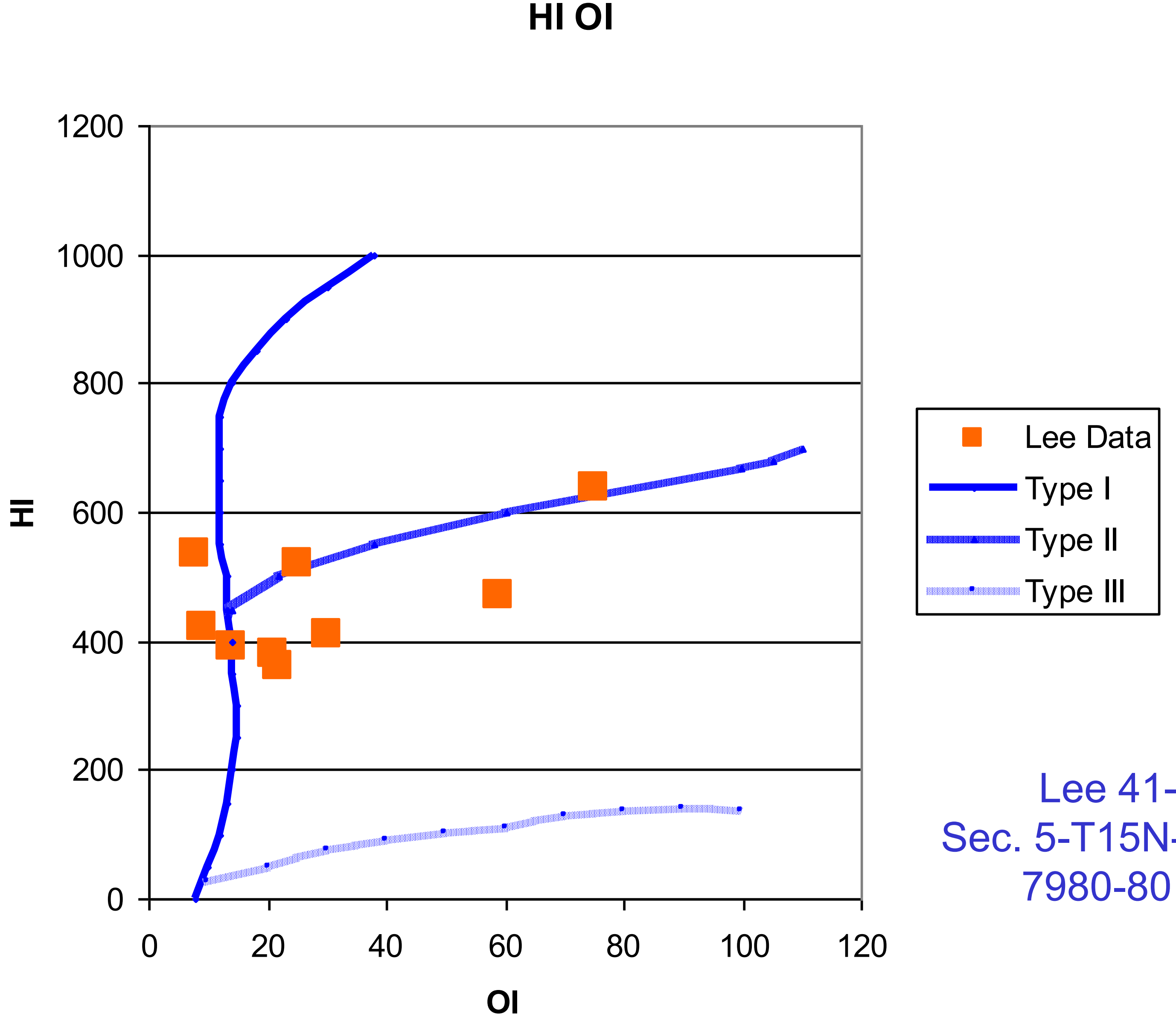
Lee 41-5
Sec. 5-T15N-R64W
XRD DATA



Niobrara Marls

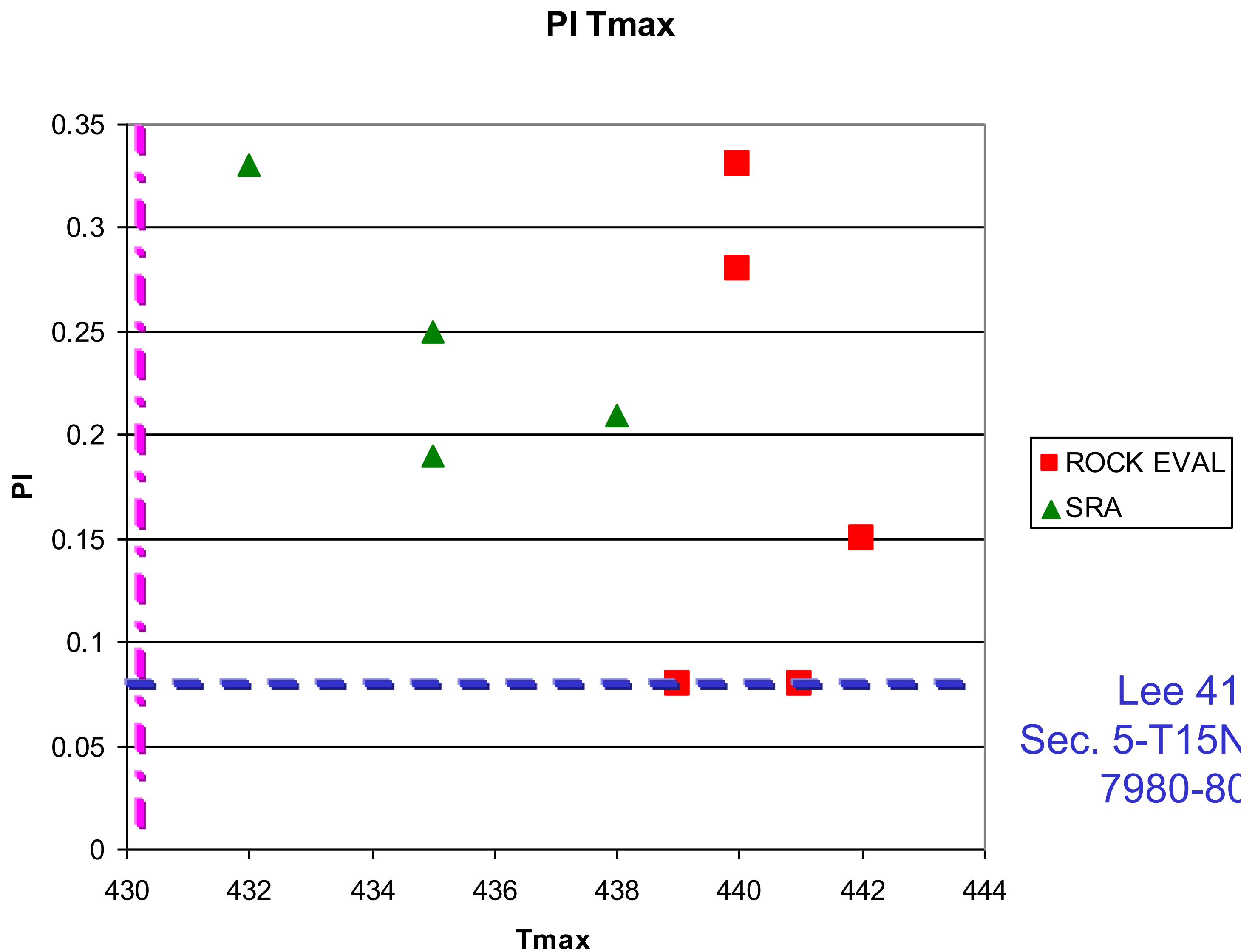
- TOC: 1 – 6 wt. percent
- Kerogen type: Type II

Source Rocks Silo Field

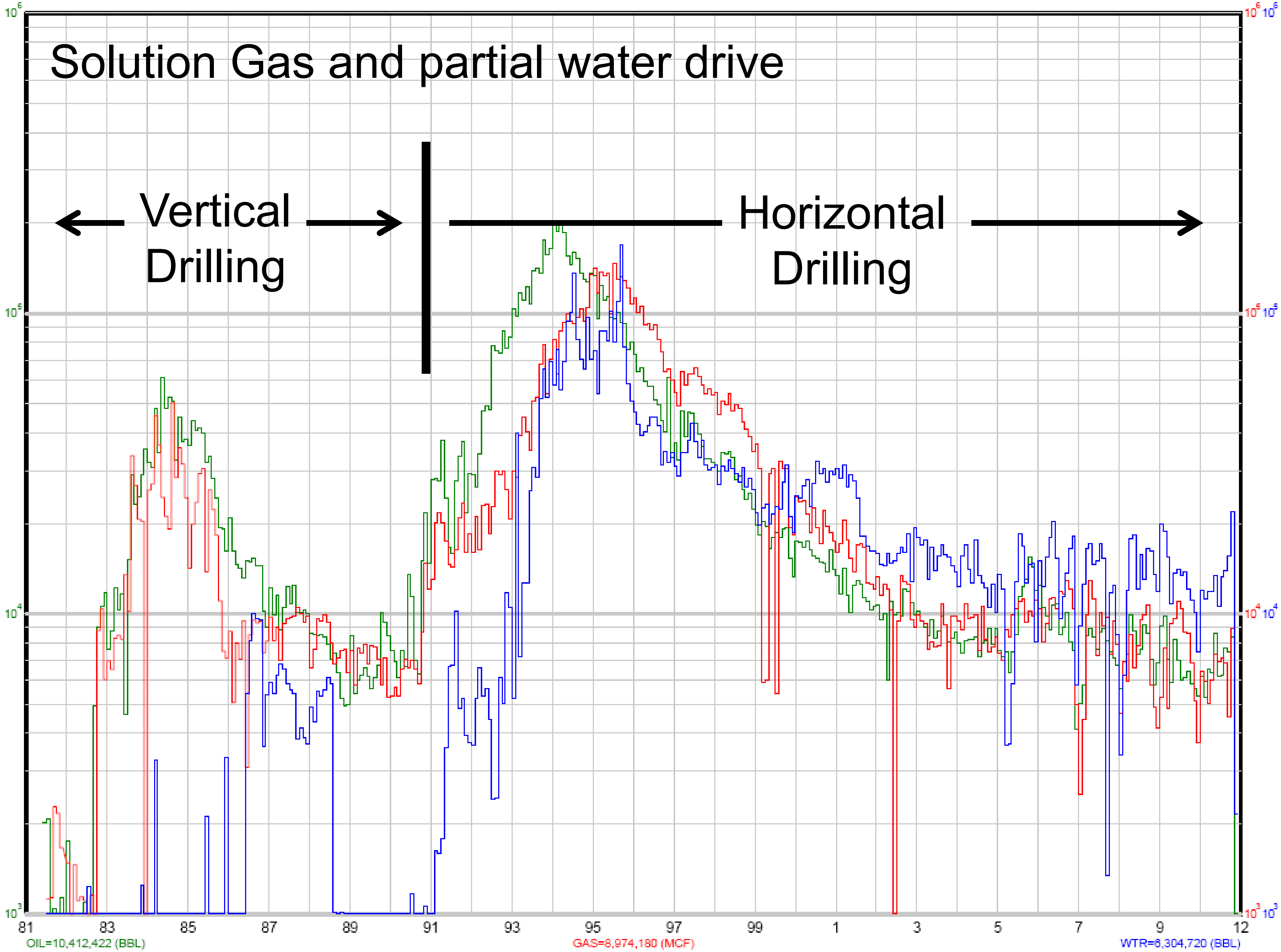


Lee 41-5
Sec. 5-T15N-R64W
7980-8017

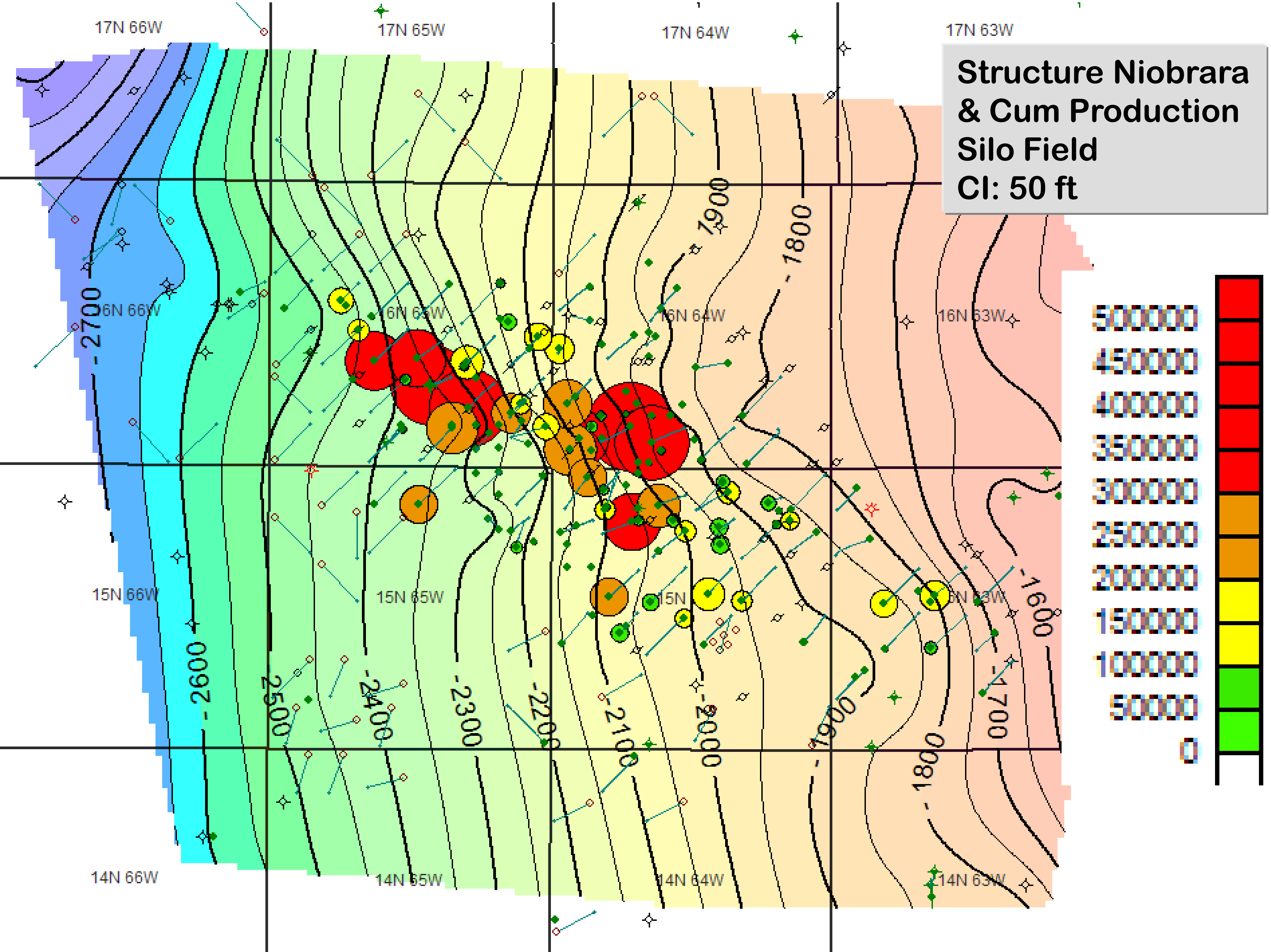
Source Rocks Silo Field



Lee 41-5
Sec. 5-T15N-R64W
7980-8017

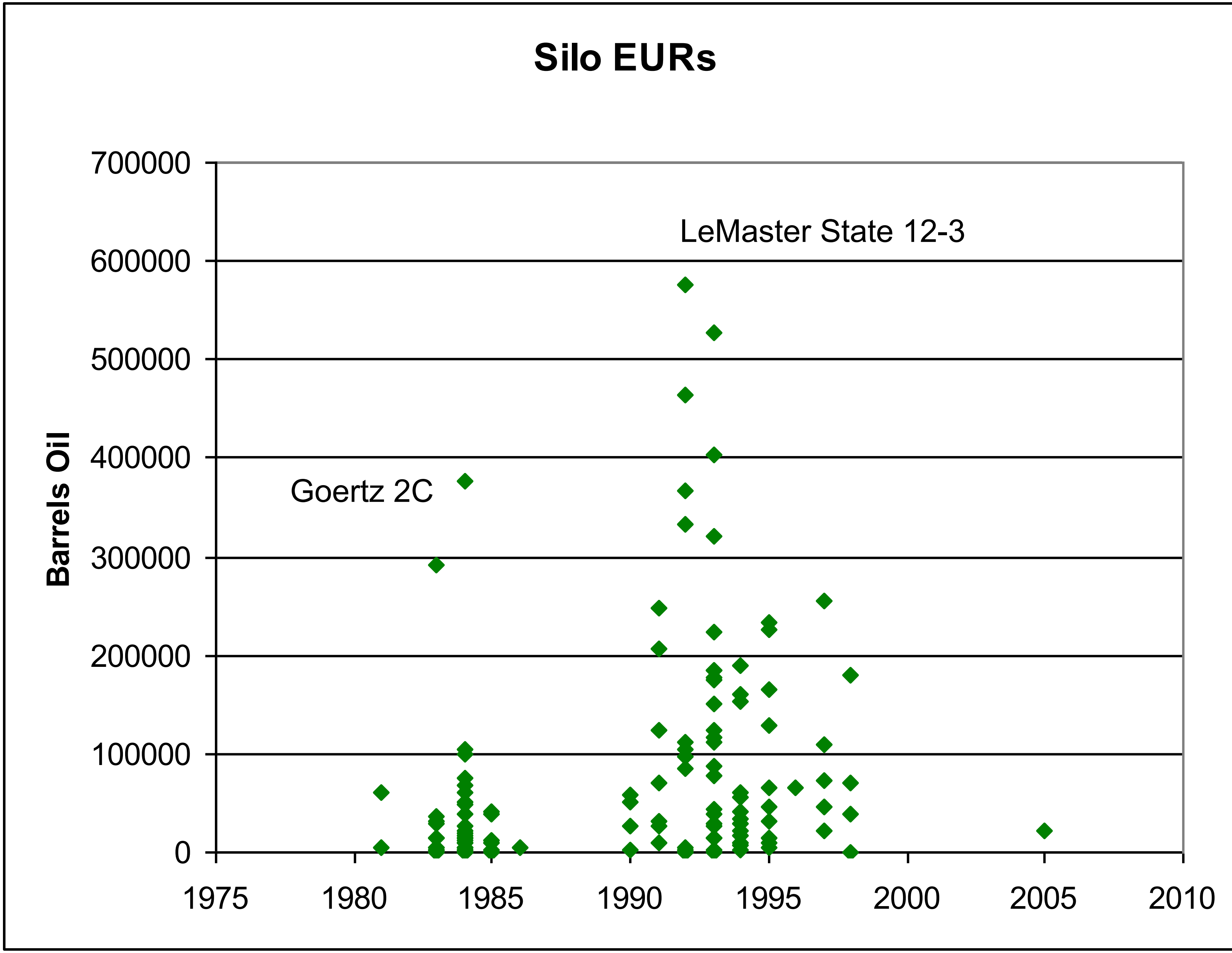


Solution Gas and partial water drive
Vertical Drilling
Horizontal Drilling
81
83
85
87
89
91
93
95
97
99
1
3
5
7
9
12
OIL=10,412,422 (BBL)
GAS=8,974,180 (MCF)
WTR=8,304,720 (BBL)


Structure Niobrara
& Cum Production
Silo Field
CI: 50 ft
17N 66W
17N 65W
17N 64W
17N 63W
16N 66W
16N 65W
16N 64W
16N 63W
15N 66W
15N 65W
15N
15N 63W
14N 66W
14N 65W
14N 64W
14N 63W
-2700
-2600
-2500
-2400
-2300
-2200
-2100
-2000
-1900
-1800
-1700
-1600
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0

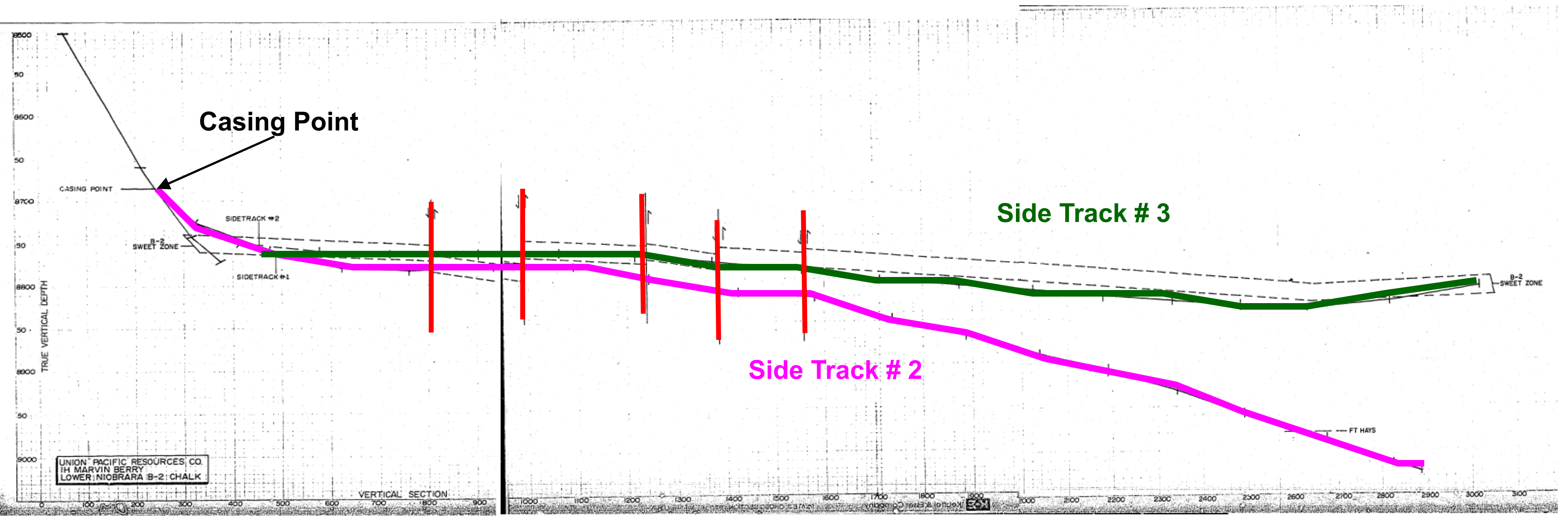
Silo Production-EUR

- Vertical wells: 34824 BO/w
- Horizontal wells: 111251 BO/w
- Field EUR 11.5 MMBO (existing wells)



Silo EURs
Barrels Oil
700000
600000
500000
400000
300000
200000
100000
0
1975
1980
1985
1990
1995
2000
2005
2010
LeMaster State 12-3
Goertz 2C

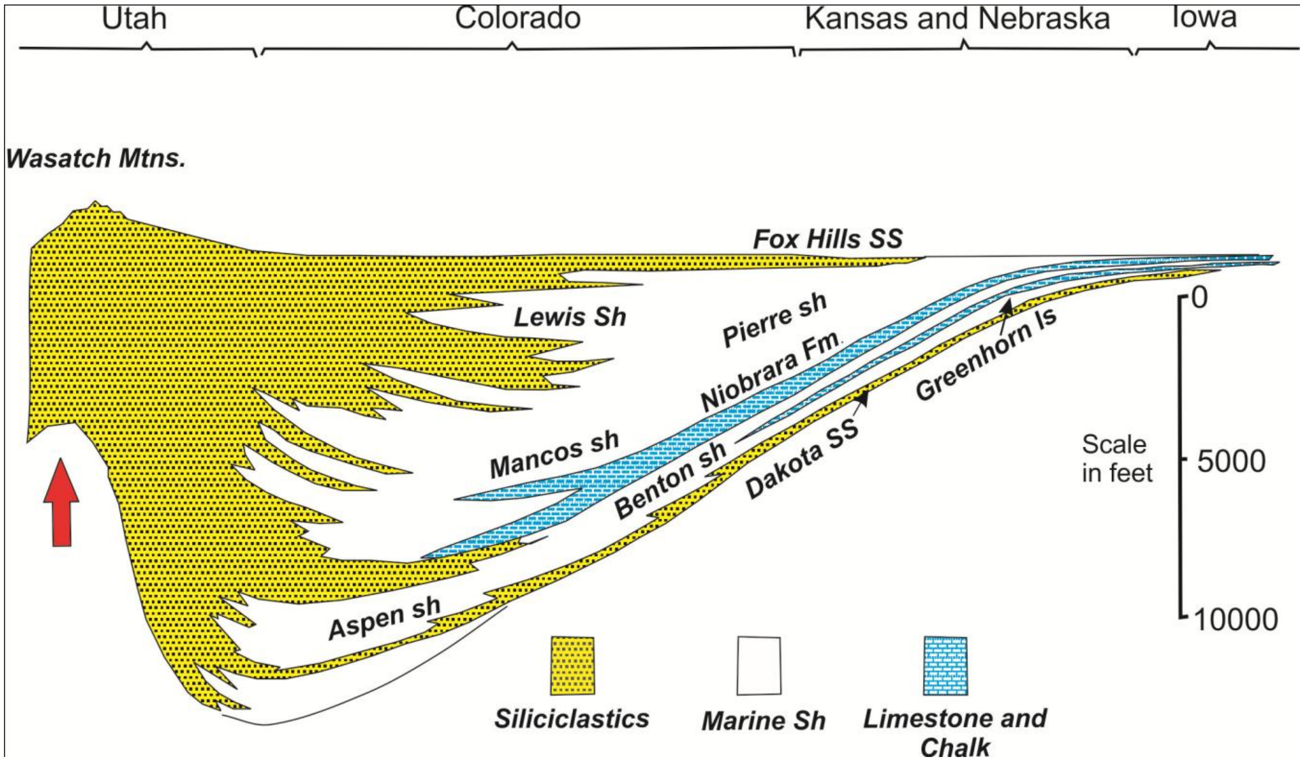
UPR Berry 41-13
NE NE NE Sec. 13-T16N-R66W



Summary

- Silo Field is located in basin-center setting
- No oil-water contact observed
- Fracturing plays a key role in production
  - Matrix porosity still present so matrix also has a role
- Dominant fracture trend NW-SE (N25-40W)
  - Subsidiary set NE-SW
- Basement faults influence Permian salt dissolution and create monocline
- Left-lateral wrenching suggested
- New wells drilled at flanks of field suggest additional potential!

Colorado School of Mines Niobrara Consortium



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