The Niobrara Petroleum System, Rocky Mountain Region*

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Abstract

The Niobrara Petroleum System of the U.S. Rocky Mountain Region is a major tight petroleum resource play. The Niobrara is self-sourced and reservoirs are low-permeability chalks, shales, and sandstones. Source beds have total organic-carbon contents that range from 2 to 8 weight percent. Source beds are thermally mature in the deeper parts of many of the Laramide basins in the Rocky Mountain region. Continuous or pervasive accumulations occur in thermally mature areas.

The Niobrara source rocks are dominantly Type II (sapropelic). Oil accumulations occur where source beds are still in the thermogenic oil window (e.g., Denver Basin). Thermogenic gas accumulations occur where the source beds have entered the gas-generating window in deeper parts of basins (e.g., Piceance Basin). Biogenic methane occurs in shallow chalk reservoirs on the east flank of the Western Interior Cretaceous Basin. In addition shallow gas fields are found in northern Montana.

Natural fractures are important in controlling sweet spots in the play and form for several causes. Several models create fractures in the Niobrara and include Laramide tectonics, Neogene extensional tectonics, solution of evaporites, hydrocarbon generation, and regional stress patterns.

The Niobrara is a technology reservoir that requires horizontal drilling and multi-stage hydraulic fracturing. The Niobrara petroleum system is present over most of the Rocky Mountain Region and is prospective in many areas.

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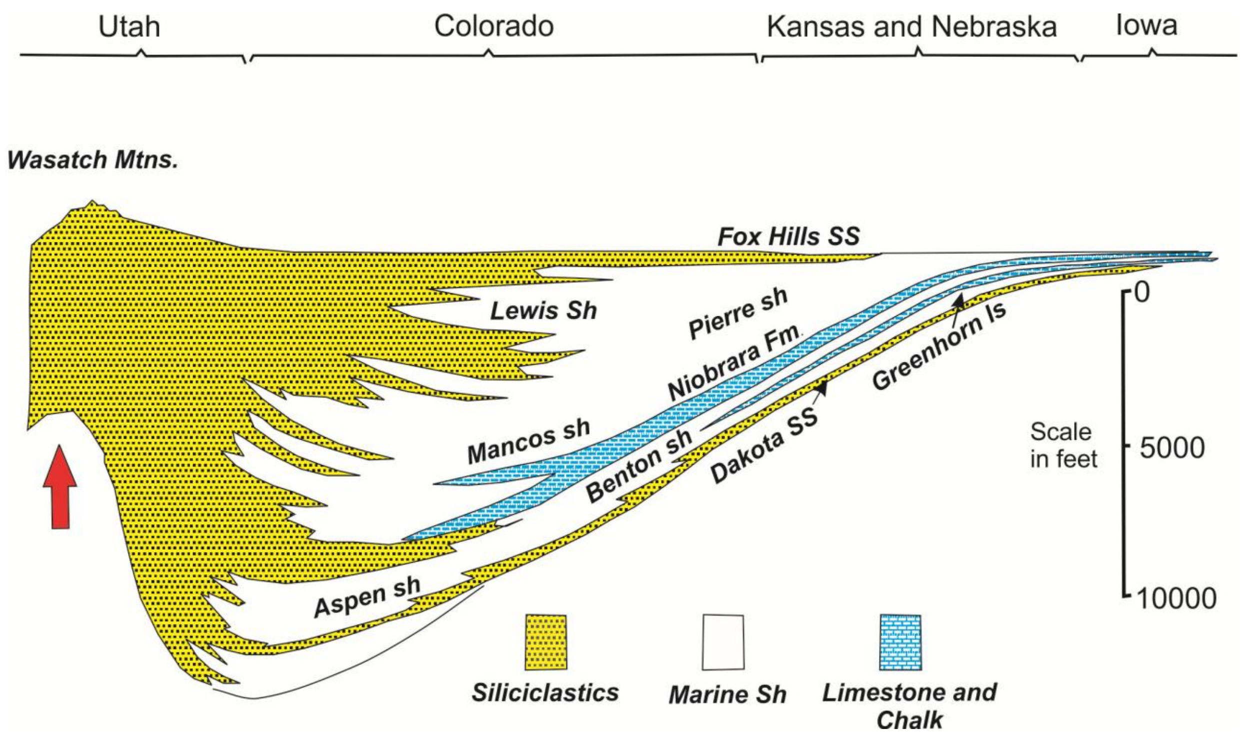
The Niobrara Petroleum System, Rocky Mountain Region



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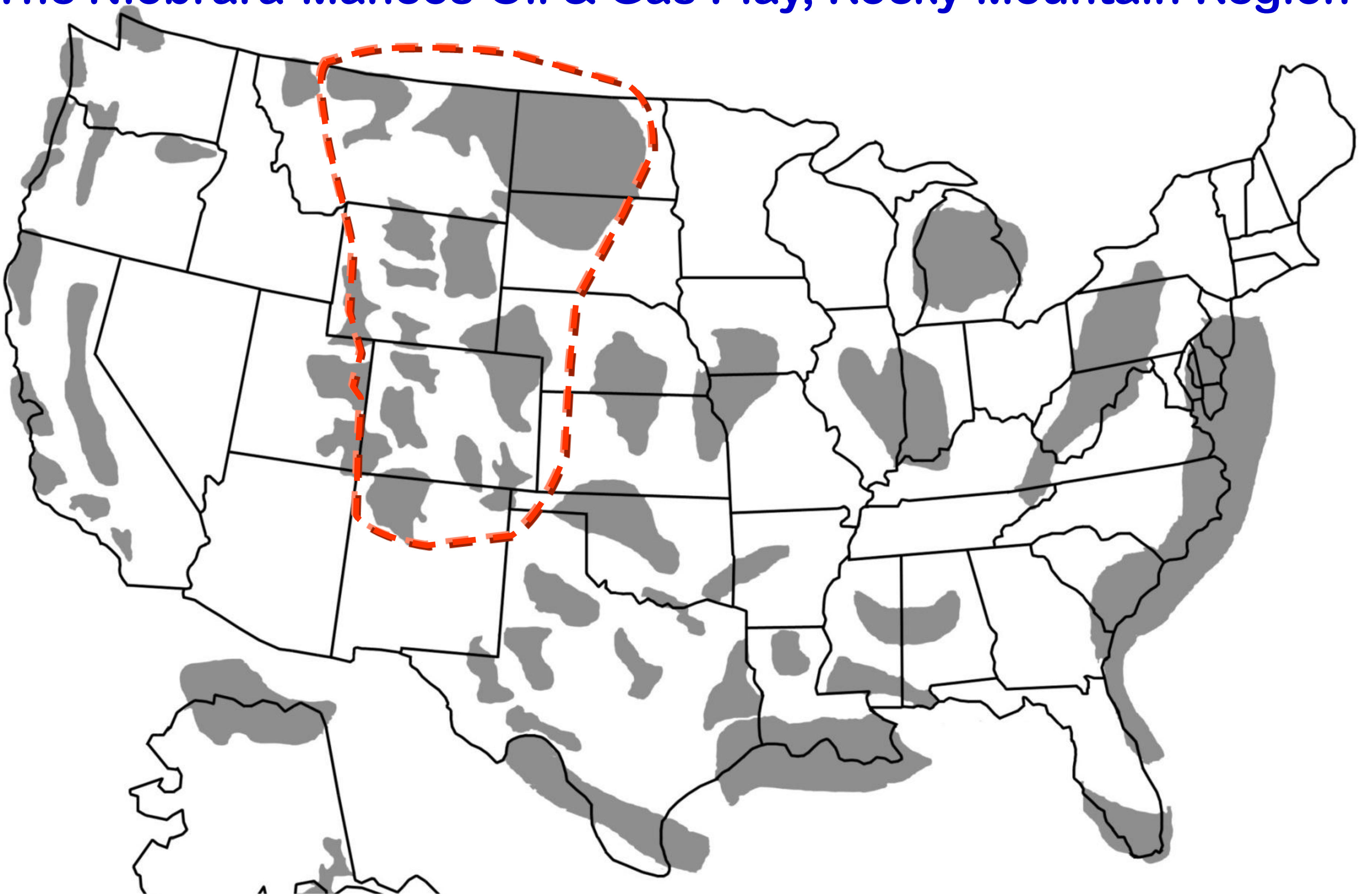
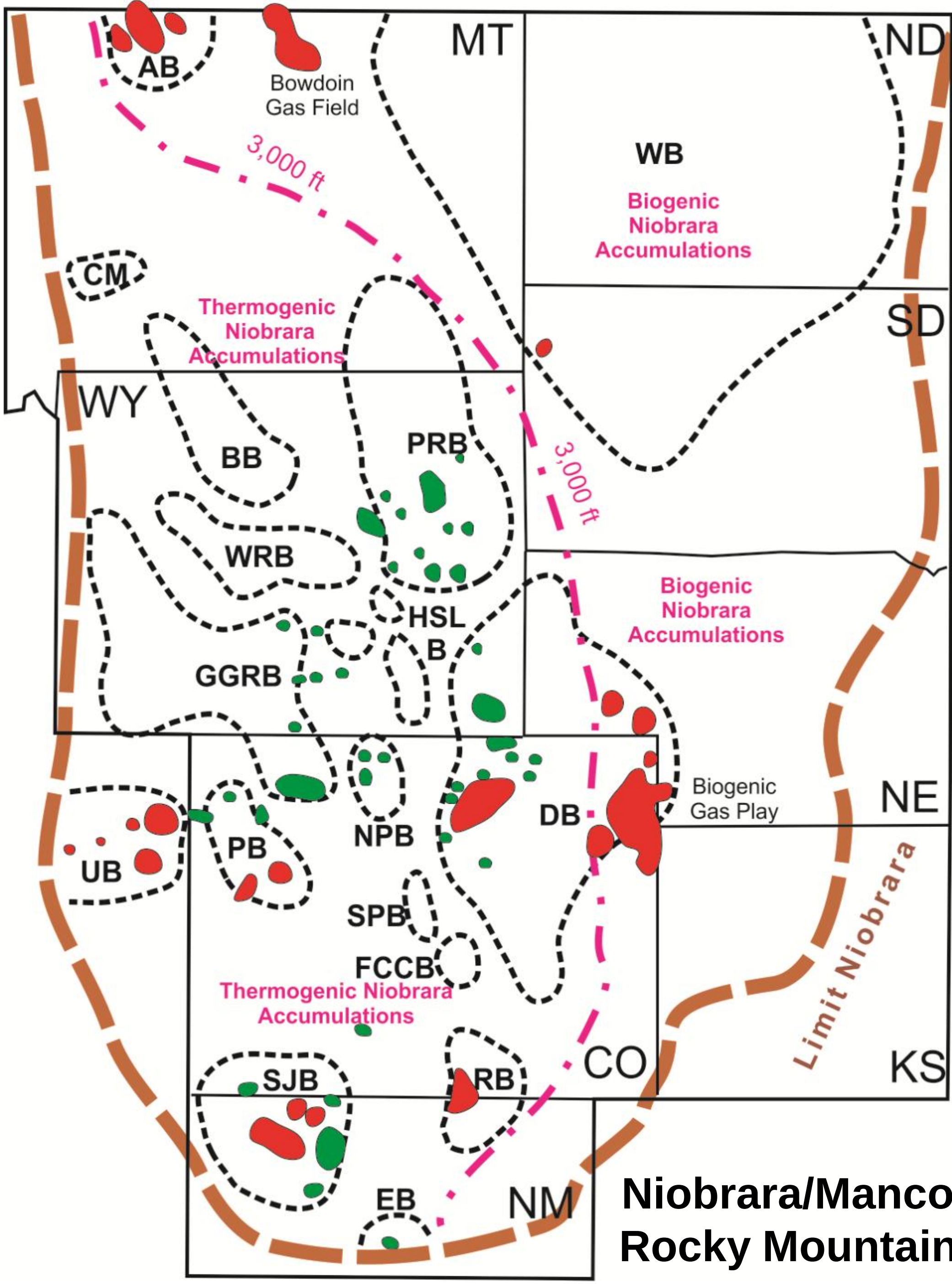
Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

The Niobrara-Mancos Oil & Gas Play, Rocky Mountain Region





Niobrara/Mancos Fields
Rocky Mountain Region

Fracture Related Fields

Florence Cañon City (Pierre Shale)
- 1881
- 15.3 MMBO

Boulder (Pierre Shale)
- 1901
- 1 MMBO

Rangely (Mancos)
- 1902
- 11.7 MMBO, 12.2 BCF

Salt Creek
- 1907
- "Upper shale" Cretaceous

Tow Creek (Niobrara)
- 1924
- 3 MMBO; 0.3 BCF

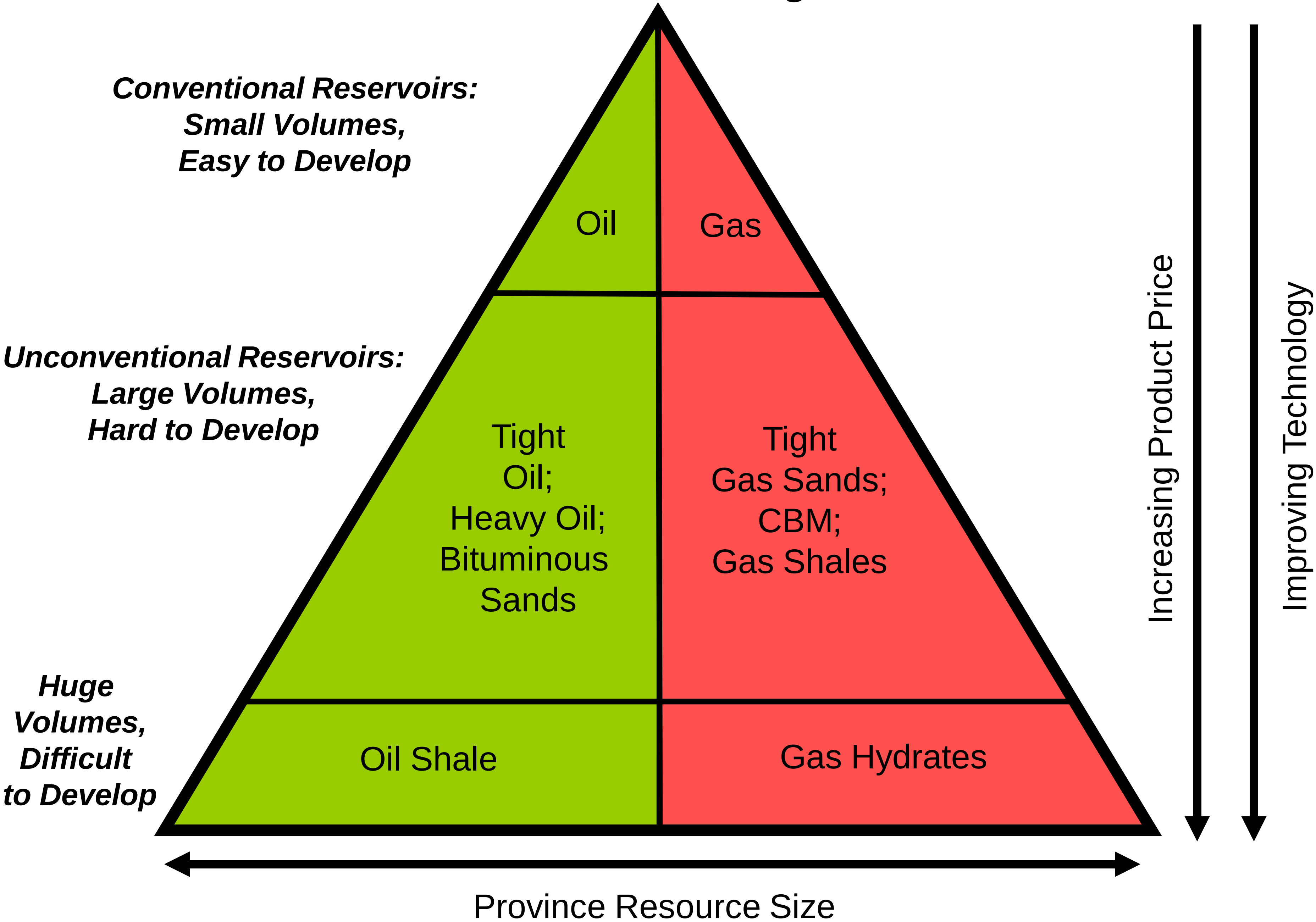
Buck Peak (Mancos, Nio)
- 1956
- 4.7 MMBO; 8.2 BCF

Puerto Chiquito (Mancos/Nio)
- 1960
- 18.7 MMBO; 52 BCF

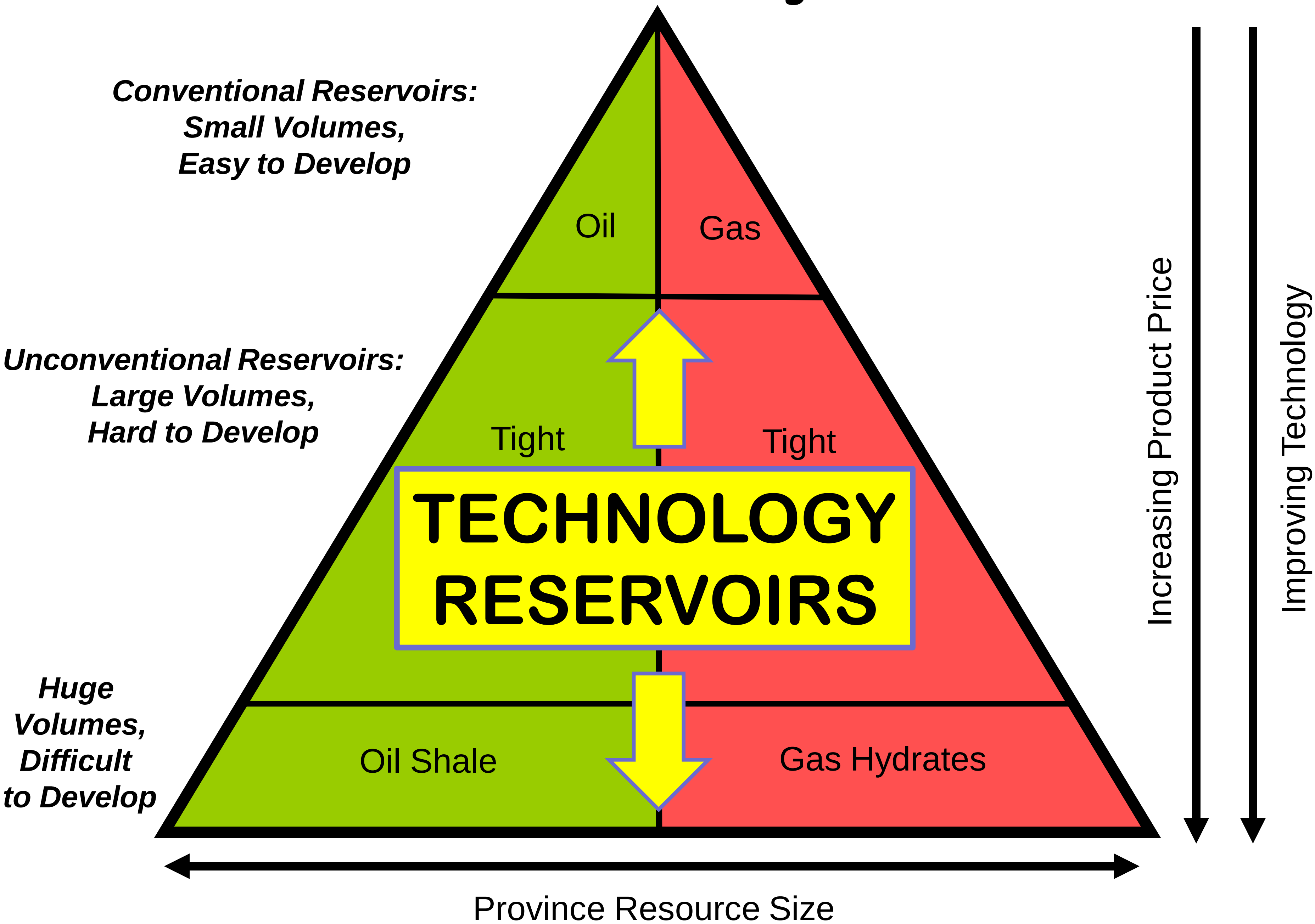
Wattenberg (Nio, Codell)
- 1970
- 86 MMBO, 1.1 Tcf

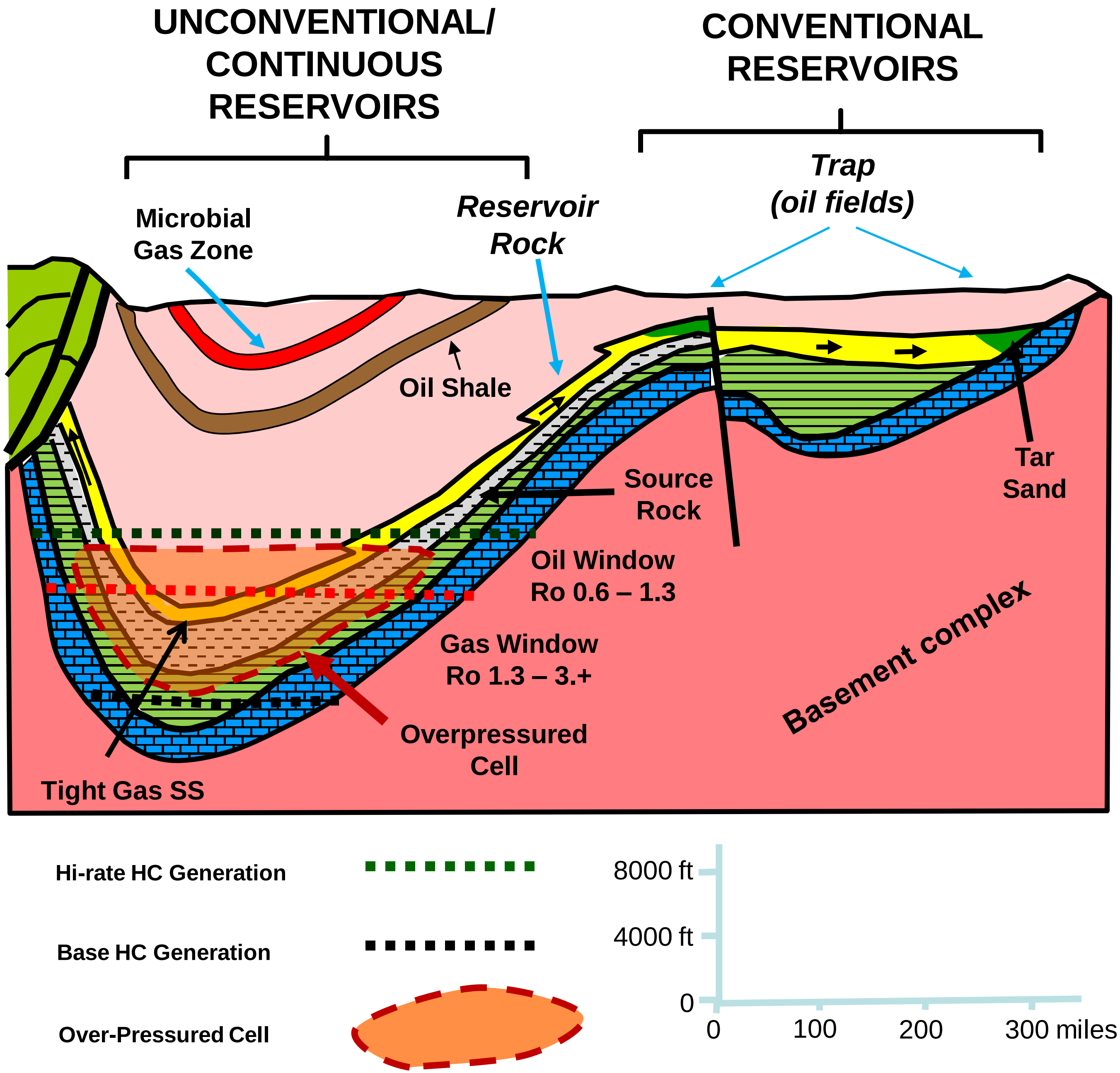
Silo (Niobrara)
- 1981
- 10.4 MMBO; 8.2 BCF

The Resource Pyramid



The Resource Pyramid





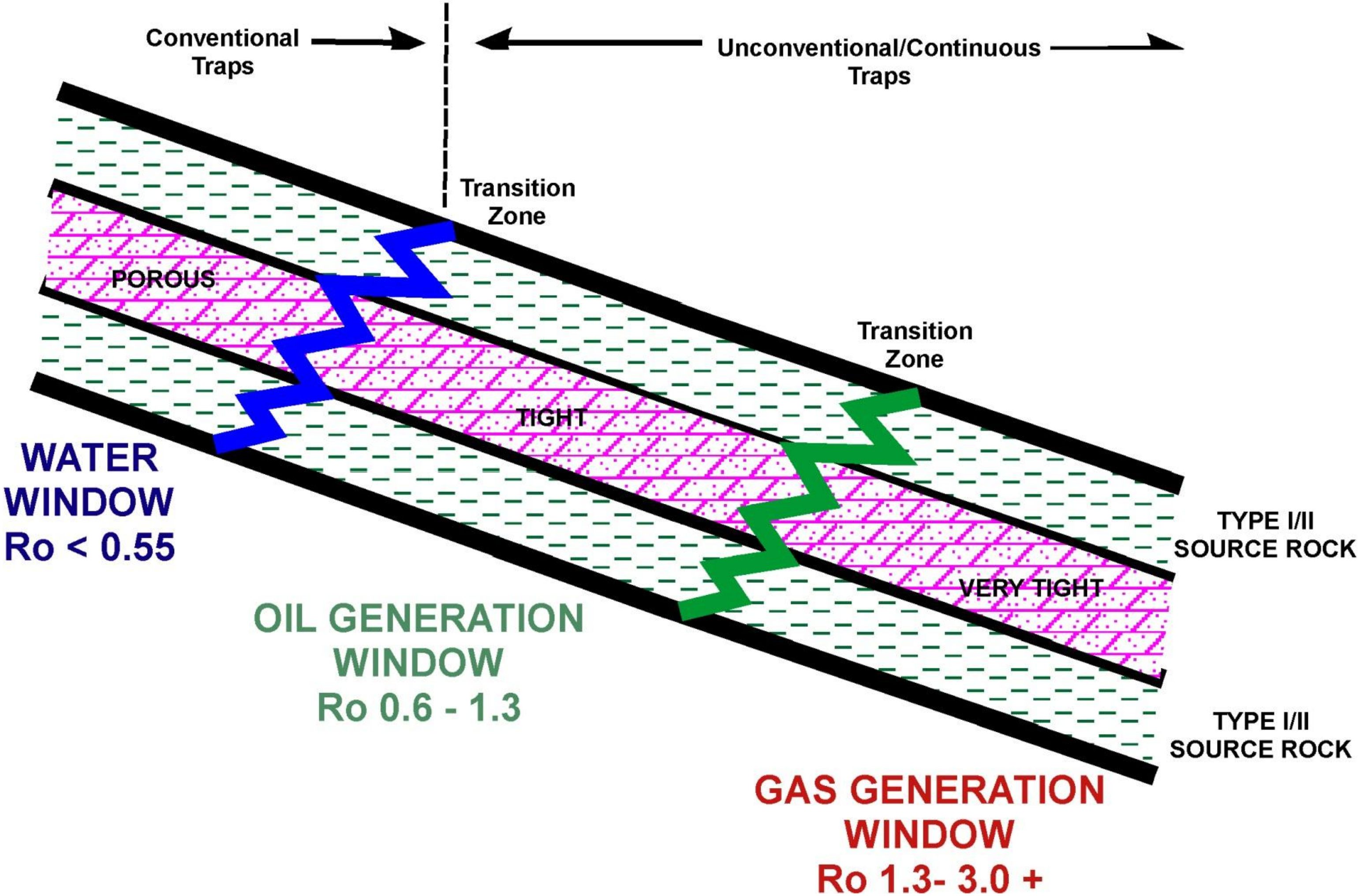
- Conventional
  - Structural
  - Stratigraphic
  - Combination
- Unconventional
  - Coalbed Methane
  - Shallow Basin Methane (biogenic)
  - Shale Gas
  - Shale Oil
  - Tight Oil ('continuous')
  - Oil Shale
  - Tar Sands

Modified from Magoon, 1988

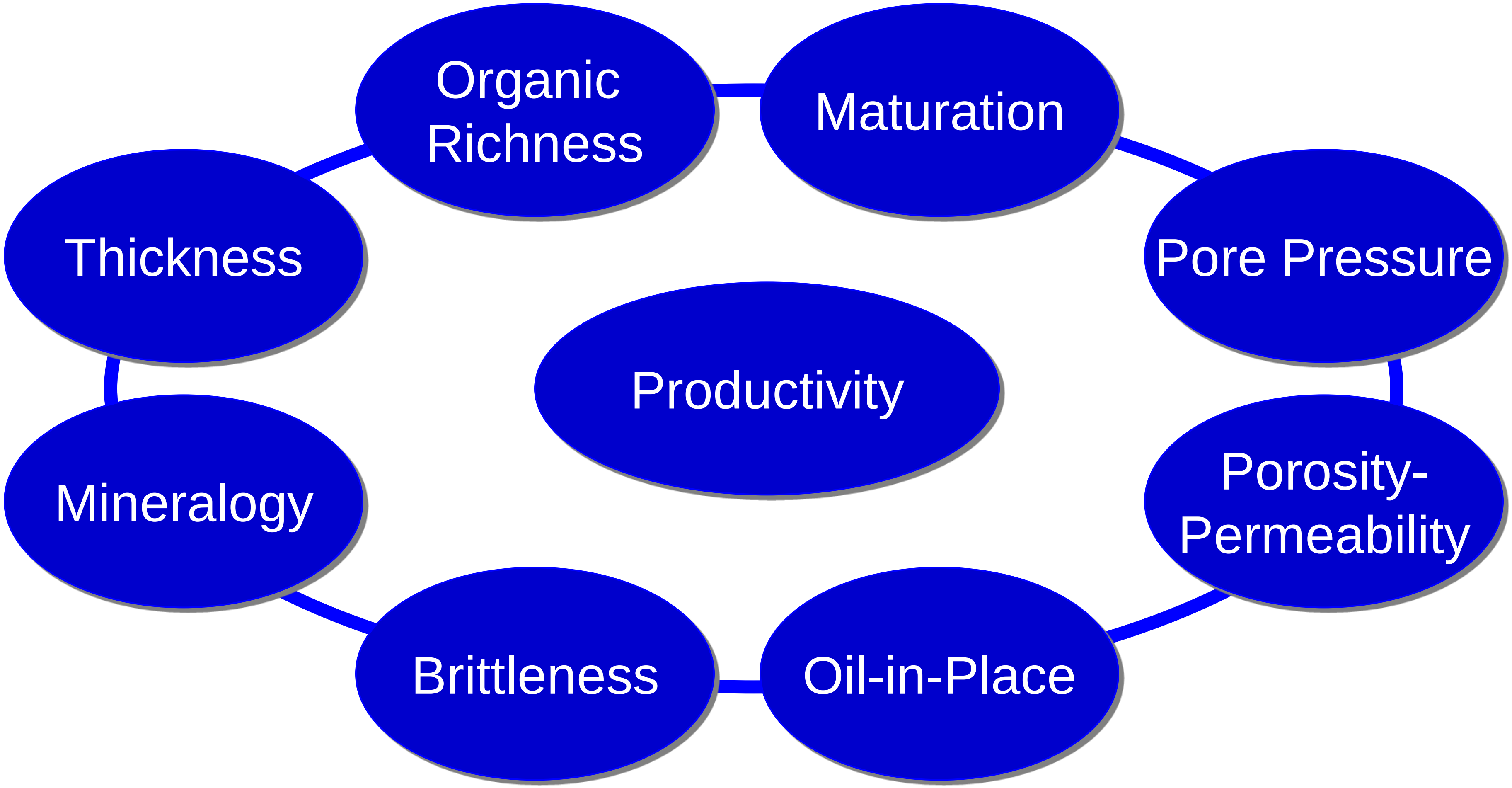
Unconventional, Continuous Tight Oil Accumulations

- Pervasive accumulations that are hydrocarbon-saturated
- Not localized by buoyancy
- Abnormally pressured (high or low)
- Commonly lack downdip water
- Updip contact with regional water saturation
- Low-permeability and low-matrix-porosity reservoirs
- Reservoirs may be single or vertically stacked
- Commonly enhanced by fracturing
- Associated with mature source rocks that are either actively generating or have recently ceased generation
- Hydrocarbons of thermal origin
- Fields have diffuse boundaries
- Inverted Petroleum Systems

INVERTED SYSTEMS



Elements of a Successful Tight Oil Play



Factors Related to Tight Oil Production

- Source beds
- Mature source rocks form continuous oil column (*pervasive saturation*)
- Reservoir - favorable facies and diagenetic history (*matrix permeability*)
- Favorable history of fracture development: folds, faults, solution of evaporites, high fluid pressures, regional stress field (*fracture permeability*)
- Mechanical stratigraphy

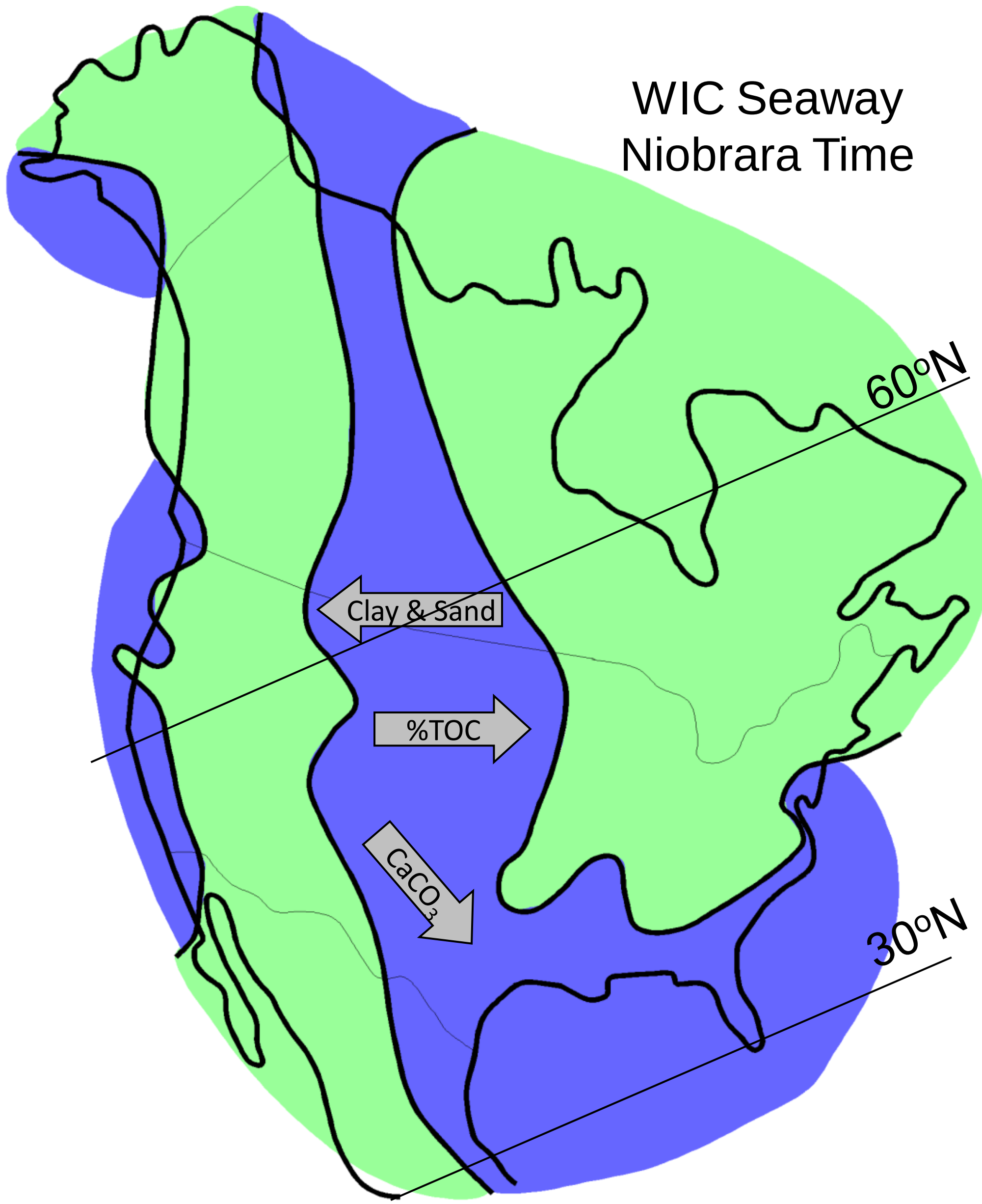
Western Interior Cretaceous Basin

Late Cretaceous

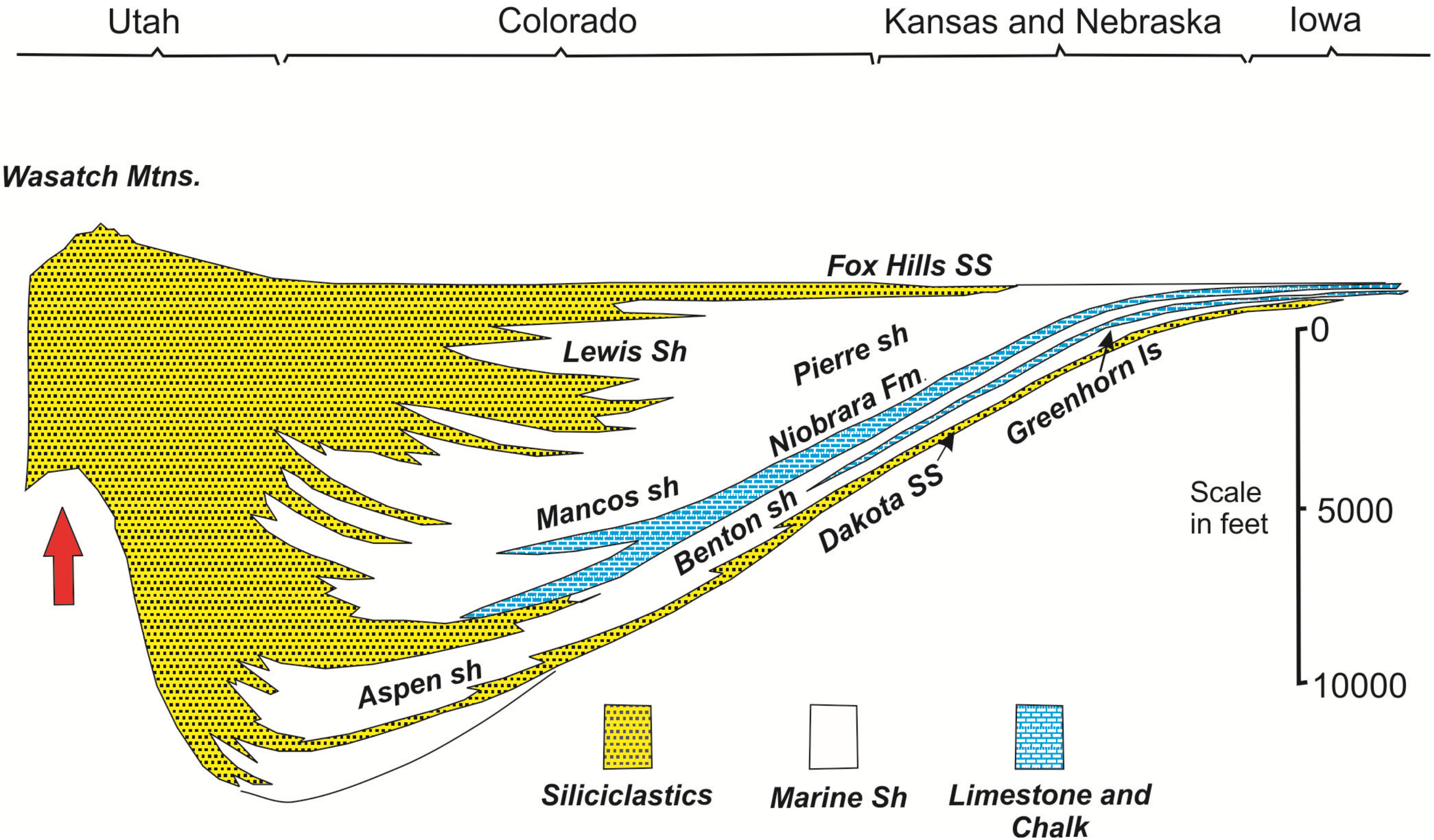
85Ma

http://jan.ucc.nau.edu/~rcb7/namK85.jpg

WIC Seaway
Niobrara Time

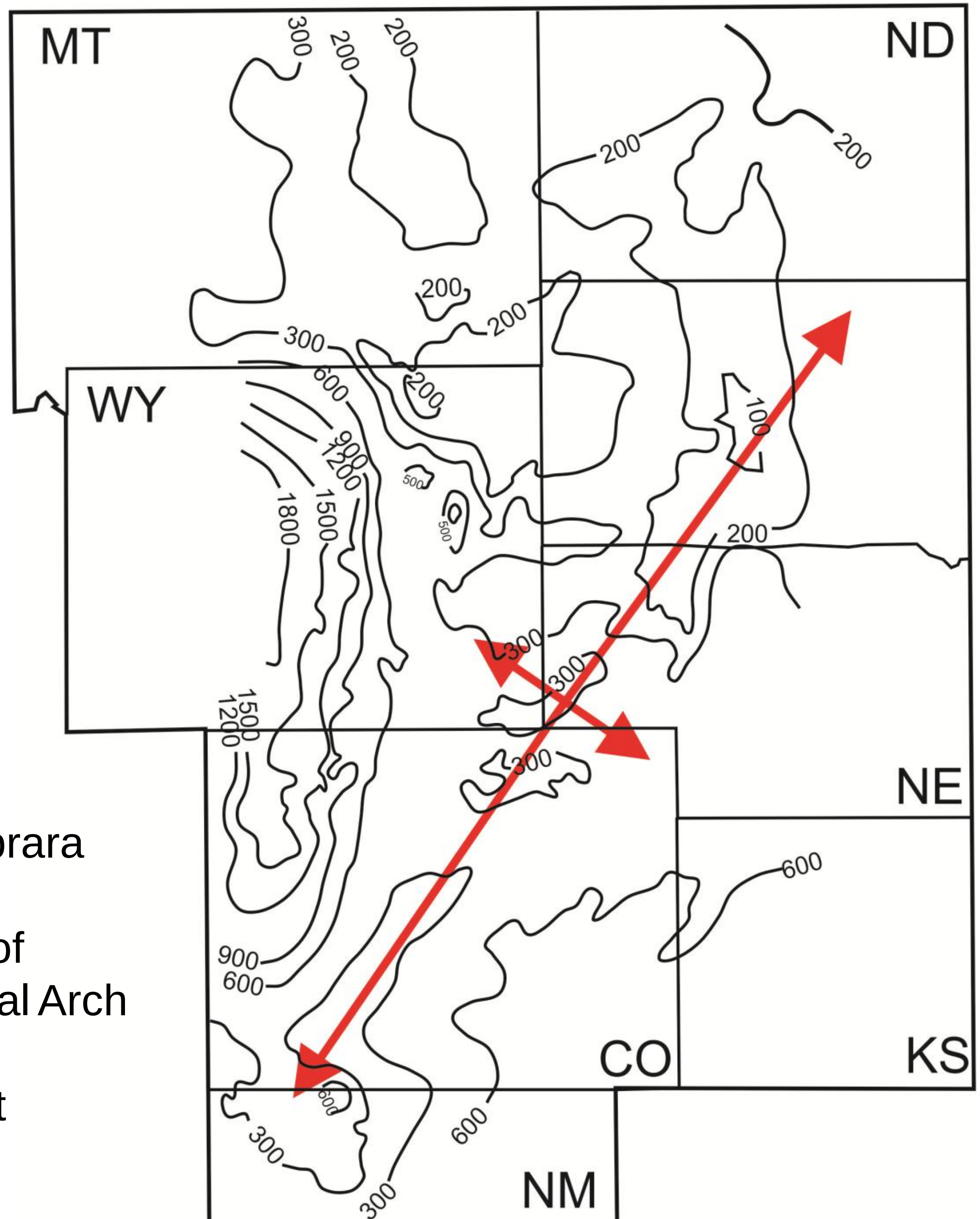


Modified from Longman et al., 1998



Cretaceous Cross Section, Western Interior Basin

Modified from Kauffman, 1977

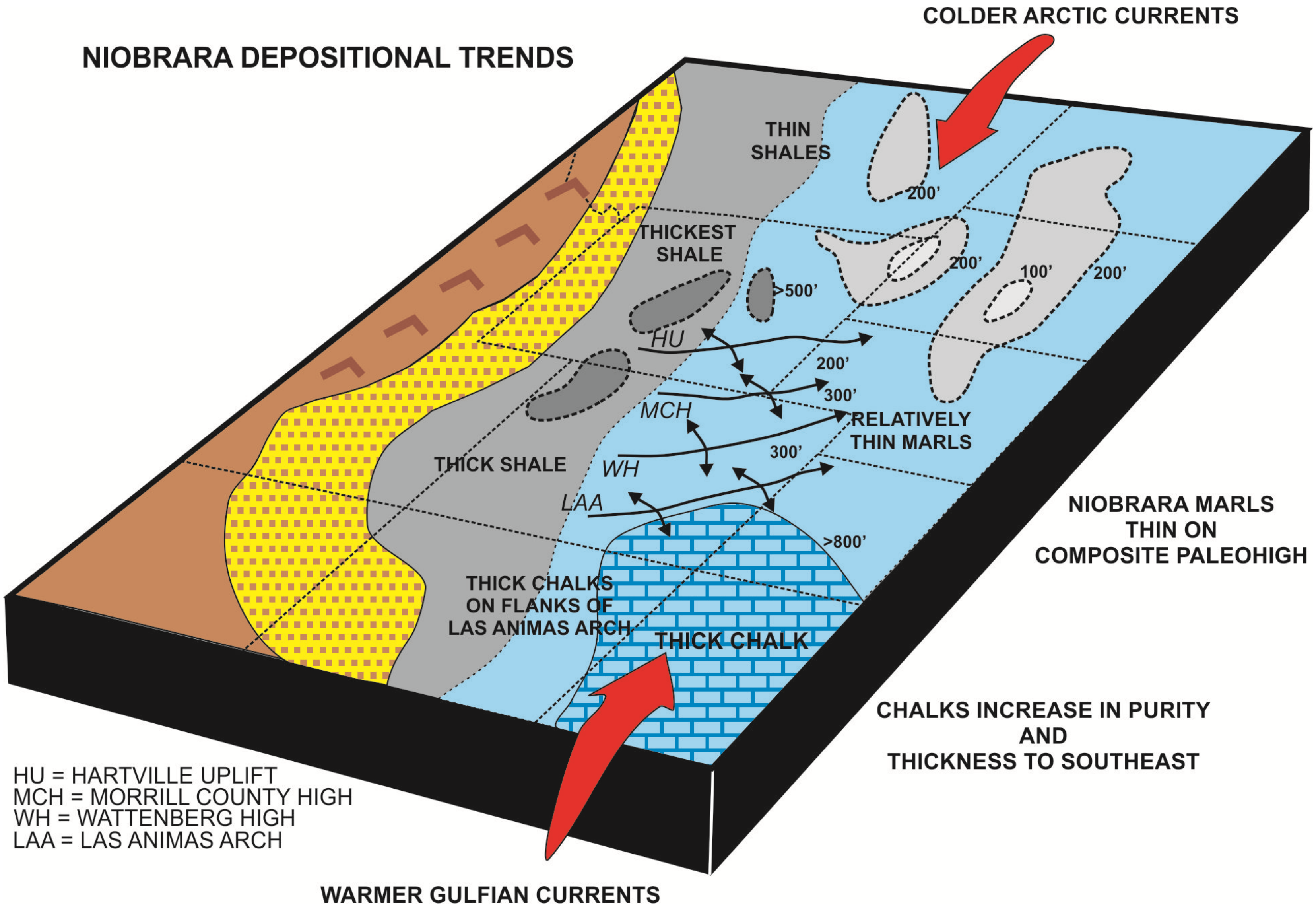


Isopach Niobrara

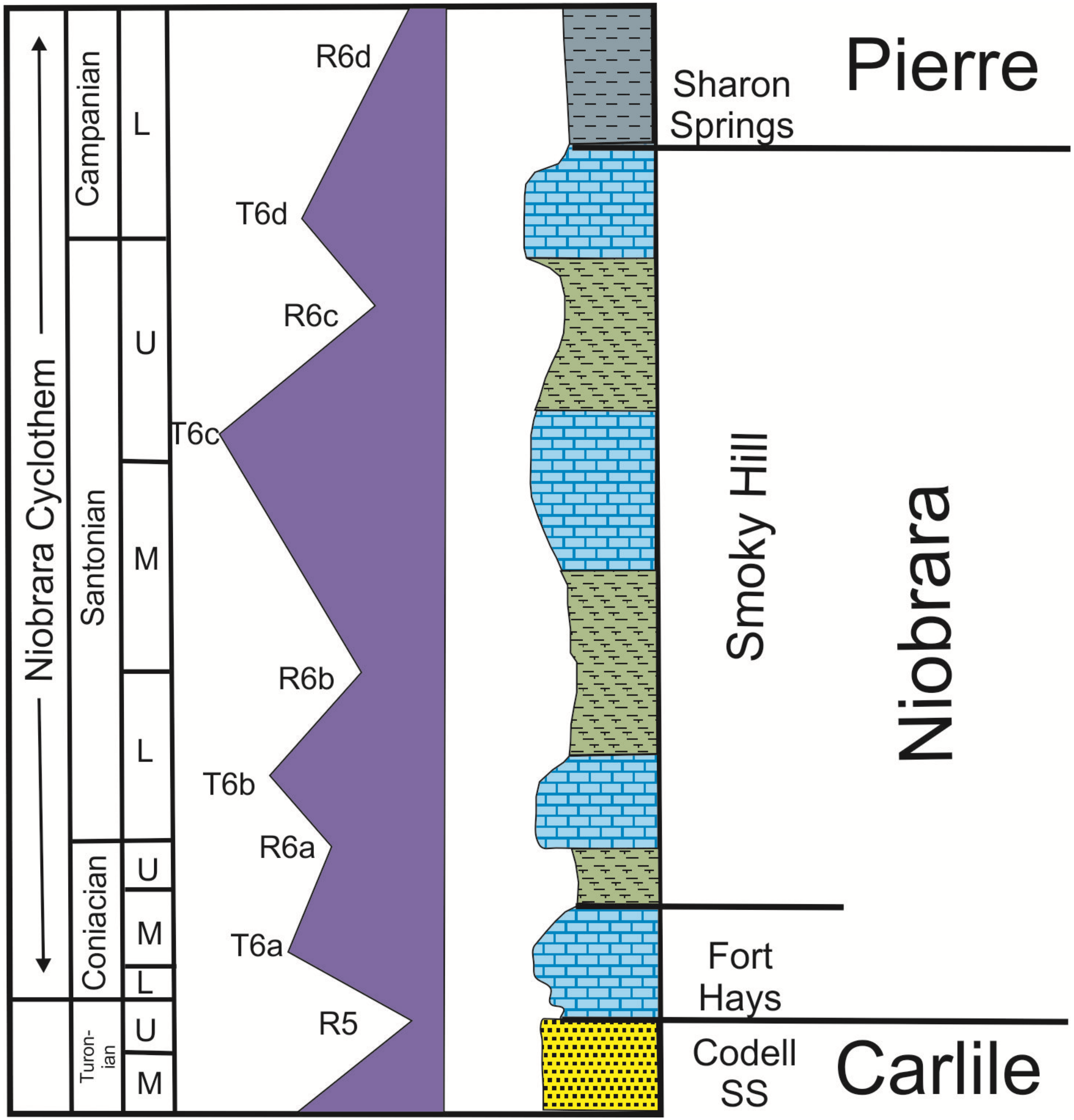
Location of Transcontinental Arch

CI: 100 ft

Modified from Longman et al., 1998; Weimer, 1978



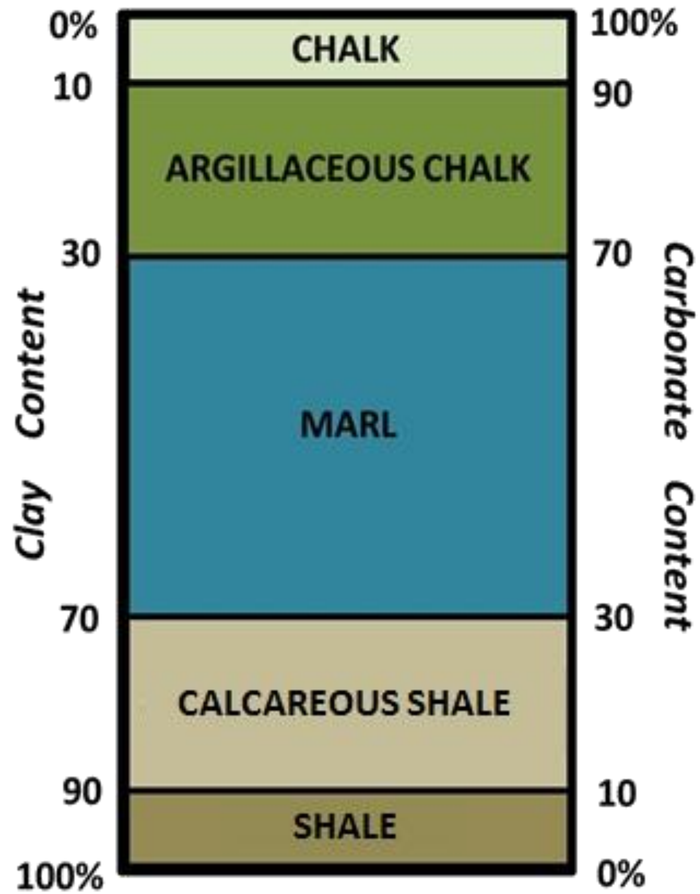
Modified from Longman et al., 1998

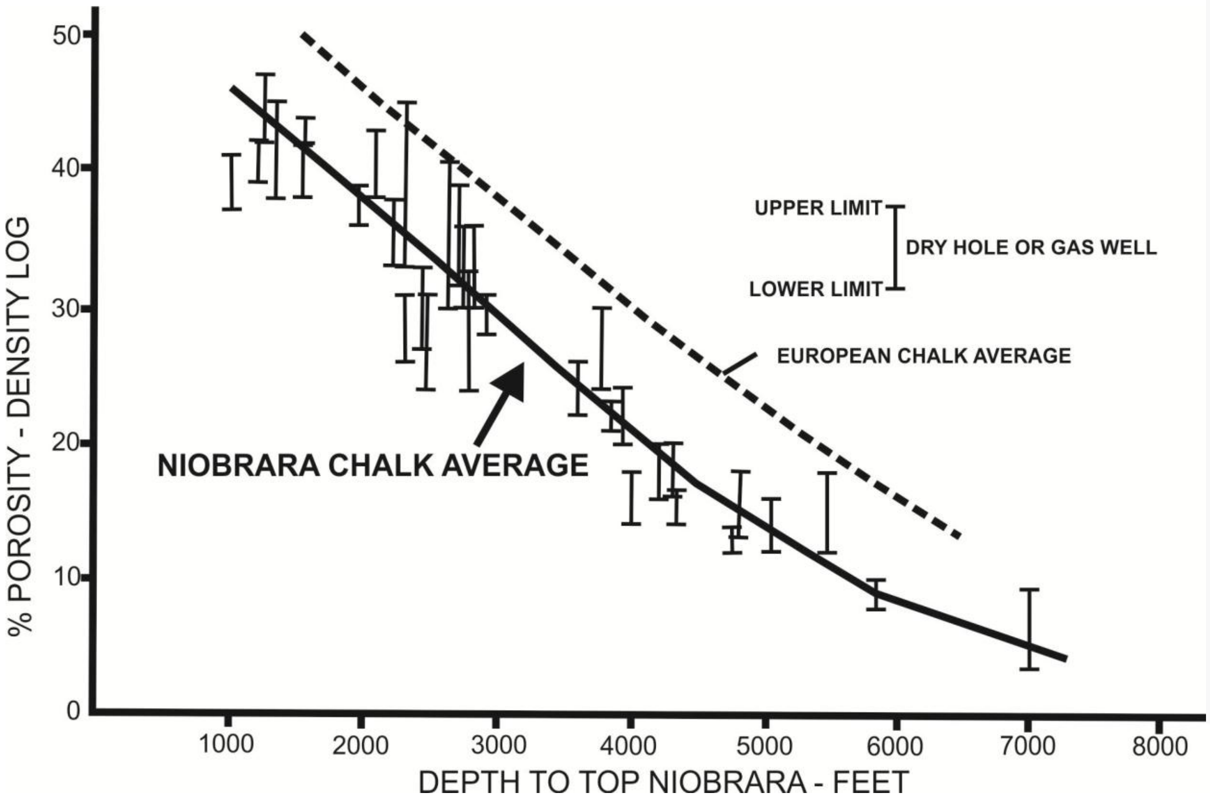


Modified from Longman et al., 1998, after Barlow, 1986

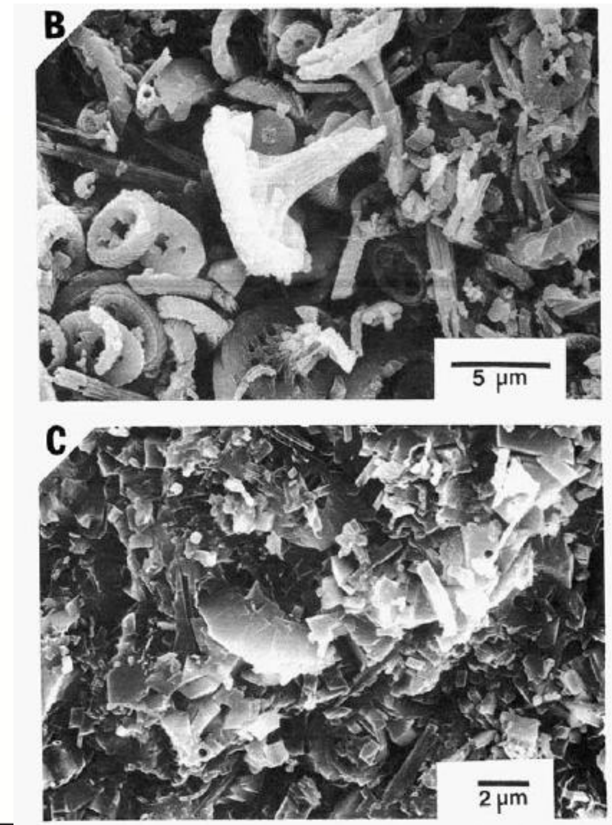
Stratigraphy

- Does not fit well into traditional classifications
- Gradation between units and similar facies makes lithostratigraphic correlations difficult





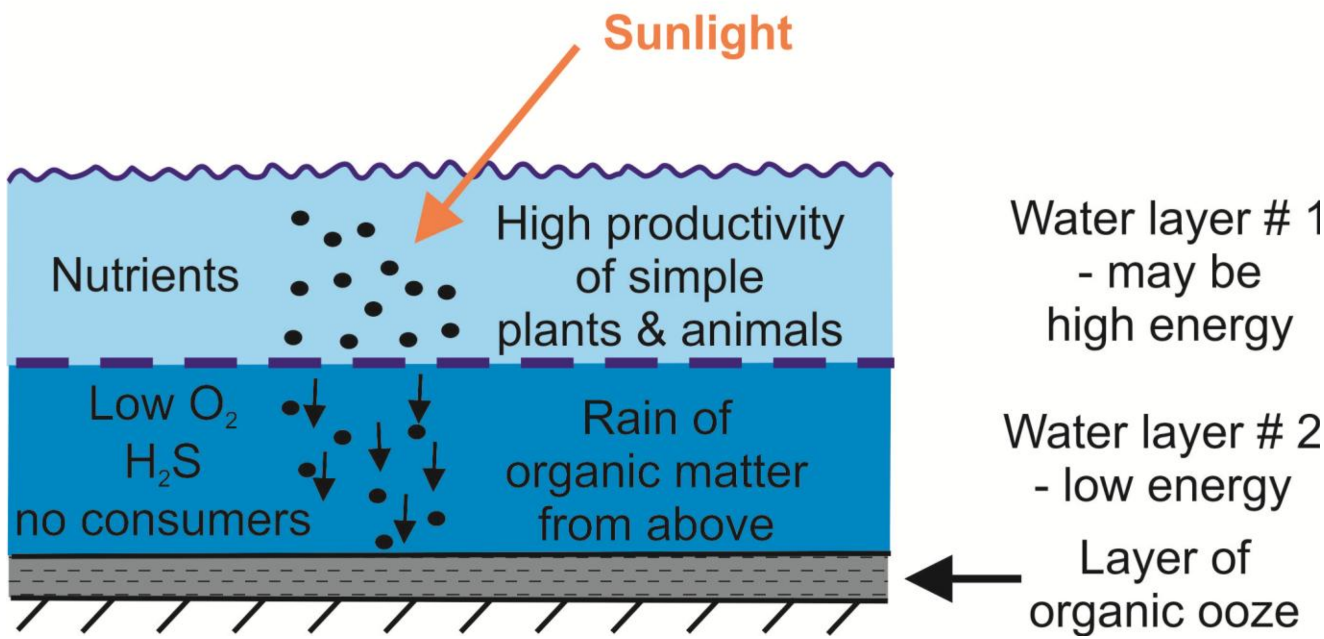
2000 ft



5600 ft

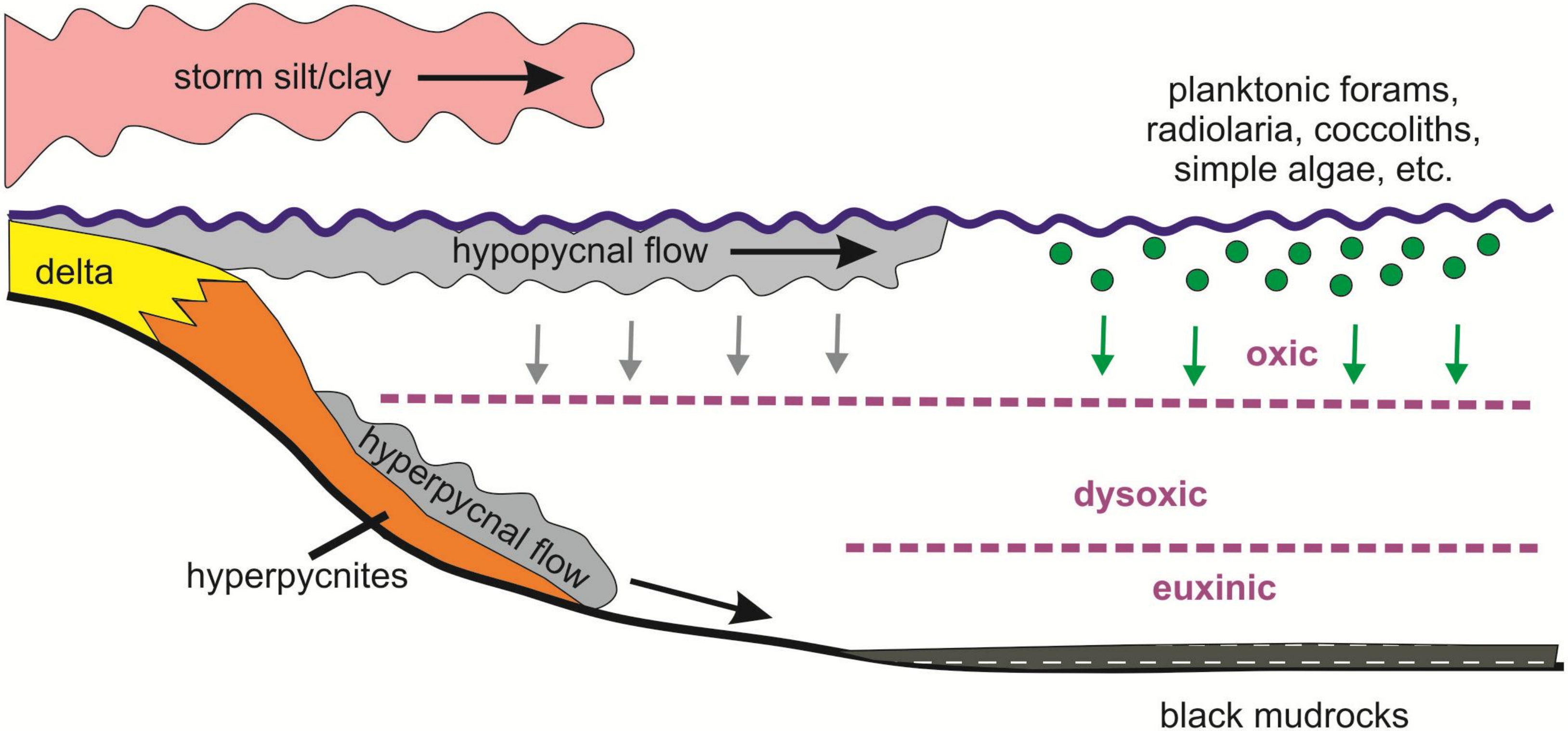
Modified from Lockridge and Pollastro, 1988

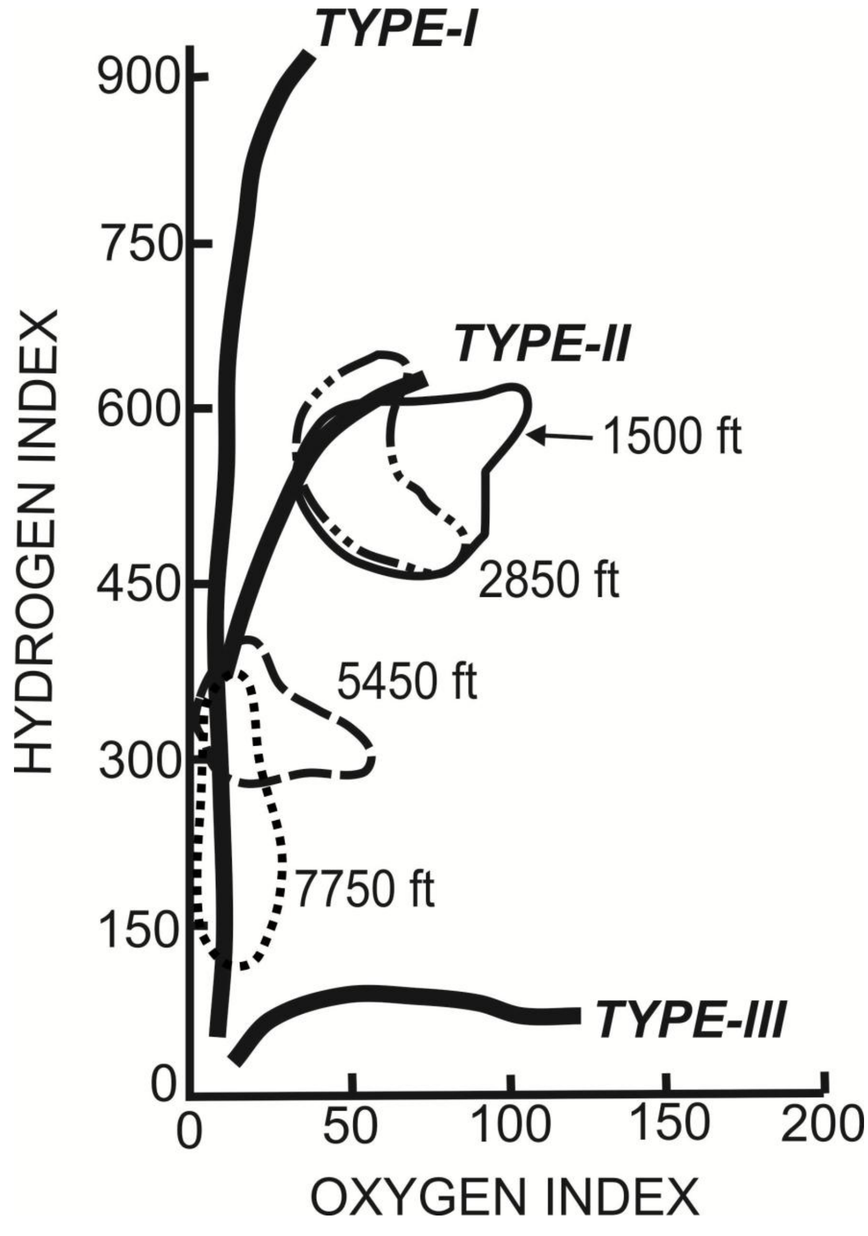
Oil Source Rocks
Sapropelic Deposition



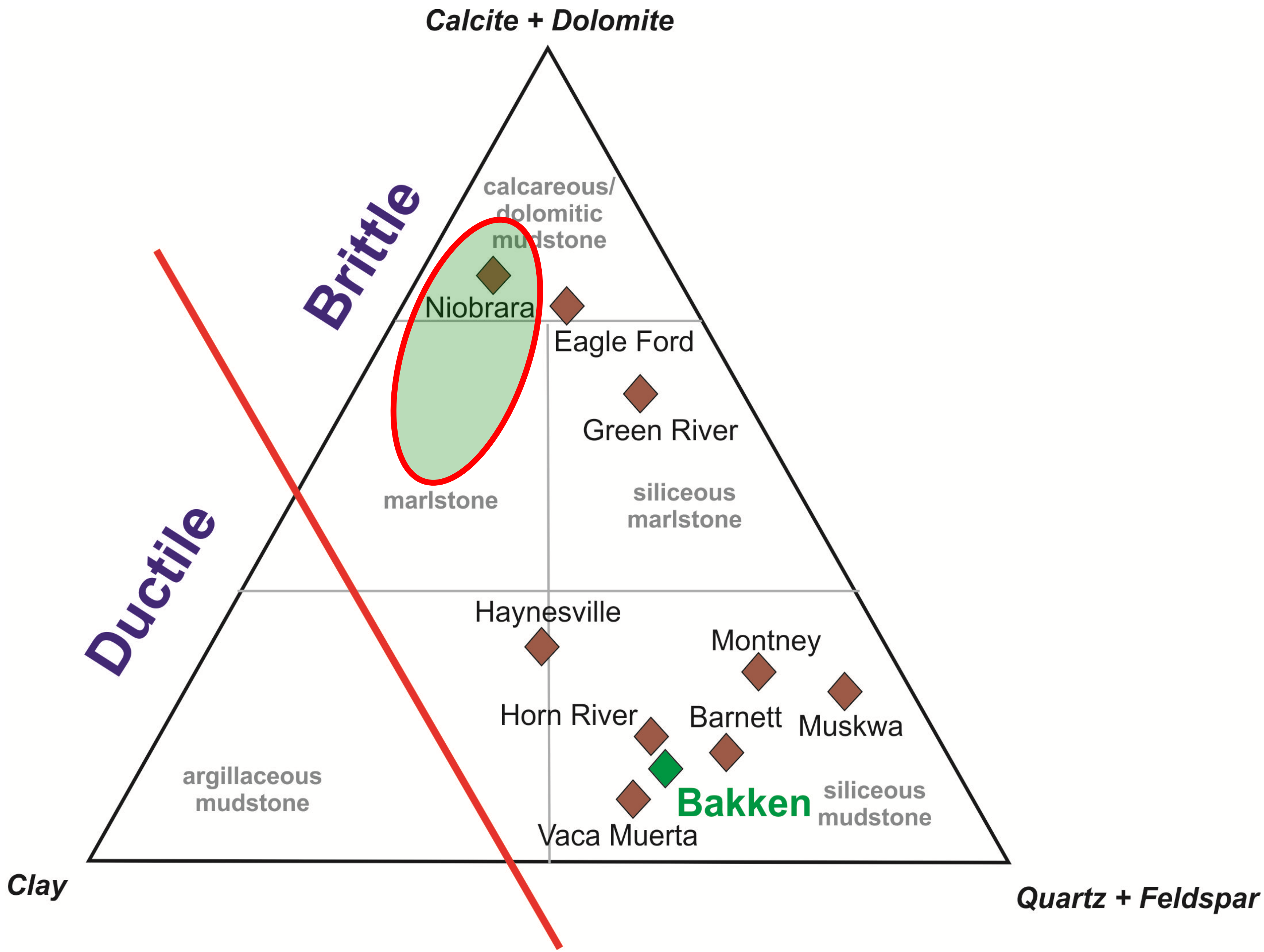
- stratified water column
- minimum depth of 150 ft (below photic zone and wave action)
- heavy rain of organic material (predominantly marine phytoplankton)

Modified from Meissner et al., 1984; Webster, 1984

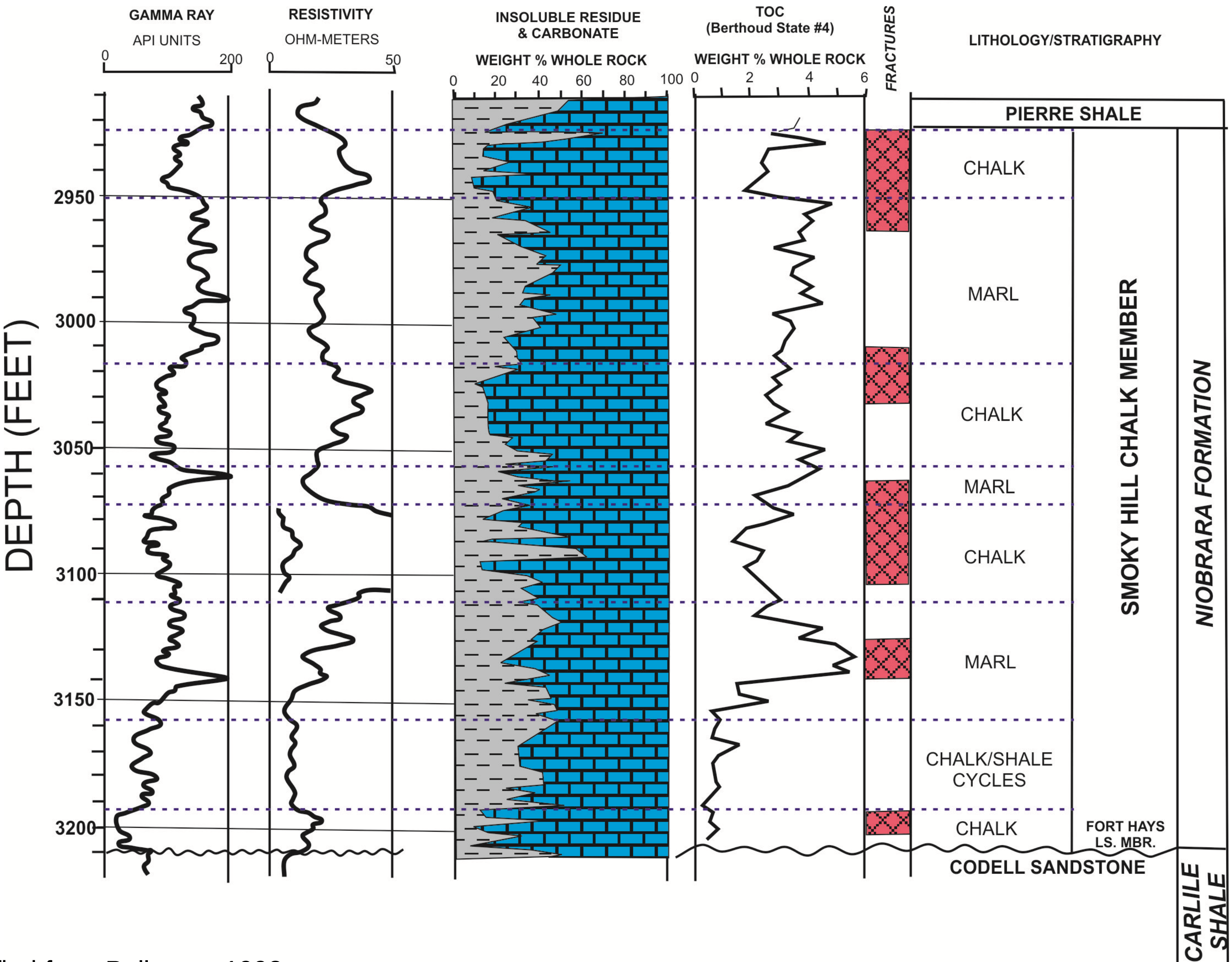

storm silt/clay
planktonic forams,
radiolaria, coccoliths,
simple algae, etc.
delta
hypopycnal flow
oxic
hyperpycnal flow
dysoxic
hyperpycnites
euxinic
black mudrocks



Modified from Sonnenberg and Weimer, 1993

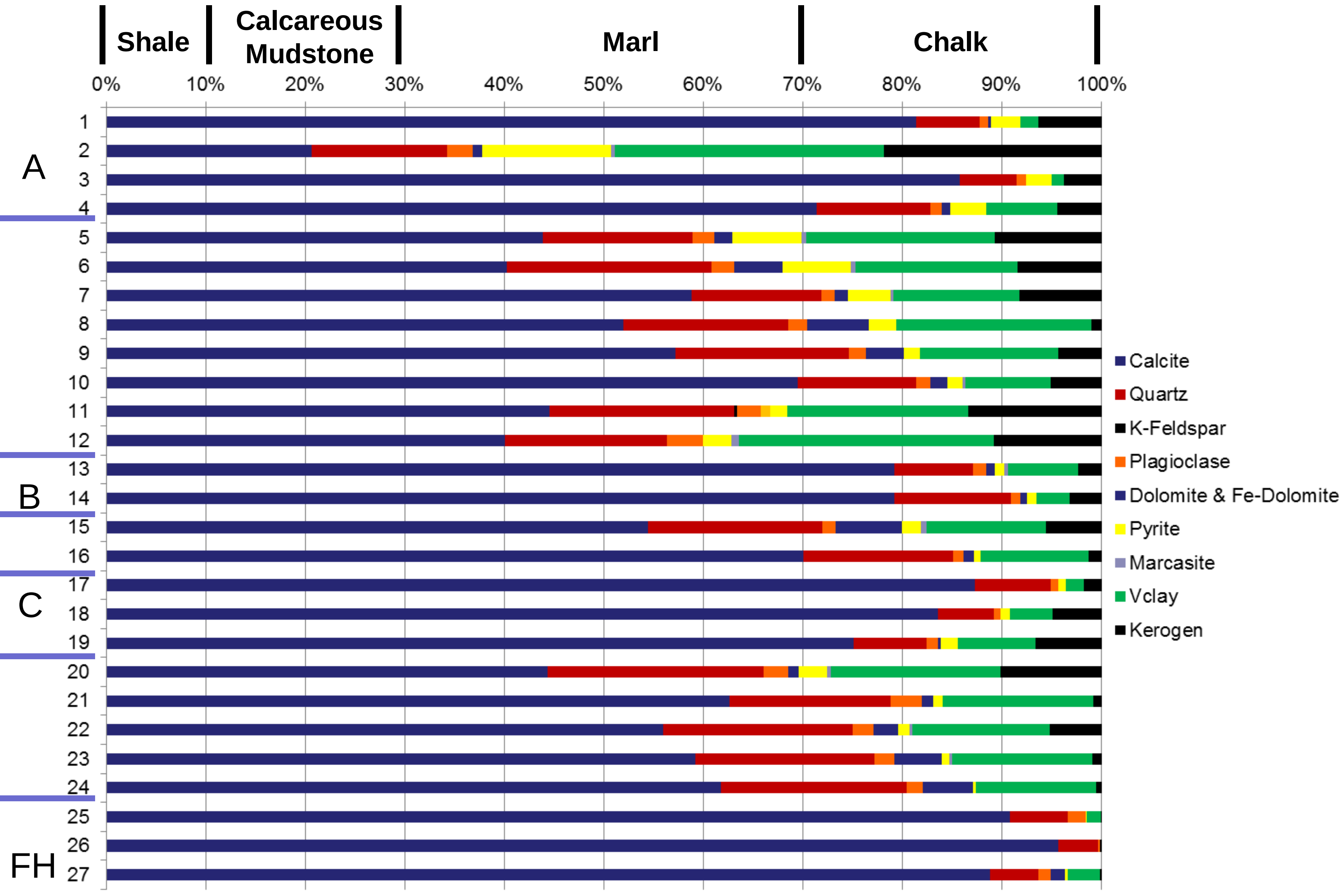


Modified from Wren, 2011



Modified from Pollastro, 1992

Berthoud # 4


Shale
Calcareous Mudstone
Marl
Chalk
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30%
40%
50%
60%
70%
80%
90%
100%
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C
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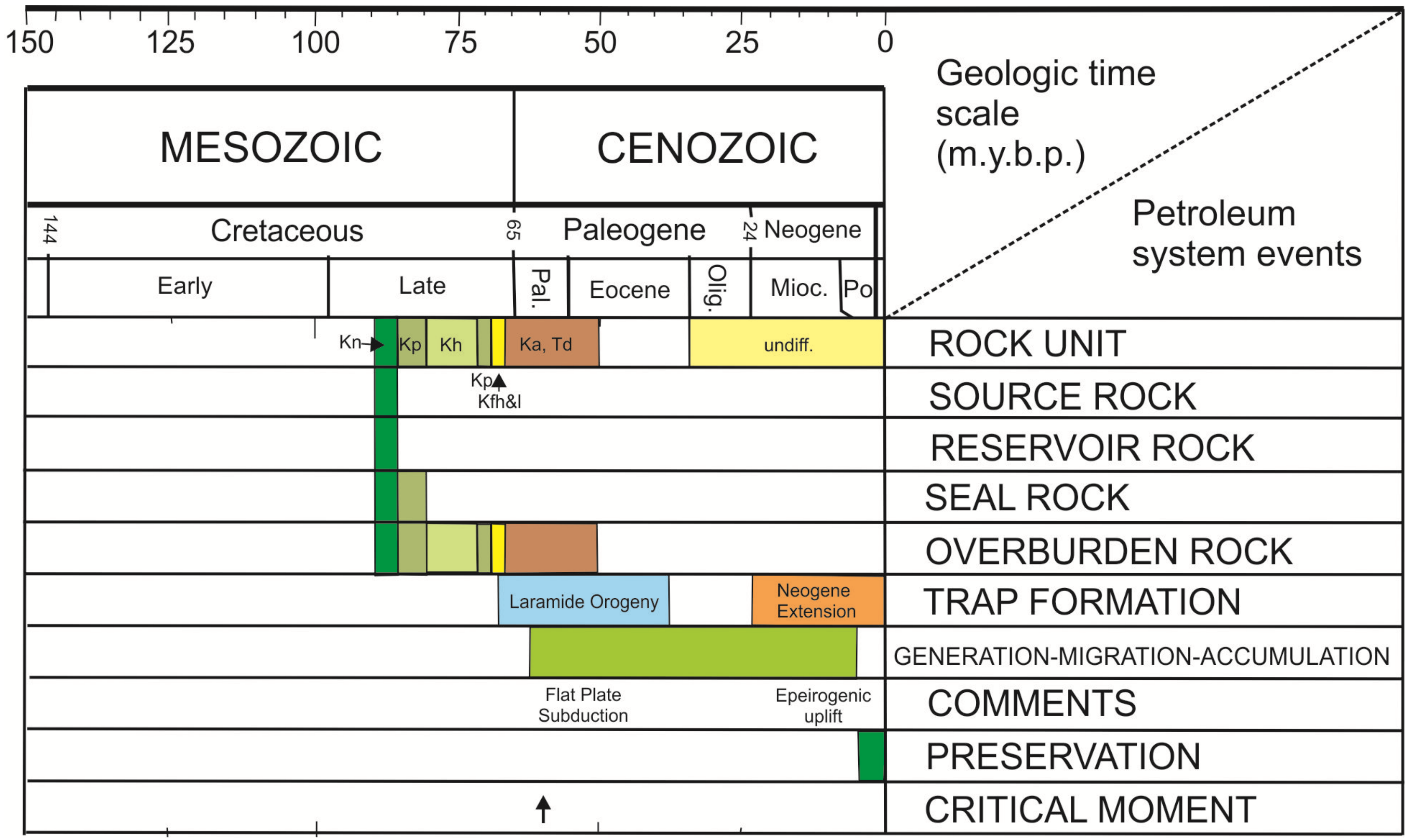
Calcite
Quartz
K-Feldspar
Plagioclase
Dolomite & Fe-Dolomite
Pyrite
Marcasite
Vclay
Kerogen

Niobrara Petroleum System Events Chart

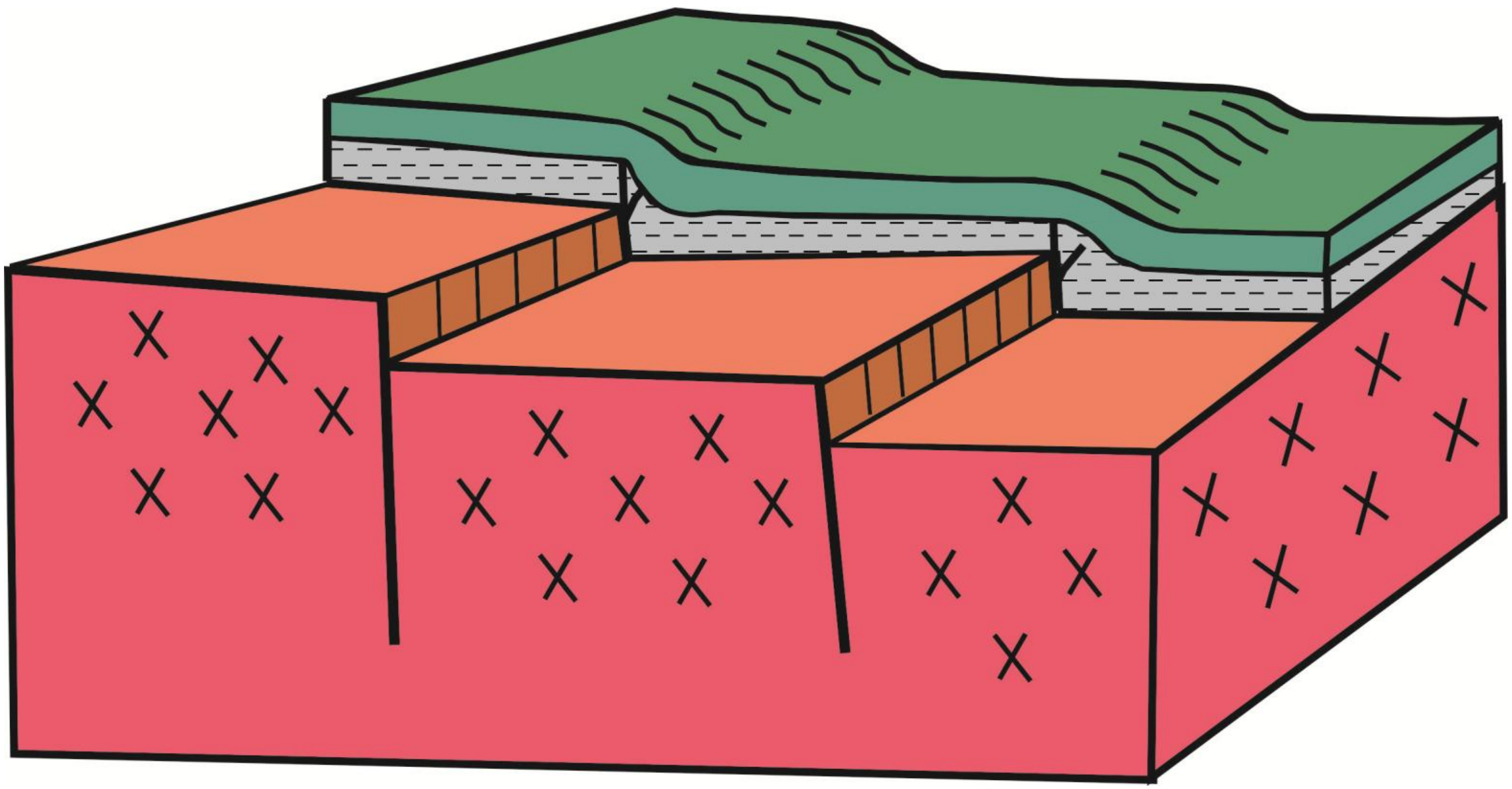


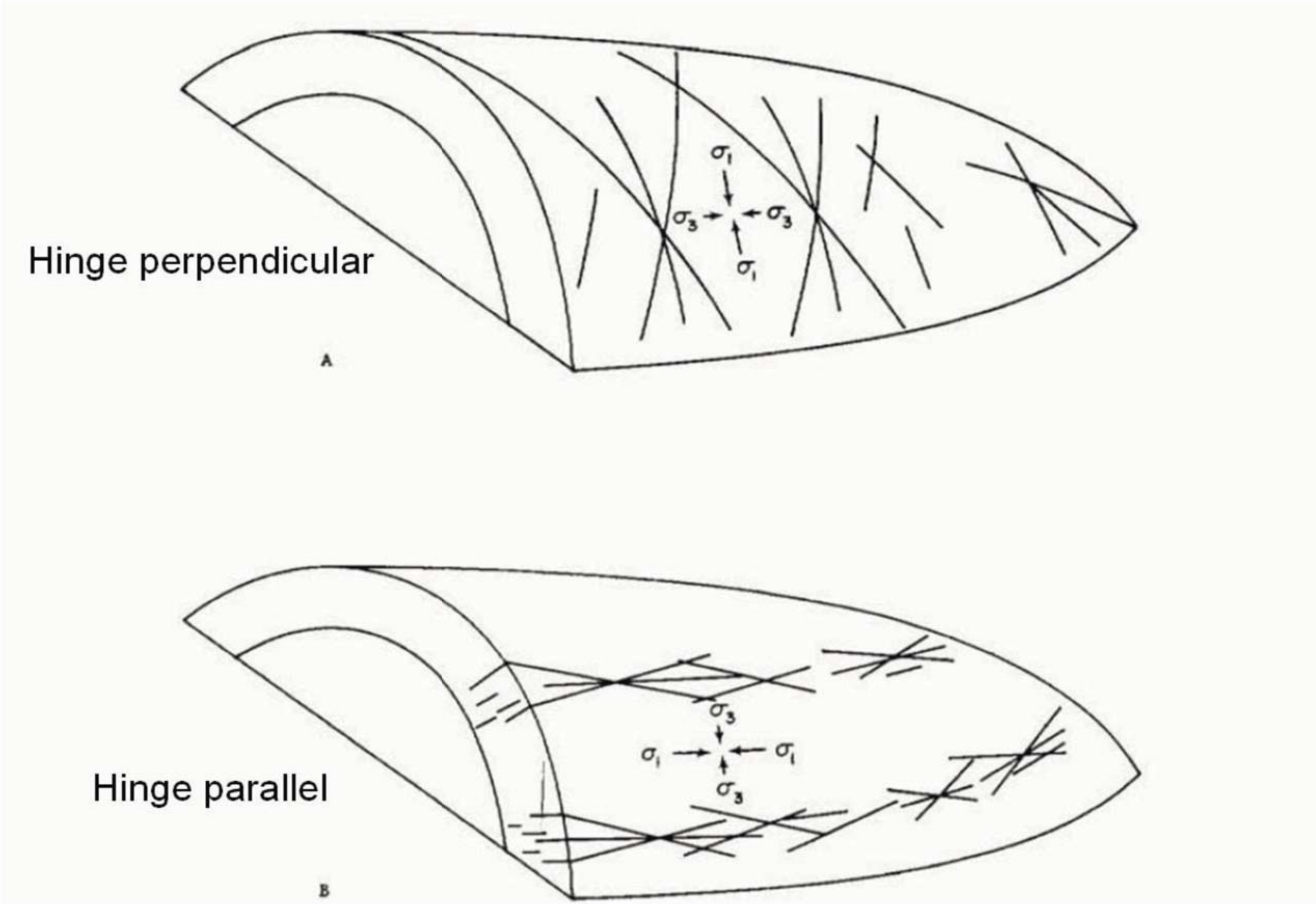
Niobrara Fractures

Origin of Fractures

- Folding and Faulting
  - Tectonic, diapiric, slumping
  - Wrench faults
- Geologic History of Fractures
  - Recurrent movement on basement shear zones
- Solution of evaporites
- High Fluid Pressure
  - Maturation of source rocks
- Compaction and dewatering
- Regional stress field
- Regional epeirogenic uplift

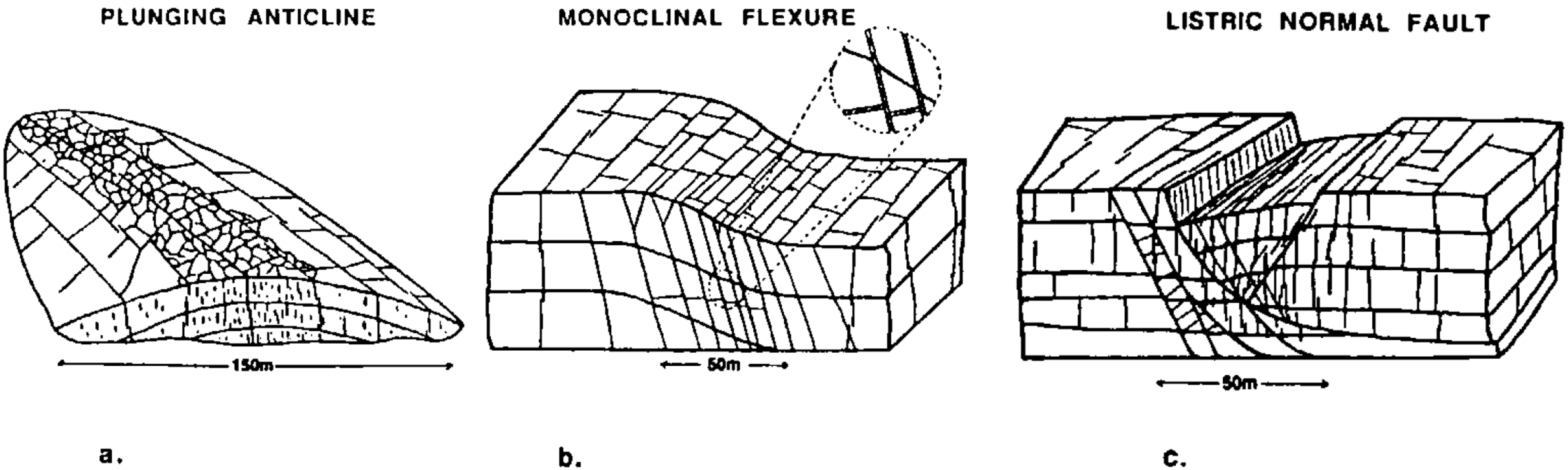
Force Folds, Faults, and Fractures





Fractures related to folds

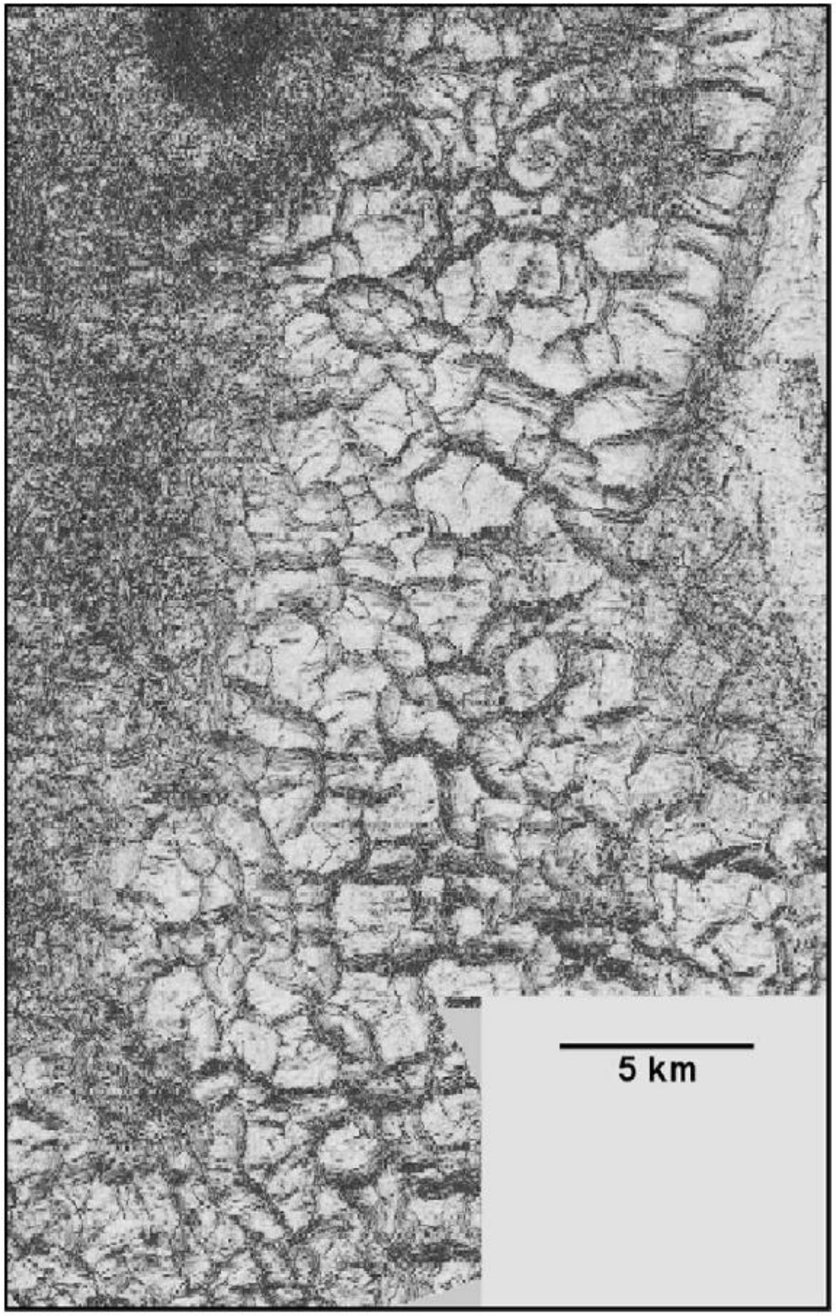
Structures and Associated Fractures



From Austin Chalk Outcrops

Friedman et al., 1992

Compaction-Dewatering
North Sea Overpressured
Shale
(Brown, 2004)

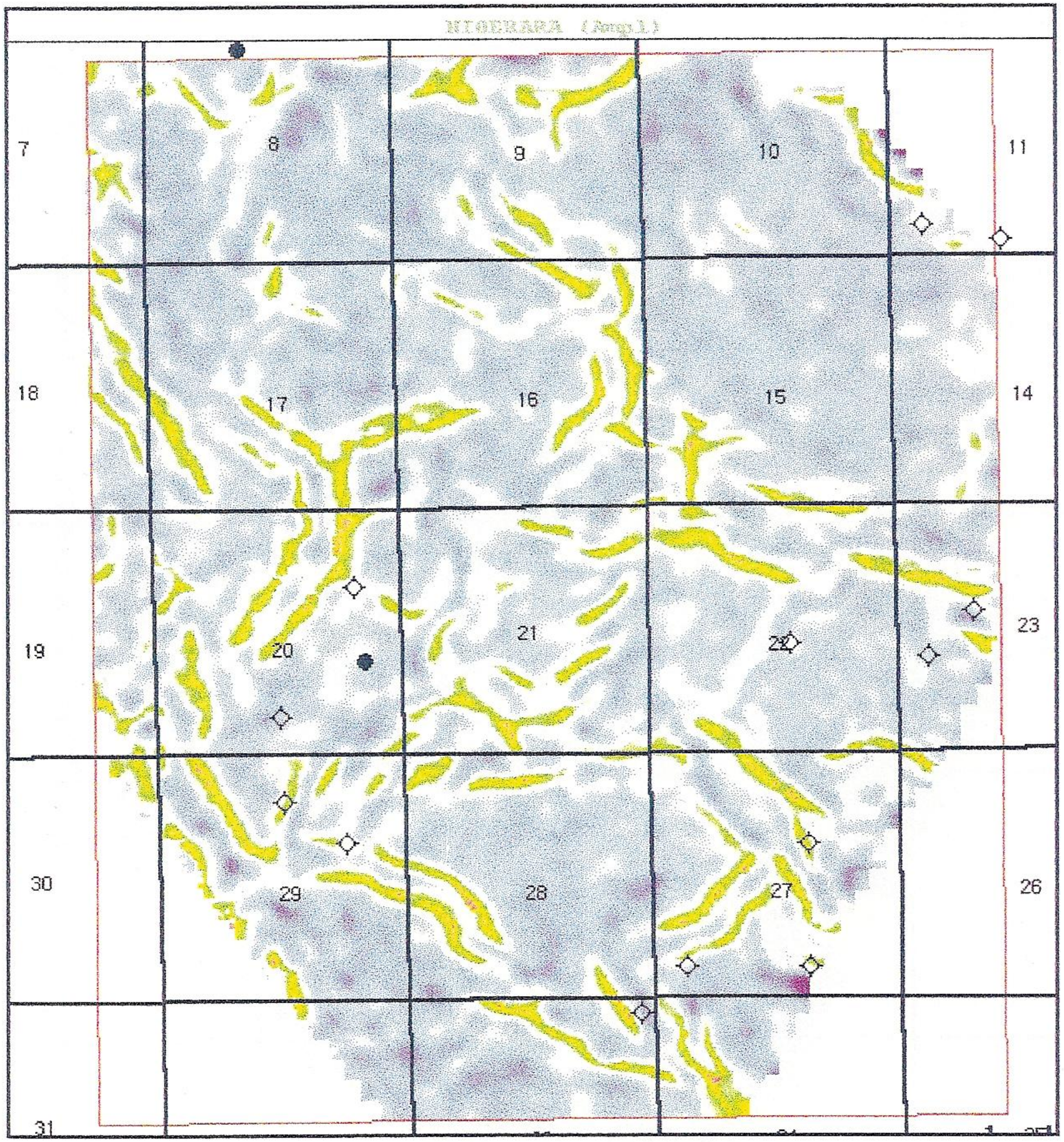


Polygonal Fault Systems

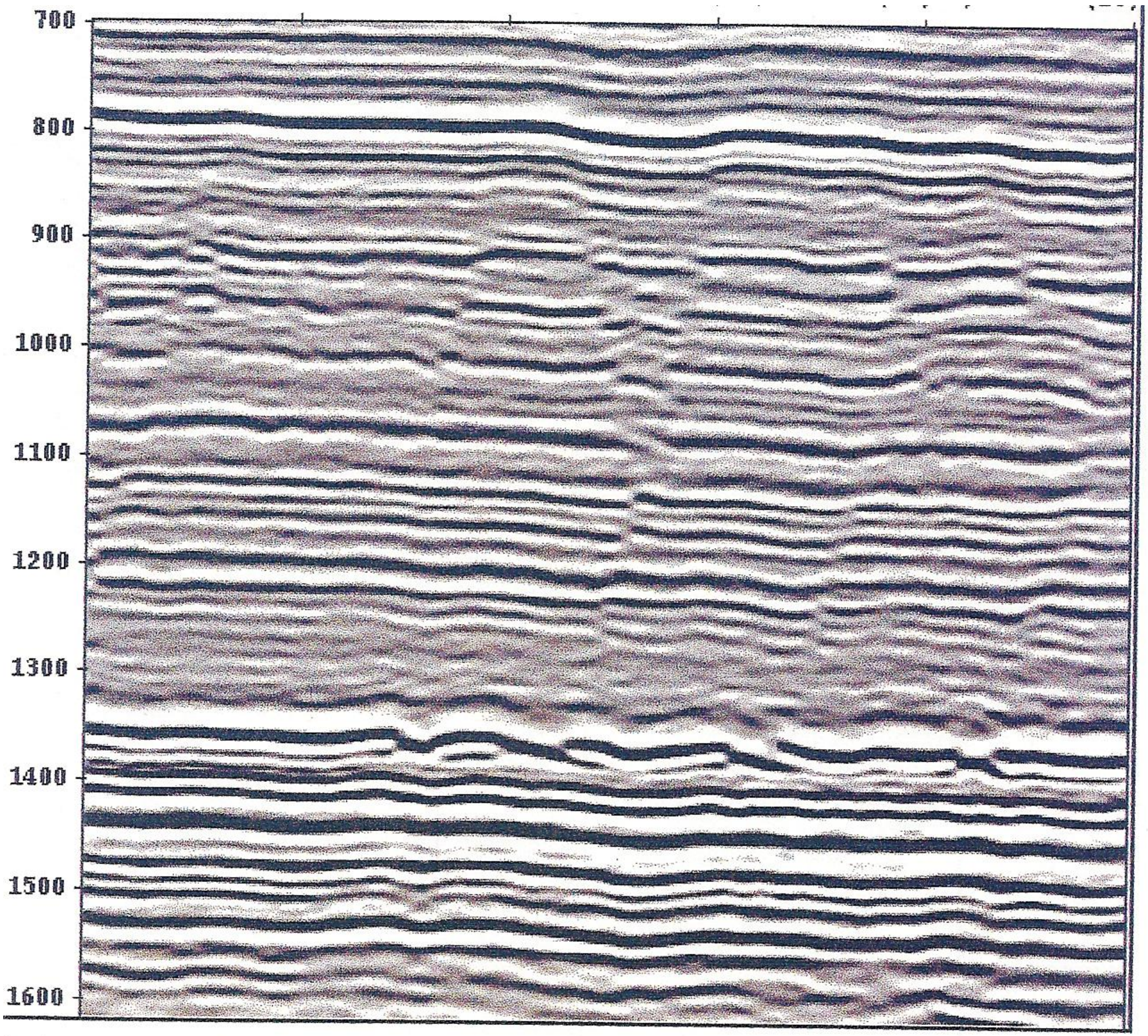
- Layer-bounded fault systems
- Small extension faults
  - 10-50 m throw
  - Faults dip 30 to 70^{o}
- Random oriented fault patterns

Polygonal Fault Systems

- Volumetric contraction resulting from compaction-driven fluid expulsion
- Compaction dewatering occurs at depth
- Vertical effective stress exceeds horizontal effective stress and inclined fractures result
- Stress state in plane in which polygons are developed is either isotropic or close to isotropic



Niobrara Amplitude Map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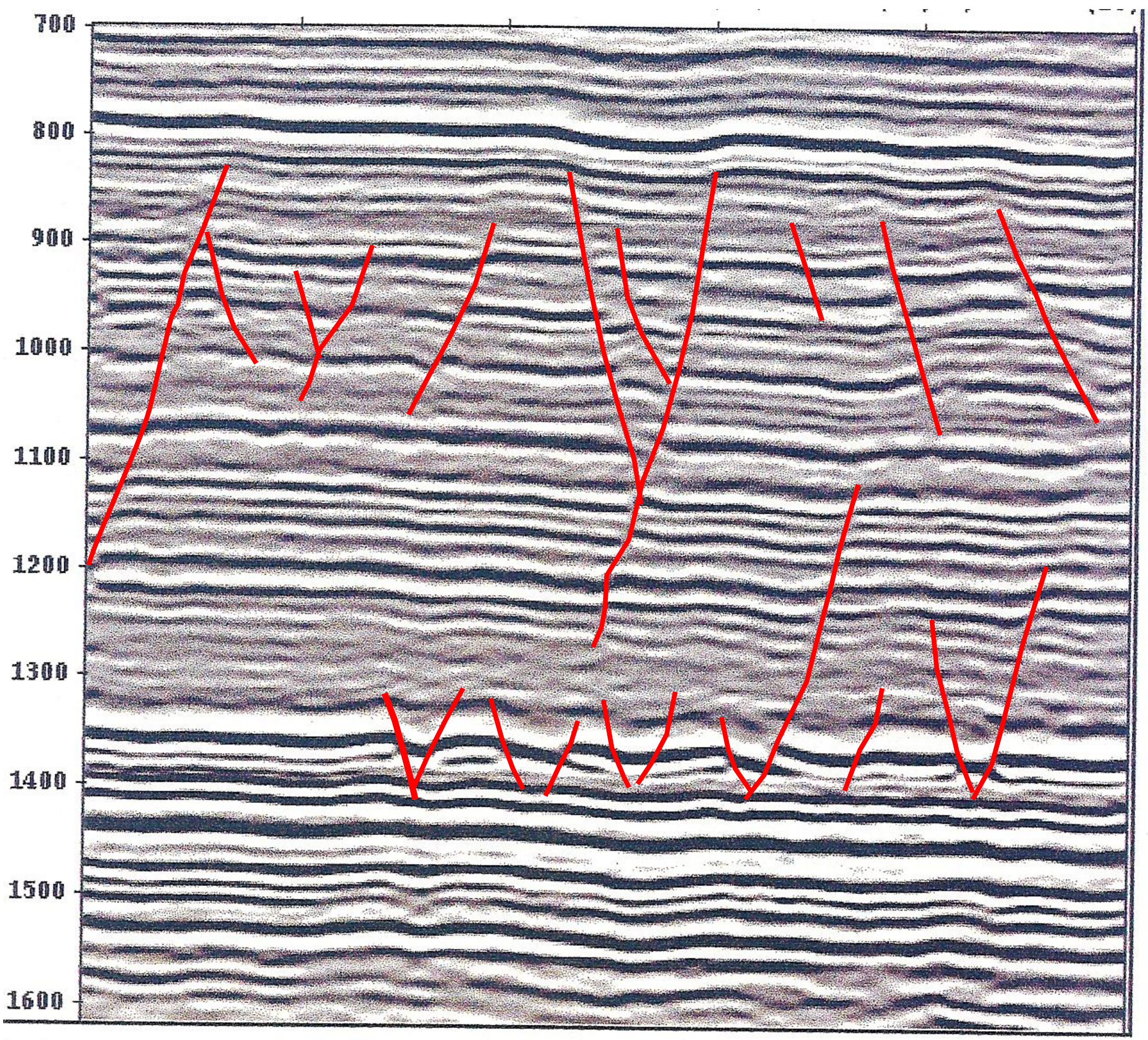

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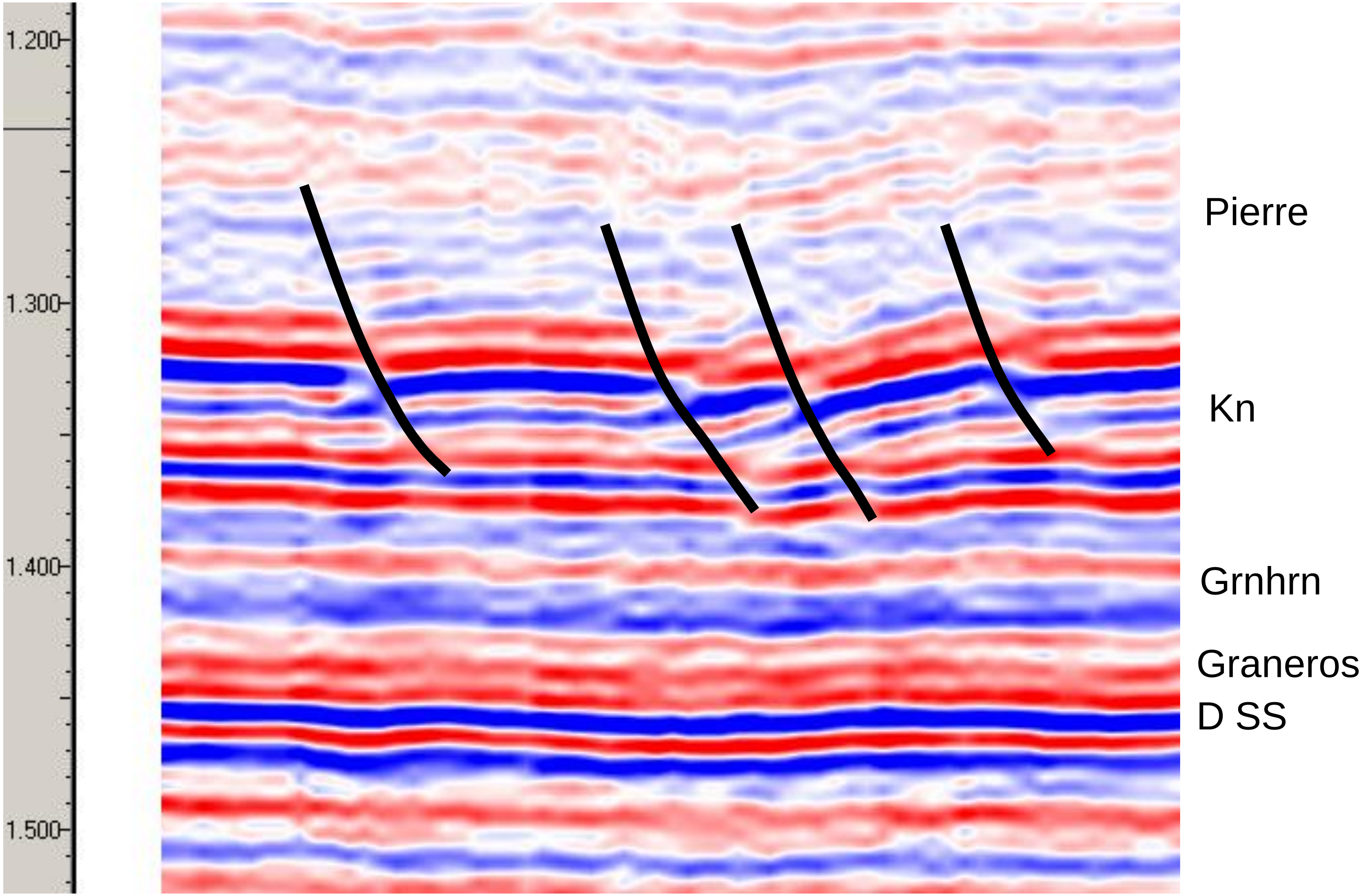
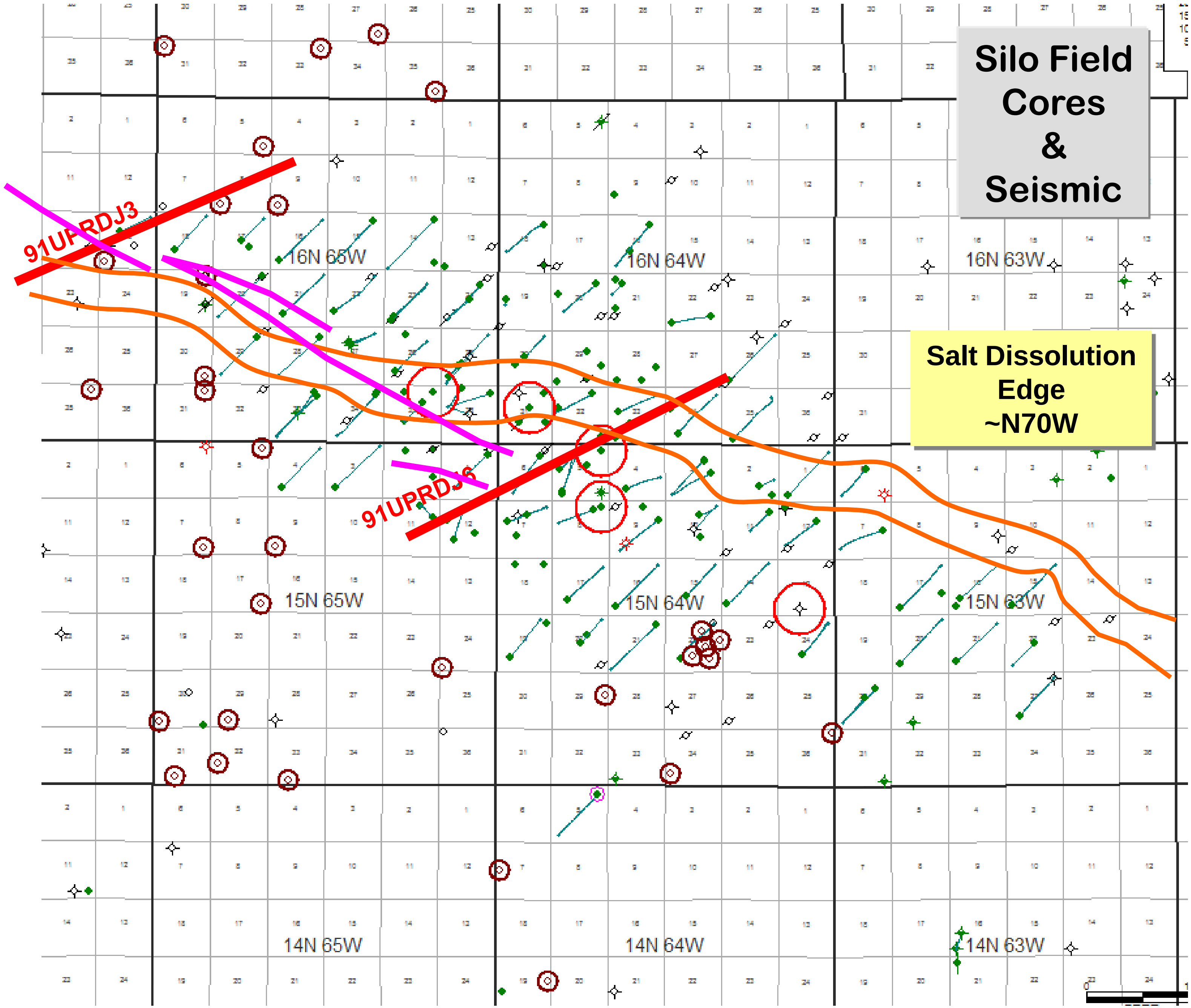
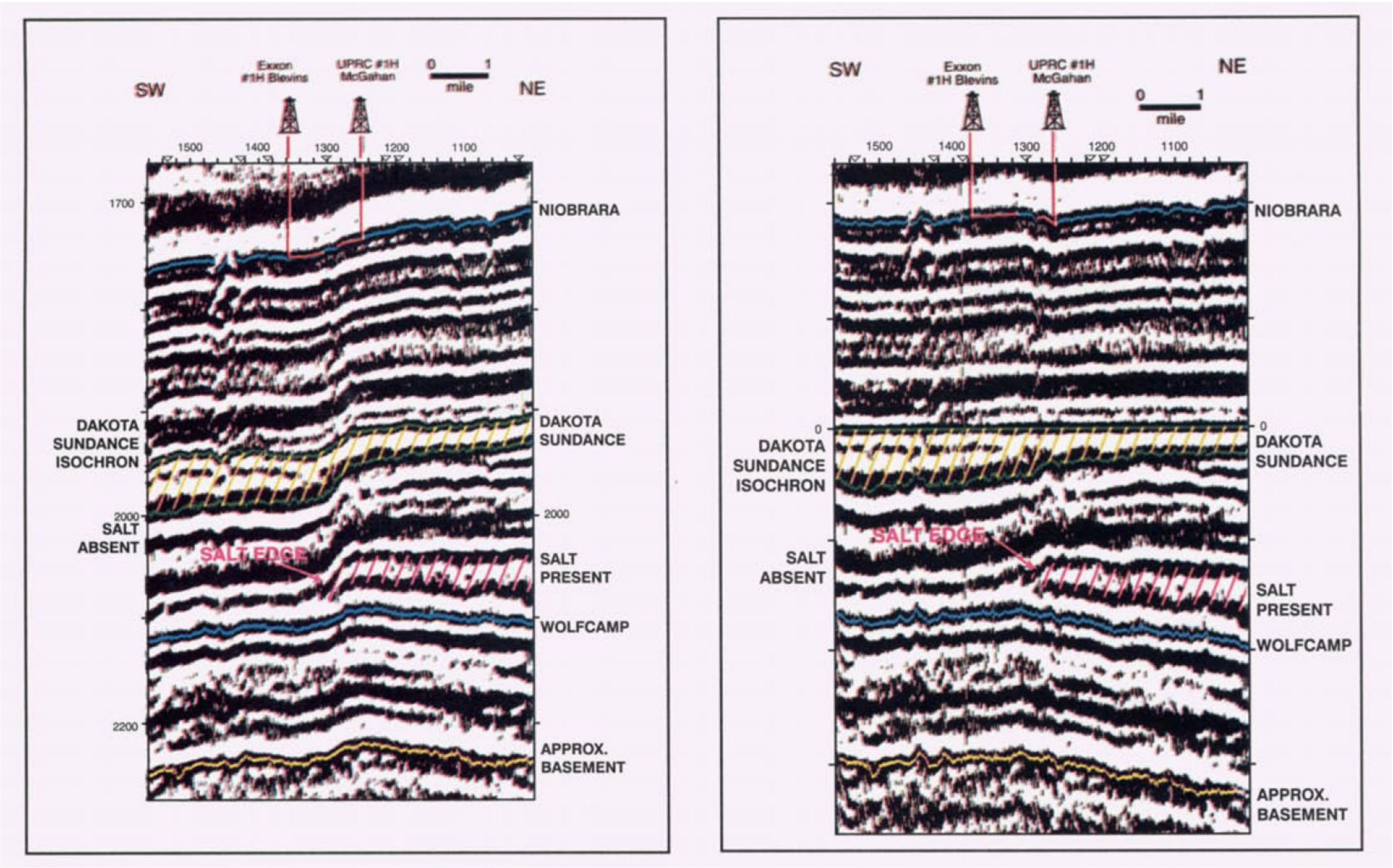
3-D Seismic





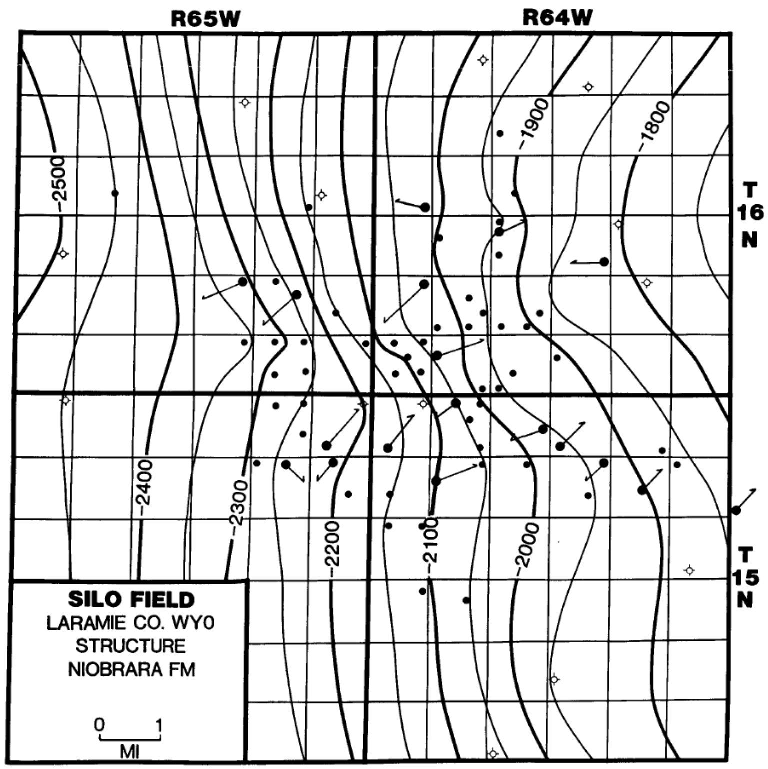
Silo Field
Cores
&
Seismic
Salt Dissolution
Edge
~N70W
91UPRDJ3
91UPRDJ6
16N 65W
16N 64W
16N 63W
15N 65W
15N 64W
15N 63W
14N 65W
14N 64W
14N 63W

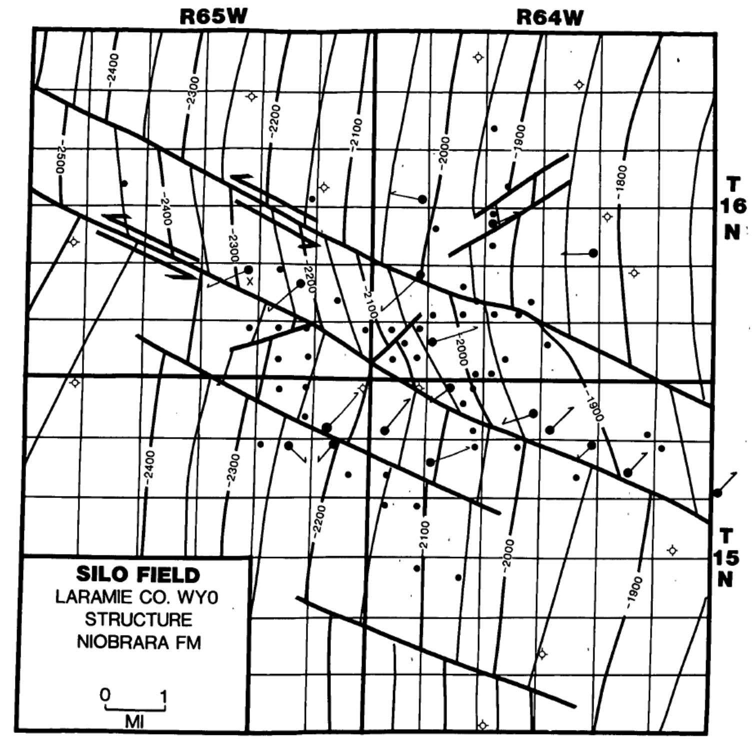
Faults and Salt Edge



Svoboda, 1995

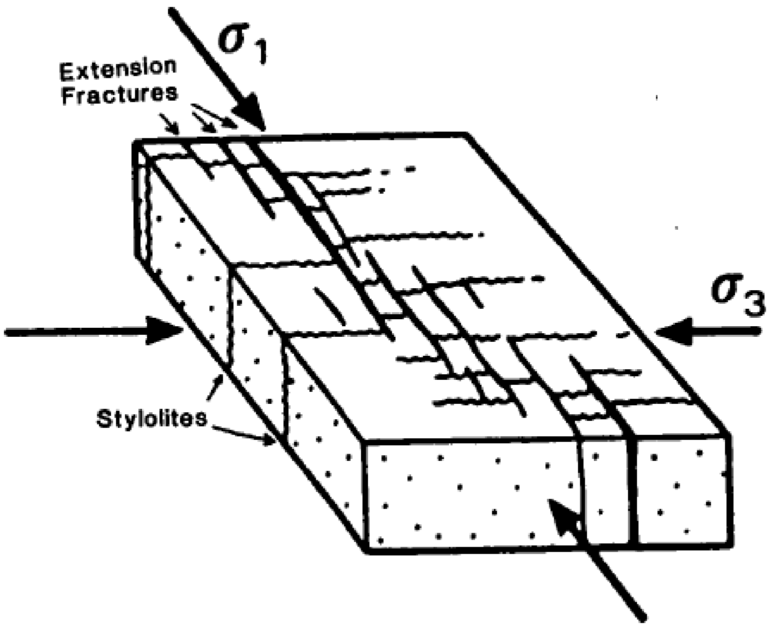
Structure Top Niobrara

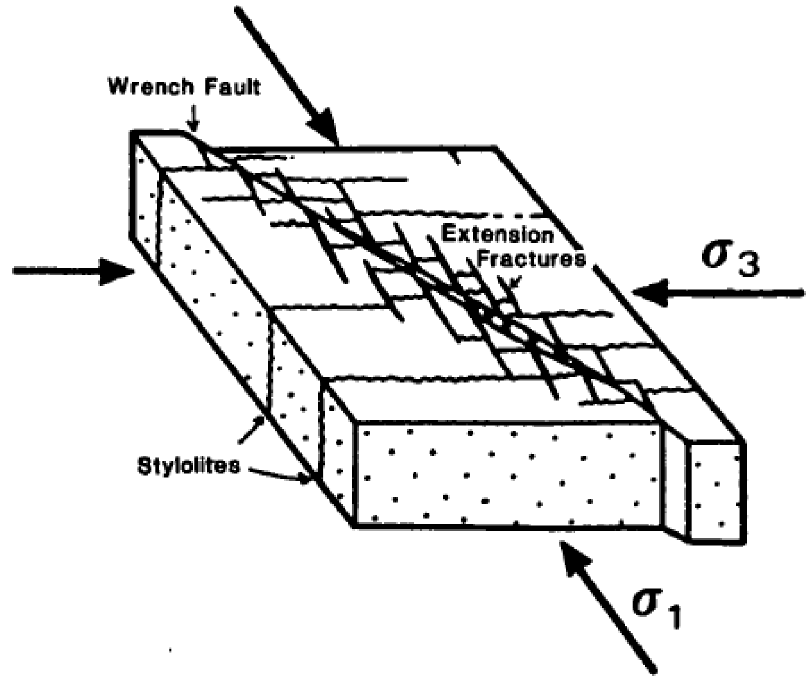




Sonnenberg and Weimer, 1993

Extension Fractures and Wrench Faults

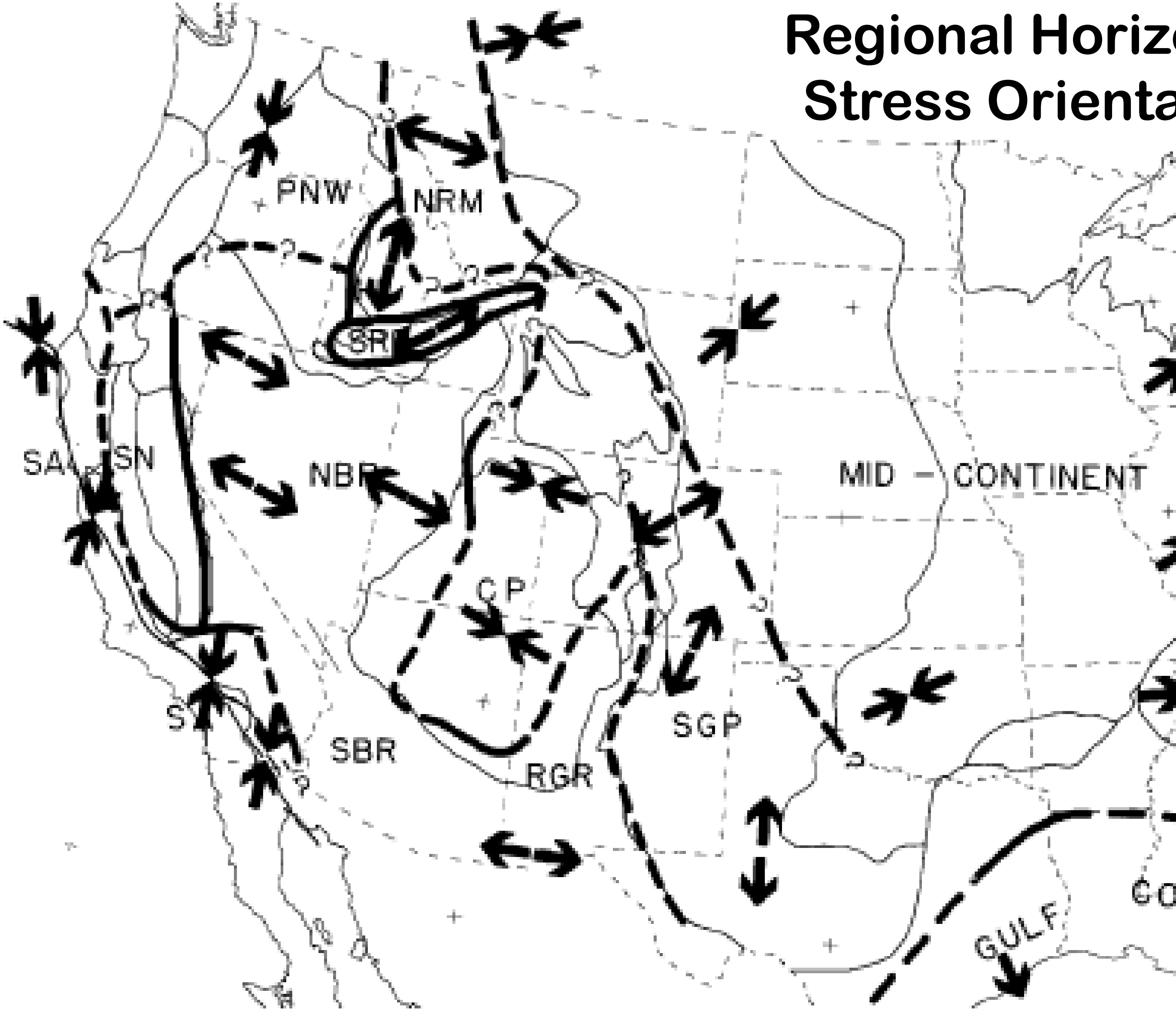




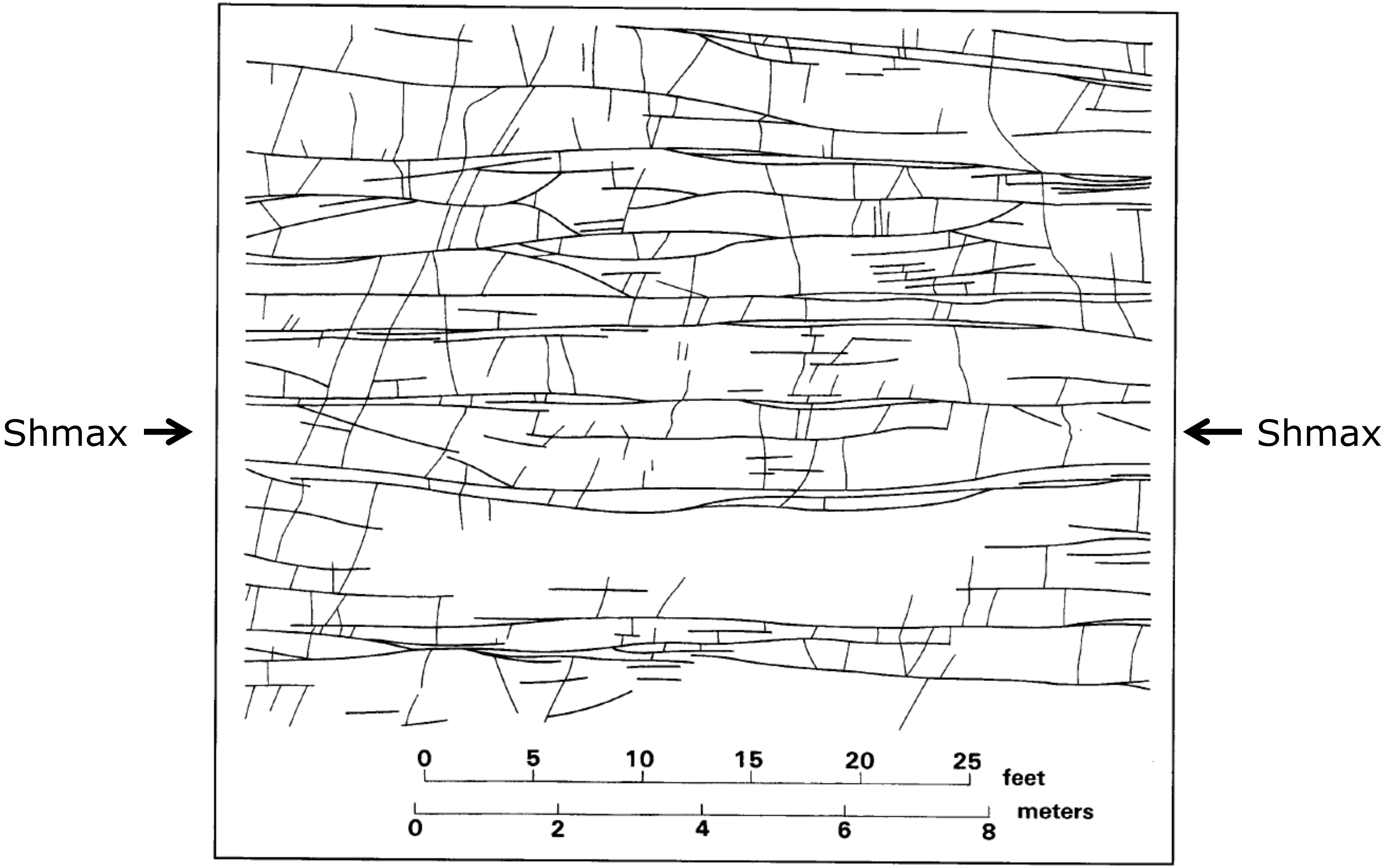
Shmax

Sonnenberg and Weimer, 1993

Regional Horizontal Stress Orientation



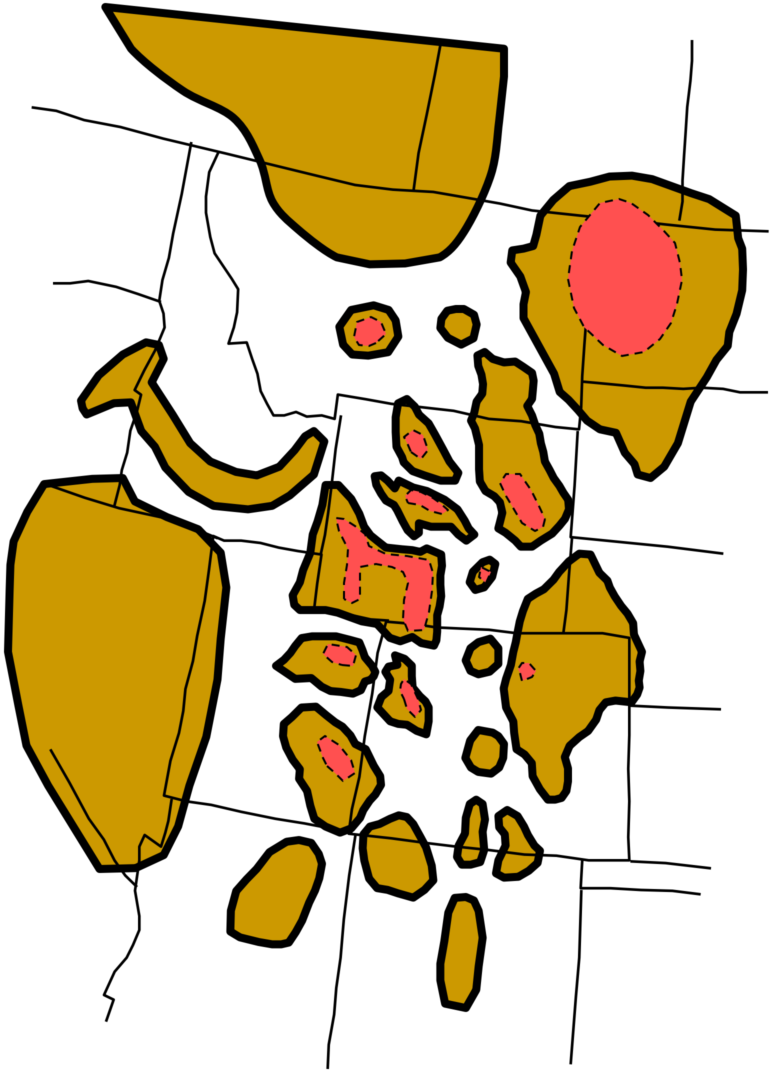
Generalized stress map, western US. Arrows represent direction of either least (outward directed) or greatest (inward direction) principal horizontal stress (modified from Zoback and Zoback, 1980)

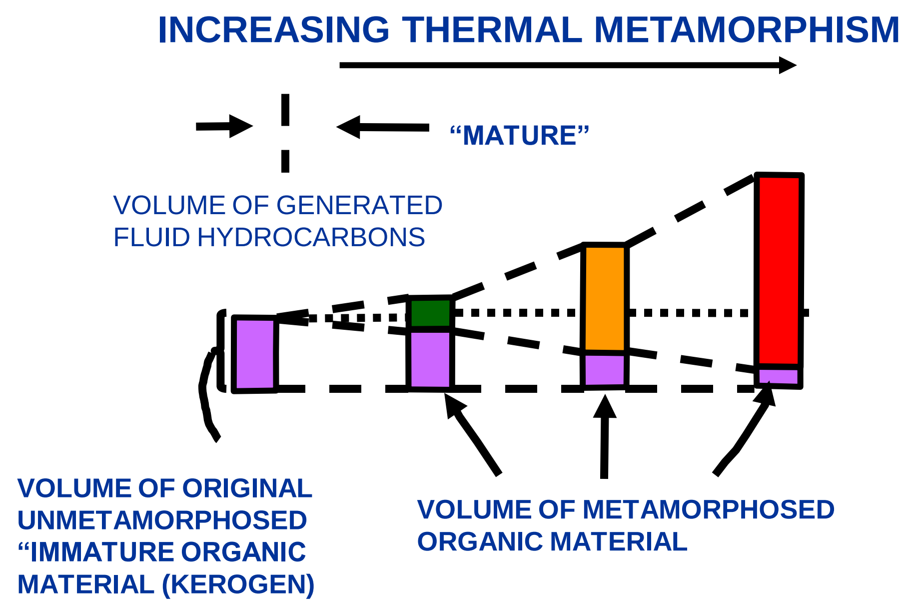


Regional Fractures
Systematic and Non-systematic

Modified from Lorenz et al., 1991, Nelson 2010

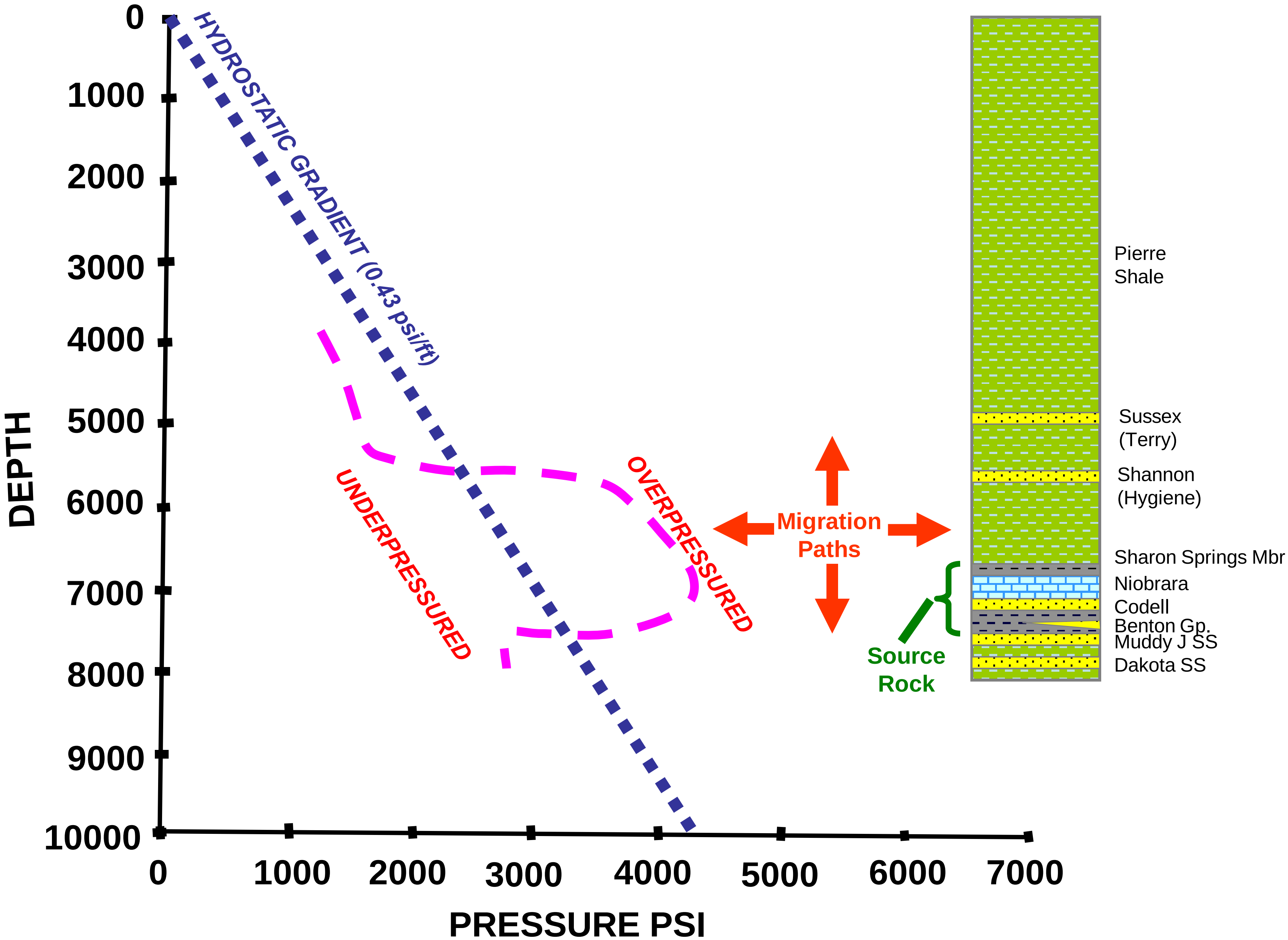
Overpressuring in Rockies Basins



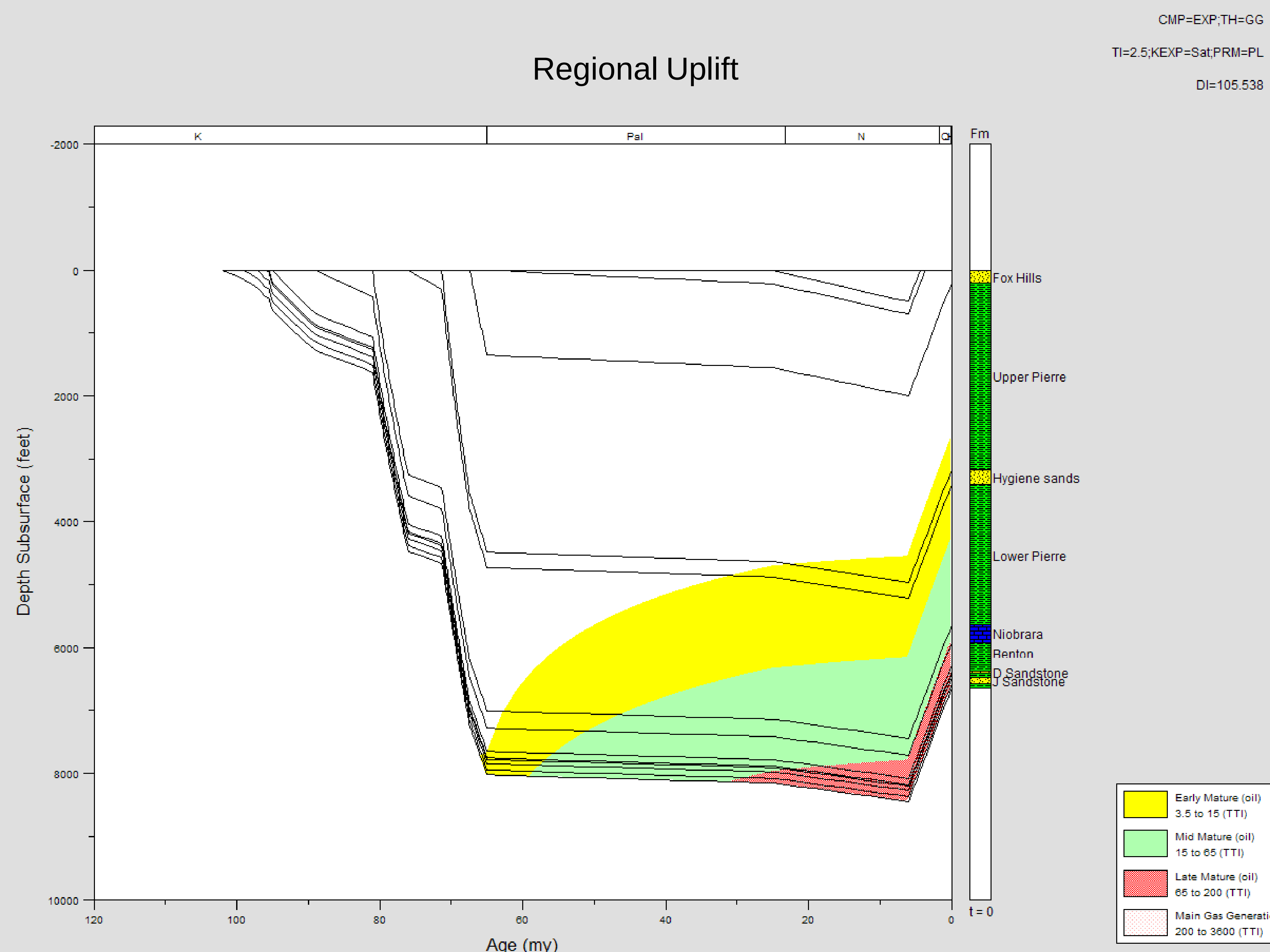


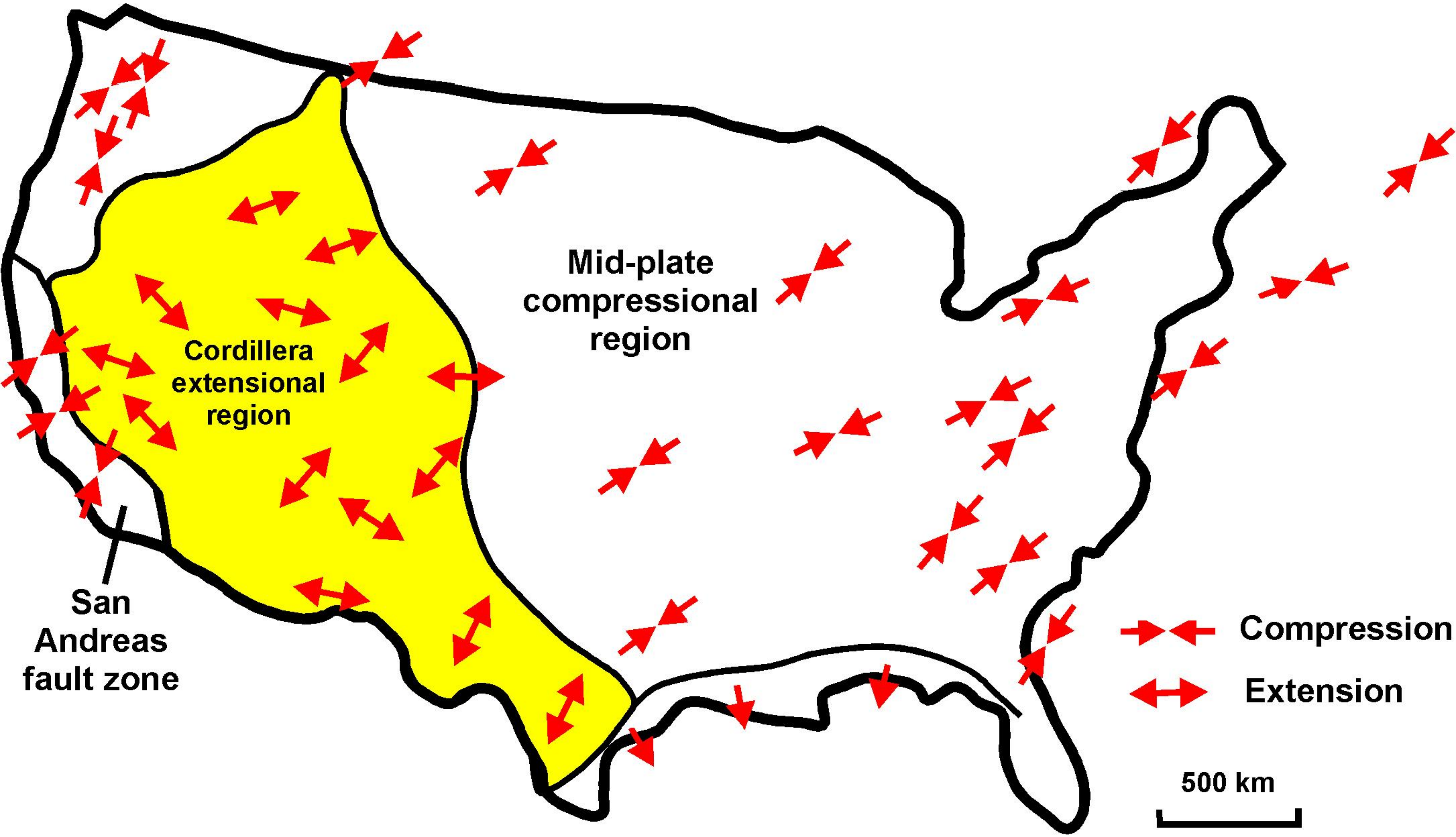
ASSUMES GENERATED HYDROCARBONS ARE RETAINED IN SYSTEM & CONVERT TO STABLE SPECIES

Modified from Spencer, 1987 and Meissner, 1980


DEPTH
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
HYDROSTATIC GRADIENT (0.43 psi/ft)
UNDERPRESSURED
OVERPRESSURED
Migration
Paths
Source
Rock
Pierre
Shale
Sussex
(Terry)
Shannon
(Hygiene)
Sharon Springs Mbr
Niobrara
Codell
Benton Gp.
Muddy J SS
Dakota SS
0
1000
2000
3000
4000
5000
6000
7000
PRESSURE PSI

Weimer, 1995

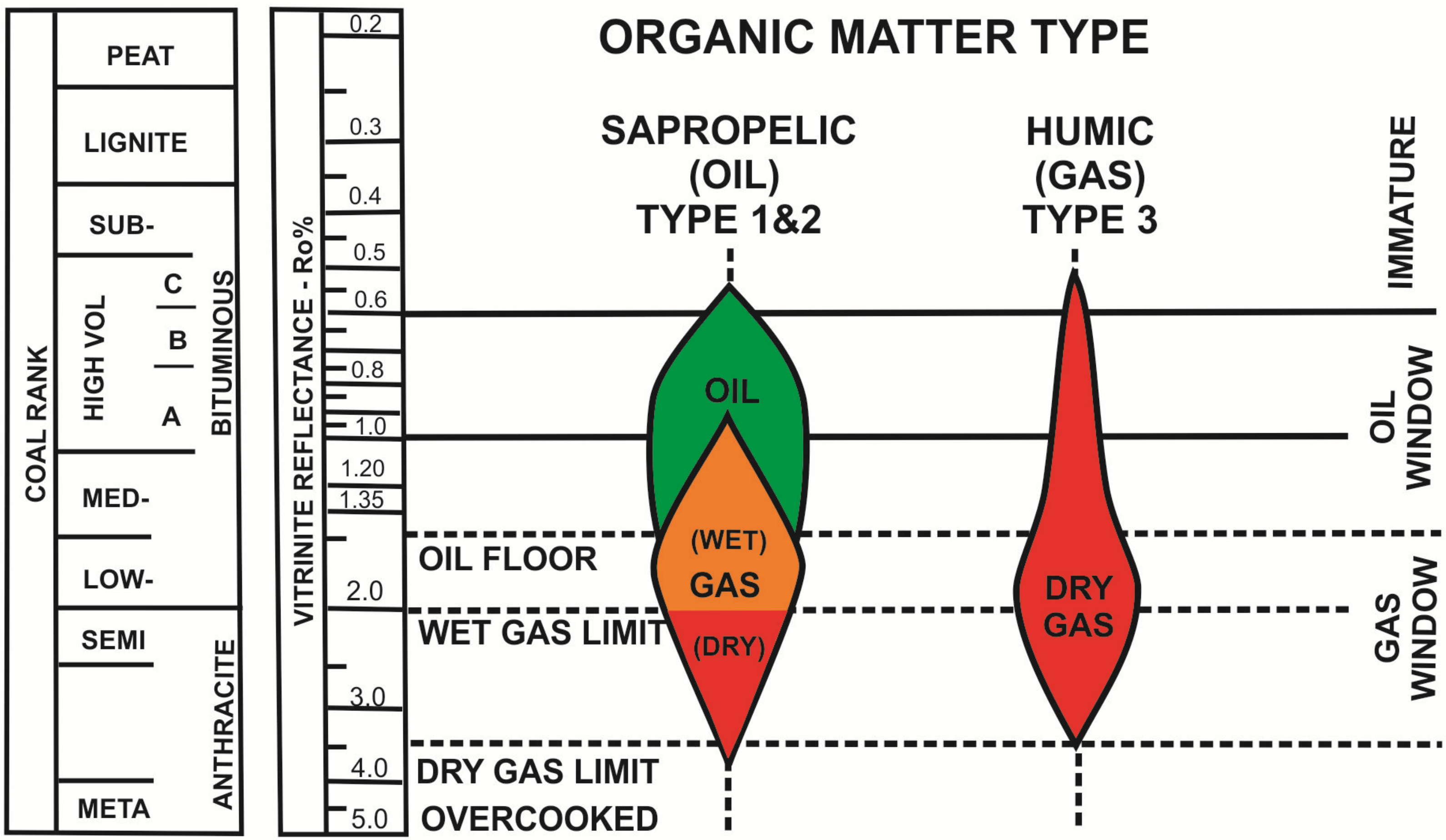

CMP=EXP;TH=GG
TI=2.5;KEXP=Sat;PRM=PL
DI=105.538
Regional Uplift
K
Pal
N
Q
Fm
Fox Hills
Upper Pierre
Hygiene sands
Lower Pierre
Niobrara
Benton
D Sandstone
J Sandstone
t = 0
Depth Subsurface (feet)
-2000
0
2000
4000
6000
8000
10000
120
100
80
60
40
20
0
Age (my)
Early Mature (oil)
3.5 to 15 (TTI)
Mid Mature (oil)
15 to 65 (TTI)
Late Mature (oil)
65 to 200 (TTI)
200 to 3600 (TTI)



http://science.jrank.org/pages/48171/stress-field-Earth.html

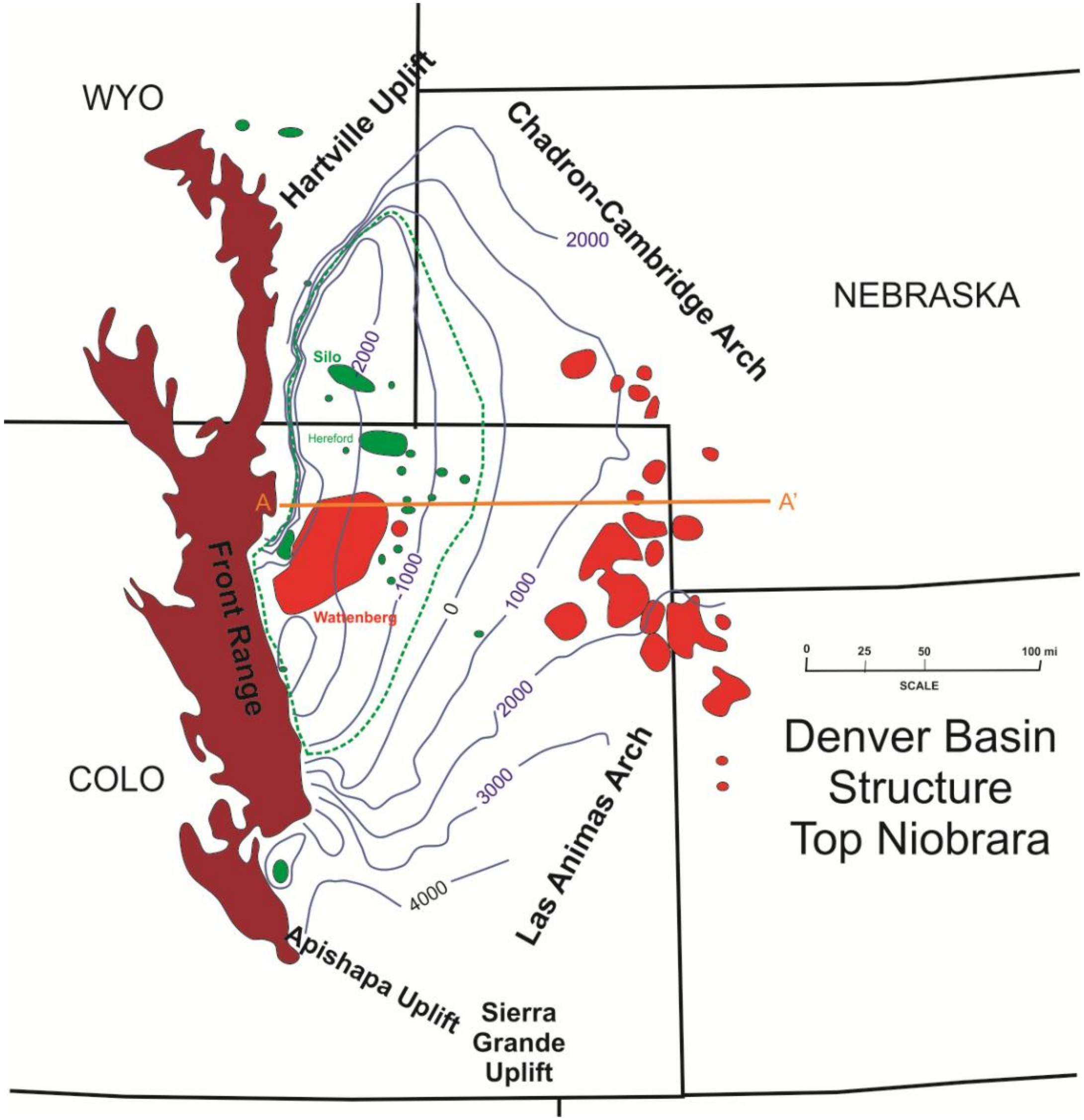
Technology for Source Bed Plays

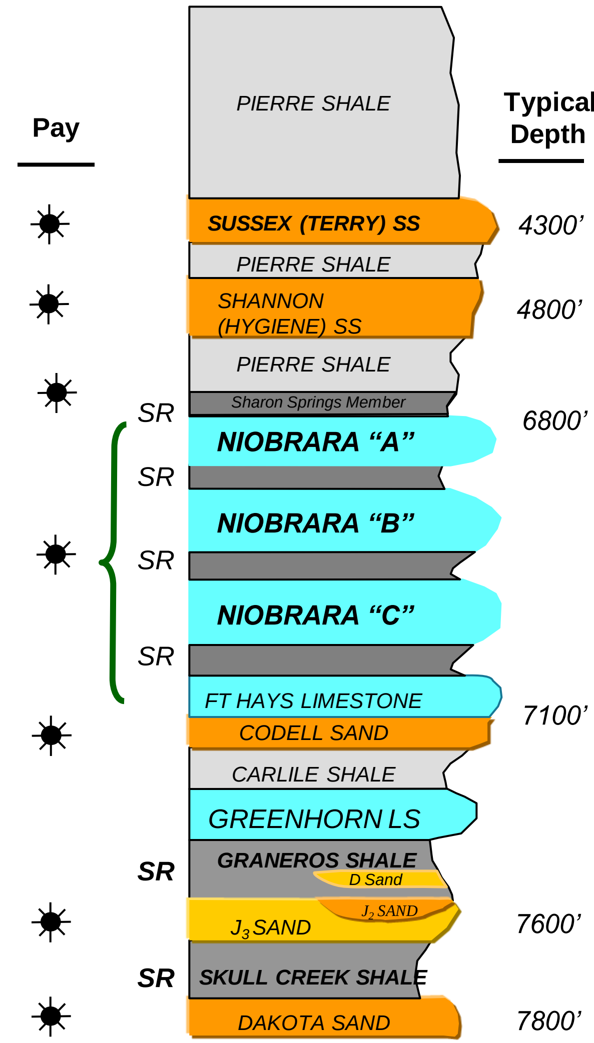
- Source rock evaluation
- Normal surface and subsurface mapping (i.e., the fundamentals)
- Resistivity mapping (e.g., logs)
- Lineament discrimination (local, regional)
- 3-D, 3-C Seismic Imaging
- Borehole fracture mapping (FMS, etc.)
- Surface geochemistry (microseeps)
- Horizontal drilling
- Microseismic
- Multistage hydraulic-fracture stimulation

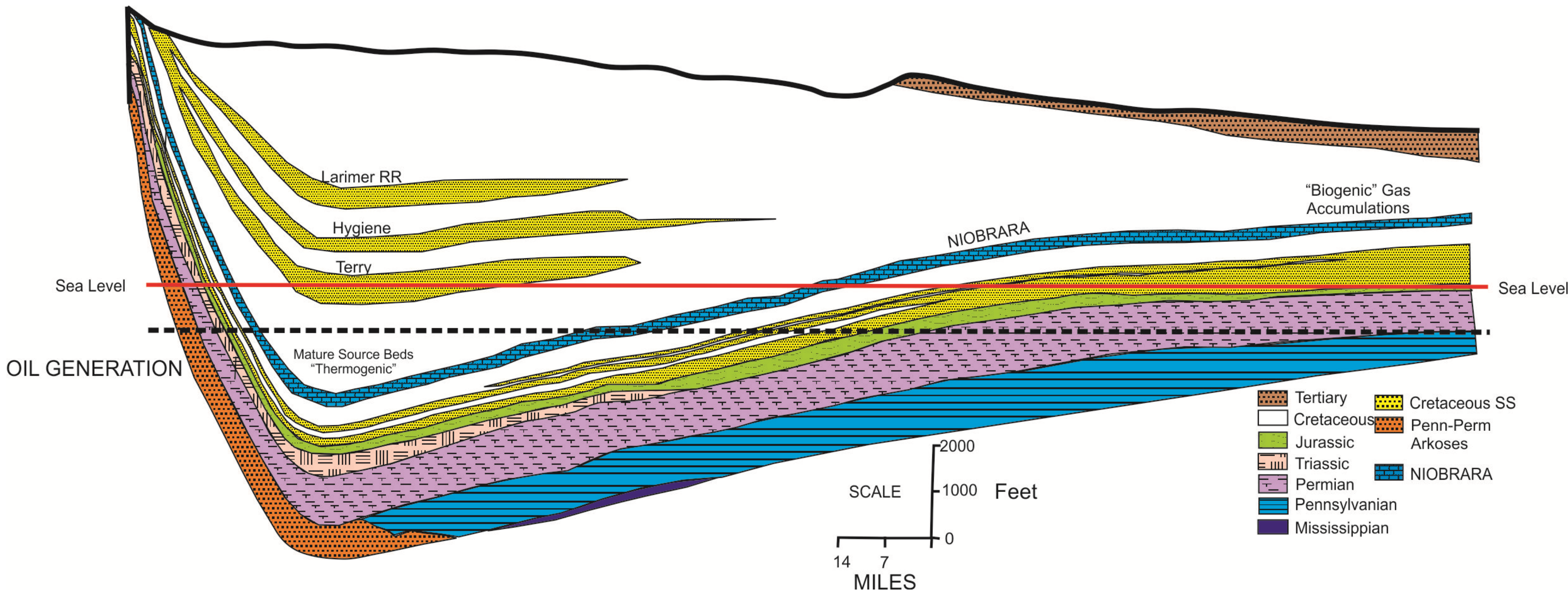


ORGANIC MATTER TYPE
COAL RANK
PEAT
LIGNITE
SUB-
HIGH VOL
C
B
A
MED-
LOW-
BITUMINOUS
SEMI
META
ANTHRACITE
VITRINITE REFLECTANCE - Ro%
0.2
0.3
0.4
0.5
0.6
0.8
1.0
1.20
1.35
2.0
3.0
4.0
5.0
SAPROPELIC
(OIL)
TYPE 1&2
HUMIC
(GAS)
TYPE 3
OIL
(WET)
GAS
(DRY)
DRY
GAS
OIL FLOOR
WET GAS LIMIT
DRY GAS LIMIT
OVERCOOKED
IMMATURE
OIL
WINDOW
GAS
WINDOW

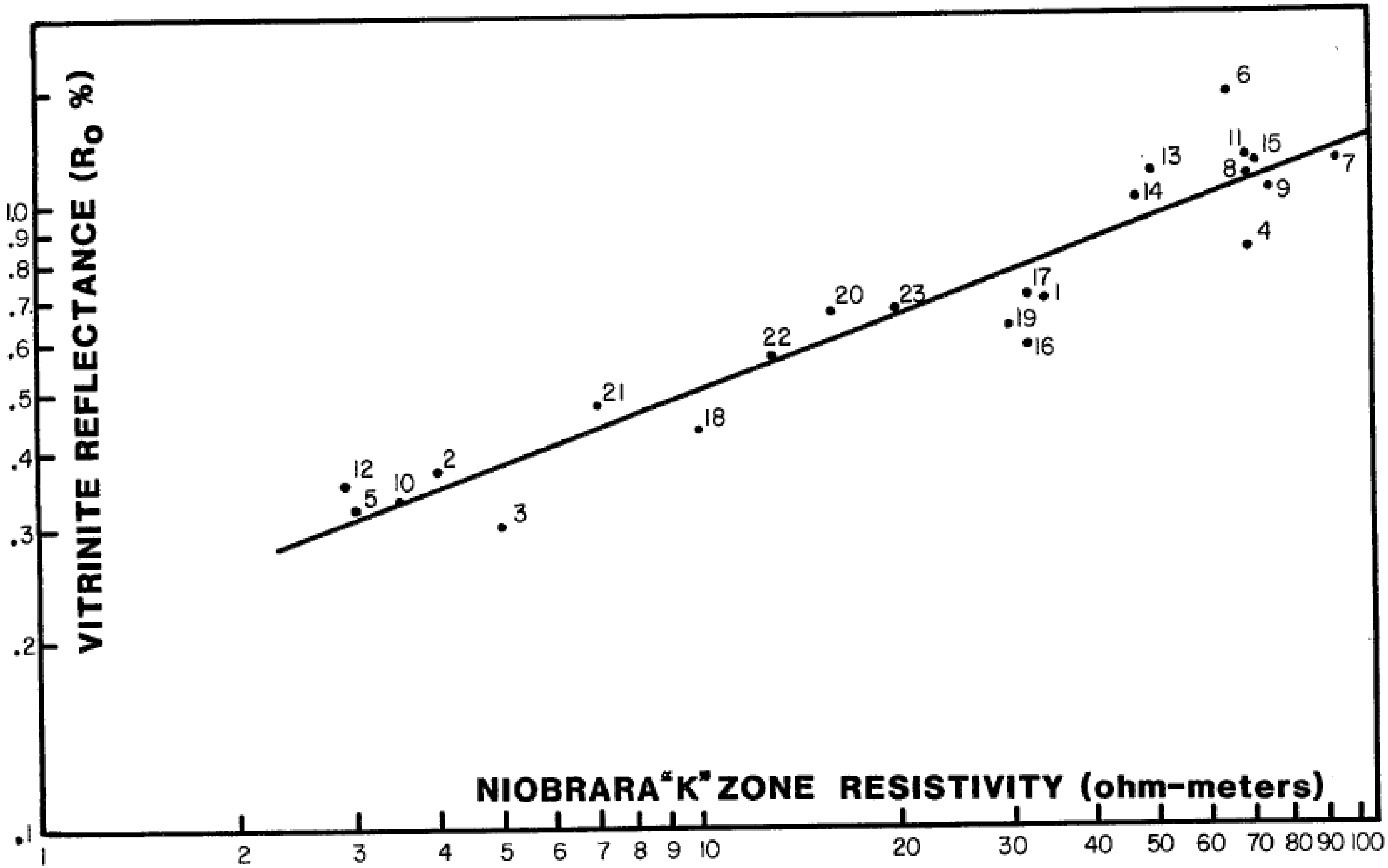
Niobrara Petroleum System - Denver Basin
Shallow Biogenic Gas
Deep Thermogenic Oil and Gas





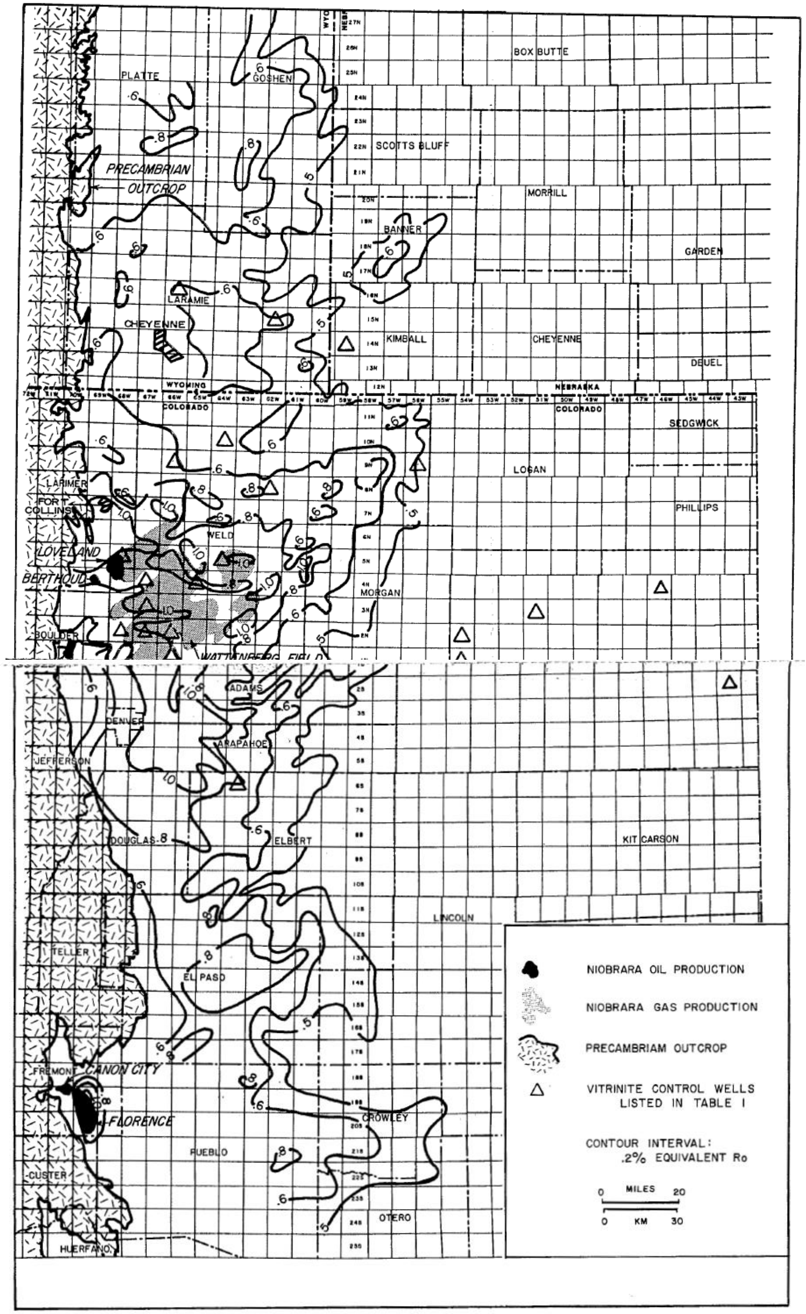


Larimer RR
Hygiene
Terry
"Biogenic" Gas
Accumulations
NIOBRARA
Sea Level
Sea Level
OIL GENERATION
Mature Source Beds
"Thermogenic"
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Cretaceous SS
Penn-Perm
Arkoses
NIOBRARA
SCALE
2000
1000
0
Feet
14
7
MILES

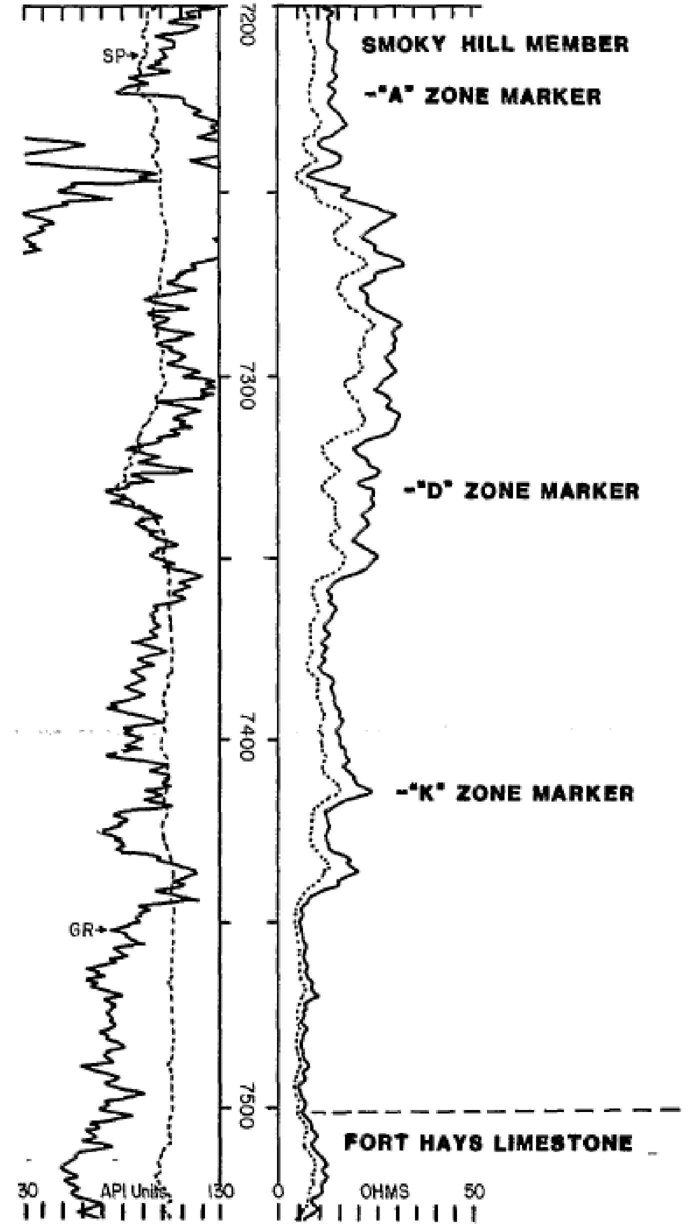


Niobrara vitrinite reflectance versus "K" zone resistivity, Denver Basin

Smagala et al., 1984

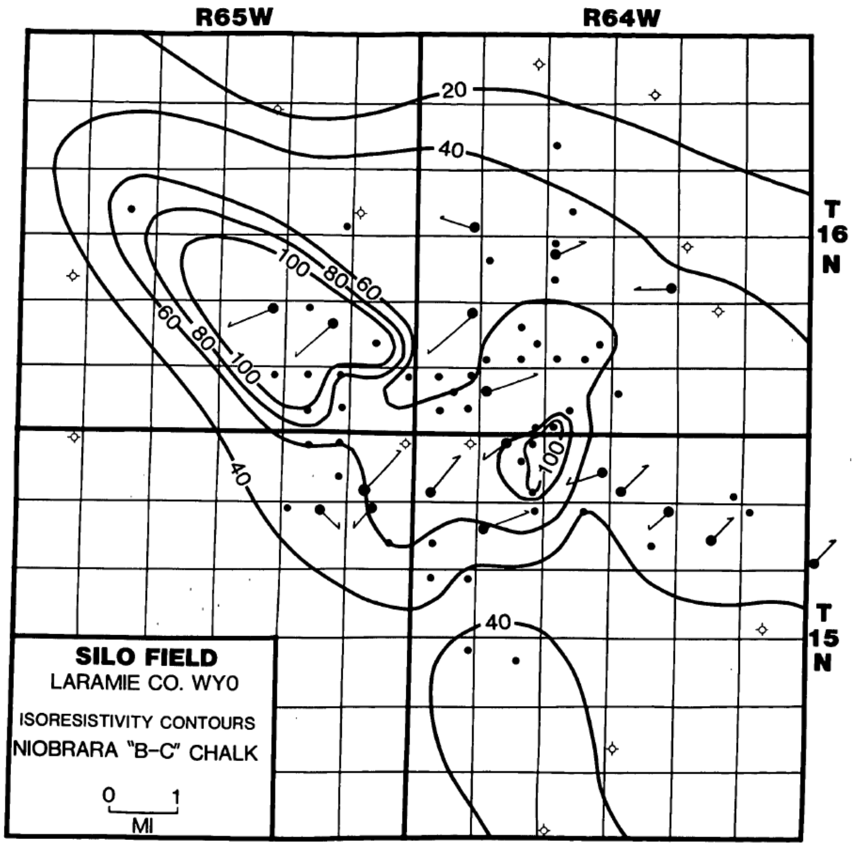


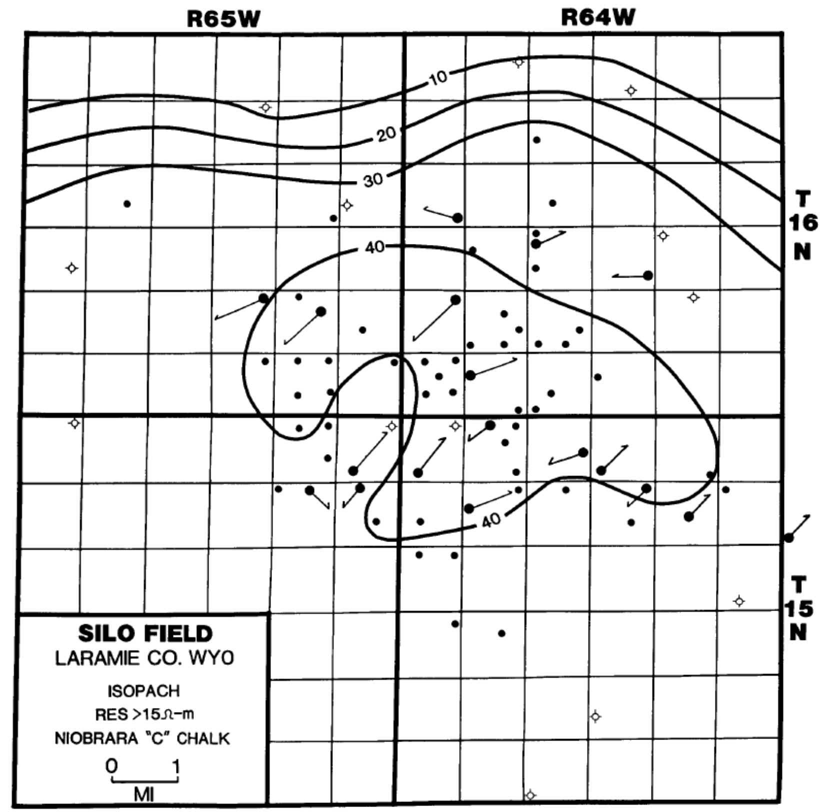
Niobrara Source Rock Maturity-Denver Basin



Smagala et al., 1984

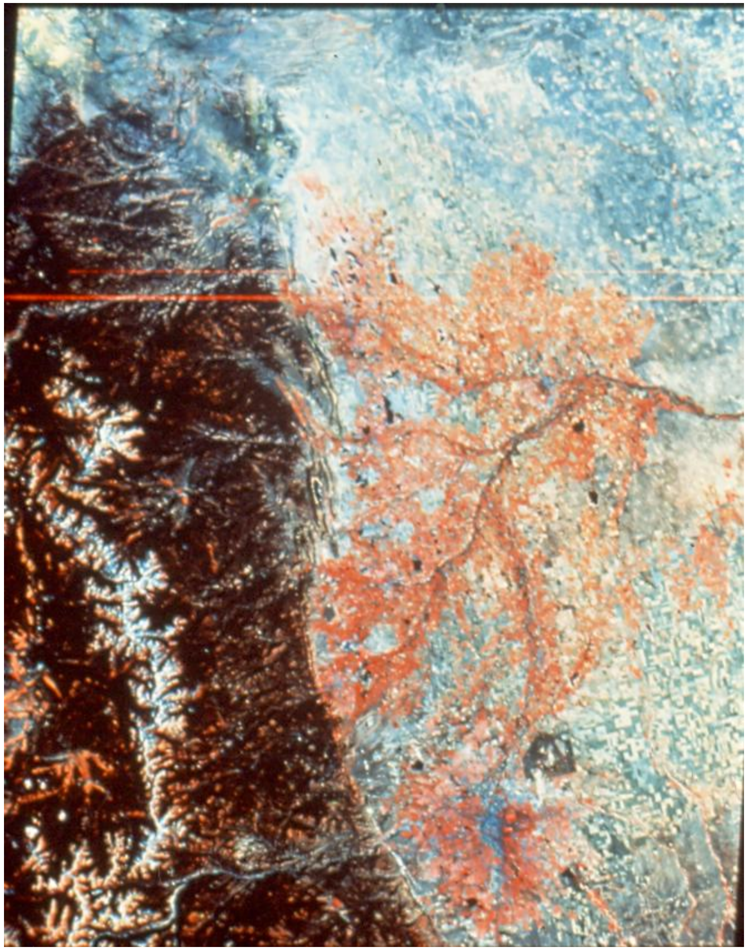
Resistivity Mapping and Accumulation

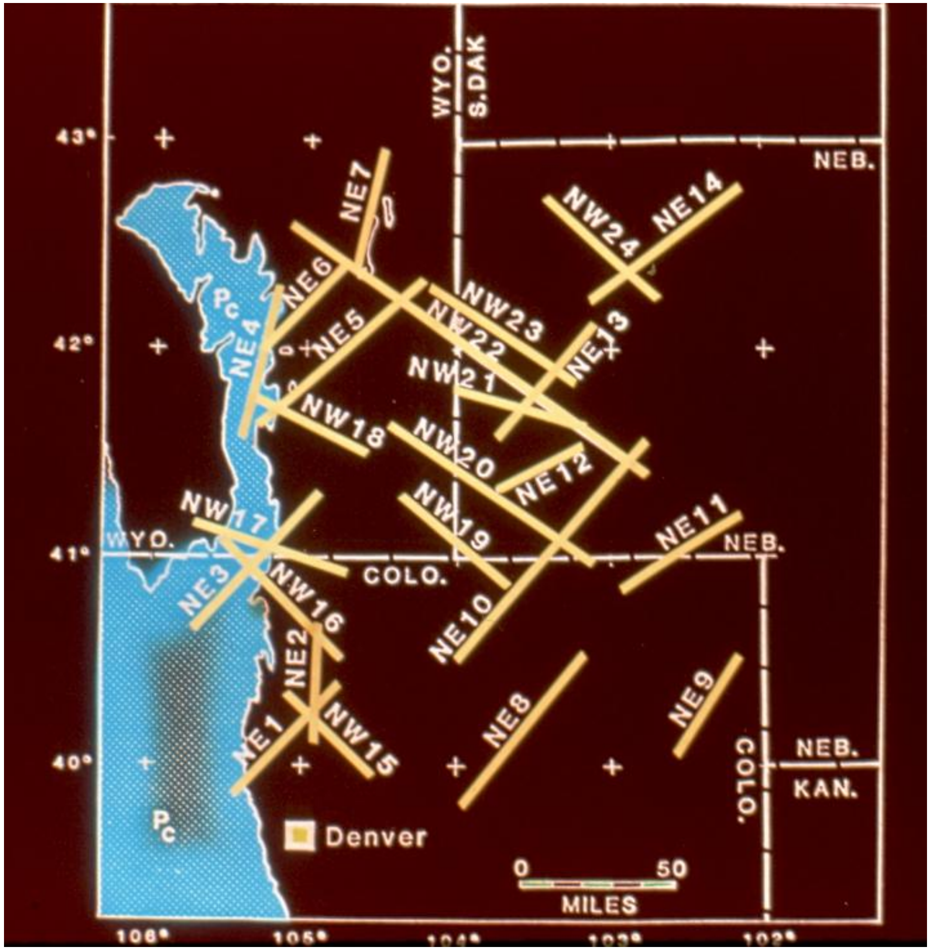




Sonnenberg and Weimer, 1993

Lineament Analysis
S. Perry, ca 1985

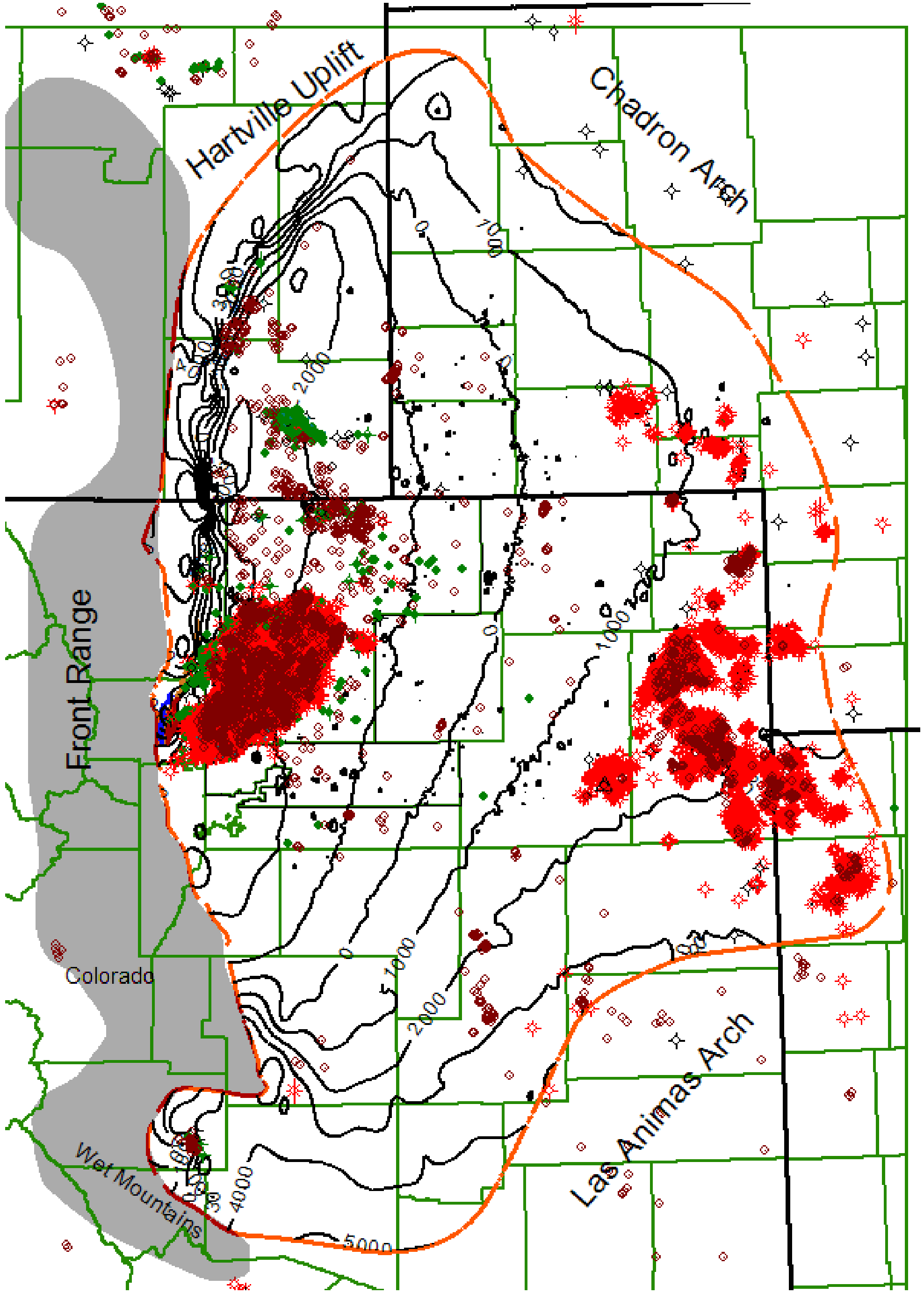




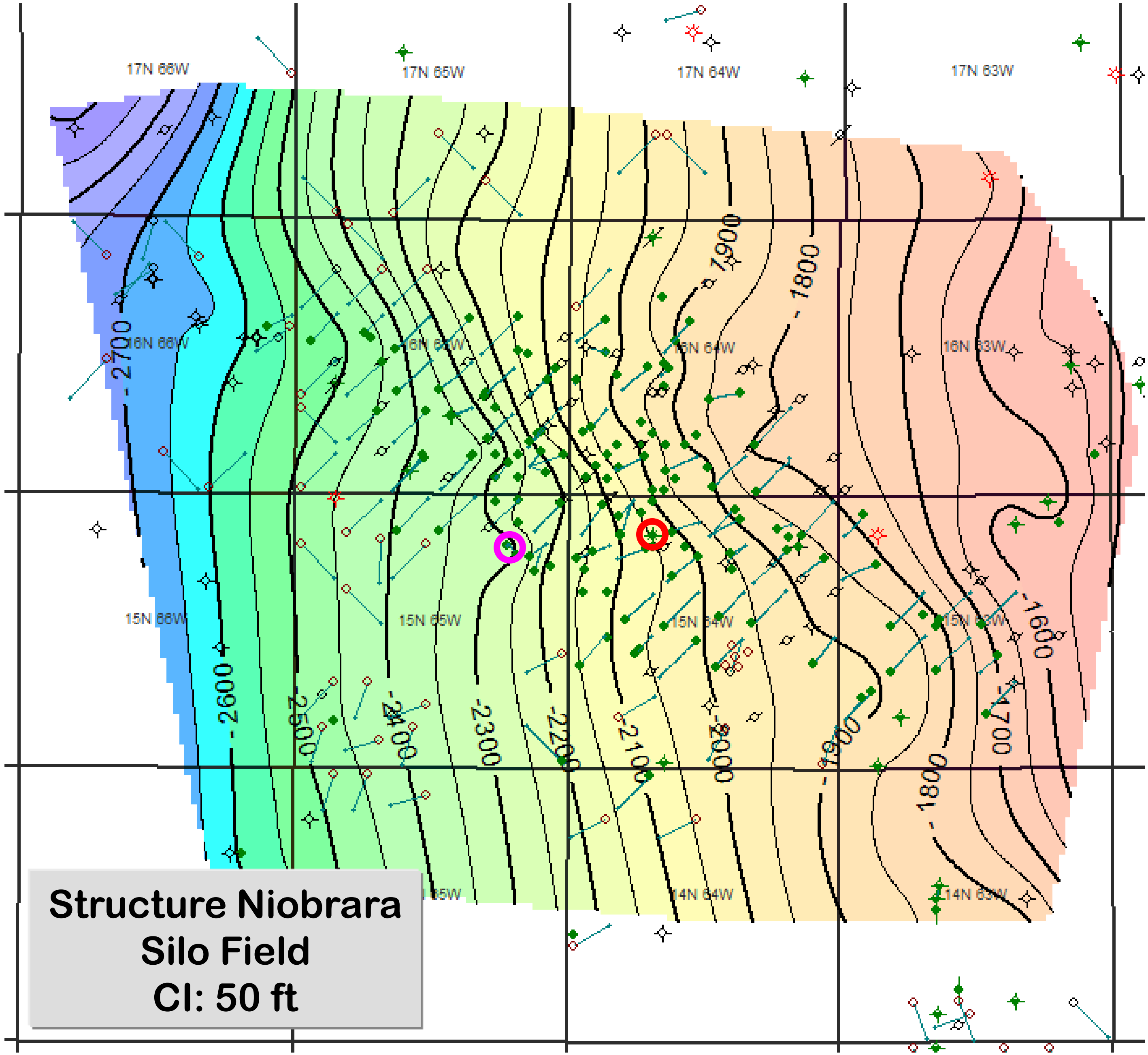
New locations (all zones)

Niobrara oil

Niobrara gas



Structure Niobrara
Denver Basin
CI: 1000 ft



SILO FIELD
Niobrara Fm.

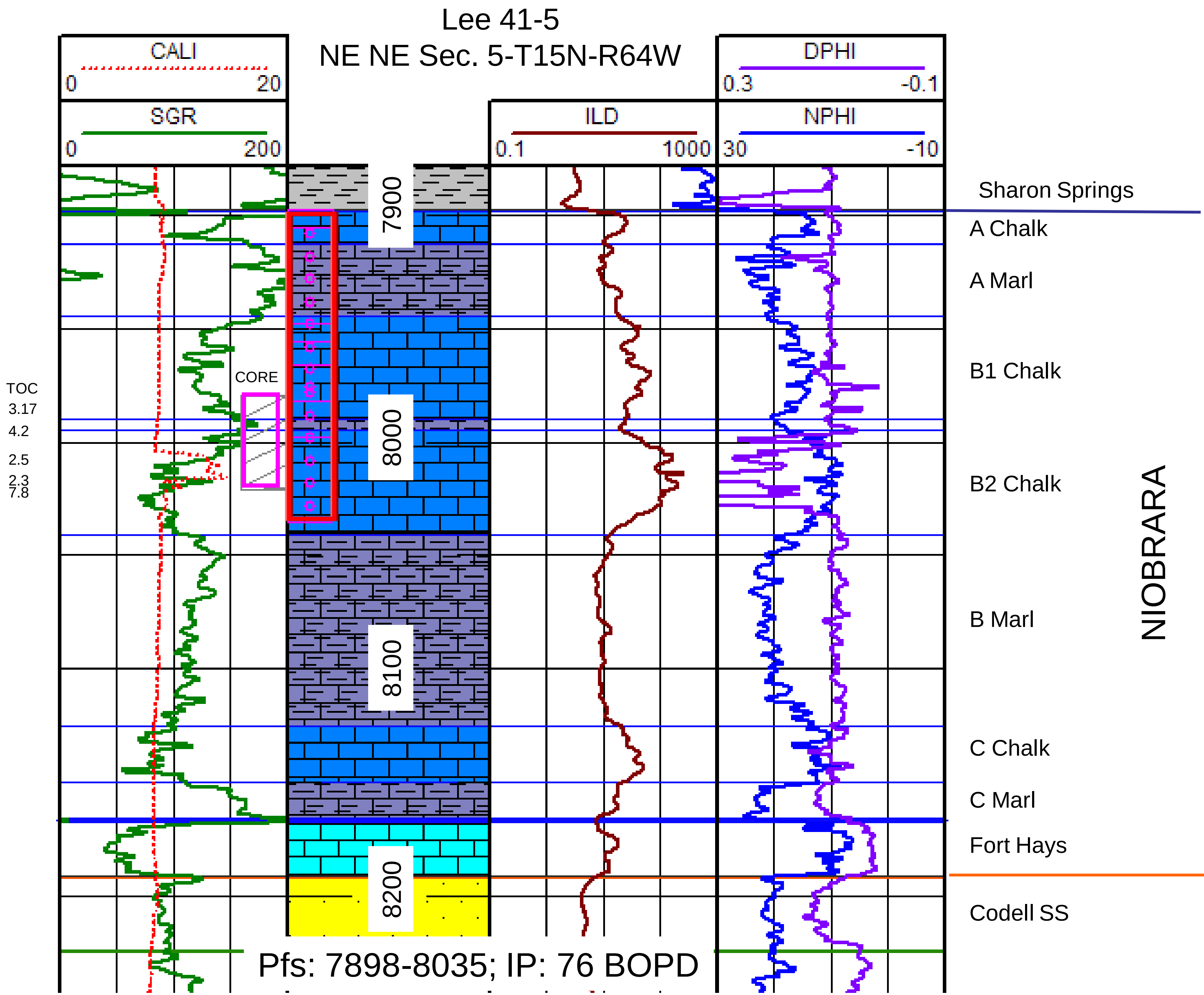
Discovery:

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

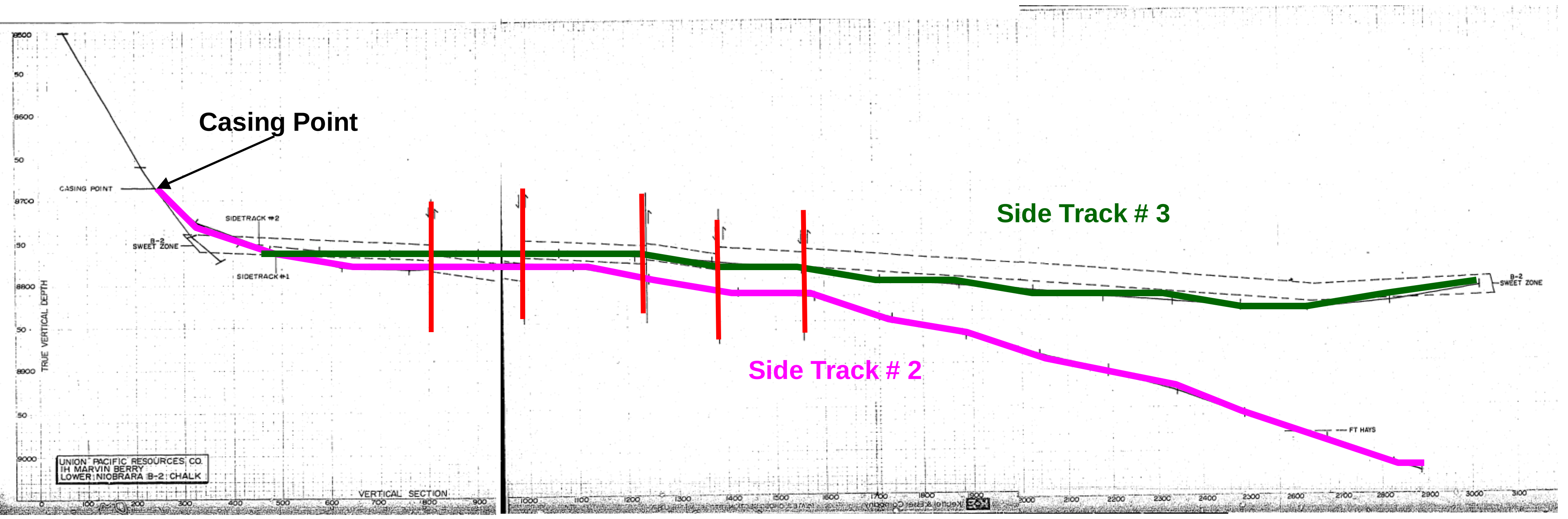
1990
First horizontal:
Warren # 1
Sec. 11, T15N, R65W
600 BOPD

Vertical Depths:
7100 to 8800 ft

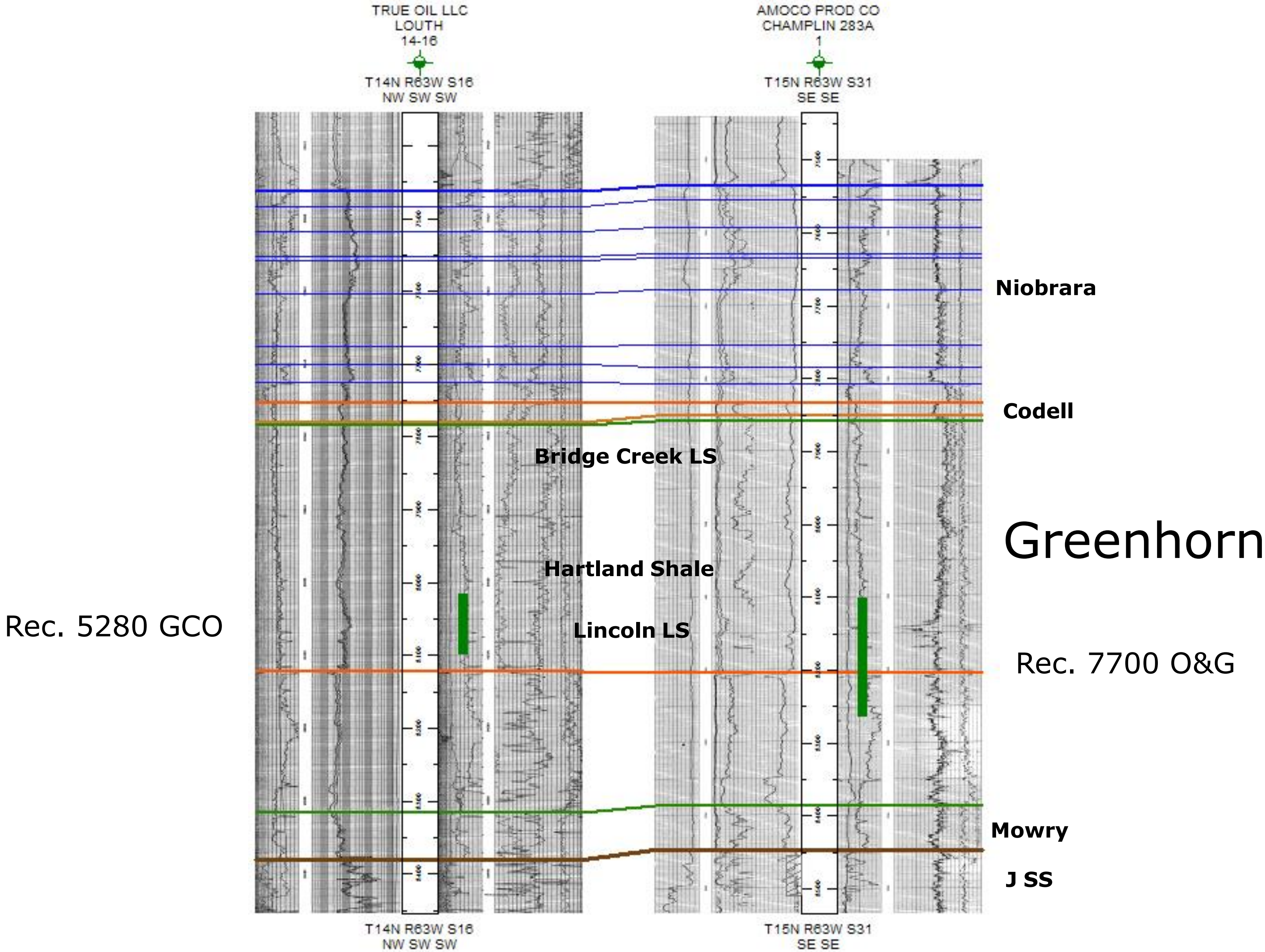
Cum Prod:
10.4 MMBO
8.9 BCFG
6.3 MMBW


Lee 41-5
NE NE Sec. 5-T15N-R64W
CALI
0
20
SGR
0
200
DPHI
0.3
-0.1
ILD
0.1
1000
NPHI
30
-10
7900
8000
8100
8200
CORE
TOC
3.17
4.2
2.5
2.3
7.8
Sharon Springs
A Chalk
A Marl
B1 Chalk
B2 Chalk
B Marl
C Chalk
C Marl
Fort Hays
Codell SS
NIOBRARA
Pfs: 7898-8035; IP: 76 BOPD

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



Other Shows of Interest



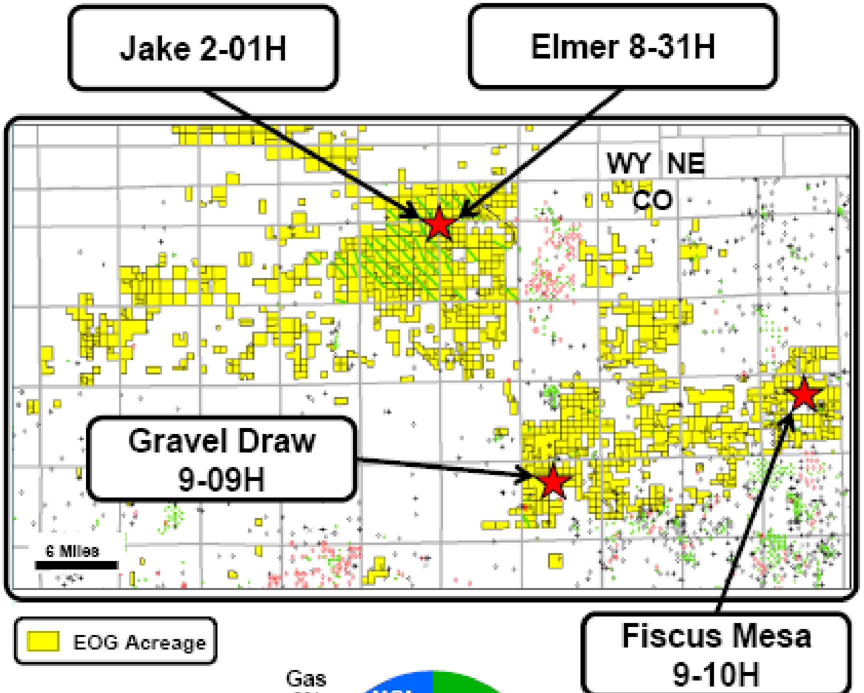
EOG Resources
DJ Basin Horizontal Niobrara

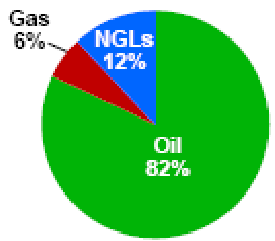
- Current 2-Rig Drilling Program
  - Plan 45 Wells in 2011

Operational Activity

- Drilling Activity to Date on 80,000 Net Acre Hereford Ranch Field
  - Continuing to Exploit with Good Well Results
- Recent Drilling on Two Additional Prospects, 89,000 Net Acres Total
- Encouraging Economic Results from 169,000 of 220,000 Total Net Acres to Date
- Good Long-Term Stable Production Rates; Wells Have Low Initial Rates and Flat Declines
  - Jake 2-01H
    - 1st Month IP Rate – Late 2009 – 645 Bopd
    - Stable Rate of 250-300 Bopd Since 1Q11
  - Elmer 8-31H
    - 1st Month IP Rate – March 2010 – 283 Bopd
    - Current 225 Bopd
- Other Recent Well Tests – Controlled Rates

	Bopd		Mfcd
- Fiscus Mesa 9-10H	335	+	174
- Gravel Draw 9-09H	277	+	146



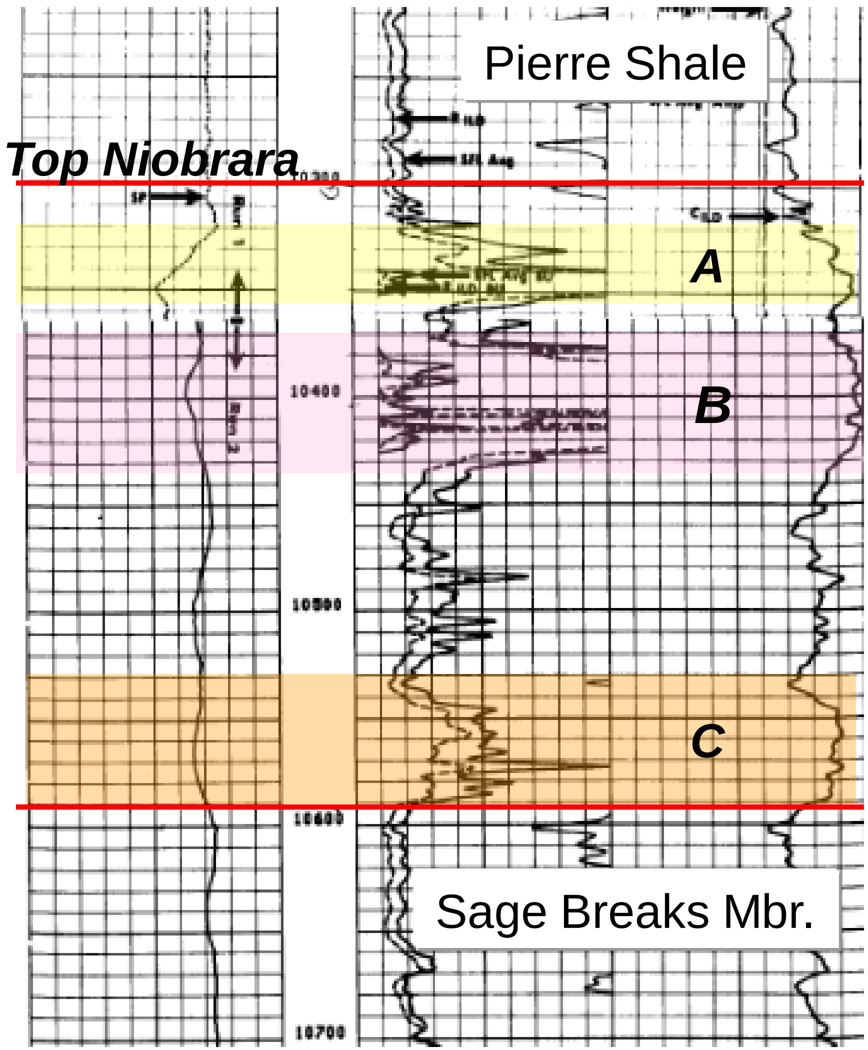


Typical Well

EOG : http://www.eogresources.com/investors/investor_pres.html

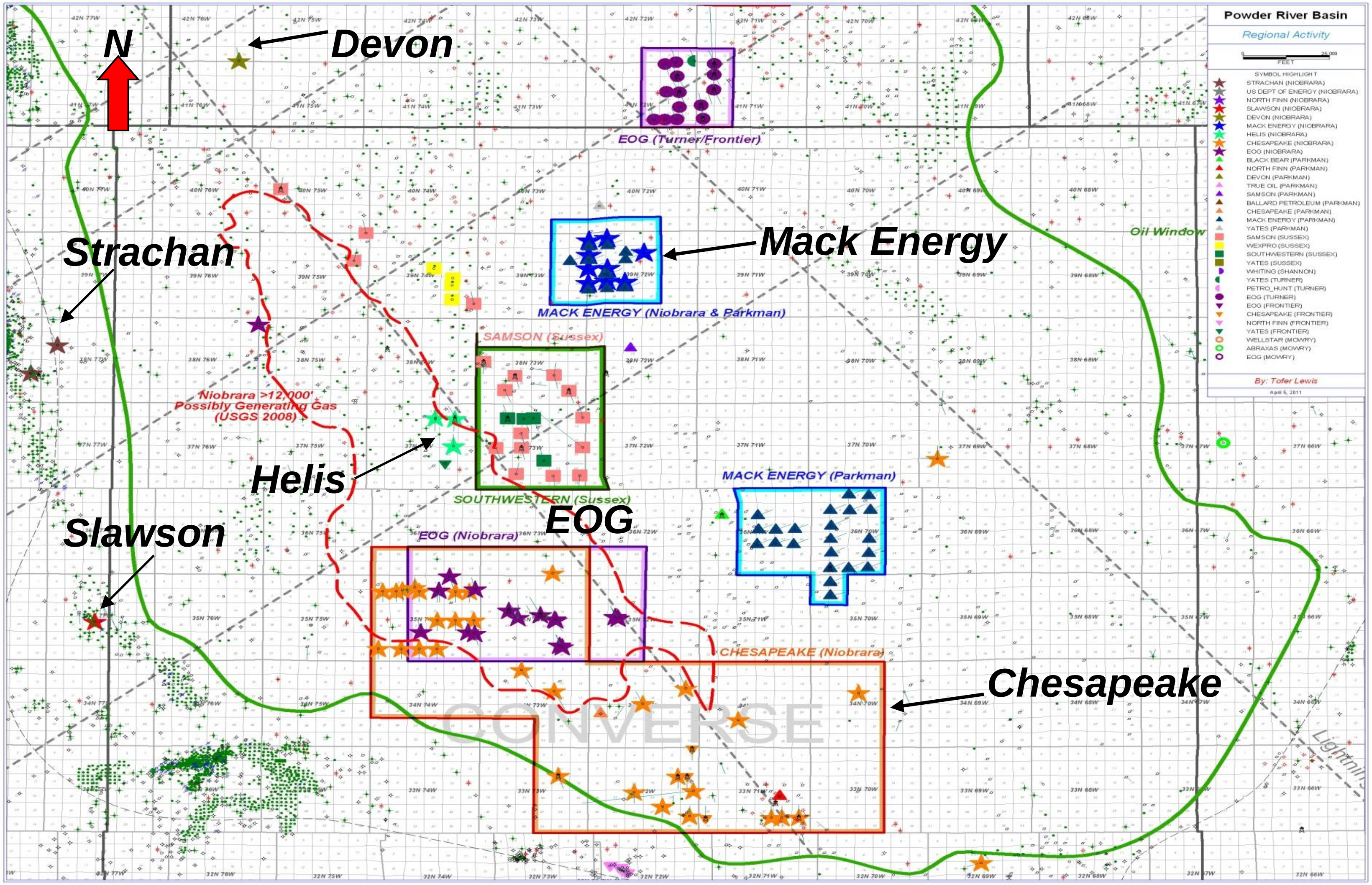
Stratigraphy – Powder River Basin

Inexco 1-12 Federal, T32N, R69W, Sec. 12



- Three chalk facies separated by marls.
  - Similar to the stratigraphy of the Denver Basin.
- No Fort Hays member.
  - Incorporated into the underlying Sage Breaks Mbr. of the Carlile Shale.
- "B" and "C" benches seem most prospective.
  - Regional Continuity
  - Historical Production/Shows
  - Thickness

Niobrara Drilling/Leasing



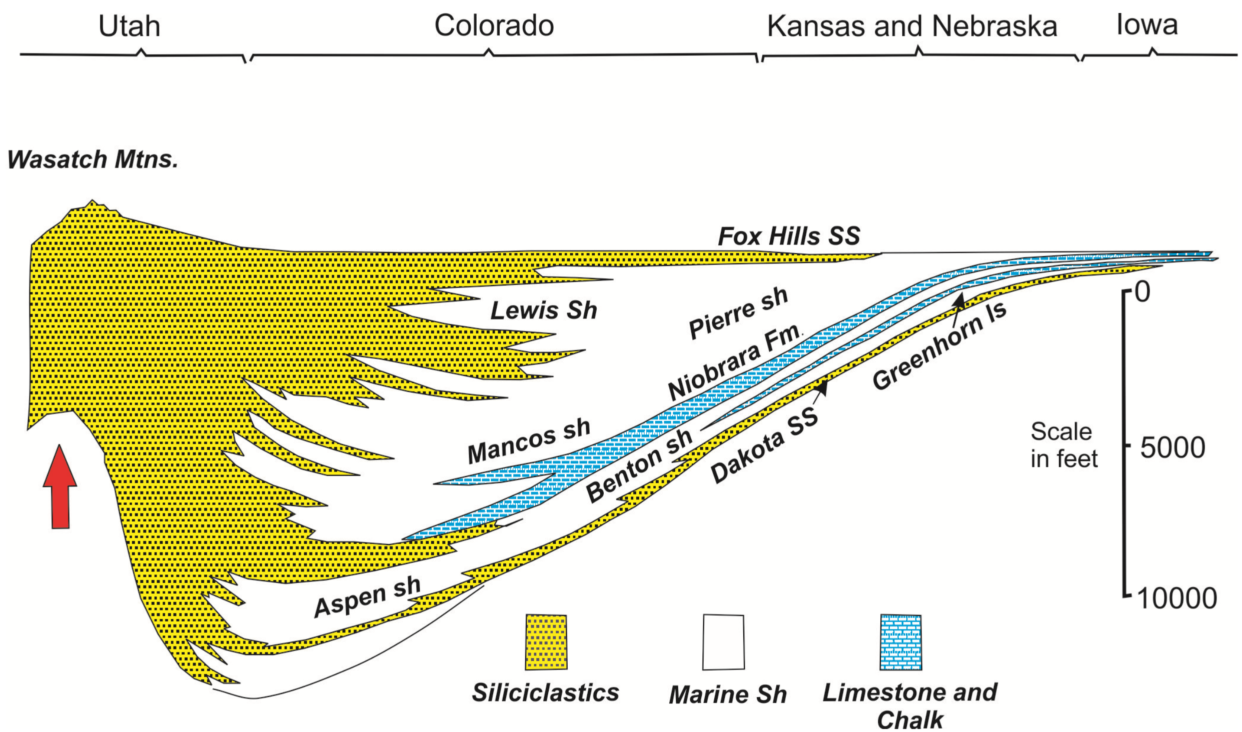
Niobrara drilling and leasing activity in the southern Powder River Basin. Stars denote Niobrara activity (Courtesy of Tofer Lewis).

	Bakken	Niobrara
Age	Late Dev/Miss	Upper Cret.
Lithology	silt, dolostone	chalk, marl
Depth	9-10,000 ft	8,000 ft
Thickness	70 ft	40 ft
Porosity	5-10%	8-10%
Perm	<0.1 md	< 0.1 md
Fractures	M & F	M & F
Spacing	1280	640
Oil Gravity	42º	32-62º
Pressure	Mod-High	Normal to H
Costs	$7-8 MM	$5-6 MM

Summary

- Unconventional tight oil resource plays are ‘changing the game’
- Niobrara Petroleum System present in most Rockies basins
- It all starts with good to excellent source beds
- Source beds mature over large areal extent
- Natural fracturing enhances tight reservoirs
- Horizontal drilling and fracture stimulation technology important in tight oil plays

Colorado School of Mines Niobrara Consortium



For Information, Contact:

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ssonnenb@mines.edu

Colorado School of Mines Niobrara Consortium

Bill Barrett Corporation

ion [CHARGED WITH INNOVATION]

Anadarko Petroleum Corporation

bp

White Eagle Exploration

Fidelity Exploration & Production Company

Total

Marathon

QEP

Whiting

Whiting Petroleum Corporation

Samson

Pioneer Natural Resources

The Energy of Enerplus

Statoil

Chesapeake Energy

Husky Energy

Anschutz Exploration Corporation

Williams

elpaso

noble energy

Hendricks and Associates, Inc.

Schlumberger

SM Energy

Rosetta Resources

devon

Texas American Resources Company

Black Hills Energy

Improving life with energy

MJ Systems

IHS

TGS

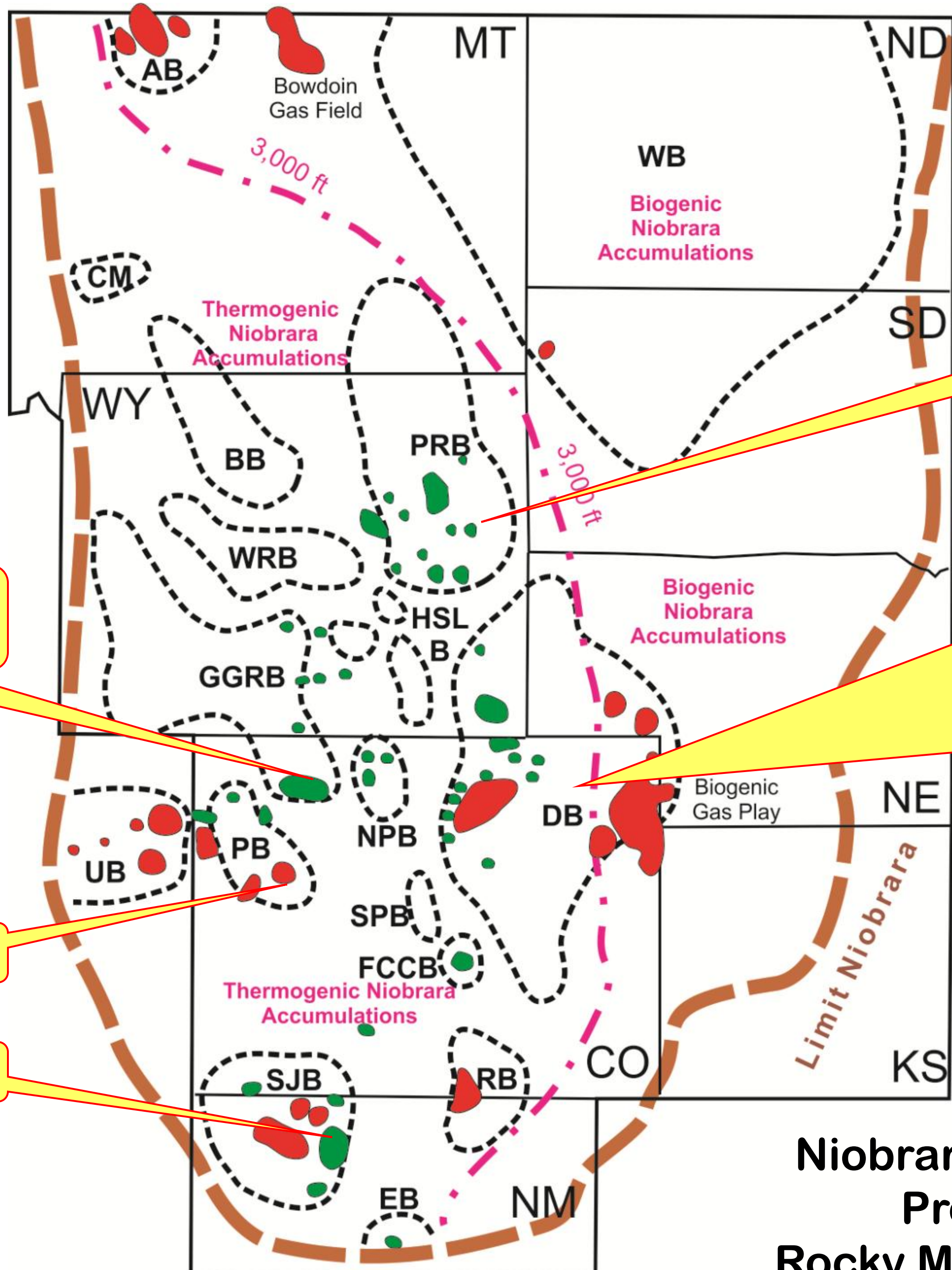
Lario Oil & Gas Company

Ward Petroleum Corporation

The Discovery Group Inc

HRM Resources, LLC

CSM Niobrara Consortium
'Unlock the Chalk'



James Taylor

Vivian Lin
Kelly Bruchez

David Thul
Phylicia Saner
Lauren Stout
Danielle Nihiser
Tofer Lewis
David Underwood
Mike Collins
Craig Kaiser
Melanie Peterson
Teresa Malesardi
Daniel Hallau
Alejandra Maldonado

Martin Krueger

Tom Arthur

Niobrara and Mancos Production, Rocky Mountain Region