Geological Overview of the Niobrara Chalk Natural Gas Play

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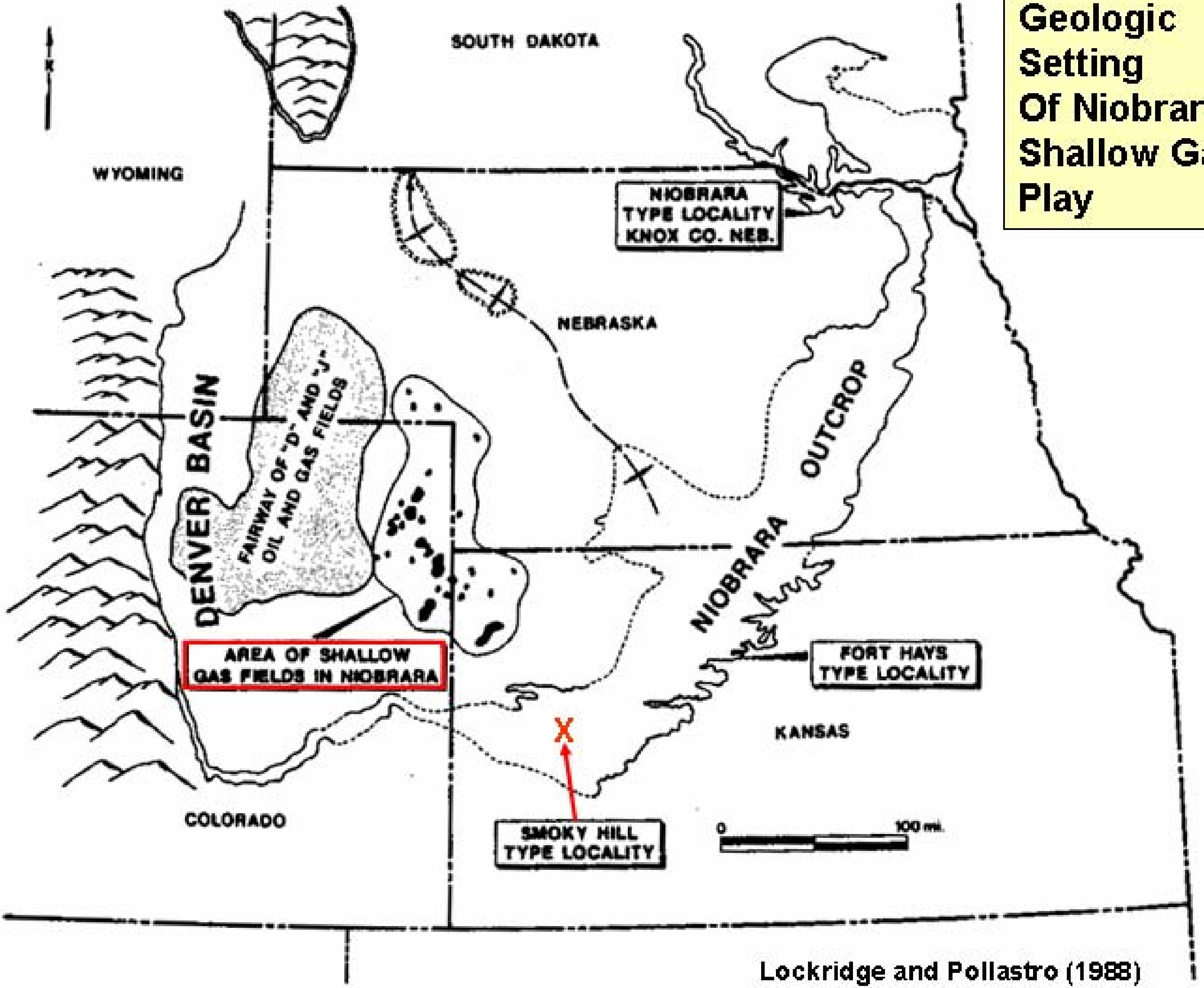
Outline

- Geologic Setting
  - Paleogeography
  - Niobrara Distribution
    - Stratigraphy
    - Reservoir
- Characteristics of the Chalk Reservoirs
    - Lithofacies
    - Structure
- Gas Fields in NE Colorado and NW Kansas
- Summary

Geologic Setting Of Niobrara Shallow Gas Play



Lockridge and Pollastro (1988)

Upper Cretaceous (Coniancian-Campanian) Niobrara Chalk
-- *A Shallow Biogenic Natural Gas Reservoir*

Castle Rock (Smoky Hill Chalk Member)
Eastern Gove County

- *Gryphaea* in the upper left
- *Pseudoperna* on *Inoceramus* (lower specimen)

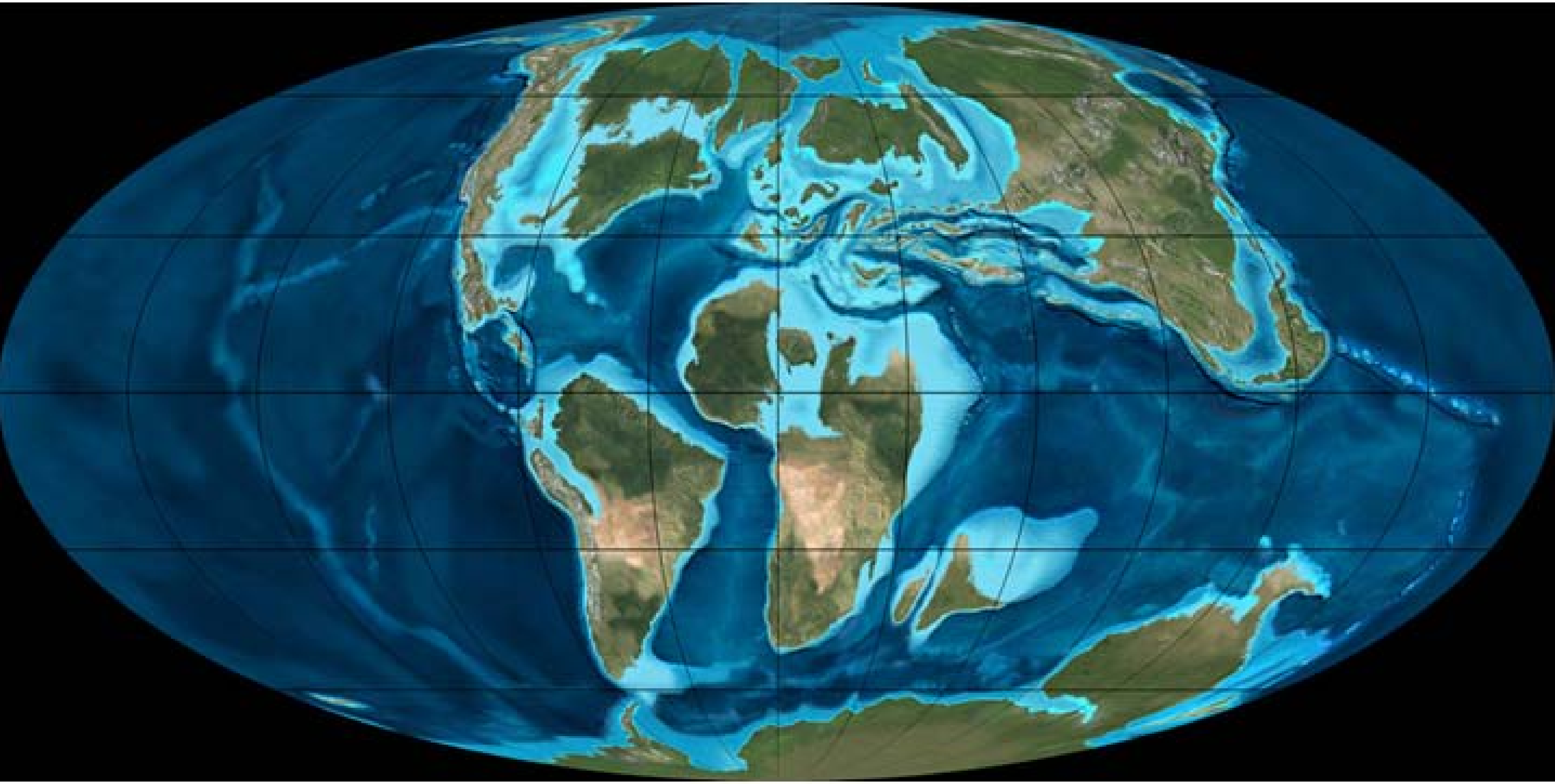
Late Cretaceous Paleogeography

The Cretaceous Period

144 - 65 Ma

Late Cretaceous Paleogeography

Extensive Chalk Deposition



R.C. Blakey
http://jan.ucc.nau.edu/~rcb7/90moll.jpg

Geologic Setting in Late Cretaceous

- Continents began to move toward their present configuration. Atlantic Ocean widened.
  - Gondwanaland breaks up
- Black shale and chalk deposits abound.
- Limited ice caps to supply cold (dense, heavy) oxygen-rich water to ocean bottoms - anoxia
- Volcanism + mountain building in western U.S. subduction. (Cordilleran region)

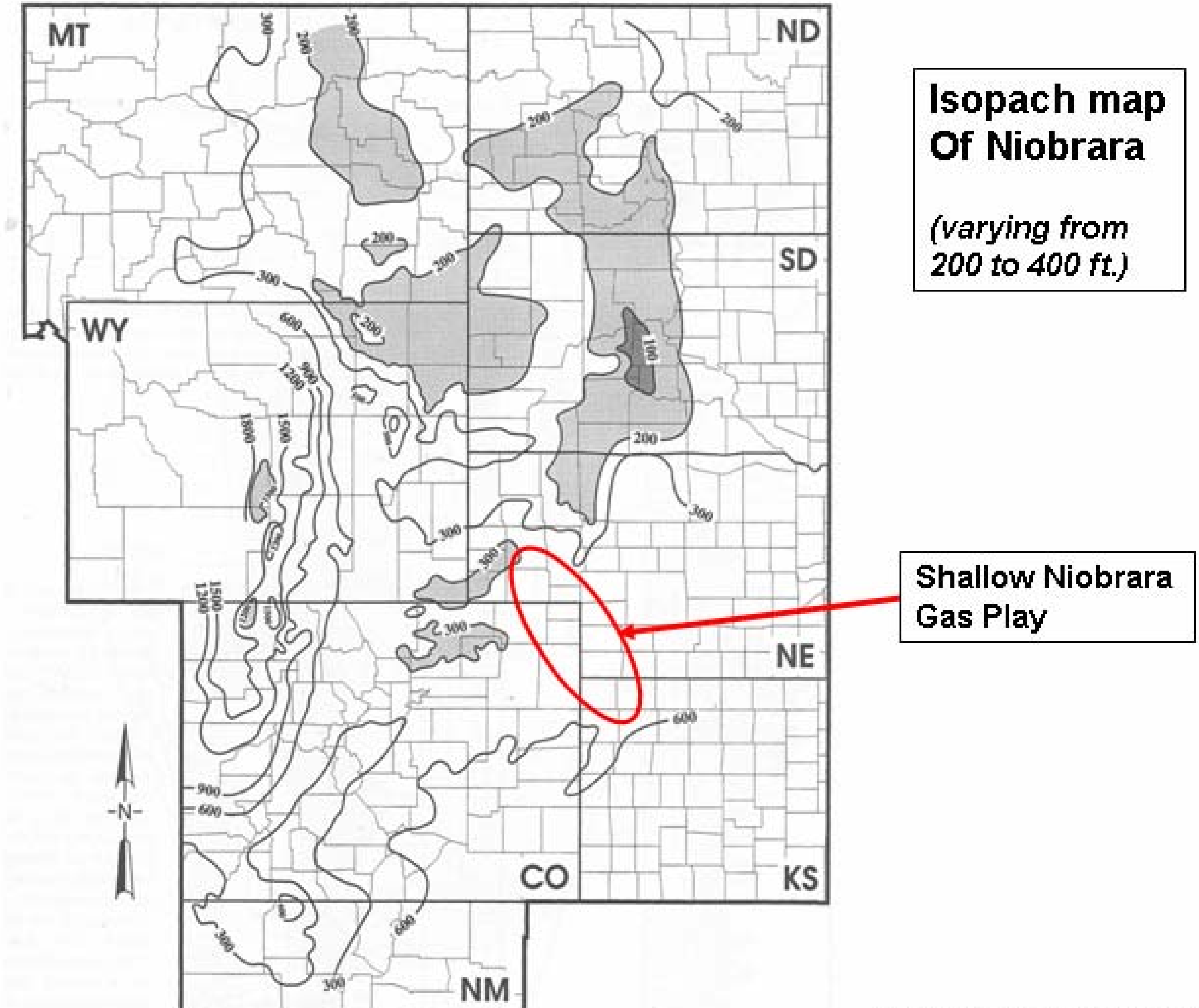
Upper Cretaceous Geologic Setting (continued)

General Conditions

- *High sea levels worldwide*
  - Continents covered by shallow seas, epicontinental seas including interior U.S.
- *Chalk deposits represent 70% of the total carbonate sediment deposited worldwide* for the past 100 m.a. (Hay et al., 1976)
- *Large-scale sedimentary cycles* reflecting synchronous transgressive/regressive pulses largely eustatic in origin (Pollastro and Scholle, 1986)

Life in the Cretaceous

- *Diversification of the planktonic foraminifera*
- *Coccolithophores became abundant*
  - Coccoliths (*low-mag calcite shells*) accumulated in large numbers on the sea floor including epicontinental sea forming CHALK
  - The word Cretaceous means "chalk bearing"



Isopach map Of Niobrara

(varying from 200 to 400 ft.)

Longman, Luneau, and Landon (1998)

Niobrara Chalk

- High porosity (40-50%) and low permeability (0.1-3 md)
  - Initial porosities from 60-80%, compacting with burial from dewatering, grain reorientation, and grain breakage
  - Permeabilities in excess of 0.5 md at shallow depths (~1000 ft, like northwestern Kansas); max reported range from 0.1 to 16 md (*Lockridge and Scholle, 1978*)
- Eastern Denver Basin and Kansas – Biogenic gas from thermally immature, organic-rich chalk beds (*Landon, Longman, and Leneau, 2001*)
- Local accumulations of shallow gas controlled by local, faulted, low-relief domal structures, or noses
- Chalk is very brittle and even minor structures lead to natural fracturing and greatly enhanced reservoir porosity
- Faulting documented as horst and graben features with faulting not extending into adjoining formations
- Higher structure and higher gas saturations, typically ~50% and less - (*Lockridge and Scholle, 1978*)
- Reservoir pressures: Goodland at 900 ft with ~60 psi to 350 psi at 1500 ft at Beecher Island, Colorado

Polastro and Scholle (1986)

Niobrara Chalk (continued)

- Chalk is fined grained micrite representing a mixture of calcareous, organic, and terrigenous components (70-80% carbonate)
- Dominant “grain size” from 0.2 to several micrometers (10^{-6} m)
- Carbonate: calcareous (low magnesium calcite) nannofossils (60-90%) including coccoliths (*golden-brown algae*), and lesser Foraminifera and calcispheres, plus macrofossils
- Local diagenetic reactions with organics and inorganics leading to authigenic minerals (pyrite and kaolinite)
- Clays dispersed and laminae consist of smectite and increasing interstratified illite-smectite (*expanding, water reactive clays*)
  - Pure chalk-marl-clay gradation reflected on gamma ray log
- Organic matter averages 3.2% and is as high as 5.8% in the Smoky Hill Chalk Member of the Niobrara Chalk Fm.
- Natural gas has chemical and isotopic composition characteristic of biogenic gas
- BTU content of gas ranges from 965 to 1025.

Polastro and Scholle (1986)

Niobrara Chalk (continued)

- Pay commonly defined by induction-neutron-density
  - Rt in pay typically from 3 to 15 ohm-m
  - Pay typically has higher neutron porosity and low density porosity reflecting presence of natural gas (excavation effect)
- Fracture stimulation necessary to make gas production from wells economically feasible
  - *Sand nitrogen foam*, *sand-carbon dioxide*, and *methanol-water* treatment have been used effectively
  - IP after stimulation range from 100 to 1,200 mcfpd with rapid decline to 50 to 300 mcf (3 to 10% per year)
  - Variation in productivity represents combined effects of matrix and natural fracture permeability

Polastro and Scholle (1986)

1 micron

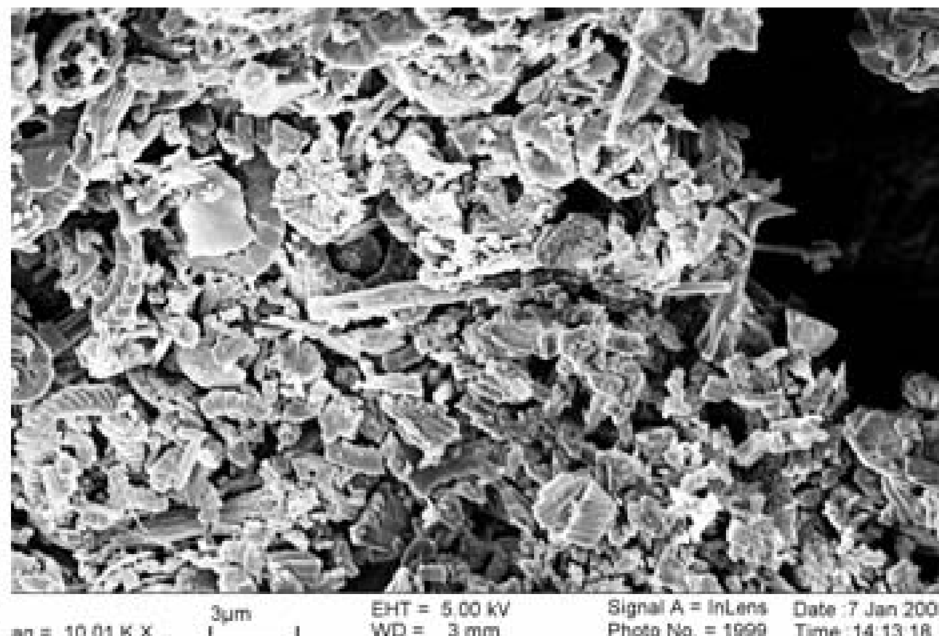
Homestead 1-4 SEM photos

<u>High permeability</u> sample

2 md, 41.1% porosity

1 inch core plug

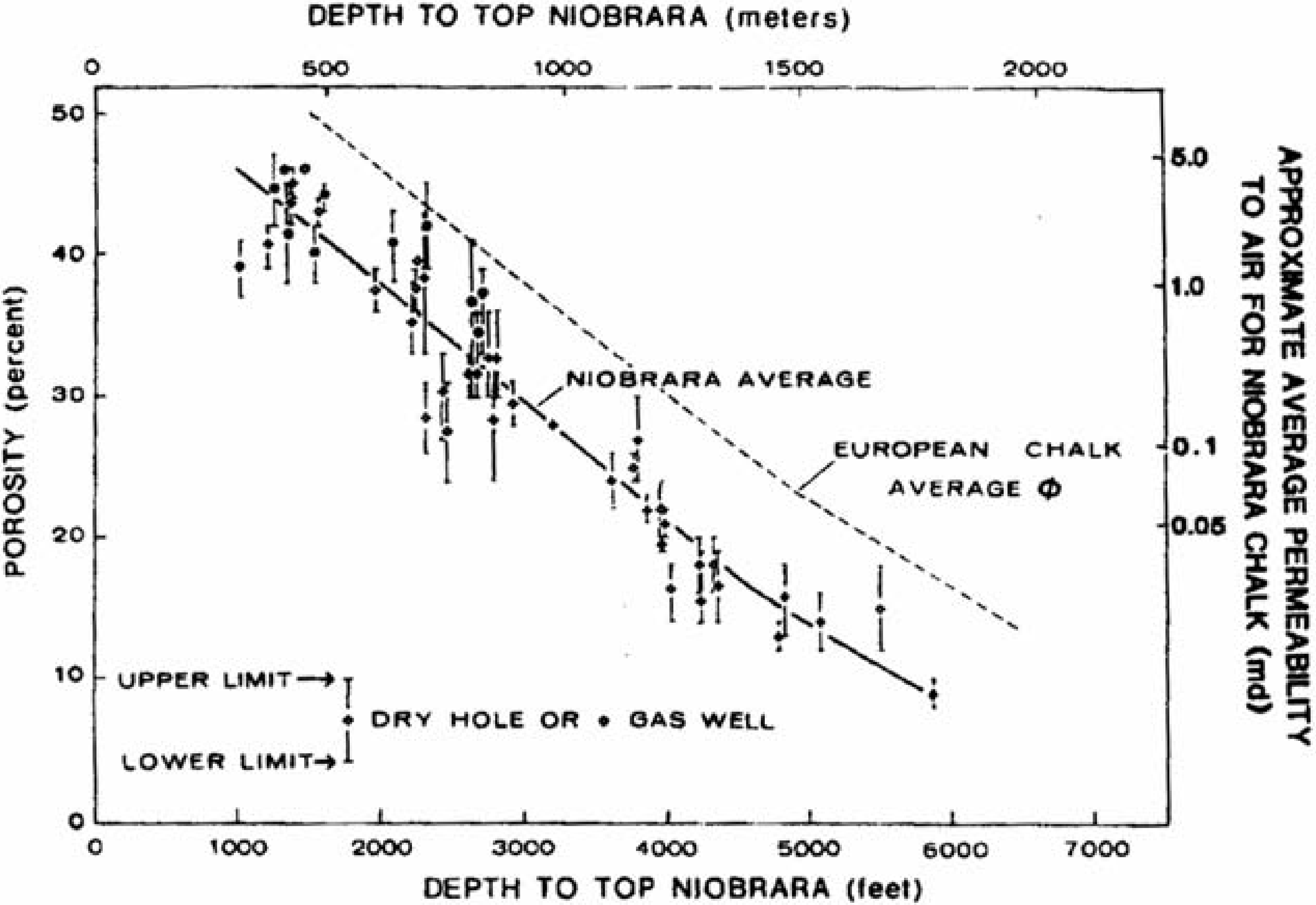
1 micron



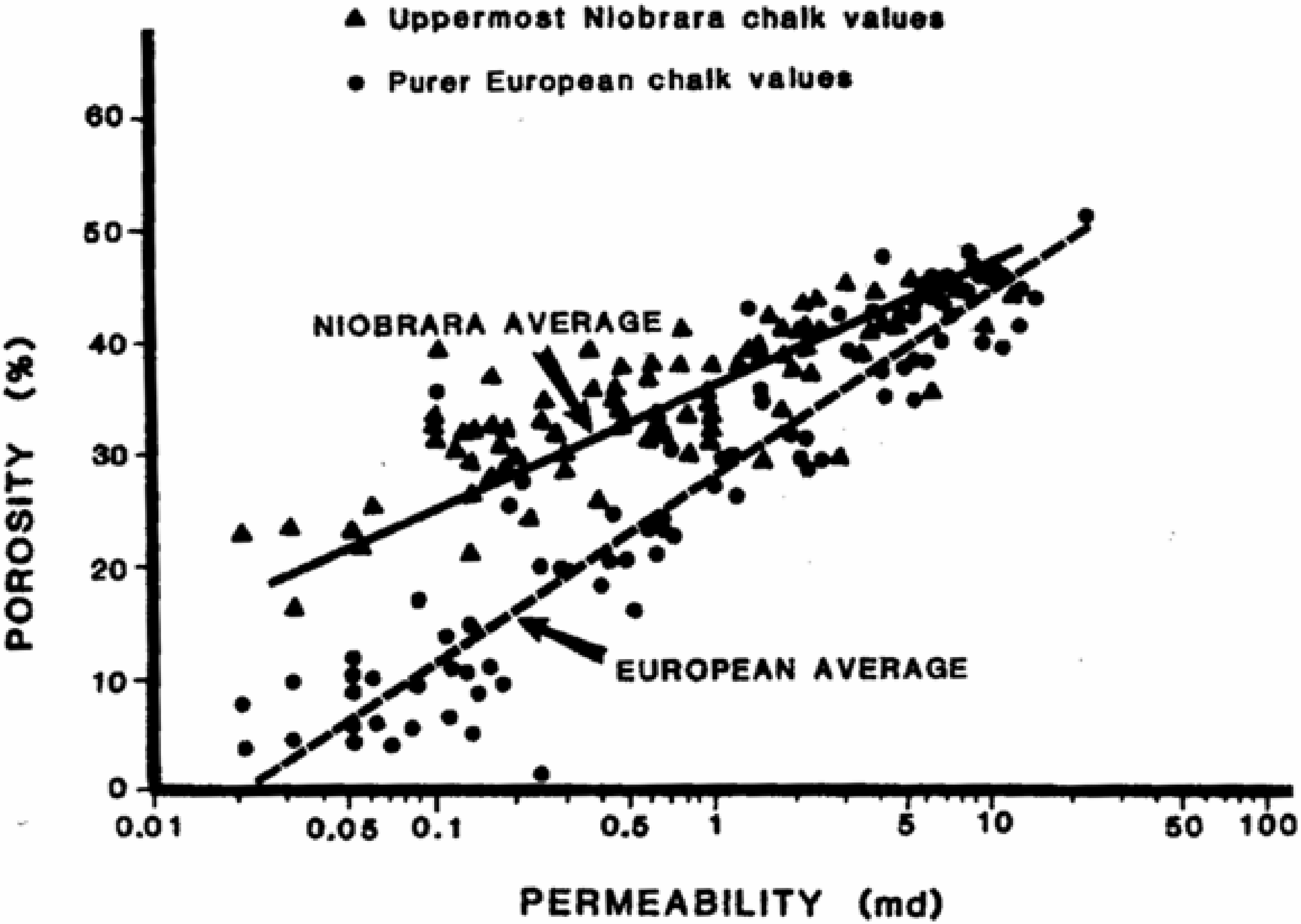
3 microns

Density log porosity and depth for *Beecher Island chalk* on east flank of Denver Basin

(from Pollastro and Scholle, 1986, after Lockridge and Scholle, 1978)

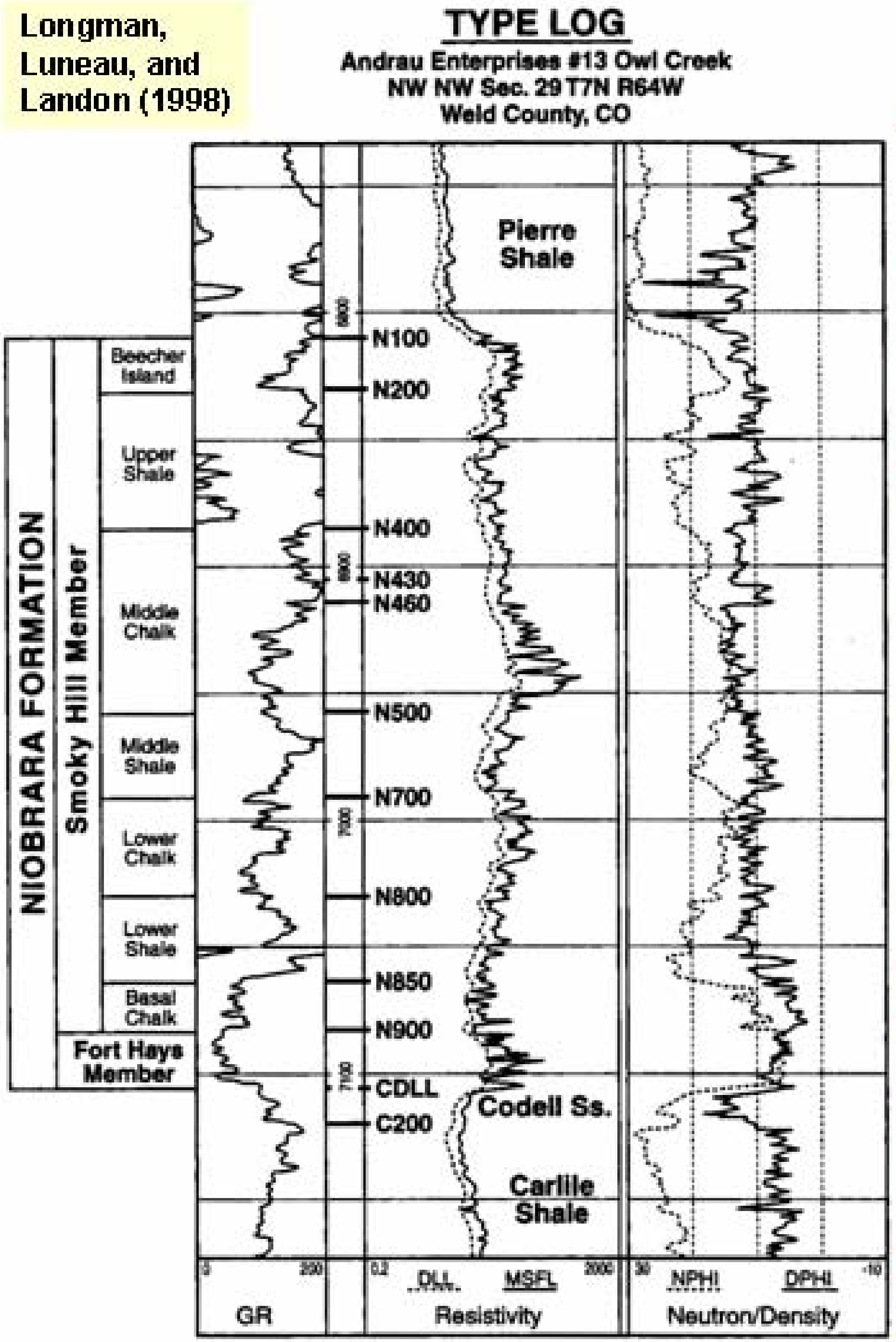


Porosity and permeability relationships in *Beecher Island zone* based on density porosity along eastern flanks of the Denver Basin

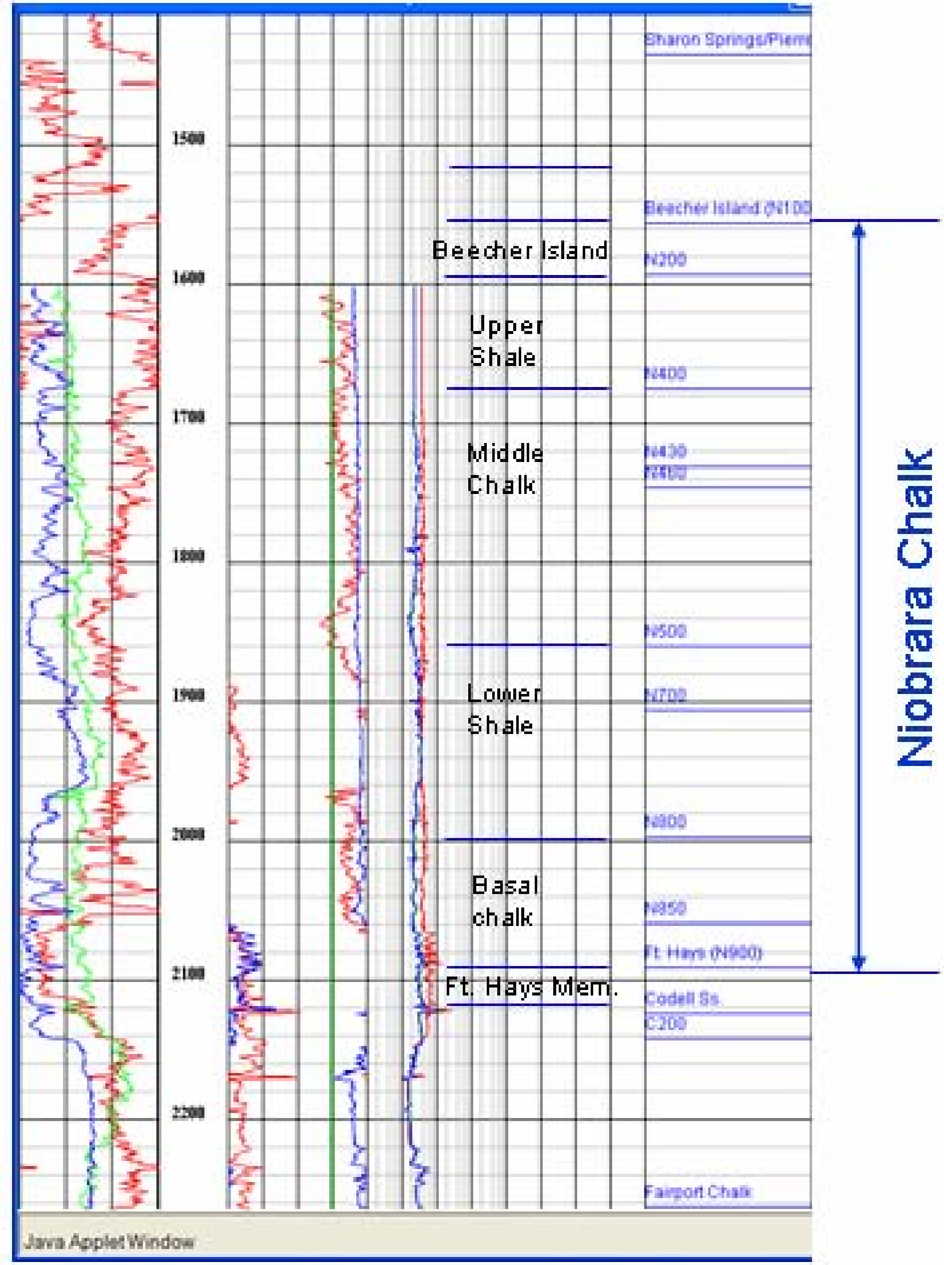


From Lockridge and Scholle (1978)

Longman, Luneau, and Landon (1998)

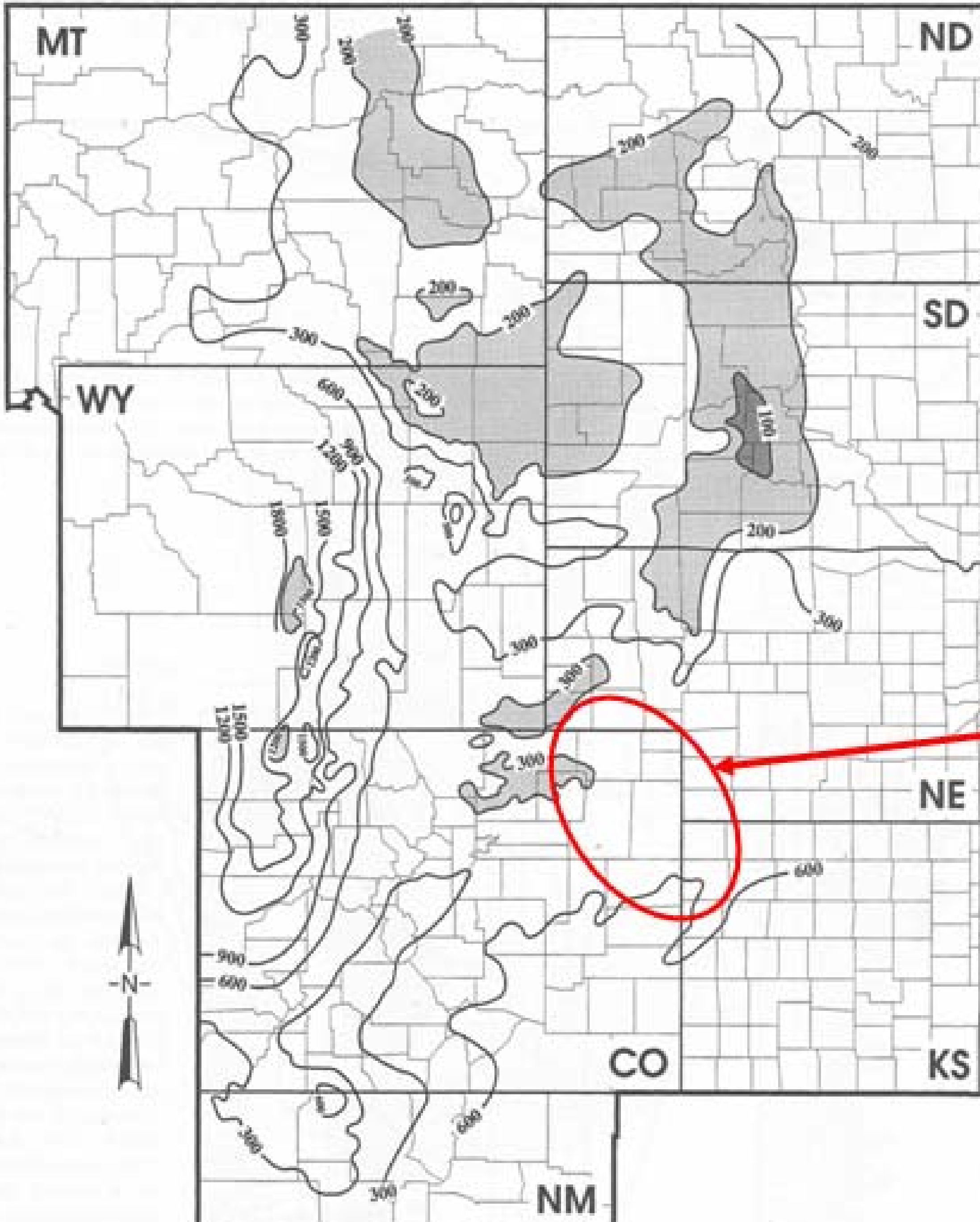


Cheyenne County, Kansas
Cherry Creek Niobrara Gas Area



Isopach map Of Niobrara

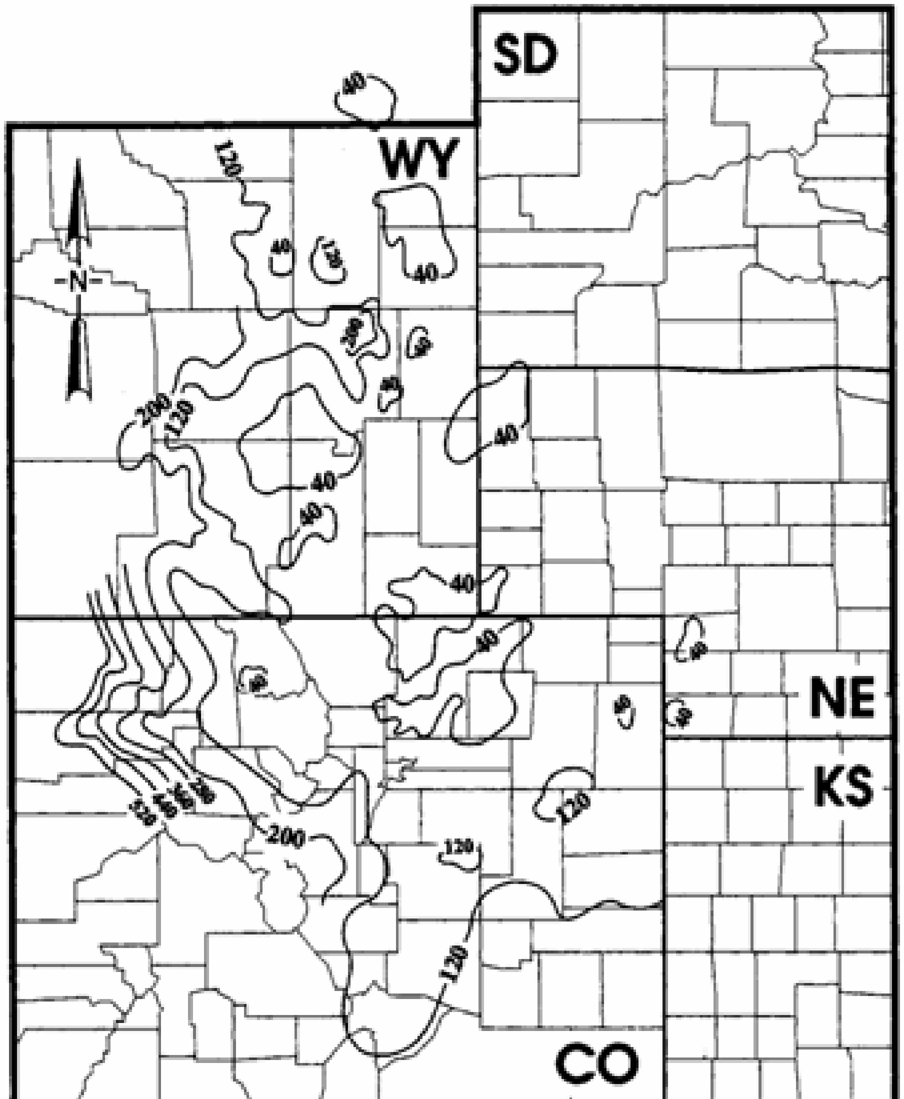
(varying from 200 to 400 ft.)



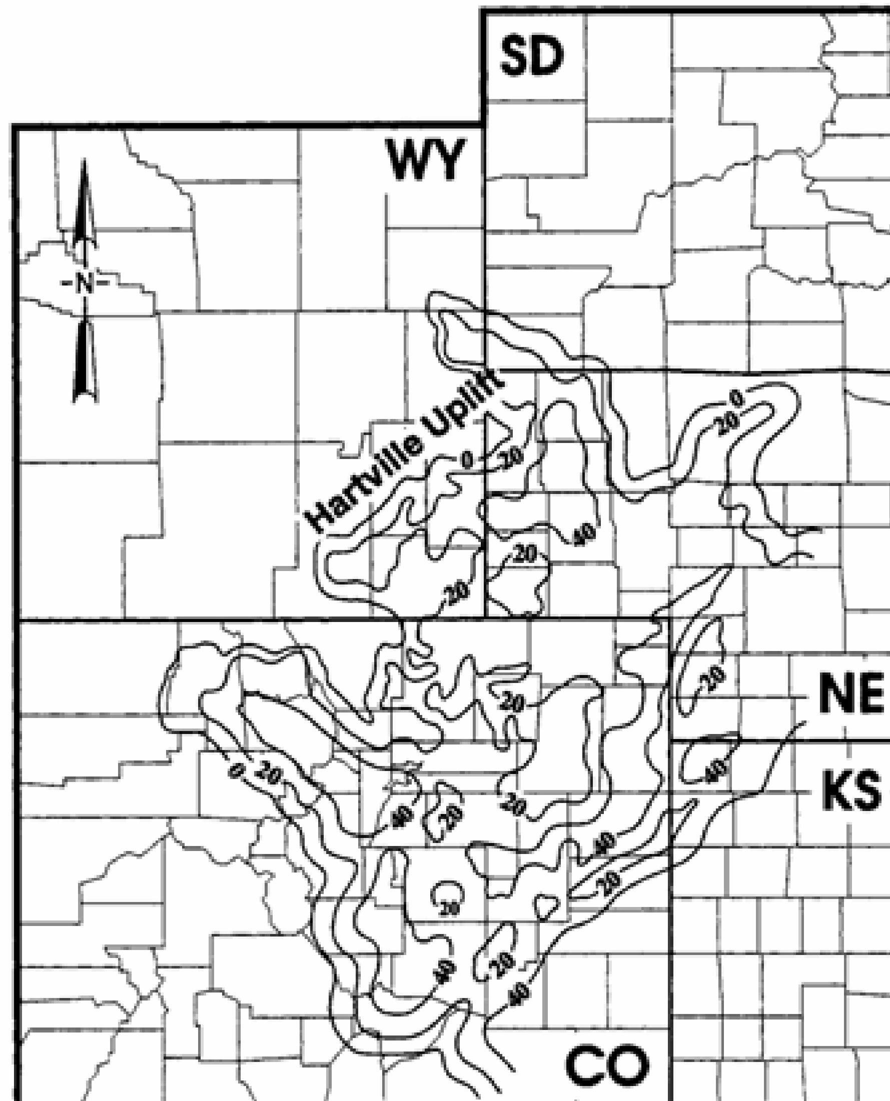
Shallow Niobrara Gas Play

Longman, Luneau, and Landon (1998)

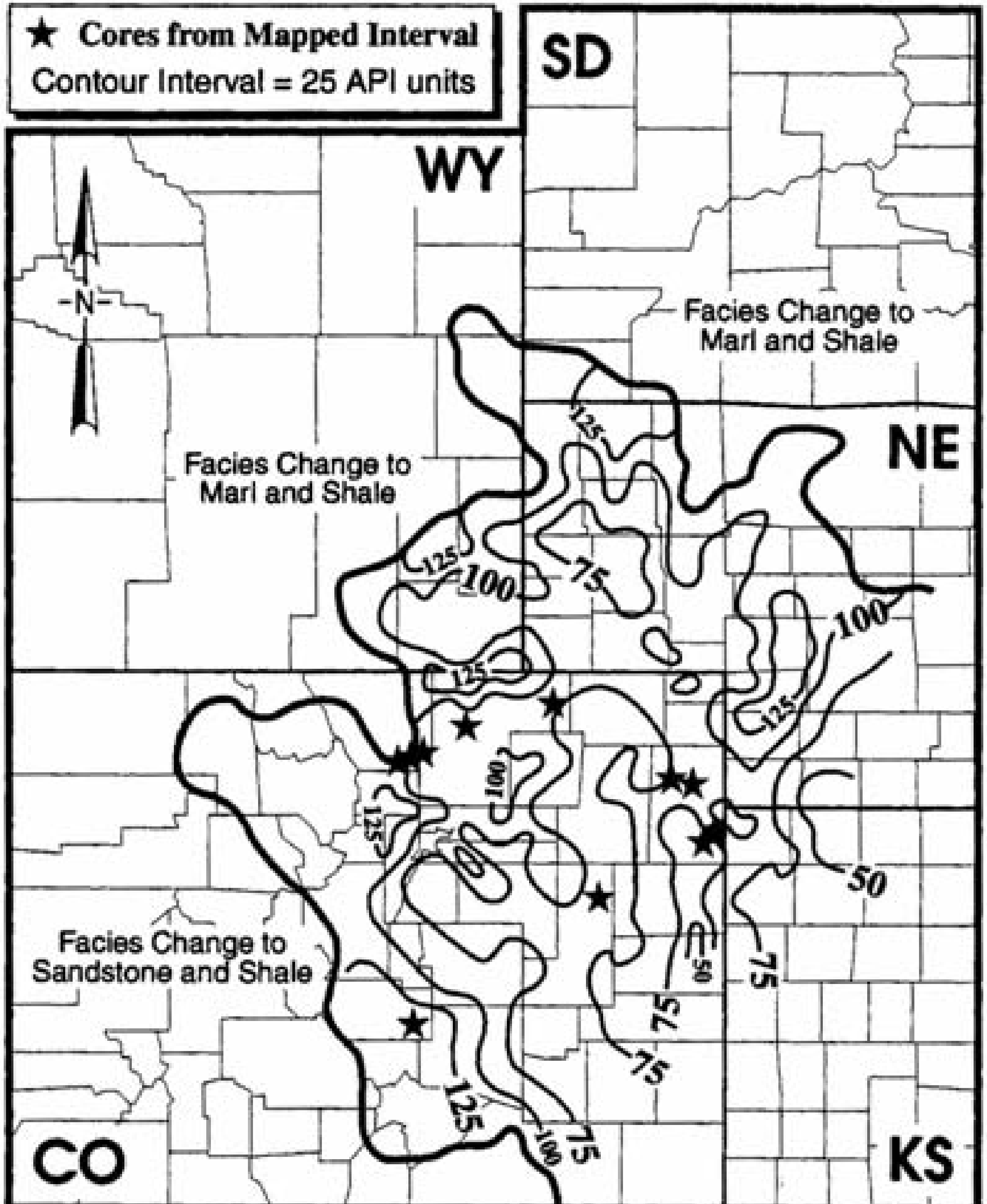
Isopach Map of N200 Interval (shalier interval beneath Beecher Island)



Isopach Map of the N100 Interval (Beecher Island zone), major gas Producing zone in NE Colo & NW Ks



Longman, Luneau, and Landon (1998)

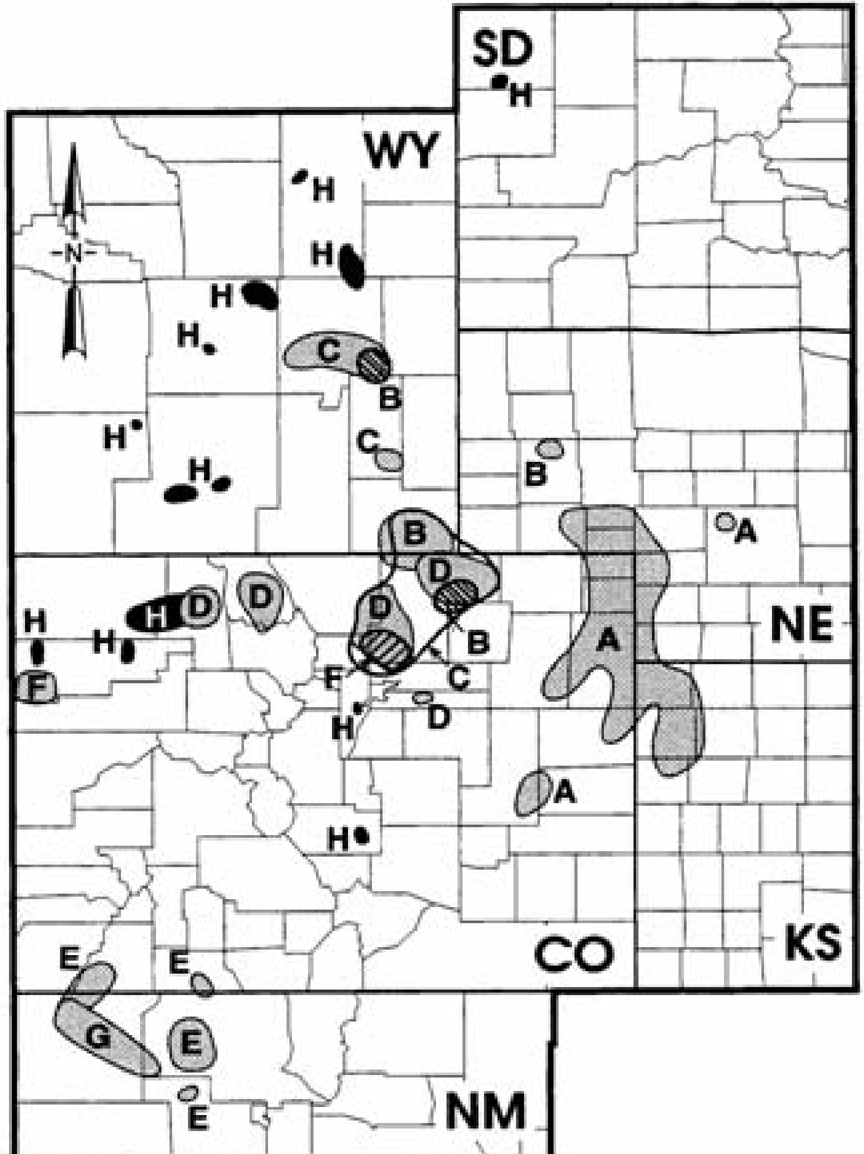


Minimum GR for N100 Interval
(40 to 140 API range)

Cleanest chalk is lowest GR in eastern portion of mapped area, site of shallow gas fields producing from N100 (<u>Beecher Island zone</u>)

Note boundaries for marl-shale-sandstone bounding chalk deposit

Longman, Luneau, and Landon (1998)



A — N100 (Biogenic Gas Play)

B — N400

C — N460

D — N700

E — El Vado SS

F — Thermogenic Gas Fieldd

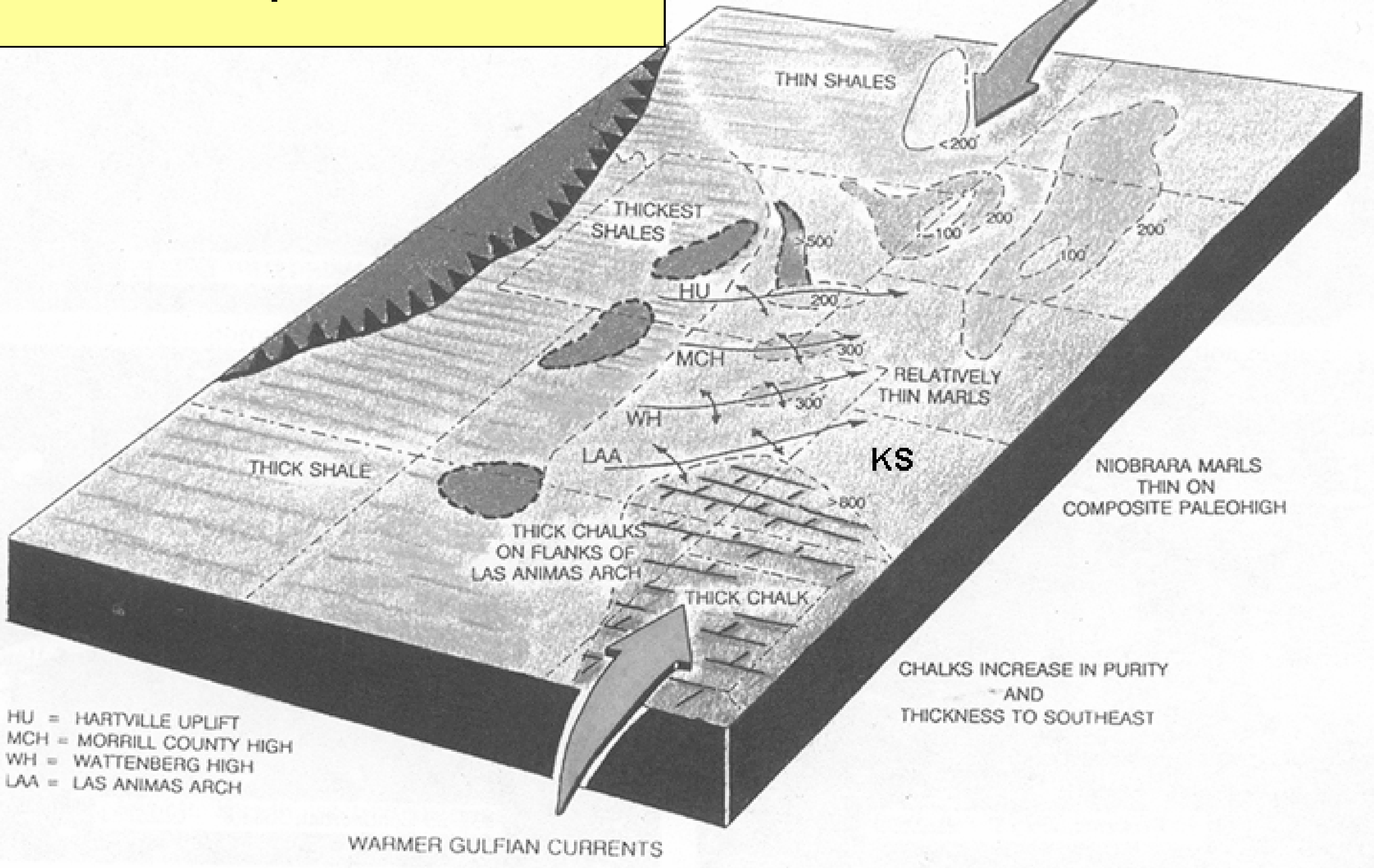
G — N900 (Tocito SS)

H — undifferentiated or long interval

Distribution of Niobrara Oil And Gas Production by Stratigraphic Interval

Longman, Luneau, and Landon (1998)

Niobrara Depositional Trends



Longman, Luneau, and Landon (1998)

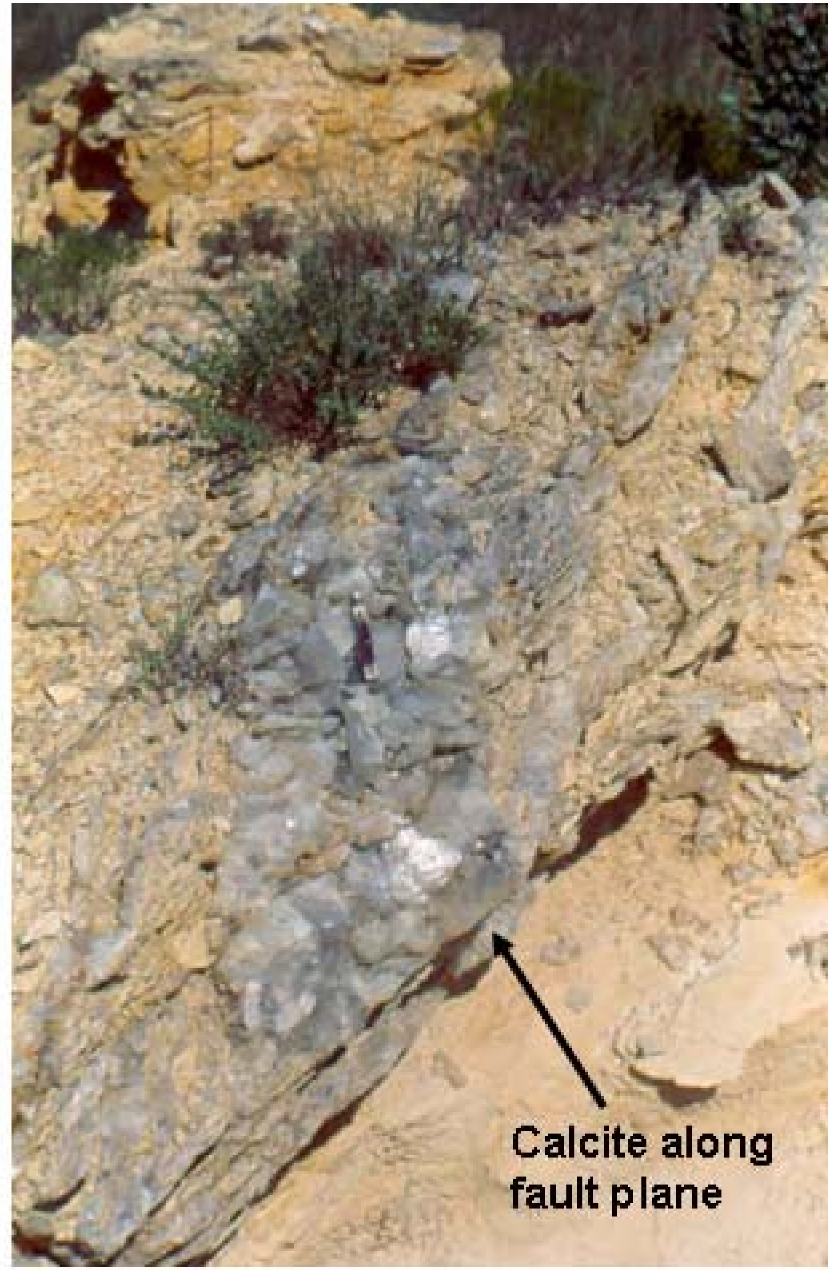
Structural Development of Shallow Niobrara Gas Play

Extensive Faulting and Block Rotation in the Outcrops Of the Smoky Hill Chalk Member in West Central Kansas

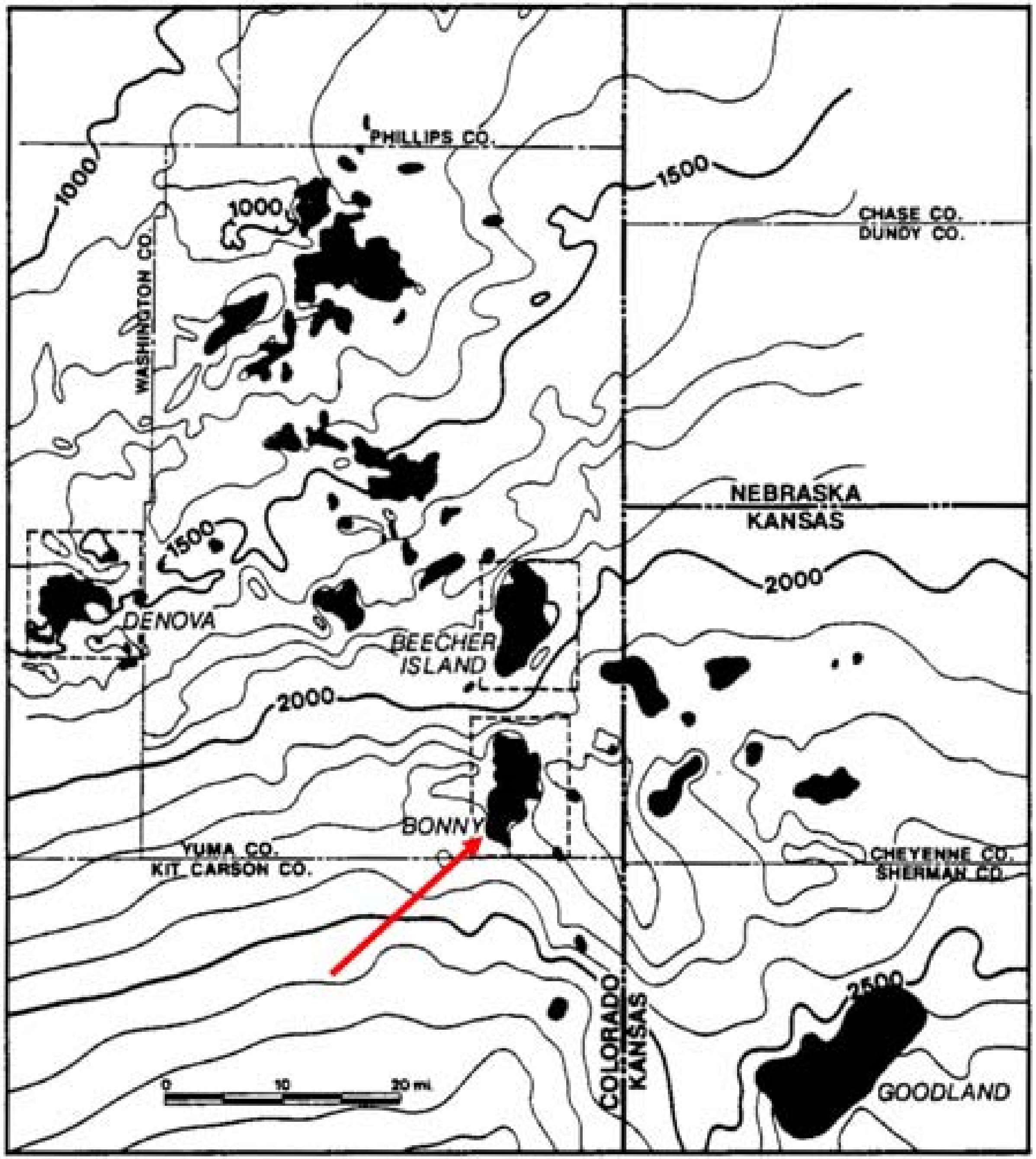
Courtesy of M. Dubois

Juxtaposed lithologies of Smoky Hill Chalk Member suggesting faulting

Courtesy of B. Sawin



Courtesy of B. Sawin



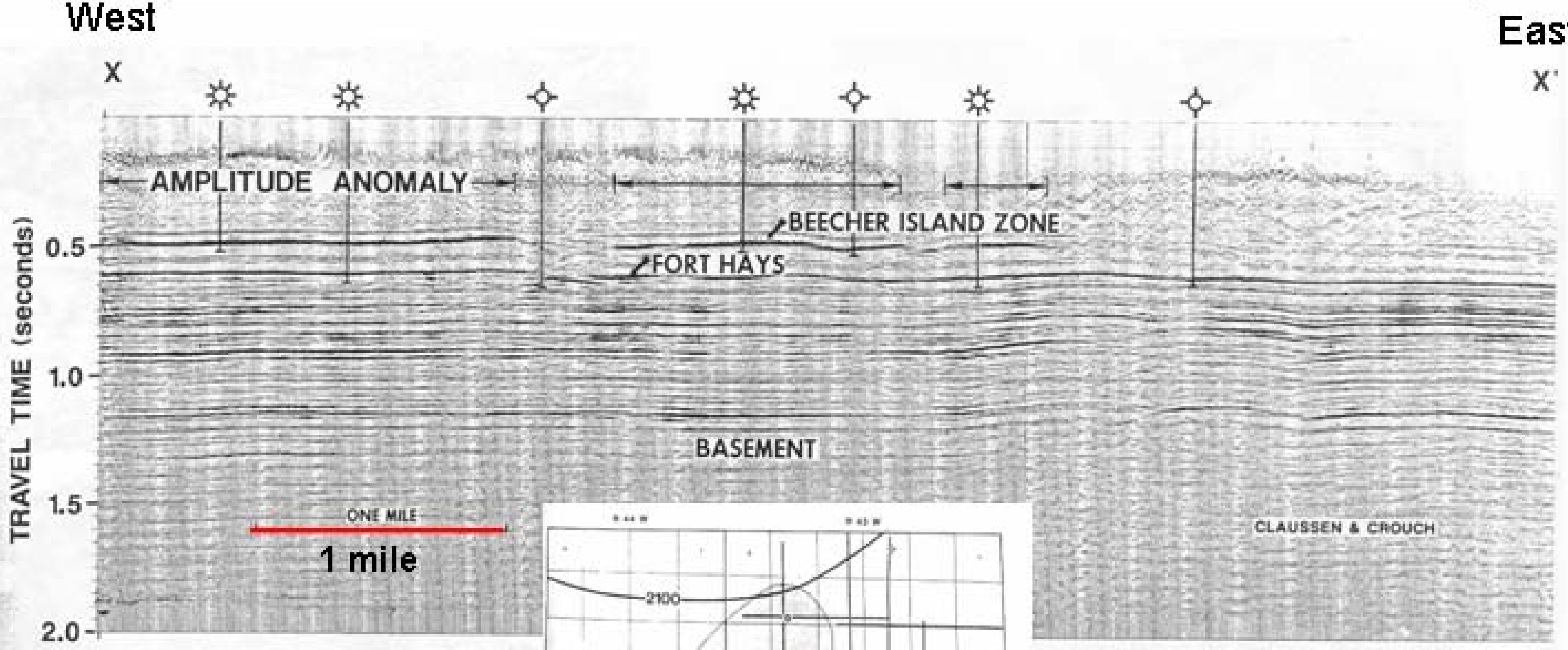
Structure map at Top of Niobrara Chalk

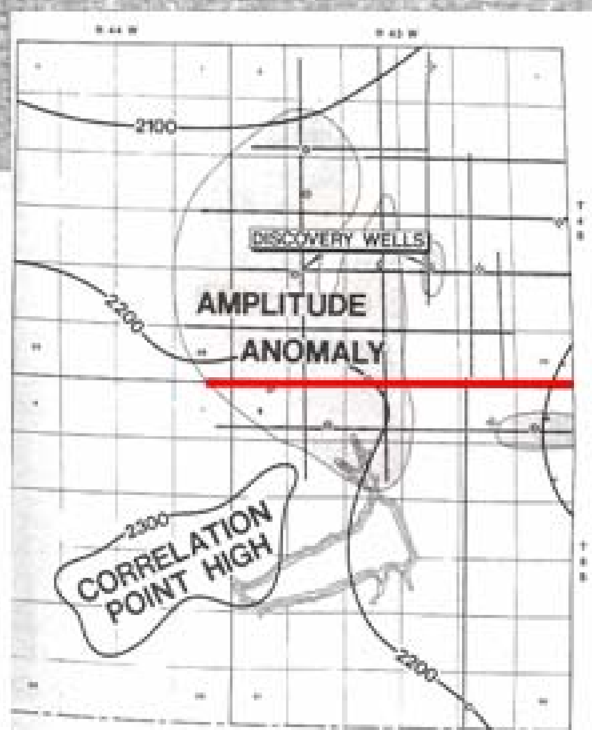
- ***Niobara gas fields associated with local structural anomalies***

20 mi.

Lockridge and Pollastro (1988)

Seismic Amplitude Anomaly Over *Bonny Field*, Yuma Co., Colorado

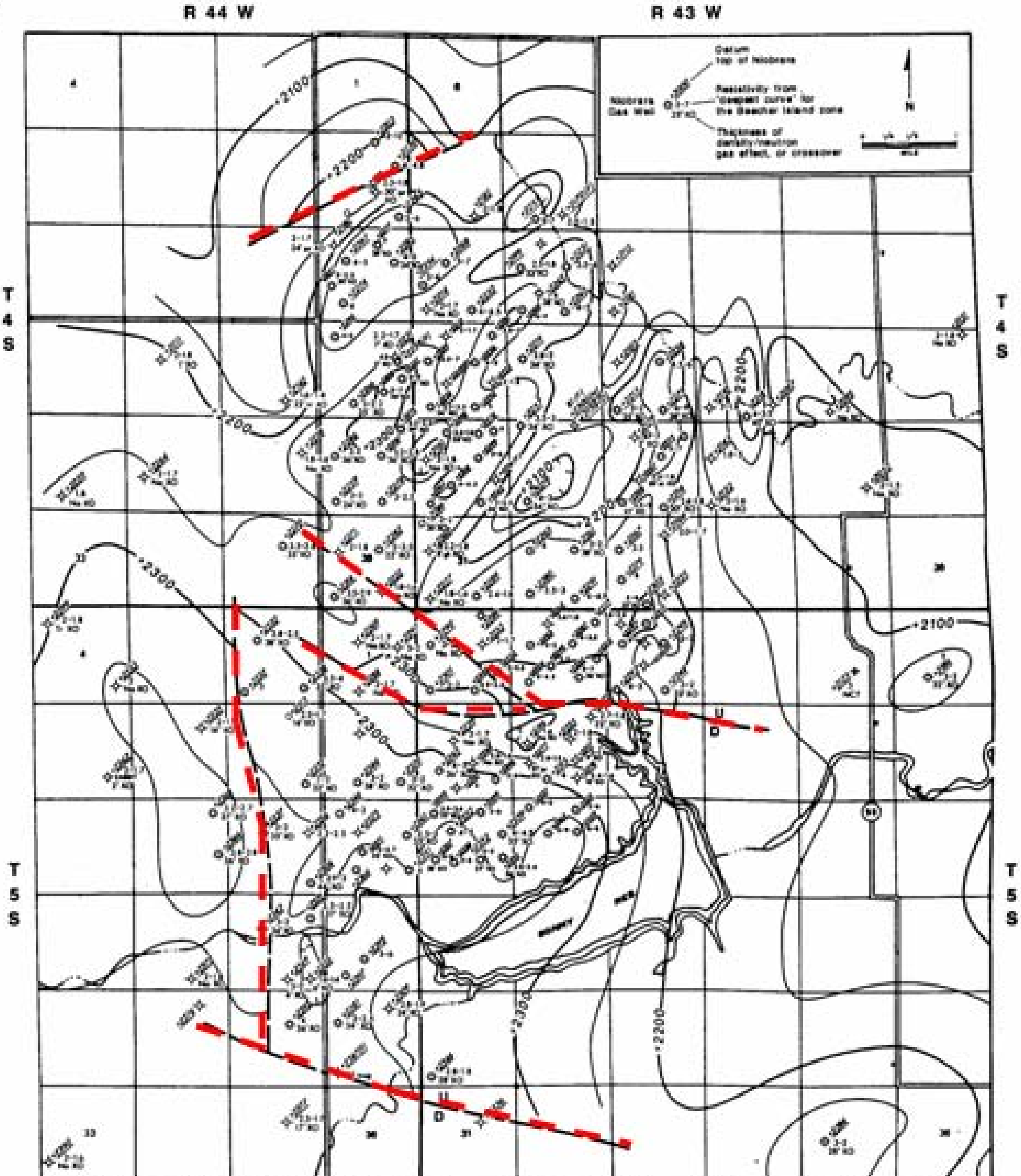




Amplitude anomalies over locally structurally high positions

Cross section index map:
Area of amplitude anomaly closely corresponds with present field outline

Lockridge and Pollastro (1988)



Structure top of Niobrara Chalk Bonny Field, Yuma Co., Colo.

Developed gas area coincides with seismic amplitude Anomalies

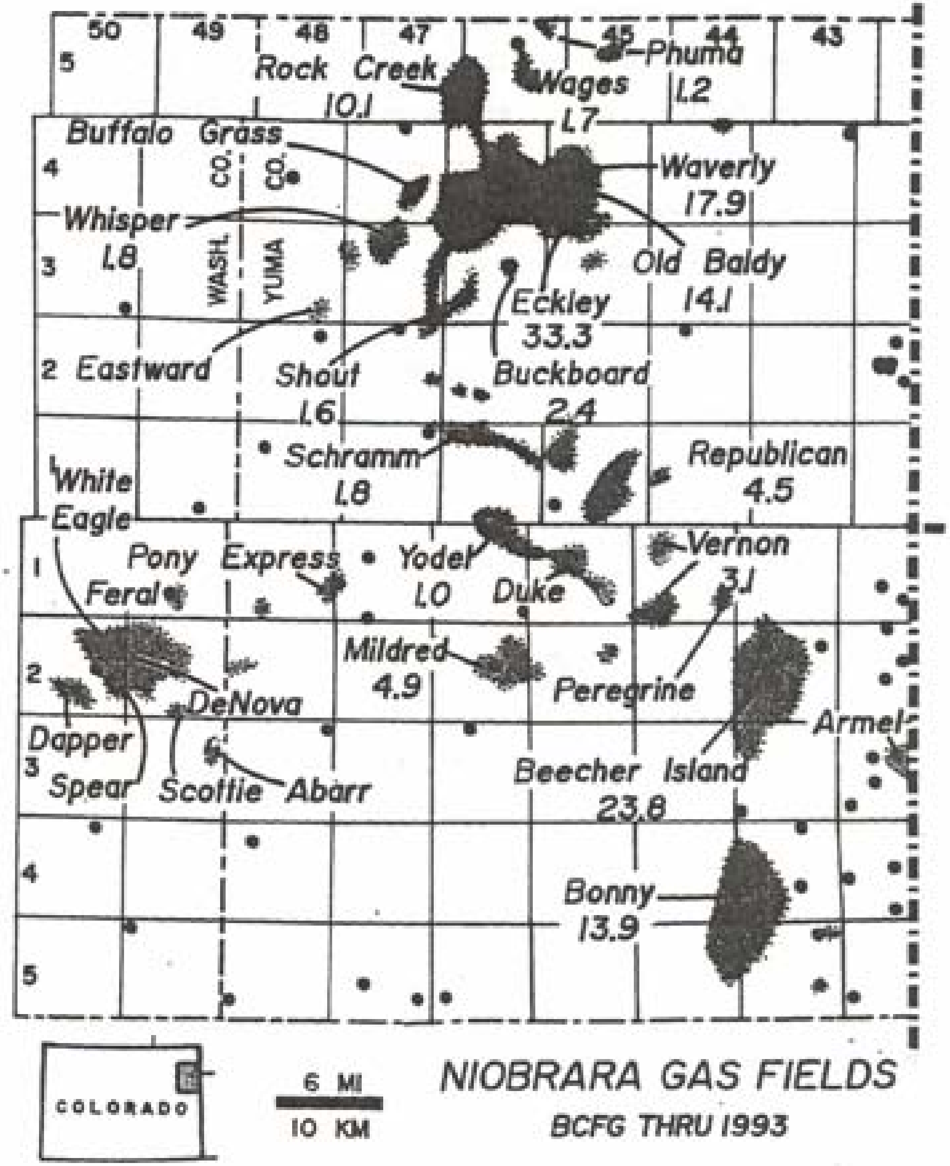
14+ BCF field

faults

2 miles

Lockridge and Pollastro (1988)

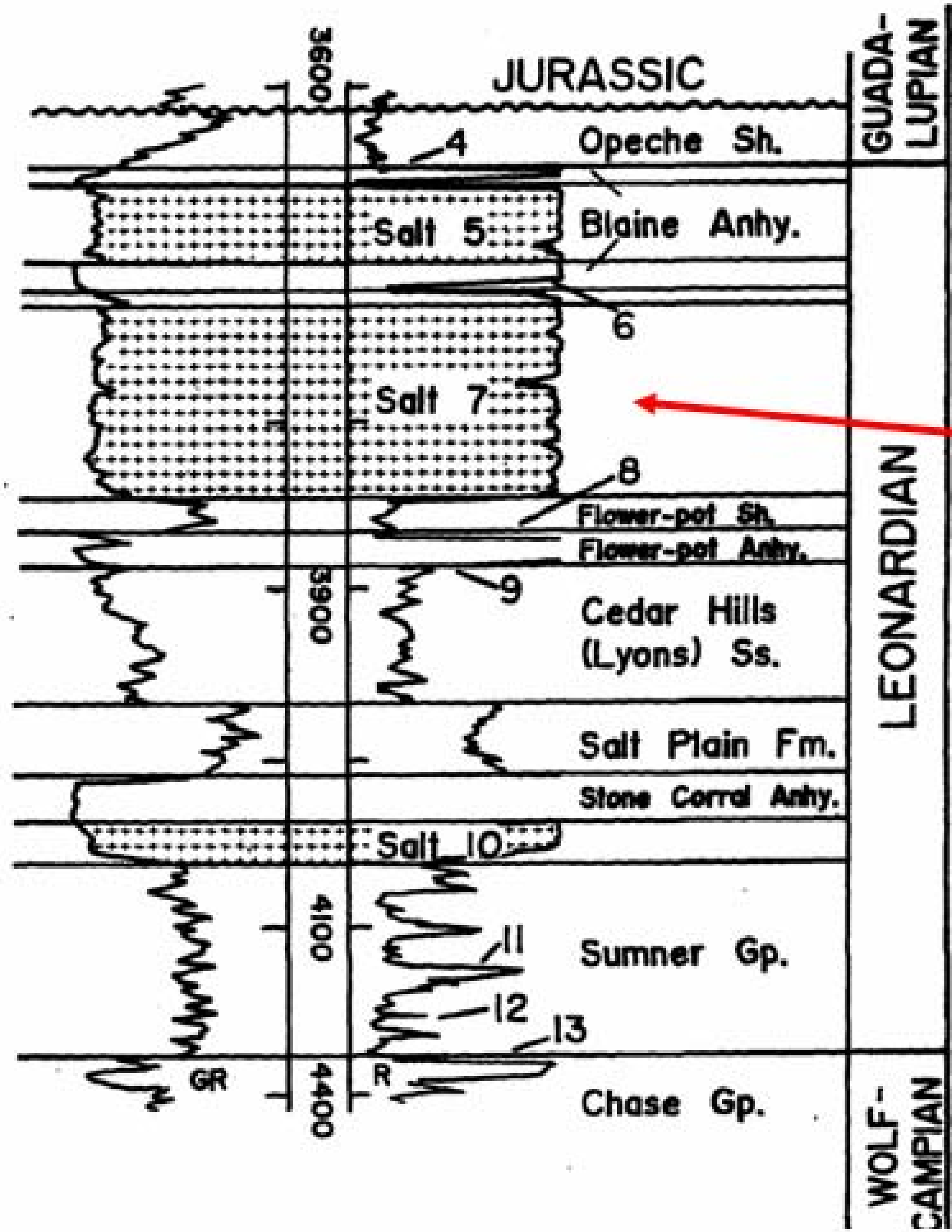
Influence of Permian Salt Dissolution in Creation of Niobrara Producing Structures



Oldham (1997)

Representative well log from Yuma County, Colorado Across Permian salt-bearing interval

Salts mapped by Oldham (1997)



Isopach map shown in next slide

Oldham (1997)

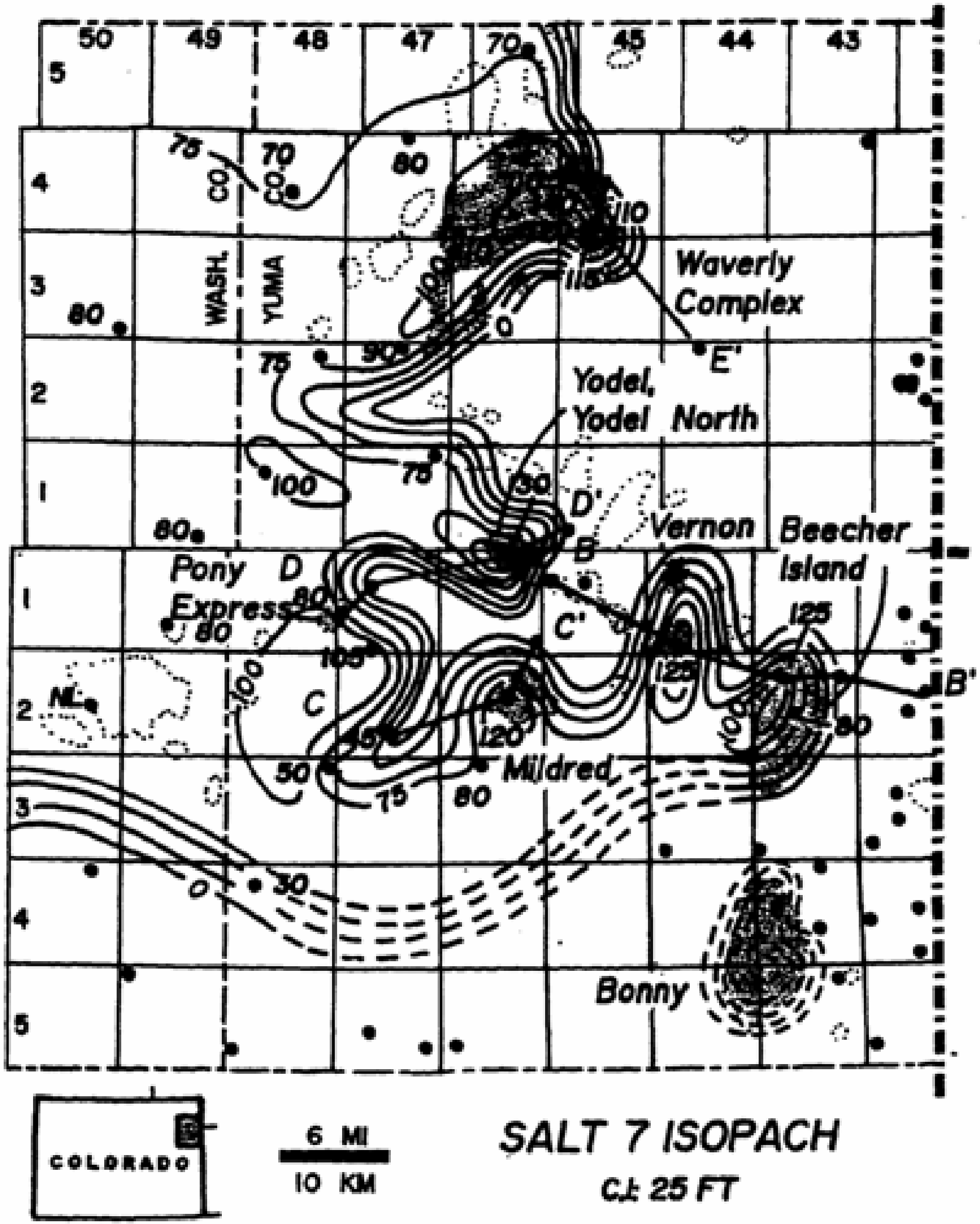
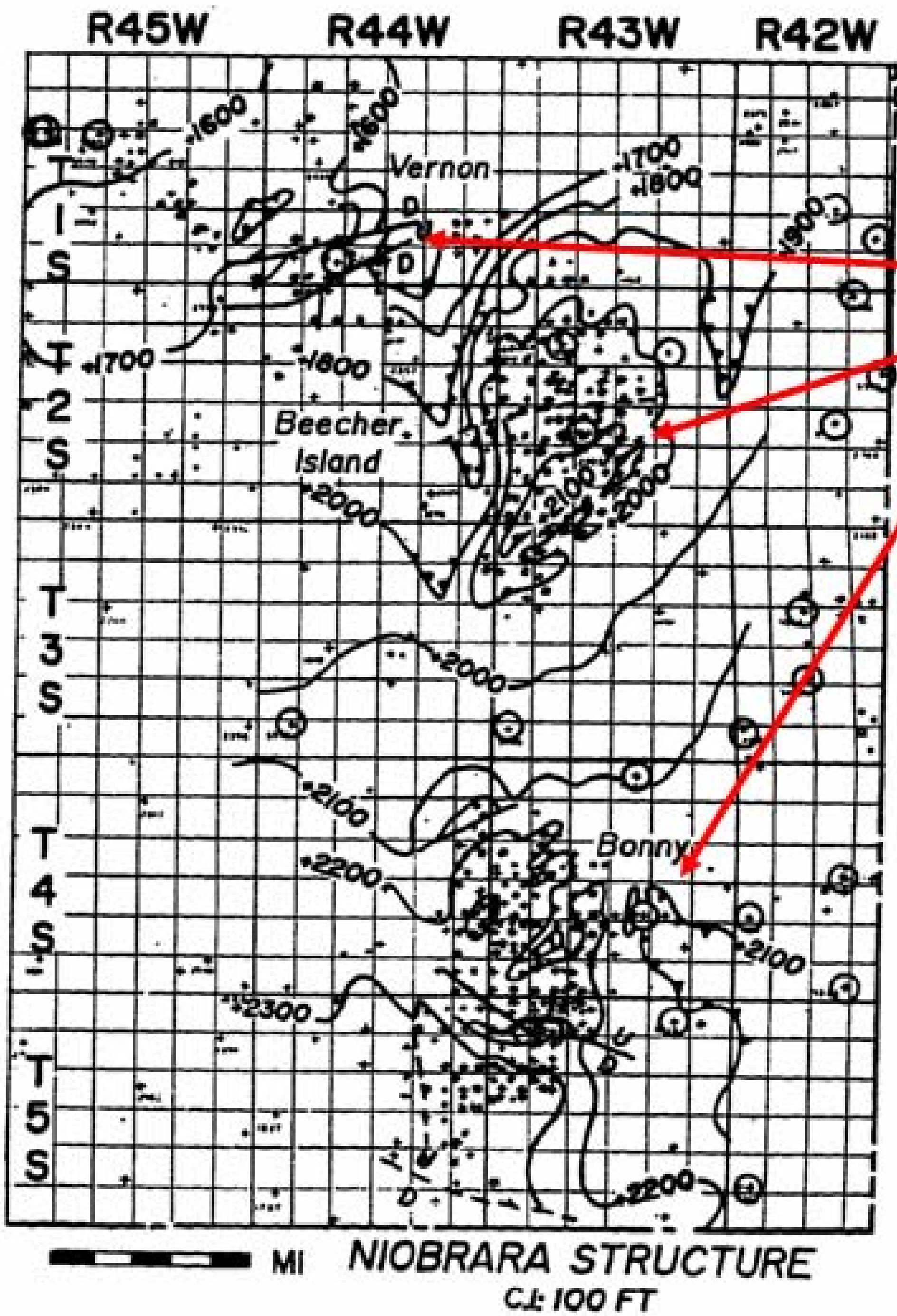


Figure 6-17. Salt 7 isopach. Contour interval 25 ft (8 m).

Isopach of Salt 7
in Permian
Blaine Formation

Niobrara Gas Fields
In northeast Colorado
are located on edges
of thicker salt

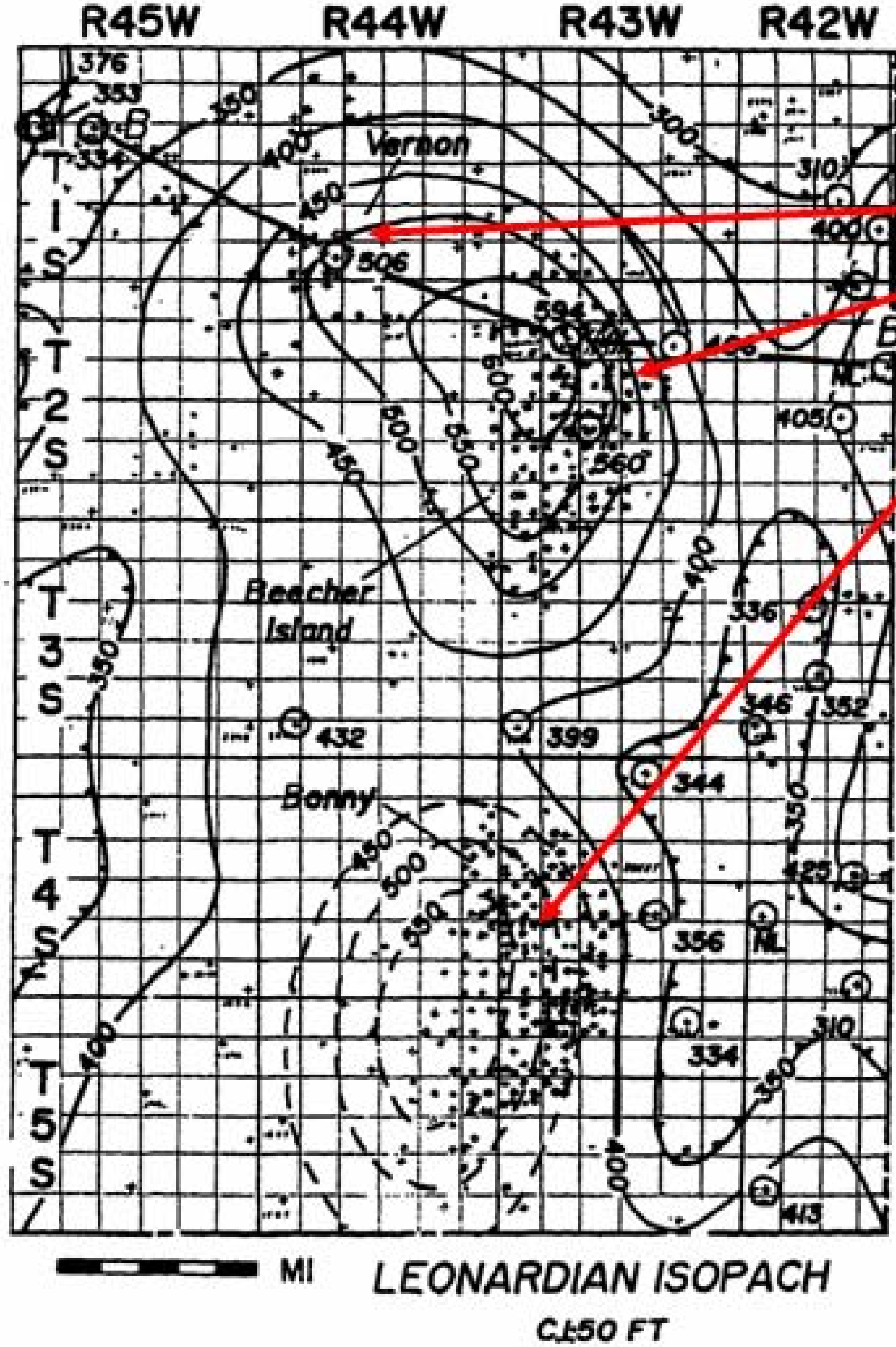
Oldham (1997)



Structure on top of *Beecher Island zone* across Vernon, Beecher Island, and Bonny fields

Related to drape overlying edges of Salt dissolution

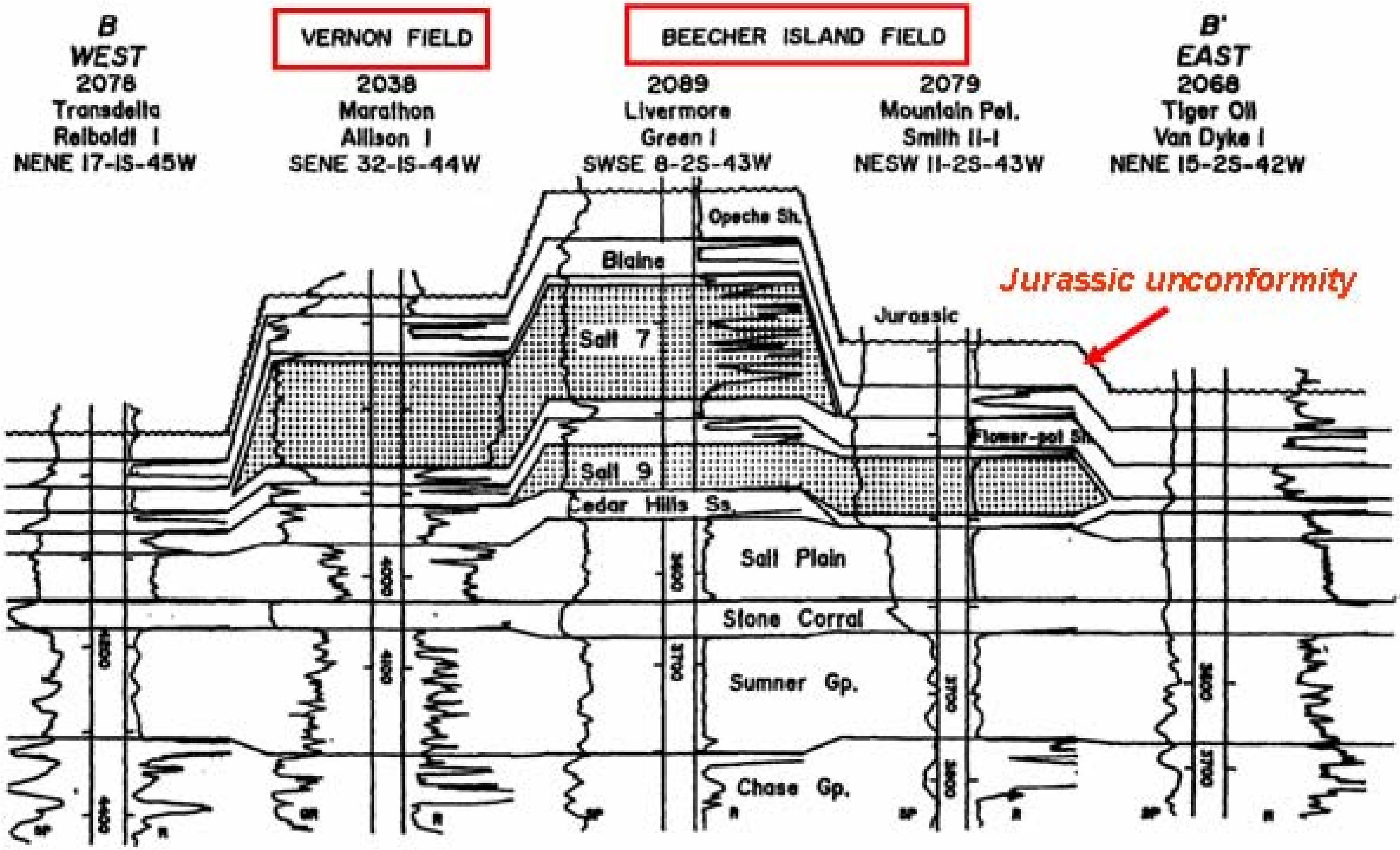
Oldham (1997)



Isopach of *Leonardian Series* below
Vernon,
Beecher Island, and
Bonny fields

Oldham (1997)

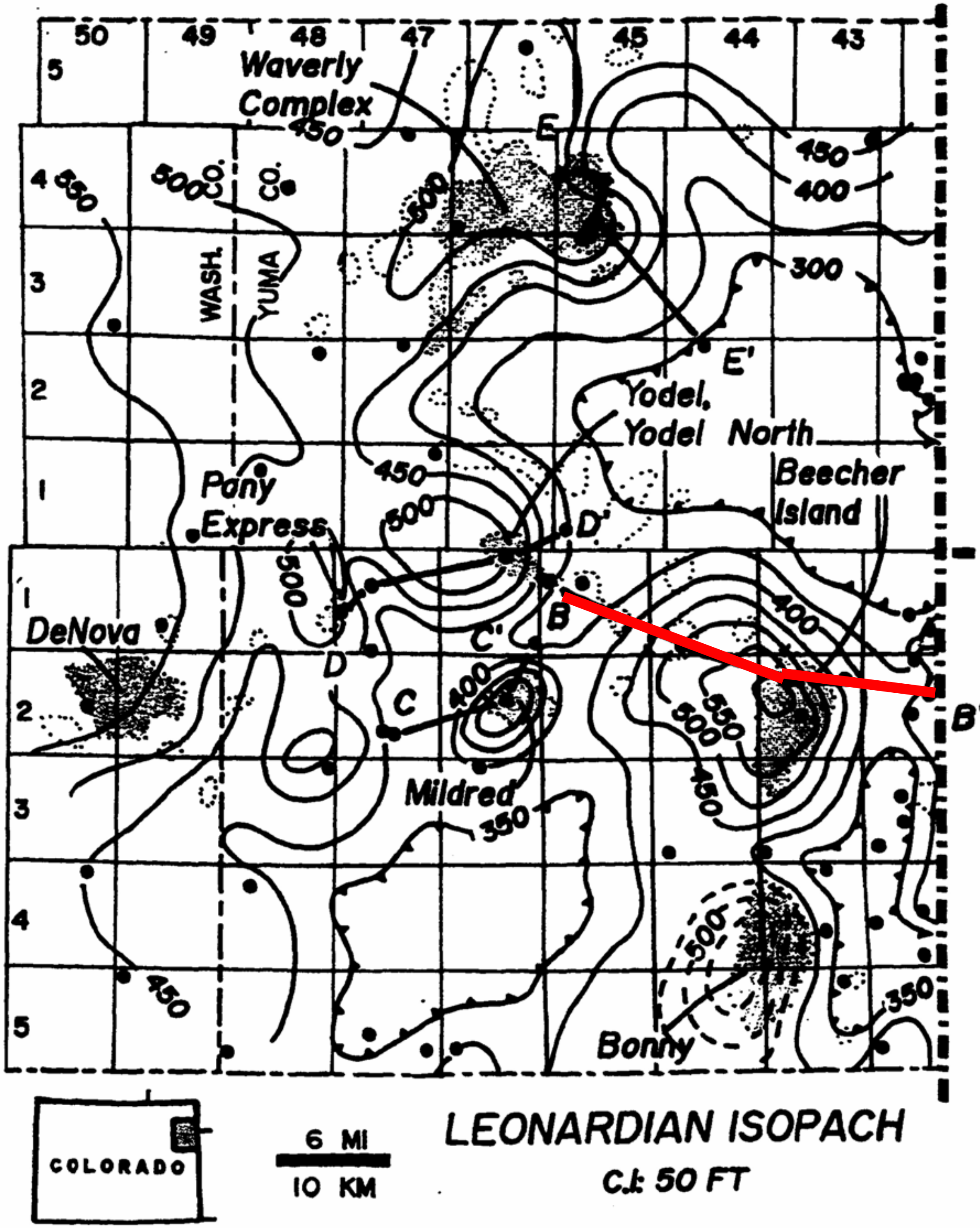
Stratigraphic Cross Section Through Permian Salt Interval Below Vernon And Beecher Island fields



Datum = Top Stone Corral
Cross section Index map, next slide

Oldham (1997)

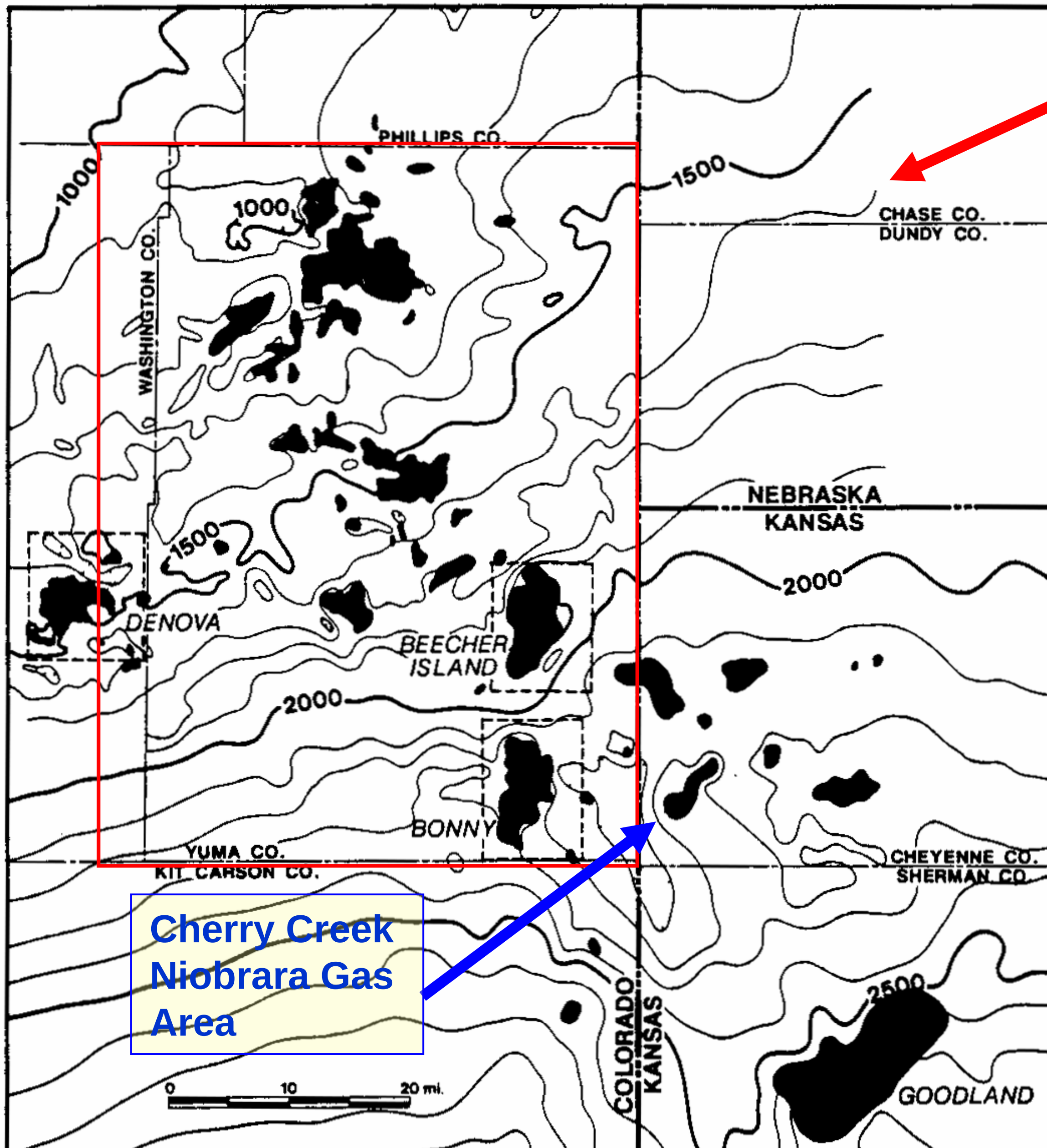
Isopach of the Leonardian Series

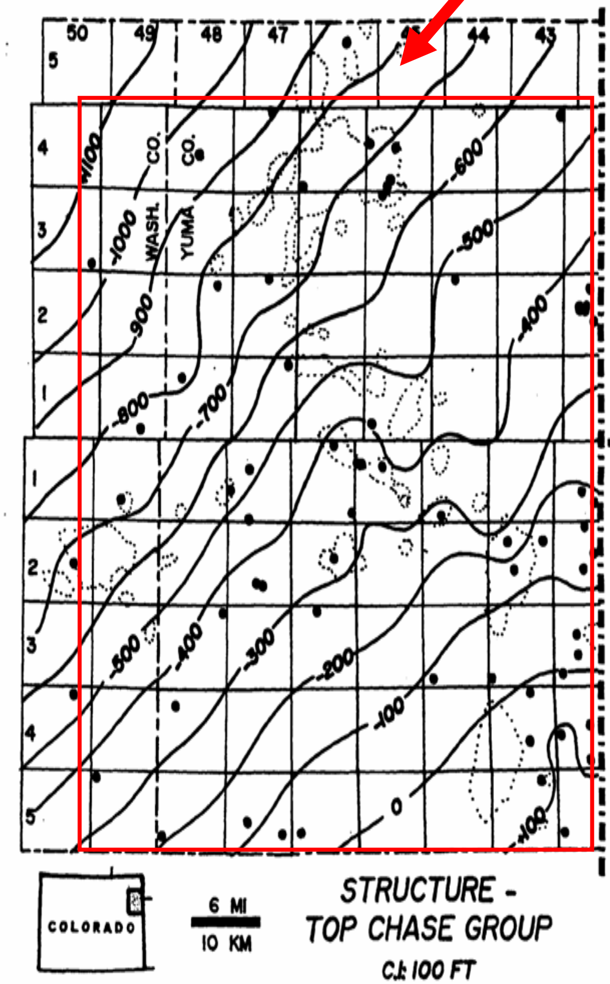


- Thicks corresponding with location of Niobrara gas fields C.I. = 50 ft.
- Cross Section index line B-B'

Oldham (1997)

Structure map at top of Niobrara Chalk Compared to top of Chase

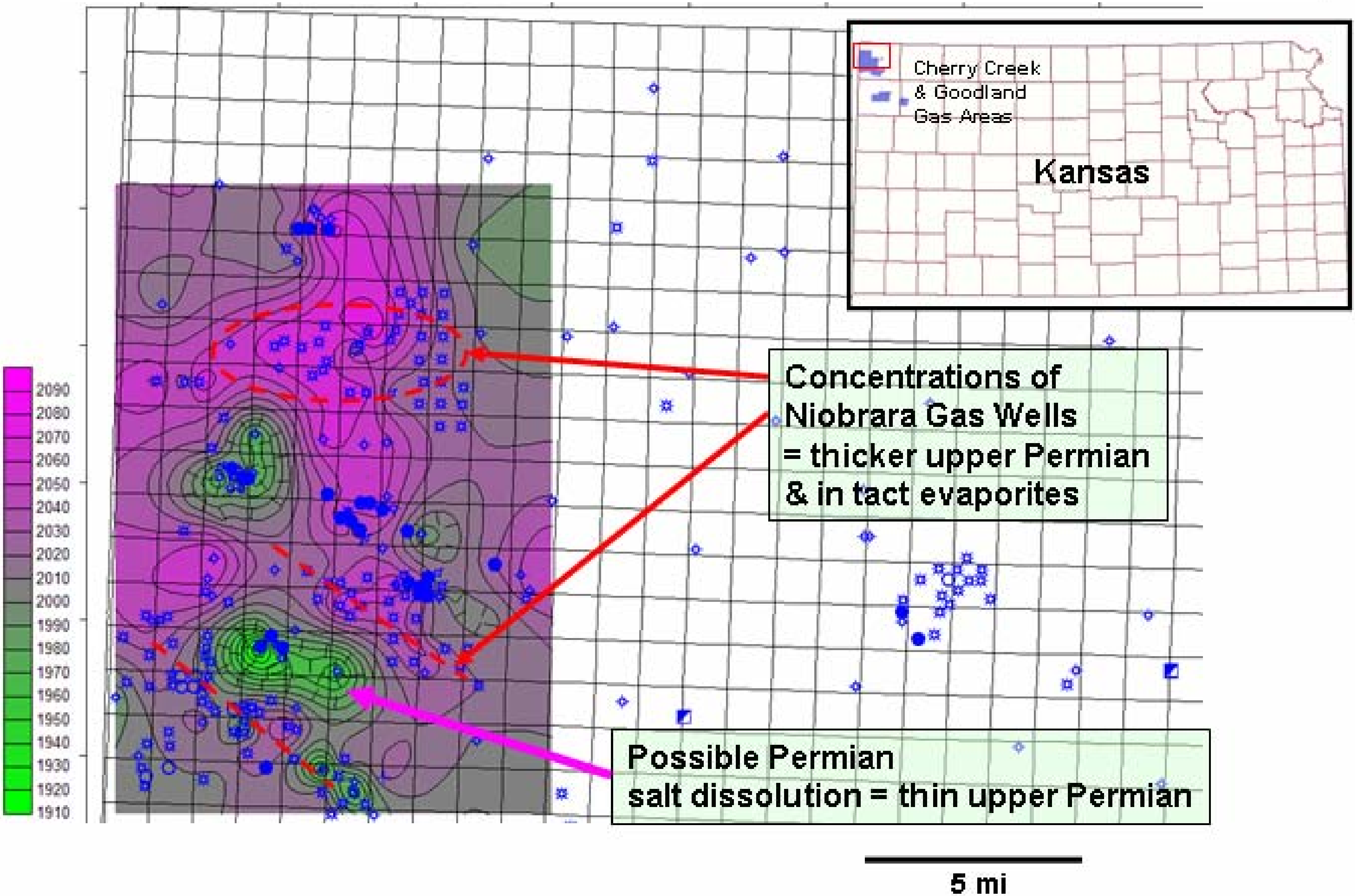




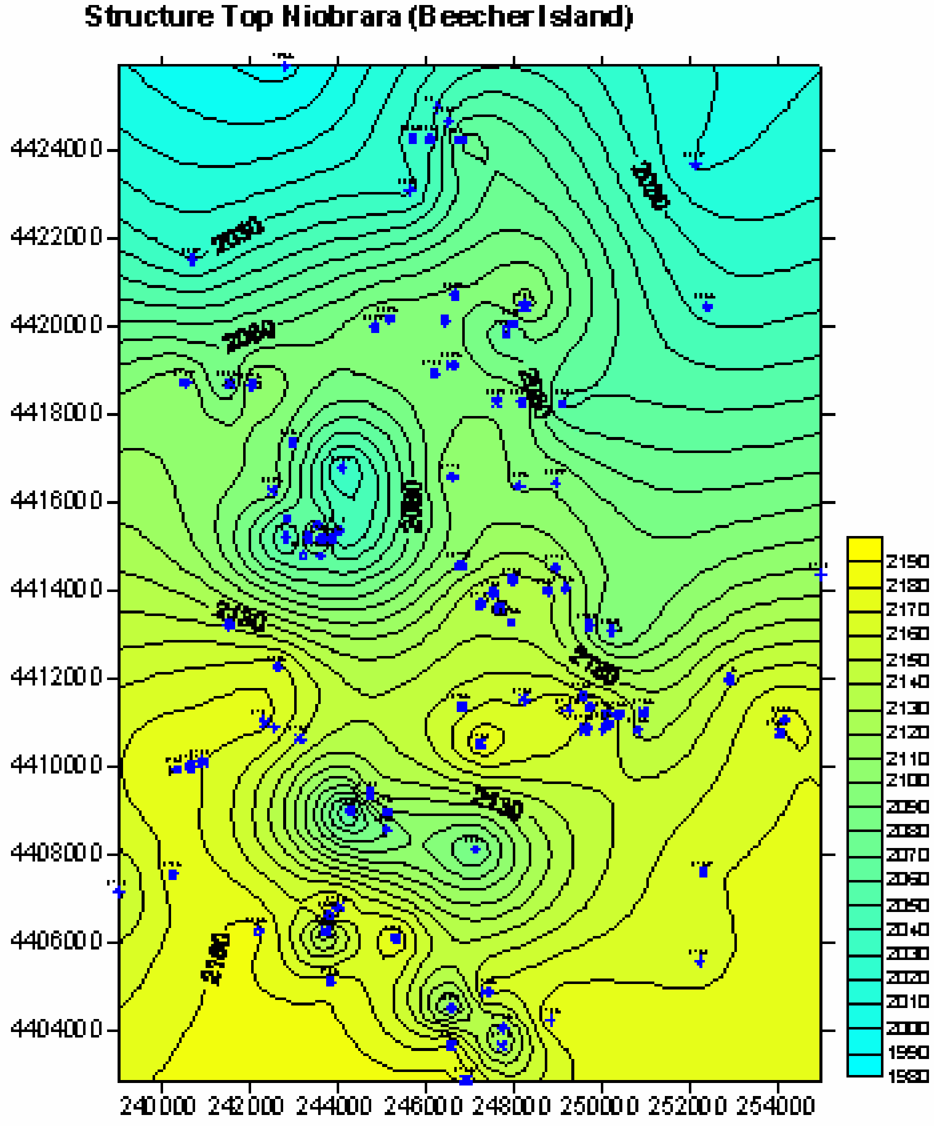
Contour Interval = 100 ft (same for both maps)

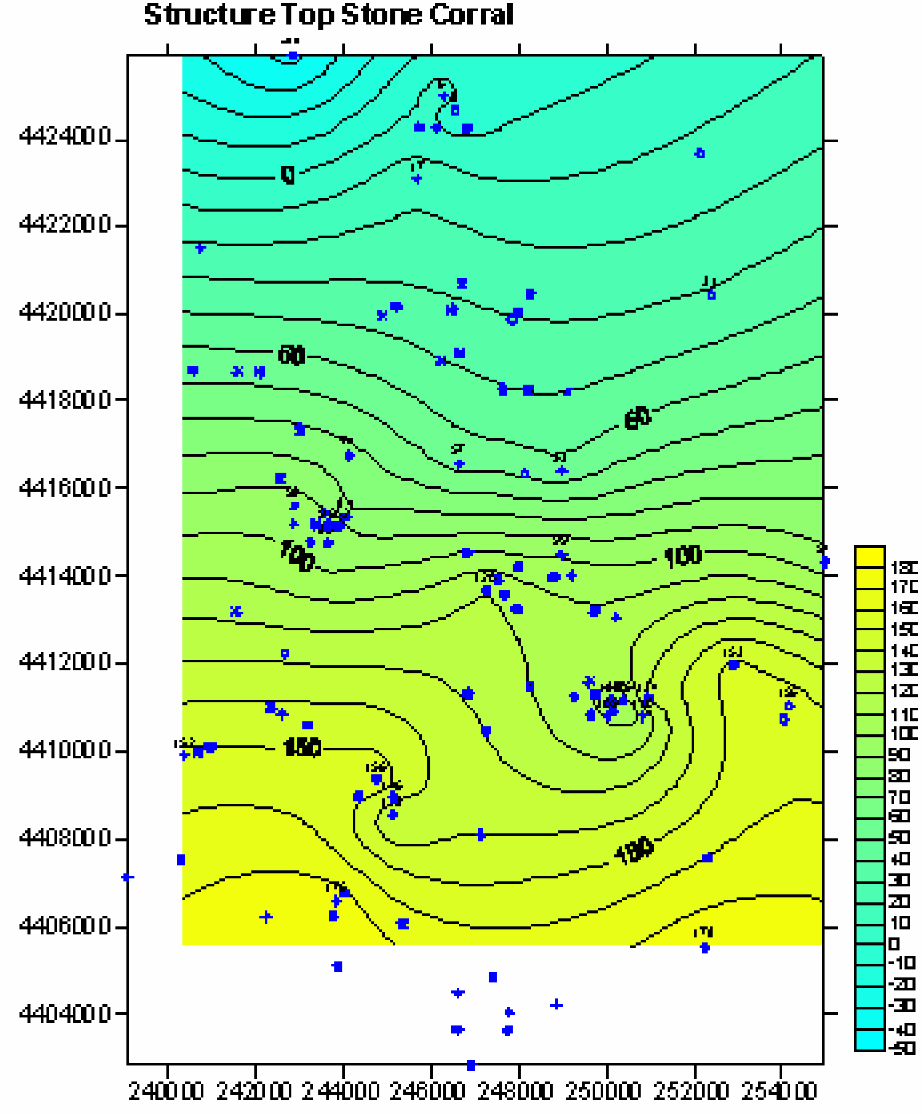
Lockridge and Pollastro (1988)

Top Beecher Island to Leonardian-age Stone Corral Fm.
in western *Cherry Creek Niobrara Gas Area*, northwest Cheyenne County, Kansas



Maps used to make Top Beecher Island to Top Stone Corral Isopach

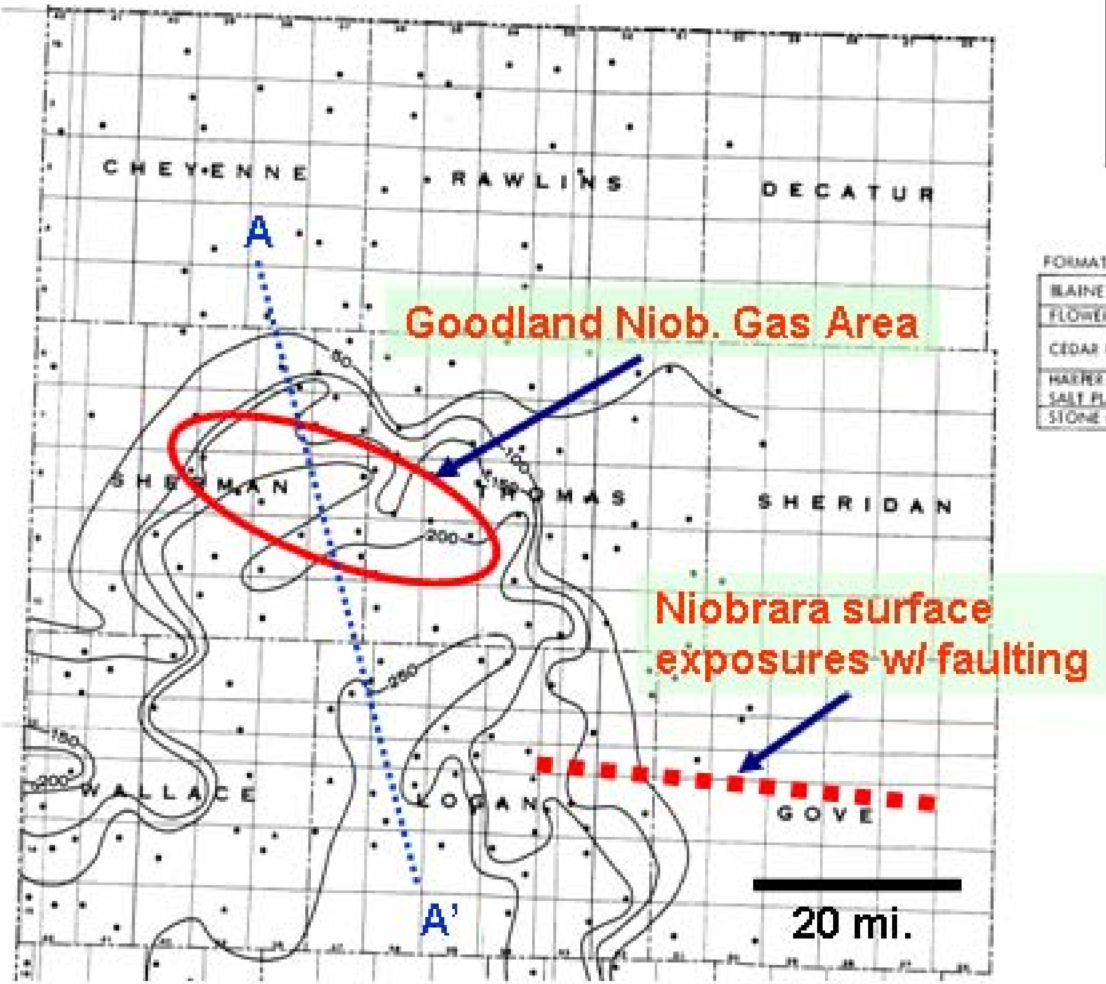


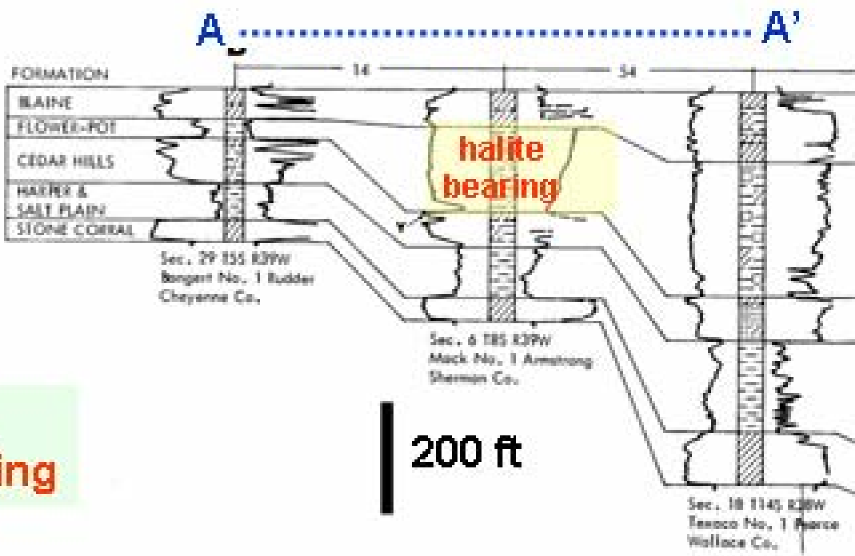


2 miles

Contour interval = 10 ft.

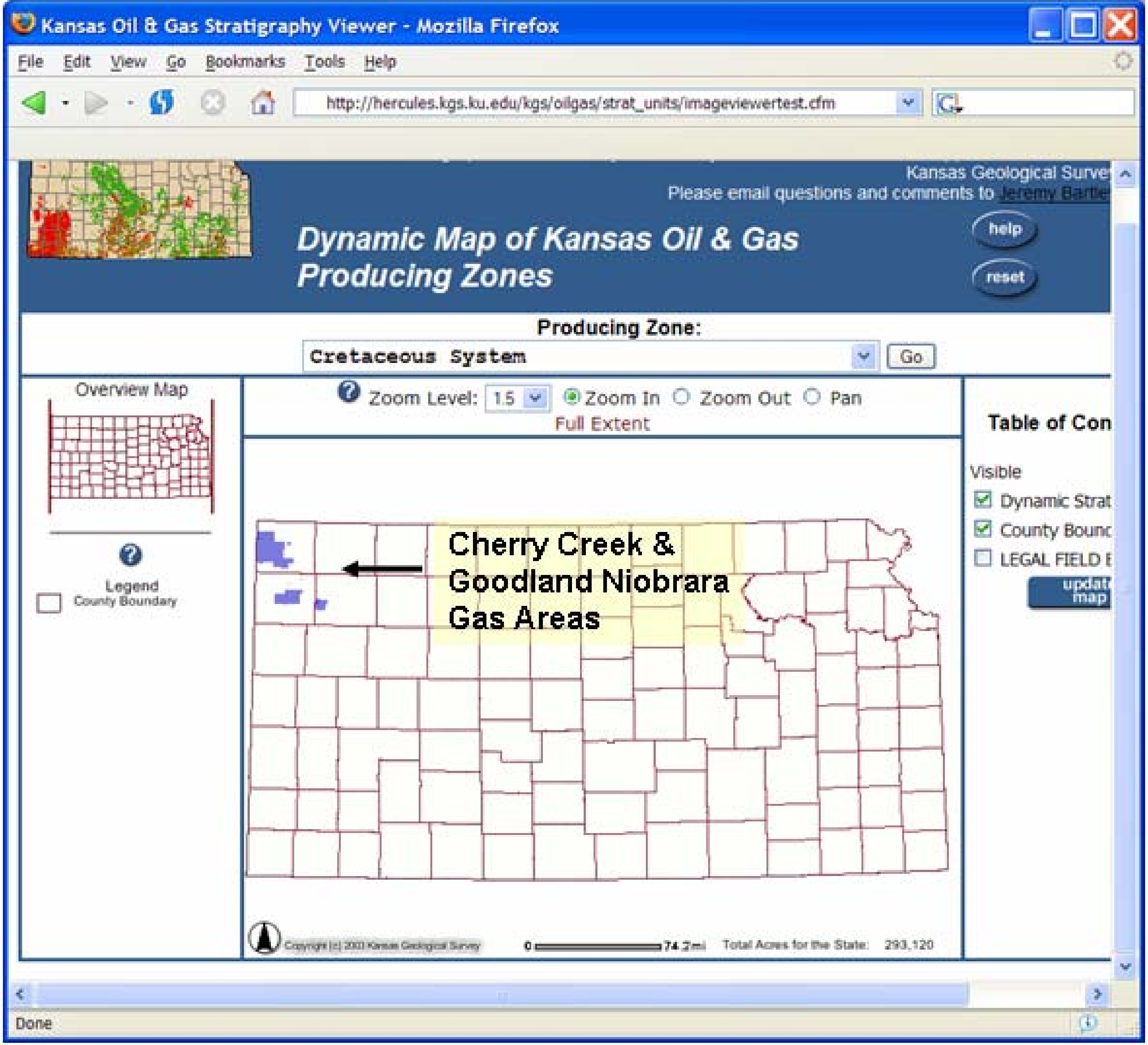
Isopach of Halite-Bearing Flower-Pot Shale below Blaine Formation In Northwest Kansas





Halite = Bed #7 of Oldham (1998)
Cedar Hills Ss. = Lyons Ss.

after Holdaway (1978)


Kansas Oil & Gas Stratigraphy Viewer - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://hercules.kgs.ku.edu/kgs/oilgas/strat_units/imageviewertest.cfm
Kansas Geological Surve
Please email questions and comments to Jeremy Bartle
Dynamic Map of Kansas Oil & Gas Producing Zones
help
reset
Producing Zone:
Cretaceous System
Go
Overview Map
Zoom Level: 1.5
Zoom In
Zoom Out
Pan
Full Extent
Table of Con
Visible
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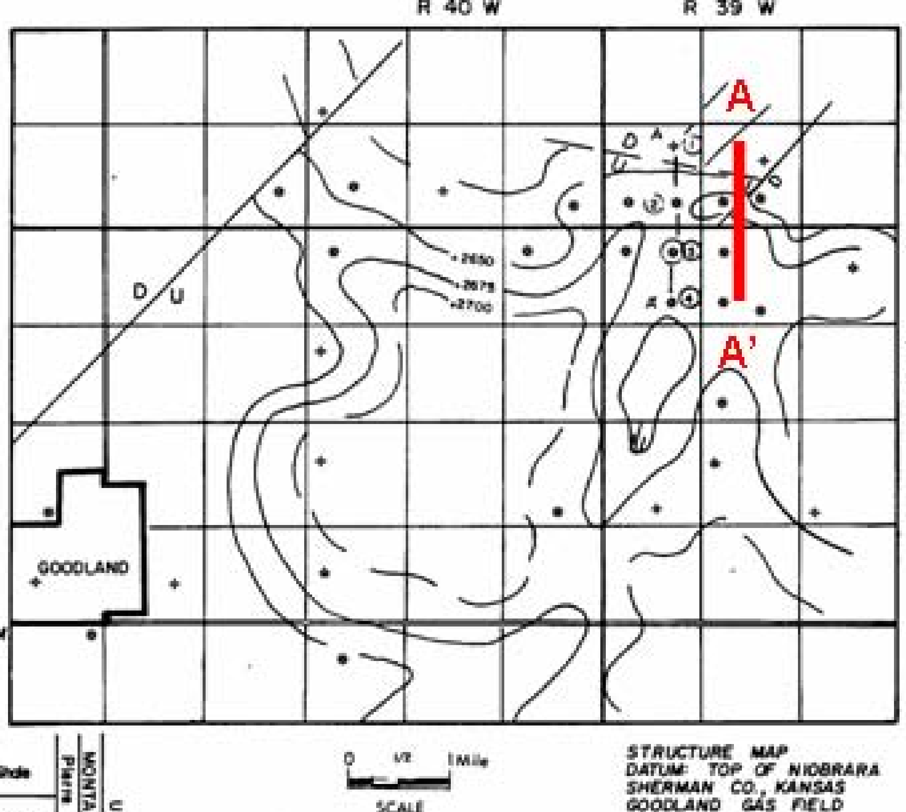
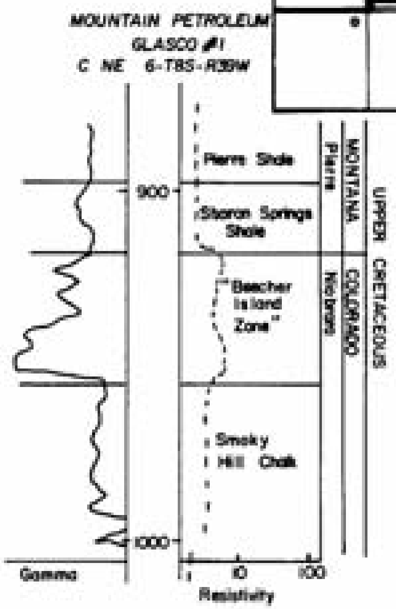
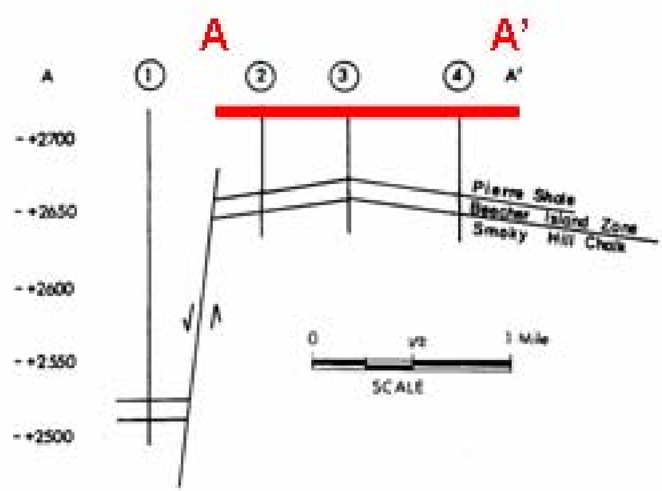
County Bounc
LEGAL FIELD
update map
Legend
County Boundary
Cherry Creek & Goodland Niobrara Gas Areas
0
74.2mi
Total Acres for the State: 293,120
Done







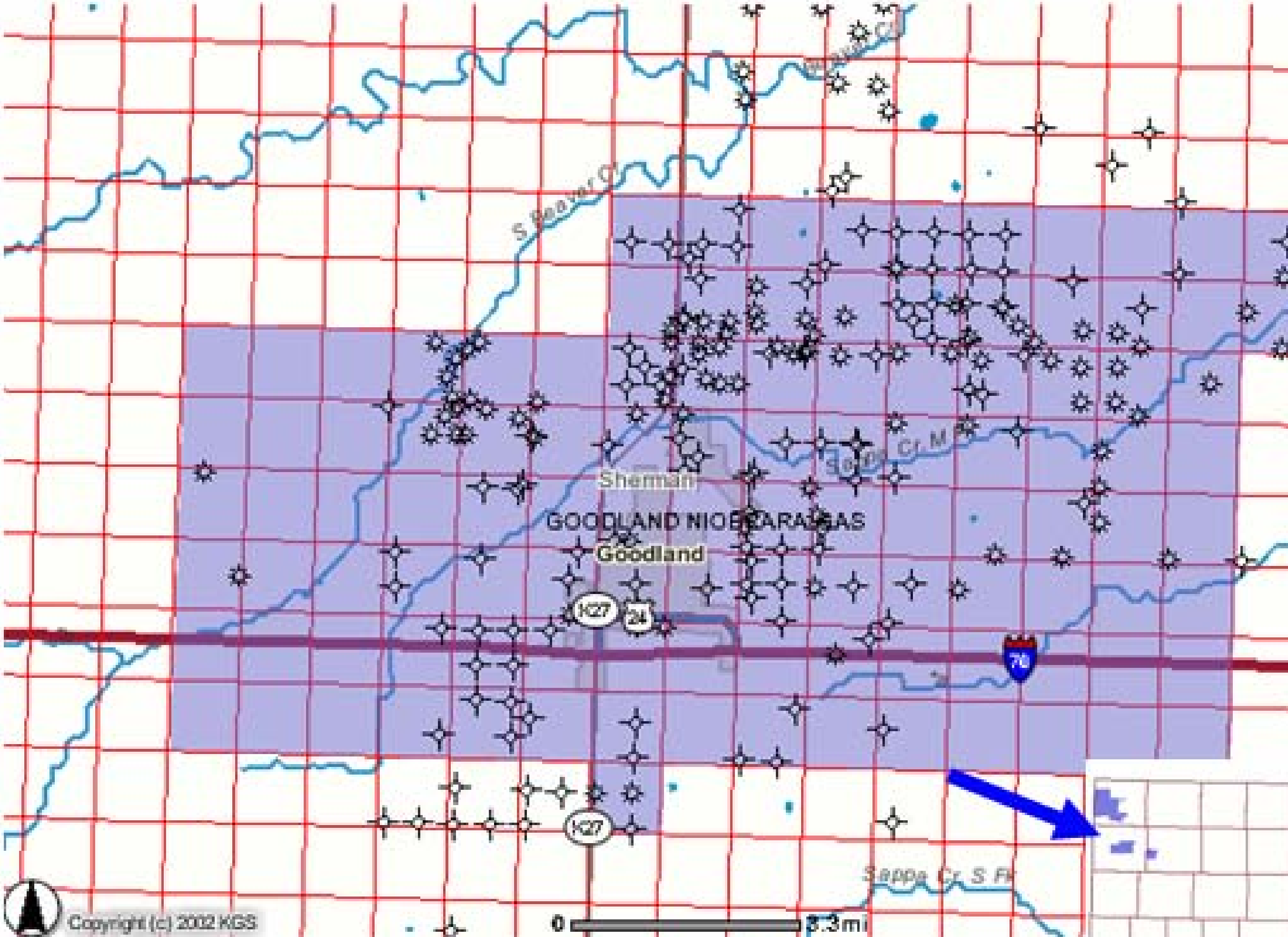
Early Development Of Goodland Niobrara Gas Area in 1982

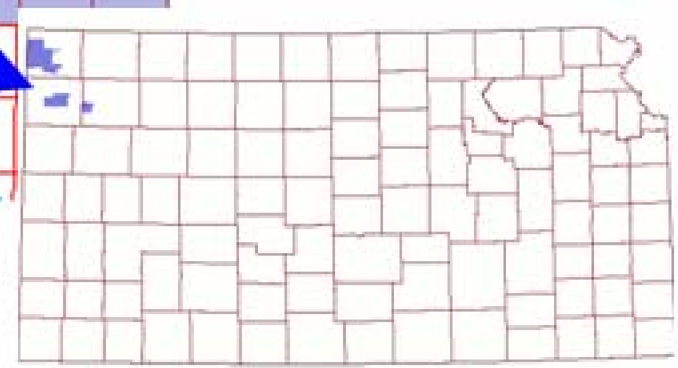
J. Jameson (1982)
1912: Discovery
1930's local use
1977: Mountain Petroleum and Wichita Industries
1978: Benson Minerals Group

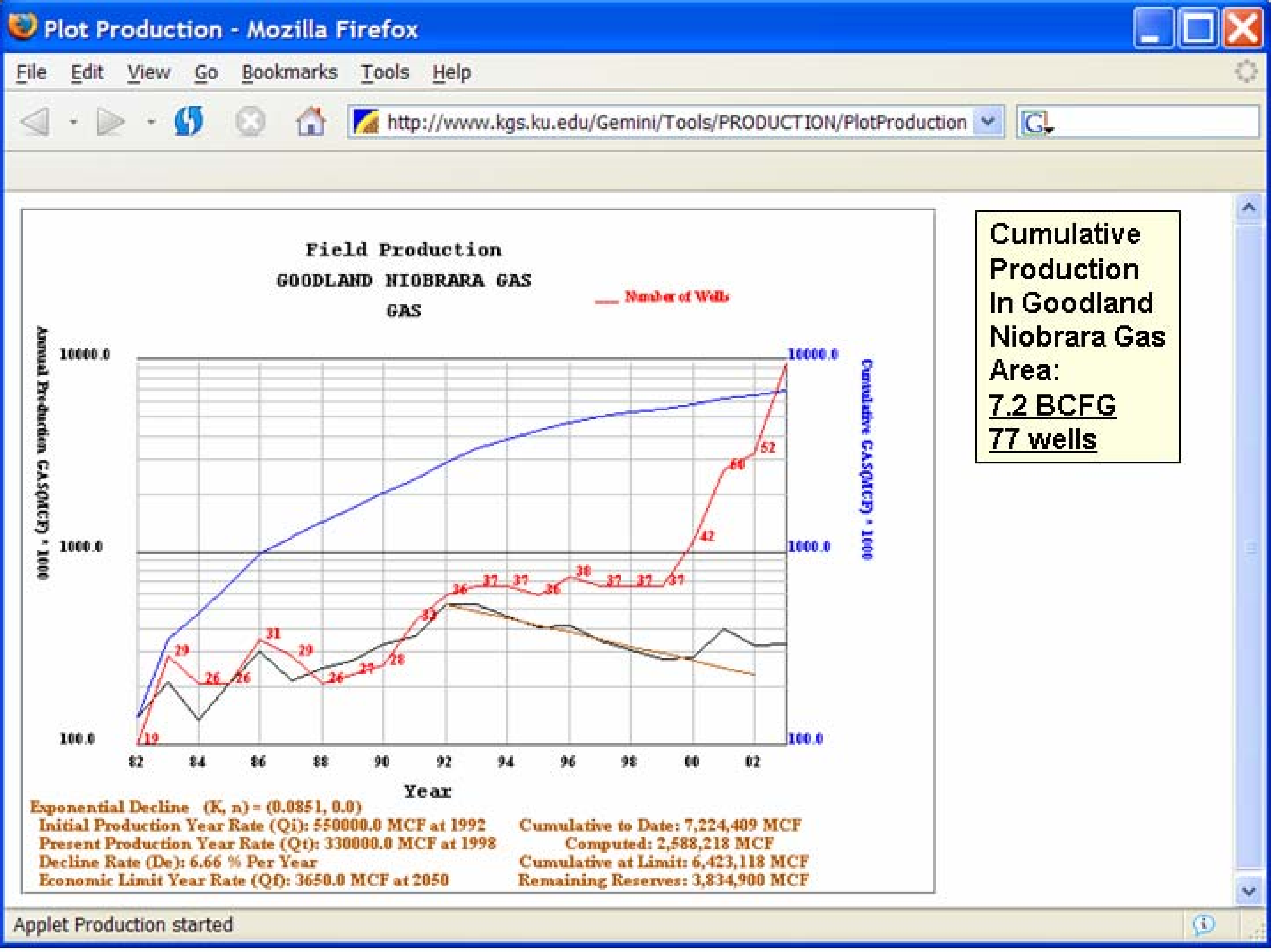
Pressure: 65 psi
Gross Pay: 40 ft;
Net Pay: 30 ft.
Phi: 32-34%, ave. 38.5%
Sw: 20-40%, ave. 30%

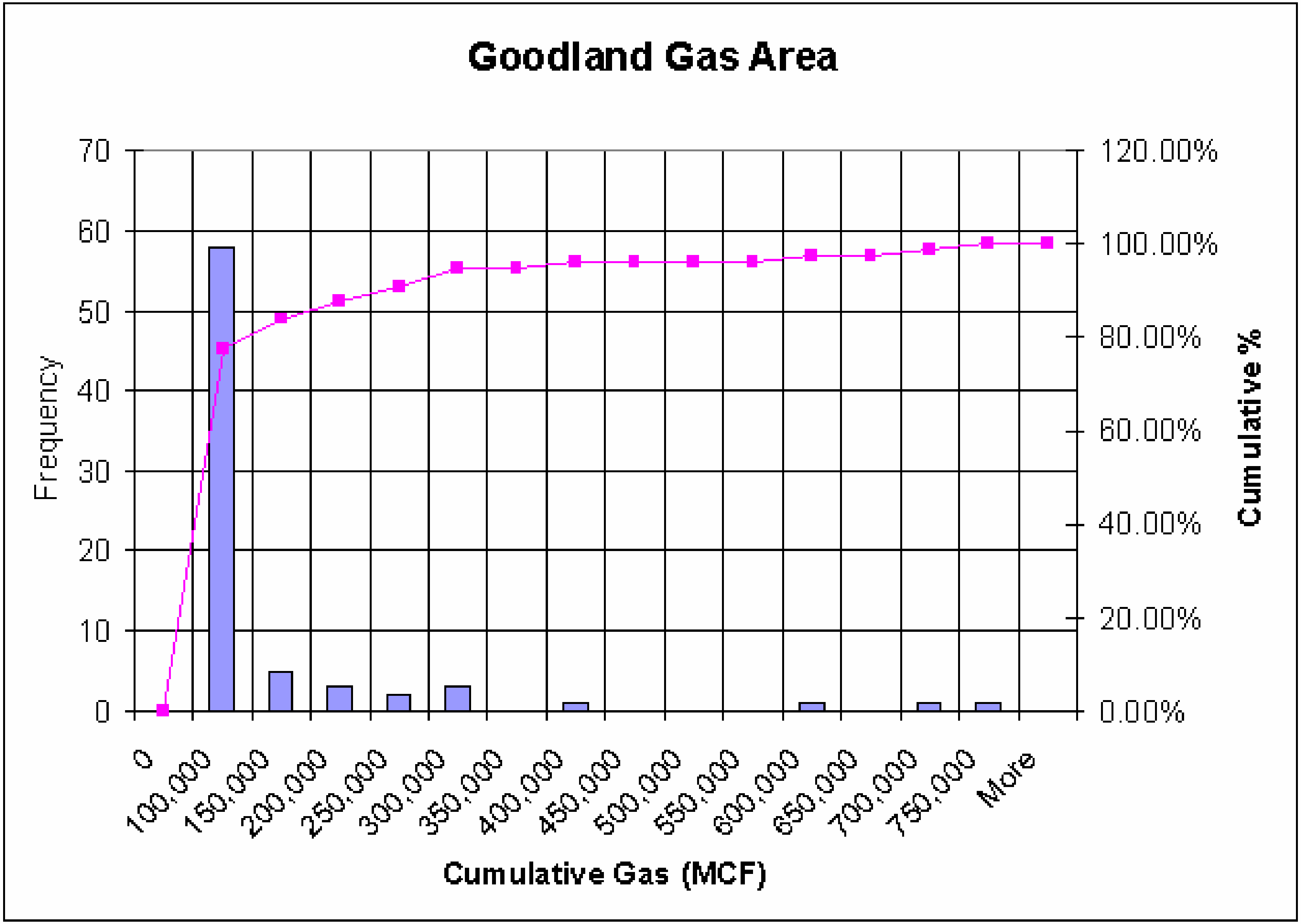
Jameson (1982)

Goodland Niobrara Gas Area



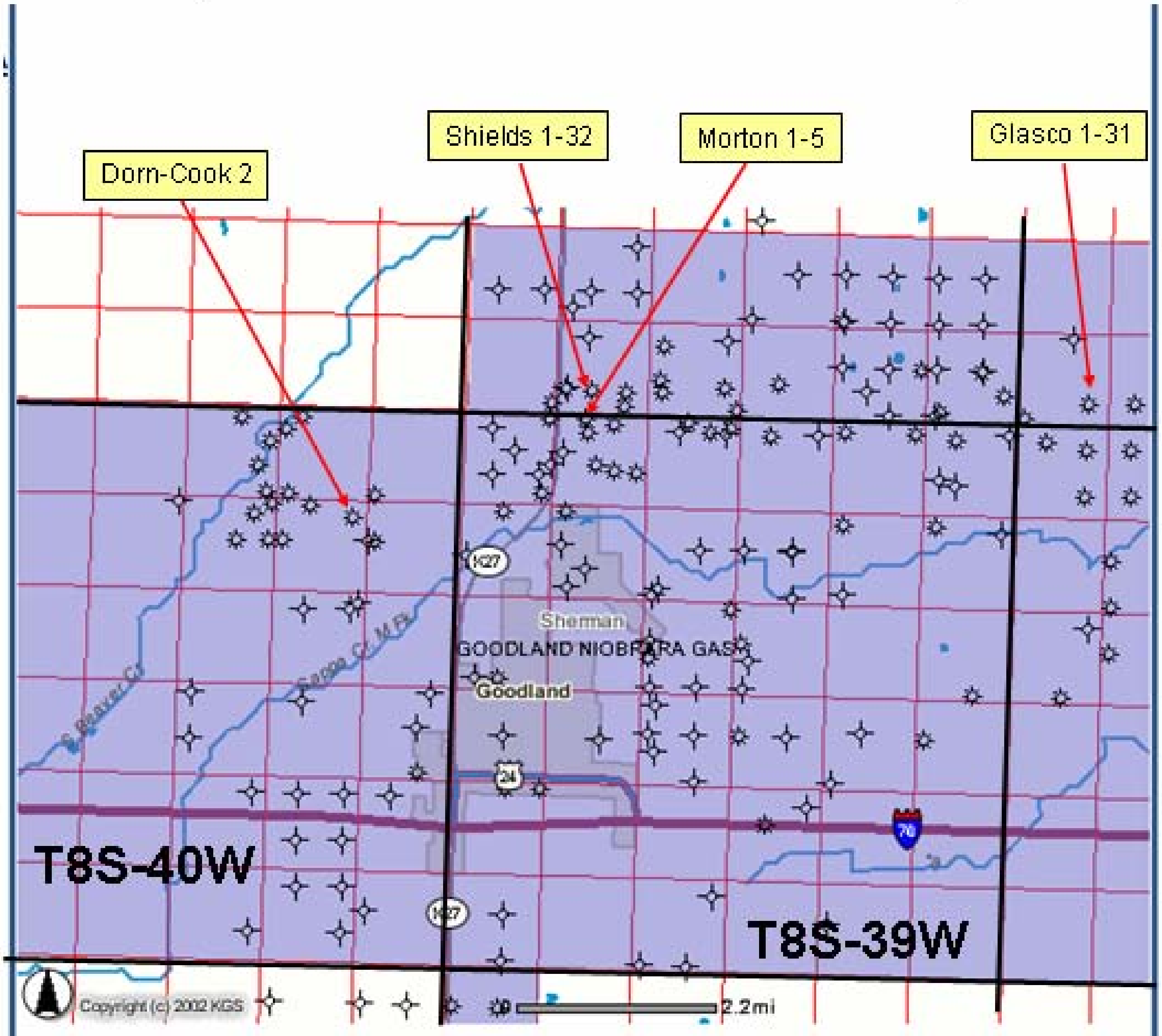



Plot Production - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://www.kgs.ku.edu/Gemini/Tools/PRODUCTION/PlotProduction
Field Production
GOODLAND NIOBRARA GAS
GAS
Number of Wells
Annual Production GAS(MCF) * 1000
Cumulative GAS(MCF) * 1000
10000.0
1000.0
100.0
82 84 86 88 90 92 94 96 98 00 02
Year
Exponential Decline (K, n) = (0.0851, 0.0)
Initial Production Year Rate (Qi): 550000.0 MCF at 1992
Present Production Year Rate (Qt): 330000.0 MCF at 1998
Decline Rate (De): 6.66 % Per Year
Economic Limit Year Rate (Qf): 3650.0 MCF at 2050
Cumulative to Date: 7,224,409 MCF
Computed: 2,588,218 MCF
Cumulative at Limit: 6,423,118 MCF
Remaining Reserves: 3,834,900 MCF
Cumulative Production In Goodland Niobrara Gas Area:
7.2 BCFG
77 wells
Applet Production started

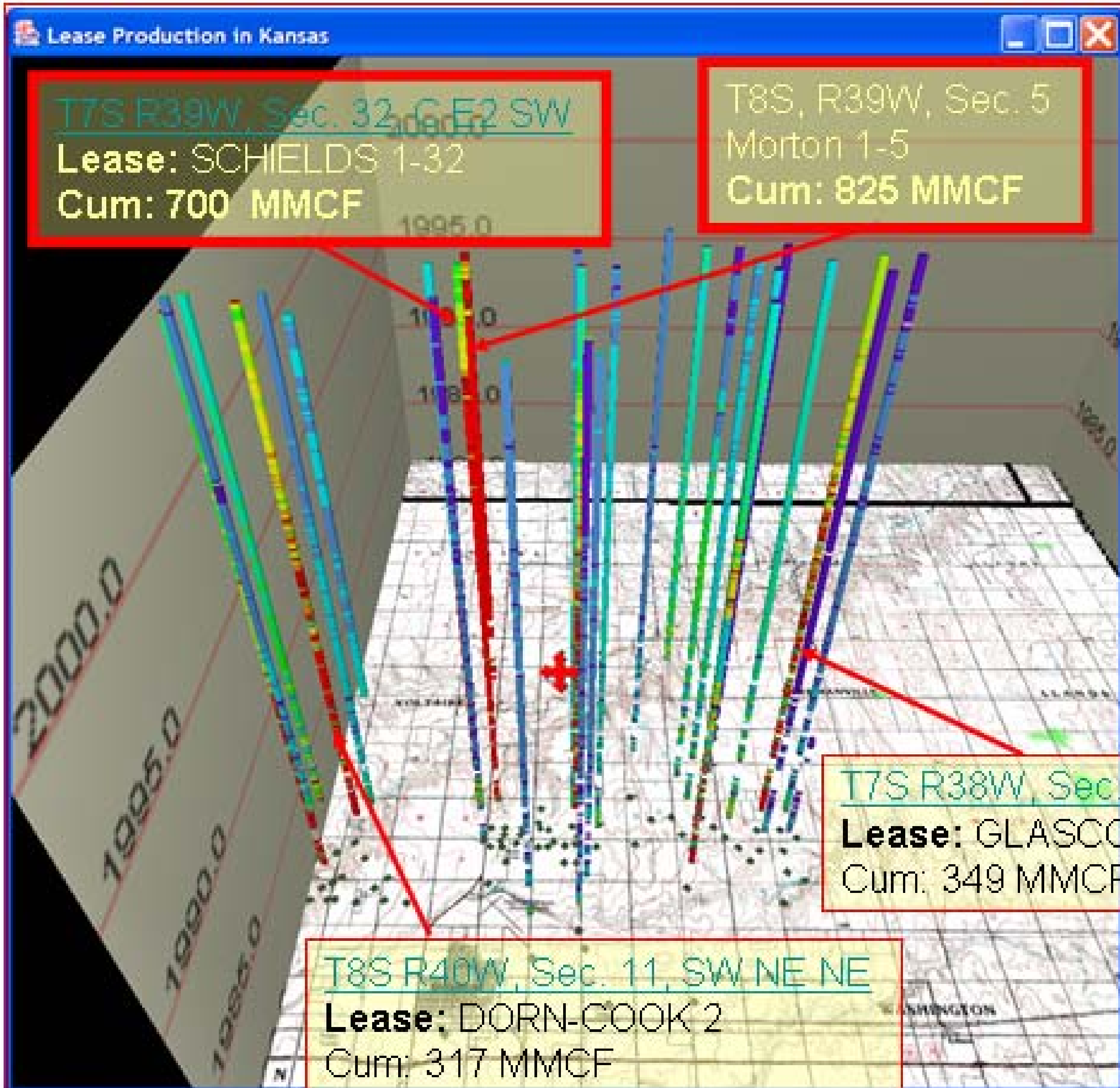


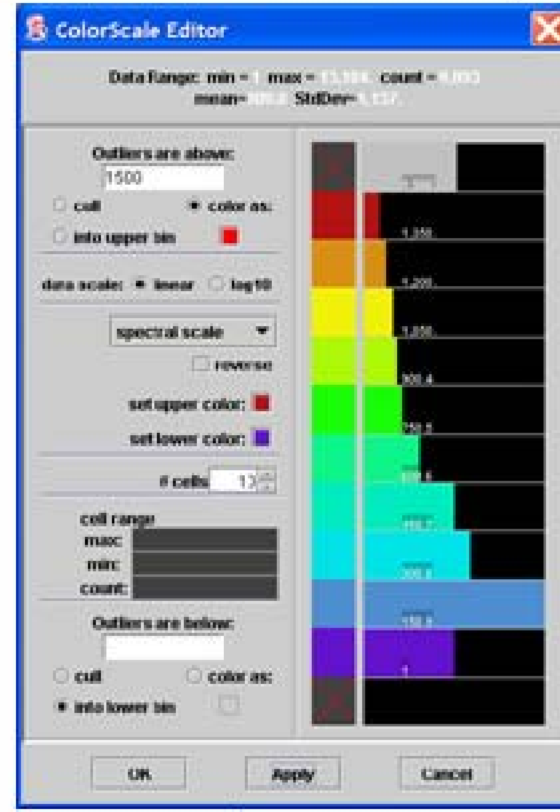
Goodland Gas Area
70
60
50
40
30
20
10
0
Frequency
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
Cumulative %
0
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000
500,000
550,000
600,000
650,000
700,000
750,000
More
Cumulative Gas (MCF)

Goodland Niobrara Gas Area
-- high productivity wells



Time-Space 3-D Model of Monthly Lease Production, North-Central Sherman Co., KS





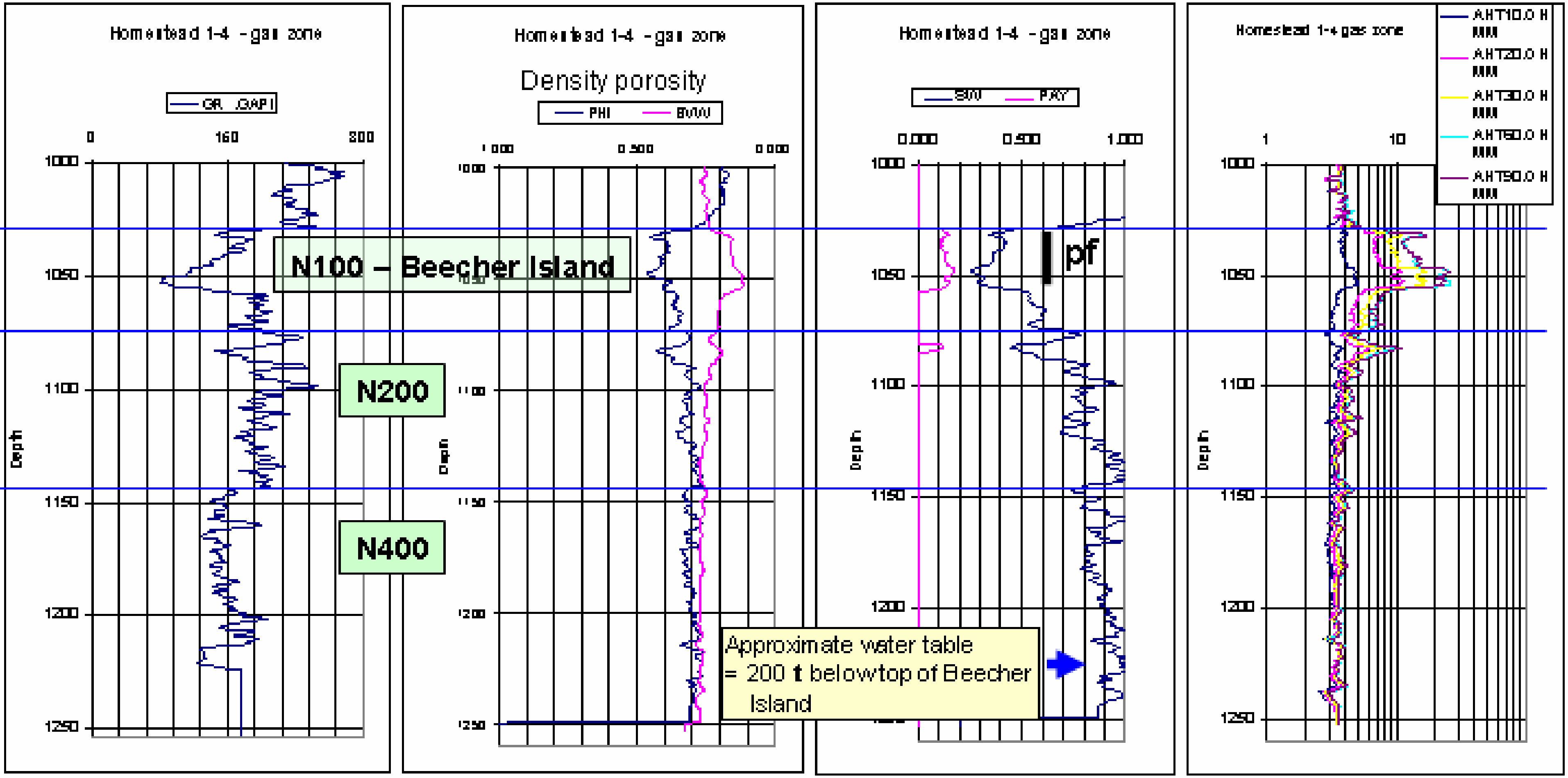
Scale in MCF

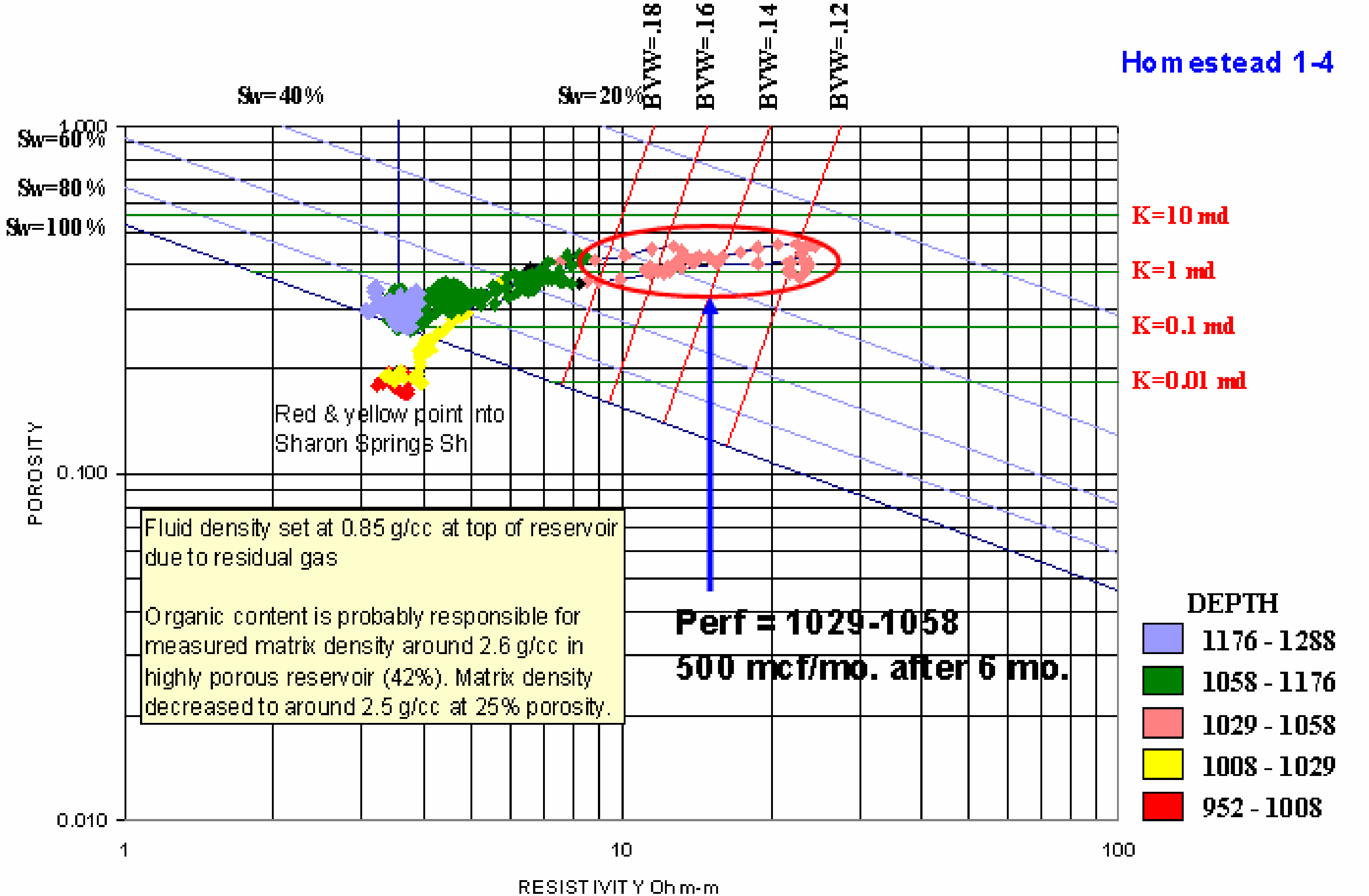
Red = >45 MCF/mo.

Goodland Gas Area
Sherman County, KS

3D Java Prototype, courtesy R. Brownrigg

Productive Beecher Island (N100) and Uppermost N200 Interval In Cored Well from *Goodland Field North*

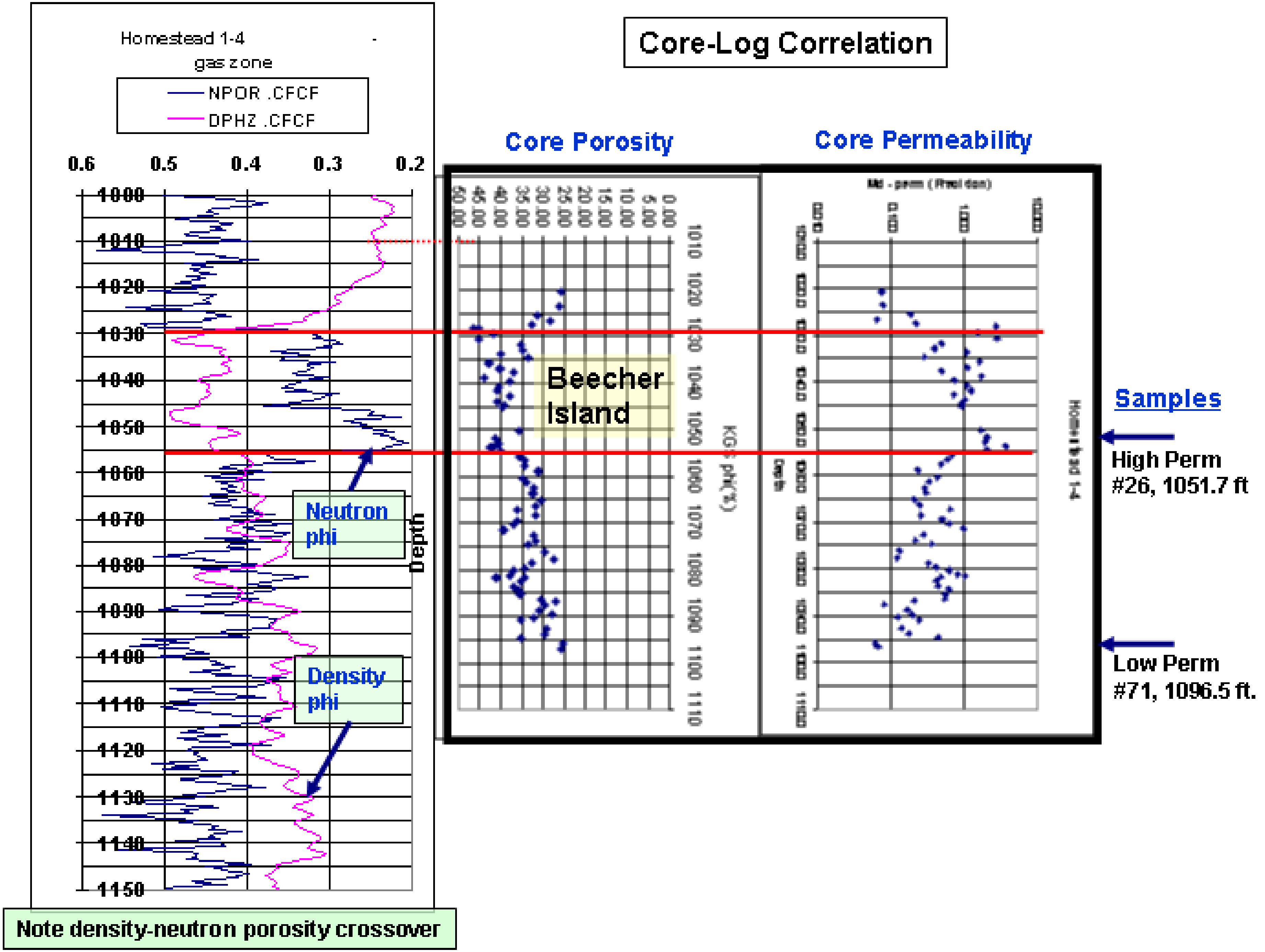




Density porosity

(using matrix density = 2.6, fluid density = 0.85)

Goodland North Field



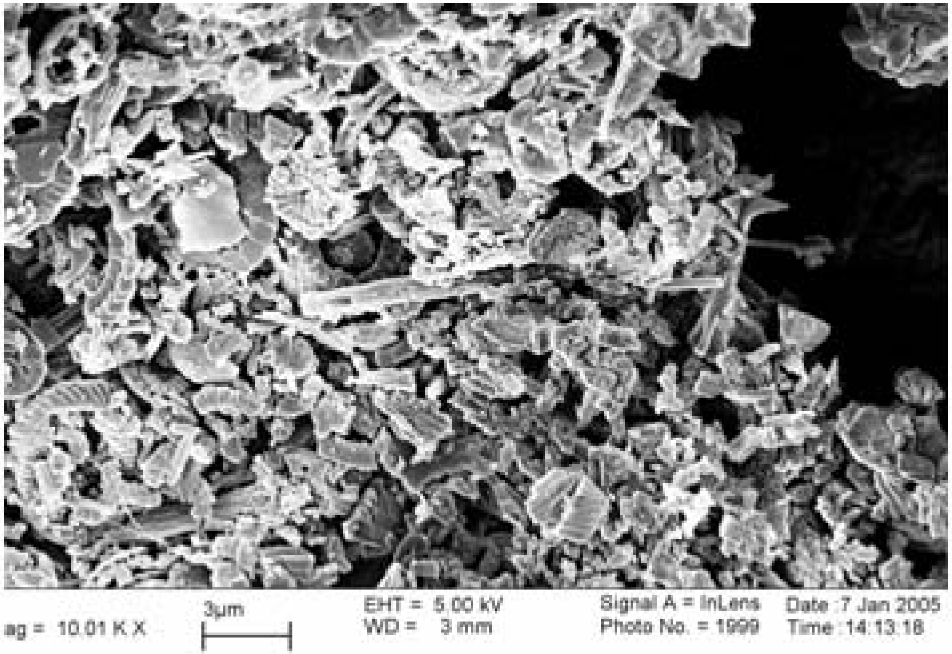
Core-Log Correlation
Homestead 1-4
gas zone
NPOR .CFCF
DPHZ .CFCF
0.6 0.5 0.4 0.3 0.2
1000
1010
1020
1030
1040
1050
1060
1070
1080
1090
1100
1110
1120
1130
1140
1150
Neutron phi
Density phi
Depth
Core Porosity
Core Permeability
Beecher Island
KGS phi(%)
Samples
High Perm
#26, 1051.7 ft
Low Perm
#71, 1096.5 ft.
Note density-neutron porosity crossover

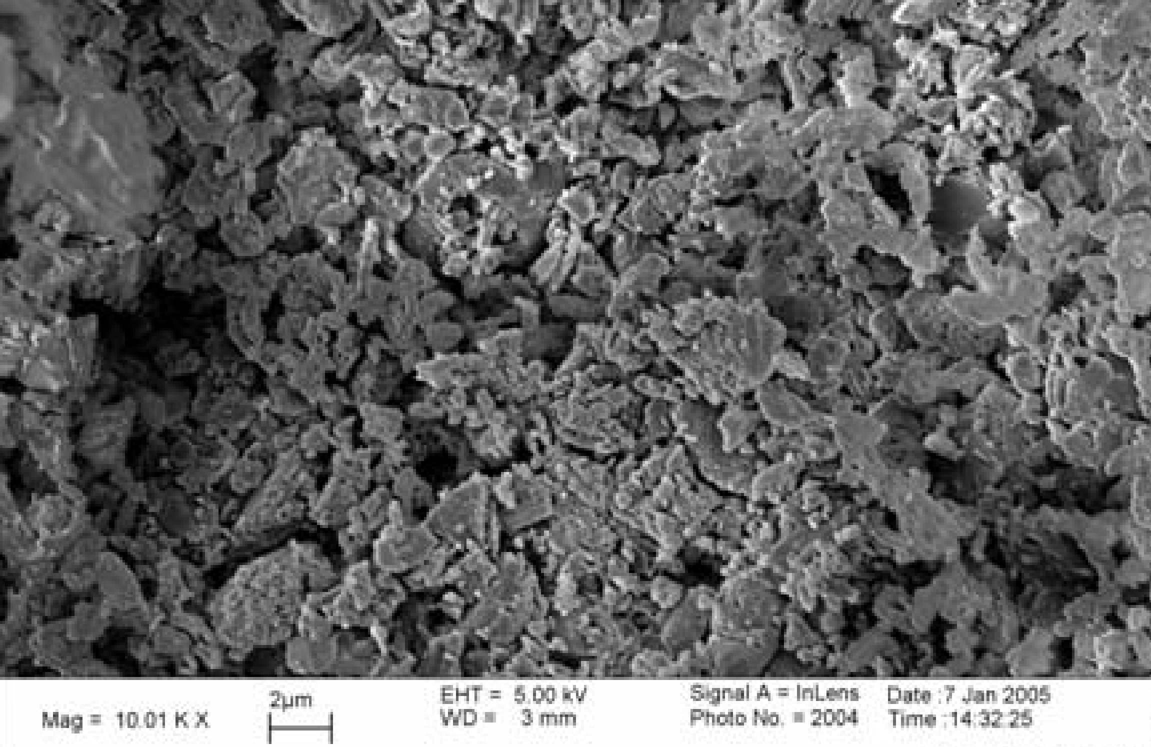
Homestead 1-4
SEM photos

<u>High permeability</u> sample
(#26, 1051.7 ft.)

<u>2 md, 41.1% porosity</u>

<u>*Intact coccoliths*</u>



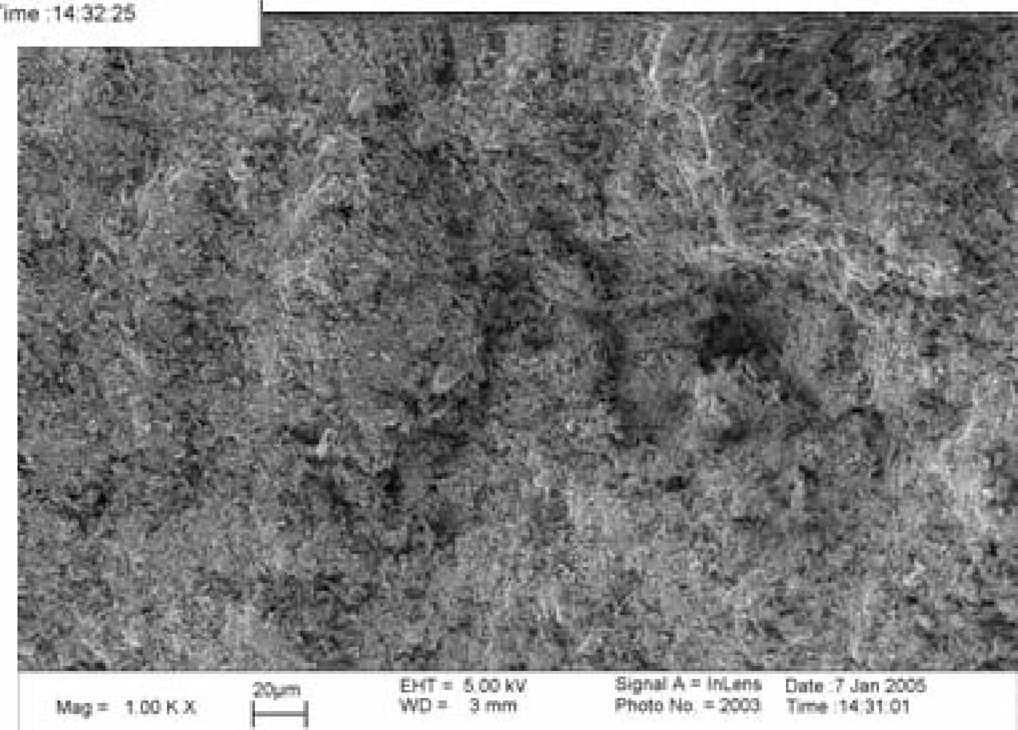


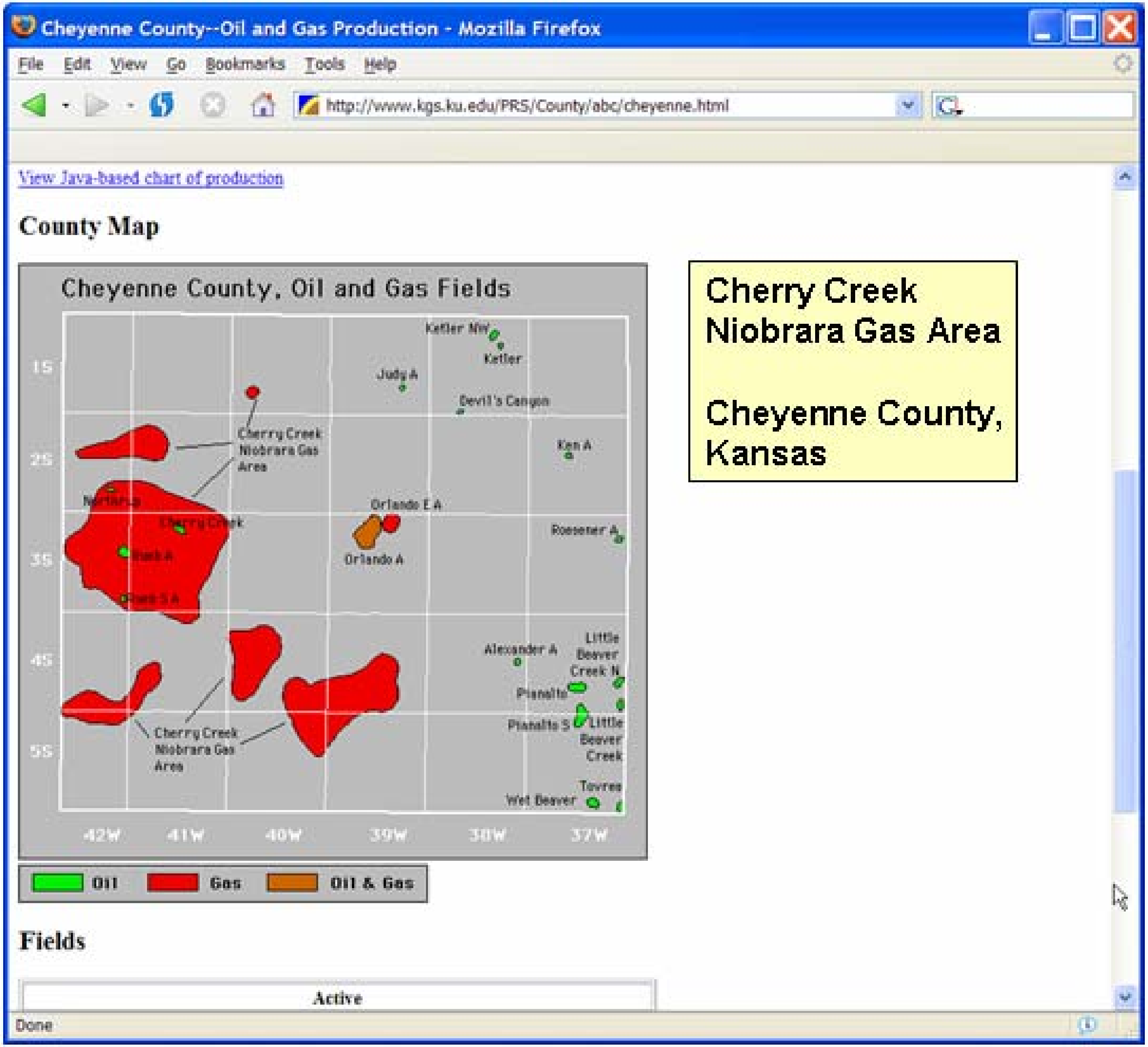
Homestead 1-4
SEM photos

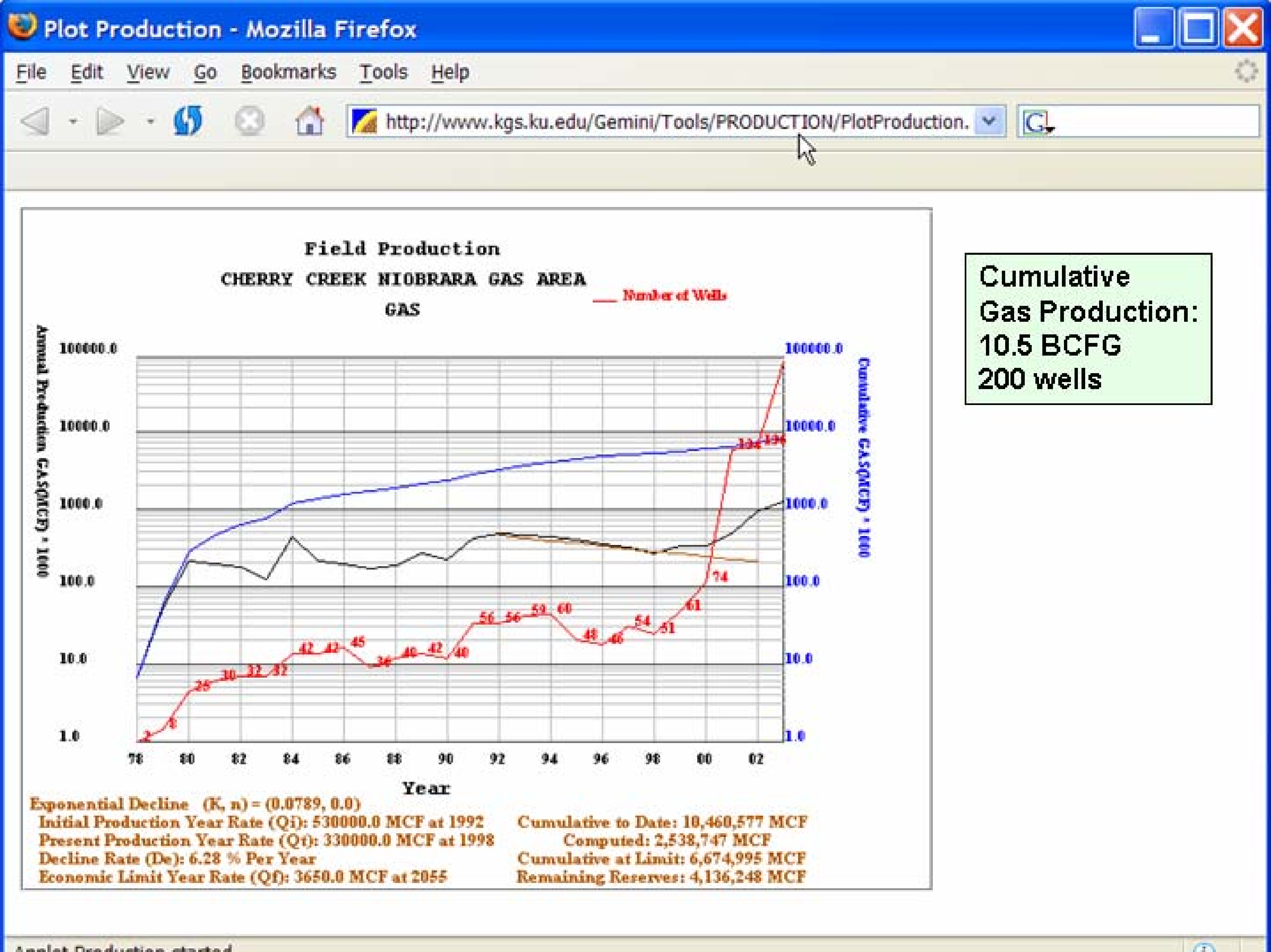
Low permeability sample
#71, 1096.5 ft.

0.69 md, 25.6% porosity

Finer pores among broken shell frags




Cheyenne County--Oil and Gas Production - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://www.kgs.ku.edu/PRS/County/abc/cheyenne.html
View Java-based chart of production
County Map
Cheyenne County, Oil and Gas Fields
Keller NW
Keller
Judy A
Devil's Canyon
Cherry Creek Niobrara Gas Area
Ken A
Orlando E A
Orlando A
Roesener A
Cherry Creek
Alexander A
Little Beaver Creek N
Pianalto
Pianalto S
Little Beaver Creek
Cherry Creek Niobrara Gas Area
Toyres
Wet Beaver
1S
2S
3S
4S
5S
42W
41W
40W
39W
38W
37W
Oil
Gas
Oil & Gas
Cherry Creek Niobrara Gas Area
Cheyenne County, Kansas
Fields
Active
Done


Plot Production - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://www.kgs.ku.edu/Gemini/Tools/PRODUCTION/PlotProduction.
Field Production
CHERRY CREEK NIOBRARA GAS AREA
GAS
Number of Wells
Annual Production GAS(MCF) * 1000
Cumulative GAS(MCF) * 1000
100000.0
10000.0
1000.0
100.0
10.0
1.0
78 80 82 84 86 88 90 92 94 96 98 00 02
Year
2 6 25 30 32 32 42 42 45 34 40 42 40 56 56 59 60 48 46 54 51 61 74
Exponential Decline (K, n) = (0.0789, 0.0)
Initial Production Year Rate (Qi): 530000.0 MCF at 1992
Present Production Year Rate (Qt): 330000.0 MCF at 1998
Decline Rate (De): 6.28 % Per Year
Economic Limit Year Rate (Qf): 3650.0 MCF at 2055
Cumulative to Date: 10,460,577 MCF
Computed: 2,538,747 MCF
Cumulative at Limit: 6,674,995 MCF
Remaining Reserves: 4,136,248 MCF
Cumulative
Gas Production:
10.5 BCFG
200 wells

Summary -- Niobrara Chalk

- High porosity (40-50%) and low permeability (0.1-3 md)
- Permeabilities in excess of 0.5 md at shallow depths
- Biogenic gas from thermally immature, organic-rich chalk beds
- Local accumulations of shallow gas
- Chalk is very brittle
- Faulting documented as horst and graben features associated with underlying dissolution of Permian evaporite beds
- Higher structure and higher gas saturations, typically around 50% and less
- Low reservoir pressures

Summary (continued)

- Chalk is fined grained micrite with nannofossils and coccoliths
- Dominant “grain size” from 0.2 to several micrometer (10^{-6} m)
- Mixed layer expansive, water reactive clays dispersed and laminae

Summary (continued)

- Pay commonly defined by induction-neutron-density
  - Rt in pay typically from 3 to 15 ohm-m
  - higher neutron porosity and low density porosity reflecting presence of natural gas
  - Low matrix density
- Fracture stimulation necessary to make gas production from wells economically feasible
- Cumulative well production in NW Kansas average between 100 to 150 MMCF