Insights into Niobrara Stratigraphic Architecture and Diagenesis, Wattenberg Field, Denver Basin, Colorado*

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Abstract

The Niobrara Formation consists of deep-water chalks and marl units in the Denver Basin. Chalk units are generally considered the reservoir rock while the marls contain higher total organic carbon (TOC) contents and are considered the source beds. Chalk and marl units consist of microscopic coccoliths, forams (dominantly pelagic), inoceramus and oyster fossils, kerogen, clay, silt, and fish bones. Chalks have 70% and above carbonate content, whereas the marls range in carbonate content from 30% to 70%. Kerogen, clays and silt comprise the remainder of the mineralogical composition. The Niobrara is subdivided into two members: the Smoky Hill and Fort Hays Limestone. The Smoky Hill is informally divided into A, B, and C intervals in descending order. The chalks are separated by marl intervals. Dramatic thickness changes occur in the chalk and marl units in Wattenberg Field. Thickness variations result from subaqueous erosion over topographic highs, onlap and downlap of various units indicating bottom current activity and topography, convergence of section (i.e. higher rates of sedimentation in one area compared to an adjacent area), possible chalk-pellet bar formation, and compensatory deposition. Many of these causes of thickness variations can be related to intrabasin basement structural movement or differential sedimentation.

The most significant erosional event removes the A chalk and parts of the A marl over an interpreted west-east paleostructure (the Wattenberg High). Differential sedimentation patterns may arise from bottom current activity either filling in topographic low areas or creating subaqueous bar-like features. Niobrara porosity is reduced dramatically by burial diagenesis. Progressive mechanical and chemical compaction and associated cementation reduce porosities within the Niobrara chalks and marls. Mechanical compaction consists of grain reorientation and breakage. Compaction is recognized by flattened fecal pellets and collapsed foraminifera tests. Chemical compaction consists of dissolution along microstylolites and grain-to-grain contacts and results in a ‘welded’ fabric. Calcite is reprecipitated as overgrowths on coccolith grains and void-filling crystalline mosaics (chambers of foraminifera, oyster fragments, and fractures).

Selected References

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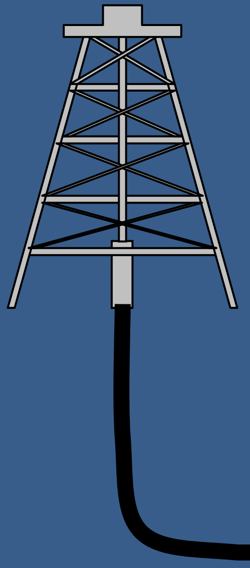
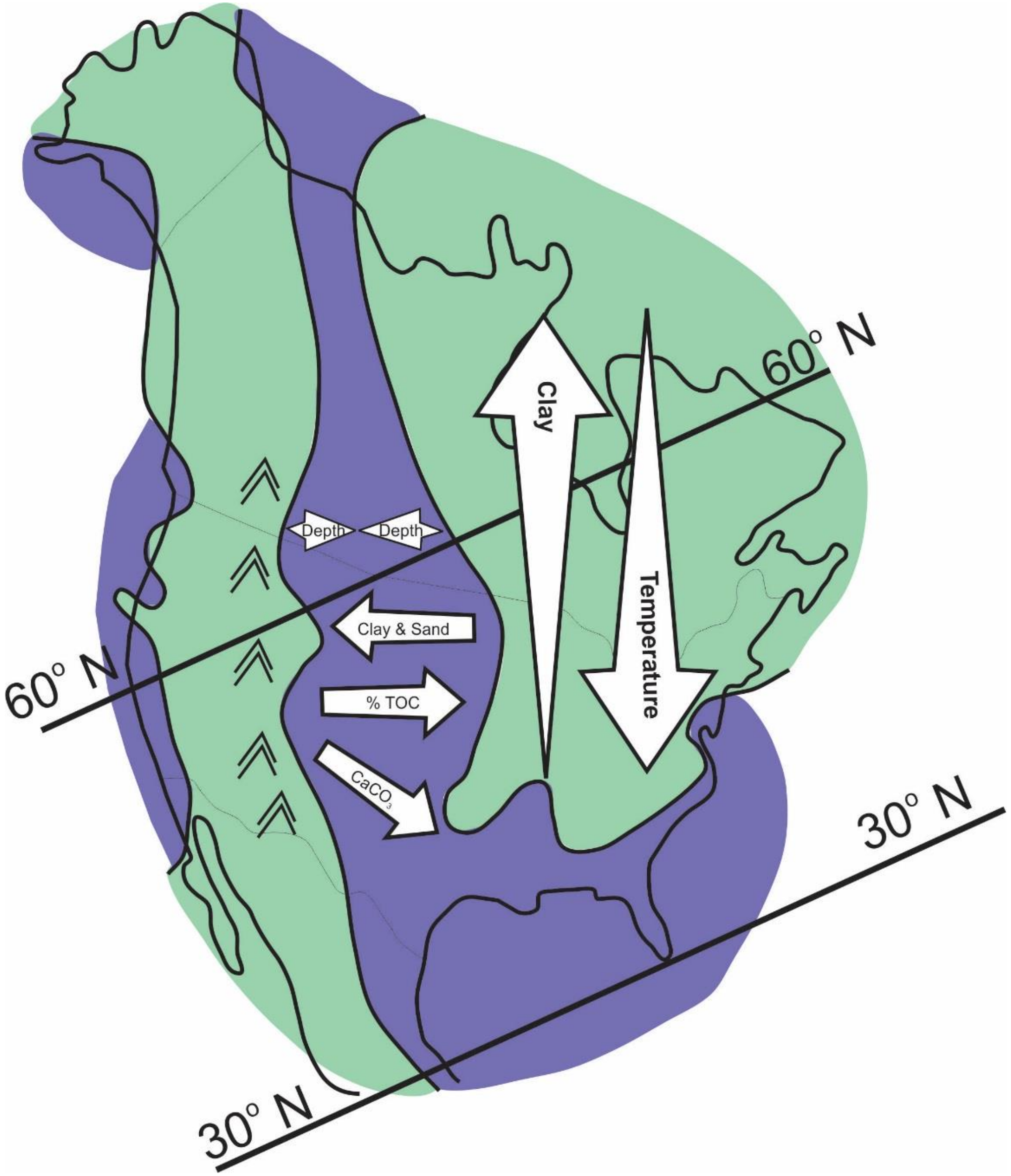
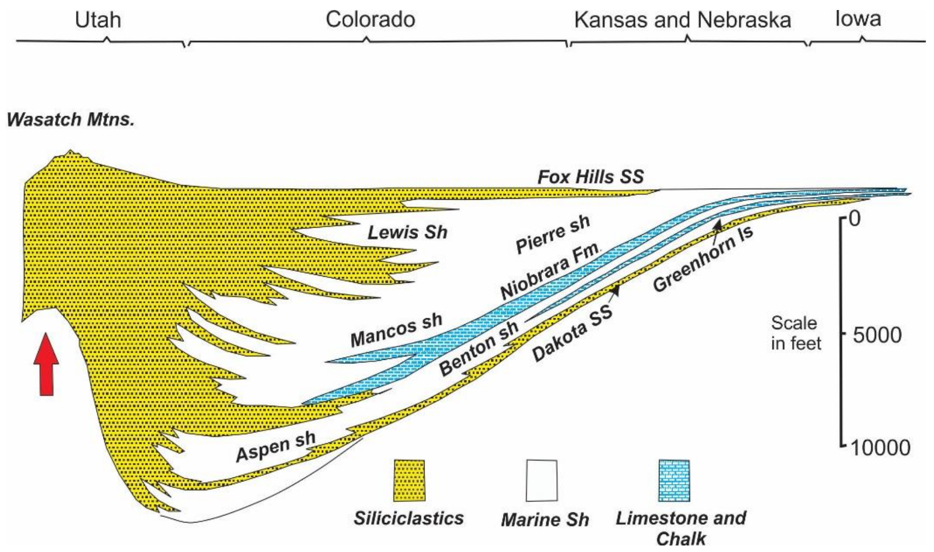
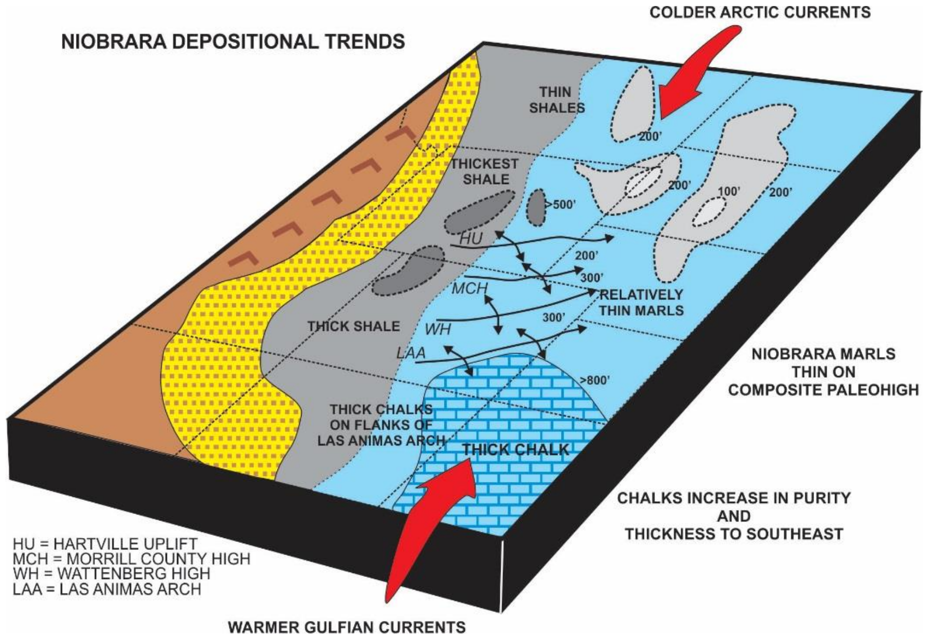
Colorado School of Mines



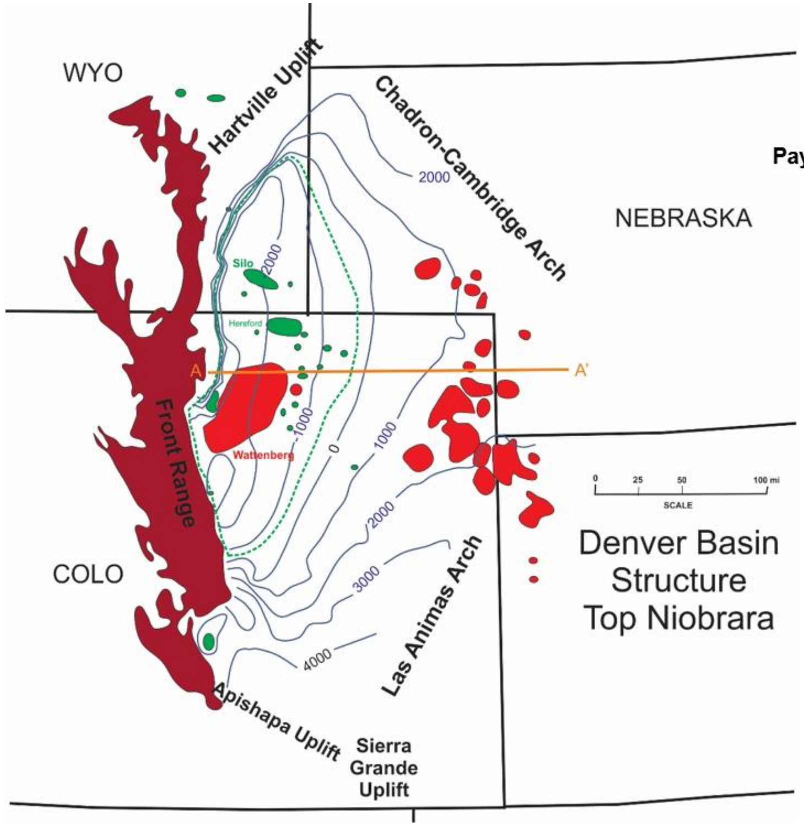
The Western Interior Cretaceous Basin
(Modified from Longman et al., 1998)

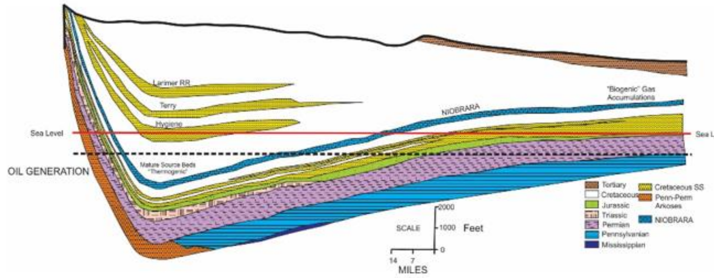


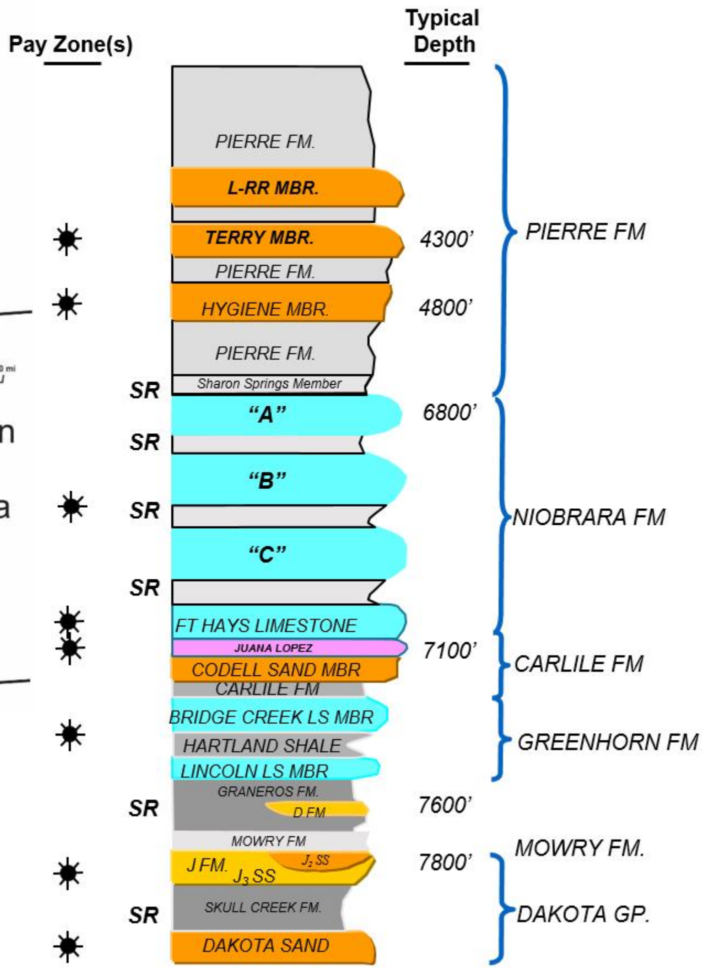




Denver Basin (a Laramide Basin)







EIA Ranking of Fields

Top 10 Oil Fields

1. Eagleville (TX) – 238 million barrels
2. Spraberry (TX) – 99 million barrels
3. Prudhoe Bay (AK) – 79 million barrels
4. Wattenberg (CO) – 47 million barrels
5. Briscoe Ranch (TX) – 62 million barrels
6. Kuparuk River (AK) – 29 million barrels
7. Mississippi Canyon (Fed Gulf) – 15 million barrels
8. Wasson (TX) – 19 million barrels
9. Belridge South (CA) – 23 million barrels
10. Green Canyon (Fed Gulf) – 27 million barrels

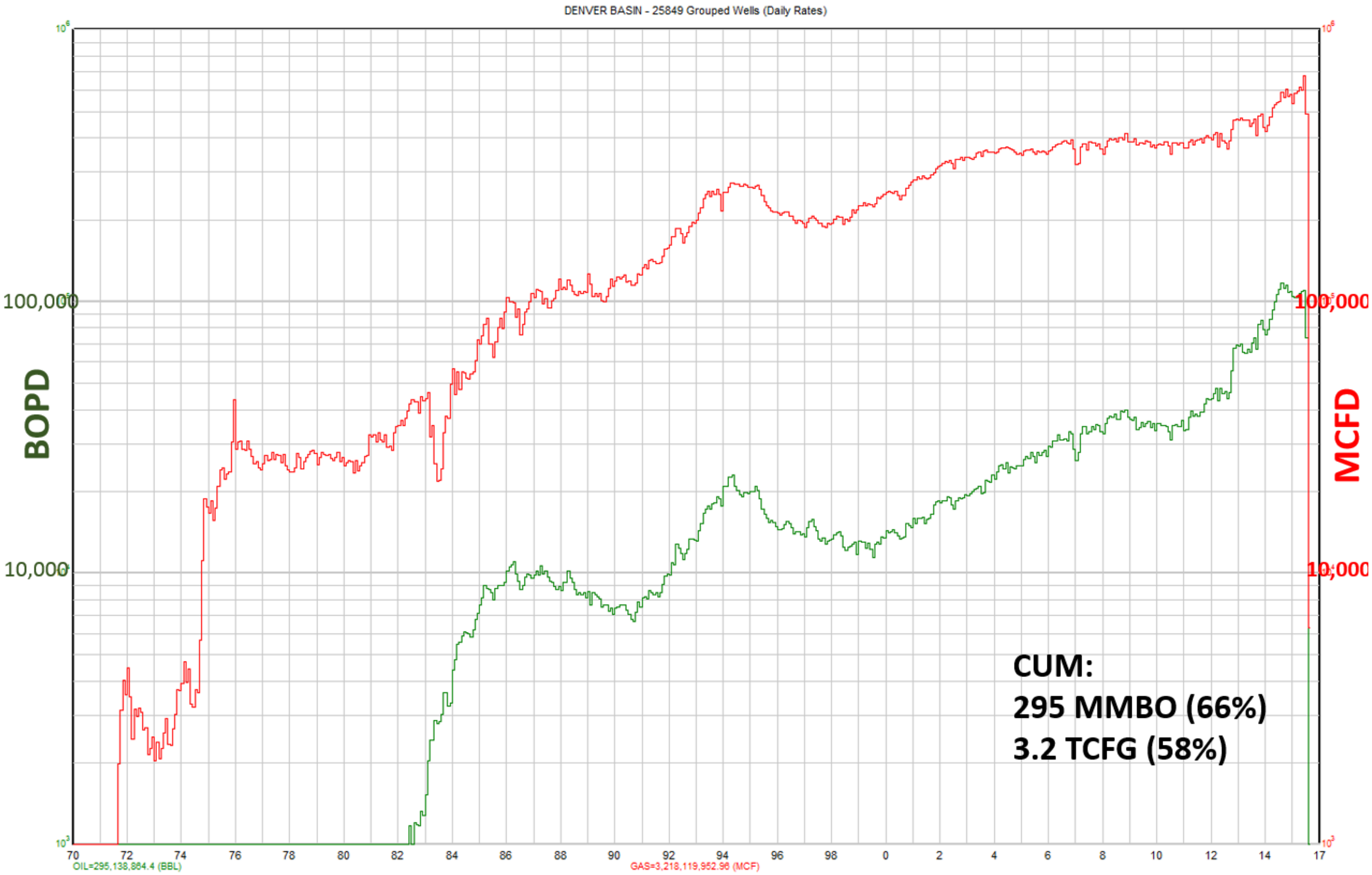
Top 10 Natural Gas Fields

1. Marcellus Shale (PA & WV) – 2,836 billion cubic feet
2. Newark East (TX) – 1,951 billion cubic feet
3. B-43 Area (AR) – 1,025 billion cubic feet
4. San Juan Basin (CO & NM) – 1,024 billion cubic feet
5. Haynesville Shale (LA) – 1,425 billion cubic feet
6. Pinedale (WY) – 568 billion cubic feet
7. Carthage (TX) – 653 billion cubic feet
8. Jonah (WY) – 239 billion cubic feet
9. Wattenberg (CO) – 304 billion cubic feet
10. Prudhoe Bay (AK) – 147 billion cubic feet

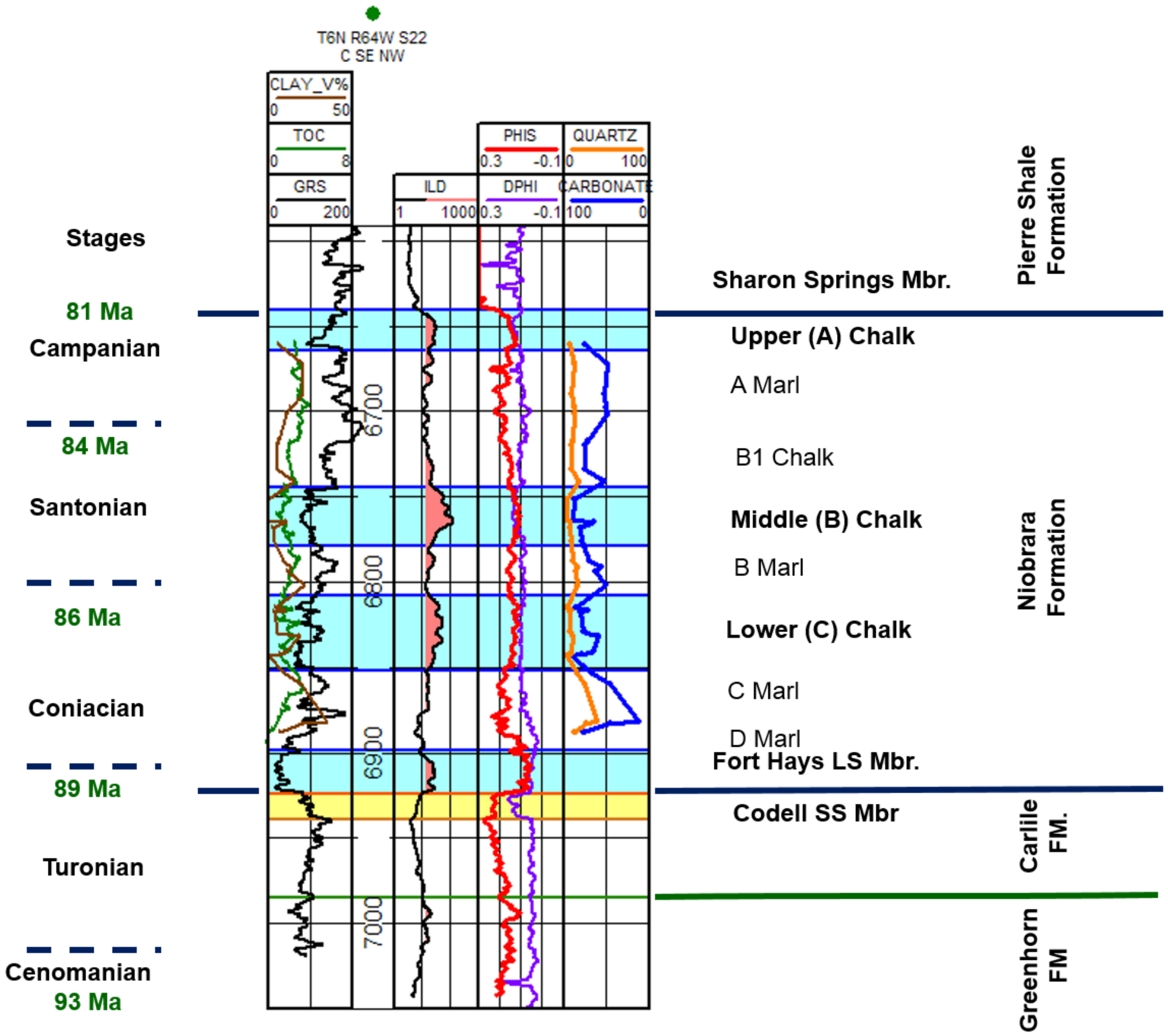
Based on reserves

- values reported are 2013 production

Niobrara and Codell Production



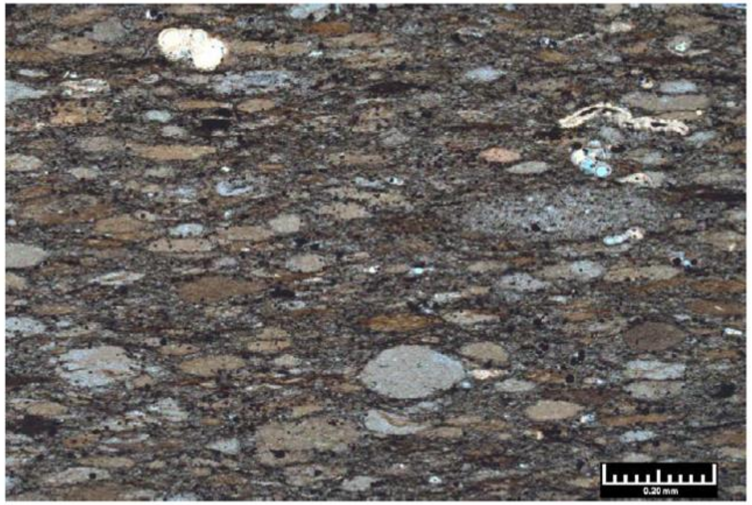
Type Log



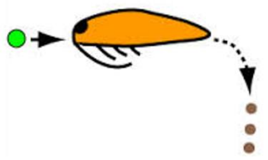
Stages
81 Ma
Campanian
84 Ma
Santonian
86 Ma
Coniacian
89 Ma
Turonian
Cenomanian
93 Ma
T6N R64W S22
C SE NW
CLAY_V%
0 50
TOC
0 8
GRS
0 200
ILD
1 1000
PHIS
0.3 -0.1
DPHI
0.3 -0.1
QUARTZ
0 100
CARBONATE
100 0
6700
6800
6900
7000
Sharon Springs Mbr.
Upper (A) Chalk
A Marl
B1 Chalk
Middle (B) Chalk
B Marl
Lower (C) Chalk
C Marl
D Marl
Fort Hays LS Mbr.
Codell SS Mbr
Pierre Shale Formation
Niobrara Formation
Carlile FM.
Greenhorn FM

Niobrara Formation

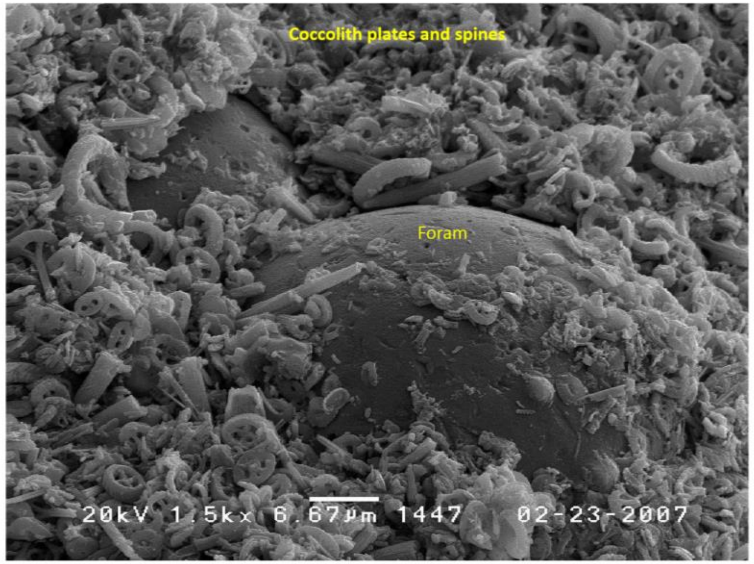
- Pellets
- Coccoliths
- Forams
- Inoceramids
- Oysters
- Ammonites
- Fish bones



TICORA 525-20A 1,414.2-1,415.2 feet 100X

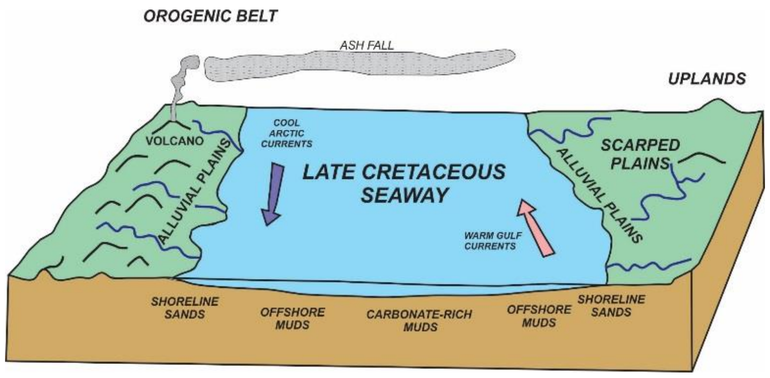


The fecal pellet express



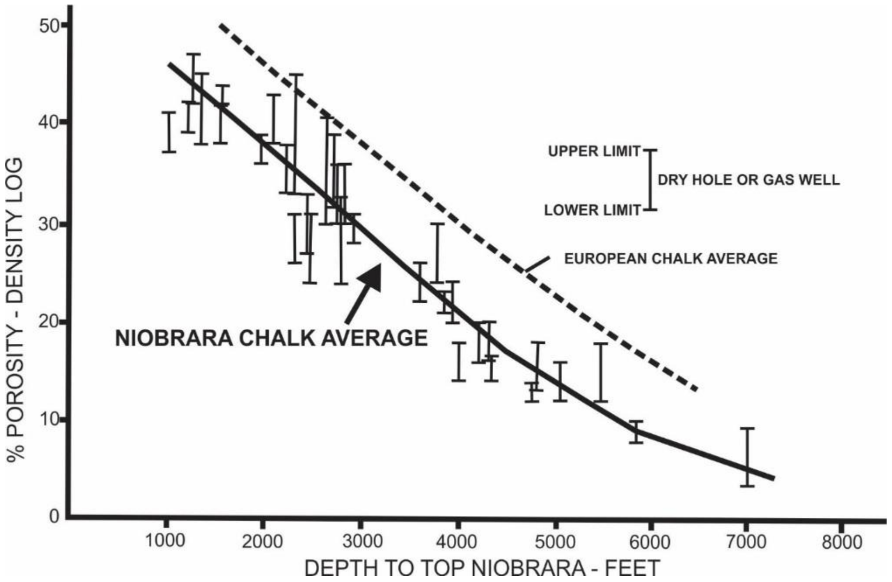
Niobrara Formation

- Massive to laminated to burrowed intervals
- Submarine currents & scours
- Small clinoforms (e.g., D marl)
- Storm events
- “Pellet” bars (e.g., C Chalk)
- Compensational stacking of chalks and marls
- Milankovitch cycles
- Water depths for chalks (?): 400 to 900 ft

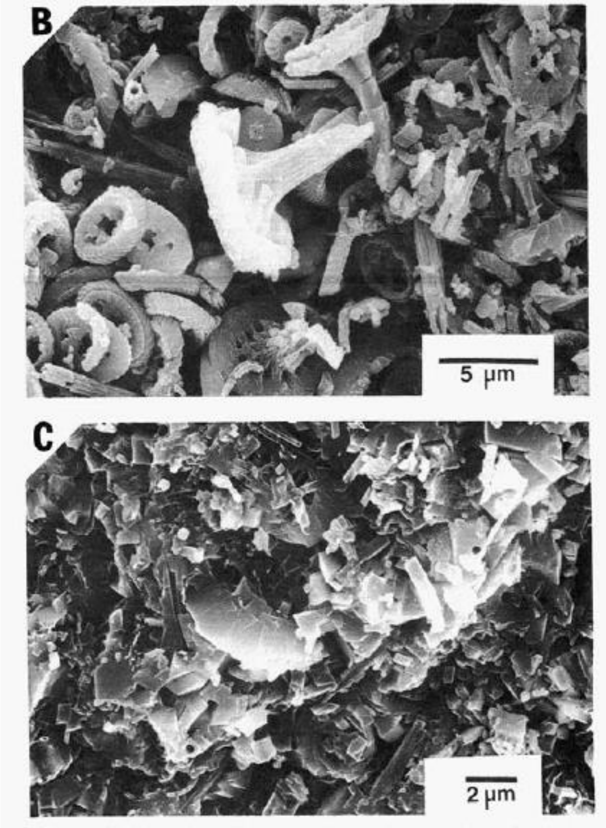


Niobrara Formation Diagenesis

- Burial-related diagenesis
- Mechanical compaction, grain reorientation and breakage (flattened pellets & foram tests)
- Calcite dissolution, microstylolites, pressure solution, reprecipitation of calcite as overgrowths on nannofossils & void-filling crystalline mosaics, "welded" and overgrowth fabrics
- Smectite to illite



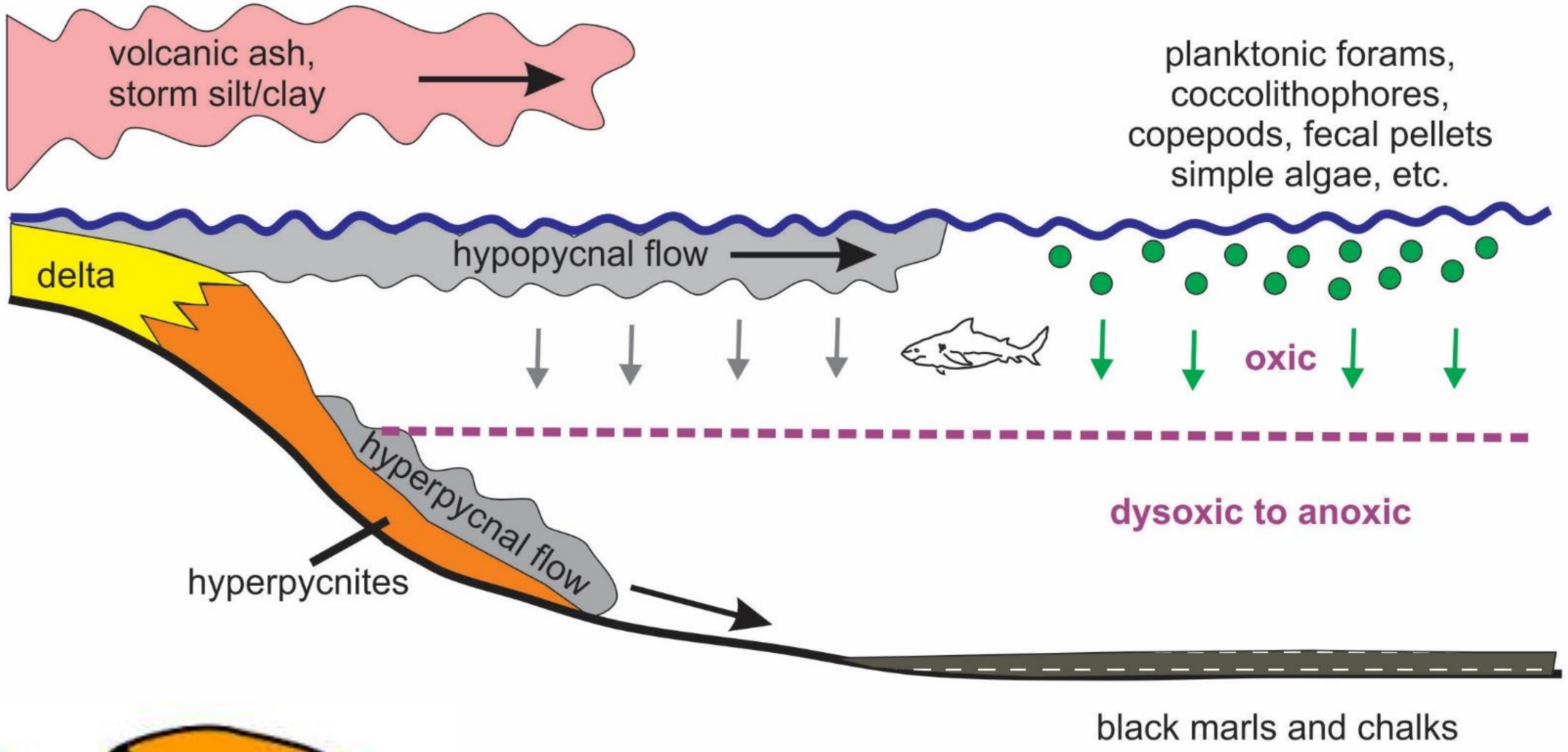
2000 ft

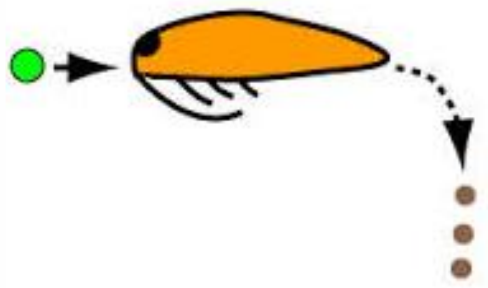


5600 ft

Lockridge and Pollastro, 1988

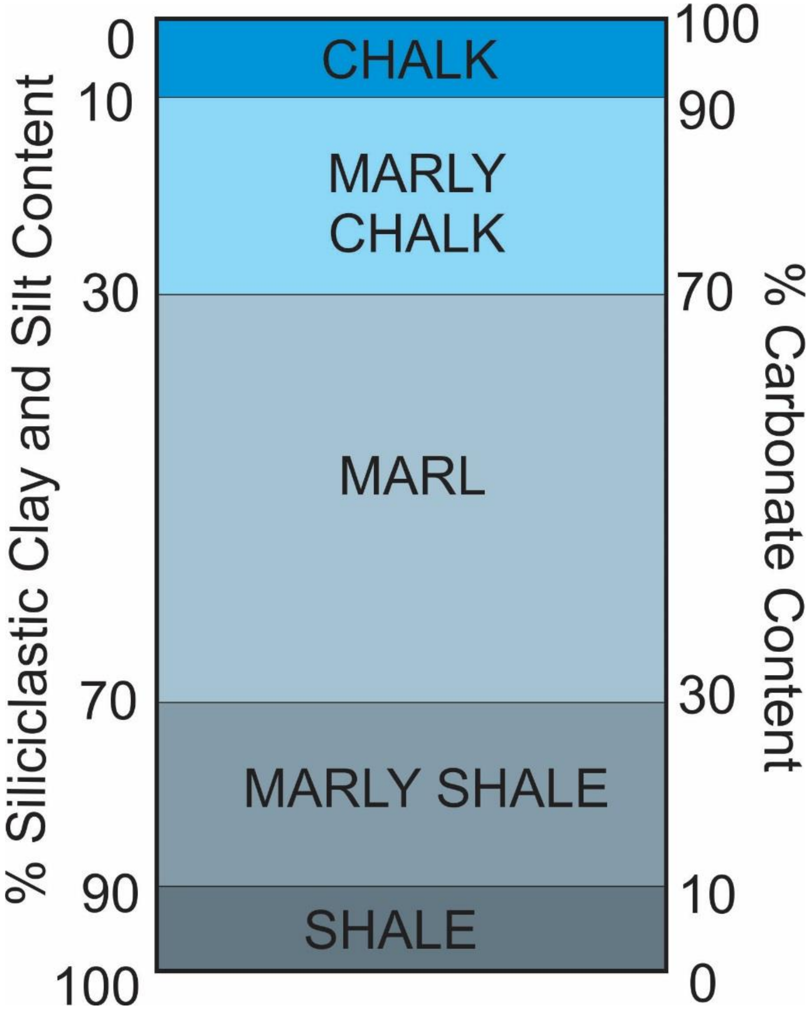
Pelagic Deposition

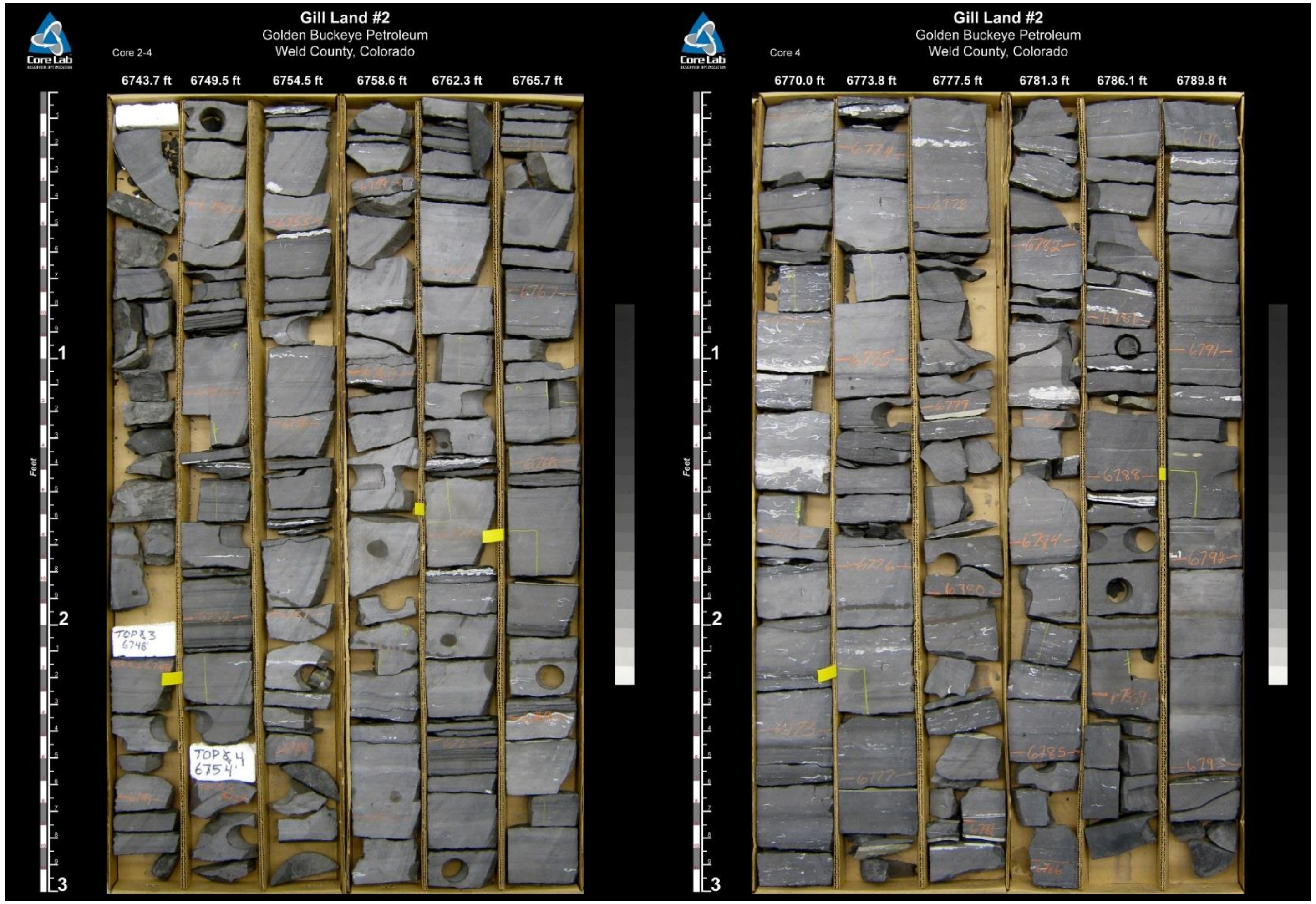




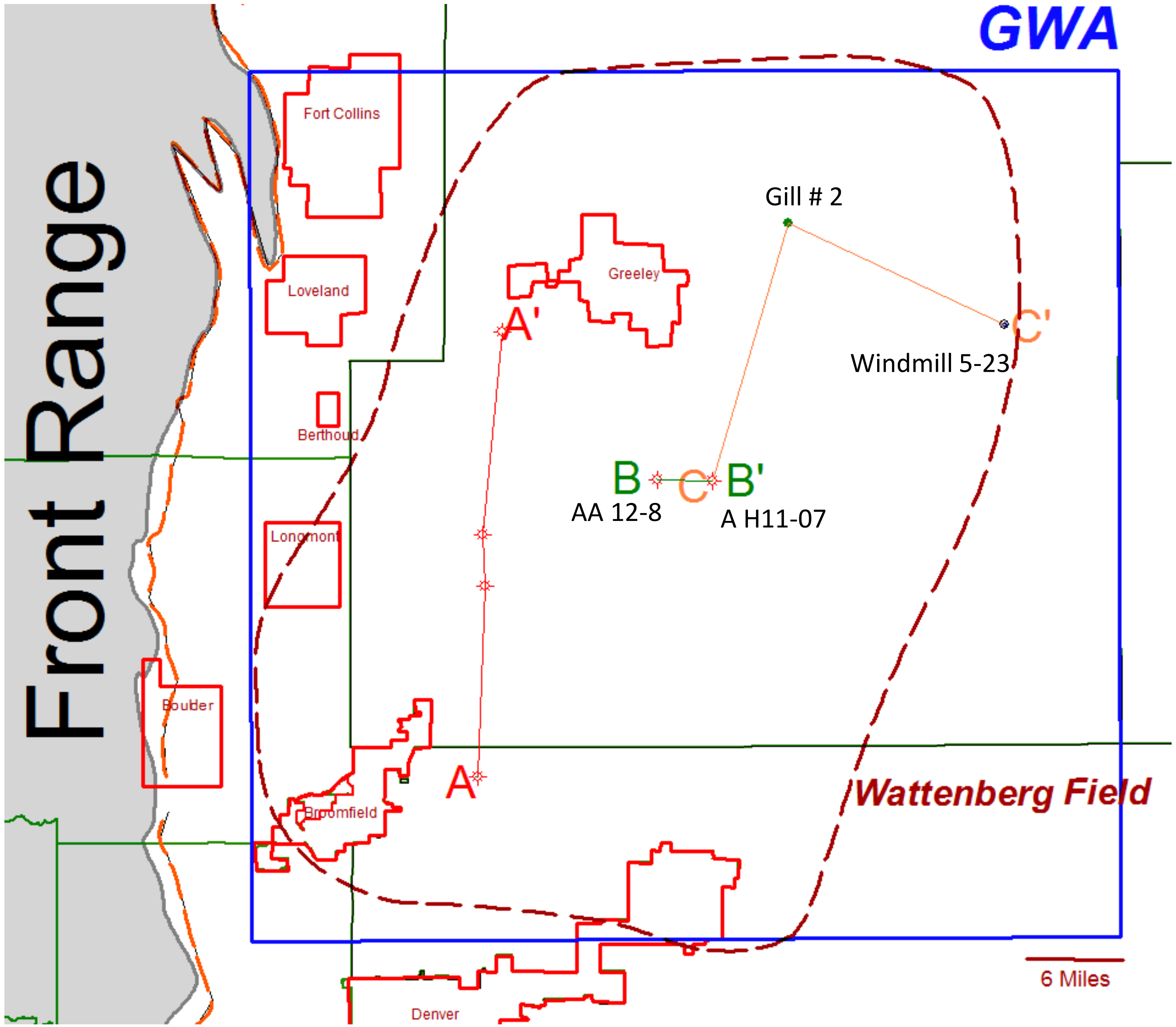
“the fecal pellet express”

Chalks, Marls, & Shales

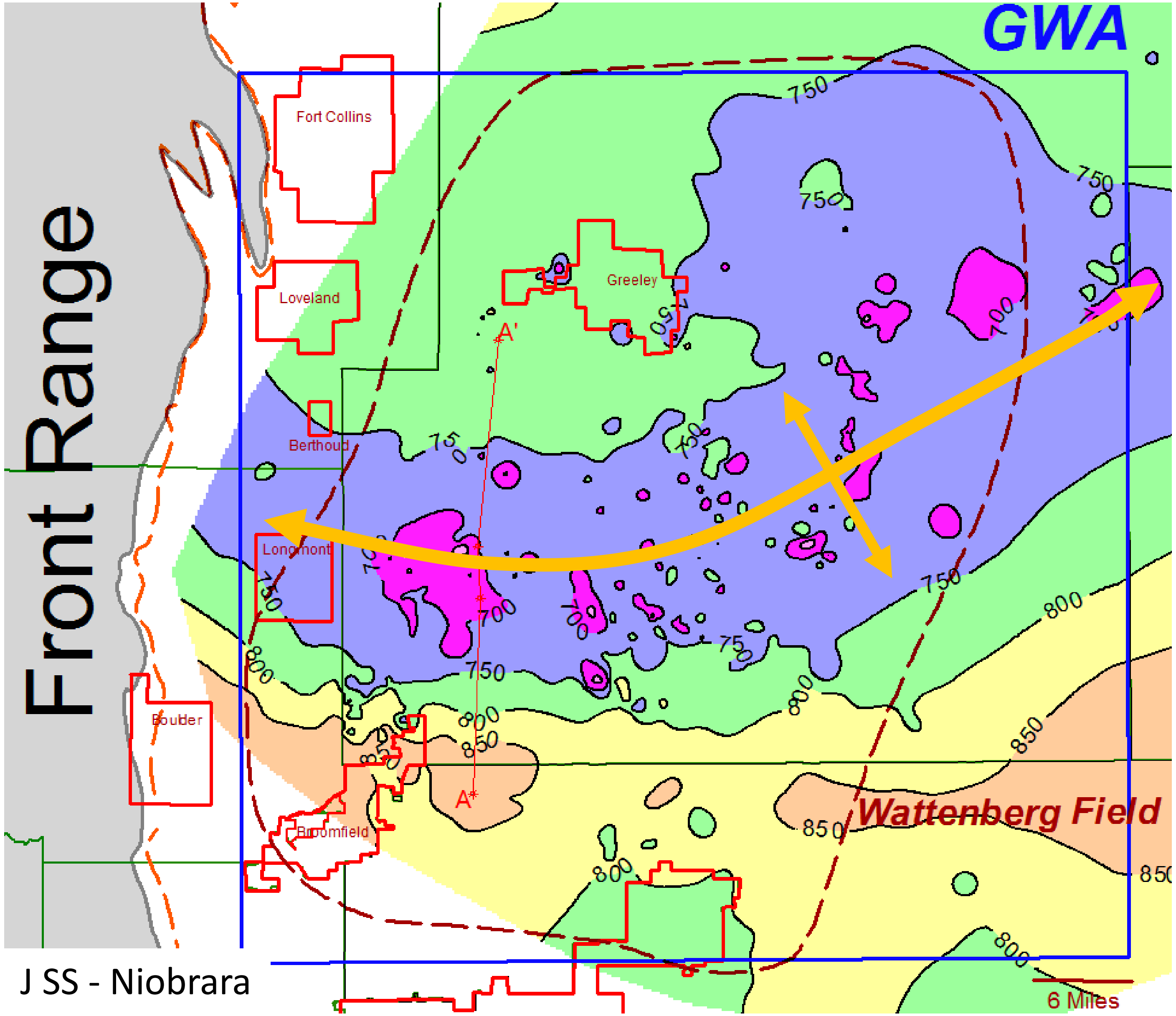




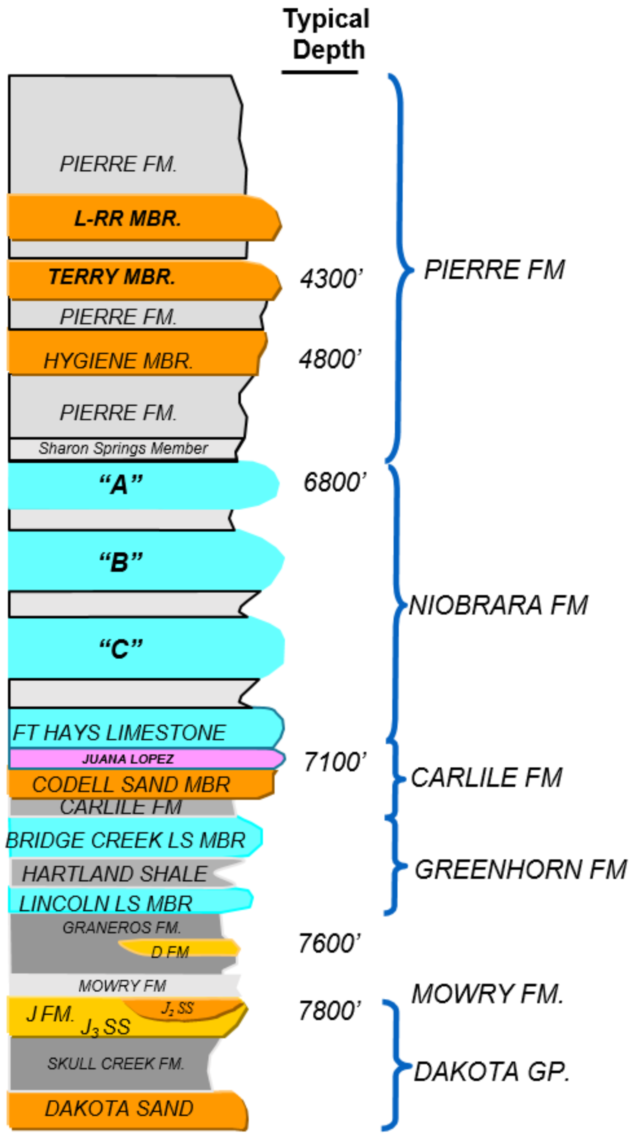
Cross Sections

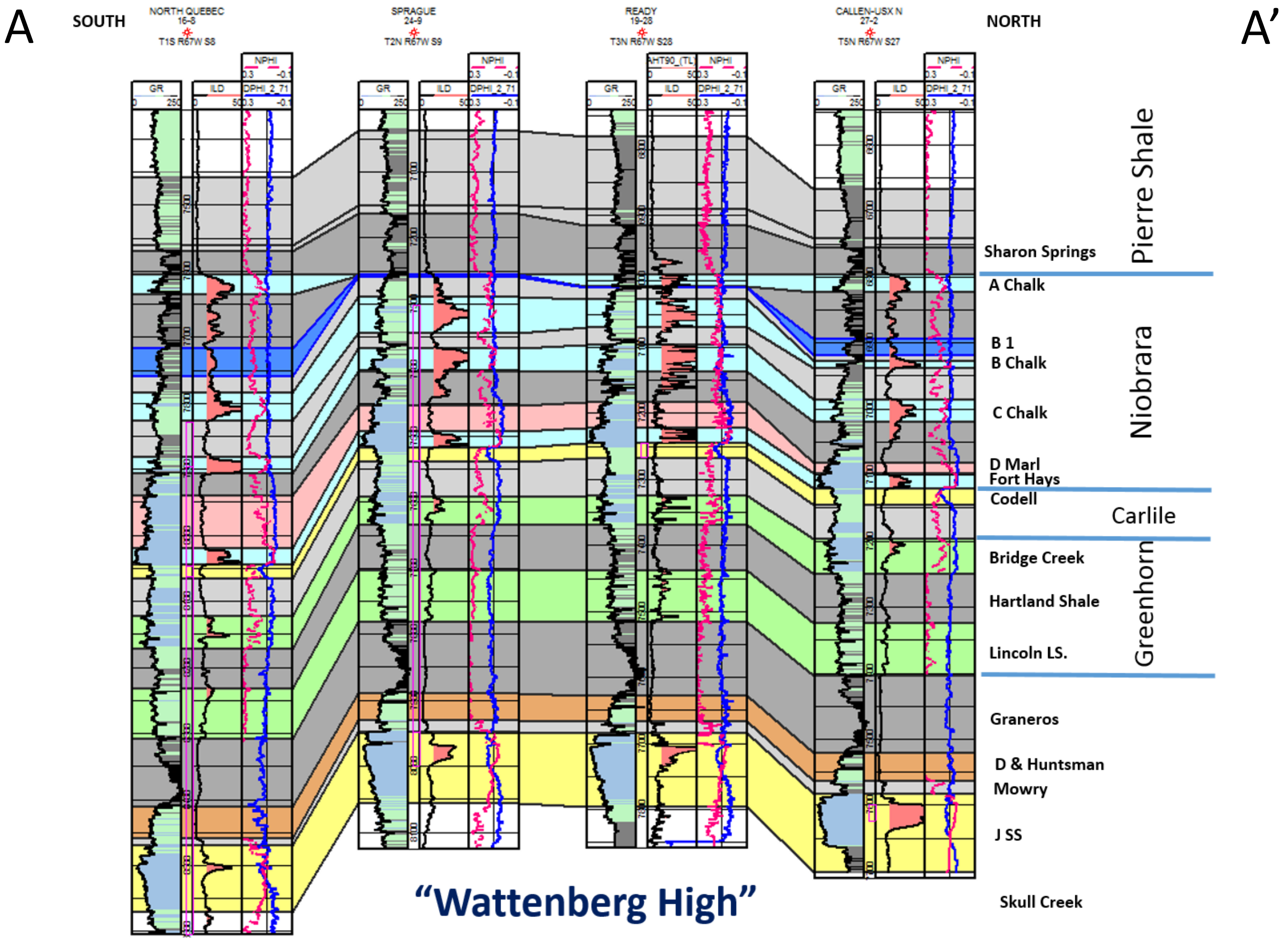


"The Wattenberg High"

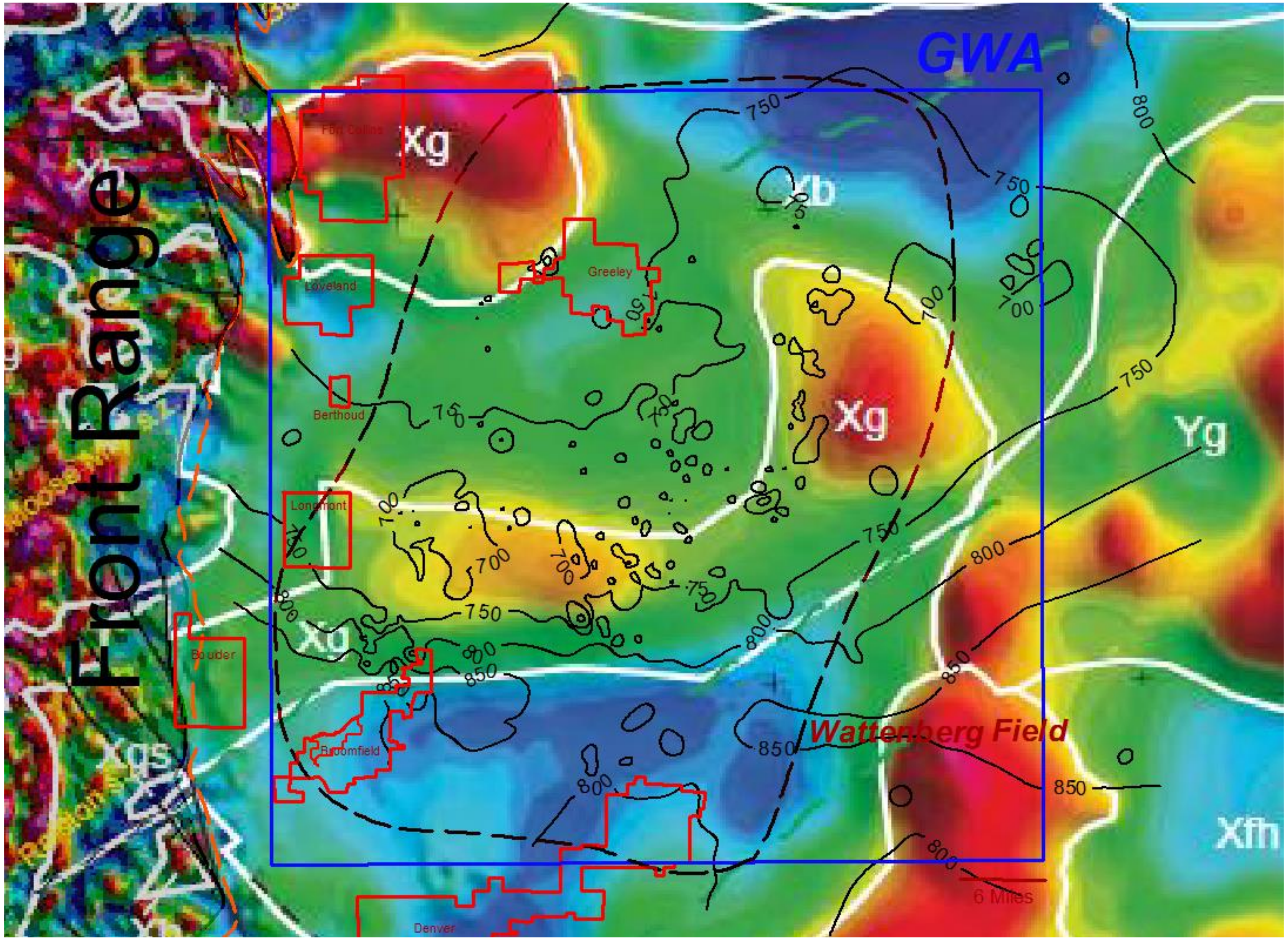


J SS - Niobrara




A
SOUTH
NORTH QUEBEC 16-8
T1S R67W S8
SPRAGUE 24-9
T2N R67W S9
READY 19-28
T3N R67W S28
CALLEN-USX N 27-2
T5N R67W S27
NORTH
A'
Pierre Shale
Sharon Springs
A Chalk
B 1
B Chalk
C Chalk
Niobrara
D Marl
Fort Hays
Codell
Carlile
Bridge Creek
Hartland Shale
Lincoln LS.
Greenhorn
Graneros
D & Huntsman
Mowry
J SS
Skull Creek
"Wattenberg High"

Aeromagnetic & Basement Map – (Sims et al., 2001)

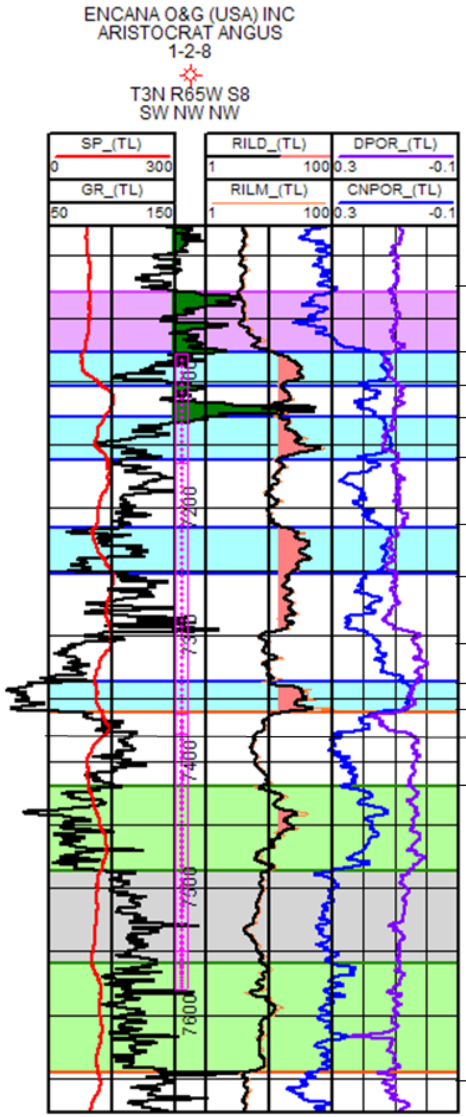


Xg-Granitic rocks, 1.7 Ga, Yg Granitic rocks ~1.4 Ga
Xb-Biotite gneiss and migmatite, Xfh-Felsic and hornblendic gneisses

Niobrara Stratigraphic Architecture

- Reservoirs in various chalks (A, B, C, FH)
  - Truncation & onlap of A chalk (submarine)
  - Truncation & onlap of B1 interval
  - Thickness variations in chalks
- Source Beds: A marl, B marl, C marl
  - Thickness variations
- Clinoforms (?) in D interval
- Compensational stacking of chalks and marls (C & B)
- Paleostructure interpretation

Reservoir Properties

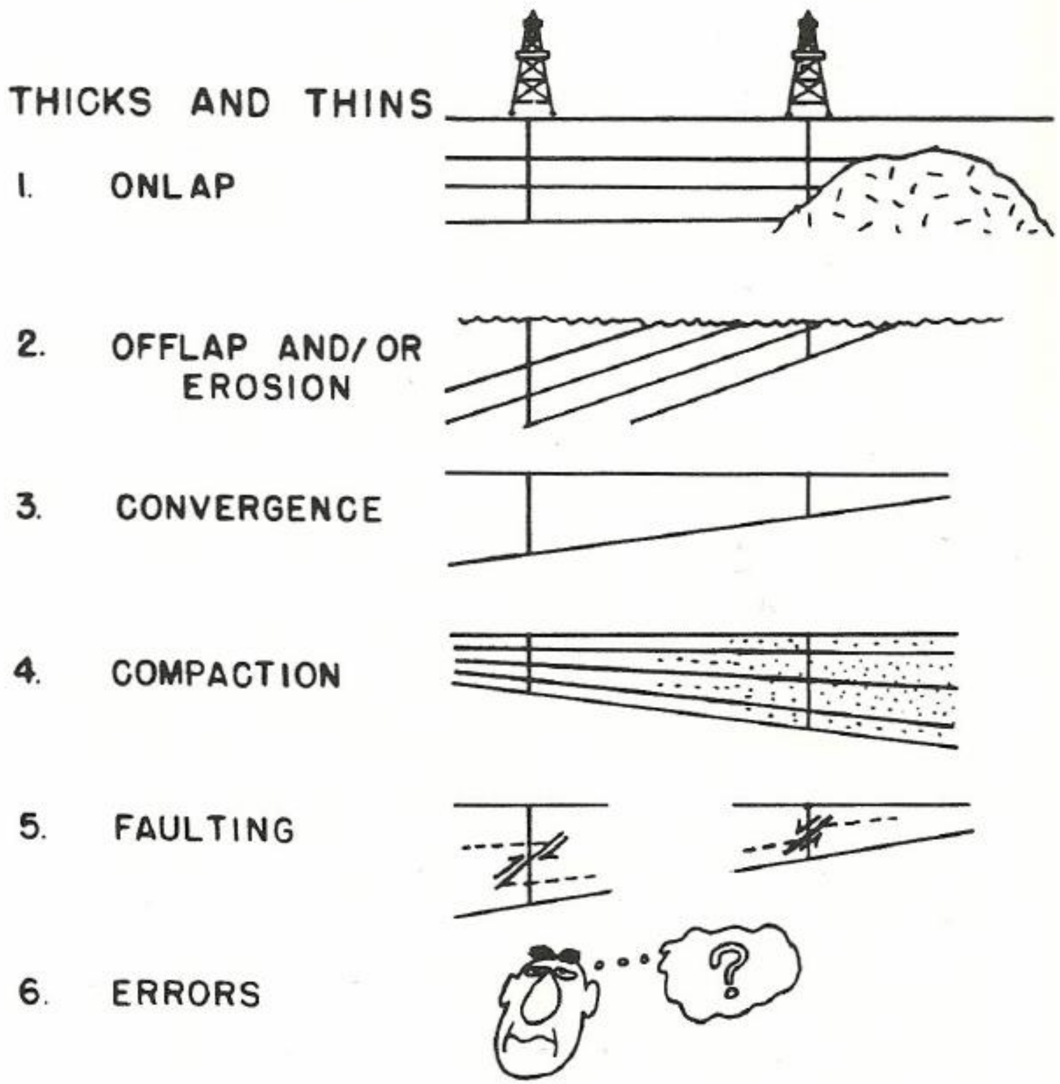


Niobrara Properties

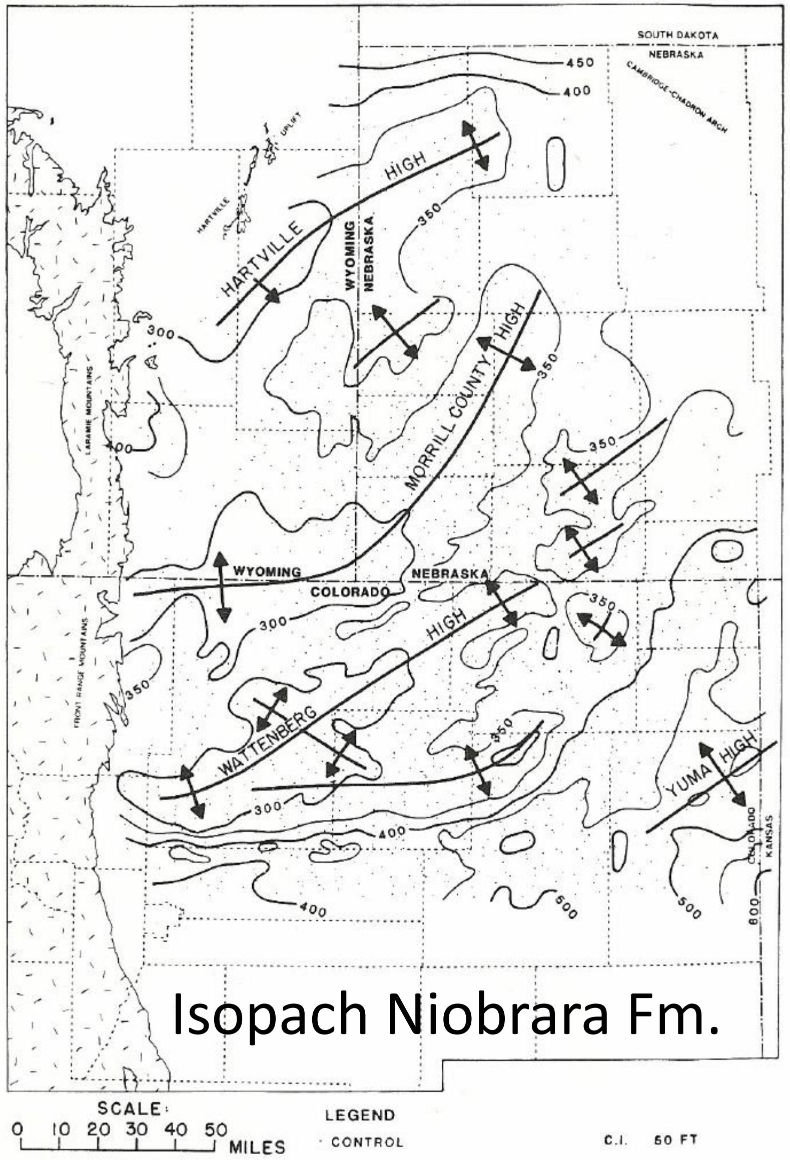
	H (ft)	TOC (wt.%)	CaCO3 (%)	PHI (%)	K (md)
Sharon Springs	47	2.9		8.2	.00013
A Chalk	27	2.1	82	9.1	.00033
A Marl	24	5.8	64	9.4	.00038
B Chalk	33	2.8	73	9.2	.00057
B Marl	55	3.5	68	7.6	.00013
C Chalk	30	2.7	80	8.3	.00029
C Marl	56	4.4	52	8.3	.00024
Lower Chalk	35	3.6	42	6.0	.00008
Fort Hays	24	0.06	94		
Codell	15	1.5	1.5	11.8	.02
Greenhorn					

Modified from Gustason and Deacon, 2010

Thickness Variations In Stratigraphic Units

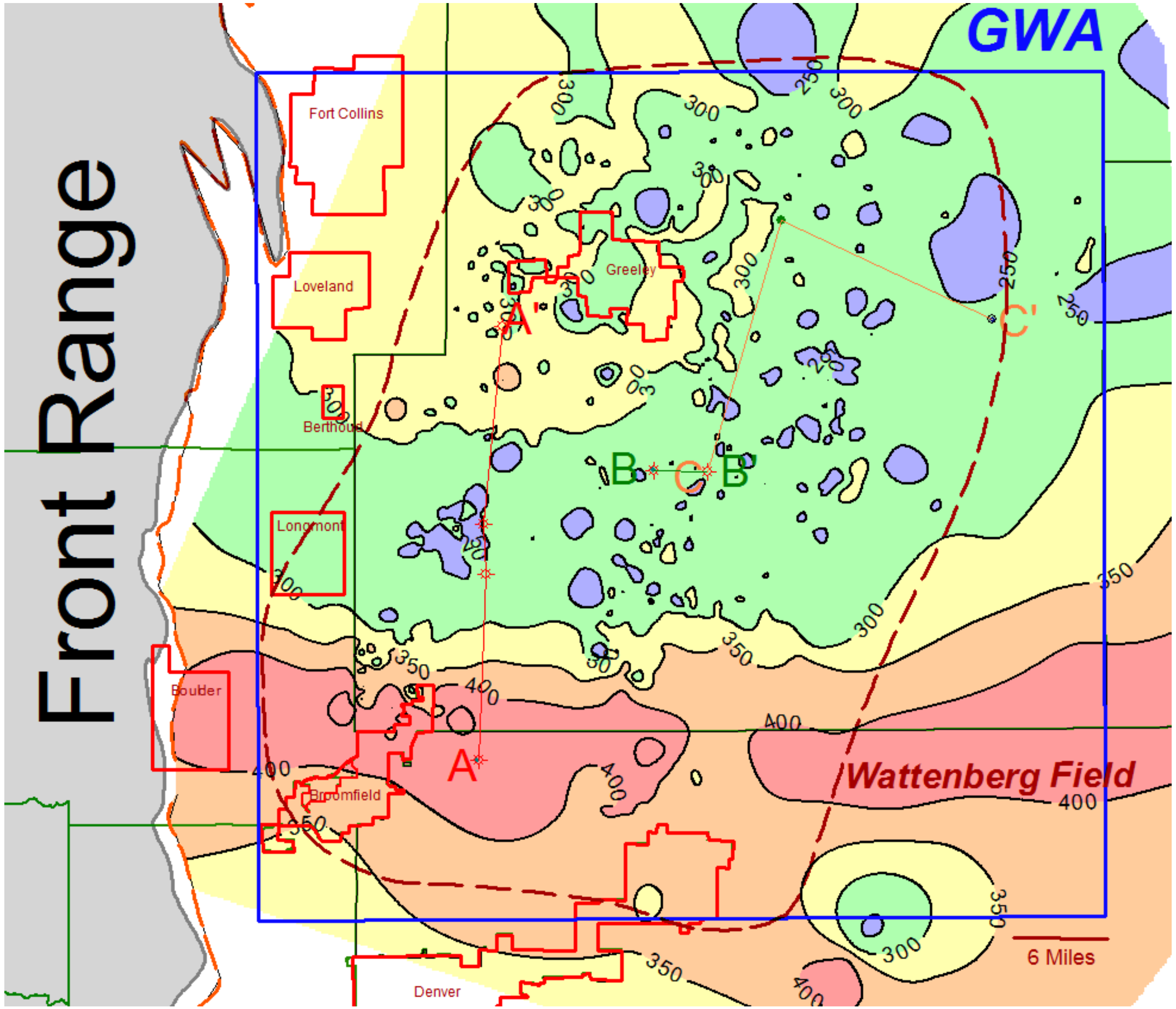


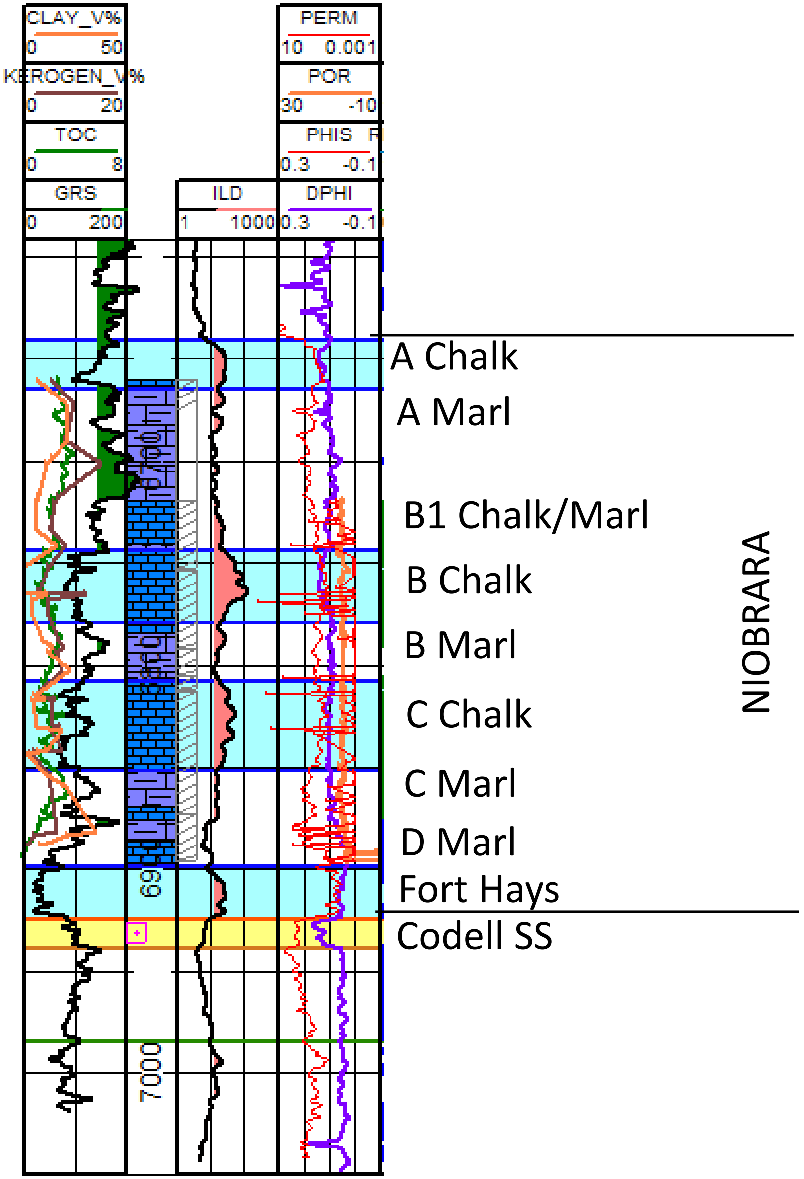
Sonnenberg & Weimer, 1981



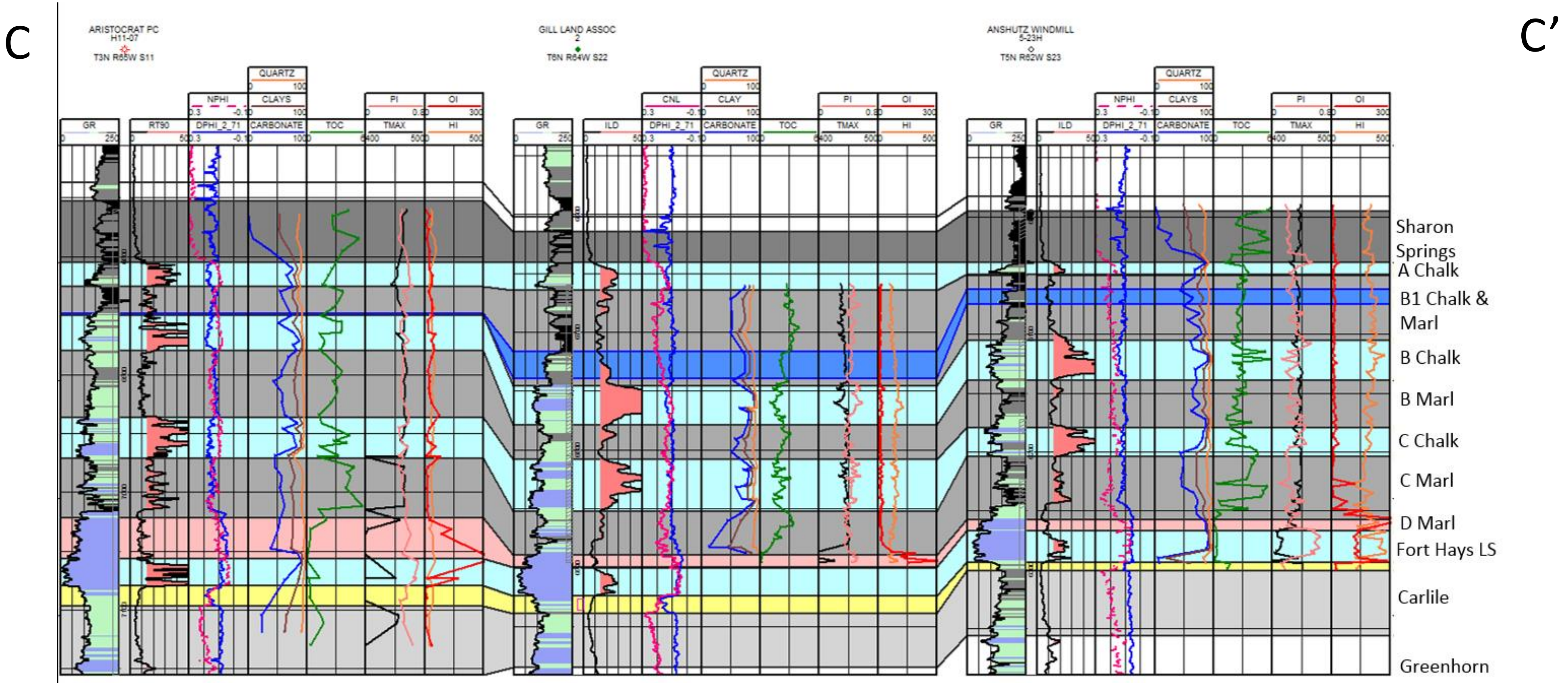
Isopach Niobrara Fm.

Isopach Niobrara





Source Beds and Reservoirs

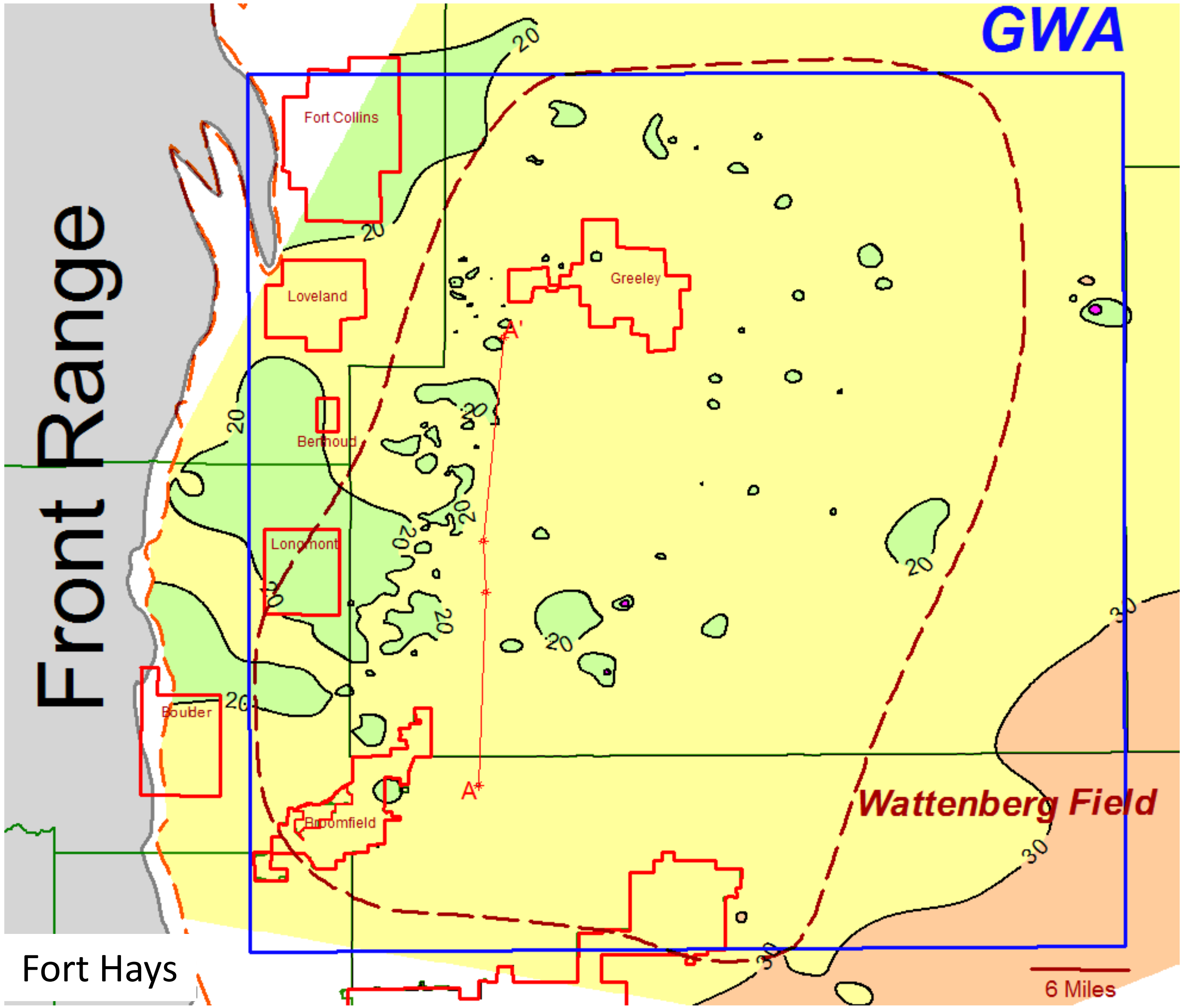


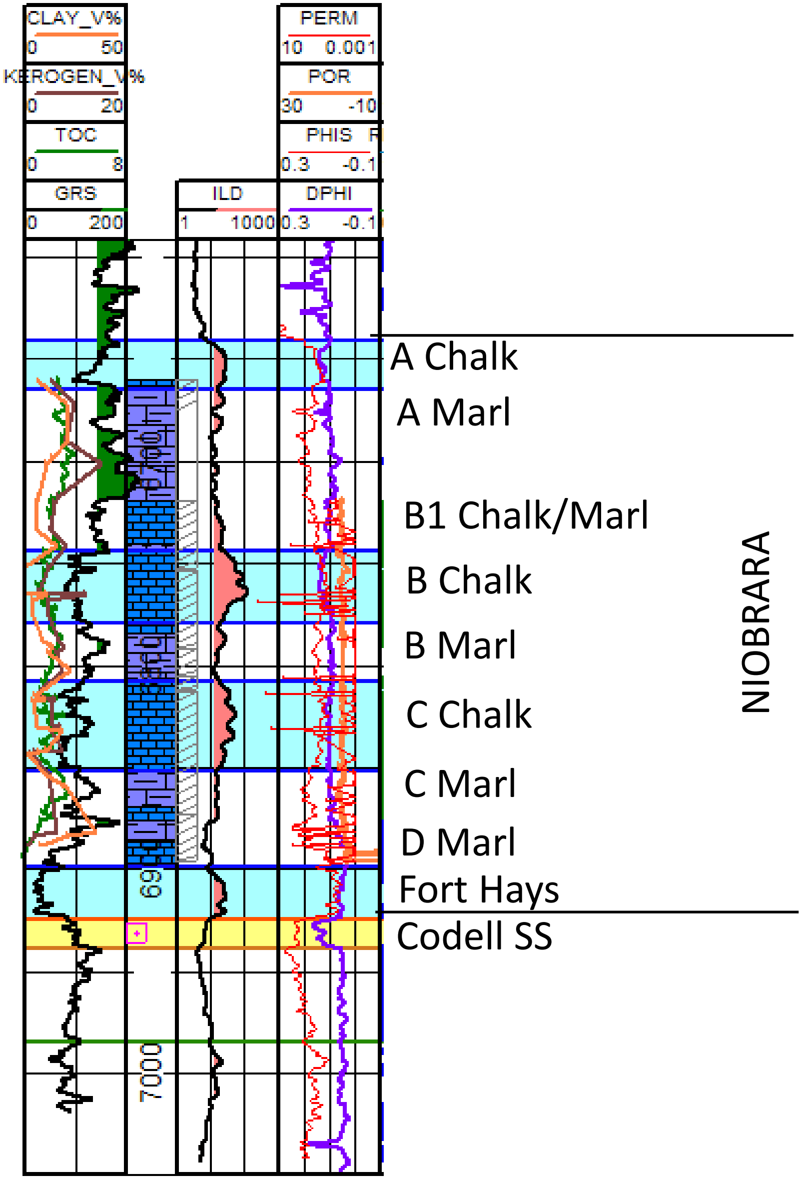
Best Source Beds: Sharon Springs, A Marl, B1 Marl, B Marl, C Marl

Poor Source Bed: D Marl

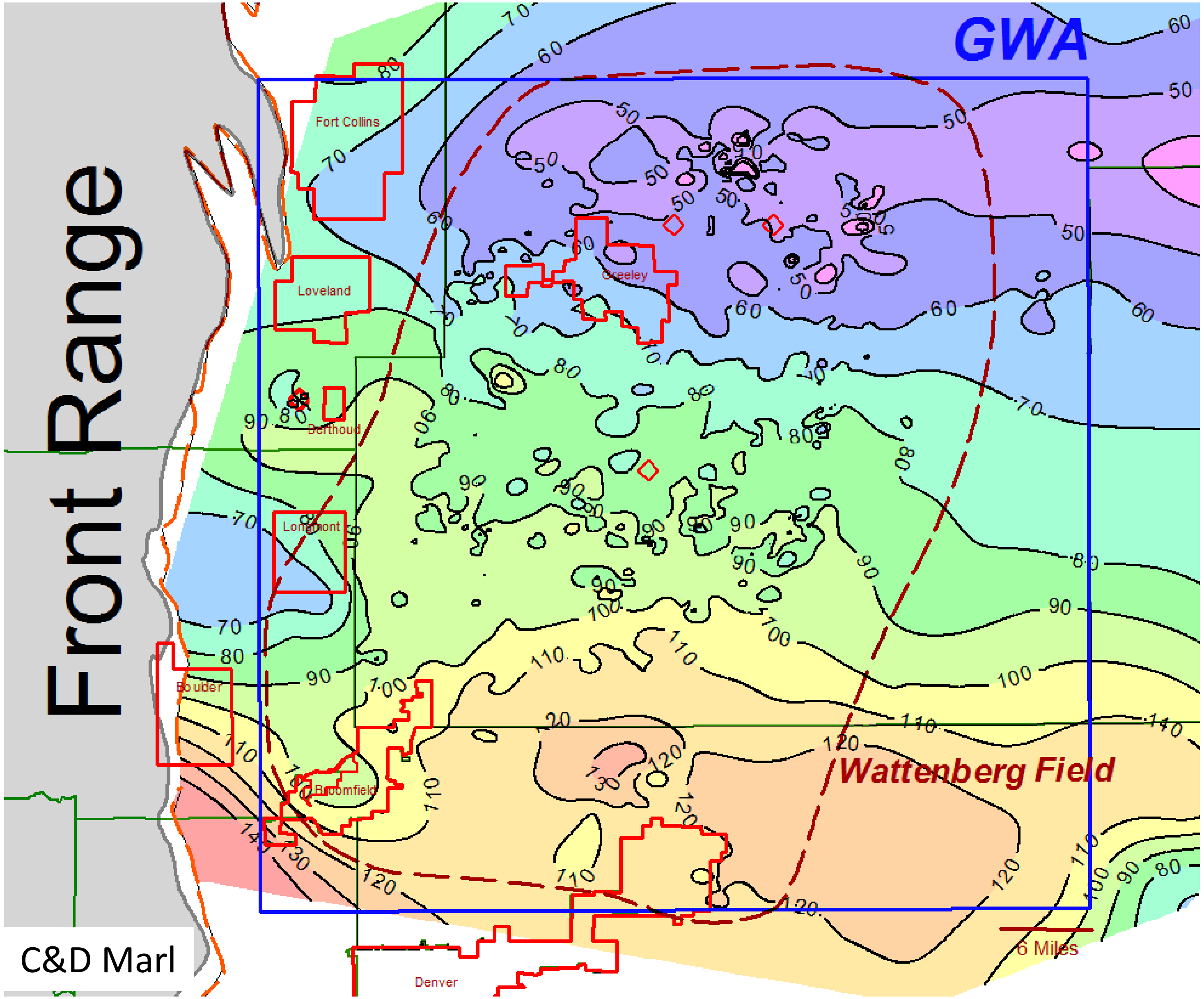
Reservoirs: A Chalk, B1 "in places", B Chalk, C Chalk, Fort Hays & Codell

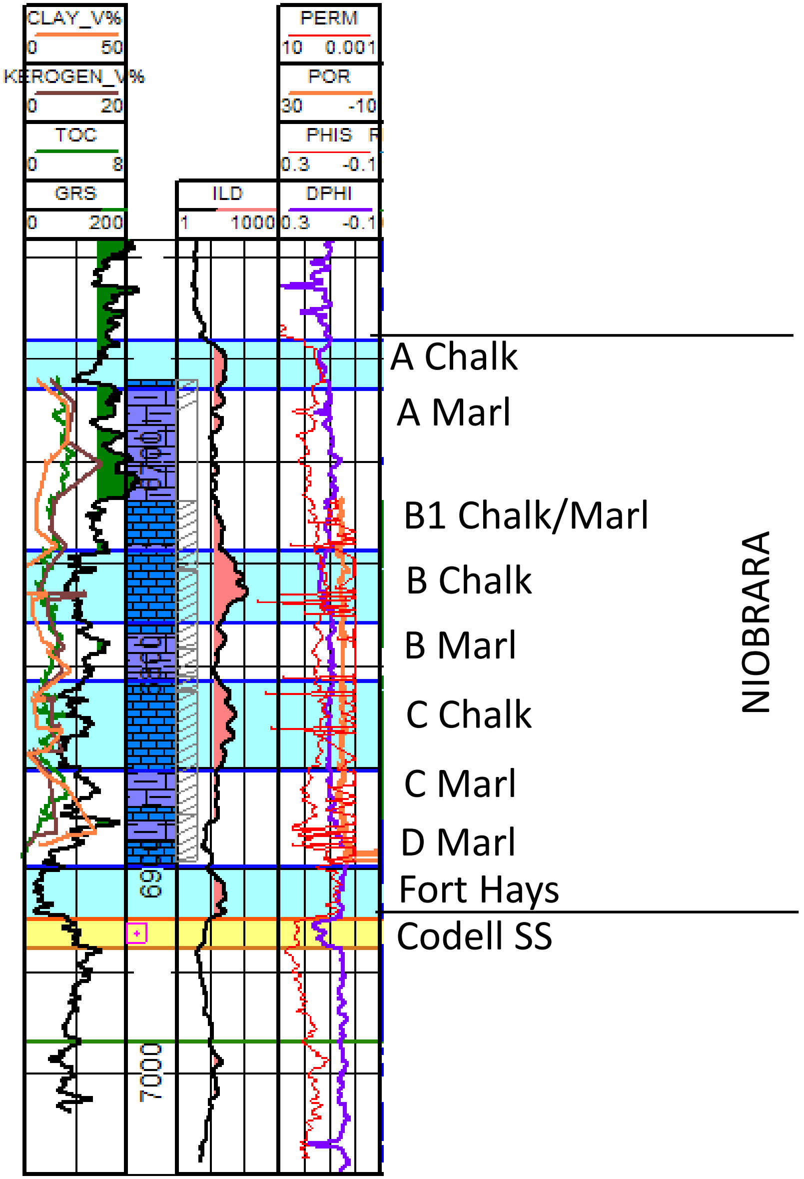
Isopach Fort Hays



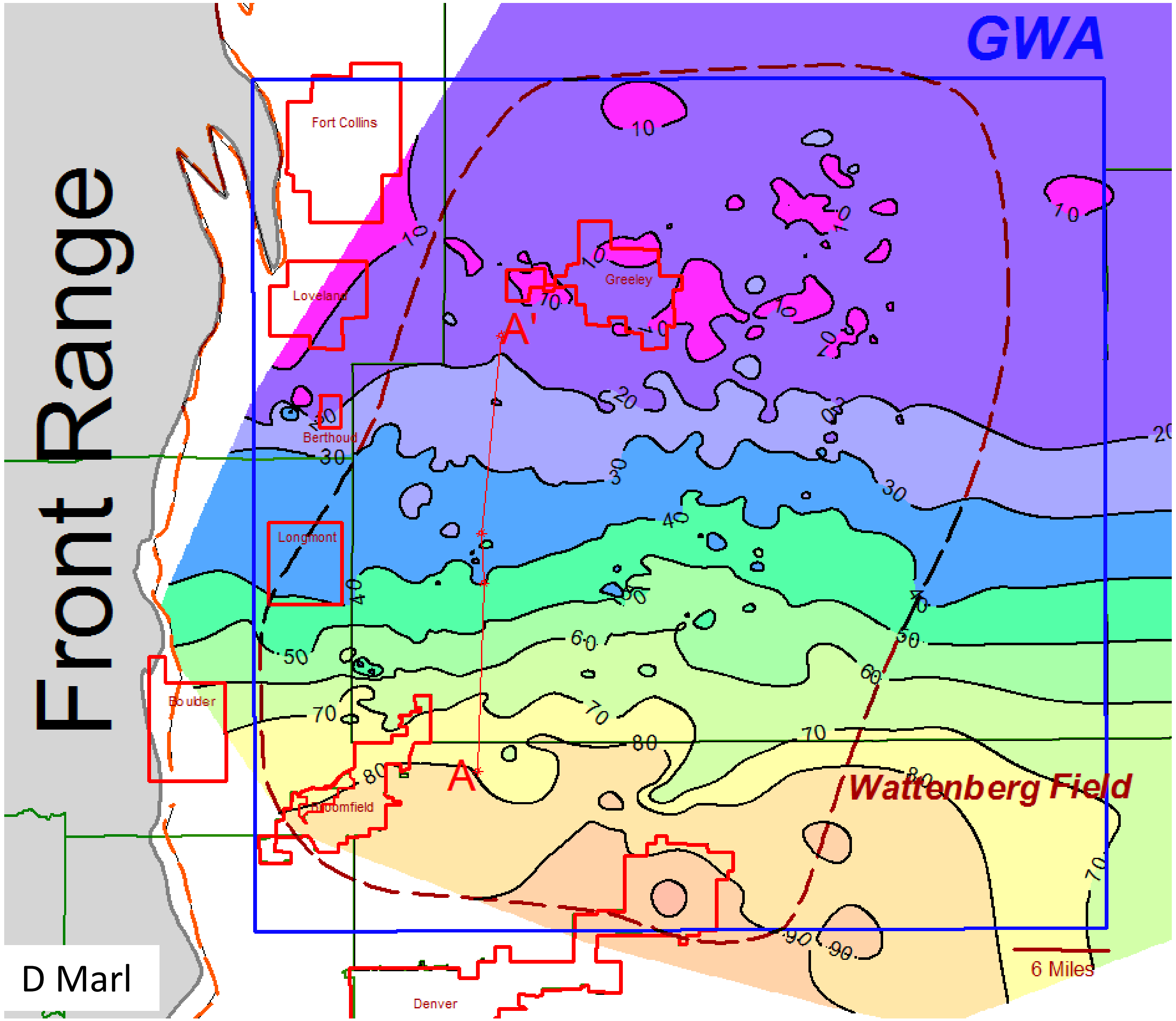


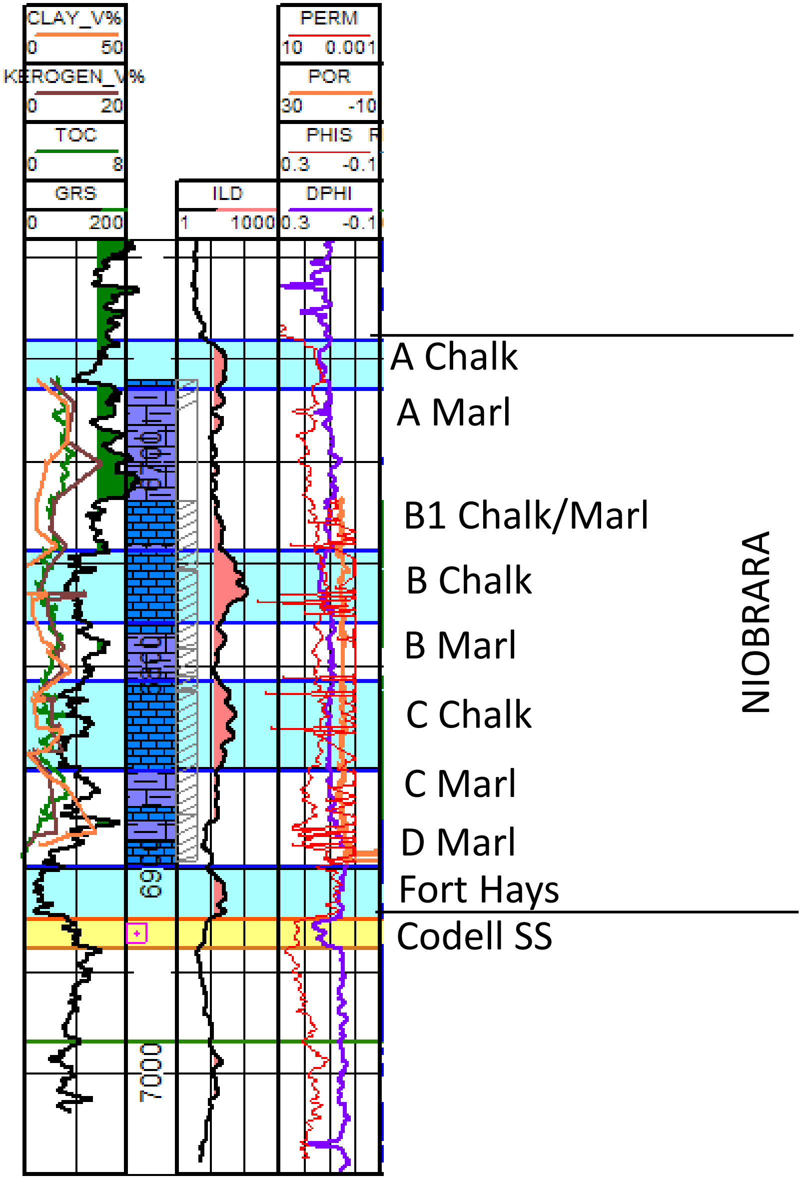
Isopach C&D Marls



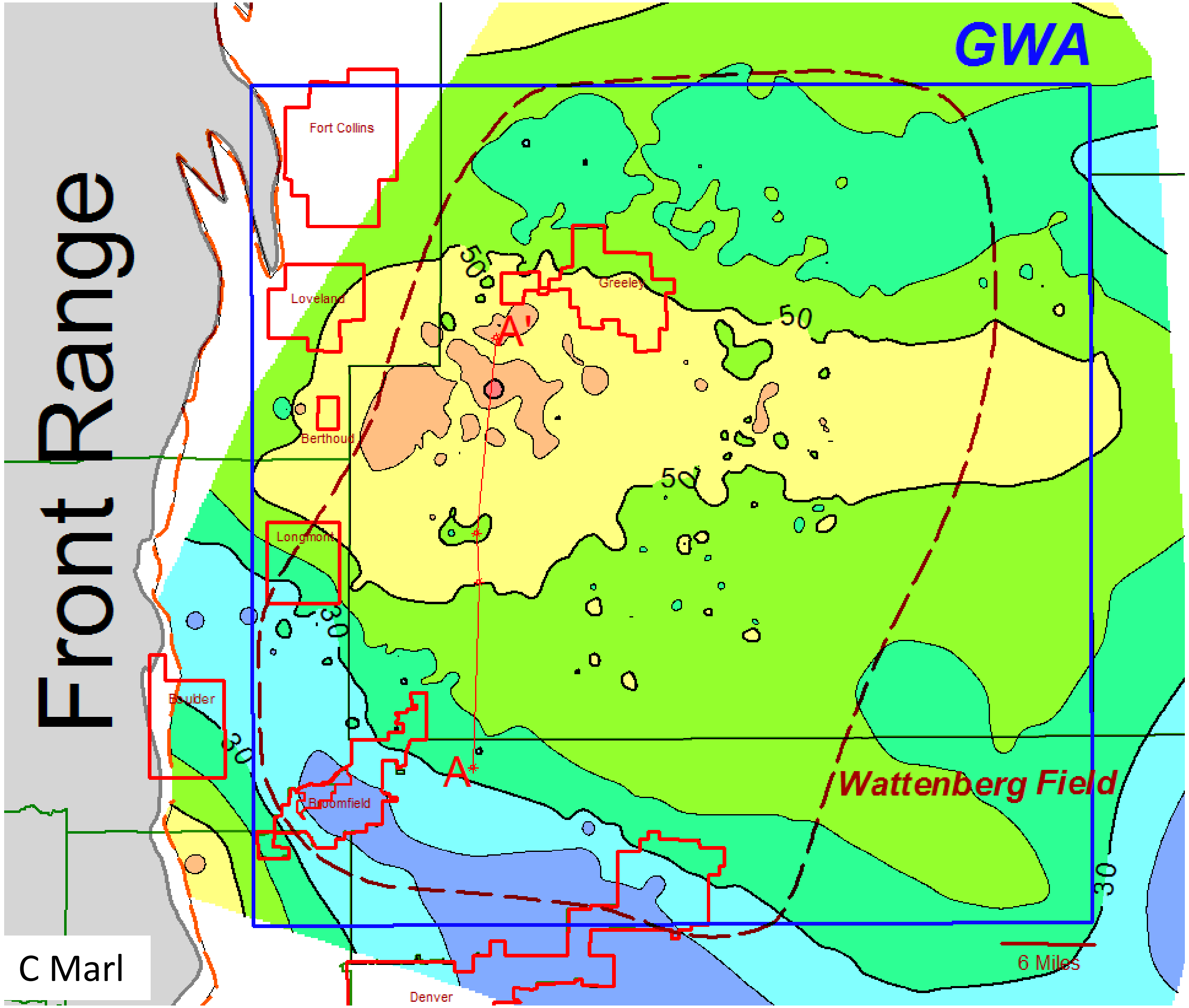


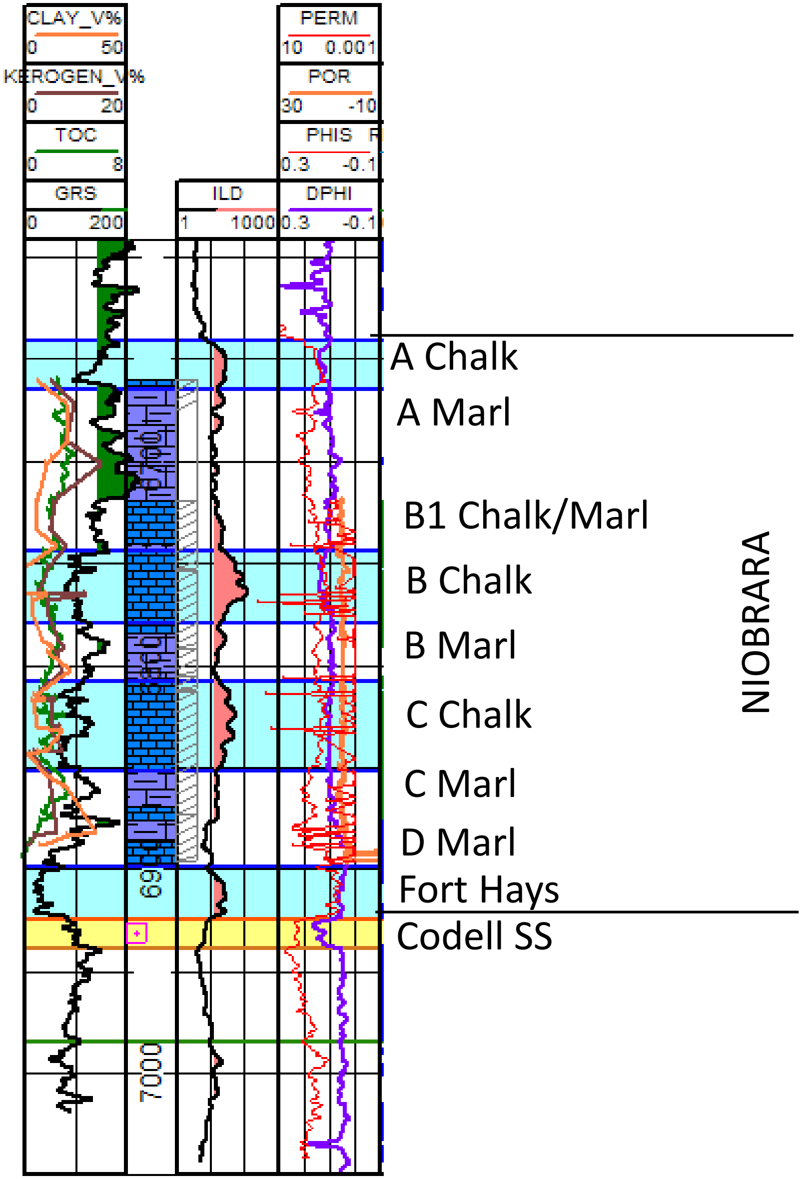
Isopach D Marl



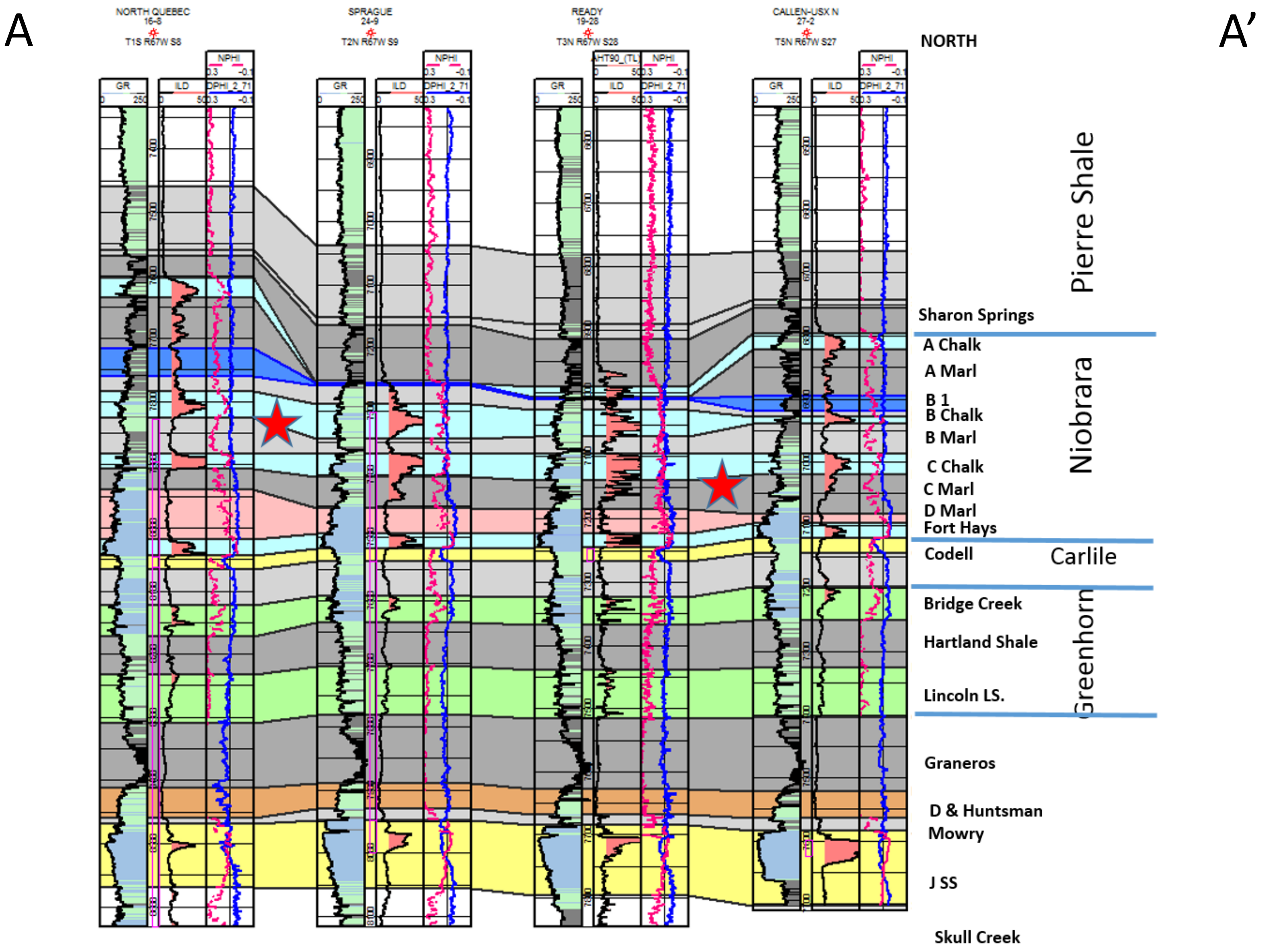


Isopach C Marl

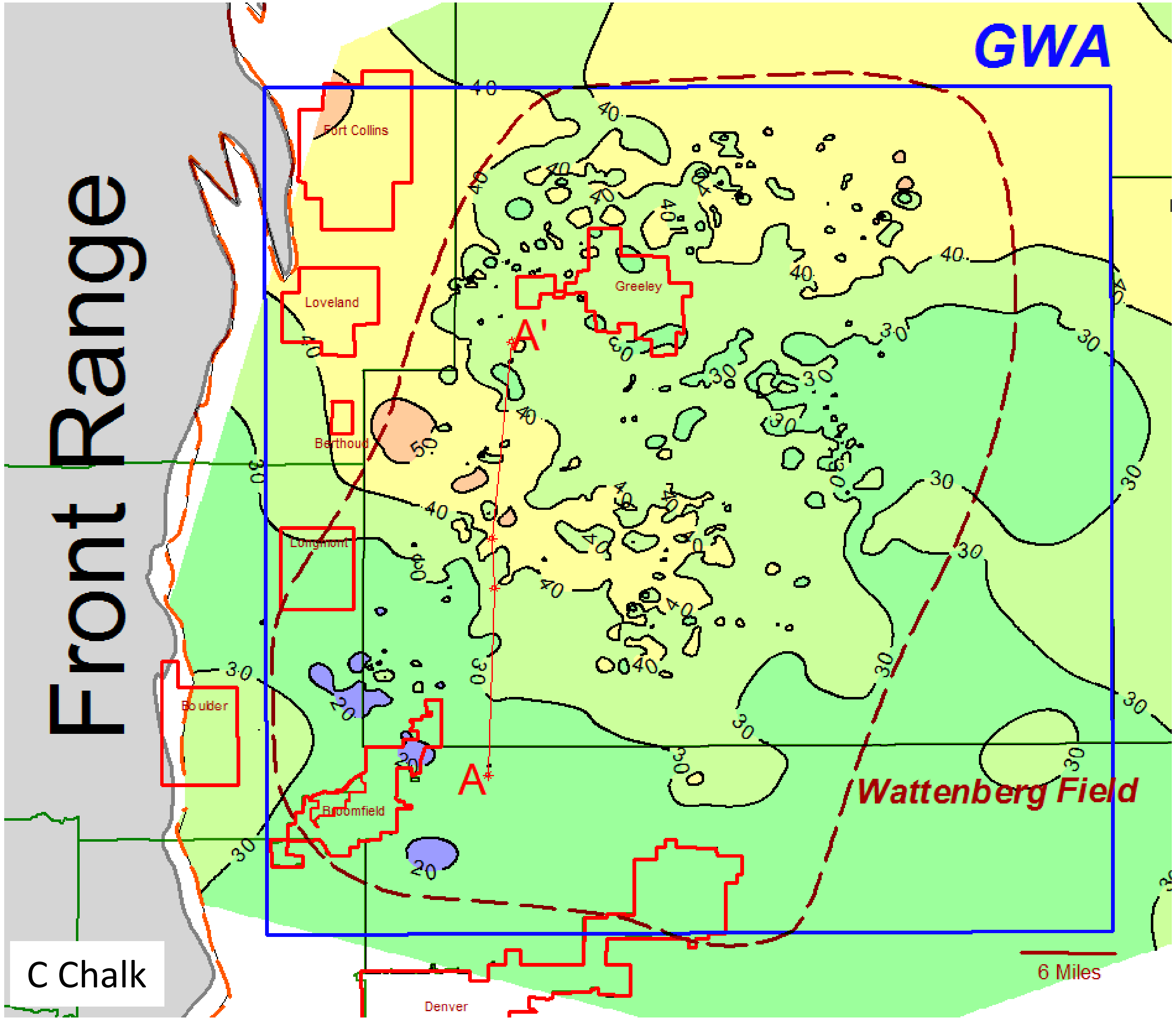


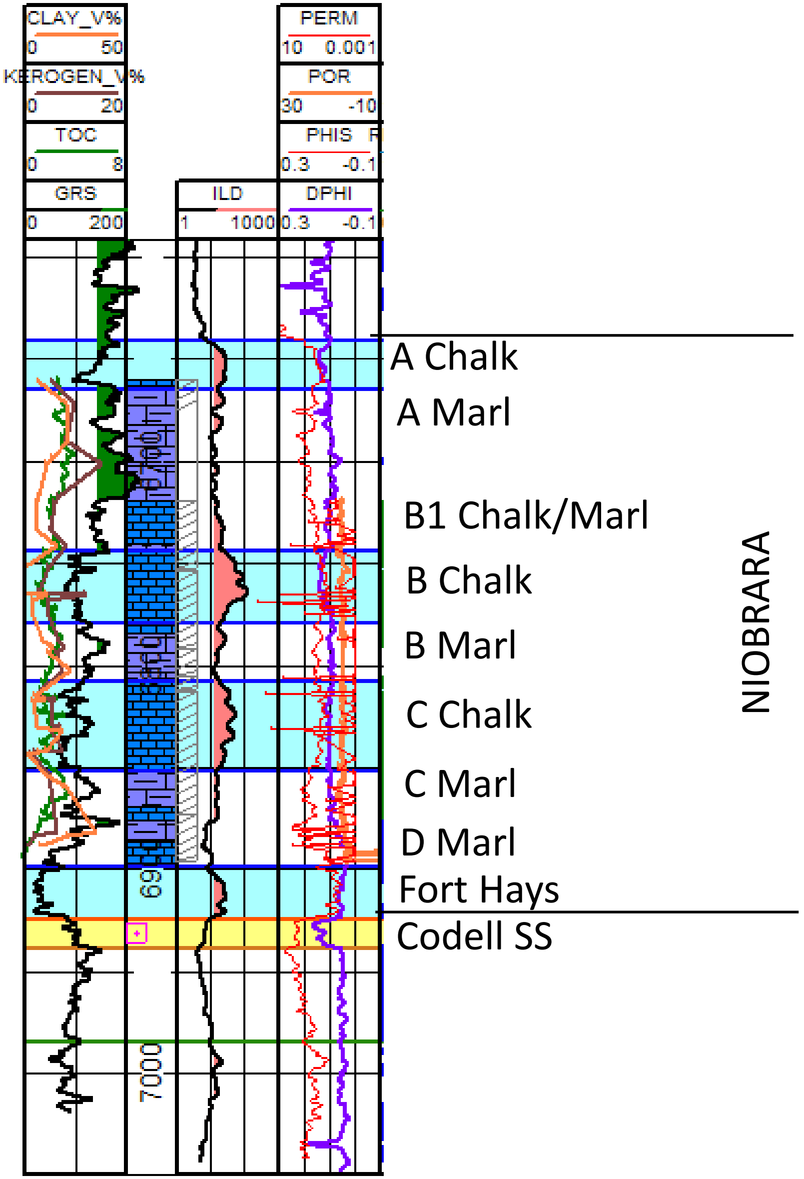


Cross Section Datum: C Chalk

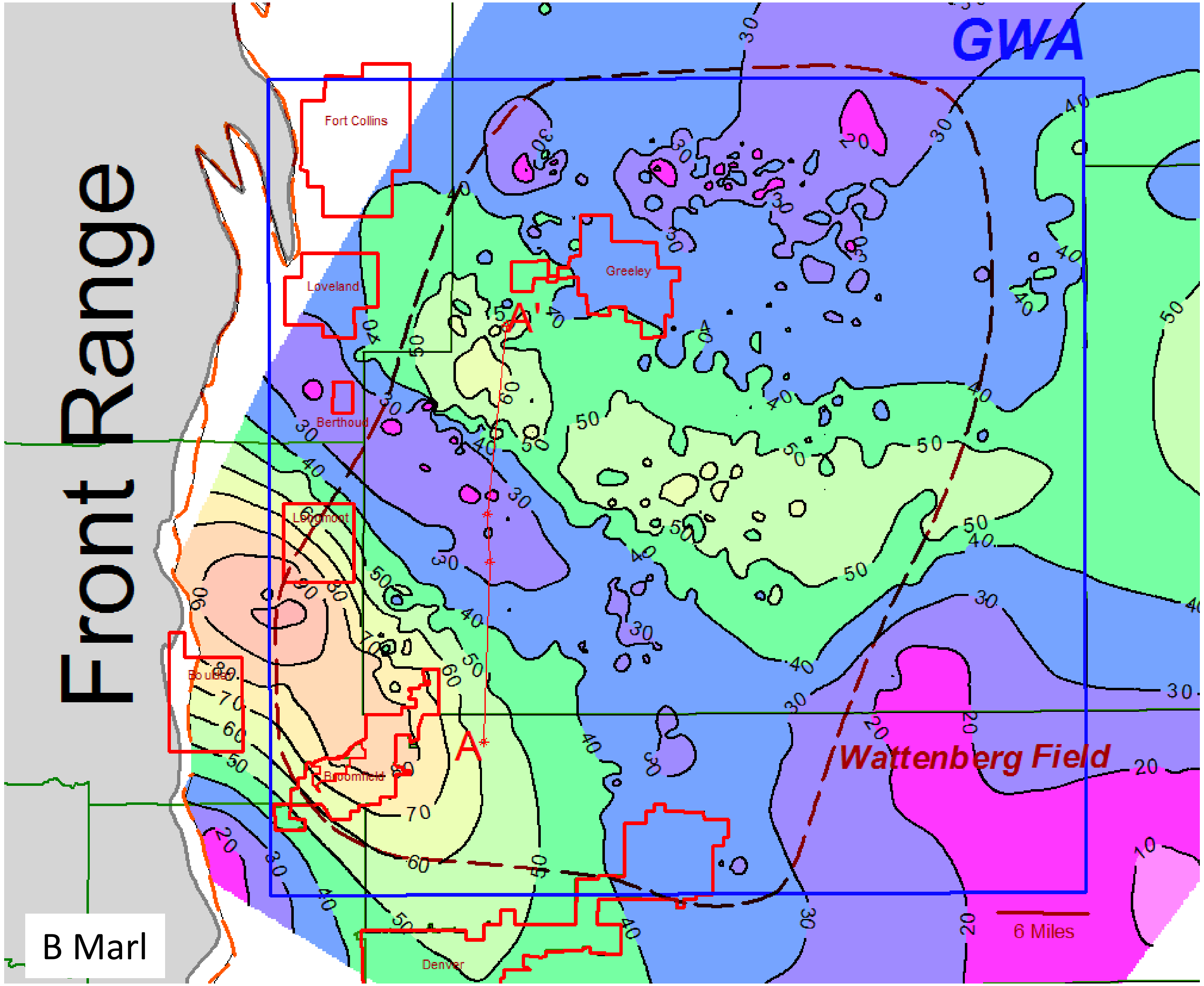


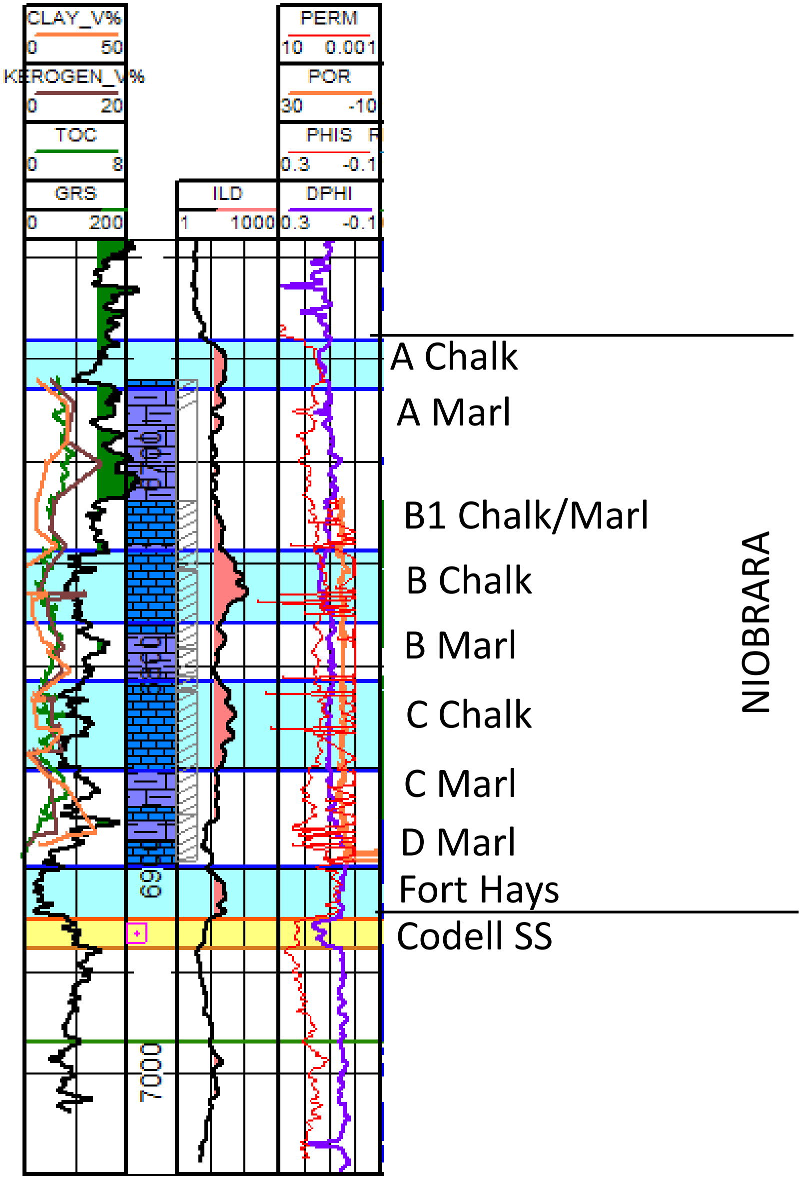
Isopach C Chalk



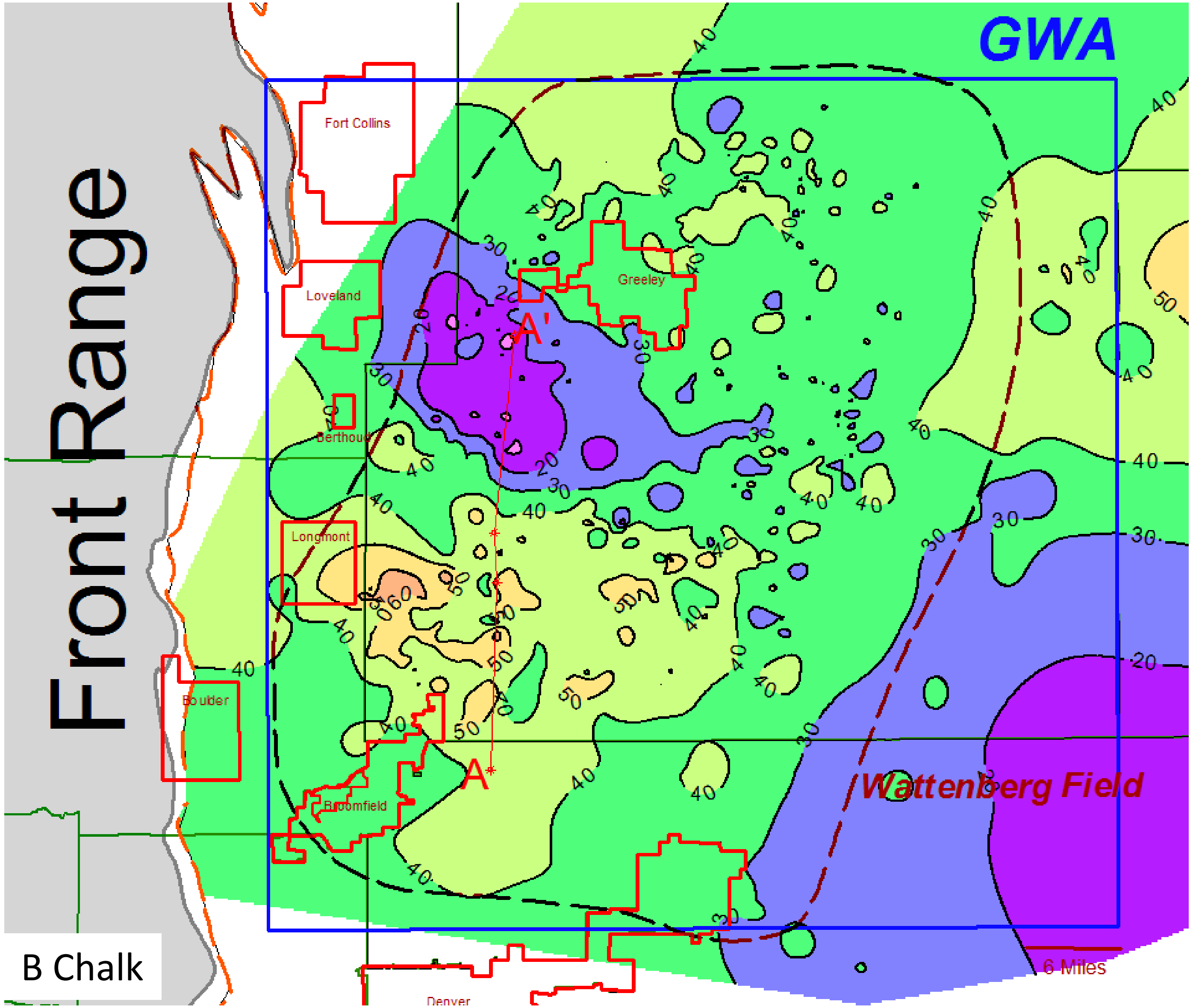


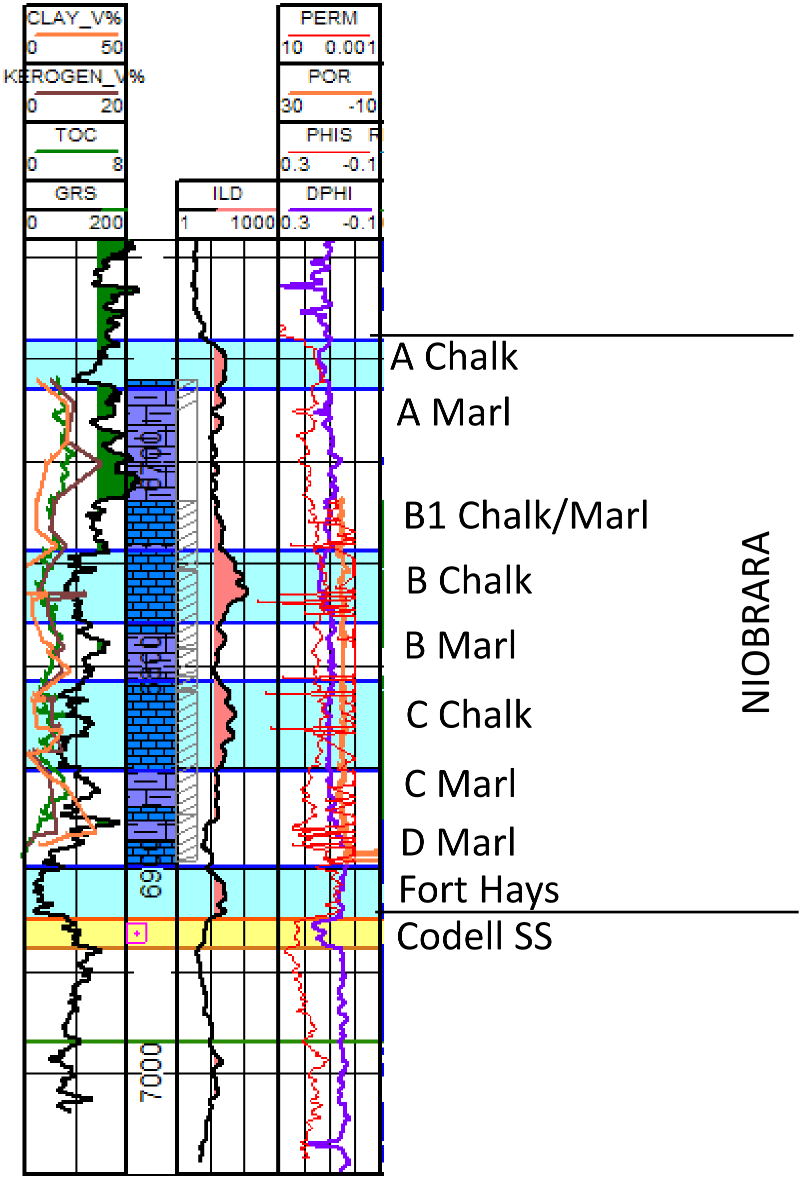
Isopach B Marl

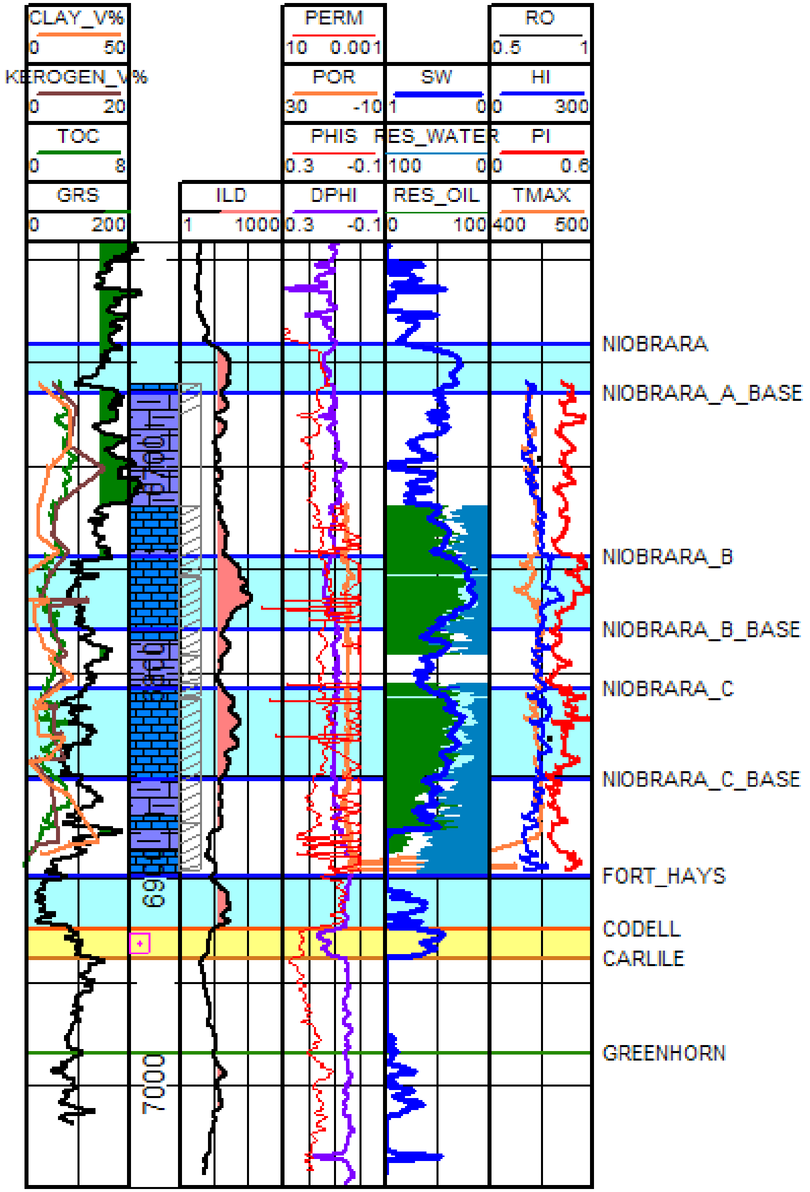


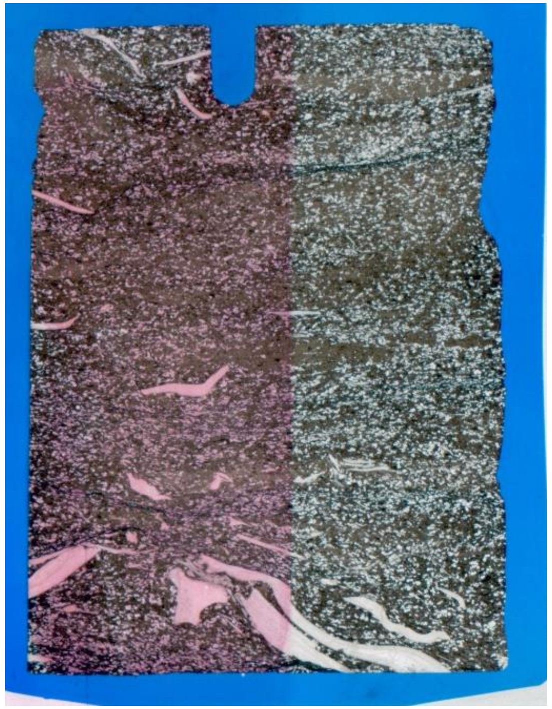


Isopach B Chalk

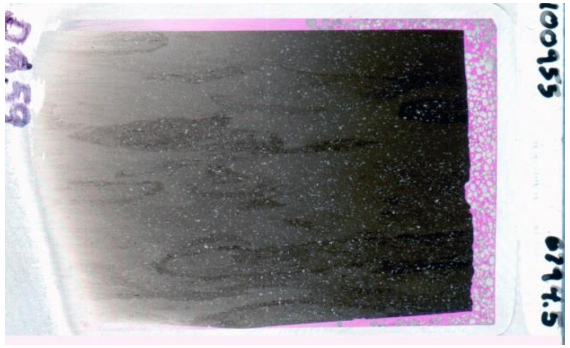




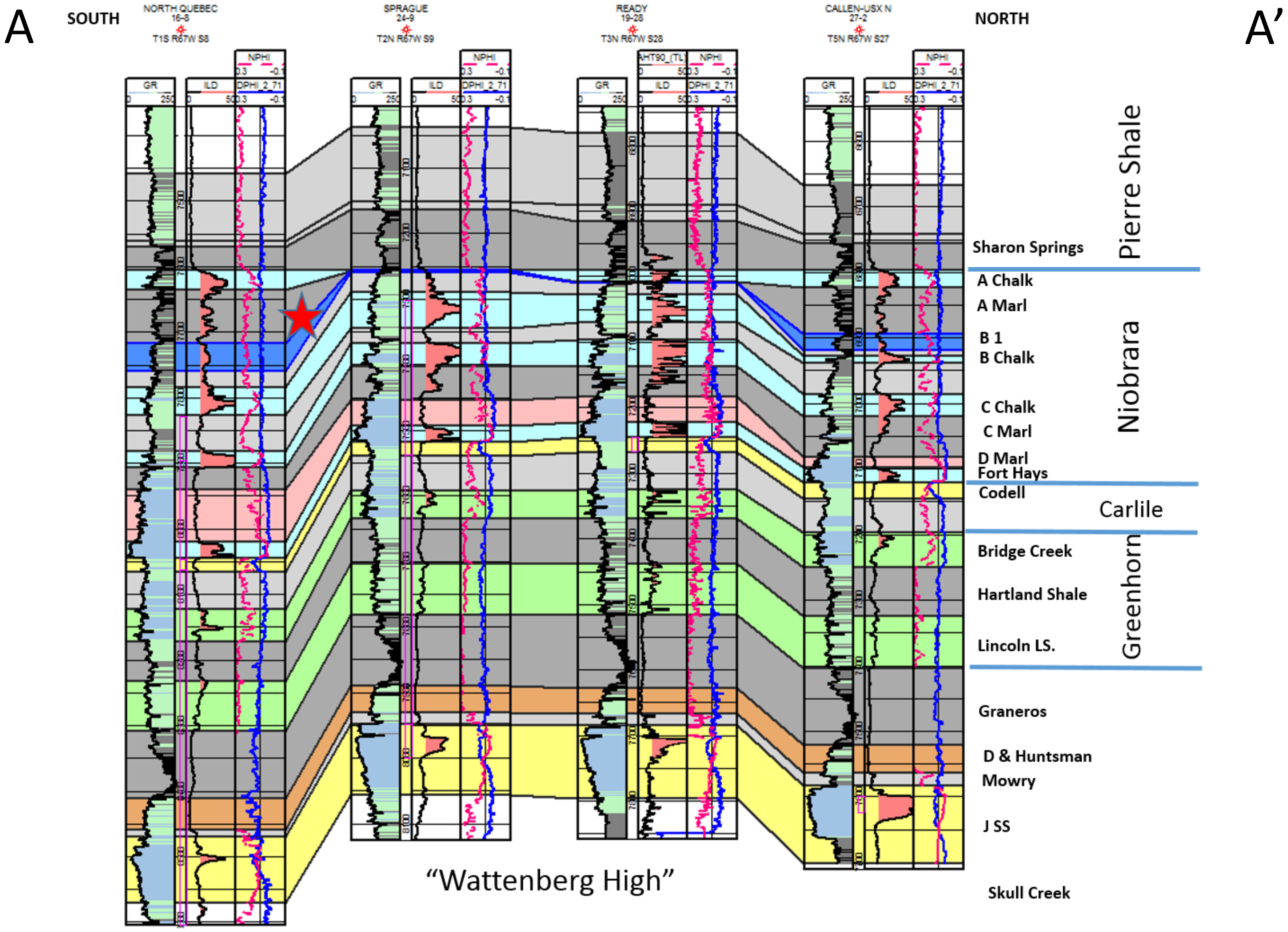




B chalk

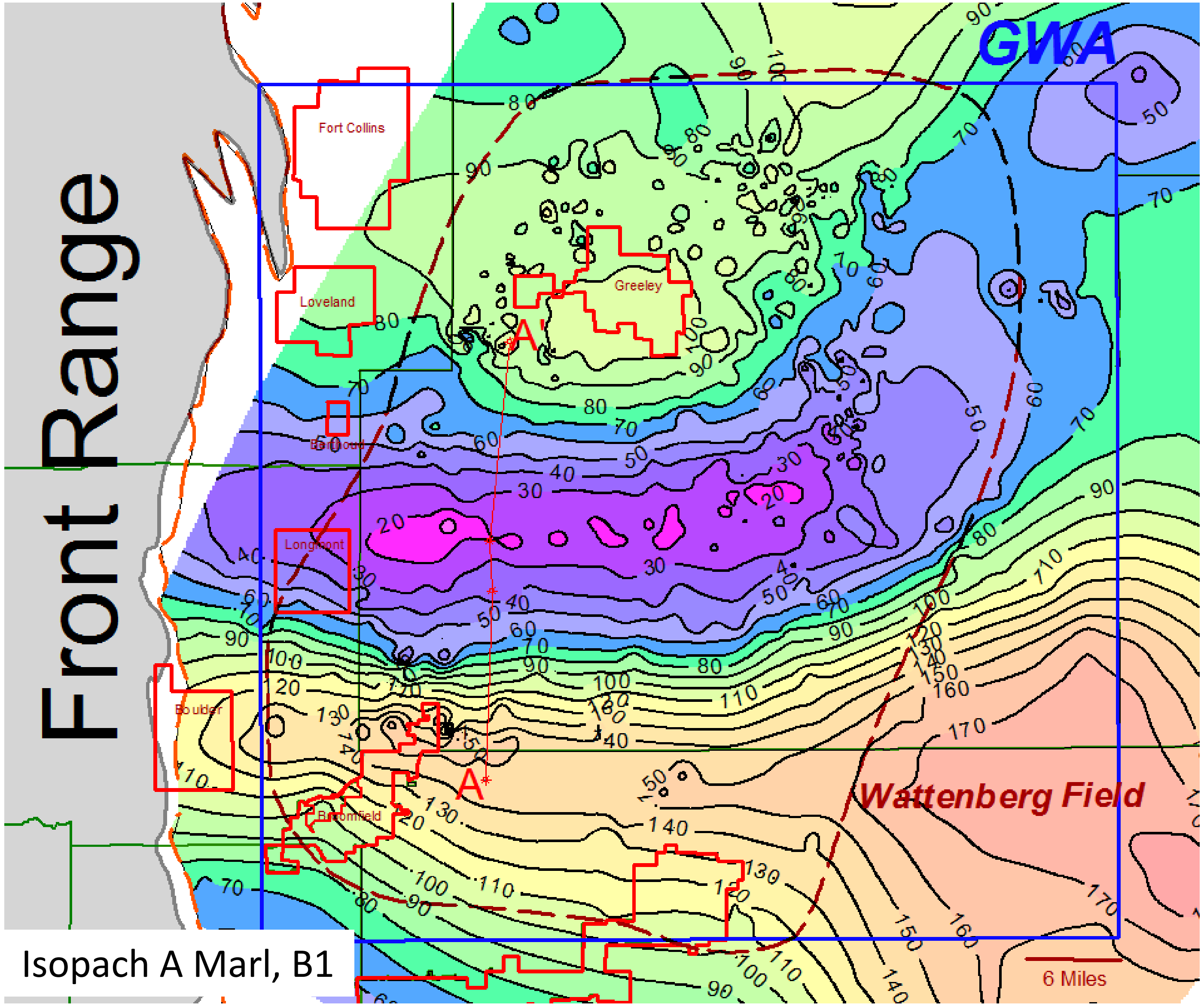


B marl

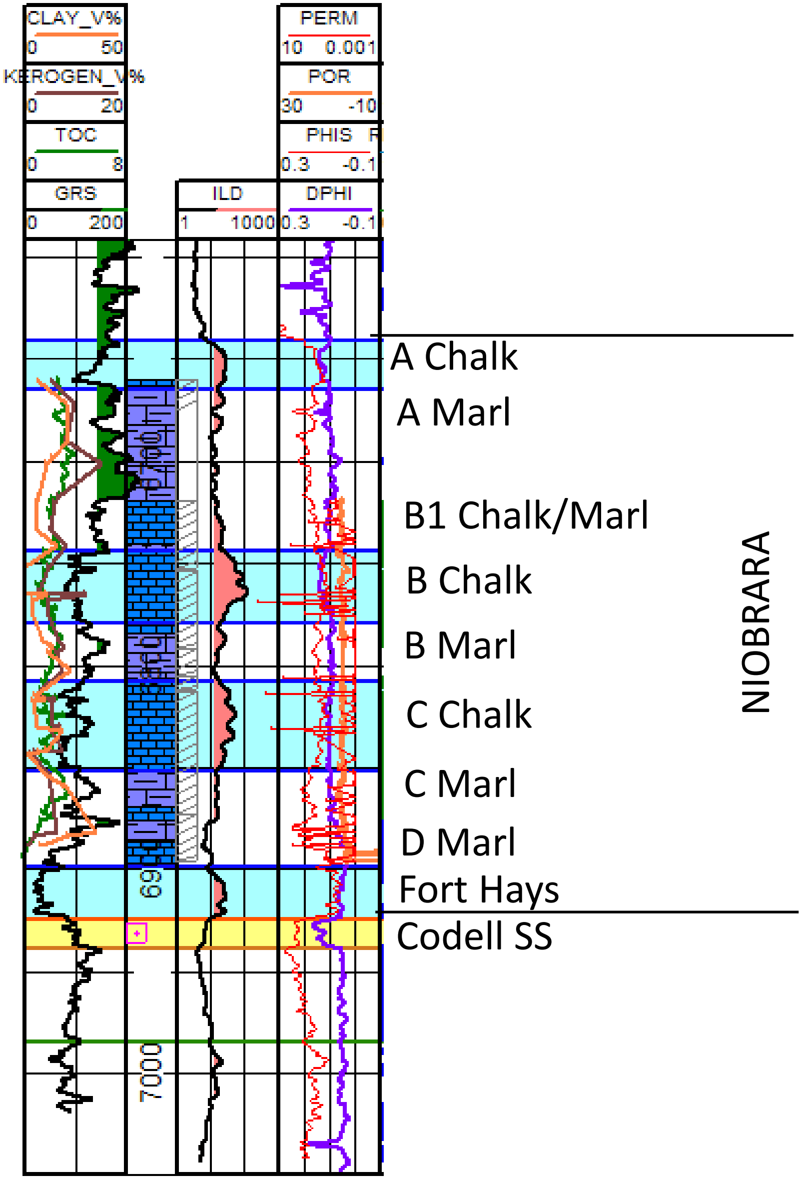


A
SOUTH
NORTH QUEBEC
16-8
T1S R67W S8
SPRAGUE
24-9
T2N R67W S9
READY
19-28
T3N R67W S28
CALLEN-USX N
27-2
T5N R67W S27
NORTH
A'
GR
ILD
NPHI
DPHI_2_71
Pierre Shale
Sharon Springs
A Chalk
A Marl
B 1
B Chalk
C Chalk
C Marl
D Marl
Fort Hays
Niobrara
Codell
Carlile
Bridge Creek
Hartland Shale
Lincoln LS.
Greenhorn
Graneros
D & Huntsman
Mowry
J SS
Skull Creek
"Wattenberg High"

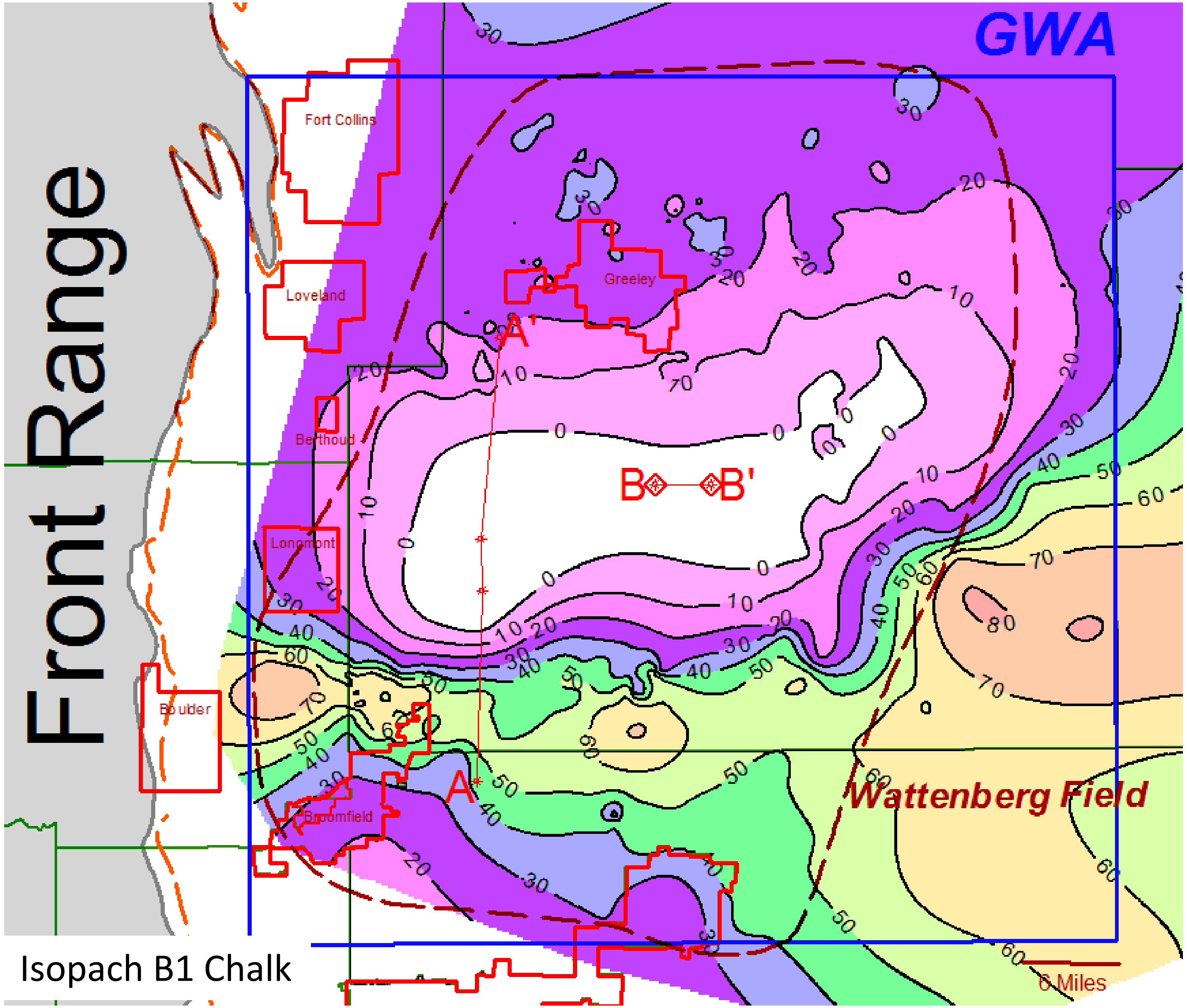
Isopach A Marl & B1



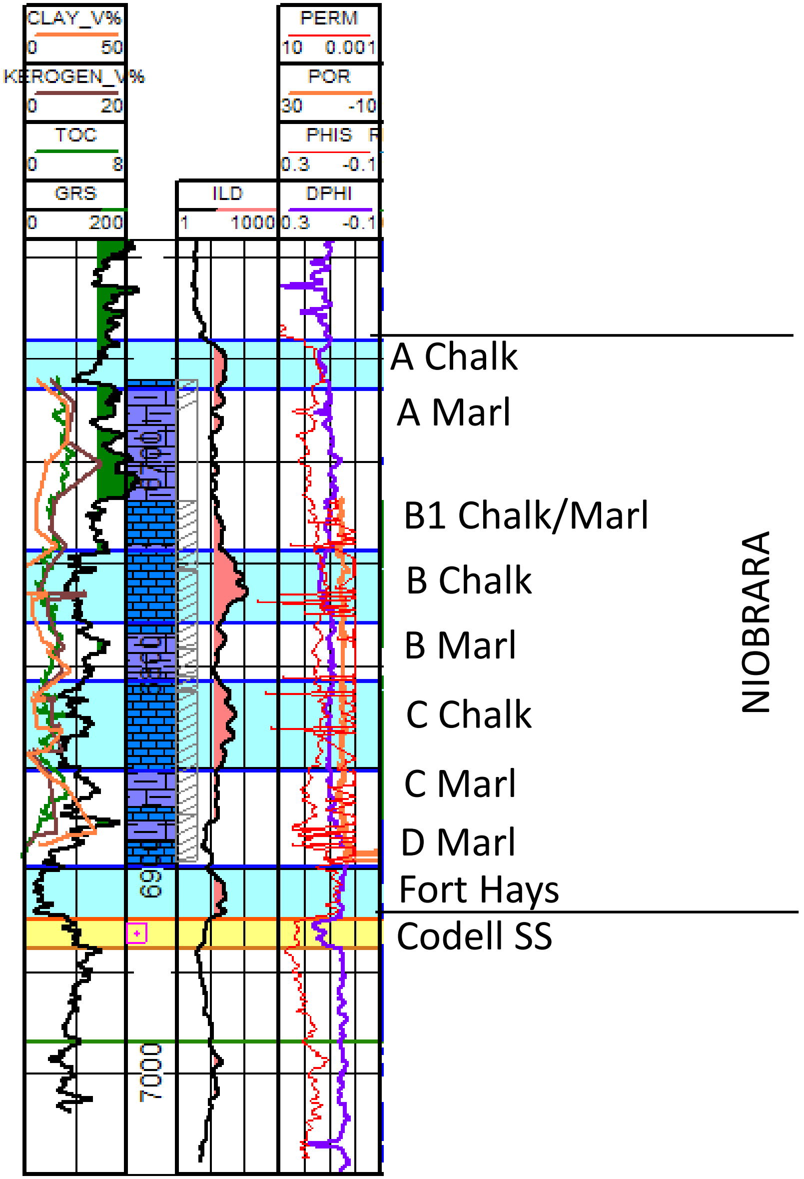
Isopach A Marl, B1



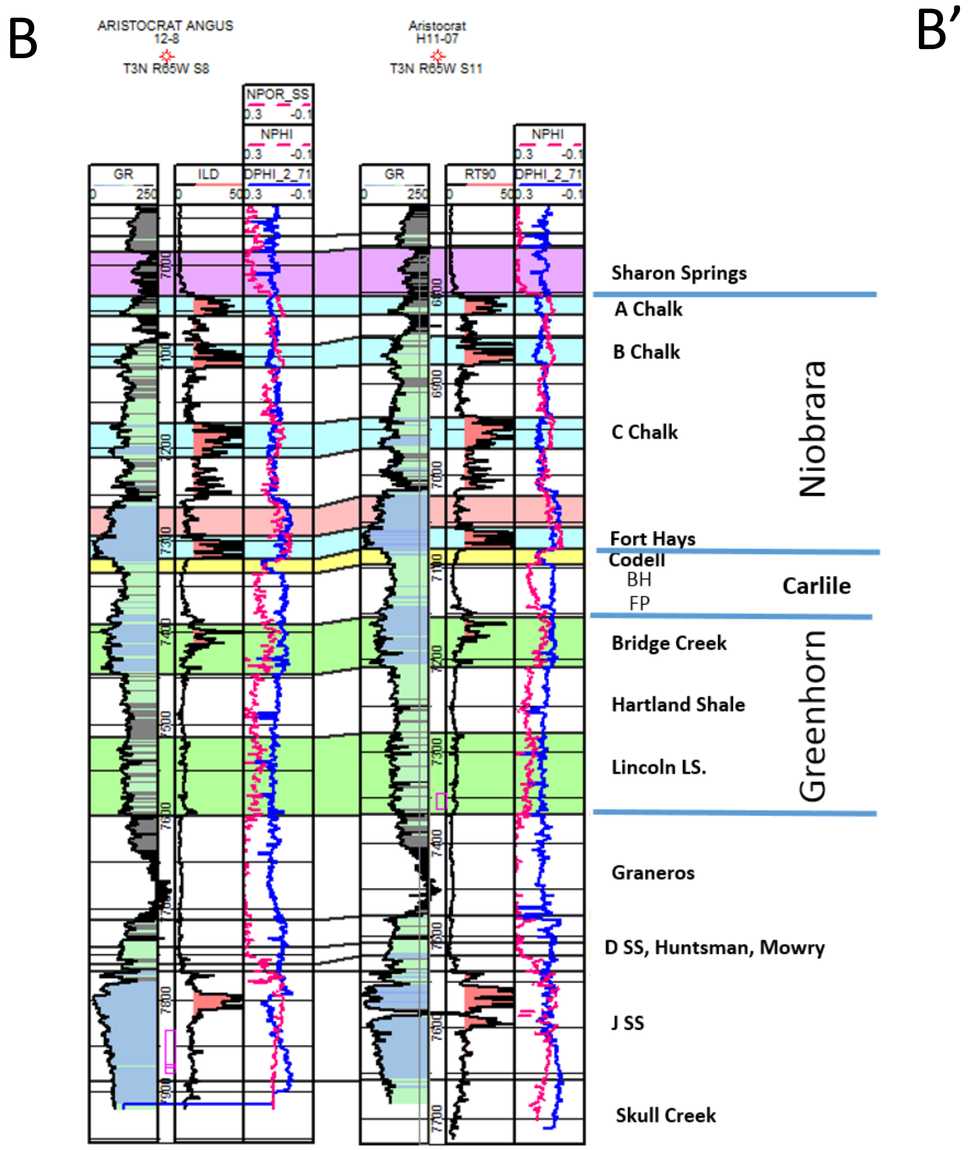
Isopach B1



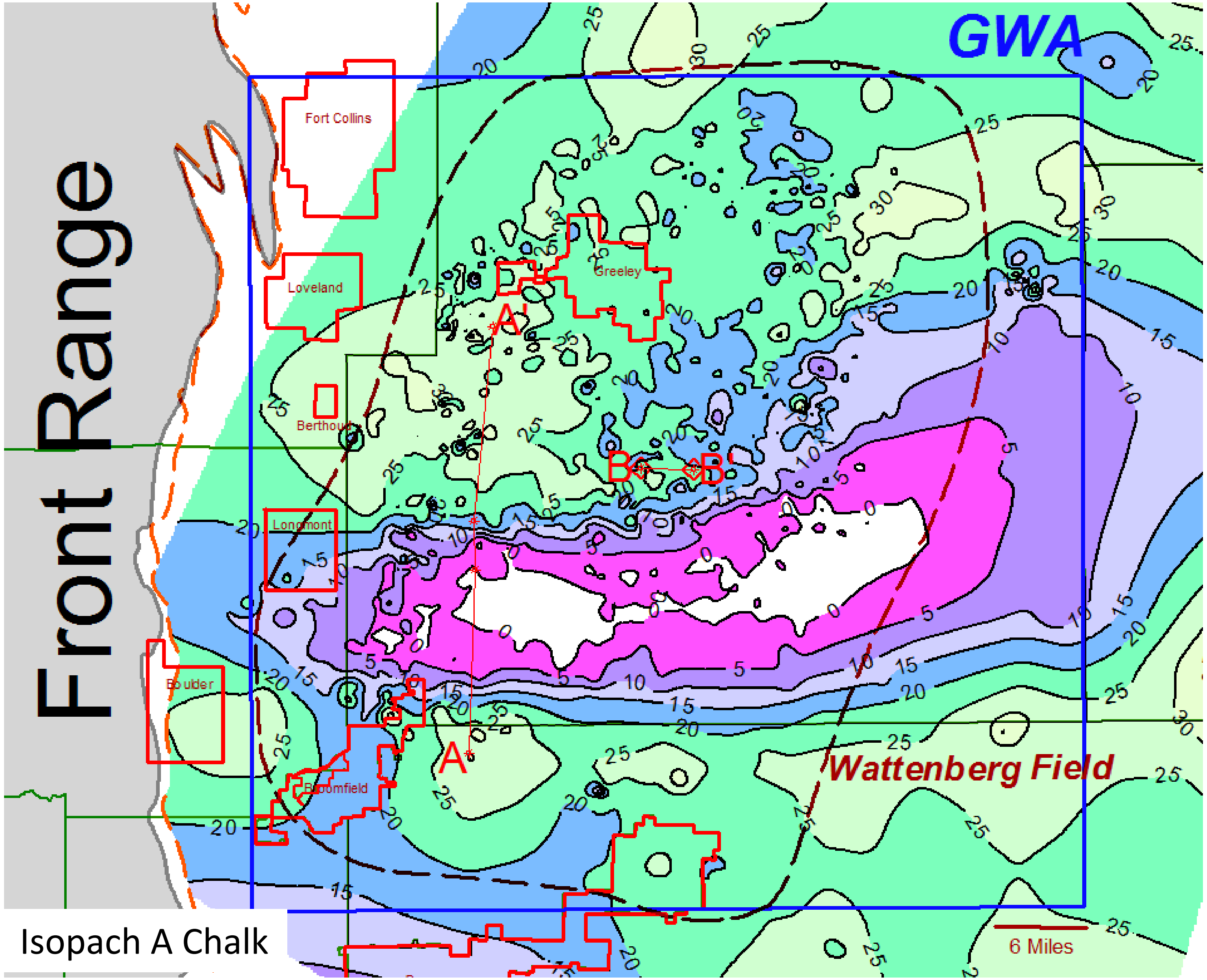
Isopach B1 Chalk



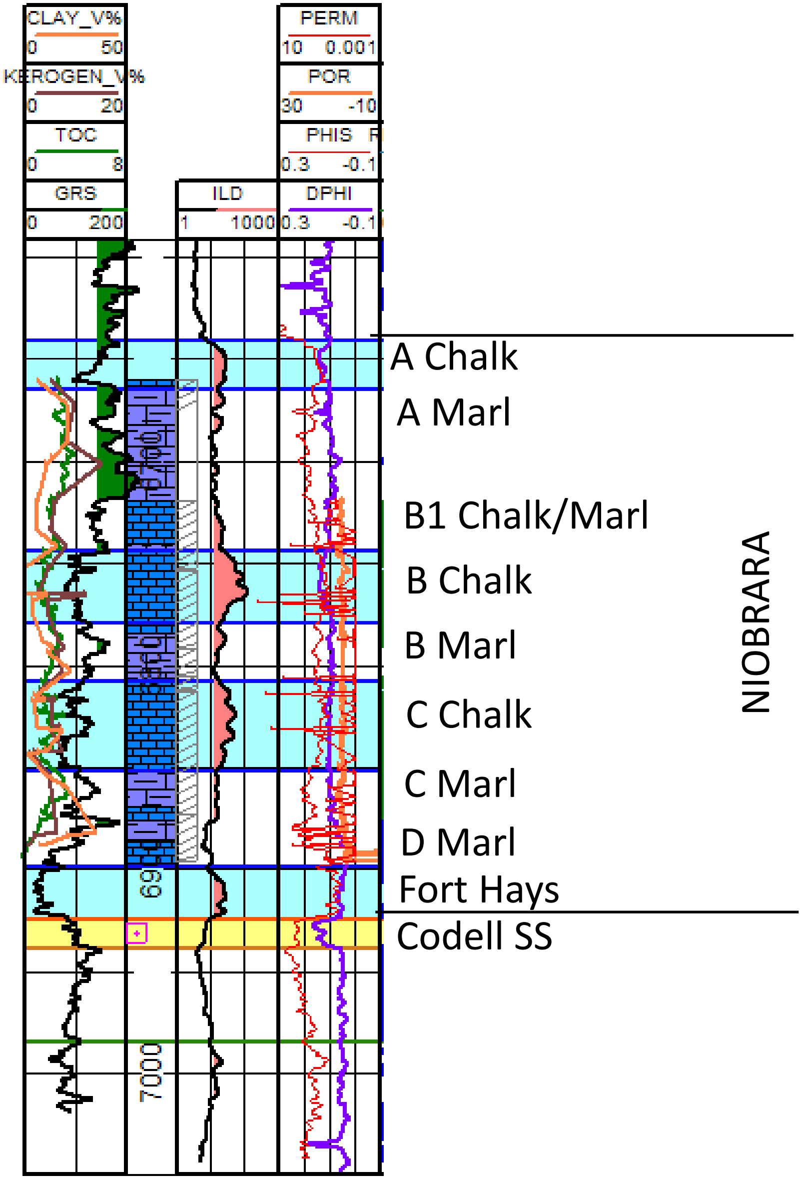
Cross Section B-B’

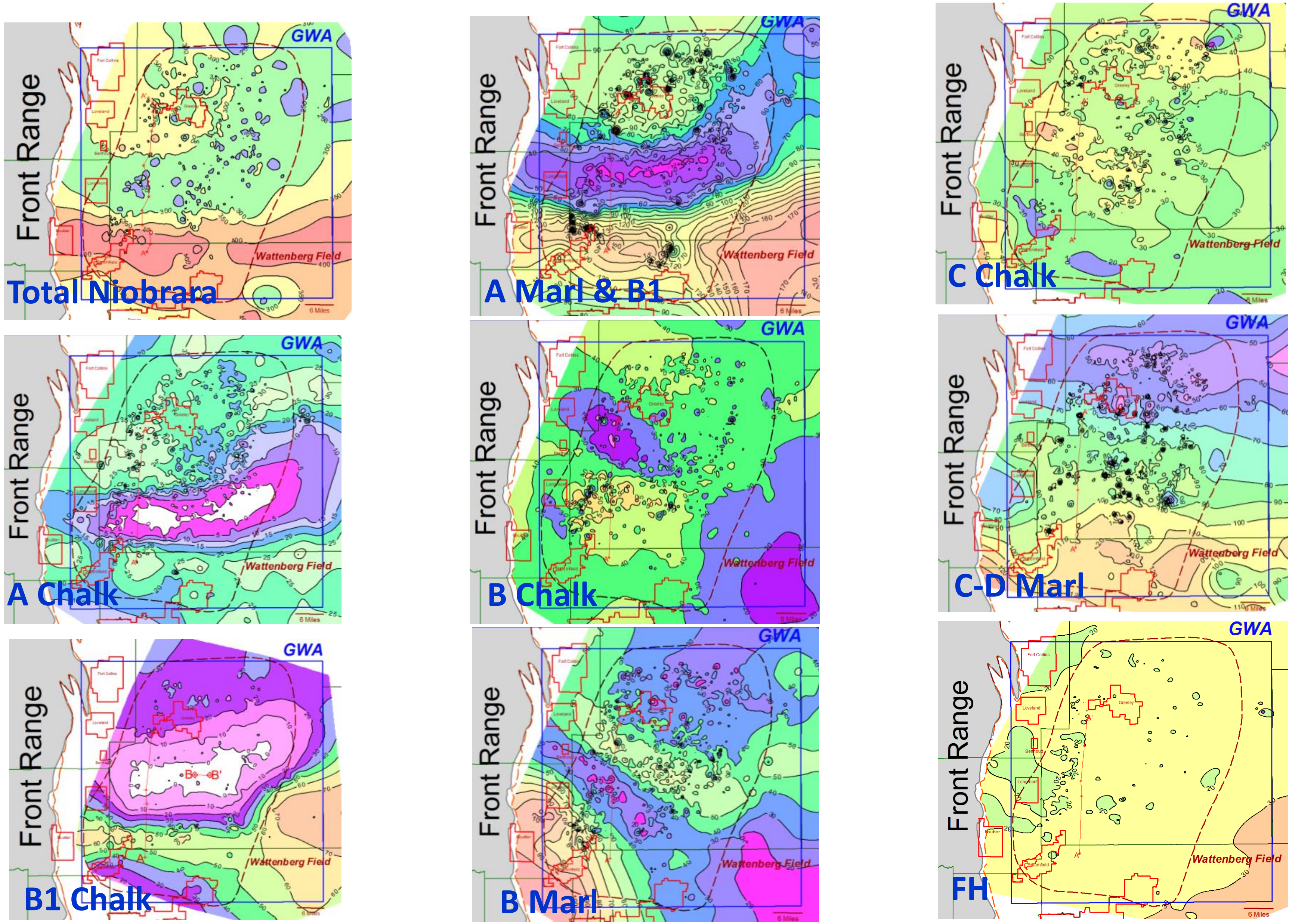


Isopach A Chalk



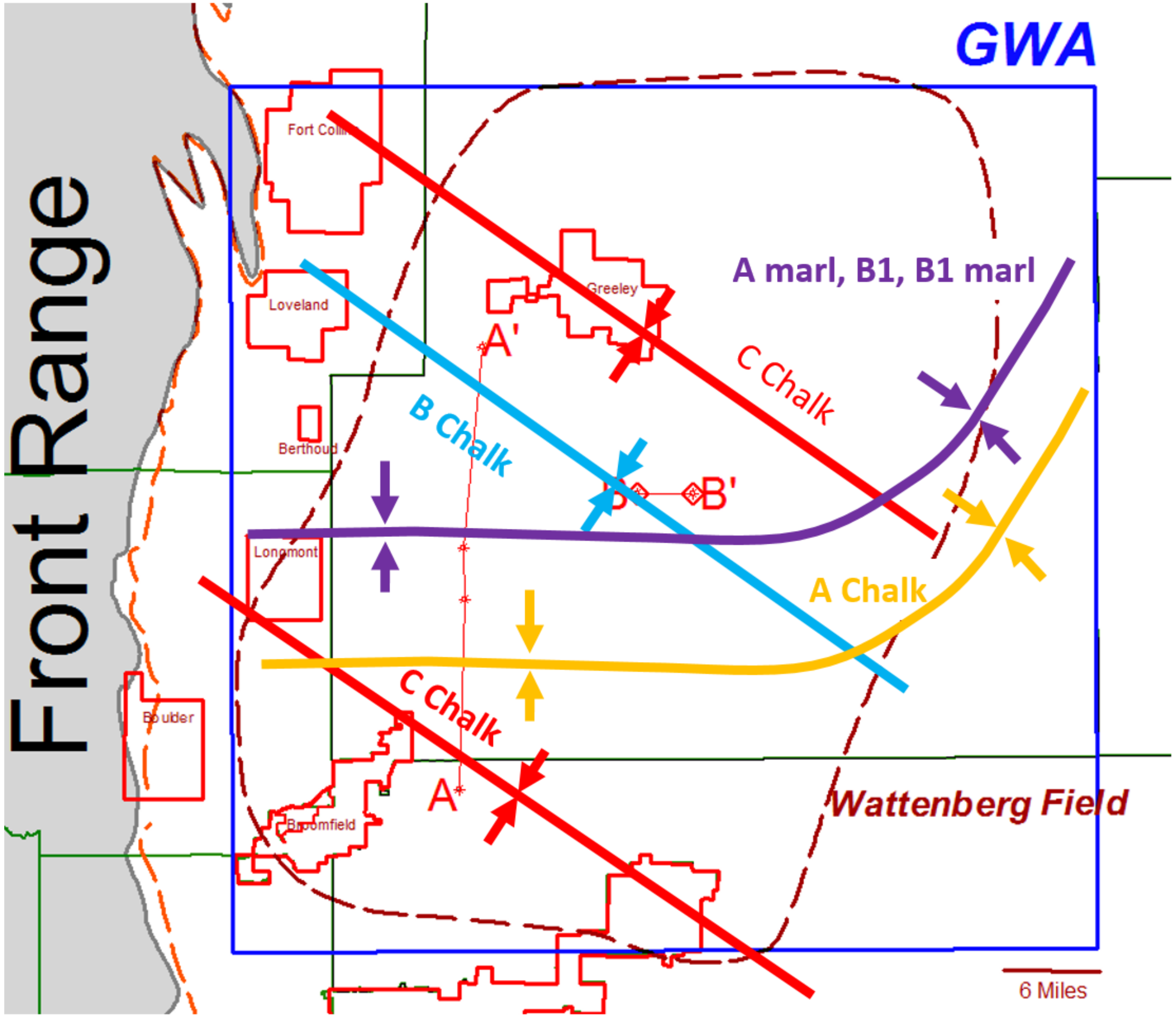
Isopach A Chalk





GWA
Front Range
Wattenberg Field
Total Niobrara
A Marl & B1
C Chalk
A Chalk
B Chalk
C-D Marl
B1 Chalk
B Marl
FH

Axes of Thinning in Niobrara Units

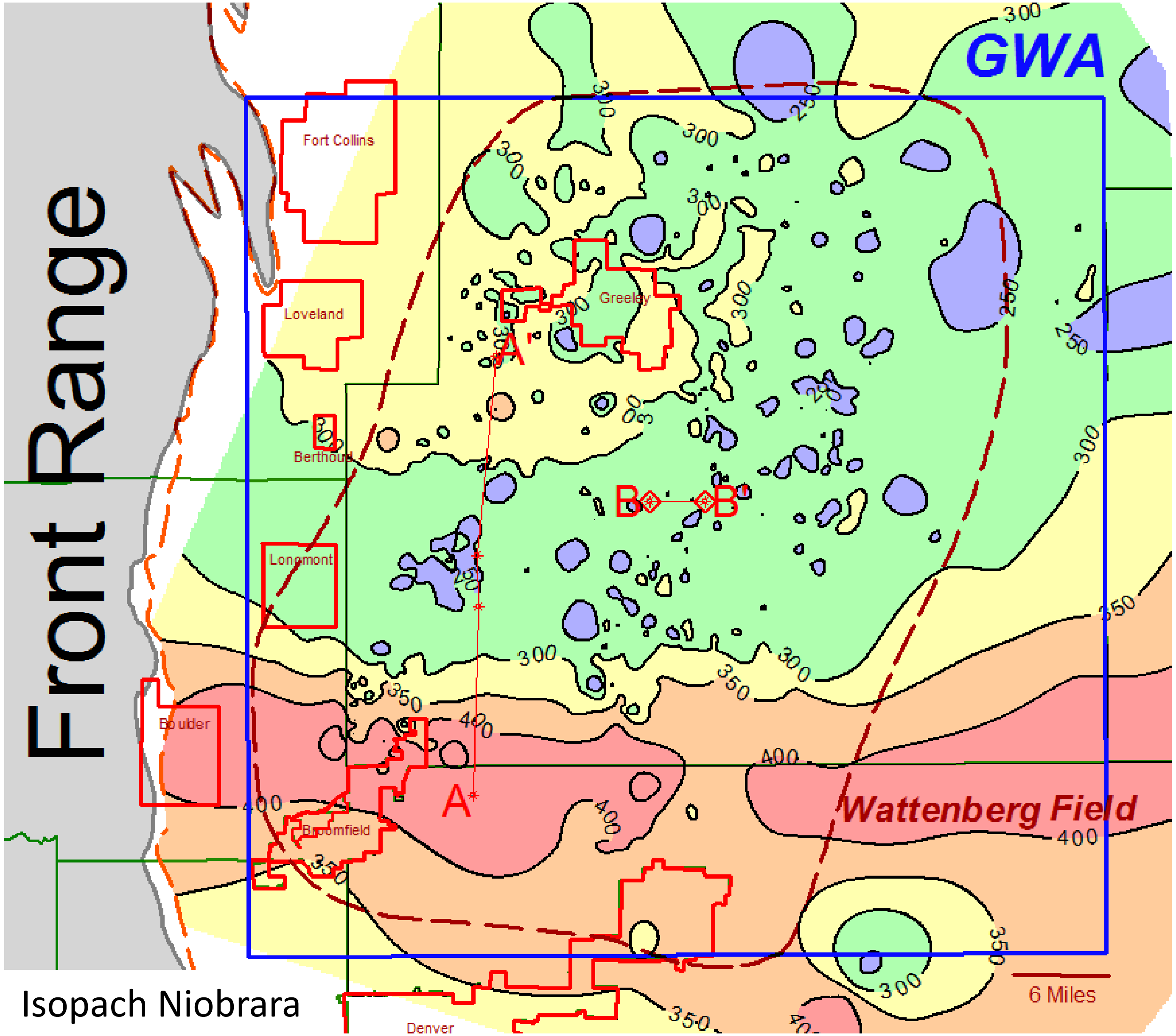


Clinoforms in C & D
(South to north)

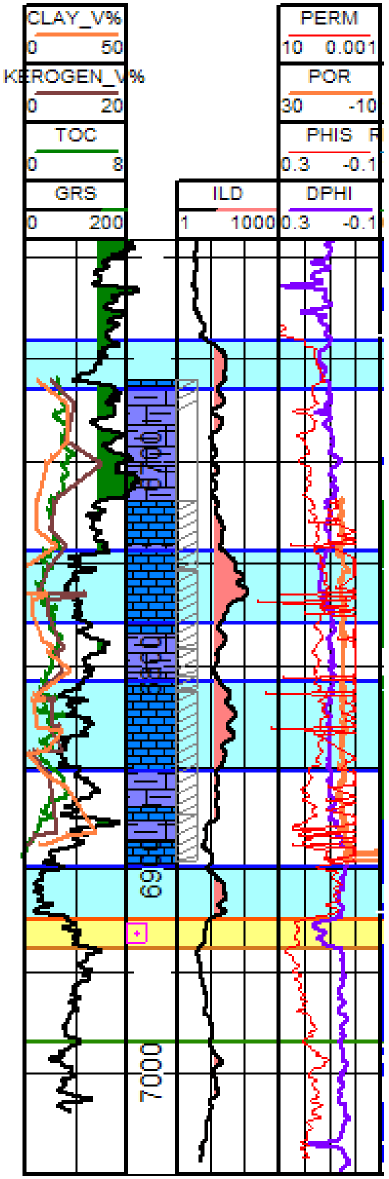
Compensational stacking patterns B & C
Associated with pellet bar formation and
other causes

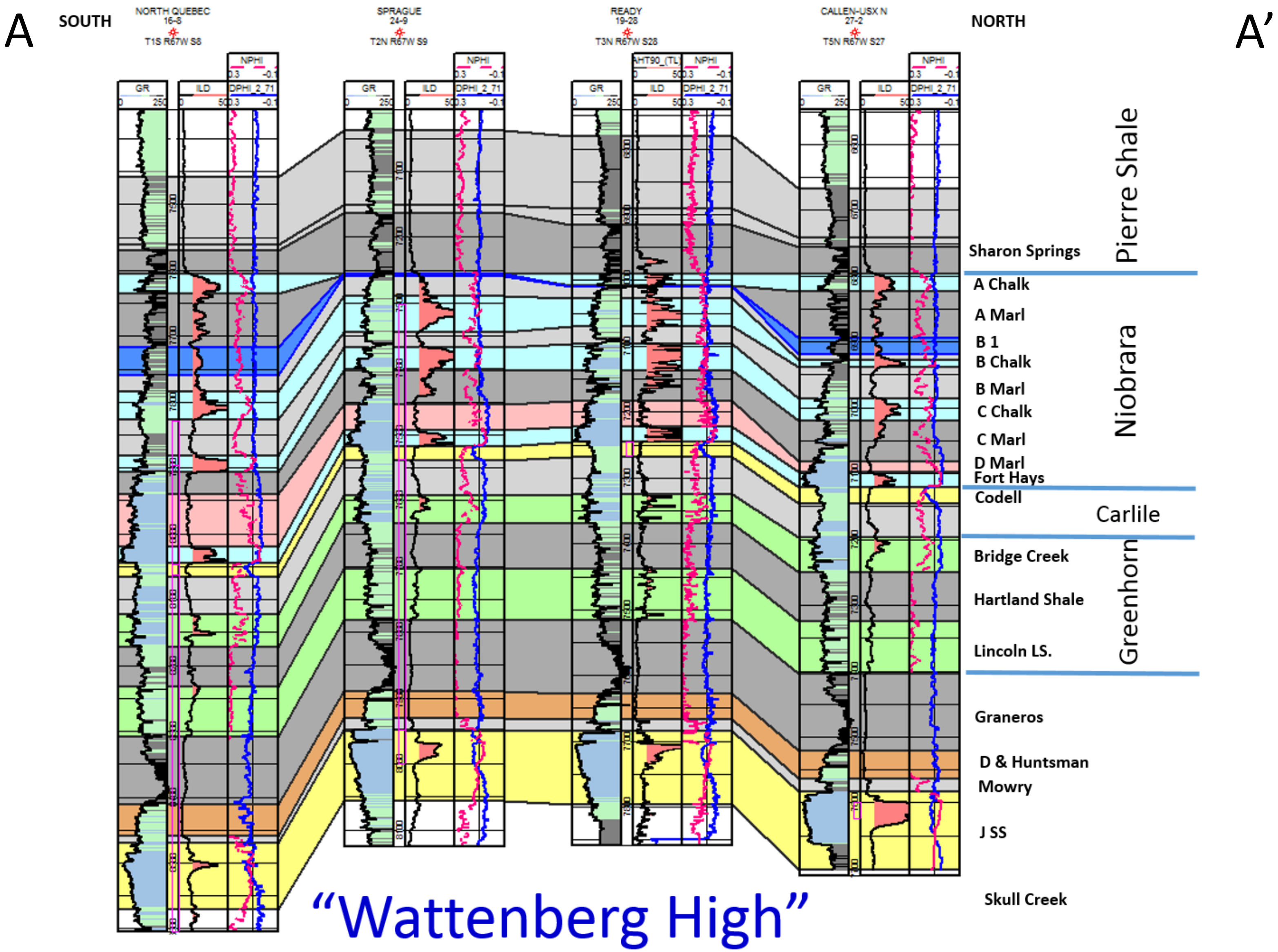
Erosion of A Chalk, A marl, B1 associated
with paleostructural movement

Isopach Niobrara



Isopach Niobrara





A
SOUTH
NORTH QUEBEC 16-8
T1S R67W S8
SPRAGUE 24-9
T2N R67W S9
READY 19-28
T3N R67W S28
CALLEN-USX N 27-2
T5N R67W S27
NORTH
A'
GR
ILD
NPHI
DPHI_2_71
Pierre Shale
Sharon Springs
A Chalk
A Marl
B 1
B Chalk
B Marl
C Chalk
C Marl
D Marl
Fort Hays
Niobrara
Codell
Carlile
Bridge Creek
Hartland Shale
Lincoln LS.
Greenhorn
Graneros
D & Huntsman
Mowry
J SS
Skull Creek
"Wattenberg High"

Summary

- Wattenberg Field is seeing a new beginning because of the Niobrara & Codell
- Stratigraphic architecture important for development planning
  - Compensational stacking affects C and B units
  - Erosional and onlap affects A Chalk, A Marl, B1 Chalk
- Source bed distribution affected by stratigraphic complexity
  - D Marl clinoforms affect C Marl distribution
  - Erosion removes A Marl in areas
- Horizontal drilling and multistage fracture stimulation are key drivers
- New reserves are found in old fields with new technology and ideas!