Reservoir Characterization of the Codell and Niobrara Formations, Postle Area, Wattenberg Field

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MS - 2023

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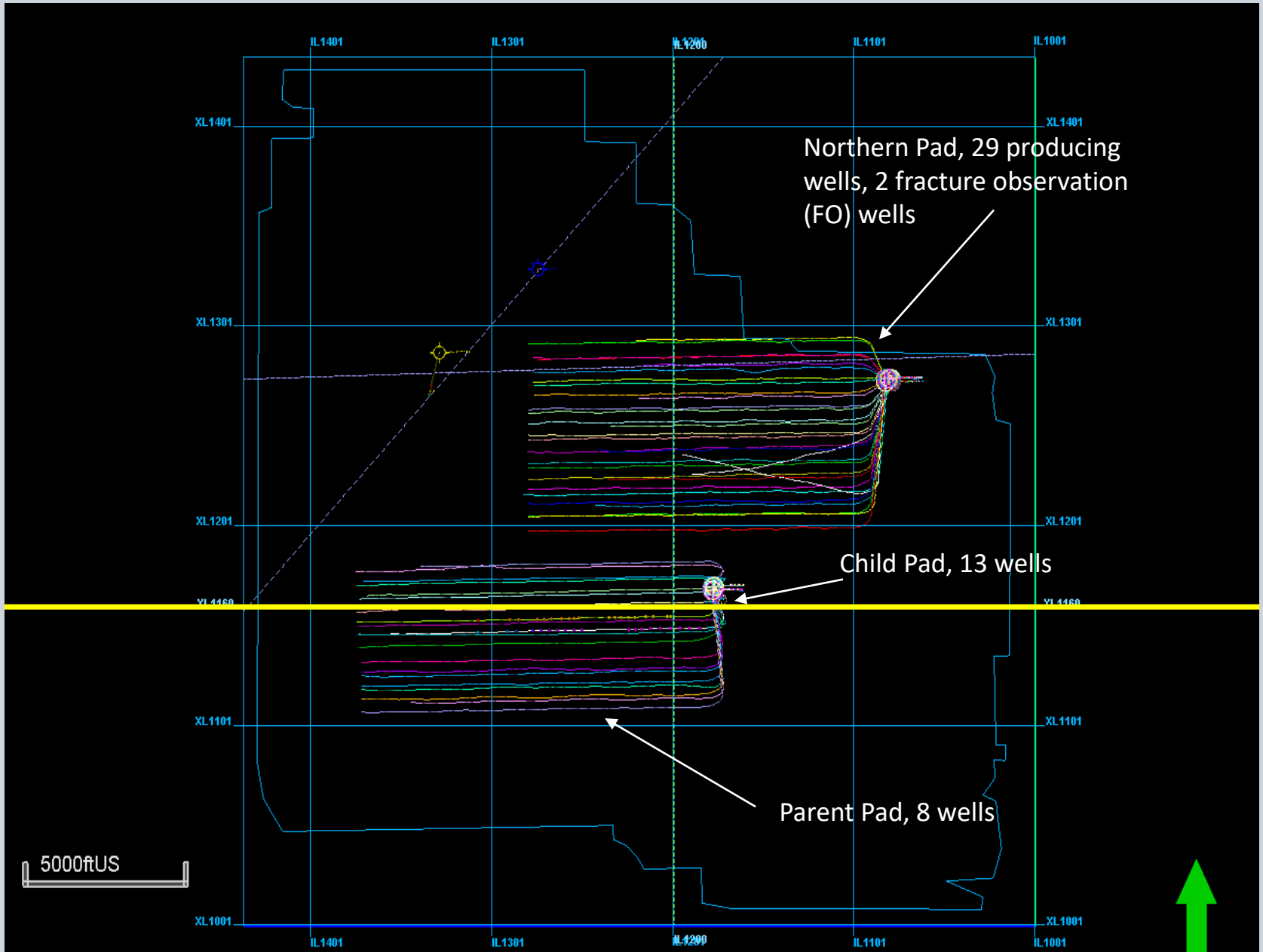
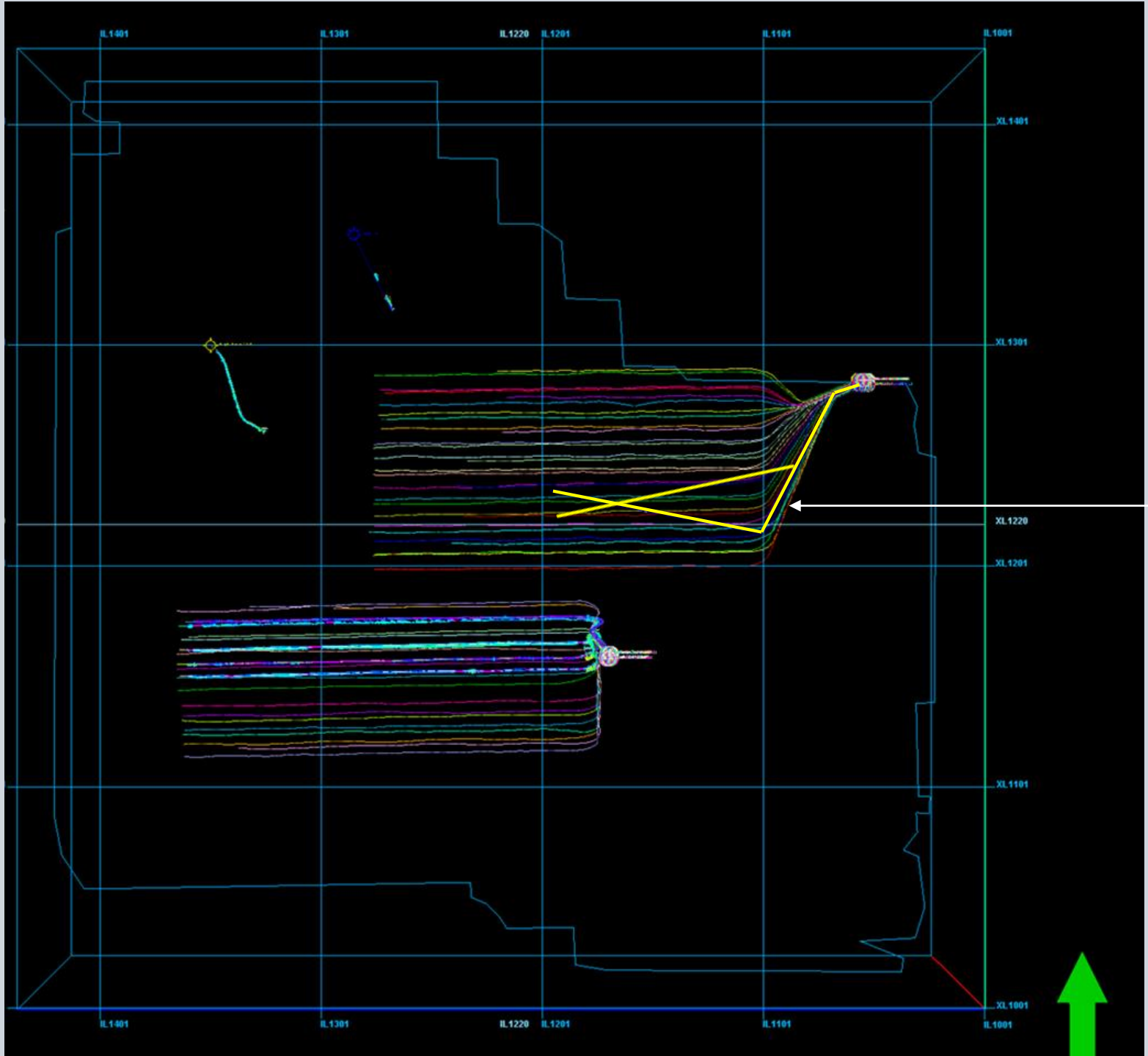
Reservoir Question to Answer

- Detailed reservoir characterization of the Codell and Niobrara formations will be performed, including both natural and induced fractures.
- Interpretation of the image log data can establish the spatial geometry of the natural & induced fractures related to hydrocarbon production.

Study Area


IL1401
IL1301
IL1200
IL1101
IL1001
XL1401
XL1301
XL1201
XL1160
XL1101
XL1001
Northern Pad, 29 producing wells, 2 fracture observation (FO) wells
Child Pad, 13 wells
Parent Pad, 8 wells
5000ftUS



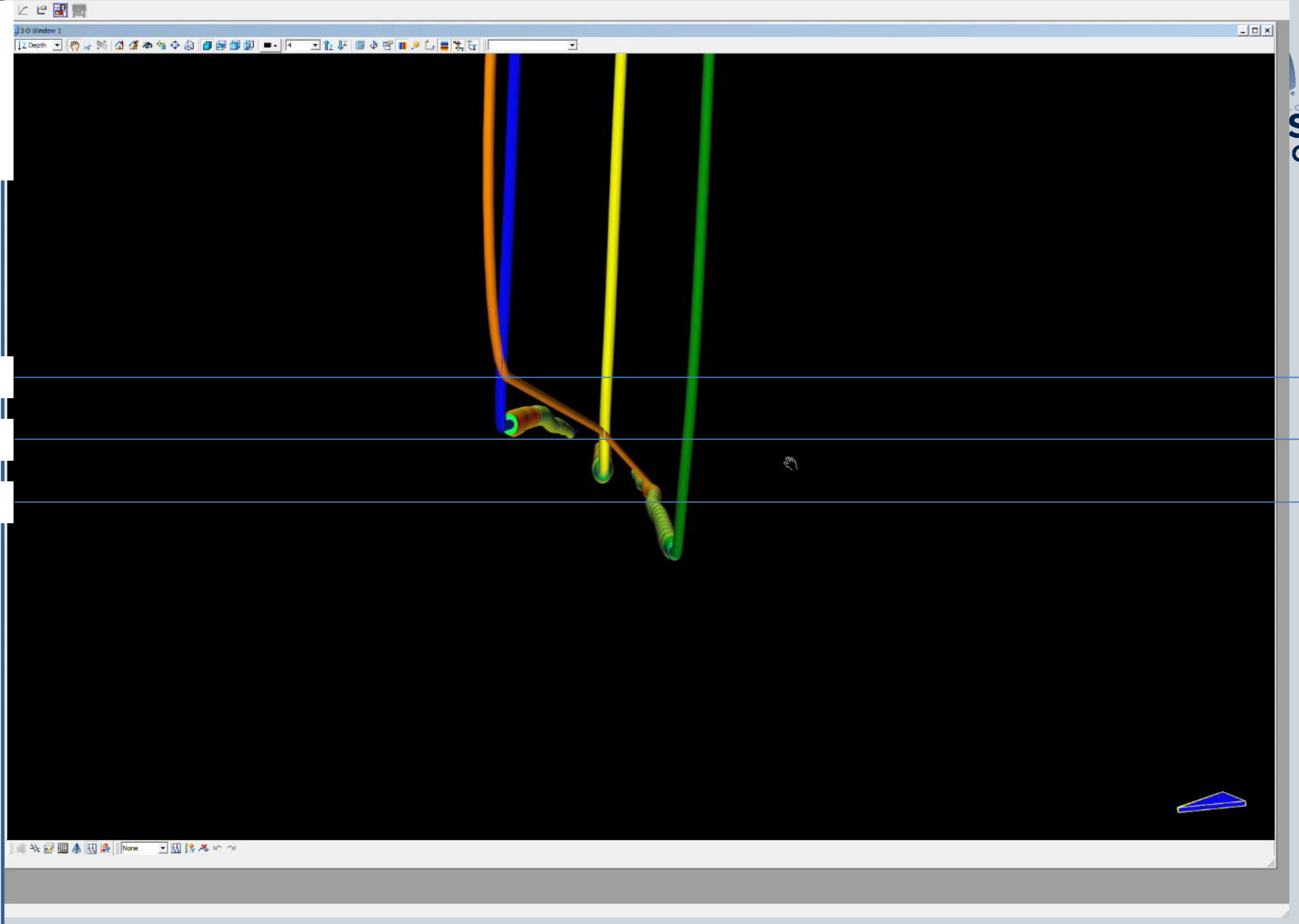
Fracture Observation (FO) Wells 1 & 2

Deviated well is FO2 -- Niobrara Chalk ~A through Codell

WNB – B Chalk

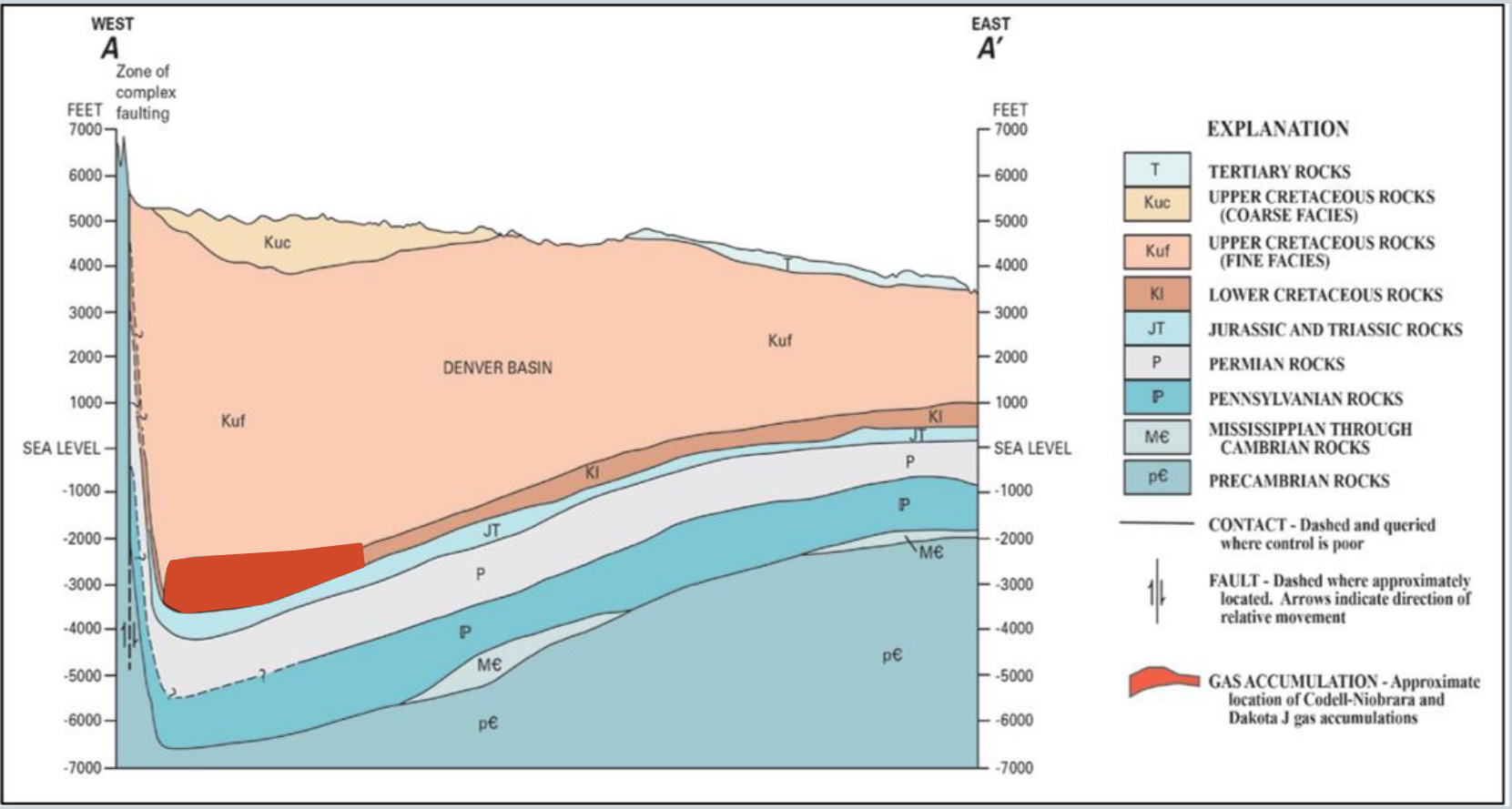
WNC – C Chalk

WC – Codell



Credit to: Damon Parker

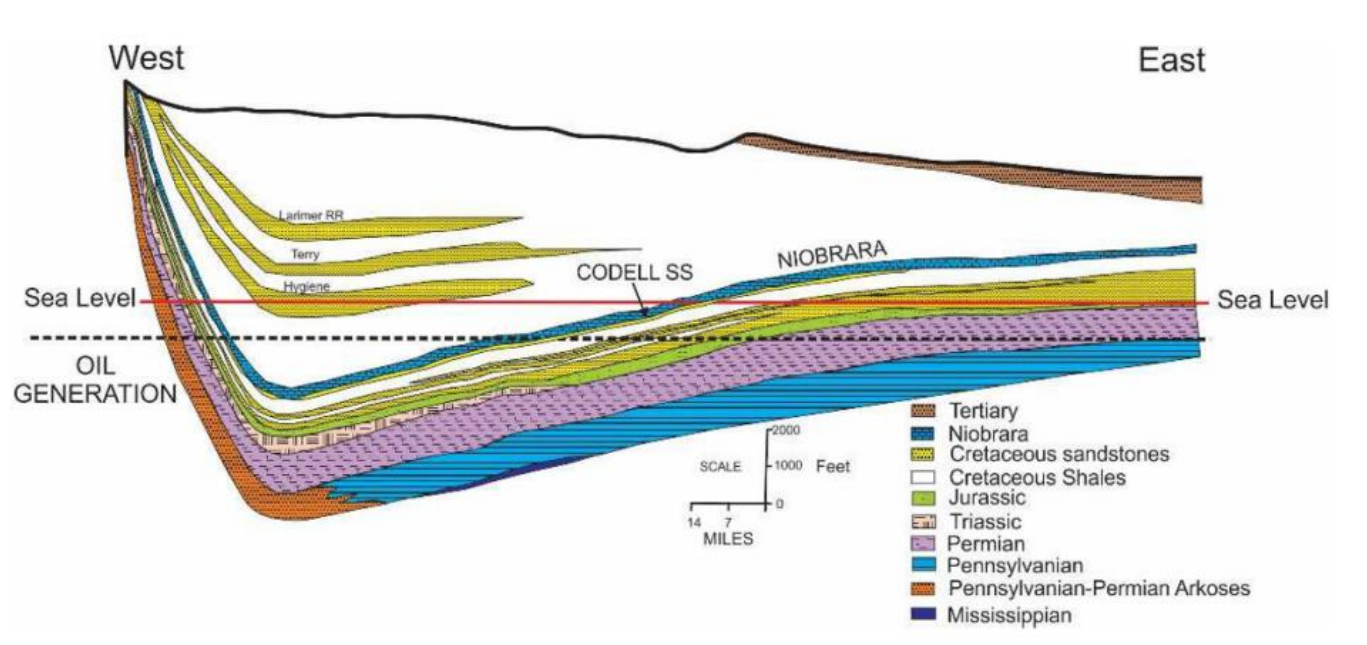
Geological Setting: Denver Basin



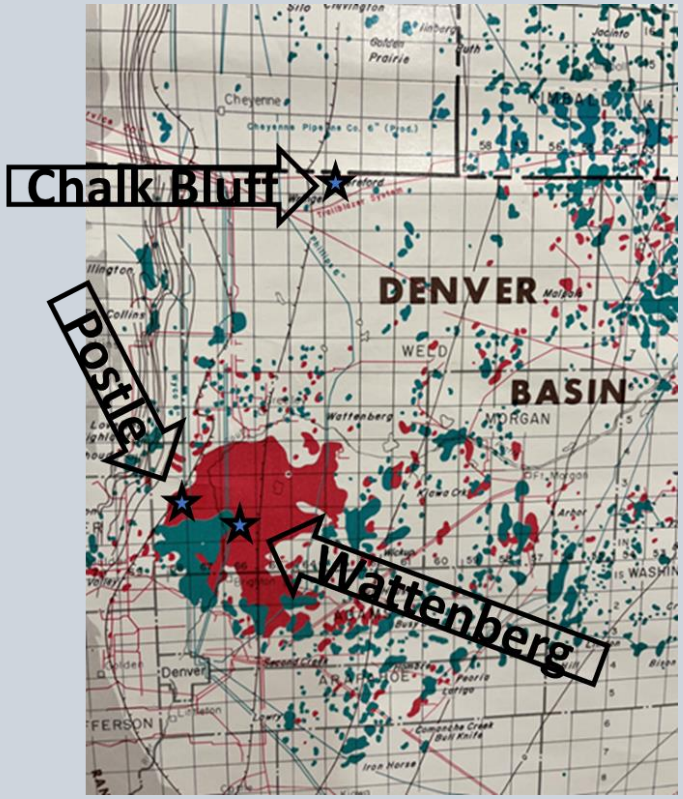
Credit to Nelson, P.,H., and Santus, S.L., USGS (2011)

- The Denver Basin encompasses more than 70,000 square miles (mi2) (180,000 square kilometers [km2]) in eastern Colorado, southeastern Wyoming, and southwestern Nebraska.
- Contains Wattenberg Gas field
- Greater than 10 TCF equivalent out of multiple horizons

Burial History- Wattenberg Field



Credit to:
(Sonnenberg, 2015).



- Covers ~ 3200 square miles
- Codell sediments derived from major deltaic source extending into the Western Interior Seaway and deposited on the flat floor of the Seaway by waxing and waning shelf currents as well as storms and waves (Longman et al., 2021).
- Niobrara was deposited within the Western Interior seaway as chalks/marls
- Source Rocks in Cretaceous- Mowry, Huntsman, Graneros, Greenhorn, Carlile, Niobrara, Sharon Springs

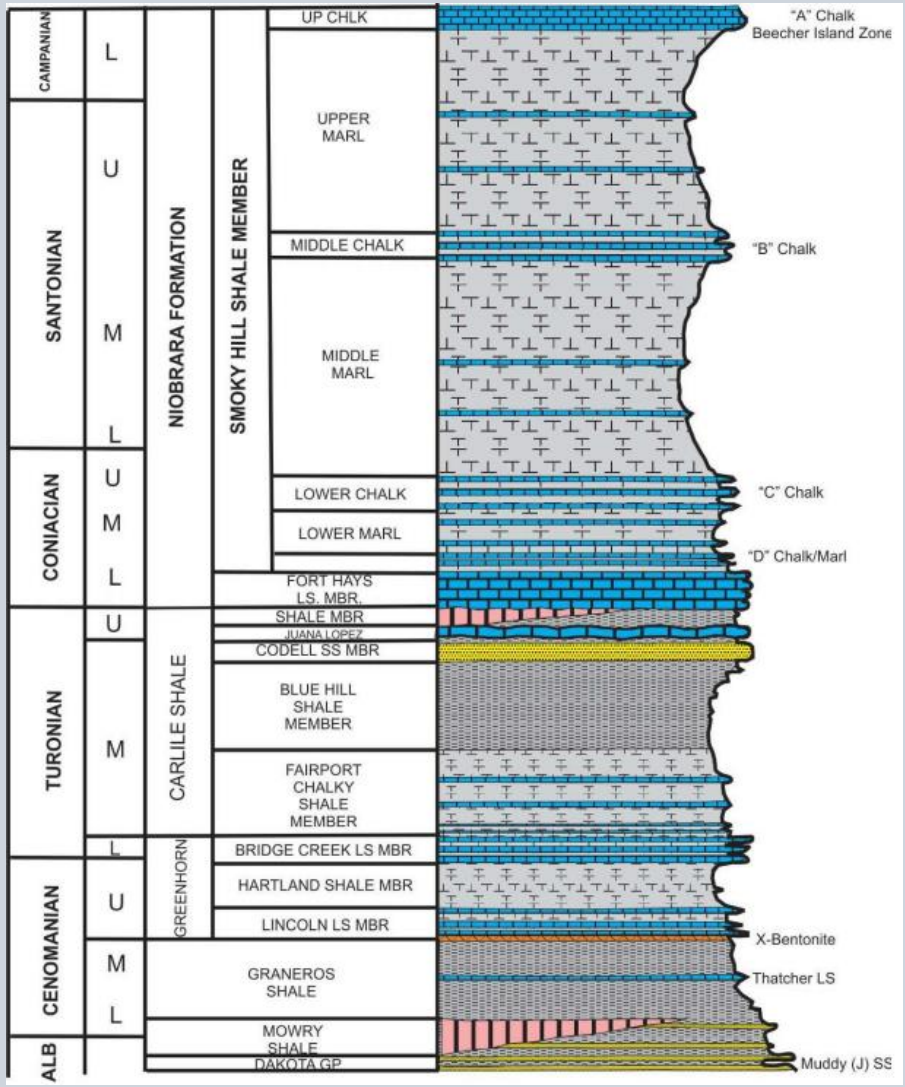
Postle Geology & Wattenberg Field Area Description

- Geological Factors:
  - Thermally mature source beds; thickness; geothermal gradients; pressure gradients; fault bounded reservoir compartments; gas-oil ratios; sufficient reservoir quality

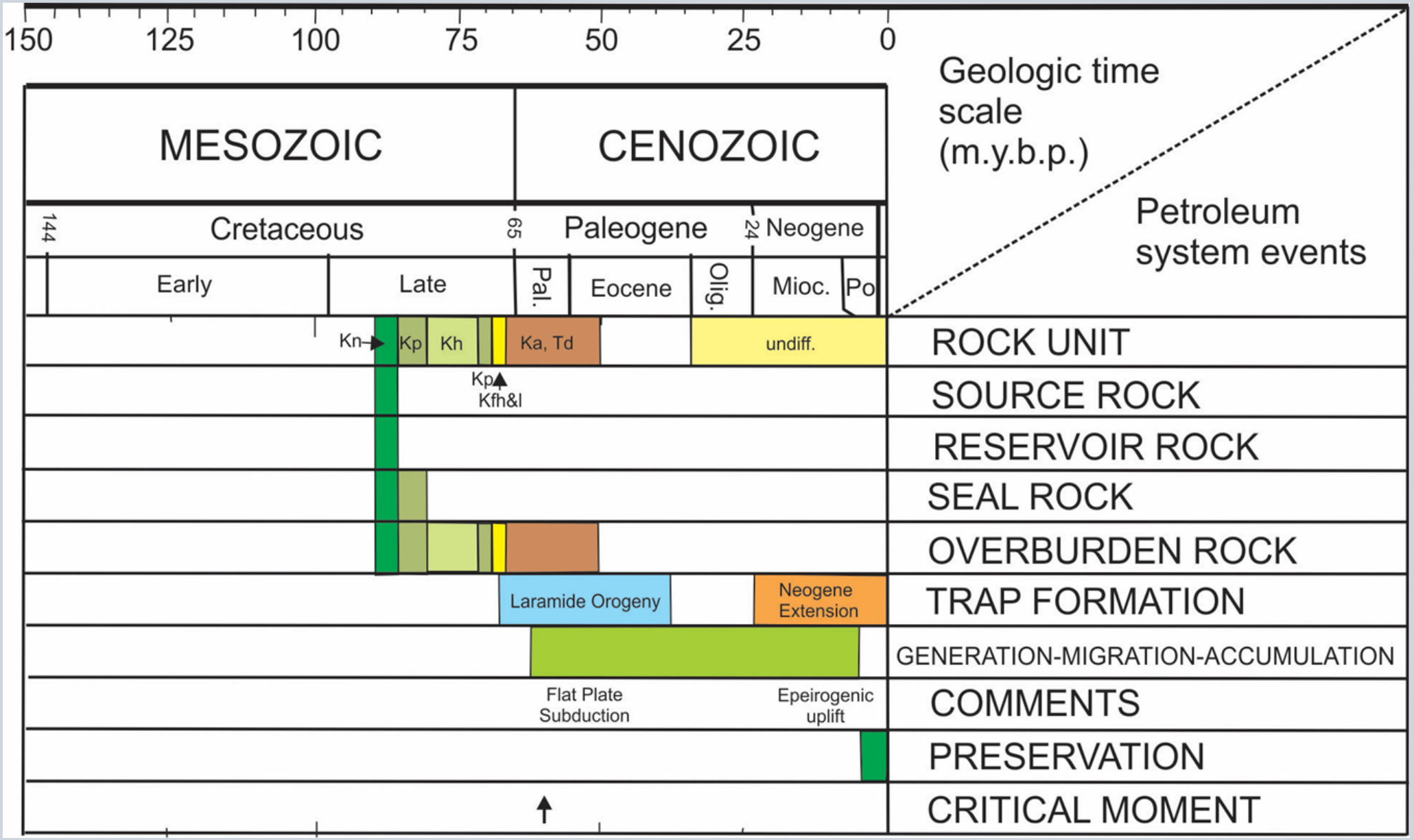
- Niobrara A, B, C chalk ~ 20-50 ft thick
  - Characterized by combination of chalks/marls/sandstones/shales
  - Unconventional system
  - Porosity: (6-10%) & permeability (<0.1 mD)
  - Geothermal gradients range: 1.6-2.5°F/100 ft (hotspot)

- Unconformities exist at top & base of Niobrara
  - Barrier & possible potential reservoir in certain areas

- Codell Sandstone ~ 5-20 ft thick
  - Characterized by tight sands, low porosity (<12%) & permeability (<0.1 mD)
  - Tight unconventional reservoir



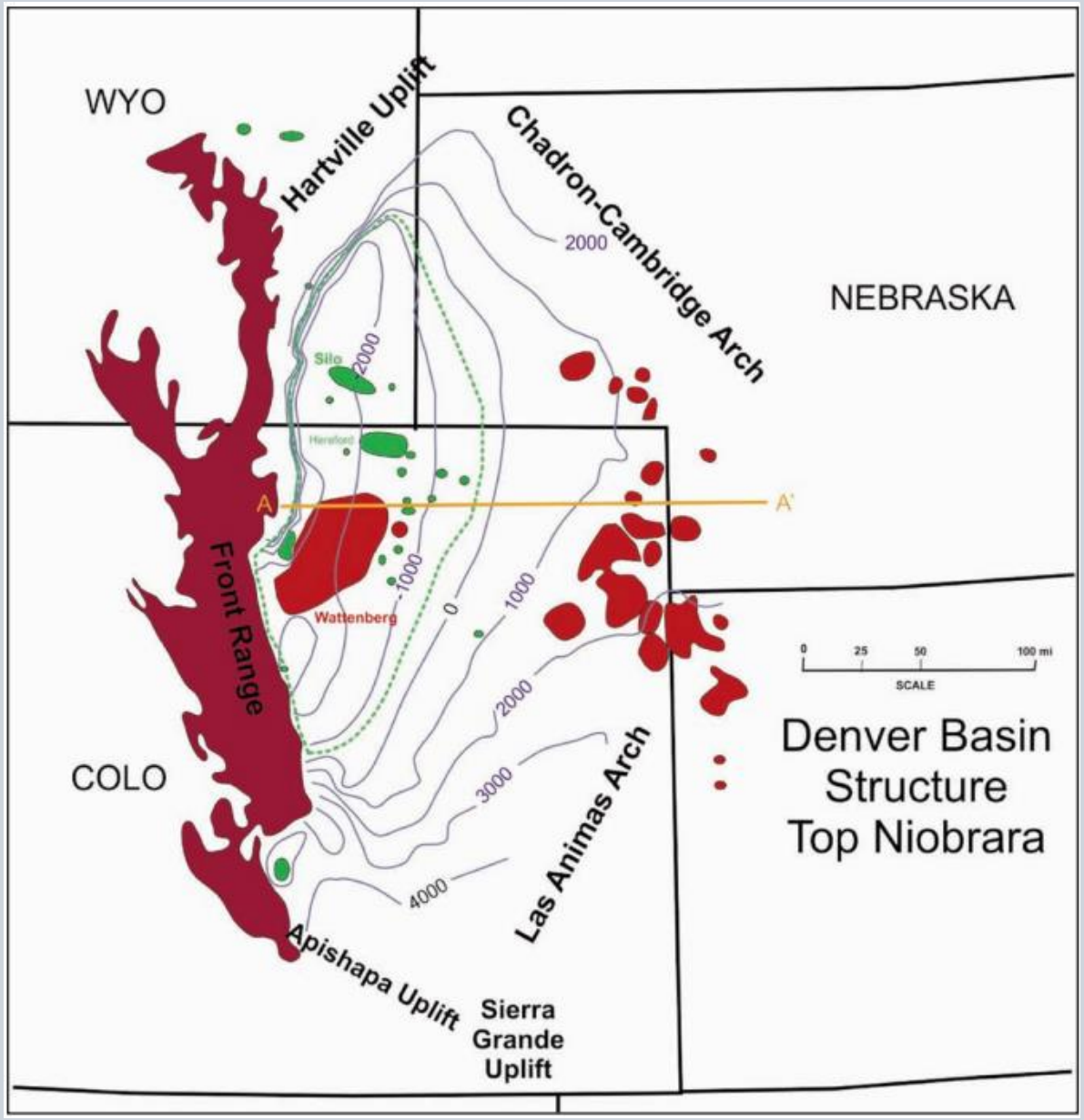
Credit to: (Kauffman, 1969)



Credit to: (Sonnenberg, 2011)

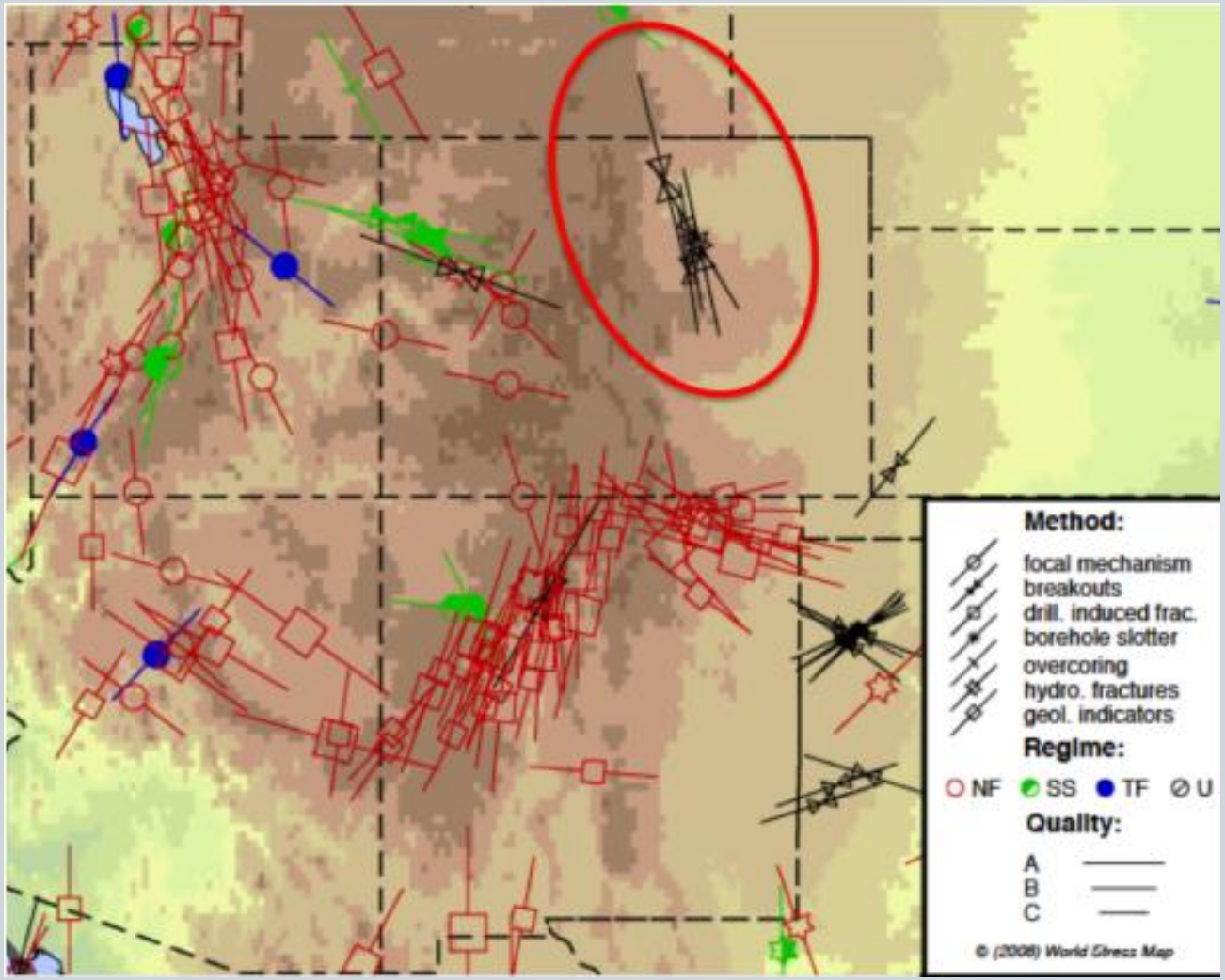
Petroleum System

- Production in Wattenberg found in Dakota, J Sandstone, D Sandstone, Greenhorn, Codell, Niobrara, Terry & Hygiene
- Thermogenic oil & gas accumulations in deeper part of basin
- Niobrara production turns from gas to oil as geothermal gradients decrease in all directions away from Wattenberg “hotspot”



Credit to: (Sonnenberg, 2011)

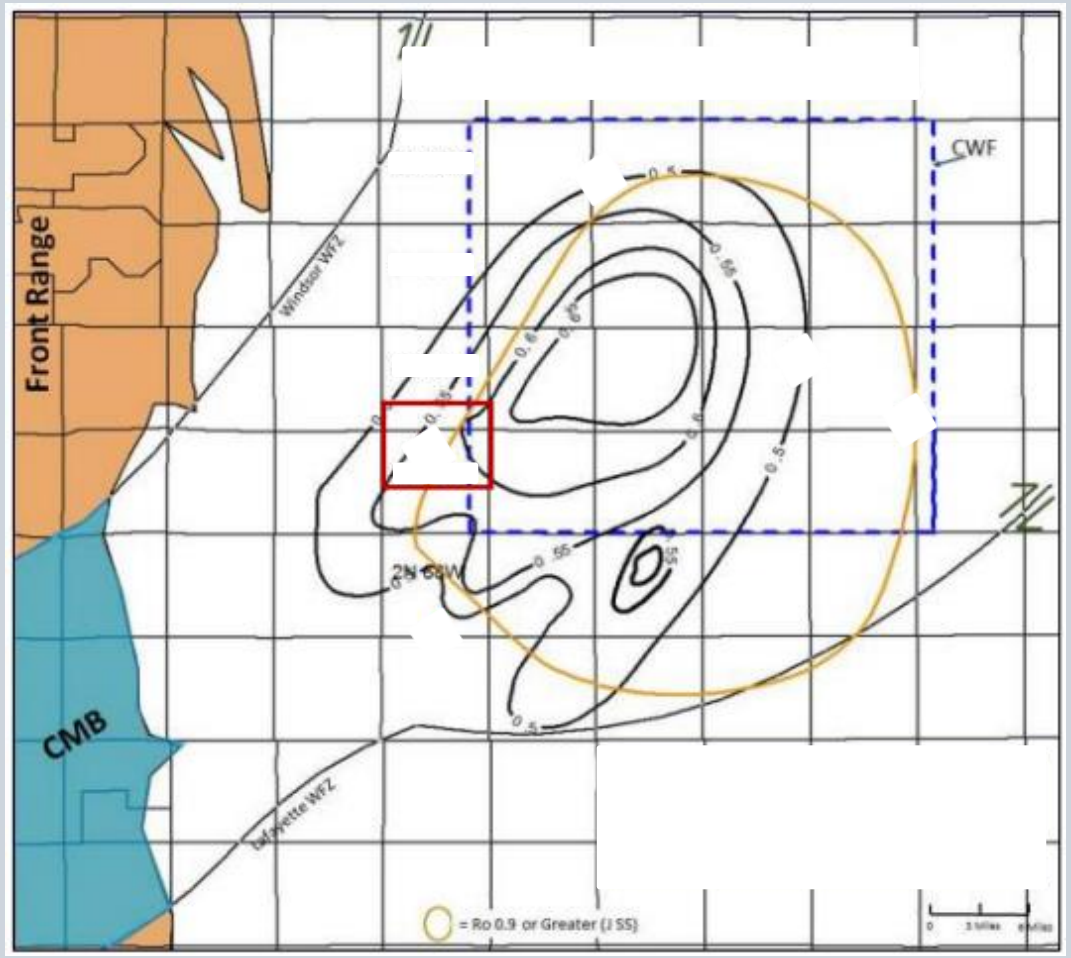
Maximum Horizontal Stress

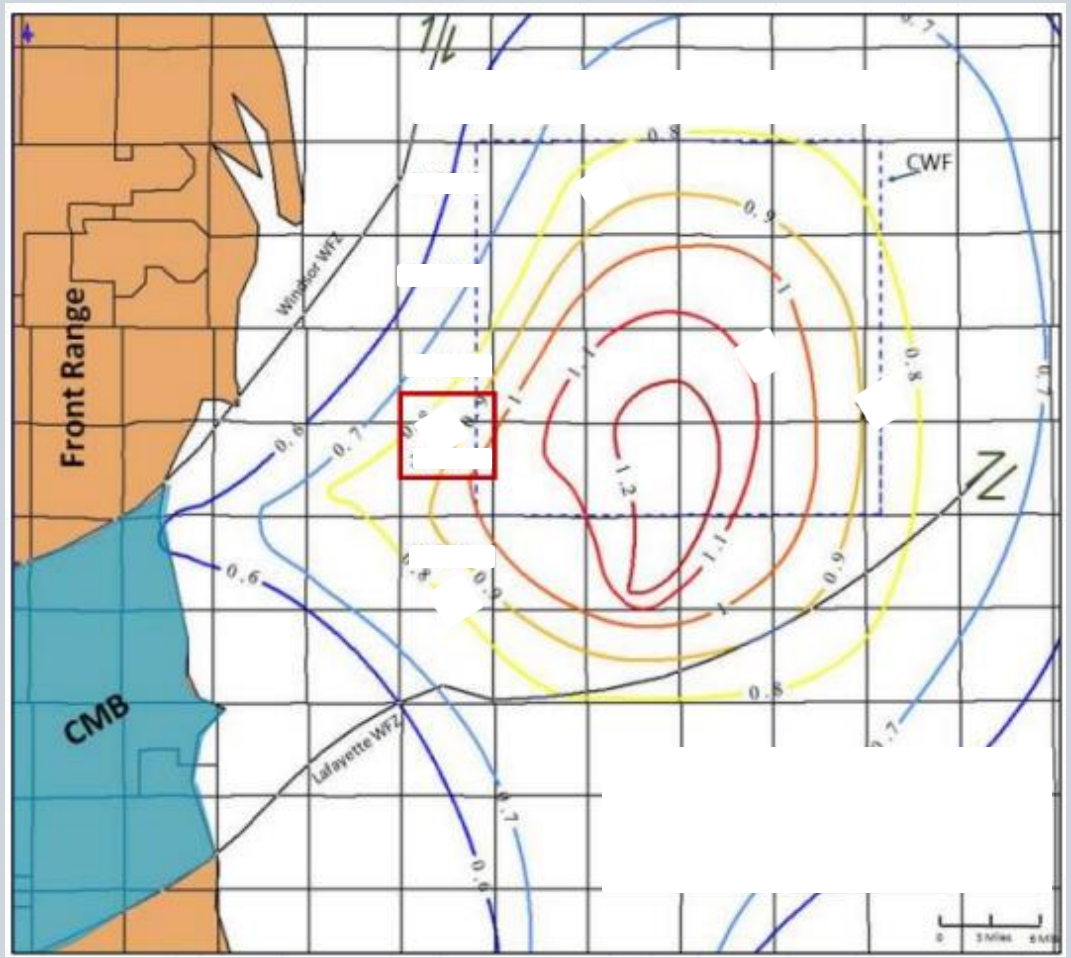


World Stress Map (2008)

- Shows a maximum horizontal stress direction of N20°W.
- Variations can be expected, but can be identified using Image logs
- Horizontal wells can't be used reliably as direct stress indicators.

Reservoir Pressures & Maturity

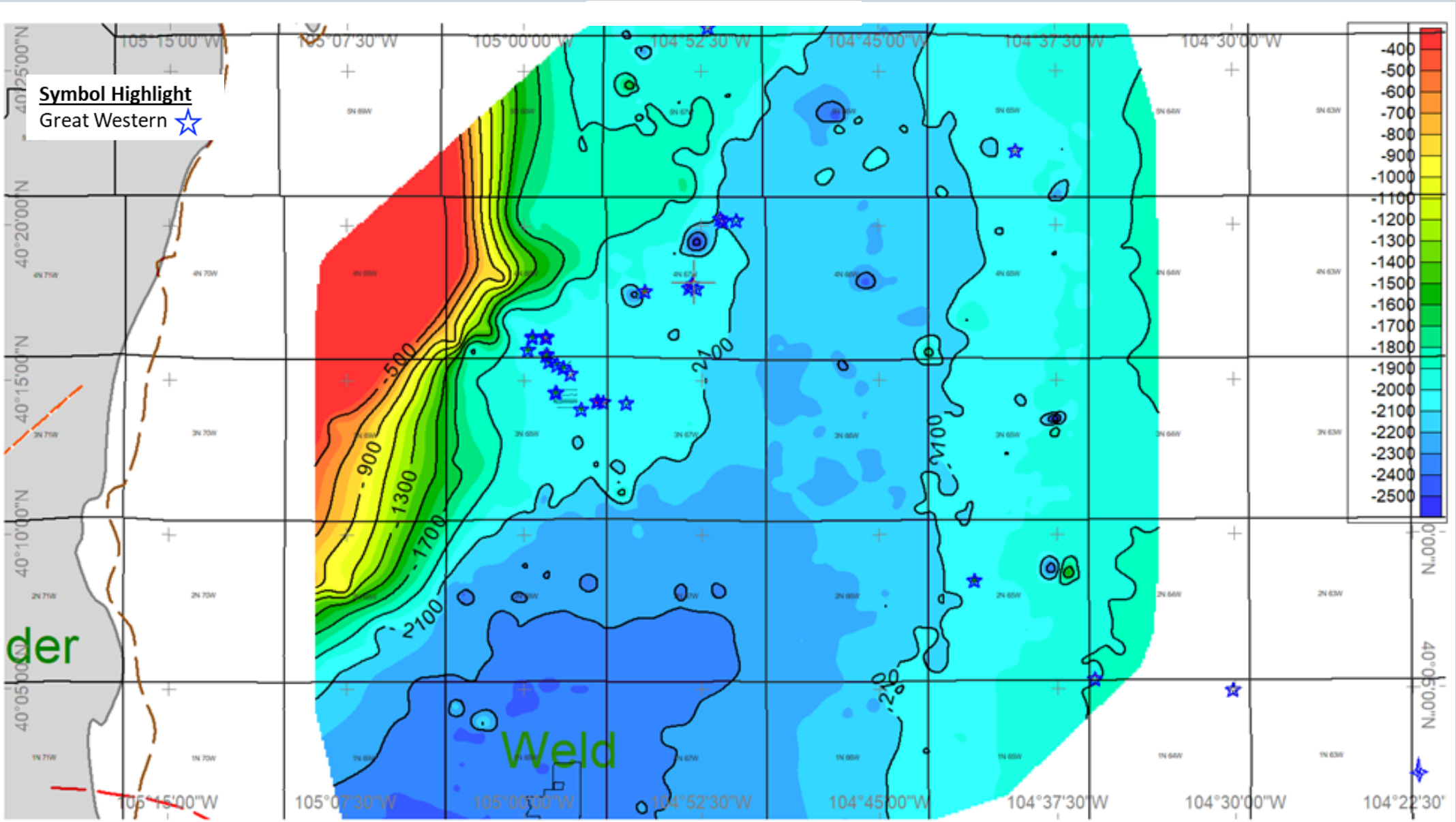




- Codell Pressure gradient (Birmingham et al., 2002).
- The Ro values greater than 0.9 outlined in orange

- Vitrinite reflectance data from source rocks showing geothermal hotspot over Central Wattenberg (Higley and Cox, 2005)

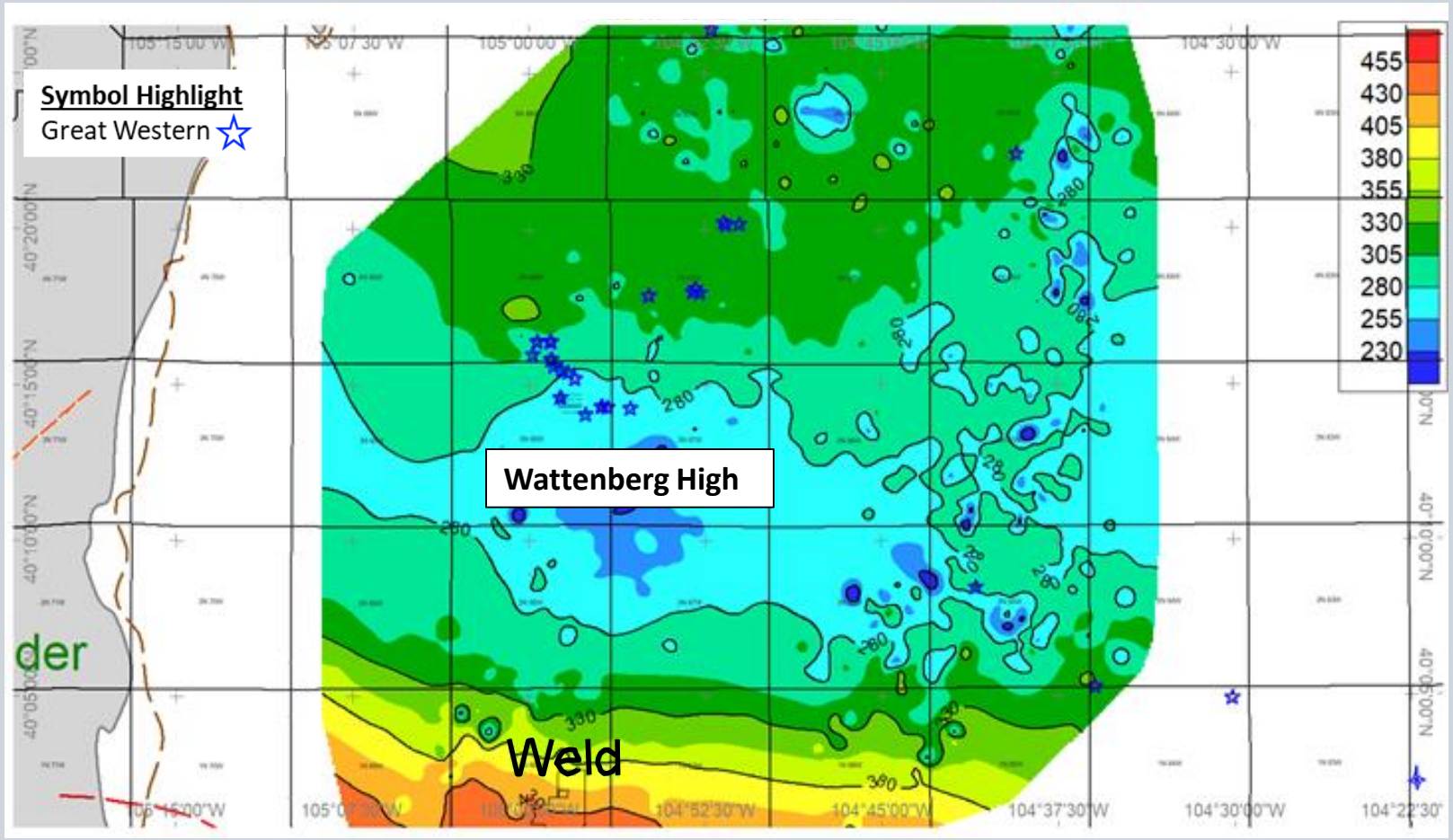
Niobrara Structure Map



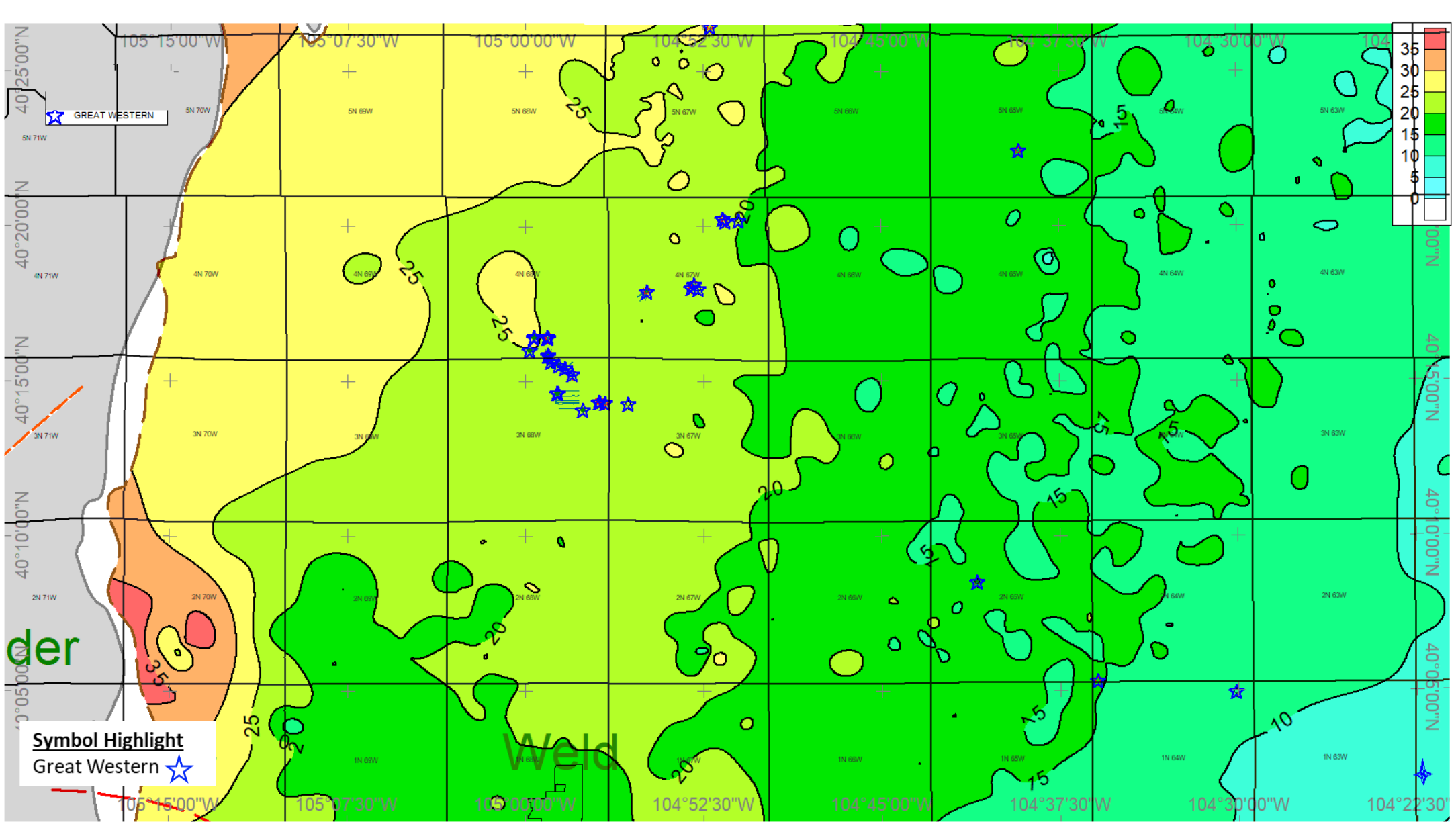
Niobrara Isopach Map

- Isopach map of the Niobrara that was based on subsurface thickness measurements

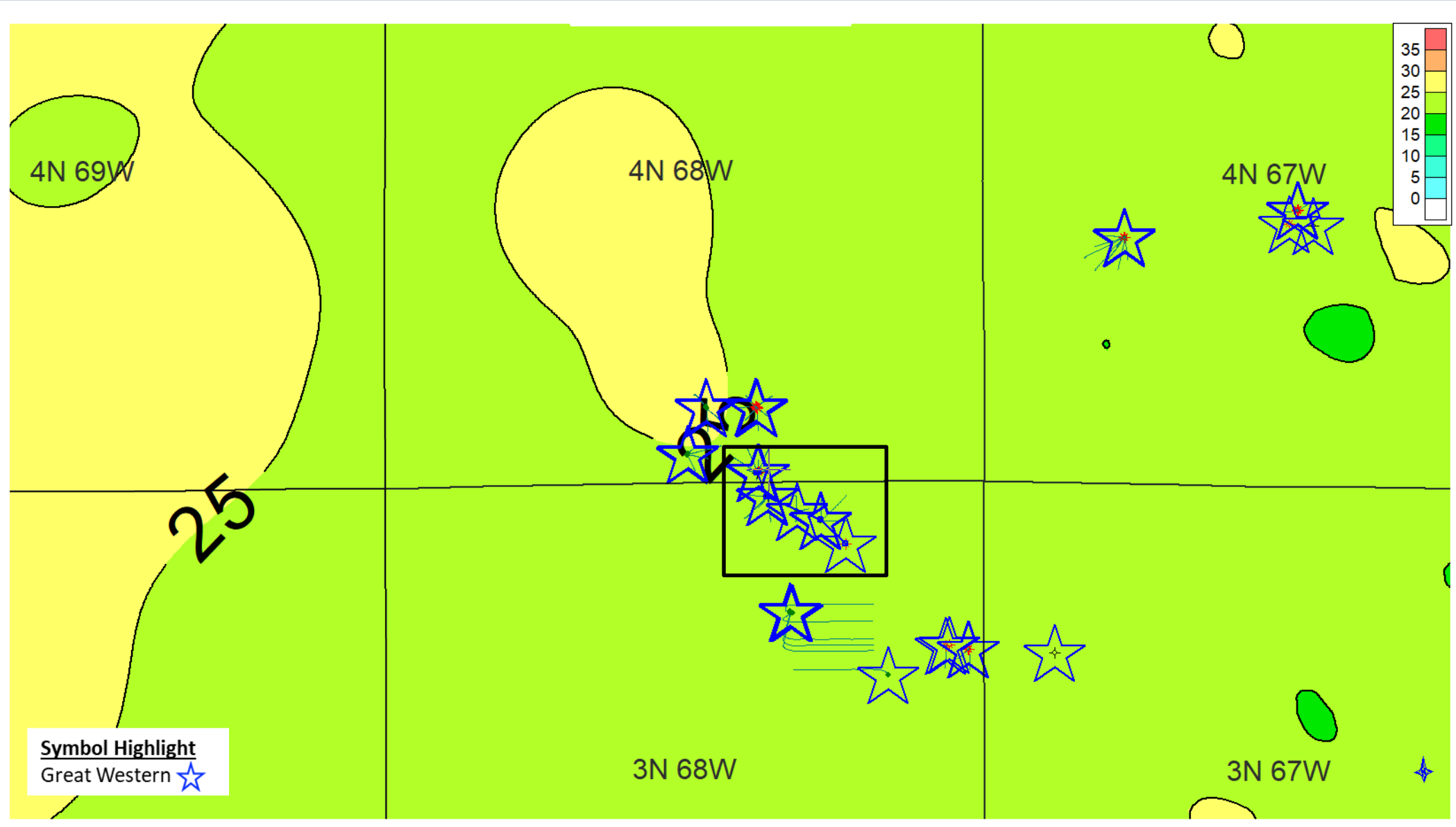
- A few thousand Raster & Digital logs were used to make this Isopach map
  - Great western wells highlighted by ☆



Codell Isopach Map



Codell Isopach Map



Stratigraphic Cross-Section

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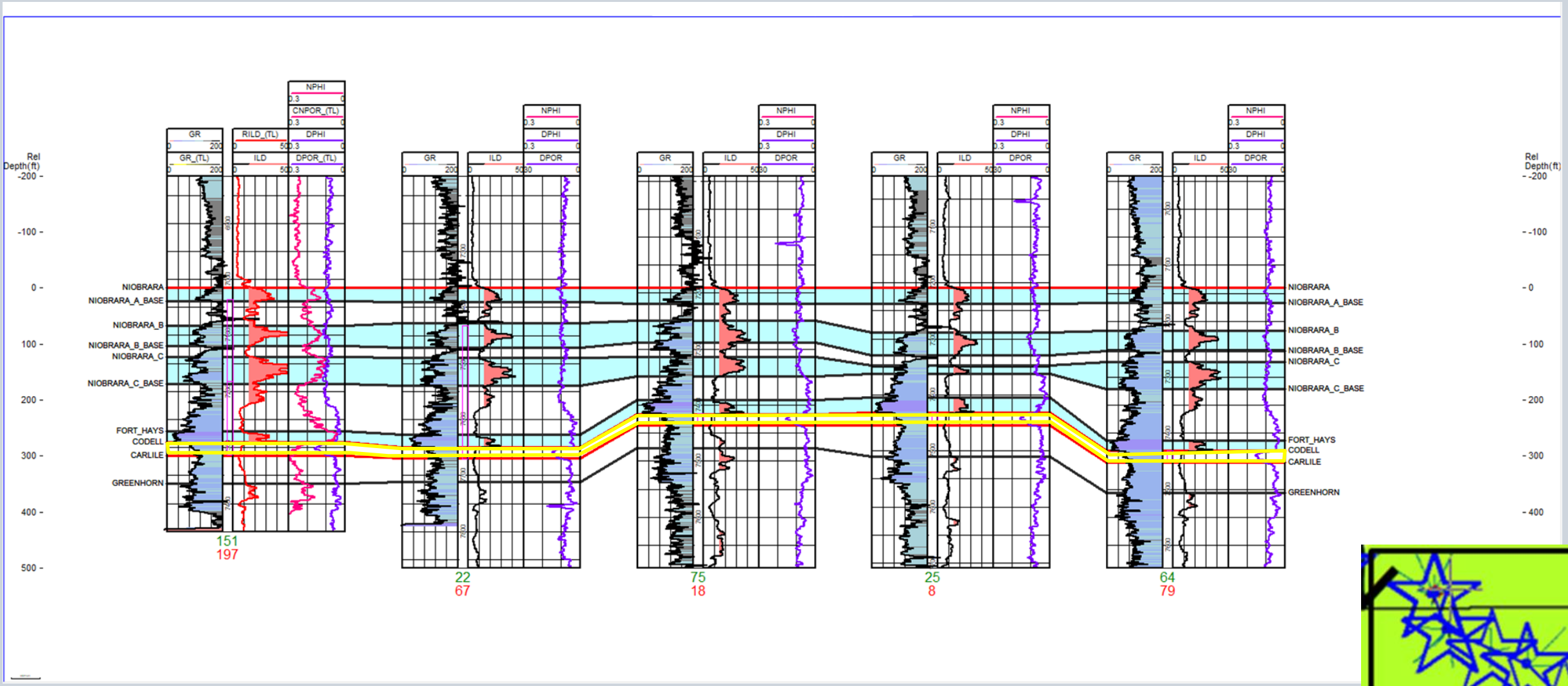
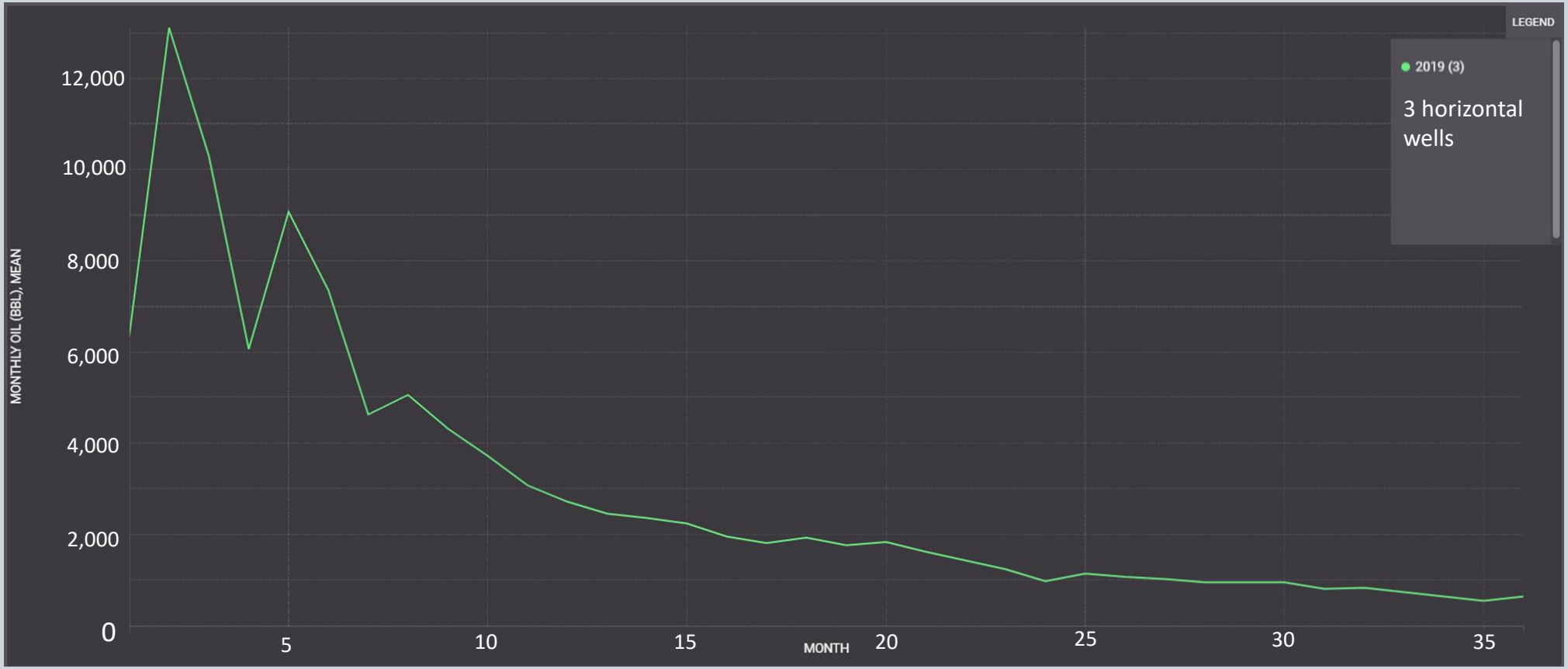
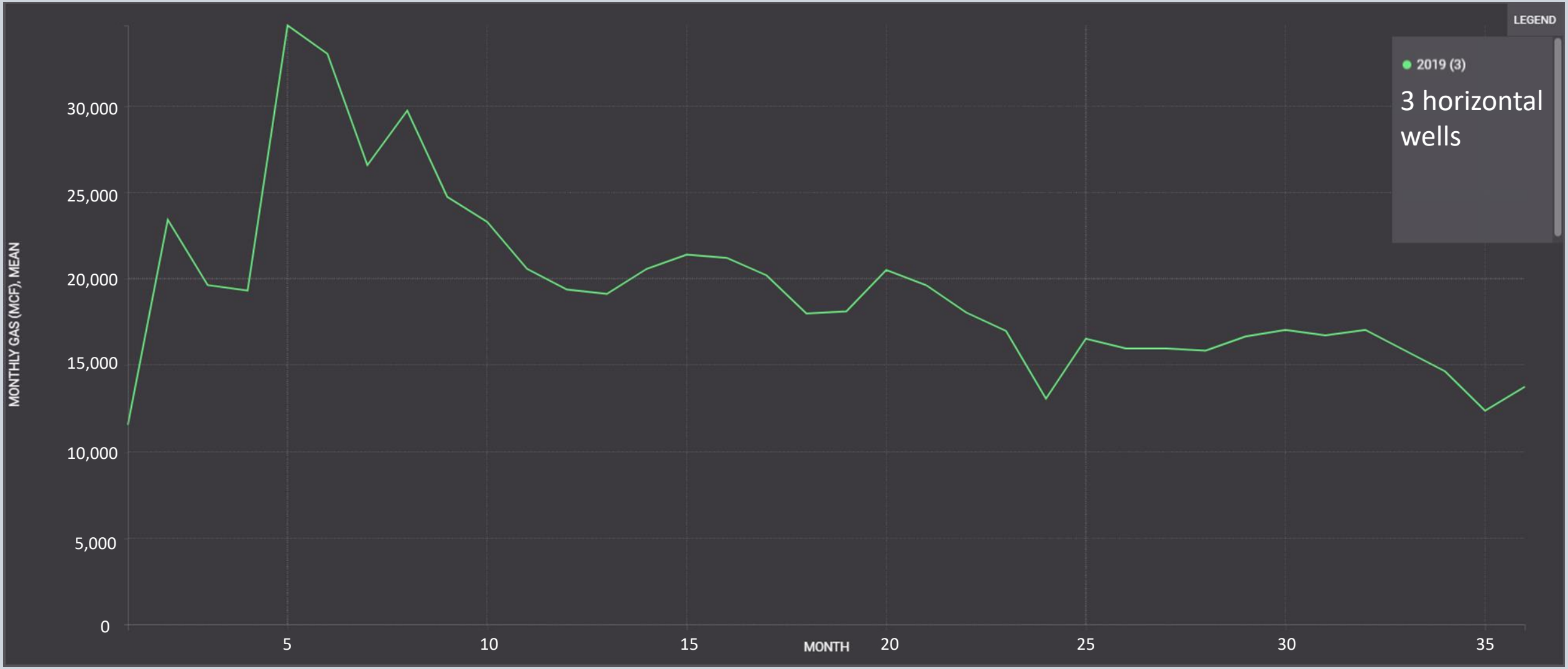


Production Decline Curve

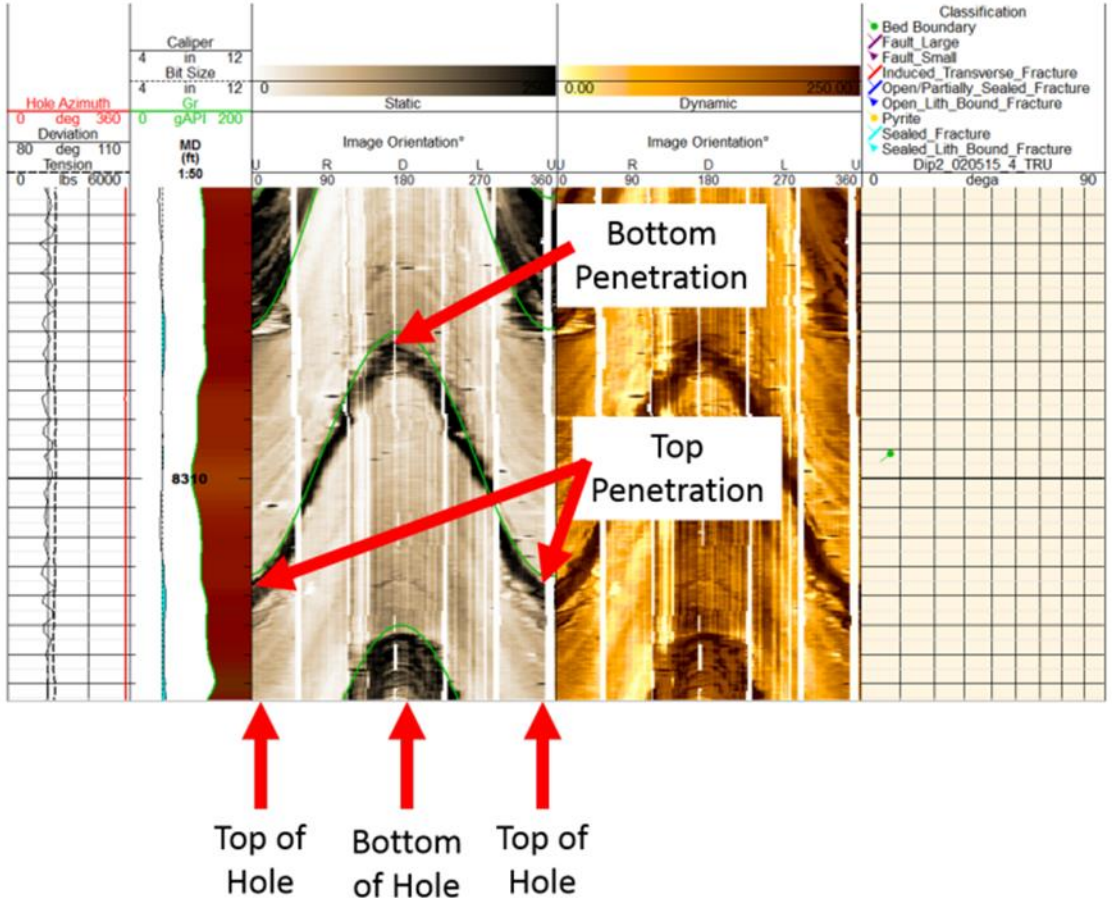


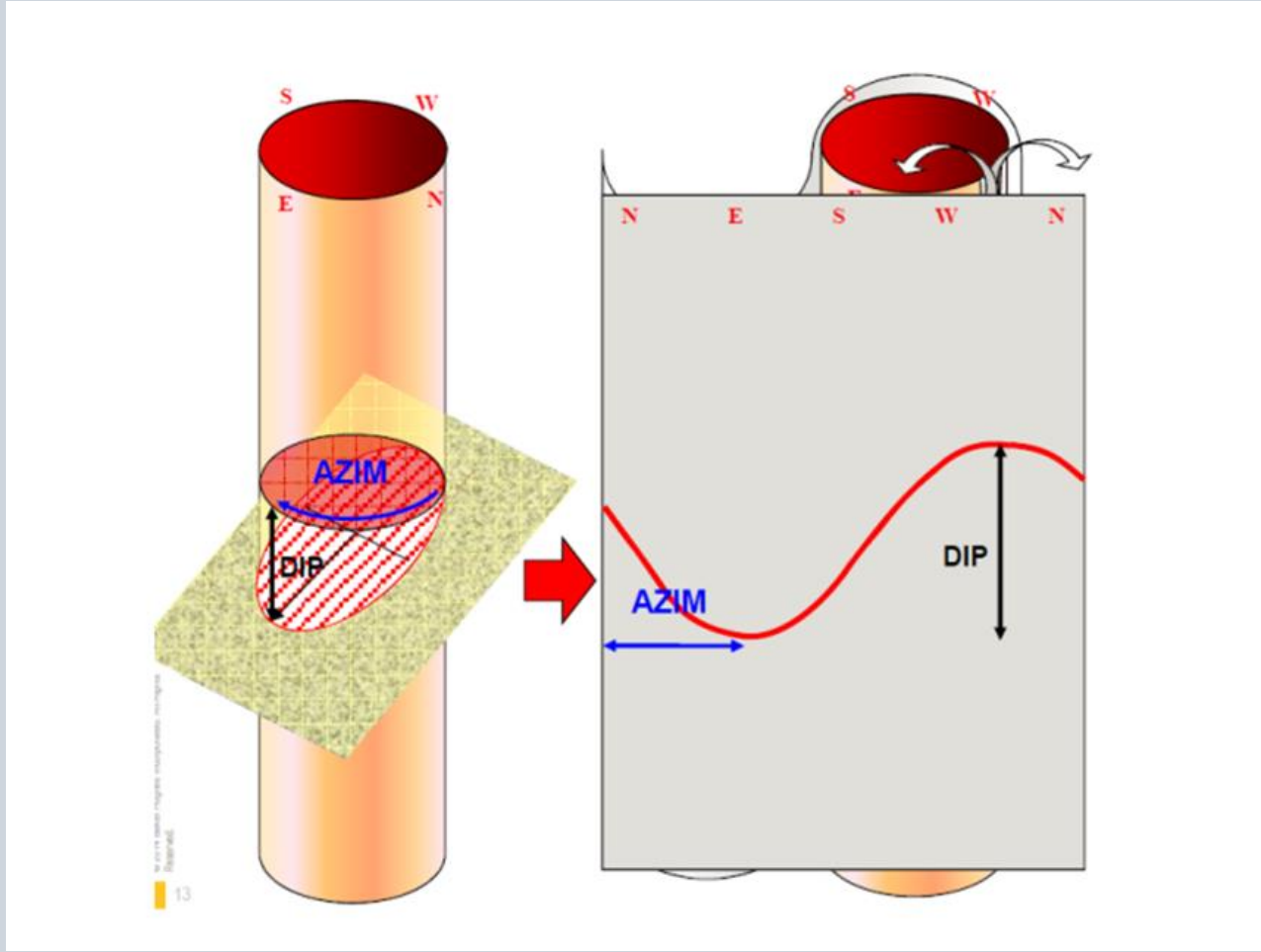
- Wells are hydraulically fractured
- Large initial production results from induced fracturing
  - Associated with radial flow of oil to well bore
- Production performance follows a power-law decline

Gas Production Curve



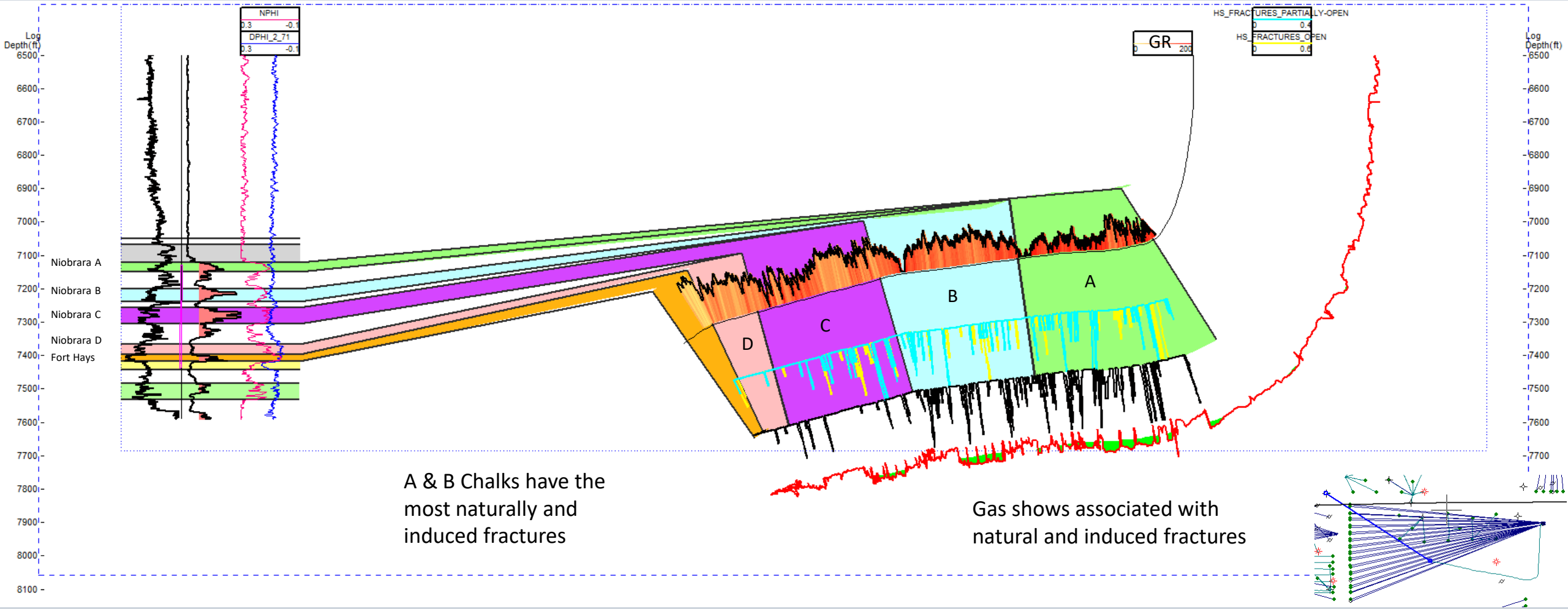
Wellbore Relation to Bedding Plane Geometry





(From Dudley, 2015)

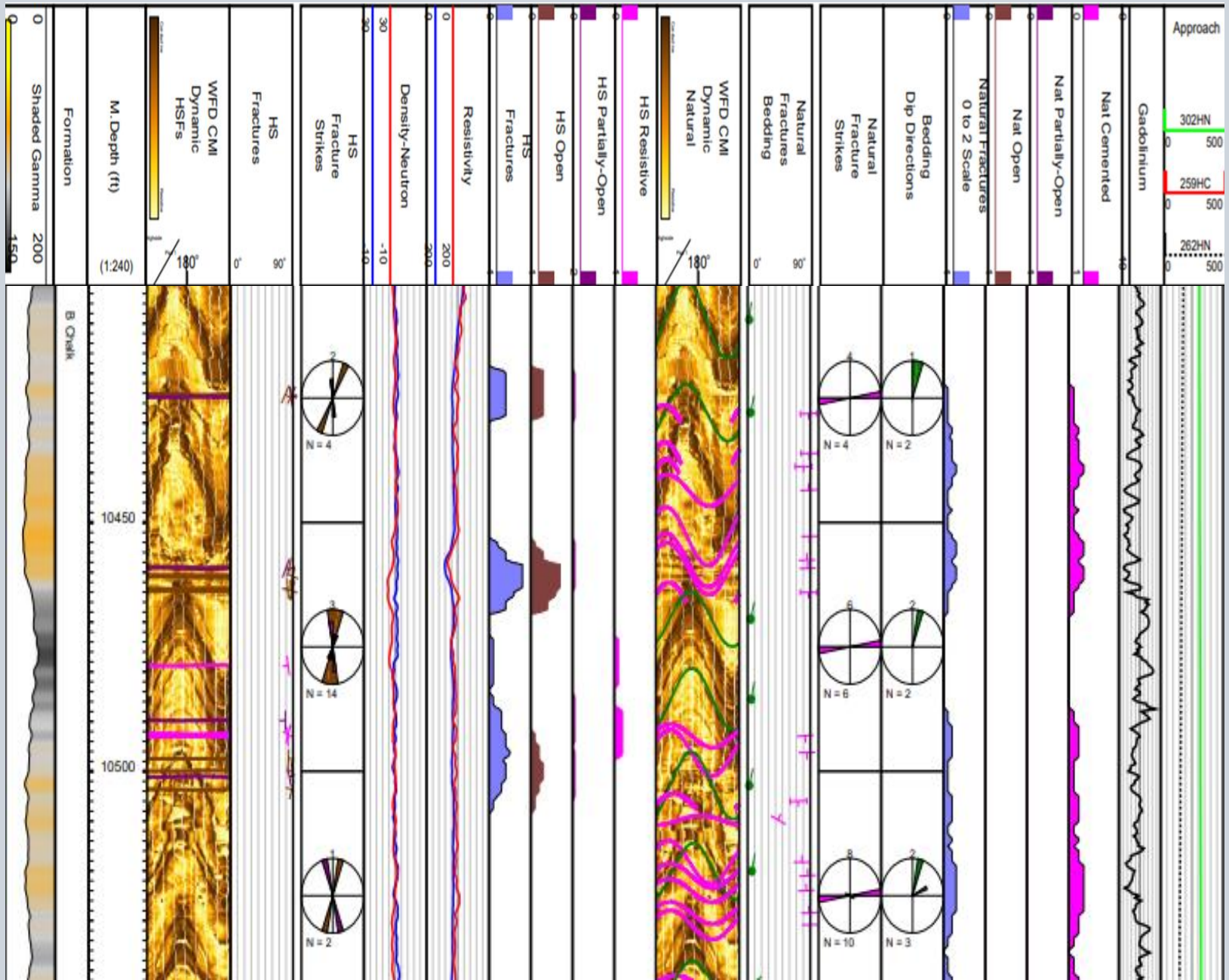
Structural Cross-Section



A & B Chalks have the most naturally and induced fractures

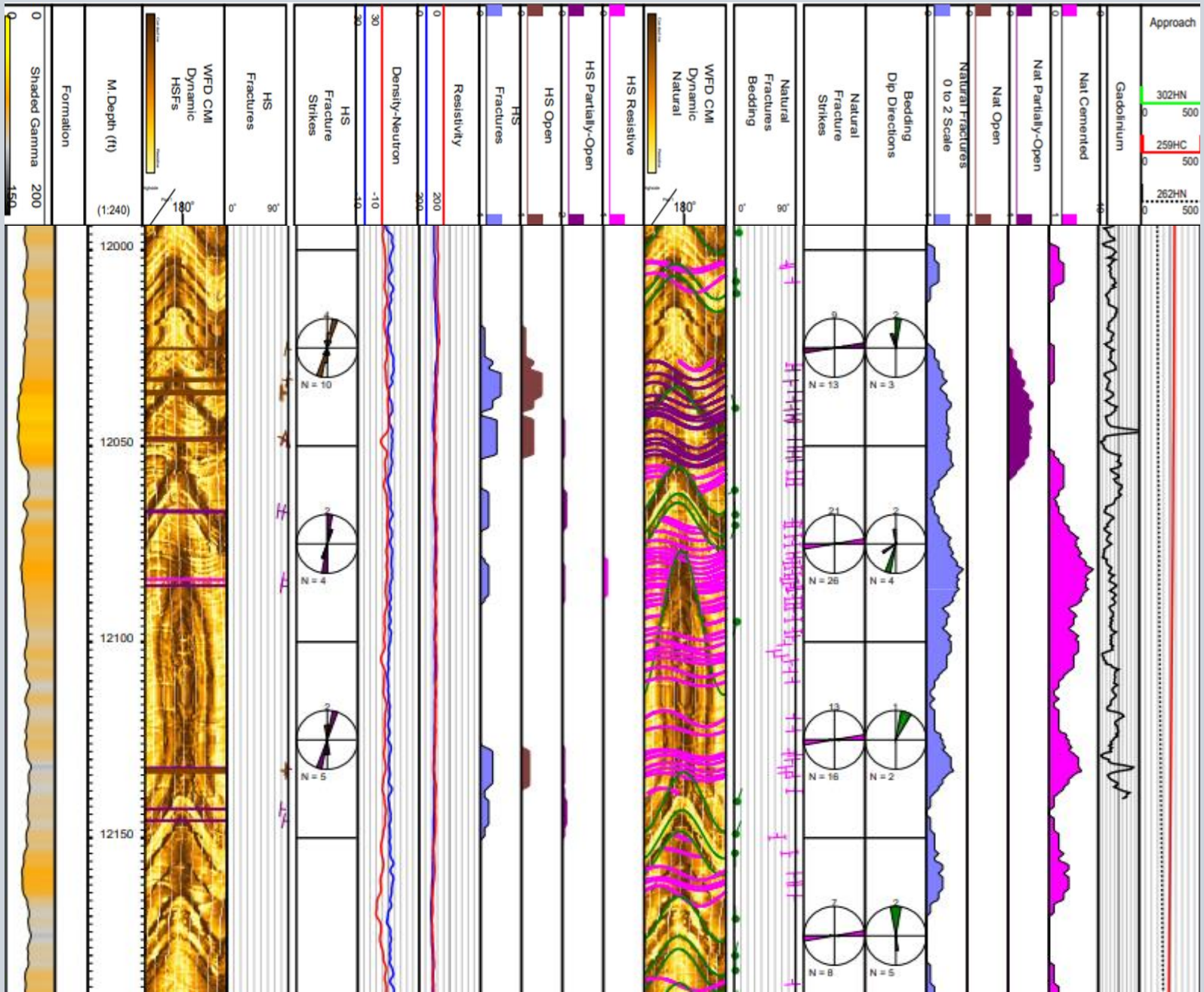
Gas shows associated with natural and induced fractures

Niobrara B Fracture Clusters



Credit to: (Borehole Image Specialist)

Niobrara C Fracture Clusters



Credit to: (Borehole Image Specialist)

Fracture Type & Count

	HS Resistive	HS Partially-Open	HS Open	Naturally cemented	Natural Partially-open	Natural Open Fractures	Natural Fractures Bedding
Nio A Chalk	73	21	40	7	0	0	27
Nio A Marl	133	35	32	34	2	0	21
Nio B Chalk	97	13	27	78	1	0	38
Nio B Marl	51	19	9	8	4	0	35
Nio C Chalk	14	22	25	169	28	3	56
Nio C Marl	15	8	6	119	1	1	69
Nio D Chalk	3	1	0	5	1	0	24
Ft Hays	0	1	5	0	0	0	8
Codell	Uninterpreted	Uninterpreted	Uninterpreted	Uninterpreted	Uninterpreted	Uninterpreted	Uninterpreted
Total	386	120	144	420	37	4	278

Future Work

- Continued FMI interpretation to establish the spatial geometry of the natural fractures within the wells.
- Characterize the fractures that help produce hydrocarbons by hydraulic stimulation.
- Continue work with my RCP Team to establish a larger scale interpretation of the field.

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