Red River “B” Reservoir Properties on the Nesson Anticline, North Dakota

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Abstract

The Nesson anticline is a major, south-plunging anticline that lies in northwest North Dakota. The Red River “B” zone is a dolostone flow unit that spans the “B” Laminated Member to uppermost “B” Burrowed Member of the Ordovician Red River Formation. Oil and gas production occurs at depths from 12,600 to 13,950 feet. Red River “B” production and oil shows (>50% oil recovery or Sw <35%) come from 62 wells that occur along crestal portions of the anticline. Intercrystal porosity is developed in dolostone with an average crystal size of 15 microns. Oil-bearing cored porosity varies from 4–20% (average 9%) and permeability varies from 0.02–5 md (average 0.75 md Ka). Average cored water saturation is 22% and average cored net pay is 8 feet for core Sw <35%. The logged oil-productive water saturation varies from 6–35%. Much of the “B” accumulations consist of volatile oil (48–50° API, with 2,100–3,200 GOR at virgin pressure) that comes from off-closure anticlinal locations. In gas caps on structural closures, oil gravity is 53–58° API and GOR is 3,600–10,000+. Capillary pressure and saturation data are consistent with intermediate wettability conditions and the presence of two large accumulations: 1) Beaver Lodge and 2) Antelope-Blue Buttes-Charlson. Both accumulations have free-water levels tilted 35 ft/mile to the east-southeast.

Red River “B” oil producing characteristics are illustrated in Blue Buttes field on the southern portion of the Nesson anticline. Average logged net pay in oil-bearing wells is 8.8 feet, with 20% water saturation and 11.4% porosity. Four vertical completions (including three commingles) were made and four wells with “B” pay were completed in other formations. Two structure-flank horizontal re-entry wells produced water and oil. One grass-roots horizontal well (Olson 9-11H) targeted the crestal portion of the plunging anticline in Sec. 9, T150N-R95W. Due to drilling challenges, the well only achieved 1,872 feet in-zone. Due to hole-obstruction issues, the well was not acidized or fracked. Initial (30-day) production was 221 BOPD (48° API), 733 MCFD and 30 BWPD and the well produced 219,939 BO, 869 MCFG and 15,352 BW in 11 years. It is likely that modernized horizontal drilling technology can overcome drilling and completion issues to achieve improved production.

References Cited

DeMis, W. D., 1995, Effect of cross-basinal hydrodynamic flow on oil accumulations and oil migration history of the Bakken-Madison petroleum system; Williston basin, North America, *in* L. D. Vern Hunter and R. A. Schalla, eds., 7th international Williston basin symposium: Montana, North Dakota and Saskatchewan Geological Societies, p. 291–302.

Petty, D. M., 2022, Duperow characteristics in Beaver Lodge field, North Dakota, AAPG Search and Discovery Article #20495, 34 slides, accessed April 24, 2022

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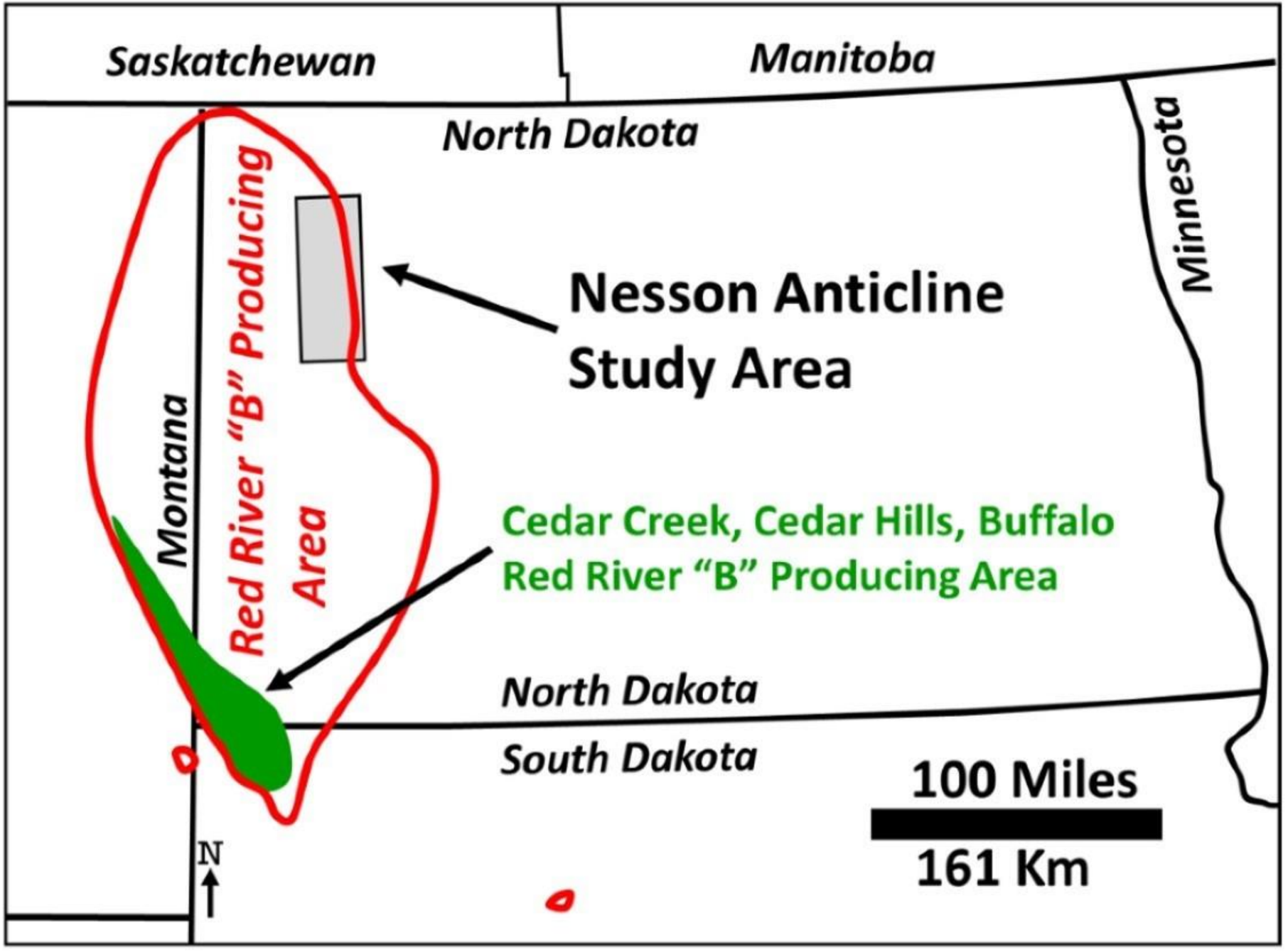
By David M. Petty

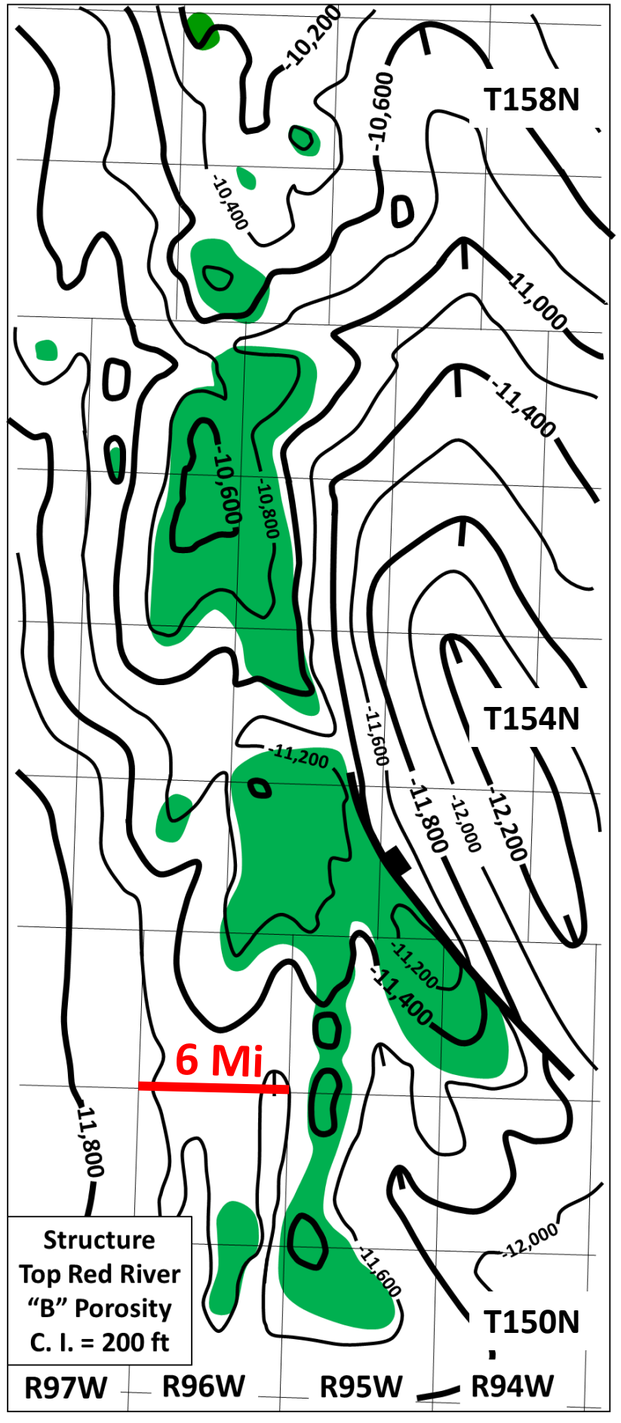
Acknowledgements

- The author worked fields on the Nesson anticline for Hess Corporation from 2006-2016 and benefited from previous work done by Hess geologists, geophysicists and engineers.
- A portion of the analysis in this study evaluates data acquired by Hess Corporation as part of a Special Core Analysis program that was initiated in 2015 and completed in 2016.
- The interpretations presented here represent those of the author and do not necessarily represent interpretations of Hess Corporation or individuals within Hess Corporation.
- Thanks for Joshua Miller for shepherding this presentation through the Hess approval process.

Geologic Setting

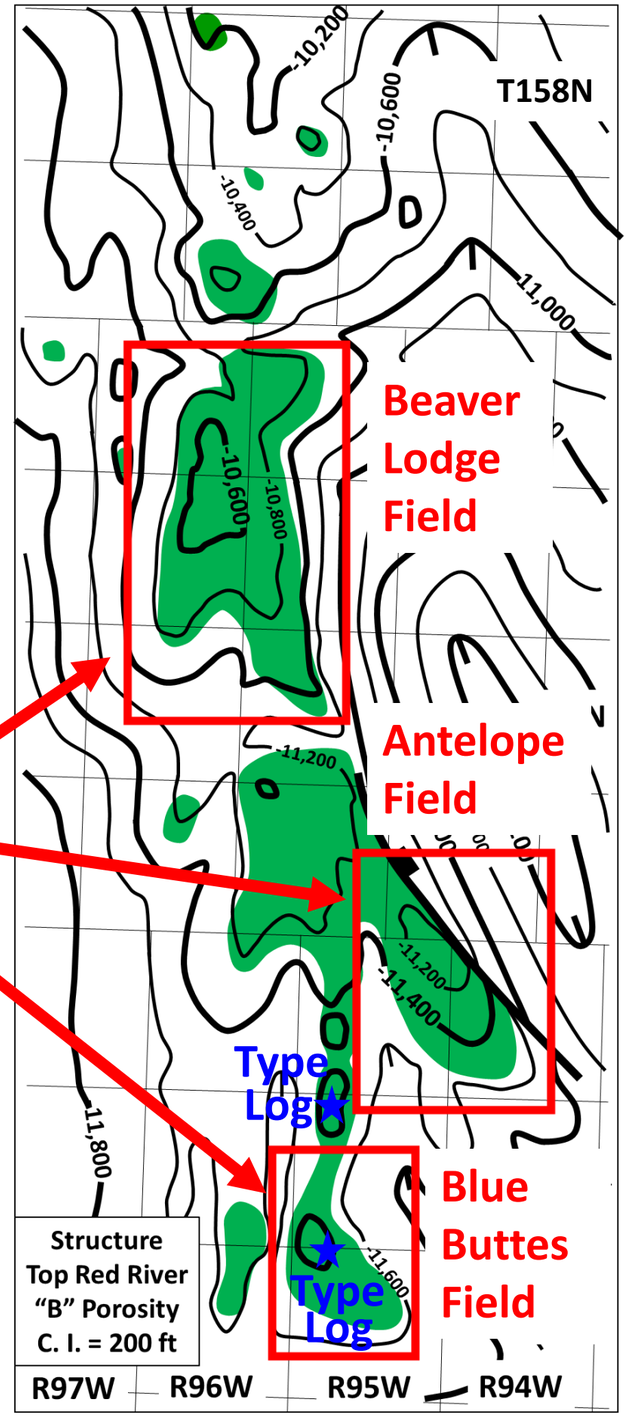

Saskatchewan
Manitoba
North Dakota
Minnesota
Montana
Red River "B" Producing Area
Nesson Anticline
Study Area
Cedar Creek, Cedar Hills, Buffalo
Red River "B" Producing Area
North Dakota
South Dakota
100 Miles
161 Km
N

STRUCTURE
Top "B" Porosity = Base "B" Anhydrite
C.I. = 200 ft

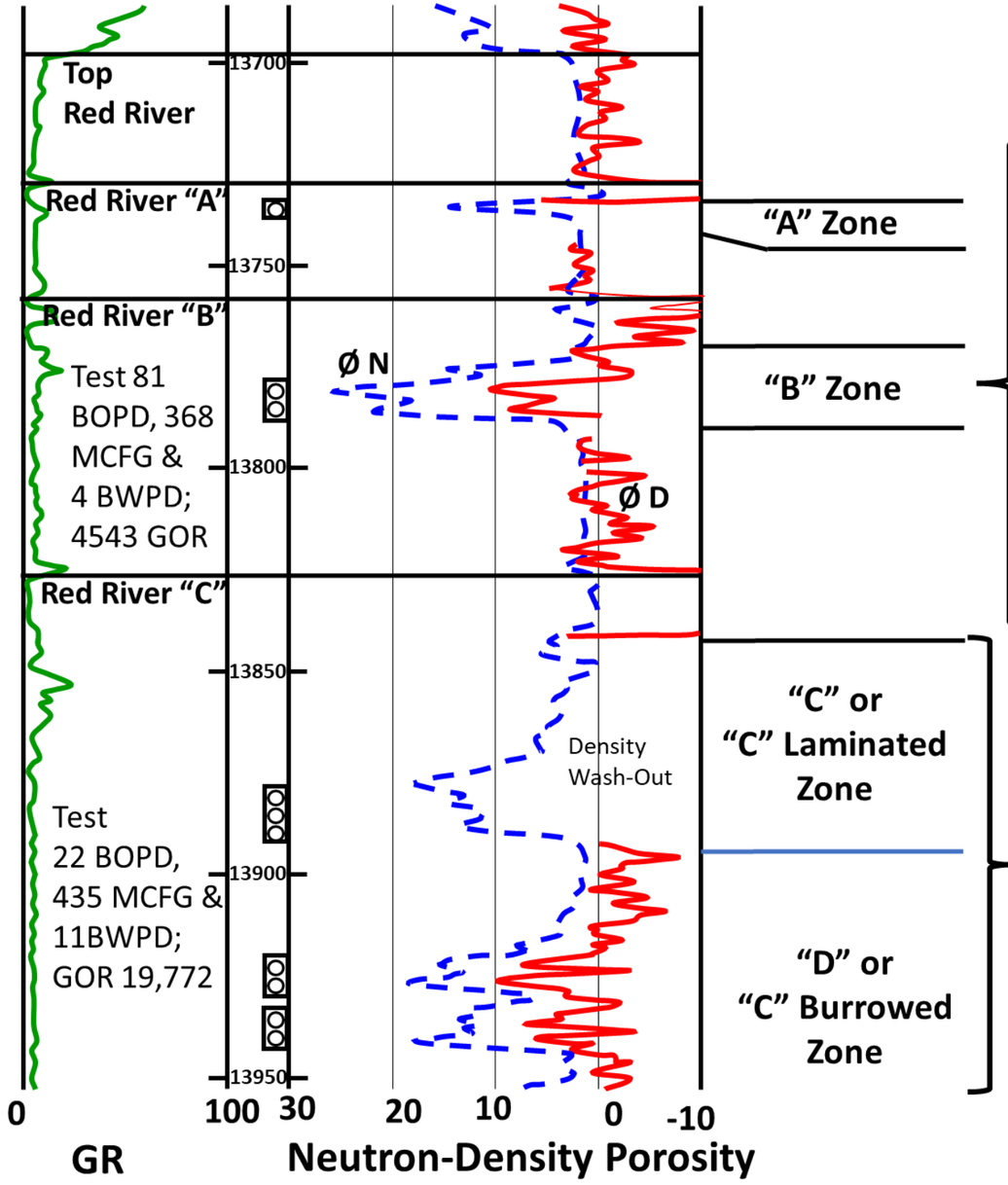


Red River "B" Oil Accumulations (areas above free-water level; not all areas are oil-productive)

Detail Study Areas



Southern Blue Buttes Field Type Log
Loomer #16, T150N-R95W, Sec. 5



Nesson Anticline
Oil and Gas Distribution

Volatile oil reservoirs

- 48-50° API
- 2,100-3,200 GOR (at virgin conditions)

Gas caps

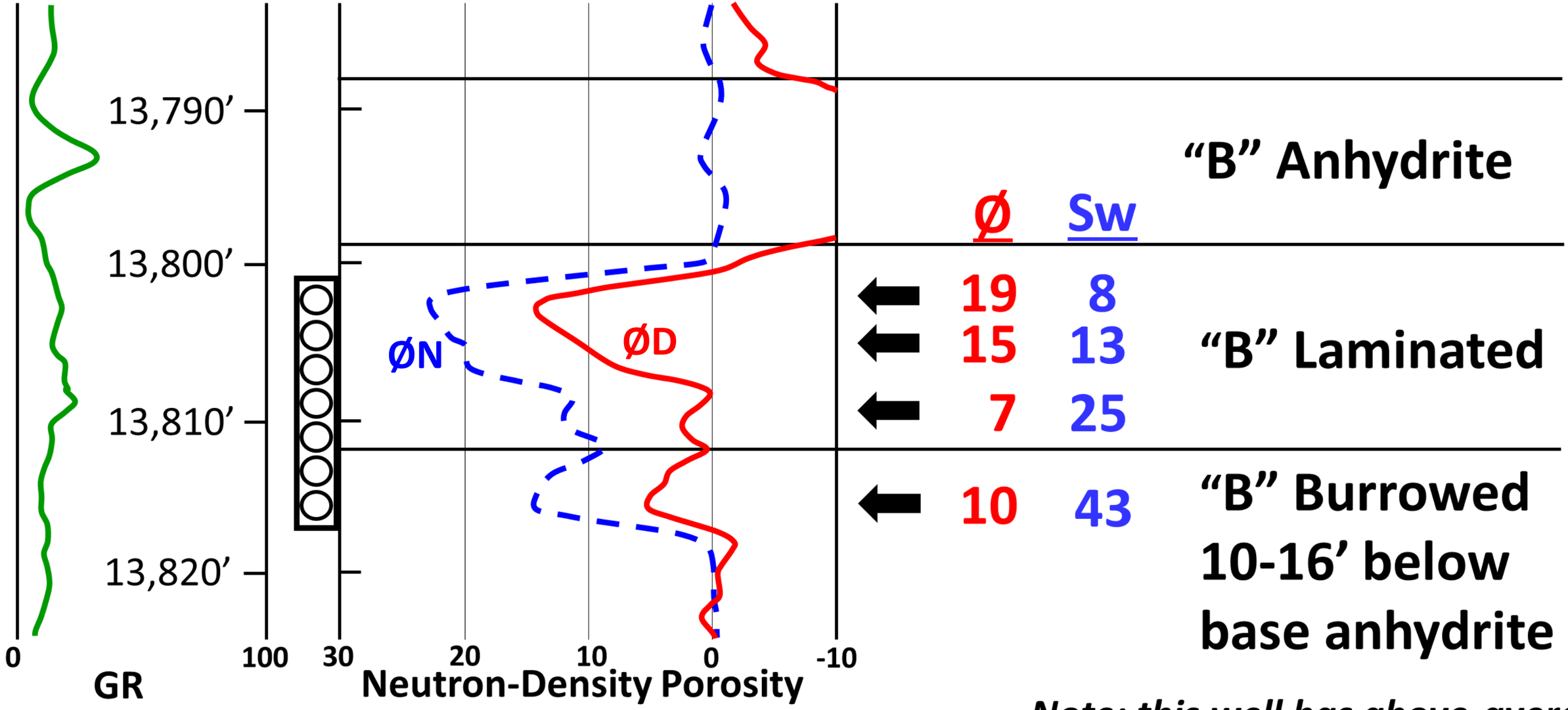
- 53-58 ° API
- 3,600-10,000+ GOR
- Overlie volatile oil columns

Gas-condensate

- >50° API with GOR > 10,000
- Confined to structural closures
- 3 small (1-well) oil accumulations

Olson 9-11 Red River "B" 48° oil

Type Log: Northern Blue Buttes Field
T151N-R95W, Sec. 5; Keogh #6; NDGS #9184

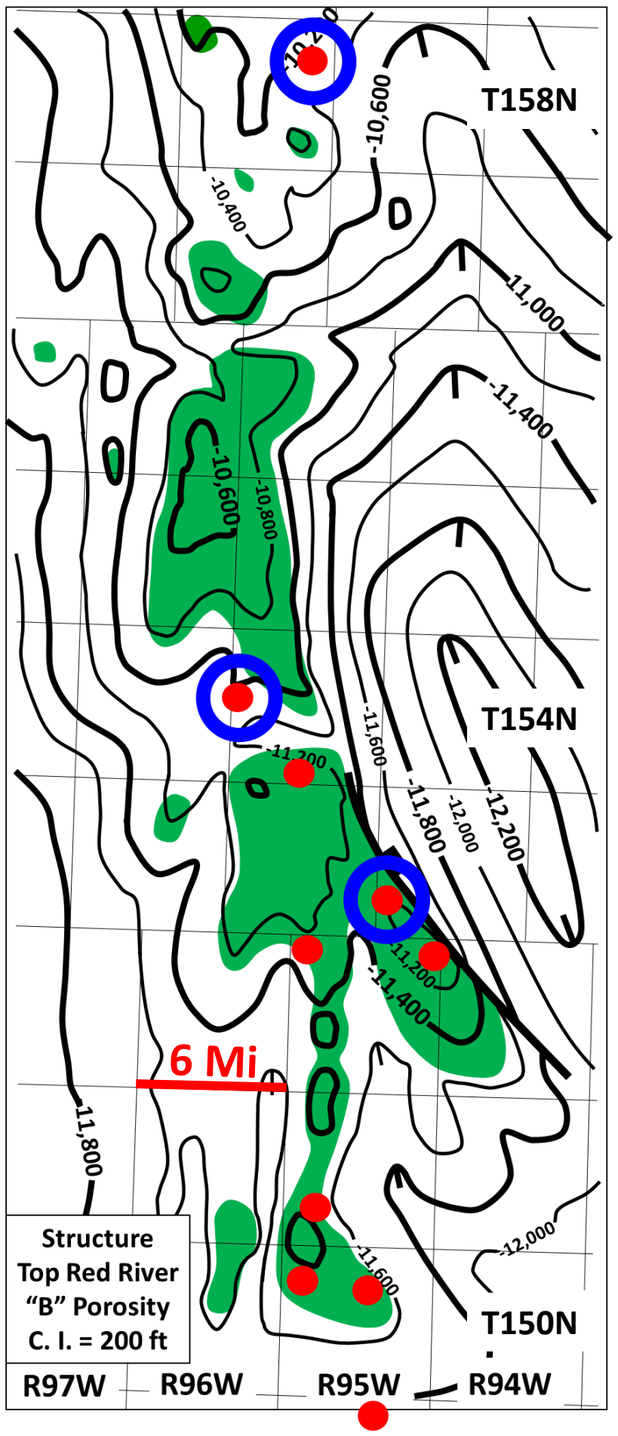


	Ø	Sw	
			“B” Anhydrite
←	19	8	
←	15	13	“B” Laminated
←	7	25	
←	10	43	“B” Burrowed 10-16’ below base anhydrite

Perf test “B” porosity: 393 BOPD, 1428 MCFD, 4 BWPD
Completed commingled with Red River “C” & “D”

Note: this well has above-average porosity in “B” reservoir

Red River “B”
Lithology & Petrophysics



Red River "B" Core Data

- 10 cored wells with routine core analyses
- 1 of 10 (10%) of cored wells tight (Ø < 6%)
- Special Core Analysis (SCA) done on 3 cored wells
- Best porosity (Ø >14%) not available for sampling in SCA

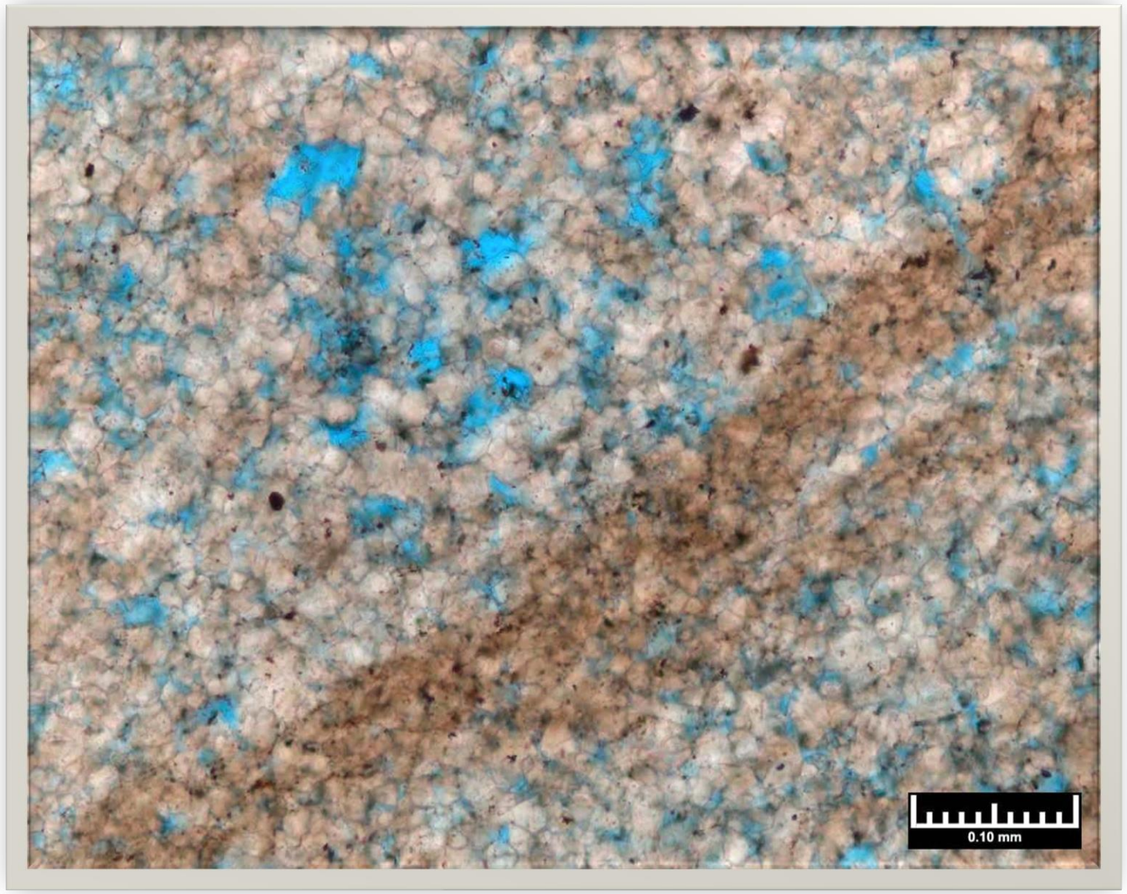
= "B" Core Analysis

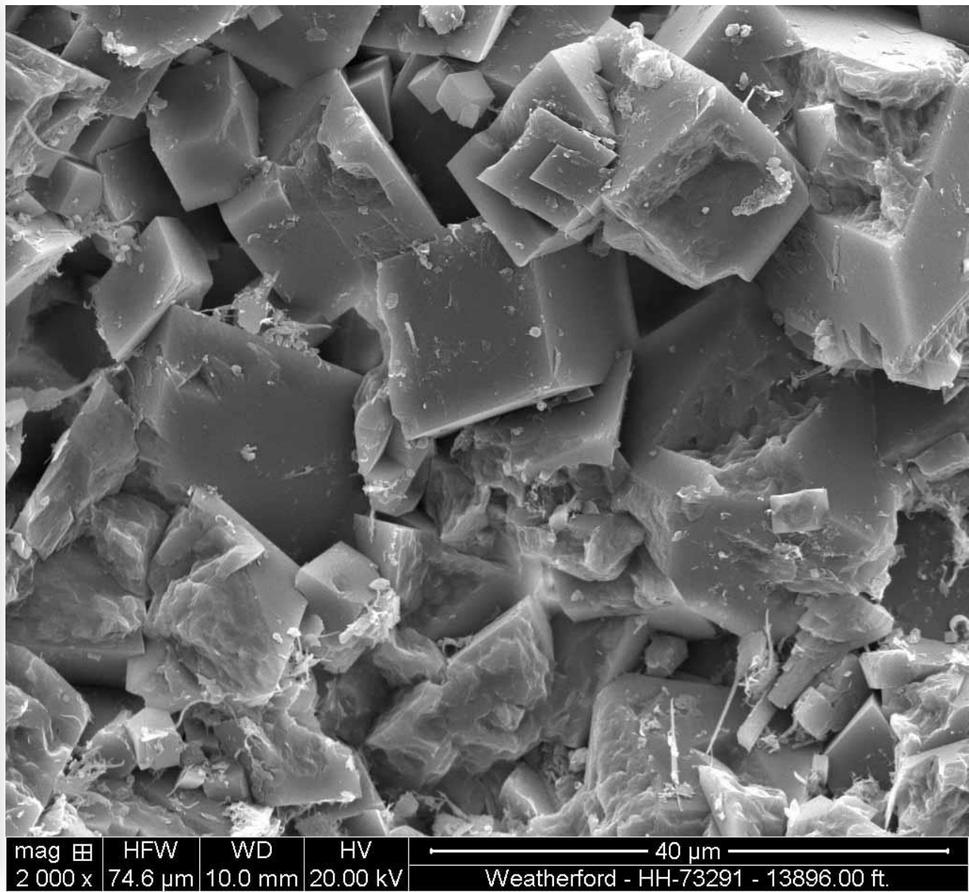
= "B" Special Core Analysis

Lithology: Dolostone

- **Higher porosity samples (>10%) are 97-99% dolomite**
- **Dolomite crystal size is highly variable; average size is ≈15 microns**
- **“B” laminated typically has better permeability than “B” burrowed**
- **Tight wells (Ø <6%) may be limestone, or dolostone or anhydritic dolostone**

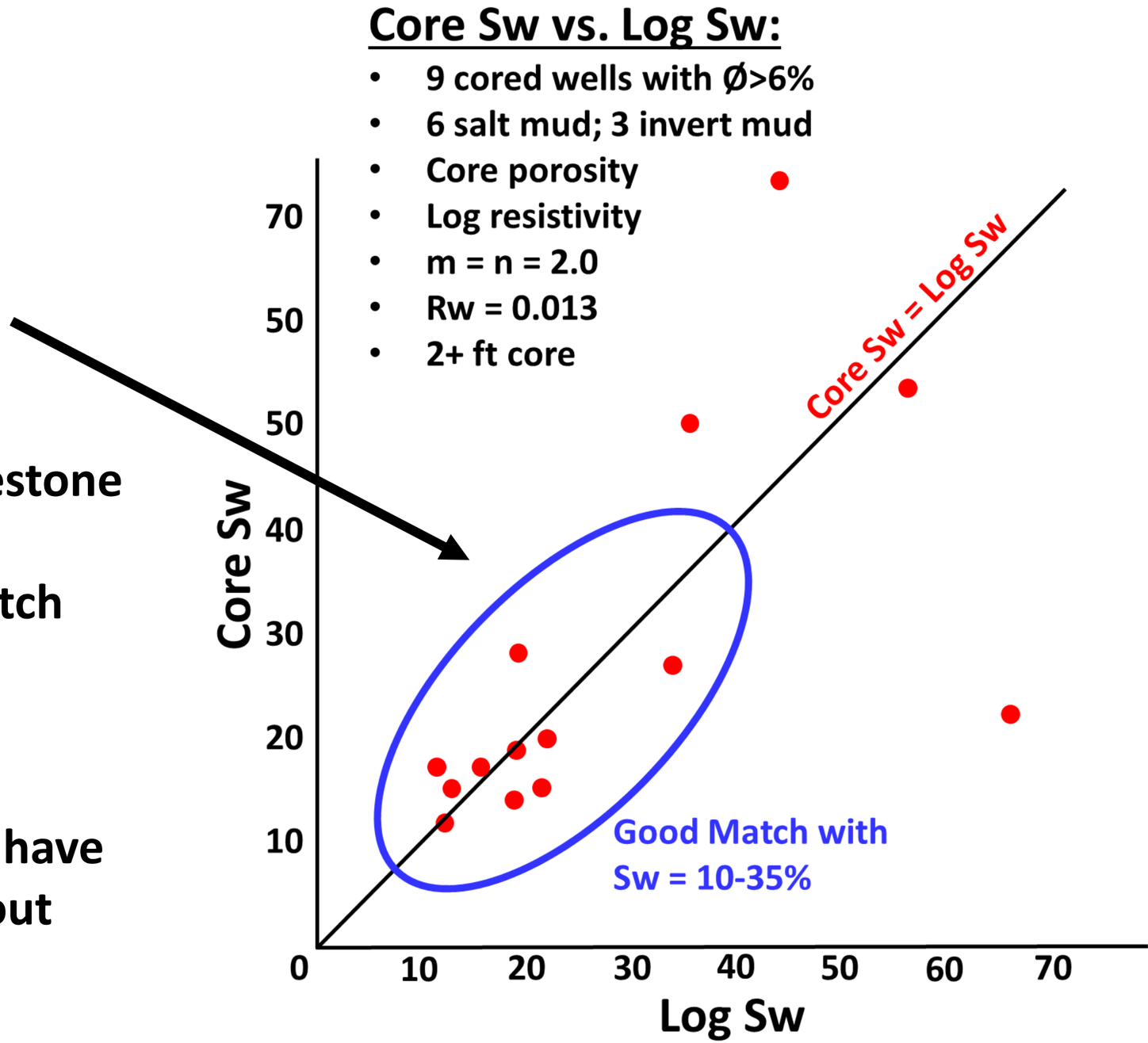
USA 18-13
T154N-R95W-
Sec. 18
13,896.0’
Ø = 13.6%
Ka = 2.6 md
“B” laminated





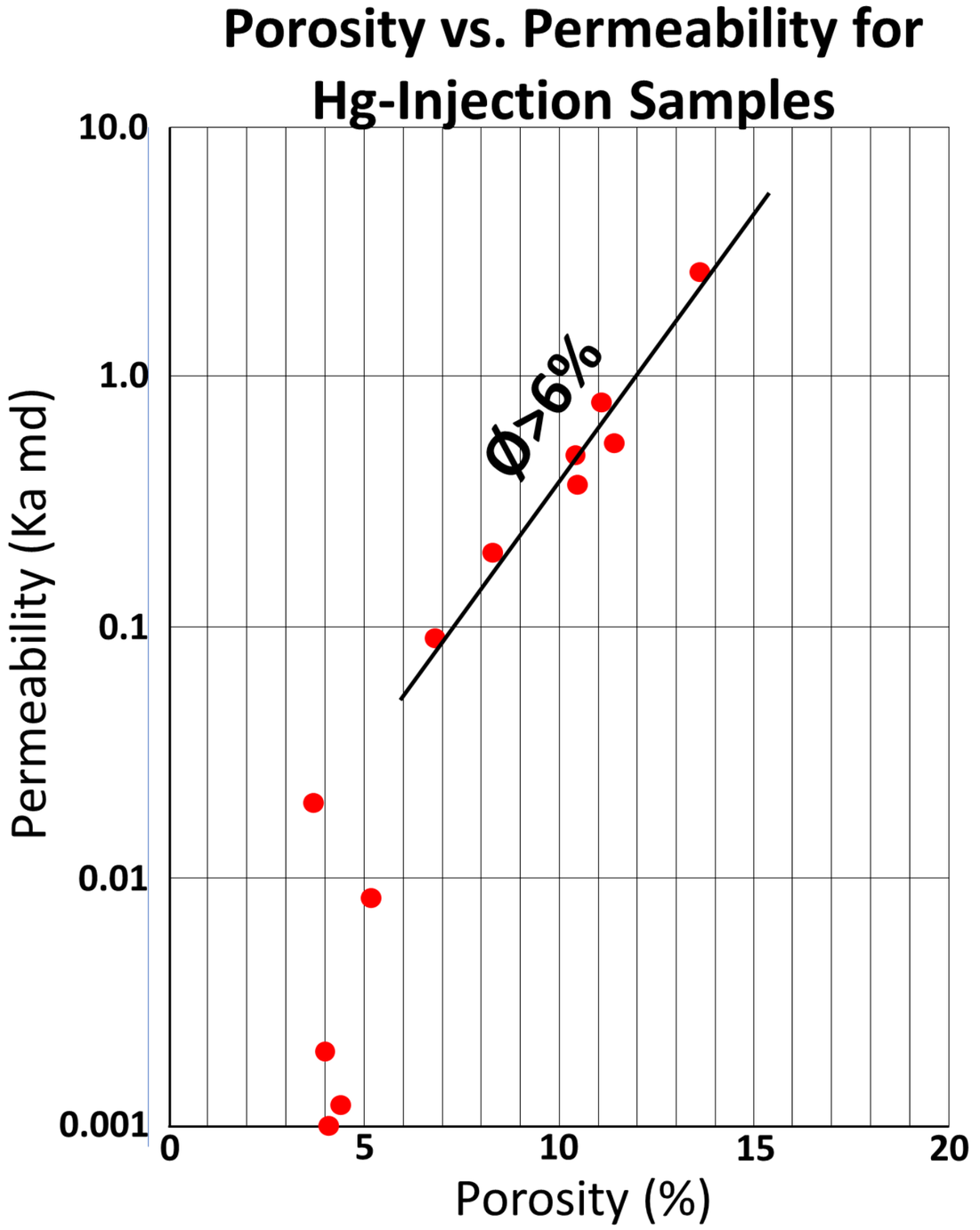
Red River "B" Log Analysis

- No lab "m" or "n" data
- Empirically, best match to core data:
  - m = n = 2.0, with Rw = 0.013
- Sonic log = poor core porosity match
  - Unknown lithology (dolostone, limestone or anhydritic) is largest uncertainty
- Neutron-Density log good porosity match
  - With no hole washout
  - Older wells (pre-1973) do not have Neutron-Density logs
  - 84 out of 188 Red River wells (45%) have minimal Neutron-Density log washout
  - 12% of 84 wells tight (Ø <6%)

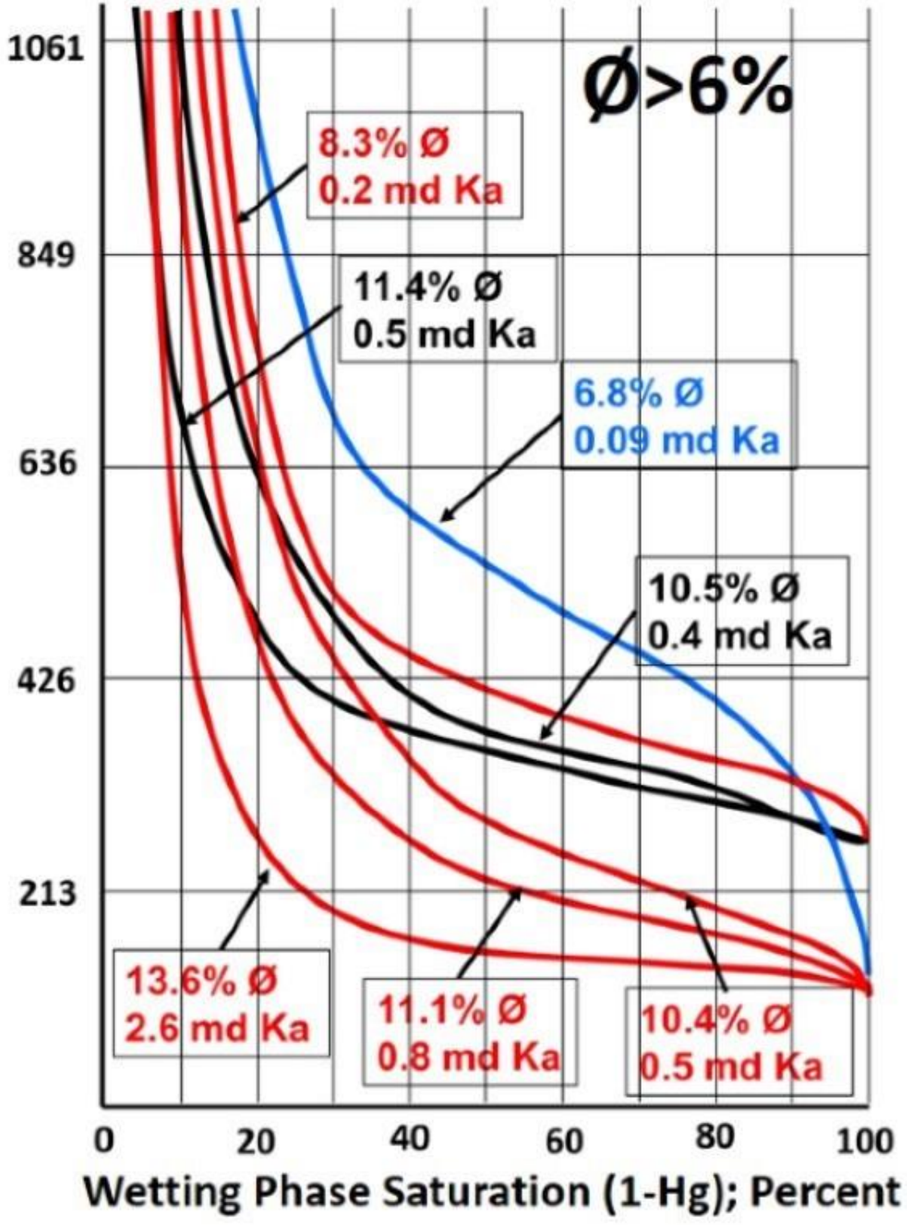


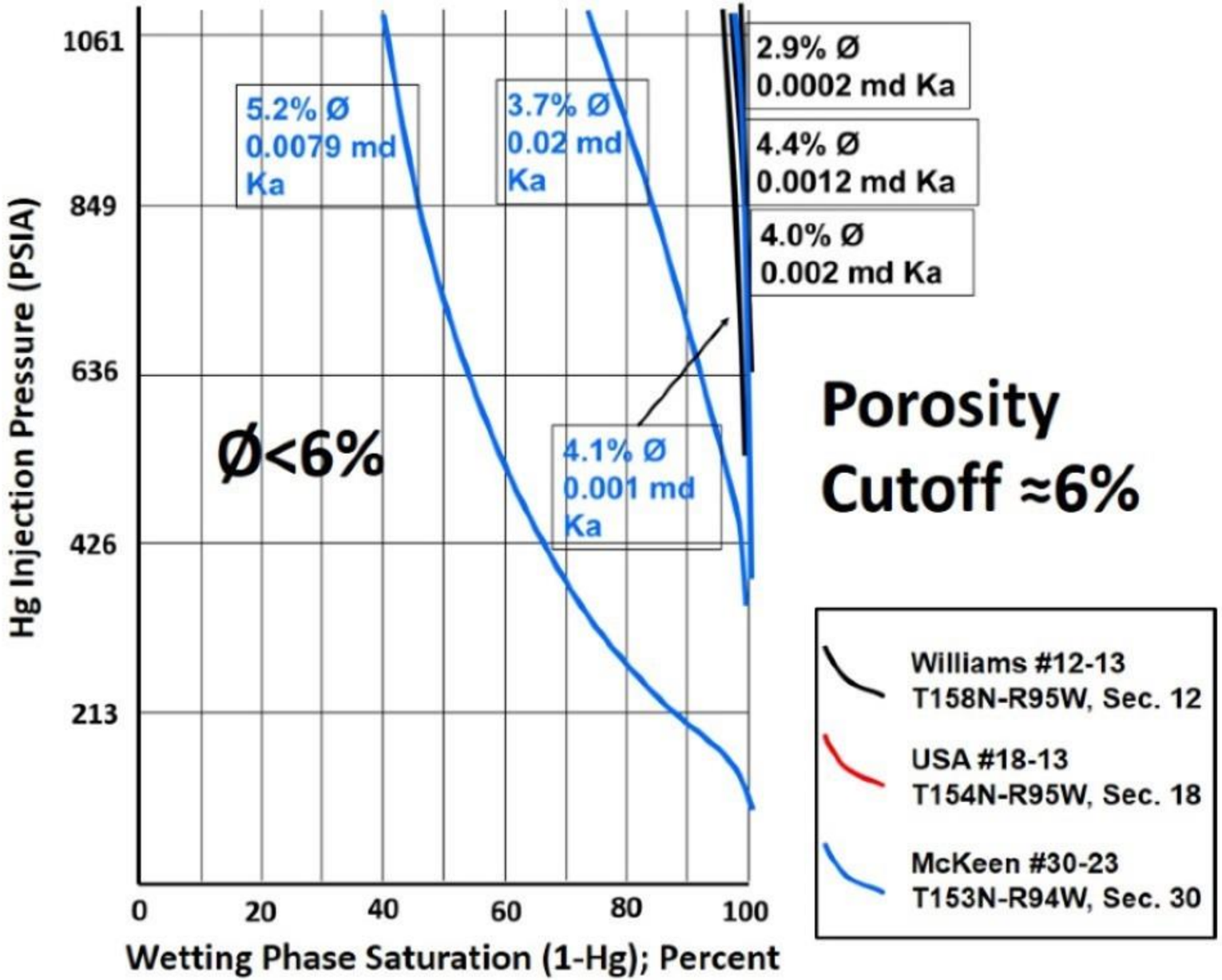
Porosity-Permeability-Saturation Data

- Logged oil-productive Sw = 6-35%
- Logged Sw >35% = water productive
- For core Sw <35%:
  - Core porosity = 4-20%
  - Average core porosity = 9%
  - Core permeability (Ka) = 0.02-5 md
  - Average core Ka = 0.75 md
  - Average core Sw = 22%
  - Average core net pay = 8 ft



Red River "B" Hg-Injection Capillary Pressure Data





Porosity Cutoff ≈6%

Williams #12-13
T158N-R95W, Sec. 12

USA #18-13
T154N-R95W, Sec. 18

McKeen #30-23
T153N-R94W, Sec. 30

Empirical Correlation =
Trial and Error Match with Well Data for
H Value (Feet)
Corresponds with
Intermediate Wettability System

160
140
120
100
80
60
40
20
0

Water-Wet System (feet)

260
208
156
104
52
0

Hg Injection Pressure (PSIA)

1061
849
636
426
213

8.3% Ø
0.2 md Ka

11.4% Ø
0.5 md Ka

6.8% Ø
0.09 md Ka

10.5% Ø
0.4 md Ka

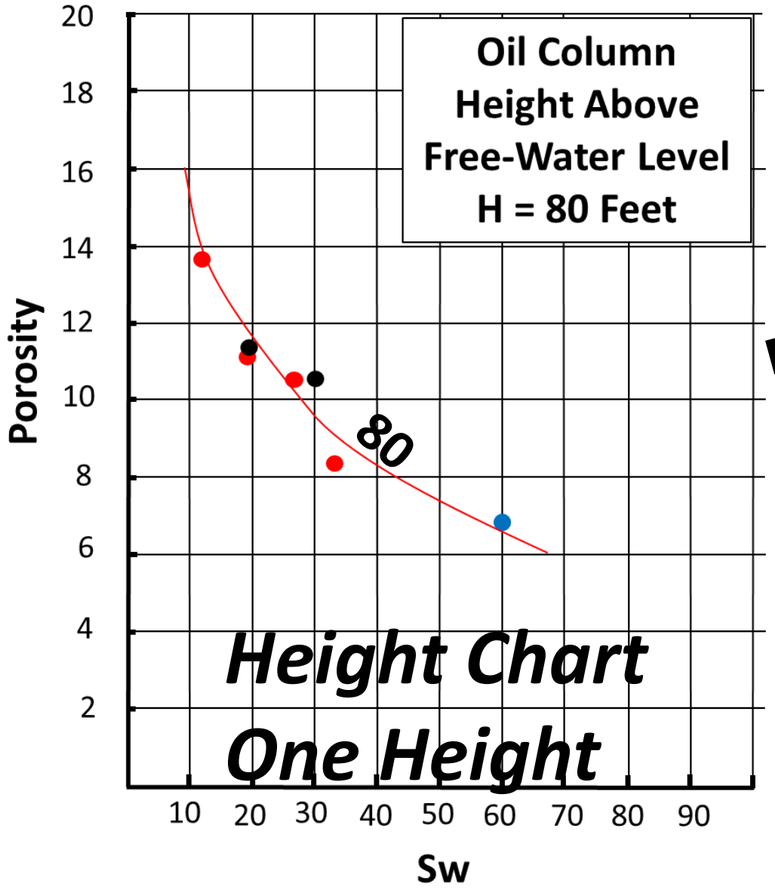
13.6% Ø
2.6 md Ka

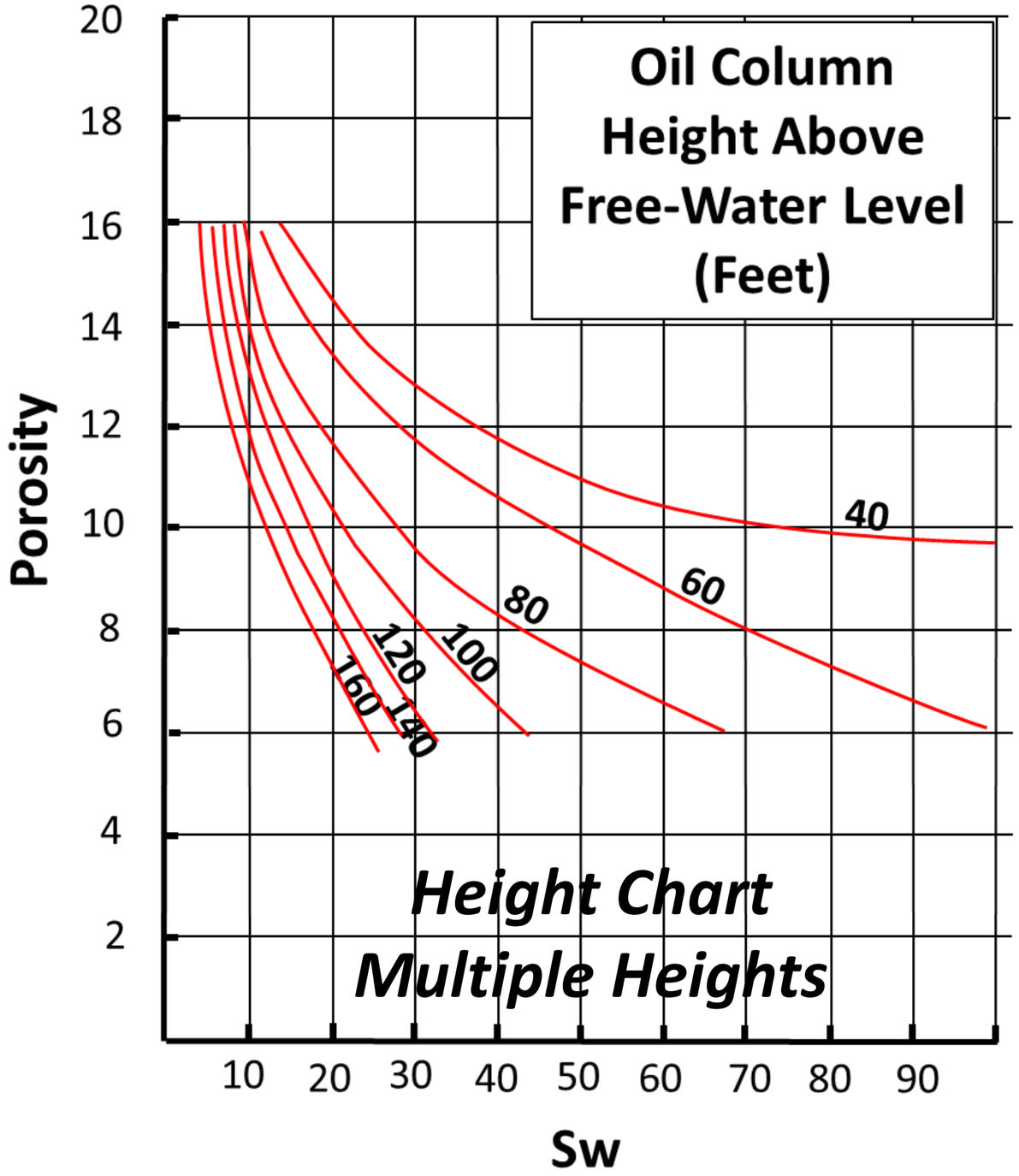
11.1% Ø
0.8 md Ka

10.4% Ø
0.5 md Ka

0
20
40
60
80
100

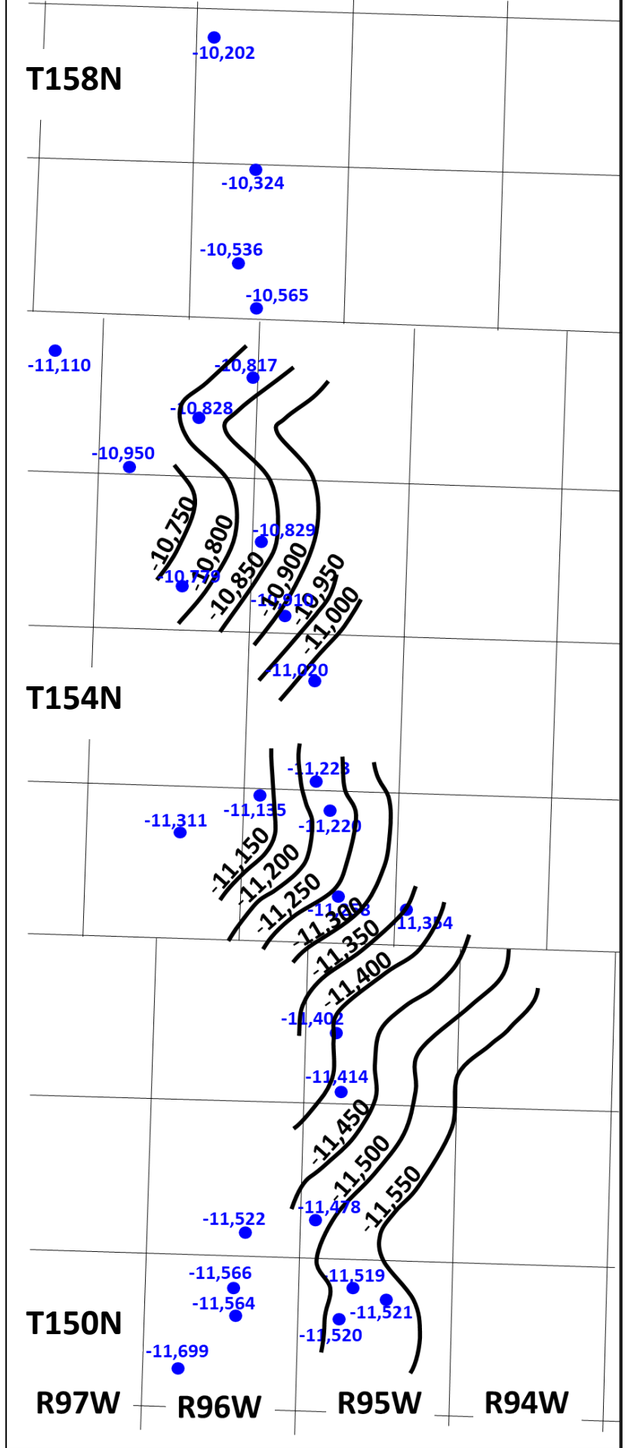
Averaging Method to Obtain Height Curves for Porosity & Water Saturation Values

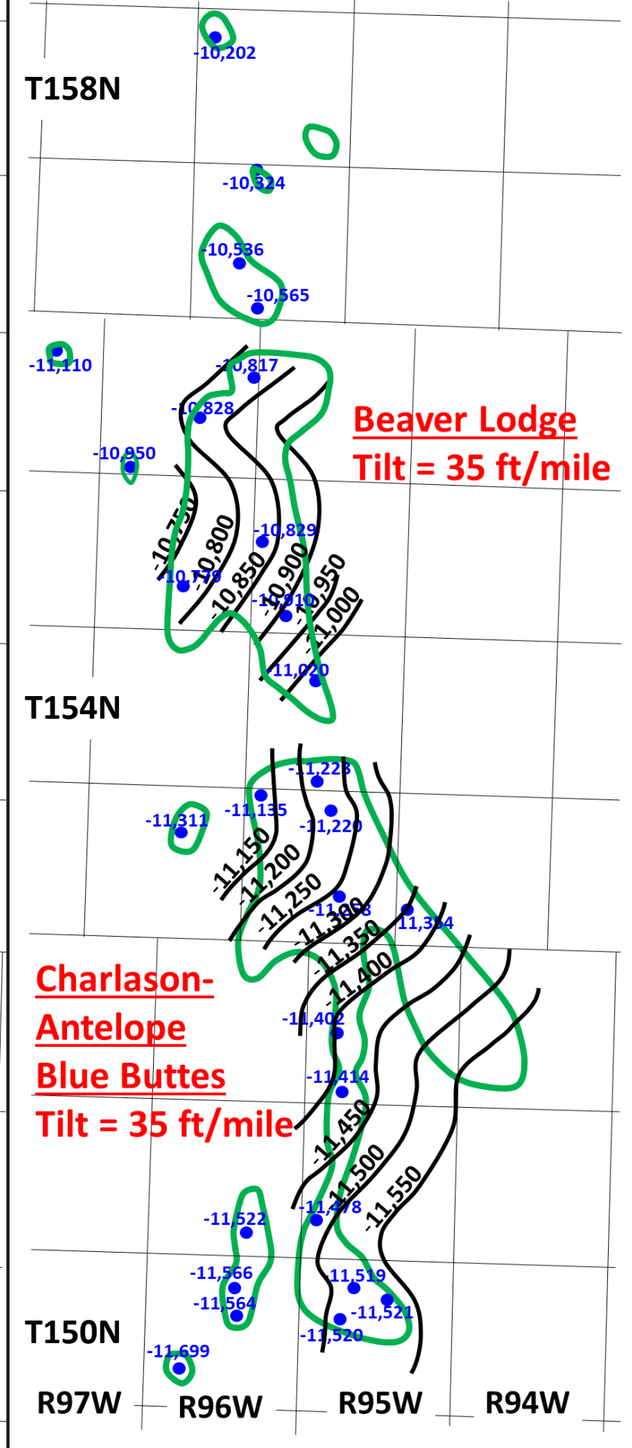




Calculating Free-Water Level

- Only wells with good quality data
- Not in gas cap
- Use Height Chart
- Convert to subsea depth for top “B” Ø
  = **BLUE NUMBERS**





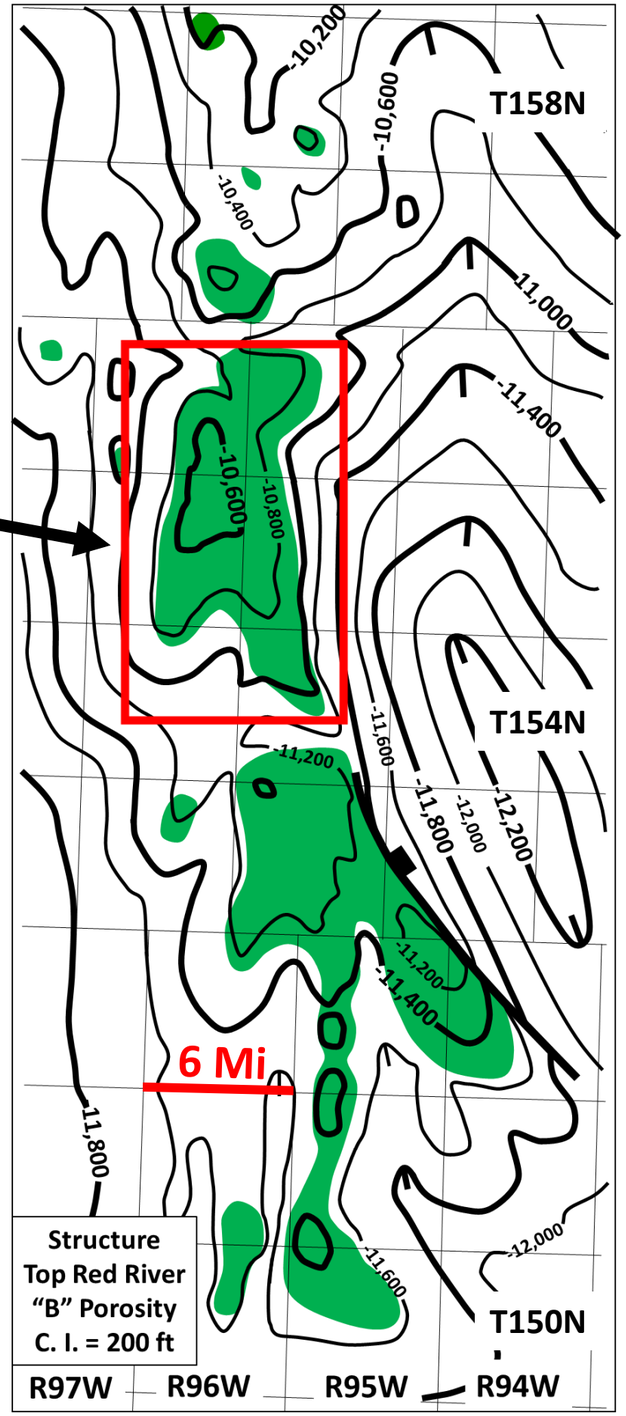
Map Free-Water Level

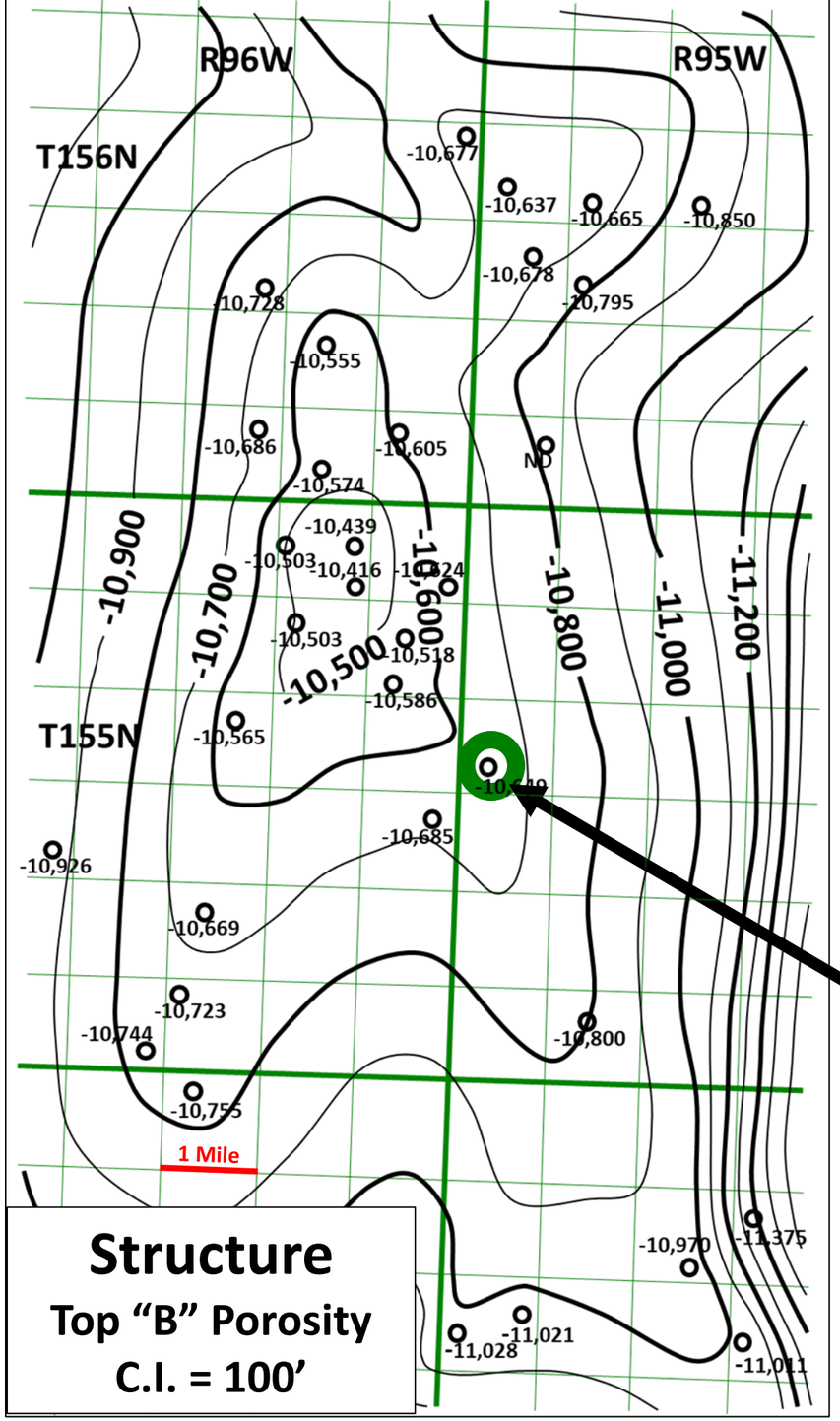
- Map FWL
  = BLACK NUMBERS
- Identify accumulations with a common free-water level
  = **GREEN OUTLINES**

Red River “B” Tilted Oil Accumulations

- **Large Red River “B” accumulations have free-water levels tilted average 35 ft/mile to east/southeast**
- **Hydrodynamically southeast tilted oil accumulations have previously been defined in the overlying Madison reservoirs (DeMis, 1995) and Duperow reservoirs (Petty, 2022) on the Nesson anticline**
- **Southeast-tilted Red River “B” accumulations are probably hydrodynamically tilted (see final slide)**

Beaver Lodge Field
Case Study





Structure
Top "B" Porosity
C.I. = 100'

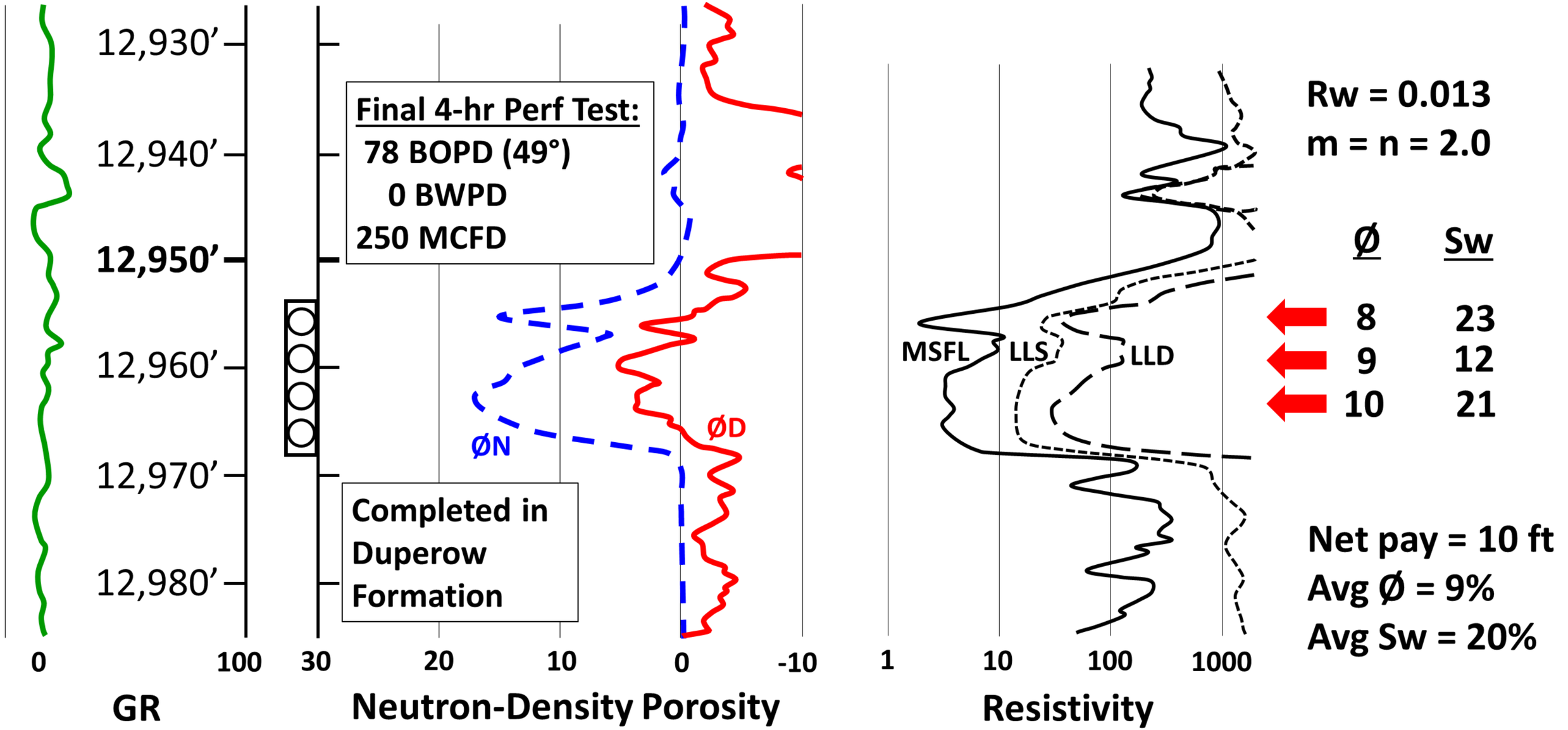
BEAVER LODGE FIELD STRUCTURE

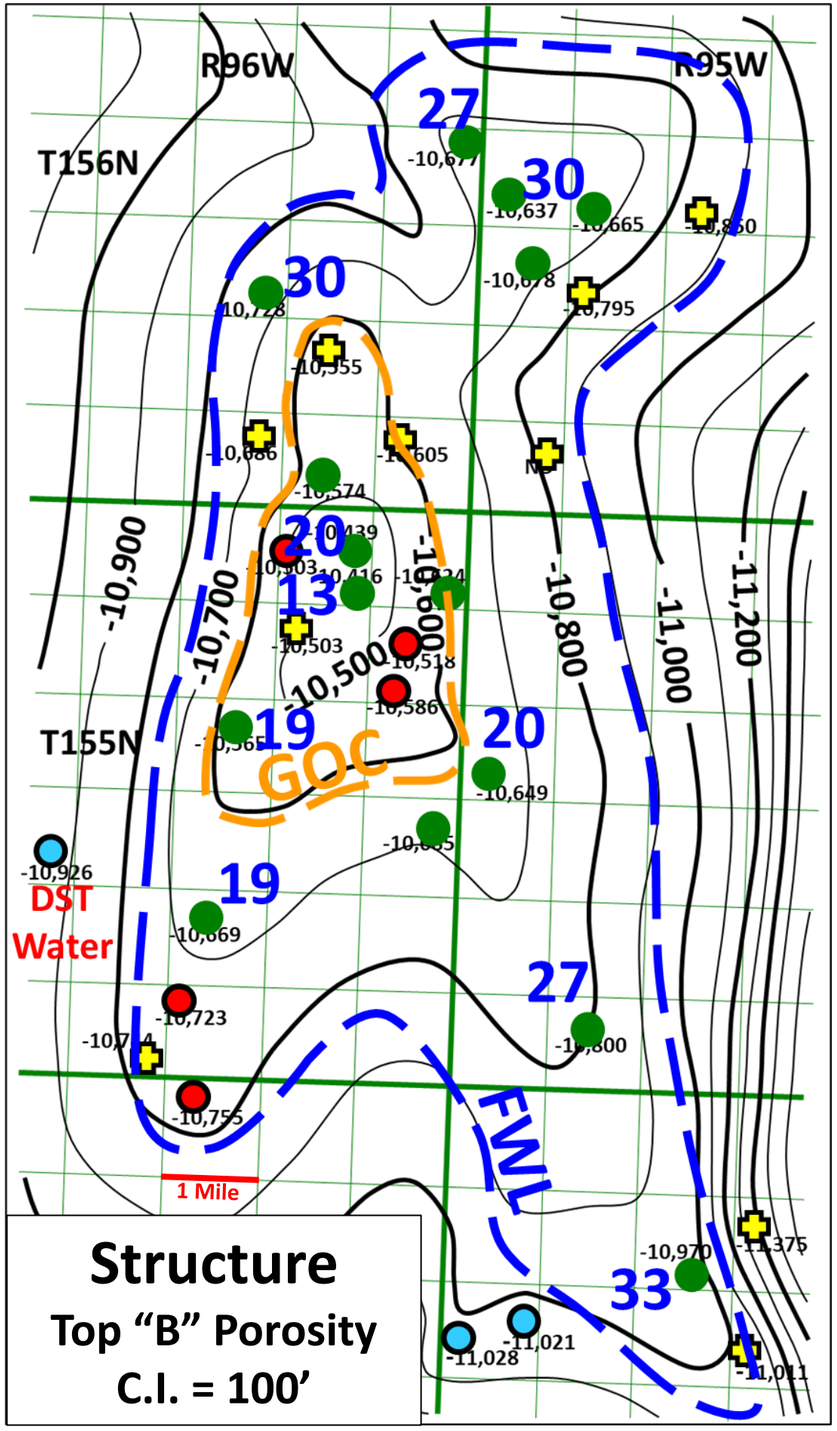
Top Red River "B" Porosity
C.I. = 100'

- Anticlinal closure
- One of largest structural closures in North Dakota

Type Log

Beaver Lodge Field Type Log
BLDU G-303
T155N-R95W, Sec. 18





Structure
Top "B" Porosity
C.I. = 100'

STRUCTURE

With "B" Contacts and "B" Data

● = Red River "B" Porosity is Oil/Gas-Bearing
= "B" Produced Oil/Gas, or Tested >50% oil, or Sw <35%

○ = Red River "B" Porosity is Water-Bearing

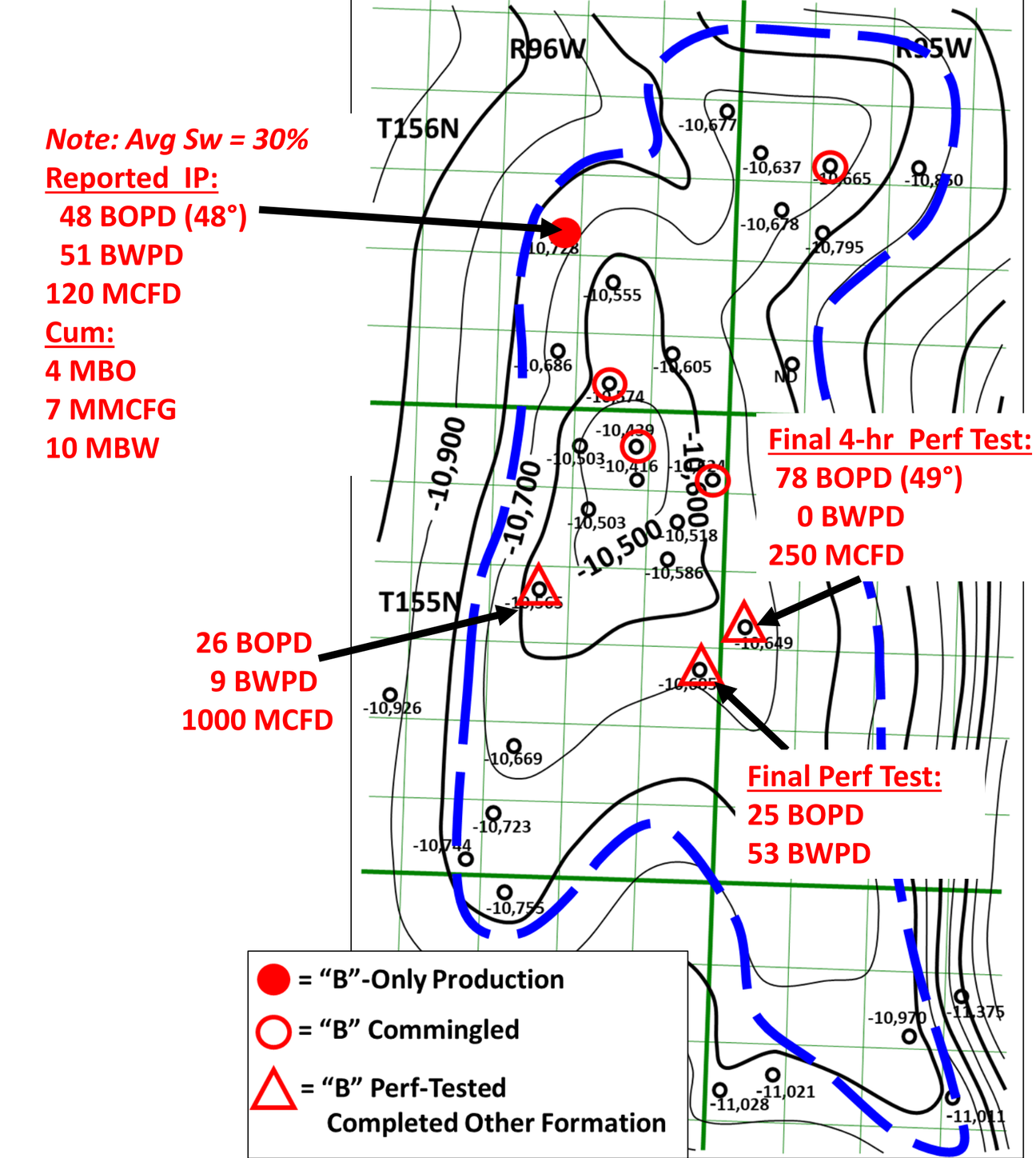
✚ = No Core Data or Usable Neutron-Density Log
= Old Well or Neutron-Density Log Washed-Out

● = Red River "B" tight (20% of wells)
= "B" Neutron-Density Porosity <6%

20 = Red River "B" Average Sw

= Approximate Gas-Oil Contact

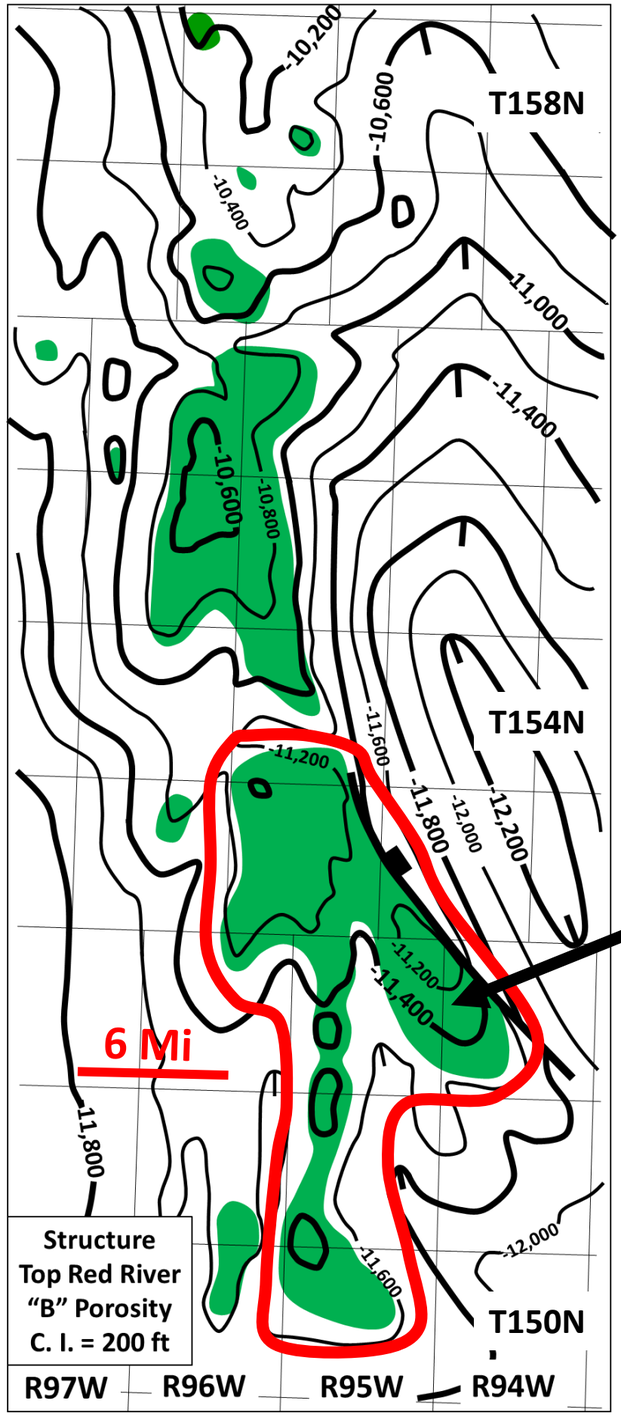
= Free-Water Level



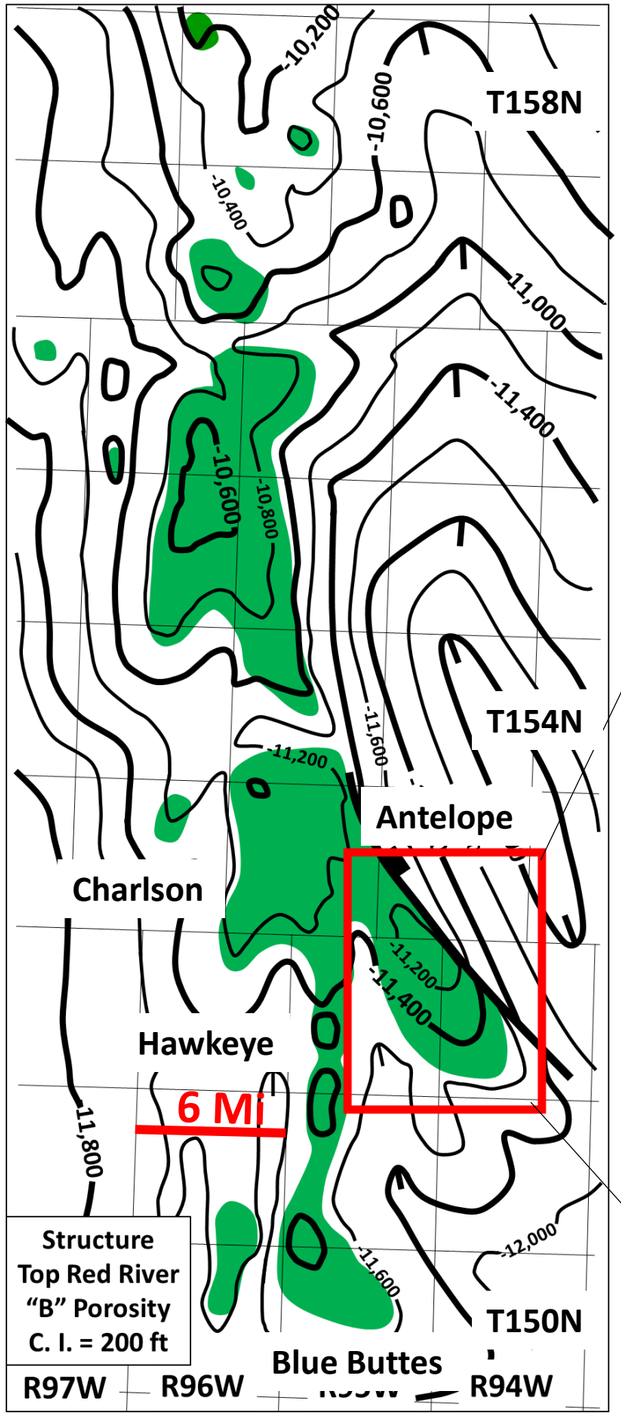
Beaver Lodge Field
Red River "B" Reservoir
With
Perf-Test & Production Data

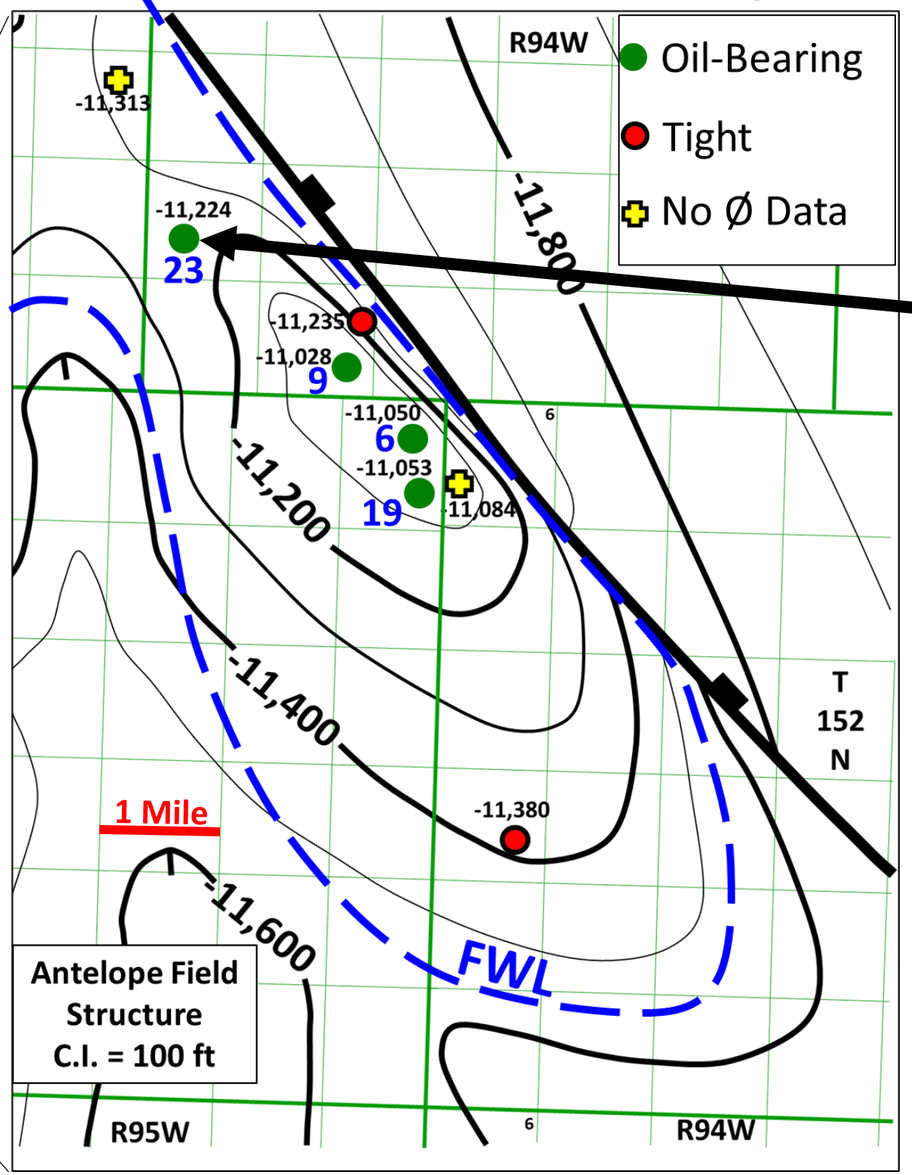
Summary:

- Most "B" production commingled
- "B" porosity is heterogeneous
- Water saturation and capillary pressure data indicate a single, large "B" reservoir,
- Oil Column Tilt = 35 ft/mile East



Antelope-Blue Buttes-Charlson Accumulation Case Study



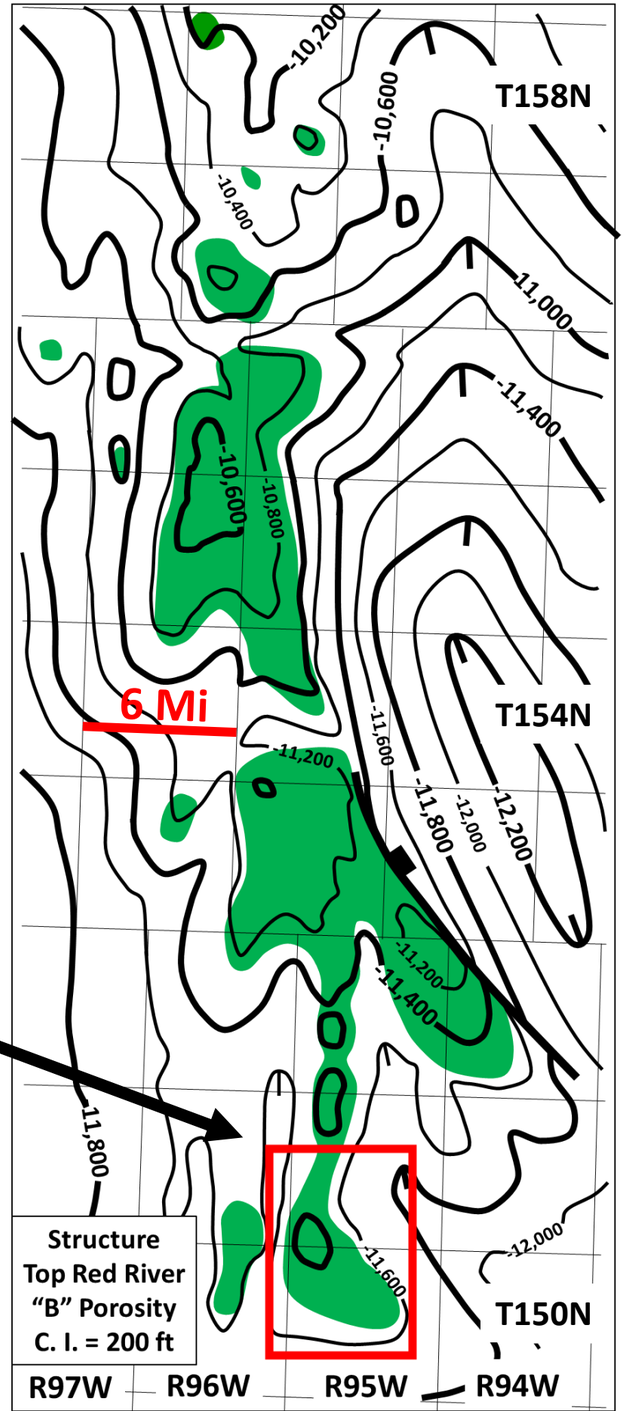


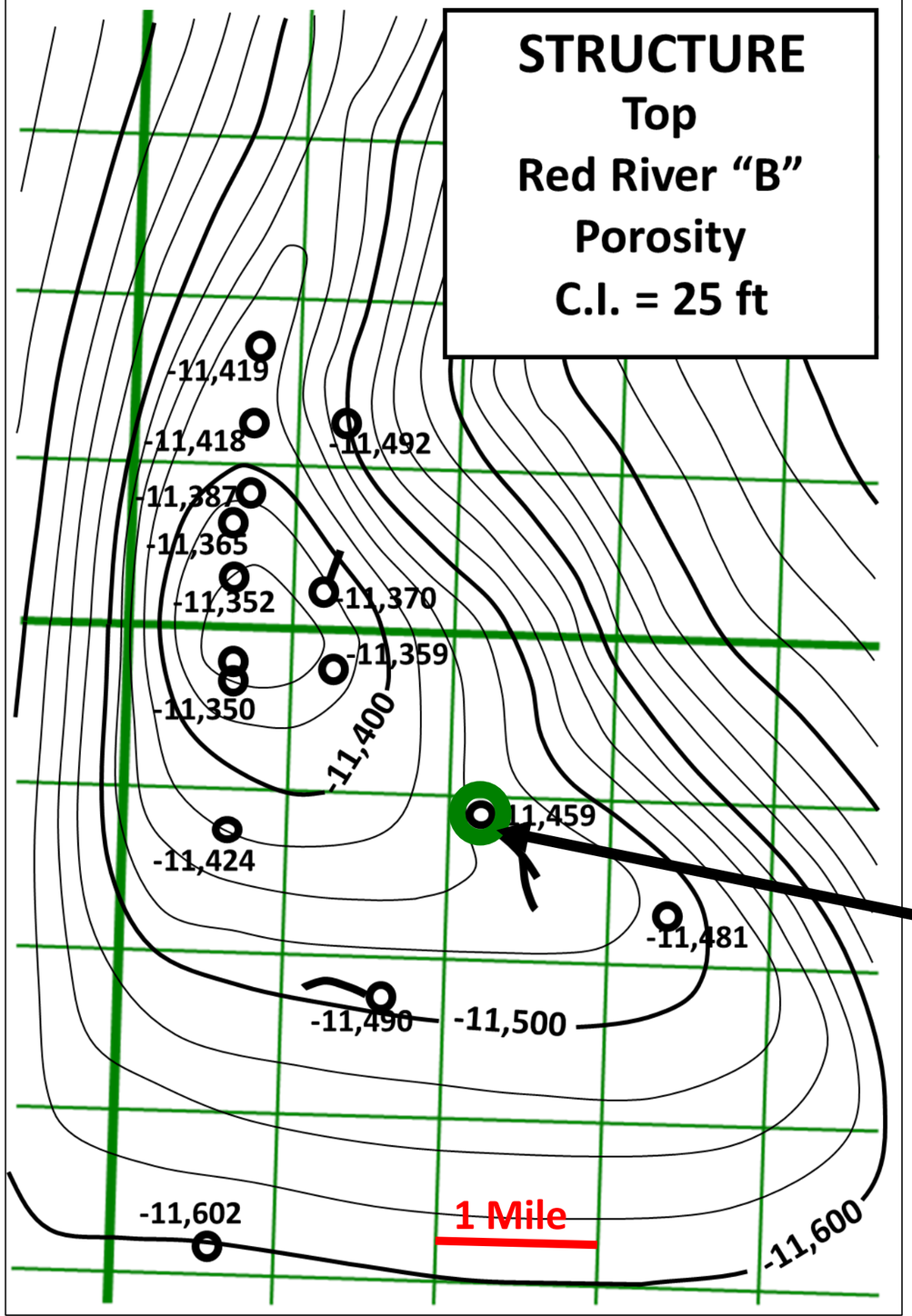
Antelope Field

McKeen #30-23
T153N-R94W, NESW Sec. 30
Oil-Productive Flank Well
3D Seismic Confirms
"Saddle" Structure
200' Low to Structure Crest

<u>McKeen Core Data:</u>
Max. Ø = 9.5%
Sw @ max Ø = 18%
H = 130 feet above FWL

Blue Buttes Field
Case Study



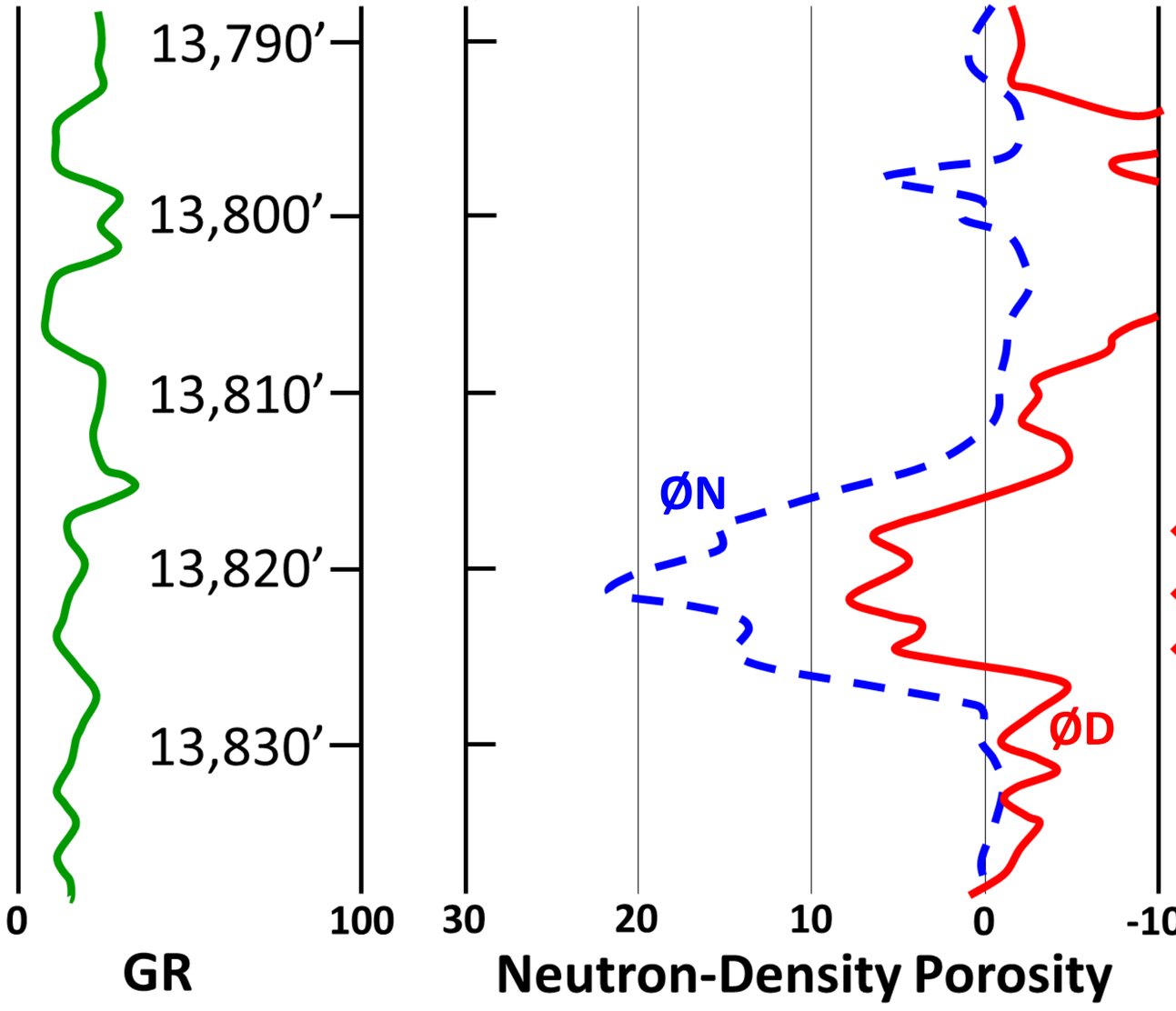


BLUE BUTTES FIELD
STRUCTURE
Top Red River "B" Porosity
C.I. = 25'

- Structural closure connected via anticline to Hawkeye Field to north
- Southeast plunging anticline

Type Log = Pilot for Horizontal

Type Log for Southern Blue Buttes
Olson 9-11H; T150N-R95W Sec. 9

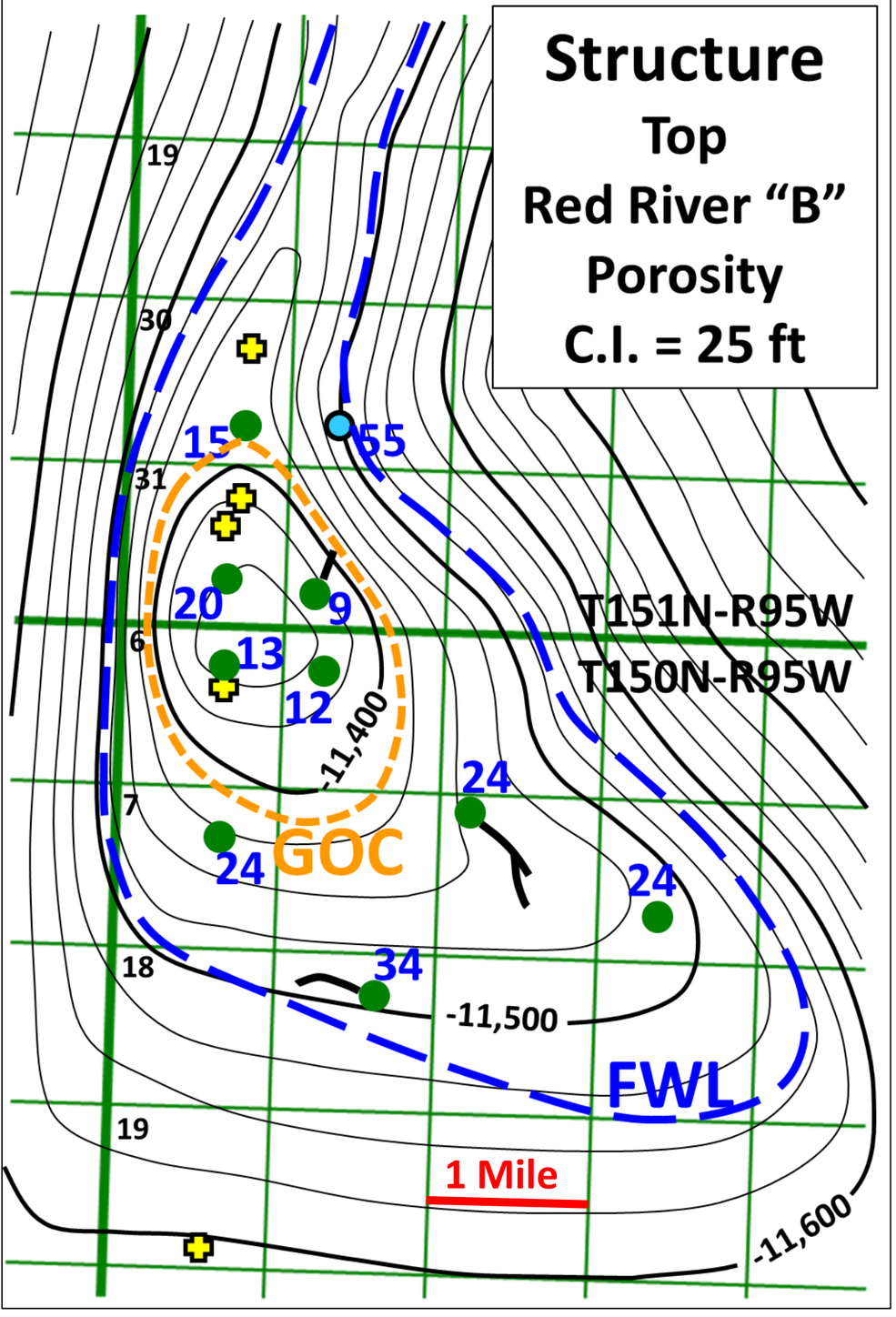


Pilot for Horizontal Red River “B” well

m = n = 2.0
Rw = 0.013

Ø	Sw
11	23
15	14
10	34

Net pay = 9’
Avg. Ø = 12%
Avg. Sw = 24%



STRUCTURE

With "B" Contacts and "B" Data

● = Red River "B" Porosity is Oil/Gas-Bearing
= "B" Produced Oil/Gas, or Tested >50% oil, or Sw <35%

◉ = Red River "B" Porosity is Water-Bearing

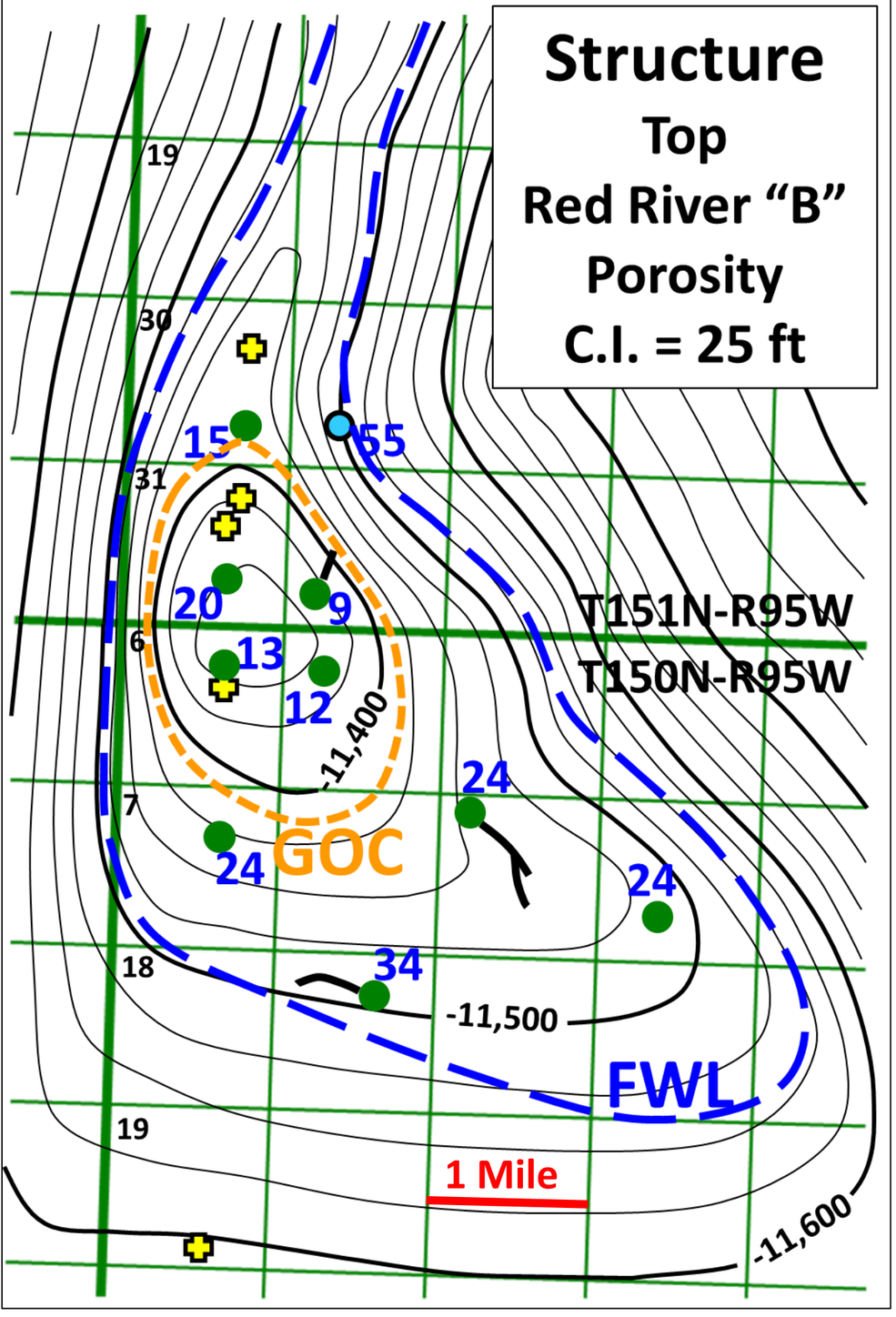
✚ = No Core Data or Usable Neutron-Density Log
= Neutron-Density Log Washed-Out

Note southeast-plunging anticline prospective area

24 = Red River "B" Average Sw

= Approximate Gas-Oil Contact

= Free-Water Level



STRUCTURE

With "B" Contacts and "B" Data

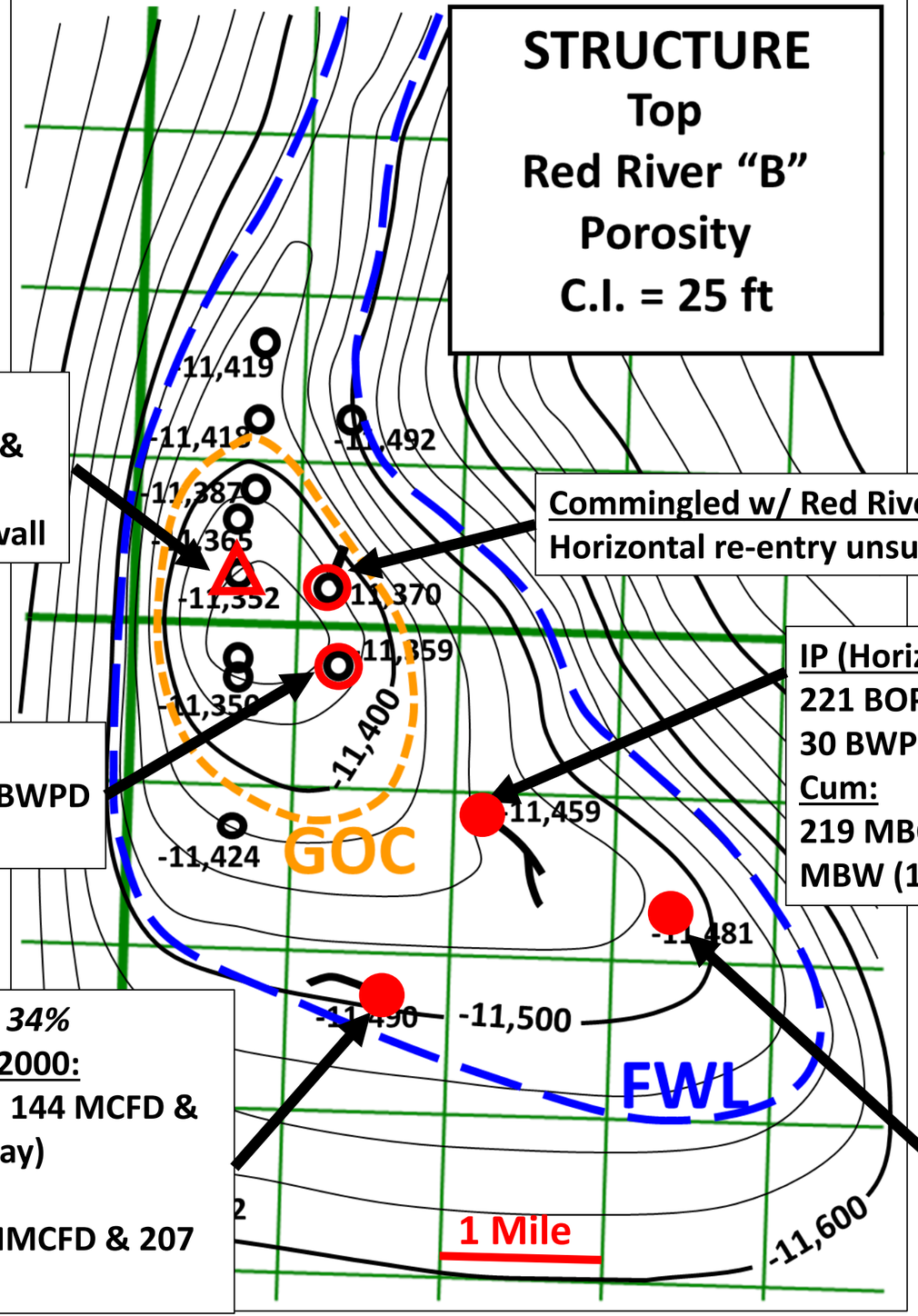
- *Deepest field (13,800' TVD) at "B" Ø*
- *No wells tight (Ø<6%) in "B"*
- *Best average Ø among larger fields*
  - *Average net pay = 8.8 ft*
  - *Average Ø = 11.4%*
  - *Average Sw = 20%*
  - *Average Ka = 1.4 md (routine analysis)*

24 = Red River "B" Average Sw

= Approximate Gas-Oil Contact

= Approximate Oil-Water Contact (Sw ≈ 35%)

Height (ft) Above OWC with "B" Production & Perf-Test Data



Swab Test
60 BOPD, 362 MCDF & 262 BWPD
Completed in Stonewall

Commingled w/ Red River "C" & "D"
Horizontal re-entry unsuccessful

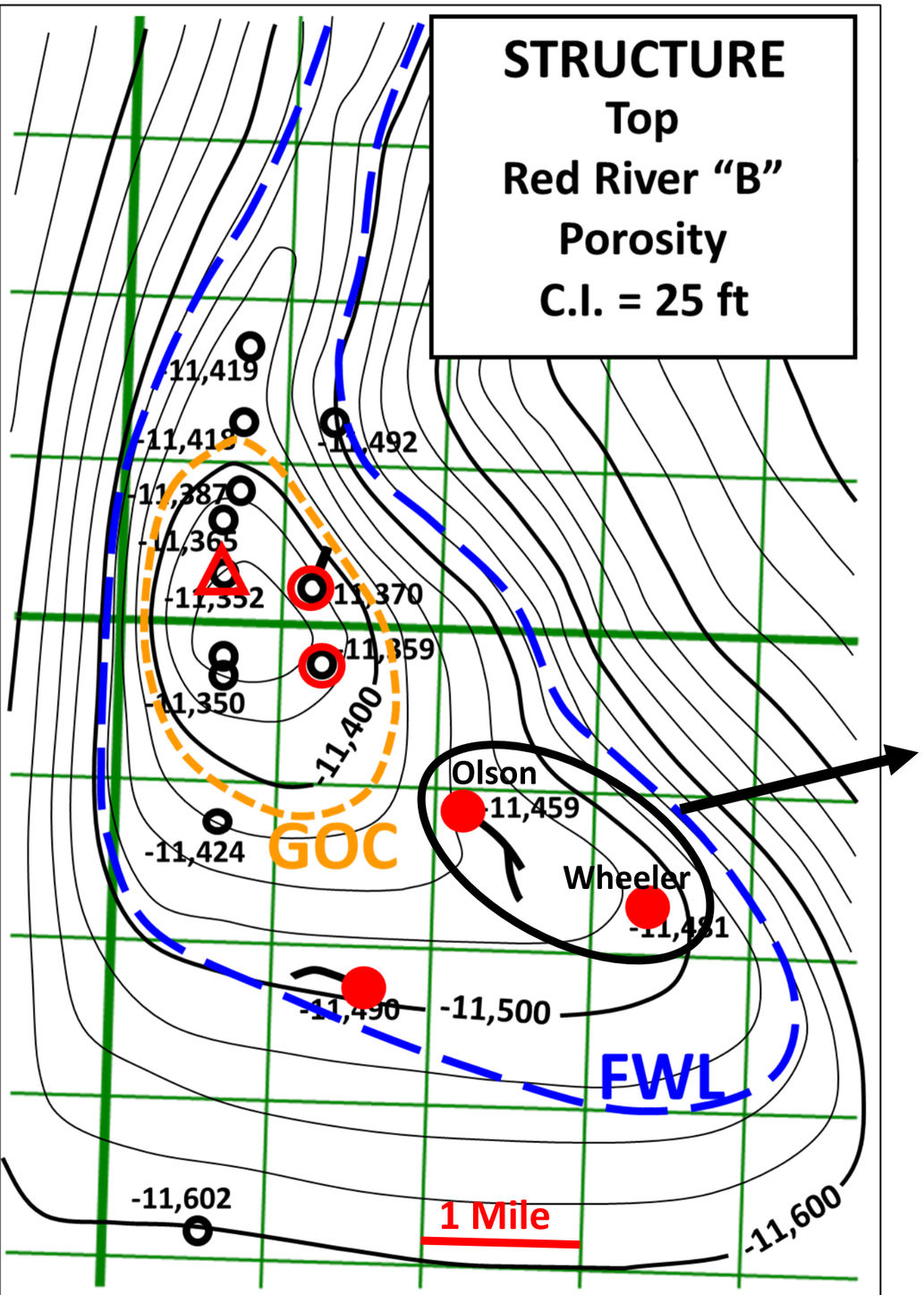
IP (Horizontal) 2008:
221 BOPD (48°), 733 MCFD & 30 BWPD (30-day)
Cum:
219 MBO, 869 MMCFD & 15 MBW (11 years)

Perf Test (Vertical)
81 BOPD, 368 MCFD & 4 BWPD
Commingled with RR "D"

Note: Avg Sw = 34%
IP (Horizontal) 2000:
55 BOPD (48°), 144 MCFD & 92 BWPD (30-day)
Cum:
42 MBO, 110 MMCFD & 207 MBW (5 years)

Note: Ø = 20% & H = 6 ft
IP (vertical) 1985::
61 BOPD (48°), 100 MCFD & 0 BWPD (30-day)
Cum:
287 MBO, 830M MCFD & 6 MBW (25 years)

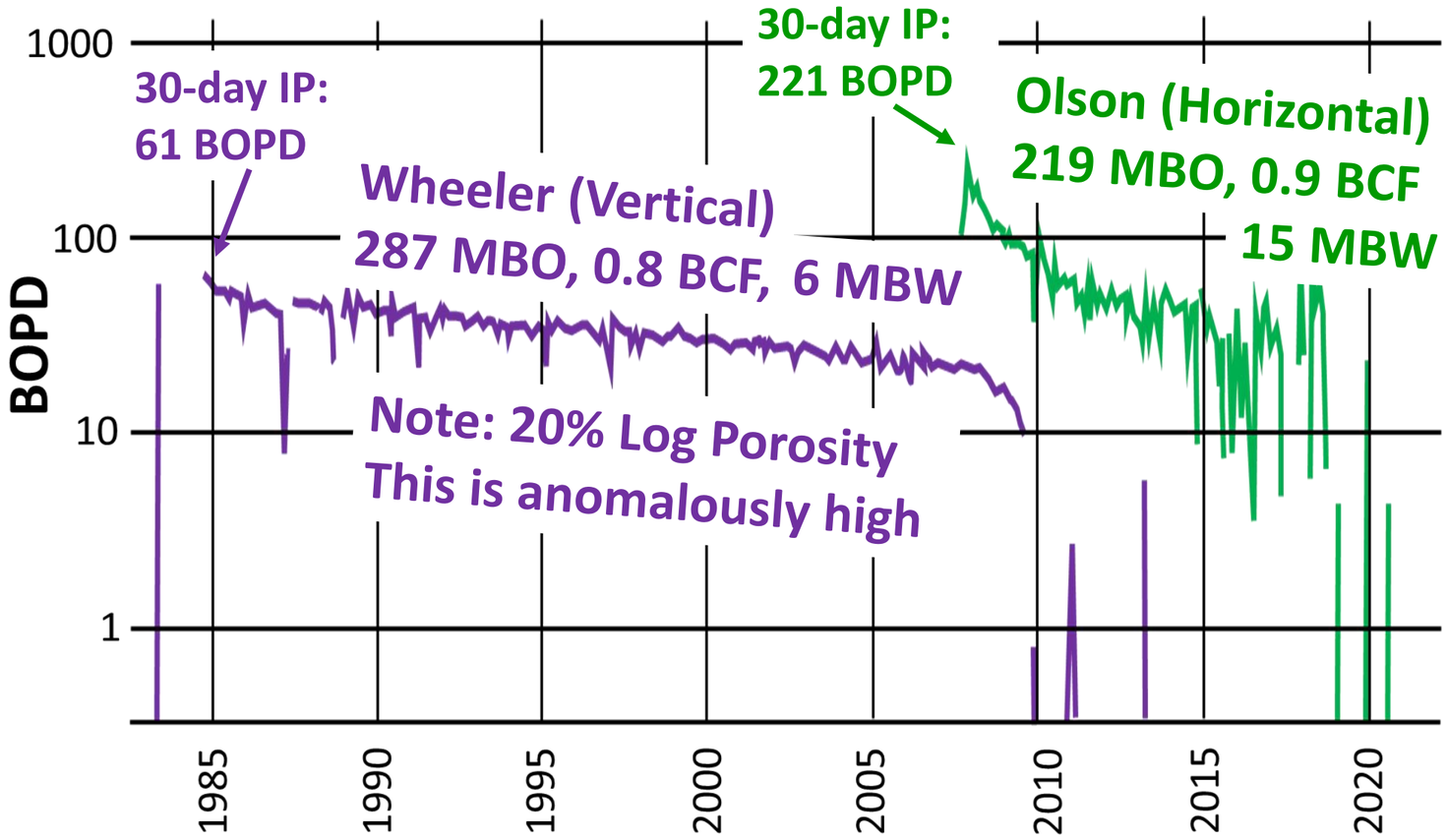
● = B-Only Production
○ = B Commingled
△ = B Tested

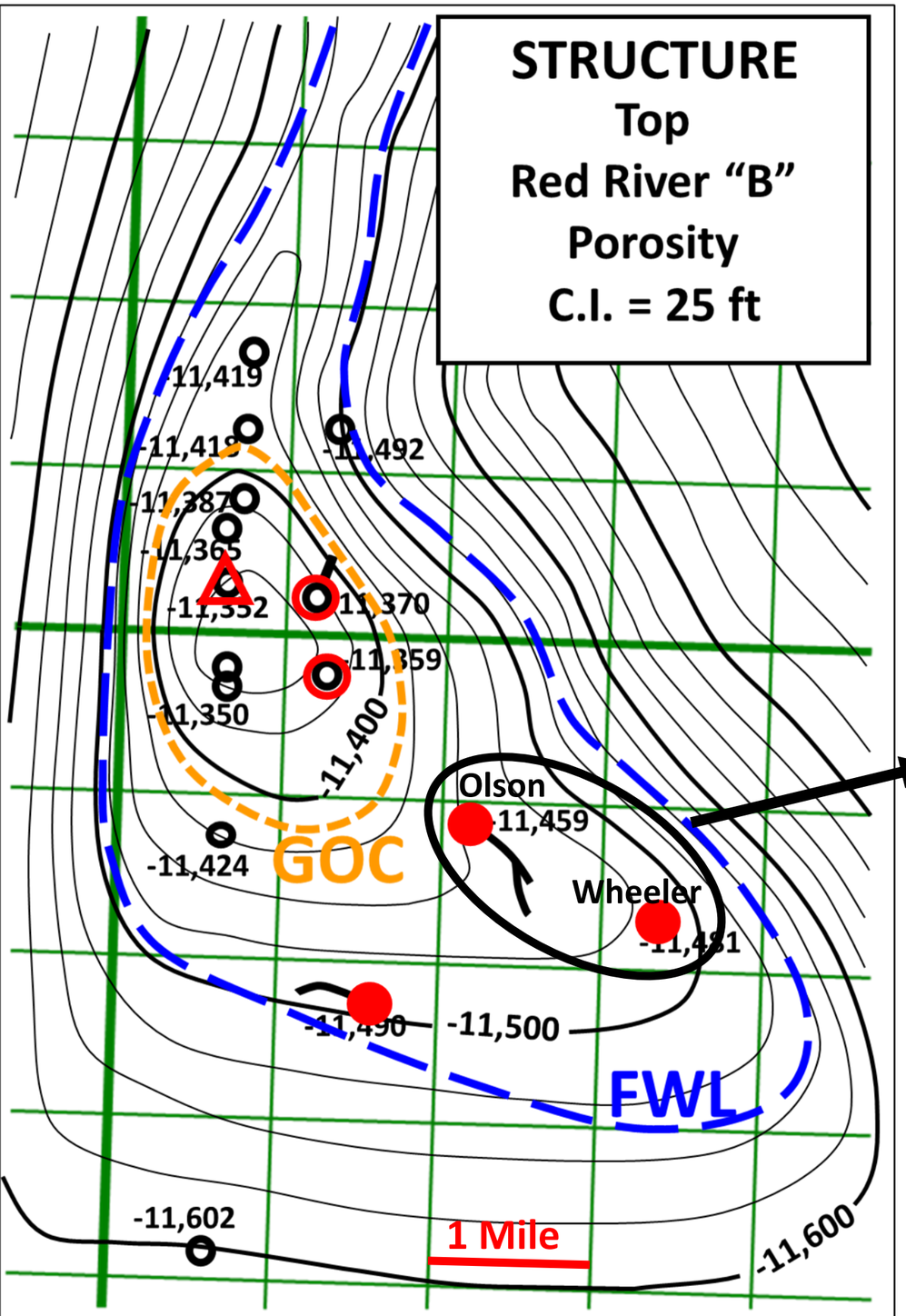


Decline Curves

Wheeler 10-23 Vertical "B"

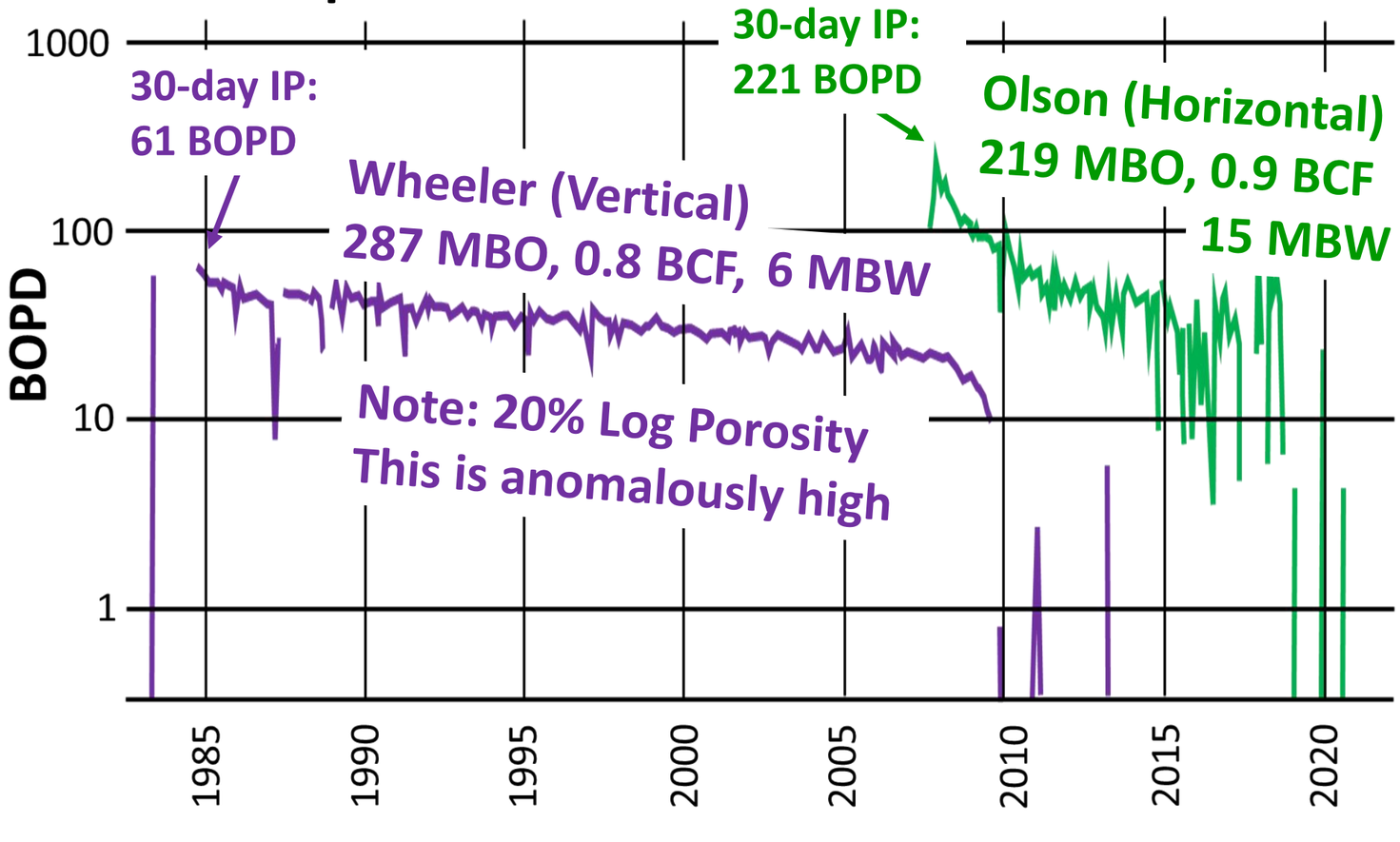
Olson 9-11 Horizontal





Olson 9-11 Horizontal

- Difficult to stay in-zone; 2 sidetrack attempts
- Pre-mature TD; 1872' in-zone
- Due to hole obstruction: No acid job; No frac
- Current or future horizontal drilling technology should be able to drill better, stimulate better and produce better



Red River “B” Conclusions

- On Nesson anticline, 10-12% of Red River “B” wells are tight (Ø<6%)
- The Red River “B” reservoir commonly has 5-15 feet of net porosity
- Average net pay in oil-bearing wells is 8 feet with average 9% porosity, 22% Sw and 0.75 md Ka
- Red River “B” oil can occur in large accumulations that are hydrodynamically tilted to the east-southeast
- Gas caps with no mappable tilt occur on structural closures
- Red River “B” horizontal economic potential in the central Williston basin is unproven but has not been tested with the most modernized technology

Broader Implications

- Most large Madison, Duperow and Red River oil accumulations in western North Dakota have hydrodynamically east-tilted OWC's
  - Petty, 2023, AAPG Bulletin; "Hydrocarbon Trapping in Hydrodynamic Salinity Gradients: Williston Basin Case Studies"
    - Accepted February 24, 2023; in-press
- All Red River through Madison conventional oil reservoirs and oil-show wells should be investigated to determine if they could be part of a larger east-tilted oil accumulation
- In the western Williston basin, east-plunging anticlines with oil production or oil shows could hold un-tapped potential in thin zones that could be exploited with horizontal wells