

Duperow Reservoir Characteristics in Beaver Lodge Field, North Dakota

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Abstract

Beaver Lodge Field lies on the Nesson anticline in northwest North Dakota near the center of the Williston basin. The upper Devonian Duperow oil accumulation is situated on a four-way closure that covers 14,750 acres at a depth of 10,300 feet. To date, 74 million barrels of 42° oil have been produced from the Duperow in Beaver Lodge Field since the initial discovery in 1951. The Duperow Formation is a 450 foot-thick, carbonate-evaporite sequence defined by prominent gamma-ray marker beds. It consists of stacked, brining-upward or shoaling-upward, carbonate to anhydrite cycles that parallel thin marker beds.

The uppermost productive cycle lies between the “A” and “B” marker beds of Wilson (1967); this is the most productive cycle within the field. Most reservoir-quality porosity occurs in the dolomite matrix of stratiform flow units that are commonly 2 to 10 feet thick, and occur interbedded with subtle, low-permeability, silt and clay-rich, gamma-ray marker beds. There are five dolostone flow units within this cycle (A1 at top, A2, A3, A4, and A5 at base). The A2 zone is the most widely porous flow unit in the field and is used to illustrate reservoir properties. As the most widely productive zone and the uppermost porous zone of significance, there is much flow-test data and excellent control on the location of the oil-water contact. Porosity occurs dominantly in a burrowed to poorly laminated, dolomitic, skeletal-peloidal packstone-wackestone. Reservoir rock in the A2 zone is developed in a north-south area where porosity is commonly 18-24%, and permeability is typically 10-20 md (Ka).

Field-wide, cycle-top anhydrite beds form vertical seals that separate stacked oil columns with separate oil-water contacts. The occurrence of structurally lower oil production in the southeast portion of the field, relative to porous and permeable, water-bearing wells in the northwest portion of the field, indicates that the oil columns are tilted. There is no evidence that stratigraphic pinchouts, fault barriers or capillarity characteristics could have produced an apparent tilt. The mappable Beaver Lodge Duperow oil-column tilt (average 30 ft/mile to the east) is similar to the documented hydrodynamic tilt in the overlying Madison reservoir and this suggests that a similar hydrodynamic gradient affects Duperow oil accumulations.

References

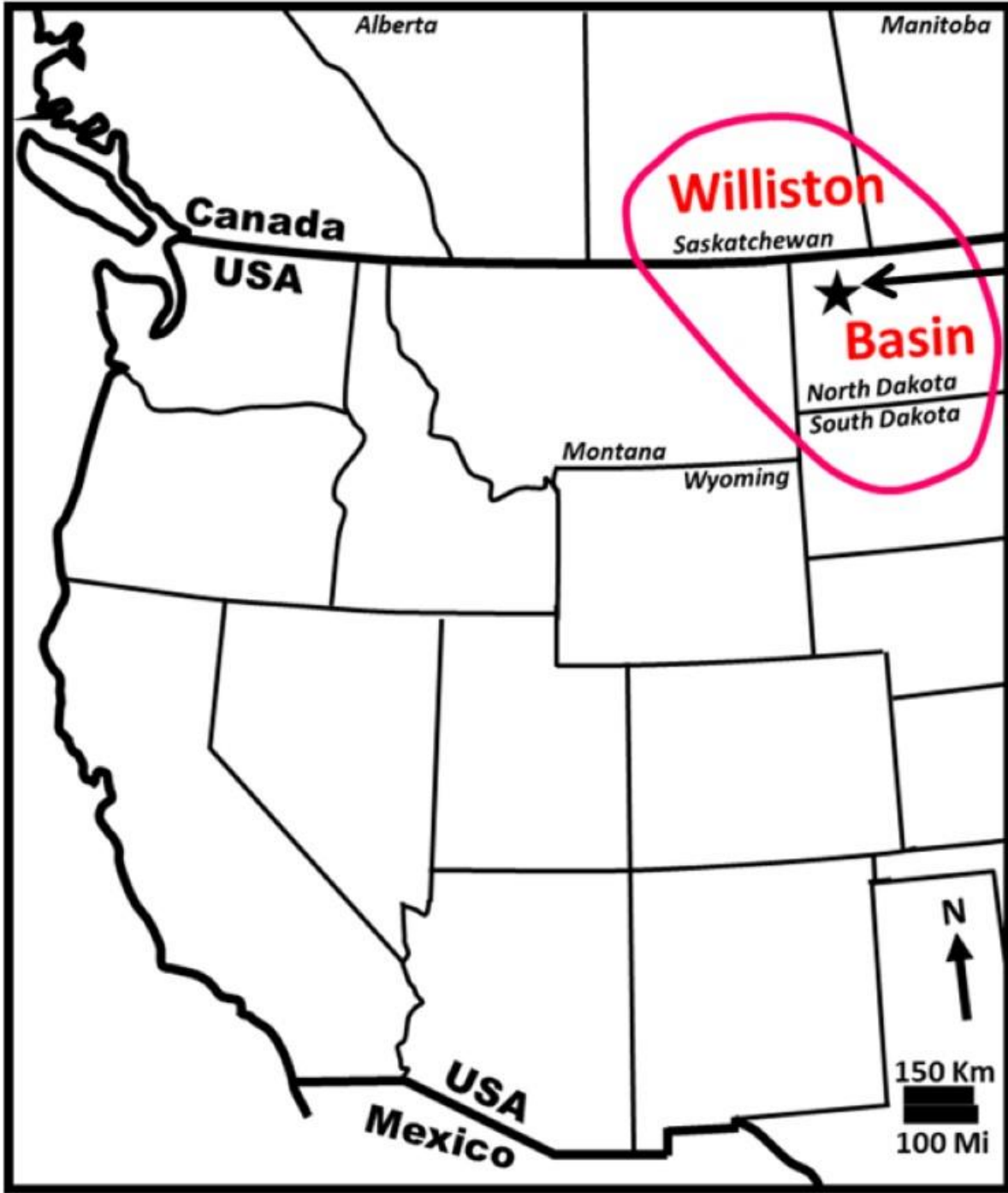
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Duperow Reservoir Characteristics in Beaver Lodge Field, North Dakota

By David M. Petty

ACKNOWLEDGEMENTS

- **The author worked fields on the Nesson anticline for Hess Corporation from 2006-2016. Dozens of geologists, geophysicists and engineers within Hess had investigated Beaver Lodge Field prior to 2006, and this provided a framework for the analysis in this study. Technical co-workers during 2006-2016 included Jiedi Wu, John LeBas, Peter Schmitz, Al Gomez, Scott Pluim, Brad Watts, Roger McGuire, Duc Lam, Jeff Hermann, and Loveena Kapur.**
- **A portion of the analysis in this study evaluates data acquired by Hess Corporation as part of a Special Core Analysis (SCA) program that was initiated in 2015 and terminated 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 to Jennifer Wolters for shepherding this presentation through the Hess approval process.**



Beaver Lodge Field

Location: Williston Basin

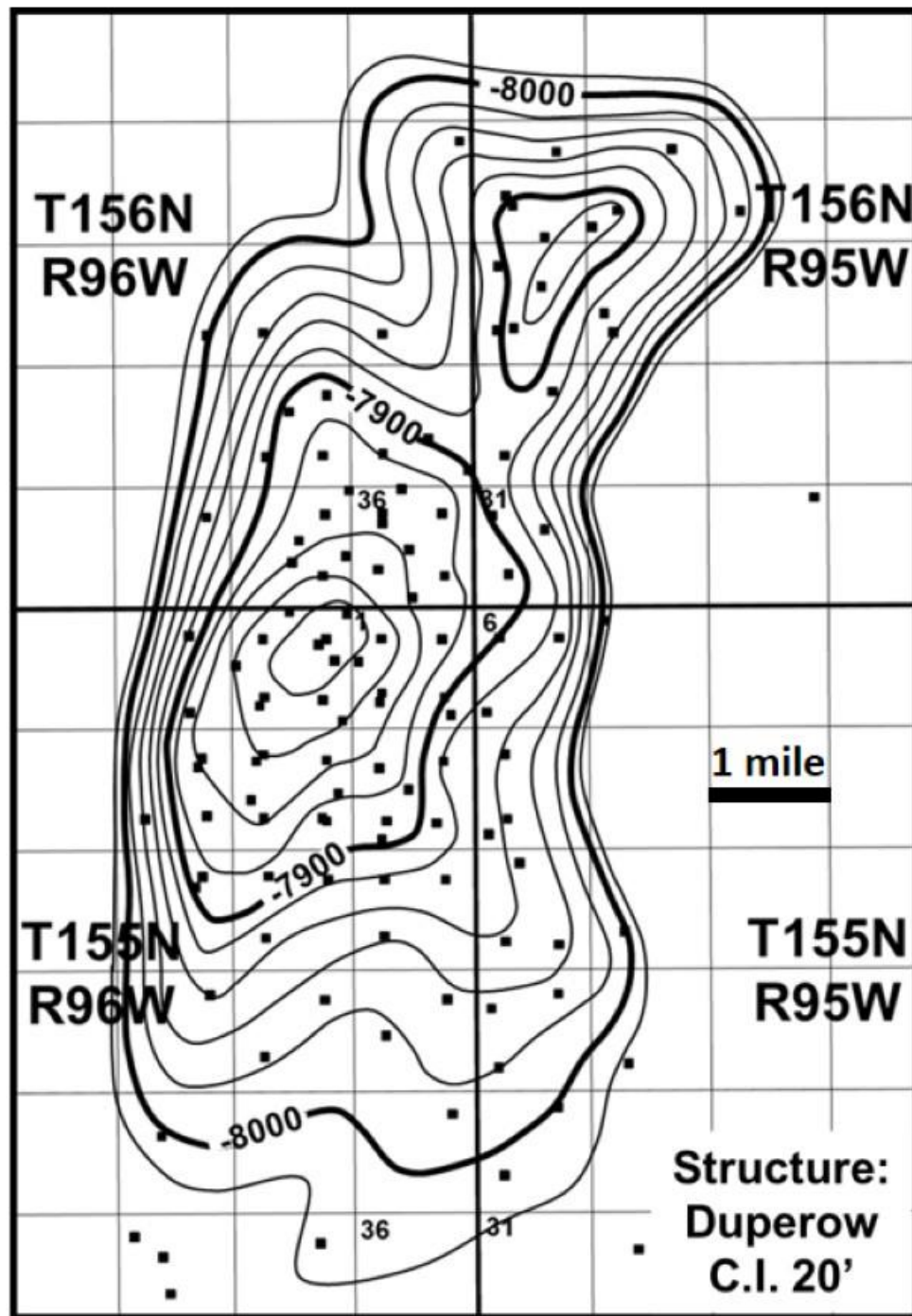
Reservoir: Duperow Formation

Age: Upper Devonian

Discovery: 1951

Waterflooding: 1963

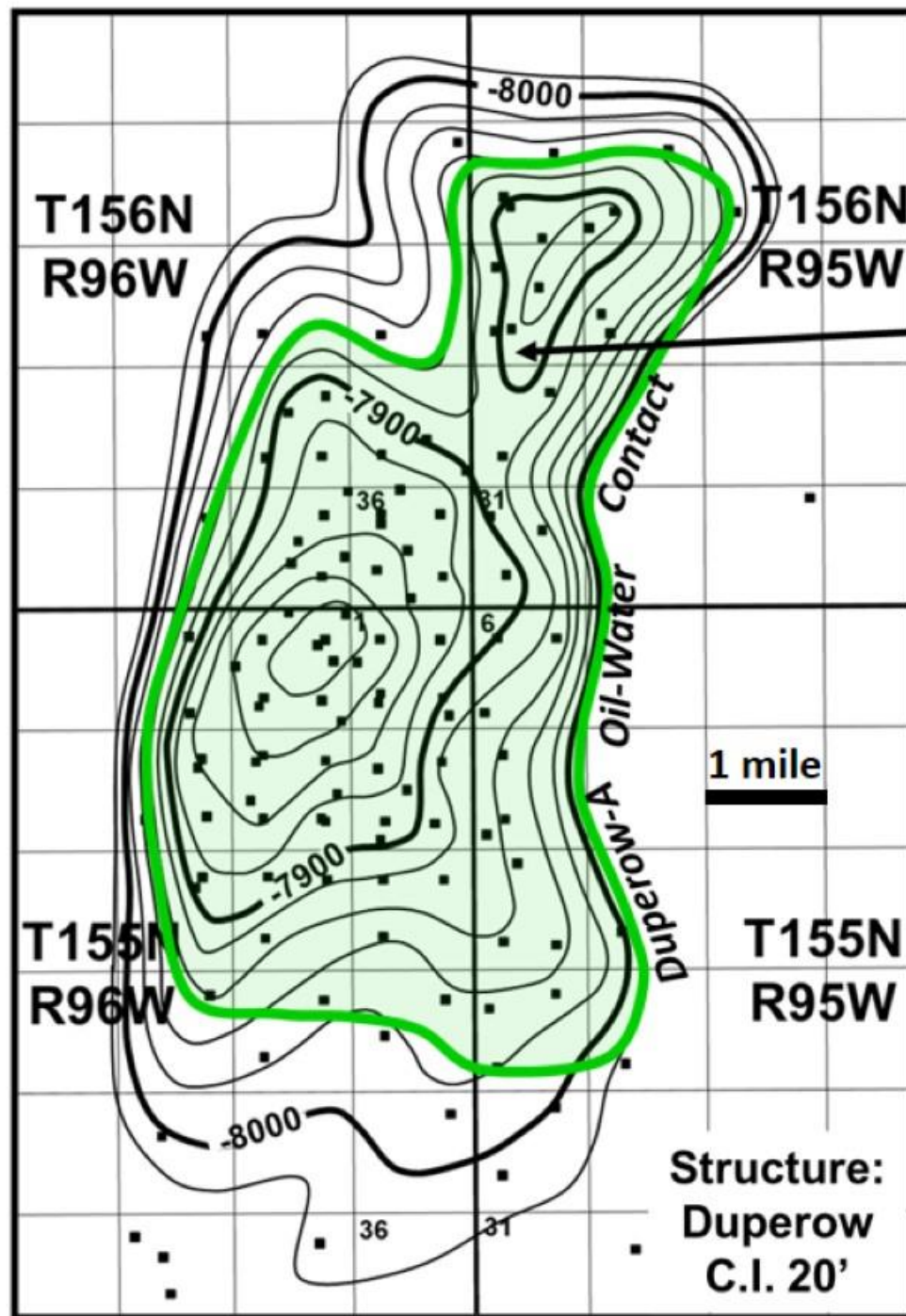
Production: 74 MMBO (42° API)



Beaver Lodge Field Structure Top Duperow "A" C.I. = 20'

Datum = Base Duperow "A" Marker Bed

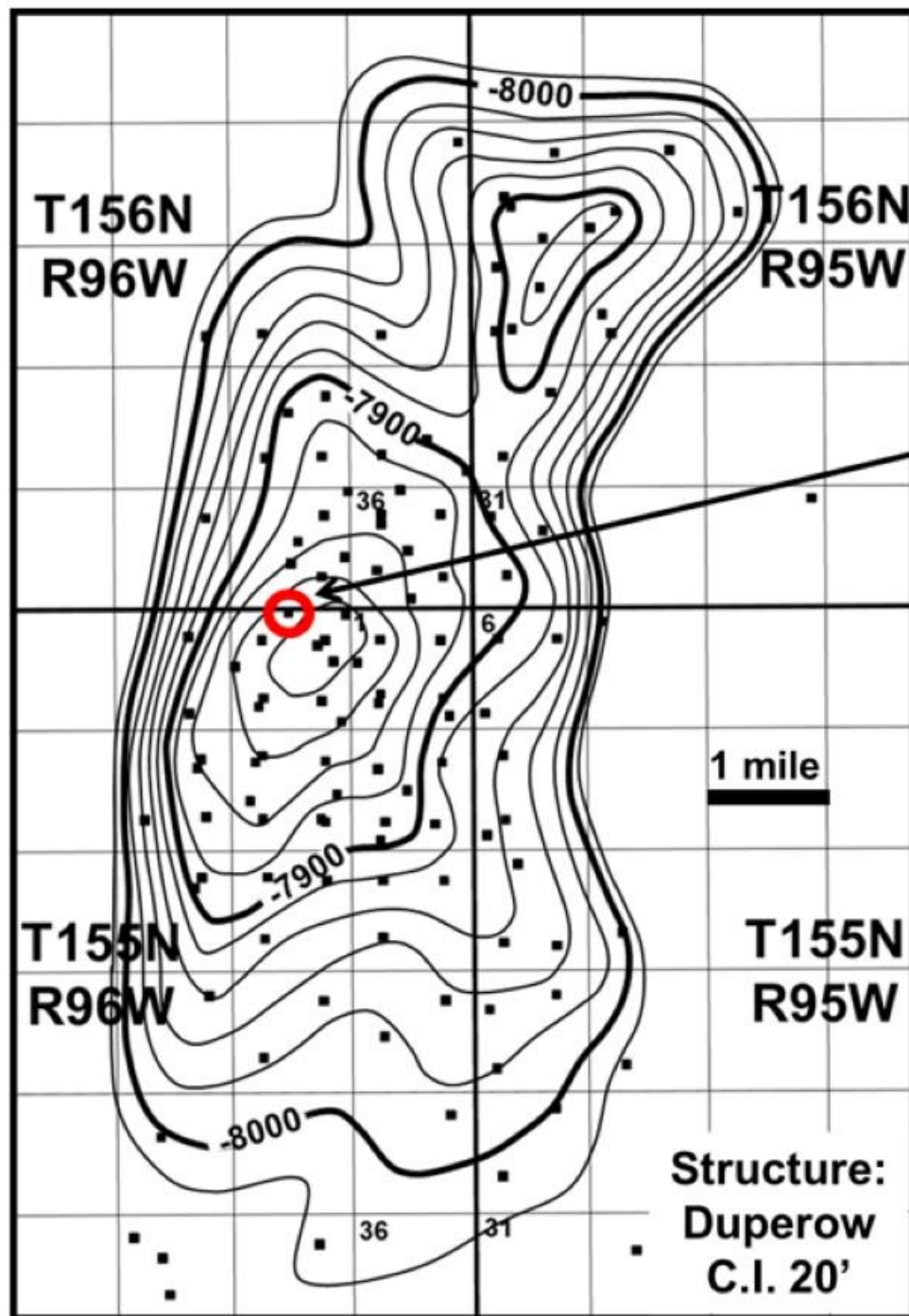
- = Duperow
Penetration
(126 Wells)



***Duperow
Oil-Productive
Area***

**Beaver Lodge Field
Structure
Top Duperow "A"
C.I. = 20'**

**• = Duperow
Penetration
(126 Wells)**



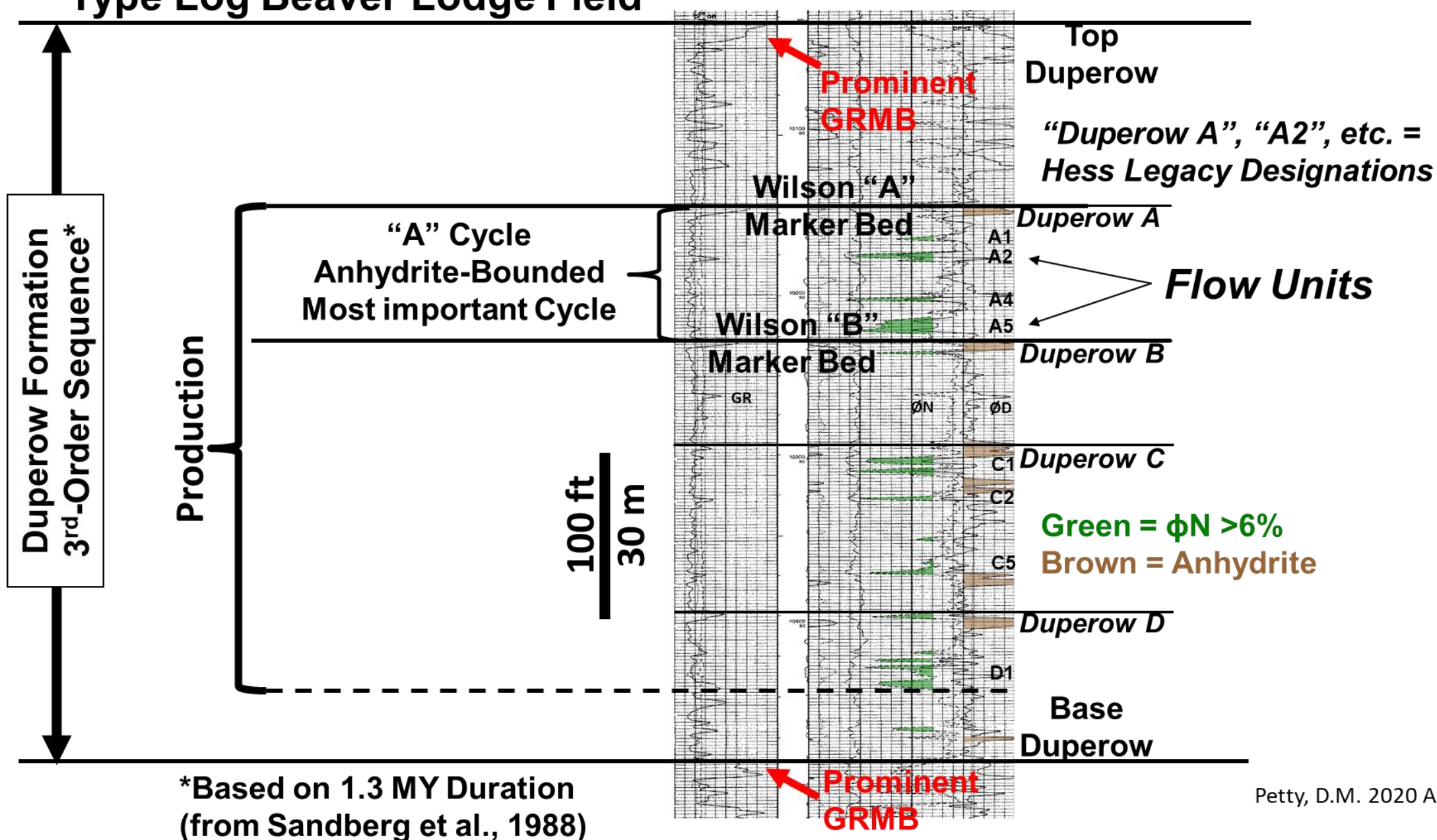
Type Log (Next Slide)

**Beaver Lodge Field
Structure
Top Duperow "A"
C.I. = 20'**

**▪ = Duperow
Penetration
(126 Wells)**

Type Log Beaver Lodge Field

NENW 2-155-96

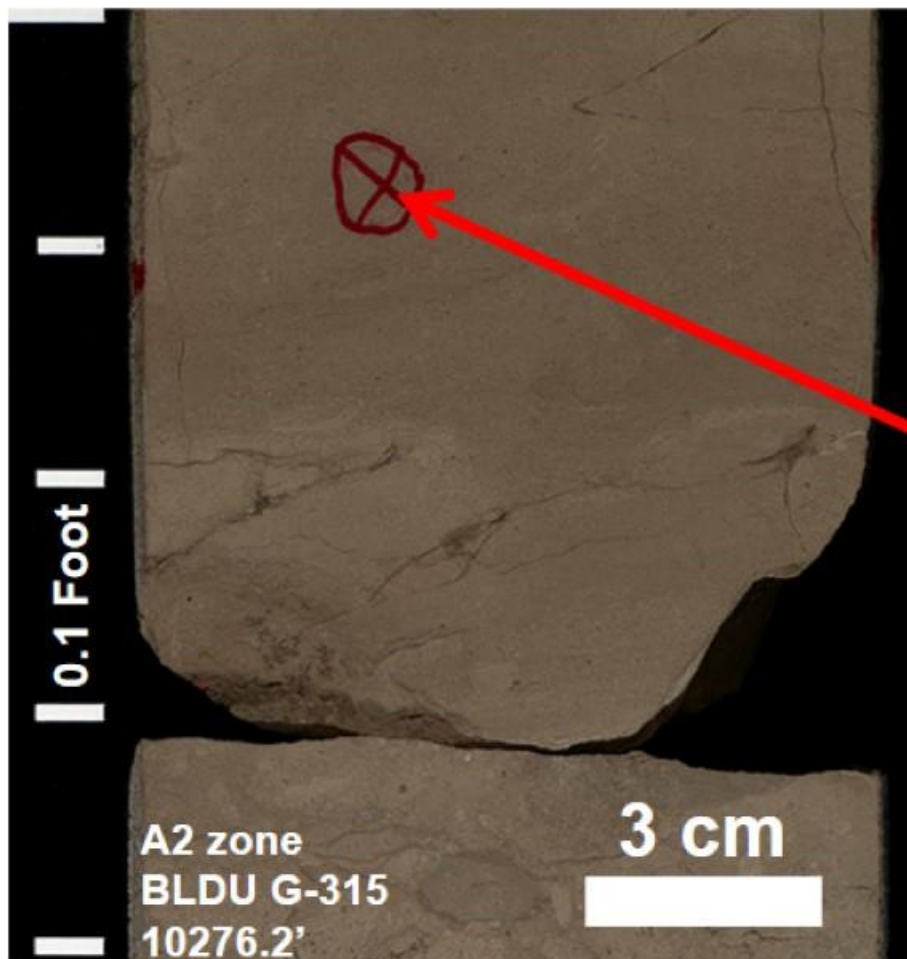


Key Lithologies

- **Reservoir facies***
 1. Burrowed to faintly laminated, skeletal-peloidal dolomitic wackestone/packstone
 2. Stromatoporoid-rich dolomitic packstone
 3. Laminated dolostone
 - Laminated dolomitic wackestone-packstone
 - Dolomitic stromatolitic boundstone
- **Non-reservoir facies***
 - Marker bed lithology

***Characterization from 2016 Special Core Analysis (SCA) project using 93 plugs (2" X 1.5") from 9 flow units**

**Burrowed to poorly laminated
Skeletal-peloidal dolomitic packstone-wackestone*
(36% of reservoir-quality SCA samples)**



***This is the most
homogeneous lithology**

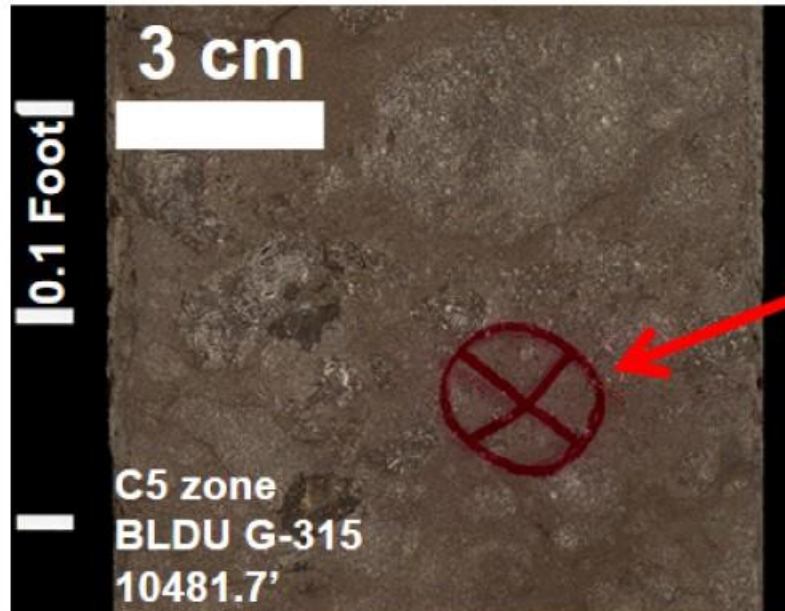
**Dolostone
 $\emptyset = 24.2\%$, $K_a = 30.9$ md**

Stromatoporoid-Rich Dolomitic Packstone (35% of reservoir-quality SCA samples)



Dolomitic Limestone

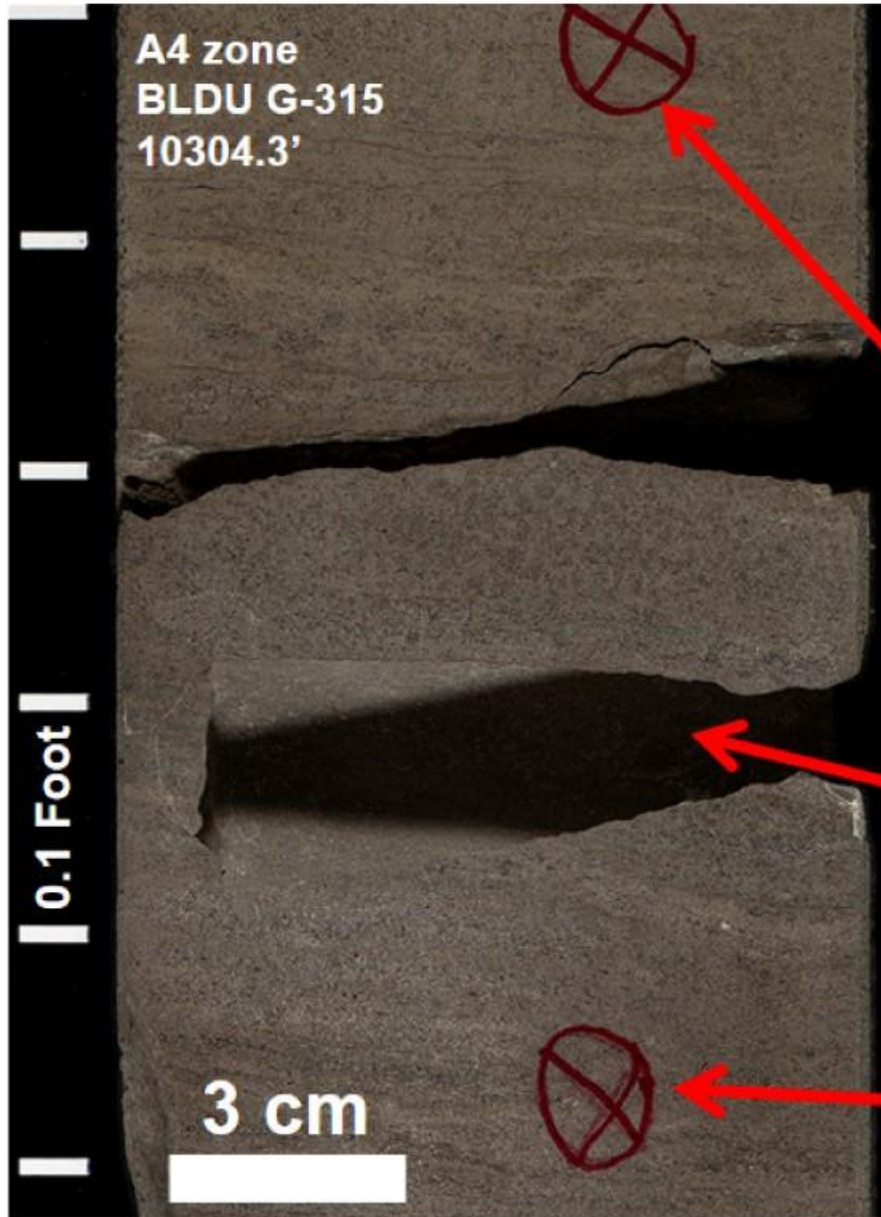
$\emptyset = 7.3\%$, $K_a = 0.154$ md



Dolostone

$\emptyset = 21.7\%$, $K_a = 179$ md*

*Highest K_a measured in SCA



Laminated Lithologies:

- Laminated dolomitic wackestone-packstone
- Dolomitic stromatolitic boundstone

Dolostone

$\emptyset = 19.0\%$, $Ka = 17.5$ md

Dolostone

$\emptyset = 14.6\%$, $Ka = 2.0$ md

Dolostone

$\emptyset = 10.5\%$, $Ka = 0.6$ md

Gamma-Ray Marker-Bed Lithology Example A2 Zone Marker Bed

Lithology

Silty, argillaceous,
microcrystalline dolostone

XRD Mineralogy

84% Dolomite

0% Calcite

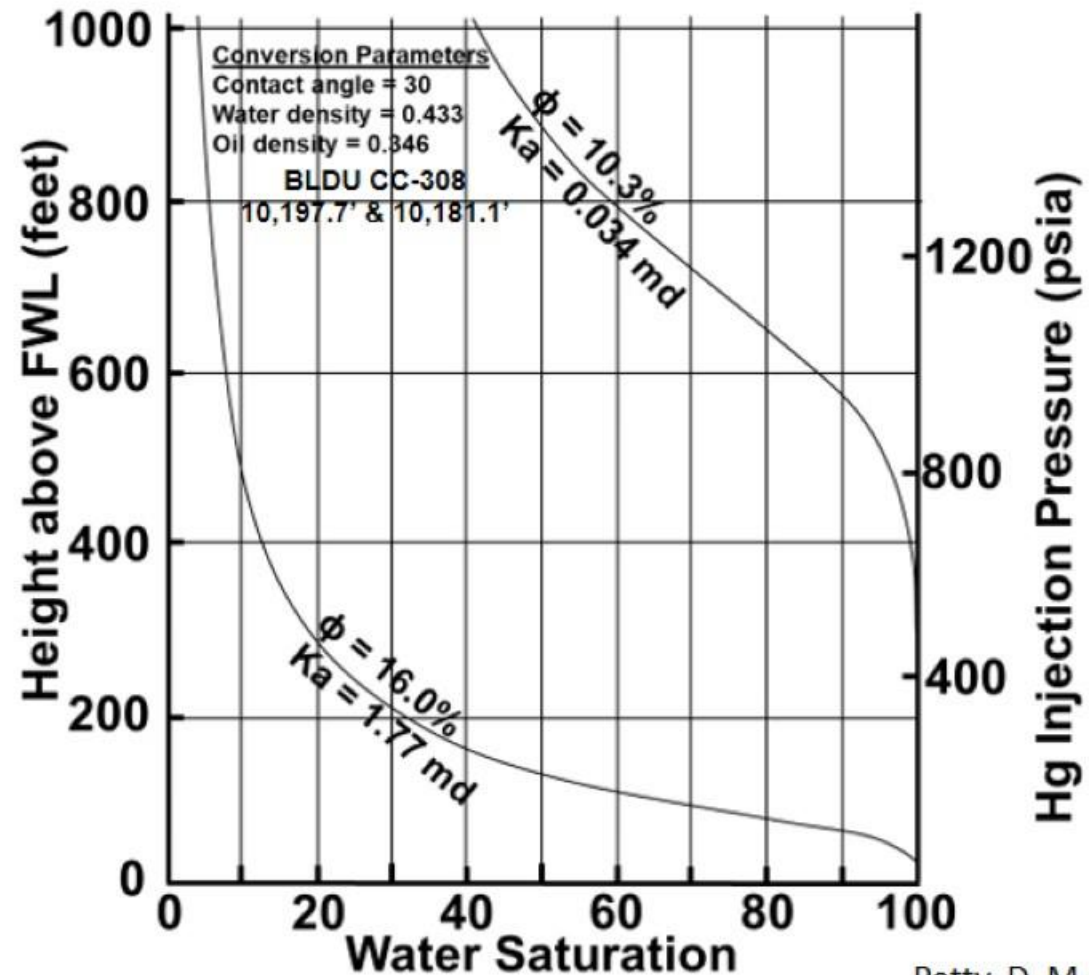
7% Quartz

5% Feldspar

4% Illite

} Silt

Mercury-Injection Capillary Pressure Data

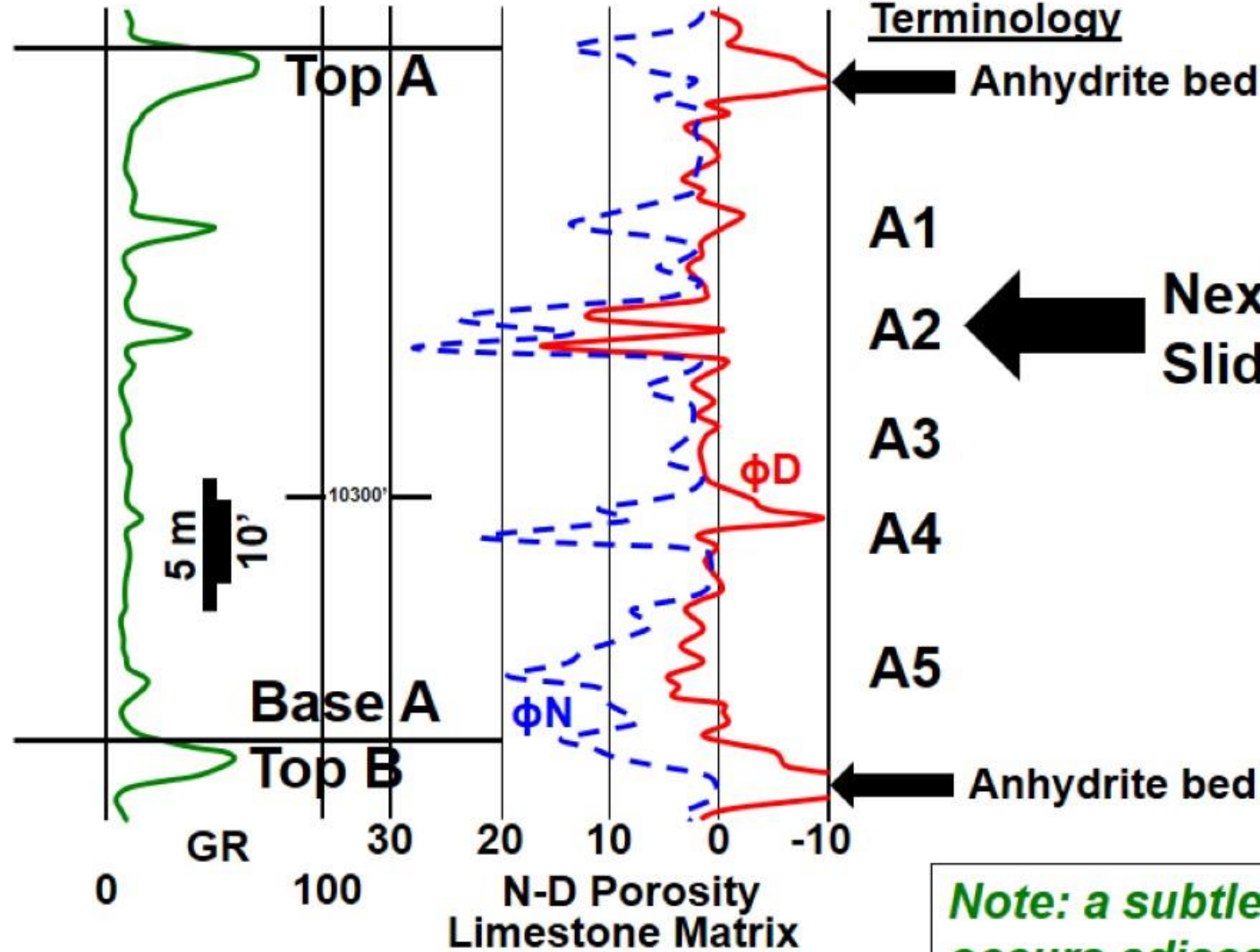


BLDU G-315 (156-95-18 SW)
Drilled 1993

Hess
Legacy
Zone
Terminology

“A” Cycle

Uppermost
Producing Cycle
Most Important
Producing Cycle



Next
Slides

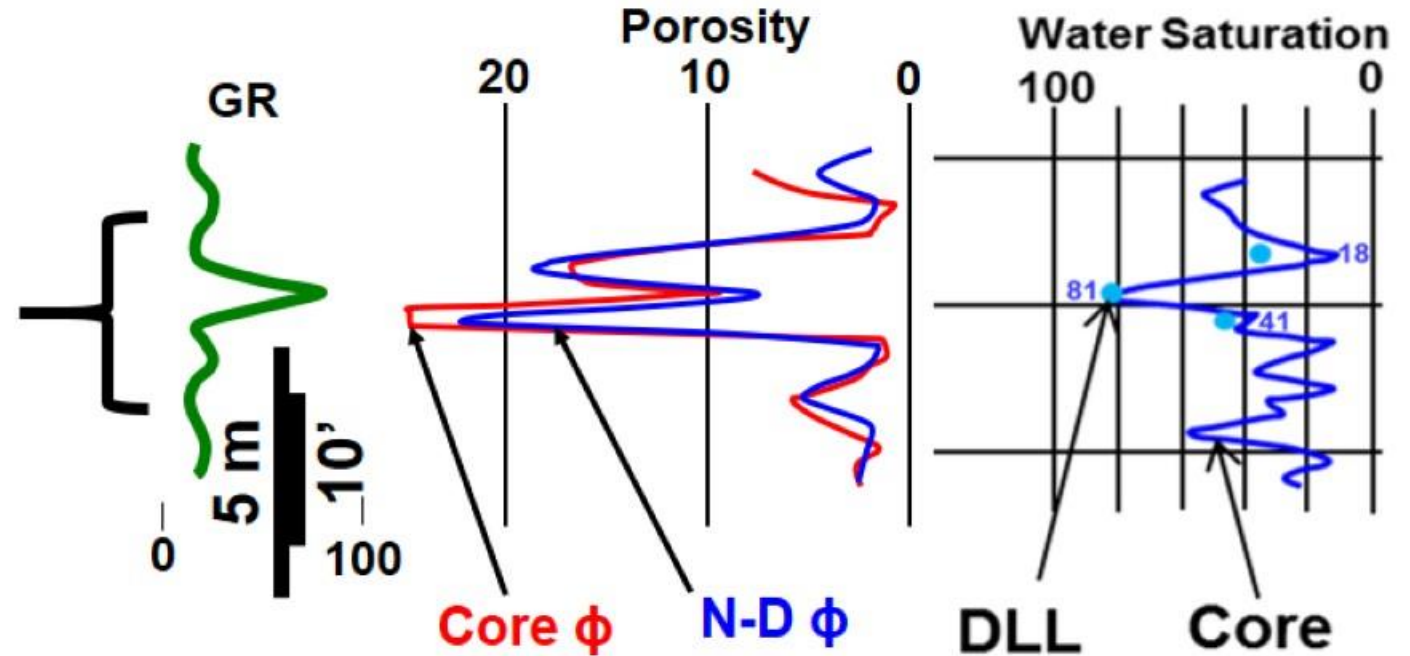
Zones = Flow Units

*Note: a subtle GR marker bed
occurs adjacent to all flow units*

Duperow A2 Zone

- **Uppermost porous zone of significance**
- **Most widely porous**
- **Most widely productive**
- **Most widely tested**
- **Relatively uniform petrophysical properties**

BLDU G-315
(156N-95W-Sec. 18)
Duperow A2 Flow Unit



For Log Analysis:

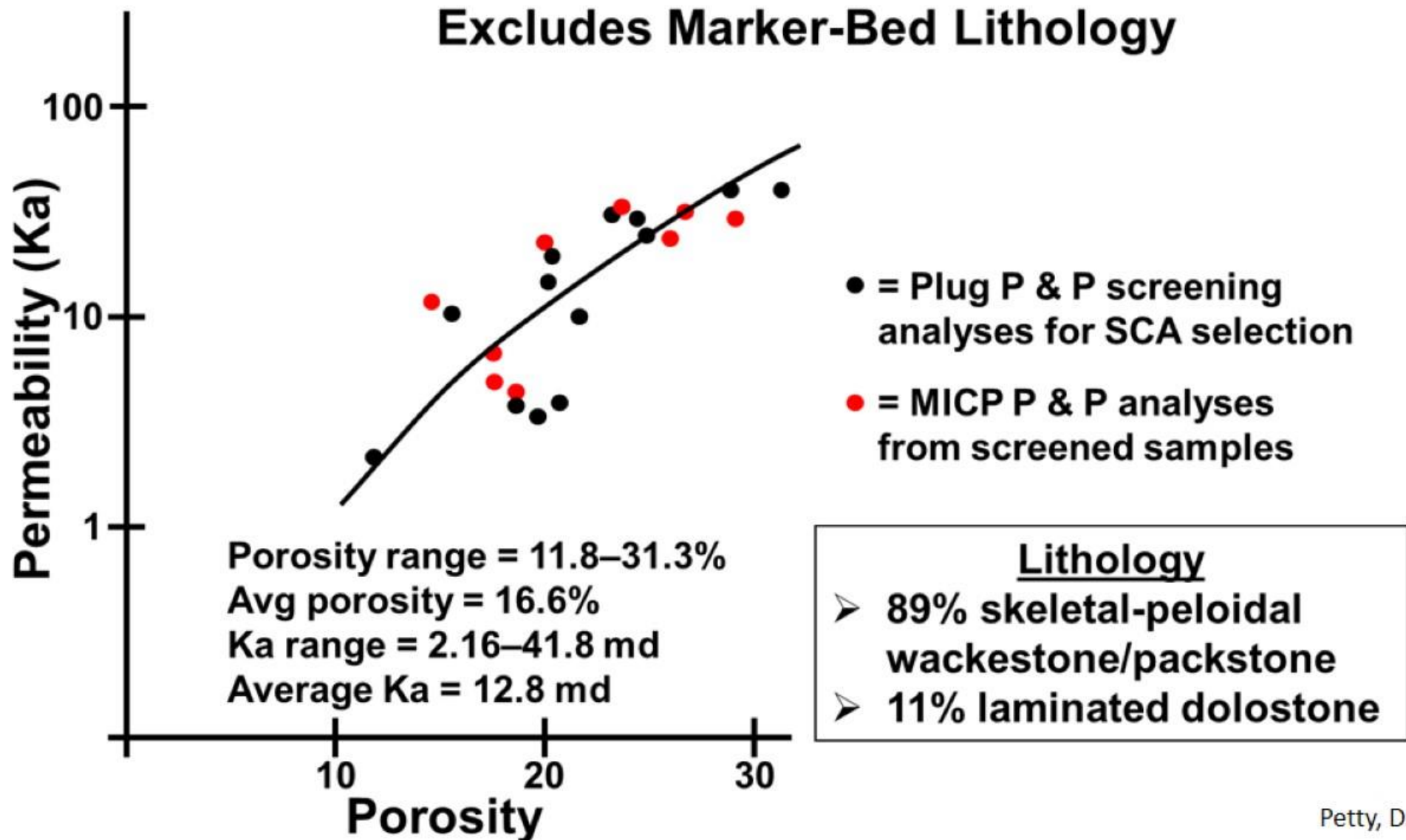
$m = n = 2.0$

$R_w = 0.013$

Duperow A2 Zone: Rock Properties

All A2 Zone SCA Data

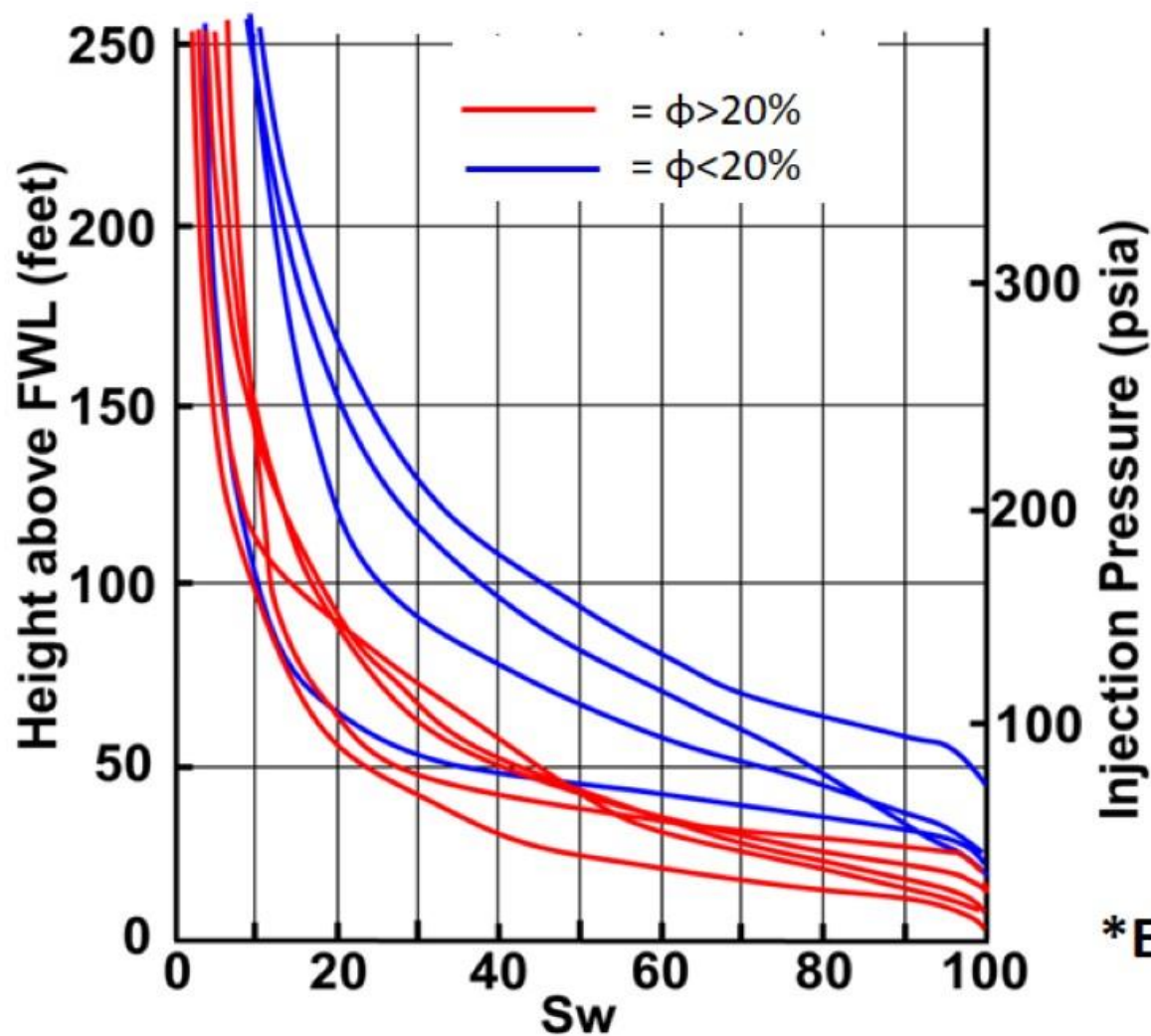
Excludes Marker-Bed Lithology



Duperow A2 Zone: Rock Properties

All A2 Zone MICP Data*

3 Cored Wells



Conversion Parameters

Contact angle = 30

Water density = 0.433

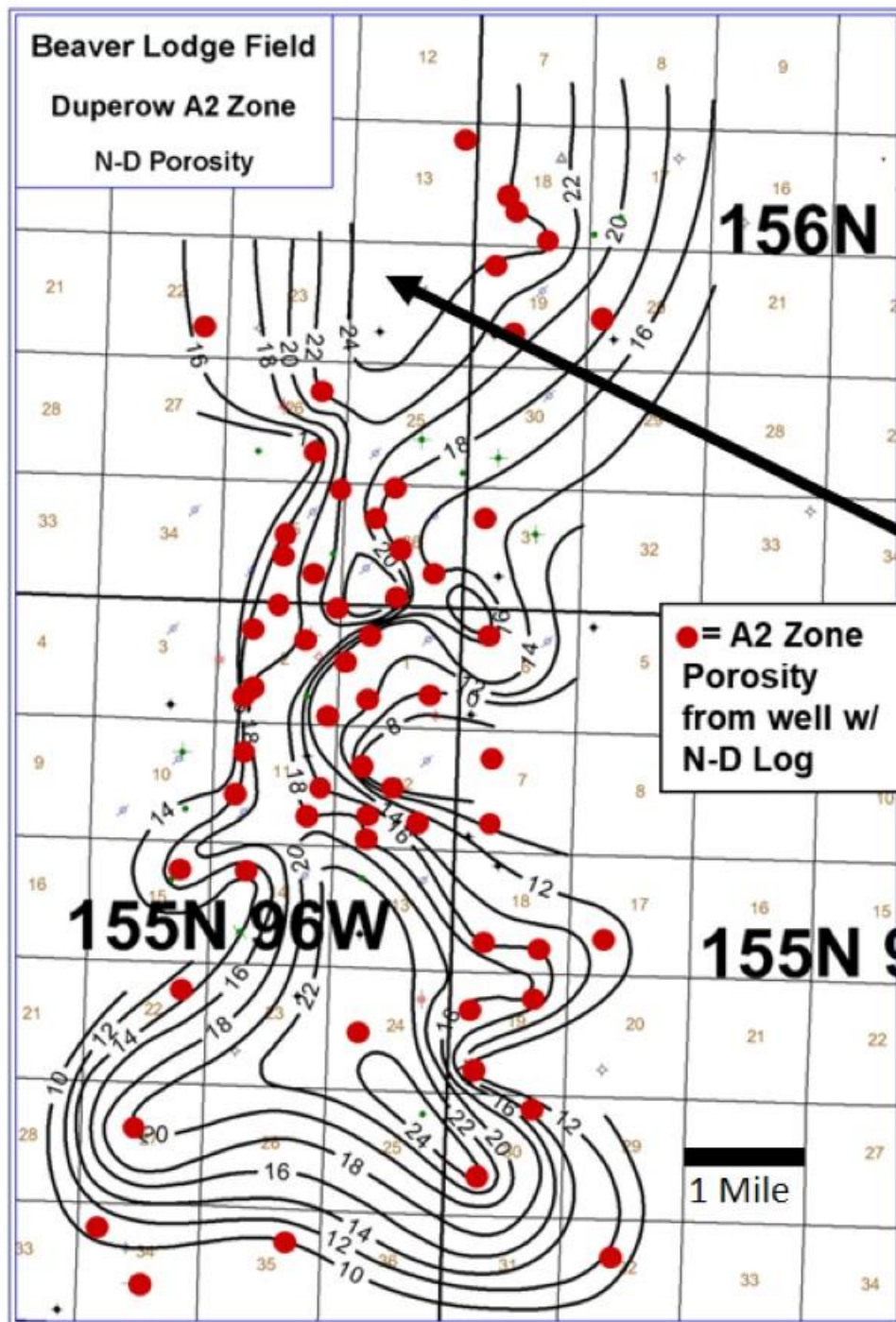
Oil density = 0.346

Core data indicates oil column of <50' above FWL will achieve producible saturations ($S_w < 50\%$) for $\phi > 20\%$ for A2 zone

Key Point:

All $\phi > 20\%$ is reservoir-quality

*Excludes Marker Bed Lithology



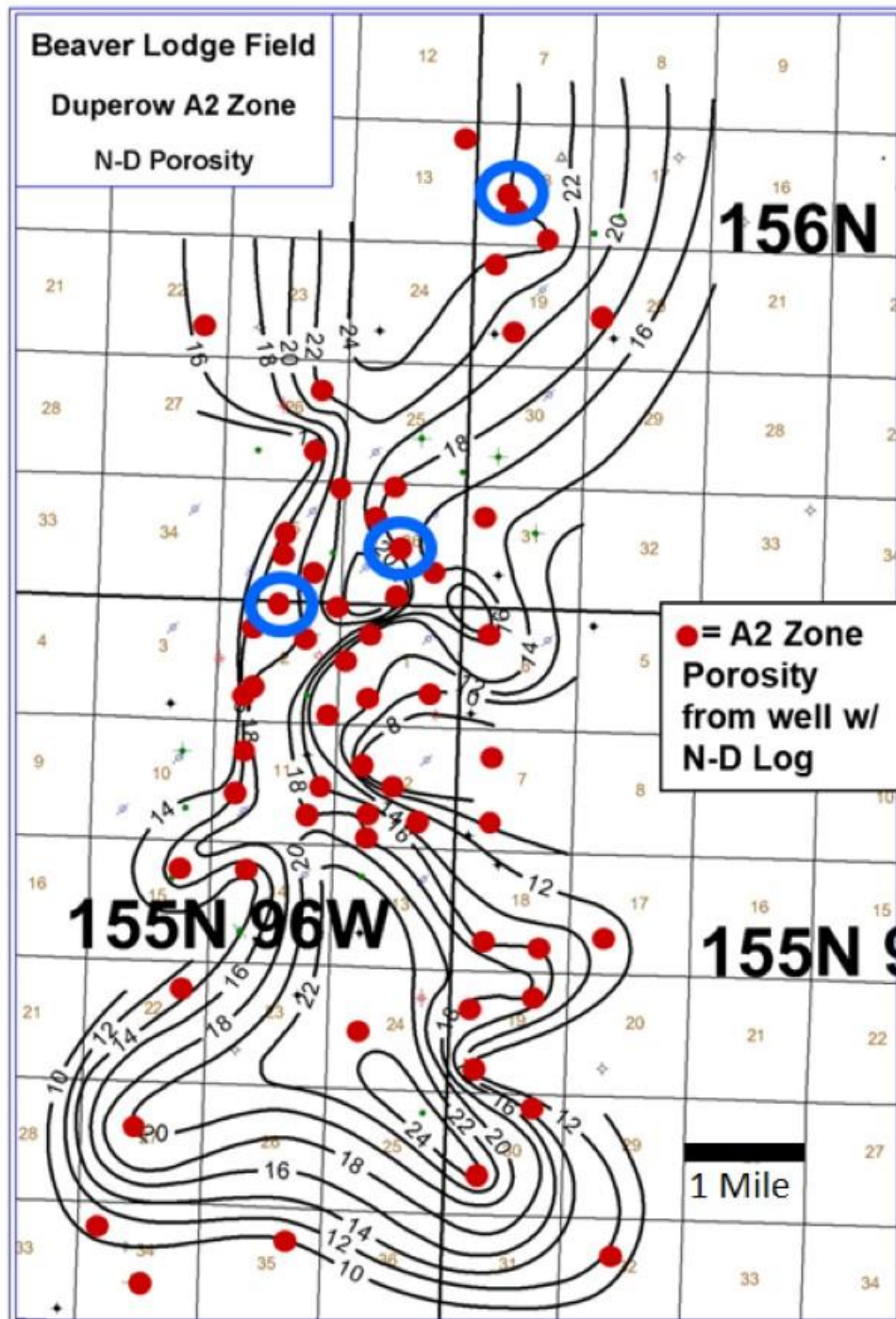
Duperow A2 Zone Porosity

60 wells with N-D Logs

C.I. = 2%

Note excellent porosity (>20%) in northern portion of field

- No evidence for stratigraphic barrier in north direction*



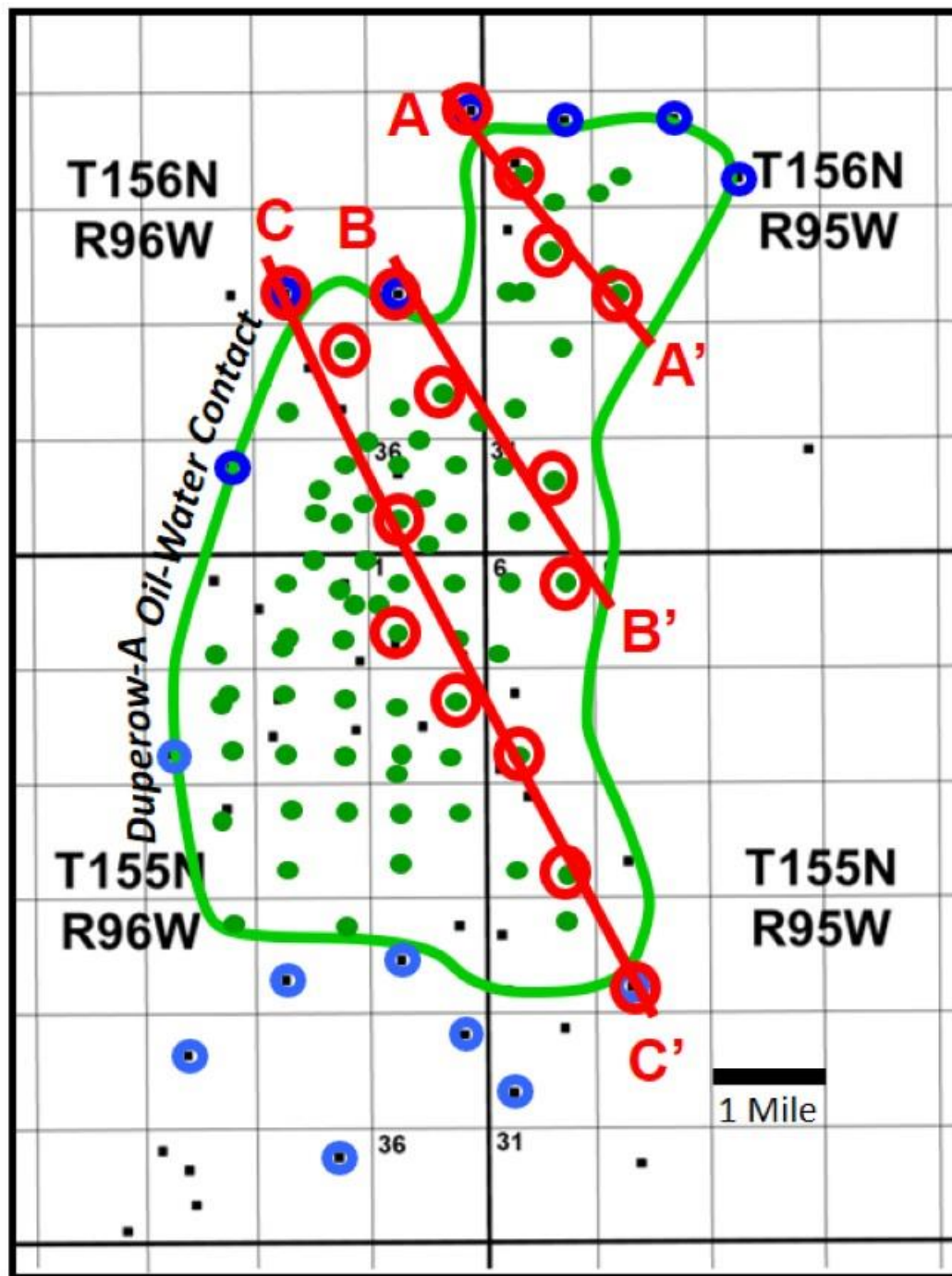
Duperow A2 Zone Porosity

○ = SCA MICP analyses

Note: sample selection for SCA limited by core suitability for collection of 2" x 1.5" plugs

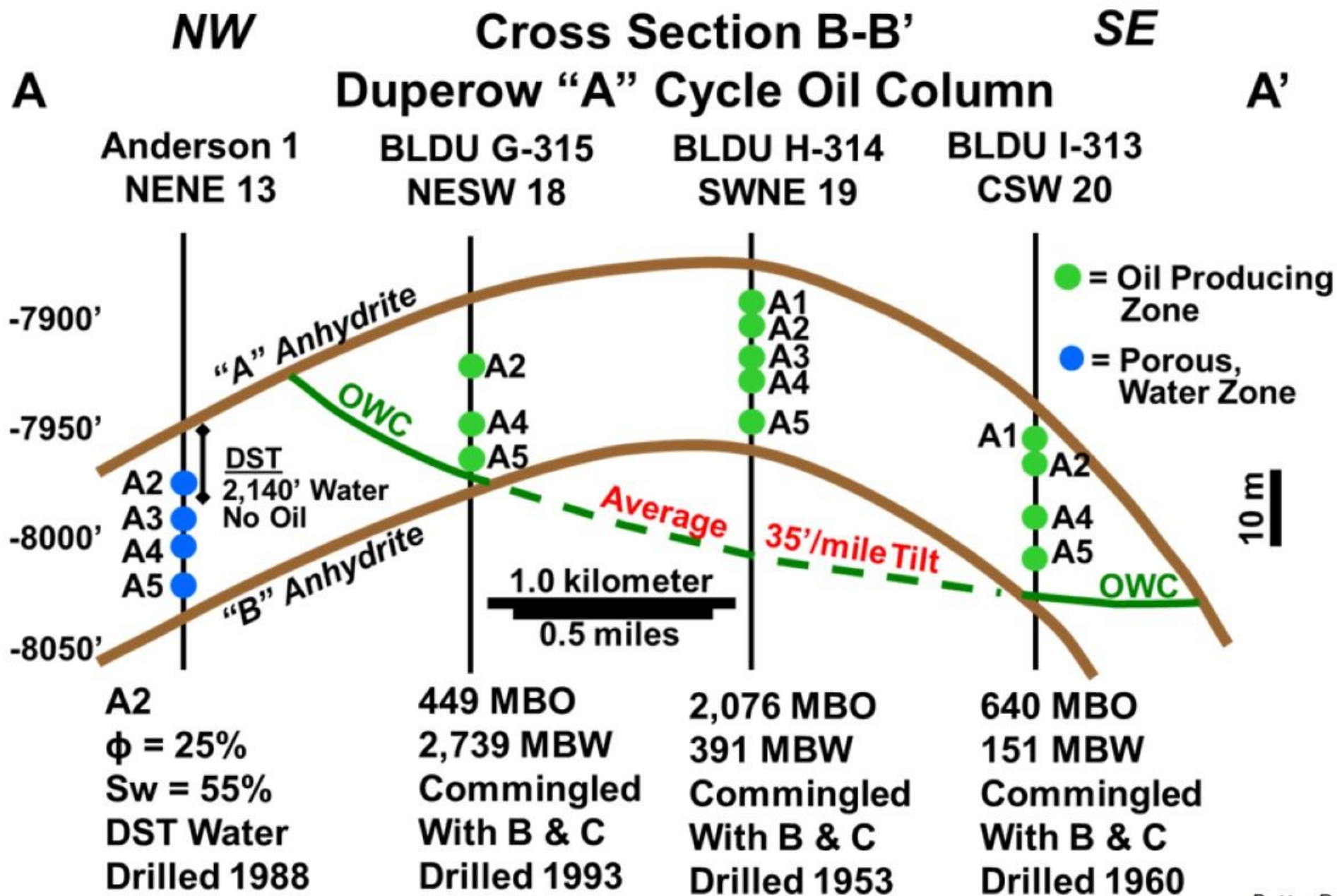
Duperow Oil Columns

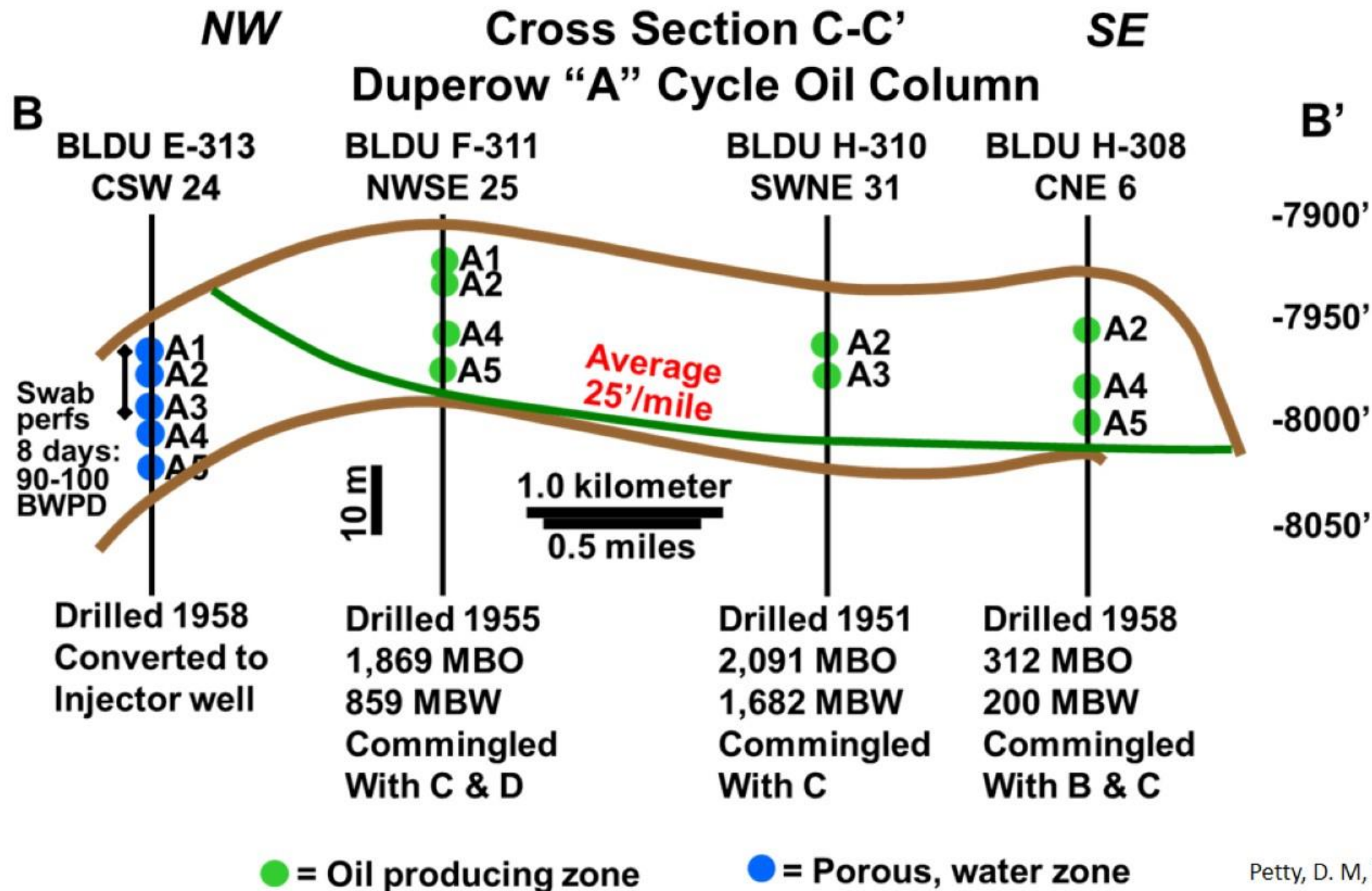
- Field-wide anhydrite beds form vertical seals that separate oil columns, which are defined by separate oil-water contacts
- At least 4 separate oil columns (OWC's) can be defined
- “A cycle” oil column will be discussed below

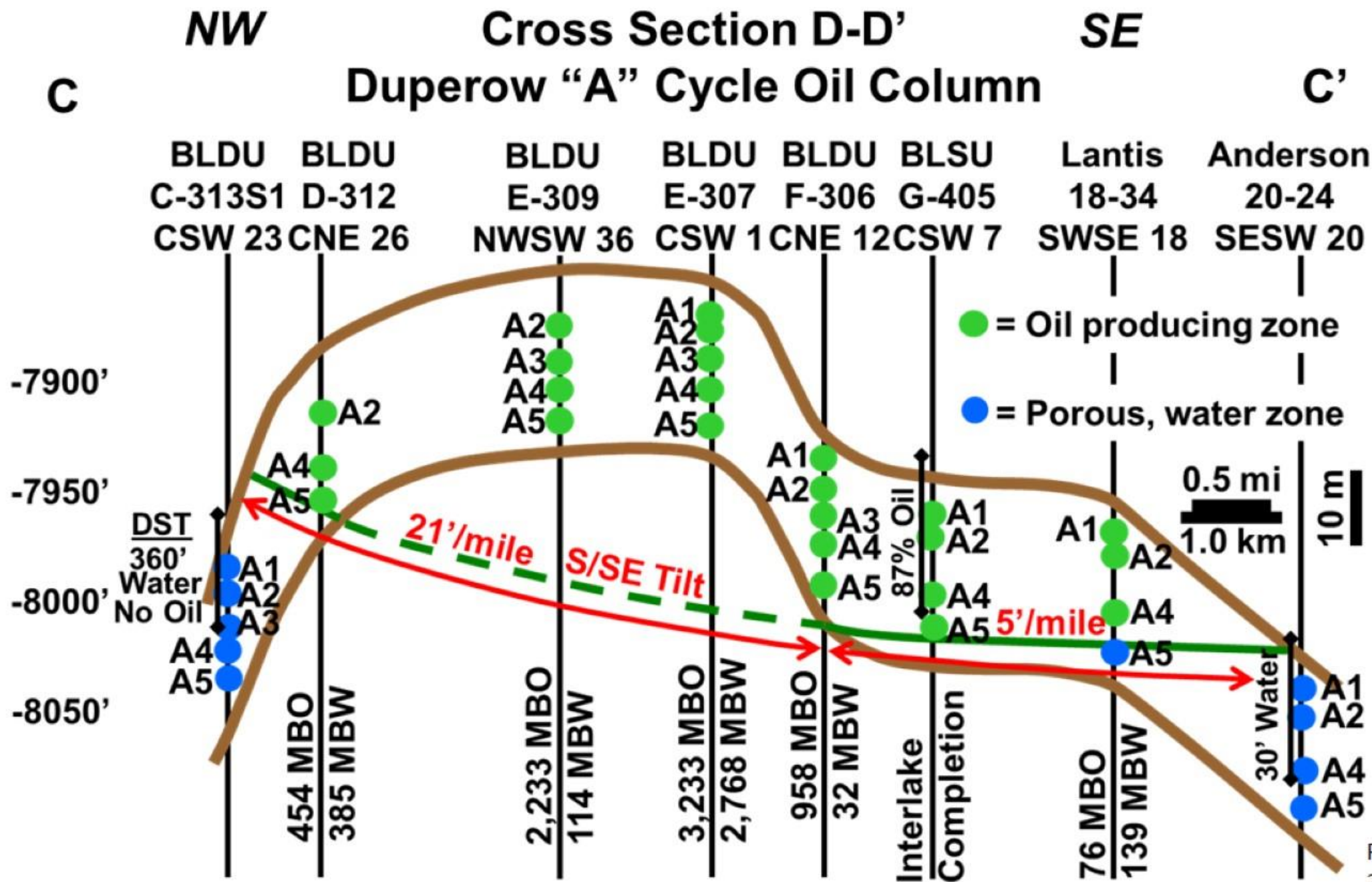


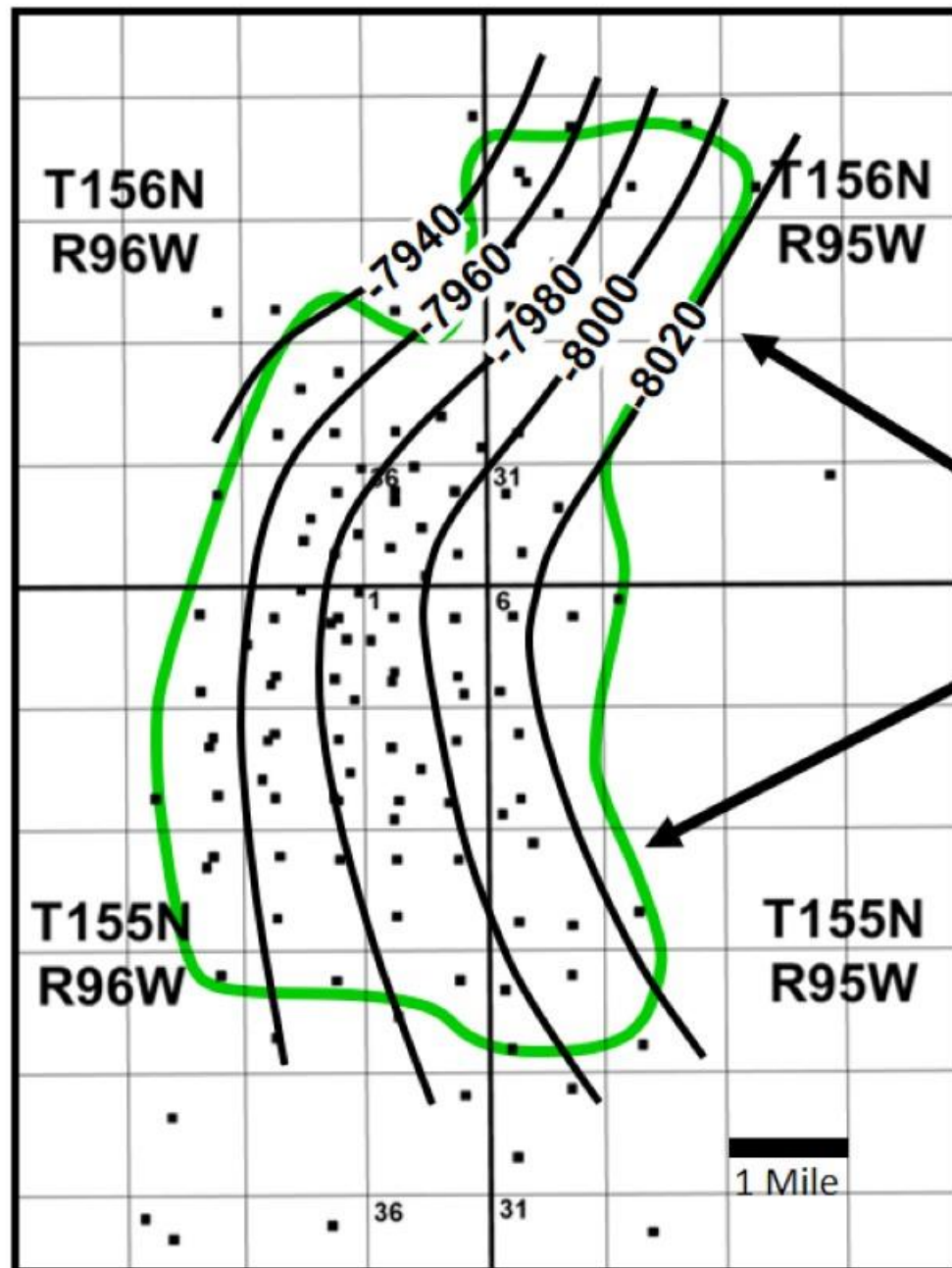
Duperow A Cycle Oil-Water Contact With A2 Zone Data Cross Sections

- = OIL FROM A2 ZONE
- = WATER FROM A2 ZONE







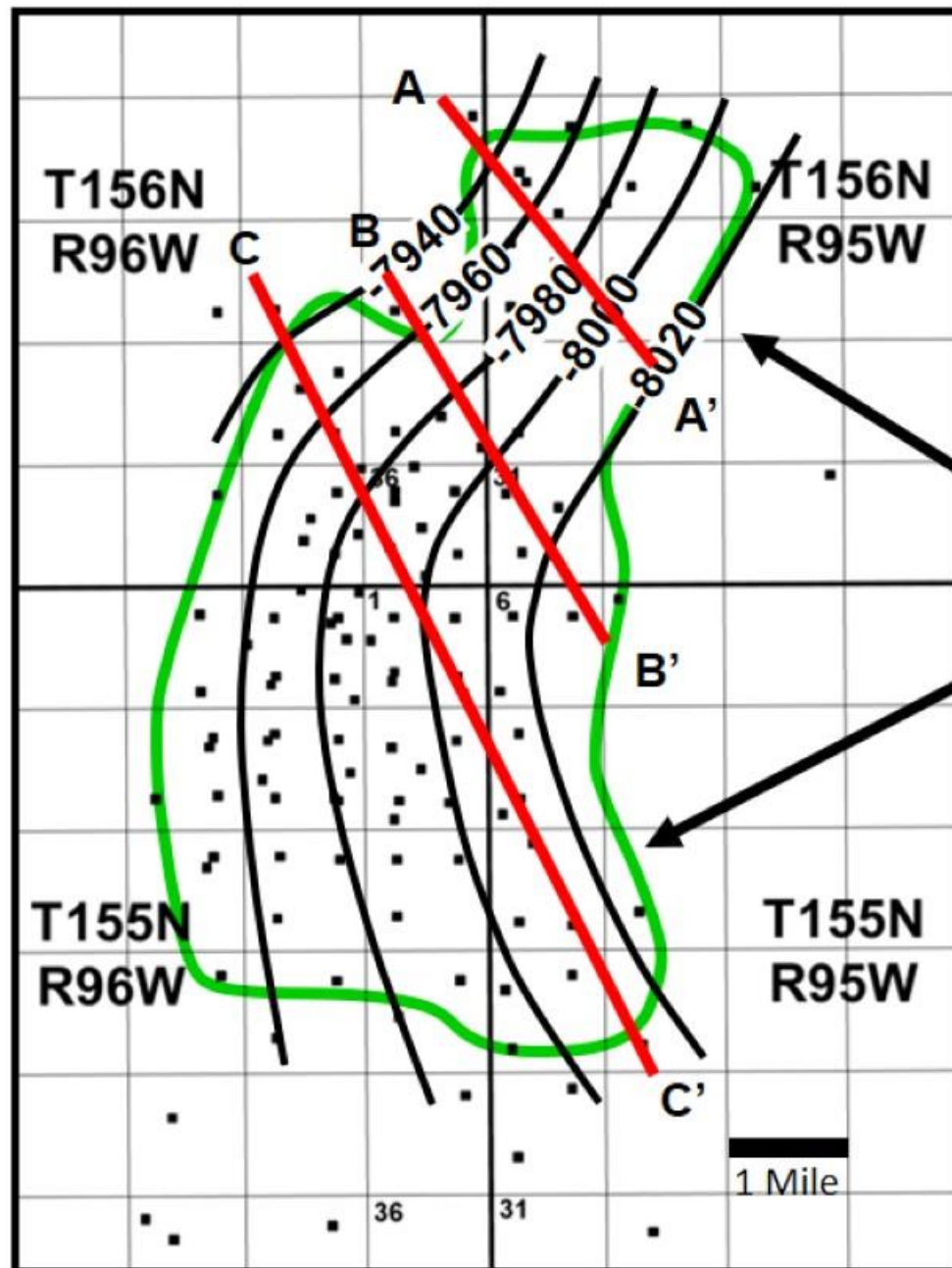


**Beaver Lodge Field
Duperow "A" Cycle
Oil-Water Contact
C.I. = 20'**

40 ft/mile tilt

25 ft/mile tilt

***Average Tilt =
30 ft/mile***



**Beaver Lodge Field
Duperow "A" Cycle
Oil-Water Contact
C.I. = 20'**

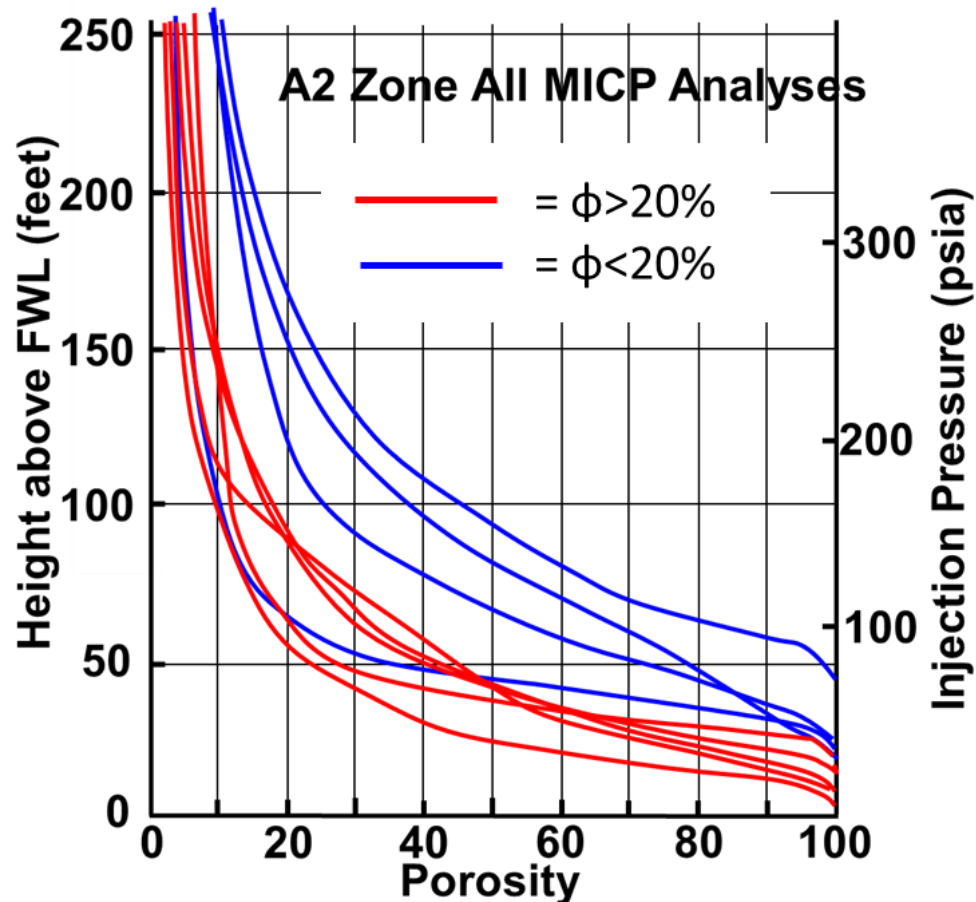
40 ft/mile tilt

25 ft/mile tilt

***Average Tilt =
30 ft/mile***

Possible Causes for Apparent East-Tilted Oil Column

- Capillarity; highly unlikely:
 - *Core data refutes this interpretation*

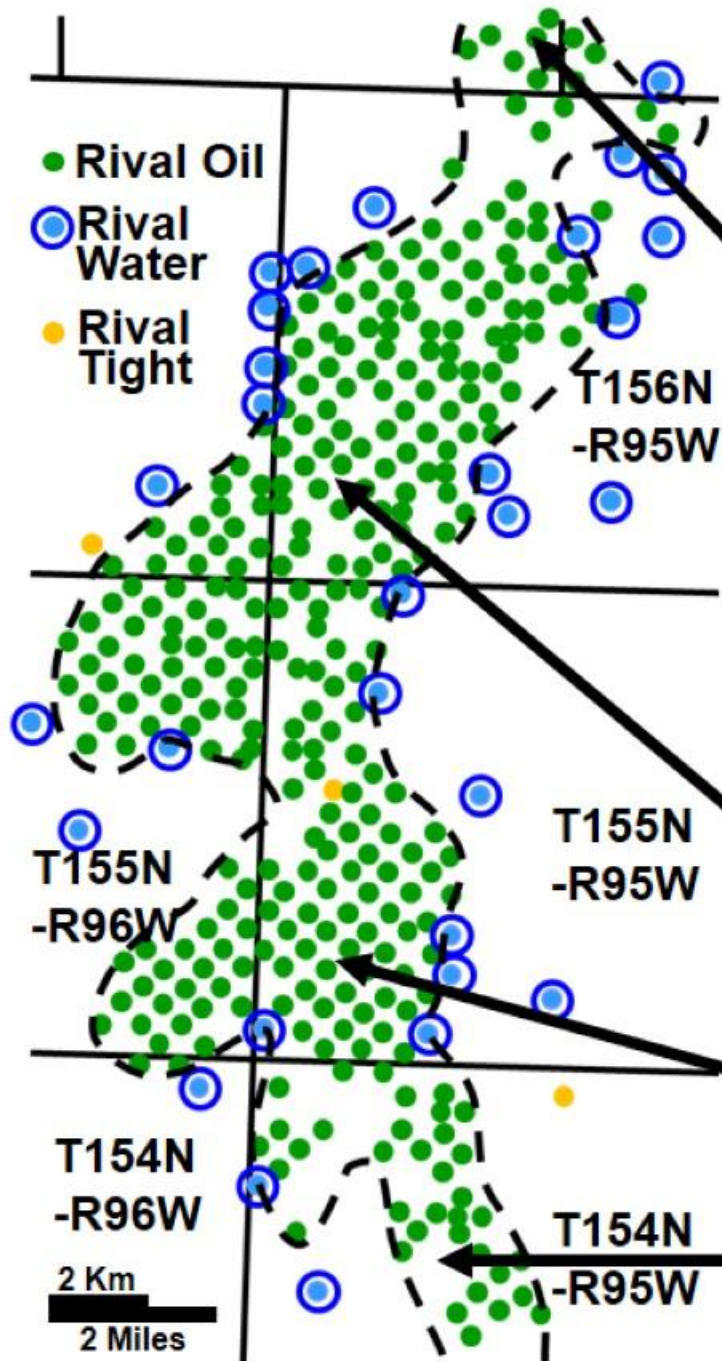


For $\phi > 20\%$ in A2 zone:
*Core data indicates
minimal saturation
difference between
samples*

Possible Causes for Apparent East-Tilted Oil Column

- **Stratigraphic; highly unlikely:**
 - *No mappable barriers in updip (northwestern) area*
 - *Excellent porosity occurs in water-bearing edge areas*
 - *Flow data (DST and perf swab tests) indicates good permeability in water-bearing edge wells*
- **Fault Compartmentalization; possible but not best explanation:**
 - *Relatively uniform, continuous tilt*
 - *No mappable faults in central to updip (north) area*
 - *From well control and 3D seismic*
- **Hydrodynamic; believed to be best explanation:**
 - *Other causes for tilted OWC are unlikely*
 - *Apparent Duperow tilt is similar to documented OWC hydrodynamic tilt in overlying Madison reservoir*

Madison (Rival) Oil Fields With OWC Tilts From Published Studies



Tioga Field: DeMis (1995) shows 10-50 ft/mile southeast tilt

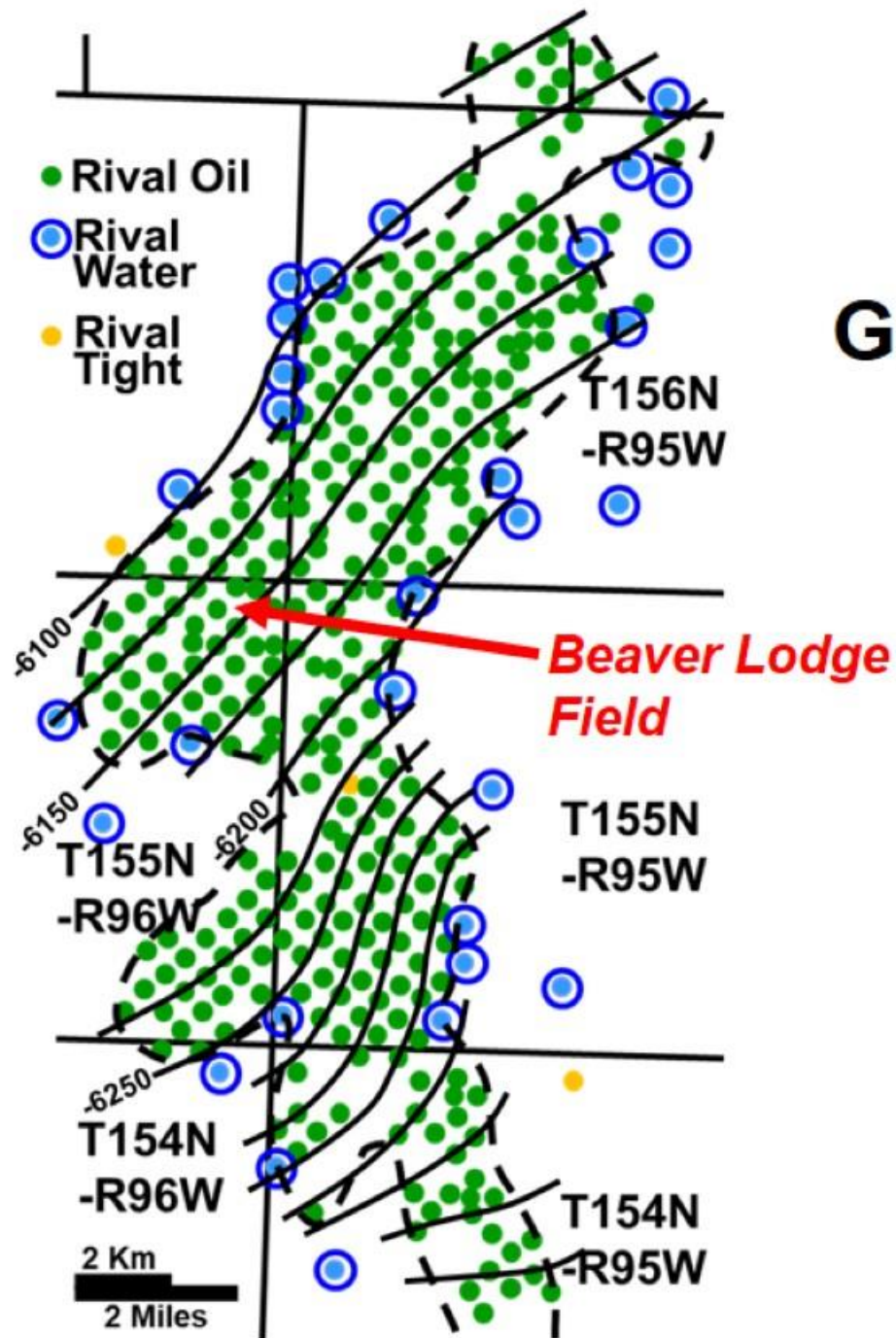
Regionally, Madison reservoirs have some of the best-documented hydrodynamic oil-column tilts anywhere:

- Bogle and Hansen (1987); DeMis (1987); Downey et al. (1987); Berg et al. (1994); Dahlberg (1995), DeMis (1995)

Beaver Lodge Field: DeMis (1995) shows 15-25 ft/mile east/southeast tilt

Capa Field: DeMis (1995) shows 50 ft/mile southeast tilt

Hofflund Field: 1967 Waterflood study shows 40 ft/mile south tilt



Madison (Rival) OWC Greater Beaver Lodge Area C.I. = 25'

Cross-Contour of Rival Structure with Rival OWC

Map made with assistance of
 Jiedi Wu (structure)
Average Tilt = 30'/mile

IMPLICATIONS FOR HYDRODYNAMIC TILT IN DUPEROW OIL ACCUMULATIONS

- **Generally east-tilted Duperow oil accumulations with possible hydrodynamic origins have been noted in other portions of North Dakota**
 - **Southwest North Dakota (Burke, 1989, p. 3)**
- **The occurrence of a eastern tilt in Duperow accumulations regionally would impact exploration and development in future Duperow drilling**
 - **Especially critical for subtle east-trending structural anticlines on western side of Williston basin where water flow and tilt direction will be downdip**

CONCLUSIONS: BEAVER LODGE DUPEROW

- **All significant Duperow reservoir rock occurs in dolostone**
- **The dominant reservoir lithologies display good capillarity characteristics in samples with good porosity**
- **Marker-bed lithology is commonly porous, low-permeability and water-bearing, and often interbedded with reservoir porosity**
- **Beaver Lodge Duperow oil columns have an apparent eastern tilt that cannot be related to reservoir-quality issues**
- **The apparent tilt most likely reflects the presence of a regional hydrodynamic gradient in the Duperow that is similar to the well documented hydrodynamic gradient in the overlying Madison reservoirs**