Stratigraphic and Geochemical Investigation of Kukersites Source Beds within the Ordovician Red River Formation, Williston Basin, North Dakota*

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Abstract

The Ordovician Red River Formation has produced over 600 million barrels of oil equivalent from the Williston Basin, over half of which has come from North Dakota. Red River hydrocarbons were originally thought to be externally sourced by the underlying Icebox Formation. However, various studies have described and examined kukersites within the Red River Formation. Kukersites are organic-rich carbonate beds that contain G. Prisca alginate (Type I kerogen), formed in an offshore marine setting, and may be the source of Red River hydrocarbons. In core, kukersites are dark grey to black, fossil-bearing in part, faintly laminated to moderately bioturbated, average 1-10 wt. % TOC, and range from inches to several feet in thickness. On wireline logs, kukersites display elevated resistivity, sometimes elevated log porosity, and negligible gamma ray signatures. Nine Kukersites can be correlated across western North Dakota within the D interval/C burrowed member. These kukersites combine for 14-15 ft. net thickness with an average of 4-5 wt.% TOC within west-central North Dakota, 6-8 ft. net thickness along the Saskatchewan and South Dakota borders, and pinch-out to the east at 30-60 miles from the Montana border. Moving from areas of lower to higher thermal maturity, kukersite core samples transition from averaging reliable Tmax values of 449° up to 460° while hydrogen index values decrease from averaging over 500 mg HC/g TOC to less than 100; thus indicating significant hydrocarbon generation has occurred. Similarly, the API oil gravity and gas to oil ratios of hydrocarbons produced from discontinuous reservoirs proximal to the kukersites (D interval/C burrowed member) both increase along with the thermal maturity of the kukersite source beds. The thermal maturity of kukersites and proximally produced hydrocarbons increases towards the central, deeper portions of the basin. Red River thermal maturity also extends along an elongate north-south trend that parallels the Nesson, Little Knife, and Billing Nose anticlines which does not always follow depth. Utilizing net thickness, geochemical, and thermal maturity data, preliminary hydrocarbon generation calculations indicate Red River kukersites have generated over 20 billion barrels of oil equivalent within North Dakota. This preliminary generated hydrocarbon volume greatly exceeds cumulative Red River production and indicates the possibility of vast remaining hydrocarbon volumes.

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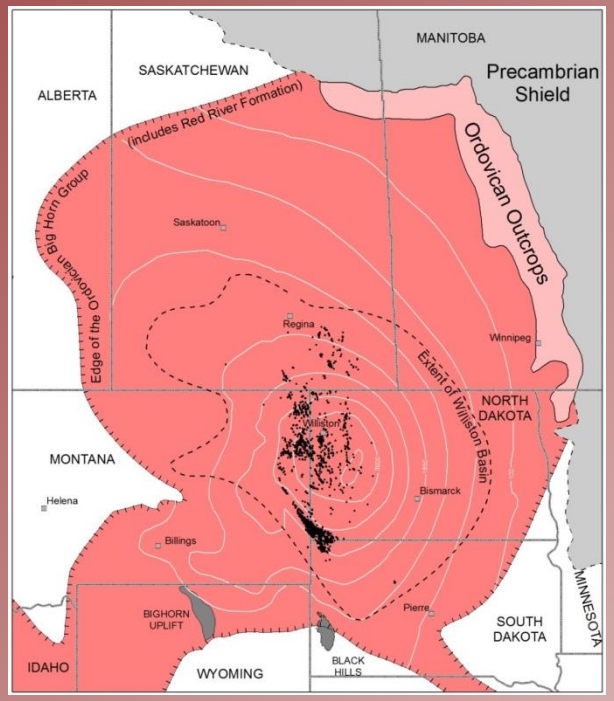
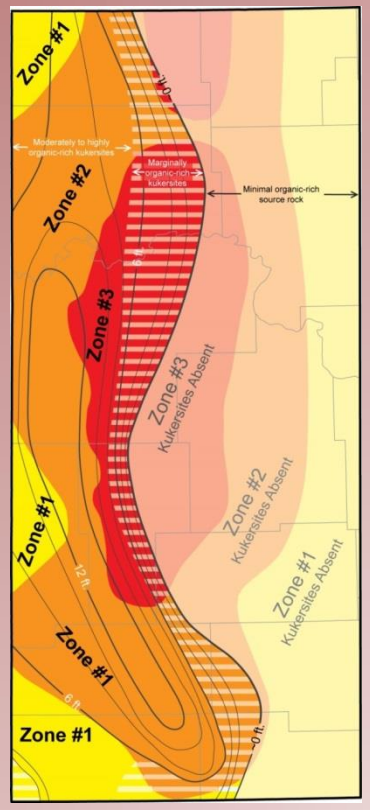
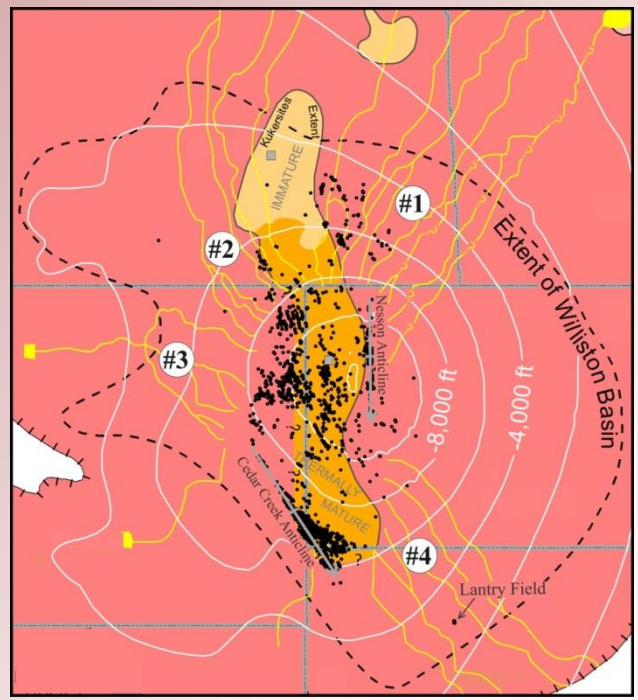


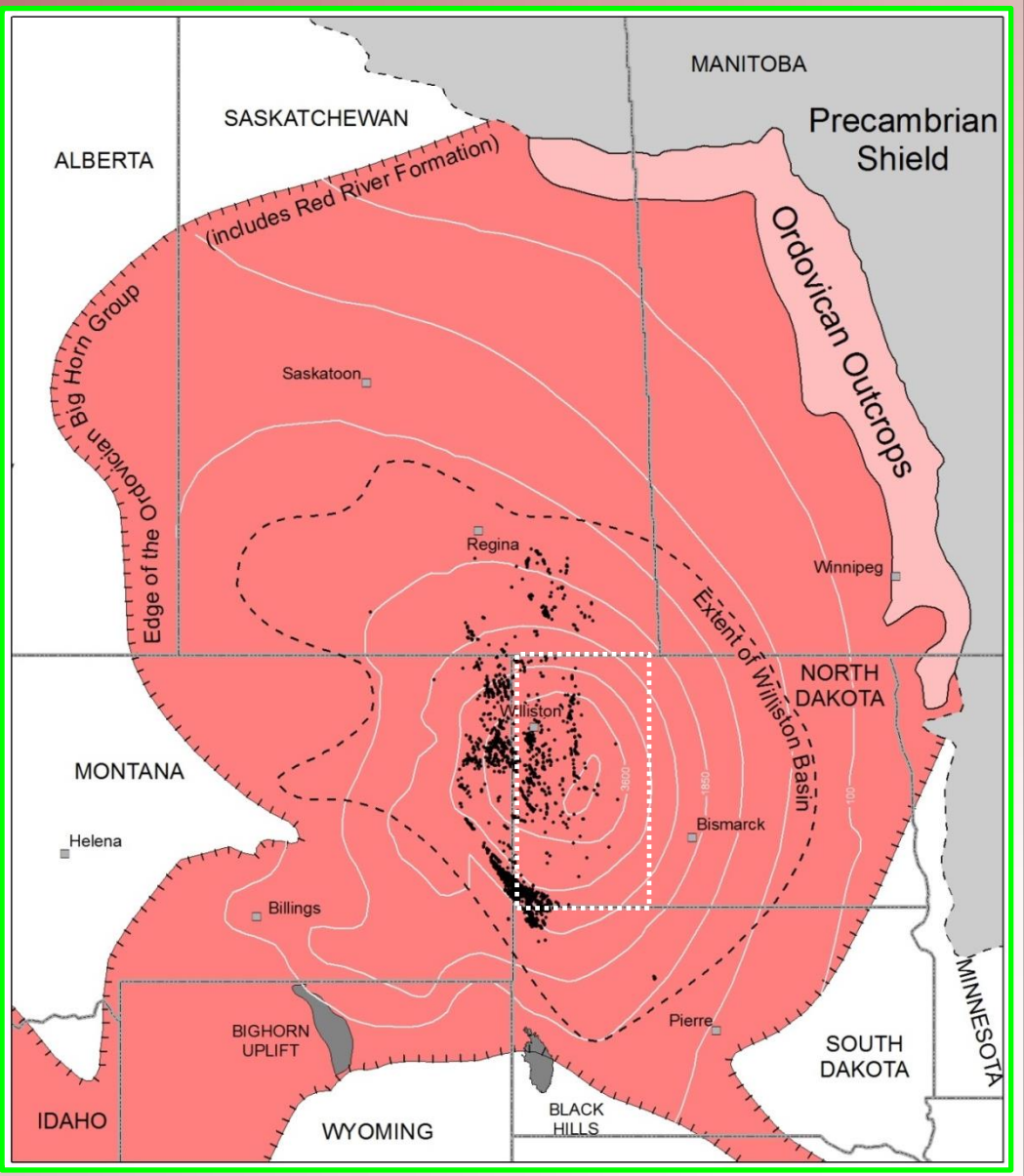




Red River Hydrocarbon Production

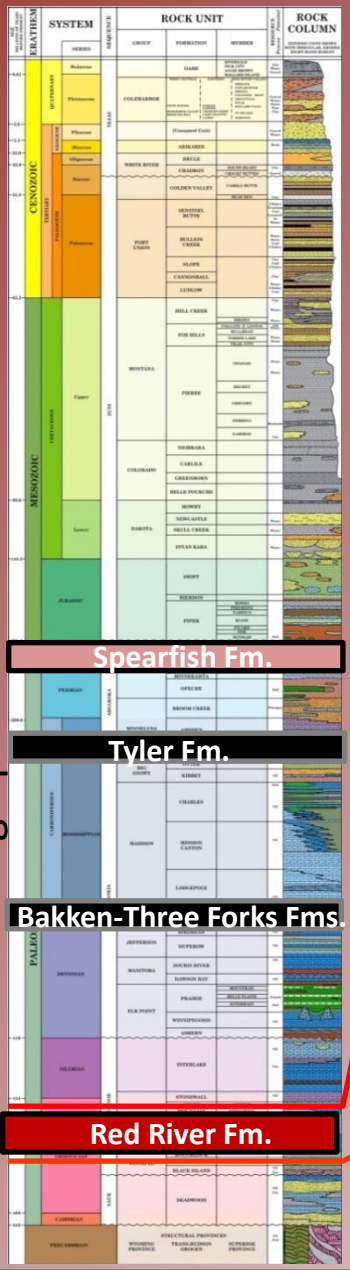
Summary of Red River Production across the Williston Basin:

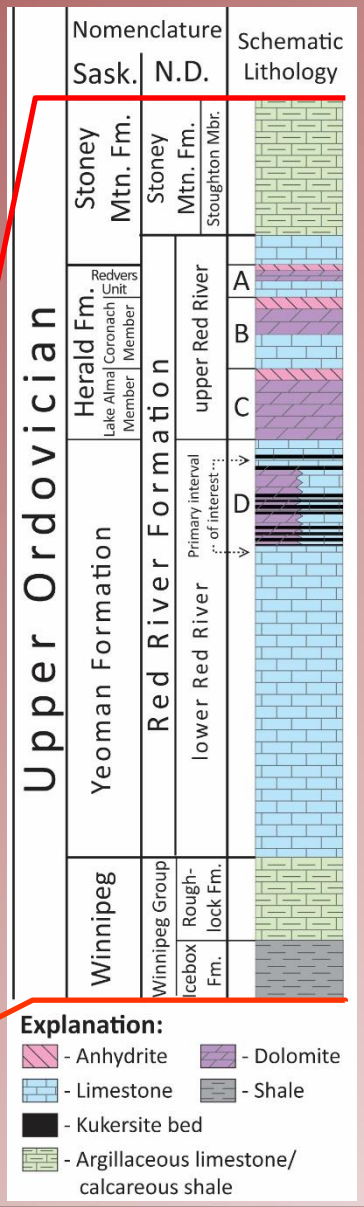
- Production extends from SE Saskatchewan to NW South Dakota
- >600 MBO cum. production
- >2,700 productive wells



Red River Stratigraphy

Stratigraphic Column of North Dakota





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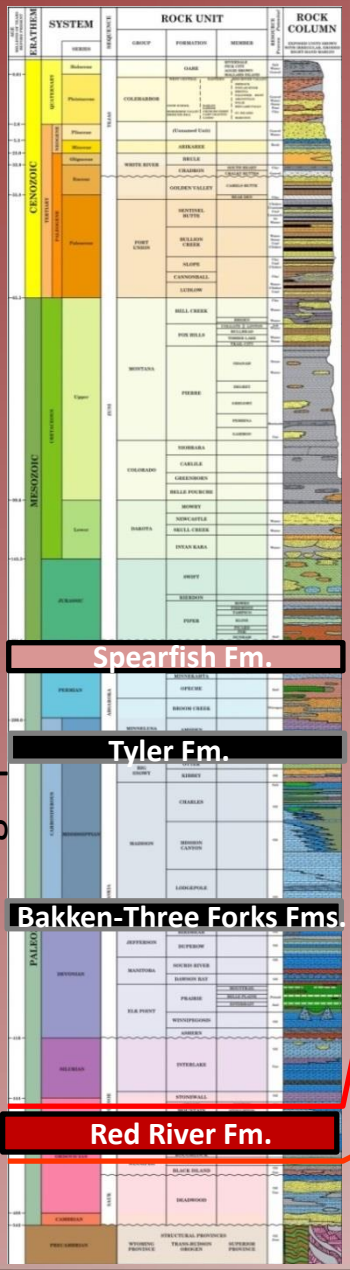

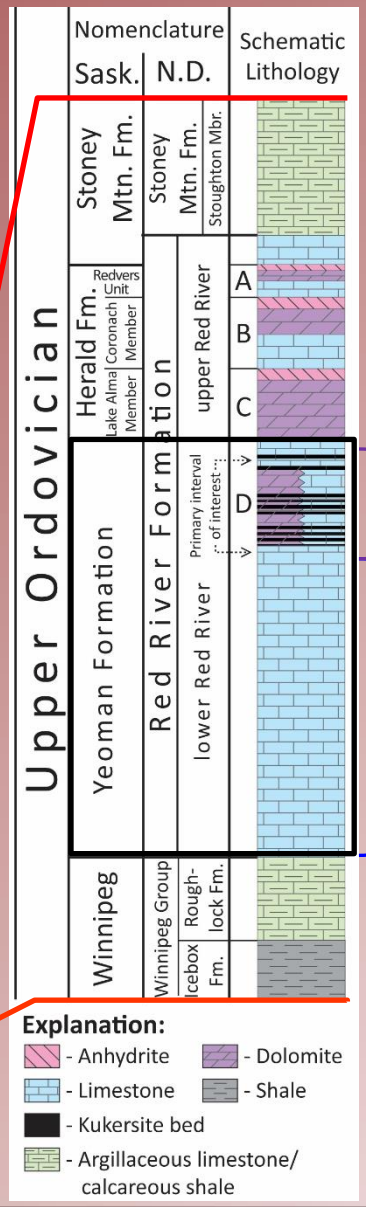

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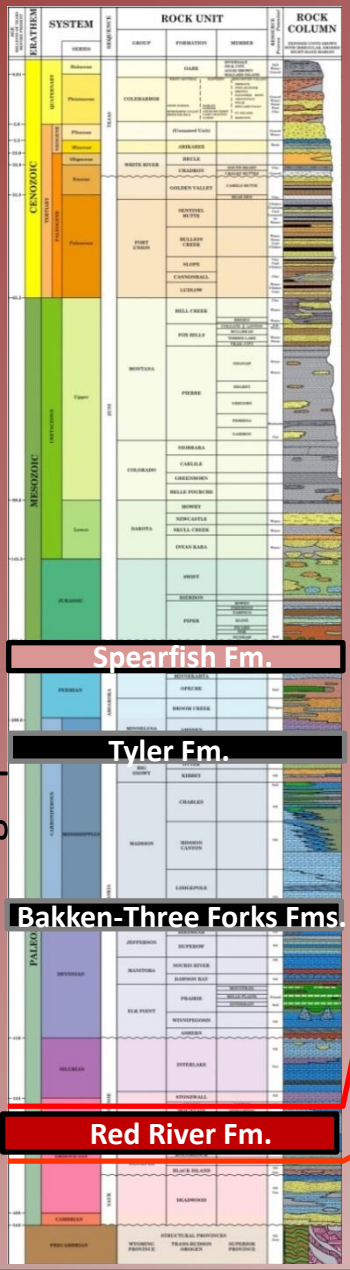
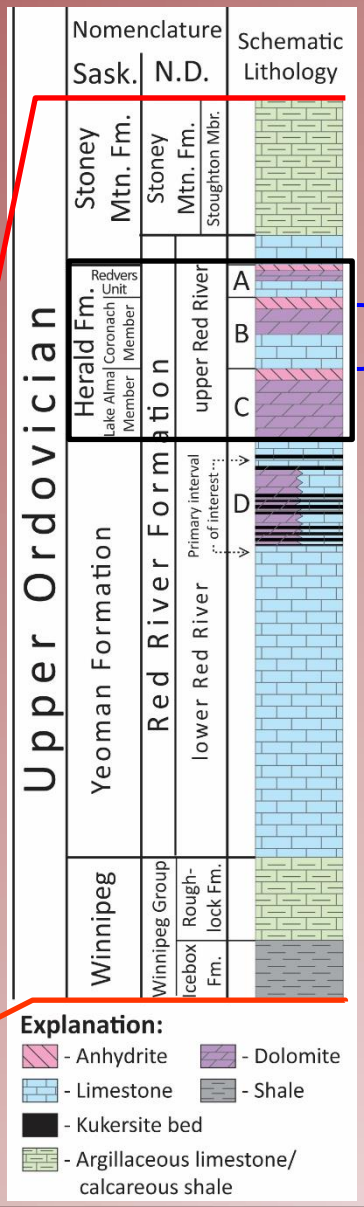
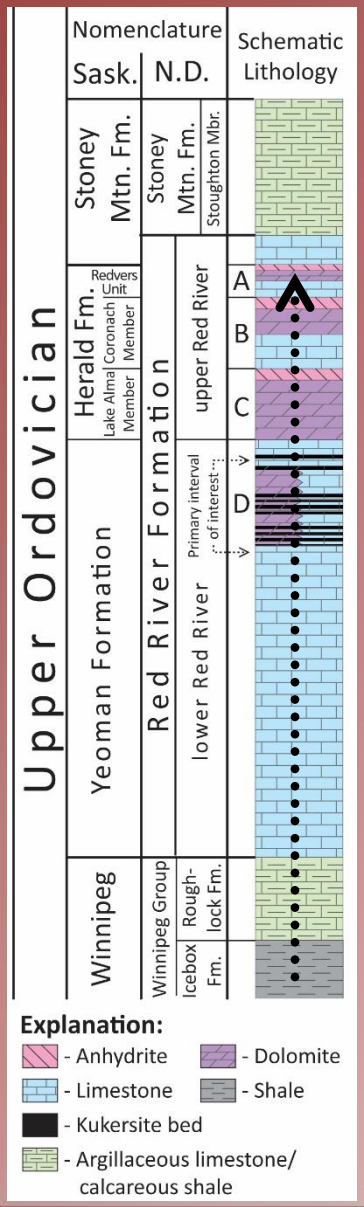




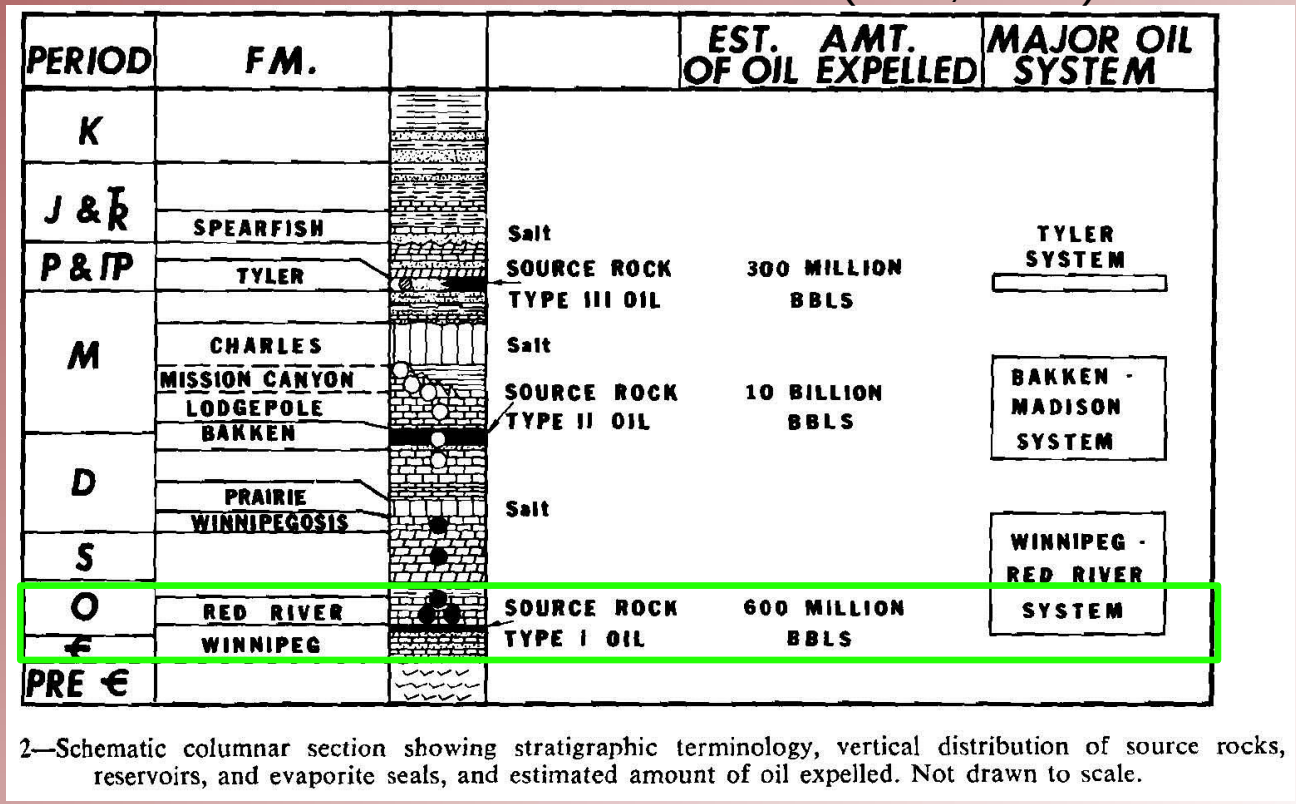
"B" Cycle

Shallowing and brining upward sequence

Source of Red River Hydrocarbons



Williston Basin Source Rocks (Dow, 1974)

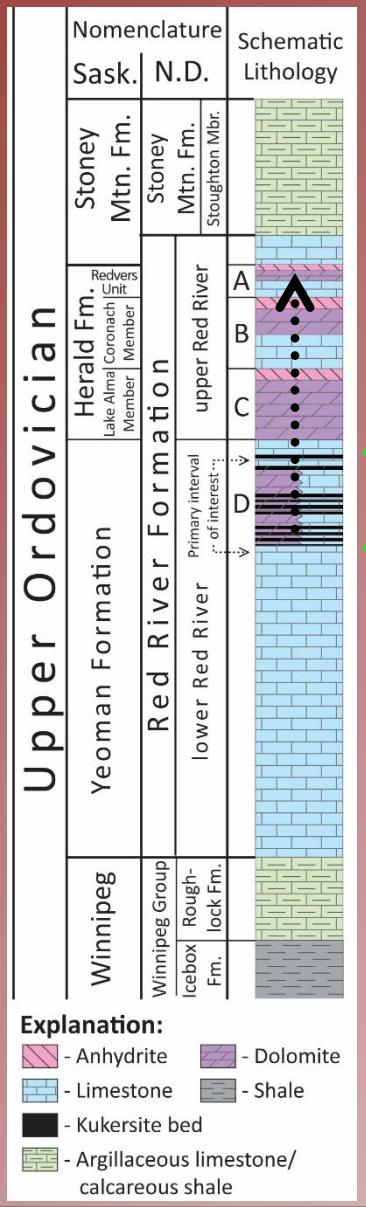


2—Schematic columnar section showing stratigraphic terminology, vertical distribution of source rocks, reservoirs, and evaporite seals, and estimated amount of oil expelled. Not drawn to scale.

Publication:

Dow, W.G., 1974, Application of Oil –Correlation and Source-Rock Data to Exploration in Williston Basin: AAPG Bulletin, v. 58, no. 7, p. 1253-1262.

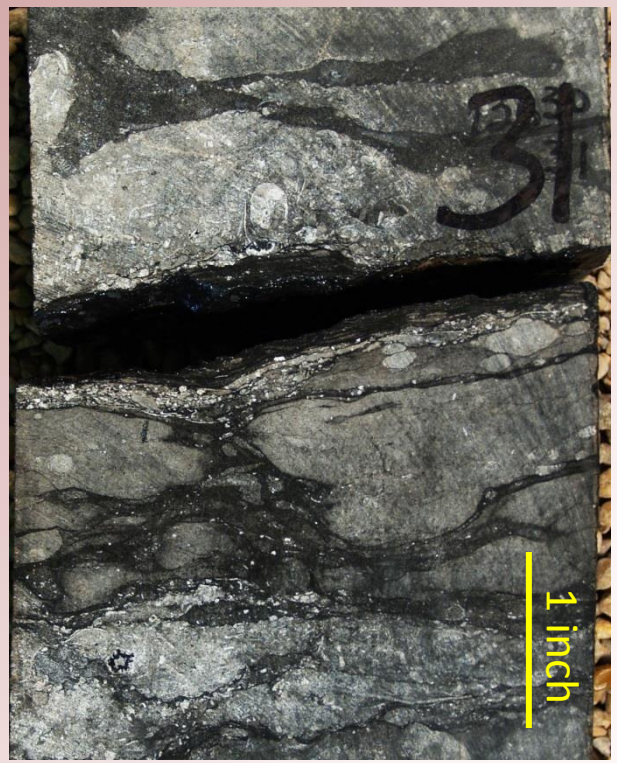
Source of Red River Hydrocarbons



Red River "D" zone (upper Yeoman Fm.) has been described to contain kukersites (a.k.a. kerogenites), 6-18 in. thick organic-rich mudstone beds.
(Kendall, 1976; Carroll, 1979; Longman et al., 1983; Osadetz and Snowdon, 1995; Stasiuk and Osadetz, 1990; Fowler et al., 1998; Nesheim et al., 2015)

Highly organic-rich (>5% TOC) kukersite

Marginally organic-rich (~1% TOC) kukersite



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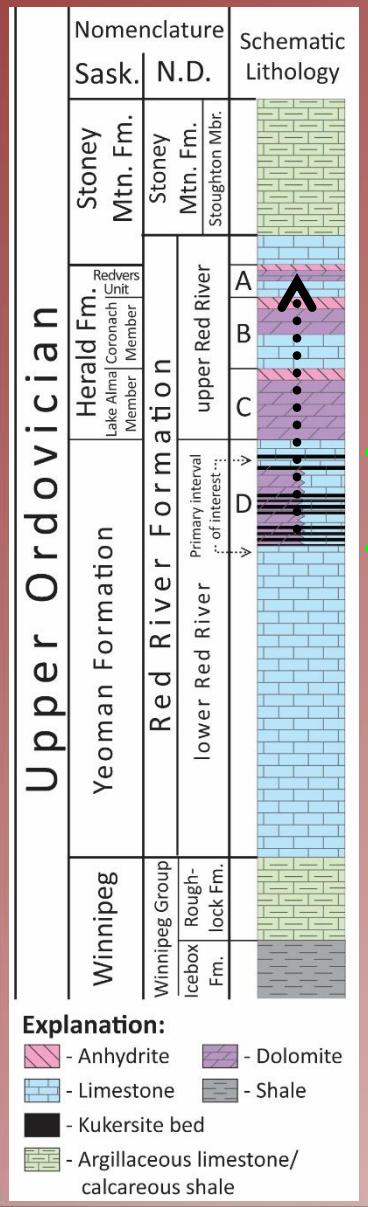

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Red River Kukersites contain abundant algae:
Gloeocapsomorpha prisca (G. prisca)

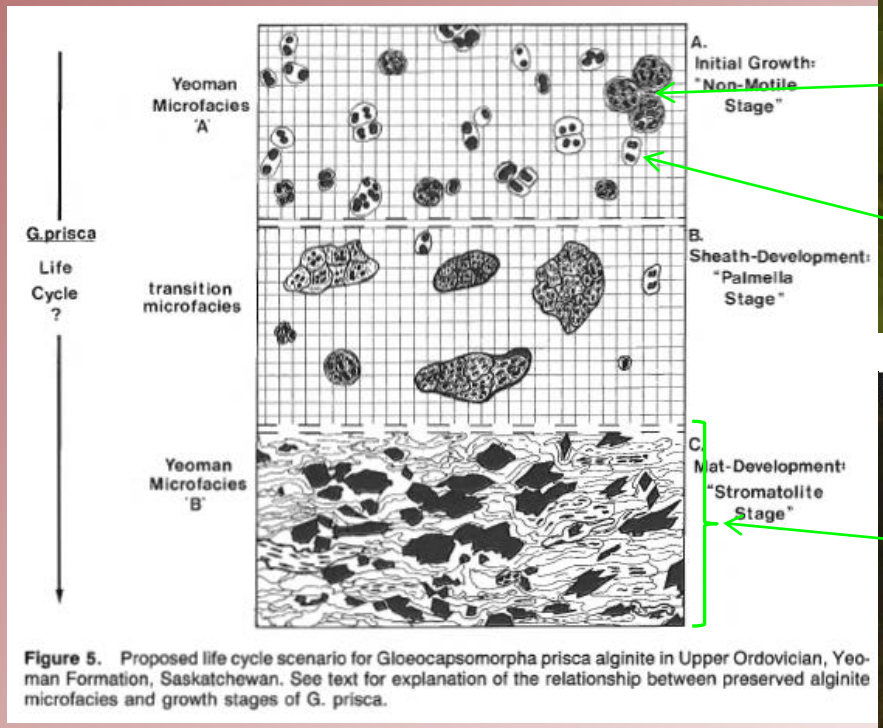
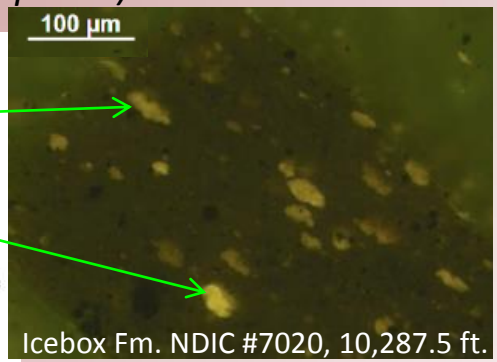


Figure 5. Proposed life cycle scenario for Gloeocapsomorpha prisca alginite in Upper Ordovician, Yeoman Formation, Saskatchewan. See text for explanation of the relationship between preserved alginite microfacies and growth stages of G. prisca.

*Diagram above from Stasiuk and Osadetz (1990)



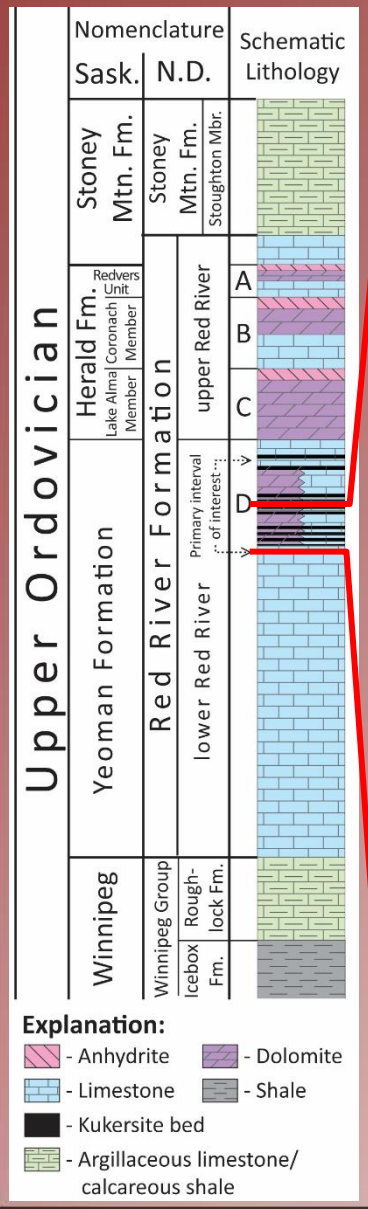
Icebox Fm. NDIC #7020, 10,287.5 ft.

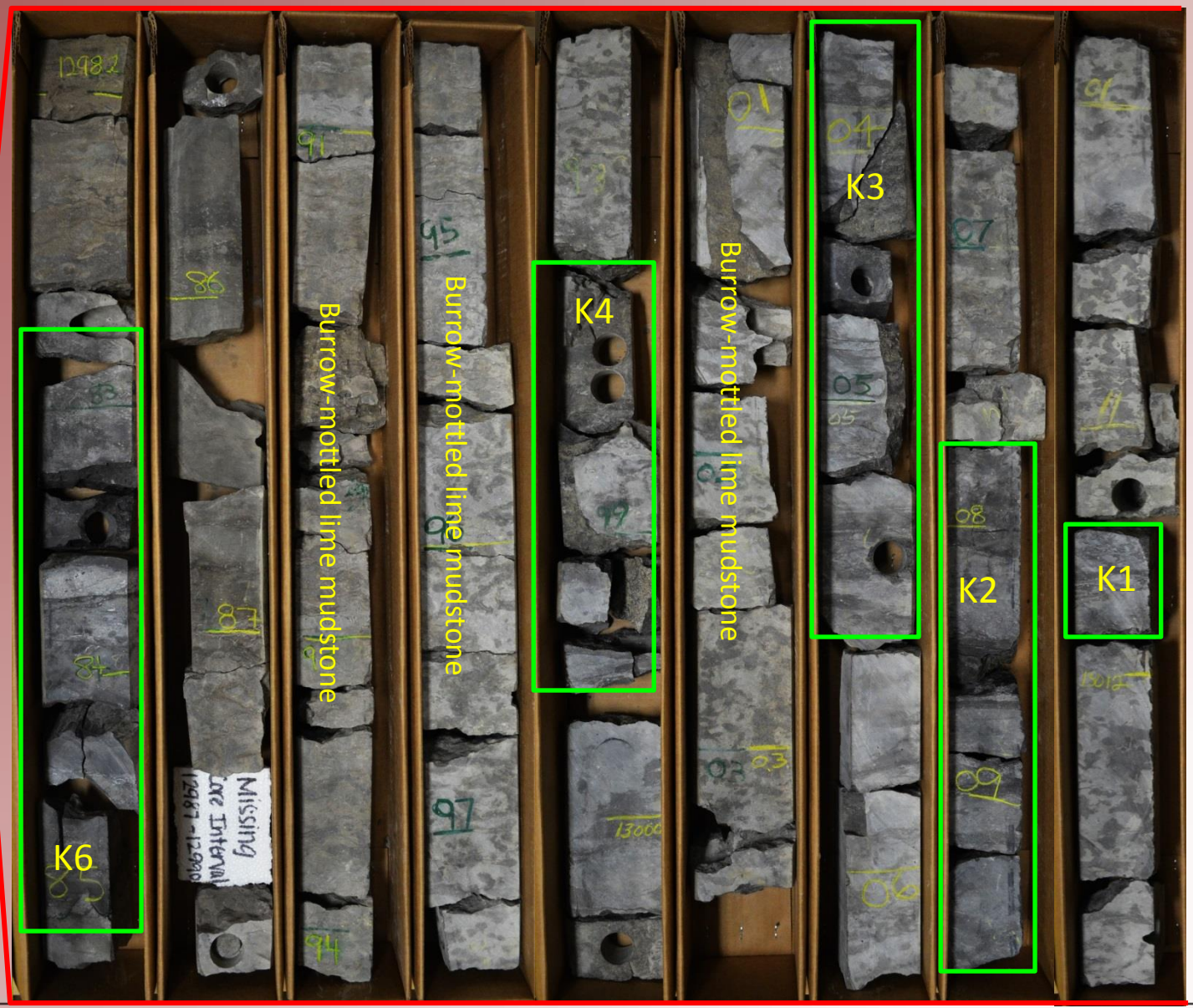
Stonewall Fm. NDIC #7612, 10,709.5 f

Photographs from Paul Hackley (USGS)

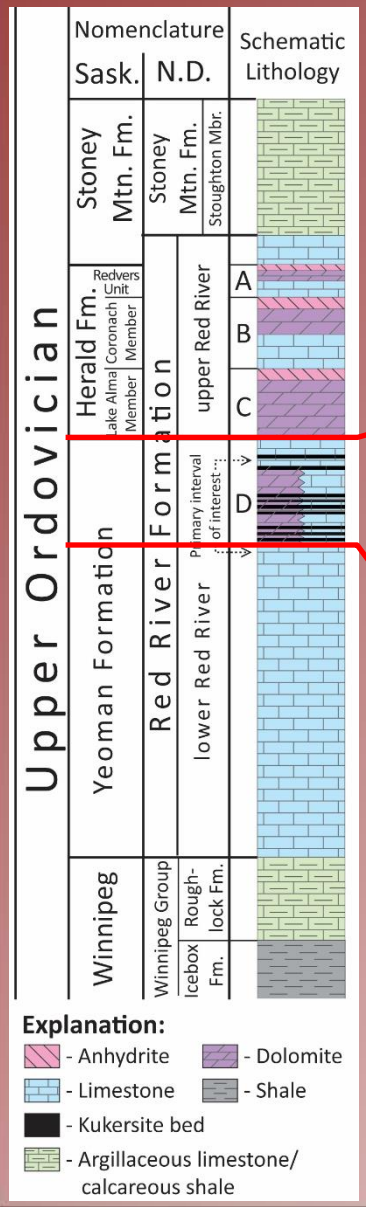
Red River kukersites in core

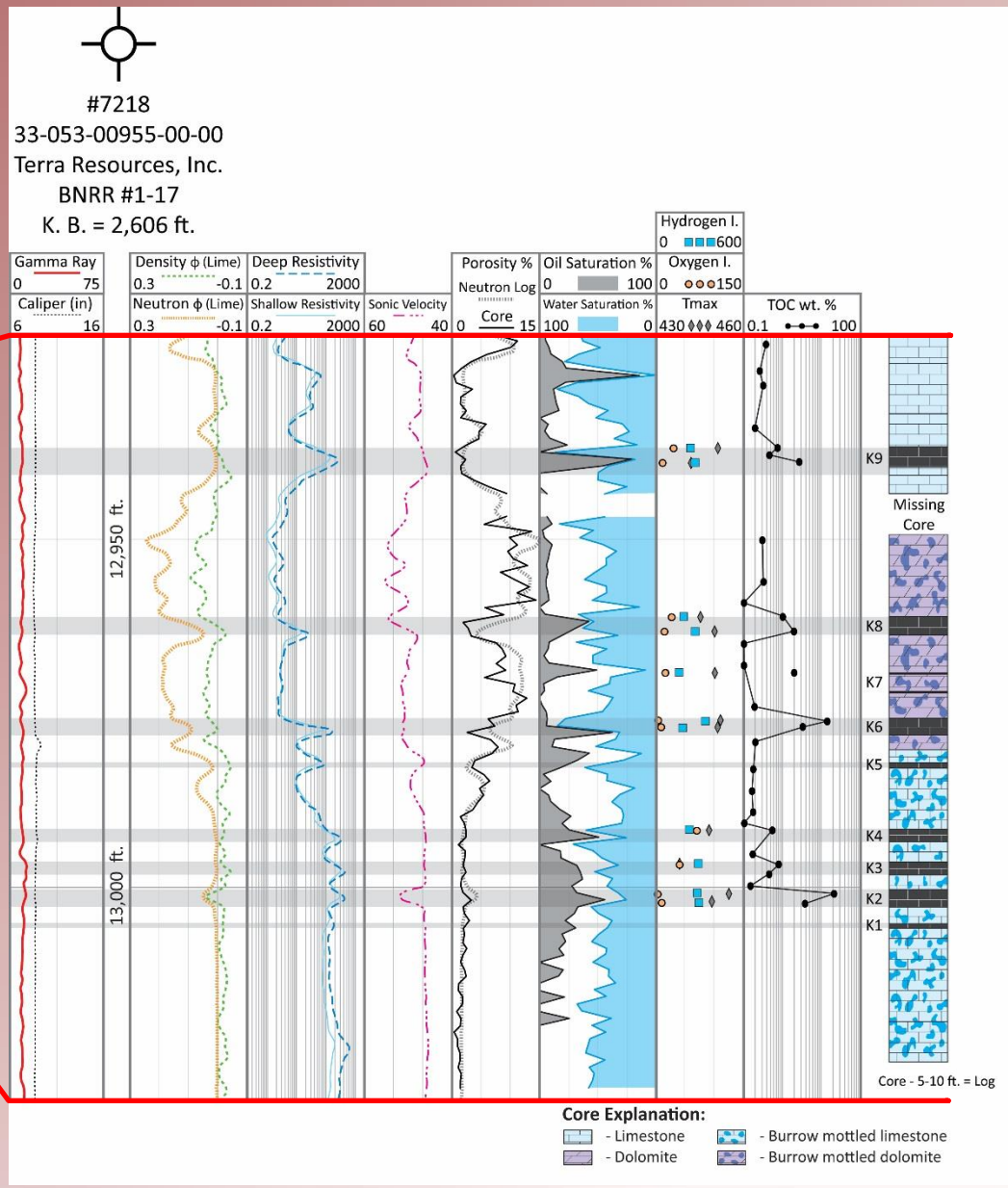
Terra Resources BNRR #1-17 (NDIC: 7218, API: 33-053-00955-00-00)





Red River Kukersites: wireline log signatures





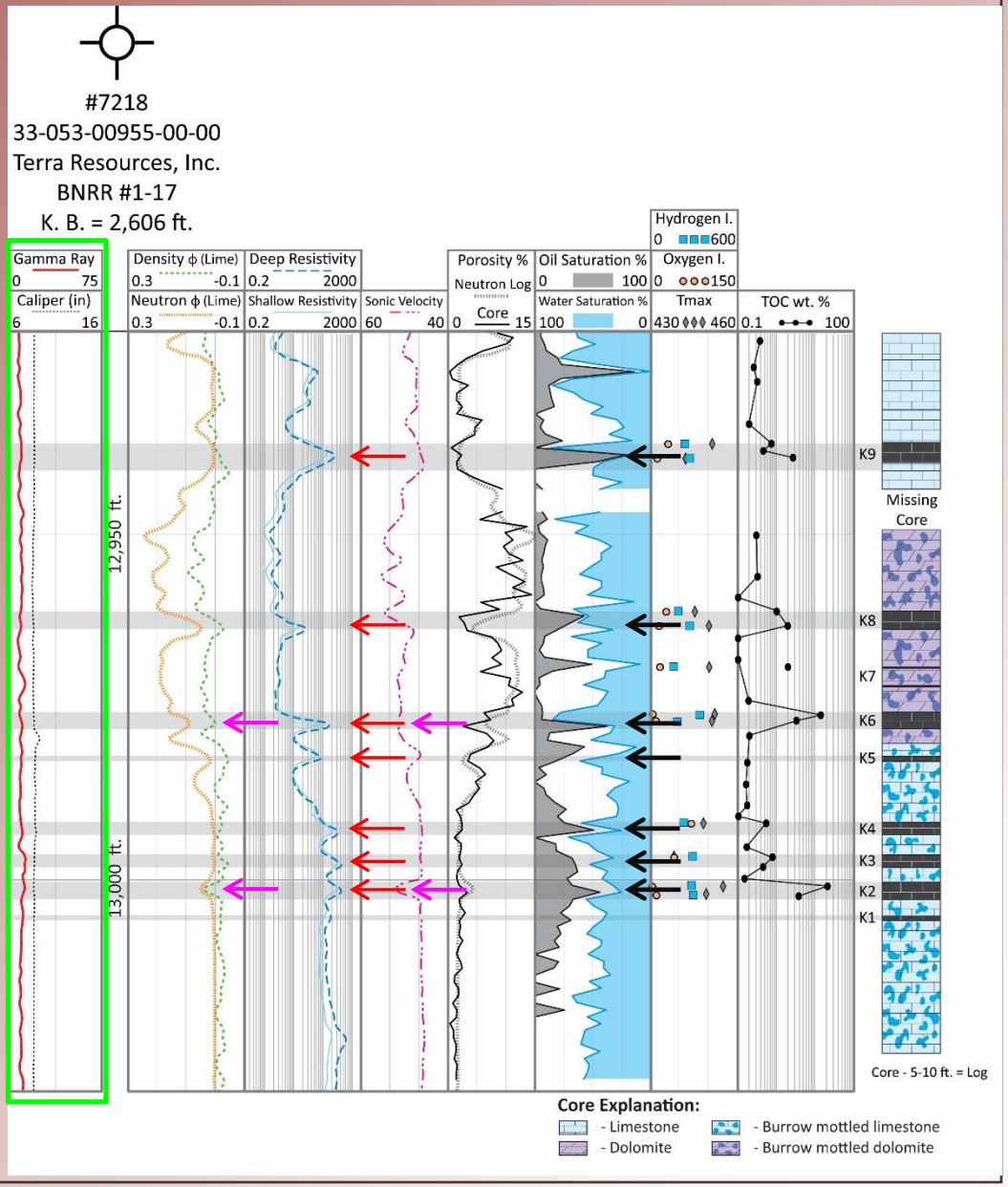
Red River Kukersites: wireline log signatures

Low, negligible gamma-ray wireline log signature, which may correspond with negligible clay content.

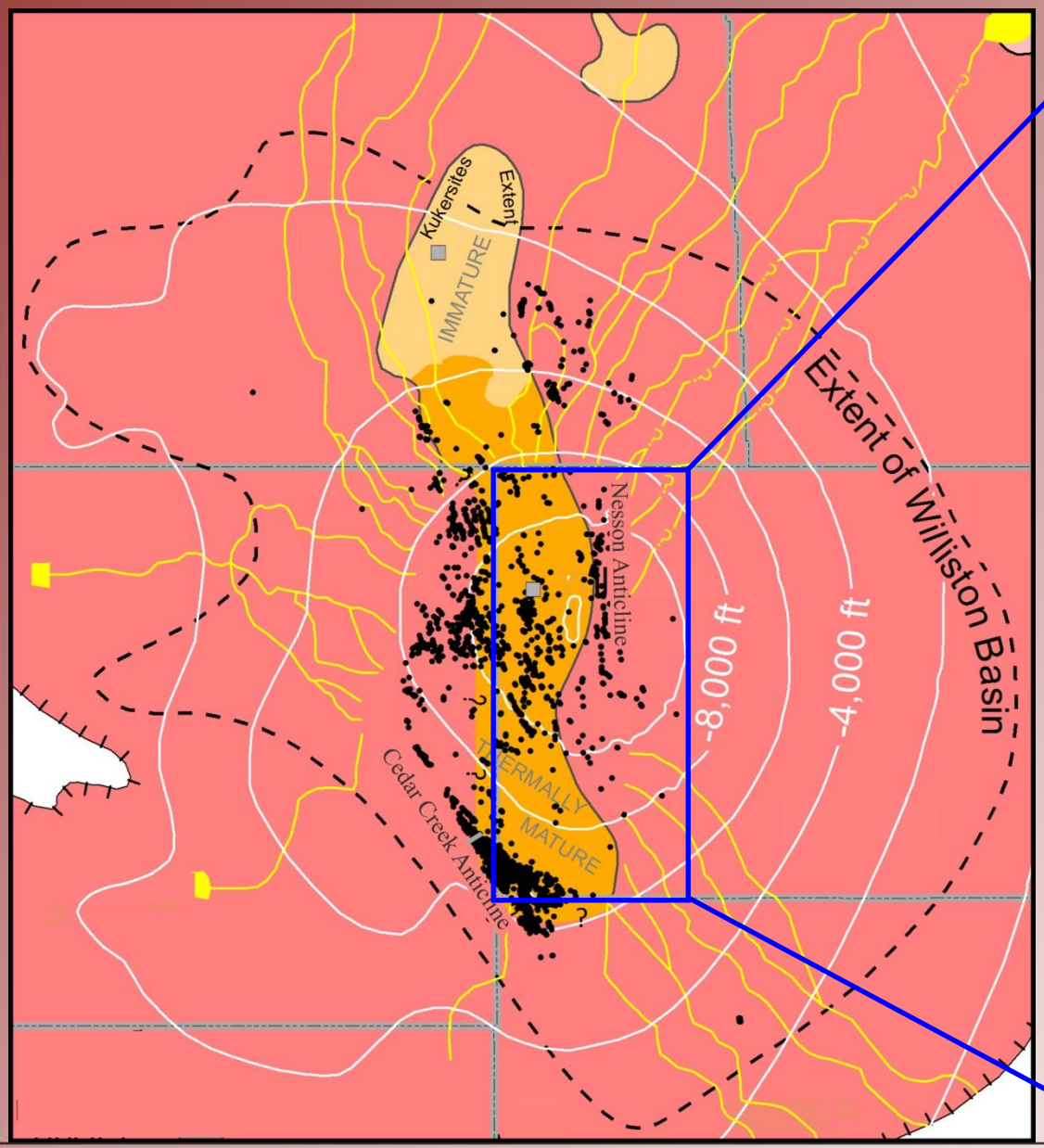
Kukersites ≥1 ft. thick typically correlate with a relatively high resistivity wireline log signatures

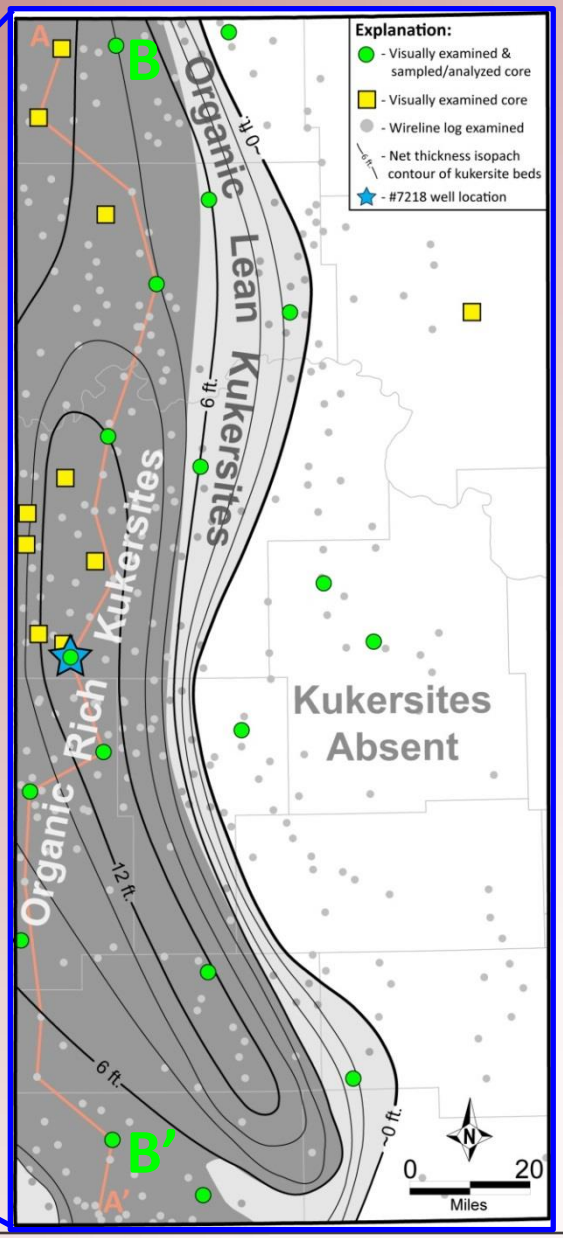
Kukersites often contain high oil saturations than the interbedded burrow-mottled facies, which is likely the cause of their higher resistivities

The more organic-rich (≥5% TOC) kukersites (e.g. K2 and K6 beds) display neutron-density porosity and sonic velocity signatures. Higher concentration of organic material lowers the density of the rock which in turn causes the porosity wireline log signatures.



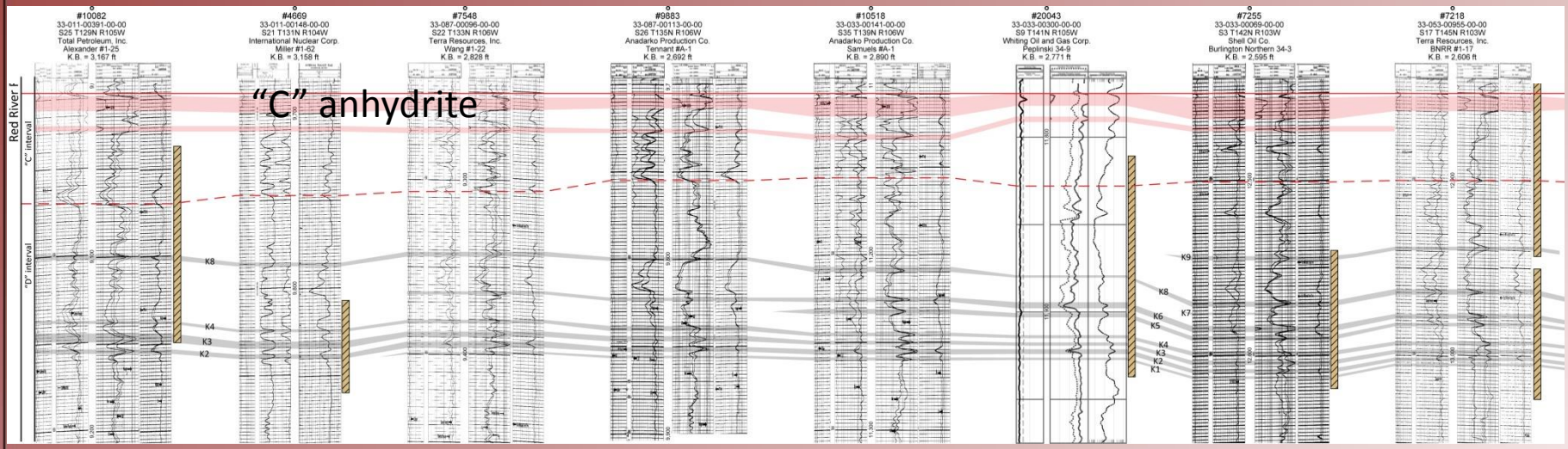
Red River Kukersite Extent and Net Thickness



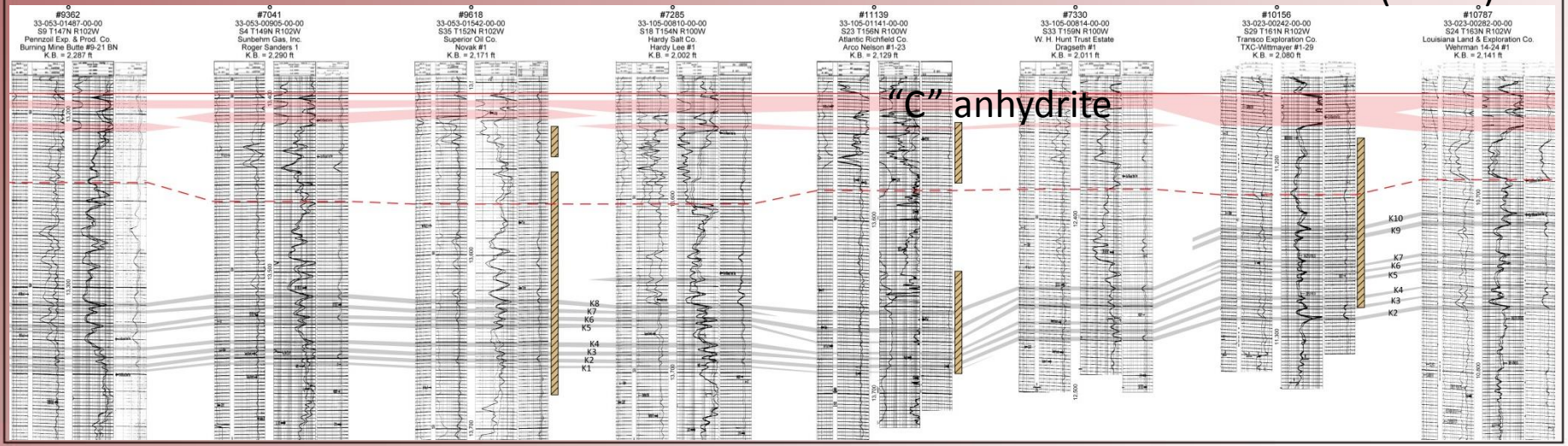


Kukersite wireline log correlations

A’ (south)



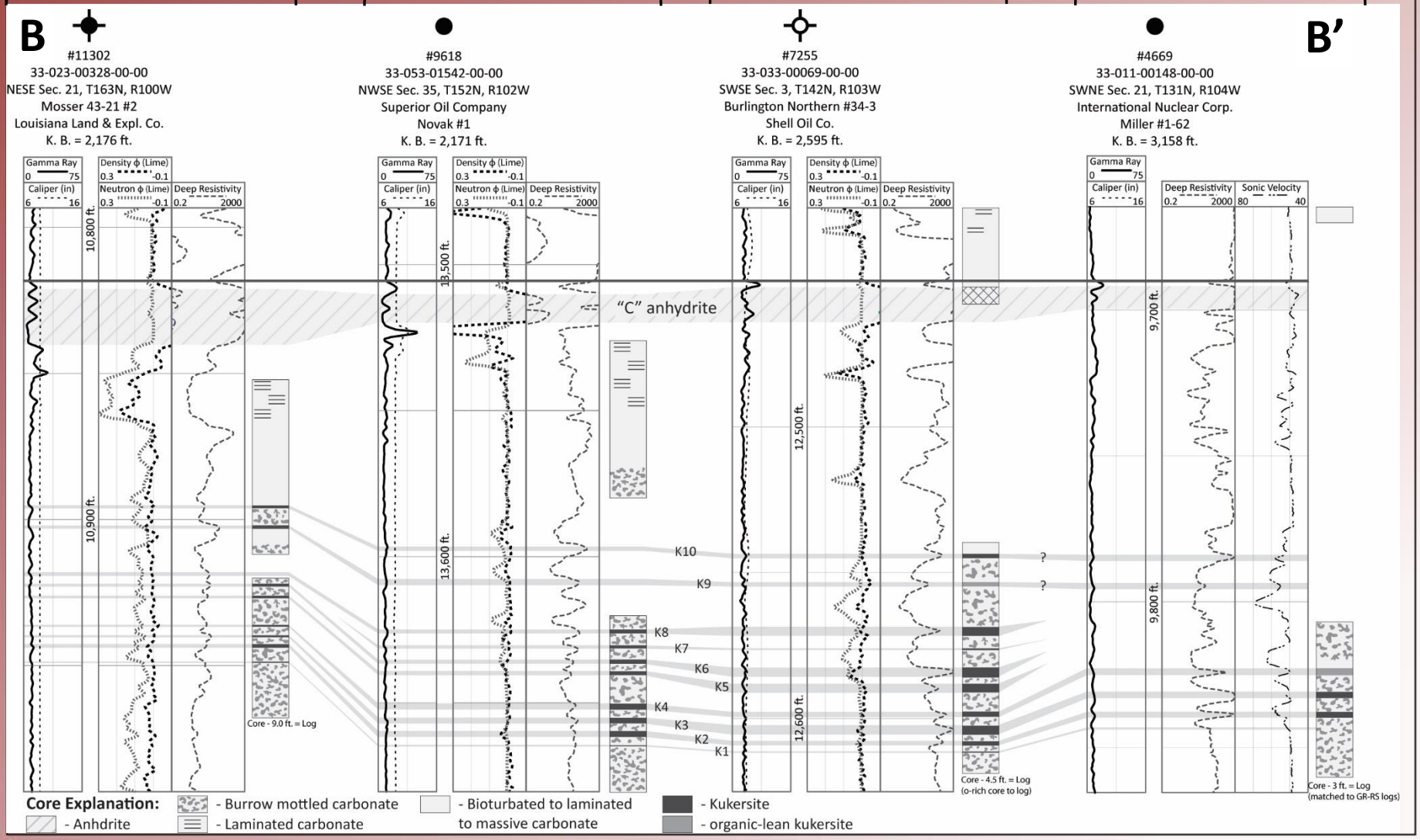
(north) **A**



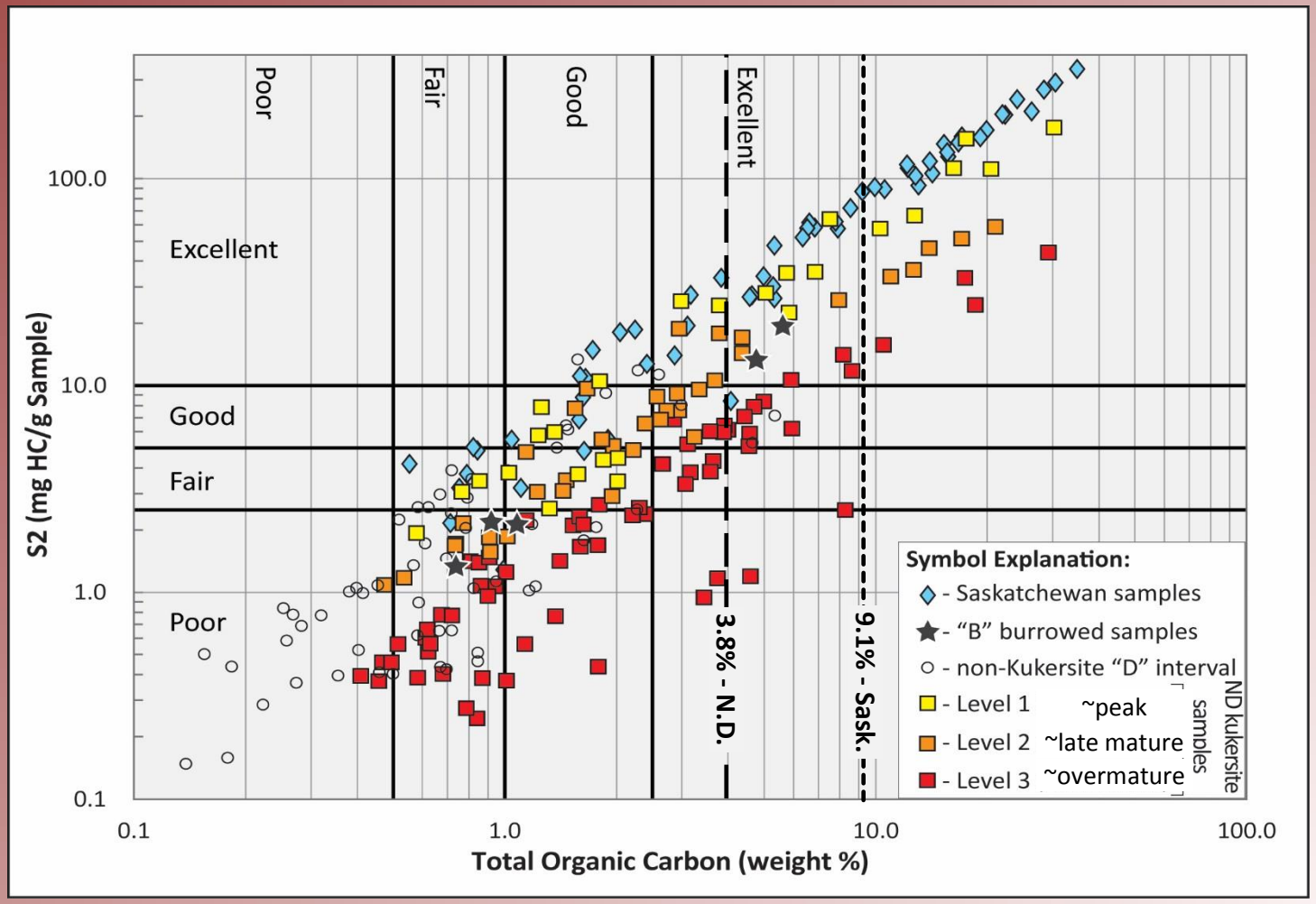
Kukersite wireline log correlations

<- north **south ->**

Divide County | McKenzie County | Golden Valley Co. | Bowman County



Kukersite Organic Richness

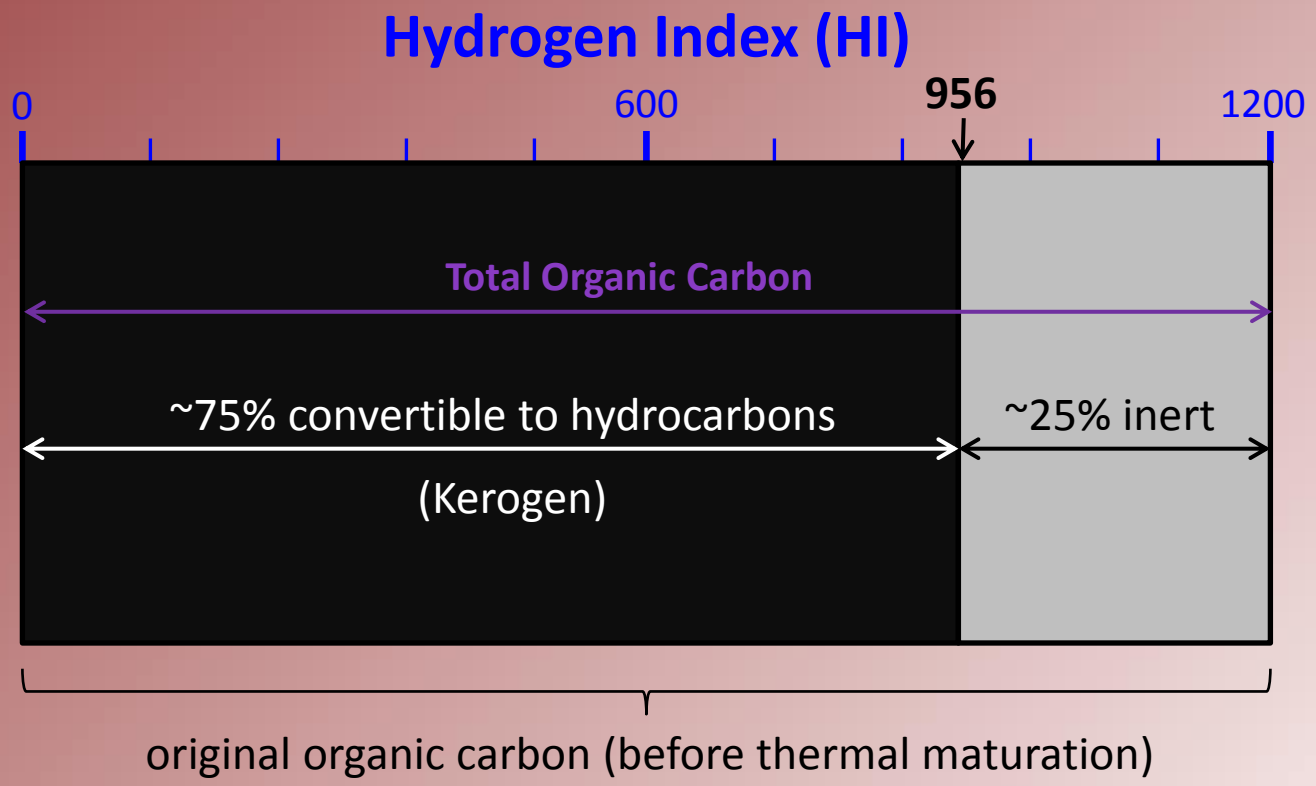


Average Kukersite TOC wt. %:

North Dakota – 3.8% TOC (Nesheim, 2015)

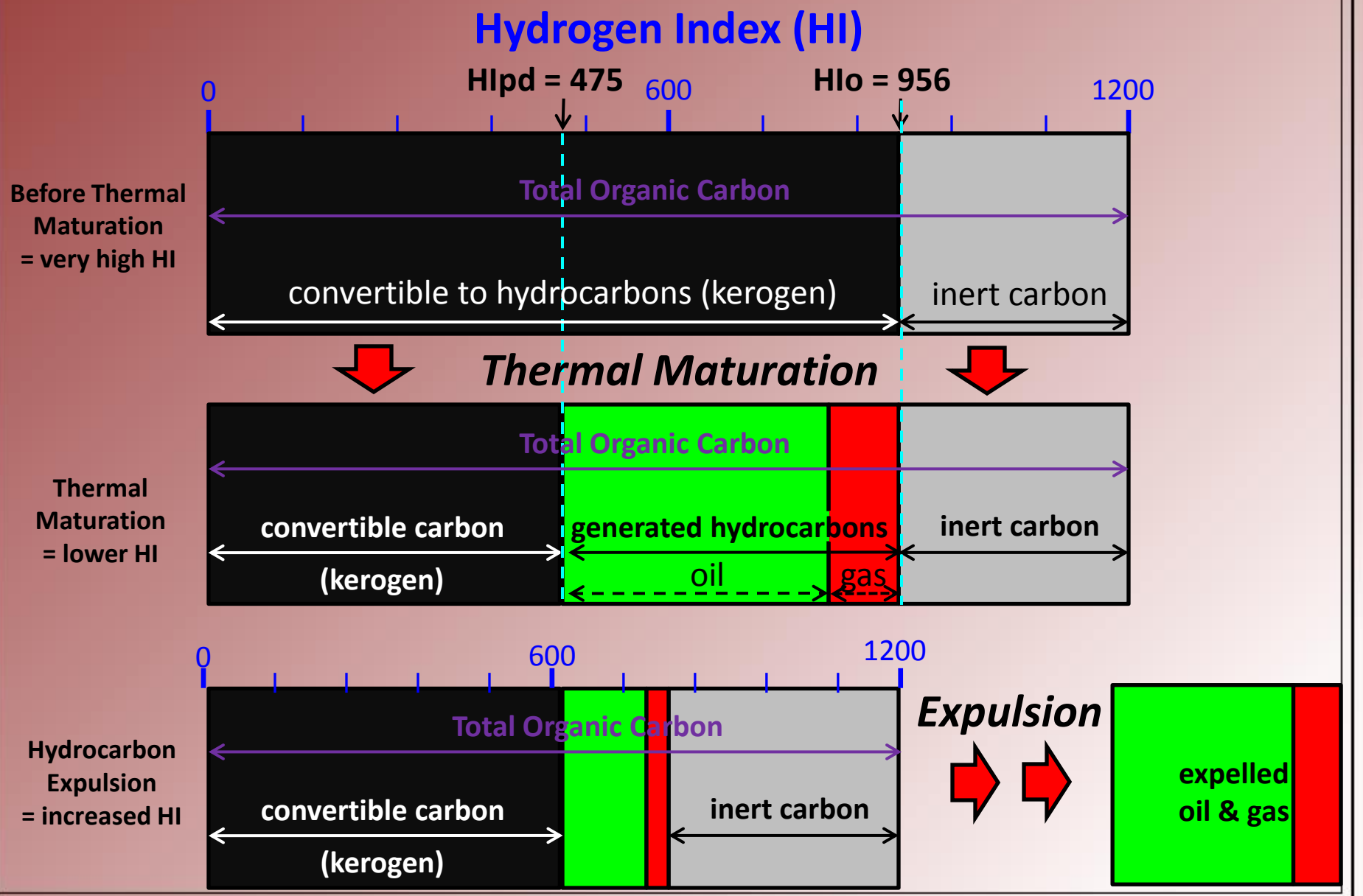
Saskatchewan – 9.1% TOC (Osadetz and Snowdon, 1995)

Red River Kukersites:

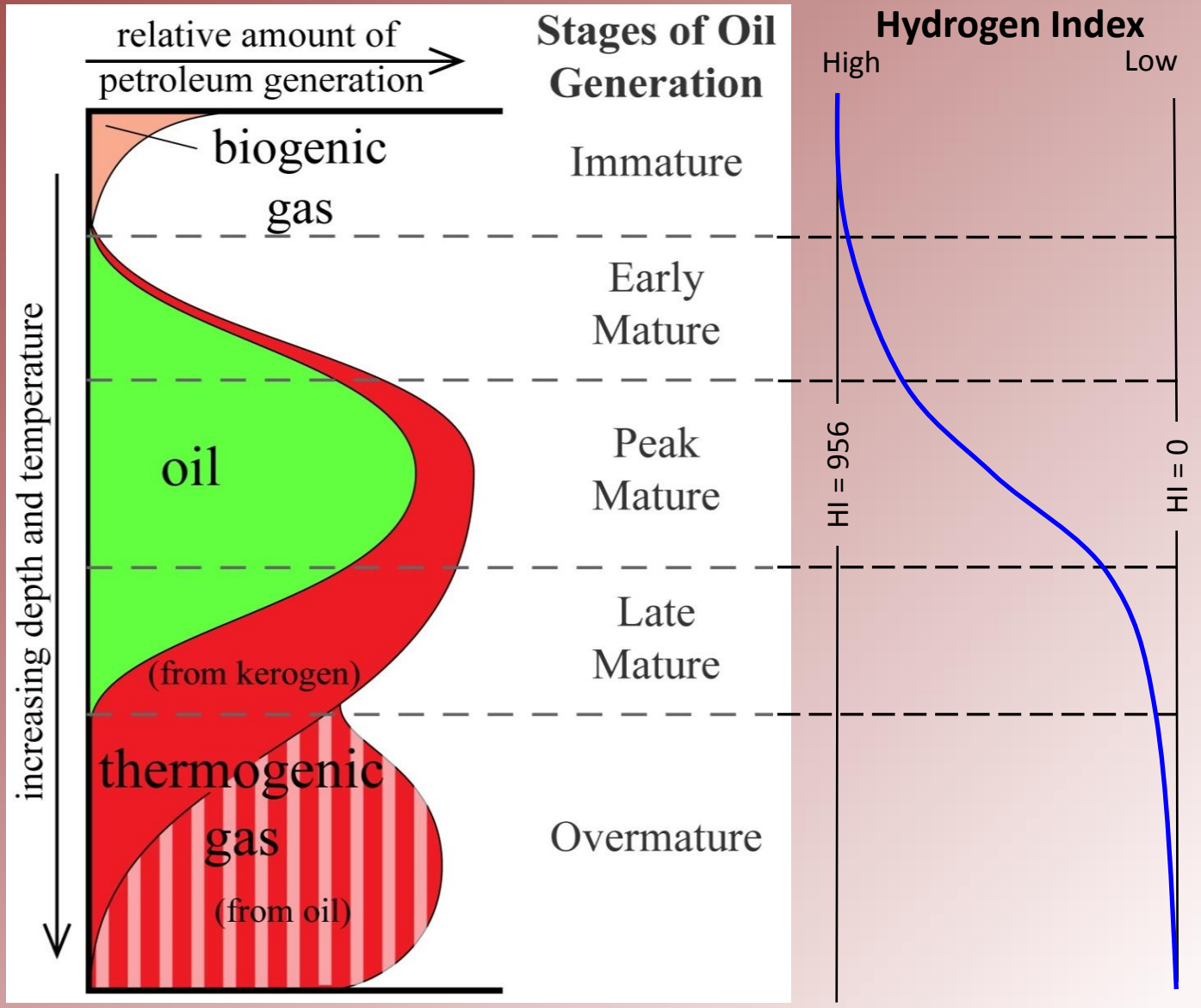


- **Immature to marginally mature Kukersite samples** from southern Saskatchewan **averaged 11.3% TOC** and an HI of 864 (Osadetz and Snowdon, 1995).
- Osadetz and Snowdon, (1995) **inferred an original HI of ≈ 956** based on these immature to marginally mature kukersite samples.

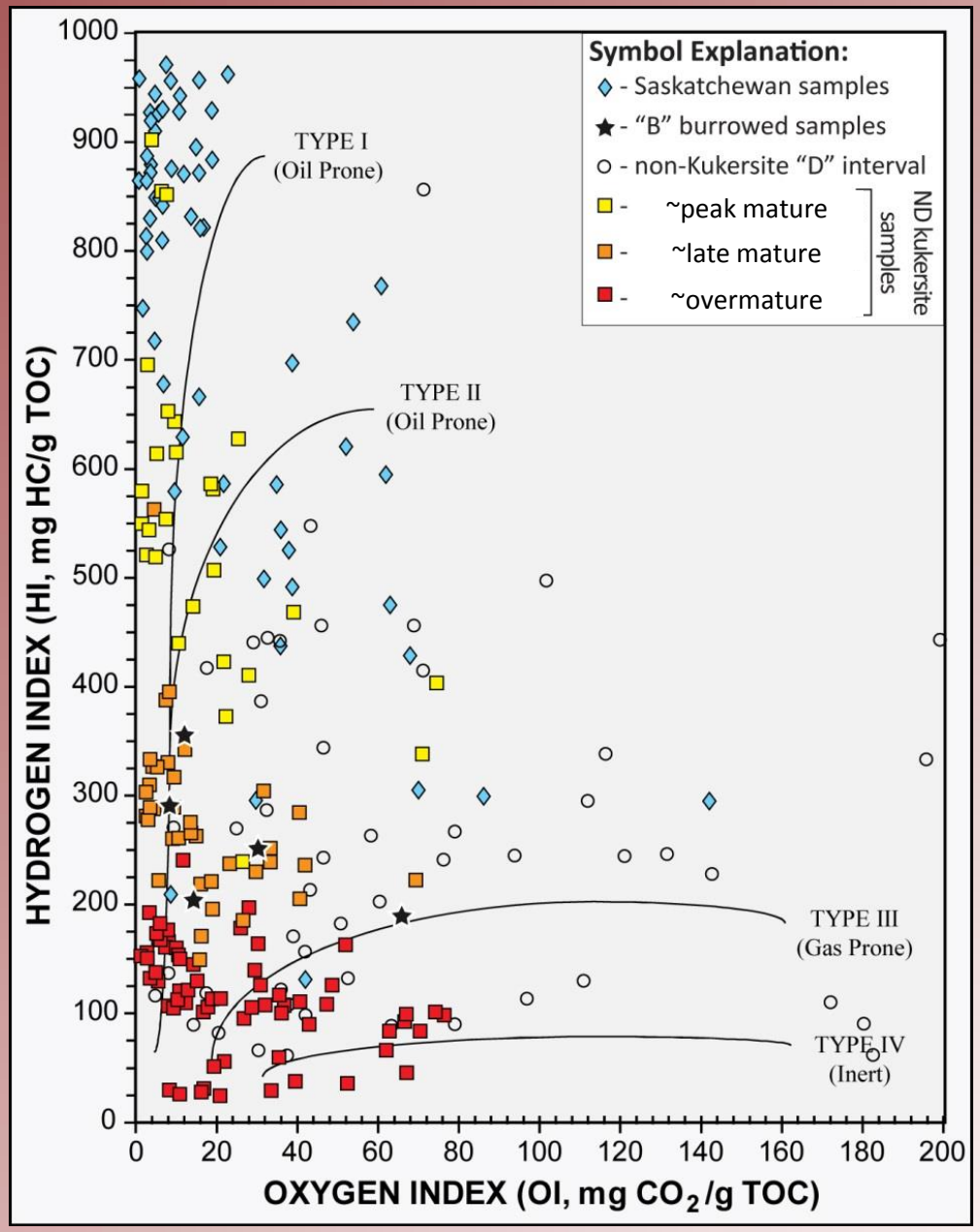
Thermal Maturation and Hydrogen Index



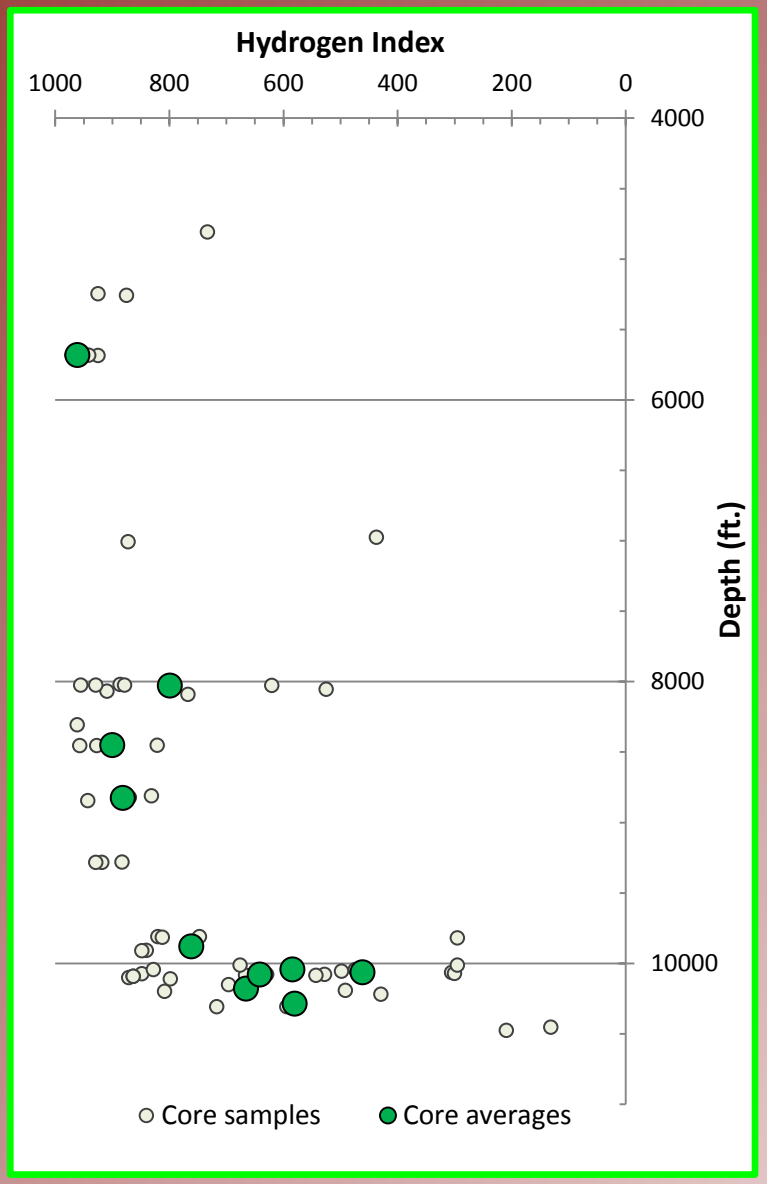
Thermal Oil and Gas Generation

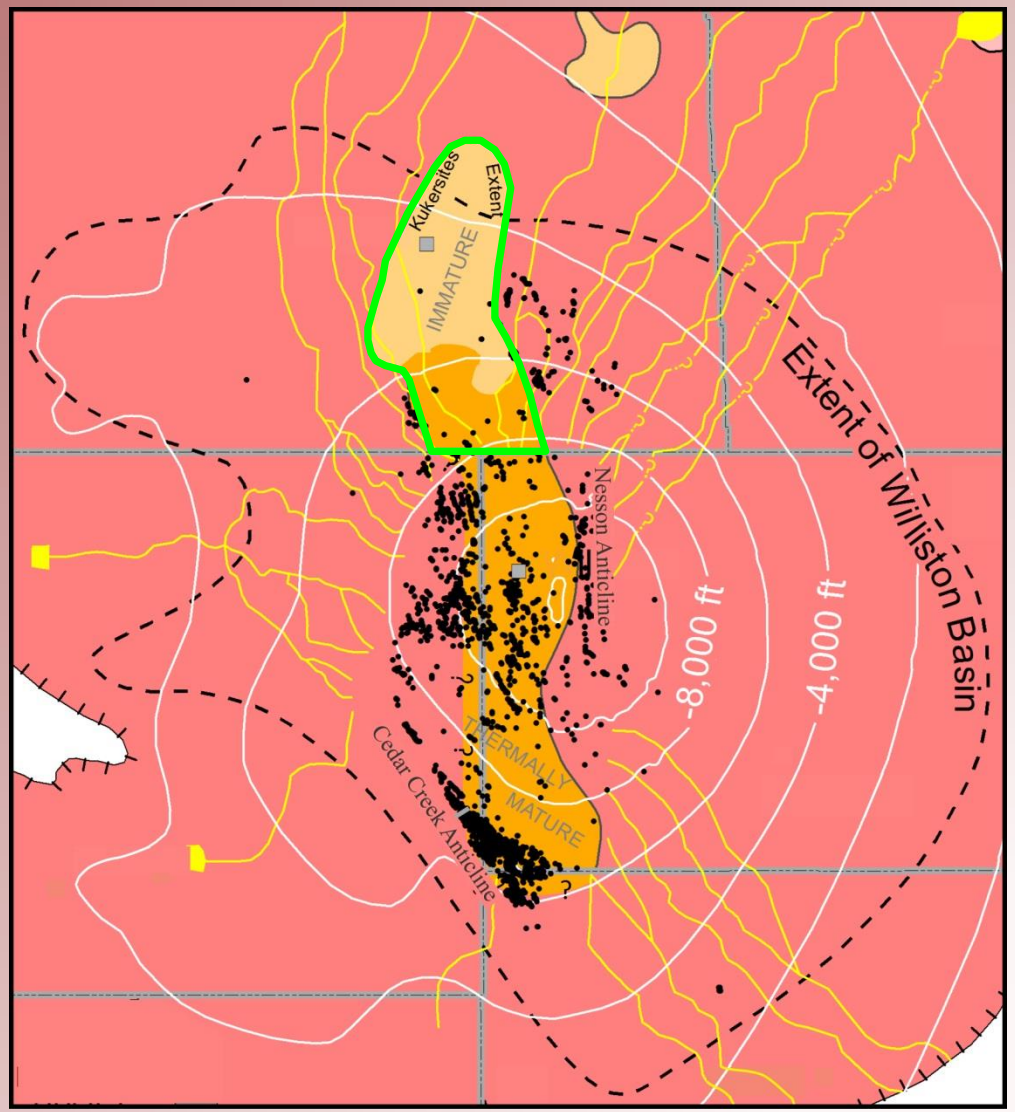


Kukersite Thermal Maturity



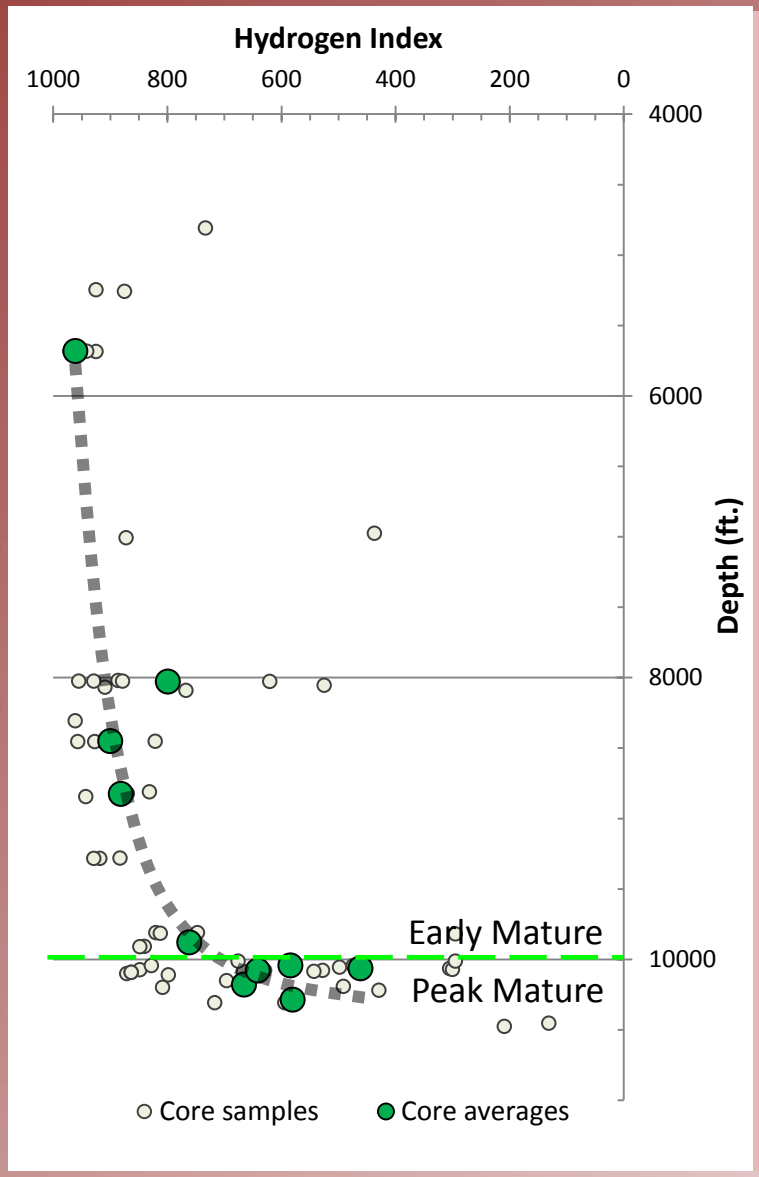
Kukersite Thermal Maturity: southern Saskatchewan

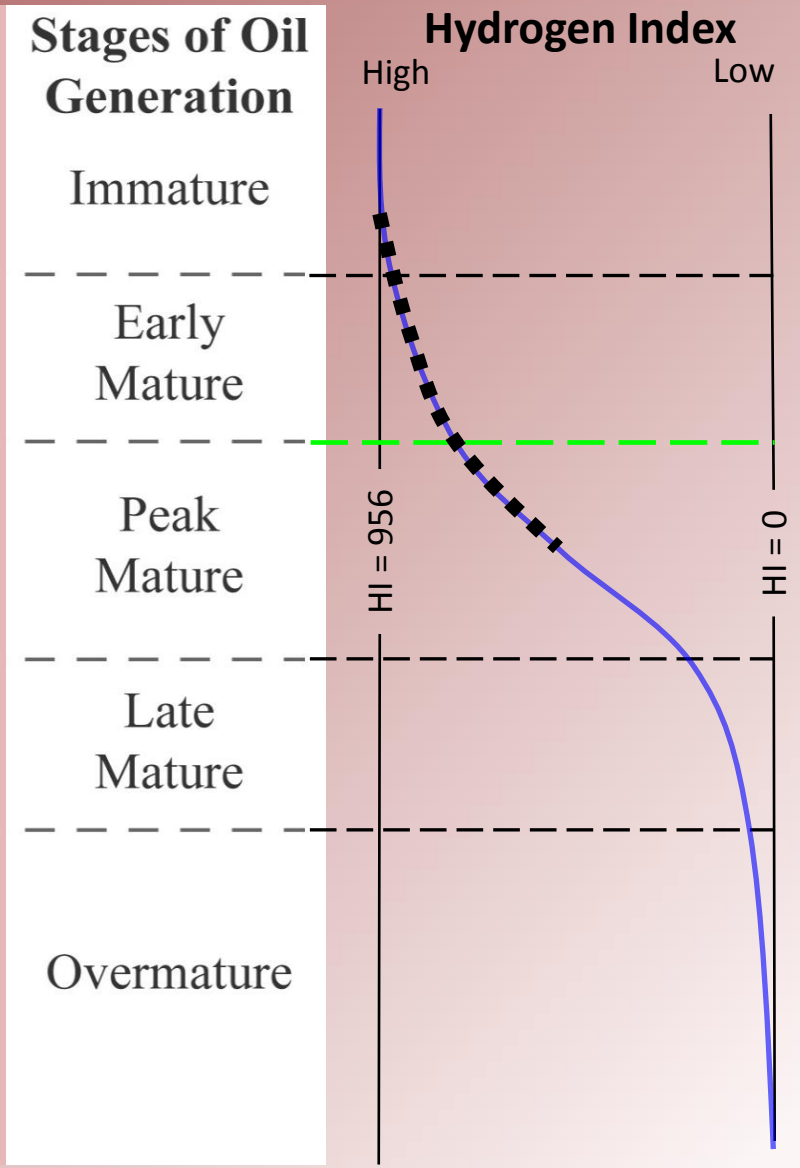




*Data above from Osadetz and Snowdon (1995).

Thermal Oil and Gas Generation





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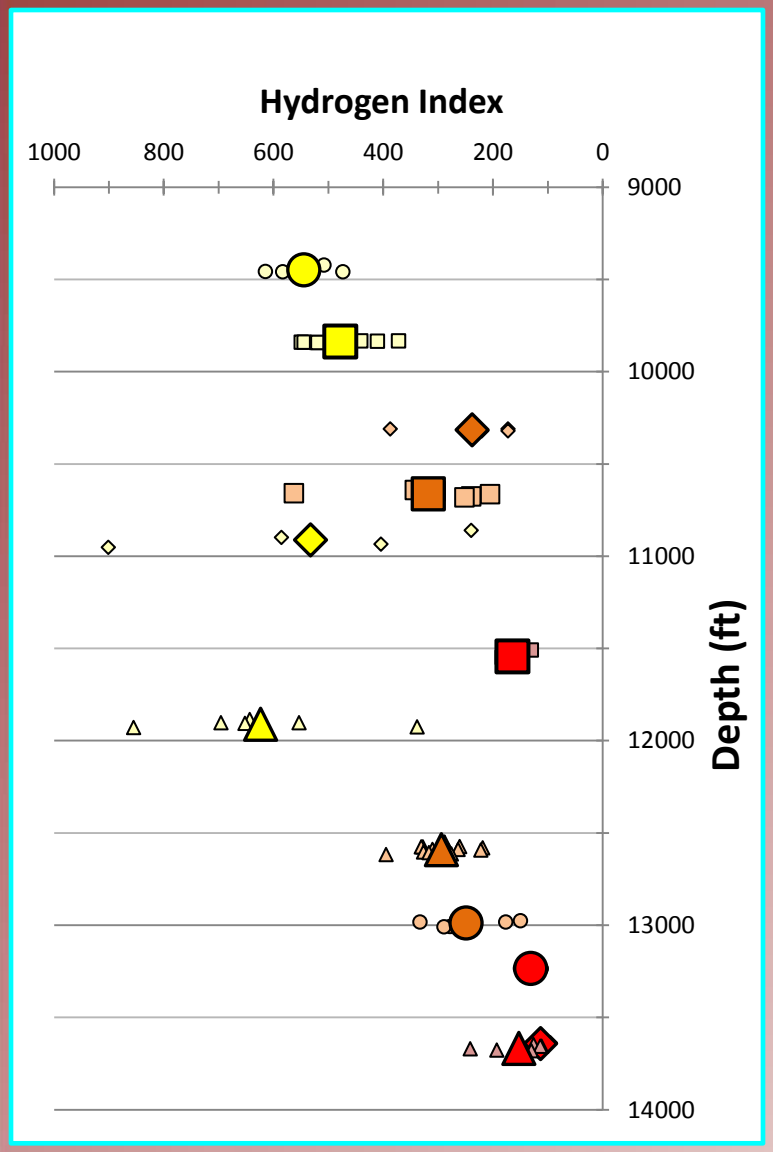
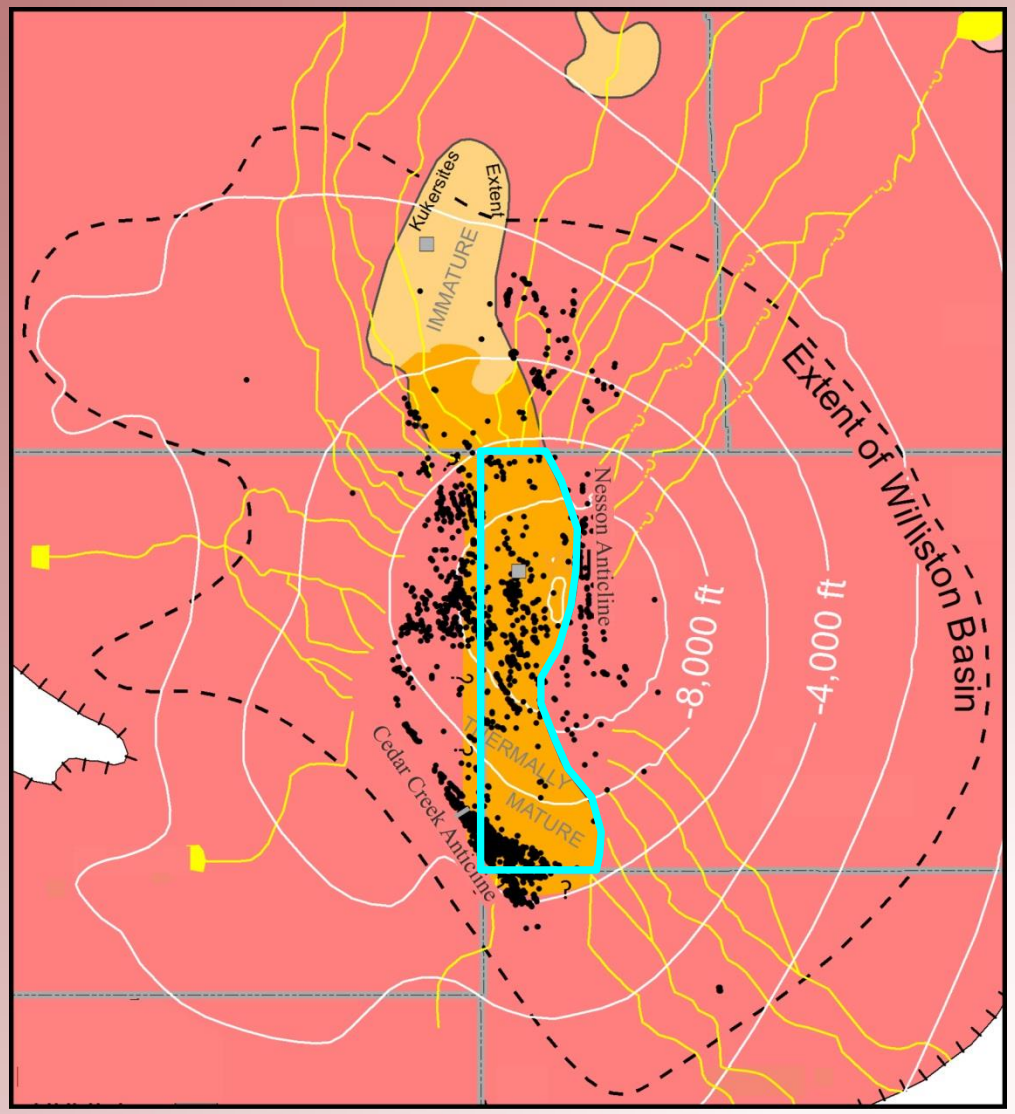
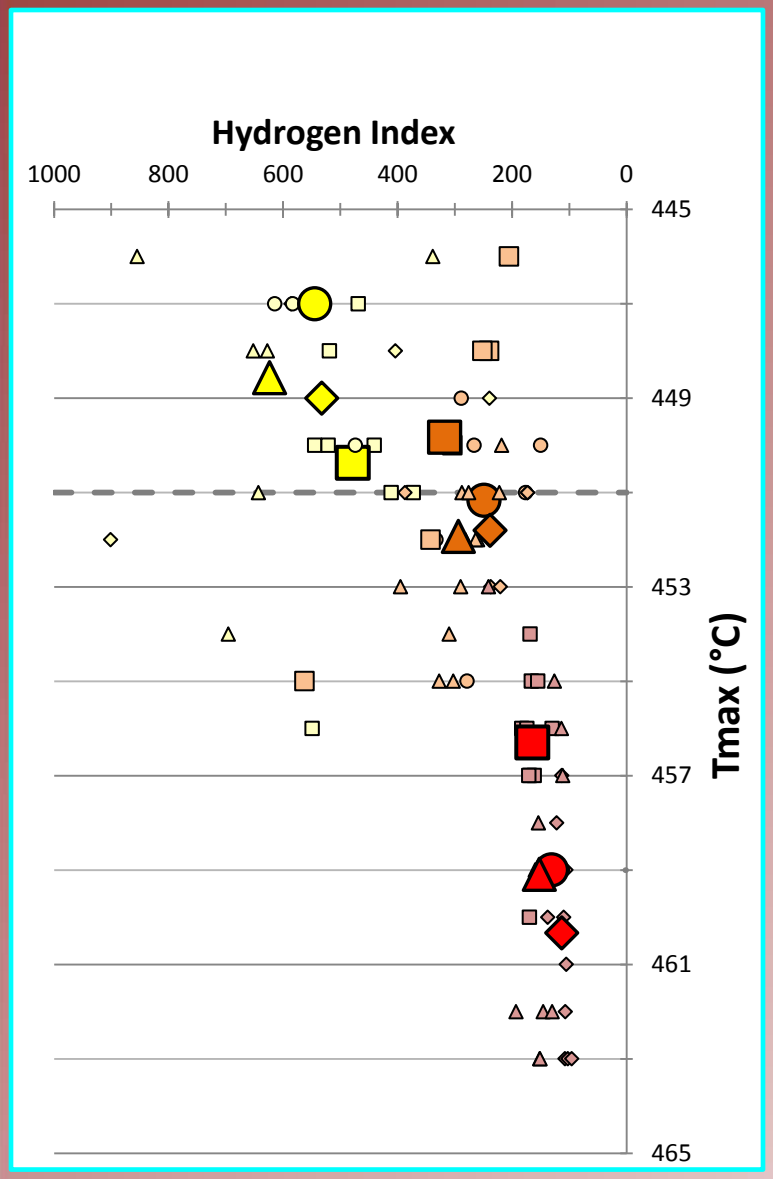
Thermal Oil and Gas Generation

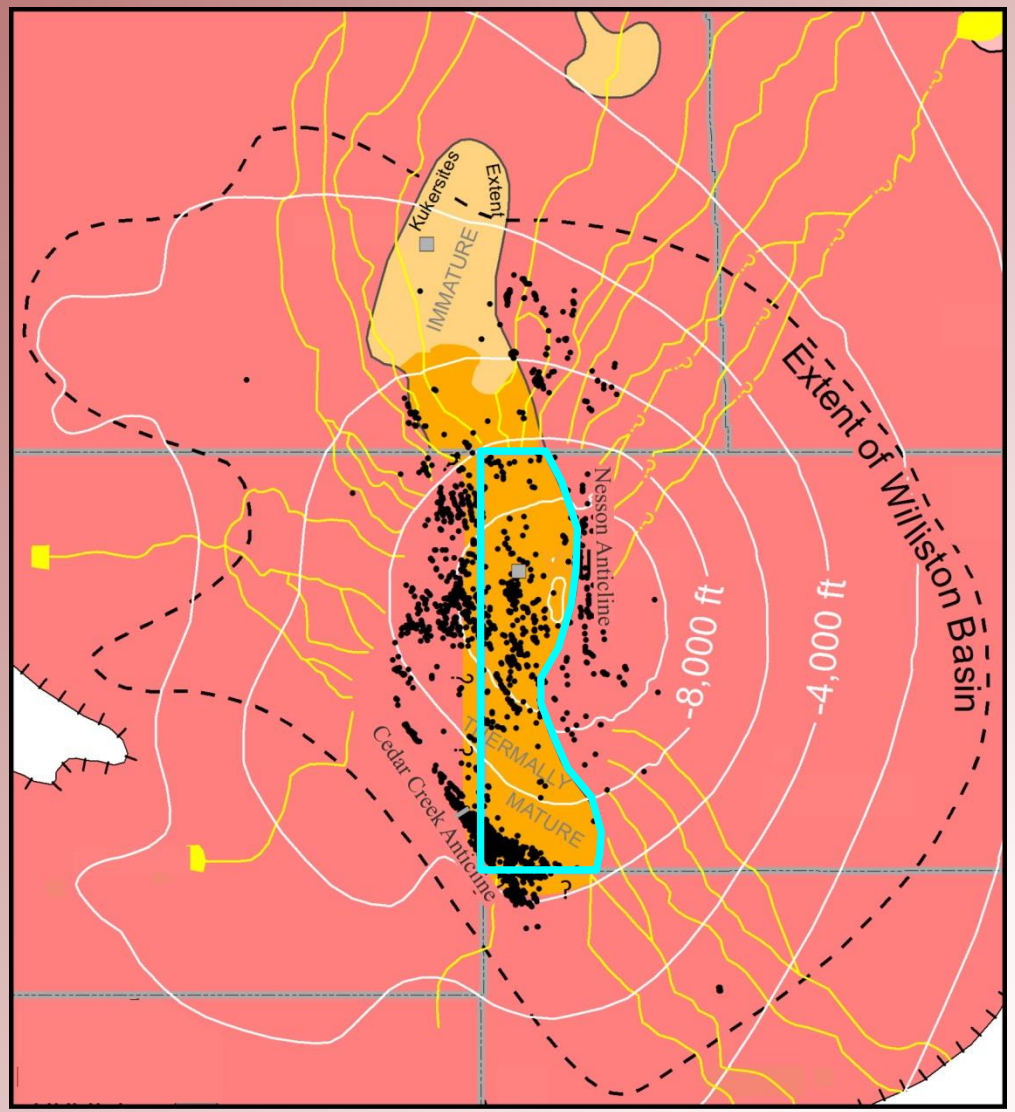




Variable heat flow in western North Dakota = source rock maturation does not perfectly trend with depth

Thermal Oil and Gas Generation





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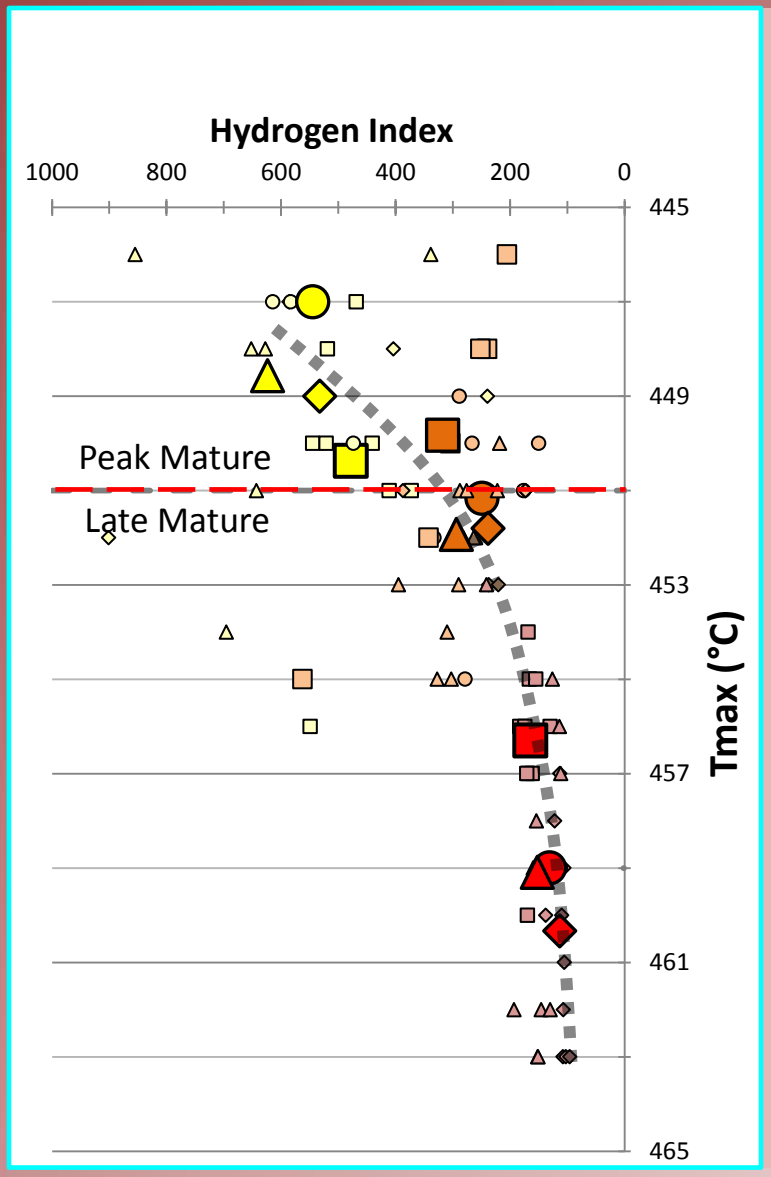
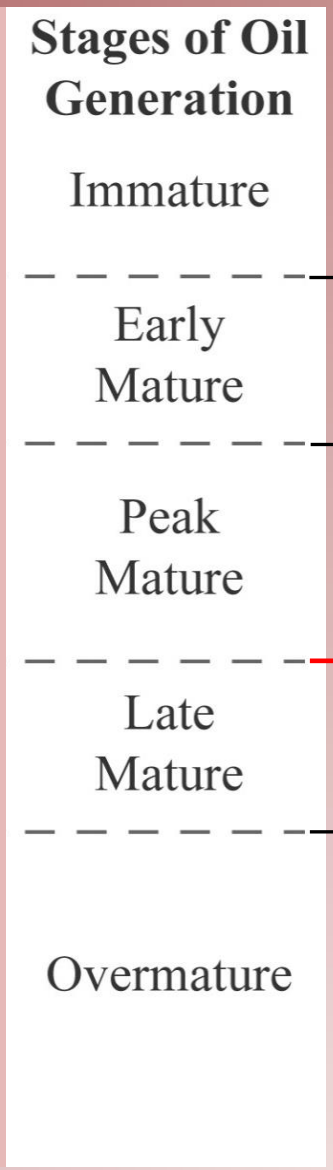
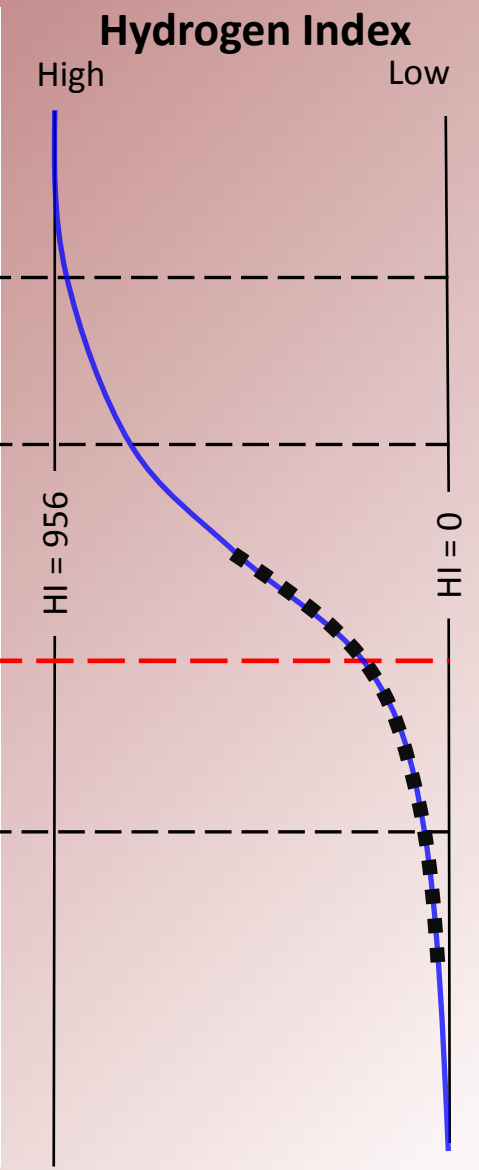
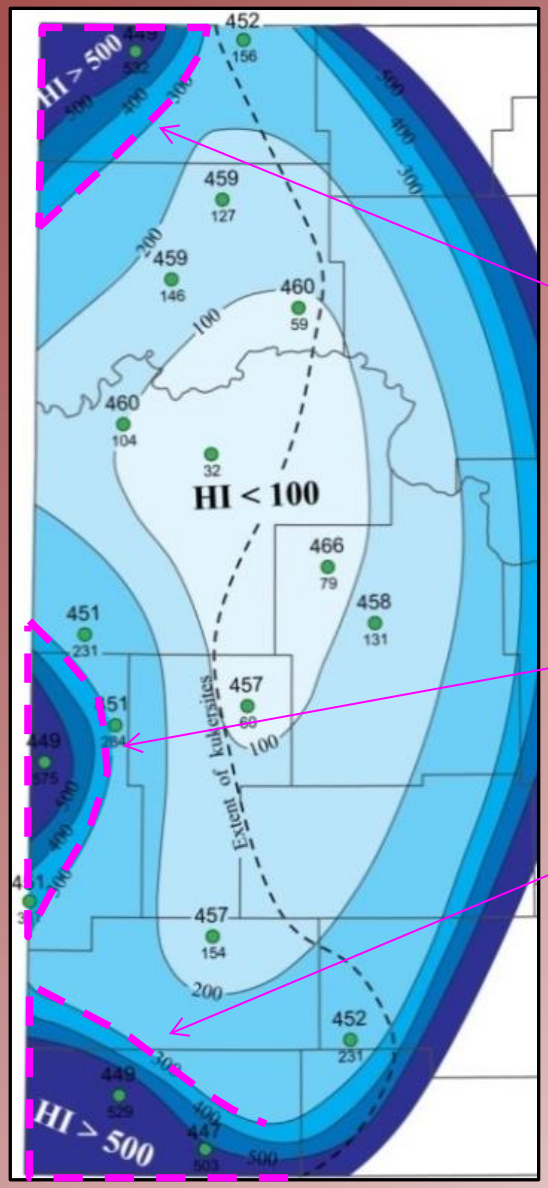
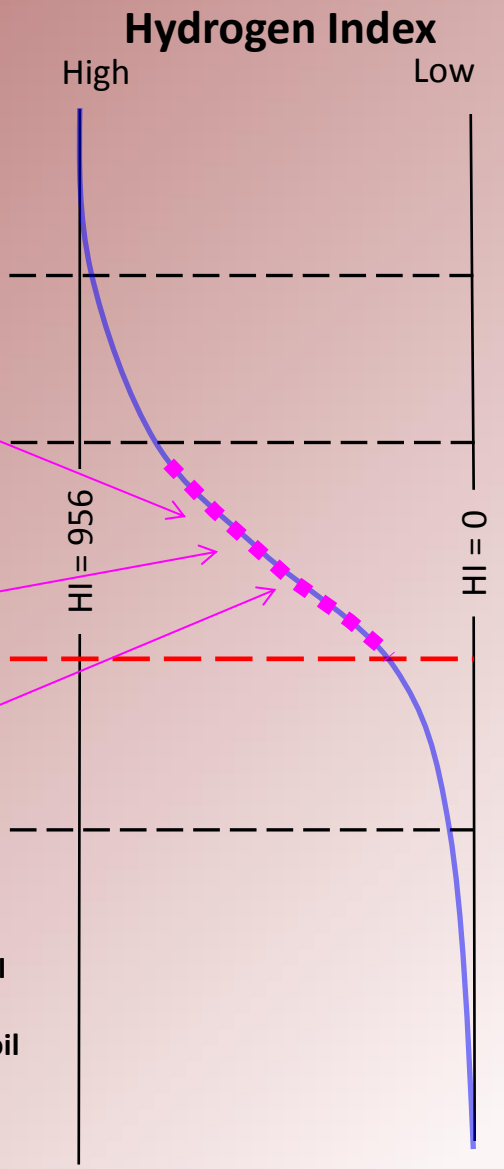






Thermal Oil and Gas Generation





Observation: abrupt decrease in kukersite HI

Interpretation: intense oil generation

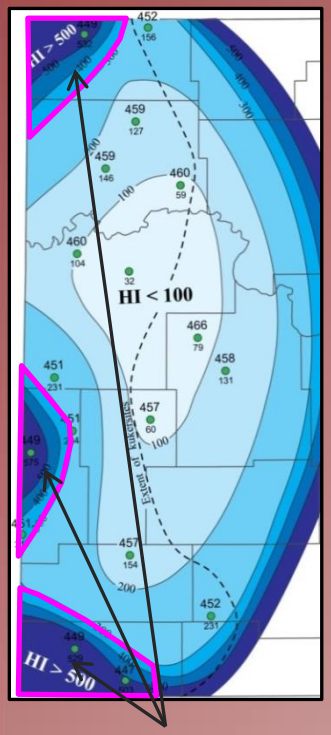
= peak mature oil generation

Thermal Oil and Gas Generation

Source Bed Maturity

Generated Hydrocarbon Thermal maturity

Average kukersite HI

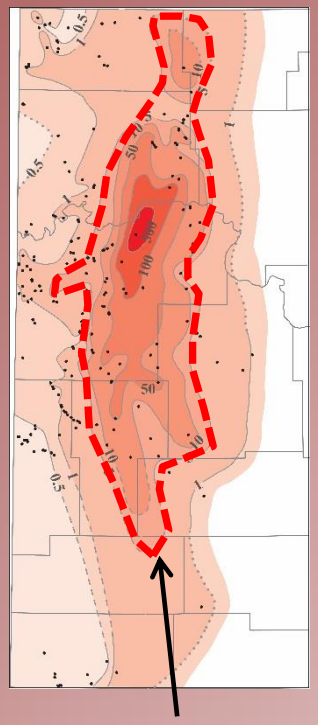


Observation: abrupt decrease in kukersite HI

Interpretation: intense oil generation

= peak mature

"C" & "D" zone GOR

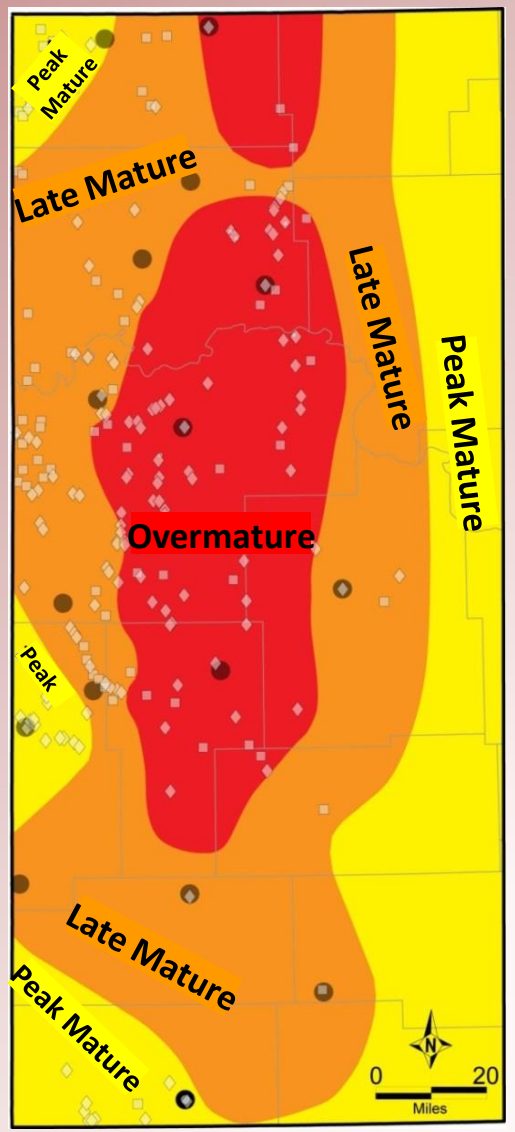


Observation: Rapid increase in produced hydrocarbon GOR values

Interpretation: generated oil is converting to gas

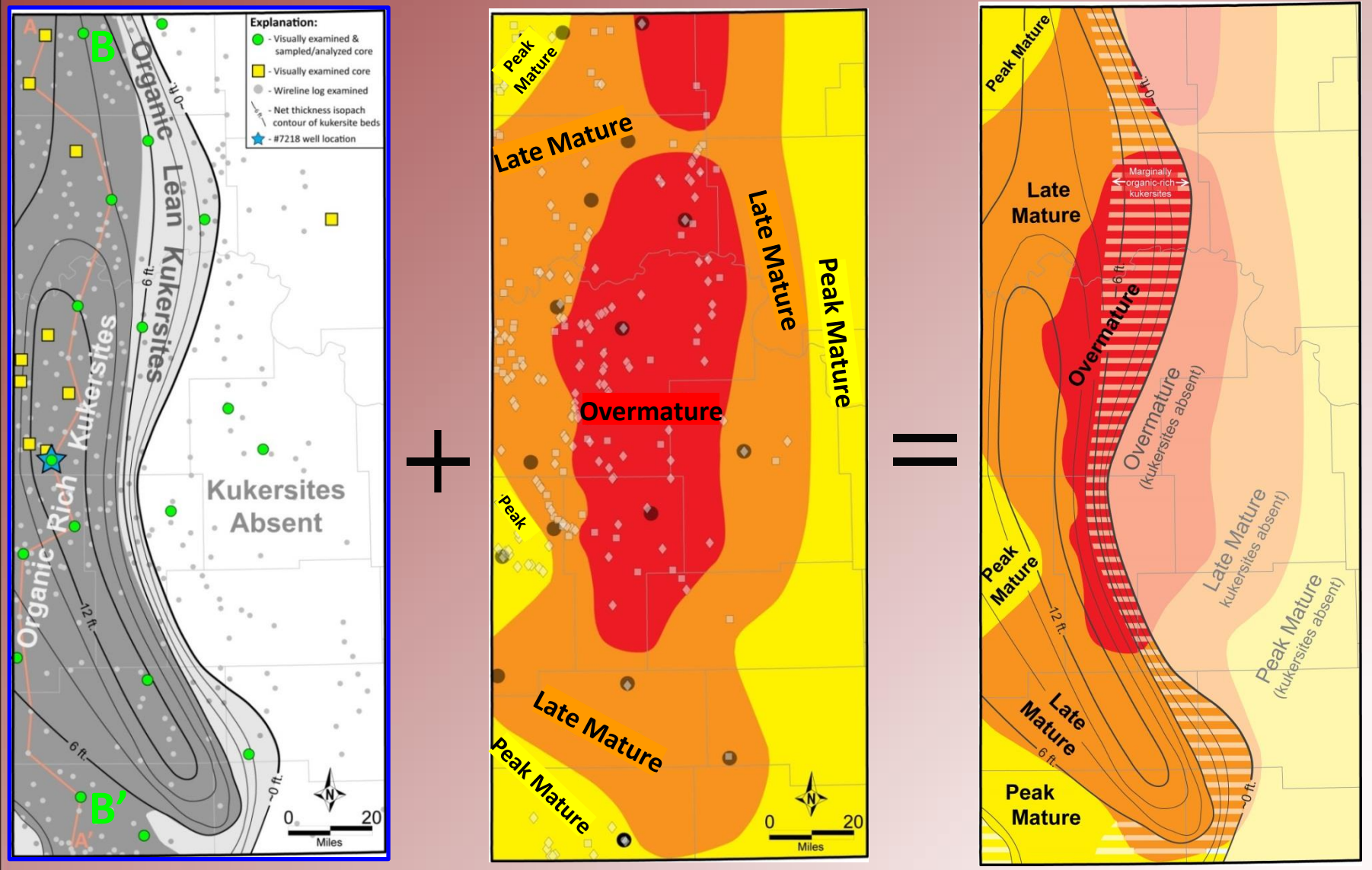
= over mature

"C" & "D" Zone API Oil Gravity



- "C" & "D" zone reservoirs are proximal to kukersite source beds

Thermal Oil and Gas Generation



Generated Hydrocarbon Volume

Equation 1. (slightly modified from Schmoker, 1994)

$$\frac{TOC_o}{100} \times \rho \times A \times T \times \left[HI_o - HI_{pd}\right] \times \frac{1}{C}$$

mass of original organic carbon (grams of TOC)			HC generated per gram TOC	conversion to bbls oil
(wt. %)	g/cm^3	cm^3	mg HC/g TOC	bbls/mg

TOC_o = original total organic carbon
ρ = formation density
A = area of source rock unit
T = average source rock net thickness
HI_o = original hydrogen index
HI_{pd} = present day hydrogen index
*C = 1.3514 x 10^8 mg/barrel of 35° API oil
HC = hydrocarbons

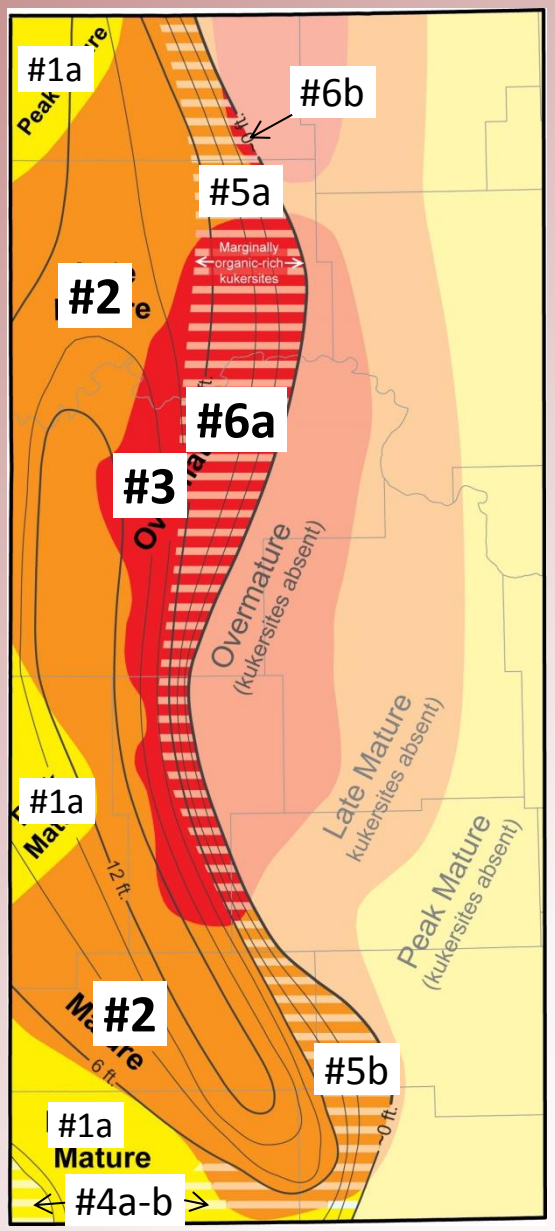
*C was calculated assuming 850 kg/m^3 = 35° API oil density, and 1 bbl oil = 6.2898 m^3

Osadetz and Snowdon (1995)

Table 1A.

Fig. X Area #	A (cm2 x 10E-10)	T (cm)	TOCo	HIo	HIpd	ρ (g/cm3)	Gen. HC (BBOE)
#1a-c	3,807	213	10	956	544	2.46	6.08
#2	12,087	290	10	956	190	2.46	48.88
#3	1,950	290	6	956	60	2.46	5.53
#4a-b	484	76	2	750	520	2.73	0.03
#5a-b	2,435	107	2	750	166	2.73	0.61
#6a-b	3,735	122	2	750	45	2.73	1.30
						Total	*62.44*

Red River Kukersite with HIo = 956 would have **generated ~~62 billion barrels~~ of oil equivalent**



Generated Hydrocarbon Volume

Equation 1. (slightly modified from Schmoker, 1994)

mass of original organic carbon (grams of TOC)				HC generated per gram TOC	conversion to bbls oil
$\frac{TOC_o}{100}$	$\times \rho \times$	$A \times T$	$\times$	$[HI_o - HI_{pd}]$	$\times \frac{1}{C}$
(wt. %)	g/cm^3	cm^3		mg HC/g TOC	bbls/mg

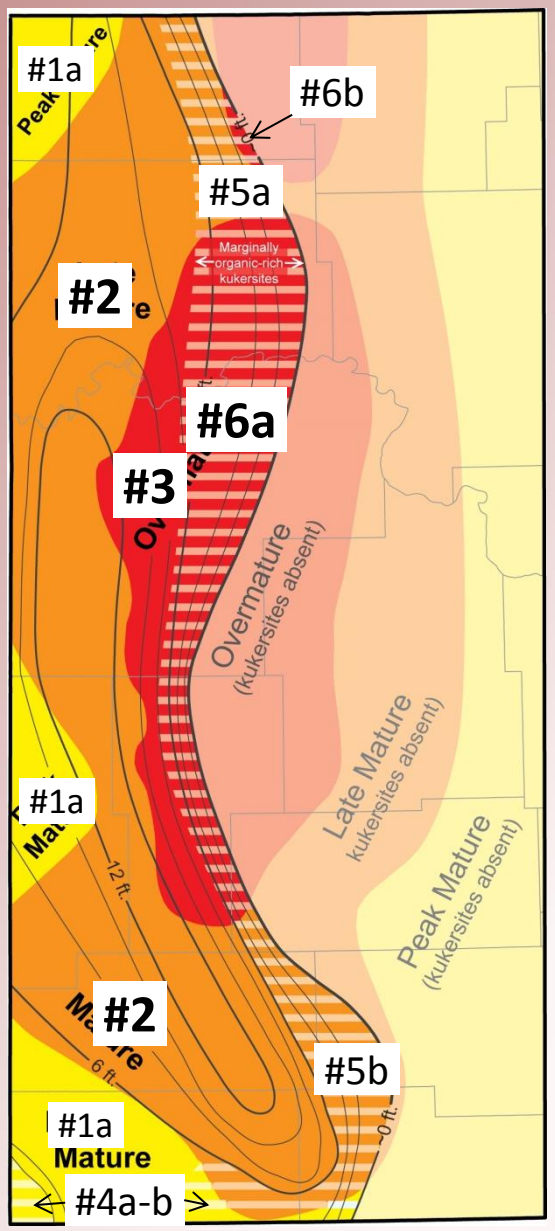
TOC_o = original total organic carbon
ρ = formation density
A = area of source rock unit
T = average source rock net thickness
HI_o = original hydrogen index
HI_{pd} = present day hydrogen index
*C = 1.3514×10^8 mg/barrel of 35° API oil
HC = hydrocarbons

*C was calculated assuming 850 kg/m^3 = 35° API oil density, and 1 bbl oil = 6.2898 m^3

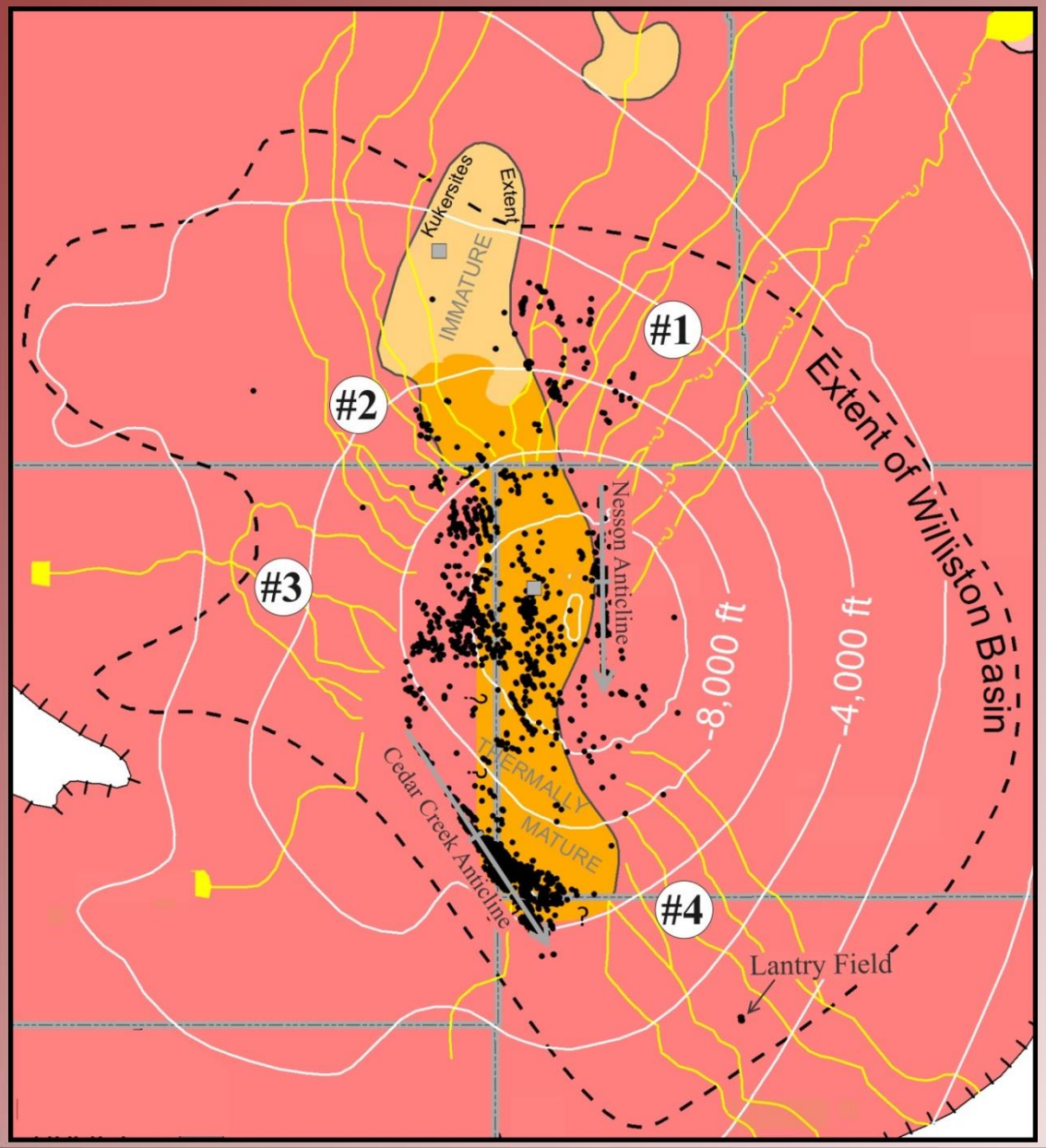
Table 1B.

Fig. X Area #	A (cm2 x 10E-10)	T (cm)	TOCo	HIo	HIpd	ρ (g/cm3)	Gen. HC (BBOE)
#1a-c	3,807	213	5.9	750	544	2.46	1.79
#2	12,087	290	5.9	750	190	2.46	21.08
#3	1,950	290	3.8	750	60	2.46	2.70
#4a-b	484	76	1.6	600	520	2.73	0.01
#5a-b	2,435	107	1.6	600	166	2.73	0.37
#6a-b	3,735	122	1.6	600	45	2.73	0.82
						Total	*26.77*

Red River Kukersite with HIo = 750 would have **generated ~27 billion barrels of oil equivalent**



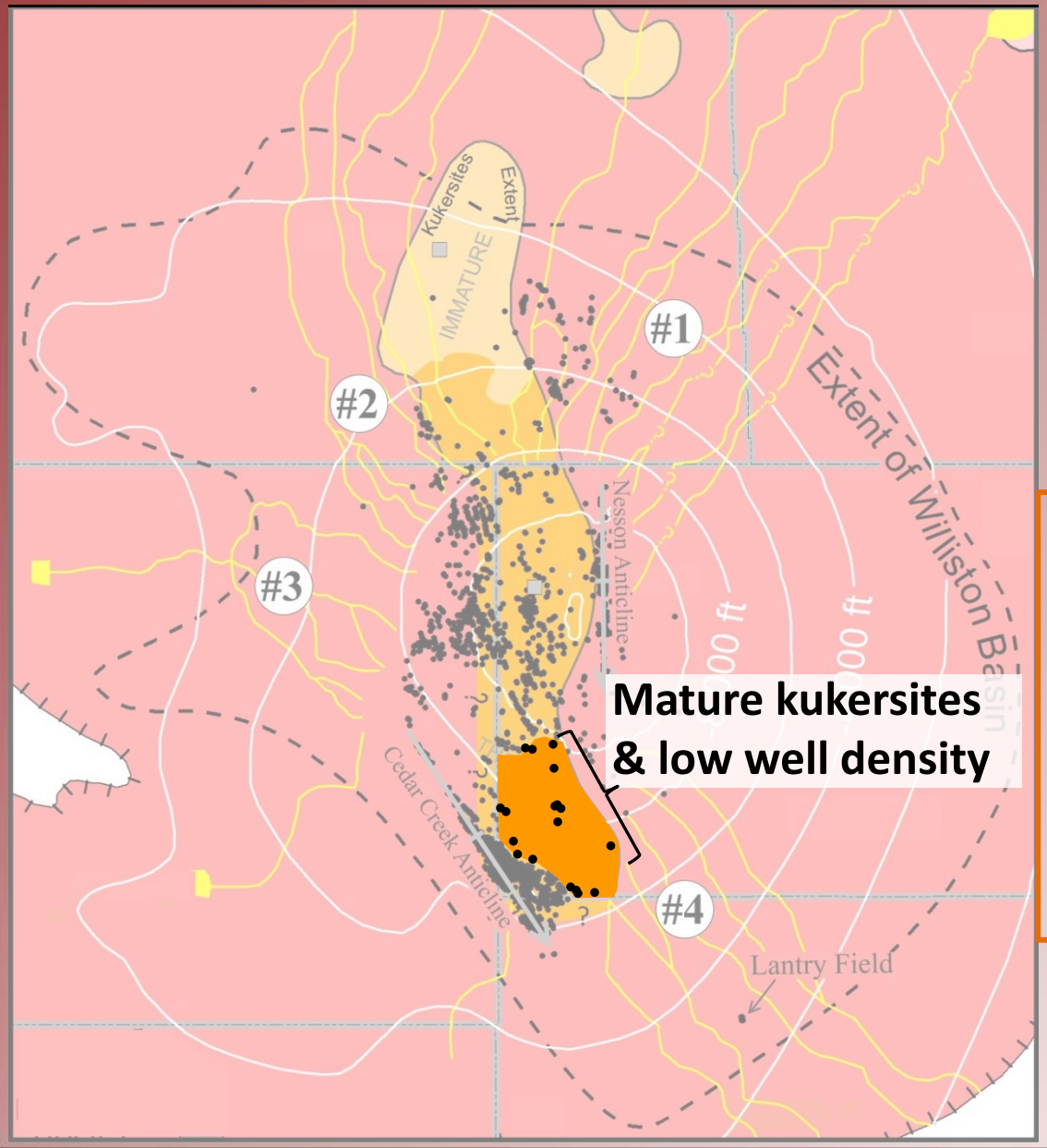
Implications for future Red River hydrocarbon exploration



- Red River Kukersites have generated approximately **27 to 62 billion barrels of oil equivalent (BOE)** beneath North Dakota's portion of the Williston Basin.
- Thermally mature Red River kukersites also appear to extend into Saskatchewan, South Dakota, and Montana.
- Cumulative Red River production across the Williston basin is ~0.62 billion BOE, which is only 1-2% of the estimated hydrocarbon generation volume within western North Dakota.

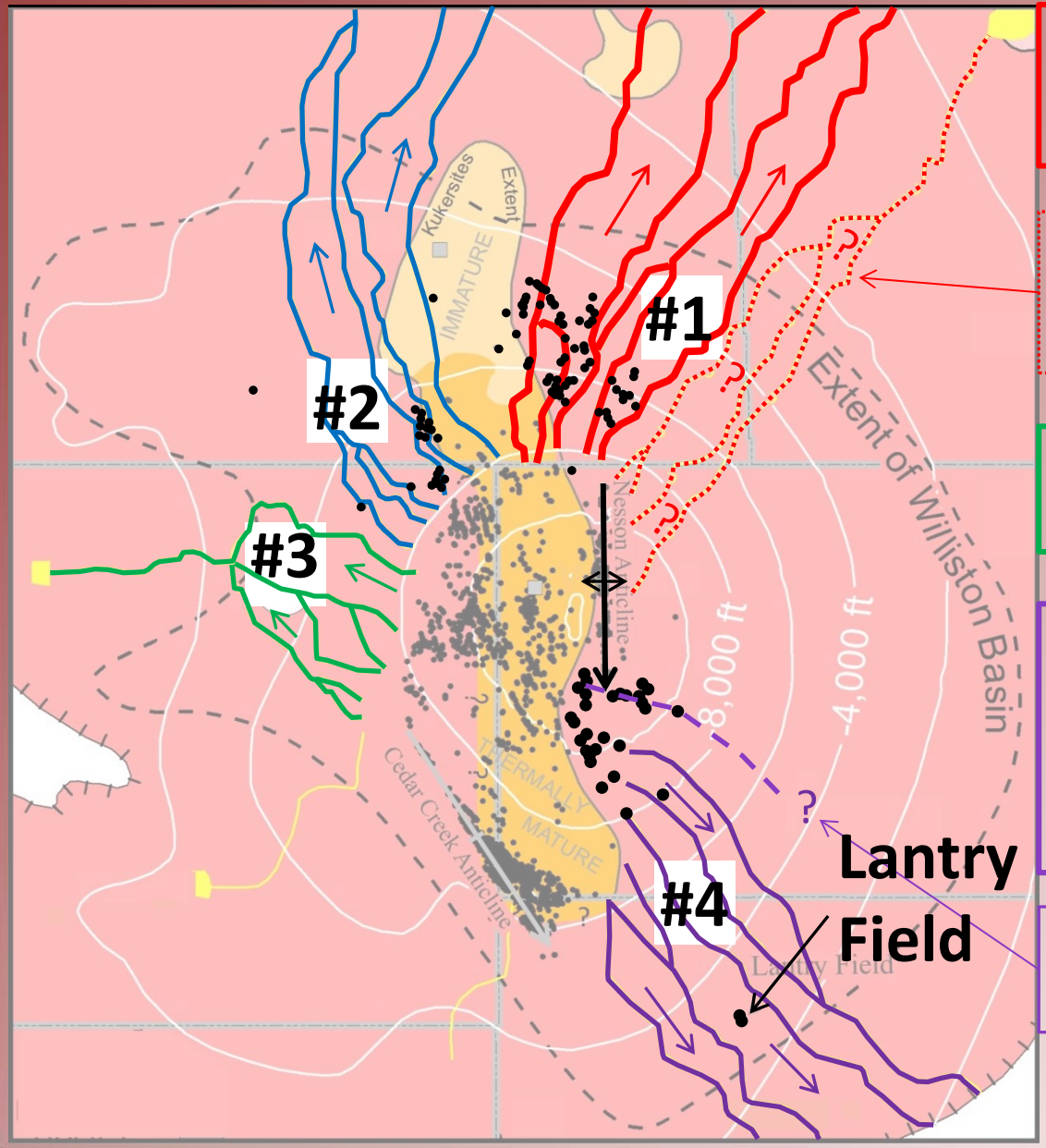
Yellow lines = hydrocarbon migration pathways modelled by Khan et al. (2005).

Implications for future Red River hydrocarbon exploration



The majority of Red River production in western North Dakota overlaps with the extent of thermally mature Red River kukersites. Southwestern North Dakota contains an area (located northeast of the Cedar Creek Anticline) which contains a substantial quantity of thermally mature kukersites but a very low overall well density. Despite the low well density, there are a handful of very production vertical Red River productive wells. The Red River Formation appears to be very under explored/developed with southwestern North Dakota.

Implications for future Red River hydrocarbon exploration



Migration trend #1 mostly correlates with a substantial amount of Red River production in southern Saskatchewan located beyond the extent of thermally mature kukersites

Migration pathways (dotted red lines) intersect the Nesson Anticline before intersecting thermally mature kukersites. The Nesson appears to form a barrier to Red River hydrocarbon migration

Migration trends #2 and #3 correlate with a few outlining Red River Producers and my hold future exploration potential

Migration trend #4 indicates migrated Red River production south of the Nesson Anticline, and also correlates with the Lantry Field of central South Dakota. While fresh water flushing along the southern margins of the basin may be an issue, there appears to be additional exploration potential along trend #4.

Additional migration pathway/s (dashed purple line) located just beyond the southern extent of the Nesson Anticline

Conclusions:

- Ten distinct kukersites (petroleum source beds) are present within the “D” zone of the Ordovician Red River Formation that can be correlated using core and wireline logs.
- Kukersites in the Red River “D” zone are continuously present beneath approximately the western quarter of North Dakota, extending 20-40 miles east of the Montana border.
- Red River kukersites have generated approximately 27 to 62 BBOE within North Dakota’s portion of the Williston Basin.
- Cumulative, basin-wide Red River production accounts for only 1-2% of the estimated generated volume and suggests a substantial amount of petroleum resource has yet to be discovered and developed in the Red River Formation.
- Thermally mature Red River kukersites appear to extend into eastern Montana and northwestern South Dakota, where they have yet to be thoroughly examined.

Thank you for your time!

Questions?

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North Dakota Geological Survey
www.dmr.nd.gov/ndgs

Kukersite Thermal Maturity