New Insights into the Bakken Play: What Factors Control Production?*

Cosima Theloy[1] and Stephen Sonnenberg[1]

Search and Discovery Article #80332 (2013)**
Posted October 31, 2013

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Colorado School of Mines, Golden, CO (ctheloy@mines.edu)

Abstract

A great variety of factors can influence production, and it is often difficult to discriminate how significant the impact of a single factor is. The unconventional nature of the Bakken tight oil play requires considering both geological and technological aspects, as completion designs evolved at a rapid pace over recent years. Based on an integrated and correlative approach, this study aims to understand why certain areas in the Bakken play are considerably more productive than others, and to identify the responsible factors.

The Upper Devonian to Lower Mississippian Bakken Formation in the Williston Basin is a world-class petroleum system and represents the most prolific tight oil play known to date. The source rocks in this unconventional system are the highly organic-rich Lower and Upper Bakken Shale members. The silty, dolomitic Middle Bakken member, sandwiched between the shales, and Upper Three Forks member, underlying the Bakken Formation are the main target horizons for production.

The Bakken is a technology-driven play, and a clear trend of increasing production rates over time is evident as drilling techniques and the completion design of wells are progressively becoming more sophisticated. As the latest, since 2010 the majority of operators employ massive hydraulic fracturing treatments, with up to 40 stages and millions of pounds of proppant. However, numerous older wells outperform younger wells despite technological advancements, suggesting that geological factors have a larger impact on production than the completion design.

Geological factors influencing productivity can reach from reservoir quality and thickness, over structural and stratigraphic framework, rock-mechanical properties, natural fractures, to pore-overpressure distribution and organic geochemical parameters. The interplay of hydrocarbon-generation potential and maturity results in tremendous overpressuring and creation of fracture permeability and secondary porosity. A combination of overpressure- and buoyancy-driven migration of hydrocarbons into updip-located traps can result in large-scale accumulations, as for example, Sanish-Parshall and Elm Coulee.

The comprehensive and integrated analysis of technological and geological data allowed identification of different Bakken play types, which are productive for different reasons. The knowledge of where and why sweet-spot and low-productivity areas occur is invaluable for both current development and future exploration.

Selected References

Alexandre, C.S., 2011, Reservoir characterization and petrology of the Bakken Formation, Elm Coulee Field, Richland County, MT, M.S. Thesis, Colorado School of Mines, 159 p.

Cumella, S.P., and J. Scheevel, 2005, The influence of stratigraphy and rock mechanics on Mesaverde gas distribution, Piceance Basin, Colorado, *in* S.P. Cumella, K.W. Shanley, and W.K. Camp, (eds.), Understanding, exploring, and developing tight-gas sands: AAPG Heberg Series, v. 3, p. 137-155.

Grau, A., and R. Sterling, 2011, Characterization of the Bakken System of the Williston Basin from pores to production; The power of a source rock/unconventional reservoir couplet: AAPG Datapages/Search and Discovery Article #40847 (2011). Web accessed October 22, 2012. http://www.searchanddiscovery.com/documents/2011/40847grau/ndx_grau.pdf

New Insights into the Bakken Play: What Factors Control Production?

Cosima Theloy and Stephen A. Sonnenberg

Department of Geology and Geological Engineering

Colorado School of Mines

ctheloy@mines.edu

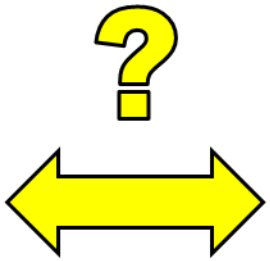
AAPG Annual Convention and Exhibition, Pittsburgh, 5/21/2013

Outline

- **Objectives**
- **Data**
- **Production Analysis**
- **Technological Factors**
- **Geological Factors**
- **Integrating Geology and Technology – Bakken Play Types**
- **Conclusions**

What factors influence productivity?

GEOLOGY	TECHNOLOGY
• Reservoir quality	• Well type
• Reservoir thickness	• Lateral length
• Oil & water saturations	• No. of hyd. fracturing stages
• HC generation potential	• Proppant volume & type
• Maturity	• Proppant loading
• Overpressure	• Fluid volume & type
• Structure and lineaments	• Fluid / proppant ratio
• Regional stress regime	• Injection rate
• Mechanical stratigraphy	• Treatment pressure
• Natural fractures	• Choke size
• Migration	• Plug & perf; sliding sleeves
• Traps	• Well spacing



Objectives (1)

- **Identify sweet spot and low-productivity** areas and analyze their causes.

- Evaluate the **effect of improving technology** and differences by operators on production.

- Develop a method to **distinguish between completion-related** enhancement of production **versus geological-induced variations in productivity**.

- Investigate the relationship between **hydrocarbon generation**, observed **pore overpressure** in the Middle Bakken and Three Forks.

- Create a **pressure map** for the Middle Bakken based on high quality BHP and DFIT data without using older, unreliable DST data.

Objectives (2)

- Determine the **role of natural fractures** in the Bakken play.
- Describe the impact of **facies variations** on rock mechanical properties and **fracturing behavior**.
- Elicit whether **migration of hydrocarbons is a significant process** in the Bakken petroleum system, in particular, for the U.S. portion of the basin.
- Examine the **importance of traps** within the Bakken play and what impact their presence or absence has on hydrocarbon accumulations.

Data

Production and Completion: General production data from all Bakken and Three Forks wells; detailed production and completion information from 1095 wells

EUR data: 2246 Bakken wells (additional data for Three Forks)

Pressure: > 90 quality-controlled Middle Bakken data points (additional data for Three Forks)

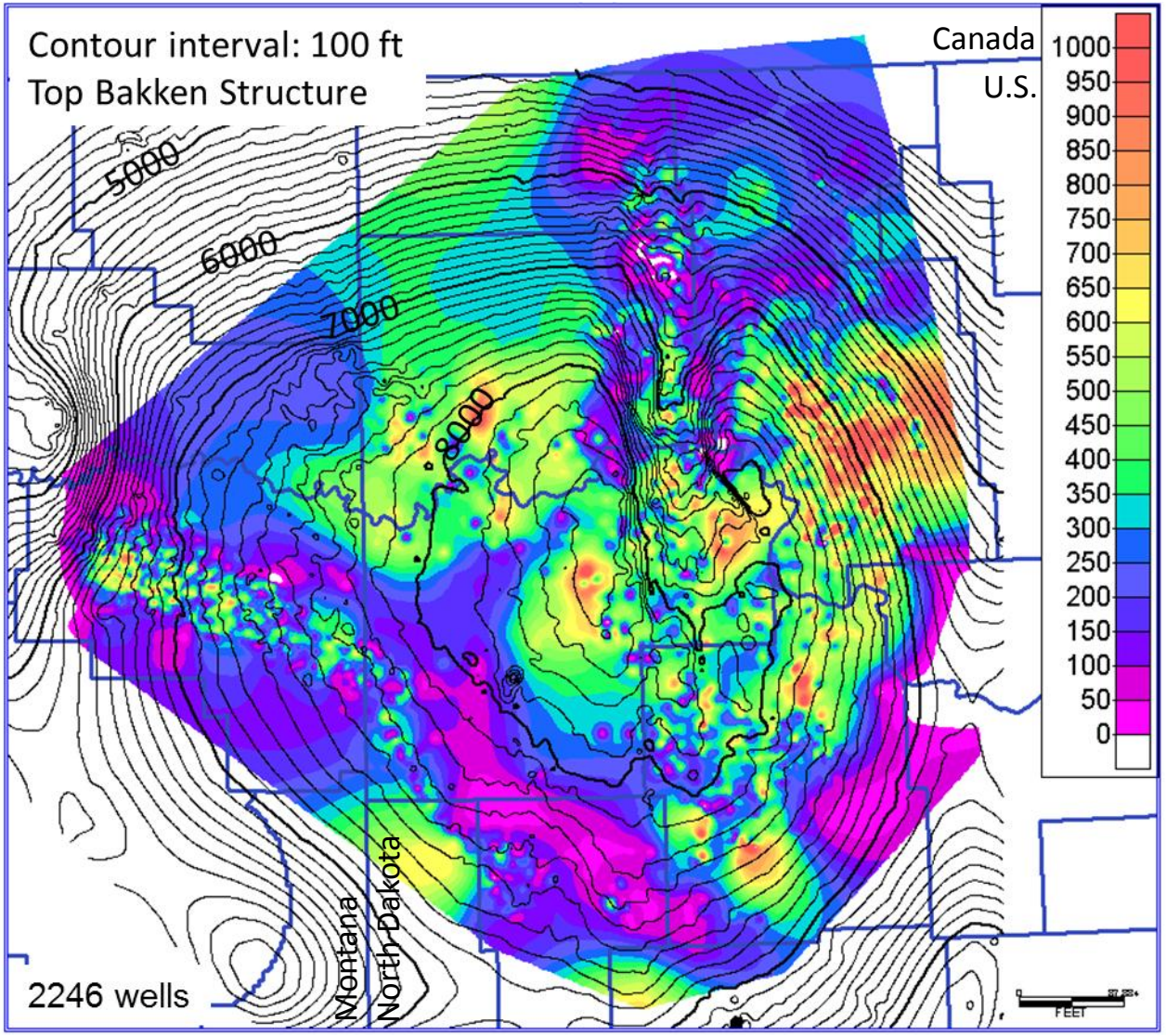
Reservoir Rock: Facies and facies variations, core analysis data, thickness, mineralogical data (QEMSCAN, XRD, thin sections)

Rock Mechanics: Static rock properties (EERC dataset) from 28 Middle Bakken & 20 Three Forks samples in ND; dynamic properties from sonic logs

Source Rock: USGS dataset (> 500 wells): source rock analysis data from Upper & Lower Bakken Shales

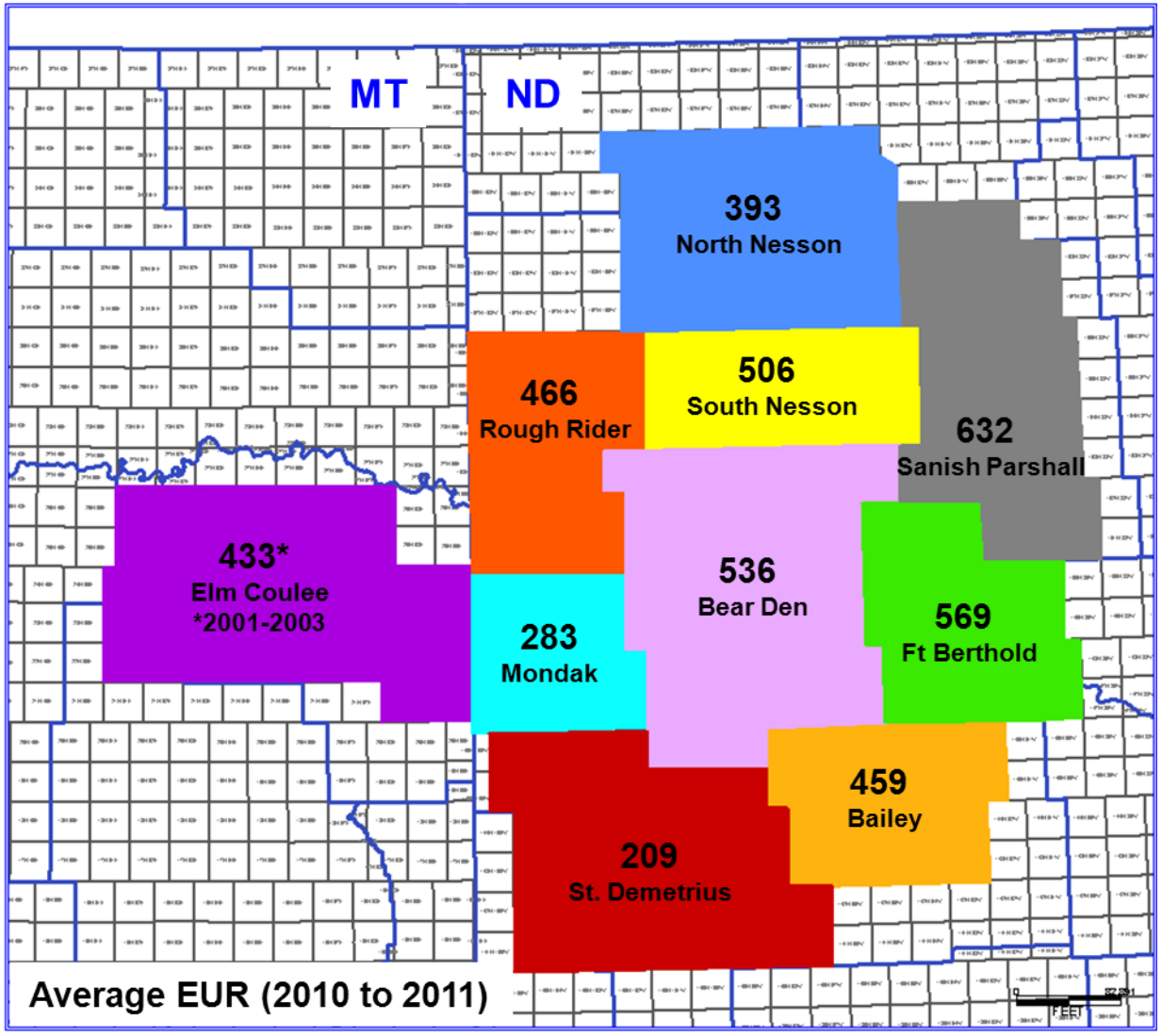
Geomark dataset: biomarker distributions from 214 oil samples and 95 source-rock extract samples

Bakken EUR (Mbbl)



Note areas of low production along the flanks of the Nesson anticline

Bakken EUR by Area

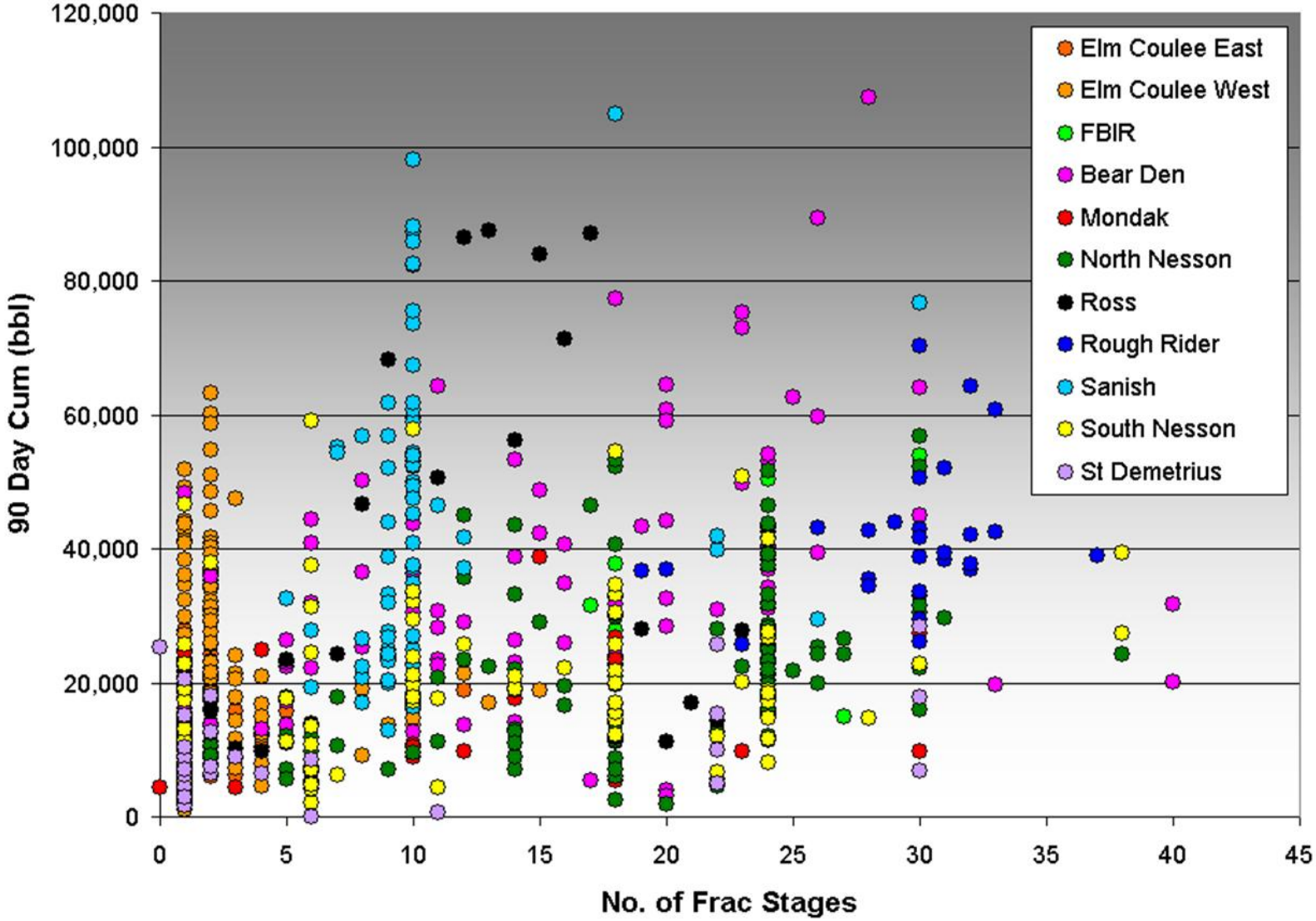


Subdivision of Bakken Play into 10 areas based on Township boundaries

Significant differences in productivity across basin

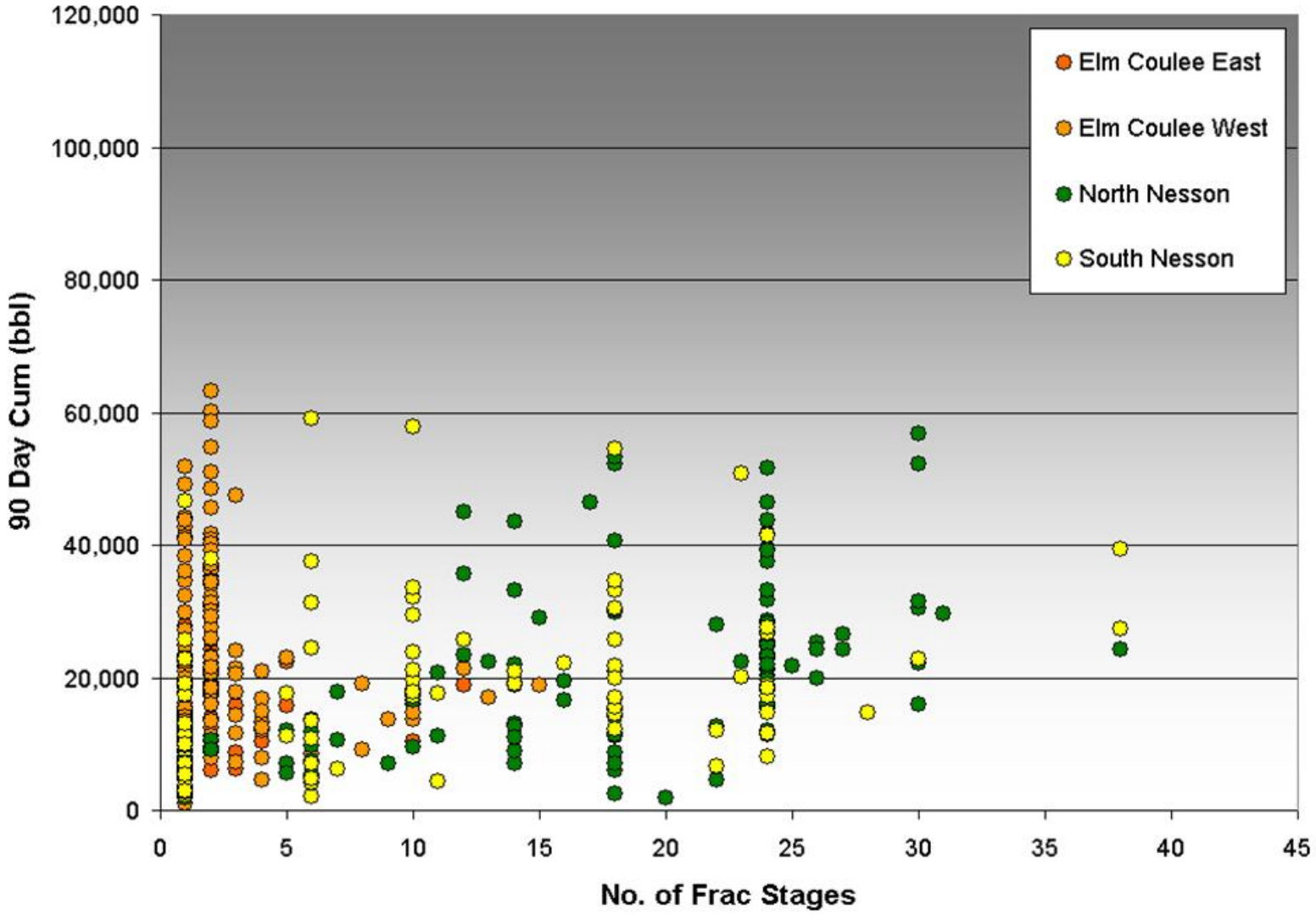
EUR (Mbbl)

Hydraulic Fracturing Stages



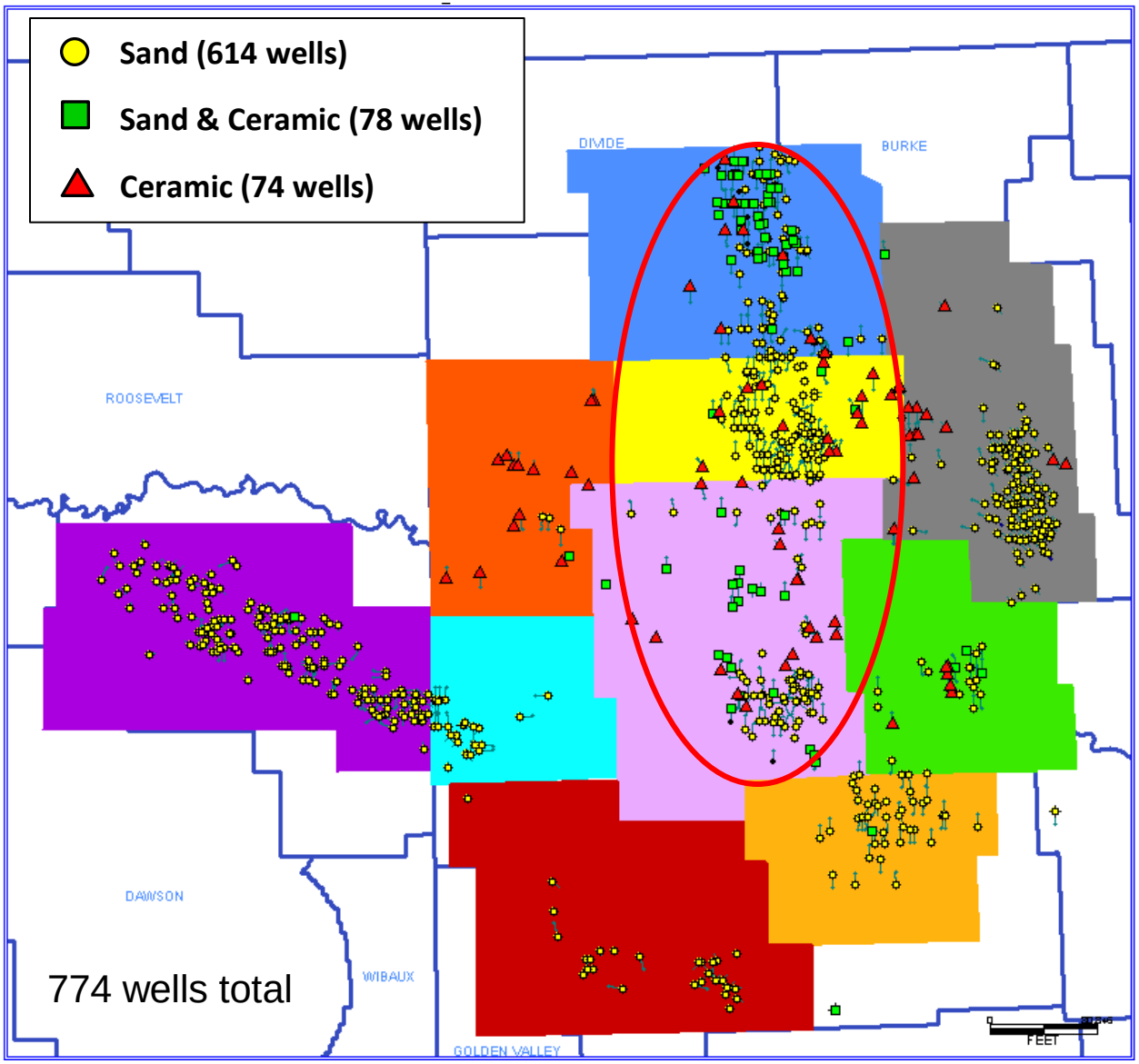
⇨ Plot inconclusive

Hydraulic Fracturing Stages



Sophisticated completions in North and South Nesson area do not yield higher production than ‘Hail Mary fracs’ in Elm Coulee

Effect of Proppant Choice



"Sand" =

Sand only

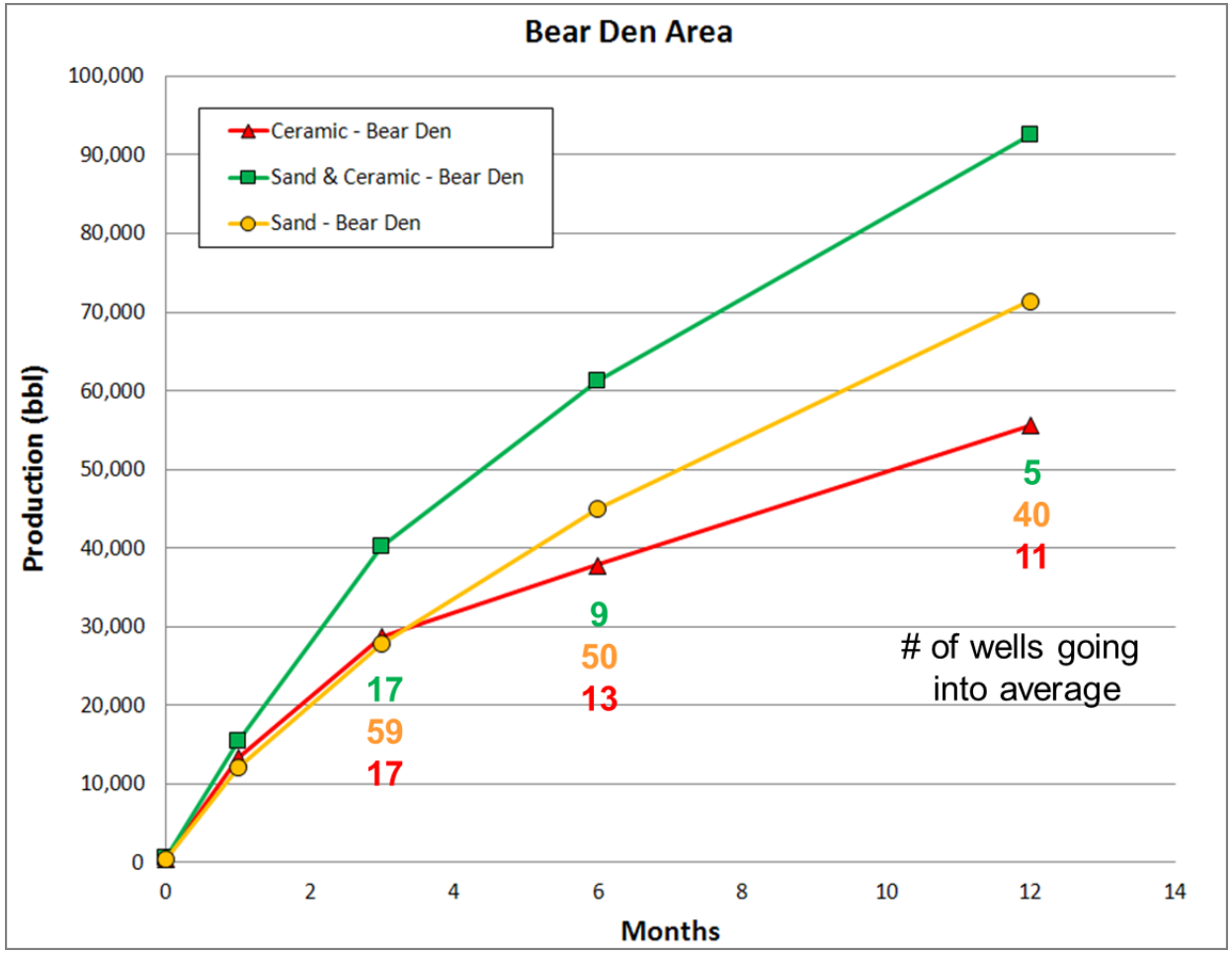
"Sand and Ceramic" =

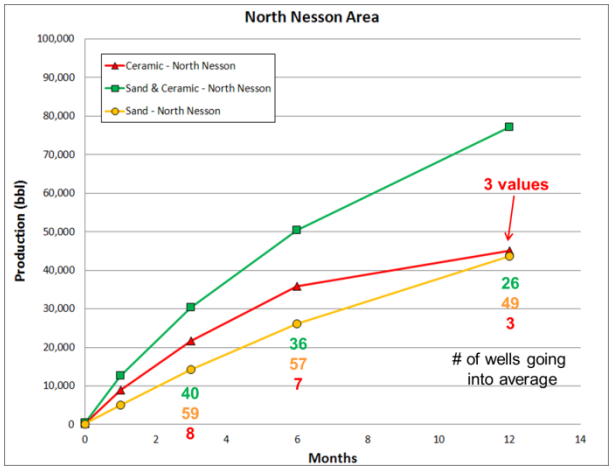
about 2/3 Sand and 1/3 Ceramic

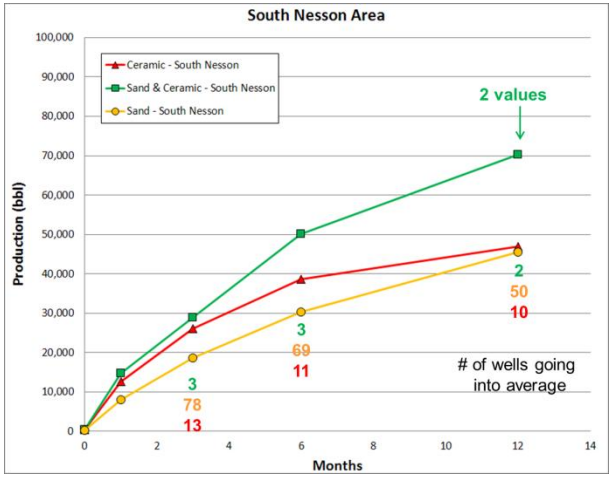
"Ceramic" =

at least 2/3 Ceramic and < 1/3 Sand

Proppant Comparison by Area

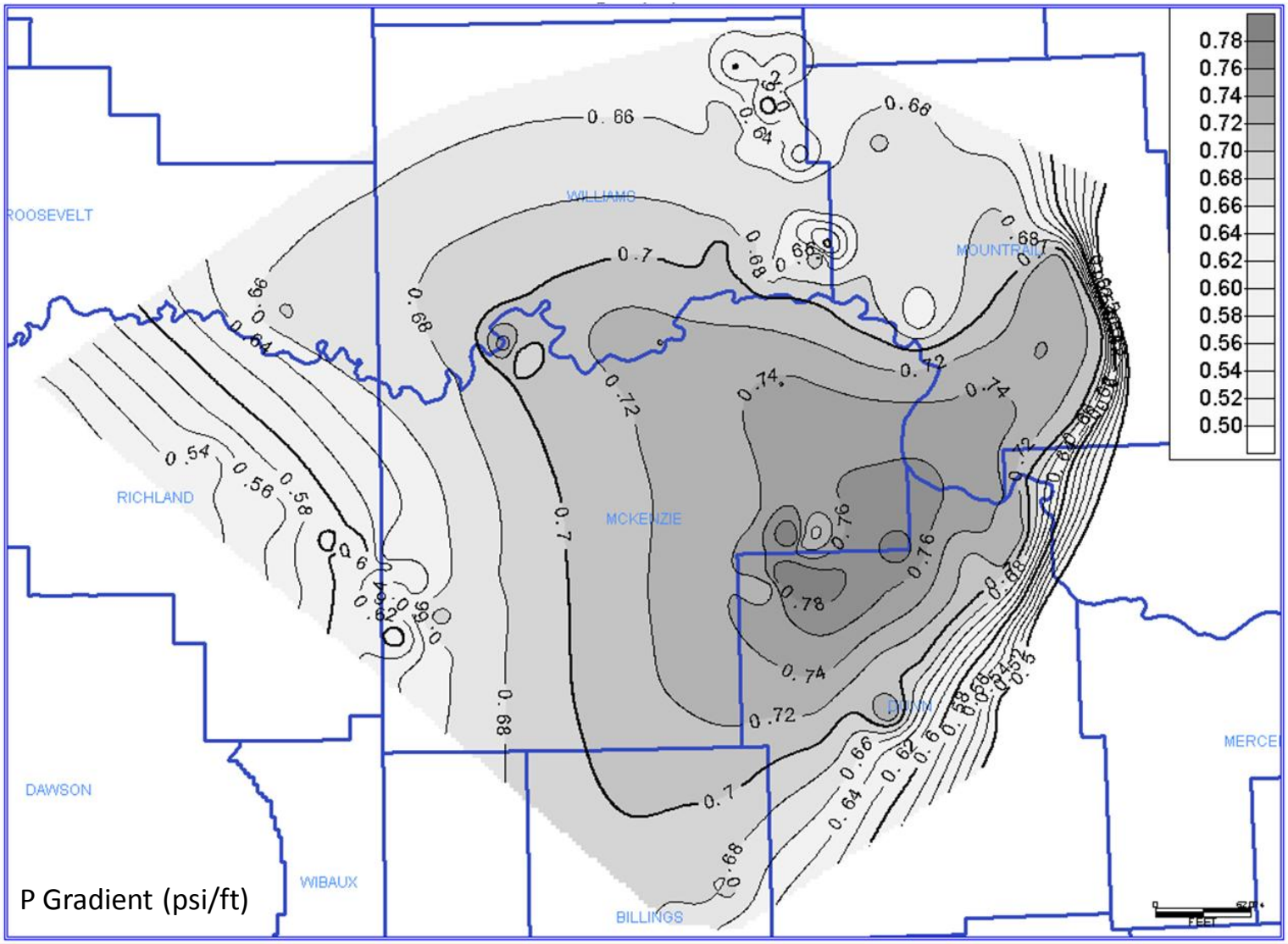






Despite ceramic being a superior proppant, a mixture of about **2/3 sand and 1/3 ceramic** proppants yielded better production results than either sand or ceramic alone (based on this limited dataset)

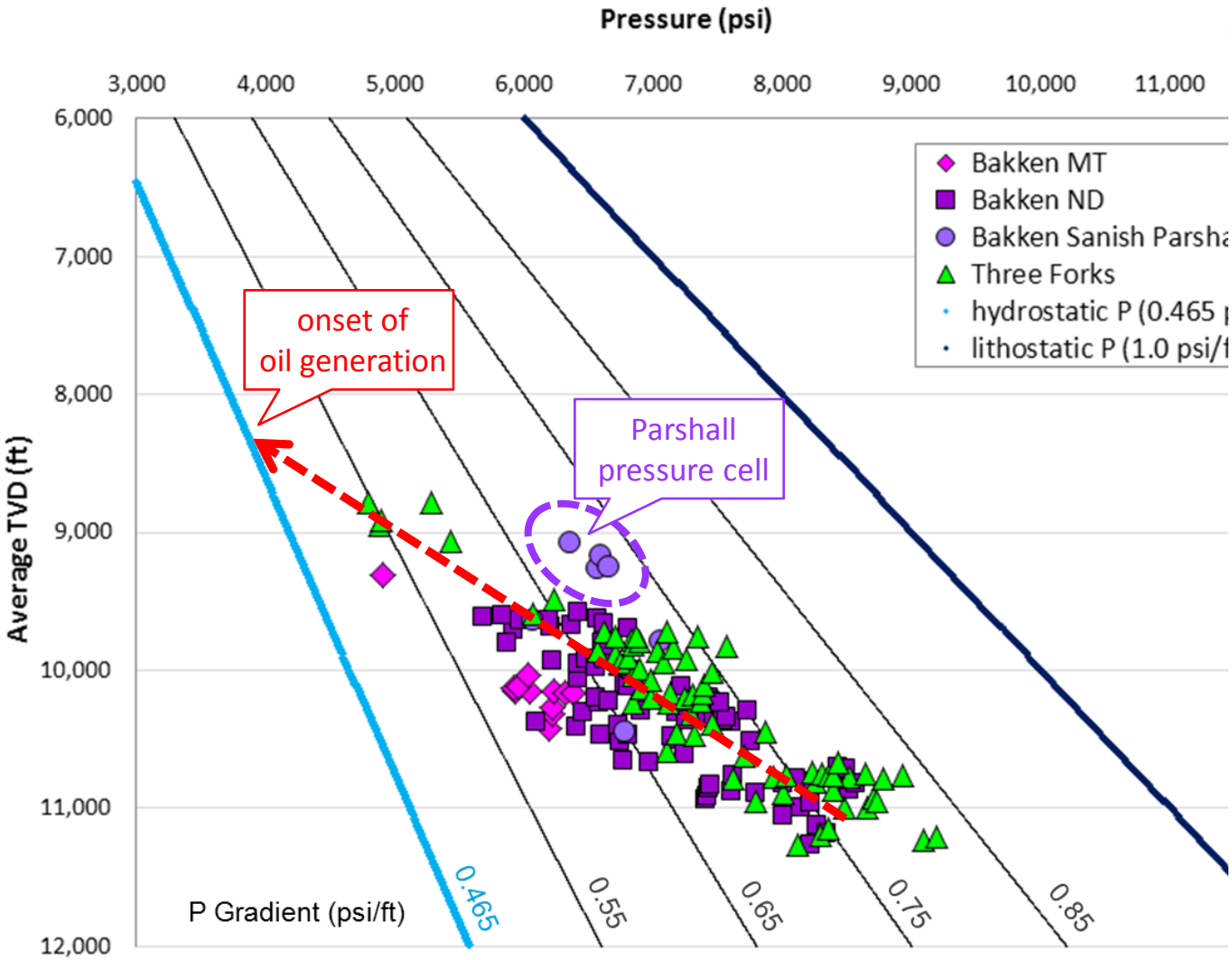
Pressure (Middle Bakken)

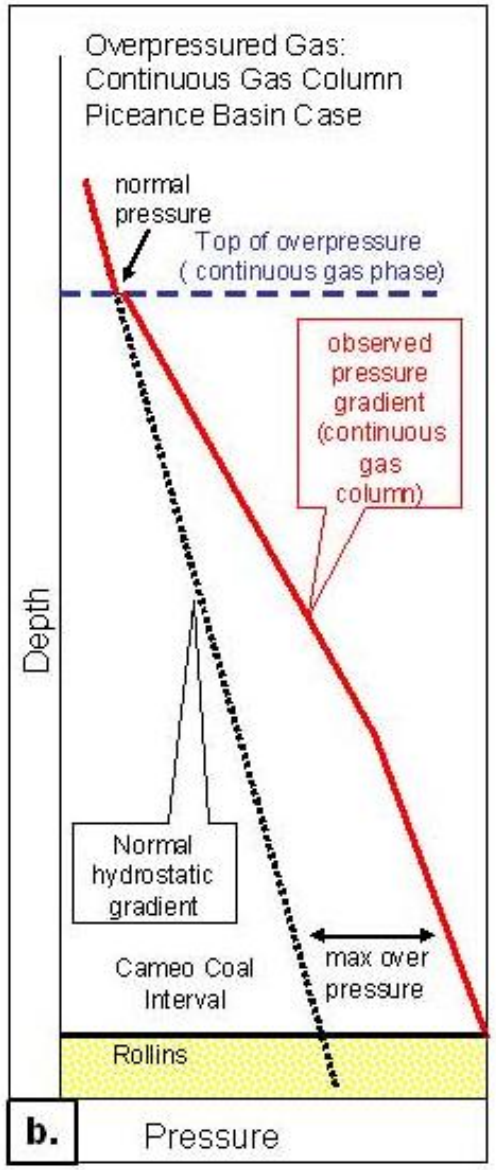


92 BHP and DFIT data points + 6 hydrostatic points at eastern margin + 6 Sanish-Parshall points

No DST data

Pressure - Depth Trend

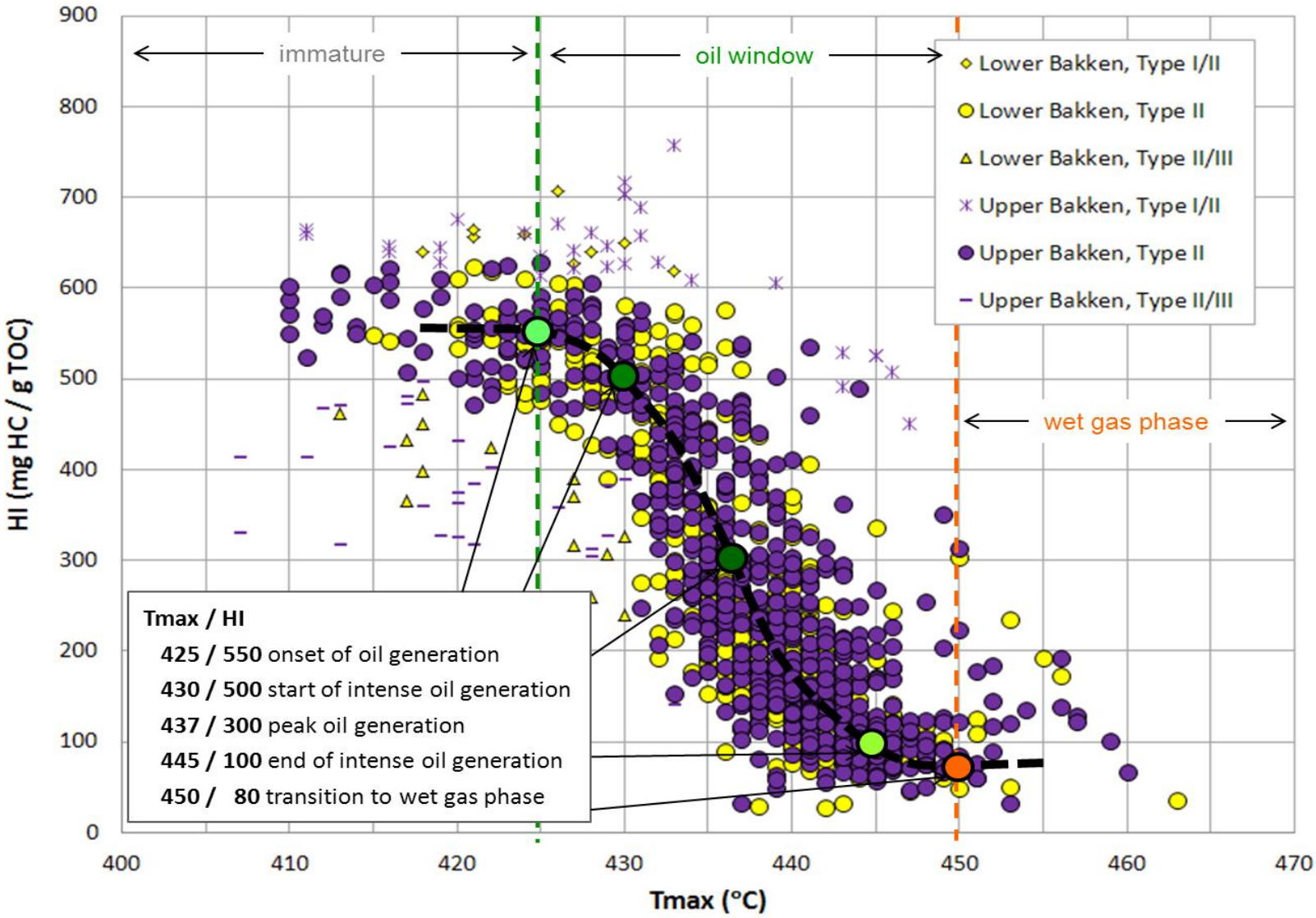




Indicative plot for **inverted continuous system**, leaking pressure at top

Cumella and Scheevel (2005)

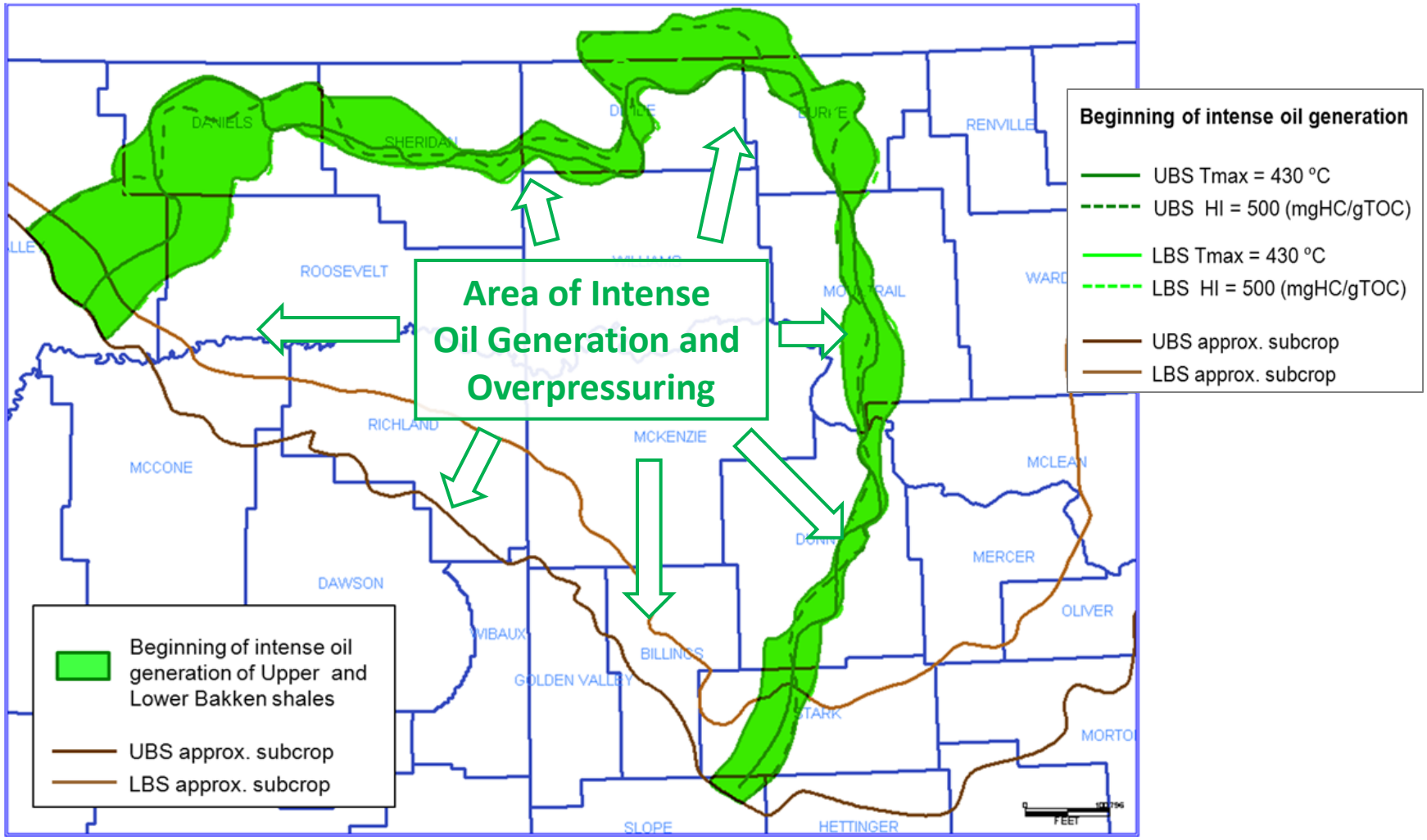
Maturity and HC Generation



Average Tmax (°C) and HI (mg HC / g TOC) values indicate **maturation path for kerogen type II** Bakken source rocks. Kerogen types from Jin, 2012.

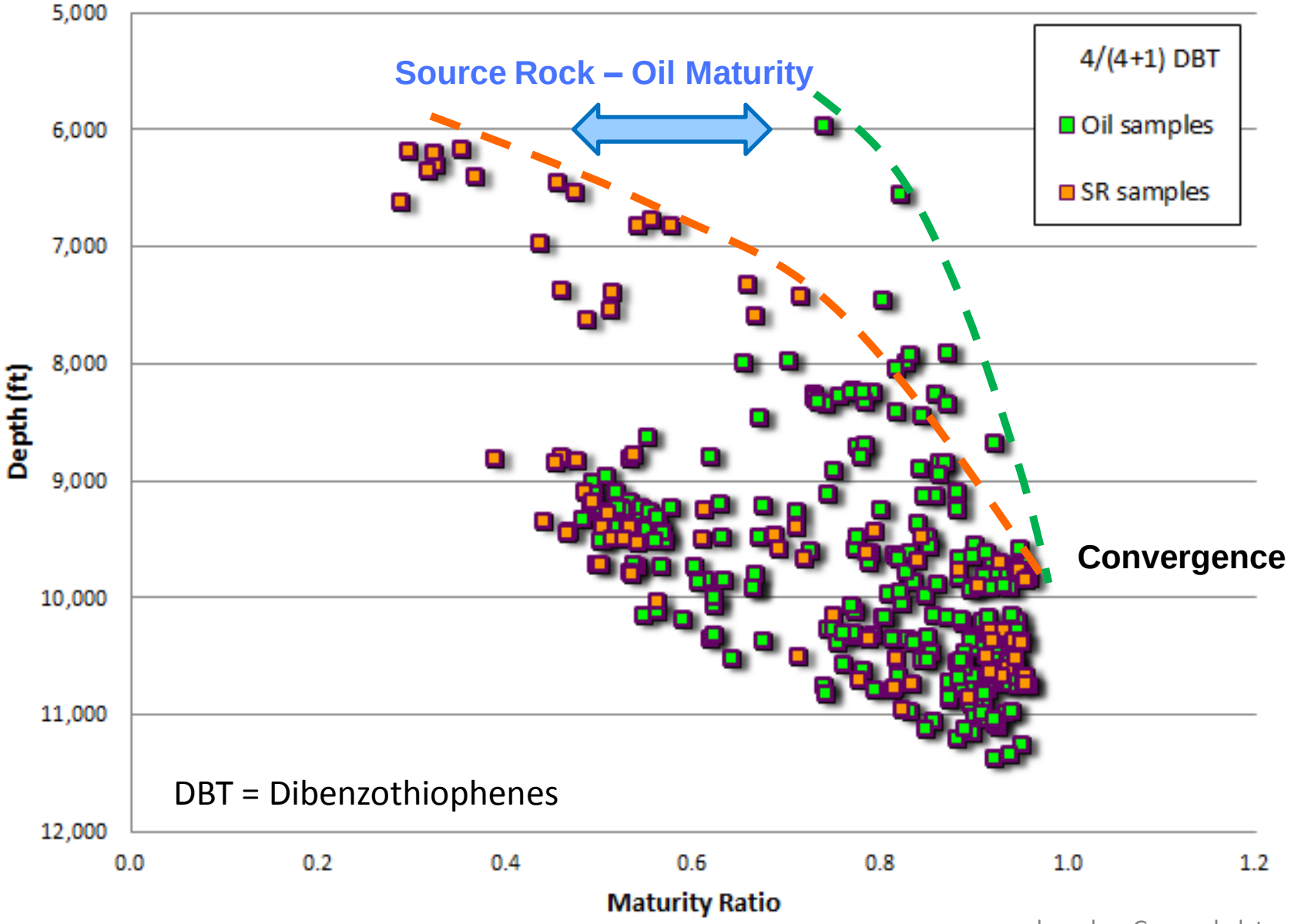
based on USGS data

Maturity Boundary



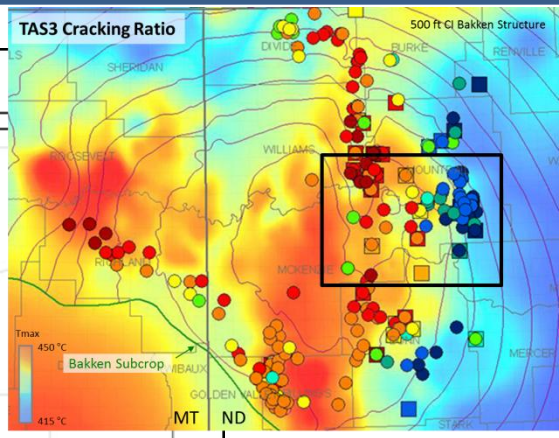
Beginning of intense oil generation based on Tmax and HI constraints of both Upper and Lower Bakken shales

Secondary Migration



based on Geomark data

Parshall – migrated or self-sourced?



TAS=Triaromatic Steranes

N

WILLIAMS

MOUNTRAIL

MCKENZIE

DUNN

MCLEAN

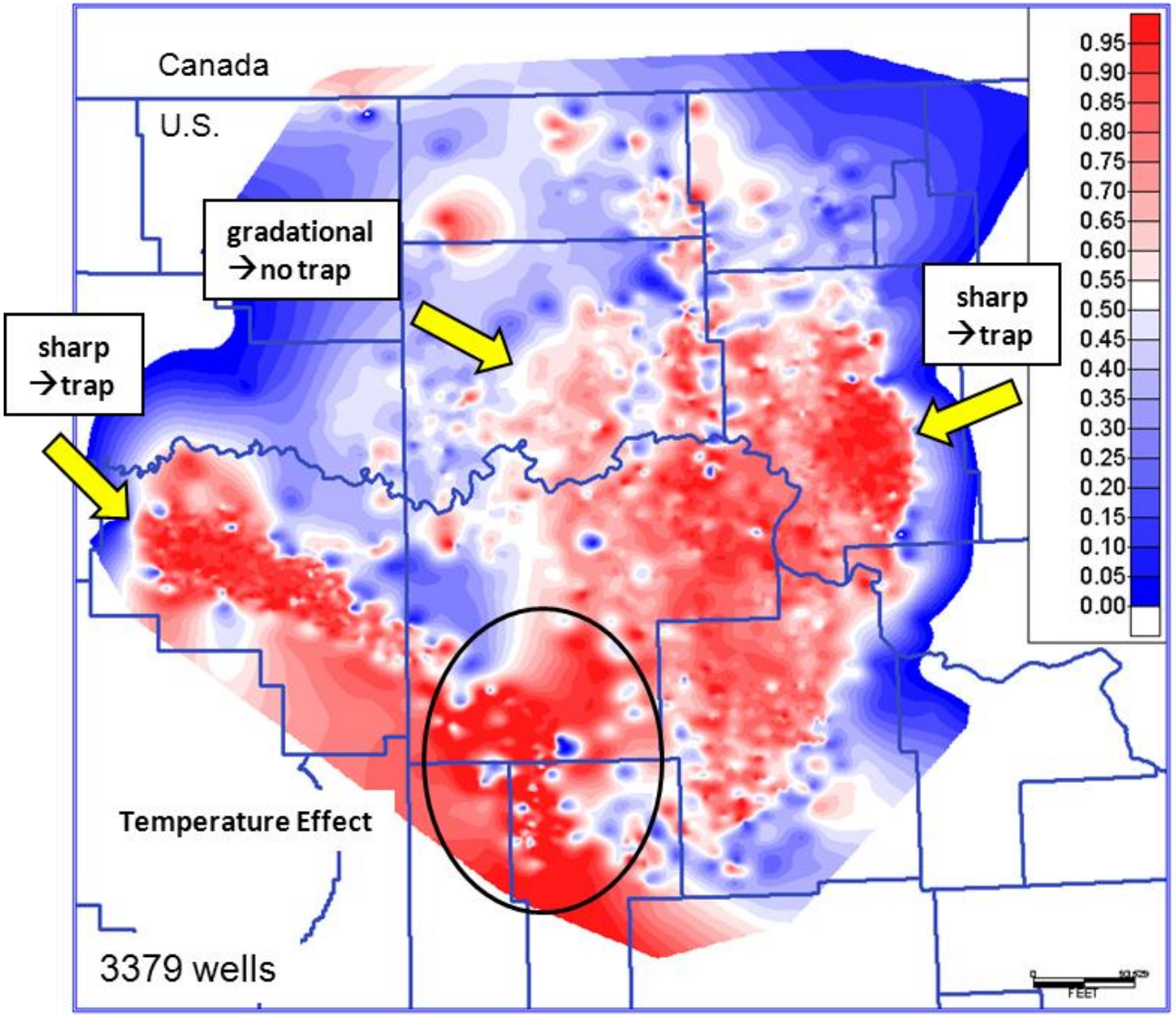
SR	Oil	TAS3
		< 0.2
		0.2 – 0.3
		0.3 – 0.4
		0.4 – 0.5
		0.5 – 0.6
		0.6 – 0.7
		0.7 – 0.8
		0.8 – 0.9
		0.9 – 1.0

TAS3 Cracking Ratio

NESSON ANTICLINE ⟷ **SANISH - PARSHALL**

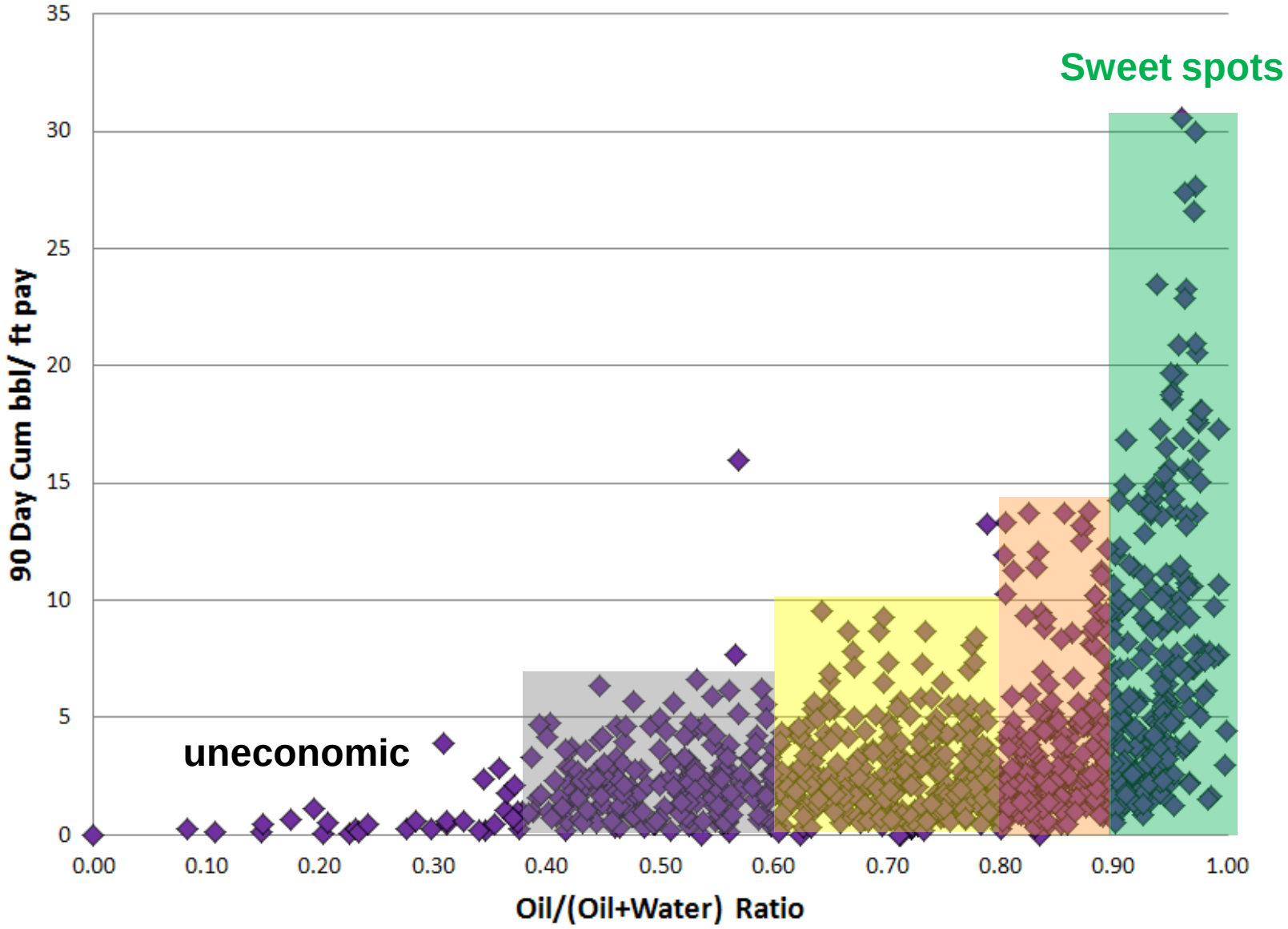
based on Geomark data

Oil and Water 'Saturations'

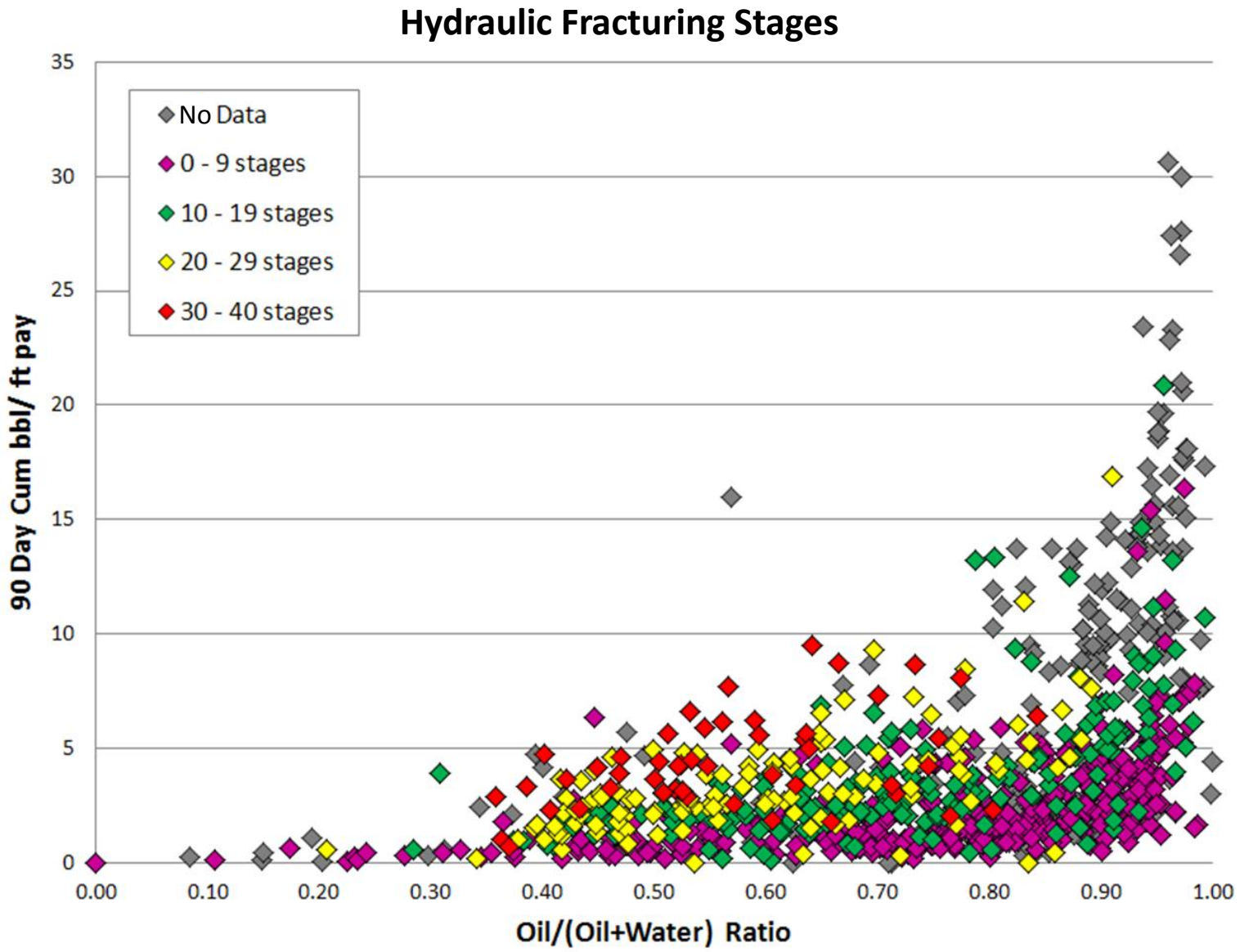


Oil / (Oil + Water) ratio based on cumulative production

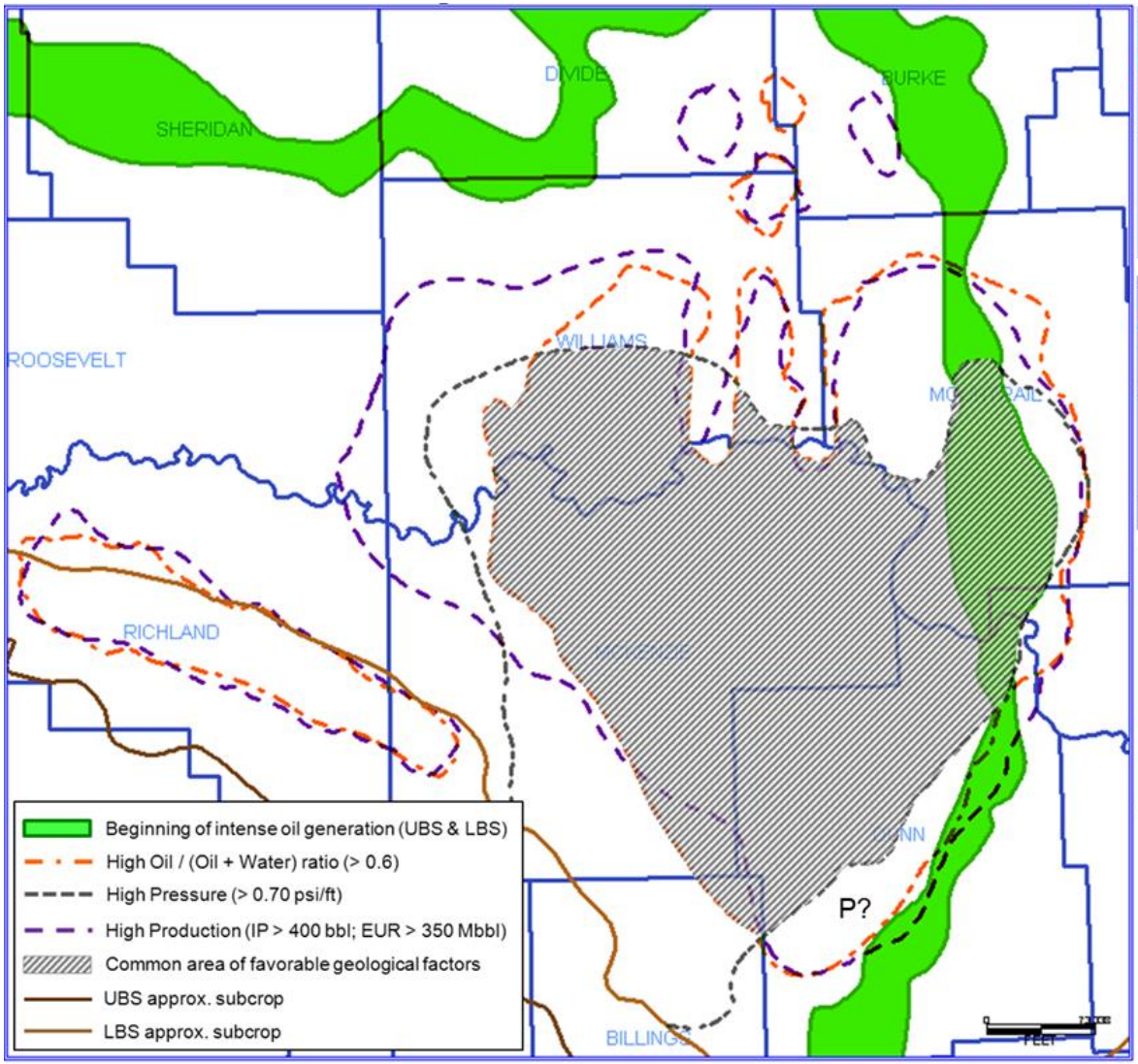
Productivity base plot

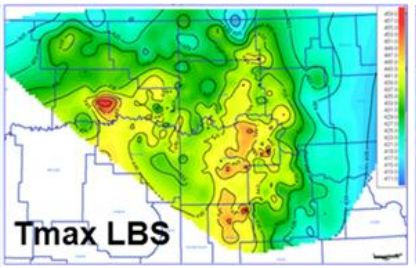


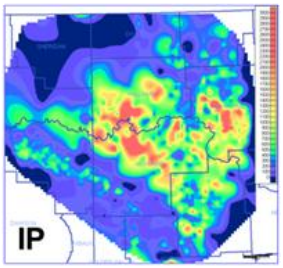
Integrating Geology & Technology

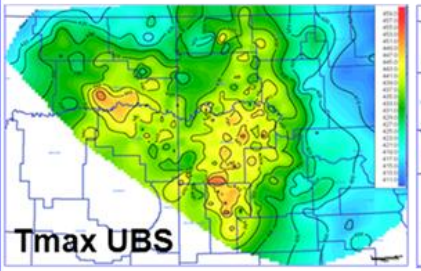


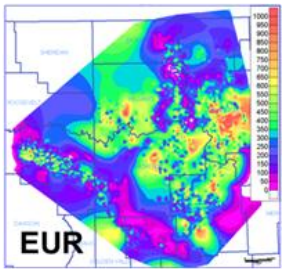
Geologically Favorable Core Area

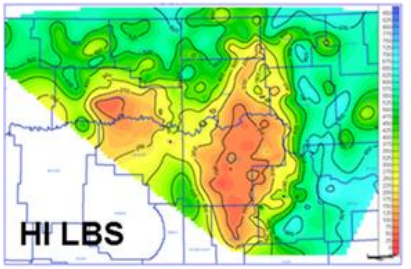


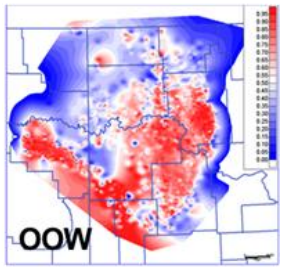


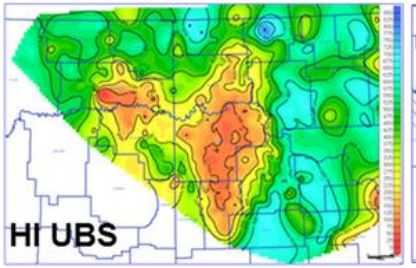


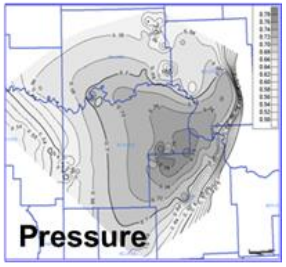




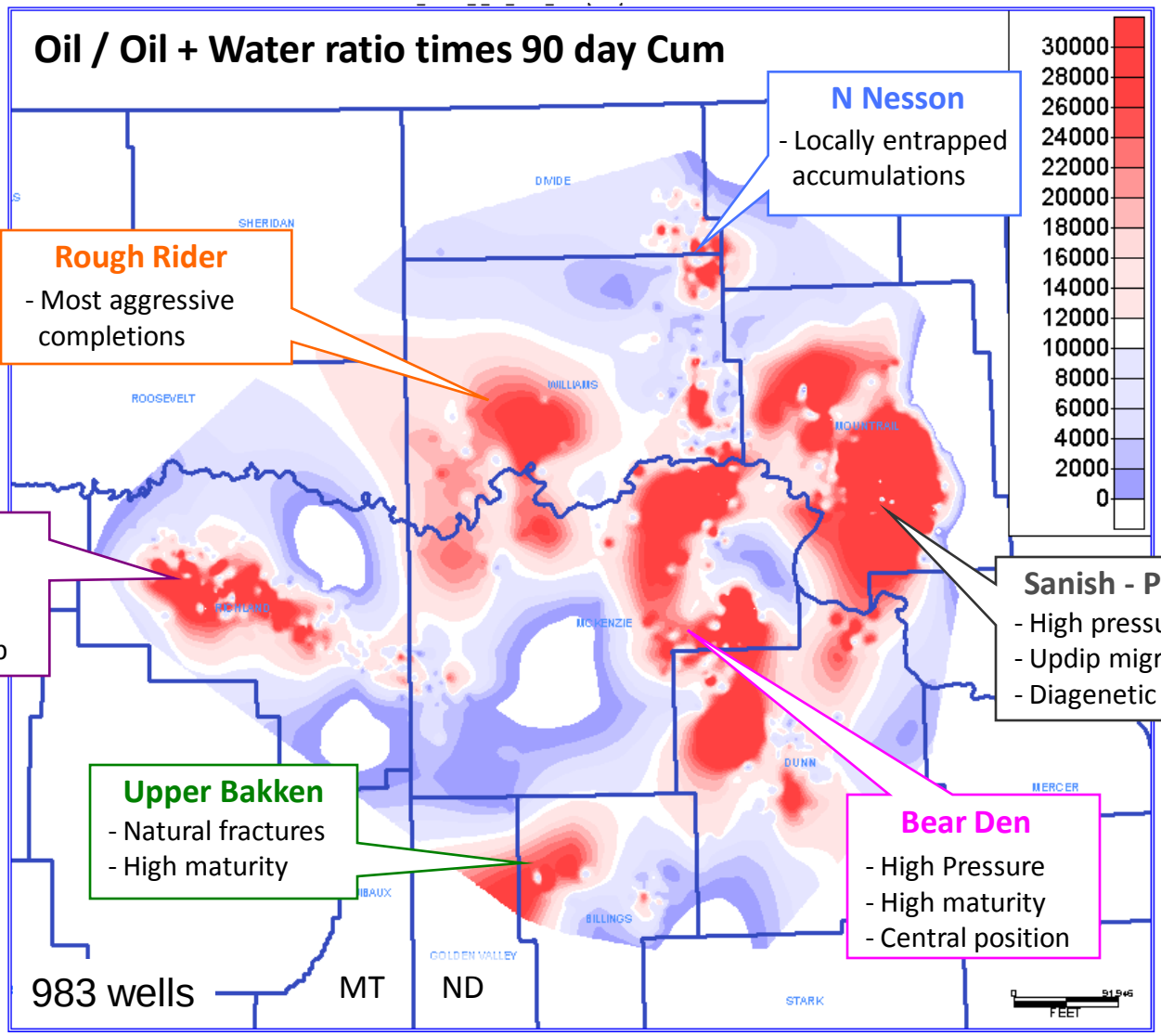








Bakken Plays



N Nesson
- Locally entrapped accumulations

Rough Rider
- Most aggressive completions

Elm Coulee
- Bar facies
- Diagenesis
- Stratigraphic trap

Sanish - Parshall
- High pressure
- Updip migration
- Diagenetic trap

Upper Bakken
- Natural fractures
- High maturity

Bear Den
- High Pressure
- High maturity
- Central position

Elm Coulee ≠ Parshall ≠ Rough Rider ≠ Bear Den

Conclusions (1)

- Production increases with more sophisticated completion technology
  but geological factors have a larger impact on productivity than technological improvements

- Good correlation between **hydrocarbon generation, pore-overpressure, inferred oil saturations and productivity**

- **Sweet spots** influenced by migration and trapping mechanisms
  (e.g. Sanish / Parshall, Elm Coulee)

- **Low-productivity areas** probably result of migration (e.g., flanks of Nesson Anticline)

- **Natural fractures** play a significant role for production, but do not define sweet spot areas

Conclusions (2)

- Differences in **rock-mechanical properties** of reservoir intervals are subtle.
- Mixture of **2/3 sand and 1/3 ceramic proppant** yields highest production rates, but limited dataset.
- Bakken and Three Forks pressures indicate an **inverted continuous system** with **pressure leaking off at top**, apart from **Parshall pressure cell**. Three Forks shows higher overpressure than Middle Bakken.
- **Oils more mature than source rocks** in basin-marginal areas and Canada. In **Parshall** area mixing of locally generated and migrated oils.
- Bakken consists of **different play types**, which are productive for different reasons.

Acknowledgements*

I wish to thank the companies, which supported me so generously and provided essential datasets for my work, but who wish to remain anonymous for confidentiality reasons.

Dr. John Zumberge, Senior Vice President of Geomark Research, kindly permitted the use of the Bakken geochemical dataset.

The EERC (Energy and Environmental Research Center) repeatedly shared their datasets, for which I am very grateful.

And of course, special thanks to my advisors Dr. Steve Sonnenberg and Dr. John Curtis who always supported me.

***of CosiƳa Theloy**