Factors Influencing Productivity in the Bakken Play, Williston Basin*

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Authors' note: The original version of this presentation was altered by adding explanations in small textboxes. They reflect the essential message of the verbal part of the presentation.

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Abstract

A great variety of factors can influence production, and it is often difficult to discern how significant the impact of a single factor is. This study aims to understand why certain areas and /or fields in the Bakken play are considerably more productive than others, and to identify the responsible factor(s).

The Late Devonian to Early 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 in-between the shales, and Upper Three Forks Member, underlying the Bakken Formation are the main target horizons for production.

Parameters, which may potentially have a strong influence on productivity, are numerous and include both geological and technological aspects. Geological factors reach from reservoir quality and thickness, over the structural and stratigraphic framework, to pore-overpressure distribution and organic geochemical parameters. Natural fractures are suspected to play a key role in recovering oil and gas at economic rates from the tight reservoir rocks. Deep-seated faults, tipping out in the underlying Prairie Salt, cause folding at Bakken level and thus may enhance the natural fracture density. Gas shows and drilling mud weights were used to investigate this relationship.

Production has increased over time as drilling techniques and the completion design of wells have become progressively more sophisticated. Initial production rates drastically improved with the advent of horizontal wells in the 1990s. Further augmentation in productivity was observed during the transition from dual and triple laterals to long single laterals with high number of hydraulic-fracturing stages.

However, often older wells outperform younger wells despite technological advancements, suggesting that geological factors have a far larger impact on production than the completion design. Based on an integrated and correlative approach, it seems that migration of hydrocarbons and trapping mechanism may be the key to identify sweet spot areas within the Williston Basin.

Reference

Peters, K.E., Walters, C.C., Moldowan, J.M., 2005. The Biomarker Guide. Biomarkers and Isotopes in Petroleum Exploration and Earth History, Volume 2: UK Cambridge University Press, 1155 p.

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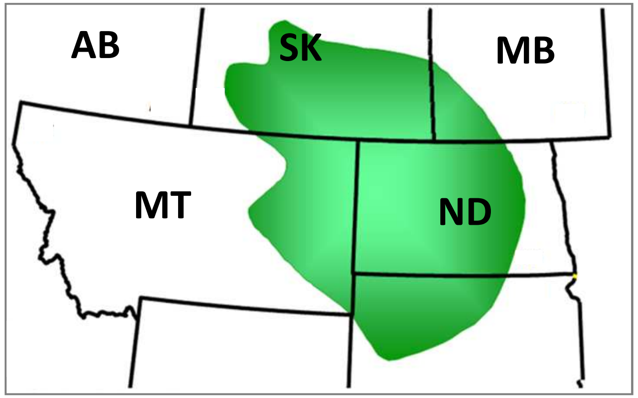
Outline

- Introduction
- Objectives
- **Factors Influencing Production**
  - Bakken Production
  - Completion Design
  - Overpressure
  - Hydrocarbon Generation Potential
  - Migration and Traps
  - Natural Fractures
- Conclusions

Bakken Tight Oil Play



Sonnenberg, 2010

Location: **US-Canadian Williston Basin**
- intracratonic, dish-shaped basin

Age: **Late Devonian - Early Mississippian**

Depth: **8000 to 11,000 ft**

Source rocks: **Upper & Lower Bakken Shales**
- finely laminated to massive black shales
- avg. TOC 10 -11 %, high original HI values
- Type II kerogen (algae), mostly oil mature

Reservoir rocks: **Middle Bakken & Upper Three Forks**
- low porosity (5- 8 %), low permeability (< 0.05 mD)
- highly overpressured (up to 0.8 psi/ft)
- Middle Bakken: silty, dolomitic (sub- / intertidal)
- Three Forks: green mudstone and dolostone (inter- / supratidal)

Production: 332 MMBO cumulative
500, 000 bbl oil / day
} North Dakota only (NDIC, 2011)
undiscovered reserves: 3645 MMBO; 2730 BCFG (USGS, 2010)

Objective

Unconventional resource play definition:
"… continuous accumulation of hydrocarbons, lacking downdip water contact …"

For the Bakken this may be true in a **geological** sense, but **not** in **economical** terms

- Recognize known and future sweetspot areas.

- Why are they sweetspots?

- What is the reason for low-productivity areas?

- How can we distinguish between completion-related improvement in productivity and geological factors?

- What is the optimal (cost-effective) completion design for which area in the Bakken and taking into consideration the stage of field maturity (early development vs. infill drilling)

What influences productivity?

GEOLOGY

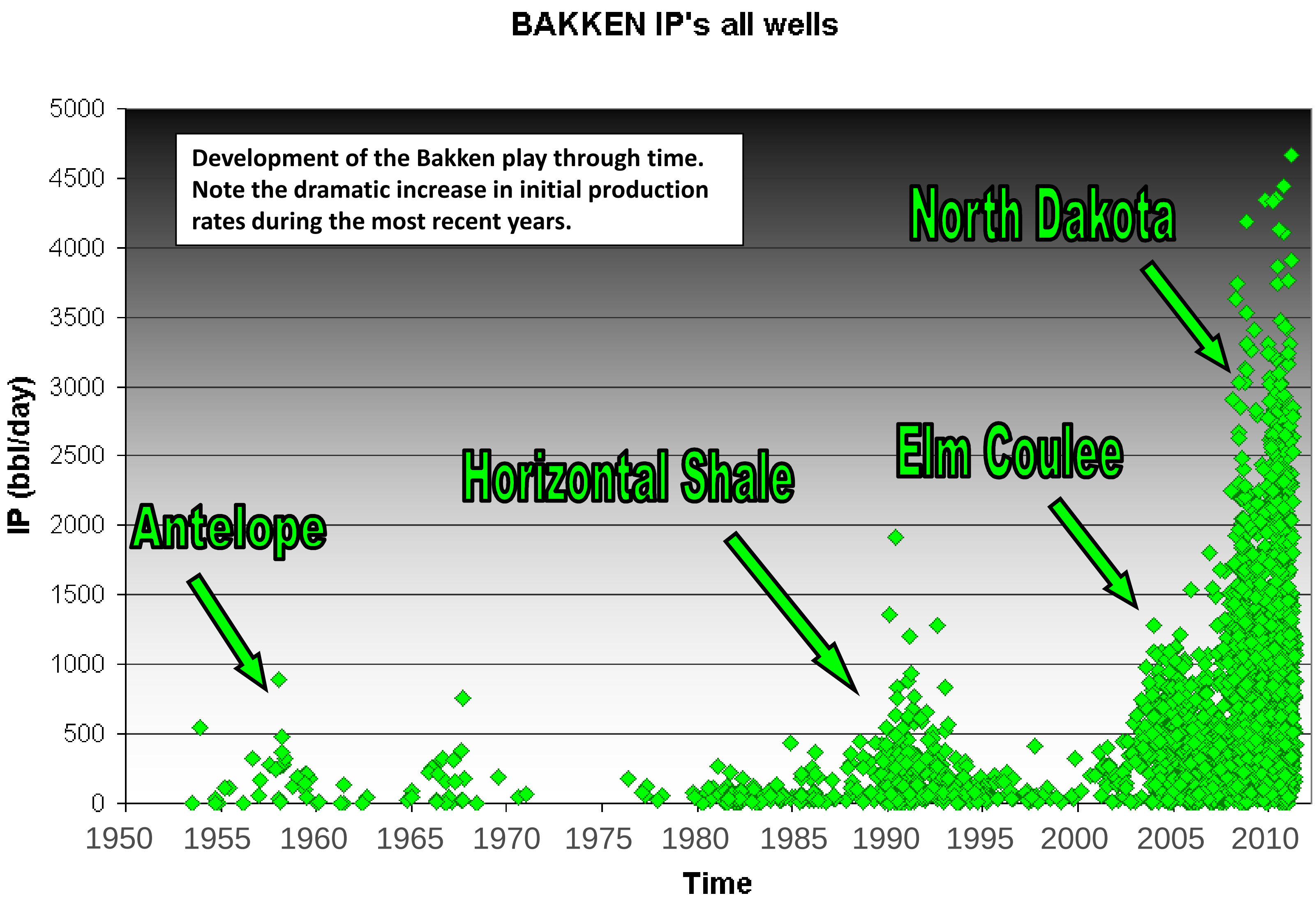
- Reservoir quality
- Reservoir thickness
- Oil & water saturations
- HC generation potential
- Maturity
- Overpressure
- Structure and lineaments
- Regional stress regime
- Mechanical stratigraphy
- Natural fractures
- Migration
- Traps

TECHNOLOGY

- Well type
- Lateral length
- No. of hyd. fracturing stages
- Proppant volume & type
- Proppant loading
- Fluid volume & type
- Fluid / proppant ratio
- Injection rate
- Treatment pressure
- Choke size

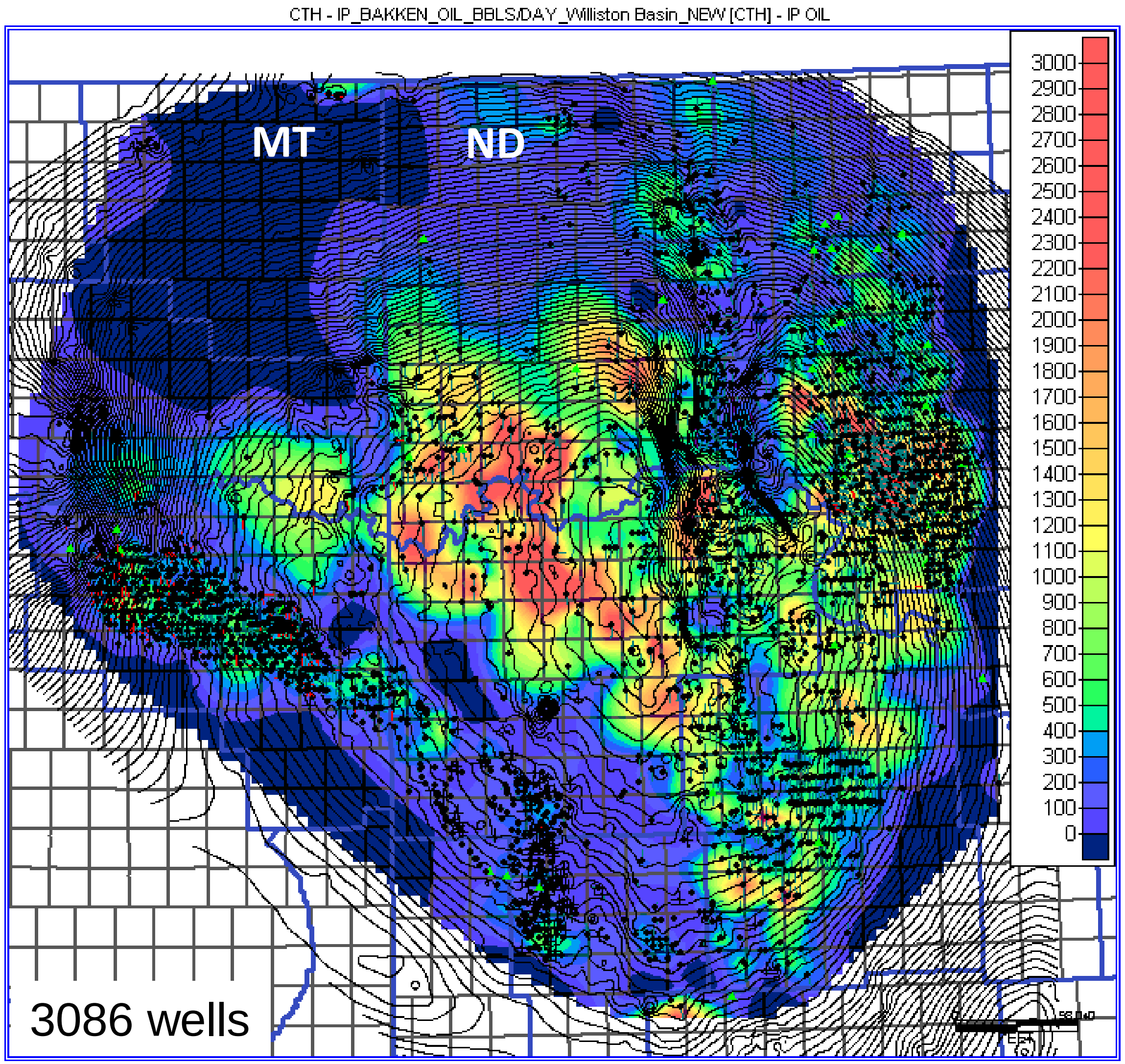
The list is long on both sides → how can we determine which are the most important factors?

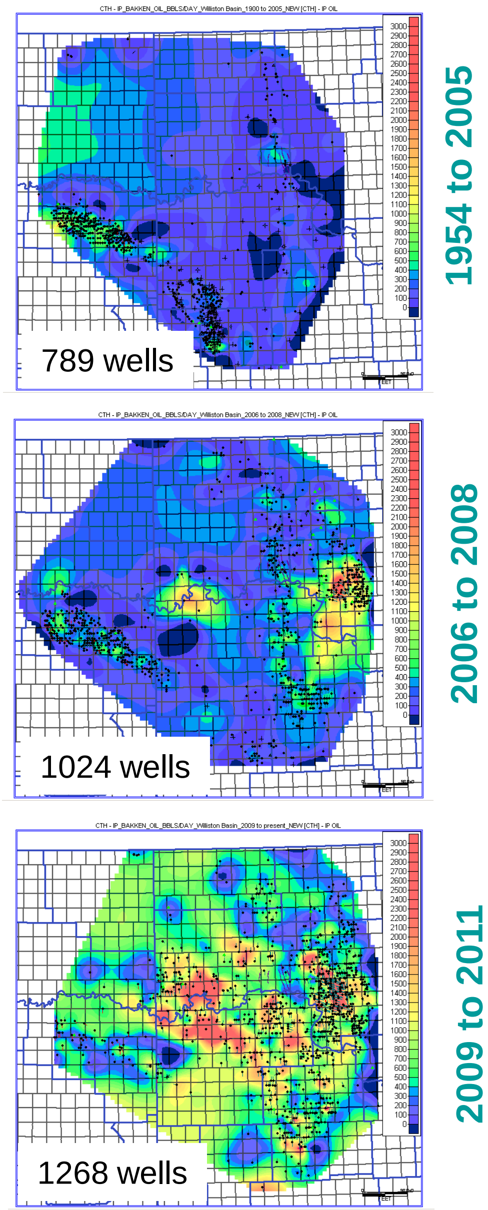
Bakken Production



Initial Production Data

IP maps show high- and low-productivity areas. Display of data in three time slices (same color scale for all maps). Most recent time slice shows highest production rates and largest areal development in ND.

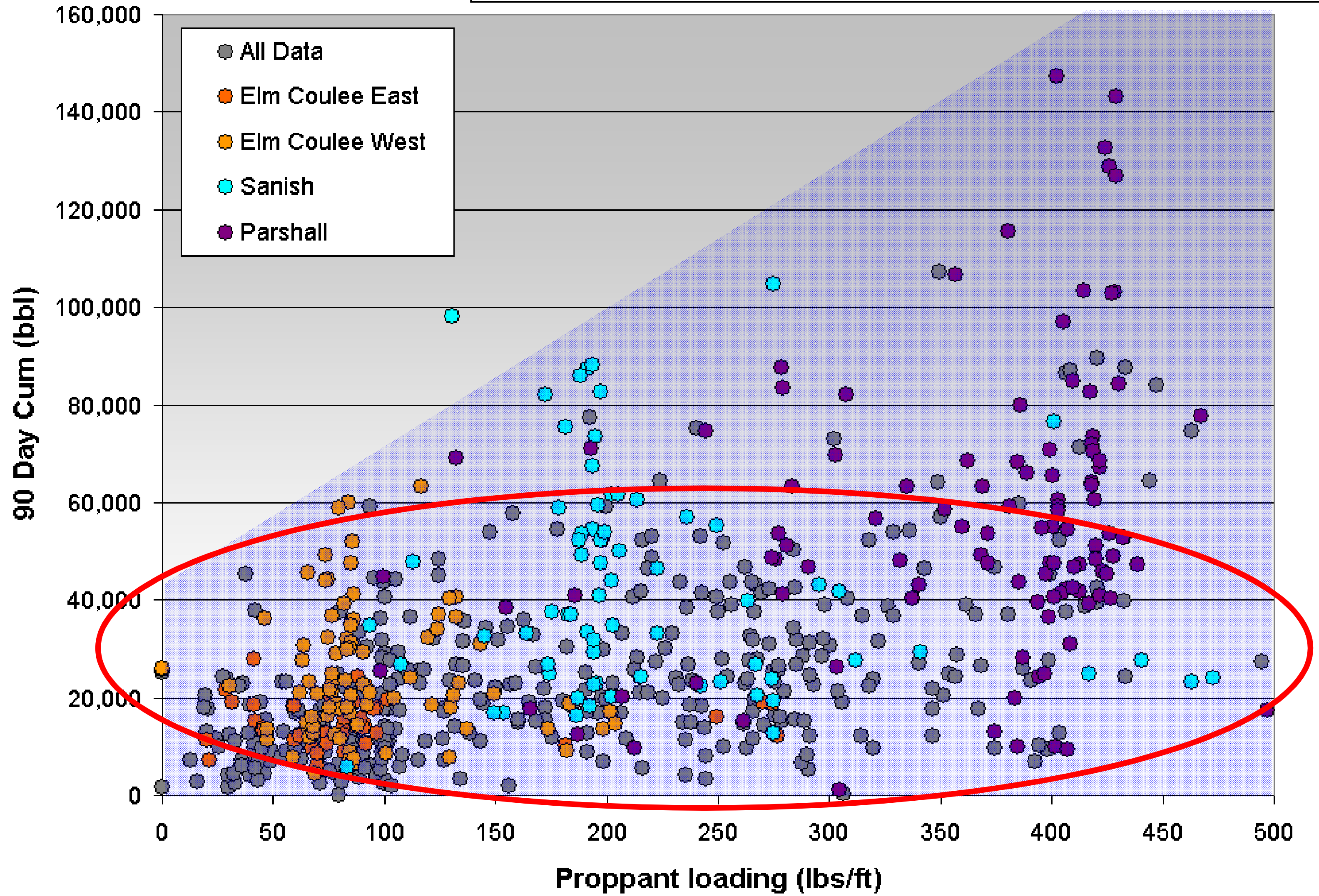




Initial Production maps (bbl/day) of Bakken producers

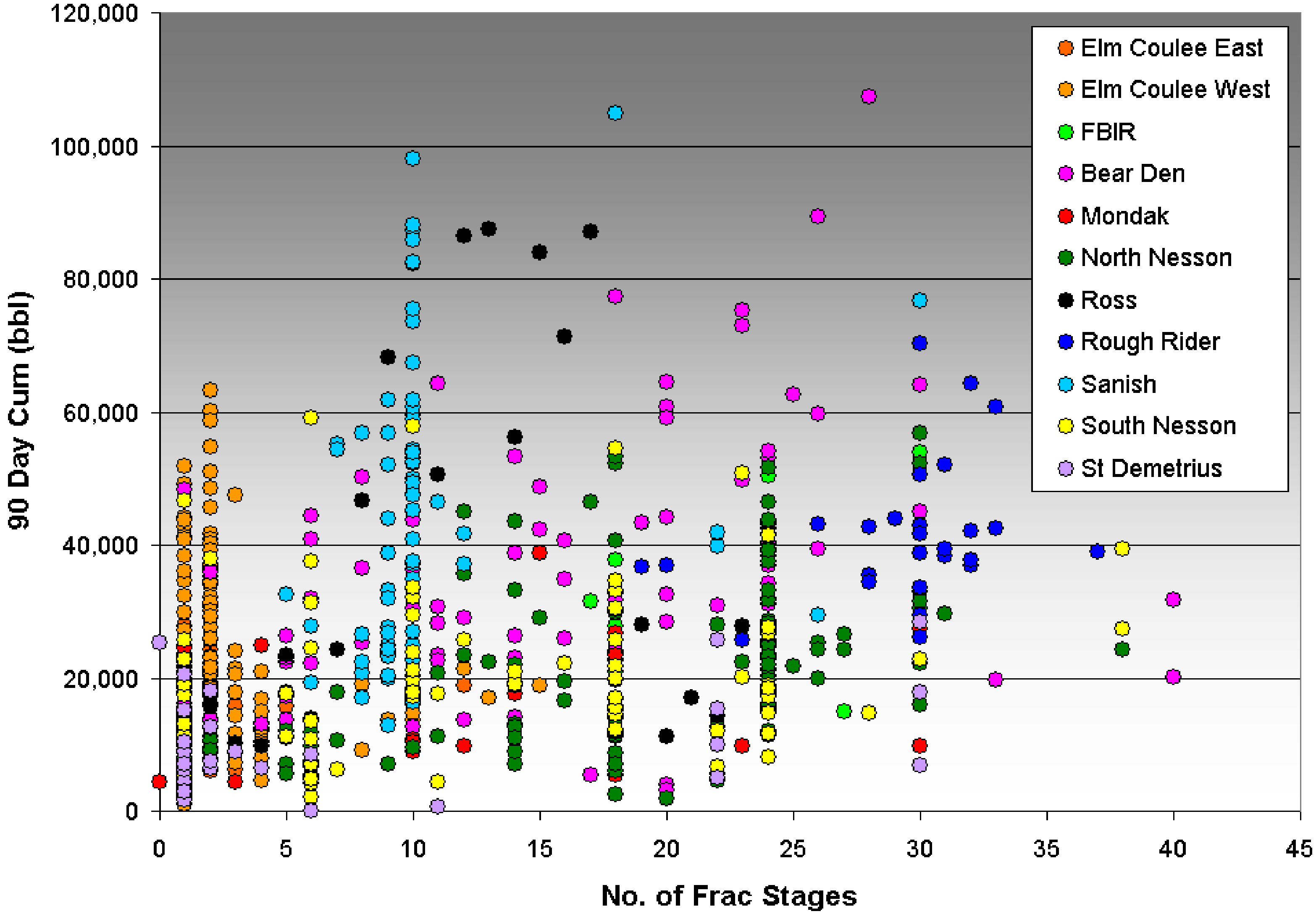
Completion Design

At the first glance , there is a positive relationship between proppant loading (lbs per ft of pay) and production;; however the majority of wells are within the same production range regardless of the proppant loading.

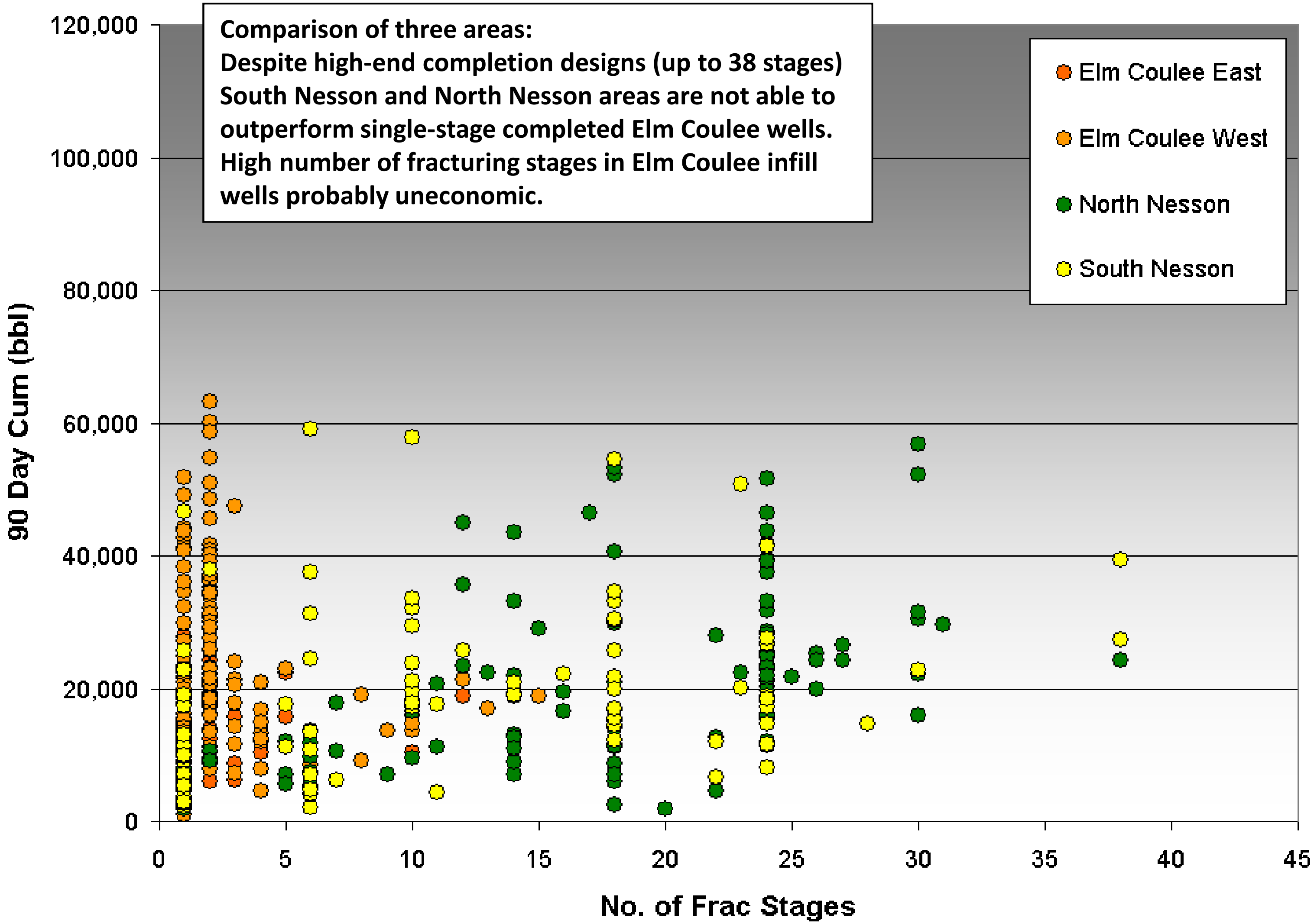


Completion Design

Similar scenario for number of hydraulic fracturing stages versus production
→ no clear correlation.

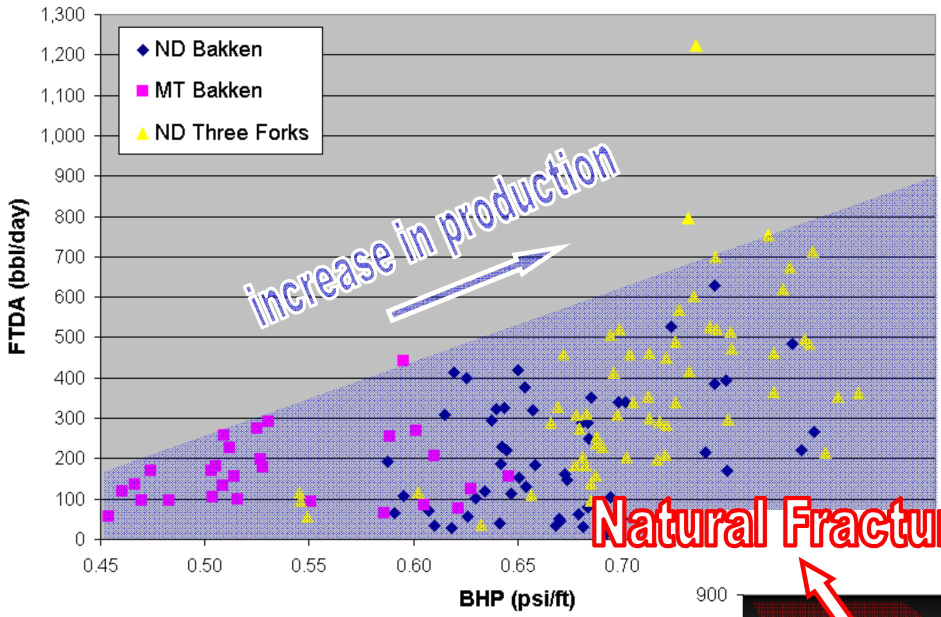


Completion Design



→ **Completion design is not the whole story!**

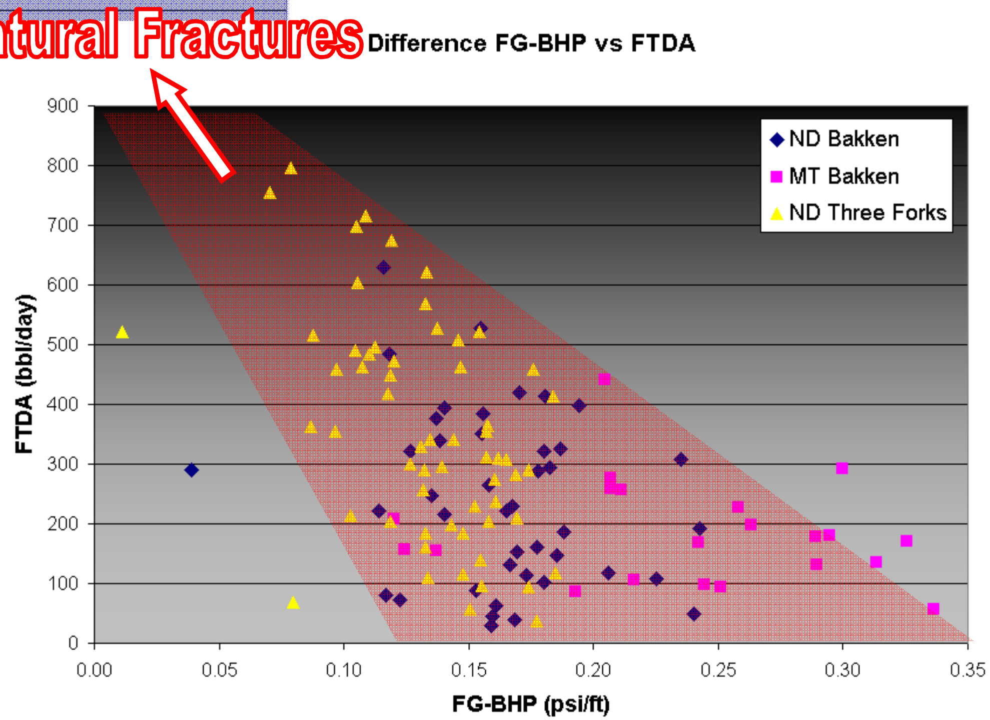
Pore-overpressure



FTDA = First 30 Day Average Production

Increasing production with increasing pore pressure

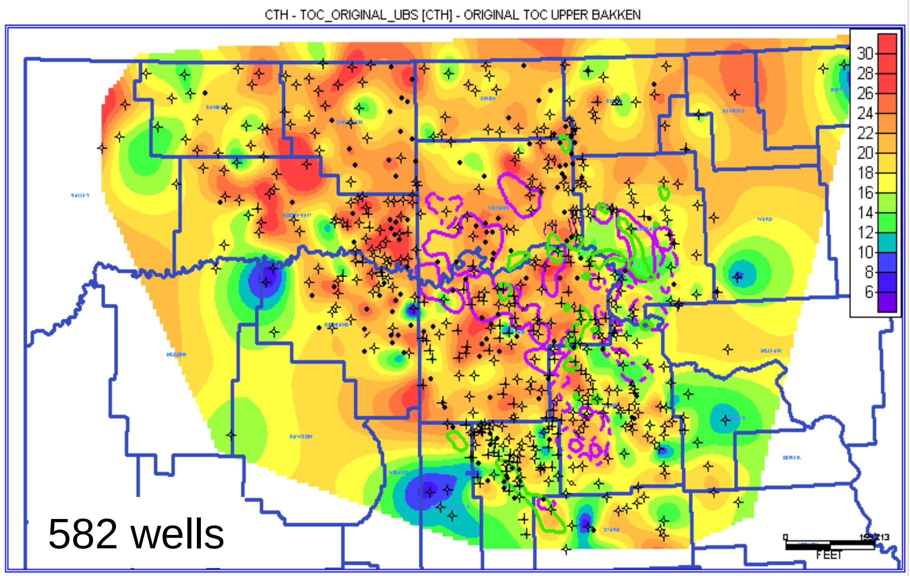
Three Forks has slightly higher pore pressure than Bakken



As the pore pressure approaches, and locally exceeds, the frac gradient of the rock, natural fractures are created; this in turn enhances permeability and thus production.

higher production with less difference in frac gradient and pore pressure

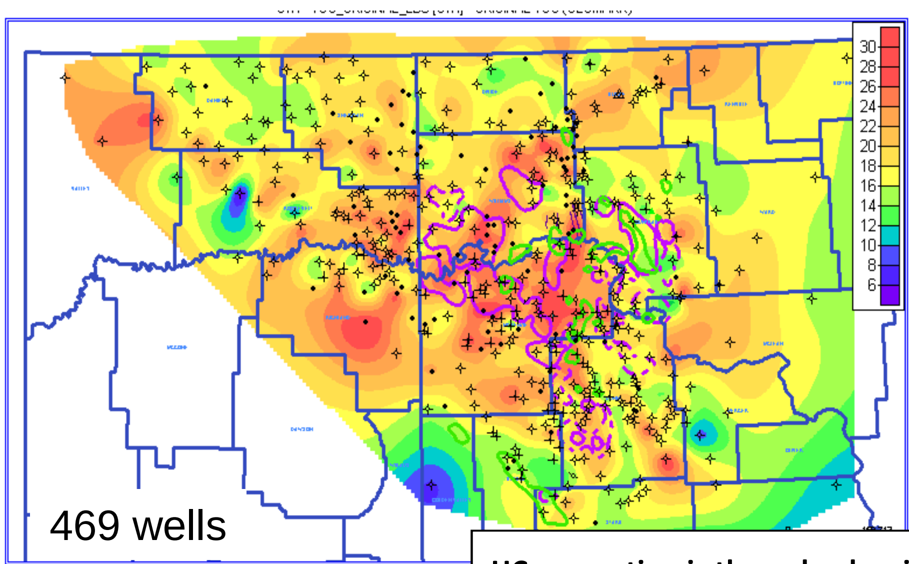
Hydrocarbon Generation Potential



Original TOC Upper Bakken

$$TOCo = \frac{HI \times TOC \times 83.33}{\boxed{HIo} \times (1 - F) \times (83.33 - TOC) + (HI \times TOC)}$$

= 650 (Peters et al., 2005)



USGS data

Original TOC Lower Bakken

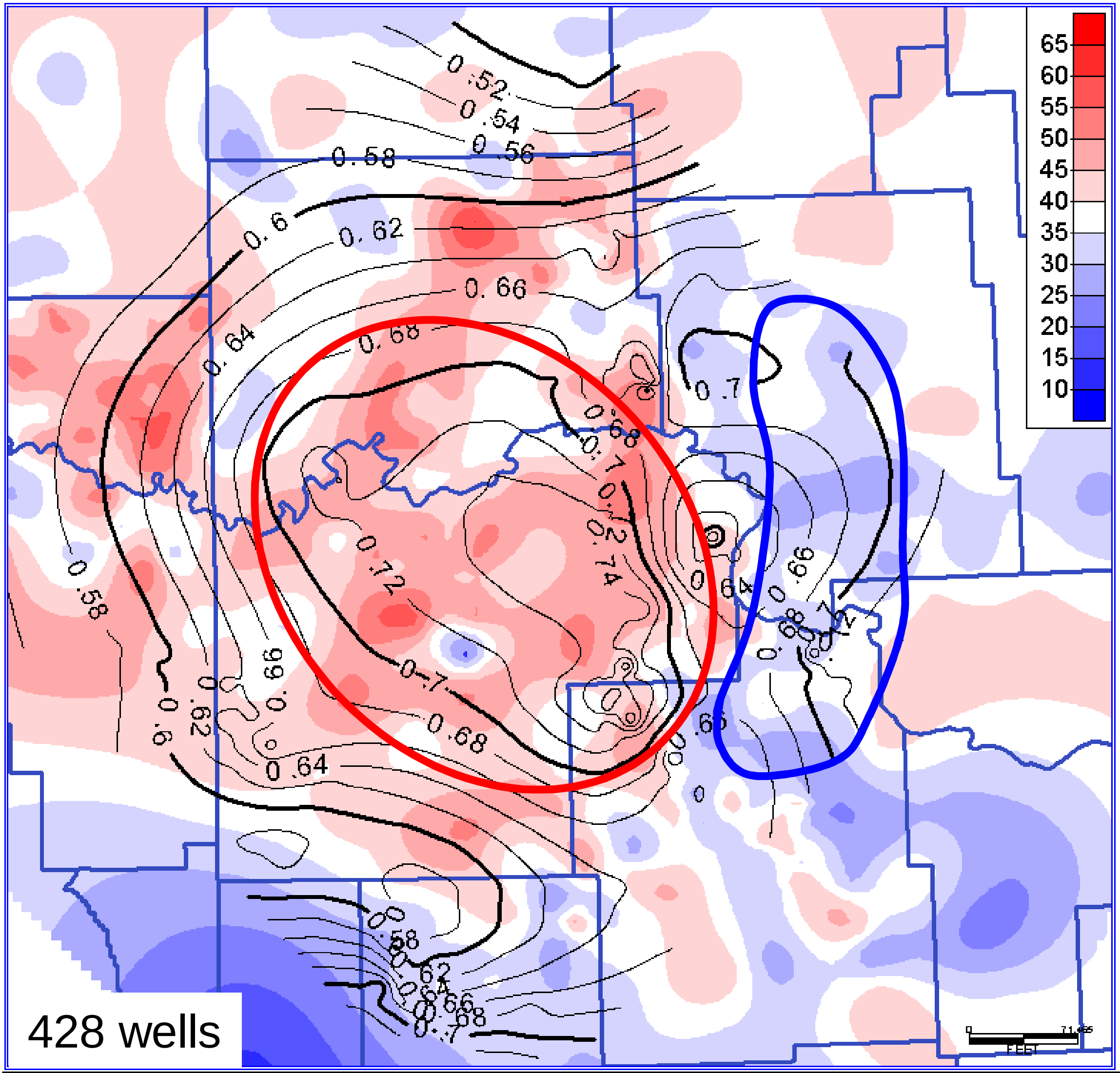
High-Productivity Areas based on IP rates

Bakken

Three Forks

HC generation is the only plausible cause for overpressure in the Bakken. Original TOC maps reveal patchy distribution and do not correlate well with high-productivity areas.

Original TOC and Pore Pressure



Sum TOCo (per "200 %")
Original total organic matter content of <u>both</u> Upper and Lower Bakken Shale

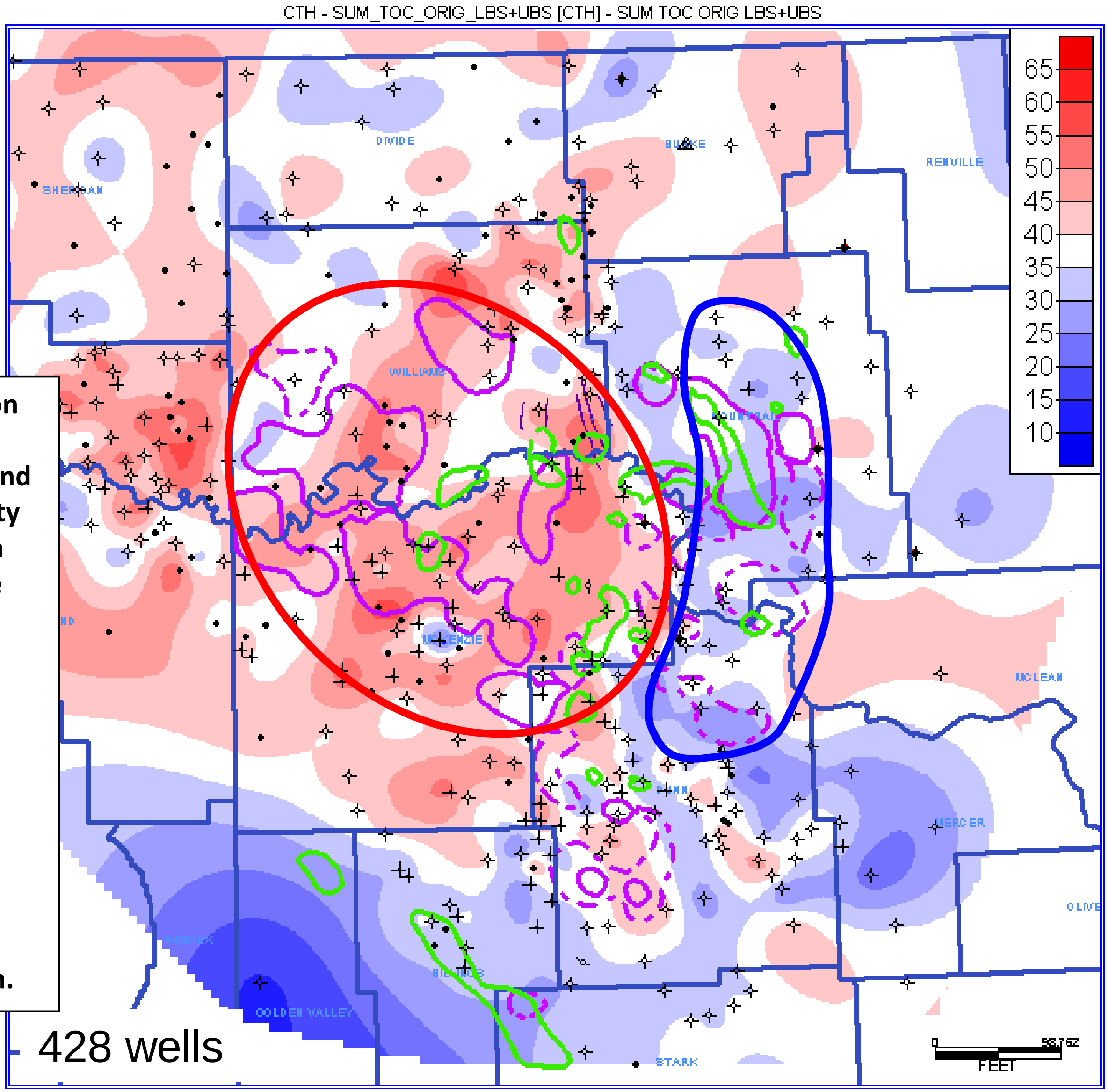
Contours = pore pressure (psi/ft) based on 80 quality controlled data points & few additional points in the East

⇨ **Good match with high-pressure area**

Eastern part likely high-pressured, but low TOCo

However, when looking at the sum of original TOC's of both shales, as it does not matter where the oil came from, there is a good correlation with the highly overpressured area in the basin center. No match though for eastern part of basin.

Original TOC and Production



Good match for bulk of highly productive areas

Fields in the East do not coincide with high TOCo values

Good correlation between high original TOC's and high productivity areas, but again no match in the eastern part → something else has to be part of the equation to explain low original TOC's in combination with high pressure and high production.

High-Productivity Areas based on IP rates

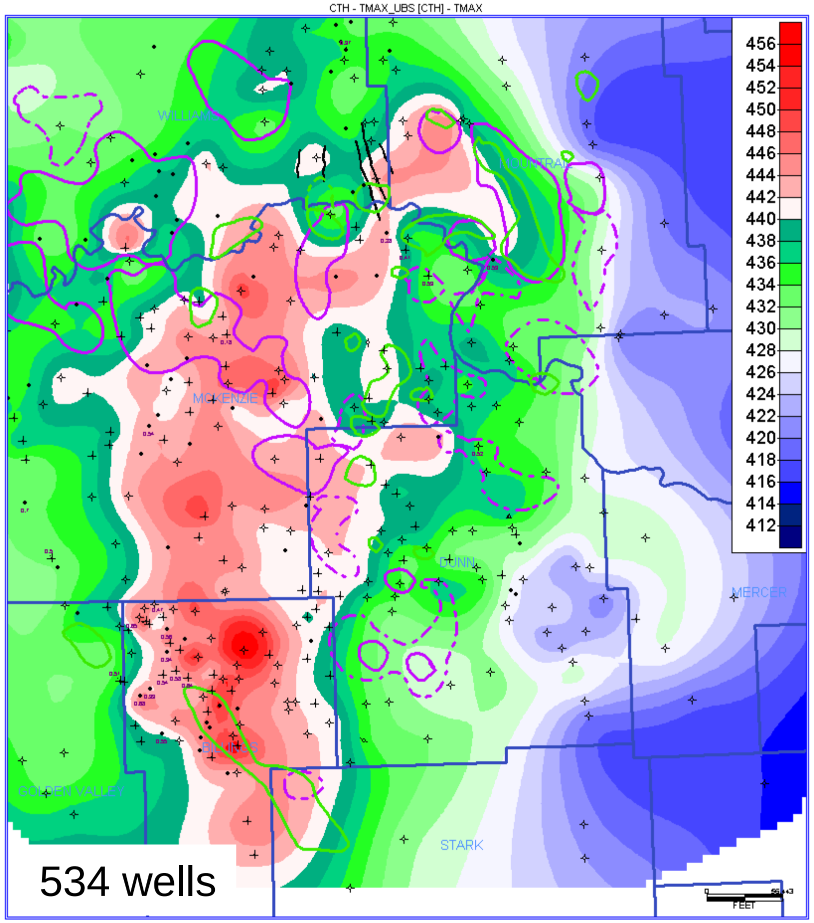
Bakken

Three Forks

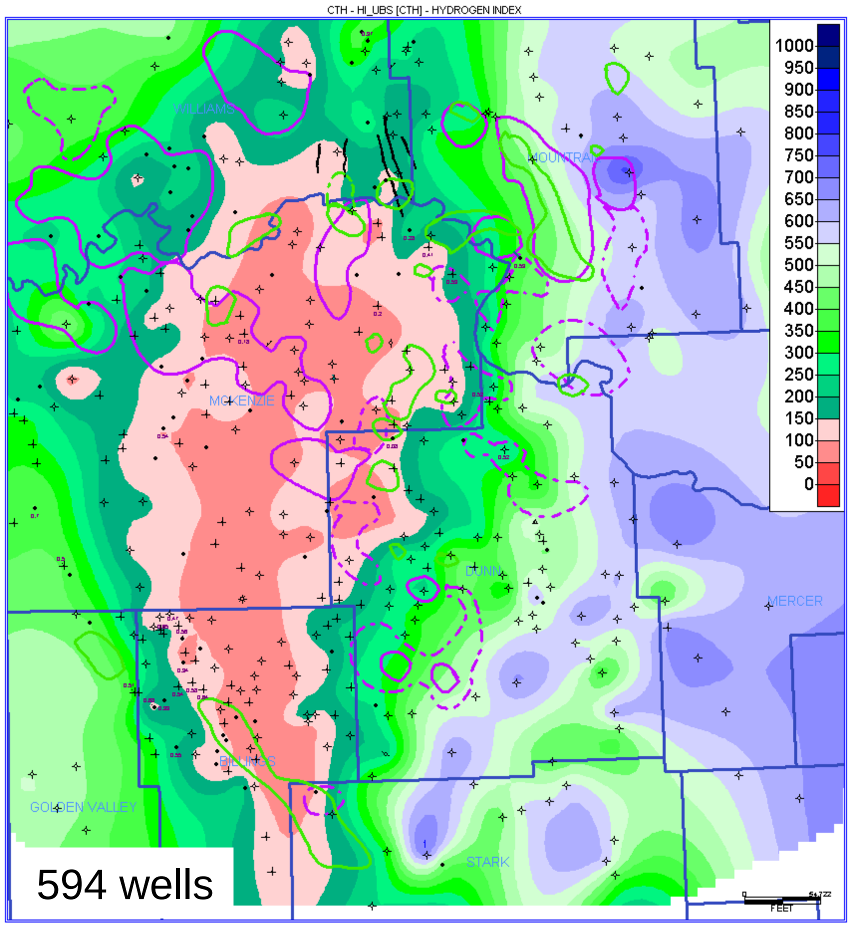
Main Oil Generation Window

The first part of the explanation is that most fields in the eastern margin are currently in the main oil generation window (green) and overpressure is created. Parshall field though is still immature / marginally mature.

Tmax Upper Bakken



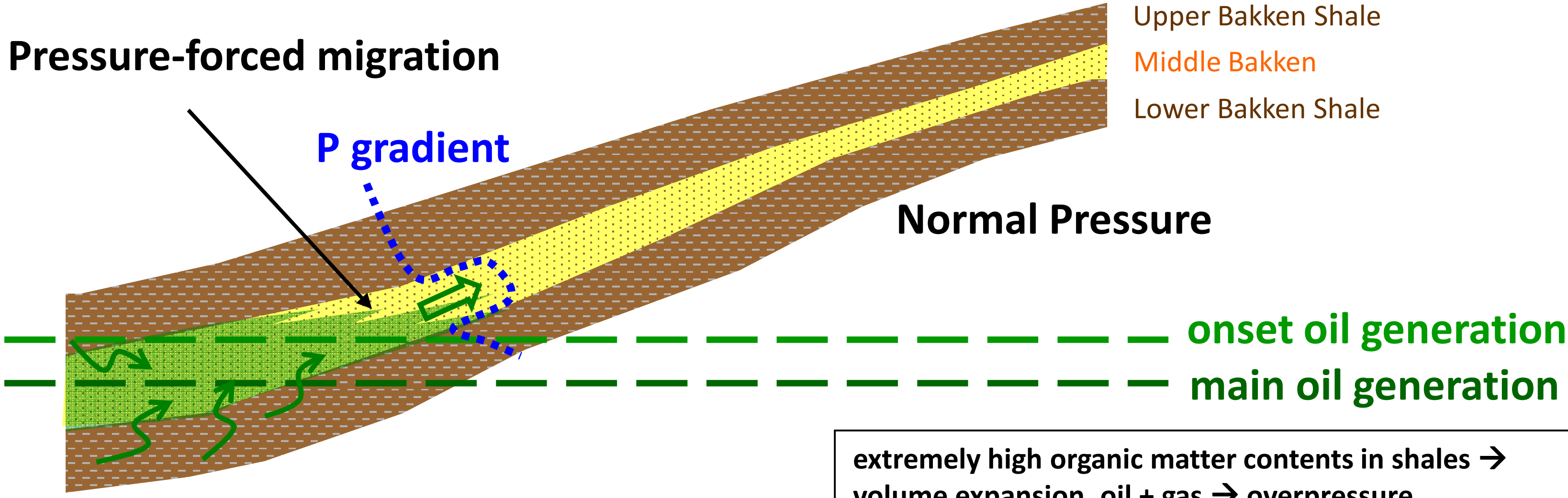
HI Upper Bakken



Fields at eastern margin largely in main oil generation window

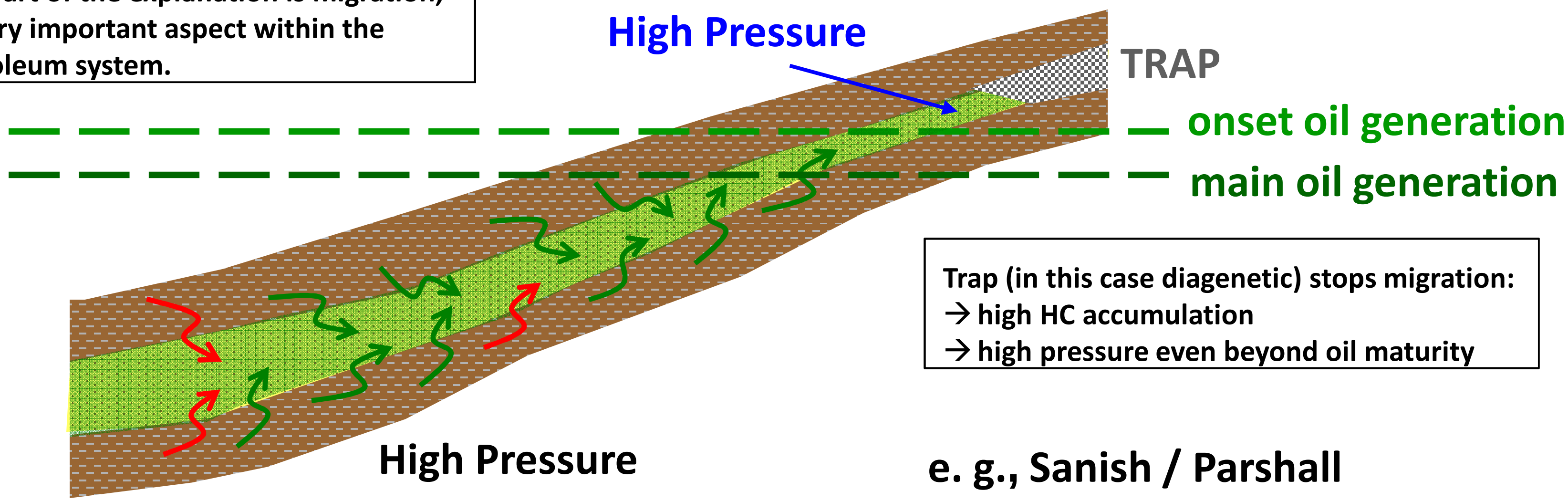
USGS data

Migration in the Pressure Cooker



extremely high organic matter contents in shales → volume expansion, oil + gas → overpressure → fractures → migration → only escape route is updip

The second part of the explanation is migration, which is a very important aspect within the Bakken petroleum system.



Trap (in this case diagenetic) stops migration:
→ high HC accumulation
→ high pressure even beyond oil maturity

e. g., Sanish / Parshall

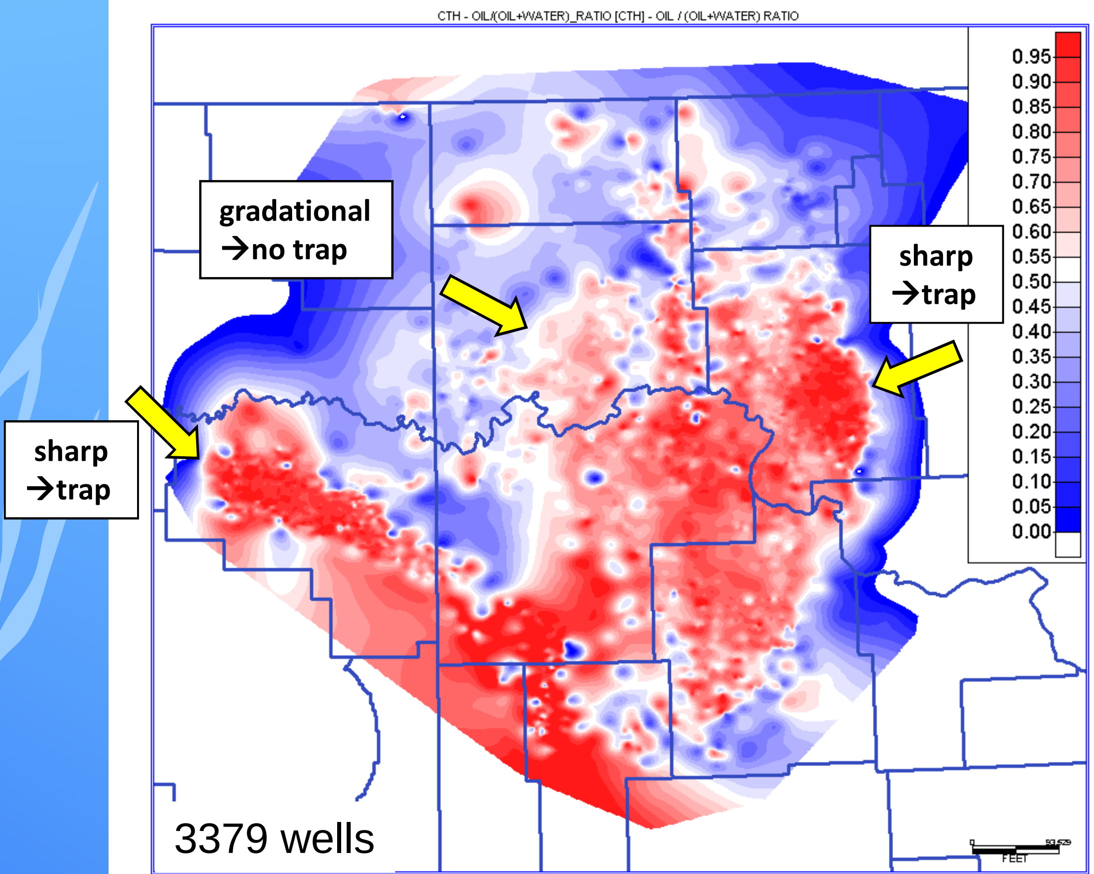
Oil & Water Saturations

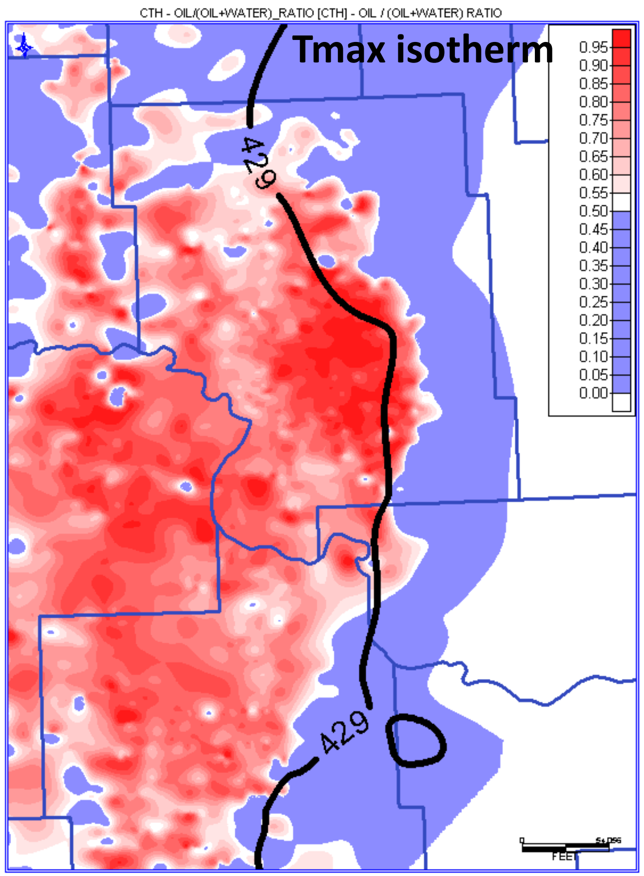
Oil / (Oil + Water) ratio based on cumulative production values

Eastern half of Parshall beyond Tmax = 429 °C contour

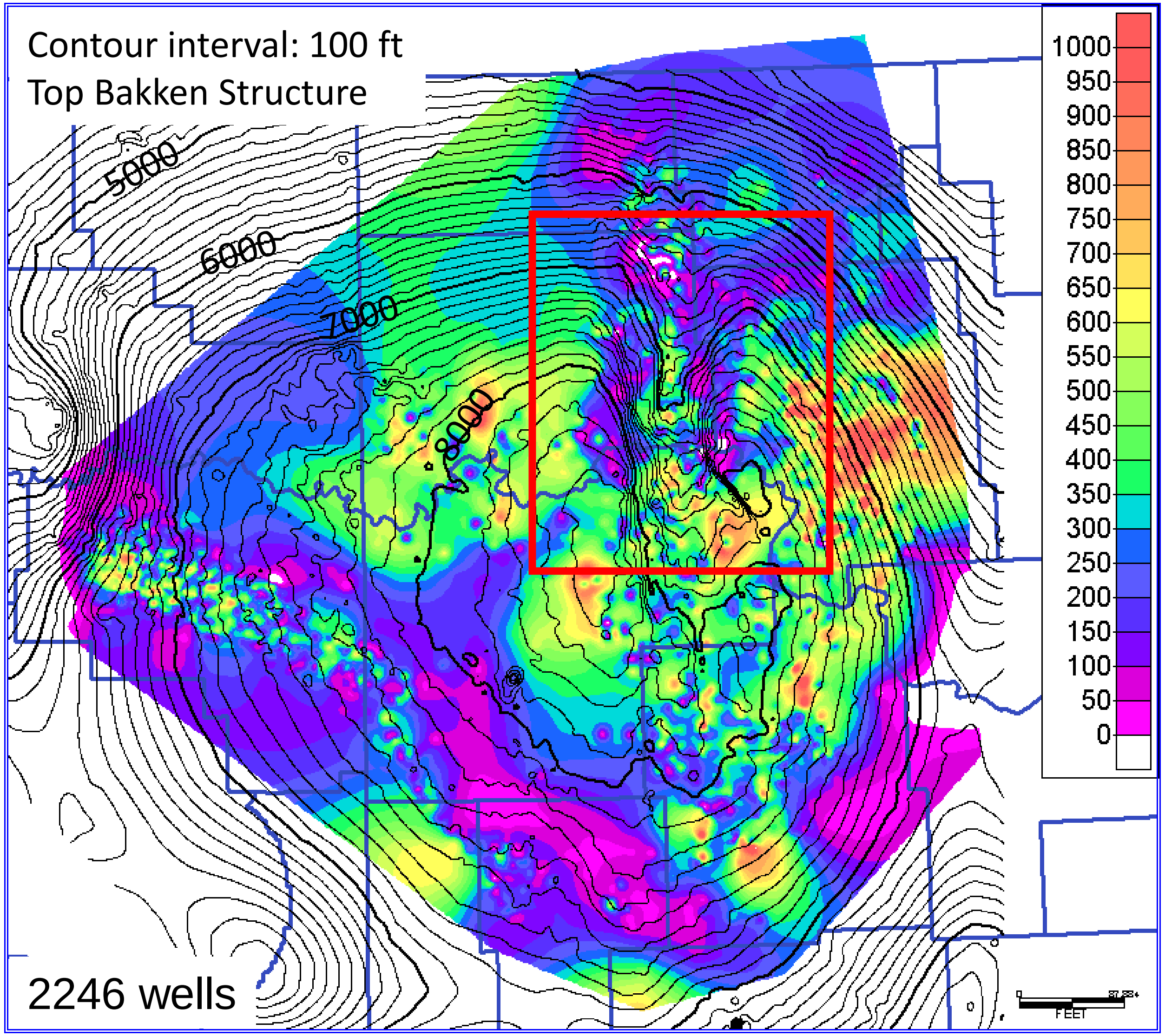
Presence / absence of traps

Map illustrates very well sweetspot areas within basin. Nature of boundary between highly oil-saturated and highly water-saturated areas allows conclusions about presence or absence of traps.





Bakken EUR (MMbbl)



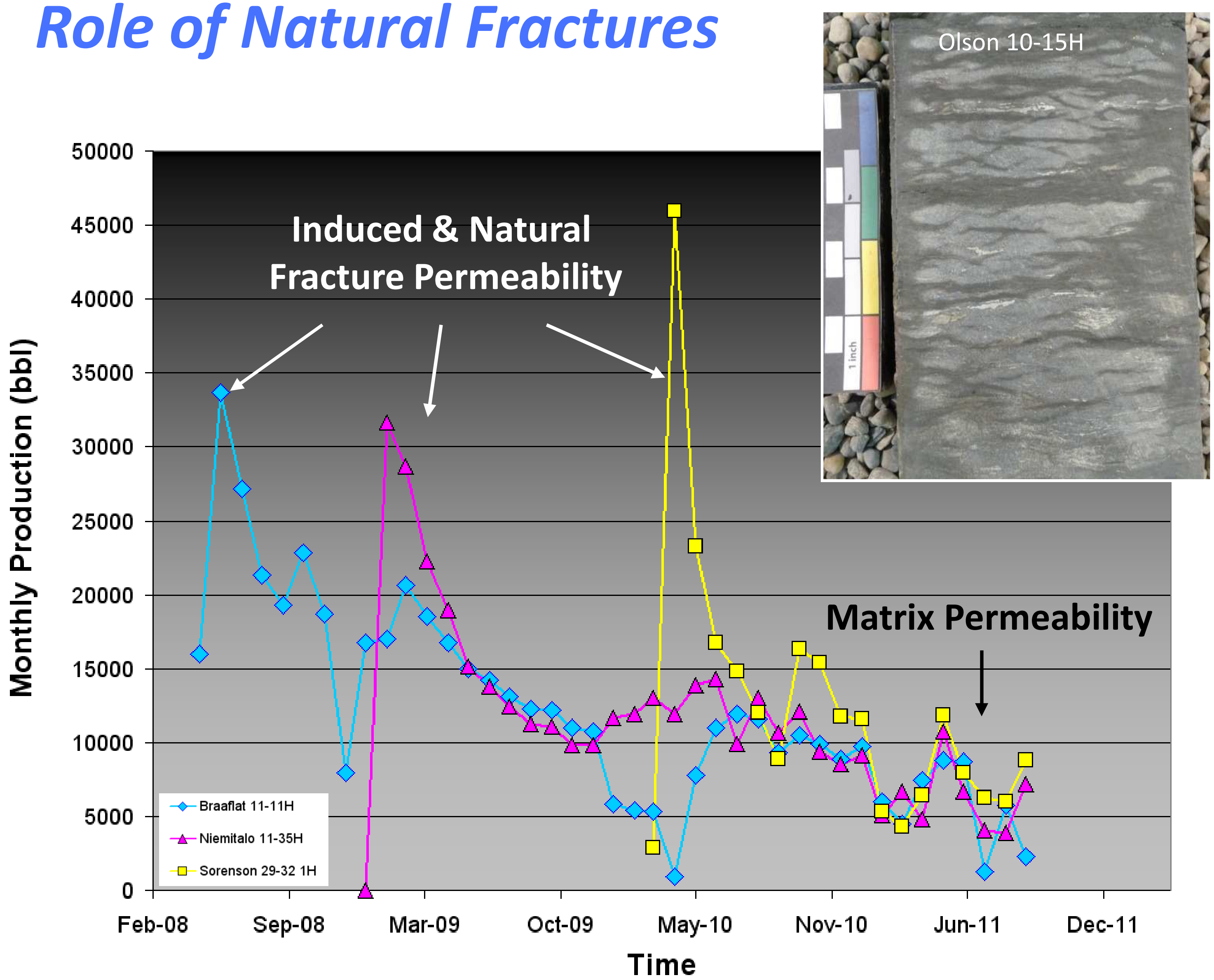
Another effect of migration

→ Depletion

Note, the high-water saturations on the previous map along the flanks of the Nesson anticline. They coincide with very low EUR values. Hydrocarbons migrated updip from this structurally low position either out onto the gentle flanks of the basin or to the crest of the anticline and off to Canada. Regional fractures associated with the anticline may have enhanced this process. Some oil and gas got locally entrapped.

Role of Natural Fractures

Natural fractures are very important for production and allow for very high initial production rates. Large-scale regional fractures are rare and quantitatively insignificant. The main type of fractures are probably those induced by hydrocarbon generation, and thus occur throughout the mature source-pod area.



Hydrocarbon-generation-induced **fractures** occur throughout mature source pod, and likely **not the discriminating factor between high- and low-productivity areas**

Conclusions

- Production does increase with more sophisticated completion technology **but geological factors have a larger impact on productivity** than technological improvements
- **Optimal completion design depends on area and field maturity**
  - 40-stage completions may not be economic in low-productivity areas
  - Simpler (cheaper) completions preferable for infill wells at late development stage
- Good correlation between **hydrocarbon generation potential, pore-overpressure and productivity**
- **Sweetspots** influenced by migration and trapping mechanisms (e.g., Sanish / Parshall, Elm Coulee)
- **Low-productivity areas** probably result of depletion due to migration (e.g., Nesson Anticline)
- **Natural fractures** play a significant role for production, but do not define sweetspot areas

Acknowledgements

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