From Monterey to Mowry, with Many Stops in Between*

Robert Sterling[1] and Anne Grau[2]

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Other presentations from this session and posted on Search and Discovery are Article #80375 (2014) by Wallace Dow, Article #80386 (2014) by Kenneth Peters, and Article #80387 (2014) by Prasanta Mukhopadhy.

[1]Cirque Resources LP, Denver, Colorado (rsterling@cirqueresources.com)
[2]Total E&P USA Inc. Houston, Texas

Abstract

Geochemistry has long been a critical aspect of defining conventional oil and gas exploration. In the development of unconventional oil resource plays utilizing geochemical properties, both organic and inorganic, enable an understanding of rock properties to be able to define the best places to expect commercial production from low-permeability source rock. Presented here is a brief history of the co-authors' use of geochemistry as another tool for developing an exploration program specifically targeting these oil-prone, low-permeability reservoirs. The Monterey Shale has long been known as a fractured "shale" reservoir and productive primarily in coastal California. Using geochemisty, a diagenetic- and thermal-maturity-controlled stratigraphic trap was defined and resulted in two discoveries, the North Shafter and Rose Fields in Kern County, California. Other oil-prone shales exhibit both similar and different characteristics. A sequential exploration program that started in the Monterey in the mid-1990's led to studying the similarities and differences of a variety of oil resource plays in the Rocky Mountain region, including the Niobrara, Mowry, Bakken, Heath, Chuar, Green River, and several others. Some of these plays have been commercial success stories, some have failed, and others are still in the process of being evaluated by industry. While specific attributes of geochemistry vary from play to play, the initial analysis of total organic content and thermal maturity remain critical to gain clear understanding of the resource. Also, the use of simple geochemical techniques, in addition to standard

pyrolysis, has been shown to be critical in defining critical items, such as parent source, reservoir compartmentalization, timing, and filling histories.

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From Monterey to Mowry
With Many Stops In-between

Anne Grau

Total E&P USA Inc.

Robert Sterling

Cirque Resources LP

Geochemistry is a necessary tool in unconventional resource plays

- Organic and inorganic geochemistry are important
  - **Organic**
    - Total Organic Content
    - Type and nature of kerogen
  - **Inorganic**
    - Lithology
    - Diagenesis
  - **Thermal history**
    - Basin heat history
    - Burial history of target horizon
- Presented here are several plays where integration of both aspects were essential
- Wally Dow was influential in all these plays either as a co-worker or through literature. *(thanks, Wally!)*

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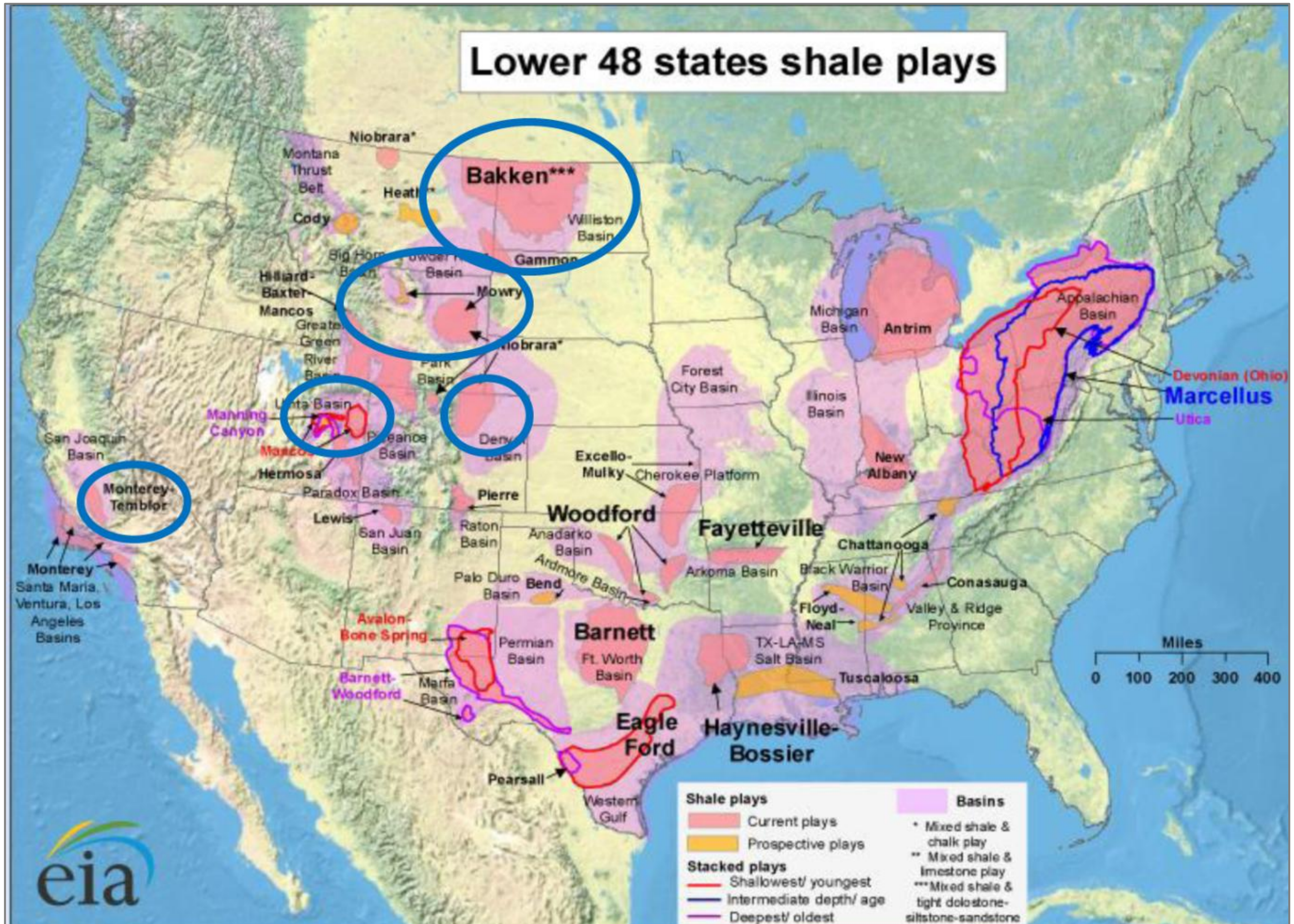
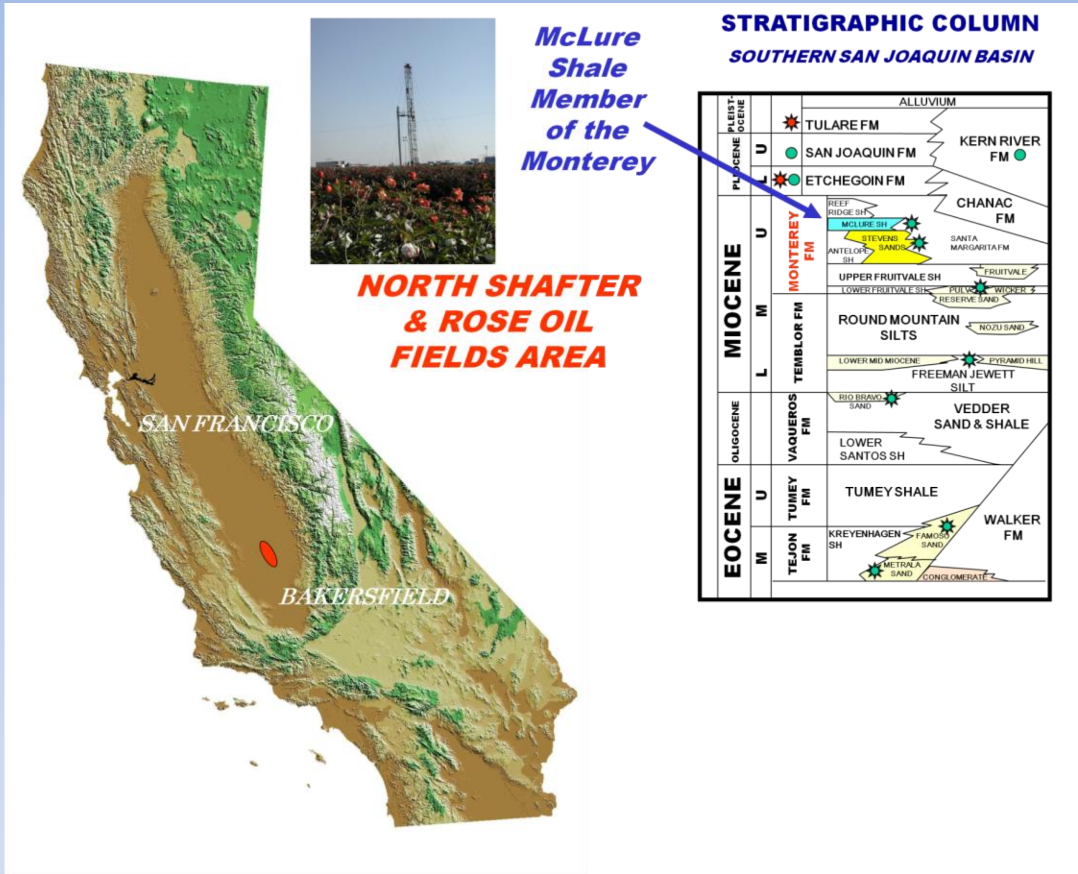


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

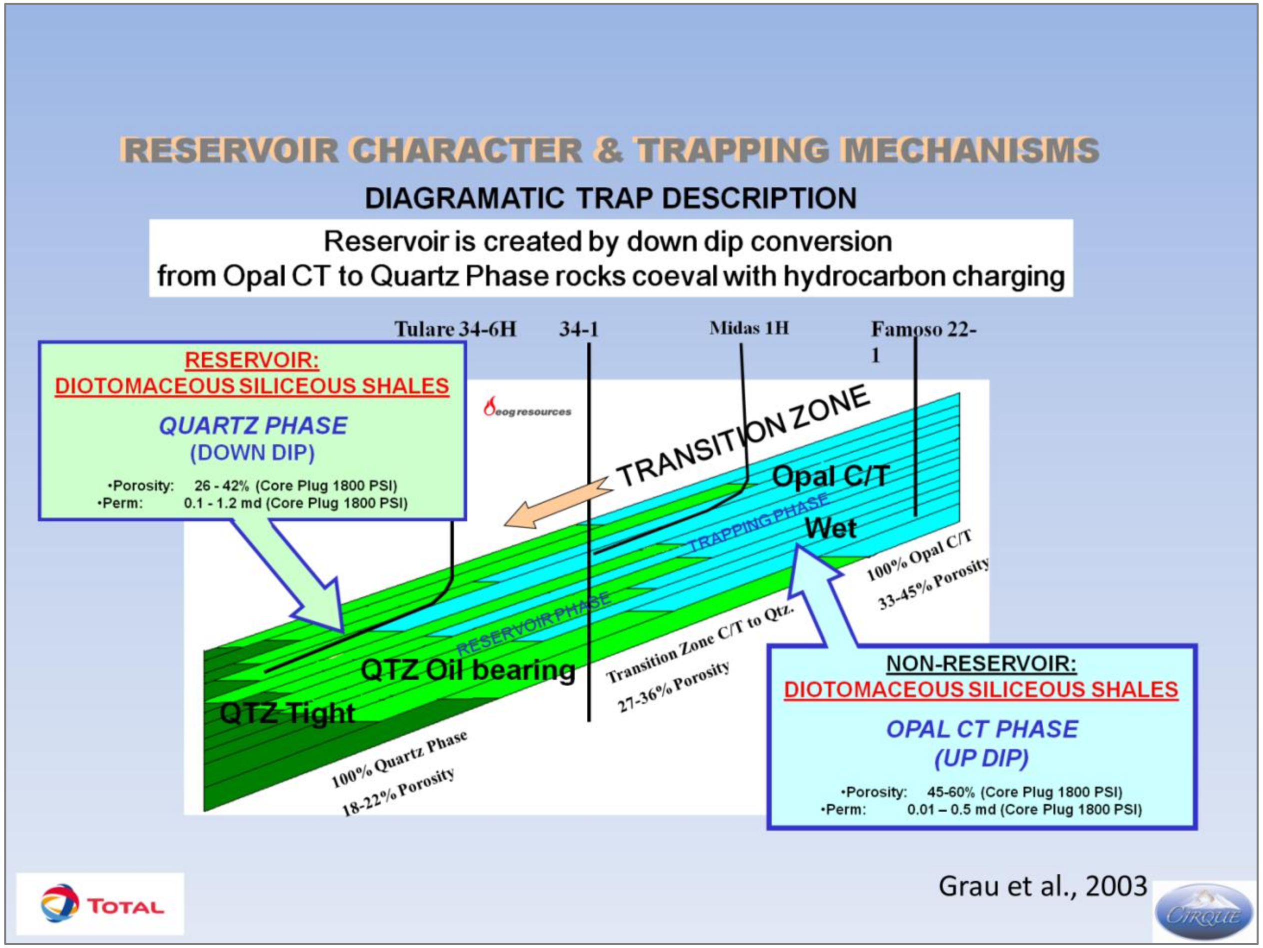
Presenter's notes: These are the different plays discussed in this presentation. Certain geochemical challenges were posed by each play. First is the Monterey, then the Uinta Basin Mesaverde play, the Bakken, Niobrara, and Mowry Shale.

Monterey Shale
Kern County, California

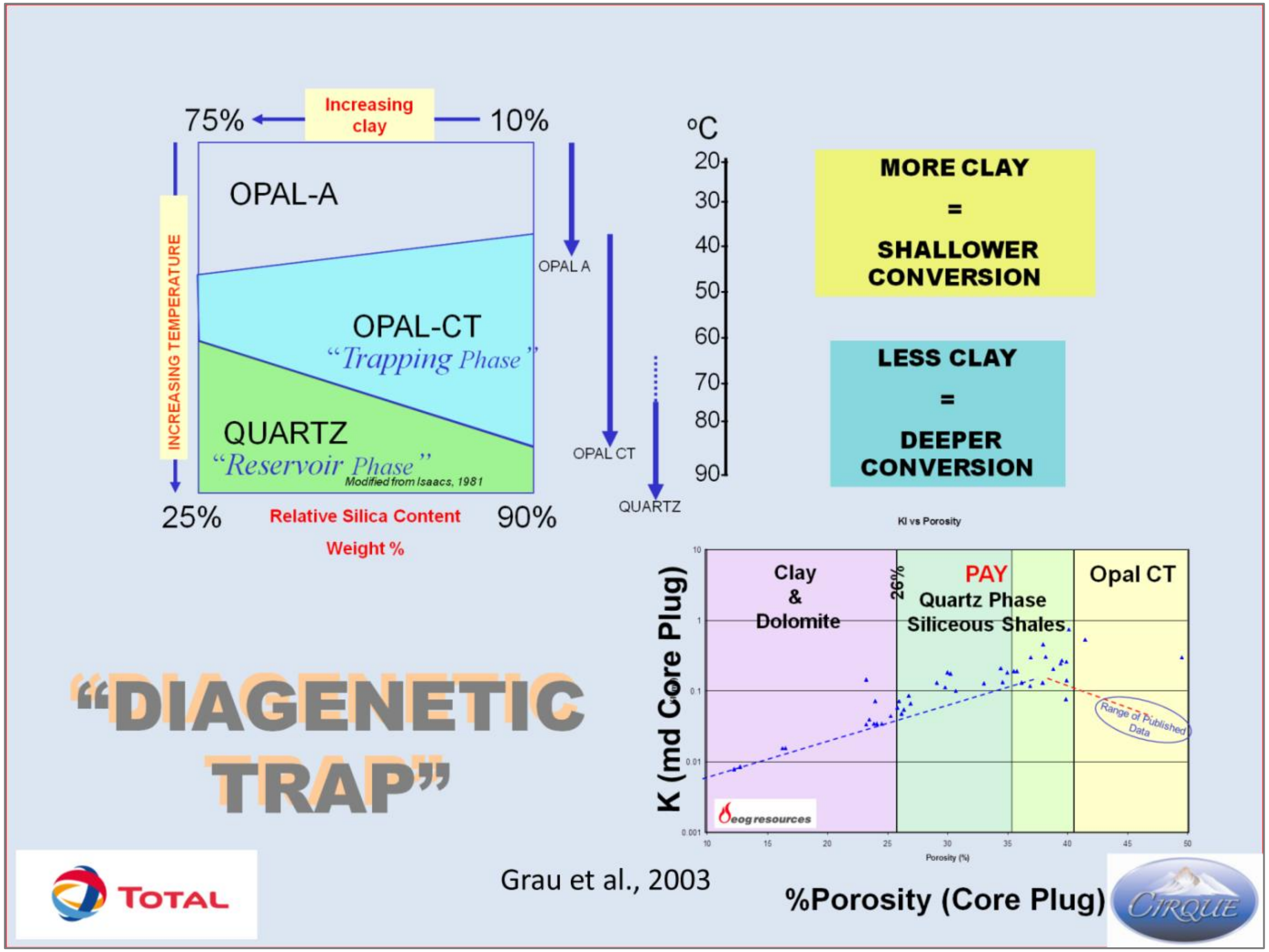
- EOG began horizontal drilling with frac stimulation in 1996 at North Shafter
- Petroleum system and trap configuration required specific organic and inorganic geochemical solutions



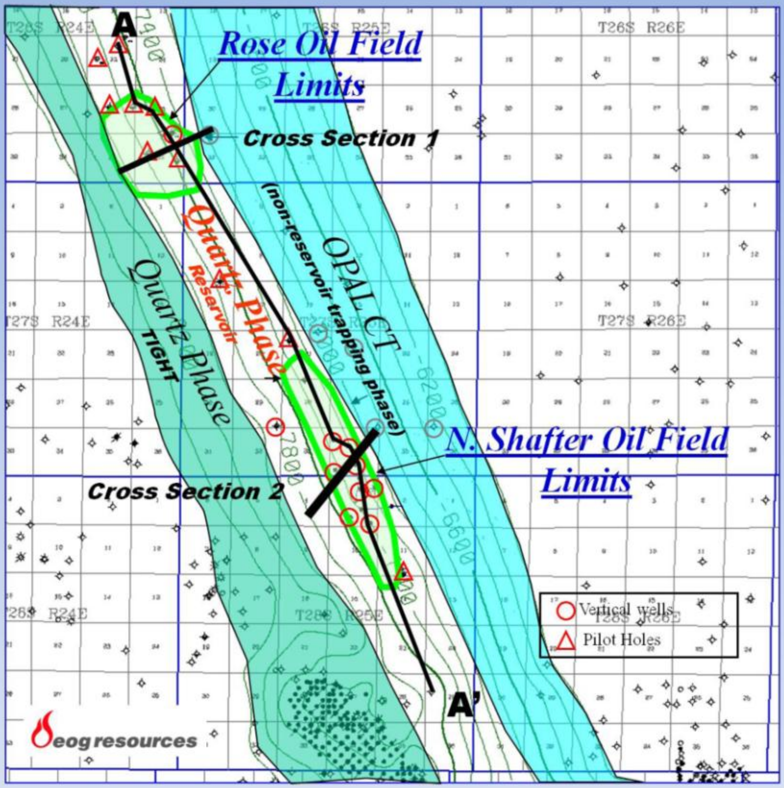
Grau et al., 2003



Presenter's notes: The "Happy Accident" of catagenesis and diagenesis resulted in a very interesting oil accumulation at North Shafter and Rose fields. Rock work, including conventional core saturation analysis along with X-ray diffraction, was essential in understanding distribution of oil in each facies.



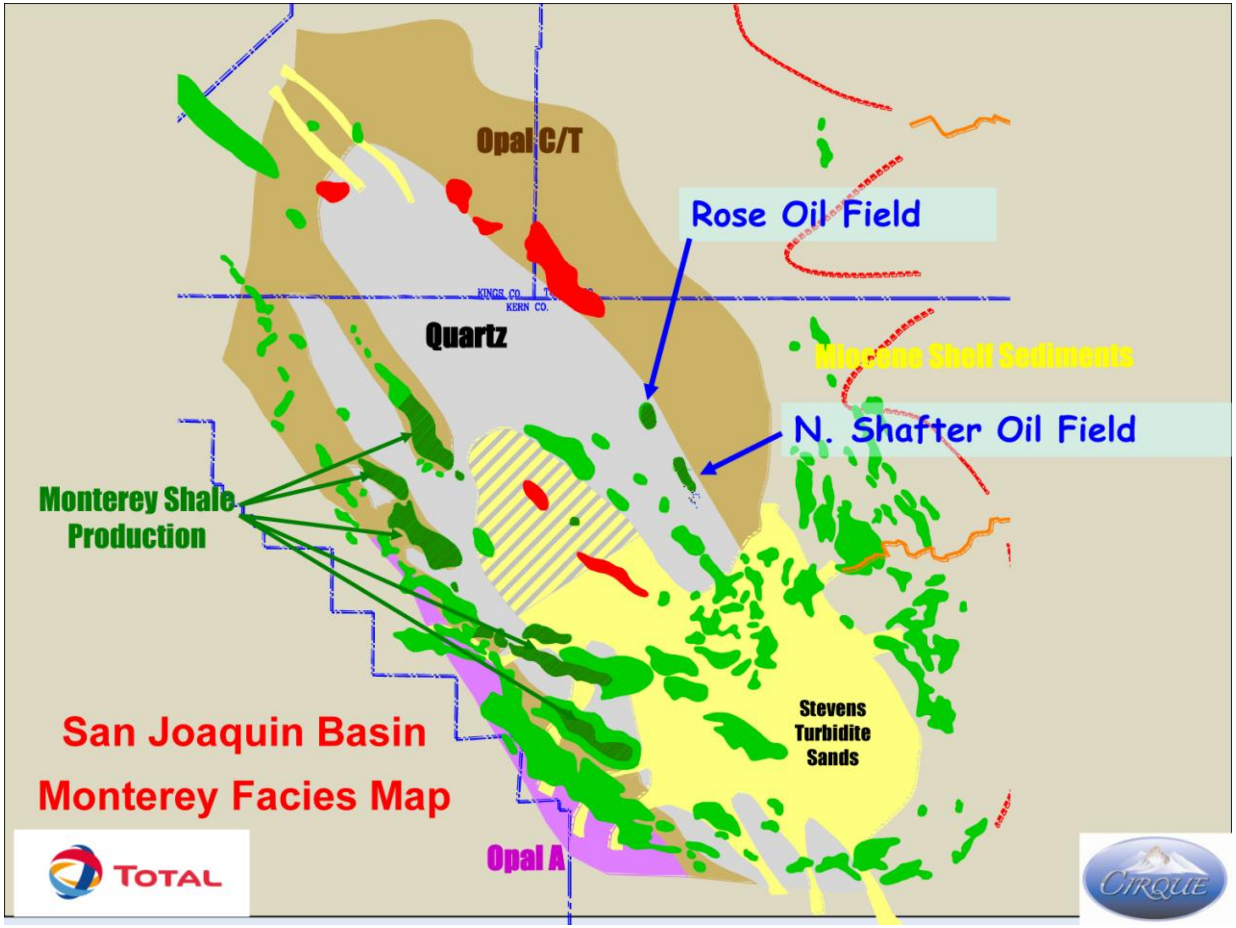
Presenter's notes: Understanding of the inorganic rock geochemistry was key to solving this puzzle. A change from opal c/t to quartz resulted in lower porosity but higher permeability due to the creation of microfractures.



STRUCTURE: Top of the McLure Shale
CI: 200'

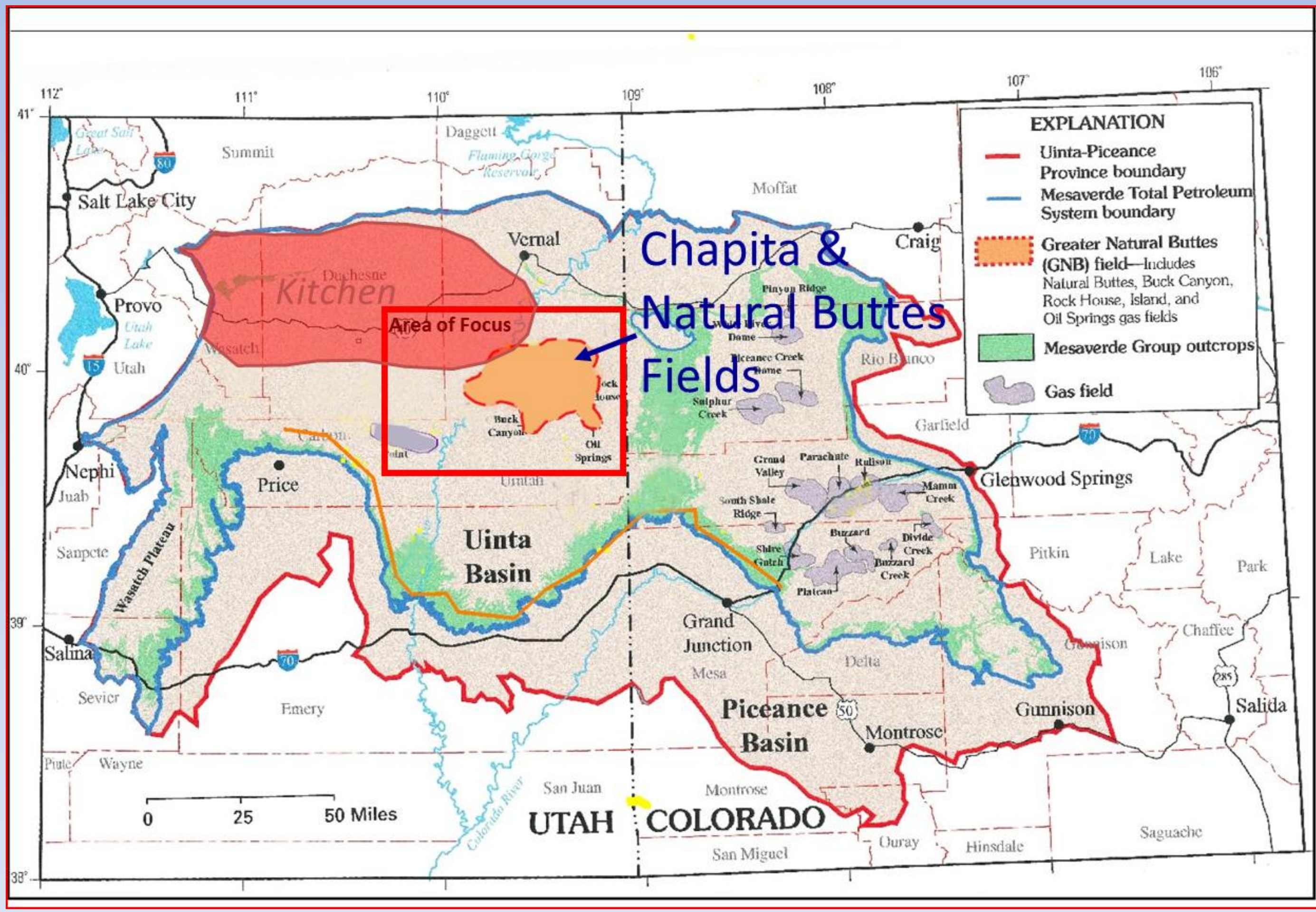
Grau et al., 2003

Presenter's notes: Integrating organic and inorganic geochemistry was critical in defining the "sweet spot" for this Monterey shale play.



Presenter's notes: Points on the fields located on the large structures. Most production is not from Monterey, but we have highlighted the areas that are. Most Monterey production on the west side is associated with the large structures and highly fractured Monterey facies. Rose and North Shafter are the only sites of Monterey production on the east side of the basin. This production is not associated with structure or tectonic fracturing of the reservoir.

Uinta Basin Gas Play

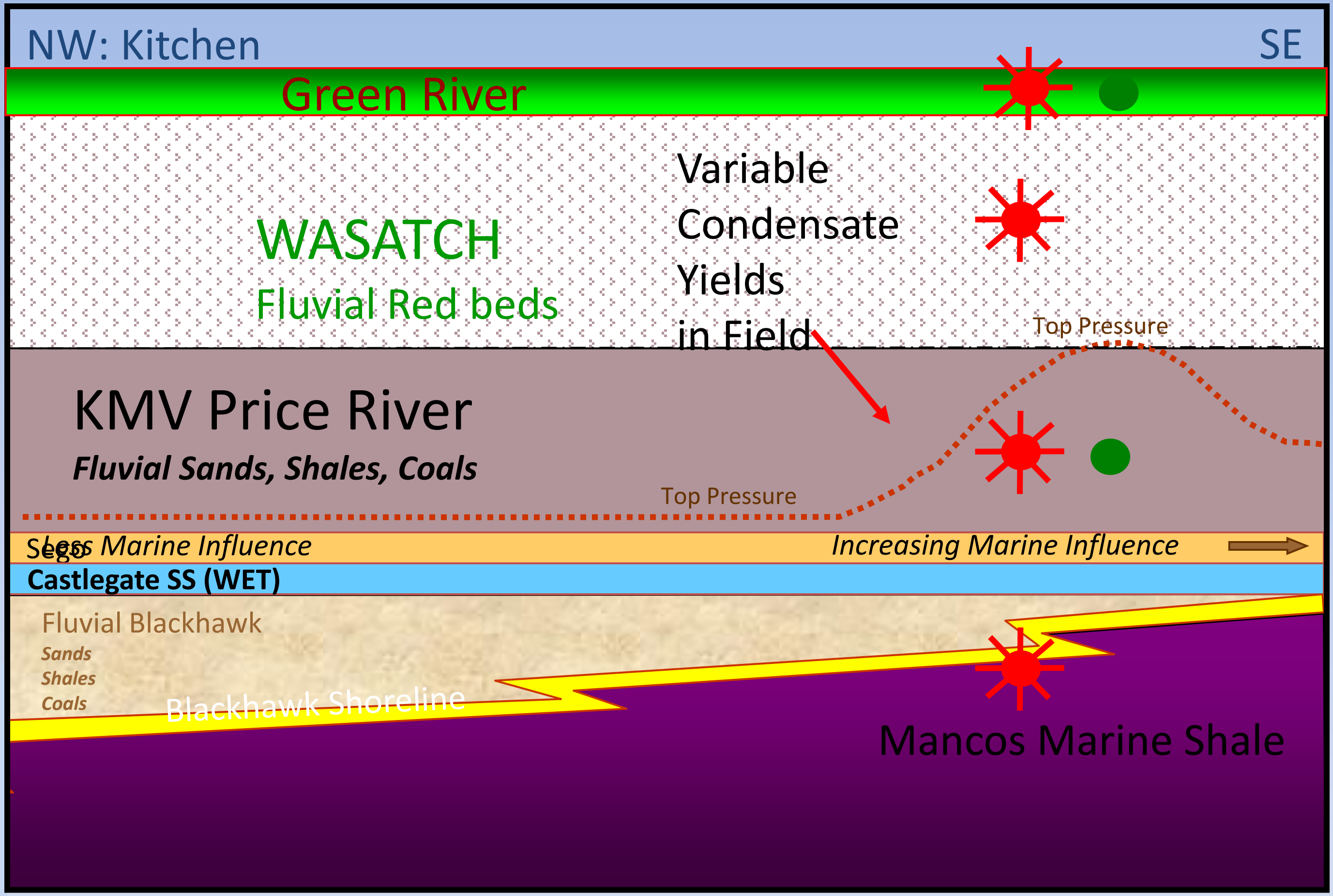


Modified from USGS

Grau et al., 2007

UINTA BASIN PETROLEUM SYSTEM MODEL CIRCA 2002

Chapita Wells/GNB



Where is the next Chapita?

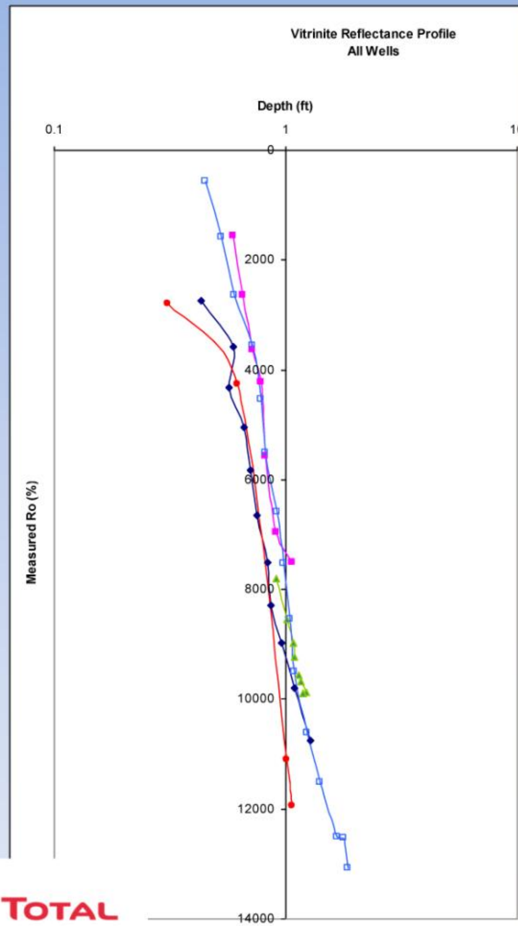
Grau et al., 2007

Questions: Chapita Geochemistry

- How many Petroleum "families" are in the field area?
- Is our field compartmentalized, geochemically?
- What is causing the difference seen in condensate yields?
- Are the Gases & Condensates genetically related or separately sourced?
- Where is the Next Chapita?

Grau et al., 2007

Presenter's notes: These questions pose a strictly organic geochemical problem.



Vitrinite Reflectance profiles for Quantitative Maturity

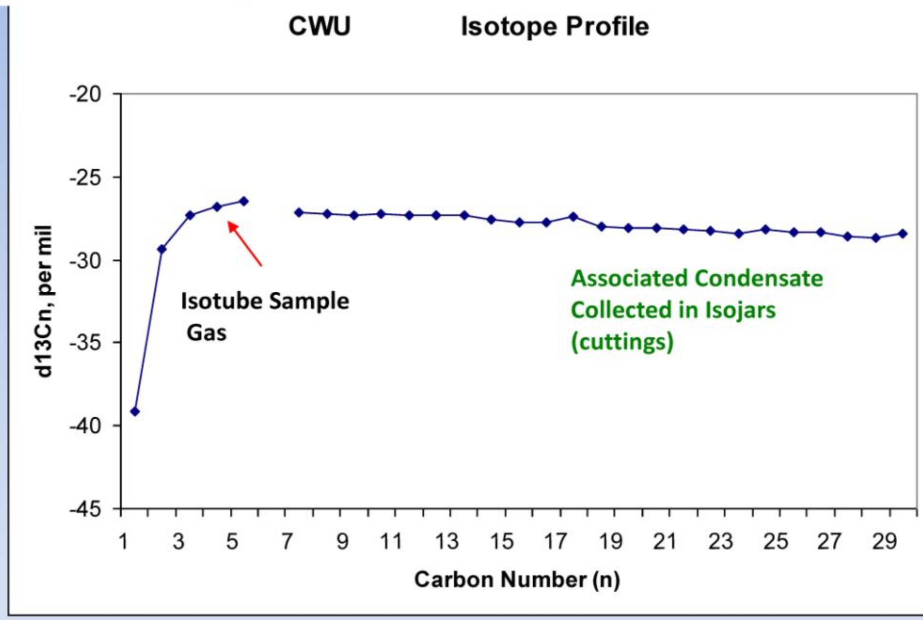
Wet Cuts are taken every 500'

- Analyzed for Ro% (Humble)
- Vitrinite reflectance profiles
- Identifies Stratigraphy in
  - Immature Zone
  - Oil Window
  - Dry Gas Window
- Useful in Burial History Profiles
- Useful in Basin Temperature modeling

Grau et al., 2007

Presenter's notes: Vitrinite work on cuttings from drilling wells was performed to develop thermal maturity profiles from the rock.

Gas and Condensate Pairs show Genetic Link: (Same Source)

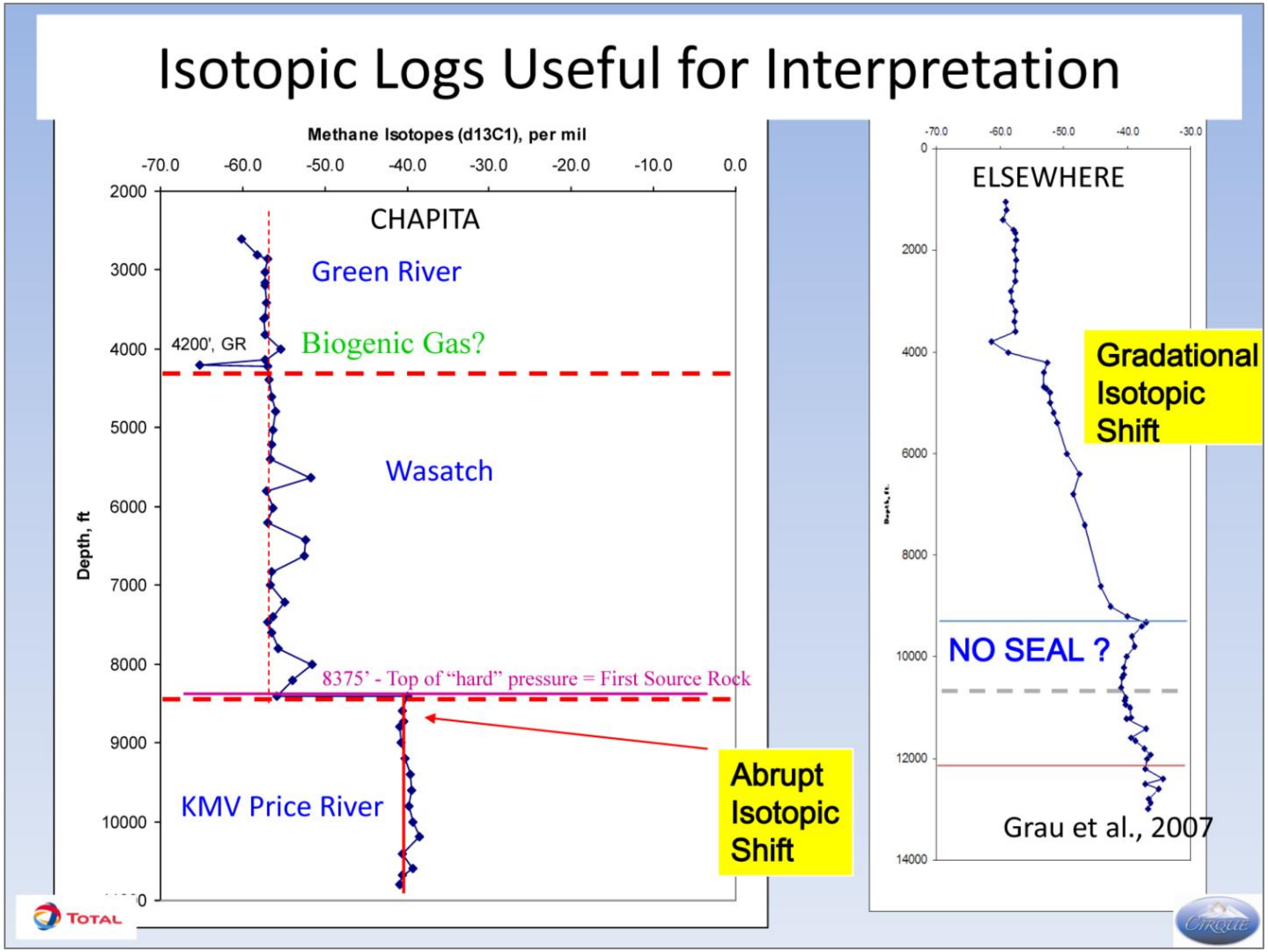


Compound Specific Isotopic Analysis

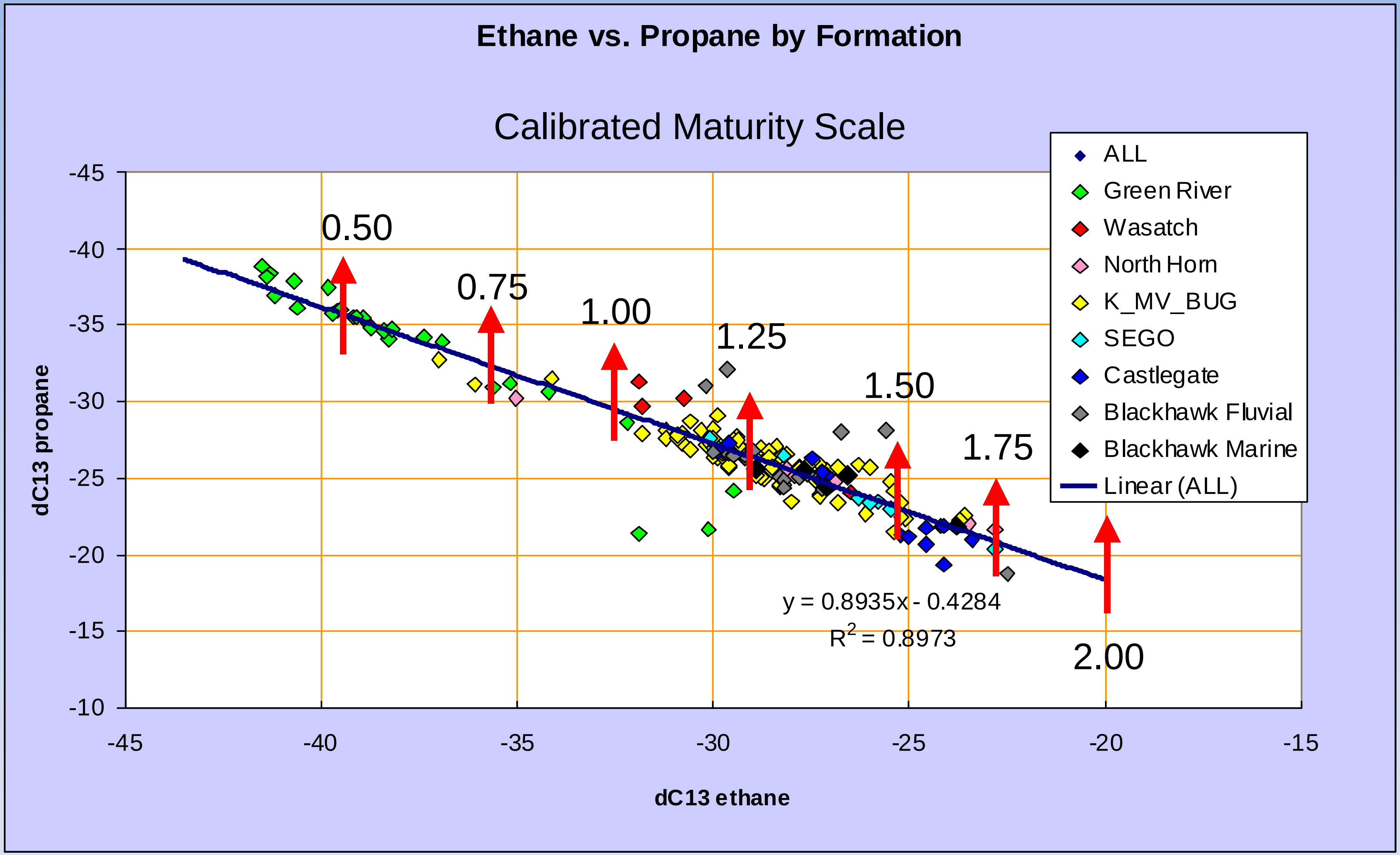
Grau et al., 2007

Do the gases and condensates have the same source in the field area? Yes

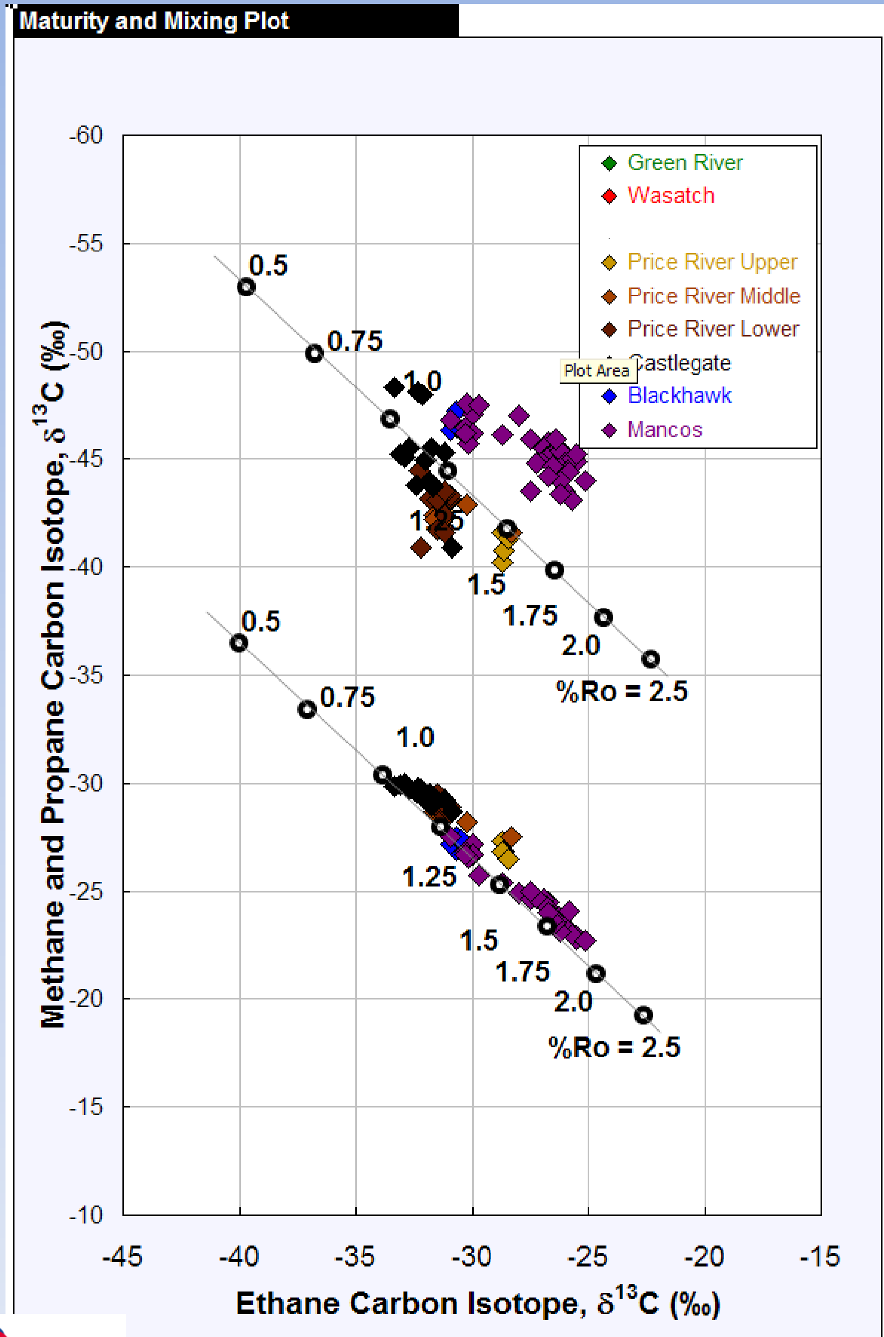
Presenter's notes: Isotube gas samples while drilling where compared to condensate collected from isojars, holding cuttings.



Presenter's notes: Isotube gas sample profiles were prepared to help develop profiles of isotopic gas data. These were key to finding the differences in areas where there are good seals and no seals.



Grau et al., 2007



Maturity can be inferred from Isotopic Measurements (MGIA)

Grau et al., 2007

Conclusions: Uinta Geochem Program

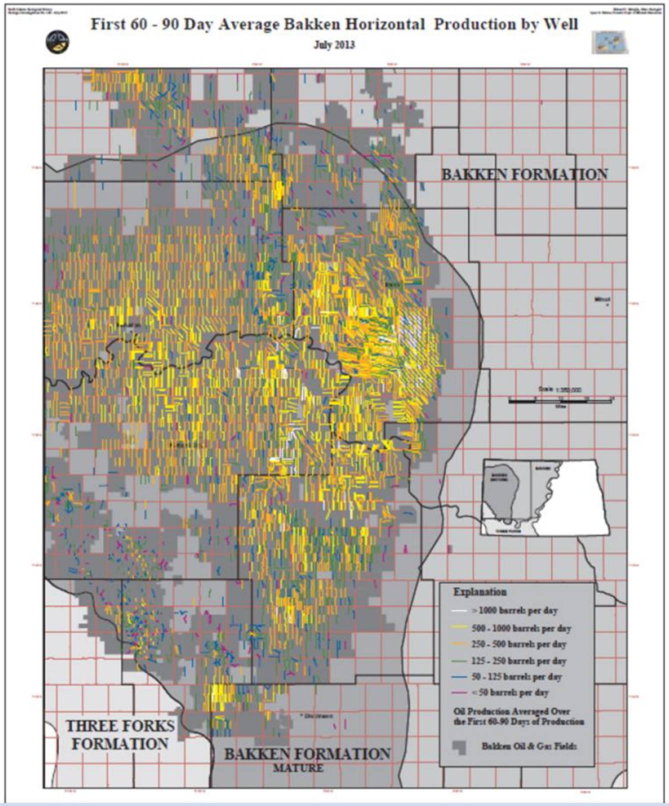
- Identified 5 Sources
- Identified 6 Petroleum Families
- Identified Sealing, Non-Sealing systems
- Identified and Quantified Maturity
- Aided in Development
- Identified Prospect Fairways

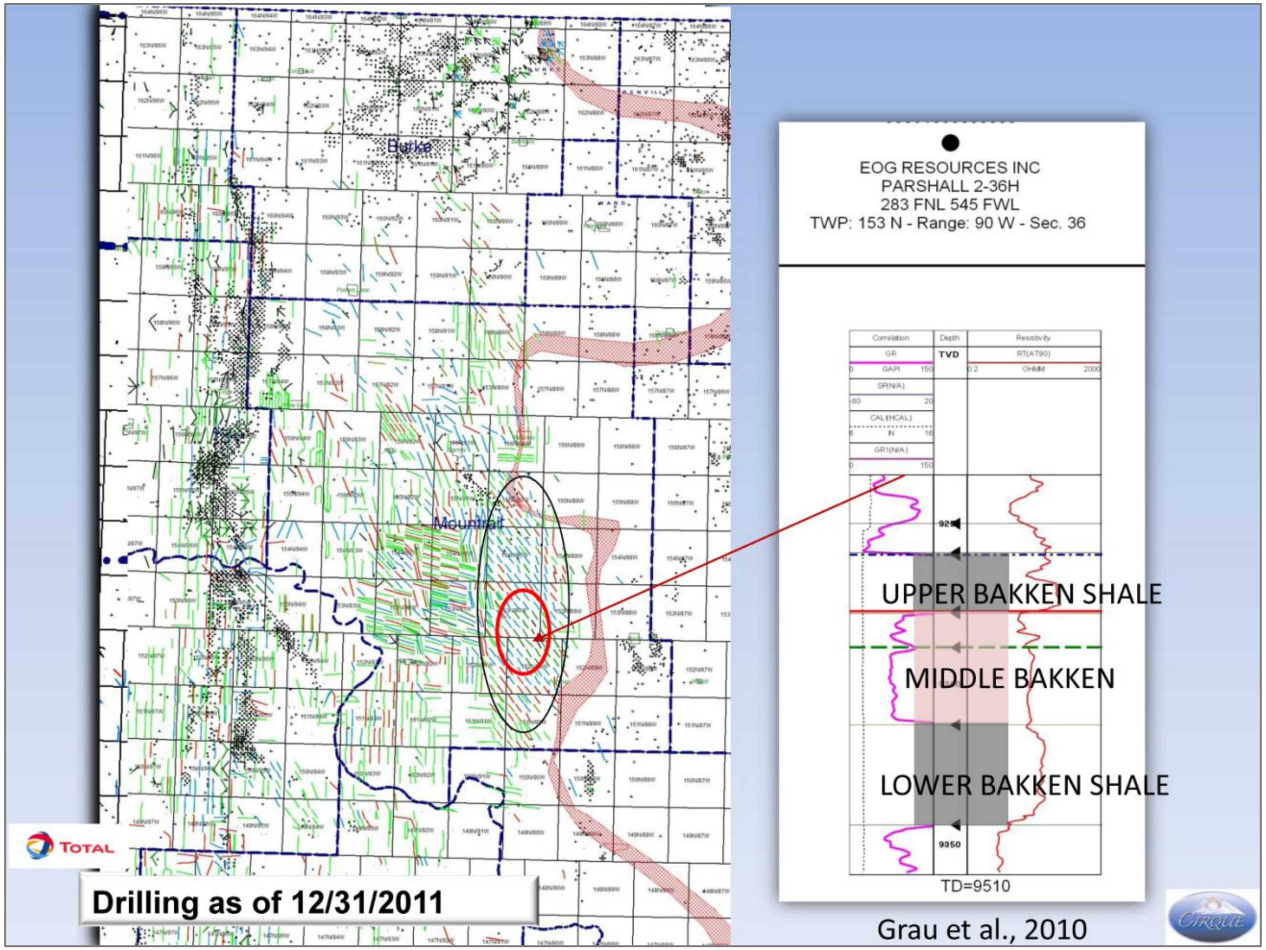
Grau et al., 2007

Bakken Play
Williston Basin, North Dakota & Montana

- Long known to contain hydrocarbons
- Long thought to be too tight to produce
- EOG applies horizontal drilling in North Dakota in June 2006
- Application of Organic and Inorganic geochemistry essential to understanding this petroleum system

Development area
> 15,000 sq mi
Size of West Virginia

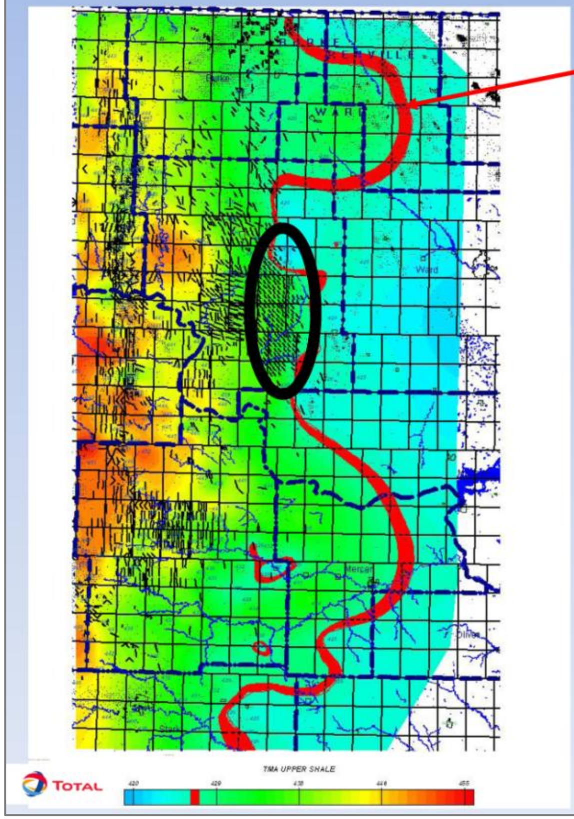




Presenter's notes: EOG initially drilled in an area with no Bakken production looking for another Elm Coulee type accumulation. Initial well results on the Parshall 1-36H led to taking a core in the Parshall 2-36H; that was critical in understanding what the "reservoir" truly is.

Another critical interaction of organic and inorganic geochemistry led to a unique area within the Bakken.

Source Rock Maturity

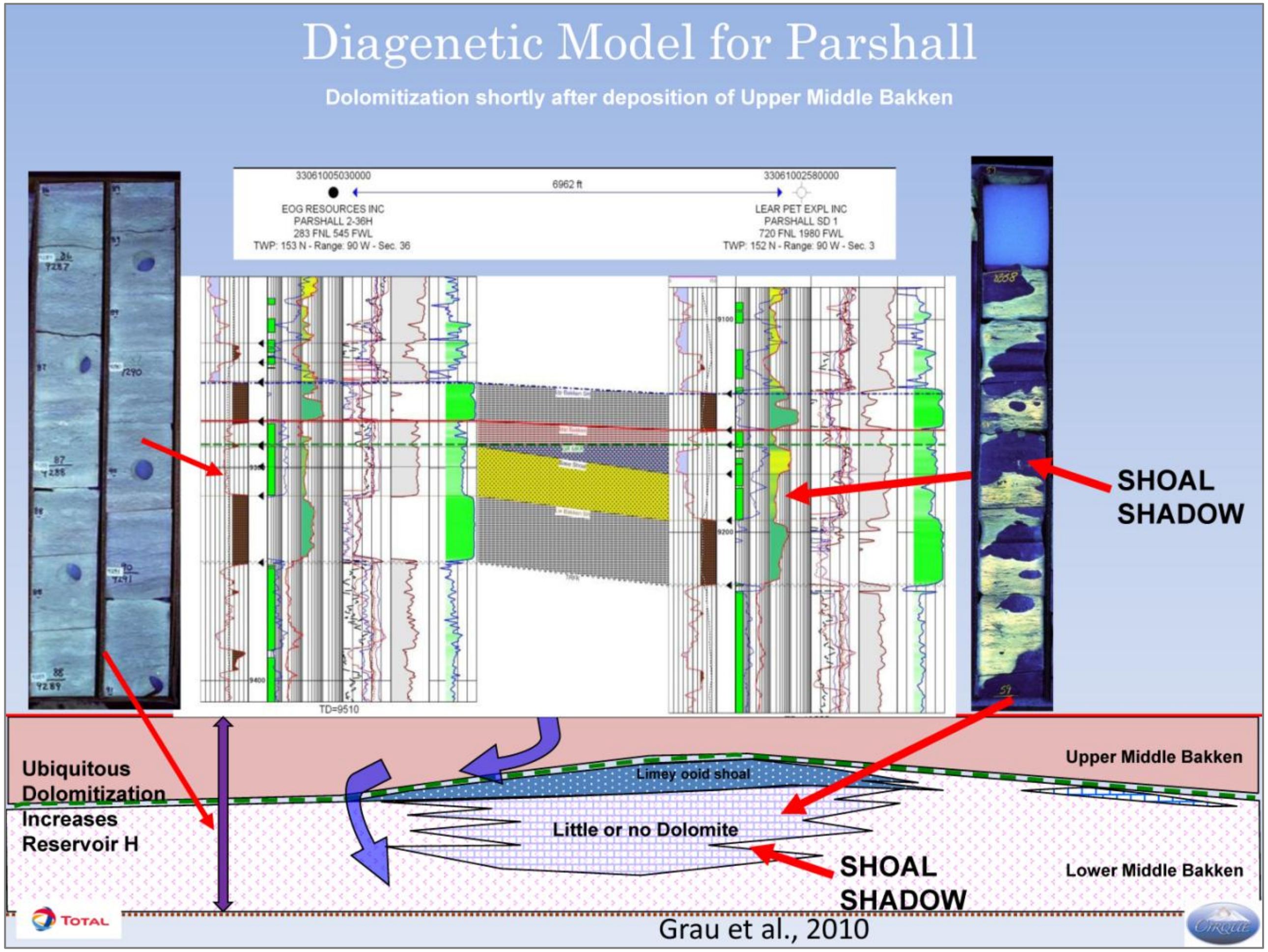


TMAX 426 Upper Shale

- Parshall Field is located in an area where thermal maturity is higher than other areas along strike
- Lineament patterns help define distribution of heat flow to the Bakken
- Higher heat flow in the Parshall area along with low activation energy in some of the kerogen allowed for early generation

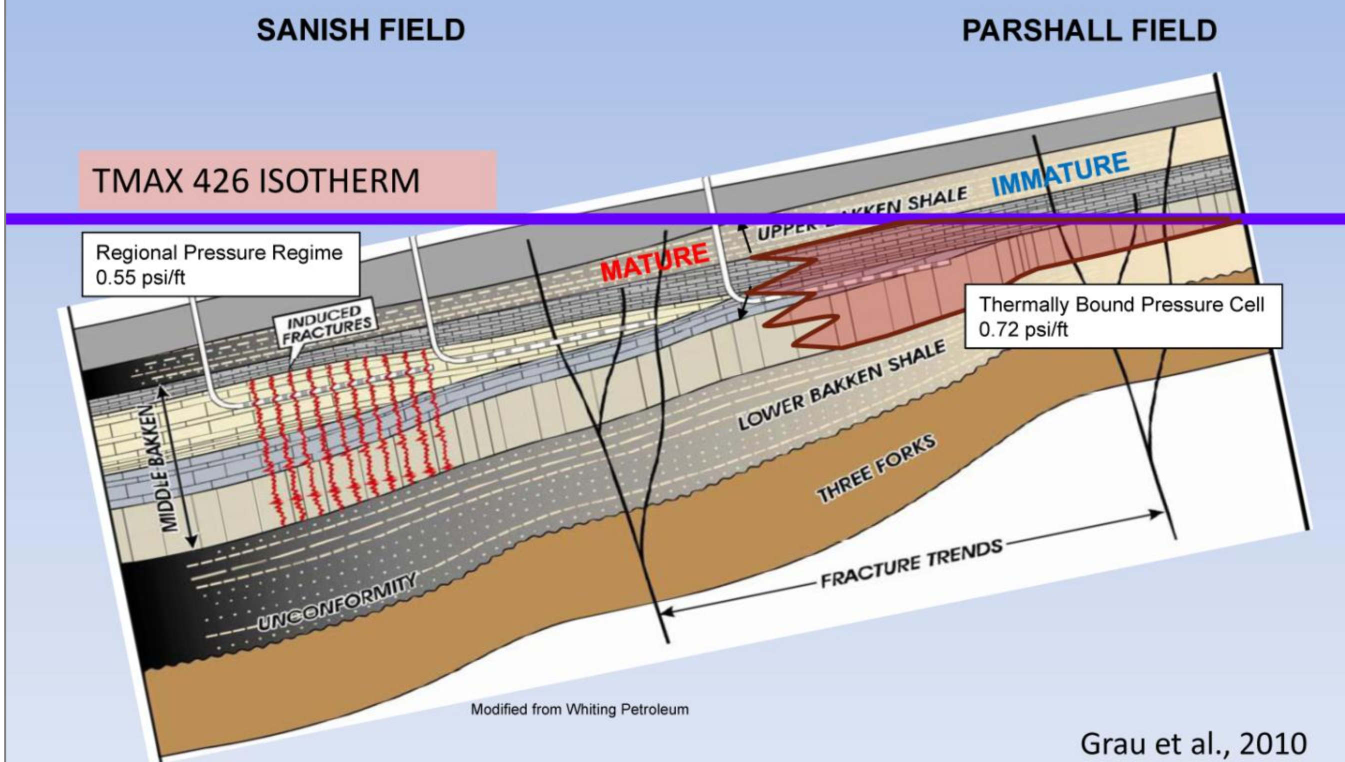
Grau et al., 2010

Presenter's notes: Thermal maturity of the Upper Bakken Shale was mapped using Rock-Eval. The onset of generation is lower than one might expect.



Presenter's notes: Understanding the diagenetic history is key to identifying the best parts of the reservoir. Identifying the mechanics that contributed to the dolomitization, or lack thereof, helped to differentiate good areas from poorer areas in this part of the Bakken play.

Pressure Model for Parshall Field

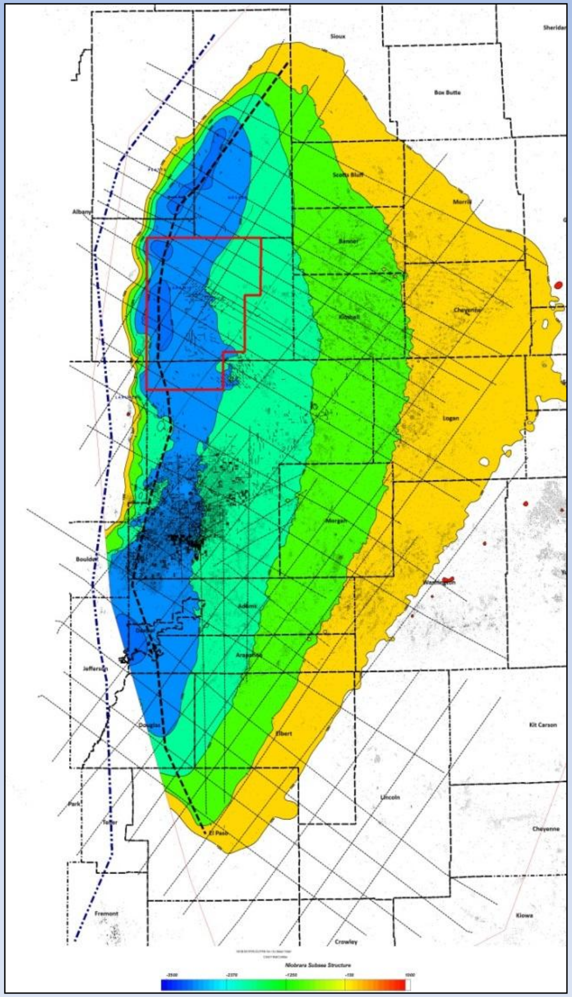


Grau et al., 2010

Presenter's notes: Here, once again, the interaction of organic and inorganic geochemistry was critical in developing an understanding of how this oil accumulation formed.

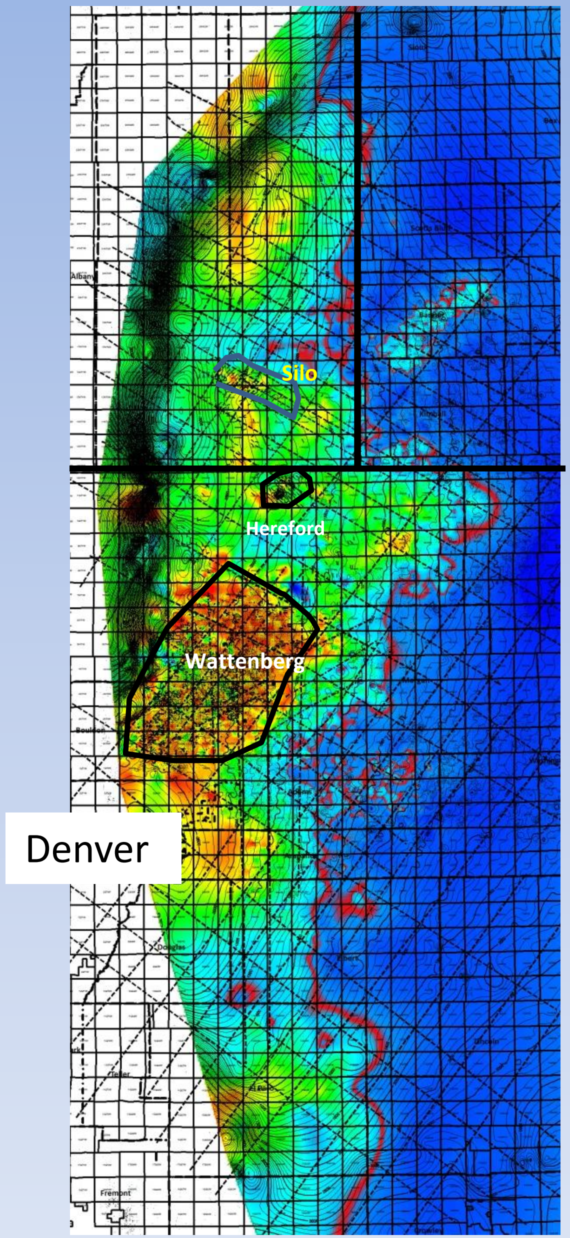
Niobrara "Shale"
DJ Basin, Colorado & Wyoming

- Productive facies is carbonate
  - Need to understand any diagenetic effects on reservoir development
- Self-sourcing
  - Understand type and distribution of organic content
  - Thermogenic history in basin is key to distribution of gas and oil portions of play

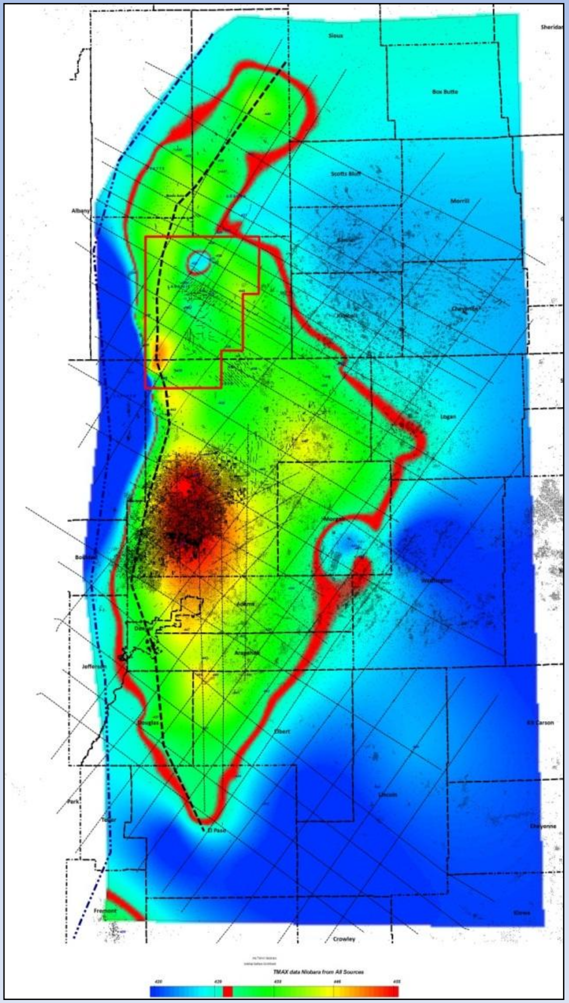


DJ Basin
Niobrara Peak Resistivity

- Resistivity in the B Bench has been used as a proxy for thermal maturity
- Higher resisitivity generally responds to structural lineamants related to basement faulting and heat flow.
- Wattenberg is a "hot spot"
  - Higher geothermal gradient
  - Gas condensate window
  - Vertical play economics diminish as the rocks grade into oil window
  - Horizontal drilling on fringes of Wattenberg is proper engineering solution for more viscous oil in tight rocks



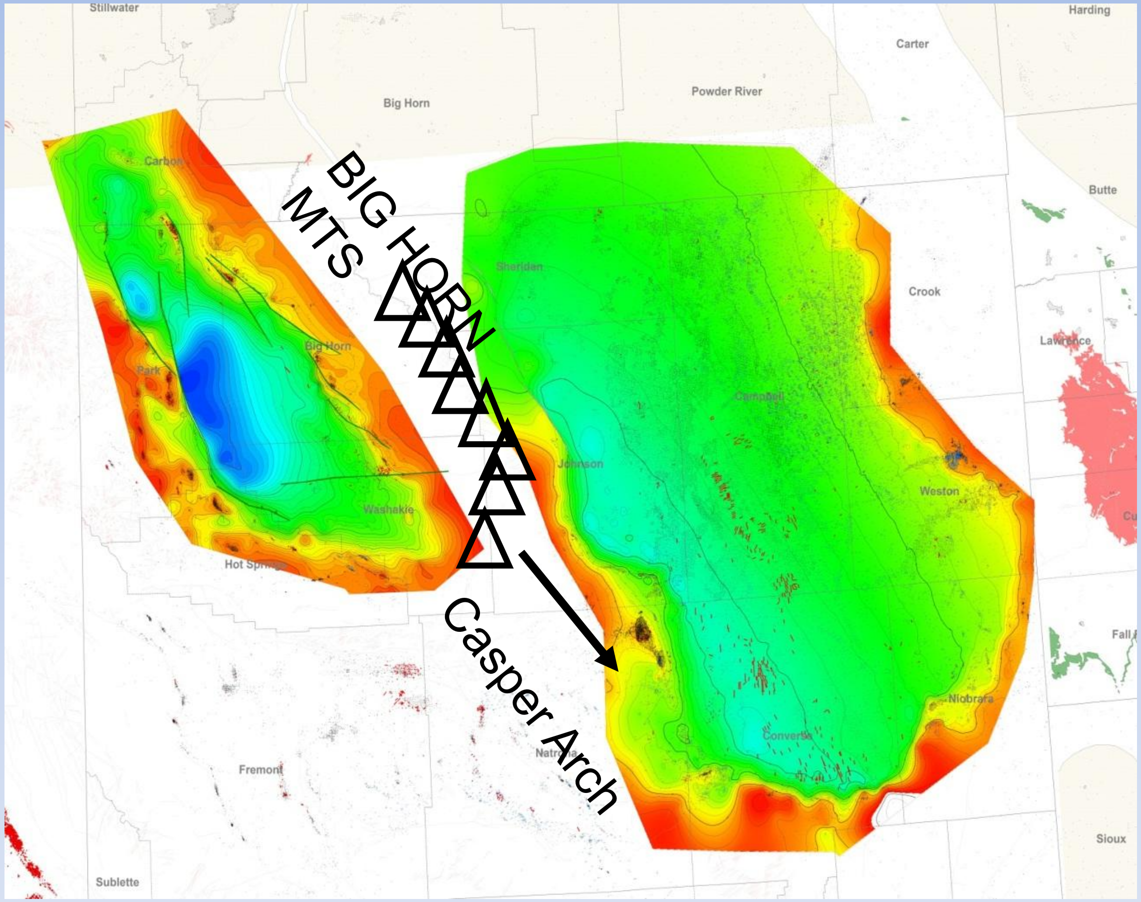
Thermal Maturity Niobrara TMAX
Greater DJ Basin



- TMAX is more reliable maturity indicator in Niobrara than vitrinite reflectance
- Codell oils are typed to be associated with Niobrara oils
- Codell saturation dependent on mature Niobrara source rock
- Wattenberg is in gas window (TMAX ~ 455 deg C)
- Vertical wells in Niobrara and Codell uneconomic in oil window (TMAX< 448 deg C)
- Basement lineaments control distribution of heat flow throughout basin.

Mowry Shale
Big Horn and Powder River Basins, WY

- Siliceous shale covering large part of Rockies basins
- Emerging play that is not fully vetted by industry



Subsea Structure Top Mowry Shale

Big Horn Basin is deeper and has steeper dip on eastern flank

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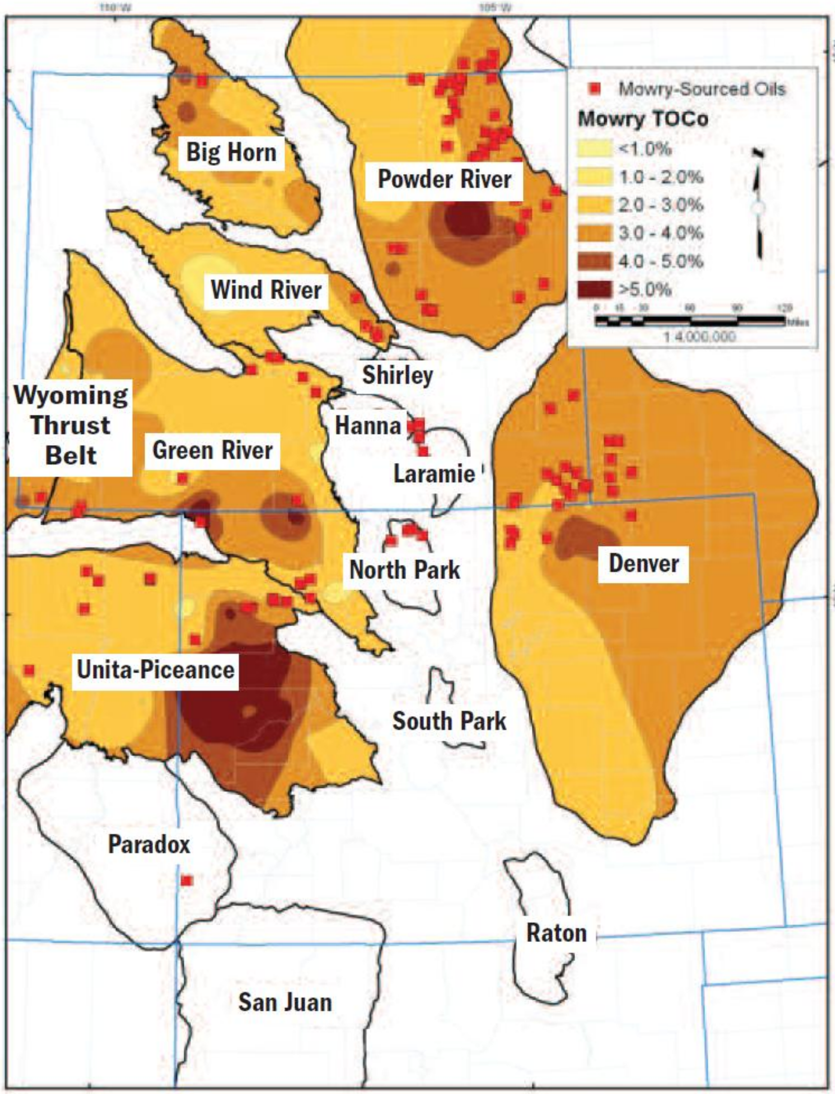
TOC and HI for Mowry Shale



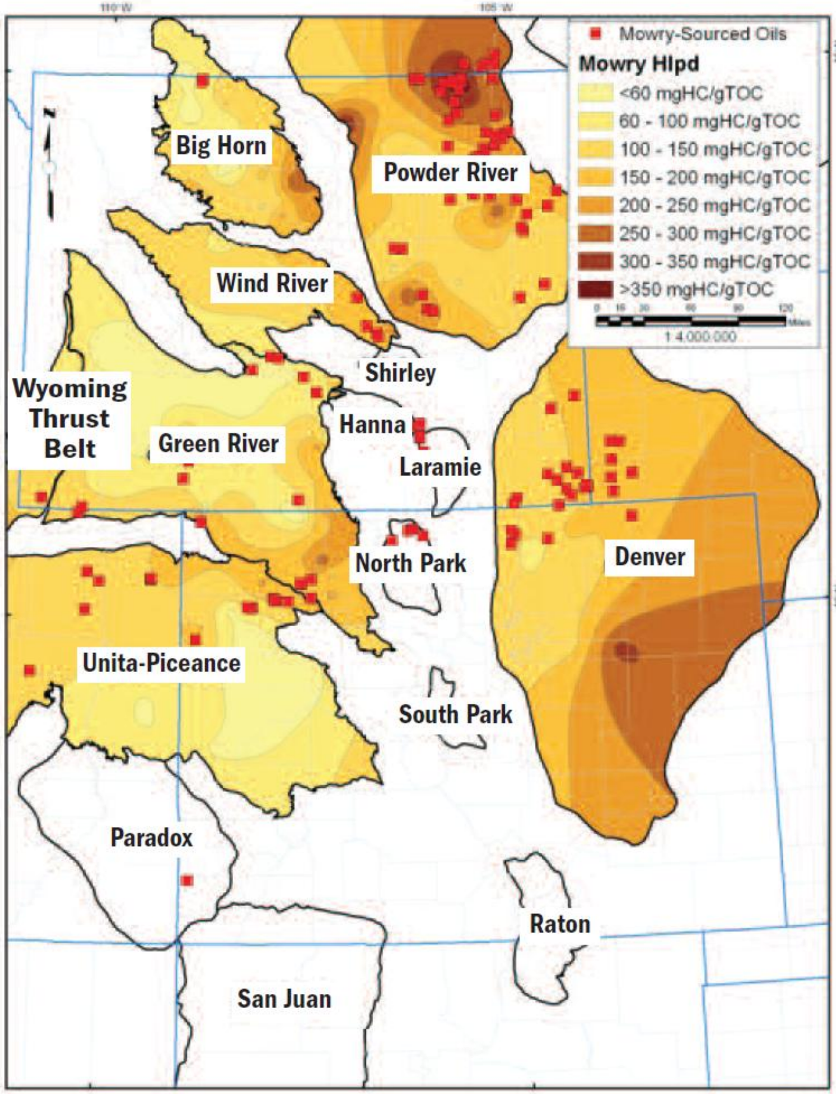
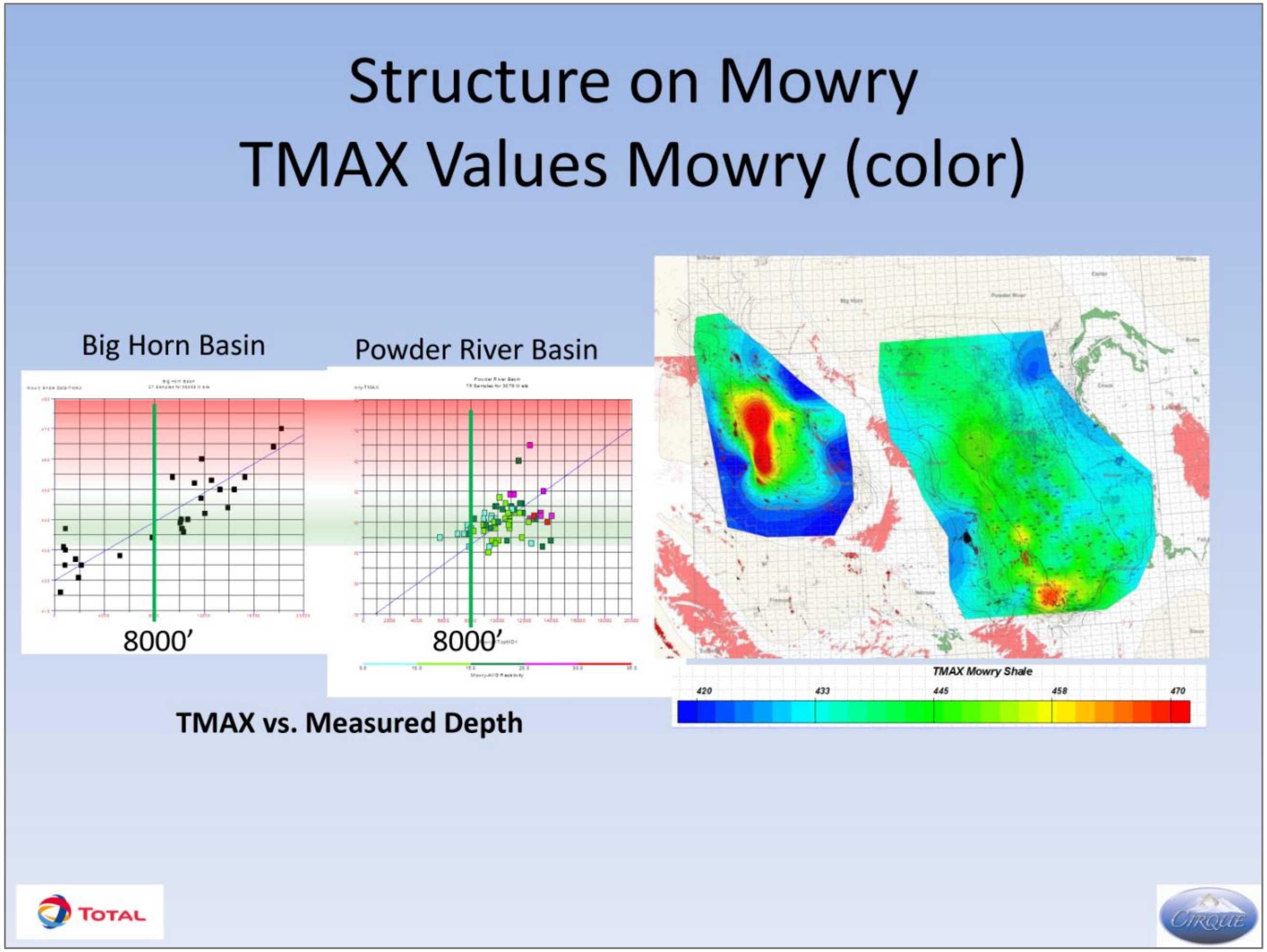


Figure 1: *Preliminary Oil Family Maps, Mowry System*

Curtis & Zumberge, 2013

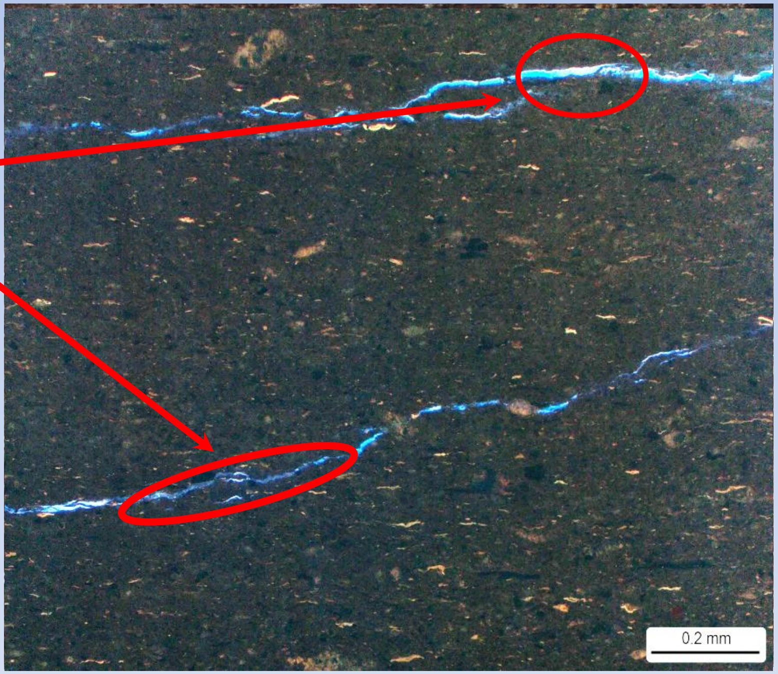


Presenter's notes: In the BHB, there is a good relationship between present-day measured depth and thermal maturity. For the PRB, that relationship is not so well established; this suggests a more complicated heat flow-dynamic for that basin. Mowry is not in the gas window in the deepest part of the BHB and only in the condensate window in the southern part of the PRB.

Mowry Microfractures

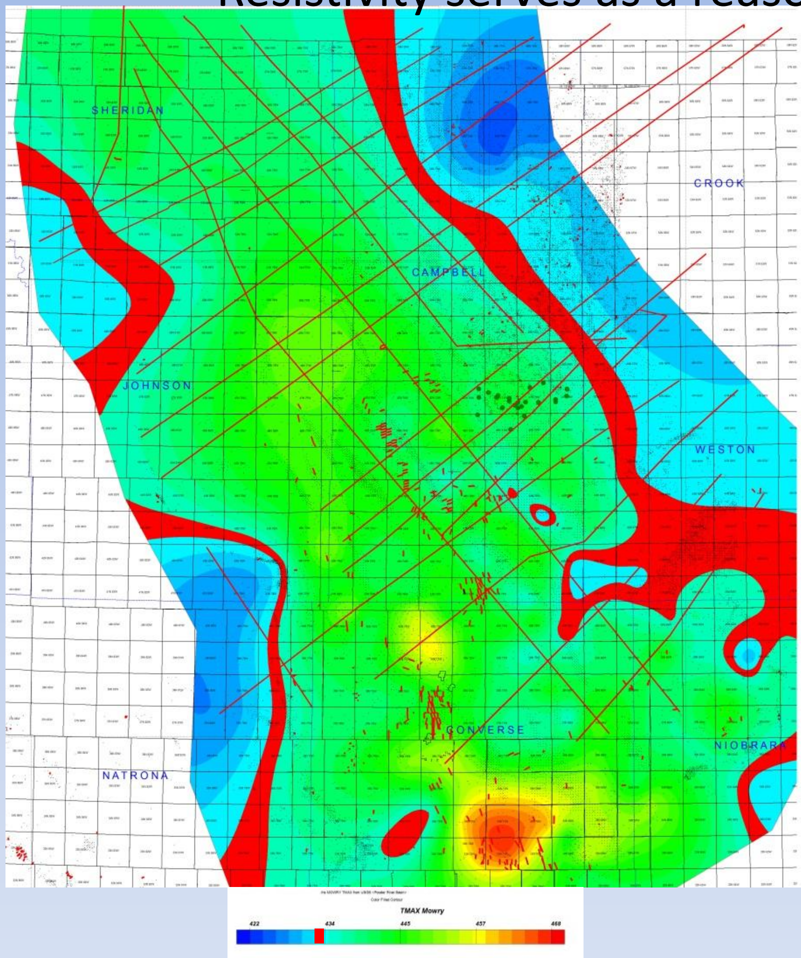
This only happens in brittle rocks!

- Microfractures not as apparent in white light
- Epiflourescence reveals complex microfractures
- Quartz cement partially fills microfractures to help keep them open
- Result of oil generation in brittle rock
  - Microfracturing due to volume expansion (10-13%) as kerogen converts to hydrocarbon
- Overpressuring develops due to limited accommodation space in the rock.
- The more brittle the rock, the more accommodation space is created in the form of microfractures
- Microfractures will align with maximum stress field present during catagenesis, forming the "fabric" of the rock



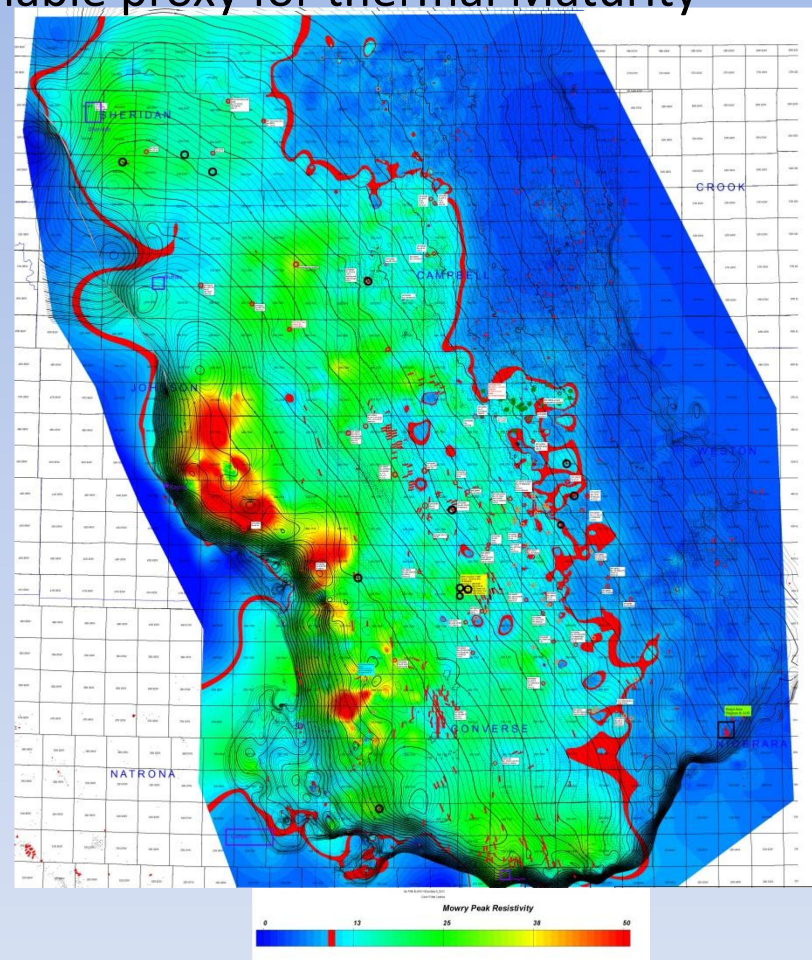
Tmax and Resistivity Mowry

Resistivity serves as a reasonable proxy for thermal Maturity



TMAX contours

433 deg. C cutoff (red line)



Peak Resistivity showing DST in Mowry notes

10 Ohm cutoff (red line)

Summary & Conclusions

- Geochemistry is key to understanding unconventional resource plays, oil or gas
- The interaction of inorganic and organic geochemistry is one of the most important aspects to understanding the play
- Geochemistry innovations by pioneers such as Wally Dow have been very important additions to the industry's ability to understand unconventional plays.

Acknowledgements

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