

Niobrara Source Rock Maturity in the Denver Basin: A Study of Differential Heating and Tectonics on Petroleum Prospectivity Using Programmed Pyrolysis*

David J. Thul^{1,2} and Steve Sonnenberg²

Search and Discovery Article #80341 (2013)**

Posted November 25, 2013

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

**AAPG©2013 Serial rights given by author. For all other rights contact author directly.

^{1,2}PetroLuminary, LLC, Denver, CO (dthul@petroluminary.com)

²Colorado School of Mines, Golden, CO (ssonnenb@mines.edu)

Abstract

The Niobrara Formation of the Denver Basin is an unconventional oil and gas drilling target composed of alternating chalk and marl units. These units act as the source, seal and trap for hydrocarbons generated in the total organic-carbon-rich marl beds of the Niobrara.

Organic geochemical data, such as oil-to-source rock correlations, oil biomarkers and gas isotopes, indicate that the fluids accumulated within the reservoirs closely match the source rocks in type and maturity; therefore, this is a system of in-situ generation and accumulation as well as low migration. In a system where migration is minimal, proximity to an effective source rock is a prerequisite for a productive well. With such a prerequisite, play delineation should begin with regional source-rock maturity assessment.

Historically, source-rock maturity has been studied through programmed pyrolysis (such as Rock-Eval™), vitrinite reflectance, log interpretation or basin modeling. Recently, a new pyrolysis instrument (the Source Rock Analyzer™) has come to market. With this new addition, questions of data congruence have arisen between the Rock-Eval™ and the Source Rock Analyzer™ that preclude combining data sets without further study.

This work establishes the veracity of the data from the Source Rock Analyzer™ and compares its results to those of a Rock-Eval™ instrument, using a suite of 103 source rock samples.

The test of data veracity shows that the S2 and Tmax parameters from the Source Rock Analyzer™ are comparable to those from the Rock-Eval™, showing good correlation and a nearly one-to-one relationship. The other parameters, S1 and S3 show similar trends but there is significant scatter in the data. The calculated parameters (hydrogen index, oxygen index, production index, and total organic carbon) are correlative but deviate significantly from a one-to-one relationship.

Using the newly understood relationship between SRA™ and Rock-Eval™ pyrolysis, regional assessment of the Niobrara shows that the onset of hydrocarbon maturity in the Niobrara is 432 degrees C Tmax and that hydrocarbon expulsion occurs between 438 degrees C and 443 degrees C Tmax. The study also shows that Niobrara production can be predicted by mapping the thermal maturity stages as well as free hydrocarbon anomalies within the basin.

References Cited

Higley, D.K., 1988, Core porosity, permeability, and vitrinite reflectance data from the Lower Cretaceous J sandstone in 141 Denver Basin coreholes : U.S. Geological Survey Open-File Report 88-527, 6 p.

Landon, S.M., M.W. Longman, and B.A. Luneau, 2001, Hydrocarbon source rock potential of the Upper Cretaceous Niobrara Formation, Western Interior Seaway of the Rocky Mountain region : *The Mountain Geologist*, v. 38/1, p. 1-18.

Longman, M.W., B.A. Luneau, and S.M. Landon, 1998, Nature and distribution of Niobrara lithologies in the Cretaceous Western Interior Seaway of the Rocky Mountain region: *The Mountain Geologist*, v. 35/4, p. 137-170.

Momper, J.A., 1980, Oil expulsion; a consequence of oil generation: *Bulletin of the South Texas Geological Society*, v. 20/5, p. 5-6.

Rice, D.D., 1984, Relation of hydrocarbon occurrence to thermal maturity of organic matter in the Upper Cretaceous Niobrara Formation, Eastern Denver Basin--Evidence of biogenic versus thermogenic origin of hydrocarbons, *in* J. Woodward, F.F. Meissner, and J.L. Clayton, (eds.), *Hydrocarbon source rocks of the Greater Rocky Mountain area: Rocky Mountain Association of Geologists Guidebook*, p. 365-368.

Tainter, P.A., 1982, Investigation of stratigraphic and paleostructural controls on hydrocarbon migration and entrapment in Cretaceous D and J sandstone of the Denver basin: Boulder, Colorado, University of Colorado, M.S. Thesis, 235 p.

Niobrara Source Rock Maturity in the Denver Basin: A Study of Differential Heating and Tectonics on Petroleum Prospectivity Using Programmed Pyrolysis

David J. Thul^{1,2}

Steve Sonnenberg, PhD²

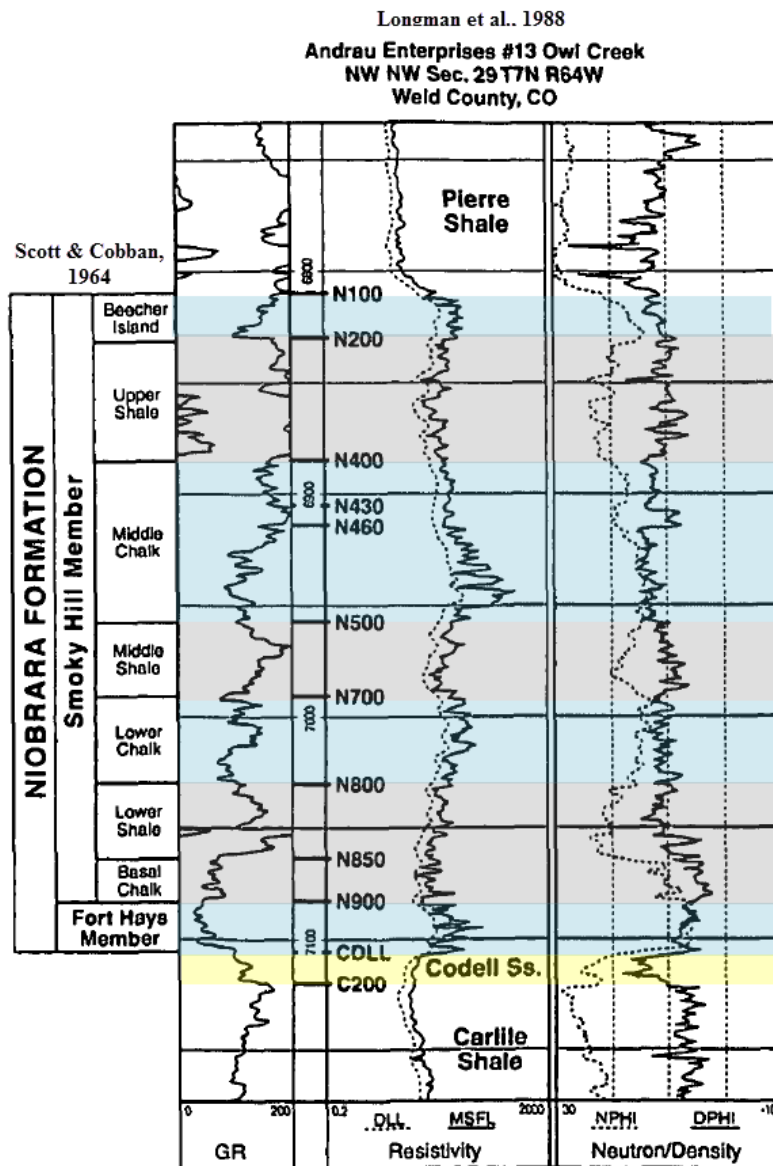
¹PetroLuminary, LLC

²Colorado School of Mines

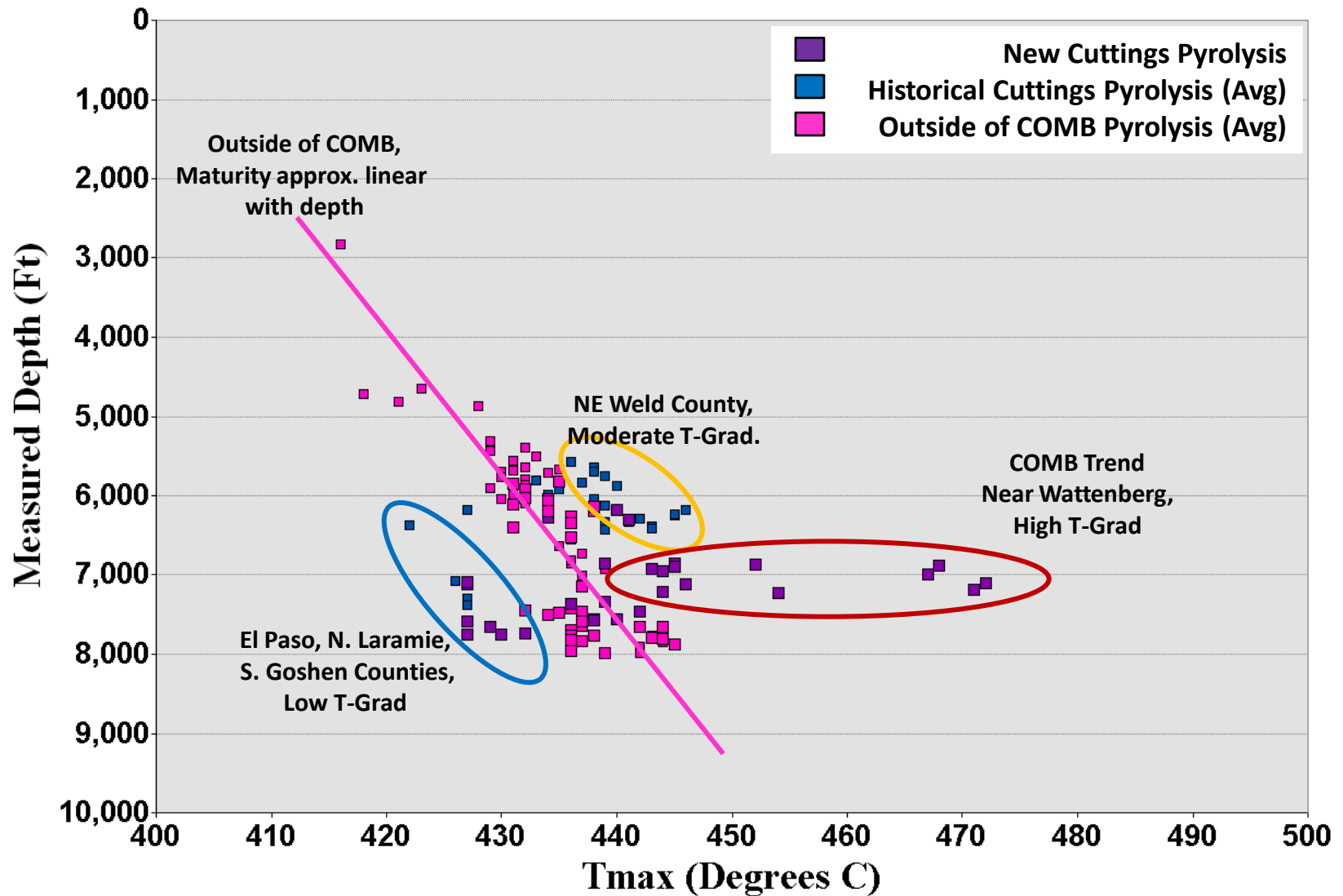
Outline

- **Niobrara Fm. in the Denver Basin**
- **Previous Maturity Studies**
 - Rice, 1984
 - Higley, 1988
 - Landon, 2001
- **Understanding the COMB Trend**
 - New Analytical Results
 - Burial History Modeling Results
- **Niobrara Regional Interpretation**
- **Conclusions**

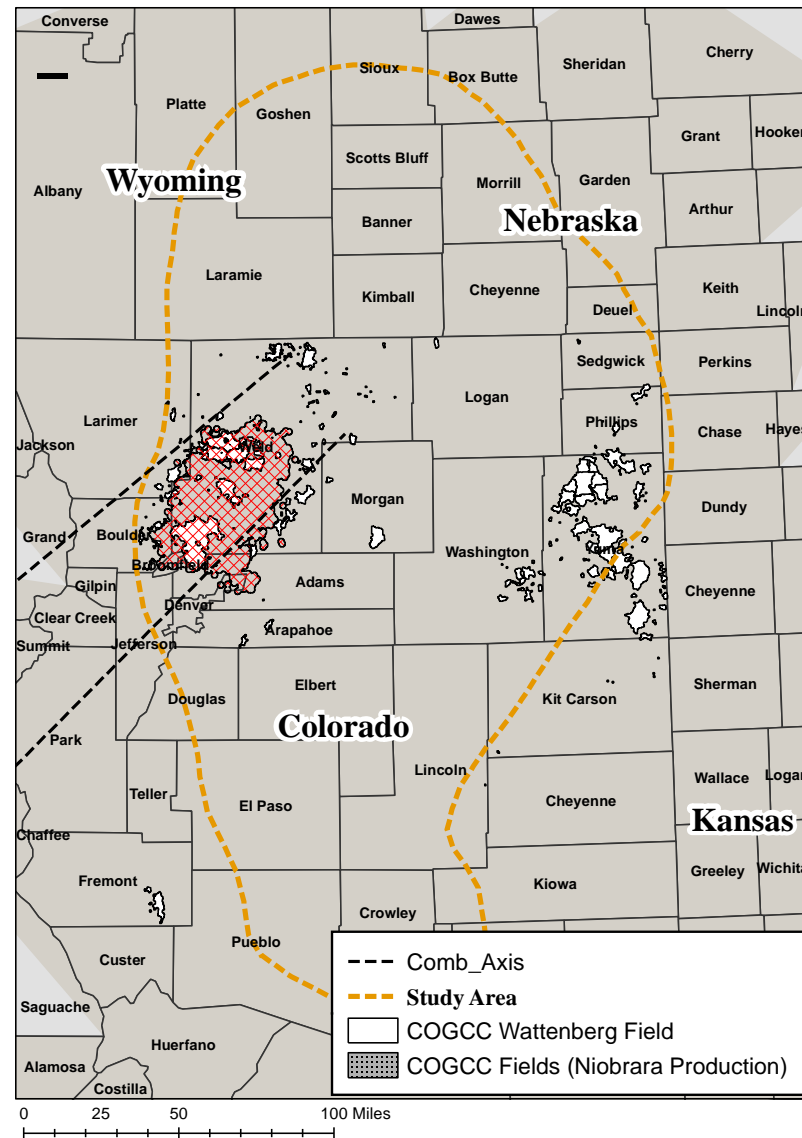
Niobrara Fm.



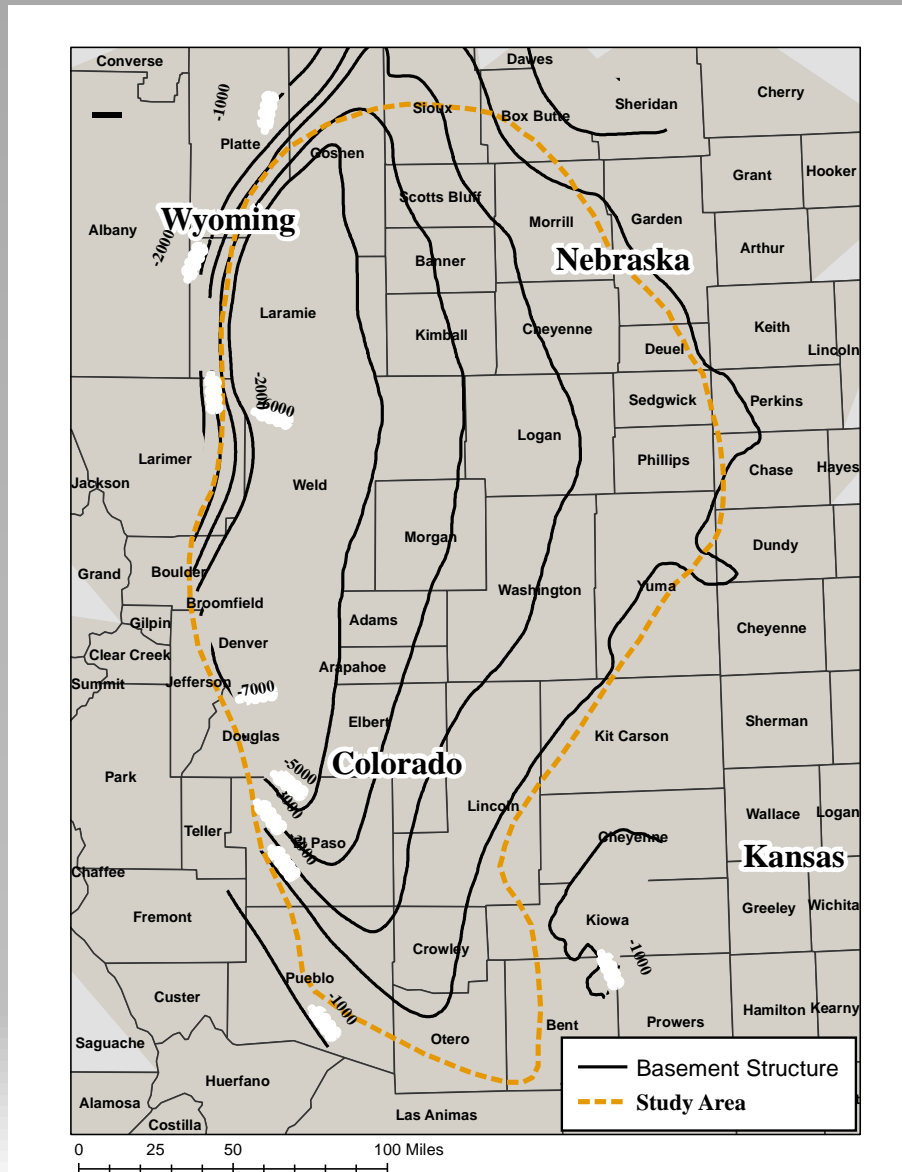
Motivation-Niobrara Maturity



Study Area

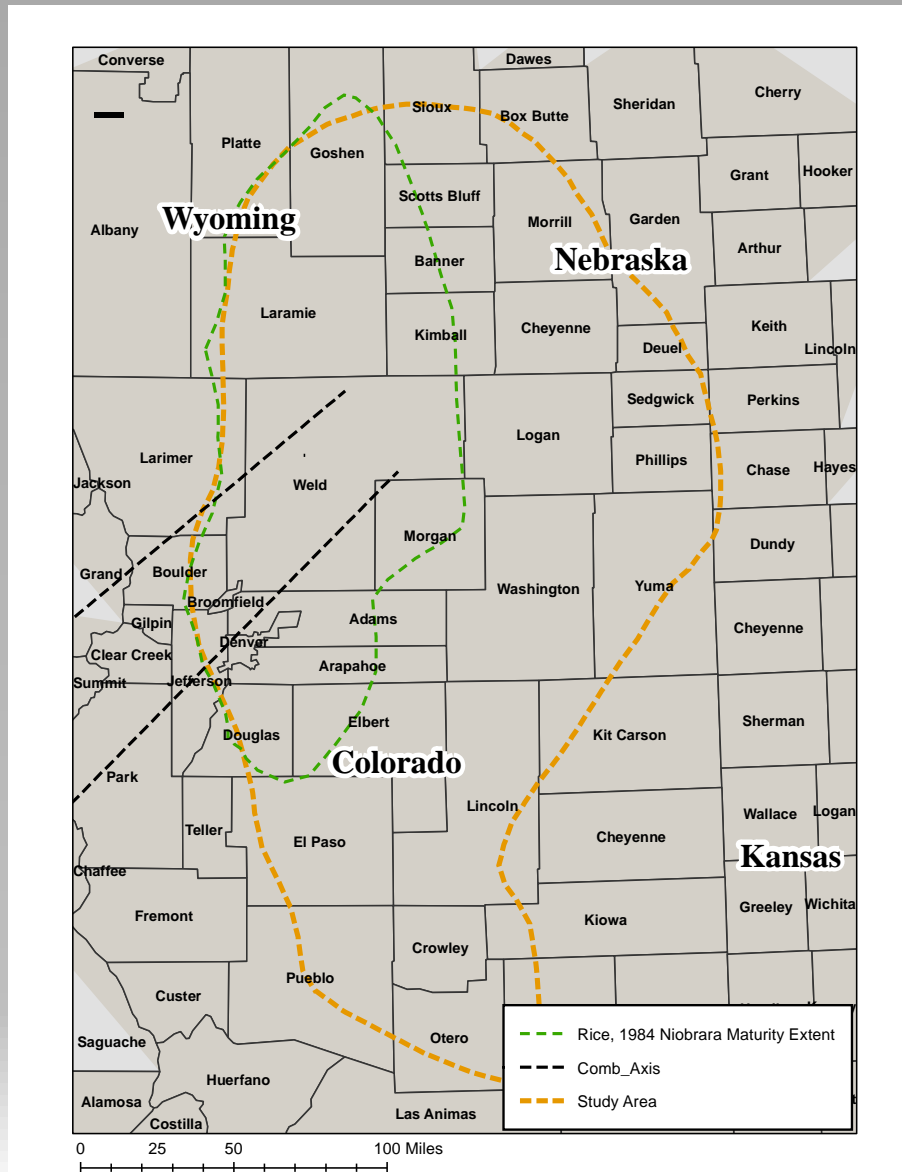


Basement Structure

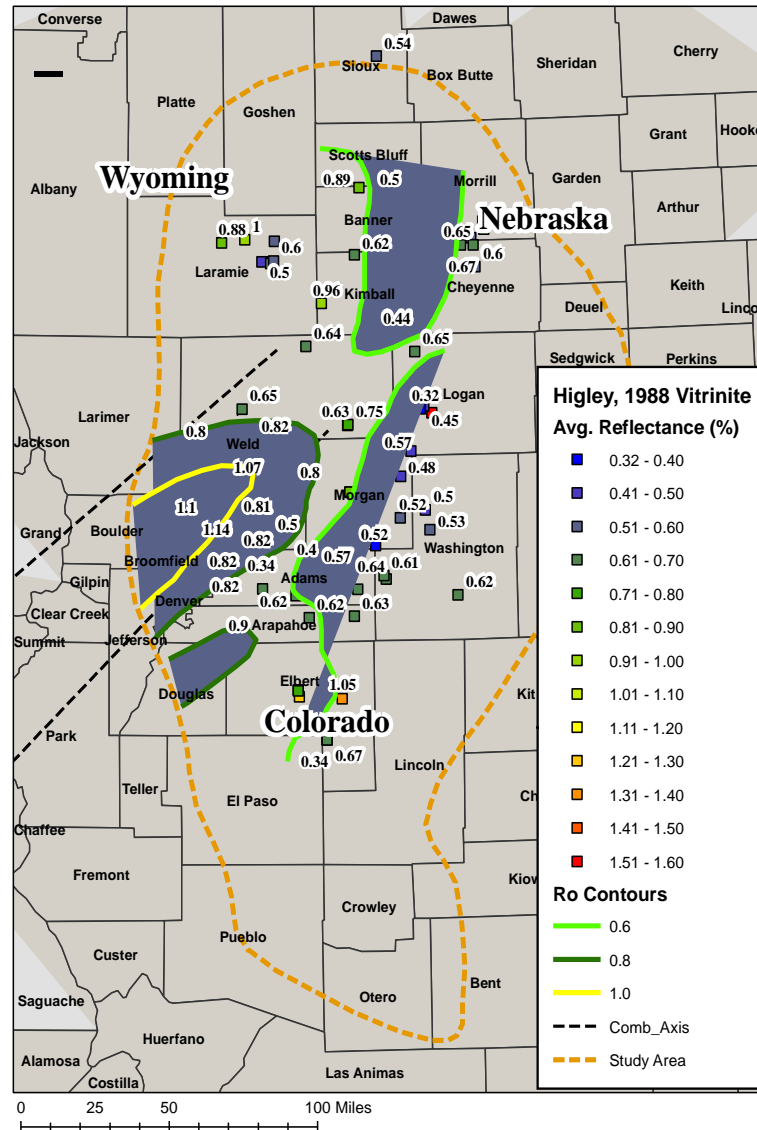


Previous Maturity Studies

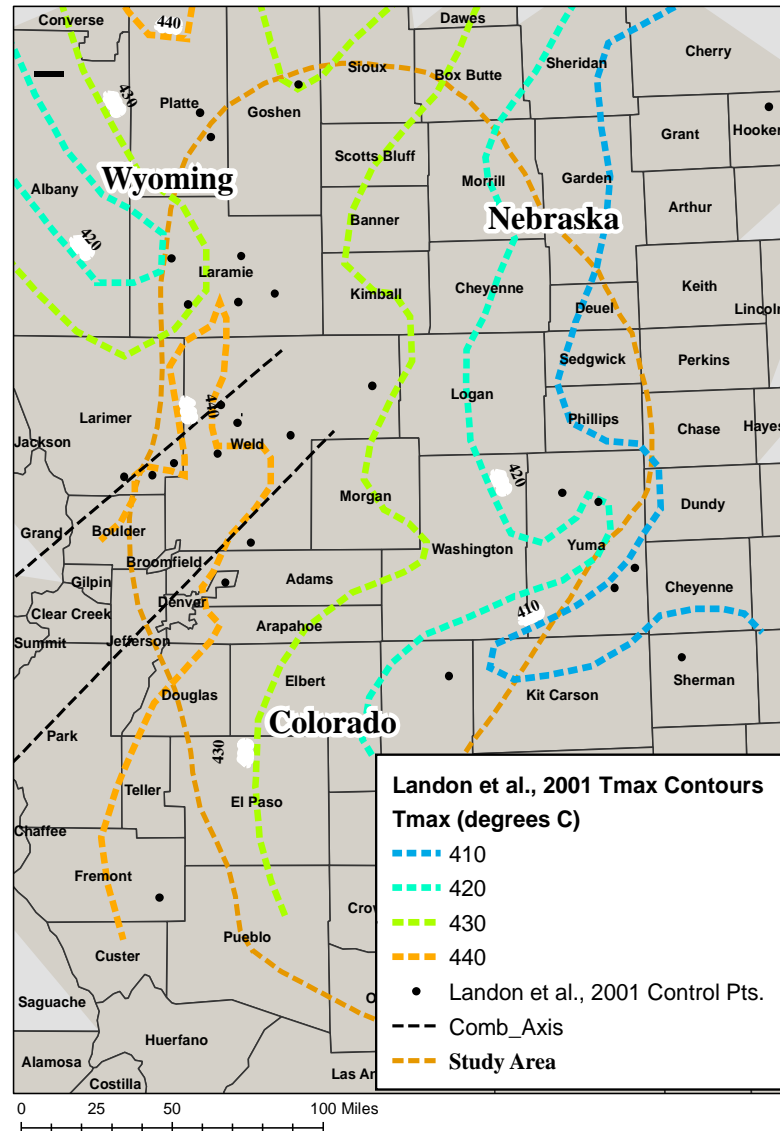
Area of Mature Source Rock



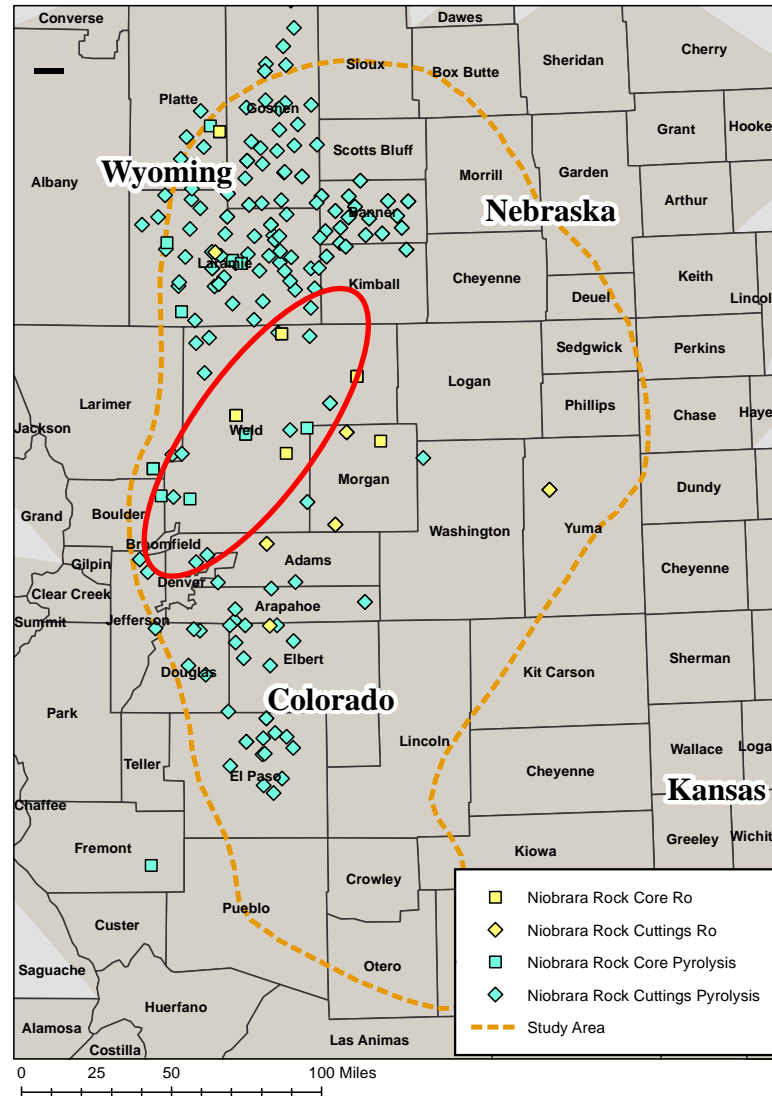
R_o of the Dakota Fm.



Tmax of the Niobrara Fm.



Data Gap as of 2010

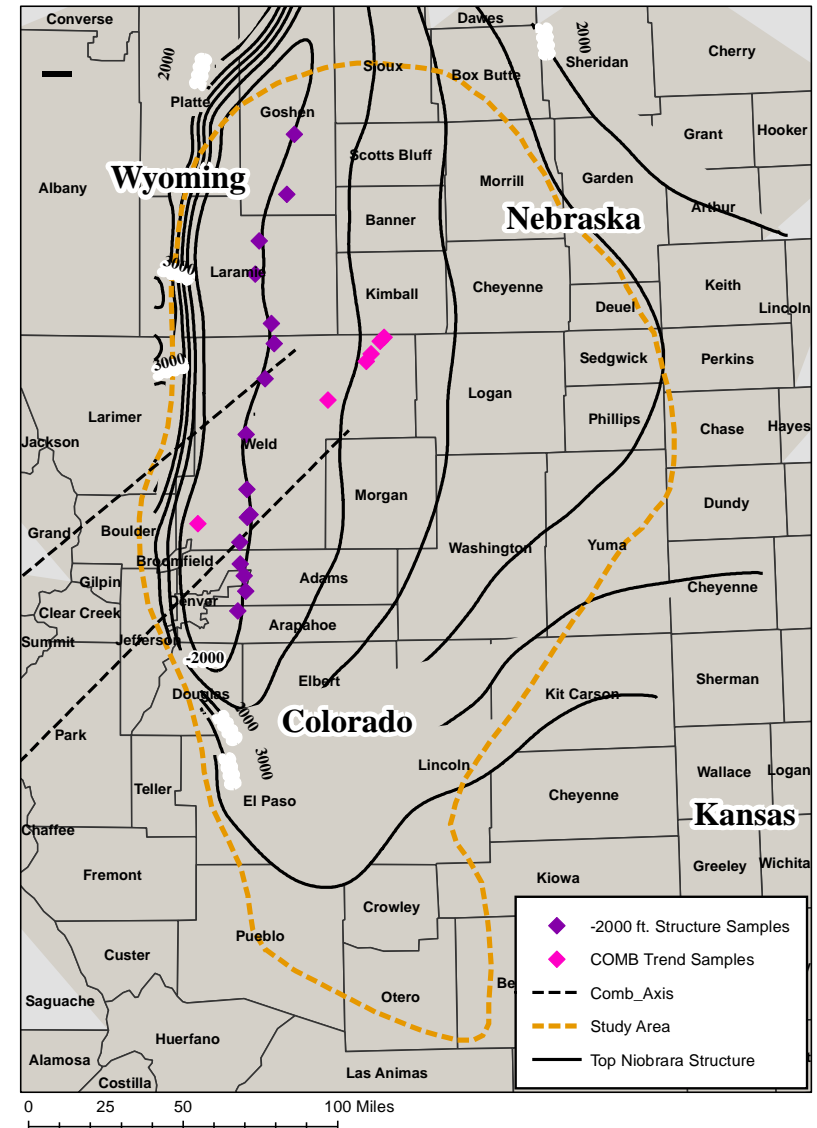


Understanding the COMB Trend & Niobrara Maturity

**70 cuttings analyses
22 locations**

COMB Trend & Niobrara Maturity

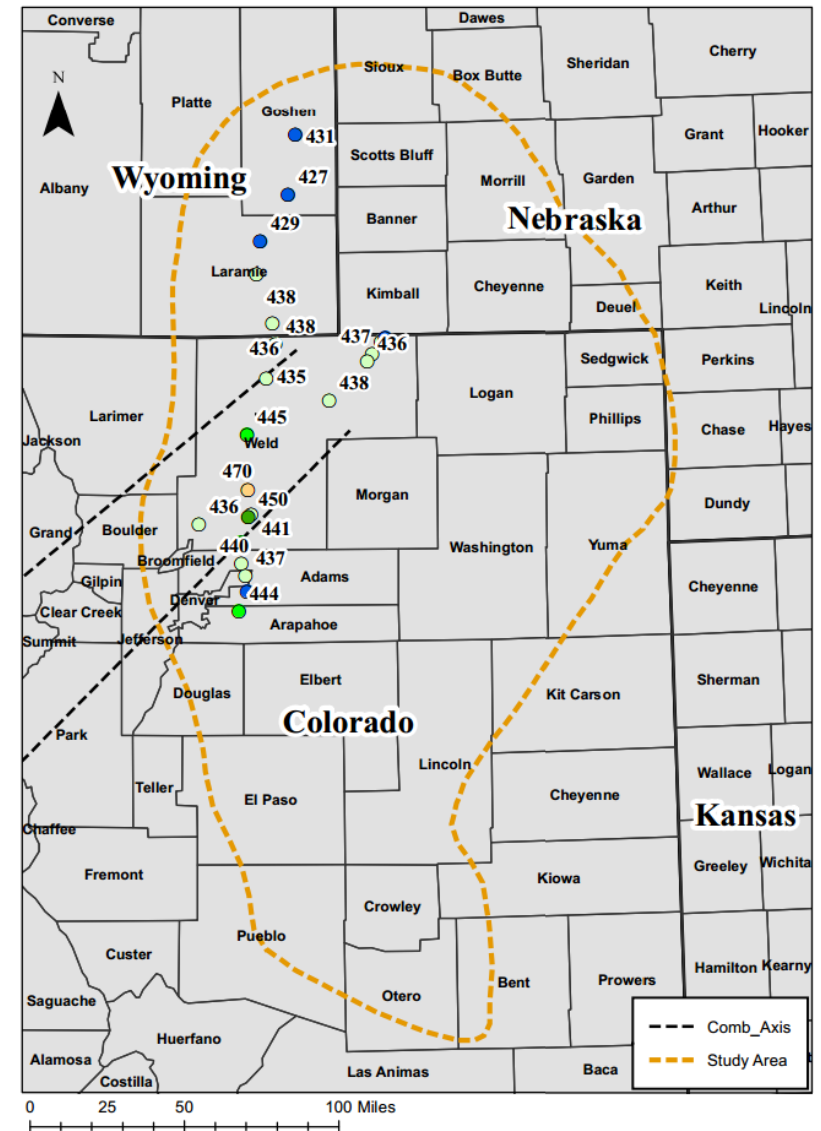
New analyses were taken along the -2000 ft structure contour (purple diamonds) as well as along the NE-SW COMB Trend (pink diamonds)



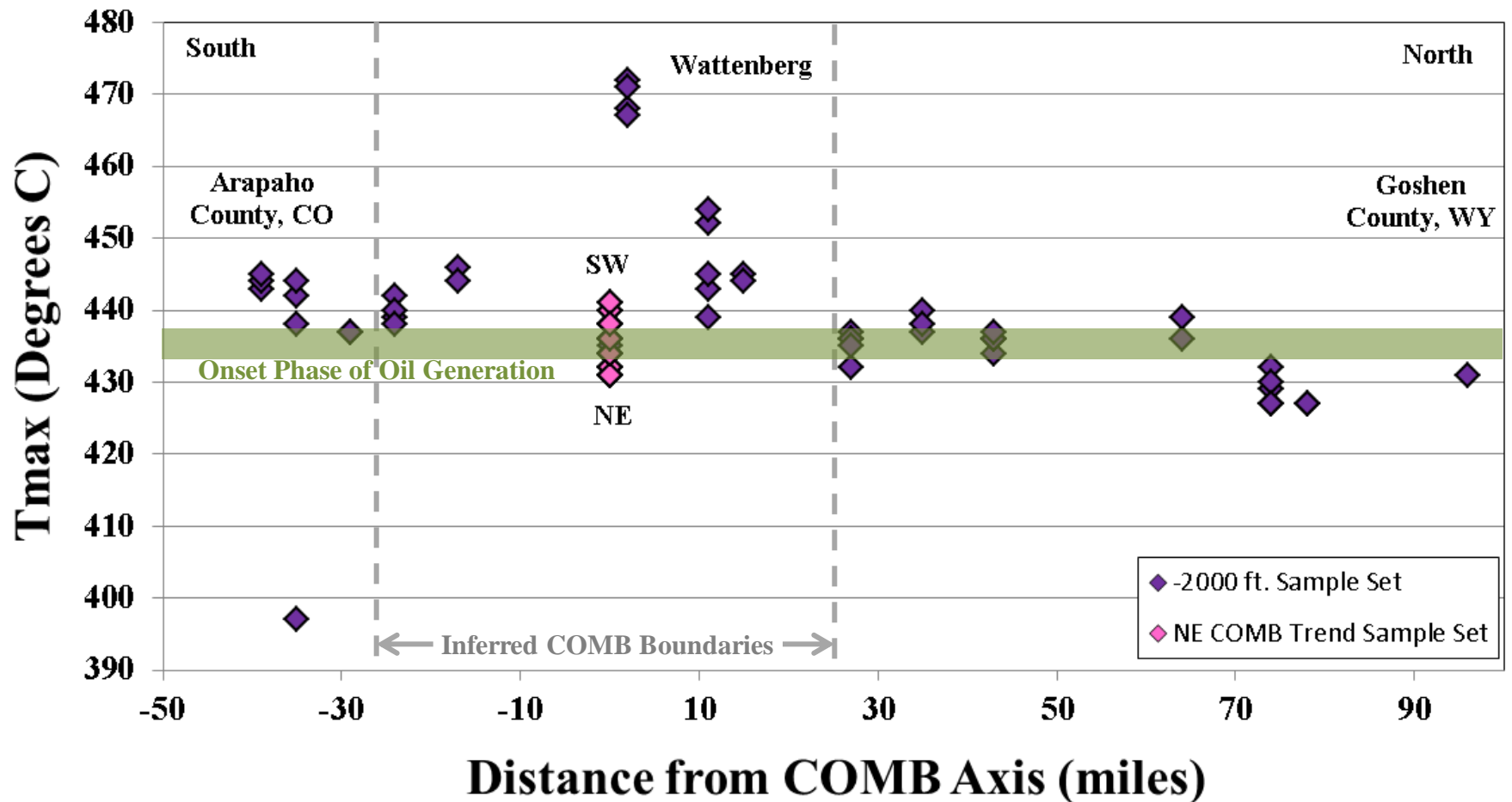
COMB Trend & Niobrara Maturity

Along the S-N transect
source rock maturity
increases through the
COMB Trend

Along the NE-SW transect
shallow samples in the NE
have similar maturities to
those deeper in the basin



COMB Trend & Niobrara Maturity



There is a clear increase in maturity within the COMB boundaries

Burial History Modeling

$R_{o \text{ Modeled}}: 0.7$

$E R_o: 0.6$

Tert. Removal: 1800 ft.
Removal Needed: 800 ft.

$R_{o \text{ Modeled}}: 0.63$

$E R_o: 0.76$

Tert. Removal: 2200 ft.
Removal Needed: 4200 ft.

$R_{o \text{ Modeled}}: 0.63$

$E R_o: 0.59$

Tert. Removal: 2360 ft.
Removal Needed: 1500 ft.

$R_{o \text{ Modeled}}: 0.74$

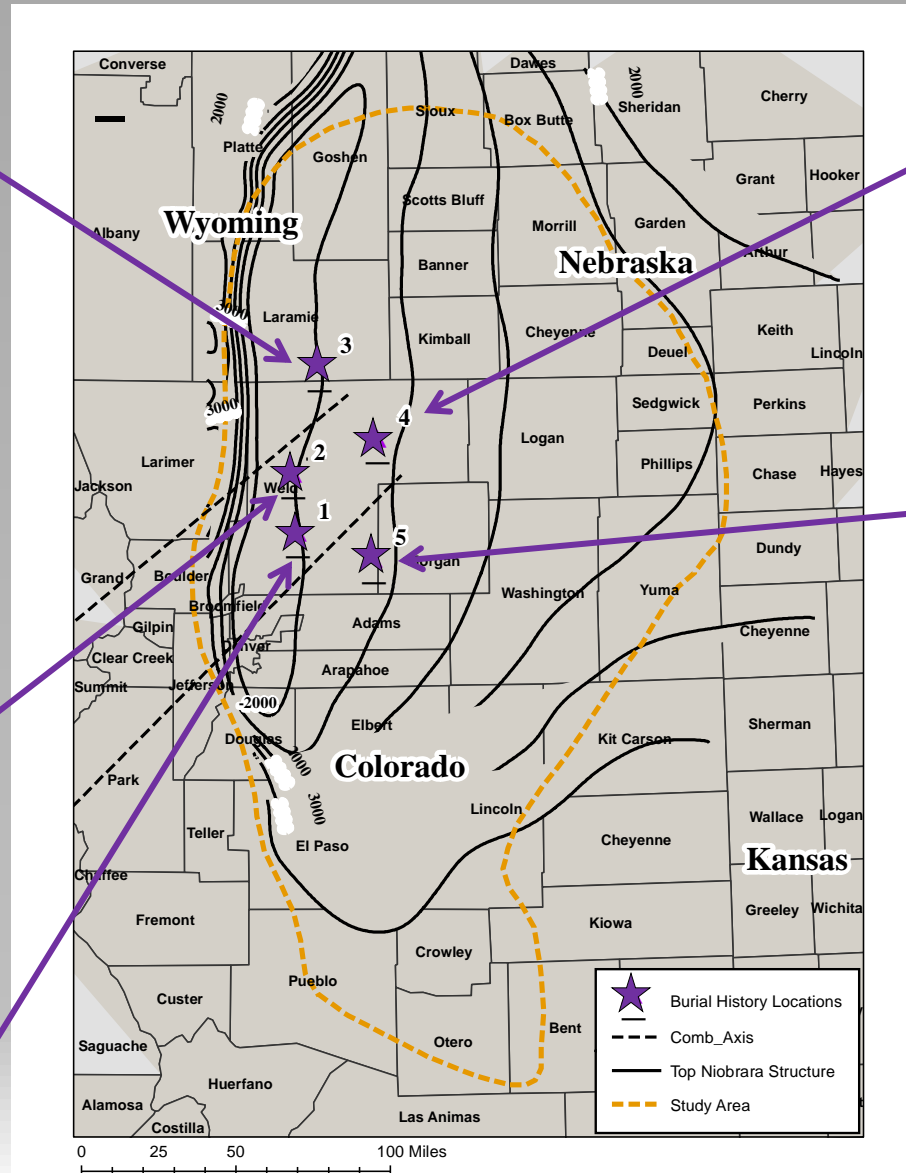
$E R_o: 0.93$

Tert. Removal: 3270 ft.
Removal Needed: 5200 ft.

$R_{o \text{ Modeled}}: 0.76$

$E R_o: 1.3$

Tert. Removal: 3210 ft.
Removal Needed: 7300 ft.



Niobrara Regional Interpretation

1360 pyrolysis analyses

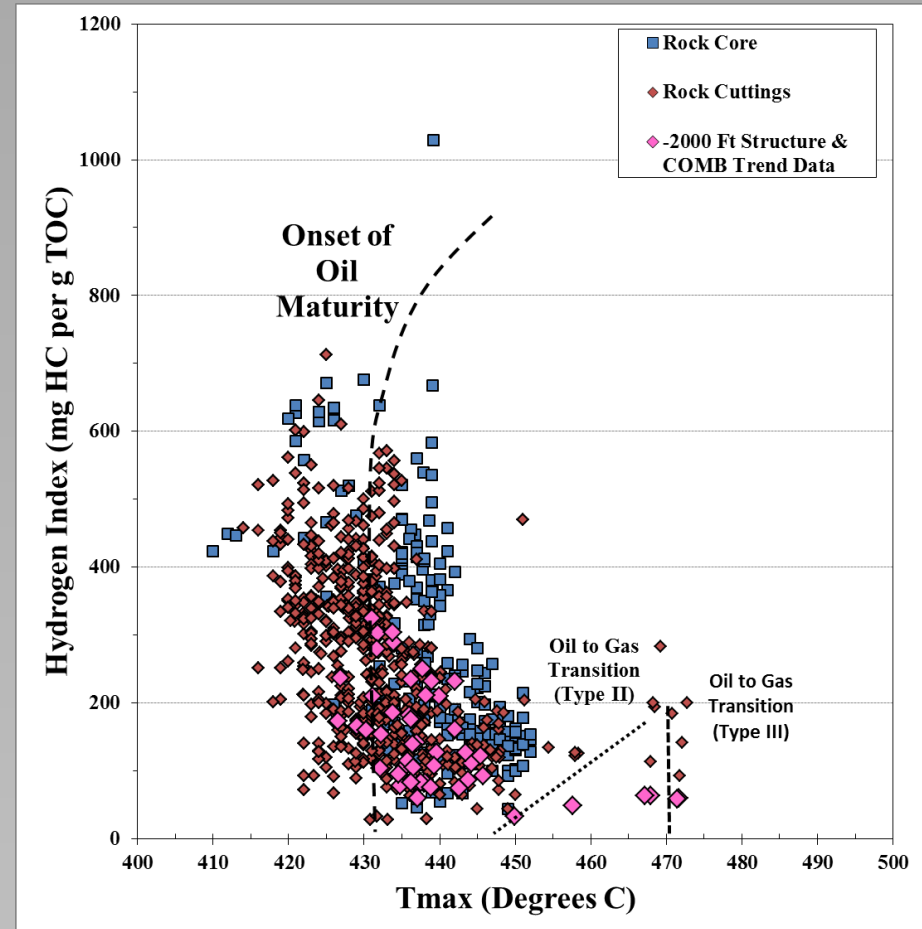
1370 TOC analyses

220 well locations

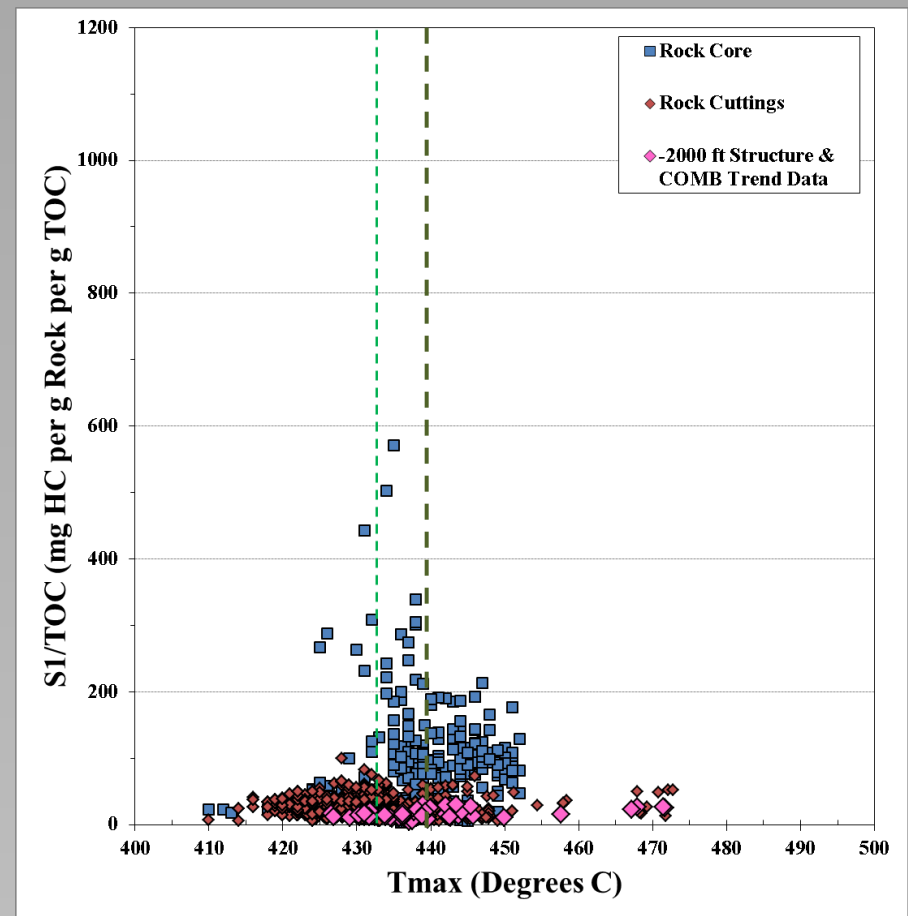
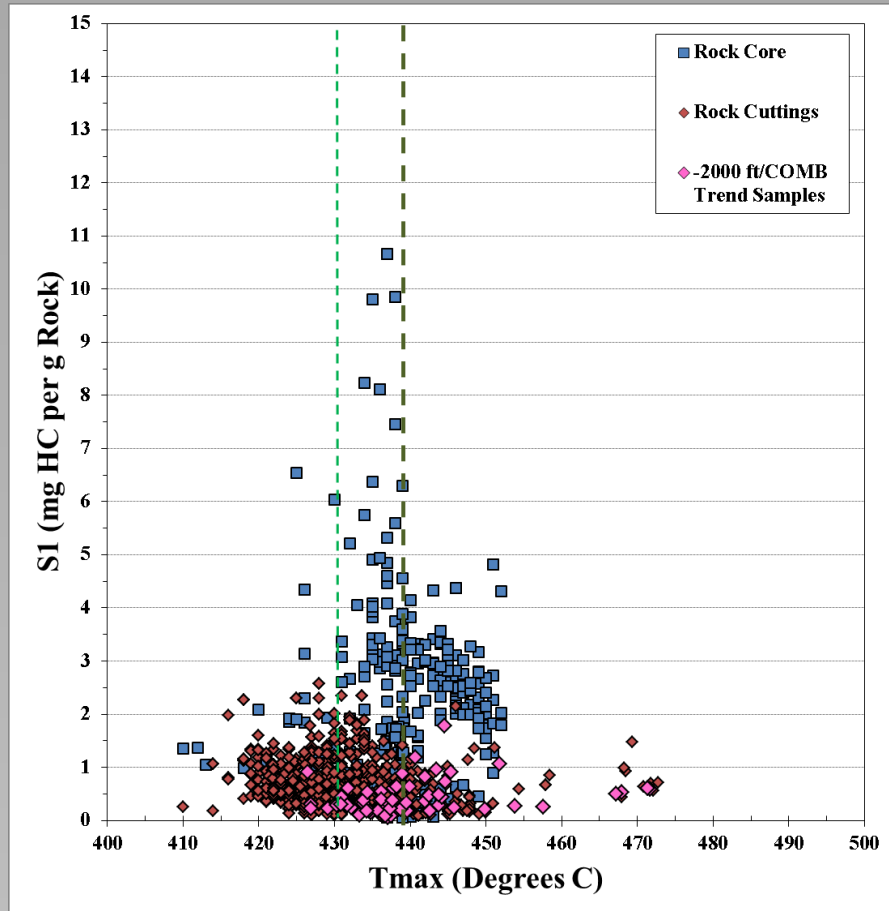
Niobrara Regional Interpretation

The maturation pathway for the Niobrara source rocks is defined by the decreasing HI with increasing Tmax

Hydrocarbon generation appears to begin between Tmax values of 430°C and 435°C

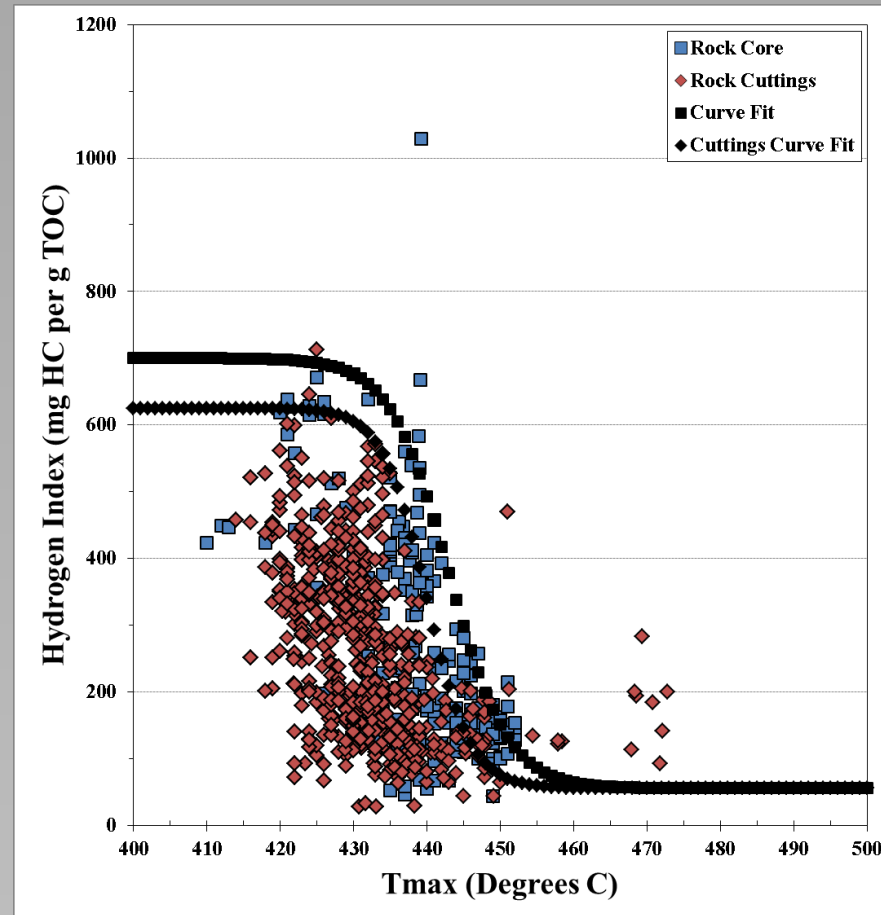


Niobrara Regional Interpretation



The free petroleum and normalized oil content show a sharp increase at a Tmax of 432°C & plateau at Tmax of 438°C. Interpreted as onset of petroleum generation & petroleum expulsion.

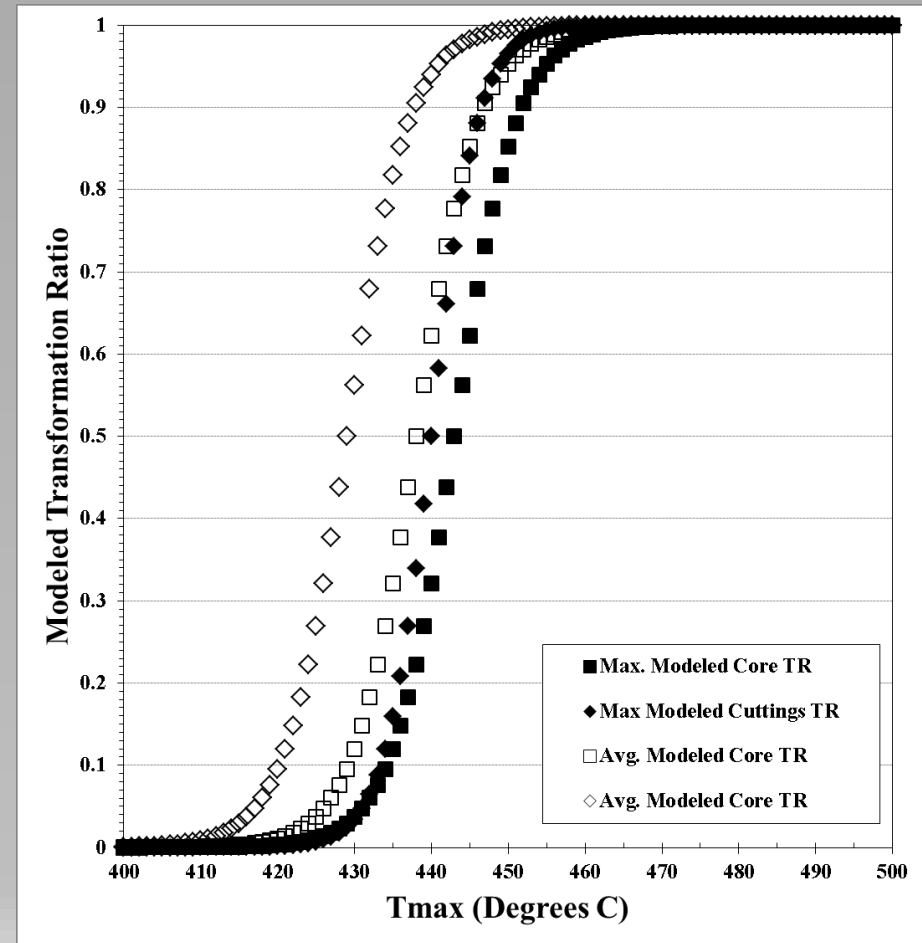
Niobrara Regional Interpretation



To eliminate analytical noise in HI (and Transformation Ratio) it is useful to model TR based on Tmax using a sigmoidal function.

Niobrara Regional Interpretation

From the modeled values, the onset of petroleum generation is 432°C Tmax (TR 0.1) and expulsion occurs at 438°C Tmax (TR 0.25) which agrees with the volumetric-based analysis of Momper, 1980



From Crossplots to Maps

Onset of HC generation: 432°C

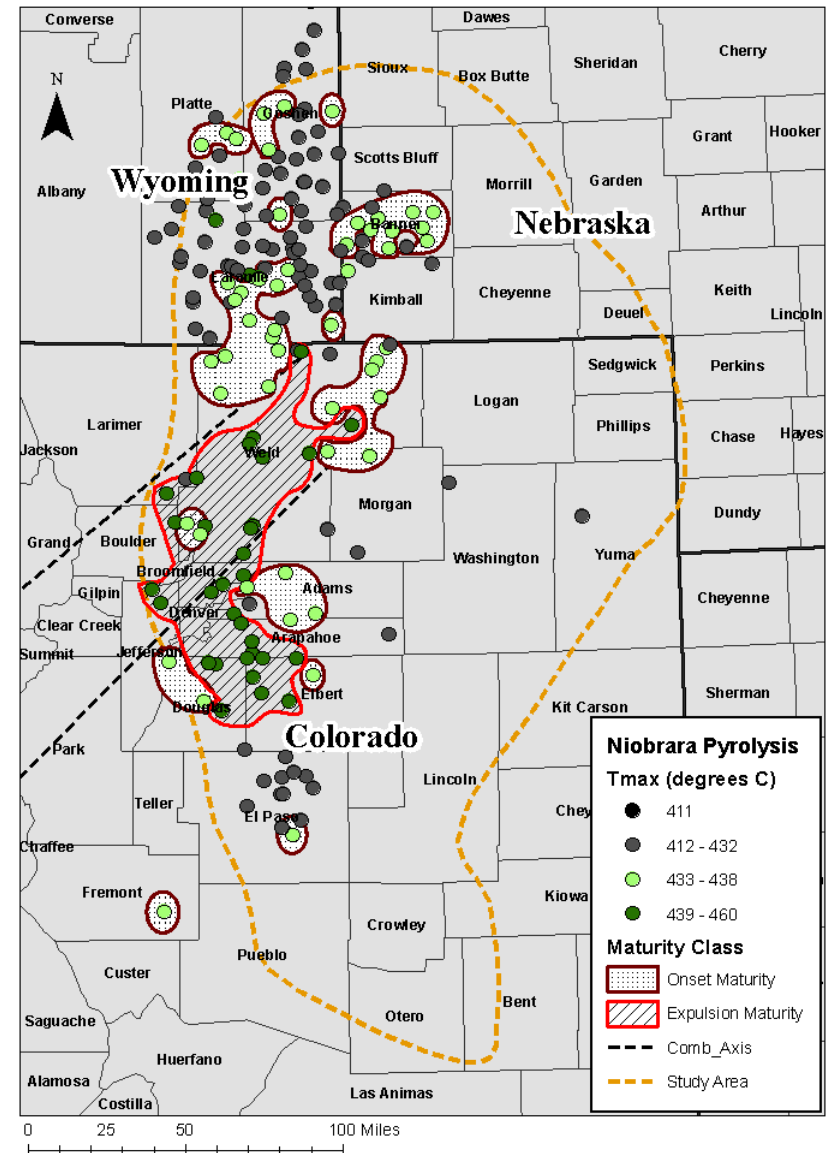
First HC expulsion event: 438°C

Niobrara Regional Interpretation

Using the data and model of HC generation and expulsion, regions of each maturity are delineated.

Expulsion maturity occurs in the greater Wattenberg area as well as Adams, Arapahoe, Elbert and Douglas counties.

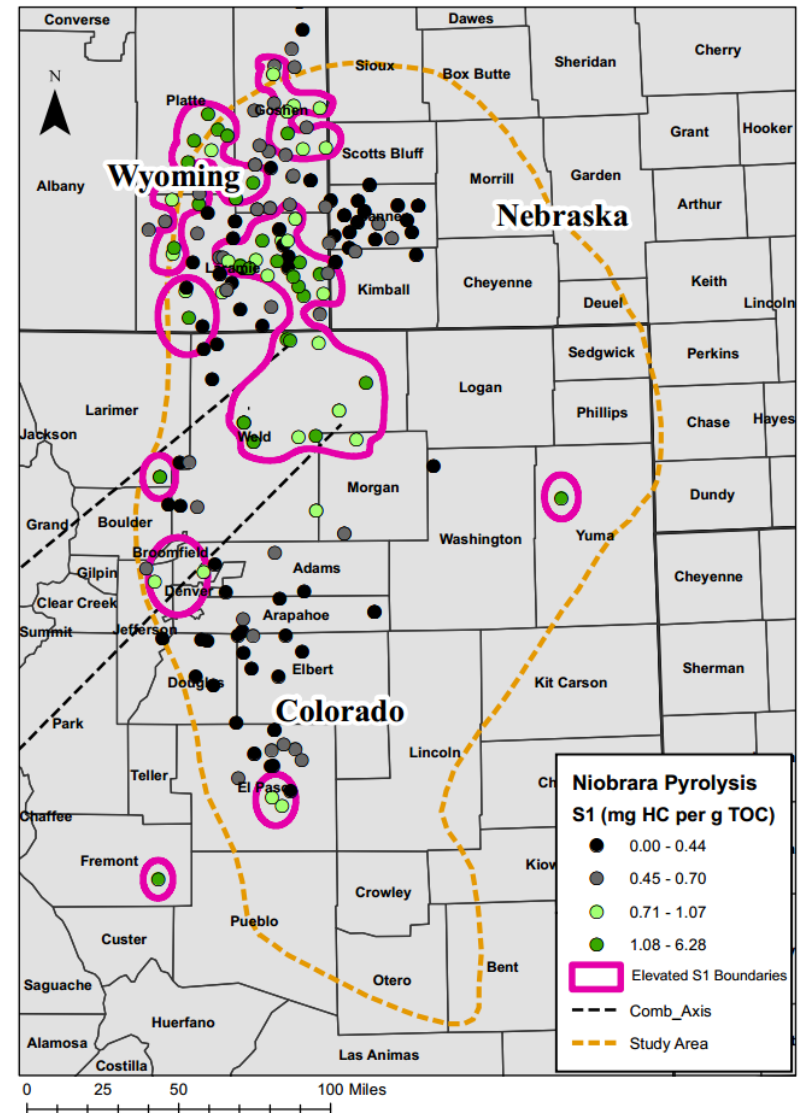
Onset maturity occurs in NE & NW Weld county as well as parts of Wyoming and Nebraska.



Niobrara Regional Interpretation

Free hydrocarbon anomalies are present in NE Weld County, SE Wyoming and in the western reaches of the basin.

The Greater Wattenberg Area, notably, shows no free hydrocarbon anomaly.



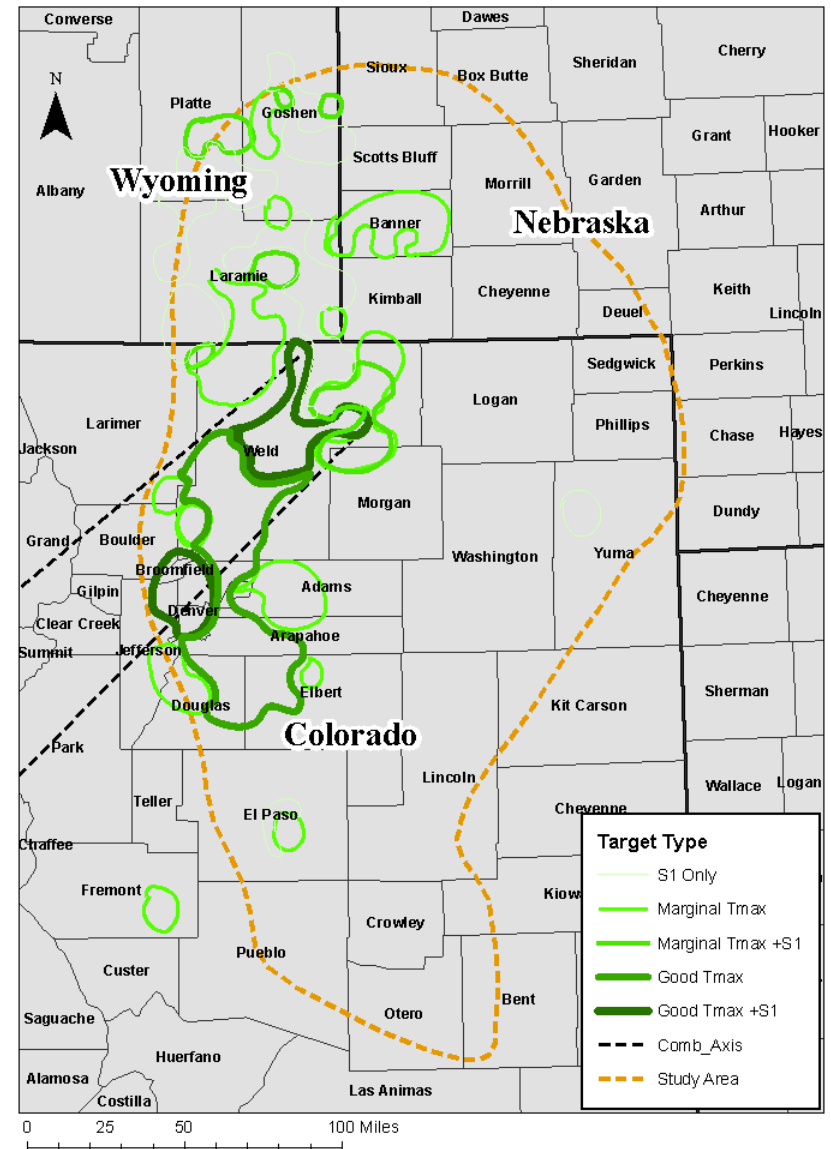
Niobrara Regional Interpretation

Prospect Ranking Definitions

Priority Level (Favorability)	Maturity	S1
1	Expulsion ($T_{max} > 438$)	Elevated
2	Expulsion ($T_{max} > 438$)	Not elevated
3	Onset ($432 < T_{max} < 438$)	Elevated
4	Onset ($432 < T_{max} < 438$)	Not elevated
5	Immature ($t_{max} < 432$)	Elevated

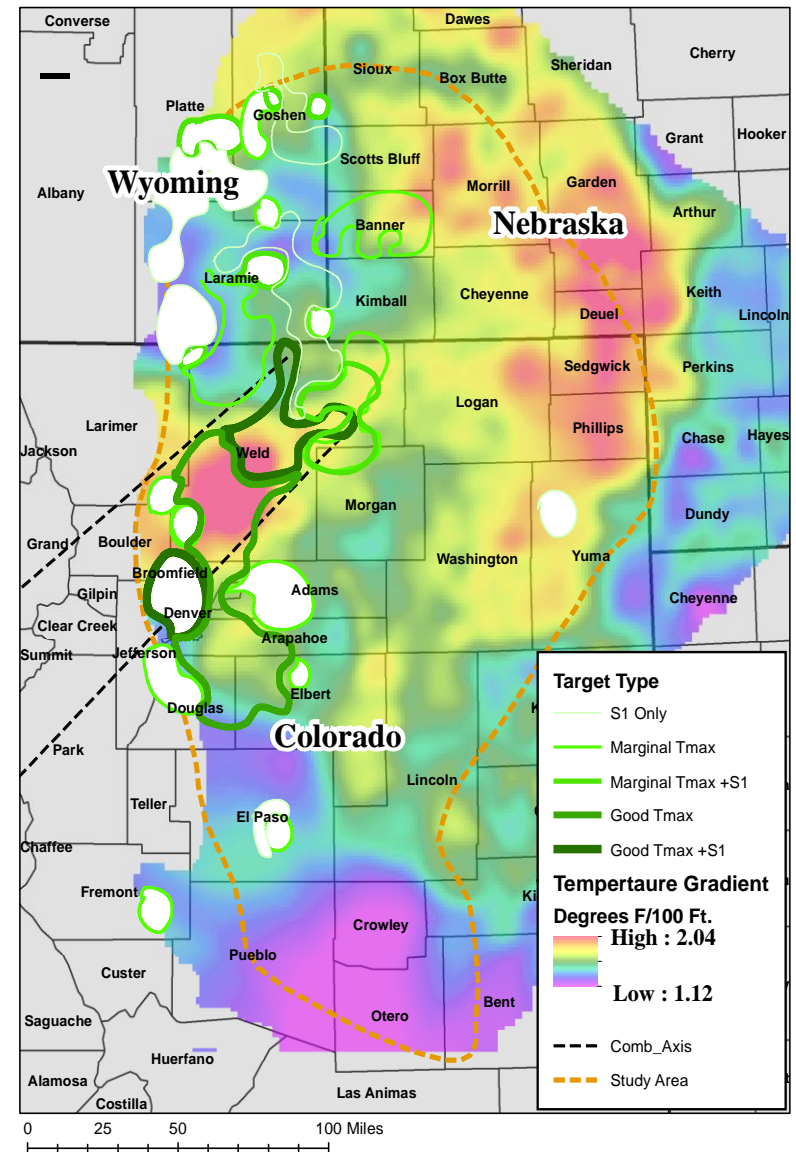
Niobrara Regional Interpretation

The highest priority targets are located along the COMB trend with lower priority targets flanking that zone and dispersed throughout the basin.



Niobrara Regional Interpretation

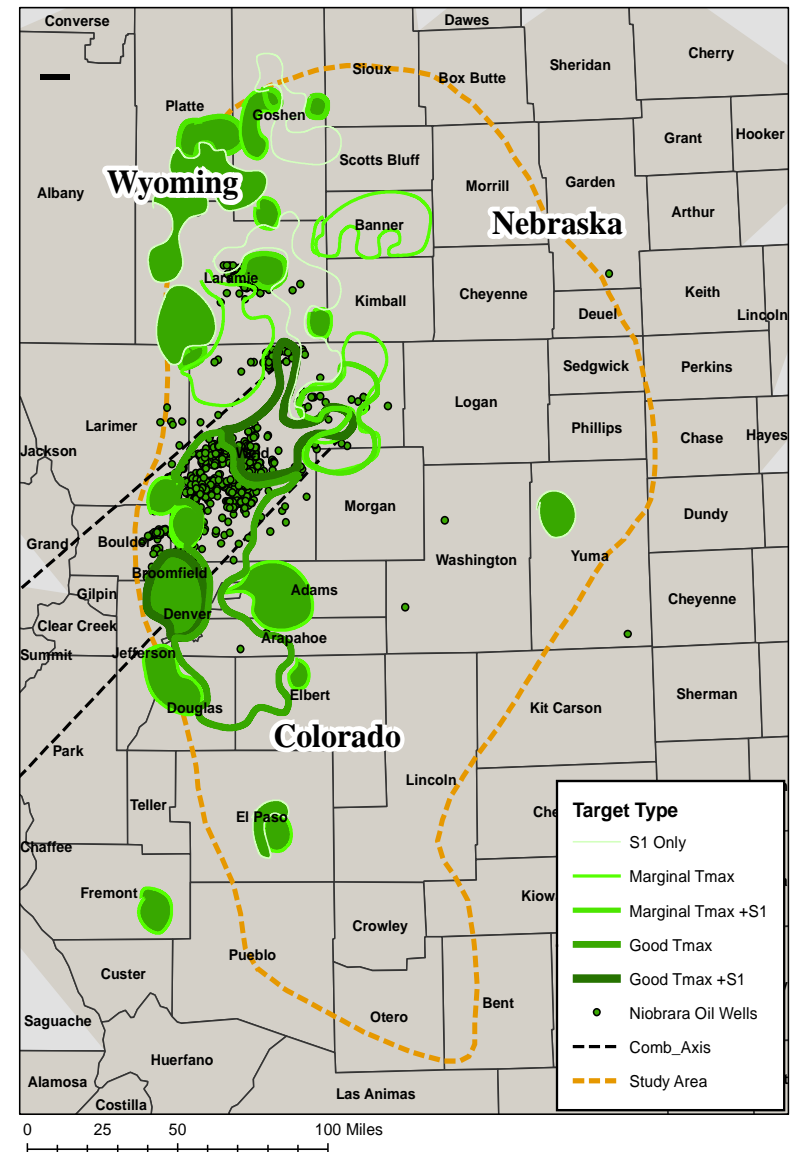
The highest level prospects are, in all cases associated with higher geothermal gradients.



Niobrara Regional Interpretation

Most of the established production is inside the two highest exploration target categories.

The notable exception is Silo Field which may be due to its favorable structural history.



Summary

Increased heat, not burial history, best explains increased source-rock maturity along the COMB Trend

Areas of varying prospectivity can be identified using regional interpretation of pyrolysis datasets.

Using a stacked polygon method (a la Tainter, 1982) creates exploration fairways that encircle existing production.

Several other areas in the basin appear prospective using this method but more data is needed.