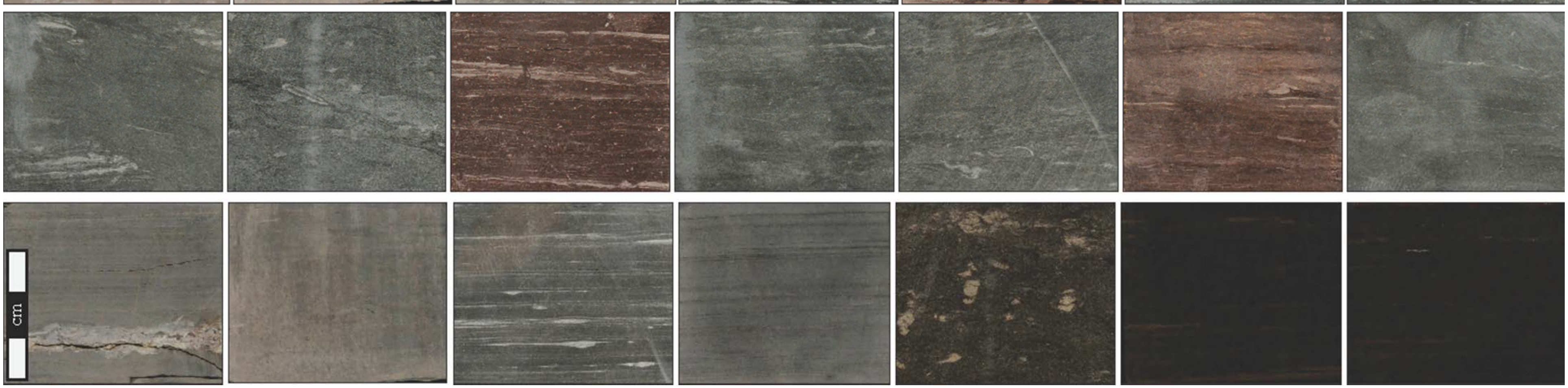
Cretaceous Mancos Shale Uinta Basin, Utah: Resource Potential and Best Practices for an Emerging Shale Gas Play

Hatch Mesa, UT

Robert Ressetar, Utah Geological Survey &
Lauren Birgenheier, University of Utah
June 9, 2015; DOE project closeout presentation



Acknowledgments

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EGI Energy & Geoscience Institute

GEOLOGY and GEOPHYSICS

RPSEA Research Partnership to Secure Energy for America

DEPARTMENT OF Chemical Engineering
COLLEGE OF ENGINEERING | THE UNIVERSITY OF UTAH

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Statement of Problem

Mancos shale, Uinta Basin key characteristics:

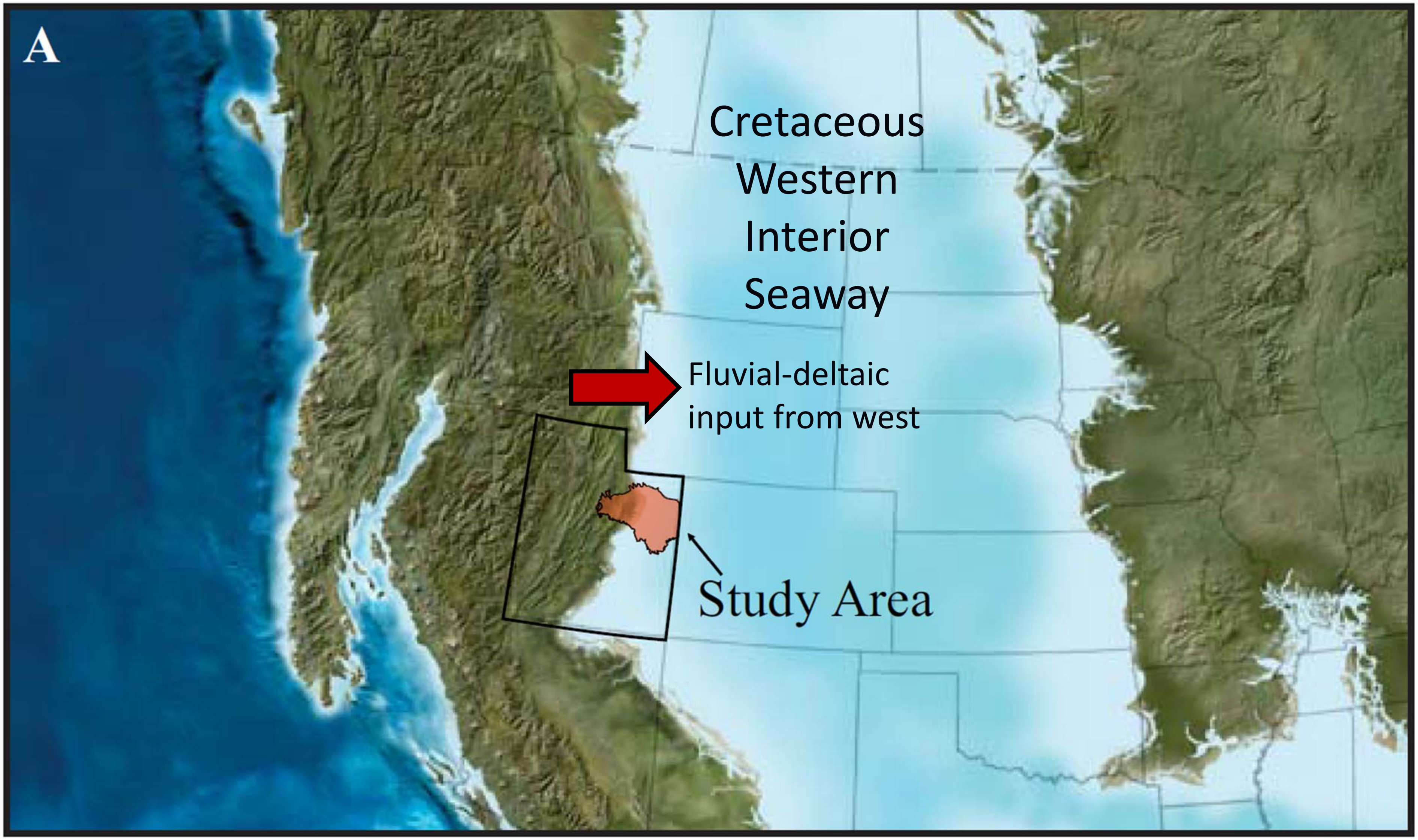
- High volume (4000 ft thick, areally extensive)
- Low TOC (avg. 1-2%, max 6.7%)
- Carbonate poor, clay rich (18% carbonate, 41% clay, 41% detrital silica)
- Known source rock
- Tight gas production from Mancos B
- Limited success as Uinta Basin shale play

Project Goals

- Where are the best horizontal targets for potential shale hydrocarbon production?
- Characterize geology, geomechanics and engineering properties of Mancos.
- Establish best drilling, completion, and production techniques for targeted intervals based on their rock properties.

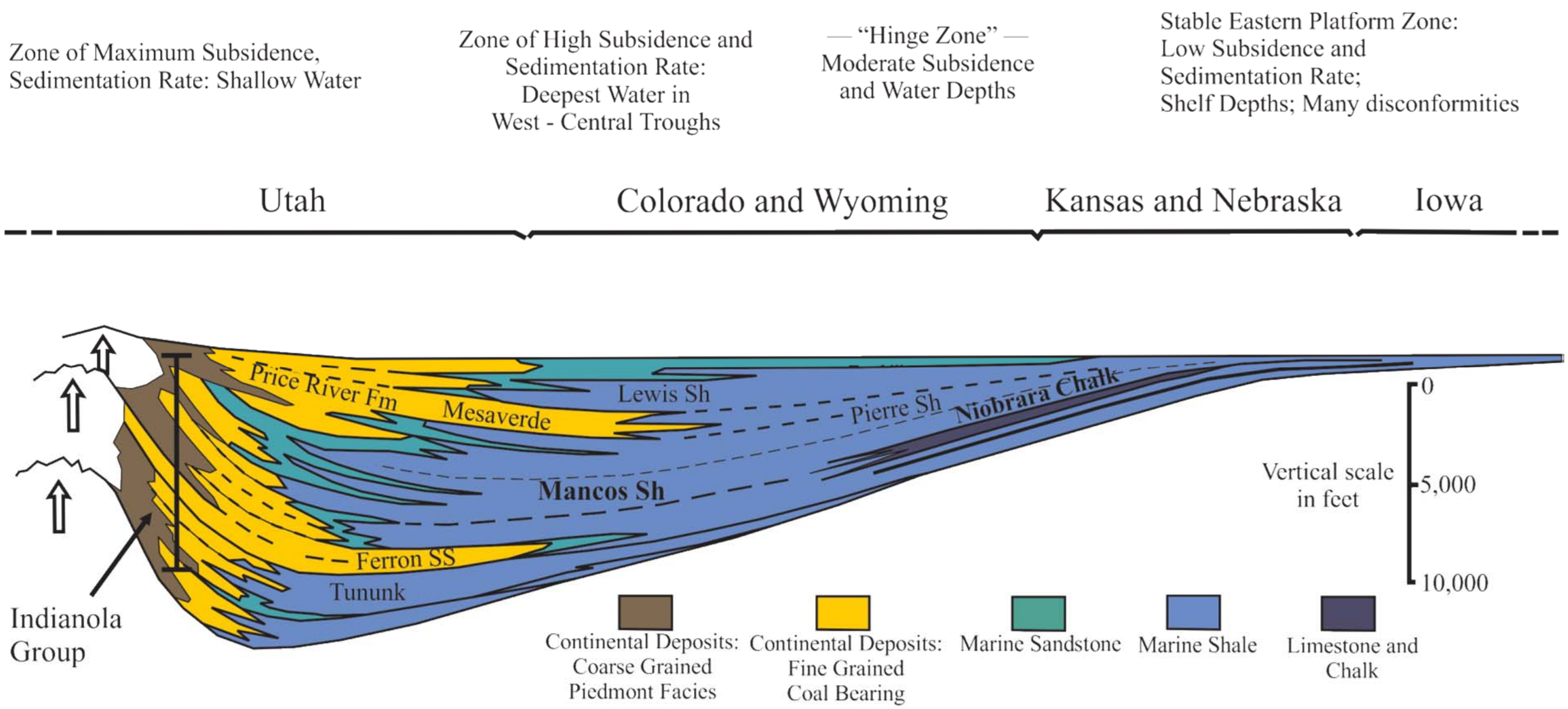
Upper Cretaceous (Early Turonian)
Tununk Mbr. of Mancos Shale Pictured

Background - Paleogeography



Birgenheier et al. (in prep); Horton (2012); modified Blakey map (2008).

Background- Stratigraphy



Birgenheier et al. (in prep.); McCauley (2013); modified from Kauffman (1977)

Mancos Shale represents transition from shallow marine sandstones in the west to chalks and marls of the Niobrara in the east.

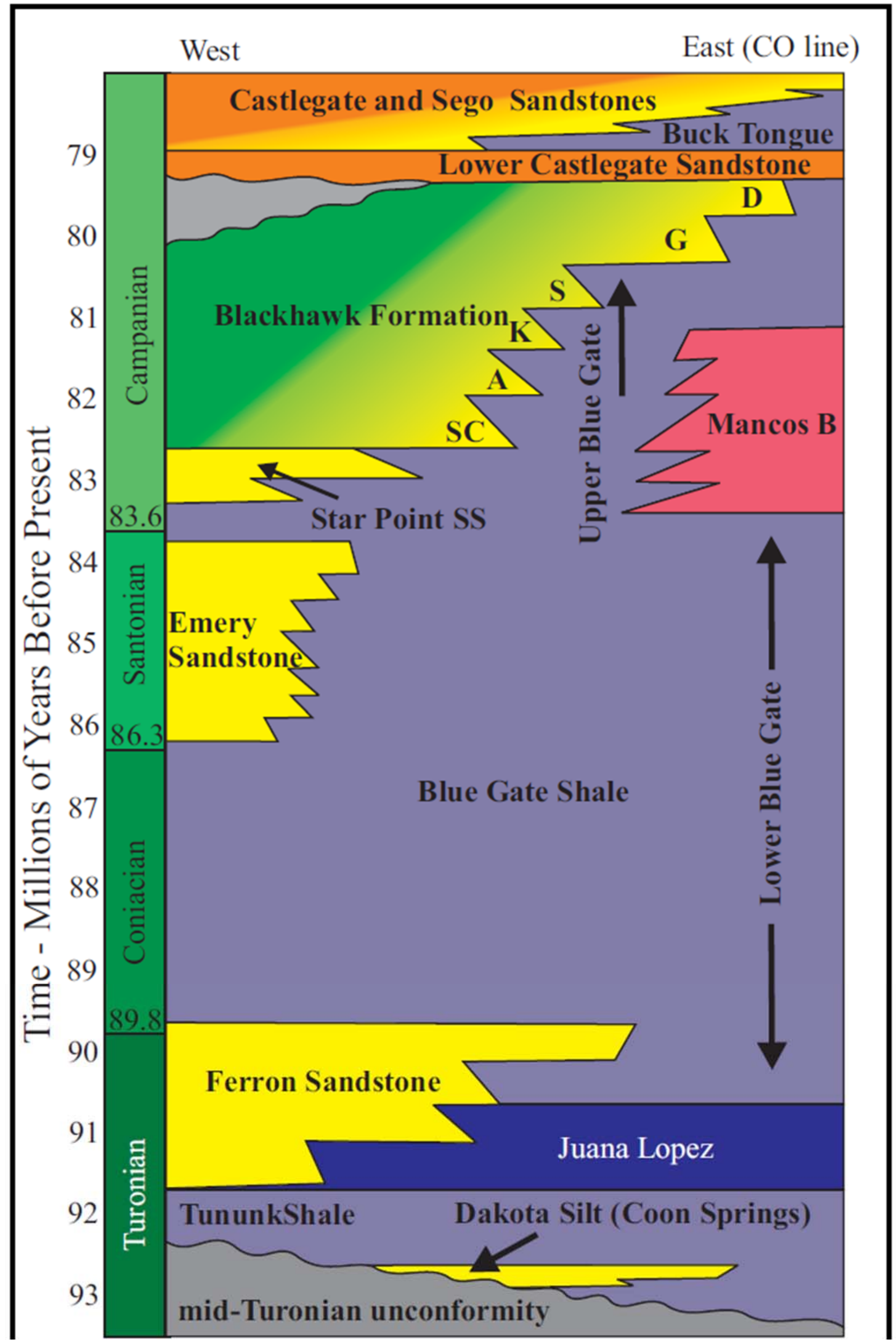
Uinta Basin Stratigraphy

Seminal sequence stratigraphic models of shallow marine sandstones – Book Cliffs.

How can high volume of downdip marine mudstones be genetically subdivided and stratigraphically correlated?

- Marine Sandstone
- Marine Mudstone
- Fluvial
- Organic Rich Heterolith
- Sandstone Rich Heterolith
- Terrestrial

Birgenheier et al. (in prep.); McCauley (2013)



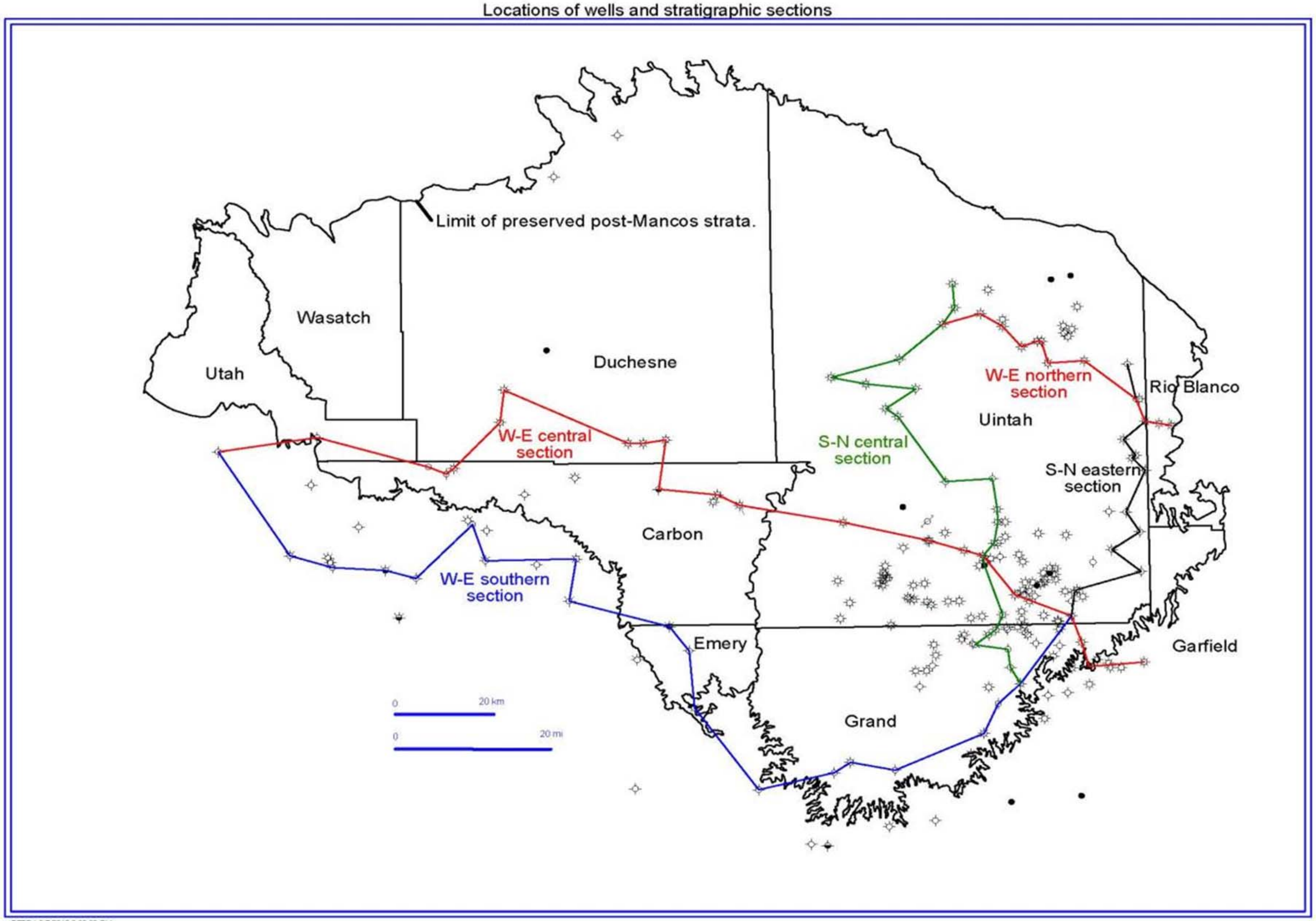
Data Compilation

Well database includes ~500 wells with

- operators and locations of wells of interest
- cores and cuttings, formation and zone, sample interval and repository, geophysical well logs, and wells with borehole imaging data
- completion data such as date of completion and current status, producing formation, targeted formation(s), and total depth (TD) and age of the formation at TD
- test-treatment data
- palynology analysis and geochemical analysis, from operators and acquired as part of this study

Regional Correlation

Locations of wells and stratigraphic sections



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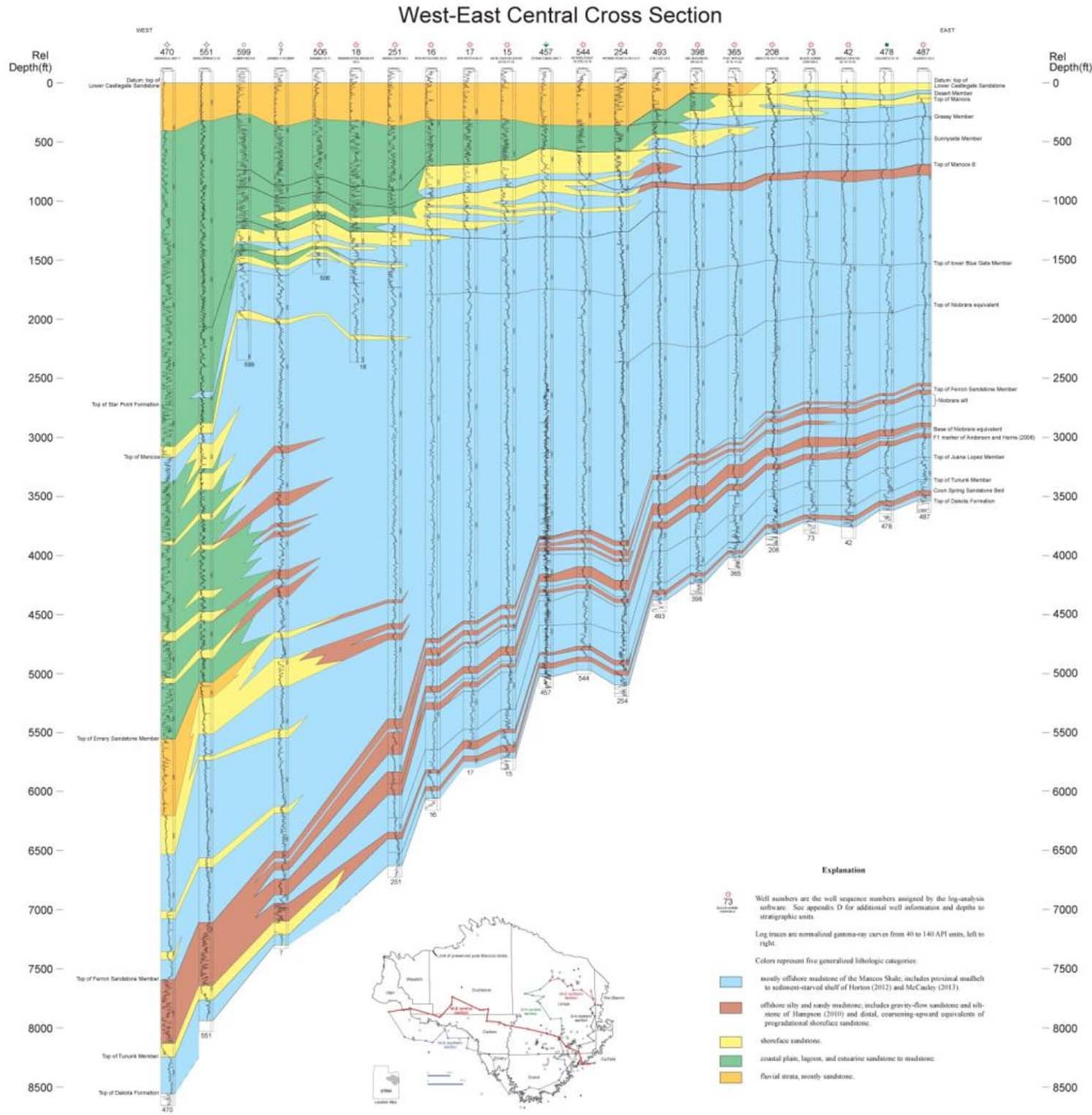
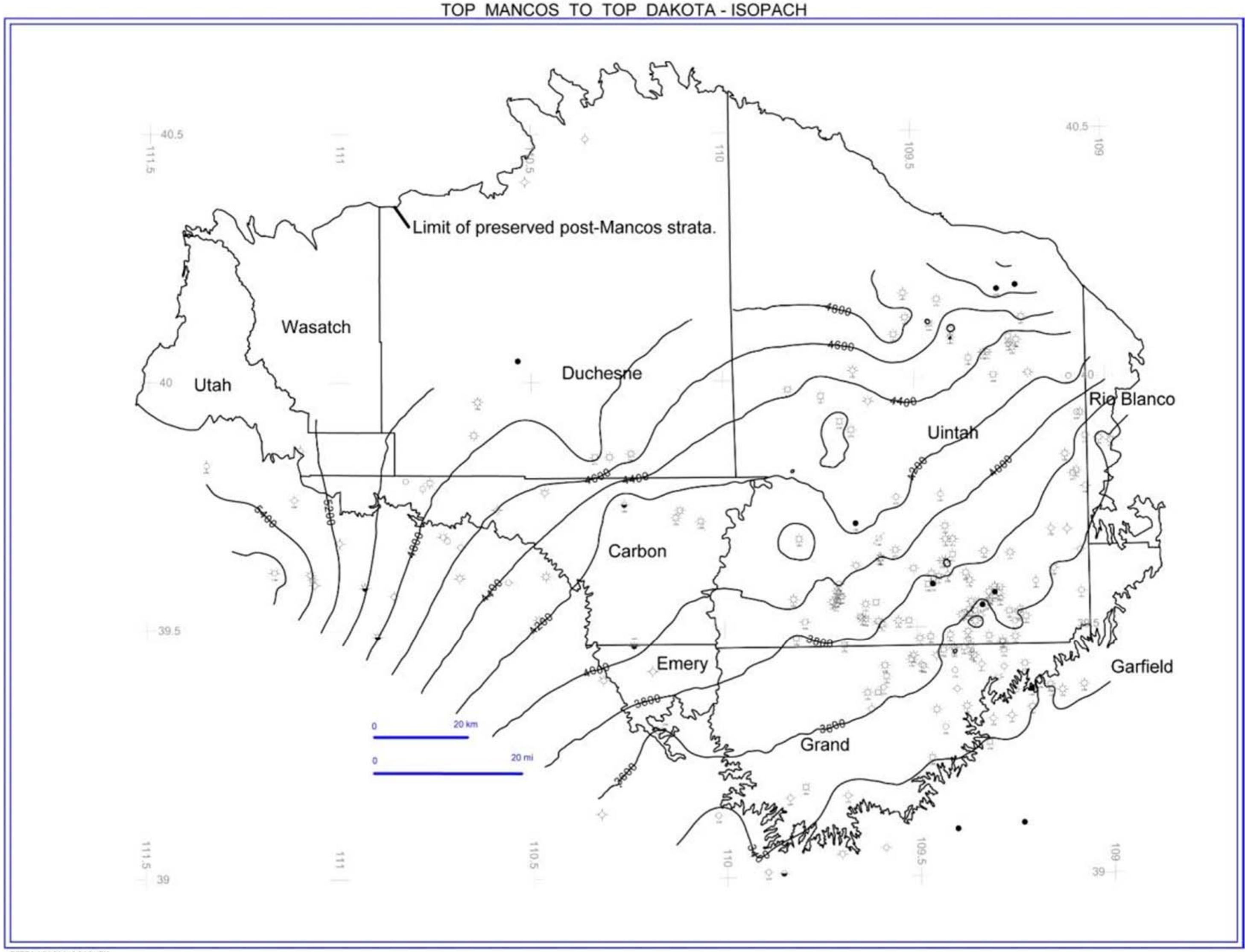
Regional Correlation



Regional Correlation

TOP MANCOS TO TOP DAKOTA - ISOPACH



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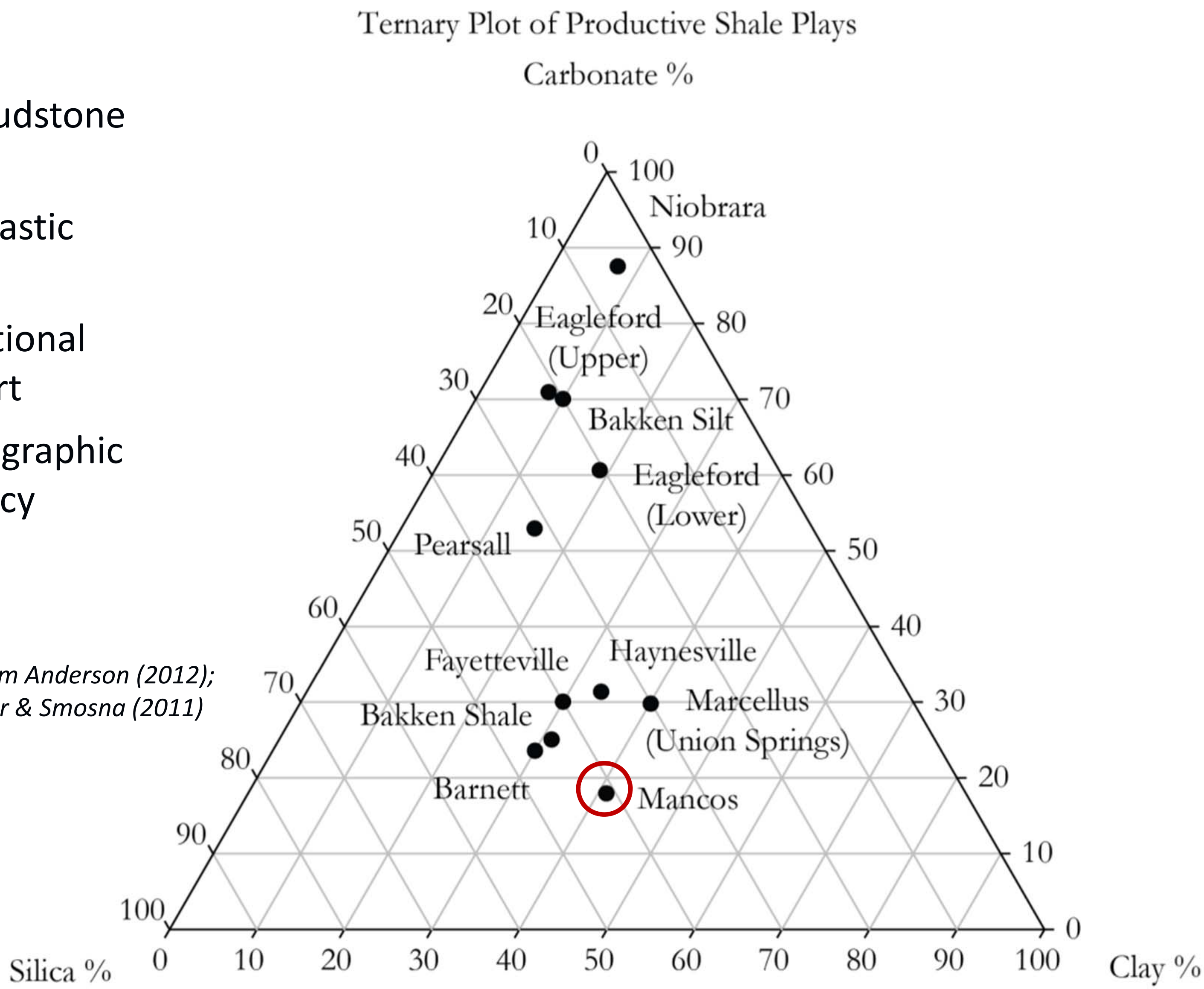
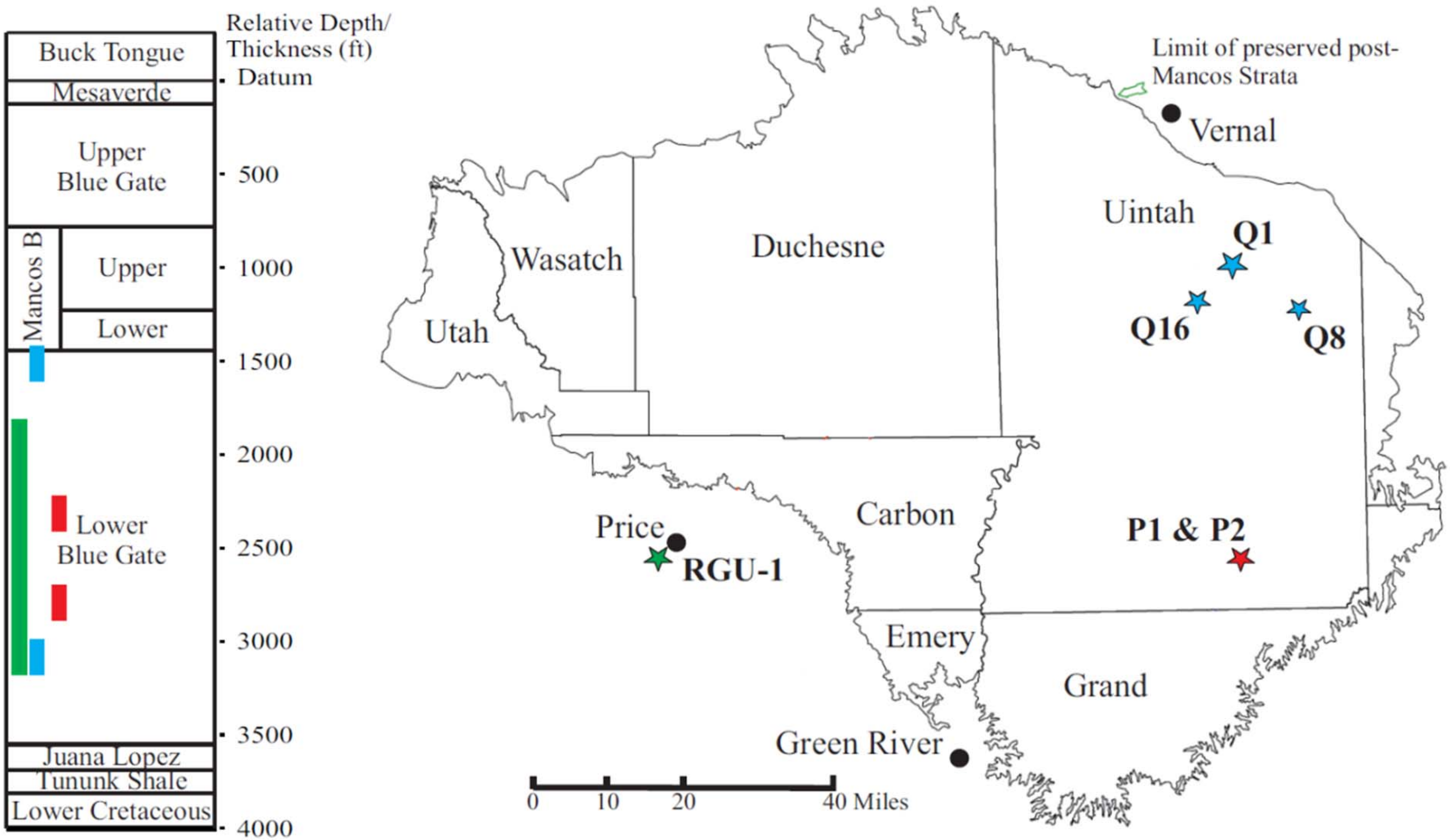
Mudstone Heterogeneity

- Spectrum of mudstone types
- Mancos "siliciclastic influenced"
- Current depositional models fall short
- Sequence stratigraphic models in infancy

Horton (2012); modified from Anderson (2012); Boyce & Carr (2009); Bruner & Smosna (2011)

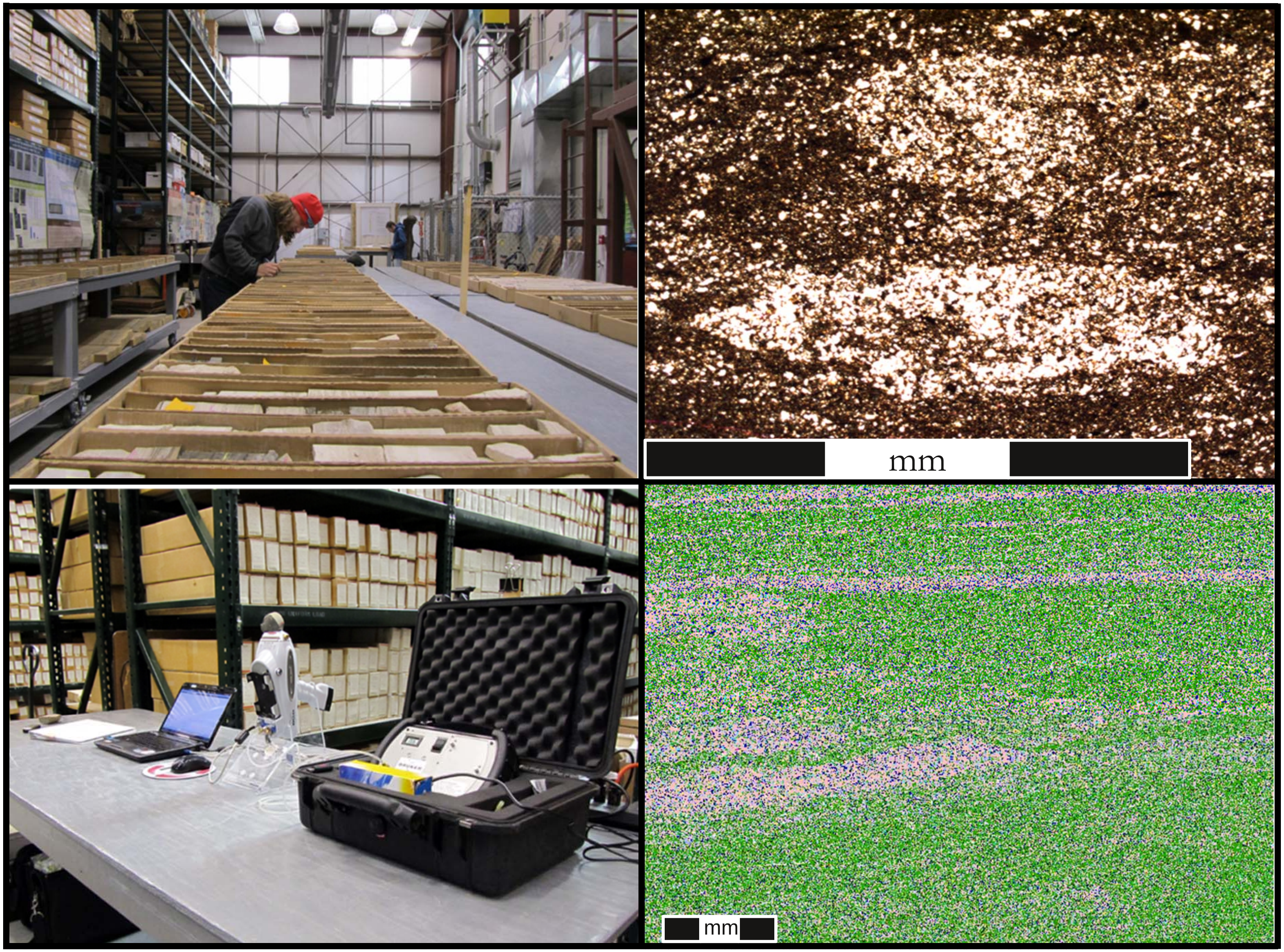


Core Datasets



Birgenheier et al. (in prep); McCauley (2013)

Characterization methods

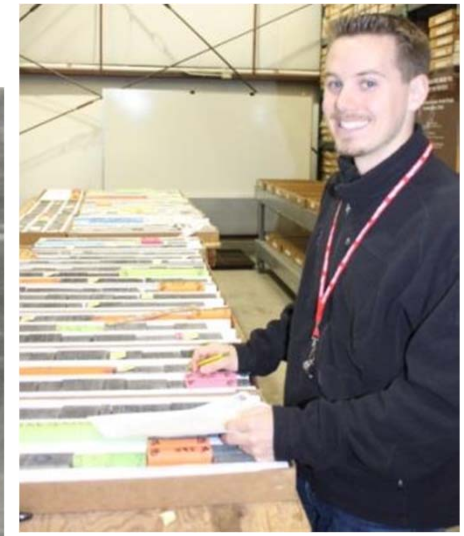


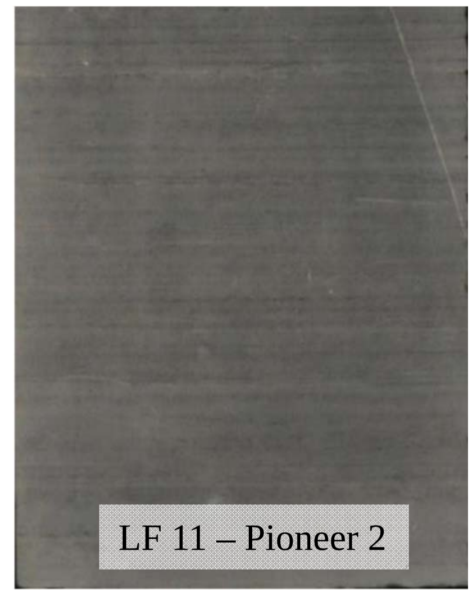
Photos: Utah Reservoirs website, www.reservoirs.earth.utah.edu

Lower Blue Gate Mbr. - facies variability

11 lithofacies identified and placed in depositional context based on:

- Grain size
- Lamination style
- Bioturbation index





Proximal, sand-rich

Distal, mud-rich

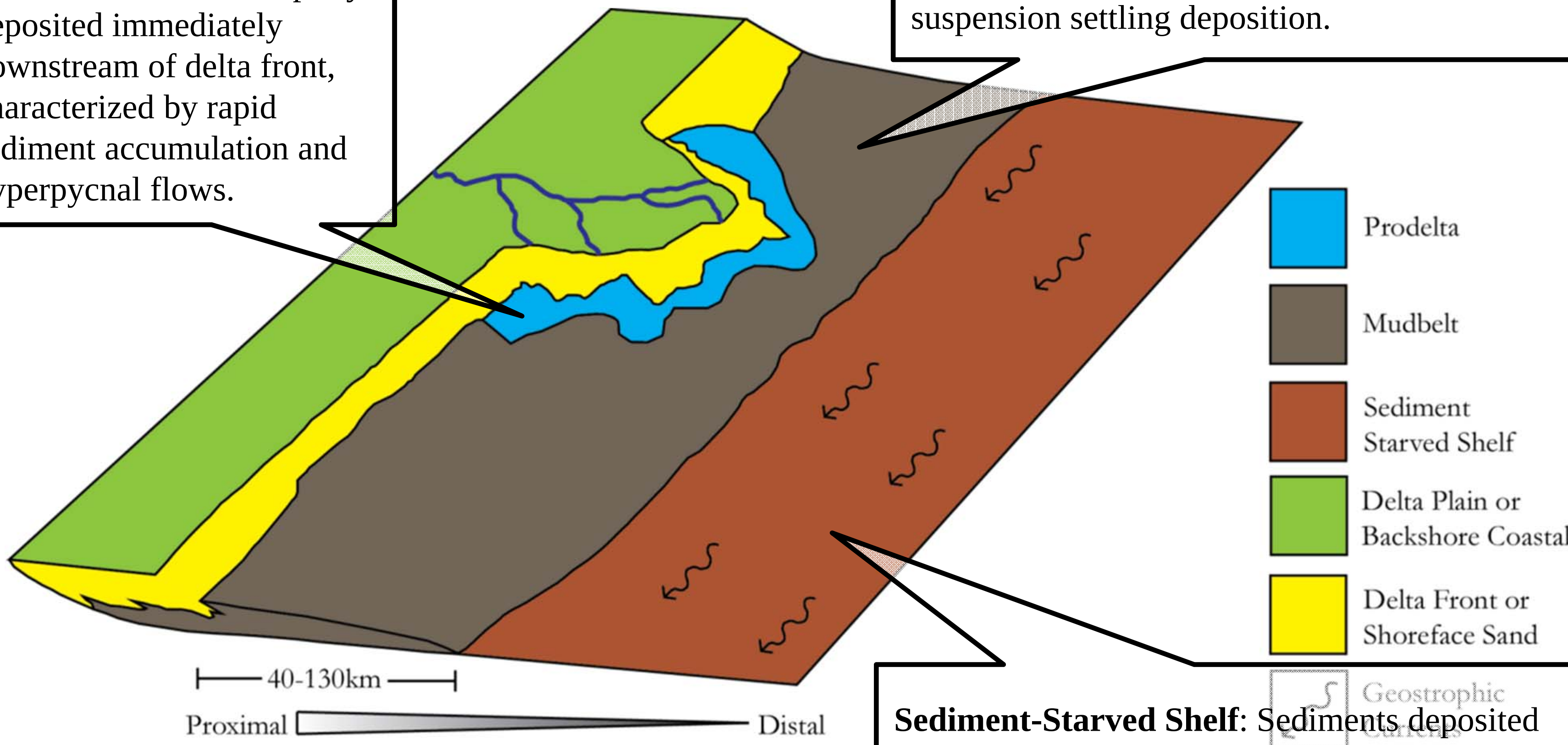
Kennedy (2011); Horton (2012); McCauley (2013)

Depositional Model:

1) prodelta, 2) mudbelt, 3) sediment-starved shelf

Prodelta: Sediments rapidly deposited immediately downstream of delta front, characterized by rapid sediment accumulation and hyperpycnal flows.

Mudbelt: Reworked sediments initially deposited at the delta front. Subject to both hyperpycnal and suspension settling deposition.

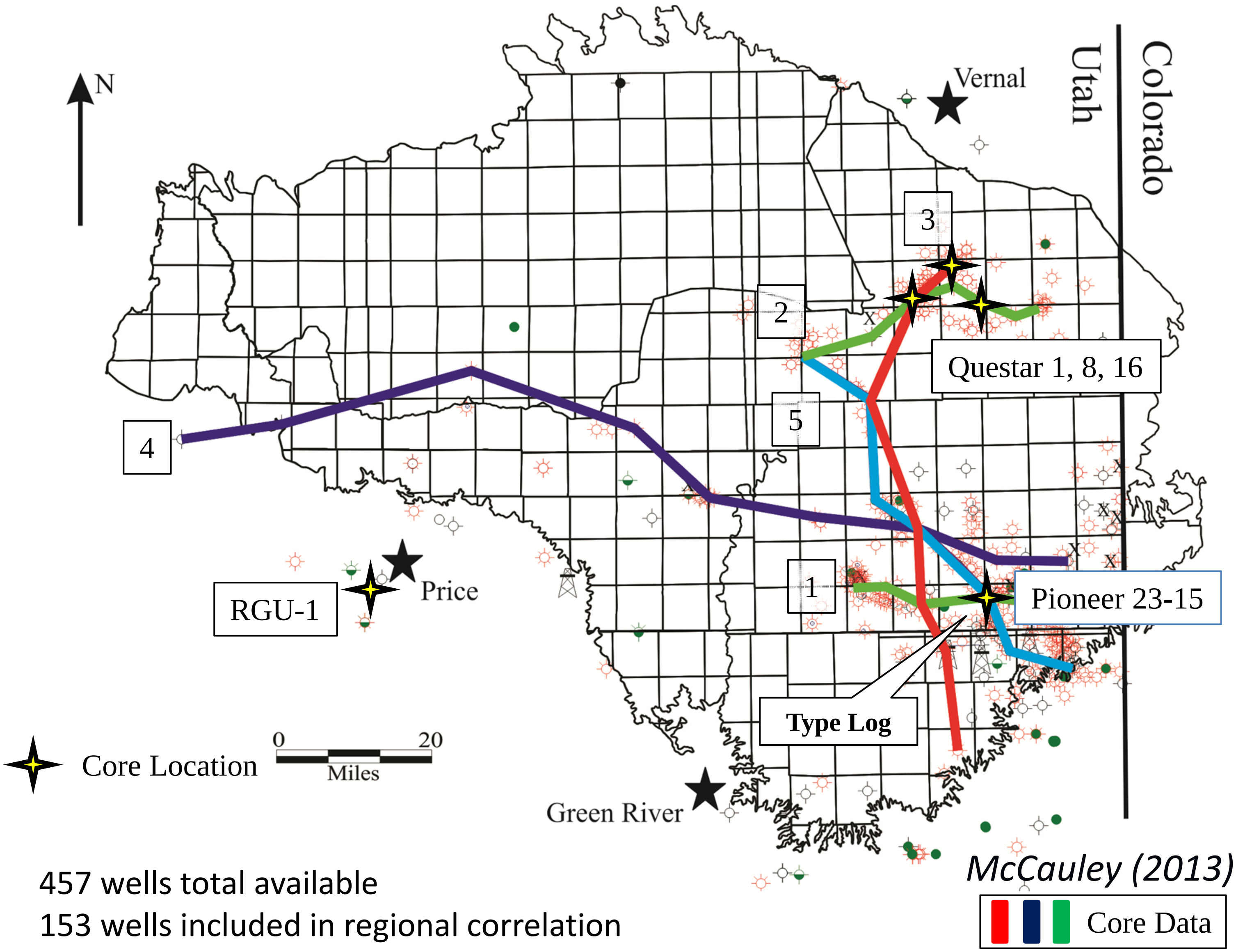


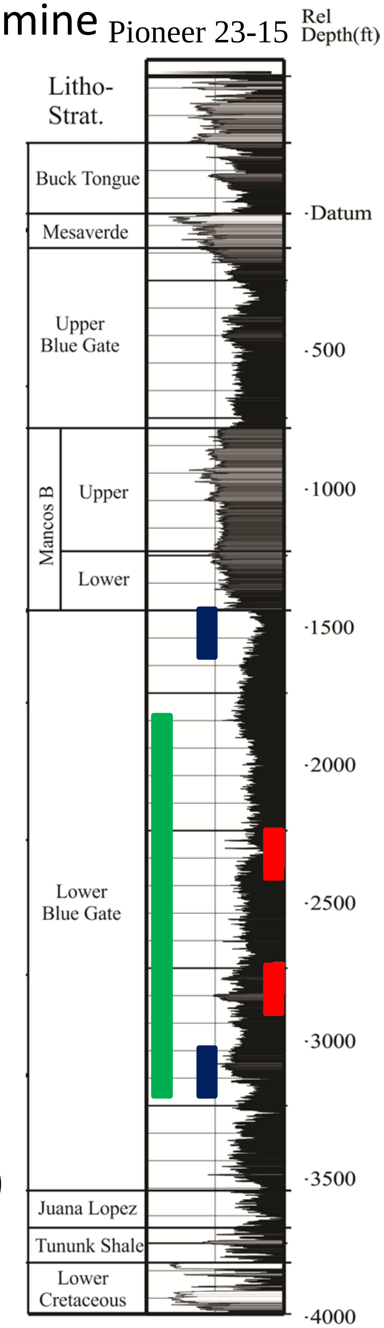
Birgenheier et al. (in prep.); Horton (2012)

Sediment-Starved Shelf: Sediments deposited basinward of the influence of hyperpycnal deposition, typically below storm wave base with influence from shelfal currents.

Well log correlation

How can we used depositional framework to examine stacking patterns and predict target intervals?

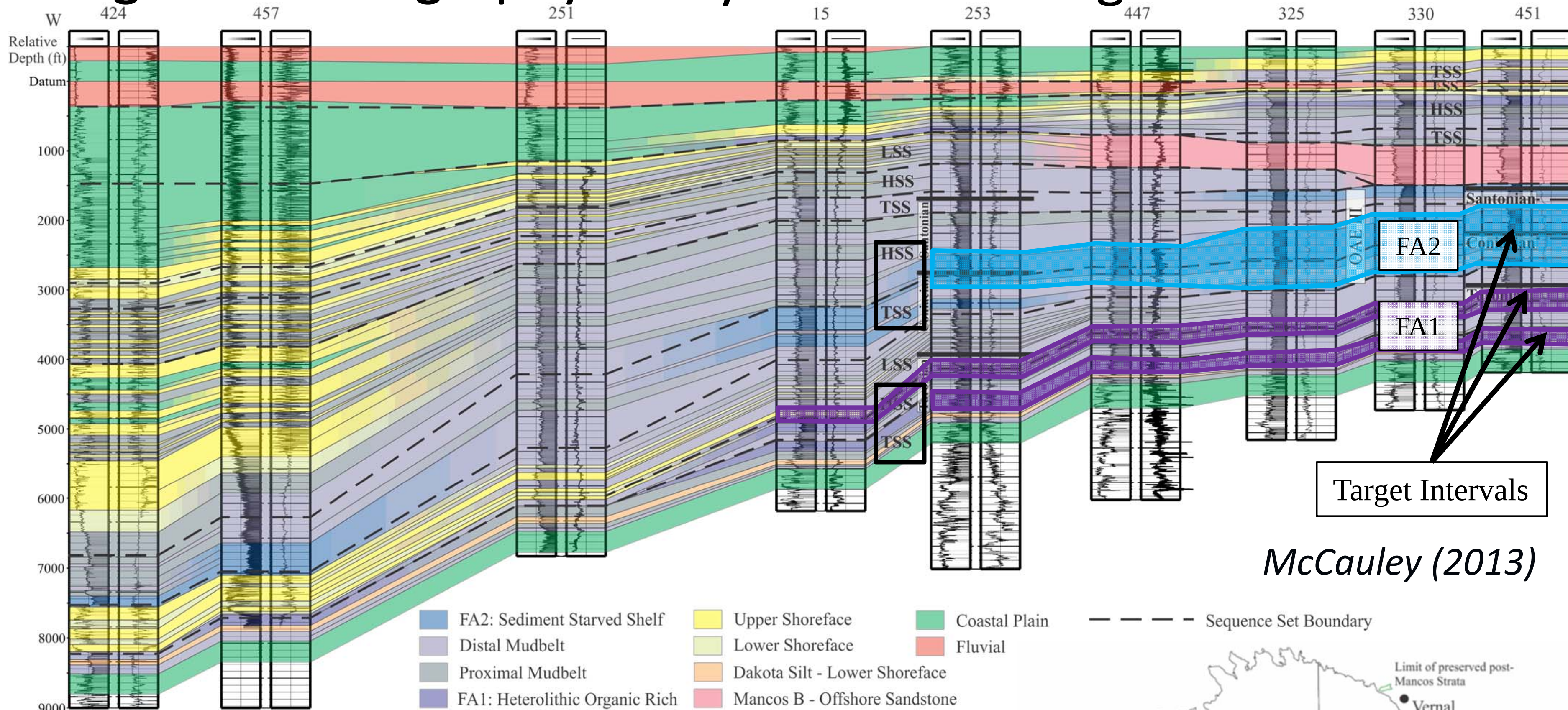




457 wells total available

153 wells included in regional correlation

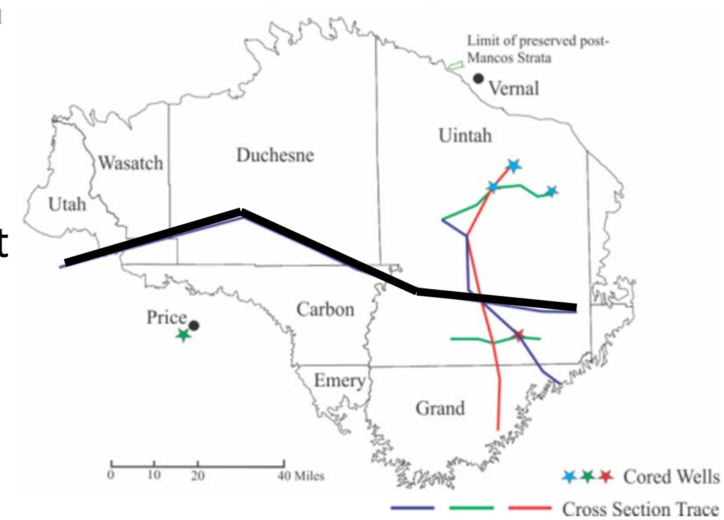
Regional Stratigraphy Hydrocarbon Target Facies



McCauley (2013)

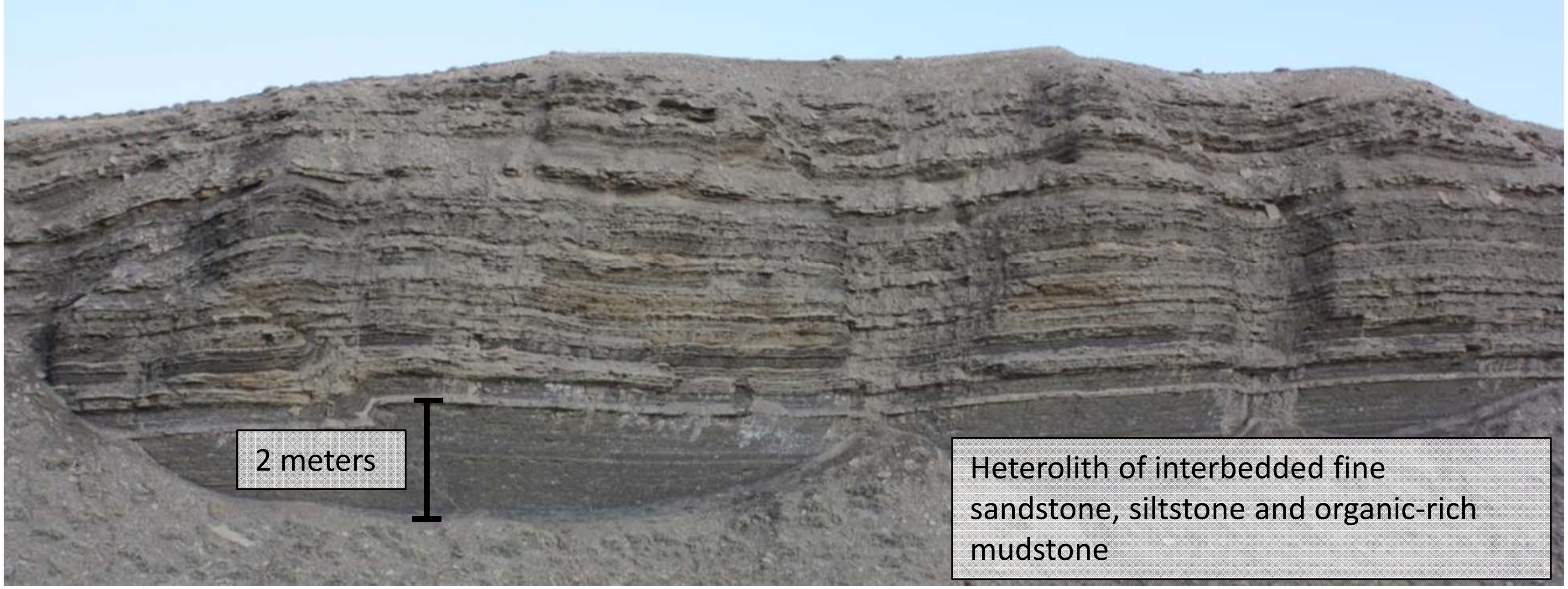
Targets share:

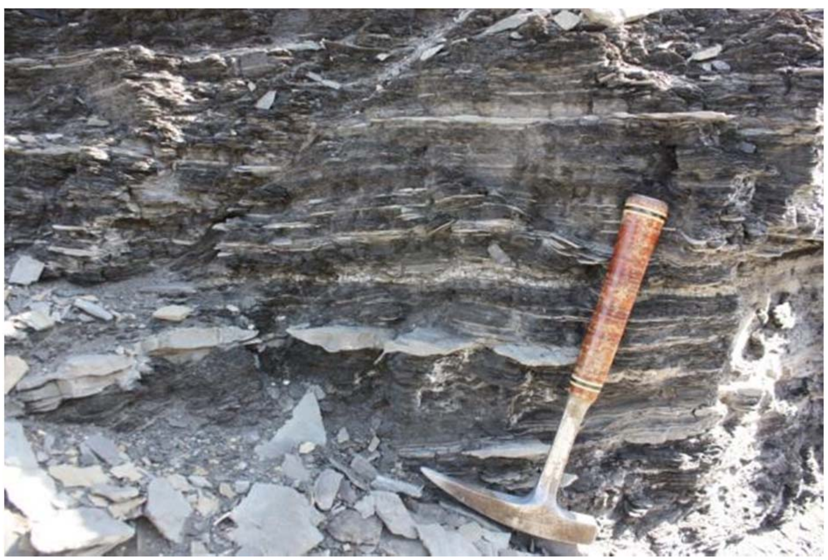
- relatively high TOC, distal deposition with low sediment dilution
- correspond with transgressive and lowermost highstand sequence sets
- mineralogy conducive to brittle fracture

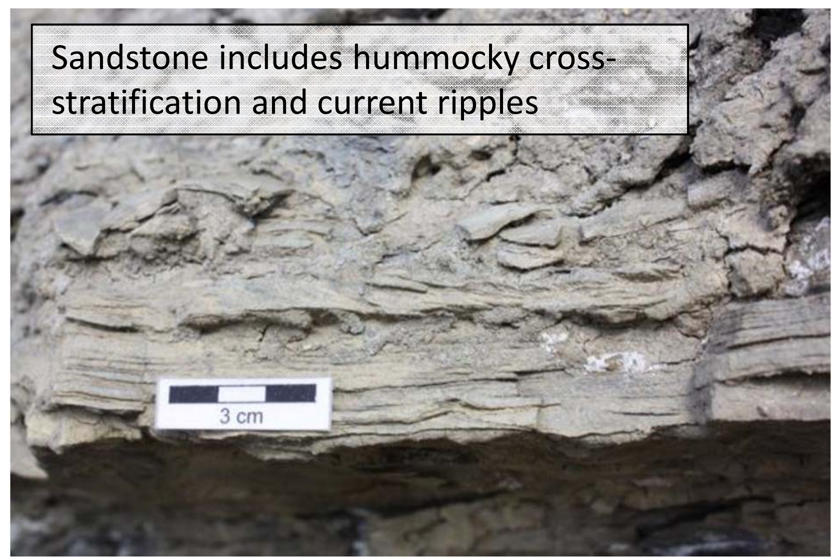


Facies Association 1

Juana Lopez Outcrops

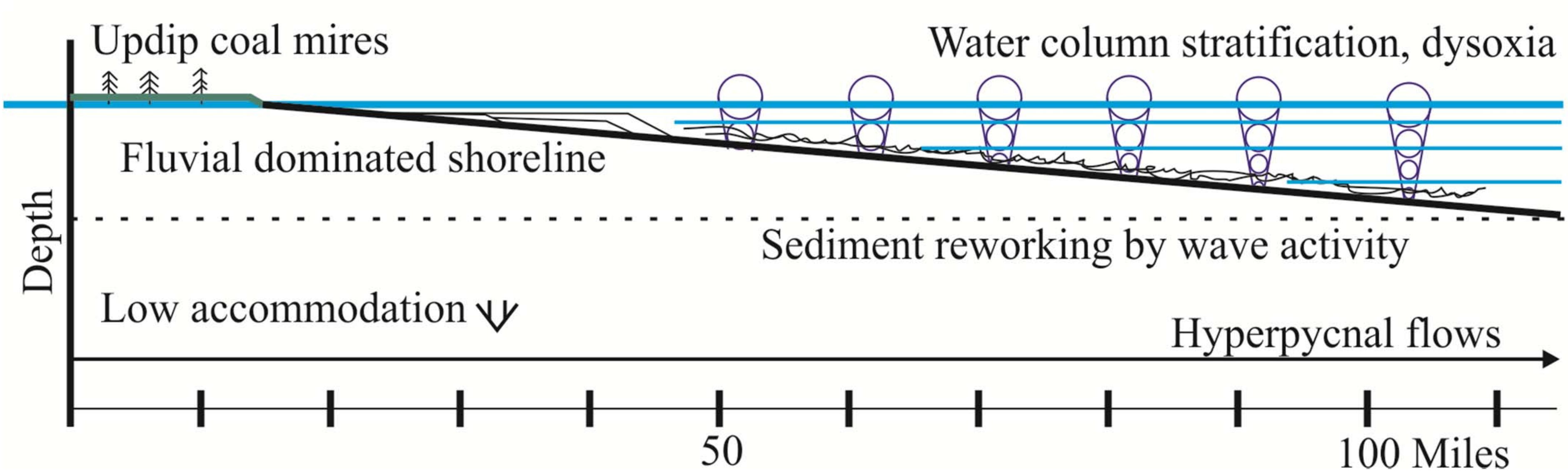






Facies Association 1 Depositional Setting

<u>Stressed shallow ramp</u>



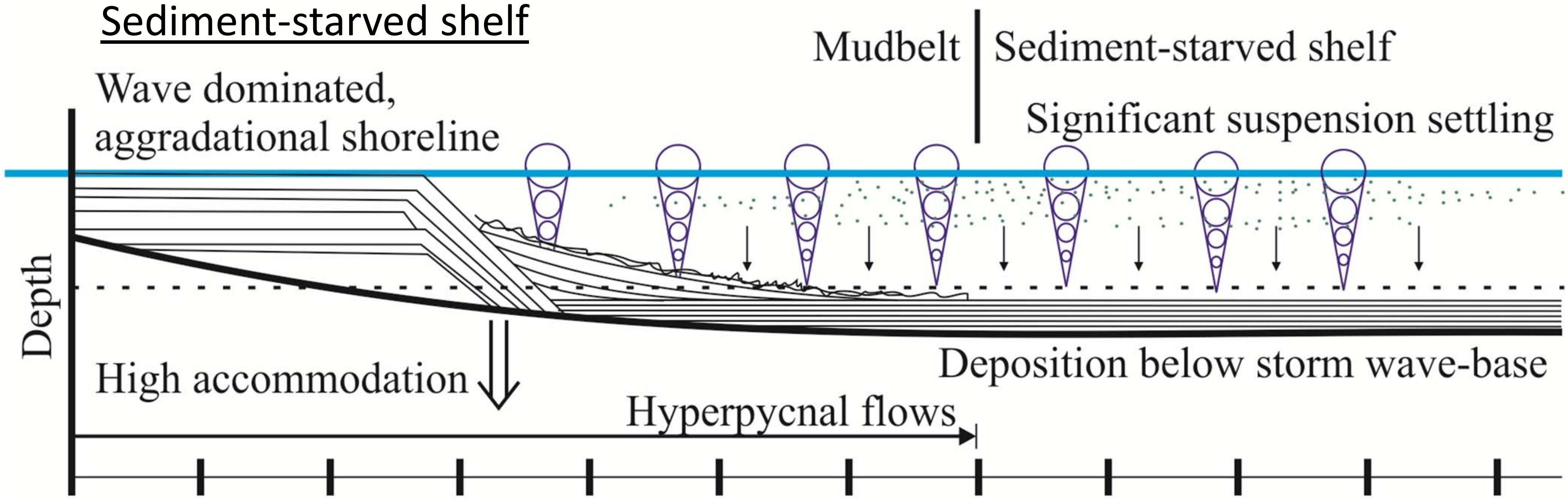
McCauley (2013)

Hydrocarbon target implications: higher TOC and detrital quartz

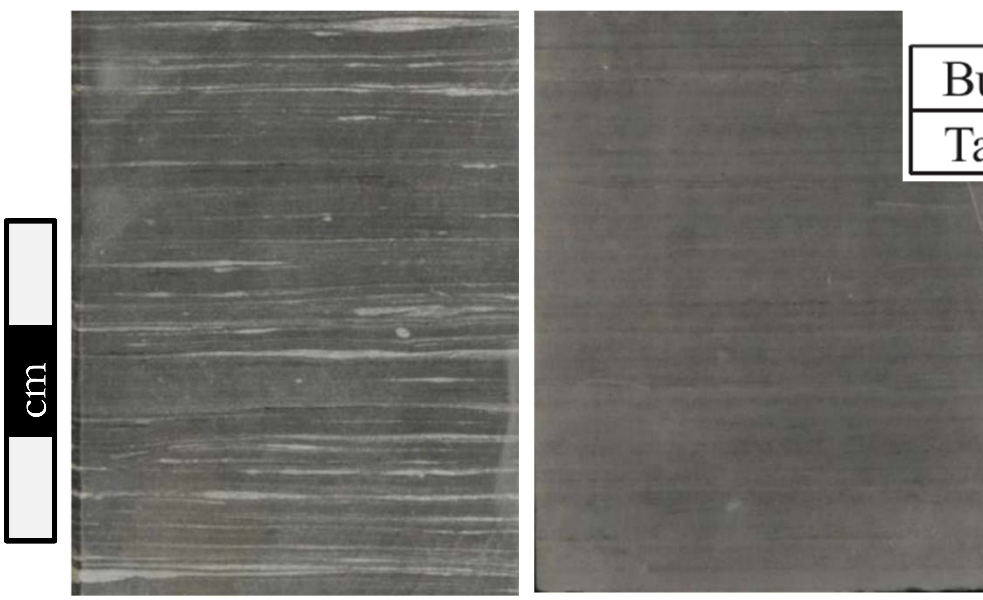
Facies Association 2

Depositional Setting

Sediment-starved shelf



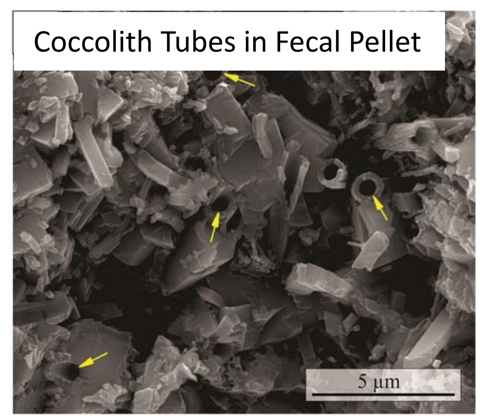
McCauley (2013)



	TOC %	Ca %	Al %	Si %
Bulk Mancos	1.25	19.8	43.3	36.9
Target Facies	1.82	29.0	42.0	29.0

Hydrocarbon target implications: higher TOC and carbonate content

Horton (2012)



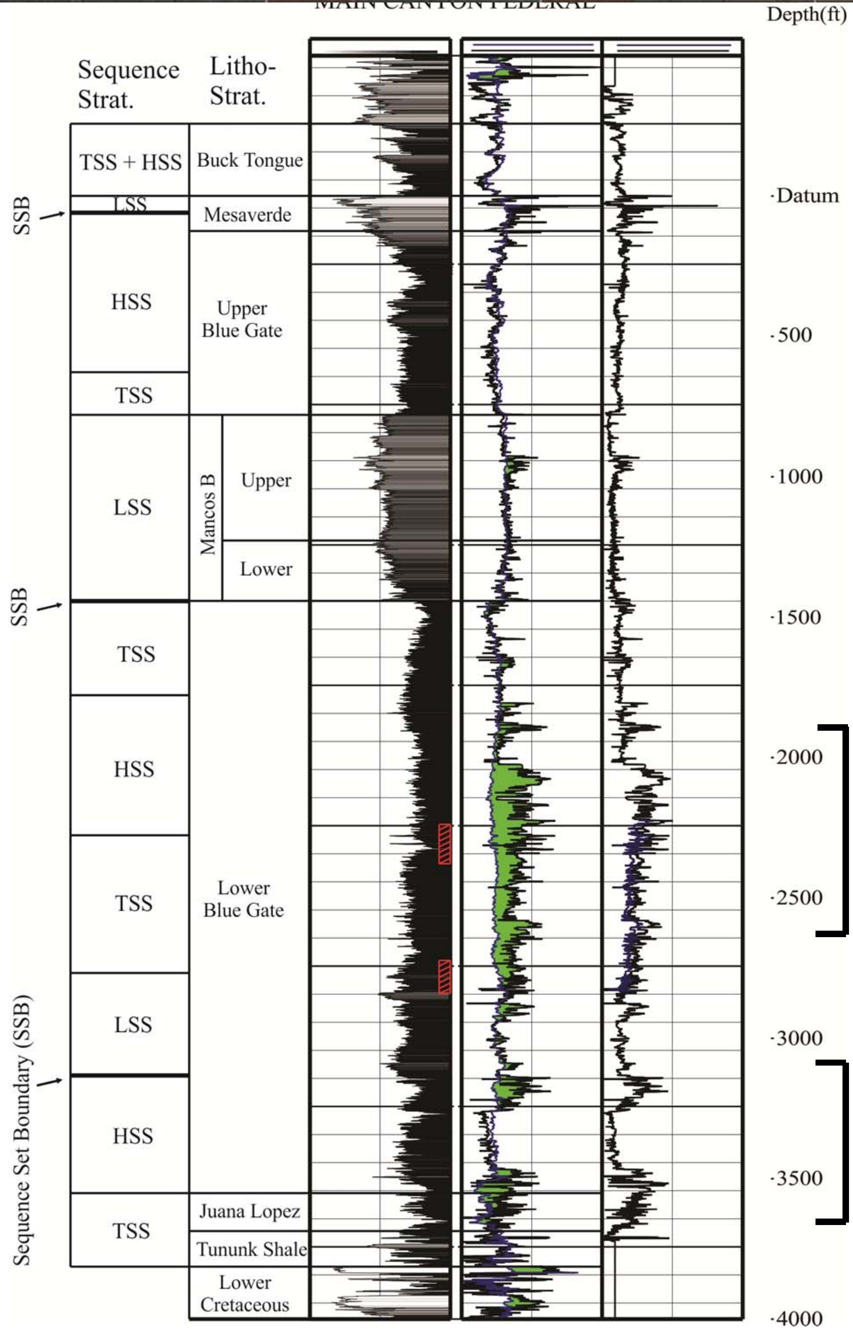
Organic content by Δ Log R

The ΔlogR method uses wireline logs, geochemical data, and thermal-maturity information to calculate an in-situ %TOC.

Apparent density (from curves NPHI, RHOB, or DT) decreases if there is kerogen present within the pore space of organic-rich source rocks.

Free hydrocarbons in the pore space will cause an increase in formation resistivity curve.

Modified from Stright & Hillier (2014); McCauley (2013)



Method must be adjusted for thermal maturity, which increases resistivity.

FA1 & FA2 contain > 3% TOC

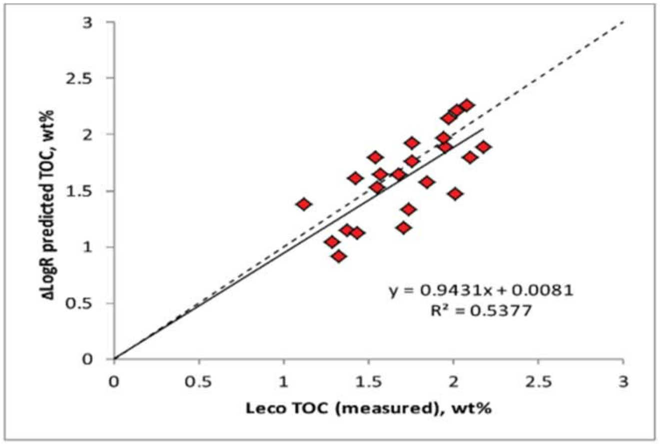
Facies Association 2, Stressed shallow ramp

Facies Association 1, Sediment starved shelf

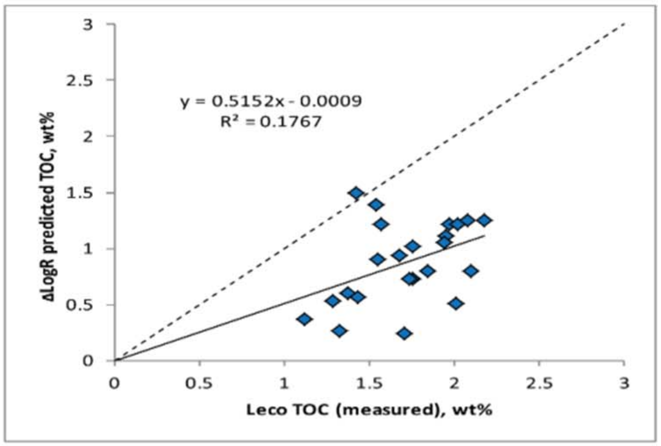
Organic Content by Δ Log R Method

Results show good correlation with sonic and neutron porosity logs.

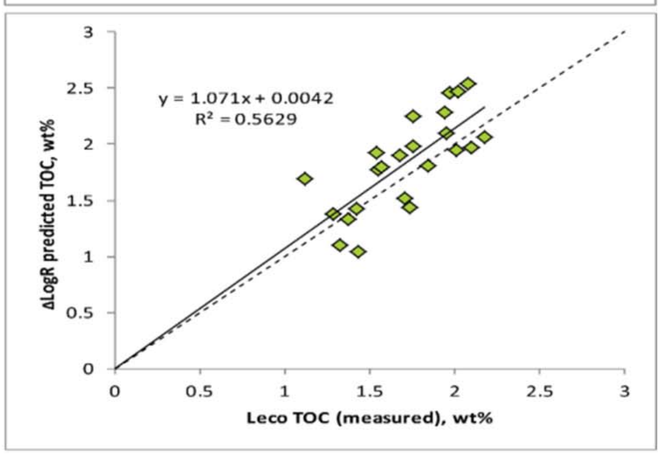
Comparison of measured TOC with calculated from three types of porosity logs.



Sonic



Bulk Density



Neutron Porosity

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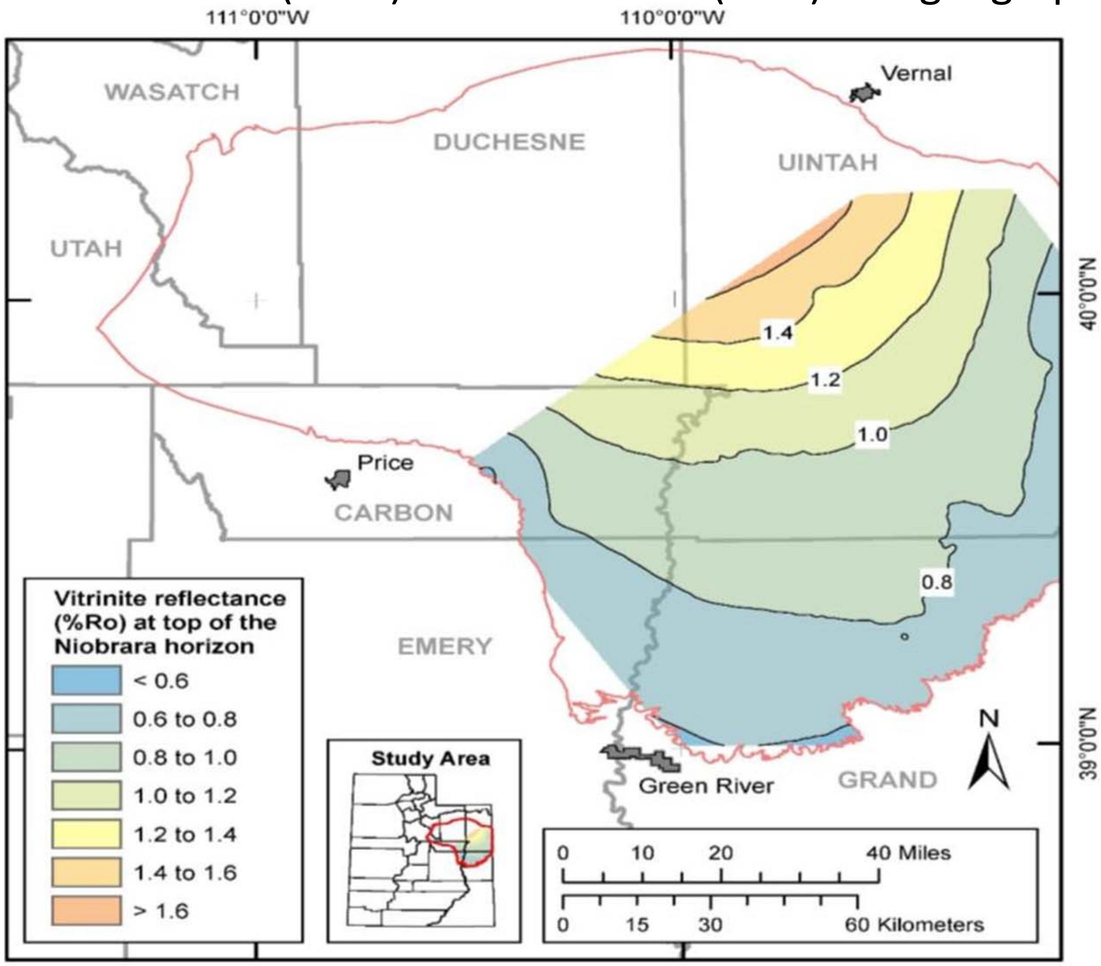
Organic Maturation Modeled from Vitrinite Reflectance

Predicts vitrinite reflectance (% Ro) from elevation (MSL) and geographic coordinates.



$\%Ro = 14.9X + 33.2Y – 80.1Z + 0.0847X^2 – 0.264Y^2 + 29.3Z^2 – 0.364XY – 2.48YZ – 642.3$

where:

X = UTM easting/100,000; Y = UTM northing/100,000; Z = 1,000,000/(300,000 + elevation [ft.])

R^2 of 0.87 and a standard error of 0.13% Ro.

1-D Burial Histories

Heat flow was set at 58 mW/m^2 (the average continental heatflow) through the Cretaceous, then adjusted linearly to the modern heatflow in the nearest available data points.

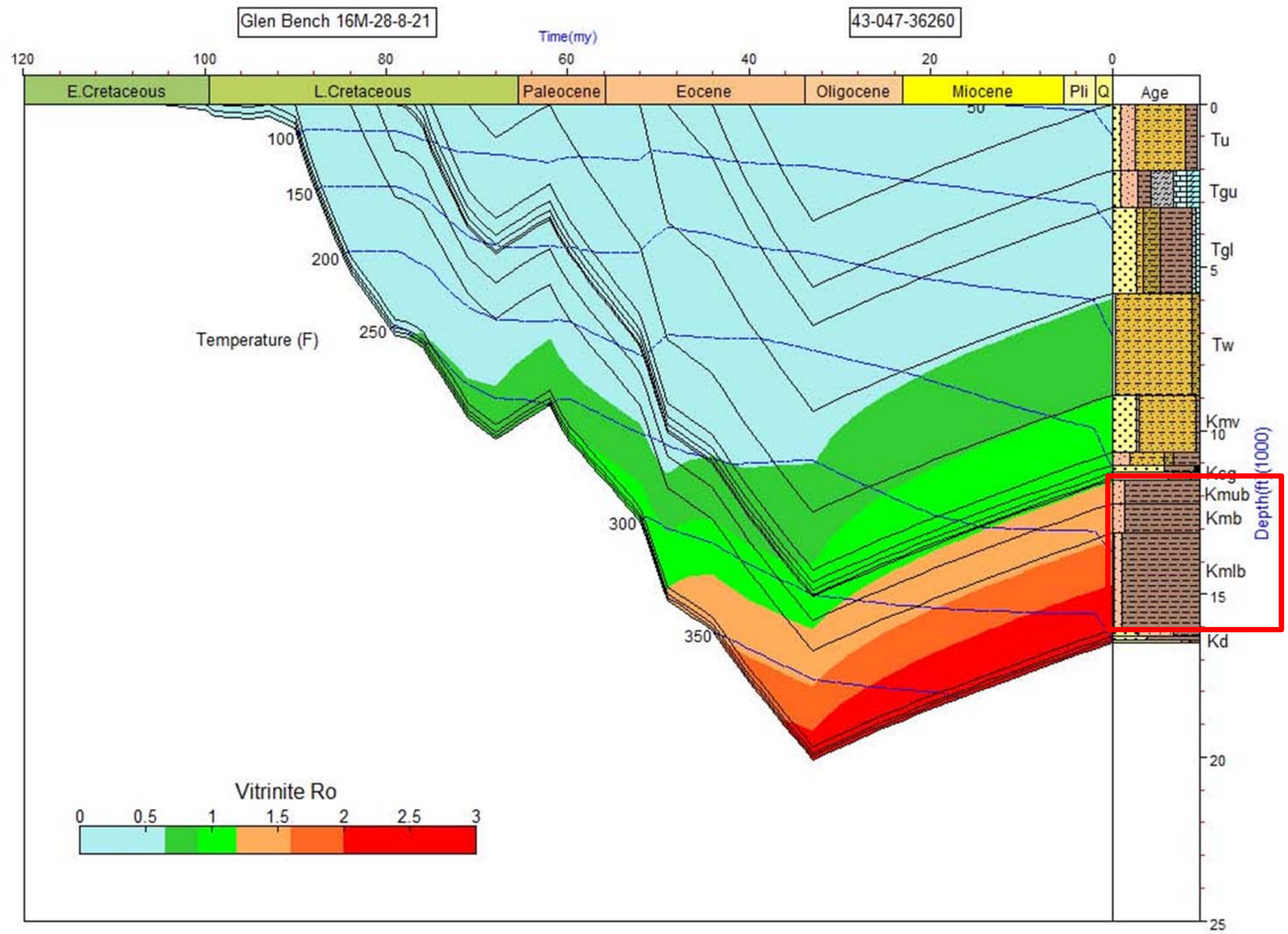
Surface temperatures from the Jurassic through the Cretaceous were determined from paleolatitudes as described by Barker (2000).

Present surface temperature is from the nearest weather station listed in U.S. National Oceanic and Atmospheric Administration, 2002, Climatography of the United States No. 81, 42 Utah.

Erosion rates were estimated from thicknesses of regional preserved sections and modern erosional rates of the Colorado River Basin.

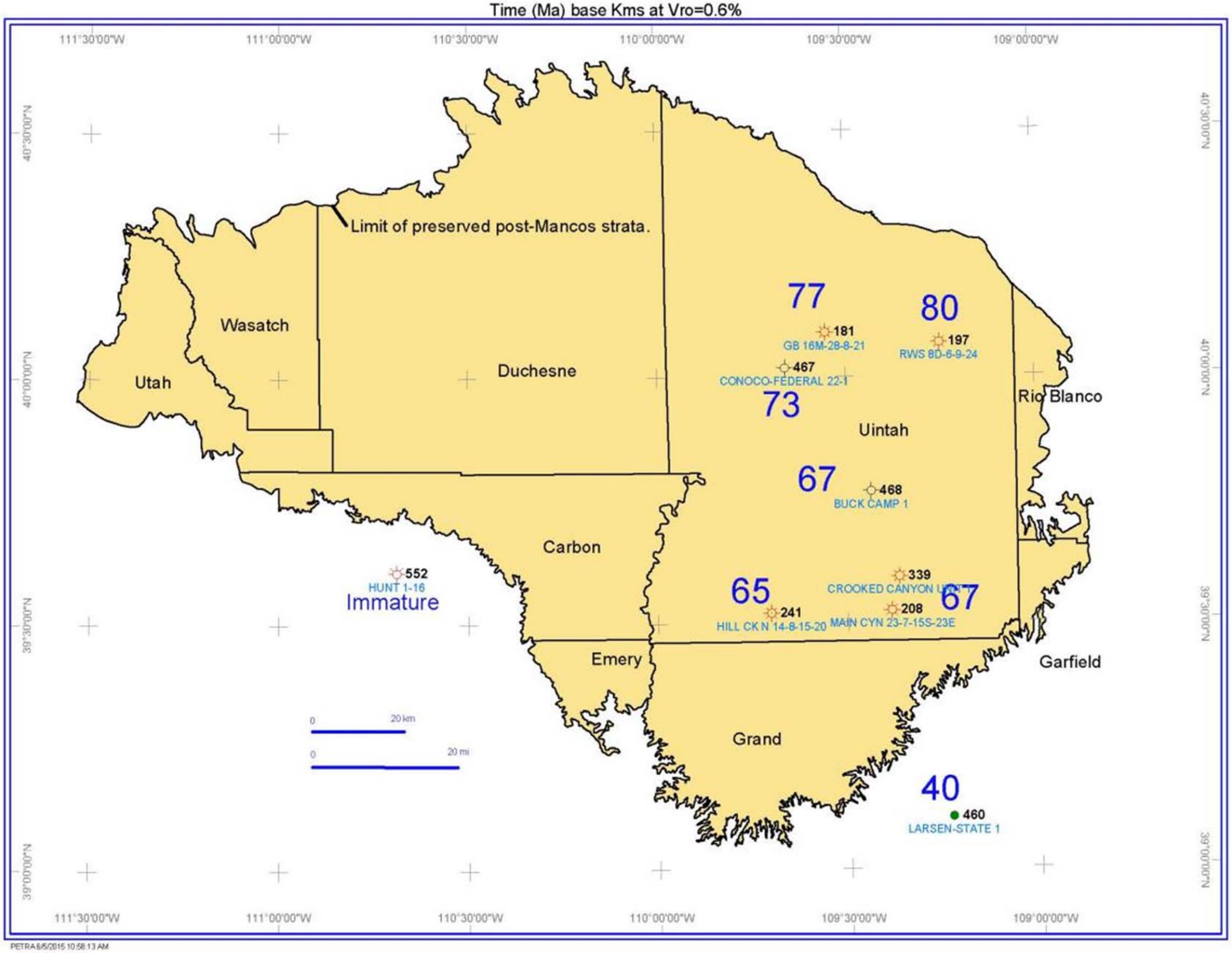
Models used Zetaware Genesis software.

1-D Burial Histories



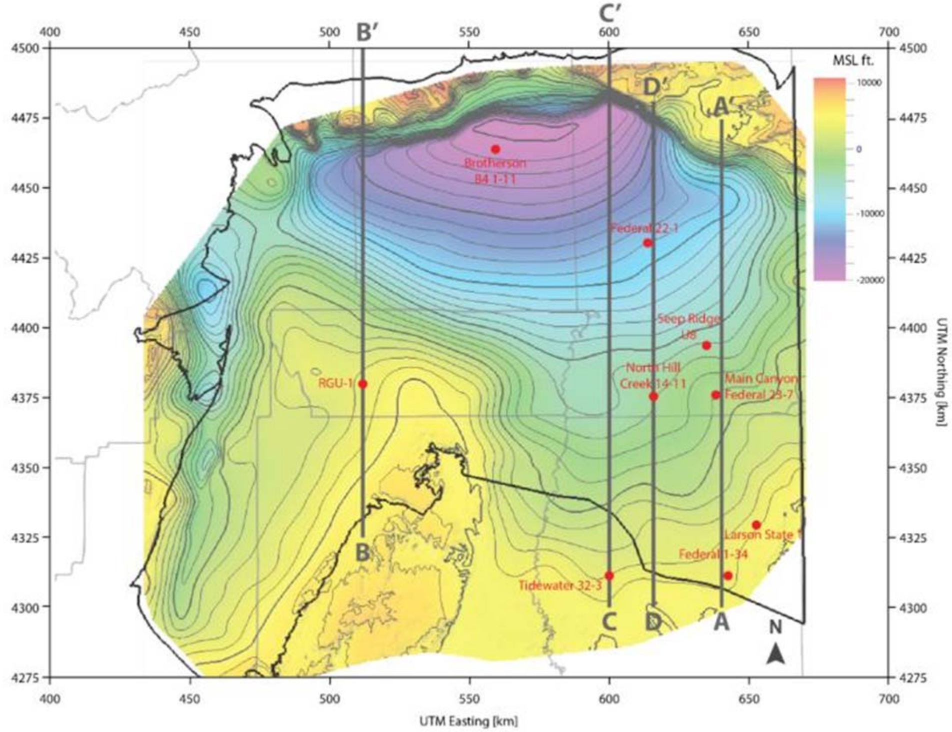
Burial history for Glen Bench 16M

1-D Burial Histories

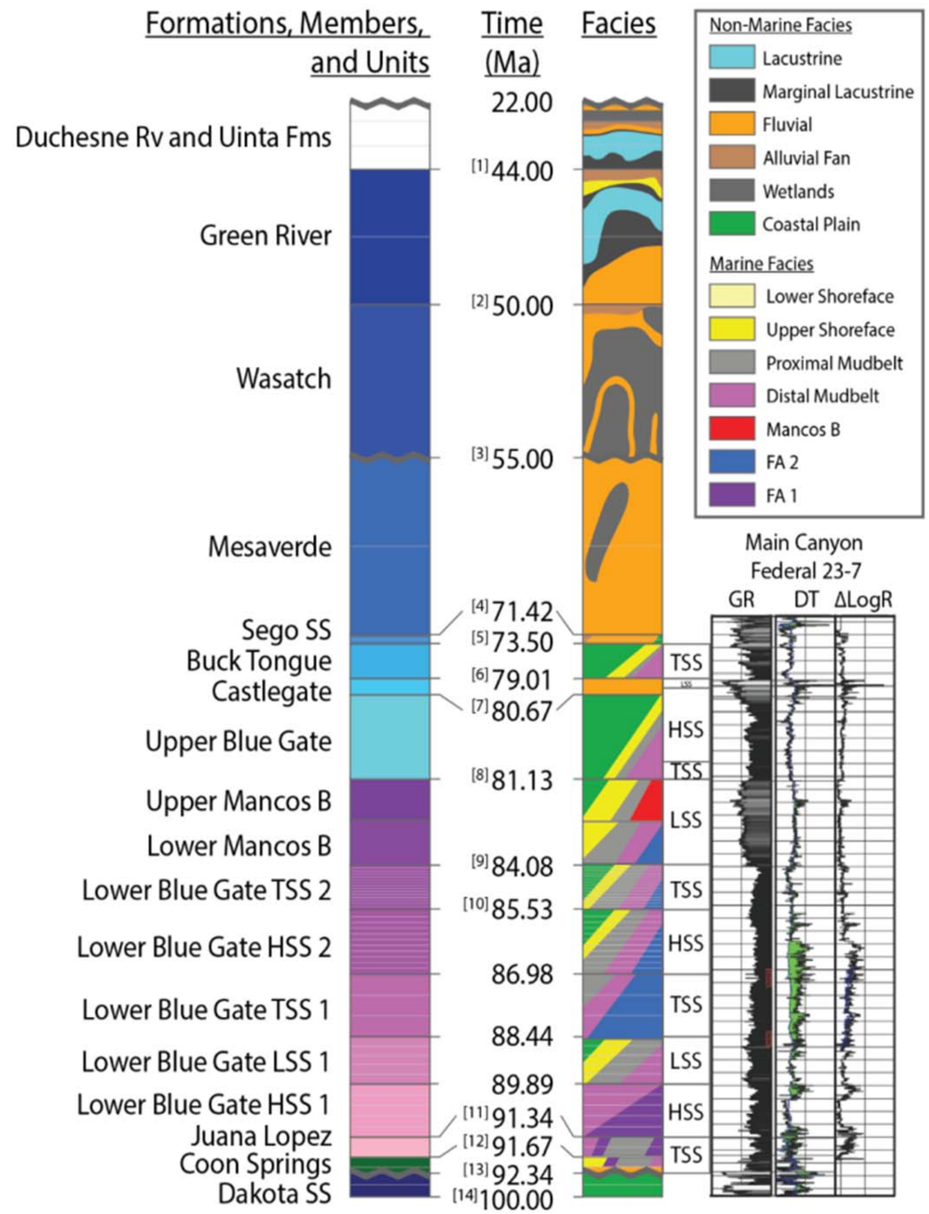


Time (million years before present) when the base of the Mancos began oil generation.

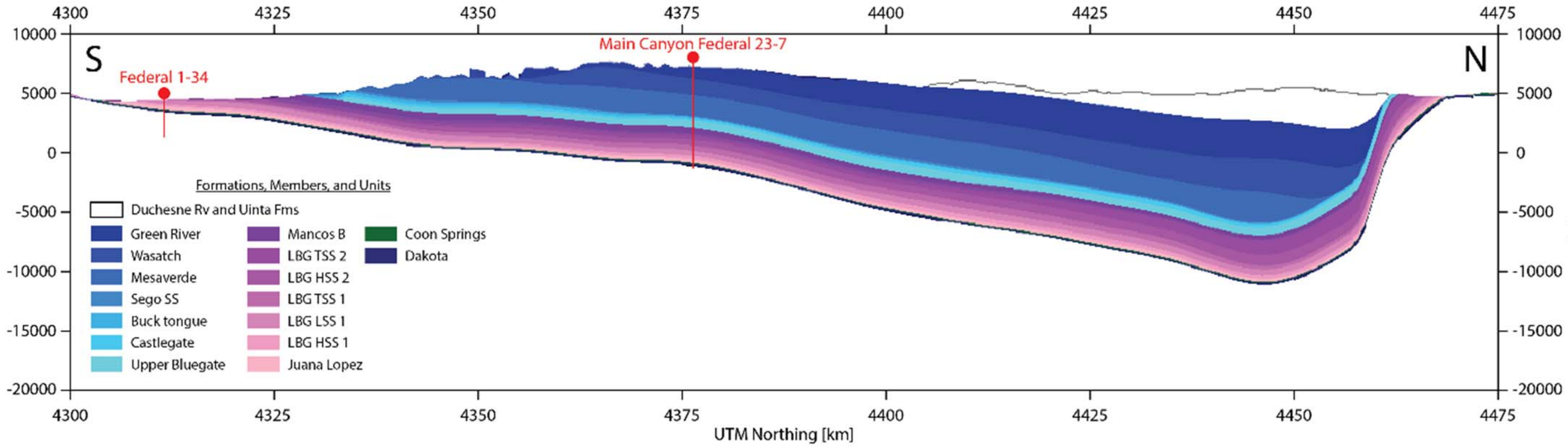
3D Basin Modeling

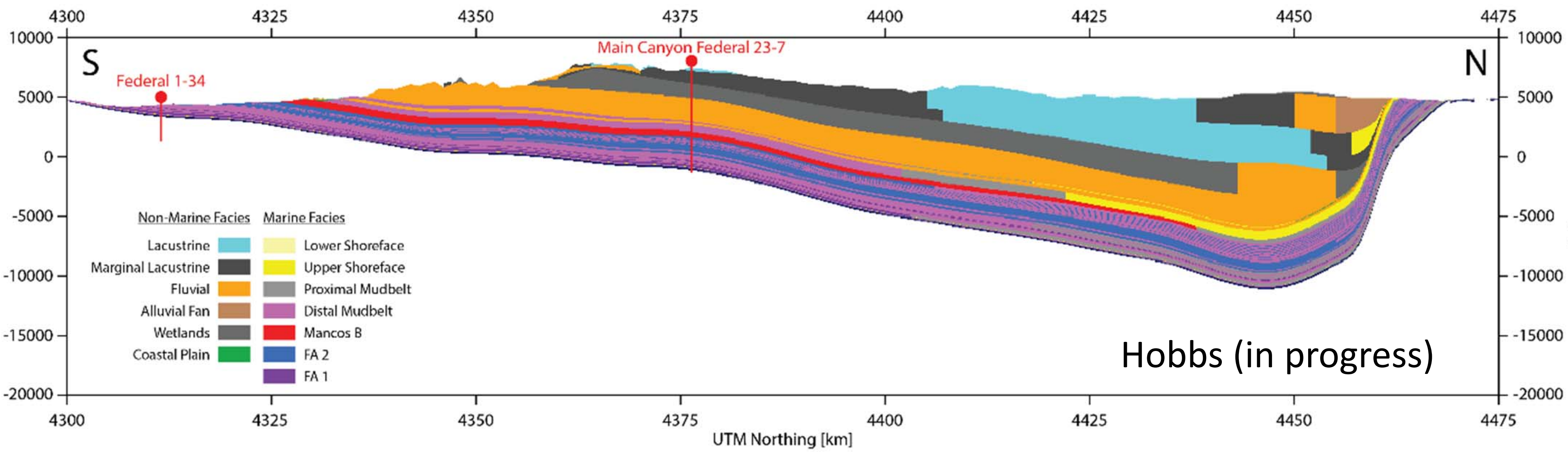


Hobbs (in progress)

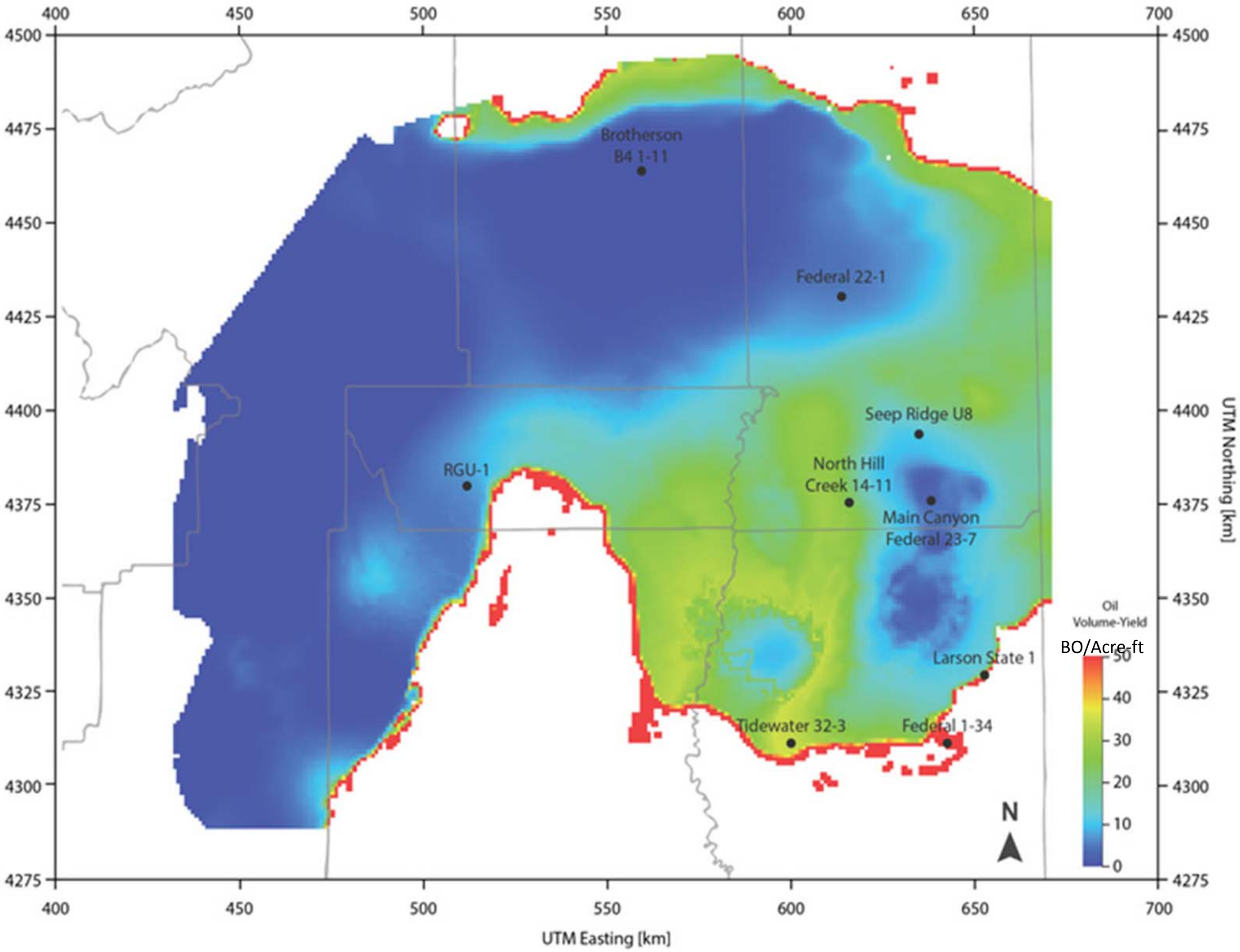


3D Basin Modeling

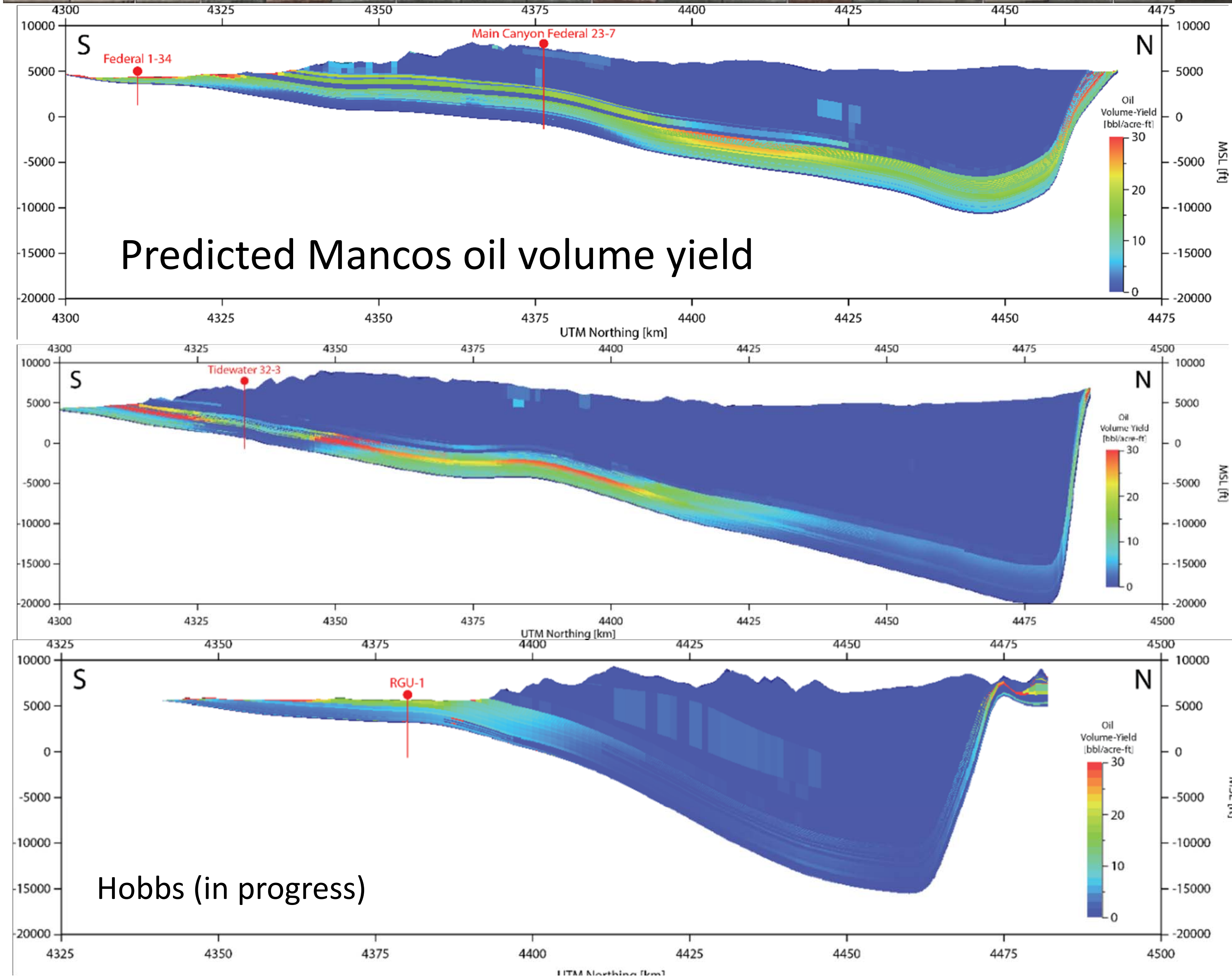




Predicted Mancos oil volume yield

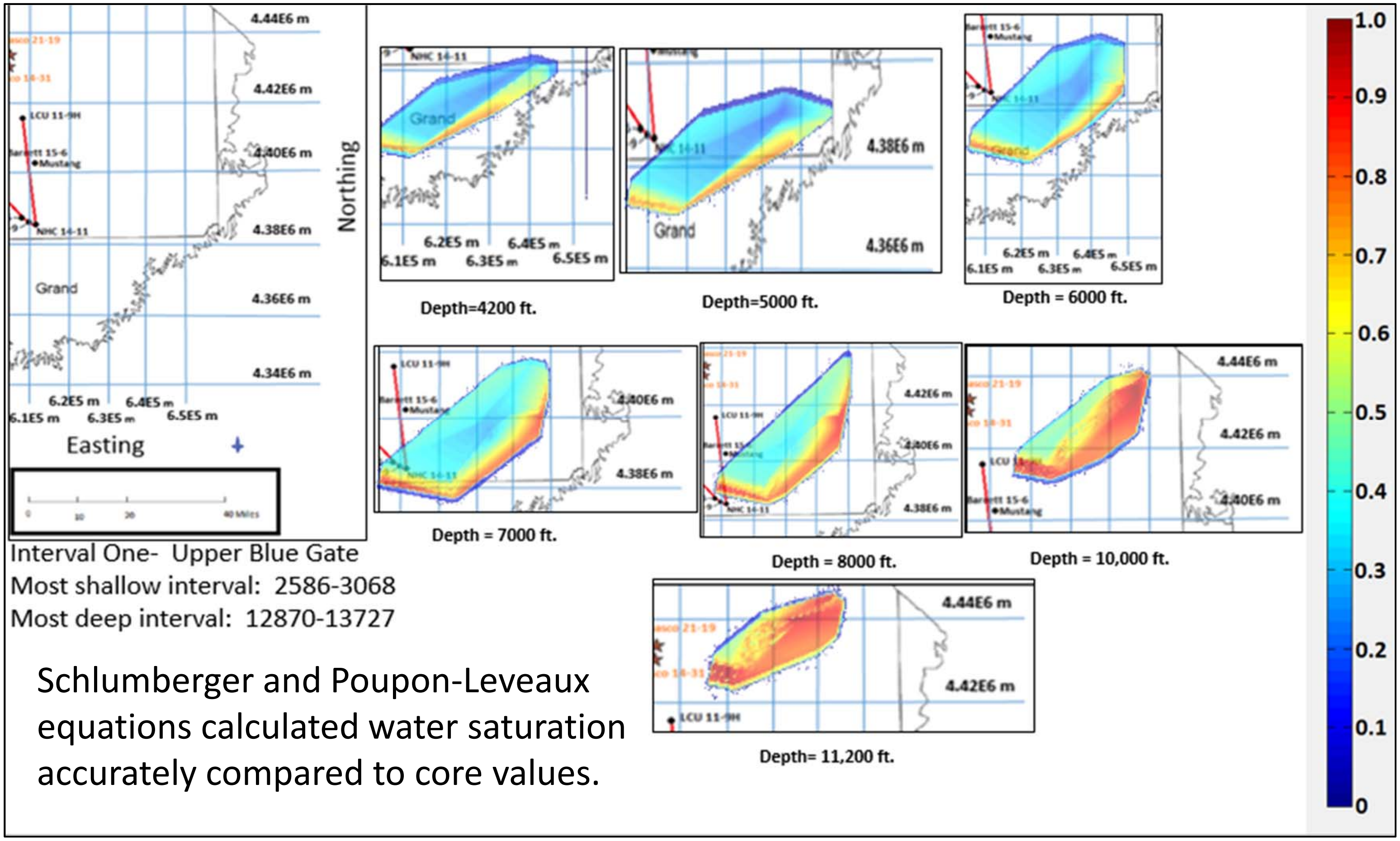


Hobbs (in progress)



Predicted Mancos oil volume yield
S
N
Federal 1-34
Main Canyon Federal 23-7
Oil Volume-Yield [bbl/acre-ft]
30
20
10
0
MSL [ft]
UTM Northing [km]
4300
4325
4350
4375
4400
4425
4450
4475
10000
5000
0
-5000
-10000
-15000
-20000
S
N
Tidewater 32-3
Oil Volume Yield [bbl/acre-ft]
MSL [ft]
UTM Northing [km]
4500
Hobbs (in progress)
S
N
RGU-1
Oil Volume-Yield [bbl/acre-ft]
MSL [ft]
UTM Northing [km]

Log Evaluation – Water Saturation

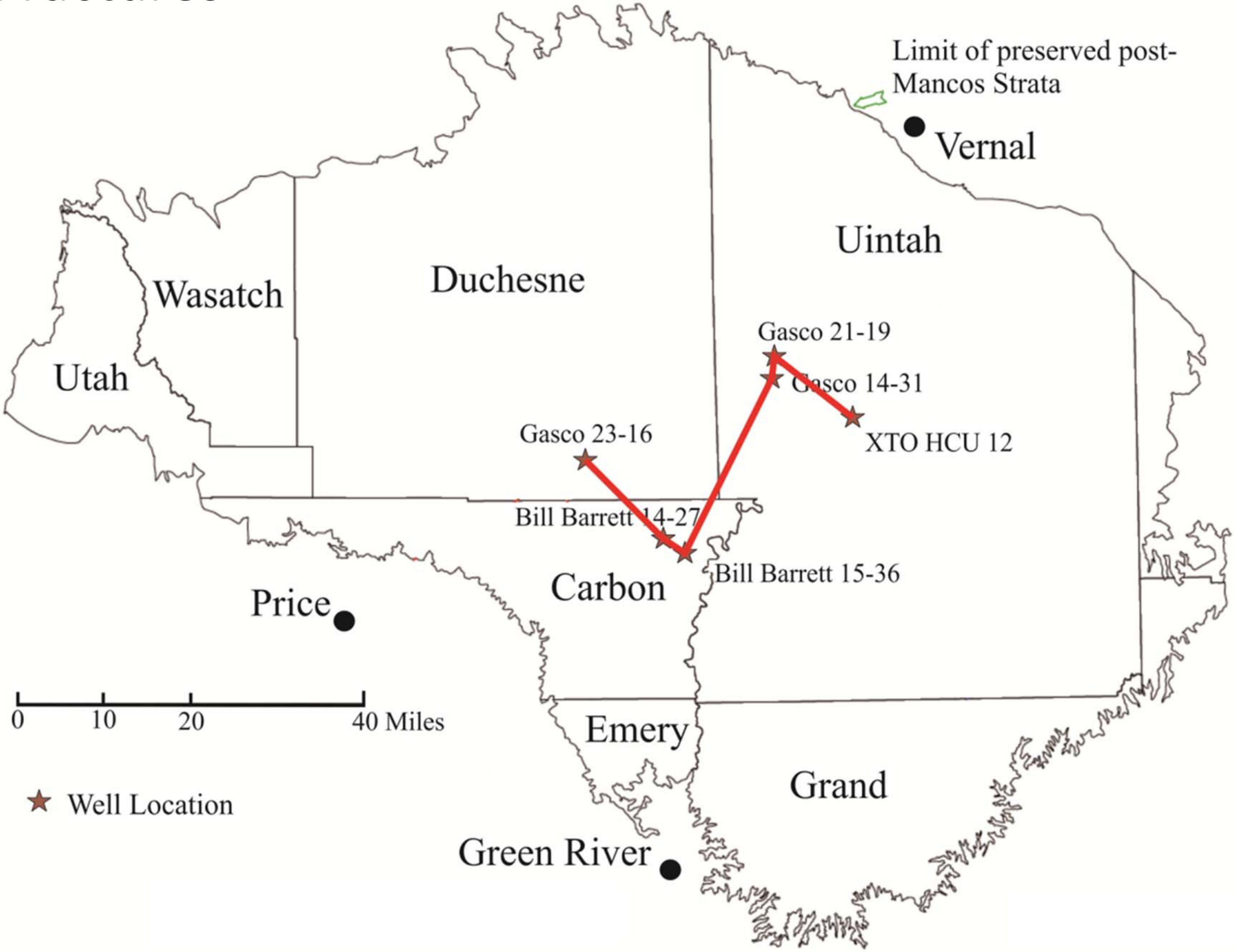


Schlumberger and Poupon-Leveaux equations calculated water saturation accurately compared to core values.

- Water saturations increase with depth.
- Calculations indicate that at great depth and in the northern basin, water saturations may be too high to economically produce.
- Locally certain zones have lower water saturation (and therefore higher hydrocarbon saturation).

Natural Fractures

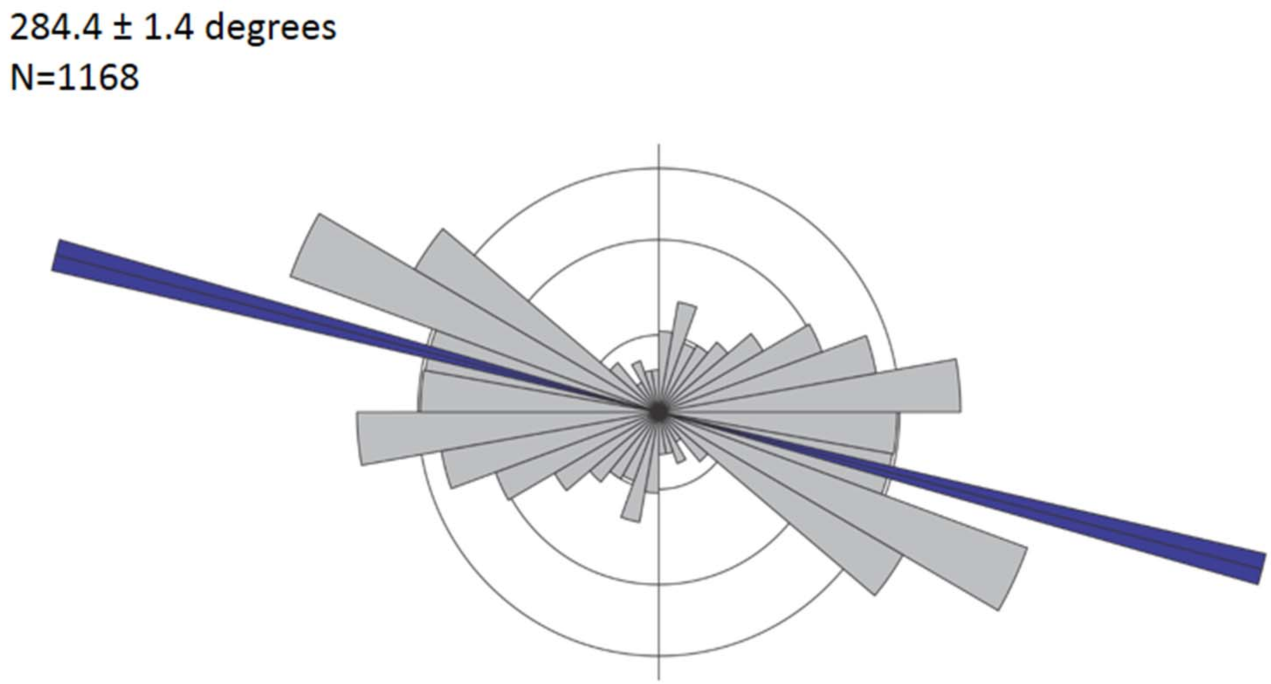
Donated Formation Image Log Locations



Yuan et al. (2013)

Natural Fractures

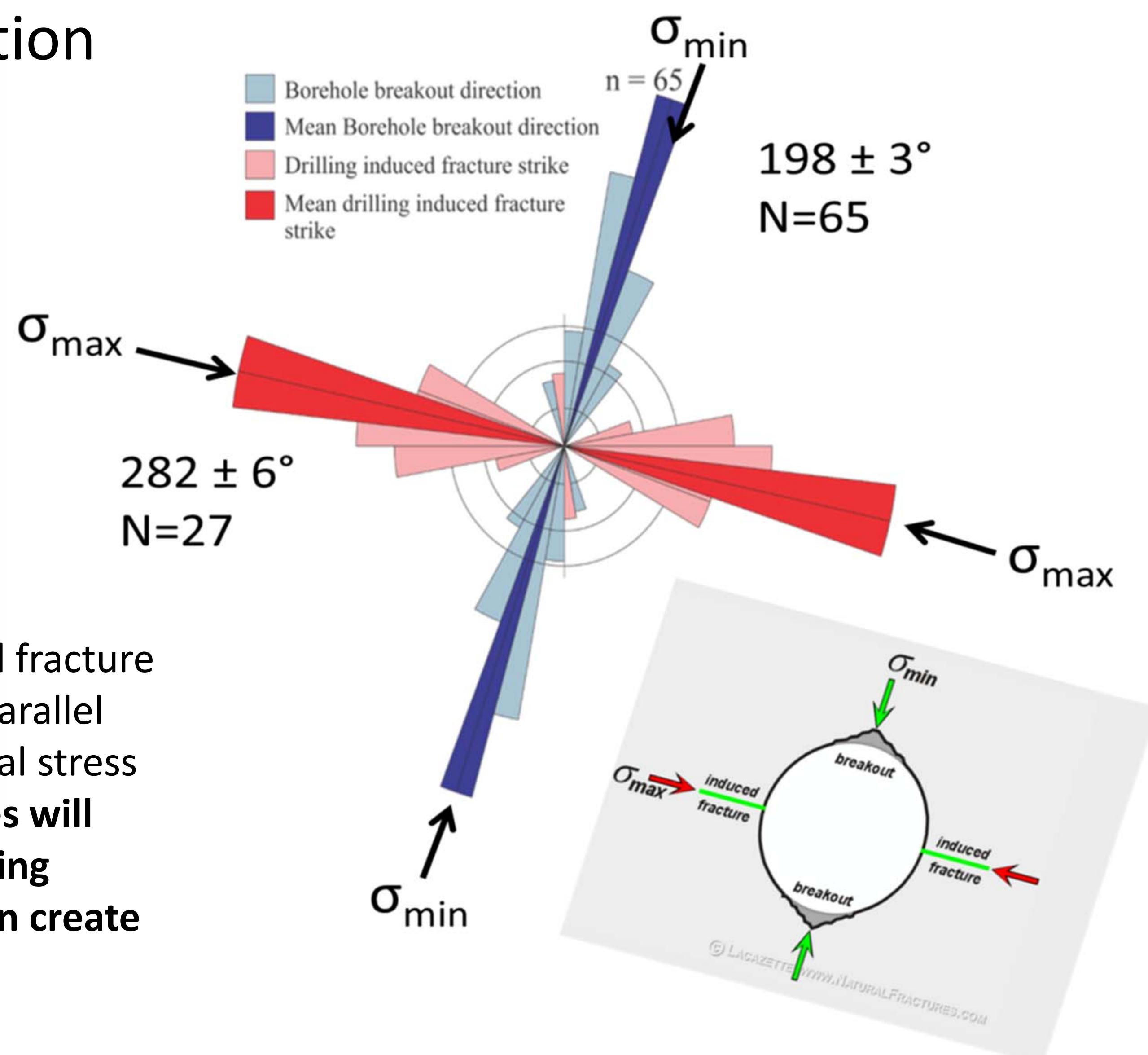
Natural fracture strike plot



For all six wells, the average strike of natural fractures is NW284.4 ˚ ±1.4˚ or SE104.4 ˚ ±1.4˚ (Opposite direction). This is similar to regional fracture trends documented in the overlying Mesaverde Group (e.g. Sonntag, 2011).

Yuan et al. (2013)

In-situ stress direction

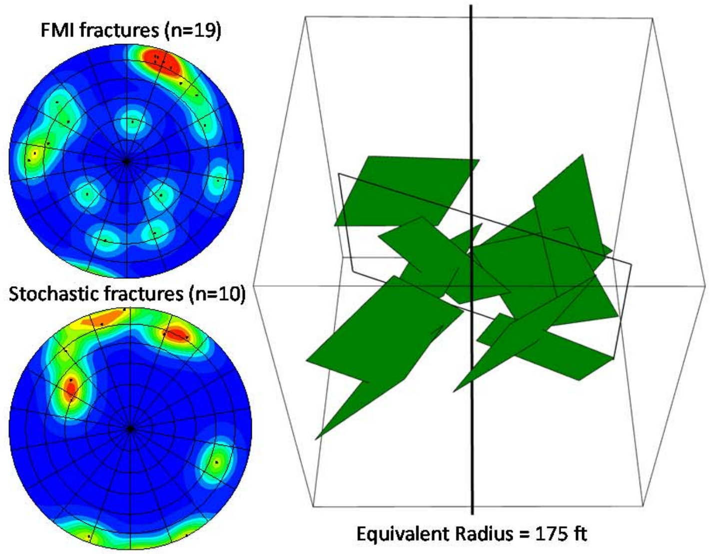


Because the primary natural fracture set strike is approximately parallel with the maximum horizontal stress direction, **hydraulic fractures will likely propagate along existing natural fractures rather than create new fractures**.

Discrete Fracture Network Modeling

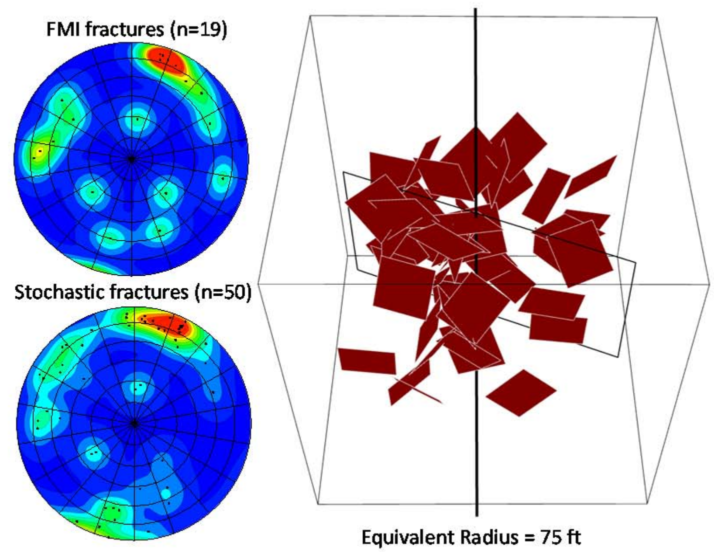
Production was simulated in Peters Point 14-27D-12-16 well assuming H_2O saturation, initial reservoir pressure, matrix and fracture permeabilities, and gas formation volume factors.

Natural Fracture Model (n=10)



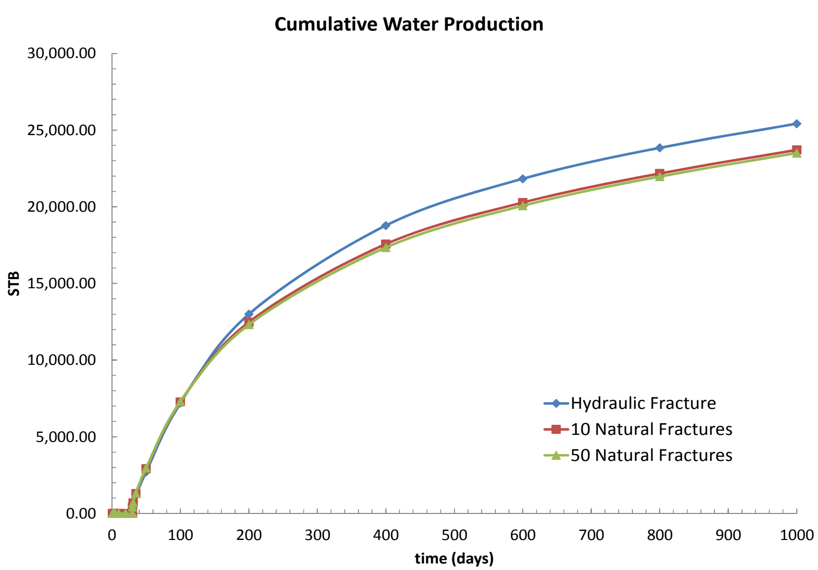
Equivalent Radius = 175 ft

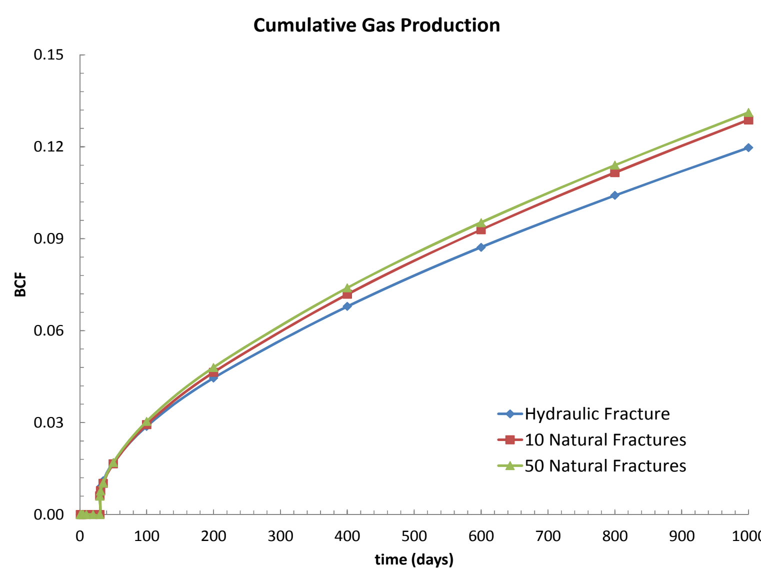
Natural Fracture Model (n=50)



Equivalent Radius = 75 ft

The secondary fracture set, which improves the connection between natural and hydraulic fractures, and the lower angle dips are critical to increasing production.

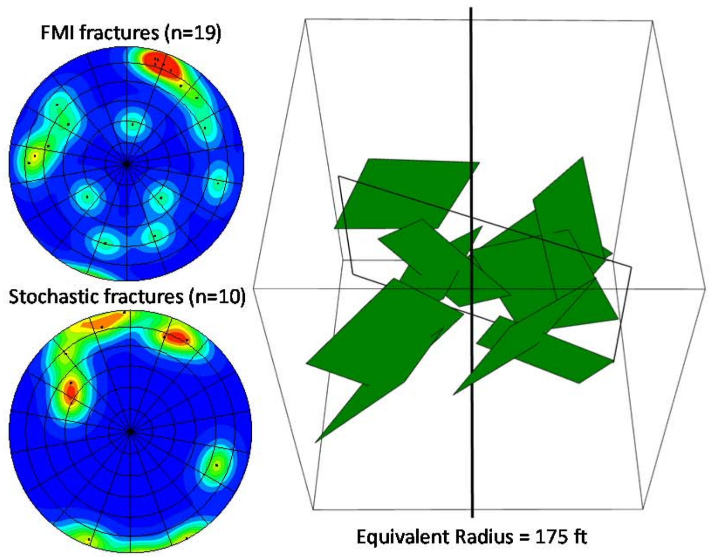




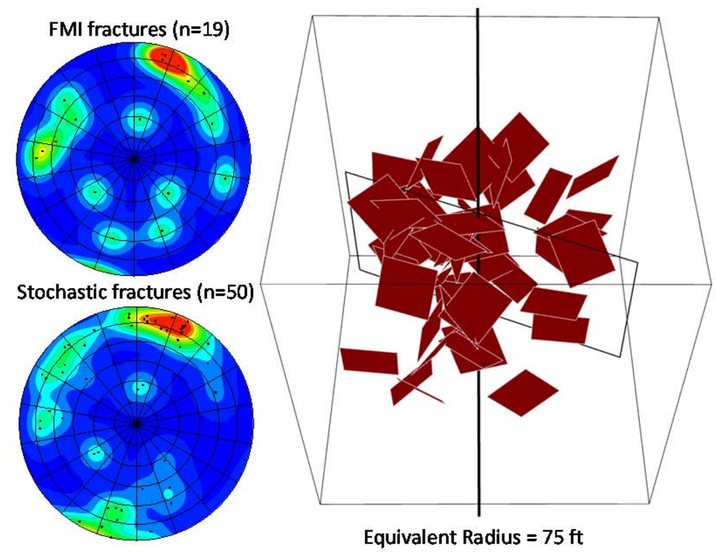
Discrete Fracture Network Modeling

Production was simulated assuming H_2O saturation, initial reservoir pressure, matrix and fracture permeabilities, and gas formation volume factors.

Natural Fracture Model (n=10)

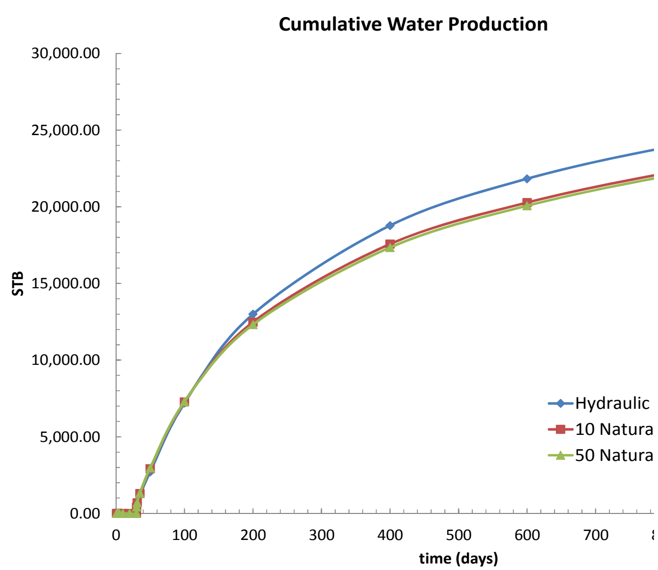


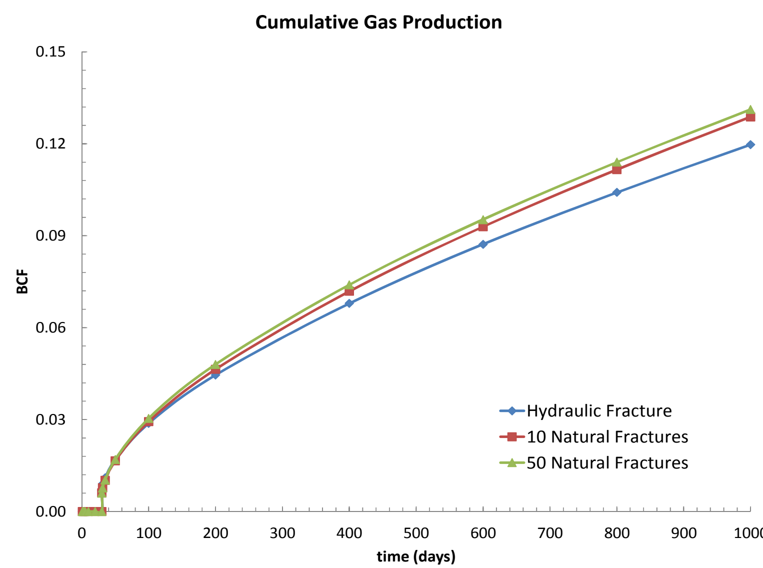
Natural Fracture Model (n=50)



Peters Point 14-27D-12-16

The secondary fracture set, which improves the connection between natural and hydraulic fractures, and the lower angle dips are critical to increasing production.

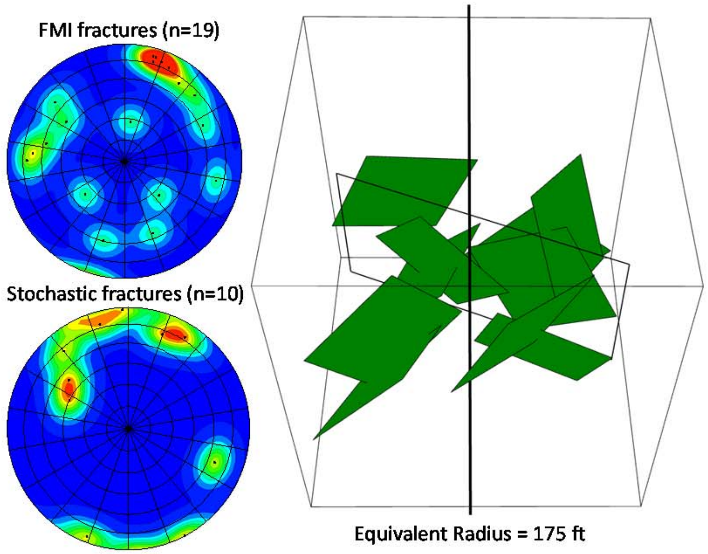




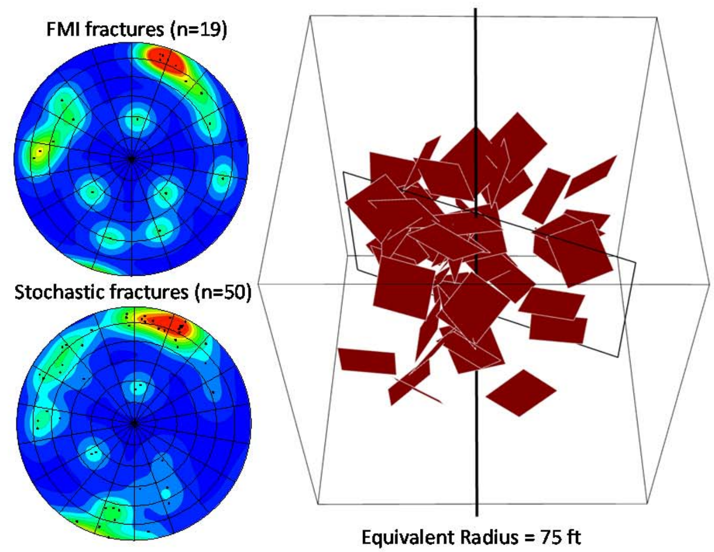
Discrete Fracture Network Modeling

Production was simulated in Peters Point 14-27D-12-16 well assuming H_2O saturation, initial reservoir pressure, matrix and fracture permeabilities, and gas formation volume factors.

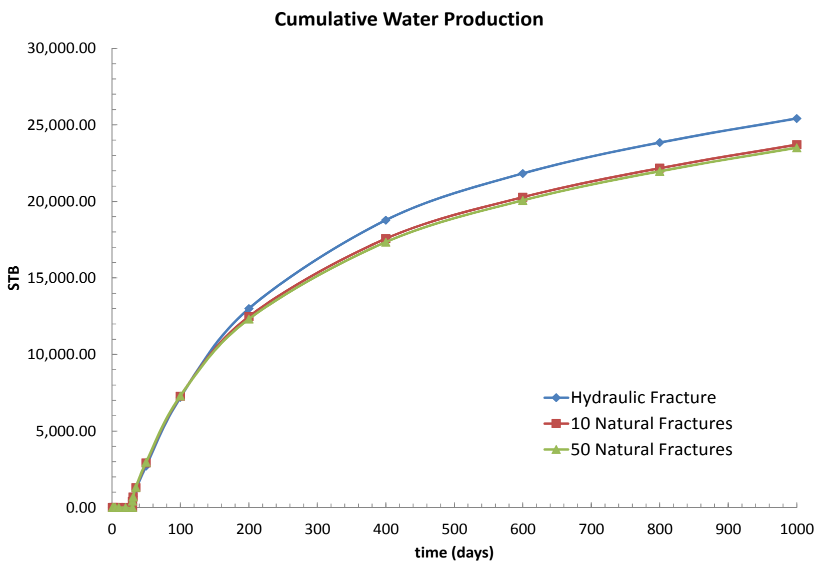
Natural Fracture Model (n=10)

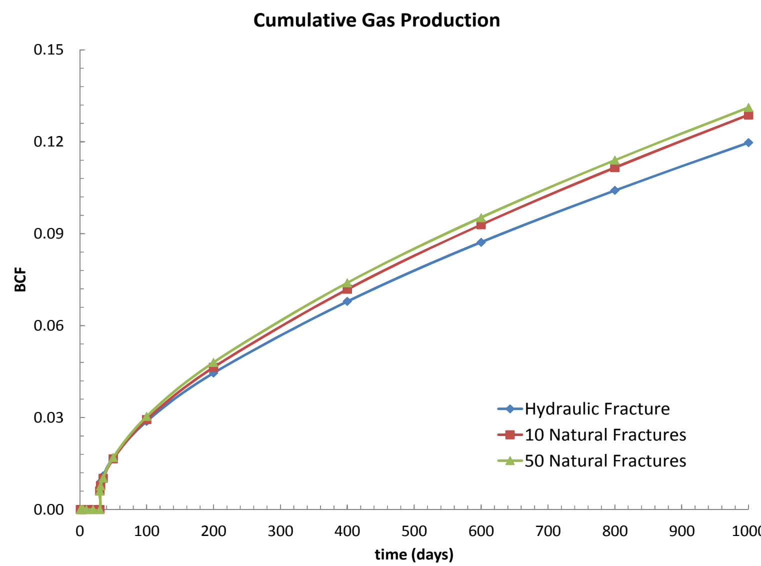


Natural Fracture Model (n=50)



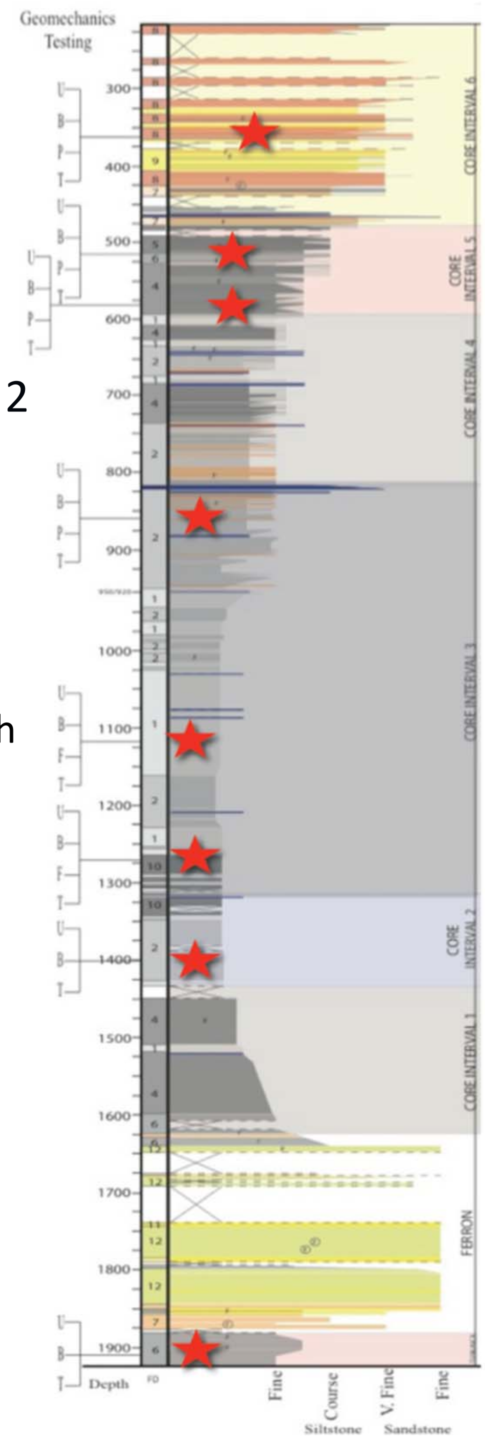
The secondary fracture set, which improves the connection between natural and hydraulic fractures, and the lower angle dips are critical to increasing production.





Geomechanics testing

Phase 1 →
RGU-1 core
Kennedy (2011);



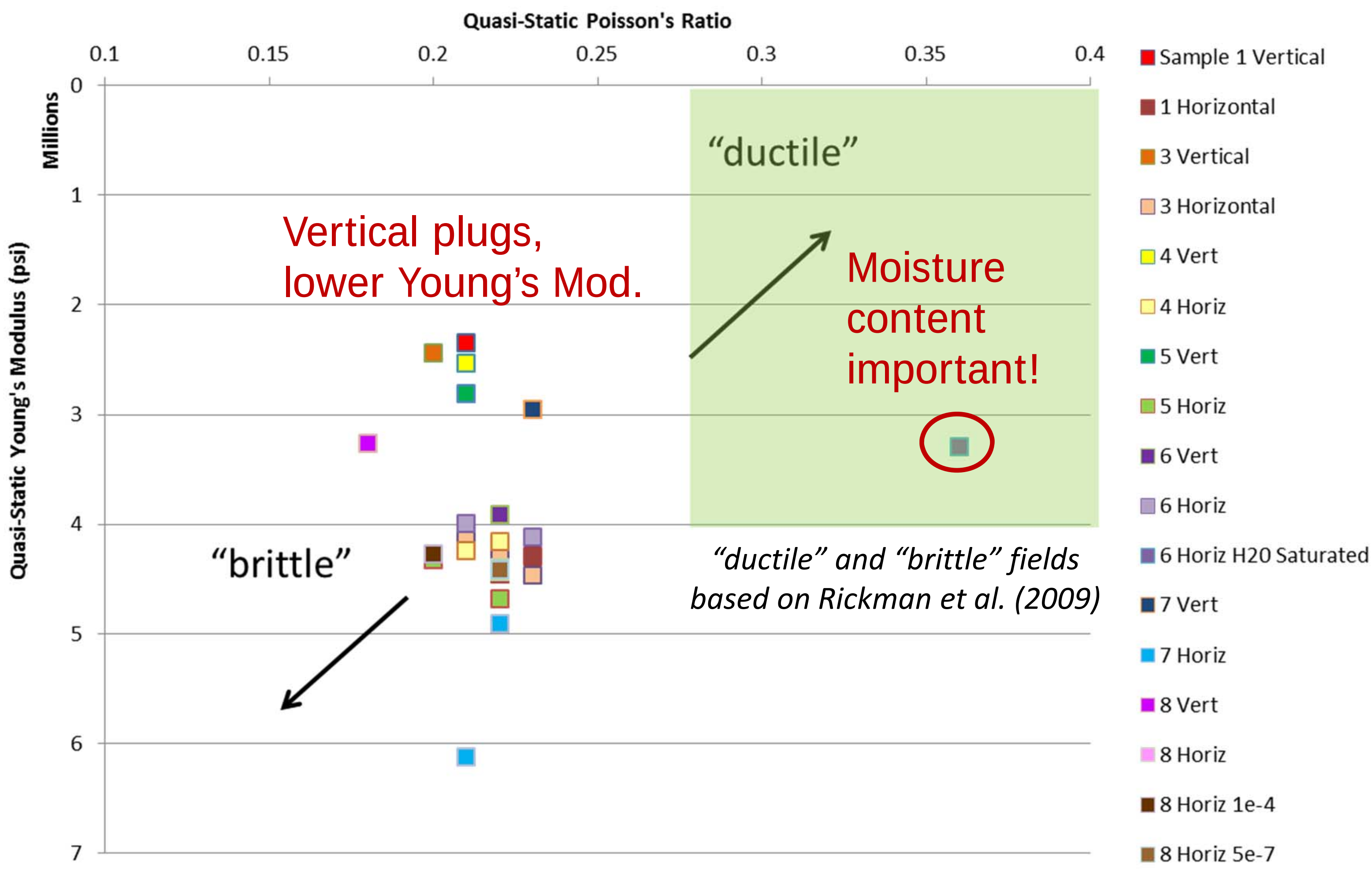
←Phase 2
Q1, Q8, Q16, P1 & 2

- Indirect Tensile Strength
- Unconfined Compressive Strength
- Triaxial (realistic production confining pressure – 6110 psi)

1 3 4 5 6 7 8 ← Sample #

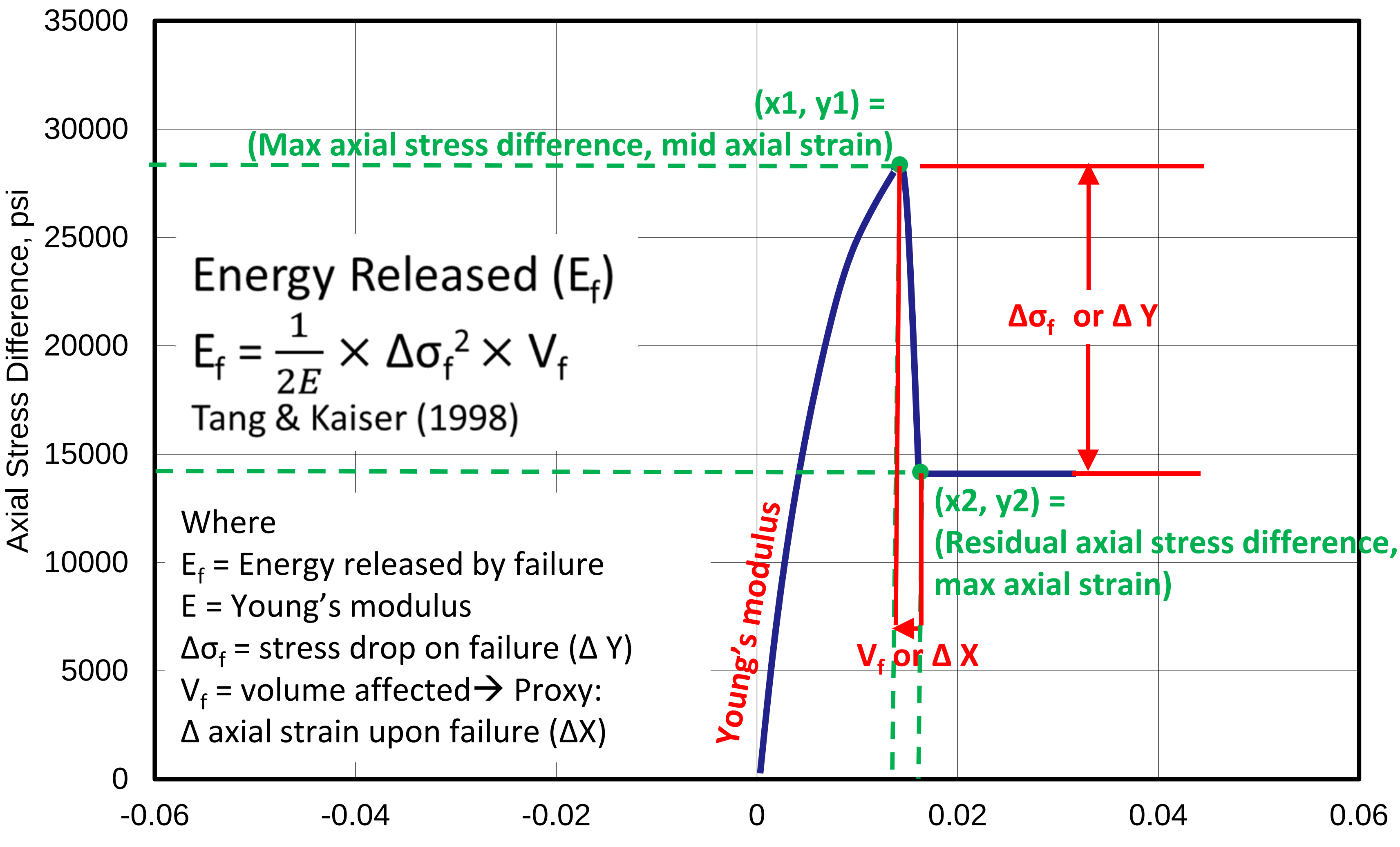
Massive Laminated Admixed Higher BI Lower BI

Mancos geomechanical behavior



Quantifying Failure Behavior

How do we quantify actual failure, not pre-failure behavior?



Birgenheier et al. (2011); Kennedy (2012)

Quantifying
Sedimentary – Geomechanics Links

Multiple regression analysis – All core (n=23)

Energy released (E_f) versus **5** geologic variables:

1) grain size
2) bioturbation
3) degree of lamination
4) Poisson's ratio
5) bulk density (g/cm^3)

Multiple R = 0.73 (correlation coefficient)

R^2 = 0.54 (coefficient of determination or "goodness of fit")

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7374157
R Square	0.54378191
Adjusted R	0.40960012
Standard E	2.82275937
Observatic	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressio	5	161.4540319	32.29080638	4.052576	0.013231262
Residual	17	135.4554983	7.967970486		
Total	22	296.9095302			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.63839091	2.614980705	1.008952344	0.327144	-2.878736115	8.1555179	-2.87873612	8.15551794
Grain size	0.86687754	0.767862766	1.128948532	0.274599	-0.753171283	2.4869264	-0.75317128	2.48692637
Bioturb no	0.12499825	0.442562067	0.28244231	0.781014	-0.80872609	1.0587226	-0.80872609	1.0587226
degree of l	-0.23439138	0.191690184	-1.222761535	0.238101	-0.638822319	0.1700396	-0.63882232	0.17003955
TXC Poiss	-0.94949806	0.809982536	-1.172245102	0.257265	-2.658411831	0.7594157	-2.65841183	0.75941571
AR Bulk D	0.289252	0.318842394	0.907194279	0.376984	-0.383446653	0.9619506	-0.38344665	0.96195064

Suggests the total combined geologic variability accounts for approximately 55% of the variability in E_f.

TOC, Poro/Perm, and mineralogy data to be added in; as well as more lithologic variability

Best Completion Practices

Utah Division of Oil, Gas and Mining data from 1200 wells were screened, identifying 26 “Mancos-only” wells.

Based on the DOGM website production data, it appears what the industry has historically done on the Mancos is not working.

Review indicates little science was behind what part of the Mancos was treated, and what type of fluid and proppant was used.

The only horizontal well drilled in the deep Mancos proved to be the best overall producer, but it too fell short of being an economic success.

Recent 2nd horizontal well drilled by Rose Petroleum in 2015 is producing oil out of the shallow Mancos.

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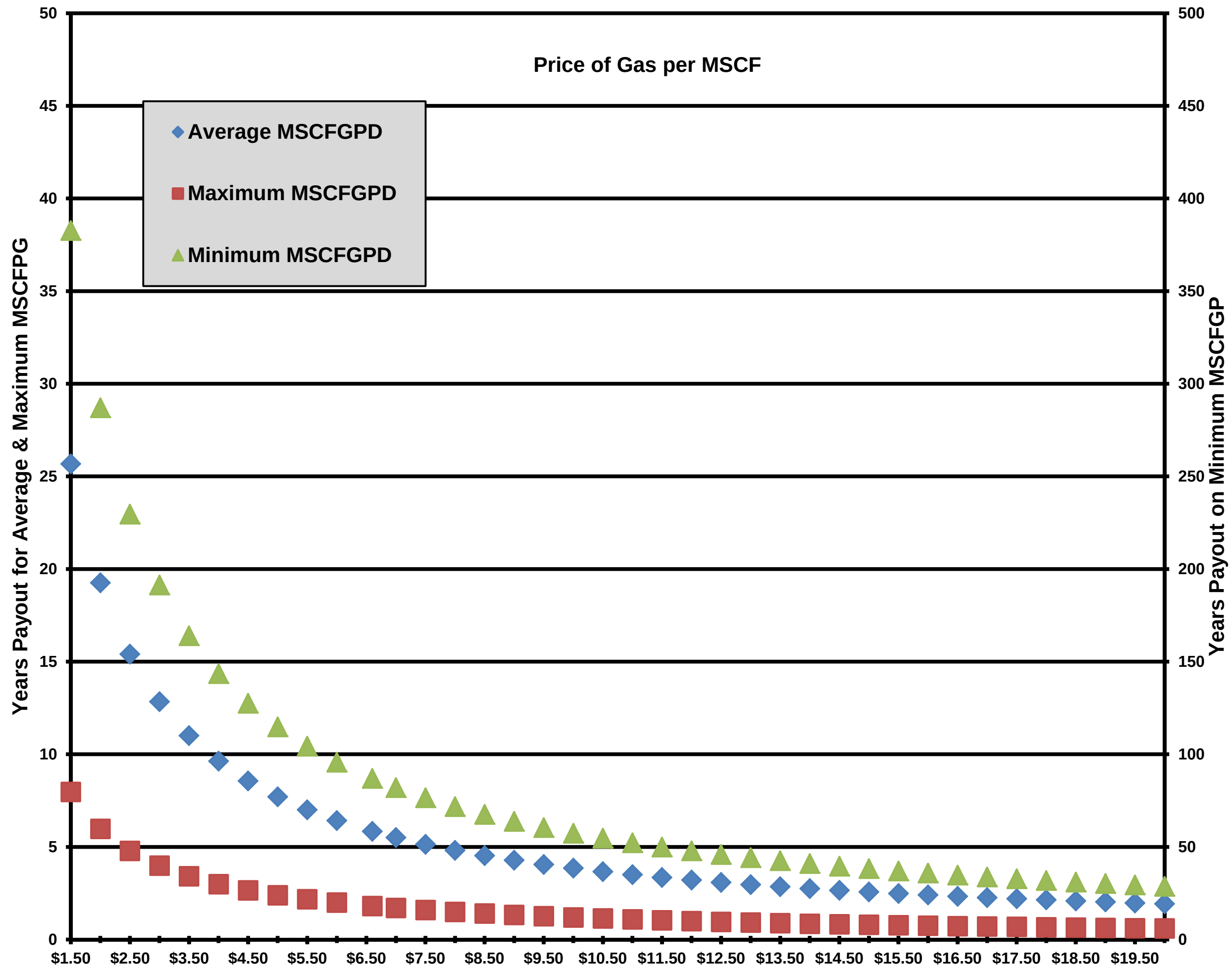
Best Completion Practices



Estimated payout of 26 Mancos-only wells

Best Completion Practices

Most processes applied to drill and complete the Mancos are based on other successful shale plays with little or no data gathering to justify their use in the Mancos.

Vertical wellbores are the most common wells drilled to date, but industry has not developed the data necessary to determine whether horizontals or multilaterals would work better.

Until these fundamental questions are answered, Mancos production will continue to be questionable.

An operator or a consortium must commit to a science project.

Technology Transfer

Presentations:

- American Association of Petroleum Geologists, 2011-2014, 13 talks & posters
- Technical Advisory Board, 2011-2013, 3 meetings
- Uinta Basin Oil & Gas Collaborative Group, 2012, 3 talks
- Rocky Mountain Association of Geologists, 2012
- Utah Geological Association, 2012 and 2013
- RPSEA onshore production conference, 2014

Publications:

- 3 MS theses completed
- 1 PhD dissertation near completion
- Technical papers in review
- Peer-reviewed publications in preparation

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Significant findings, lessons learned, & future research

- Detailed core & basin-wide log analysis identified 2 prospective stratigraphic zones in the lower Mancos. Success!
- Core-calibrated log based calculations of organic content (Δlog R) and water saturation, as well as indices of thermal maturation and migration pathways (Ro regression, 1D and 3D basin modeling) indicate oil sweet spots in the SE portion of the basin within the 2 target intervals. Success! Migration within the Mancos is significant to understanding this unconventional play. Additional 3D basin models of unconventional systems needed.
- Geomechanics testing of the Mancos Shale indicates generally brittle behavior conducive to hydraulic fracturing. Correlation of geologic facies variability to energy released show promise as a predictor of hydraulic fracture behavior. Further testing and facies variability is needed to develop the energy released concept further (separate project underway).

Significant findings, lessons learned, & future research

- Due to lack of strong heterogeneity at the seismic scale, 3D seismic attribute analysis didn't provide a lot of information. Most attribute analysis in shales is being performed on pre-stack data, which was not available. Highlights the need for pre-stack seismic data.
- Limited natural fracture and in-situ stress direction data do not indicate favorable conditions for creation of new induced fracture networks. Fracture modeling indicates importance of a conductive secondary set of natural fractures for economic production.
- Drilling and completion practices clearly need more comprehensive geologic and engineering data for optimization—most pressing item for future research but weak present market will hinder this.

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Thank you