Characterization of the Most Promising Formations for Geologic Carbon Sequestration in the Central Rocky Mountain Region (RMCCS)

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

Acknowledgements

• Many thanks to the U.S. Department of Energy and NETL for supporting this project

• We express our gratitude also to our many industry partners, who have committed a great deal of time, funding and other general support for this project

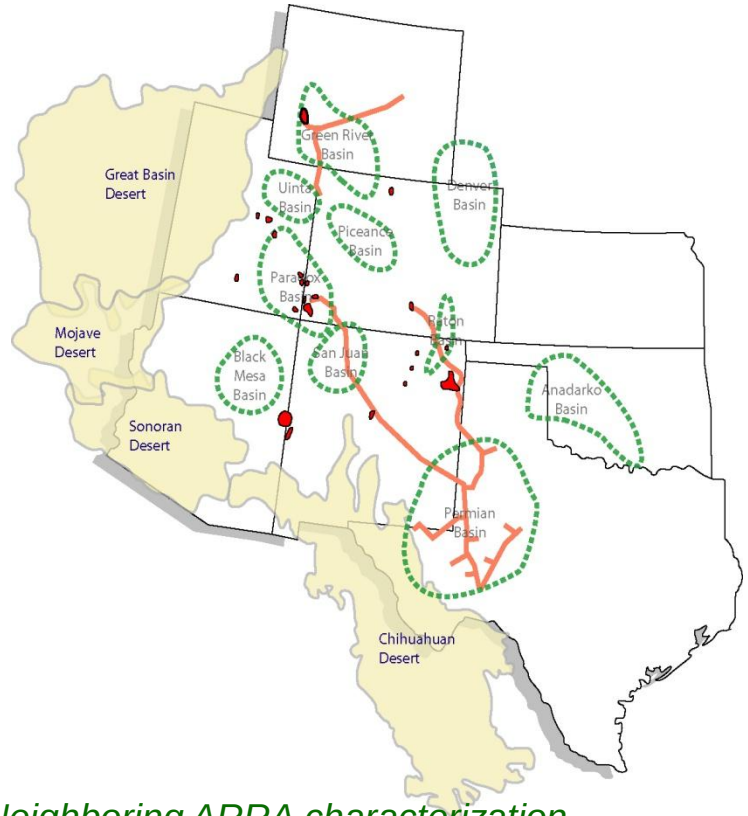
• The work presented today is co-authored by many partners in the RMCCS project

Presentation Outline

- **Technical Team**
- What's the Goal?
  - local site analyses for each section of region (each state):
    - Arizona results
    - Utah results
    - Colorado results:
      - Sandwash Basin near Craig, CO
  - How we are using these data: quantitative assessment of capacity, AOR, and uncertainty estimation
  - National Atlas contributions for region

Partners

The project team consists of the geological surveys in each state of the region, some invaluable industry partners, and of course NETL.



Neighboring ARRA characterization projects in Wyoming and Kansas are also essential partners.

Colorado Geological Survey

Southwest Carbon Partnership

The University of Utah™

Utah Geological Survey

Schlumberger

Arizona Geological Survey

Shell

TRI-STATE Generation and Transmission Association, Inc.

NETL

New Mexico Bureau of Geology and Mineral Resources

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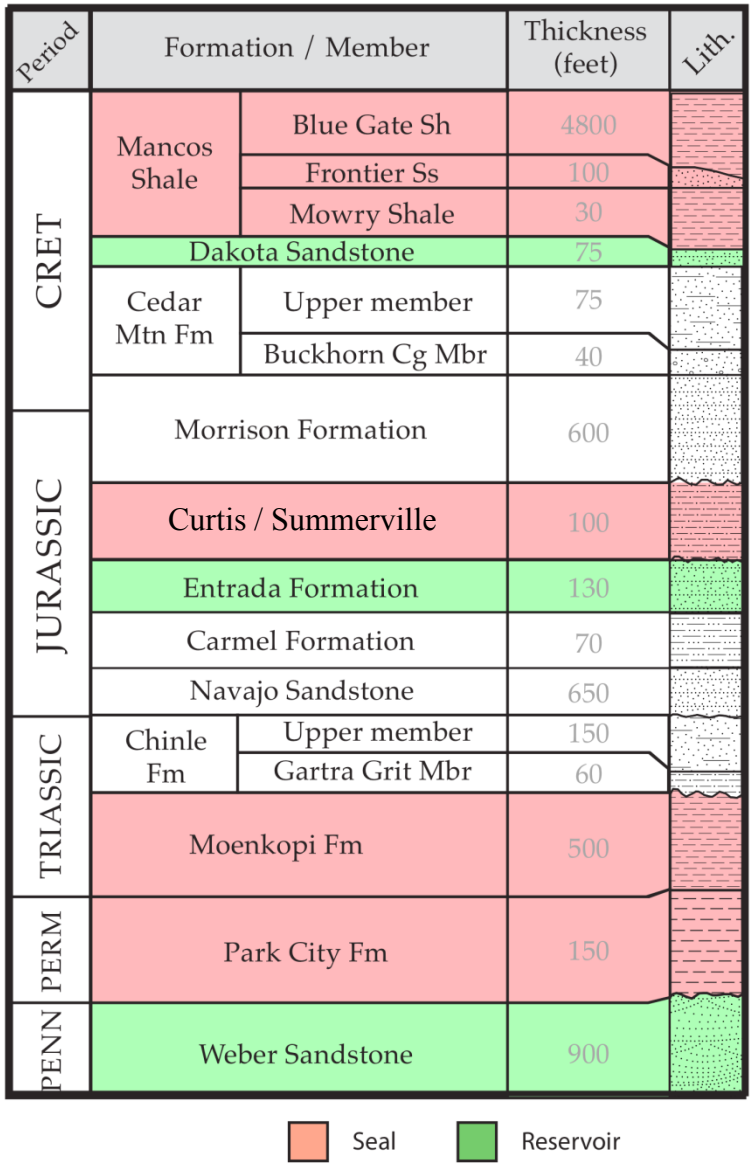
What's the Goal?



If you've already chosen a CCS site, you'd characterize it by:

- boots on ground mapping and analysis
- drilling stratigraphic wells
- geophysical logging
- lots of core
- lots of outcrop sampling
- 2D and 3D seismic imaging
- basically, everything a big oil company might employ

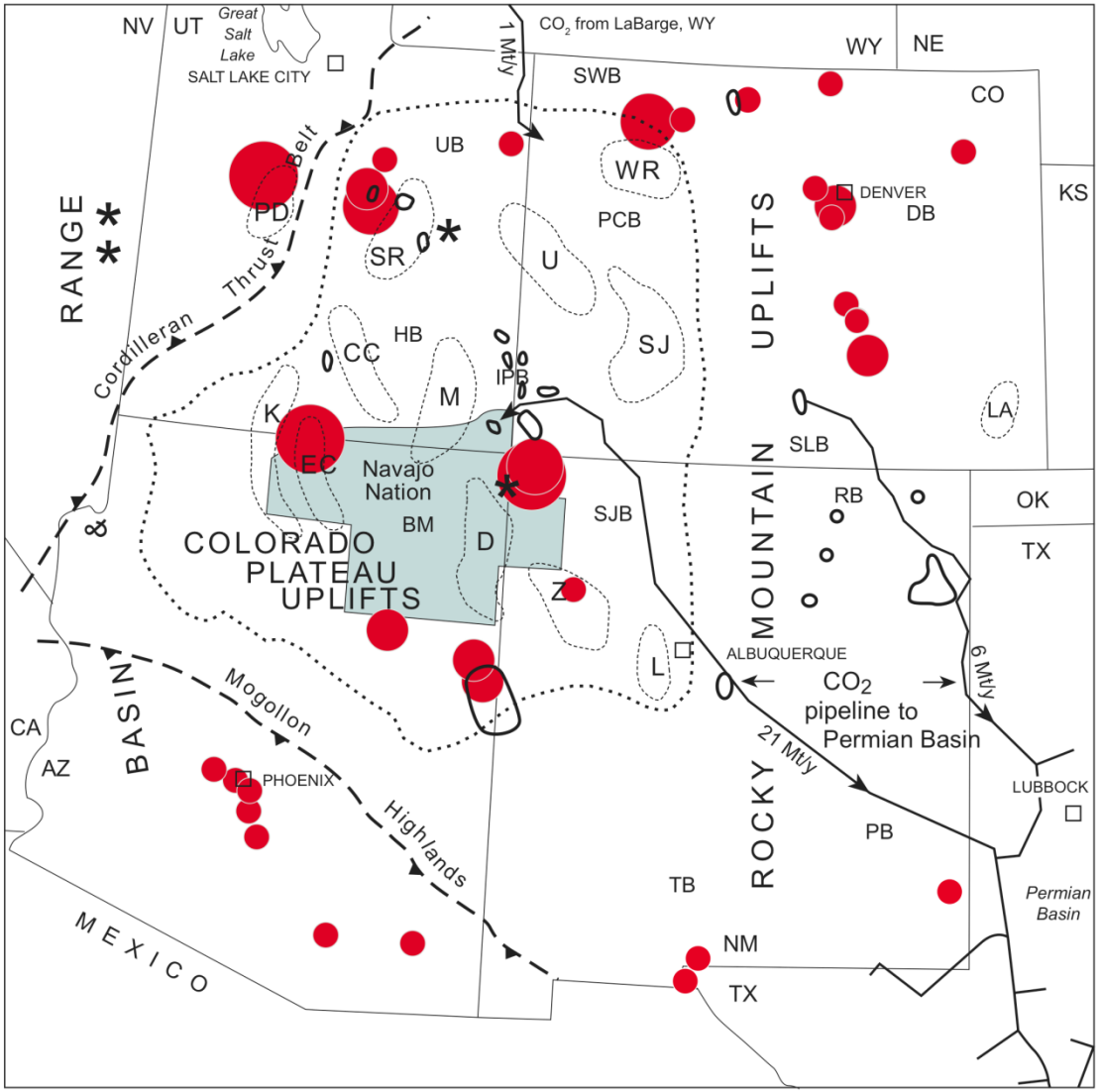
But, it is simply impractical to do such for every candidate site (and you'd need a bit of cash for such....)

What's the Goal?

Develop optimized protocol for characterization of the most promising formations, to optimize sink-to-source match.

Period	Formation / Member		Thickness (feet)	Lith.
CRET	Mancos Shale	Blue Gate Sh	4800	
		Frontier Ss	100	
		Mowry Shale	30	
	Dakota Sandstone		75	
	Cedar Mtn Fm	Upper member	75	
		Buckhorn Cg Mbr	40	
JURASSIC	Morrison Formation		600	
	Curtis / Summerville		100	
	Entrada Formation		130	
	Carmel Formation		70	
	Navajo Sandstone		650	
TRIASSIC	Chinle Fm	Upper member	150	
		Gartra Grit Mbr	60	
	Moenkopi Fm		500	
PERM	Park City Fm		150	
PENN	Weber Sandstone		900	

Seal Reservoir



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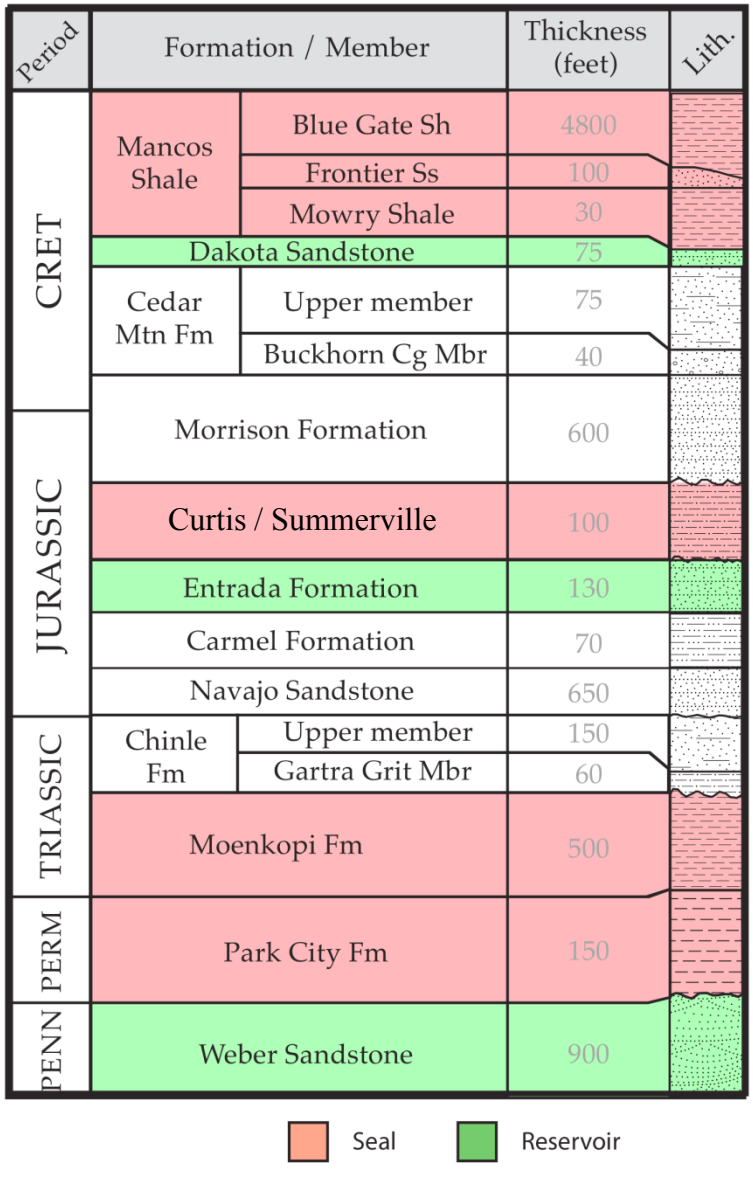


So, how much data is enough to build a meaningful characterization?

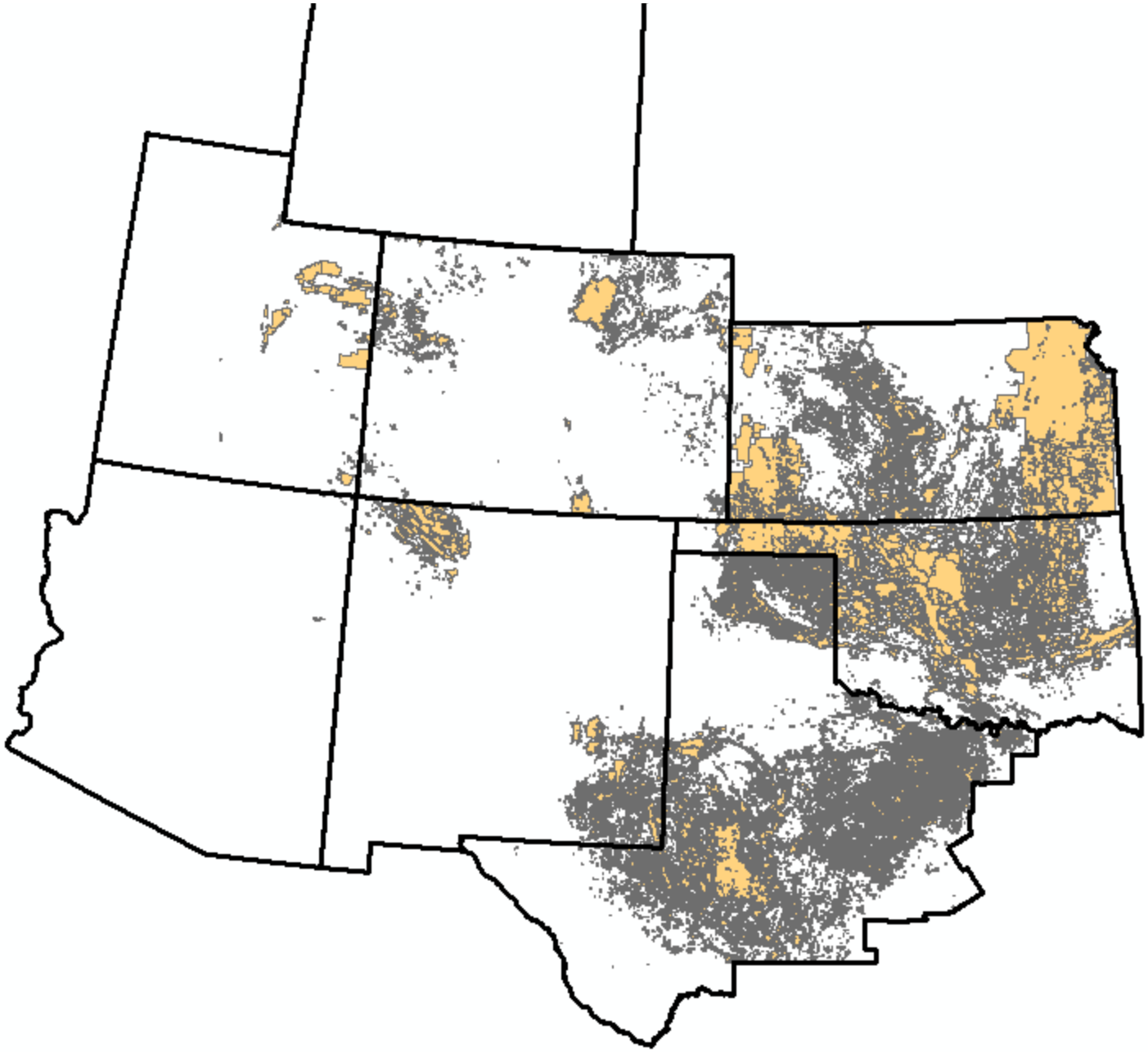
This question is one of our goals.

Another key goal is uncertainty.

What's the Goal?

- We are characterizing one representative site with everything modern geology and geophysics has to offer.
- We are tackling the rest of region, too, and benchmarking against that site
- We are developing maps of capacity WITH overlays of estimated uncertainty.
- Key deliverables include:
  - characterization of entire region, including methods for local and best methods for extrapolating capacity and other assessments to regional-scale
  - estimates of uncertainty for entire region (and methods for estimating that uncertainty)

Simple Estimate of Uncertainty (Proxy = Well Density)



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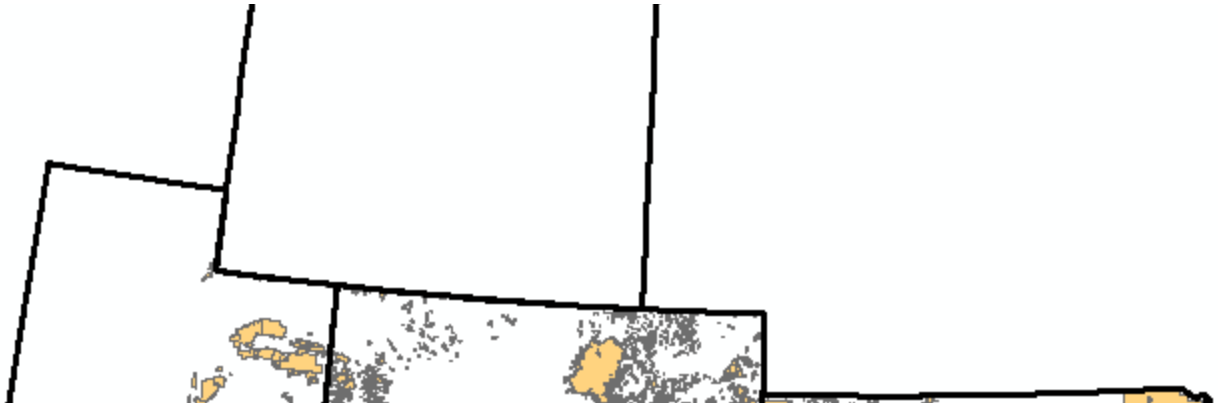
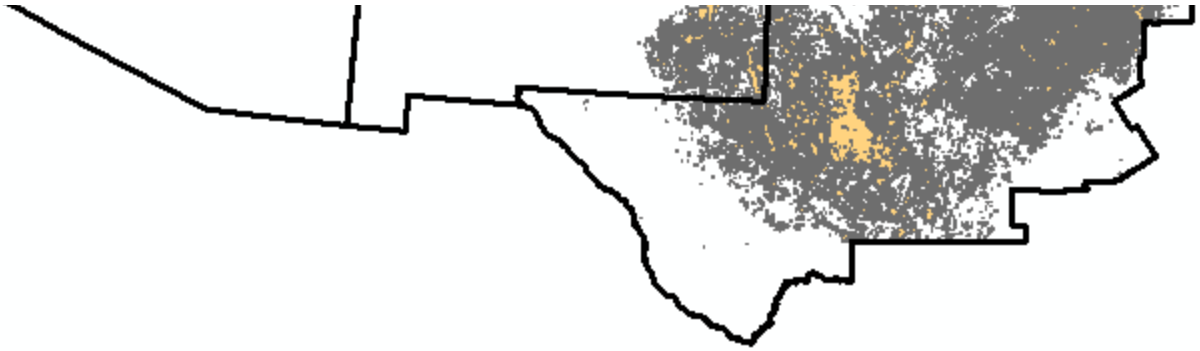


We are working on methods to translate these data and other indicators into meaningful, quantitative estimates of uncertainty on a regional basis.



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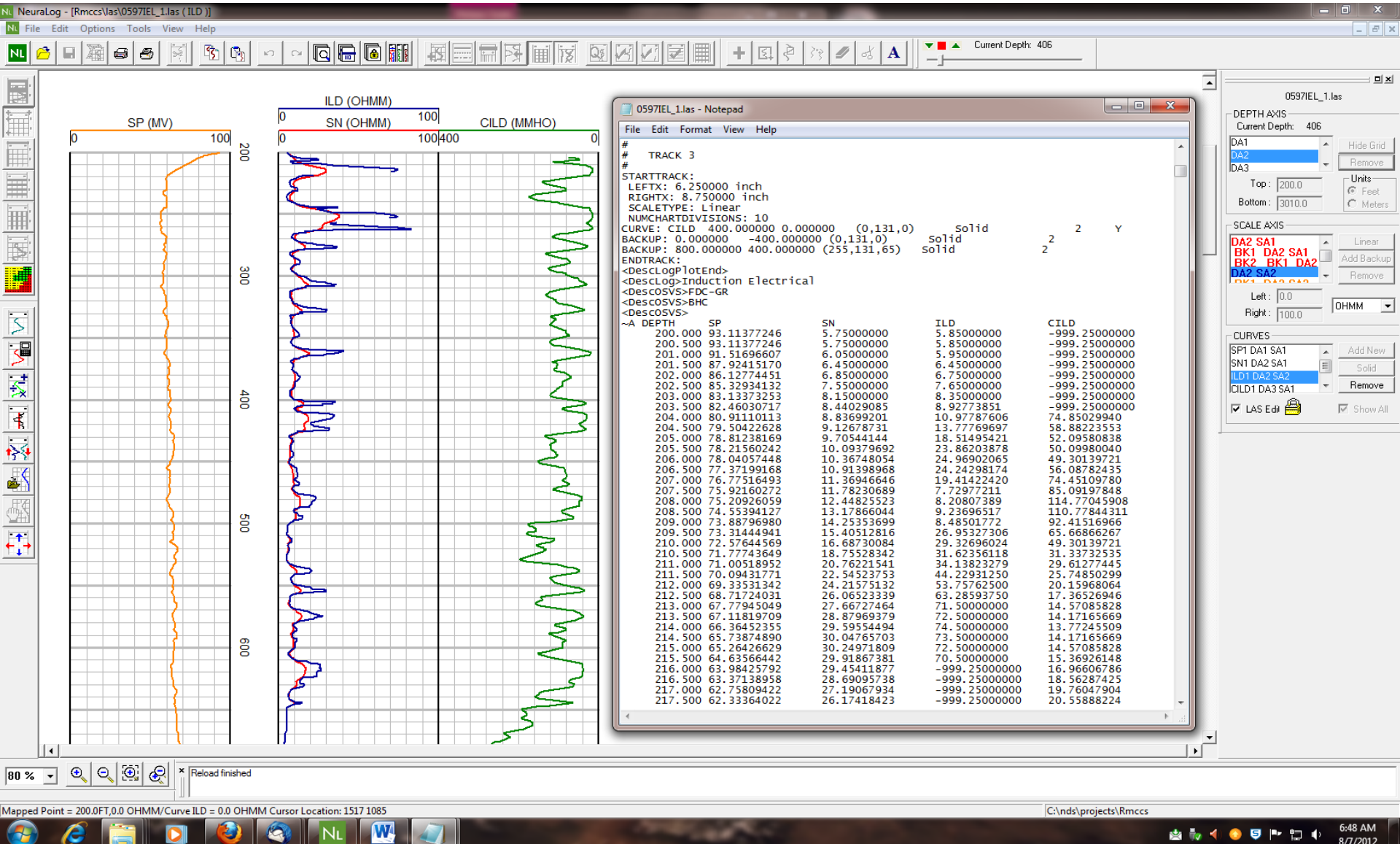
Local-Scale Characterization: Arizona

The Arizona Geological Survey developed a comprehensive CCS characterization database for Arizona, including all appropriate storage attributes:

Arizona Database Structure

Sectio	Townsh	Range	Permit	Operator	Well name	Elevation	Date	Stat	Total Dept	Dakota depth (ft)	Dakota thickness (ft)	Dakota p
15	26N	16E	307	Texaco	1 Hopi-A	5547 KB	1965/05	D	5915	absent		
09	28N	15E	312	Atlantic Re	9-1 Hopi	5820 KB	1965/07	D	6640	absent		
08	29N	19E	310	Amerada P	1 Hopi	6183 KB	1965/05	D	7750	821	89	
35	30N	17E	309	Skelly Oil	1 Hopi-A	6119 KB	1965/05	D	7780	918	79	
20	36N	18E	574	Walker & P	1 Navajo	6458 GL	1971/12	D	1270	1252	not reached	
20	36N	18E	580	Walker & P	1A Navajo	6458 GL	1972/05	D	1258	no data		
24	38N	19E	283	Tenneco O	1 Navajo	5865 KB	1964/07	D	7400	absent		
29	38N	21E	281	Superior O	21-29 Nava	5561 KB	1964/07	D	7207	absent		
36	39N	21E	270	Texaco	1 Navajo-A	5516 KB	1964/04	D	7182	absent		
34	42N	18E	13	Texaco-Ske	1 Navajo	6662 KB	1953/06	D	4523	absent		

Local-Scale Characterization: Arizona



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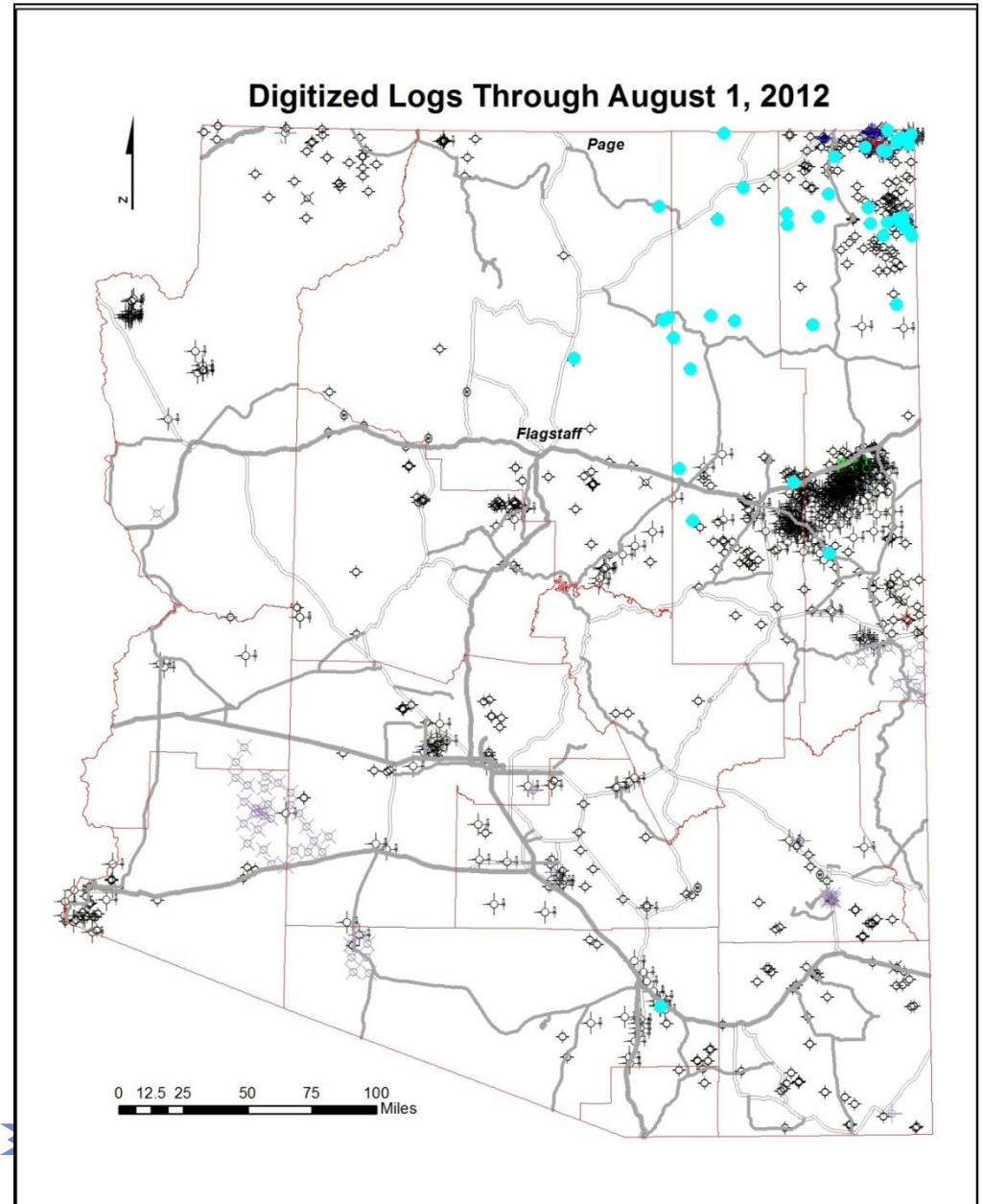

Blue dots represent wells digitized from raster tiff images to LAS (Log ASCII Standard) format using Neuralog. Approximately 100 logs for a total of about 250 curves have been digitized through July 2012.

Local-Scale Characterization: Arizona

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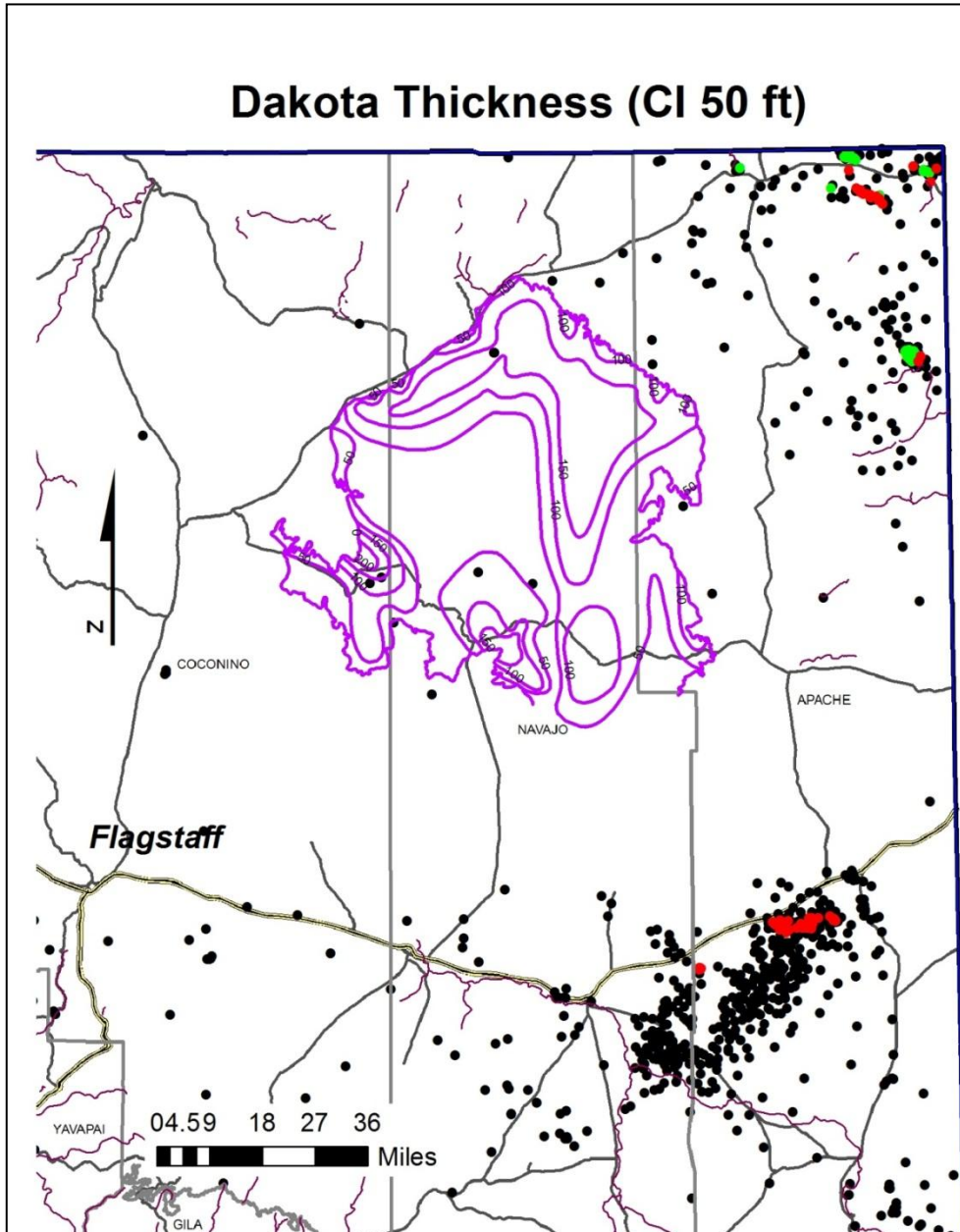
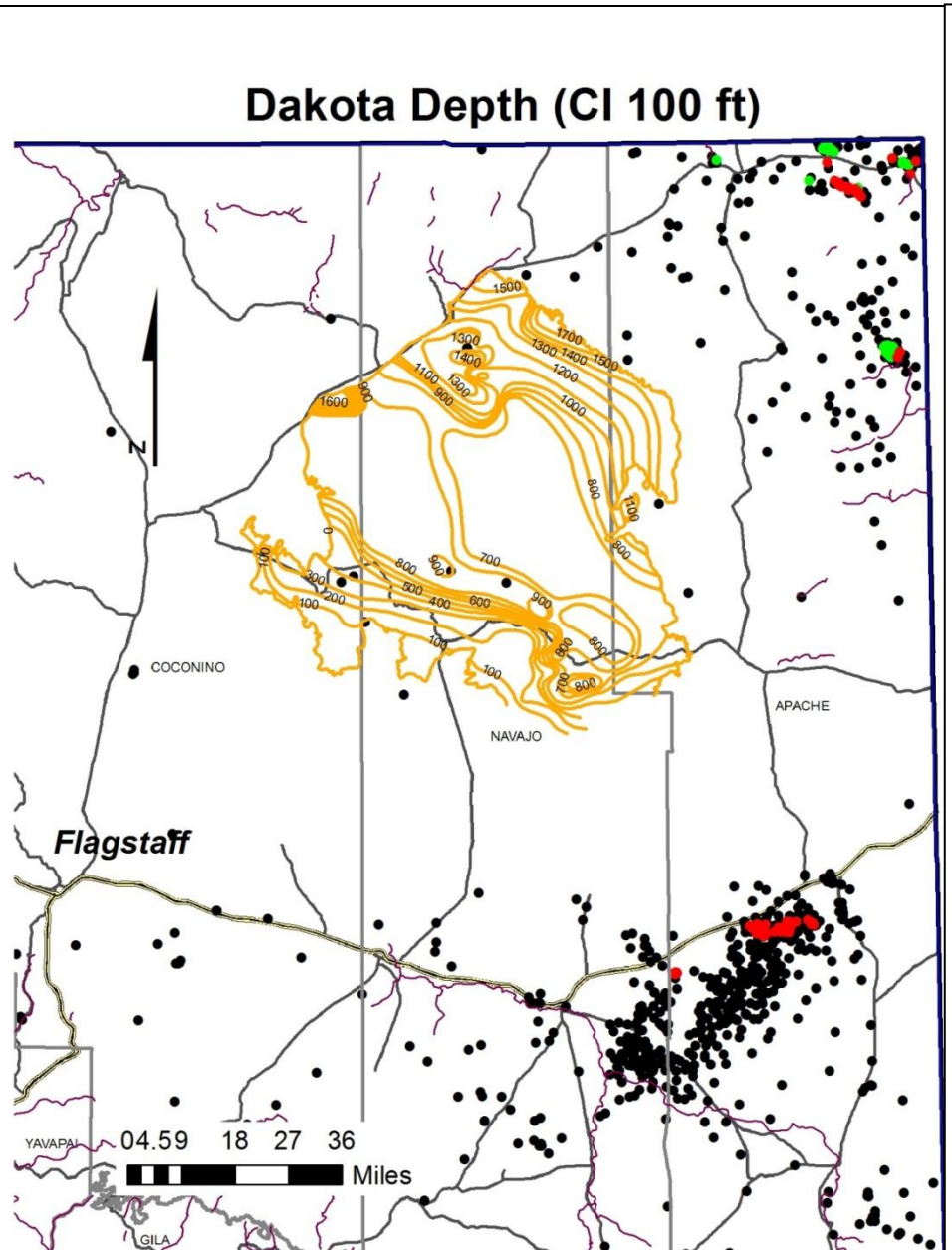
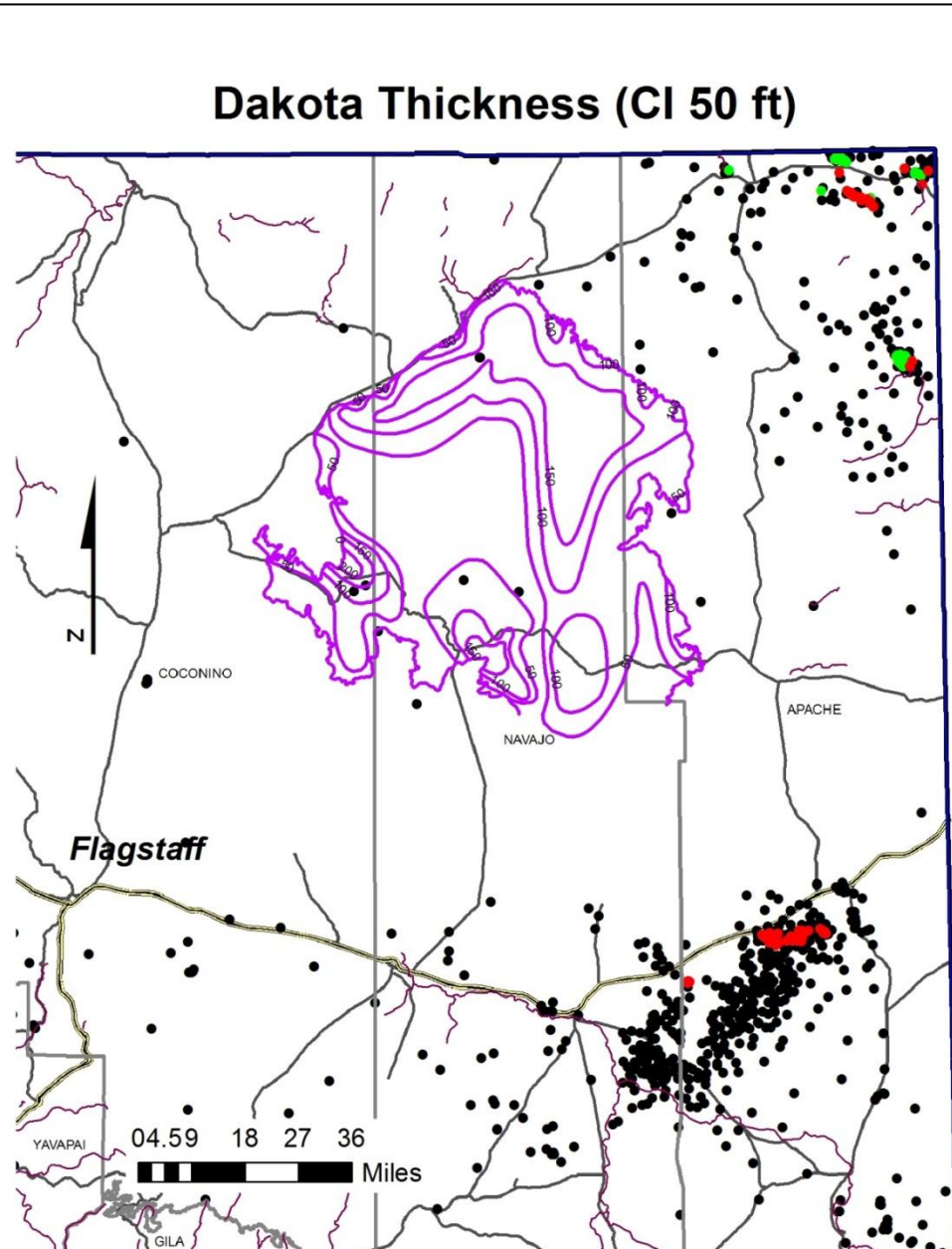
PENN	Weber Sandstone		900	

Seal Reservoir



Local-Scale Characterization: Arizona





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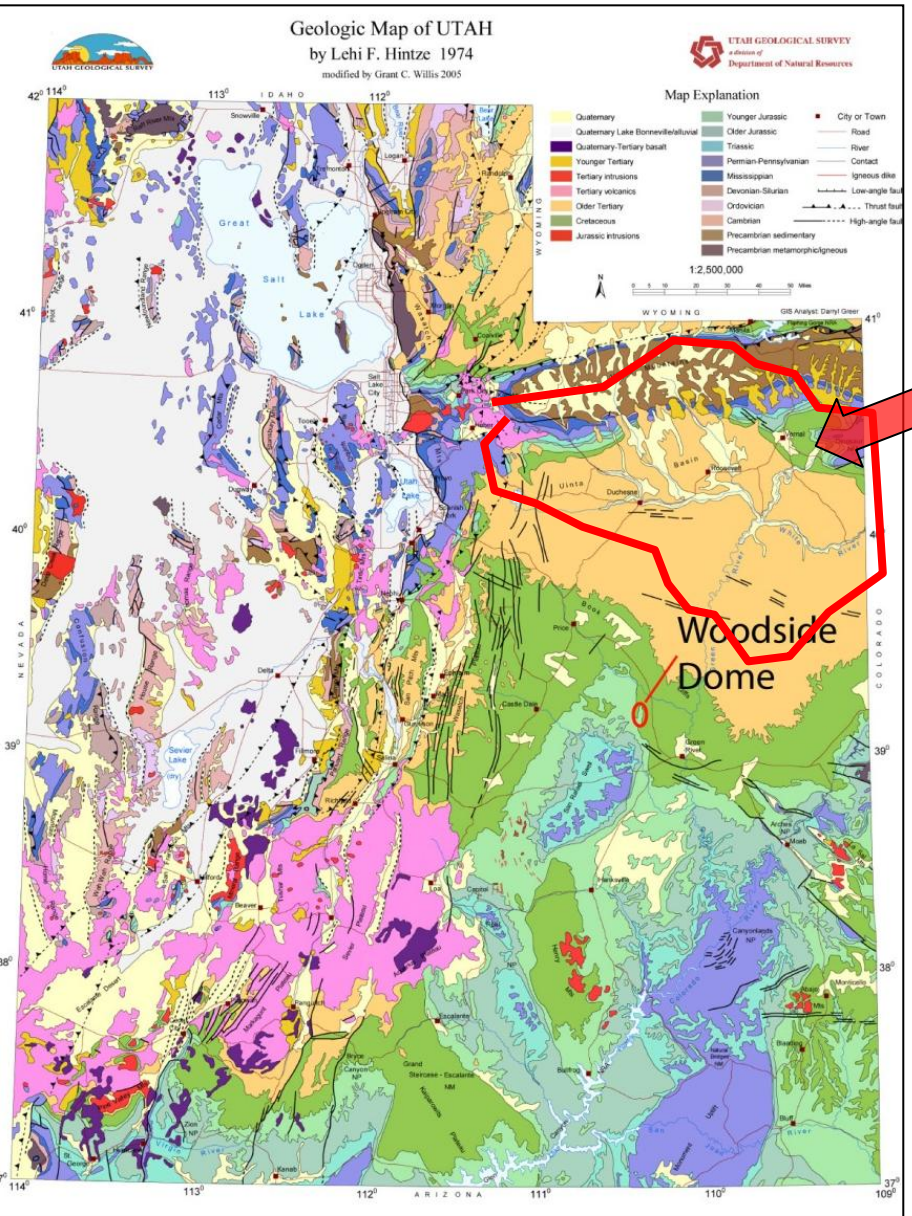
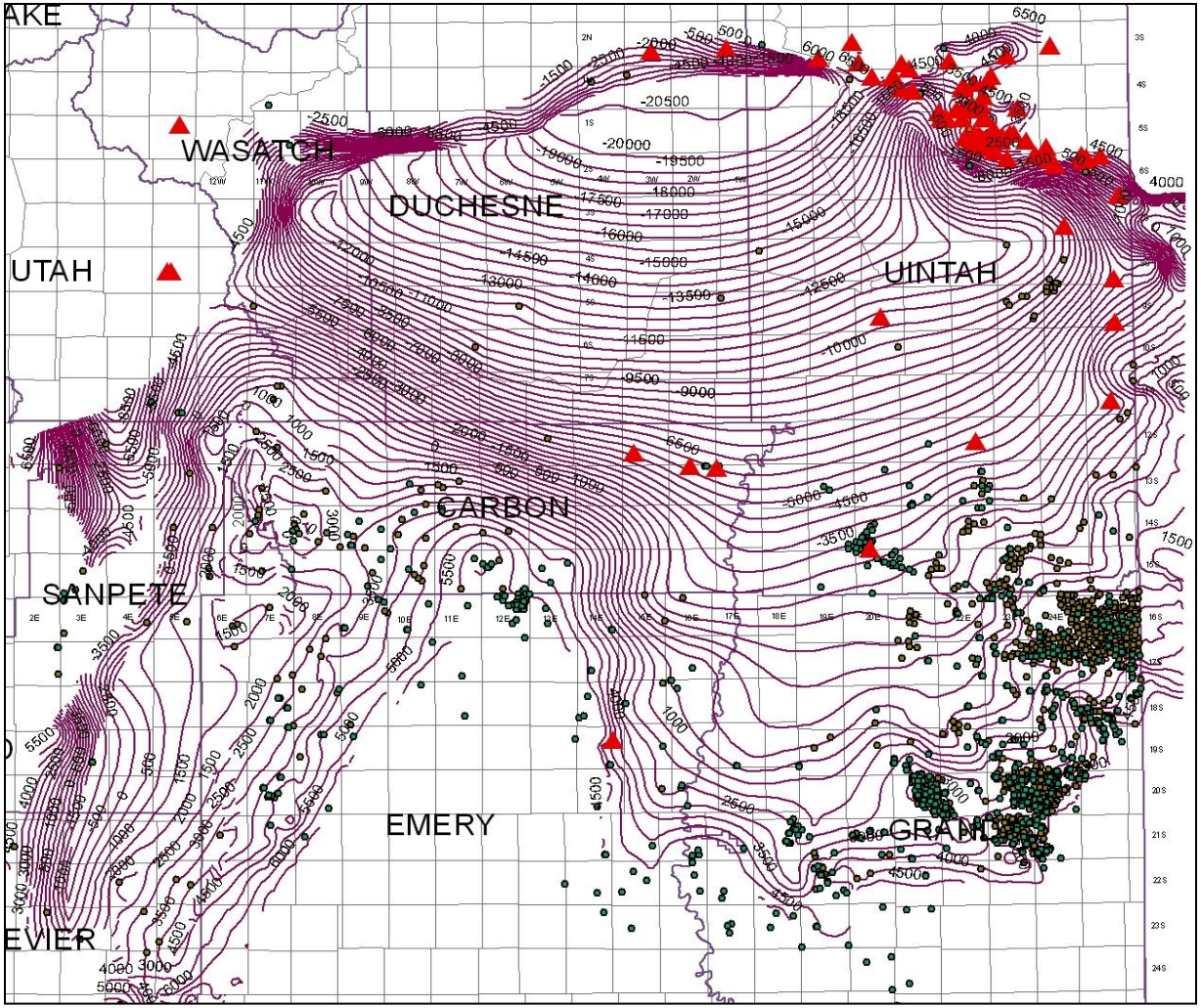
Local-Scale Characterization: Utah



Local-Scale Characterization: UINTA BASIN, UTAH

- Cretaceous Dakota Sandstone
- Jurassic Entrada Sandstone
- Permian/Pennsylvanian Weber Sandstone

Local-Scale Characterization: Utah

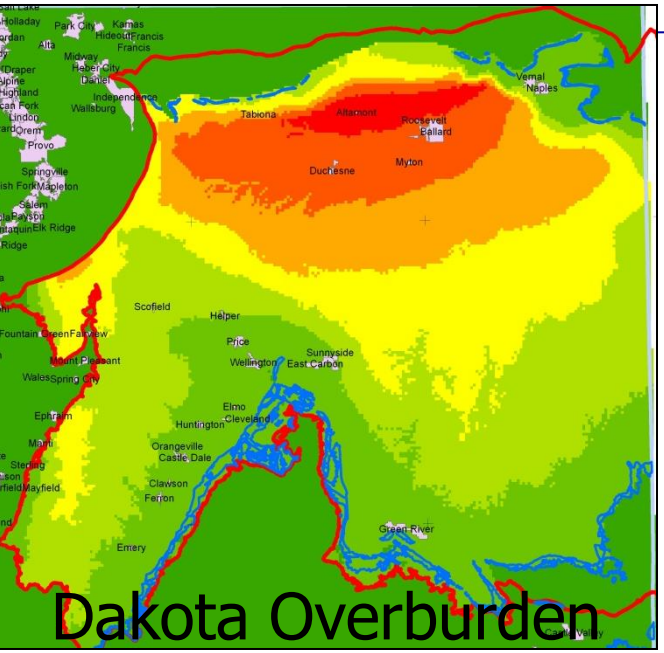


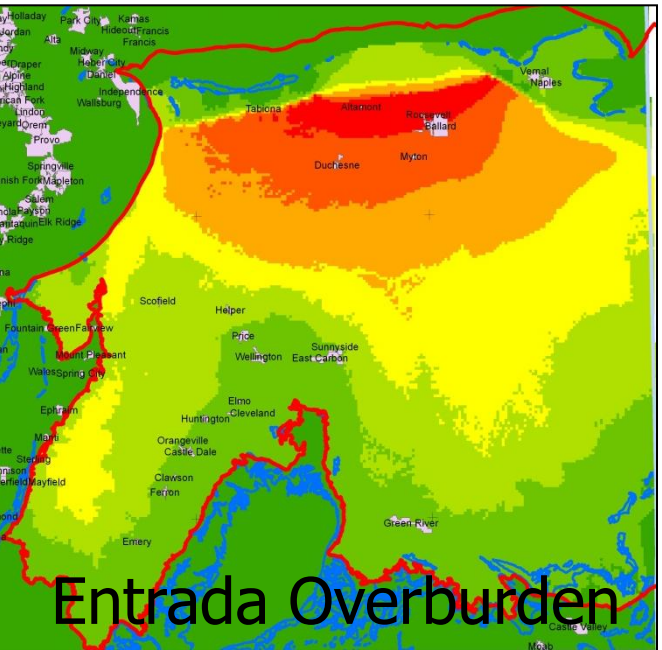
Green circles are Dakota completions

Red triangles are Weber completions

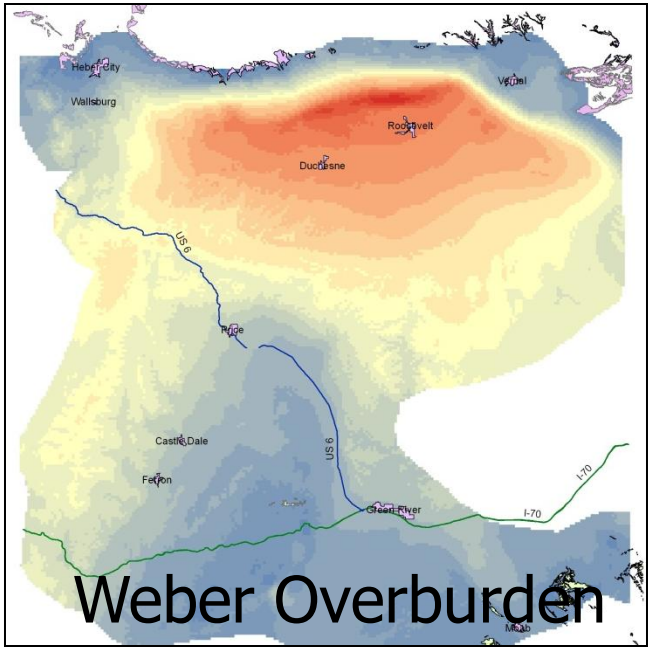
Structure Contour Map Cretaceous Dakota Sandstone and Well Database

Local-Scale Characterization: Utah





Overburden Maps Generated from structure maps and DEM data



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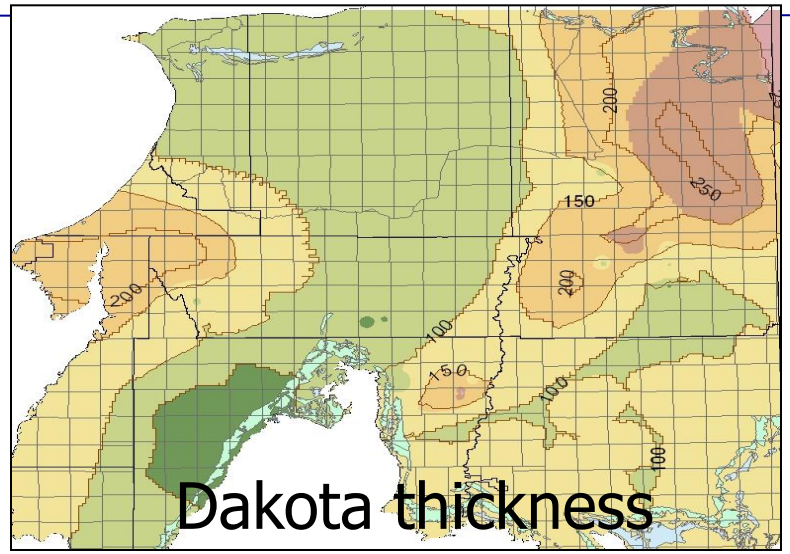
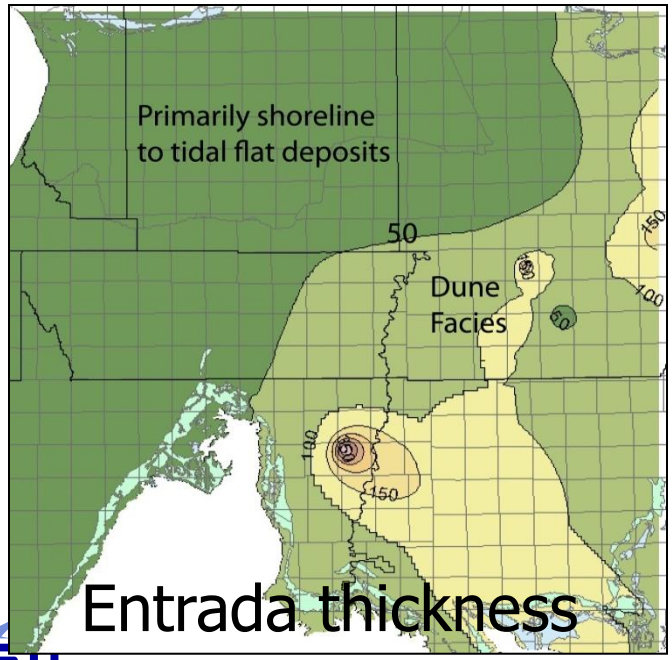
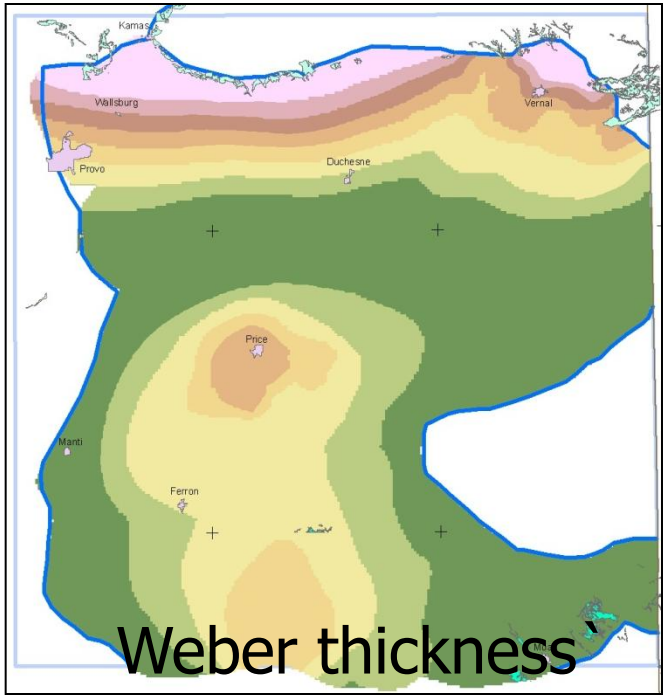


Dakota thickness



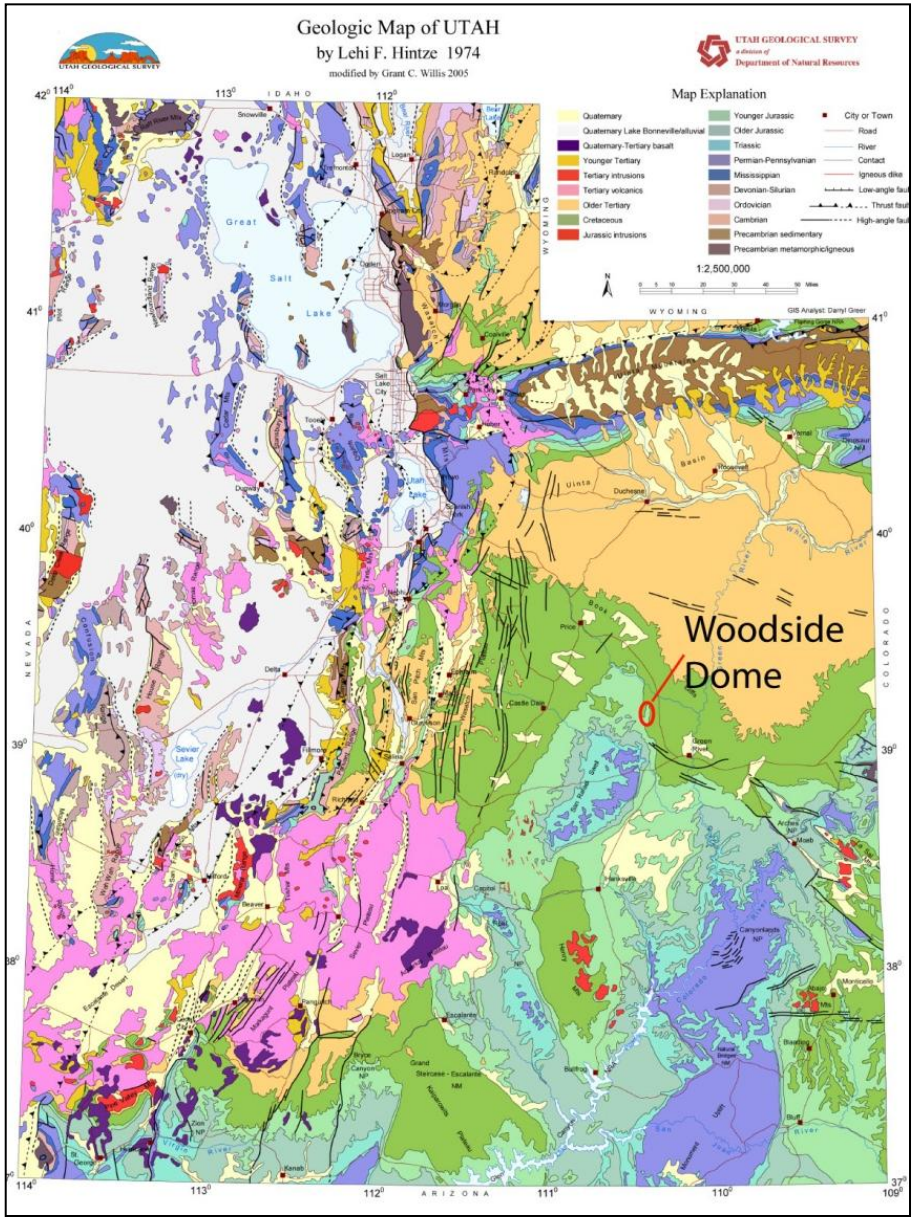
Entrada thickness

Reservoir Thickness



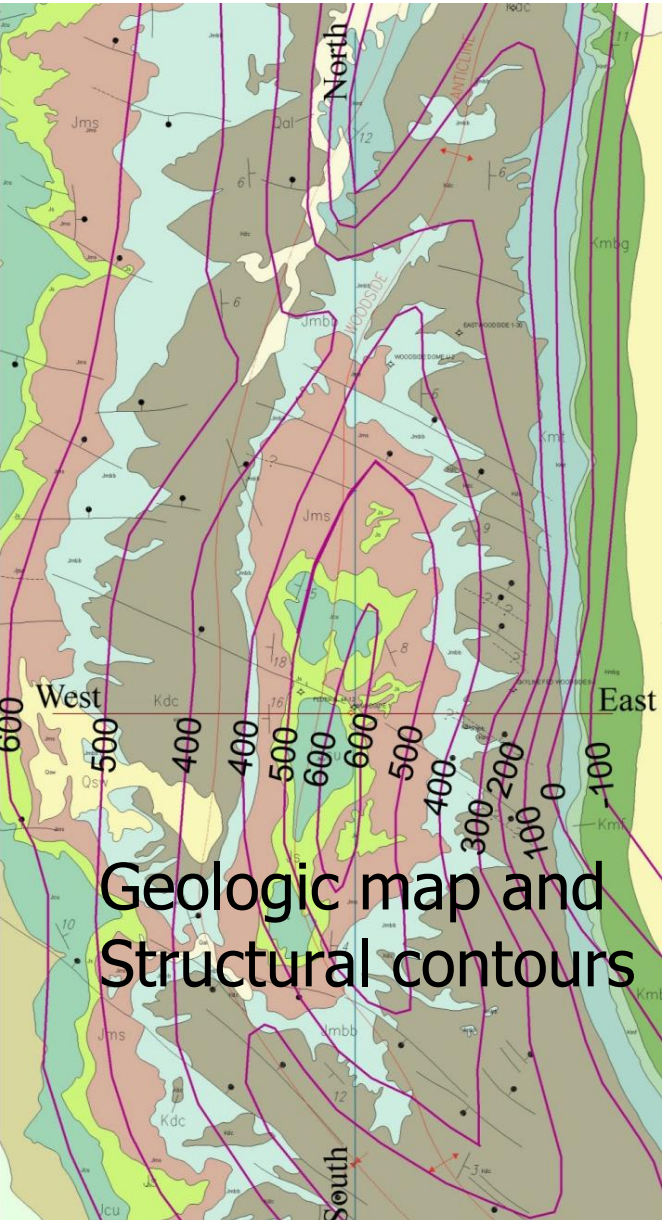
Weber thickness

Local-Scale Characterization: Utah



Even more local-scale (smaller scale focus): WOODSIDE DOME, UTAH

Local-Scale Characterization: Utah

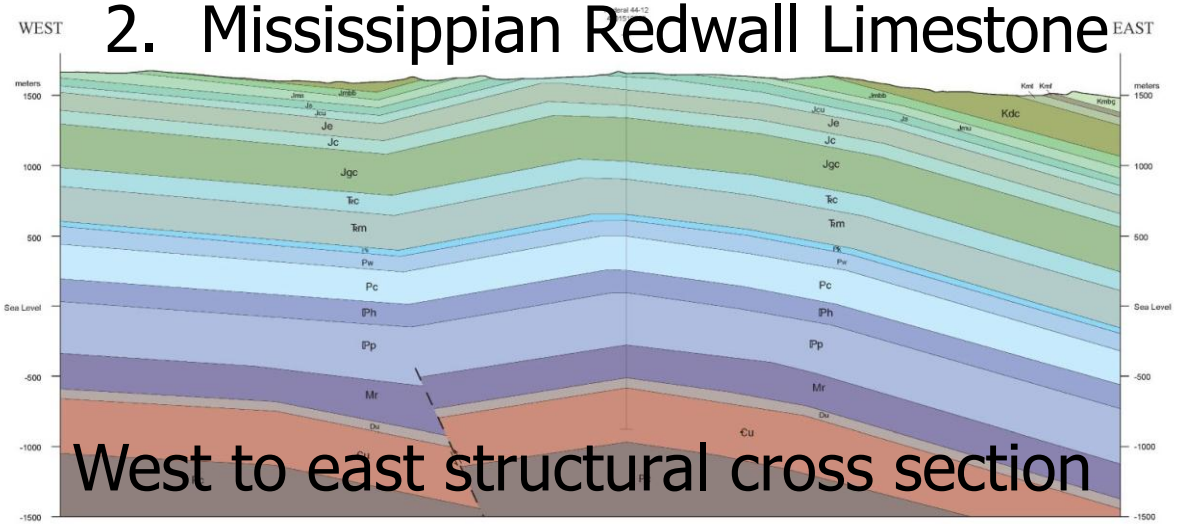


Geologic map and Structural contours

Even more local-scale:
WOODSIDE DOME, UTAH

Capacity estimates promising for:

1. Permian White Rim/Weber SS
2. Mississippian Redwall Limestone



West to east structural cross section

Local-Scale Characterization: Utah

Even more local-scale:
WOODSIDE DOME, UTAH

Capacity estimates promising for:

1. Permian White Rim/Weber SS
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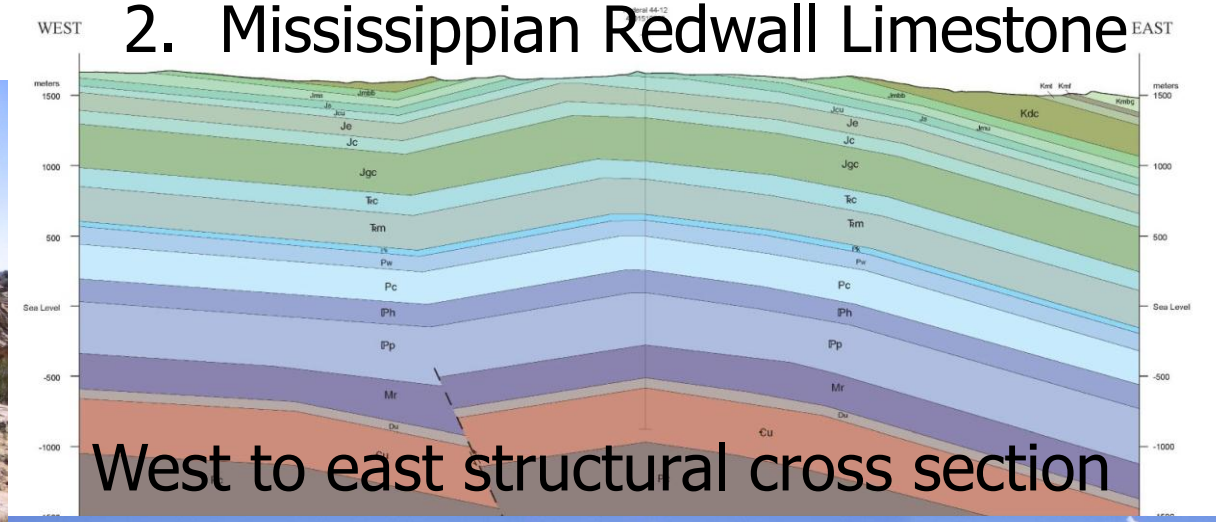
White Rim Outcrop



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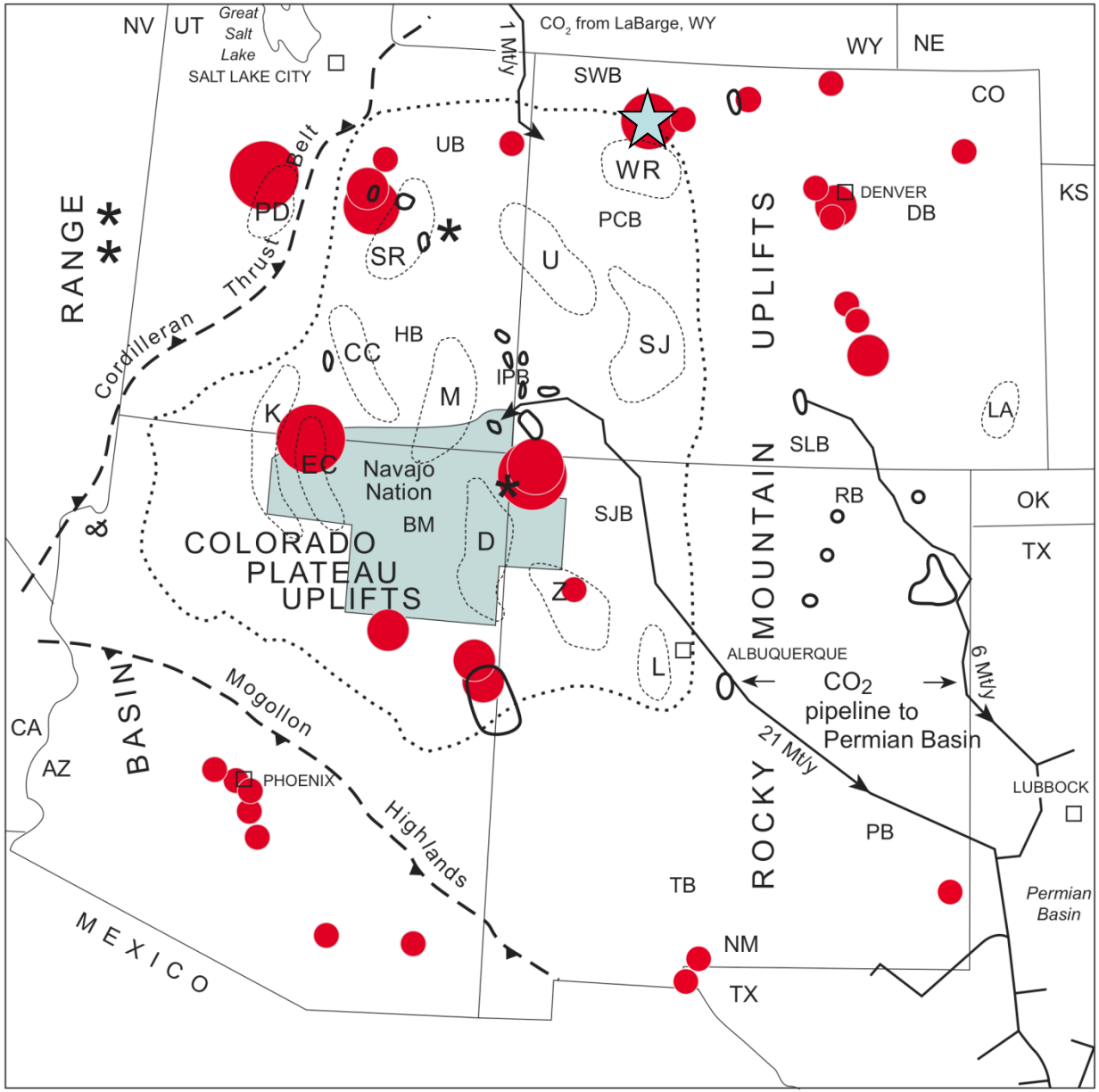

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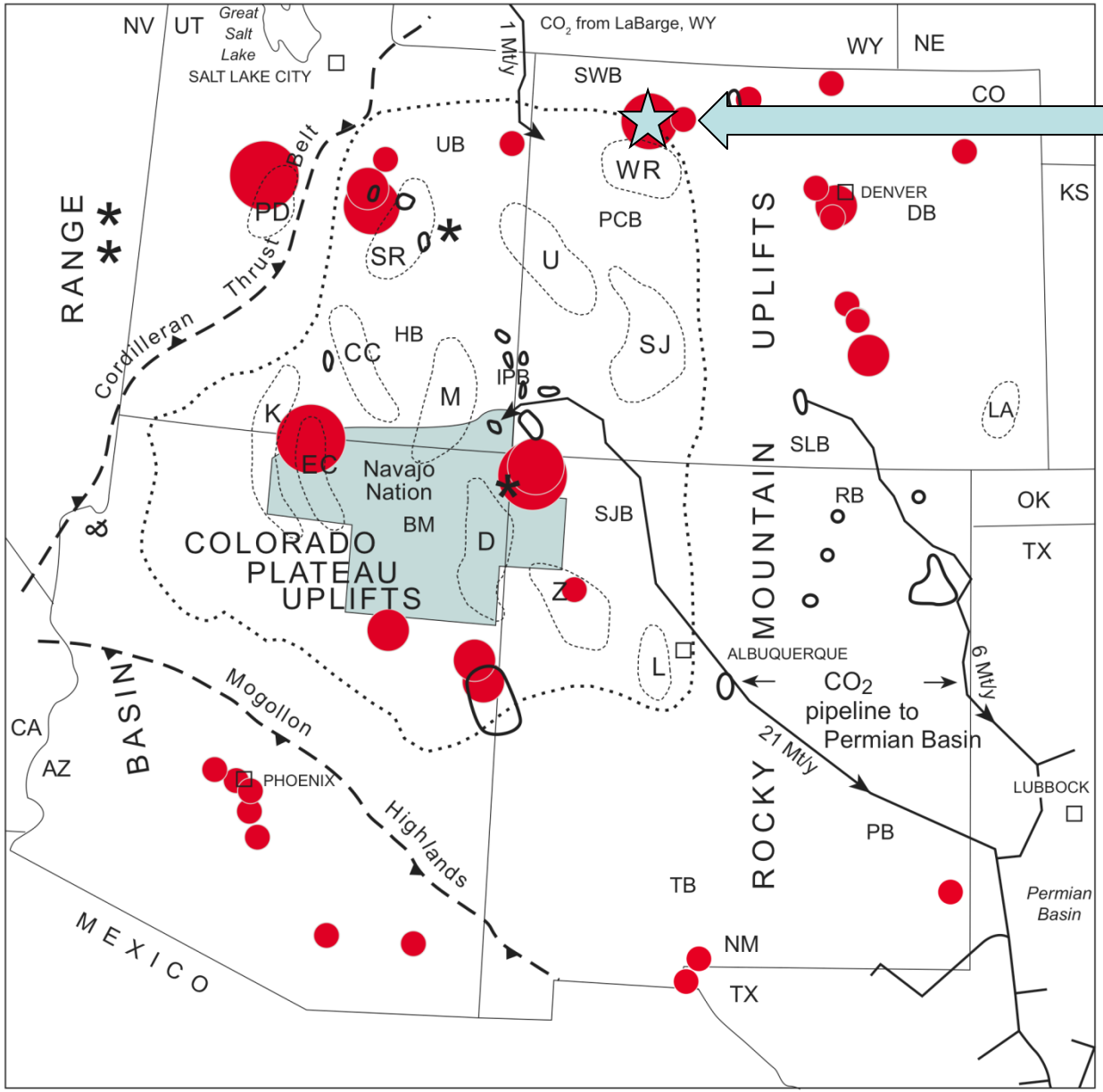
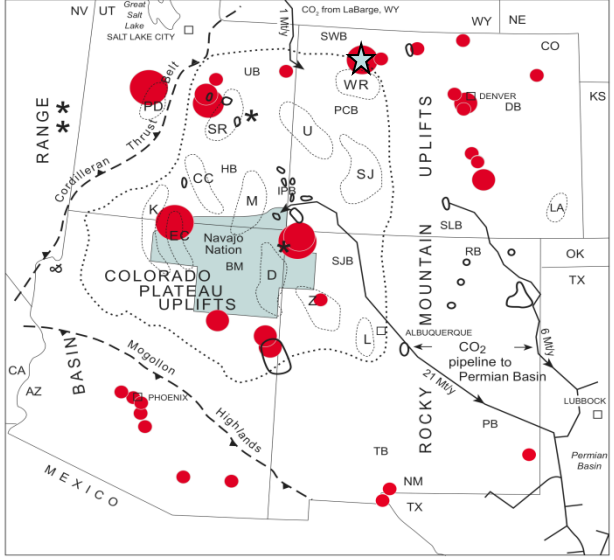


Case Study Area

Local-Scale Characterization: Colorado



This Case Study Area is representative of the geology throughout most of the region, including its unique set of Laramide structures

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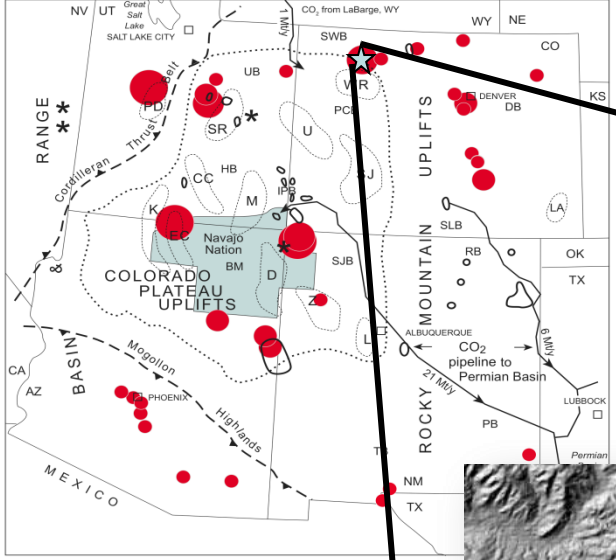

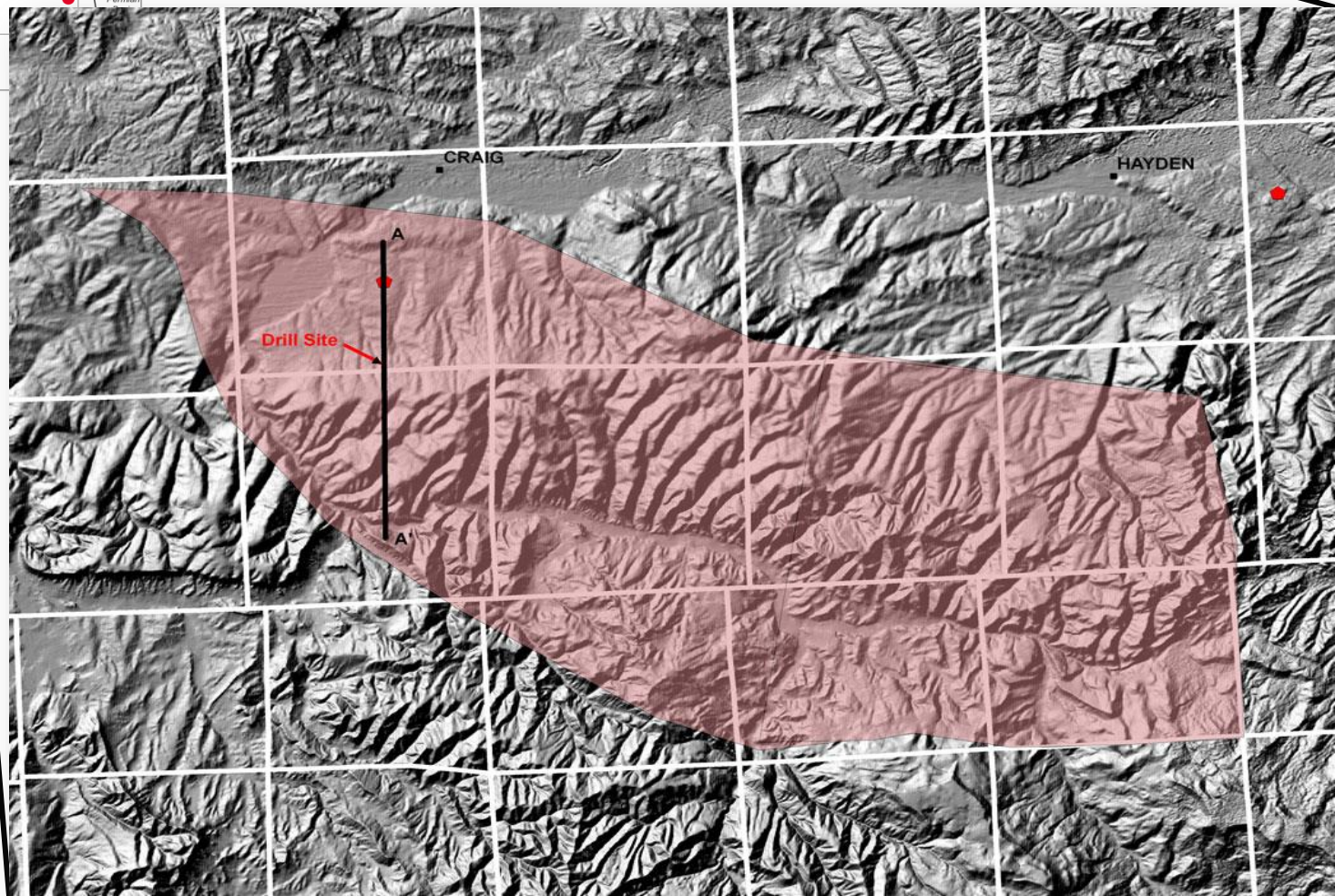

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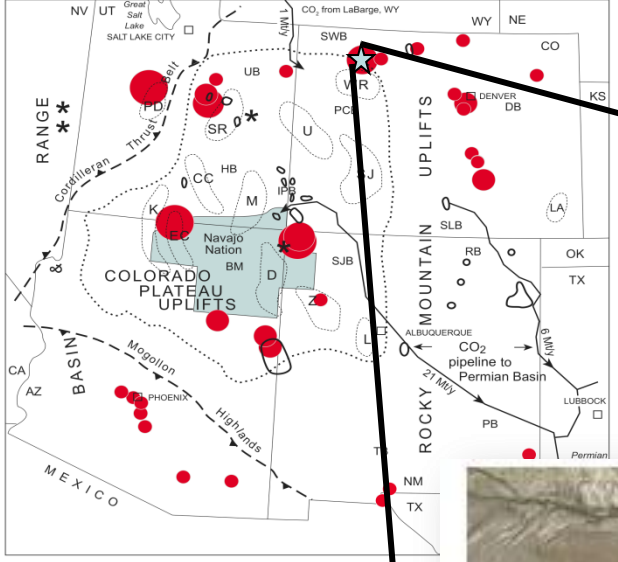
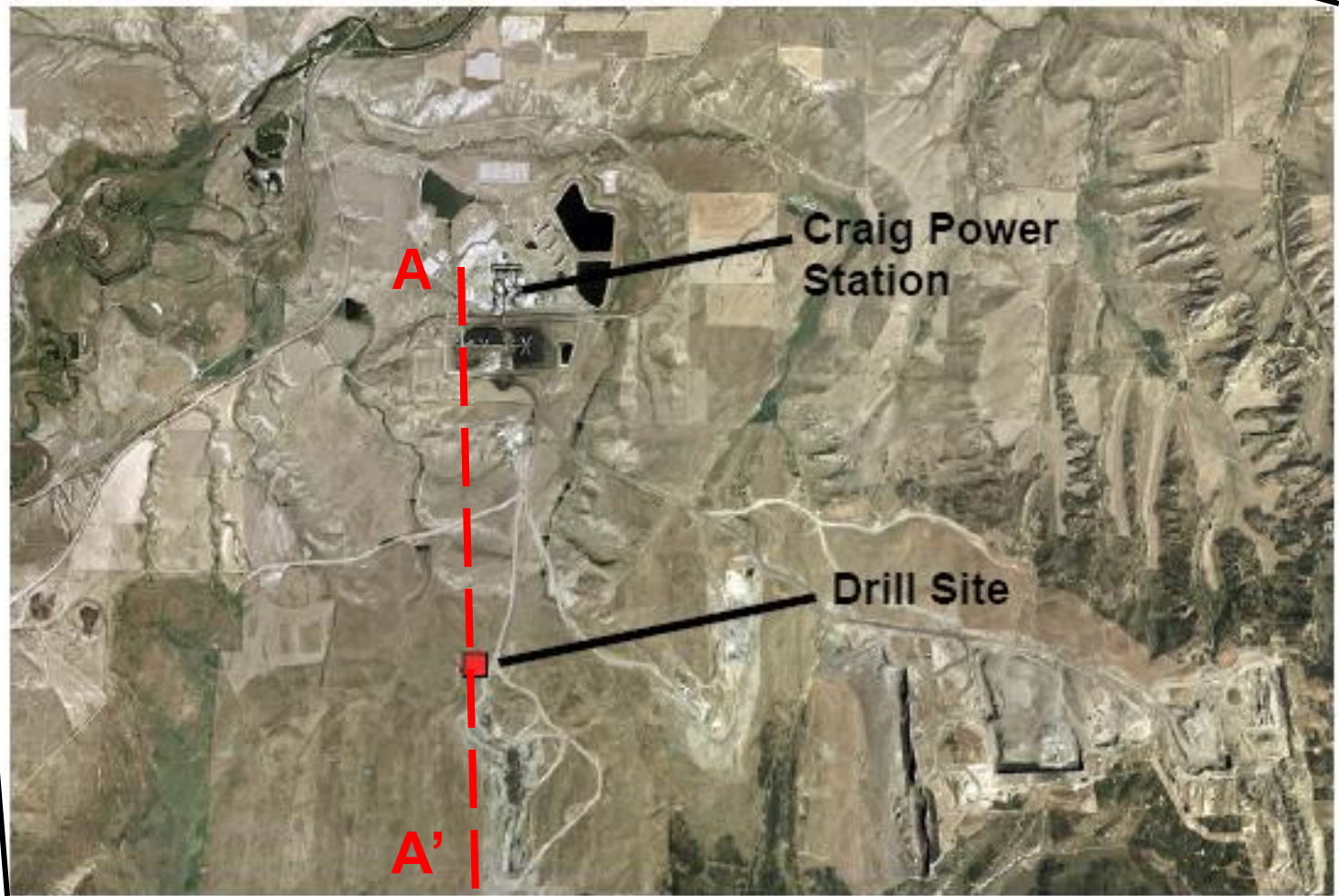


Cross-Section A – A’



Local-Scale Characterization: Colorado

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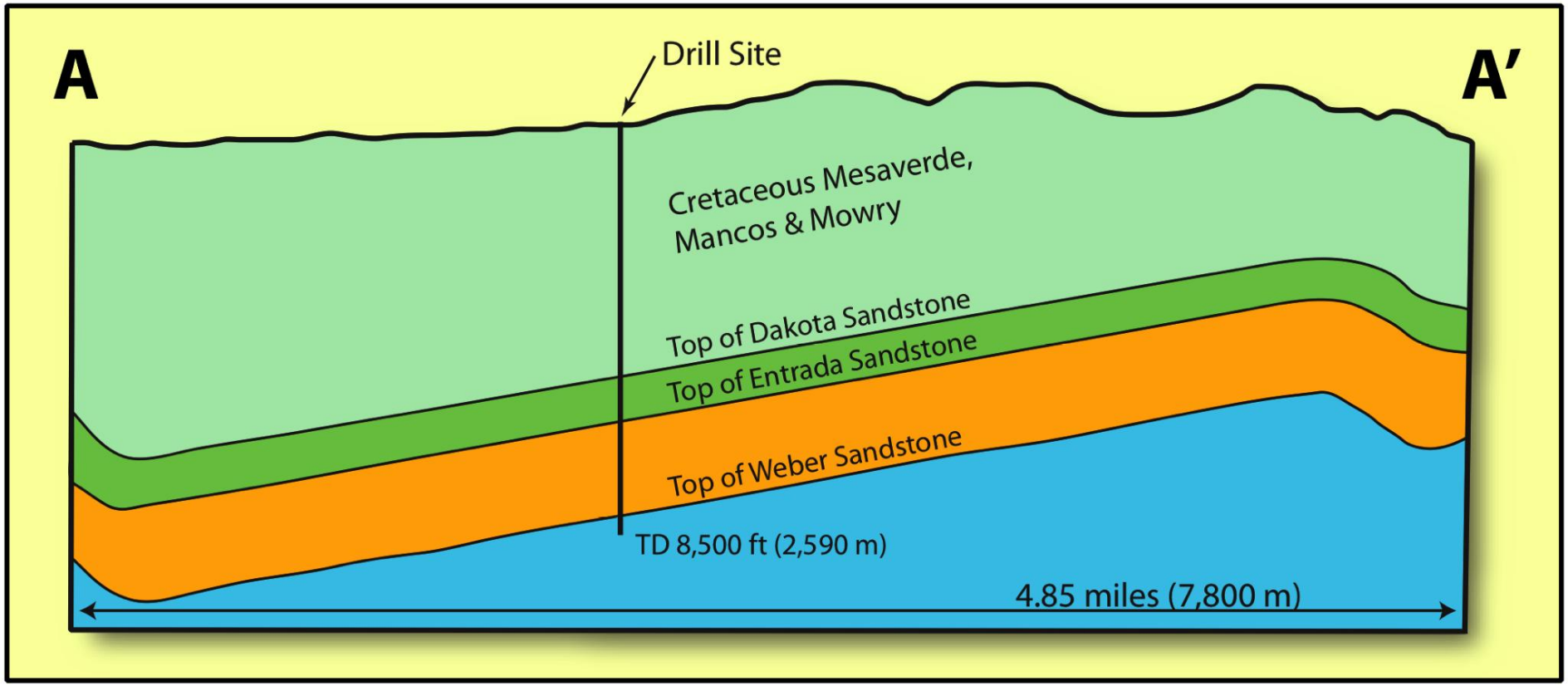
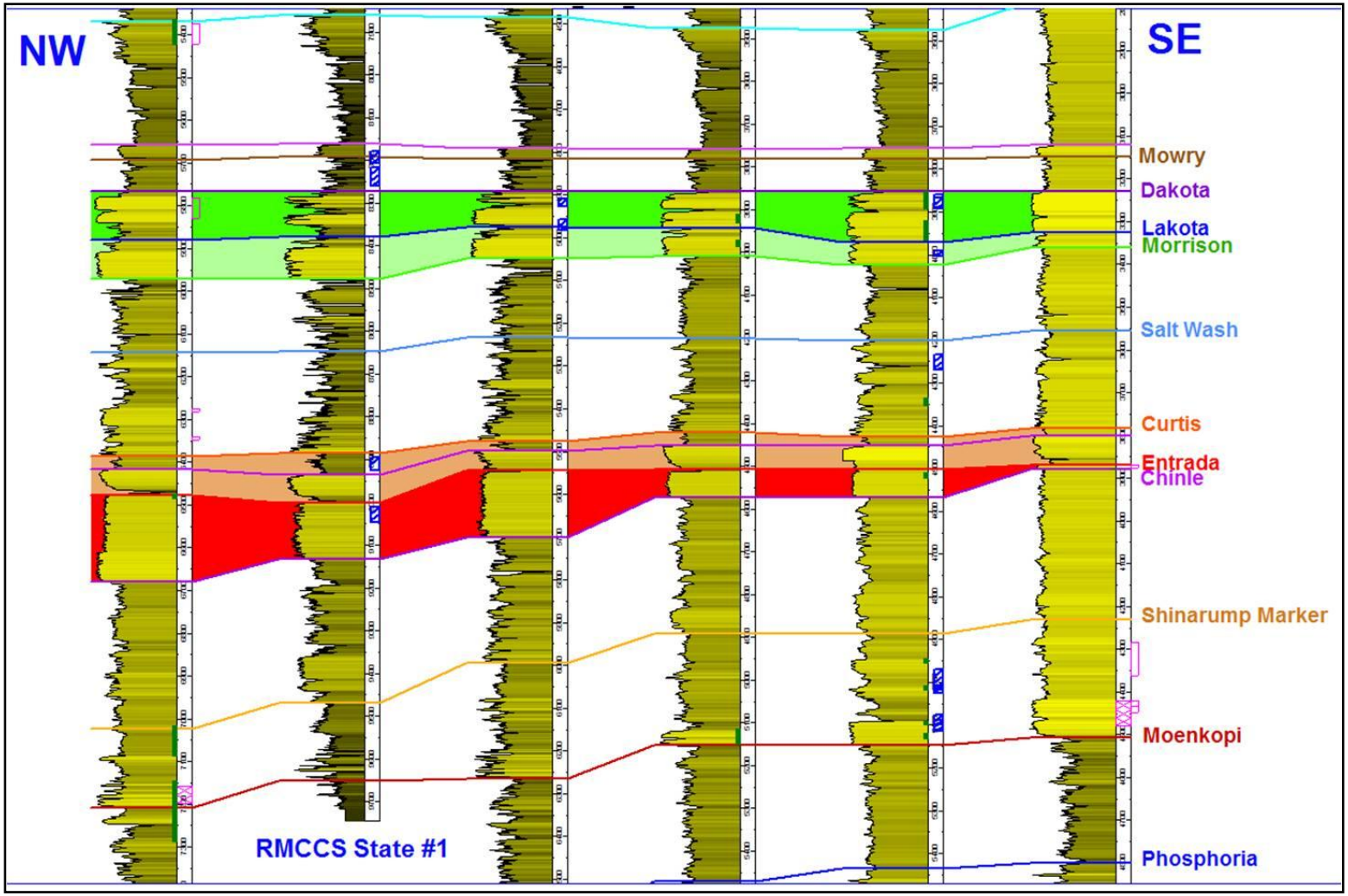


Local-Scale Characterization: Colorado

A

Cross-Section A – A’

A’



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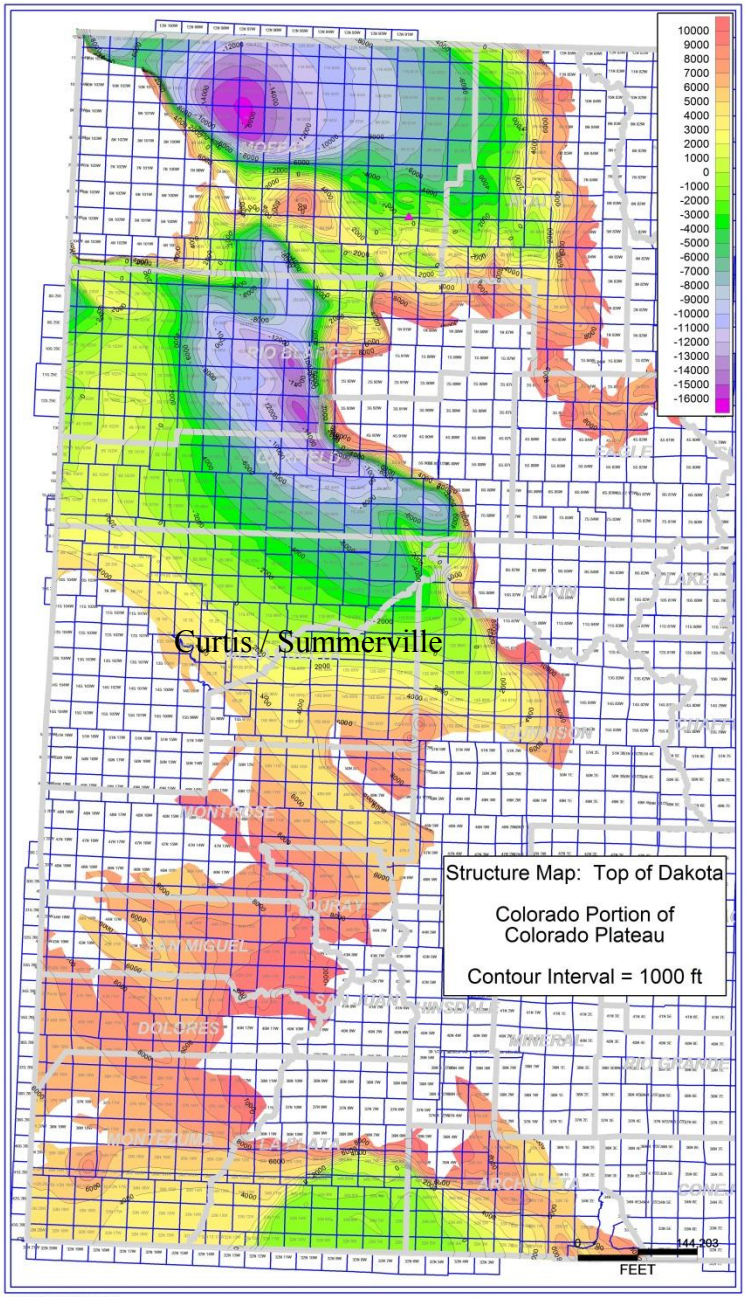
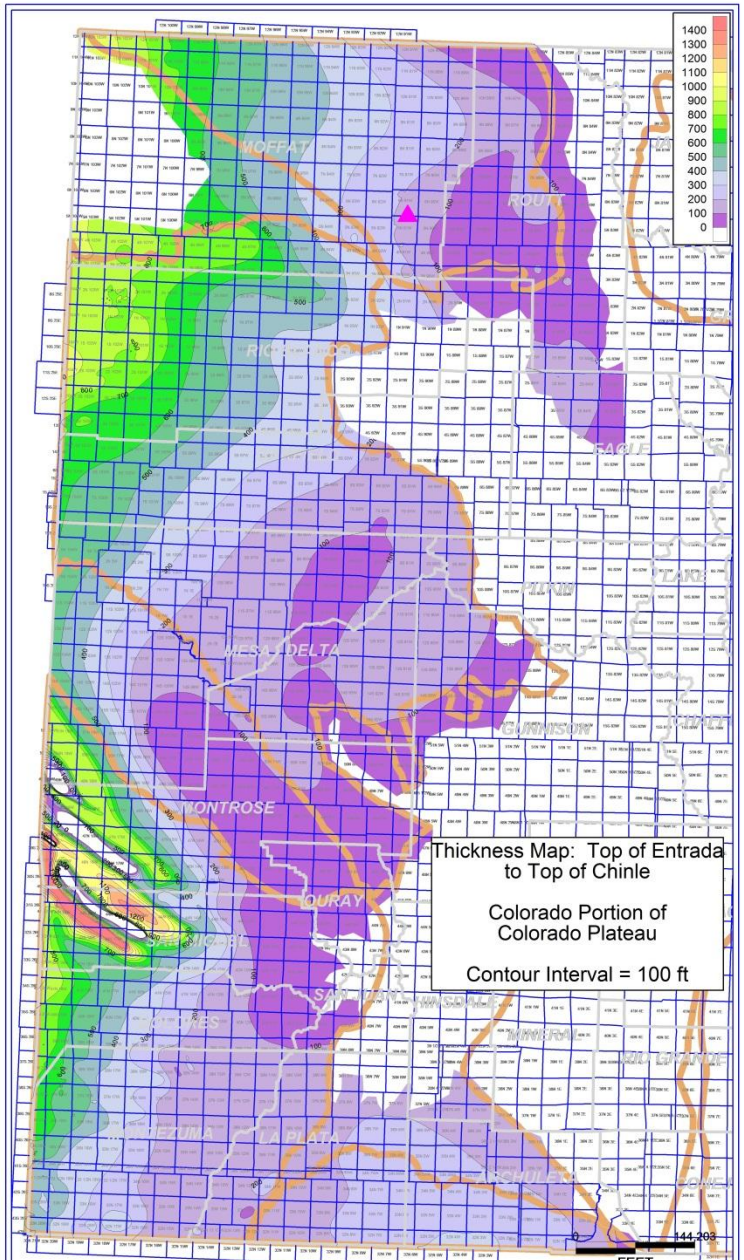


Dakota Surface

Local-Scale Characterization: Colorado

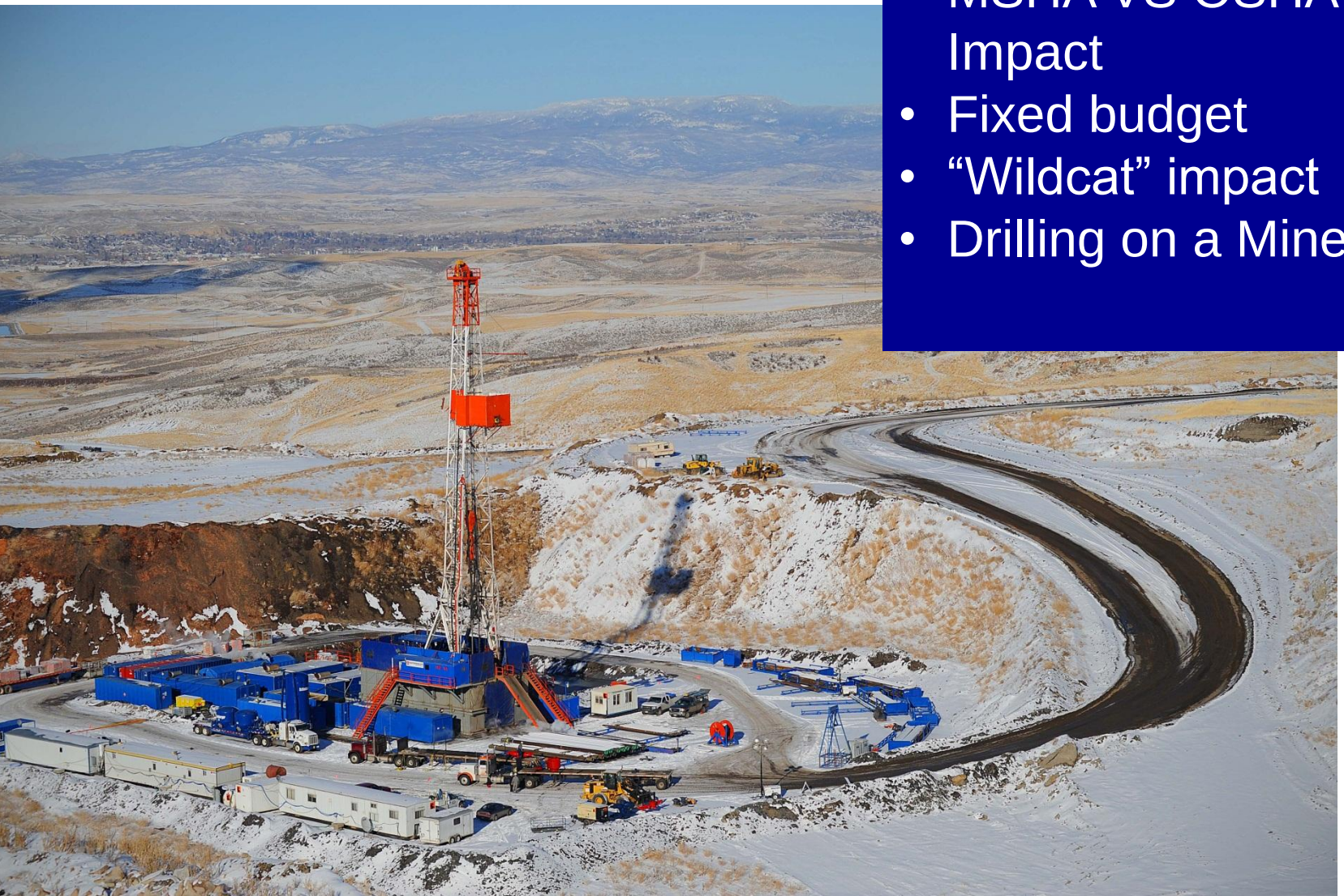


Entrada Surface

Local-Scale Characterization: Colorado

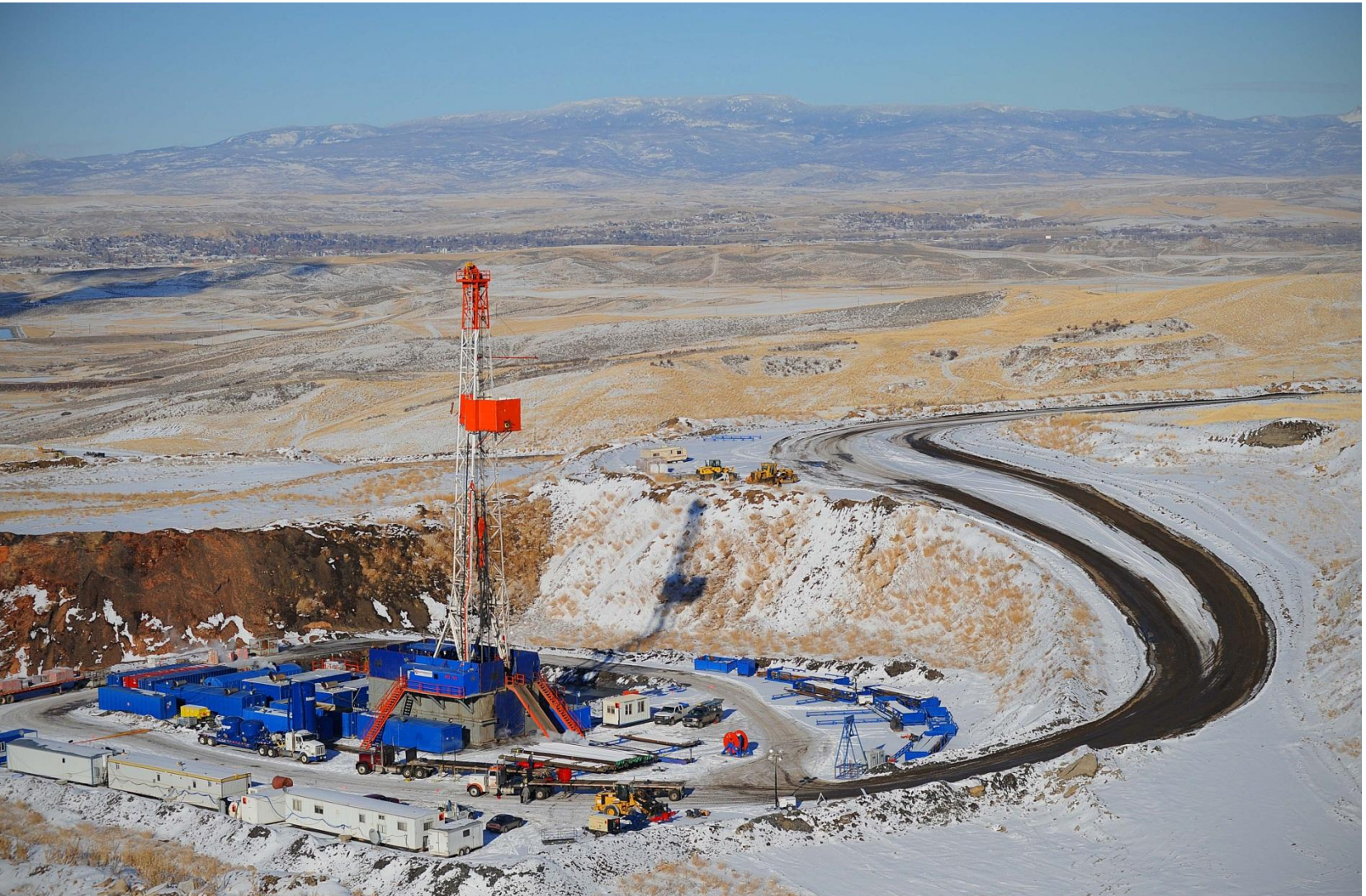
Drilling Lessons Learned

- MSHA VS OSHA Impact
- Fixed budget
- “Wildcat” impact
- Drilling on a Mine



Local-Scale Characterization: Colorado

Cores



Local-Scale Characterization: Colorado

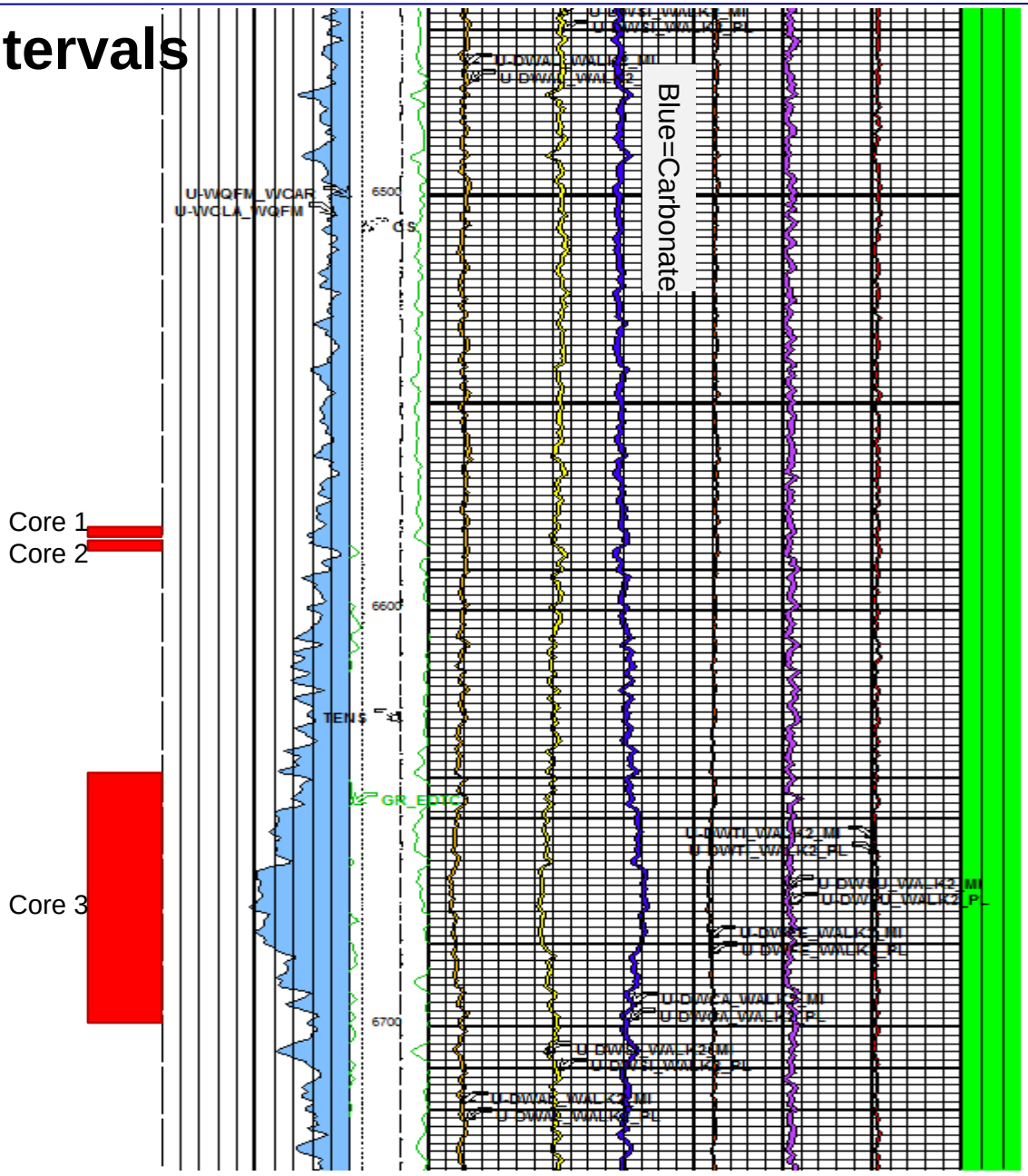
Cores

Coreviewing: 131’ of slabbed RMCCS State #1 core

Niobrara Core Summary

RMCCS Niobrara core intervals on ECS Log

- 60’ acquired within the Tow Creek Bench
- ~6’ acquired in Interbench 1



Niobrara Core Quality

These are pervasive in all but 4 ft of core

Longitudinal, drilling-induced cracks in core

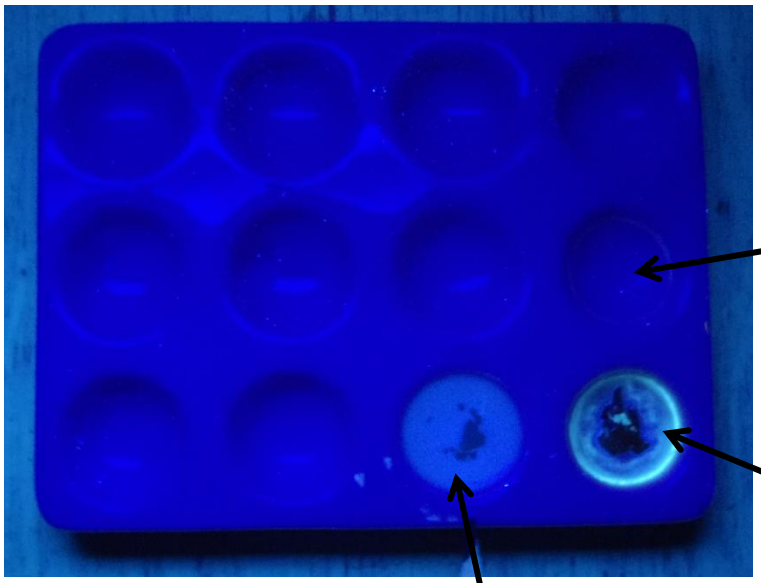
(no calcite lining)

Poker chipping at bottom of core 3

Niobrara Core Quality

Little white specks are small fossils: forams (and poss. small gastropods?) @ 6666’

Cut fluorescence of core chips



Niobrara Core Quality

- Coring performance substandard for basin/target and industry performance
- Industry has had great success (20-40 ROP, > 100% recovery) using OBM
  - RMCCS choice of WBM produced outstanding log data, but may have affected coring performance
  - Shell will acquire first Niobrara core using WBM in Q3/Q4 2012 in Sandwash, will provide clarity to this question
- Also, coring operator used equipment setup for DJ Basin; Sandwash is very different rock properties (more clastic, etc.)
- Shell's opinion is that due diligence was performed by project team, operator (SLB) or coring operator responsible.

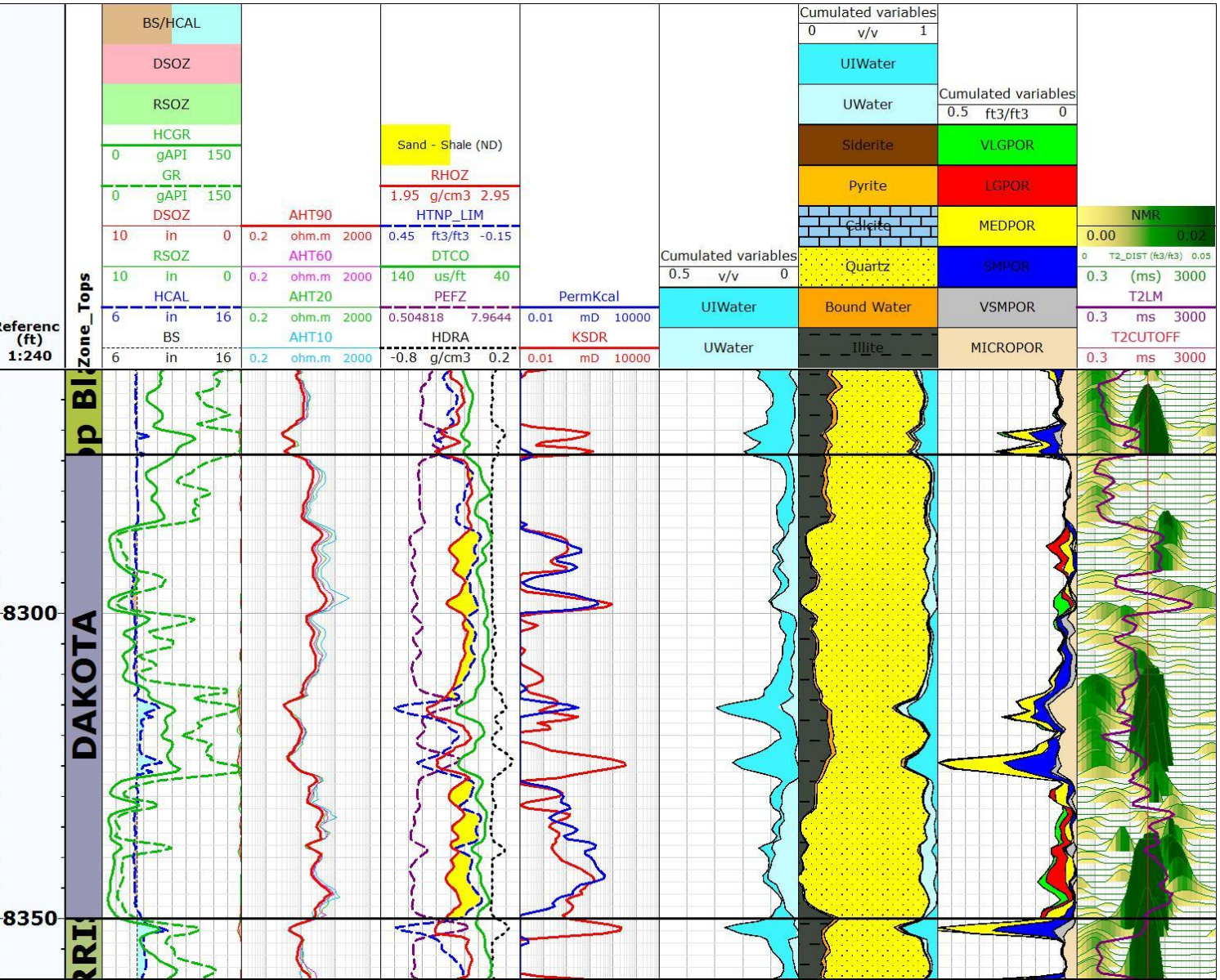
Niobrara Core Analysis Plan

- Handling / Slabbing / Analysis to be performed by Corelab
  - 100% funded by Shell / All raw data shared
- Longterm storage : Core to be donated to USGS Denver facility
  - Basic Rock Properties (GRI method)
    - Completed
  - Rock Mechanics on 10 samples (1/6')
    - In progress – data expected in Q4 2012
  - Fracture Study on Niobrara Core
    - Completed
  - Core / Log calibration
    - Completed
  - Core Photos

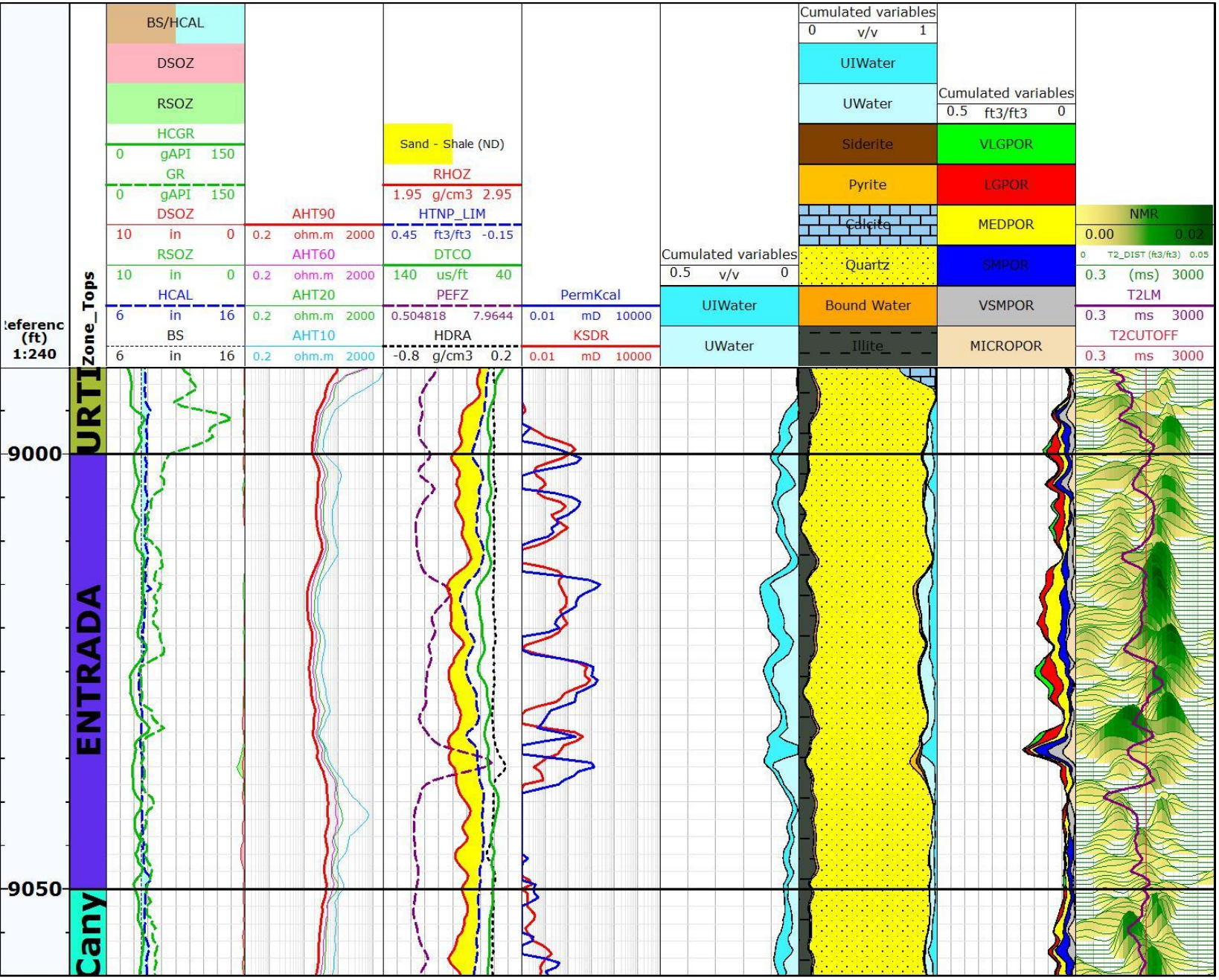
Niobrara Core – GRI Data

- Basic Rock Properties from Tow Creek Core
  - Avg Perm : 5.922 E-07 mD
  - Avg Water Saturation : 0.488
  - Avg Fm Density (RhoB) : 2.524
  - Bulk Density : 2.504
  - Poissons Ratio : 0.213
  - Youngs Modulus : 5.66
  - Avg TOC : 3.28%

Local-Scale Characterization: Colorado

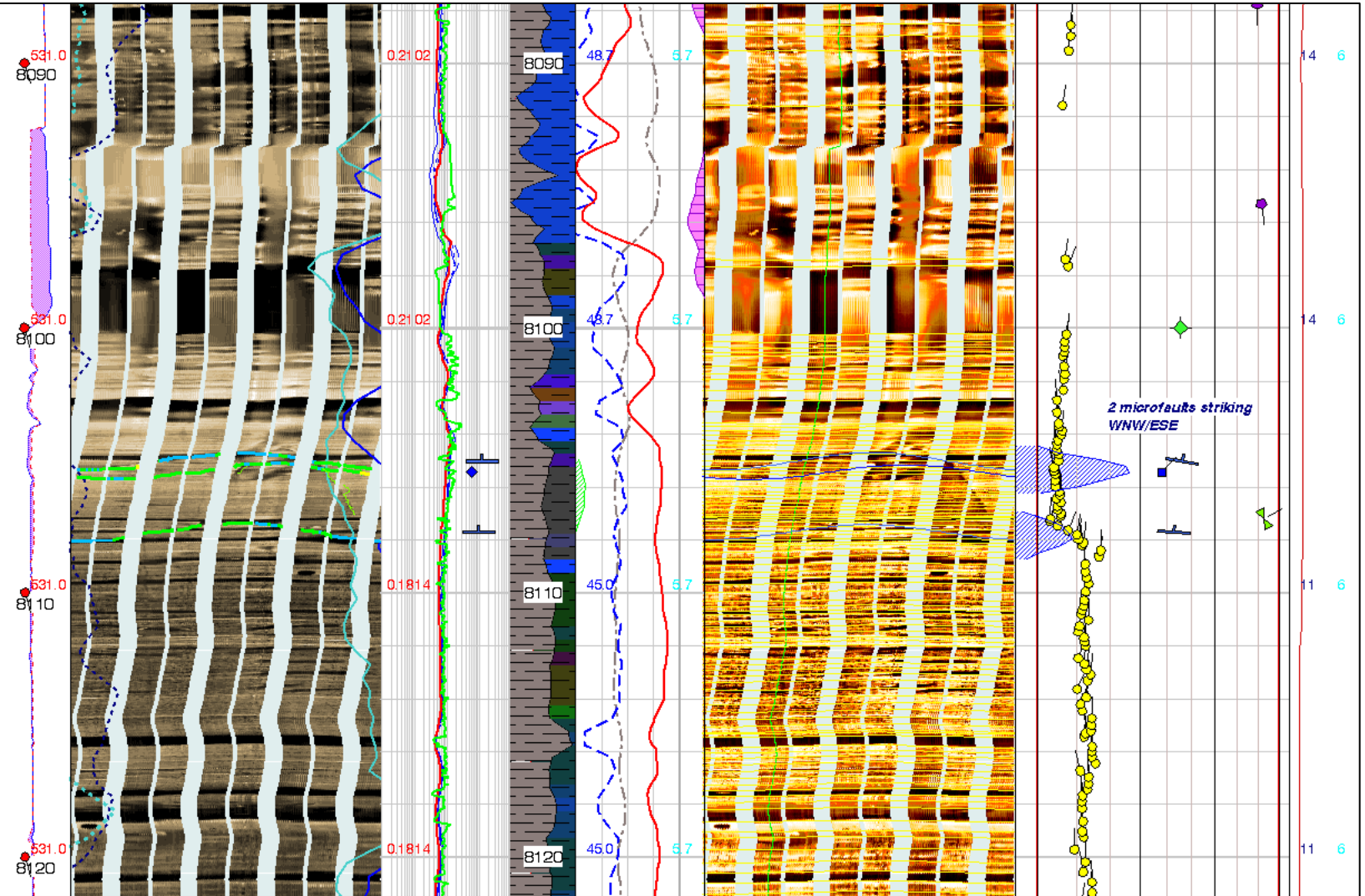


Well Logs


BS/HCAL
DSOZ
RSOZ
HCGR
0 gAPI 150
GR
0 gAPI 150
DSOZ
10 in 0
RSOZ
10 in 0
HCAL
6 in 16
BS
6 in 16
Zone_Tops
AHT90
0.2 ohm.m 2000
AHT60
0.2 ohm.m 2000
AHT20
0.2 ohm.m 2000
AHT10
0.2 ohm.m 2000
Sand - Shale (ND)
RHOZ
1.95 g/cm3 2.95
HTNP_LIM
0.45 ft3/ft3 -0.15
DTCO
140 us/ft 40
PEFZ
0.504818 7.9644
HDRA
-0.8 g/cm3 0.2
PermKcal
0.01 mD 10000
KSDR
0.01 mD 10000
Cumulated variables
0.5 v/v 0
UIWater
UWater
Cumulated variables
0 v/v 1
UIWater
UWater
Siderite
Pyrite
Calcite
Quartz
Bound Water
Illite
Cumulated variables
0.5 ft3/ft3 0
VLGPOR
LGPOR
MEDPOR
SMPOR
VSMPOR
MICROPOR
NMR
0.00 0.02
0 T2_DIST (ft3/ft3) 0.05
0.3 (ms) 3000
T2LM
0.3 ms 3000
T2CUTOFF
0.3 ms 3000
Reference (ft) 1:240
9000
9050
URTI
ENTRADA
Cany

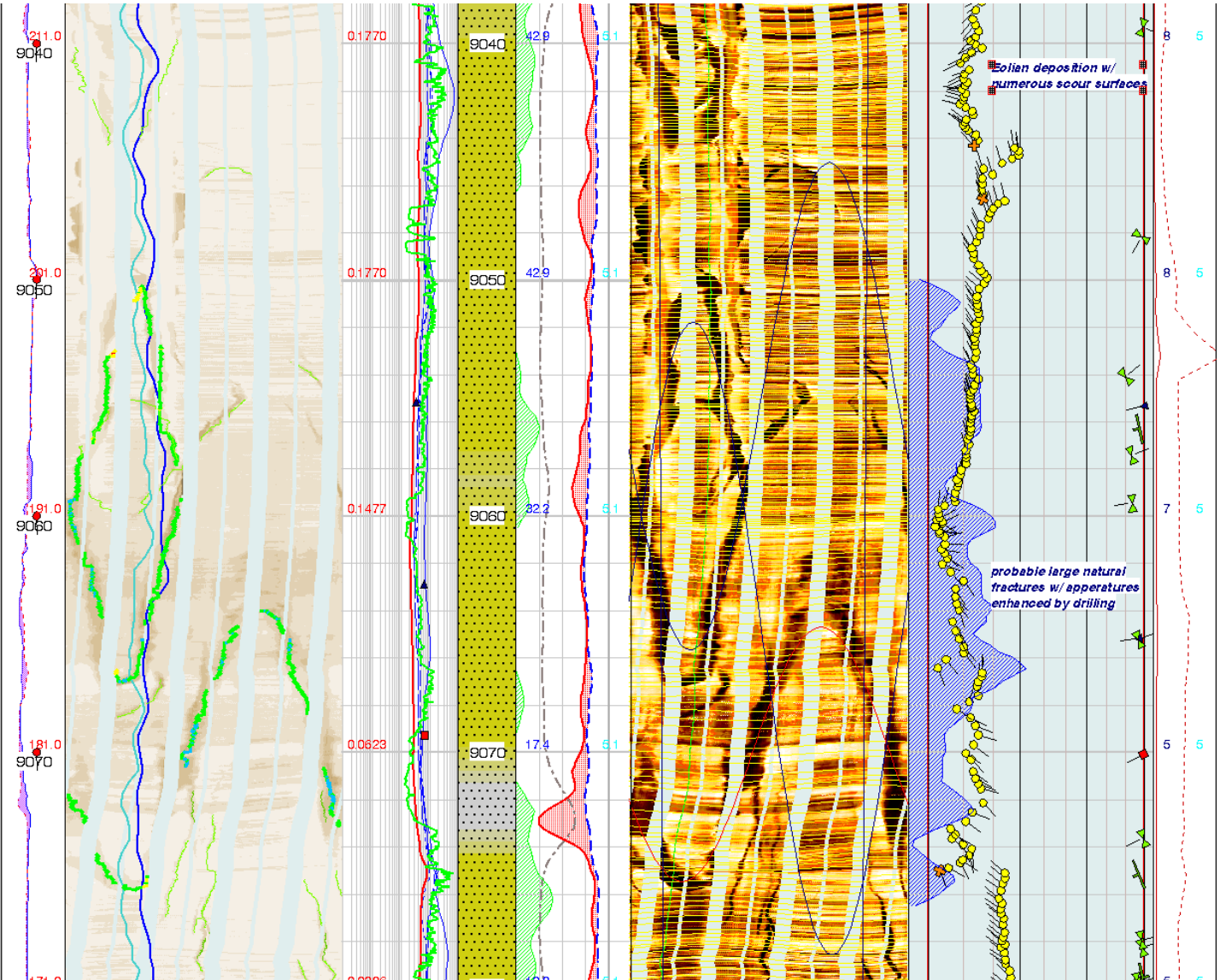
Local-Scale Characterization: Colorado

Dakota Micro-faults



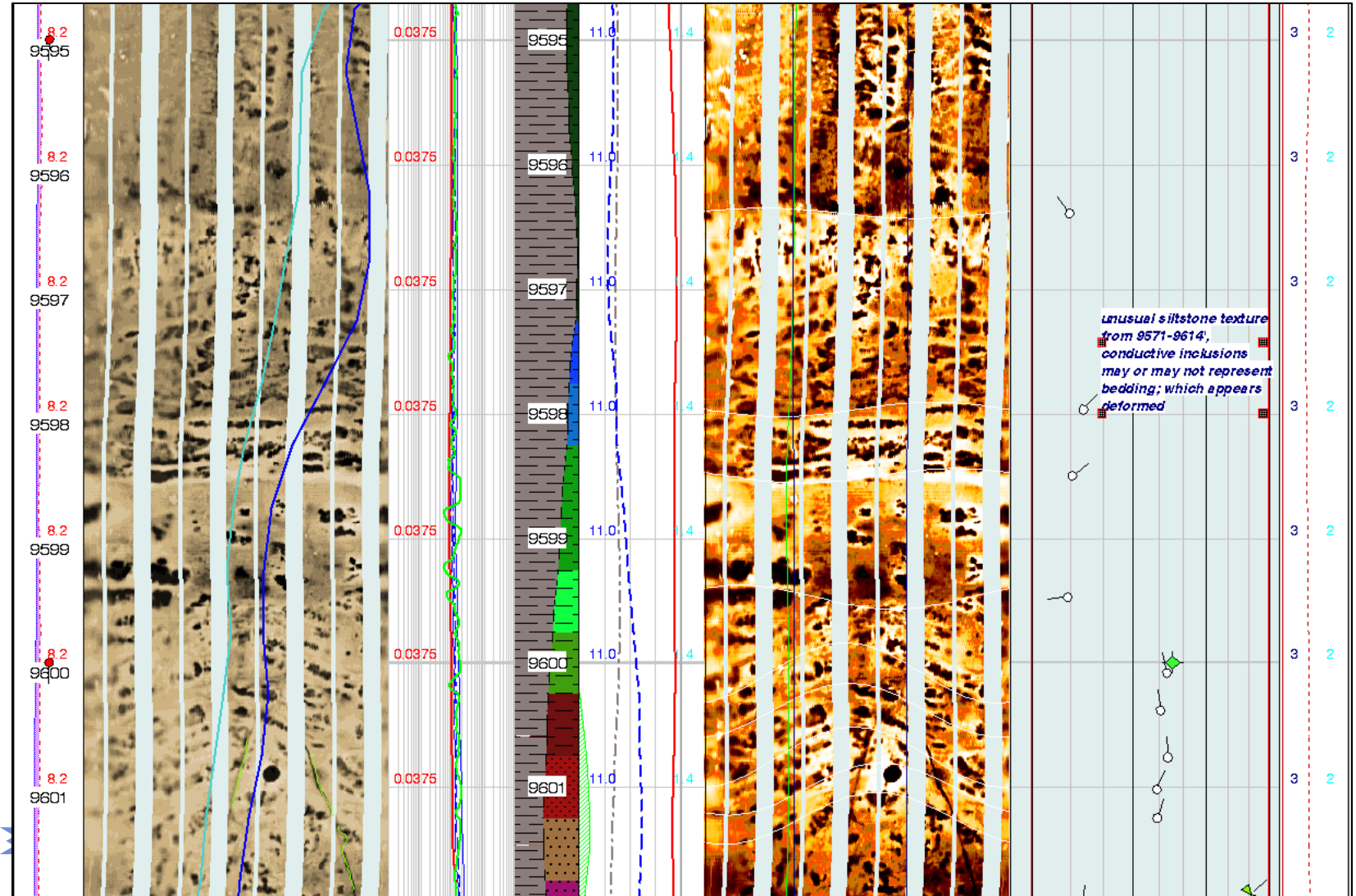
Local-Scale Characterization: Colorado

Dakota Micro-faults



Local-Scale Characterization: Colorado

Dakota Micro-faults

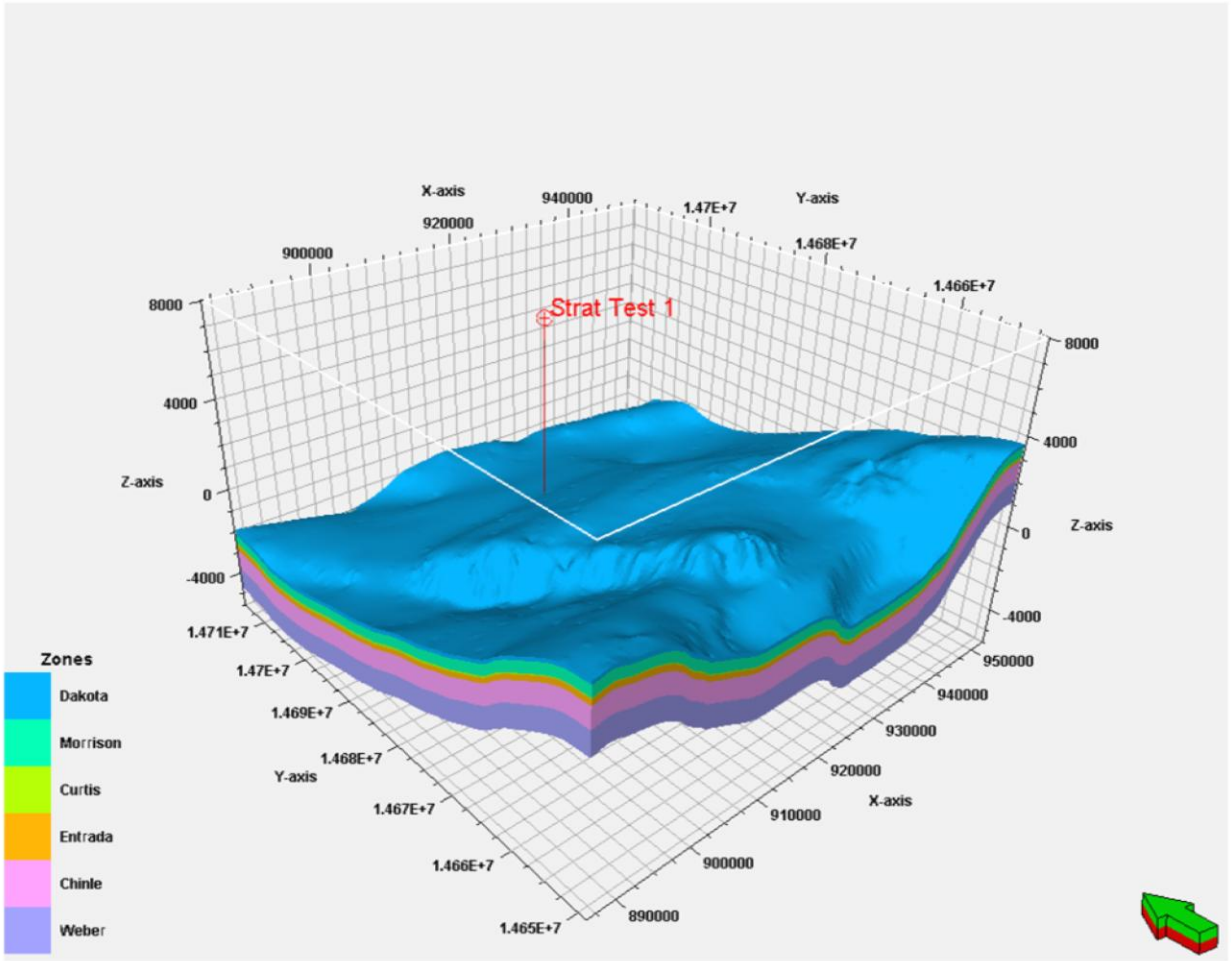


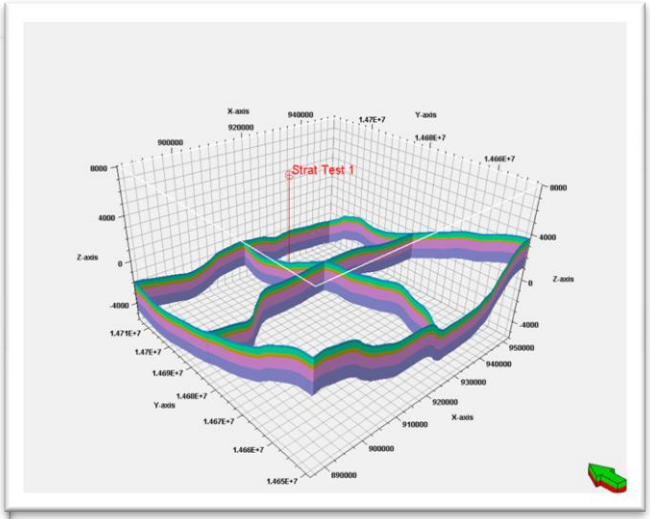
Presentation Outline

- Technical Team
- What's the Goal?
  - local site analyses for each section of region (each state):
    - Arizona results
    - Utah results
    - Colorado results:
      - Sandwash Basin near Craig, CO
  - **How we are using these data: quantitative assessment of capacity, AOR, and uncertainty estimation**
  - National Atlas contributions for region

Quantitative Assessment of Capacity, AOR, and Uncertainty

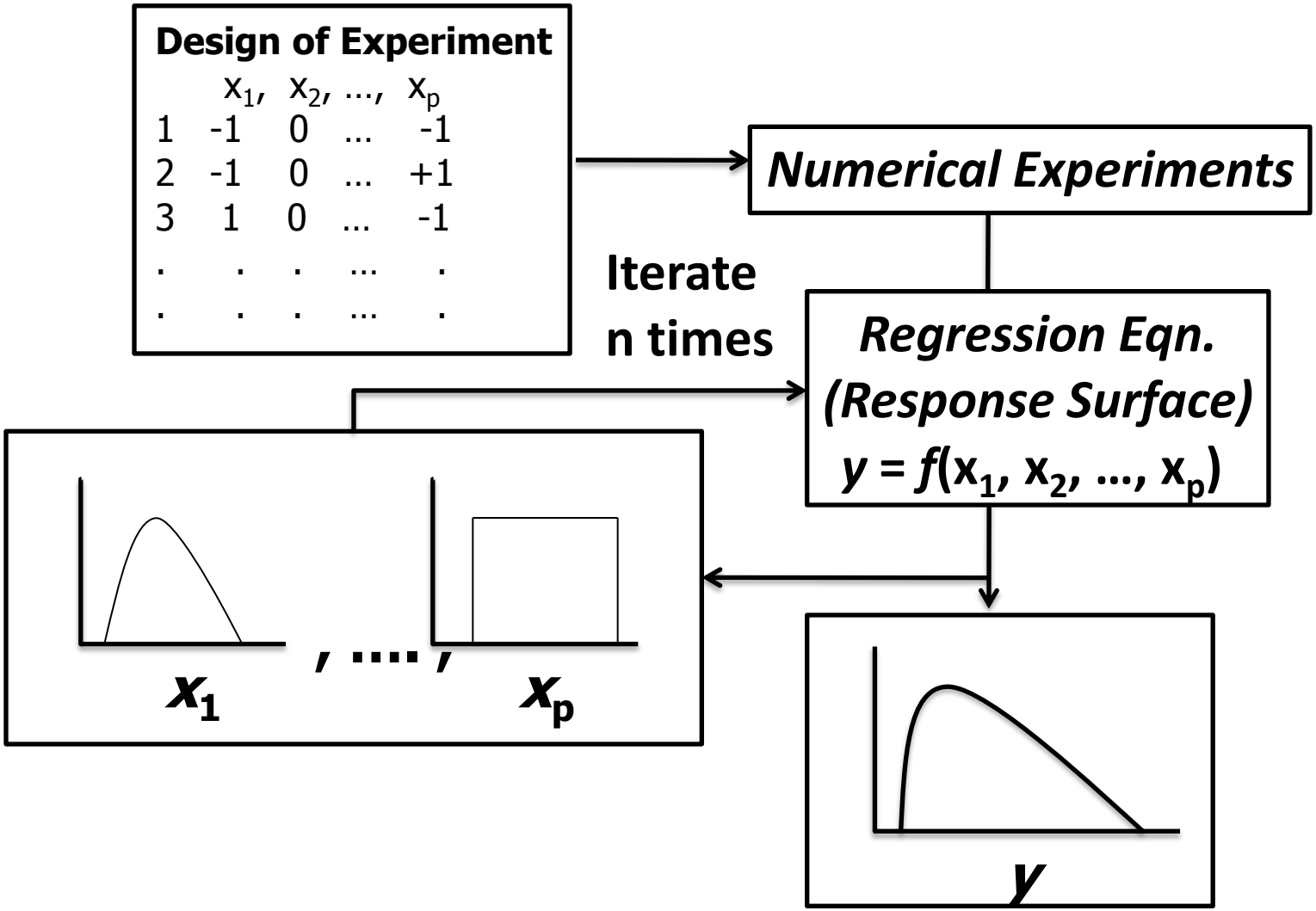
Models of each basin in region; some very high resolution, others not so much (!)





Quantitative Assessment of Capacity, AOR, and Uncertainty

MCS through Response Surface Methodology

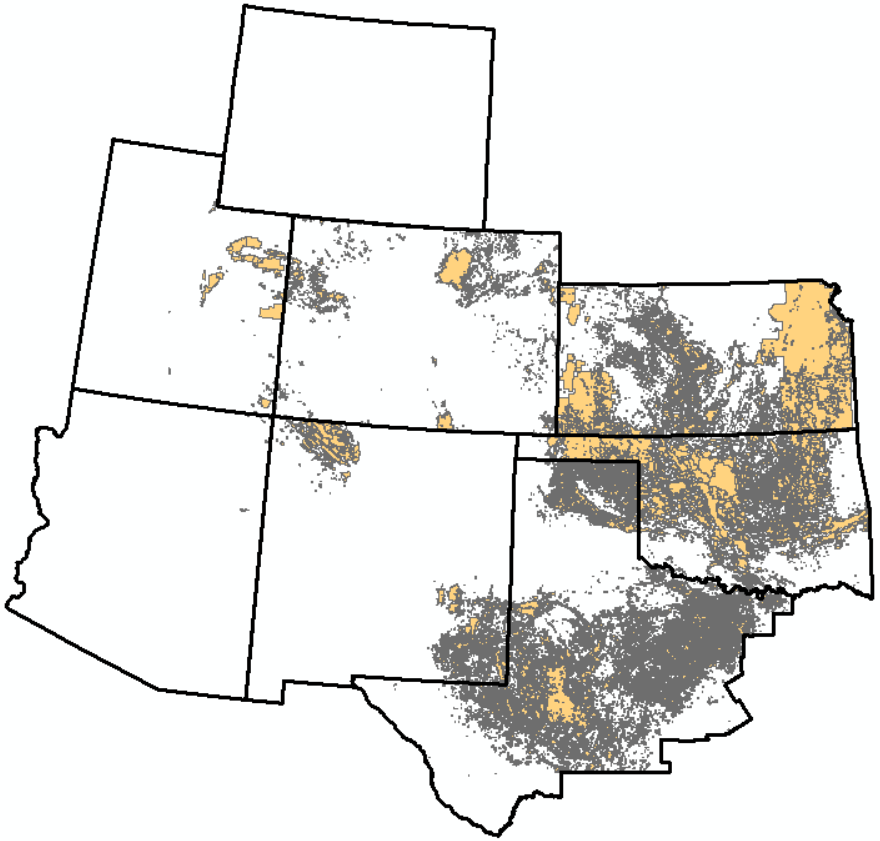


Quantitative Assessment of Capacity, AOR, and Uncertainty

- Regression modeling using modified Monte Carlo Simulations with response surface method

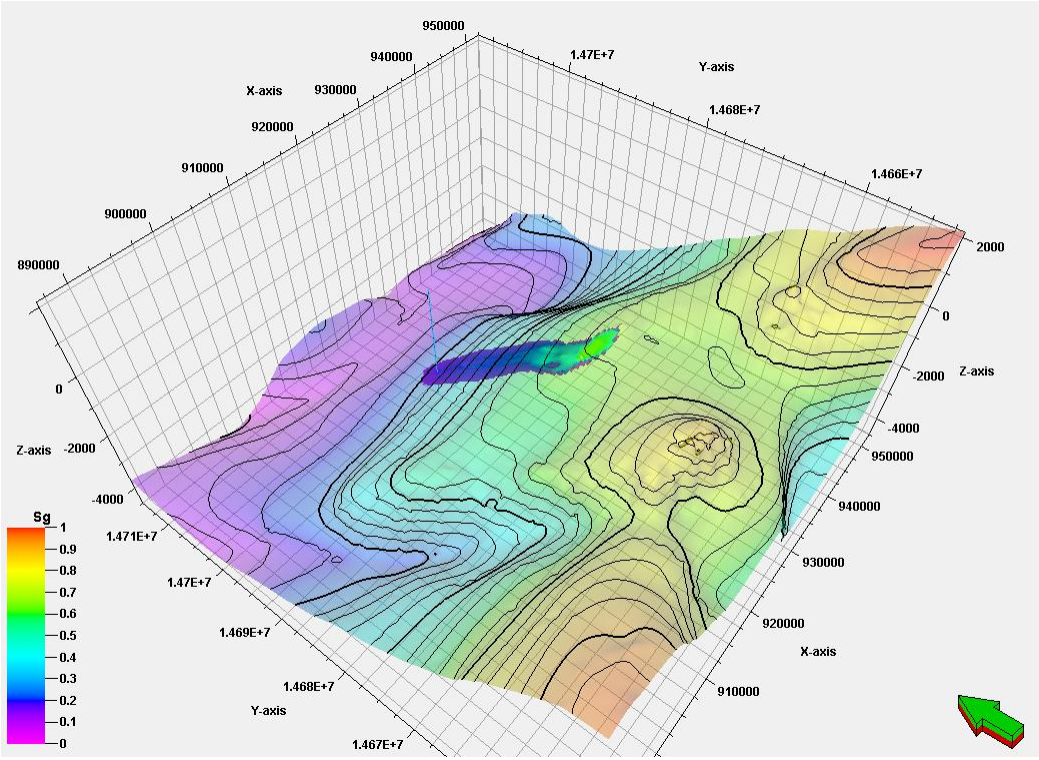
- Commonly referred to as second-order model fit to the data/responses from a specific experimental design

- Higher data density translates to narrowed parameter space and thus reduced uncertainty



Quantitative Assessment of Capacity, AOR, and Uncertainty

Responses (output)



Dependent variables

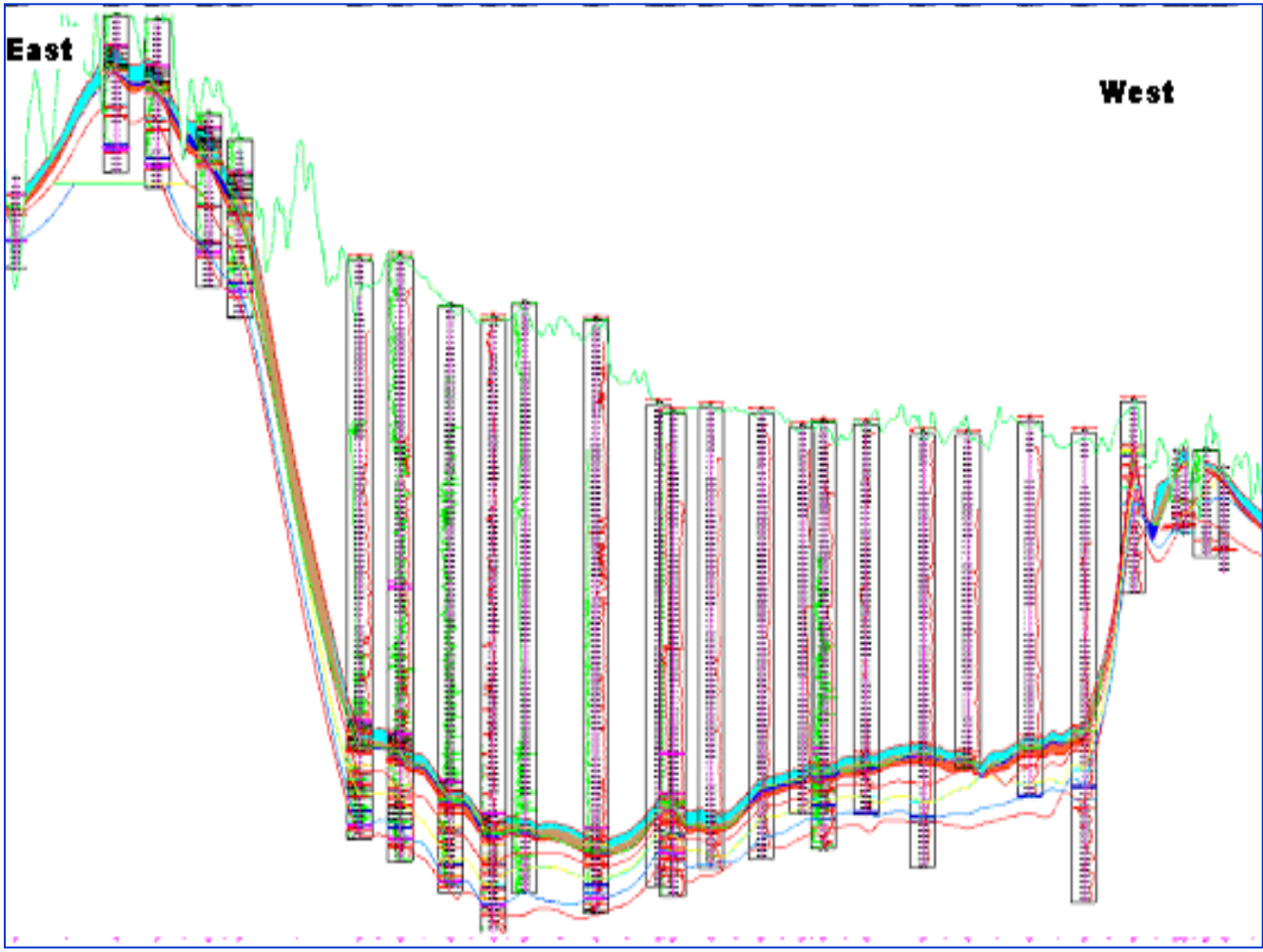
- ***Area of Review***
- ***x-dir 1st moment***
- ***y-dir 1st moment***
- ***Pressure build-up***
- ***storage capacity***

Sand Wash Basin (Craig, CO) AOR Results

Quantitative Assessment of Capacity, AOR, and Uncertainty

Comparison Effort:
Paradox Basin

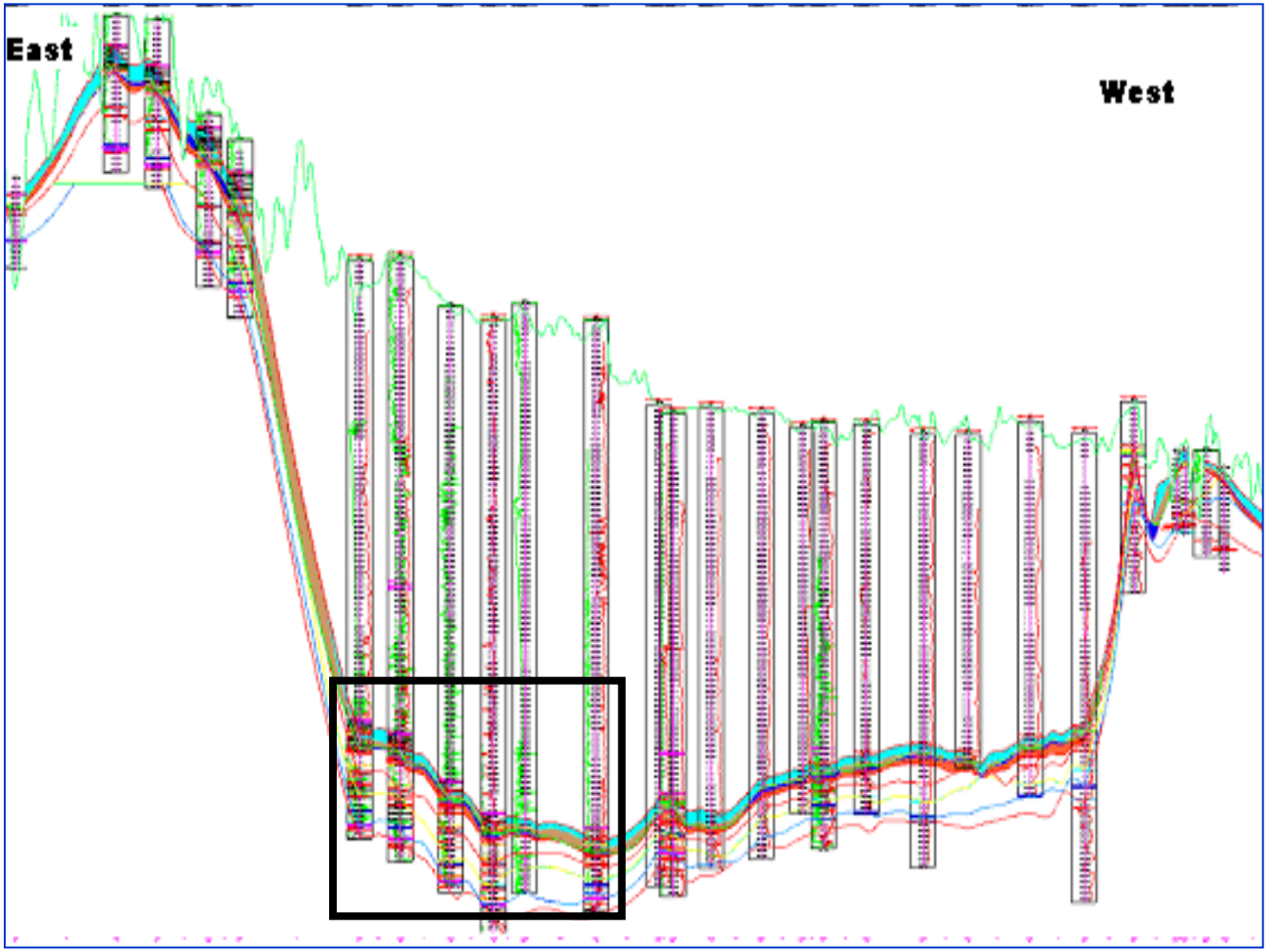
Log-correlation and cross-section development: Paradox



Quantitative Assessment of Capacity, AOR, and Uncertainty

Comparison Effort:
Paradox Basin

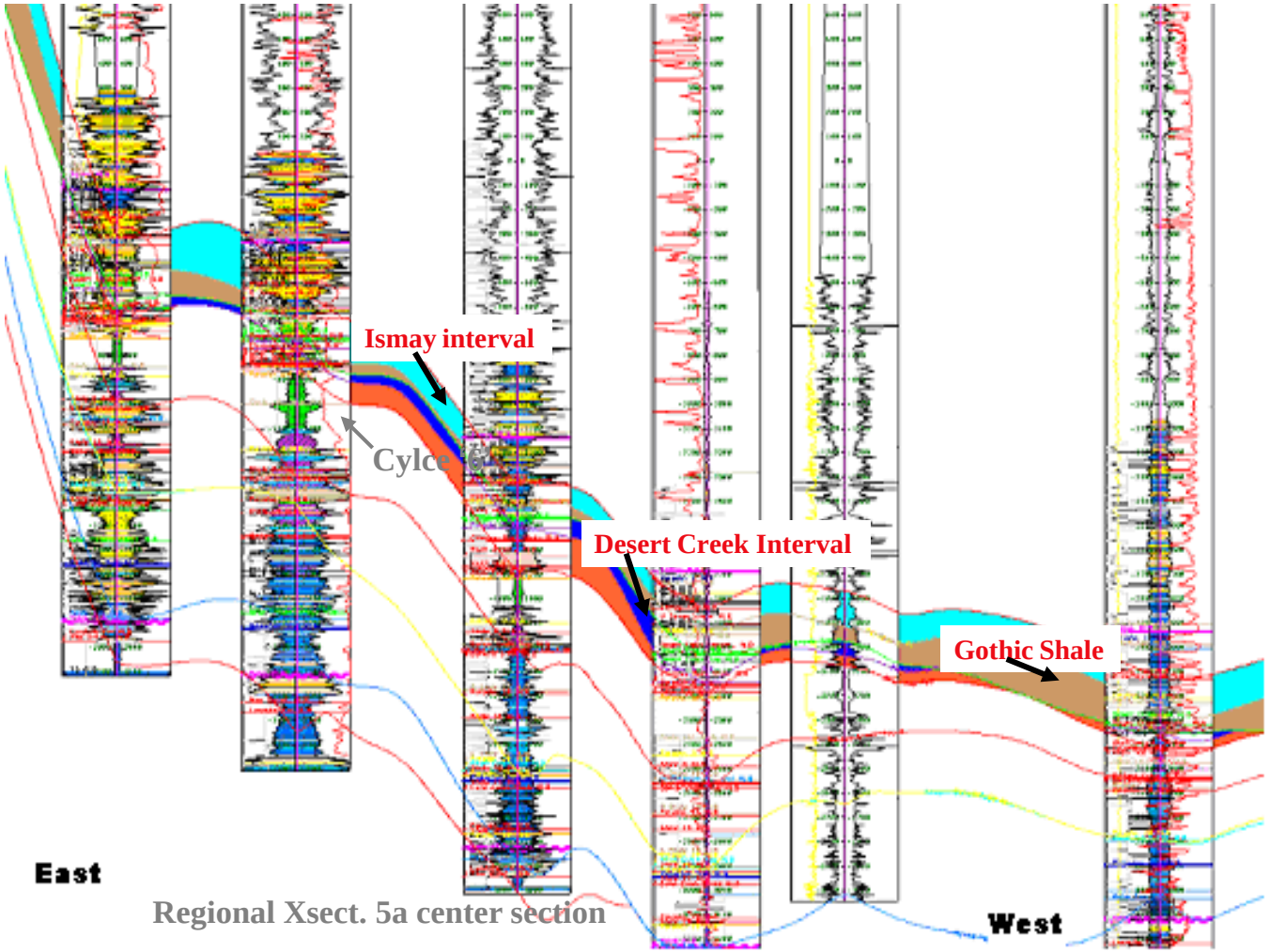
Log-correlation and cross-section development: Paradox



Quantitative Assessment of Capacity, AOR, and Uncertainty

Log-correlation and cross-section development: Paradox
Desert Creek = Sequestration Target Gothic = Primary Seal

Comparison Effort:
Paradox Basin



Regional Xsect. 5a center section

Using Subsurface Log Correlations to Build 3-D Reservoir Models: This may look like a lot of data, but it really is never enough!

Comparison Effort:
Paradox Basin

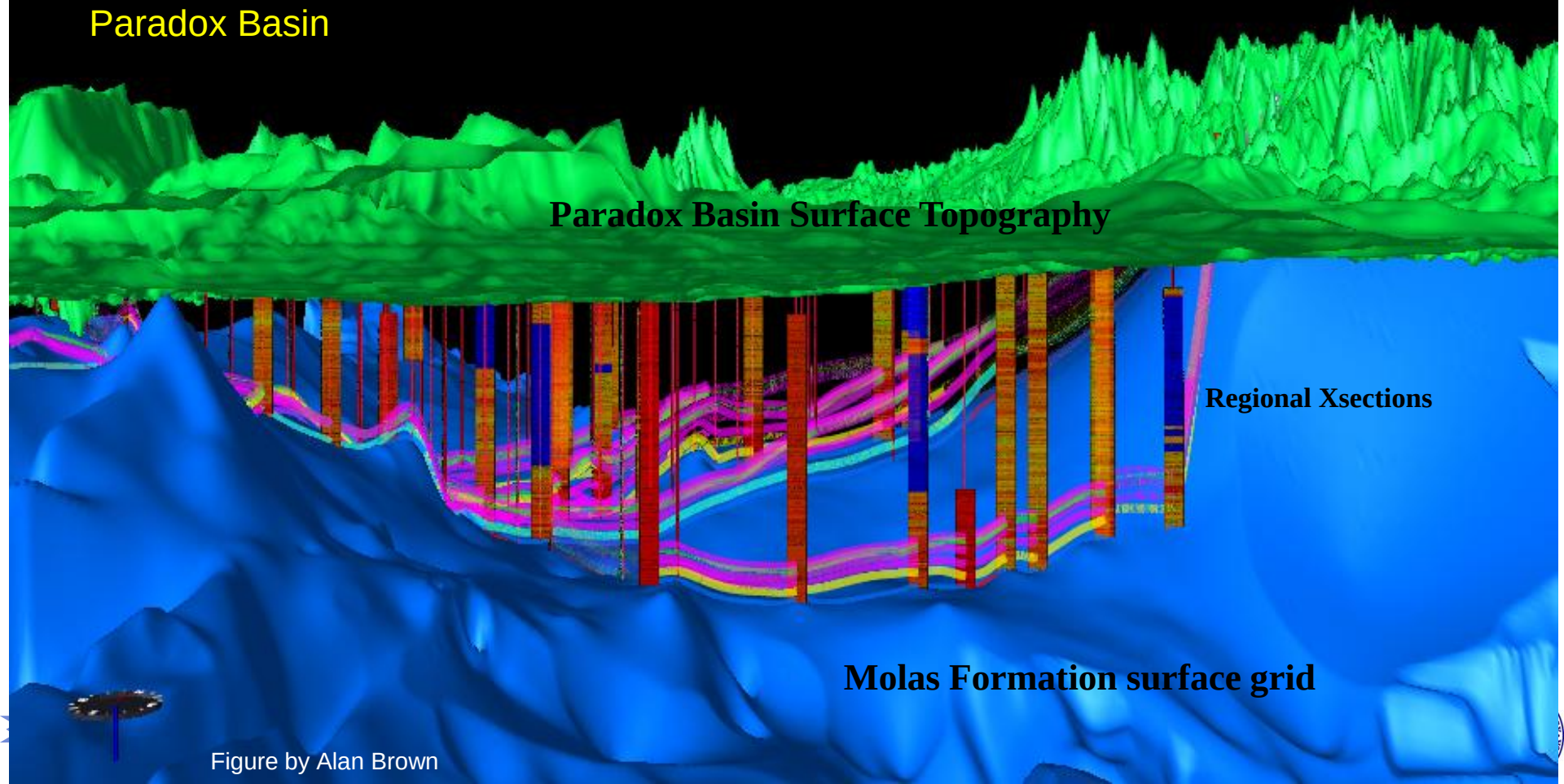


Figure by Alan Brown

Using Subsurface Log Correlations to Build 3-D Reservoir Models: This may look like a lot of data, but it really is never enough!

One new effort is to parameterize this Paradox basin model with hydrologic analysis results of the Sand Wash basin, to assist with evaluation of uncertainty. Specifically, how effective will be extrapolation of local results to other parts of the region? Can we expect predictable degrees of uncertainty?

Molas Formation surface grid

Figure by Alan Brown

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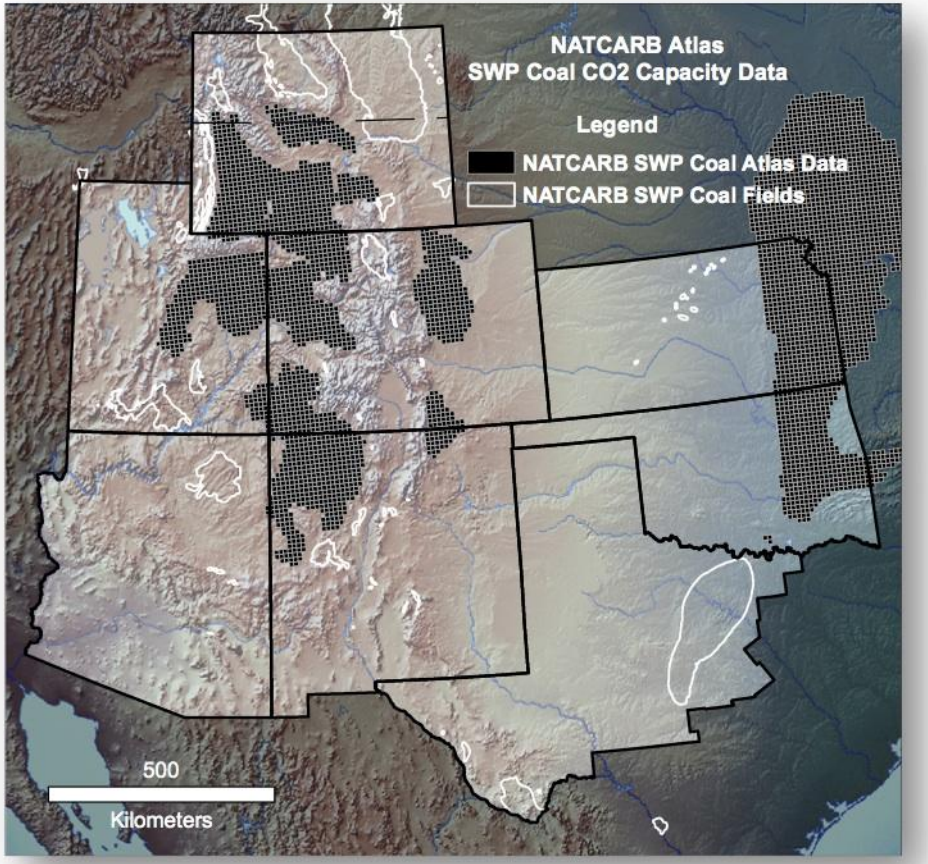
National Atlas Contribution

RMCCS and SWP Regional Coal Layer



Atlas 4 data were reformatted from the Atlas 3 data using the Basins to estimate the CO_2 capacity from:

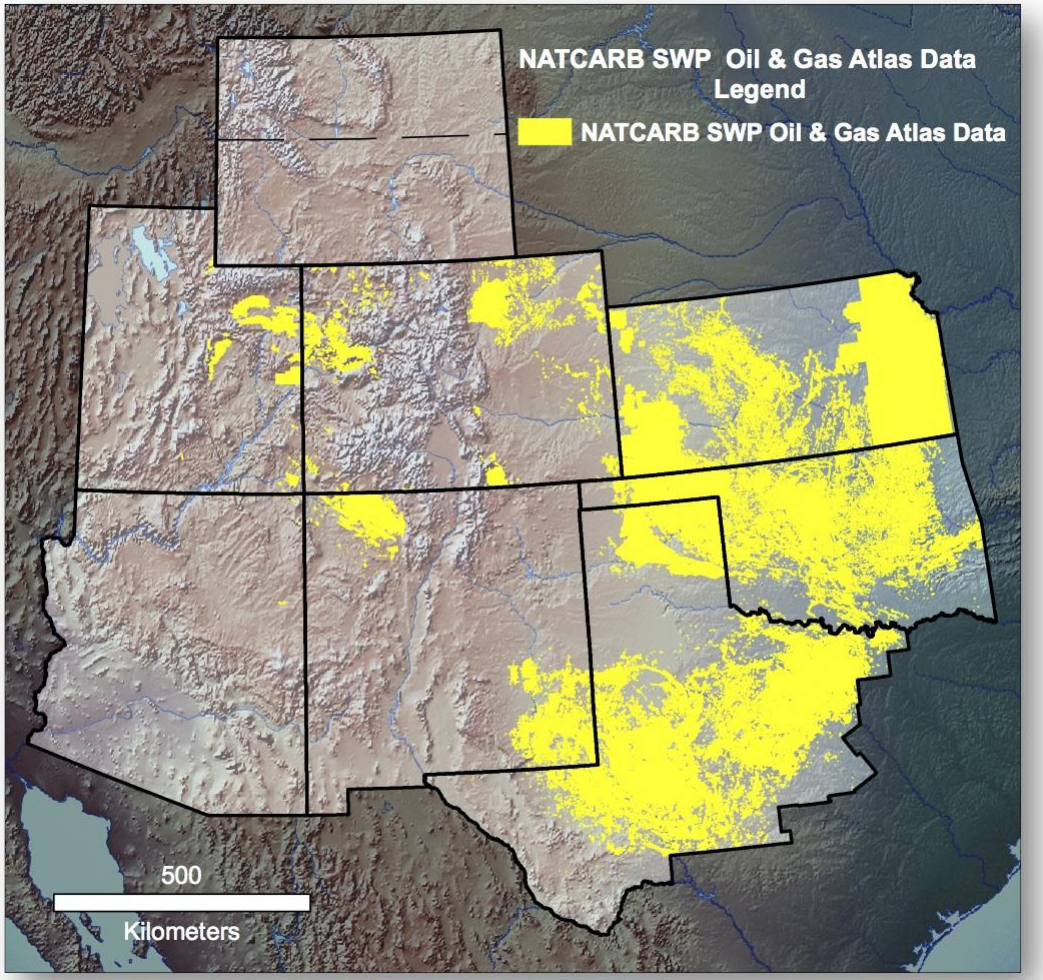
4535 cells (each 10 km^2 by 10km^2)
CO_2 capacity vol-low: 715 million tonnes
CO_2 capacity vol-high: 1.7 billion tonnes

P_Coal_10K_Statistics

RESOURCE_NAME	FREQUENCY	SUM_VOL_LOW	SUM_VOL_HIGH
Arkoma Basin	210	1037014	4148173
Cherokee/Forest City	2083	9056347	36225363
Denver Region	236	427667652	610953917
Green River Region	614	79696072	318784698
Hanna Field	42	30033902	120135589
Raton Mesa Region	79	6000007	24000009
San Juan River Region	604	103999991	415999973
Uinta/Piceance Region	556	43000127	172000158
Wind River Region	111	14000000	55999993

National Atlas Contribution

RMCCS and SWP Oil & Gas Layer



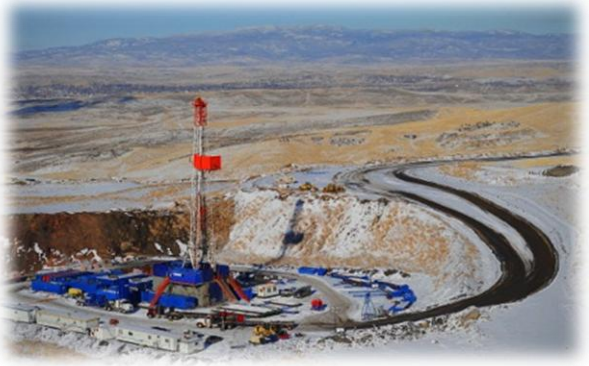
Atlas 4 data were calculated based on historic production data provided by the State Surveys, State agencies and commercial (IHS) data.

Estimated CO2 capacity of all fields in the region exceeds 95 billion tonnes

Summary

- We are characterizing one representative site with everything modern geology and geophysics has to offer.

- We are tackling the rest of region, too, and benchmarking against that site



- We are developing maps of capacity WITH overlays of estimated uncertainty.

- Key deliverables include:
  - characterization of entire region, including methods for local and best methods for extrapolating capacity and other assessments to regional-scale
  - estimates of uncertainty for entire region (and methods for estimating that uncertainty)

Summary

For more information, access:

http://www.rmccs.org

SLB RMCCS State #1
Log Tops Correlated by CGS

Formation Top Name	Formation Top Depth (feet)	Estimated Top Depth (feet)
Trout Creek	1340	
Iles	1593	
Mancos	2726	
Morapos	3763	
Niobrara (Buck Peak)	6266	
Tow Creek	6608	
Base of Wolf Mt.	7131	
Carlisle	7606	
Frontier	7861	
Mowry	8191	
Dakota	8274	
Morrison	8477	
Curtis Shale	8885	
Curtis Sand	8936	
Entrada	9000	
Chinle	9133	
Shinarump Marker (Shale)	9469	
Shinarump Sand	9596	
Moenkopi (?)	9630 to 9686	
Phosphoria	Not Reached	10049
Weber	Not Reached	10239