Geomodelling for Class VI well application: Lessons Learned from the San Juan Basin CarbonSAFE Project

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Outline

- Project Introduction
- Geologic Setting
- UIC Class VI Requirements
- Geologic Modeling & Key Challanges
- Lessons Learned

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Project Introduction

San Juan Basin CarbonSAFE Phase III: Ensuring Safe Subsurface Storage of CO_2 in Saline Reservoirs

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Project Participants

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

UNIVERSITY OF WYOMING

Hilcorp

New Mexico Bureau of Geology and Mineral Resources
NEW MEXICO TECH
Earth Science for the 21st Century

Los Alamos
NATIONAL LABORATORY
EST.1943

TALLGRASS
Leading Energy Solutions

WHEATON

Sandia National Laboratories

THE UNIVERSITY OF UTAH

THE UNIVERSITY OF NEW MEXICO

GEOLEX®
INCORPORATED

Schlumberger

Robert L. Bayless, Producer LLC

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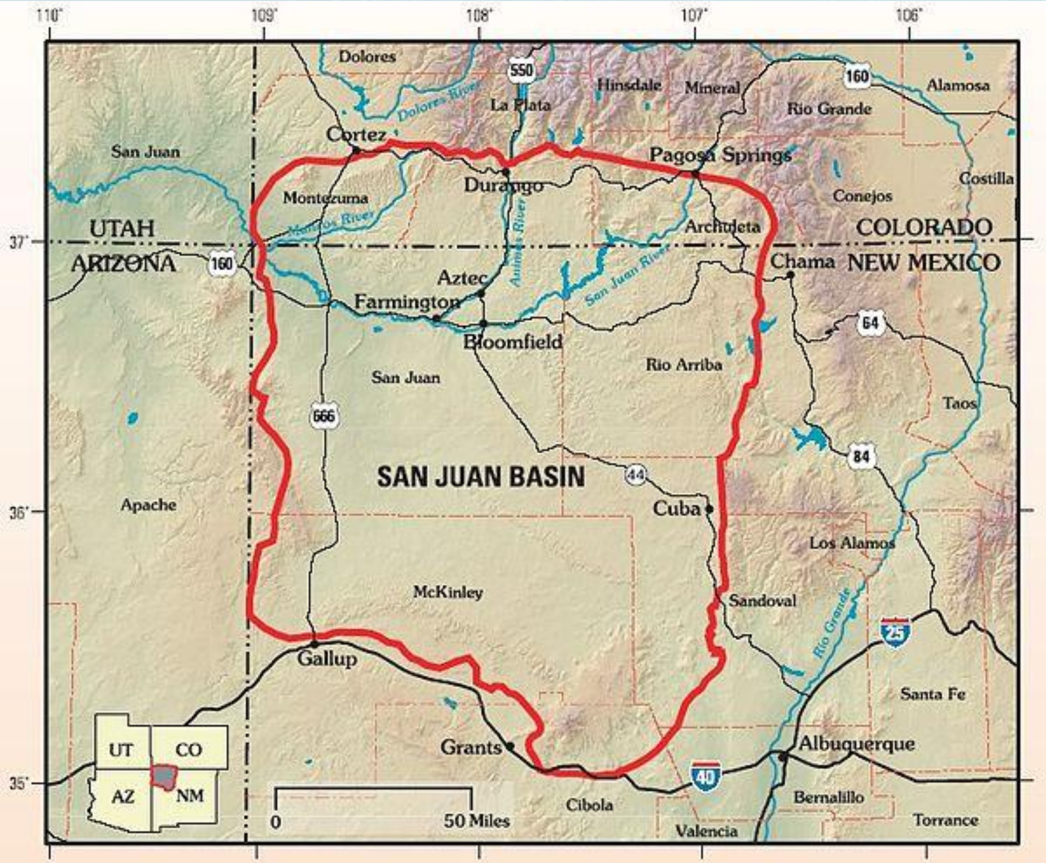
Project Goles



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1. Conduct a comprehensive commercial-scale site characterization to support CCS deployment at the San Juan Generating Station (SJGS)
2. Collect and analyze new and legacy data to develop site-specific datasets for regulatory approval
3. Prepare, submit, and attain a Class VI permit for CO_2 injection and storage of at least 50 million tonnes
4. Utilize simulation models to evaluate storage potential, CO_2 behavior, seal integrity, and induced seismicity risks
5. Complete an Environmental Information Volume (EIV) to address NEPA-related concerns
6. Continue public outreach and education programs to promote awareness of the integrated CCS project

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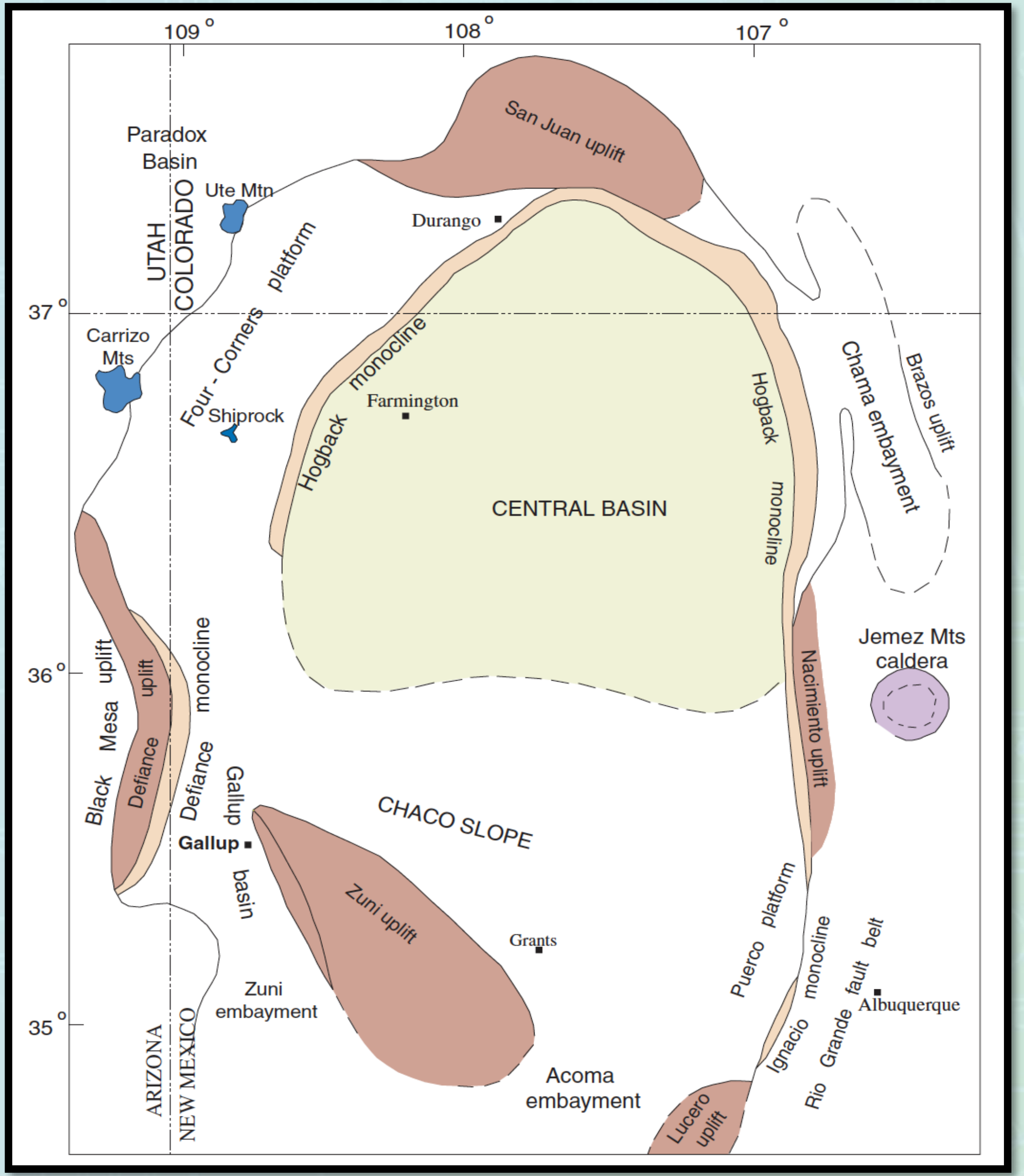
Geologic Setting

San Juan Basin

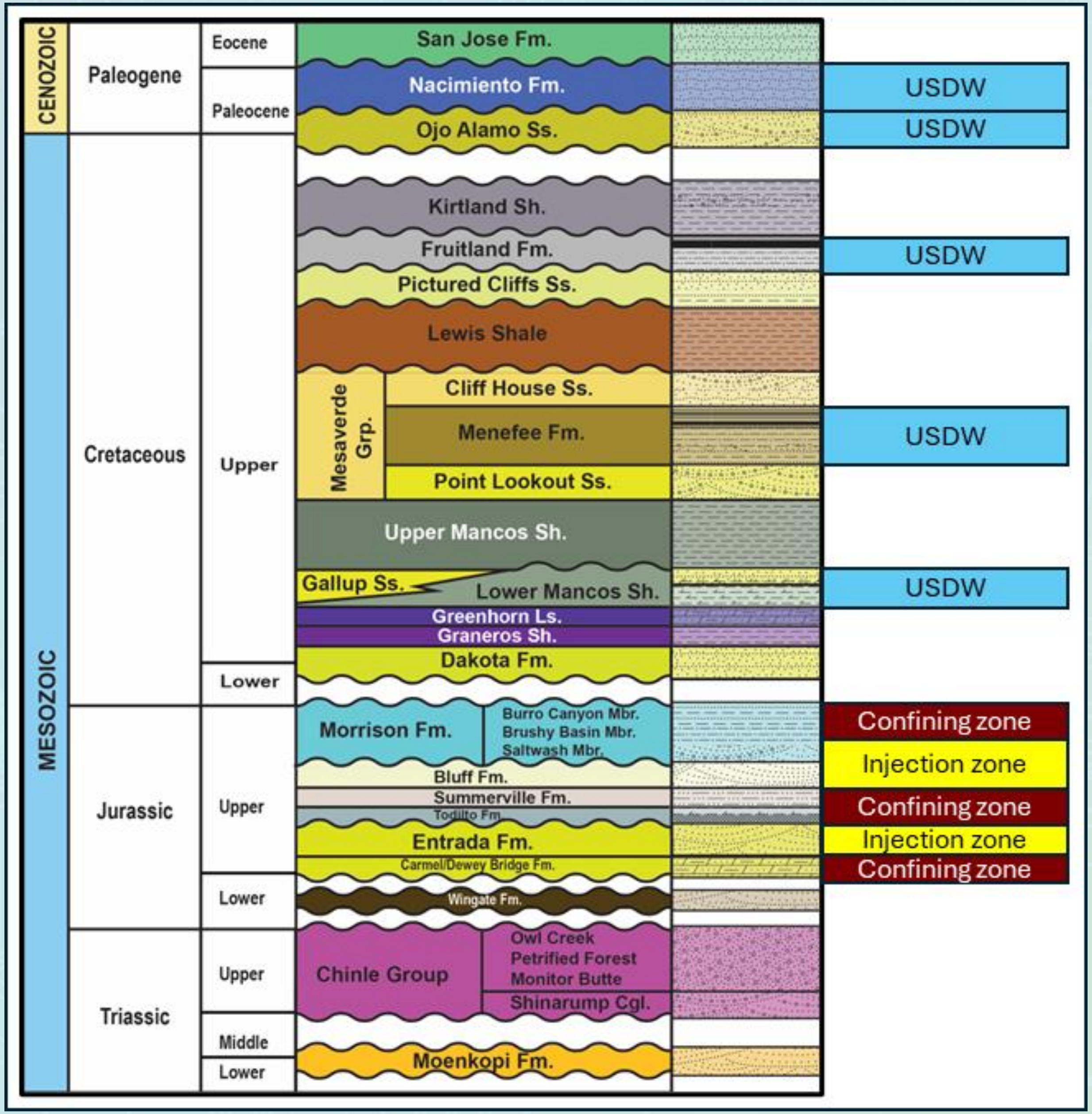
San Juan Basin

- **Asymmetrical foreland structural basin**
- **Formed during the Laramide Orogeny**
- **Surrounded by numerous uplifts**
- **Hogback monocline circles the norther half of the basin**
- **Extensive oil and gas exploration and production**
    - **Over 2,500 wells within 10 miles of proposed site characterization target**
    - **Over 31,000 wells in SJB**
- **Cumulative production (2009)**
    - **42.6 trillion cubic feet of gas**
    - **381 million barrels of oil**

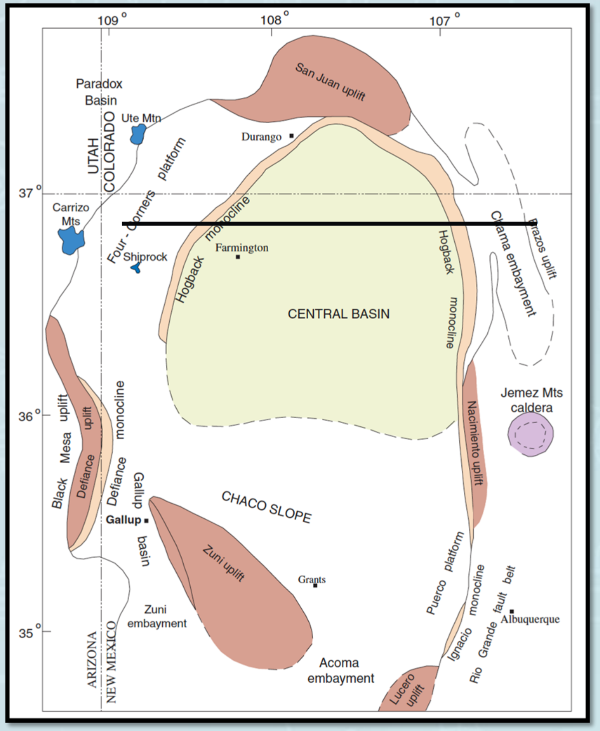


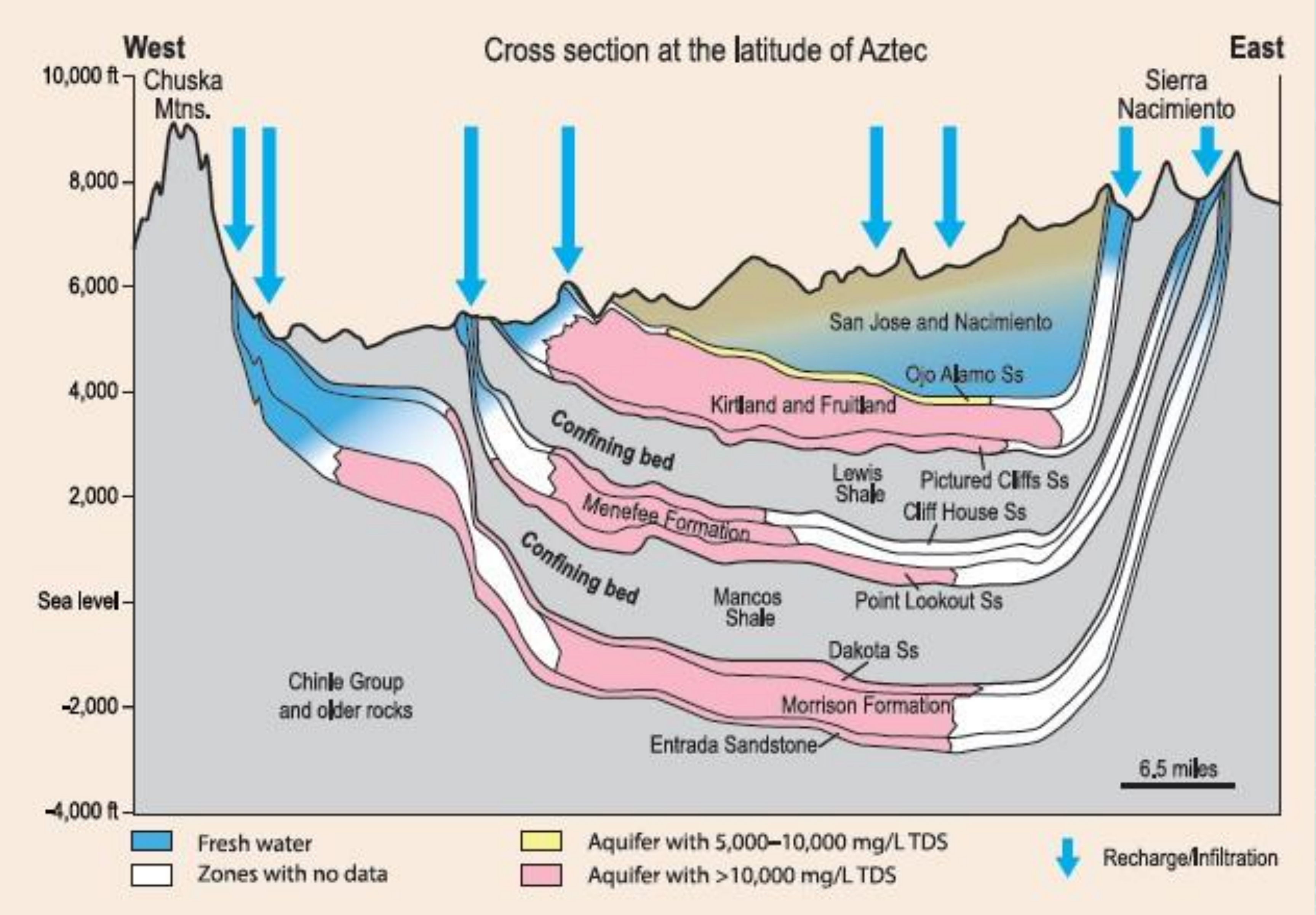
Stratigraphy

1. Reservoir Units
    1. Entrada (primary)
    2. Bluff
    3. Saltwash
2. Sealing Units
    1. Todilto
    2. Summerville
    3. Brushy Basin
3. USDWs
    1. Ojo Alamo
    2. Kirtland
    3. Menefee
    4. Mancos
    5. Morrison (Saltwash)



Aquifers


109°
108°
107°
37°
36°
35°
Paradox Basin
Ute Mtn
Durango
San Juan uplift
UTAH
COLORADO
platform
Carrizo Mts
Four Corners
Shiprock
monocline
Farmington
Hogback
CENTRAL BASIN
Hogback
monocline
Chama embayment
Brazos uplift
Jemez Mts caldera
Nacimiento uplift
Black Mesa
uplift
Defiance uplift
monocline
Defiance
Gallup
Gallup
basin
CHACO SLOPE
Zuni uplift
Grants
Zuni embayment
ARIZONA
NEW MEXICO
Acoma embayment
Puerco platform
monocline
Ignacio
Rio Grande fault belt
Albuquerque
Lucero uplift


West
Cross section at the latitude of Aztec
East
10,000 ft
8,000
6,000
4,000
2,000
Sea level
-2,000
-4,000 ft
Chuska Mtns.
Sierra Nacimiento
San Jose and Nacimiento
Ojo Alamo Ss
Kirtland and Fruitland
Confining bed
Lewis Shale
Pictured Cliffs Ss
Cliff House Ss
Menefee Formation
Confining bed
Mancos Shale
Point Lookout Ss
Dakota Ss
Chinle Group and older rocks
Morrison Formation
Entrada Sandstone
6.5 miles
Fresh water
Zones with no data
Aquifer with 5,000–10,000 mg/L TDS
Aquifer with >10,000 mg/L TDS
Recharge/Infiltration

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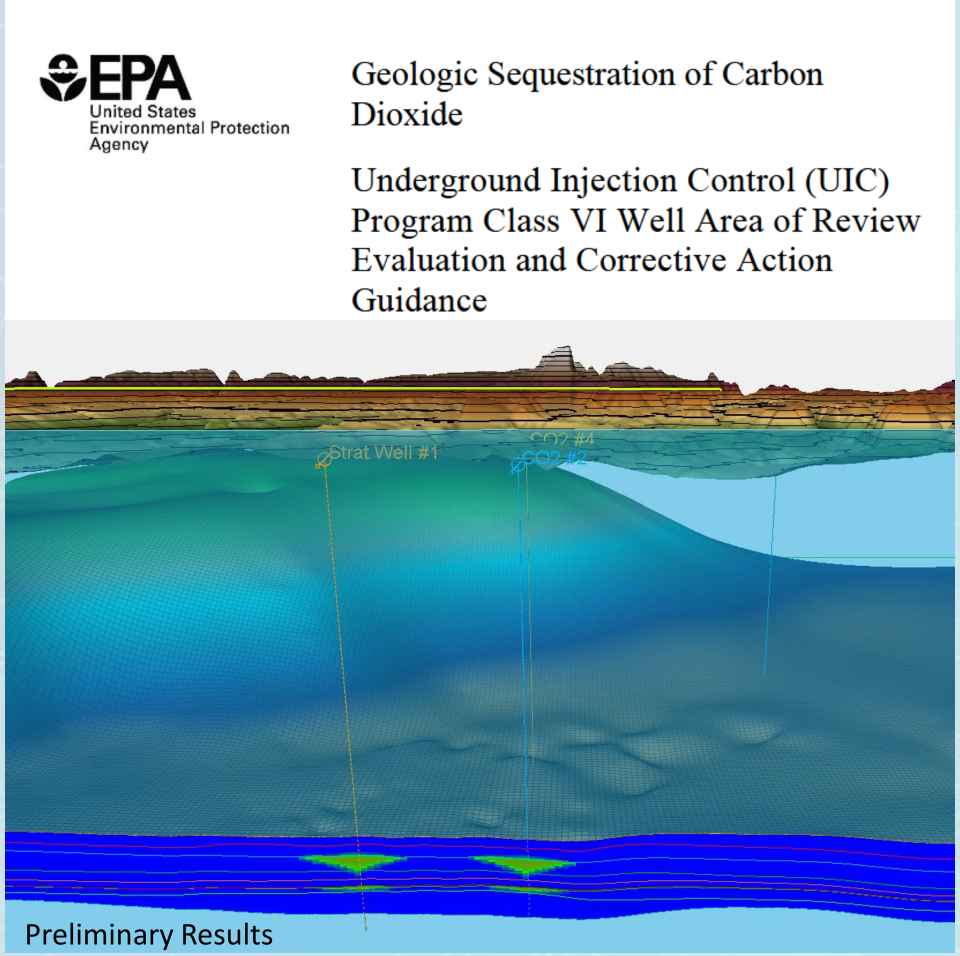
UIC Class VI Requirements

Computational Model Requirements

UIC Class VI Modeling Requirements

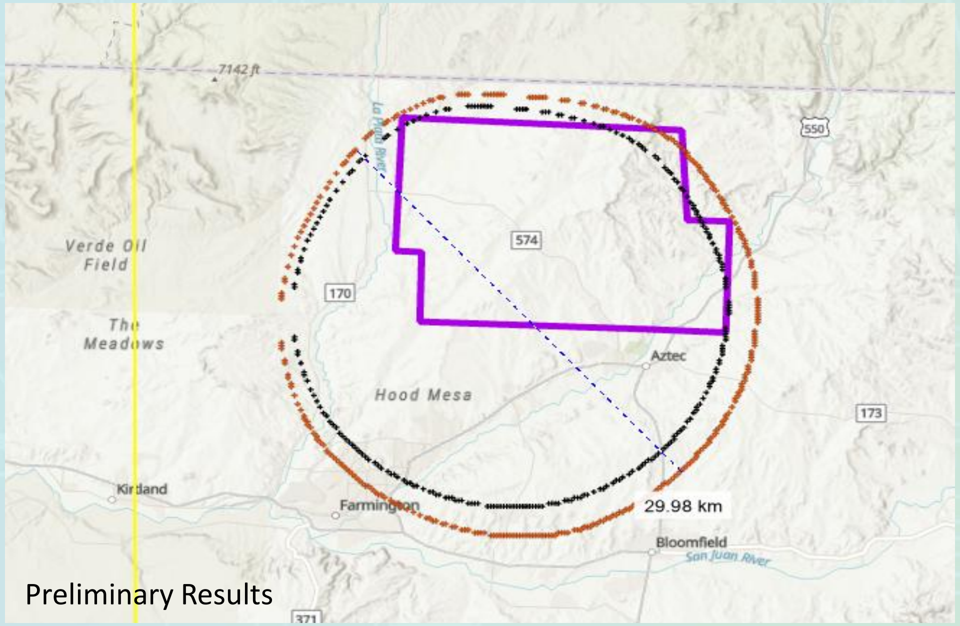


1. **Collection of relevant site characterization data.**
2. **Determination of relevant operational data that will inform the Area of Review (AoR) modeling.**
3. **Development of an AoR and Corrective Action (CN) Plans.**
4. **Performing AoR modeling and delineation of the AoR areal extent.**
5. **Identification and assessment of artificial penetrations within the AoR to assess CO_2 and/or brine leakage into the lower most Underground Source of Drinking Water (USDW).**

UIC Class VI Modeling Requirements

AoR delineation methods

1. **Under-pressured Injection Zones**
   1. **-** $P_{i,f} = P_u + \rho_i g * (z_u - z_i)$
   2. **-** $\Delta P_{if} = P_u + \rho_i g * (z_u - z_i) - P_i$
2. **Hydrostatic Injection Zones**
   1. **-** $\Delta P_c = \frac{1}{2} * g * \xi * (z_u - z_i)^2$
   2. **-** $\xi = \frac{\rho_i - \rho_u}{z_u - z_i}$
3. **Over-pressured Injection Zones**
   1. **Numerical modeling**



Project has over-pressured conditions and used Method 3

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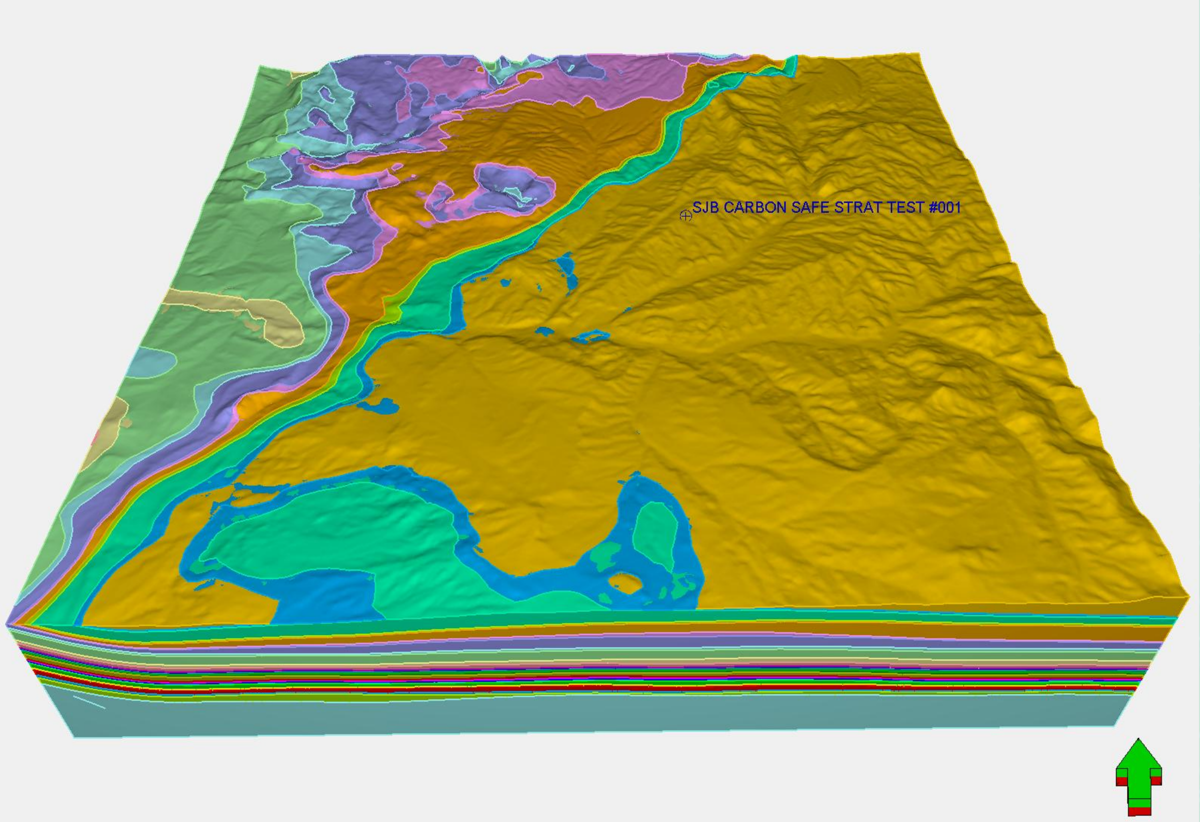
Geologic Modeling

Key Challenges in Developing a Structural and Geologic Model

Modeling Objective

- **Develop structural and geologic model**
  - **Forms the basis of the multi-phase simulation model for AoR modeling**
  - **Delineate USDWs needed for AoR modeling**
- **Incorporates key geologic data**
  - **Well log data and analysis**
  - **Formation tops**
  - **Hogback monocline and near surface faults**
  - **USDW data**



Key Challenges

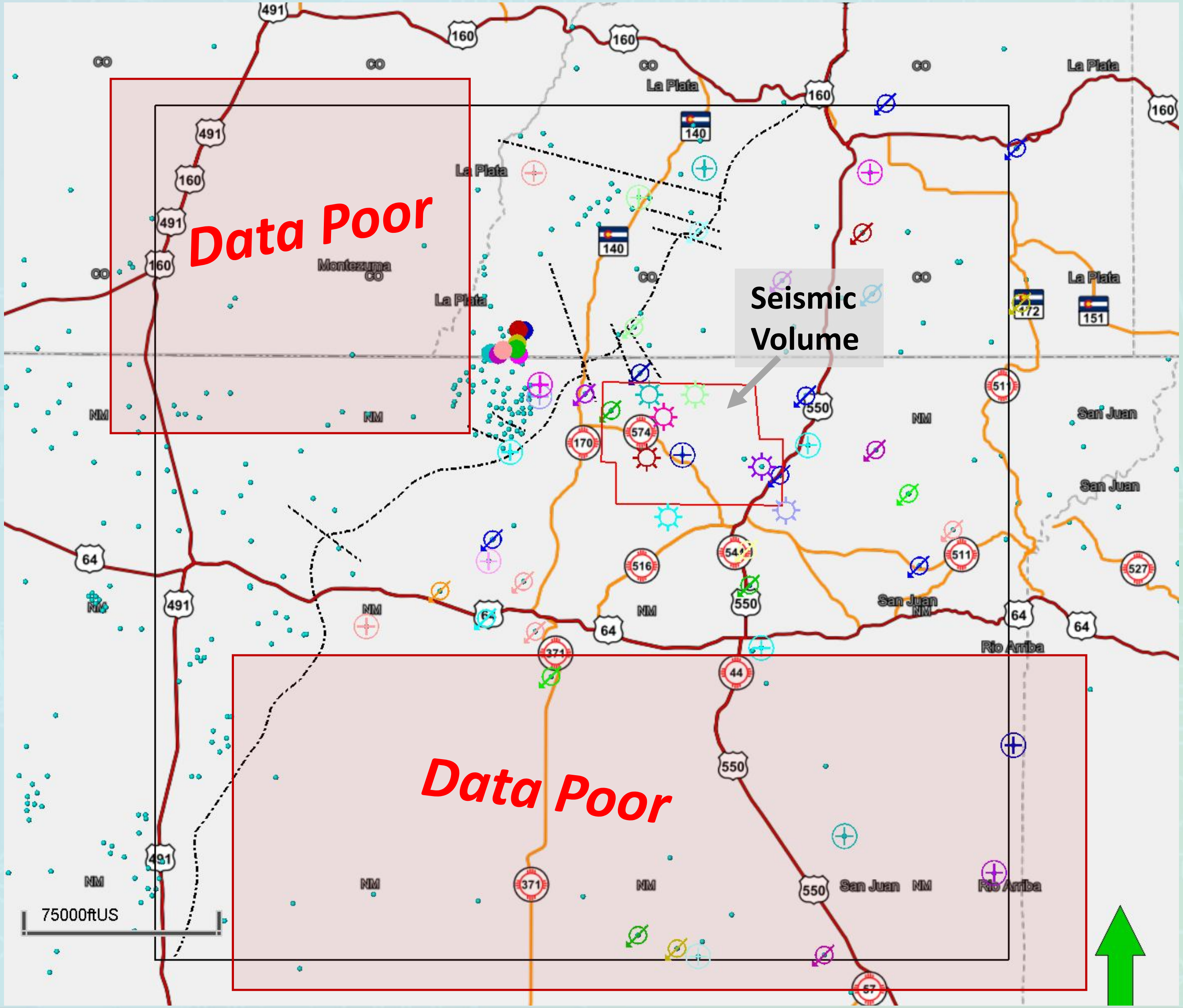
Well logs and formation tops

- 2,349 wells with 26,934 formation tops
  - 1070 Dakota tops
  - 220 Entrada tops
  - 148 Honaker Trail tops
- 3,673 sqmi area model domain
  - (60.6 miles x 60.6 miles)
- Sparce data in key areas

Hogback and fault modeling

- No seismic to help resolve these features

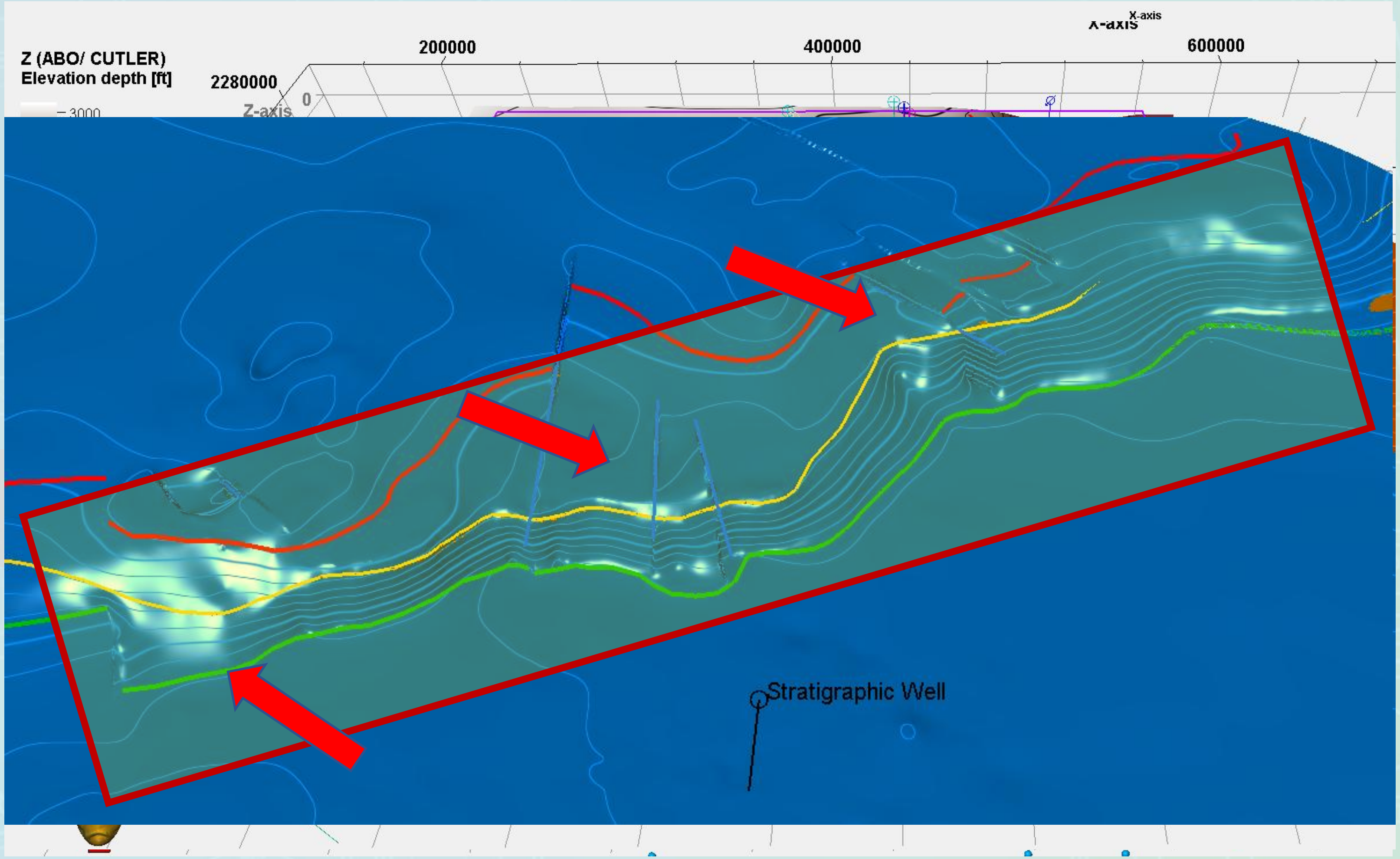
Number of wells	
2349	Wells with formation tops
1977 / 1070	Wells with Dakota formation tops
601 / 220	Wells with Entrada formation tops
319 / 148	Wells with Honaker Trail formation tops
69	Wells with porosity logs (DPHI and/or NPHI)
23	Wells with Gamma Ray + Permeability + Porosity so vClay and sand facies could be estimated



Key Challenges

Surface generation

- Formation tops need extensive QC
- Required both repicking by geologic team and recontouring by modeling team to identify and fix all outliers
- Geometry of the Hogback monocline
- Basement fault offset up to Honaker Trail
- Abo/Cutler to the surface drape over monocline
- Hand editing of surfaces to address formation overtopping



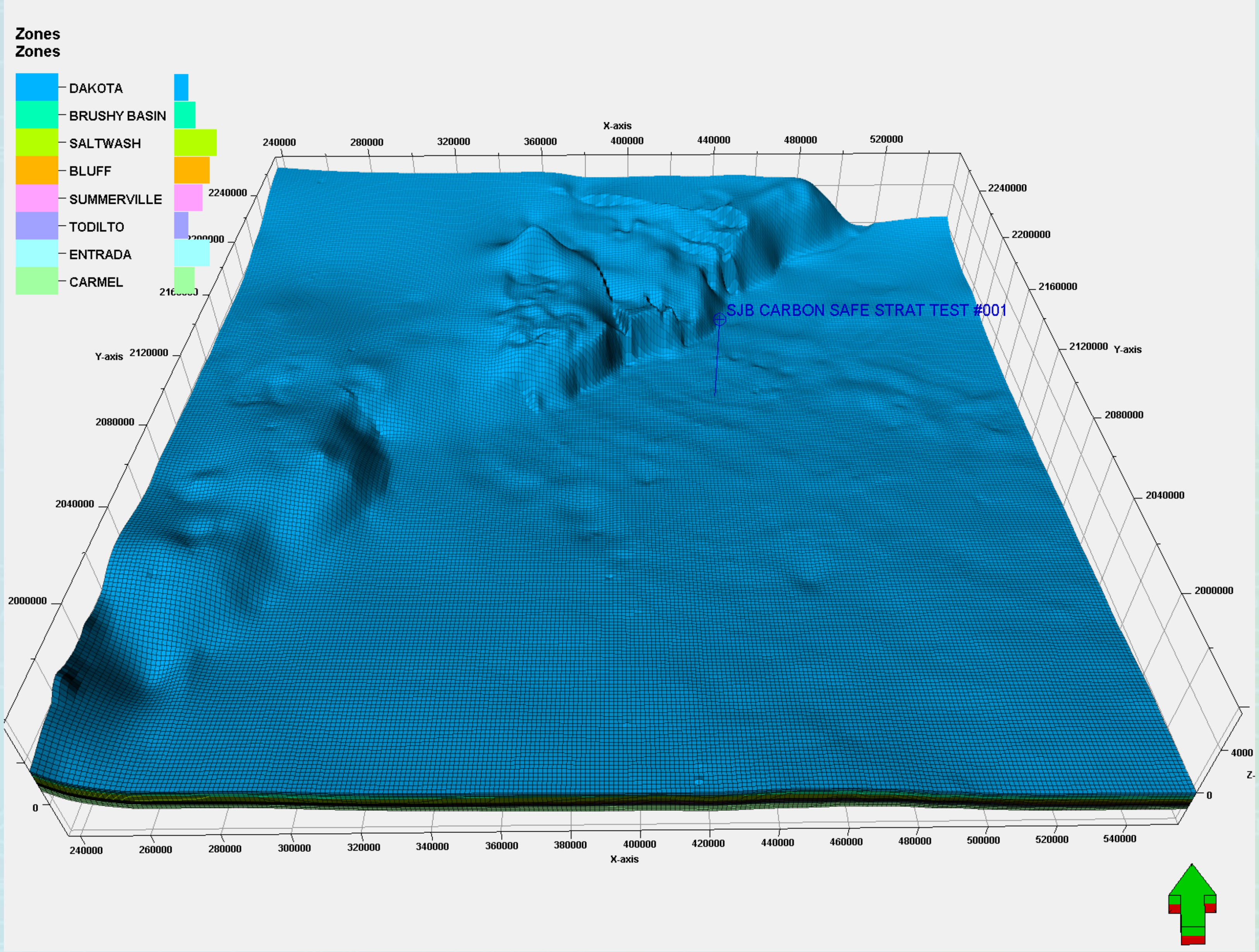
Key Challenges

Gridding and property population

- Structural model is from Abo/Cutler to Surface only
    - Unable to build full geomodel – surface to basement
    - Geometry between Honaker Trail and Abo/Cutler caused errors

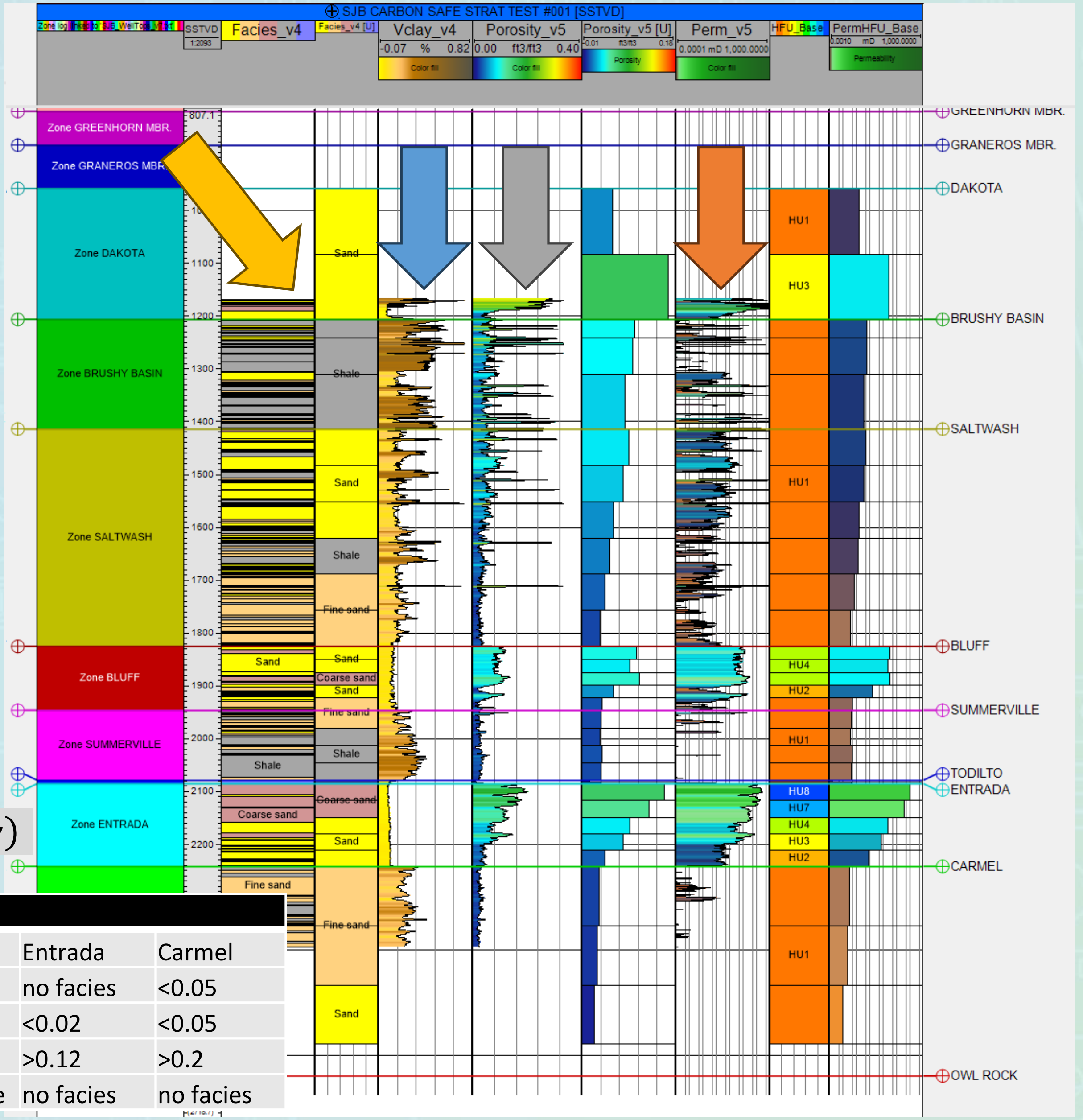
Version 7.1 – simulation grid

- 60.25 x 60.5 mile^2
- 1320ft x 1320ft cells
- 241 x 242 x 30
- 1,749,660 active cells



Key Challenges

- **Limited wells with logs for sand facies modeling**
  - **23 key wells with Vclay, Porosity, and Permeability well logs**
- **Winland R35 method to calculate logR35 values for permeability distribution**
  - **69 wells with Porosity**
  - **42 wells with Porosity and Permeability**
- **Upscaled Sand Facies, Porosity, and logR35 to simulation grid**



$$LogR35 = 0.732 + (0.588 * \log Permeability) - (0.864 * \log Porosity)$$

	Porosity Cut-off							
Facies Cut-offs	Dakota	Brushy Basin	Salt Wash	Bluff	Summerville	Todilto	Entrada	Carmel
Shale: >20% Vclay	no facies	<0.04	<0.02	no facies	<0.04	no facies	no facies	<0.05
Sand: <0.1mD	<0.03	<0.04	<0.02	<0.02	<0.04	no facies	<0.02	<0.05
Sand: >10mD	>0.1	>0.13	>0.09	<0.09	>0.10	no facies	>0.12	>0.2
Limestone:	no facies	no facies	no facies	no facies	no facies	100% limestone	no facies	no facies

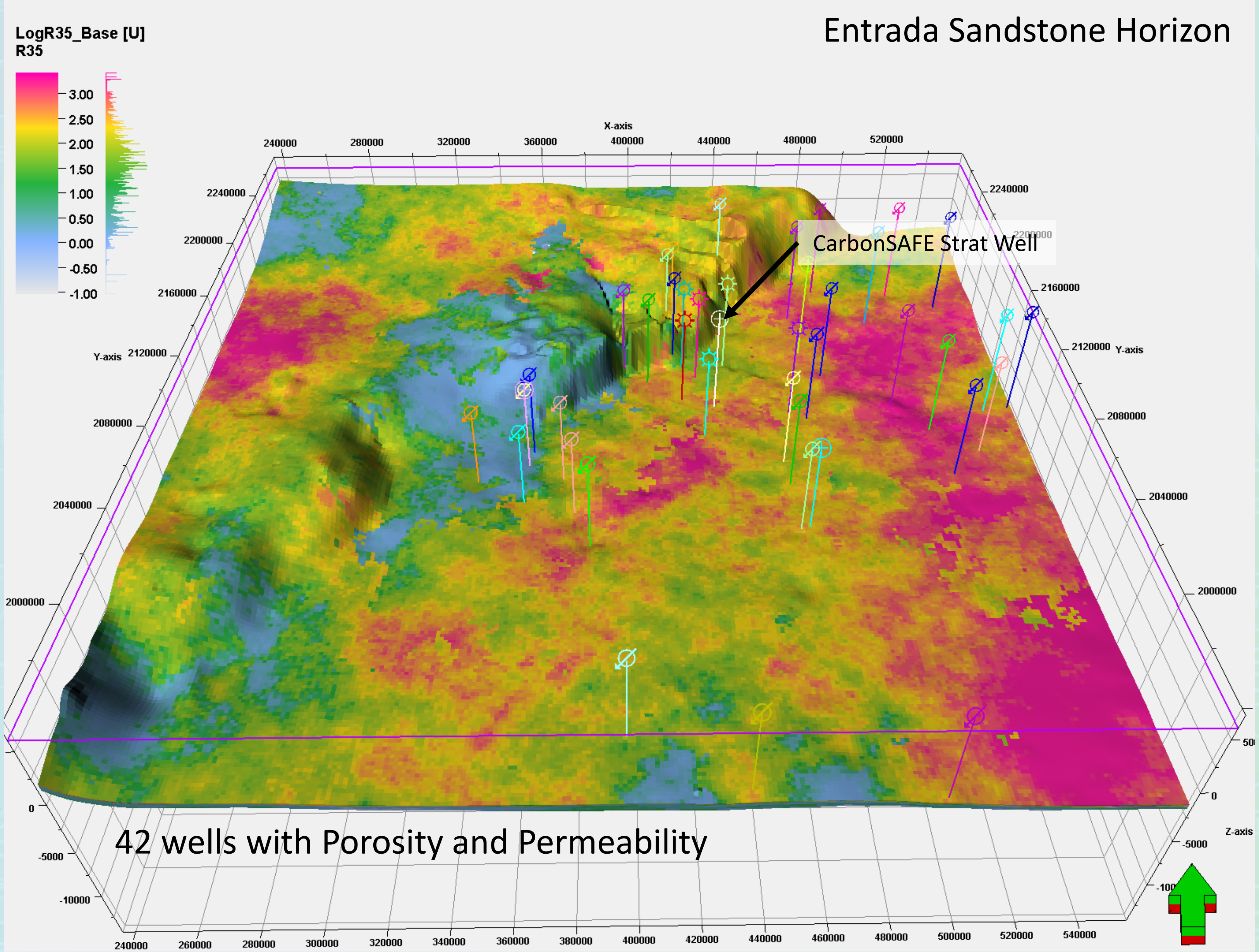
Key Challenges

Modeled each facies using sequential indicator simulation algorithm in Petrel

- **Same variogram for all facies in each formation**
- **Geology team provided variogram information for each of the eight formation**

Sequential Gaussian Simulation to populate properties based on facies

- **Porosity**
- **LogR35**



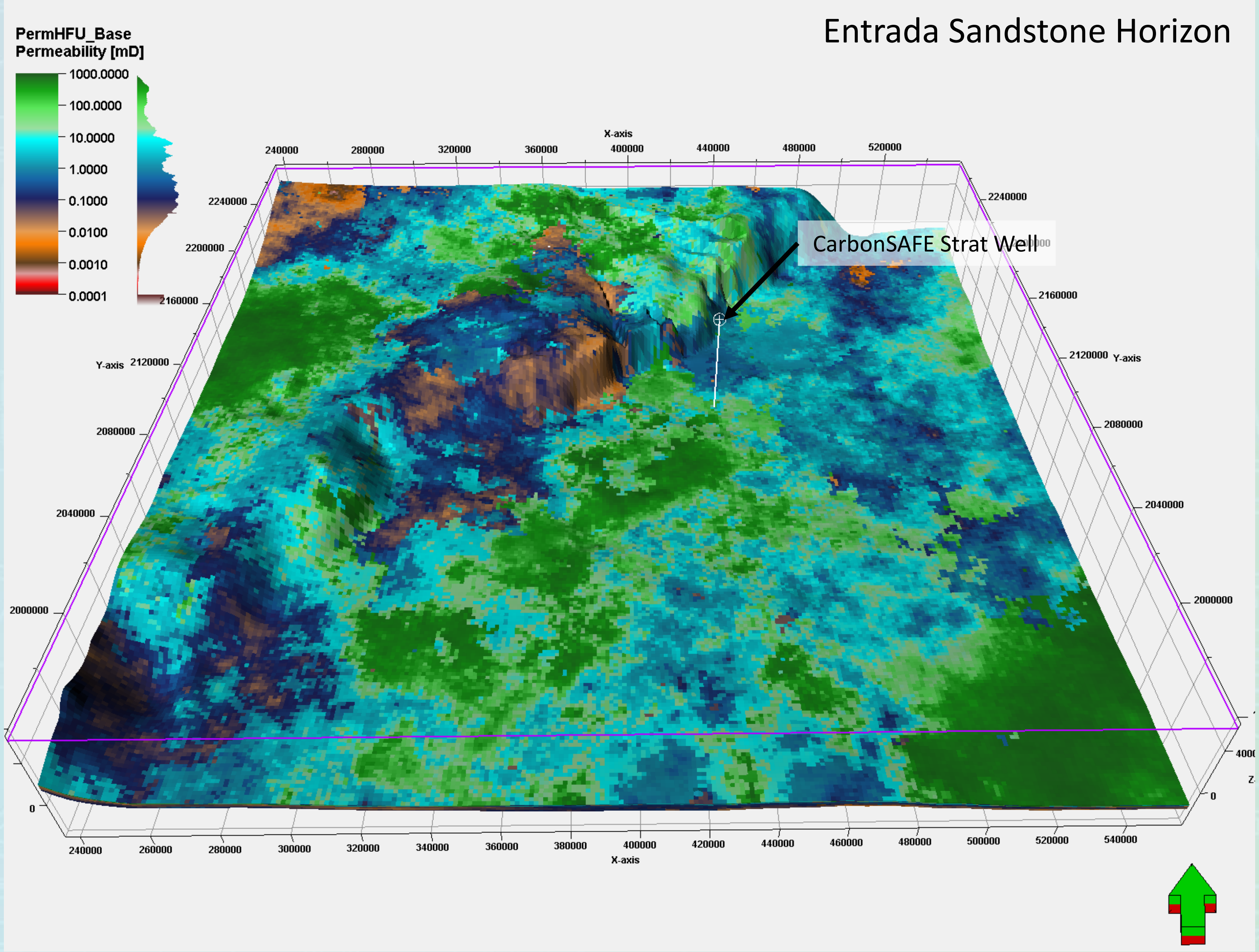
Key Challenges

Delineate Hydraulic Units (8)

Permeability calculated for each HU co-kriged to porosity

$$logk[HU\ 1\ to\ 8] = \ a * POR^{b})$$

Hydraulic Unit	logR35	a	b
1	<1.55	25.122	1.9588
2	1.55 to 1.75	41.162	1.4946
3	1.75 to 2	81.401	1.4261
4	2 to 2.2	242.11	1.5534
5	2.2 to 2.3	460.81	1.5253
6	2.3 to 2.4	5288	2.3572
7	2.4 to 2.5	19206	2.7603
8	>2.5	39183	3.0282



Key Challenges
USDW delineation

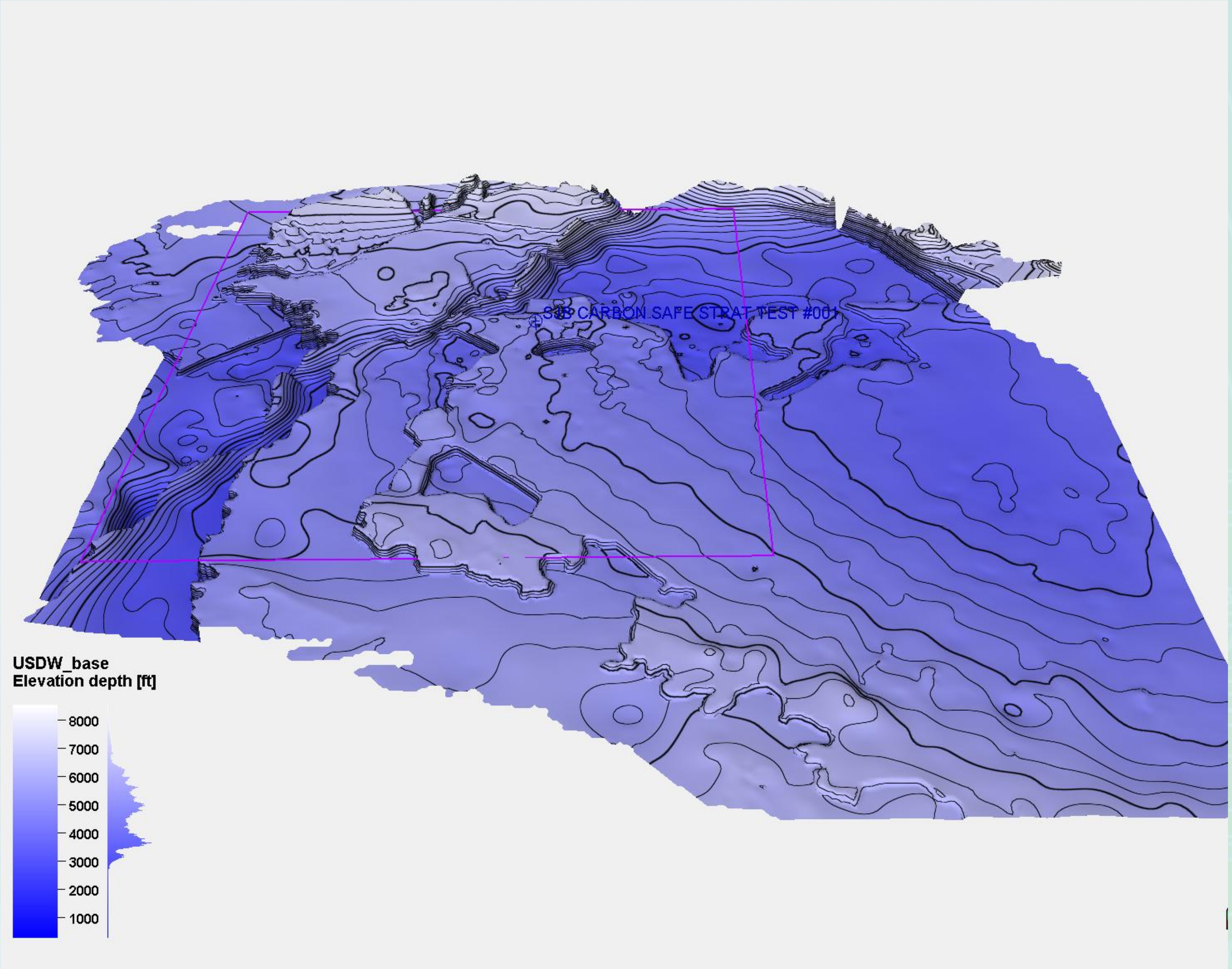
Identify the lower most USDW across complex geology of the basin

- **<10,000 ppm TDS**

Identified 221 wells with USDW elevations

Identified 5 different formations containing a USDW

- **Ojo Alamo**
- **Kirtland**
- **Menefee**
- **Mancos**
- **Salt Wash Member of the Morrison**



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Lessons Learned

Recommendations for Future Class VI Projects

Lessons Learned

1. **Early collaboration across teams reduces redundant work**
2. Gather and QC formation top data for all wells that penetrate the sealing and injection zones before the modeling process starts.
3. Acquire as much seismic data as possible and process and interpret before the geomodelling process starts.
    a. Formation tops cannot identify faults beyond giving an idea that there is some feature between wells
4. Design the regional geological model as large as practically possible
    a. avoid expanding model after initial sims
    b. allow project to explore different injection sites without having to rebuild the model
5. Acquire all digital wells logs across the area of interest and digitize legacy logs as needed.
    a. Key control for property population algorithms without making large assumptions.
    b. Gather logs outside of the model domain area, can add additional information for areas without sufficient well log coverage.
    c. Do as much advanced well log analysis as budget allows, ie ELAN
6. Build the model using a defined workflow, workflow editor in Petrel proved invaluable for updated model with new data
7. Computational hardware may limit model size and complexity of model

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Questions