Subsurface Seismic Structural Characterization of the Hogback Monocline and Thermal Characterization of the San Juan Basin, New Mexico

Regional Initiative to Accelerate Carbon Capture, Utilization, and Storage (CCUS)
Deployment: Technical Assistance for Large-Scale Storage Facilities and Regional Carbon
Management Hubs (AOI-2)

DE-FOA-0002799

Luke Martin (PI)

08/09/2024

New Mexico Tech
Petroleum Recovery Research Center

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
Earth Science for the 21st Century

Divisions of New Mexico Institute of Mining and Technology

New Mexico Tech

Project Participants

- New Mexico Bureau of Geology and Mineral Resources
  - Luke Martin (PI)
  - Dr. Nelia Dunbar
  - Dr. Martin Reyes Correa
  - Dr. Shari Kelley
  - Cynthia Connolly
- Petroleum Research and Recovery Center
  - Dr. Adewale Amosu (Co-PI)
  - Dr. Sai Wang (Co-PI)
  - Dr. William Ampomah
  - Dr. Dana Ulmer-Scholle
  - George El-kaseeh
  - Jean-Lucien Fonquergne

Divisions of New Mexico Institute of Mining and Technology

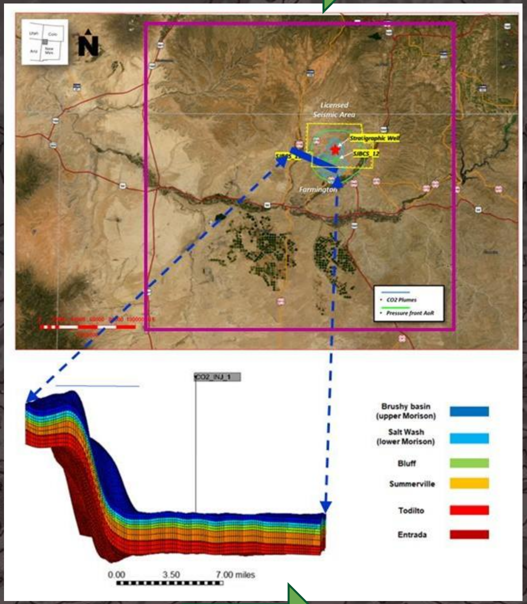
Project Objectives/ DOE Goals

- Project active 12/1/2023 - 11/2025
- DOE funds = $906,965, Cost Share = $273,885
- Enhance geological data gathering, analysis, and sharing in the San Juan Basin of the Four Corners area
- Fill the subsurface knowledge gaps to enable deployment of carbon management activities
- Complement ongoing and future DOE projects on carbon management in the San Juan Basin, and the Four Corners region
- Accelerate deployment of Carbon Capture Utilization and Storage (CCUS)
- Community Engagement

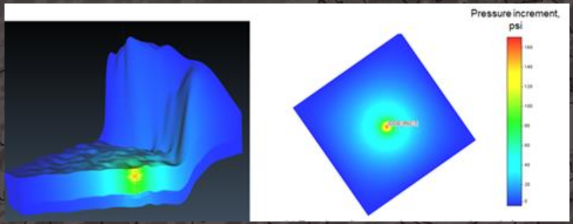
Structural Characterization

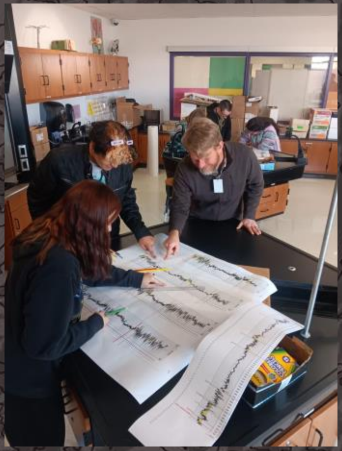
Thermal Characterization

Improved Basin Model



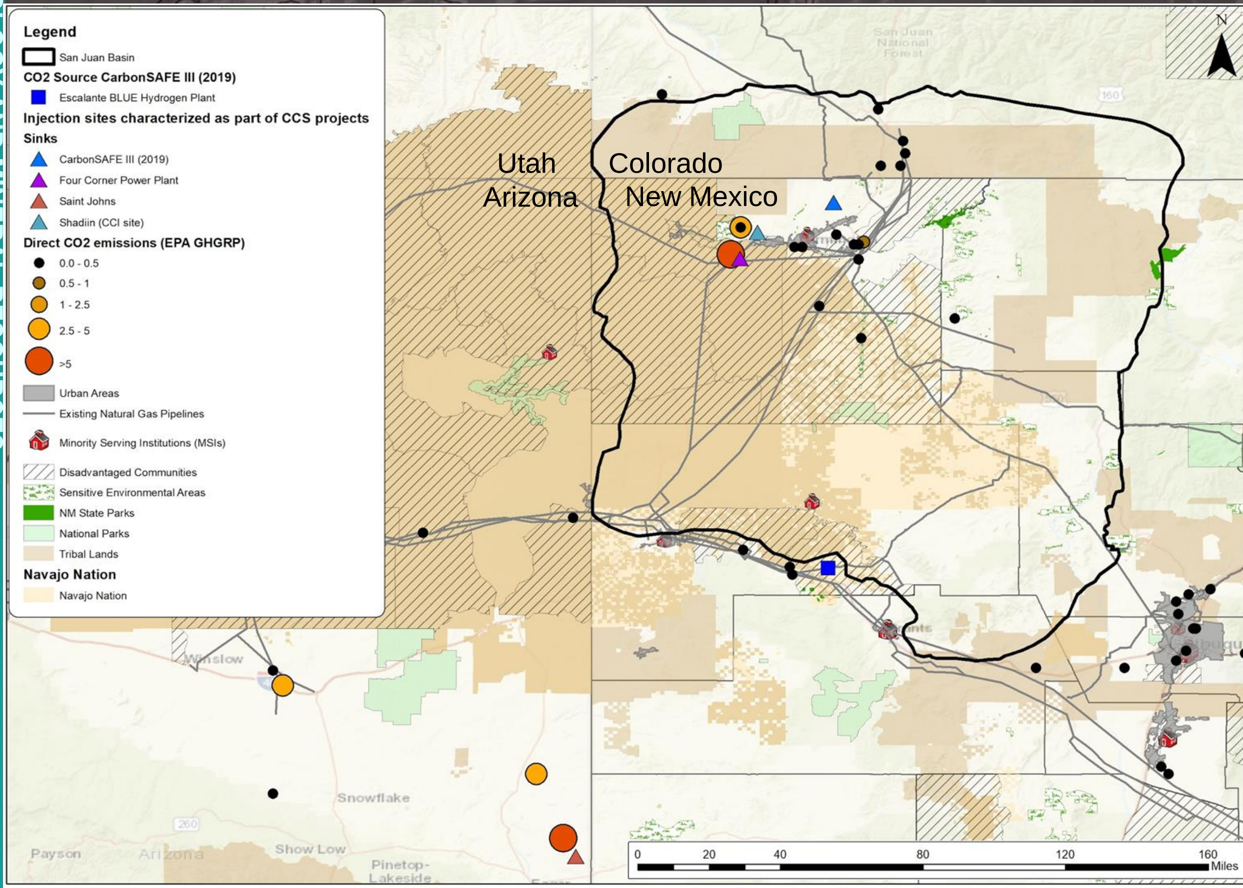
Improved Resource Assessment & Outreach

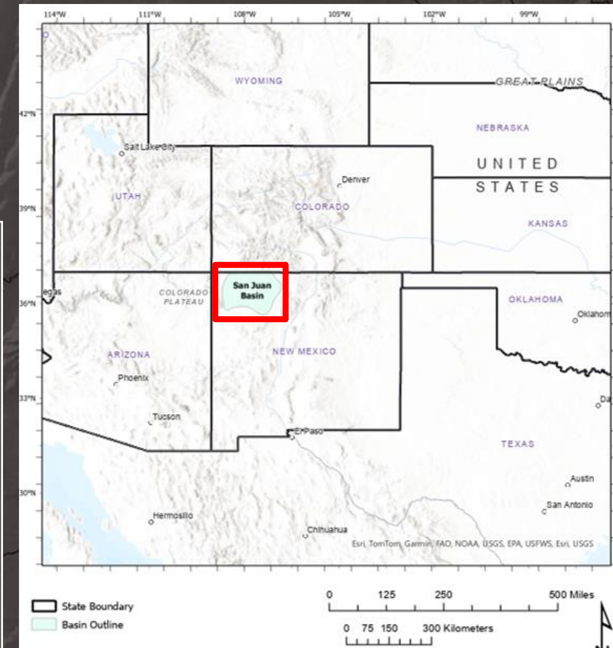




BUREAU OF GEOLOGY AND MINERAL RESOURCES

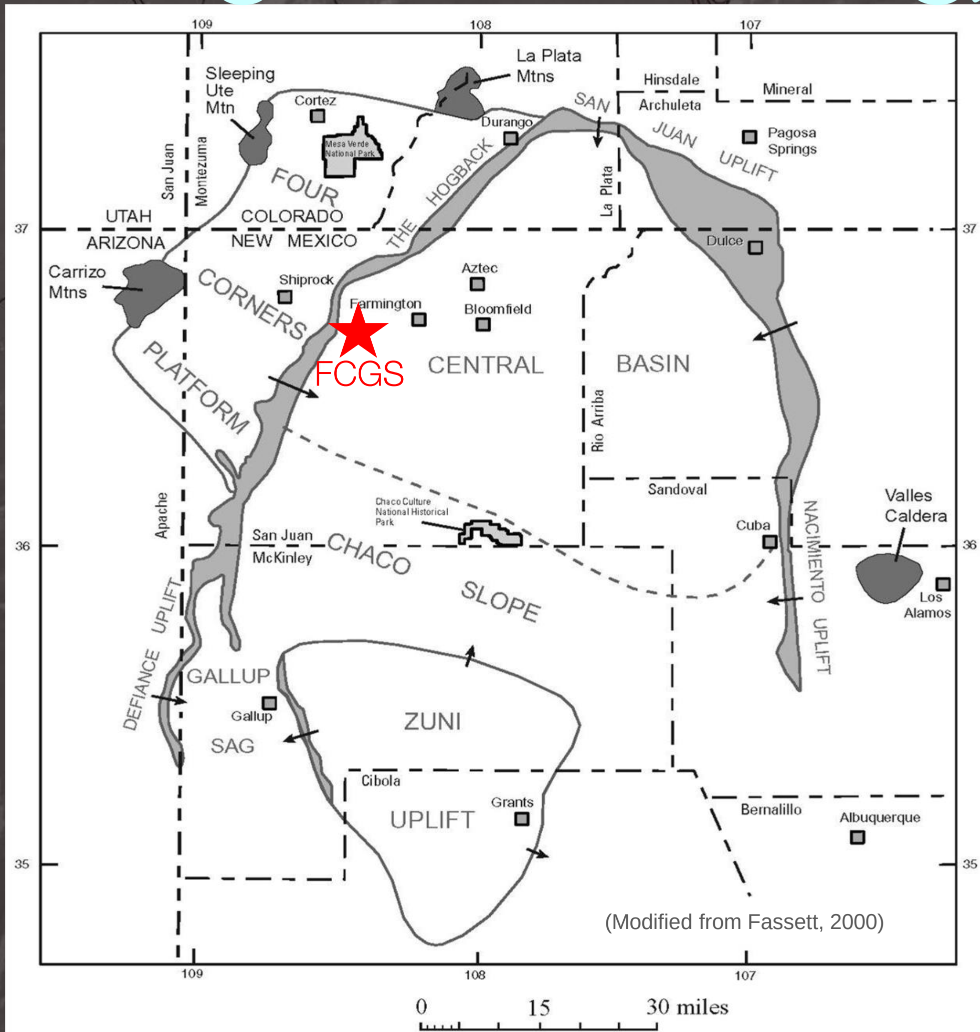
Project Location



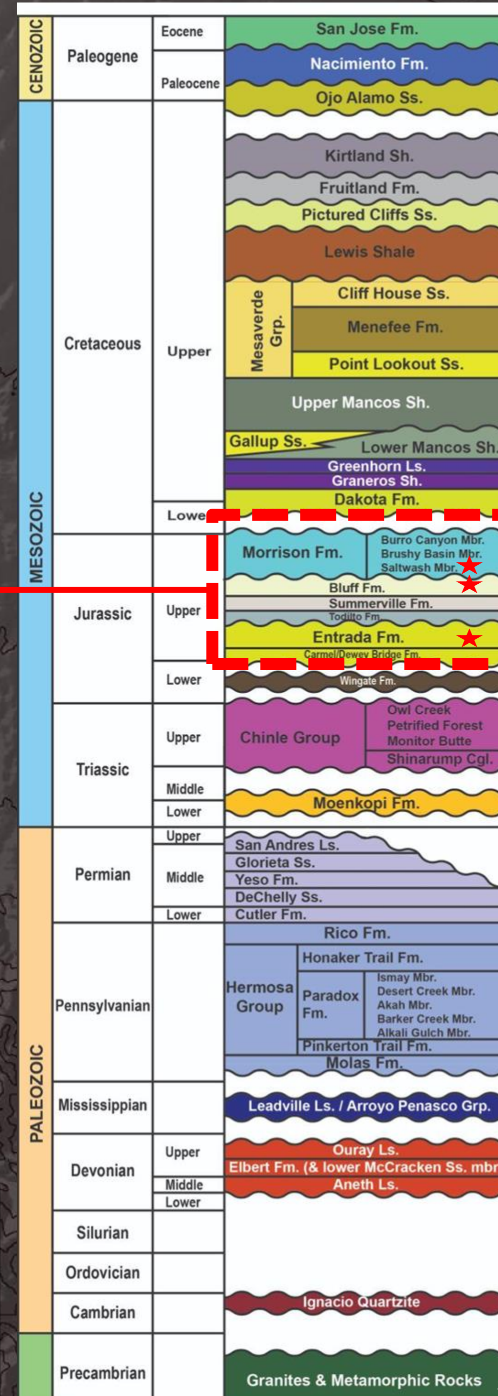


- Project builds upon other CCUS work in the region
  - San Juan Basin CarbonSAFE Phase III project
  - Western USA: The Carbon Utilization and Storage Partnership (CUSP)
- *Recognized need for further subsurface understanding*

Background Geology



(Modified from Fassett, 2000)



Modified from Ulmer-Scholle et al., 2022

Coal

Oil and Gas Production

Carbon Sequestration Targets (Current disposal zones - SWD, AGI)

Oil and Gas Production

Project Plan

- **Task 1.0 – Project Management and Planning**

- **Task 2.0 – Community Benefits Plan**

- **Task 3.0 – Compiling Geological Data**
- Subtask 3.1 - Evaluation of existing well log data
- Subtask 3.2 - Evaluation of existing seismic data
- Subtask 3.3.1 - Licensing new seismic data
- Subtask 3.3.2 - Processing seismic data
- Subtask 3.3.3 - Interpreting seismic data
- Subtask 3.4.1 - Compilation of Thermal Data
- Subtask 3.4.2 - Thermochronometry data
- Subtask 3.4.3 - Compilation of Vitrinite Reflectance Data
- Task 3.5.1 - Compilation of Paragenetic Data
- Task 3.5.2 - Paragenetic Analysis

Subsurface Data

- **Task 4.0 – Geologic Modeling**
- Subtask 4.1 - Creation of the model
- Subtask 4.2 - Updating storage models
- Subtask 4.3 - 3D fault model
- Subtask 4.4 - Integration of thermal data, thermochronology data, and vitrinite reflectance data
- Subtask 4.5 - Machine learning analysis of basin-wide geological data
- Subtask 4.6 - Resource assessment

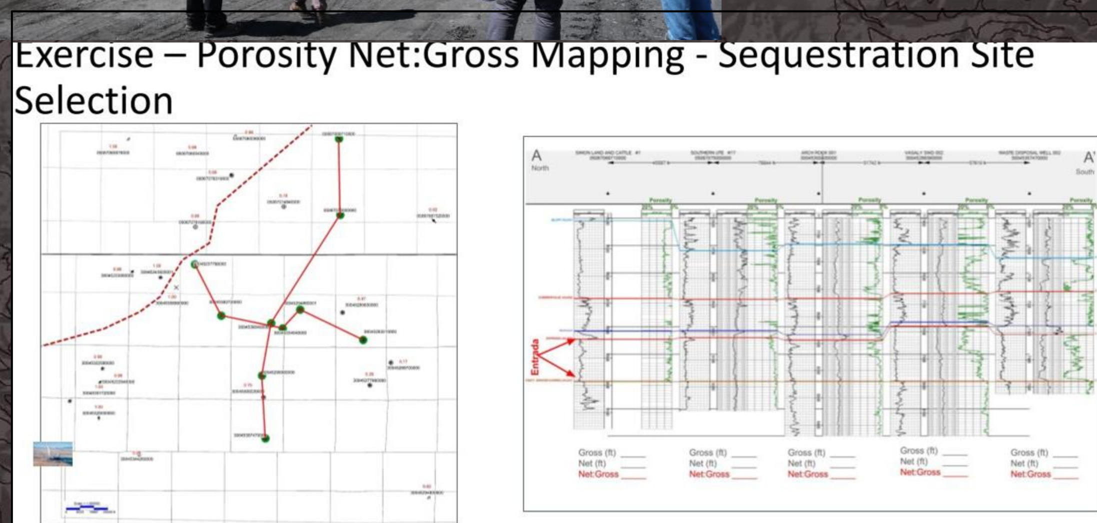
Subsurface Model

- **Task 5.0 – Coordination with other DOE Projects**

Task 2: Community Benefit activities

- Geology Lite - Geology Outreach publication - planned for Spring 2025
- Rockin Round NM - Workshop for K-12 Teachers, July 10-12, 2024: New Mexico State University - Grants Community College

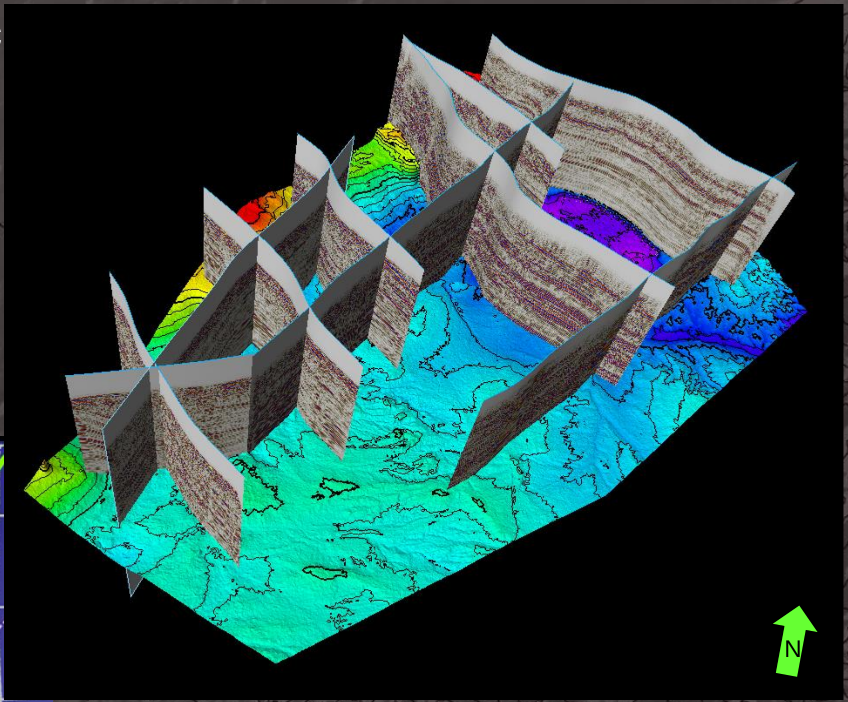
El Segundo Mine (sponsored by Peabody Energy)

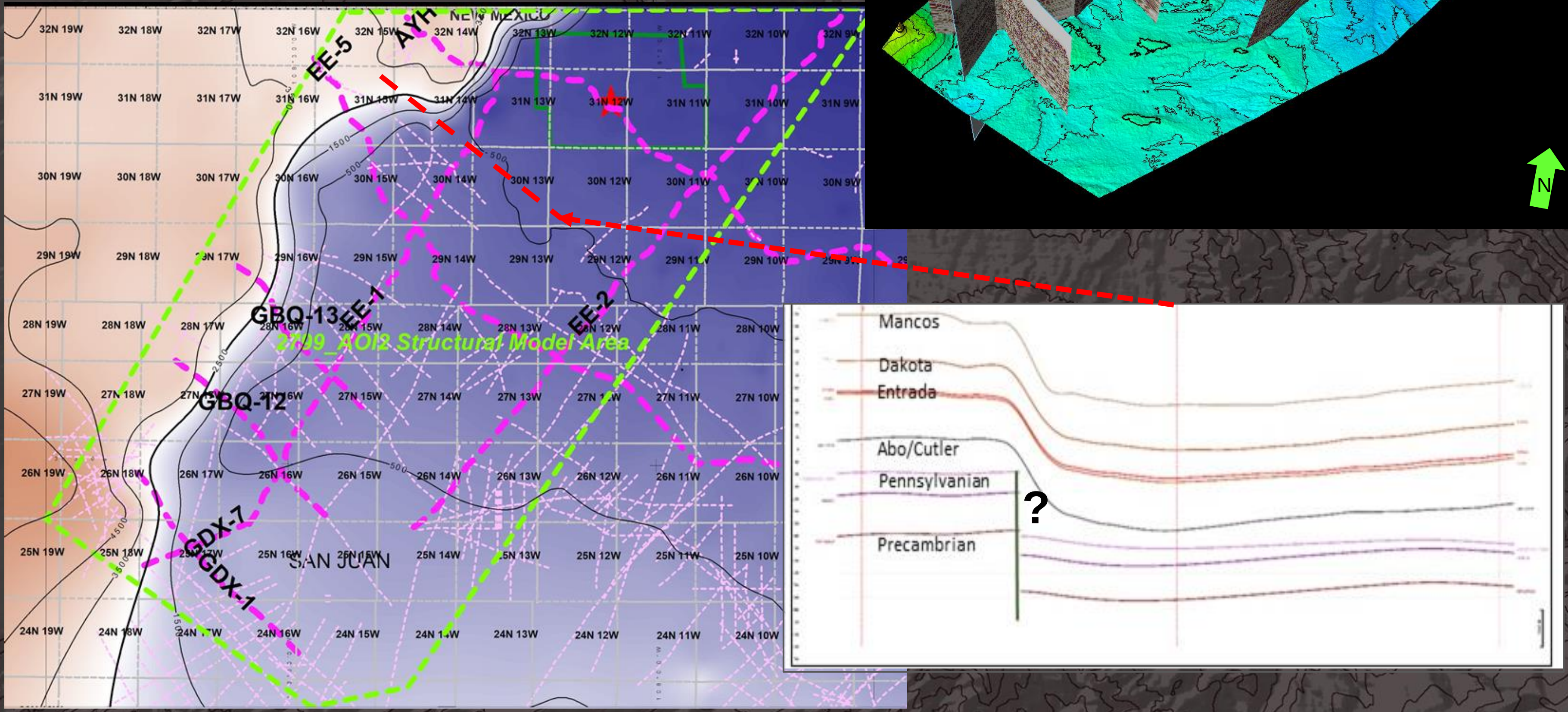


- Coal mine tour
- Subsurface resources and career paths presentation
- Exercise - Net:Gross Mapping and Sequestration site selection

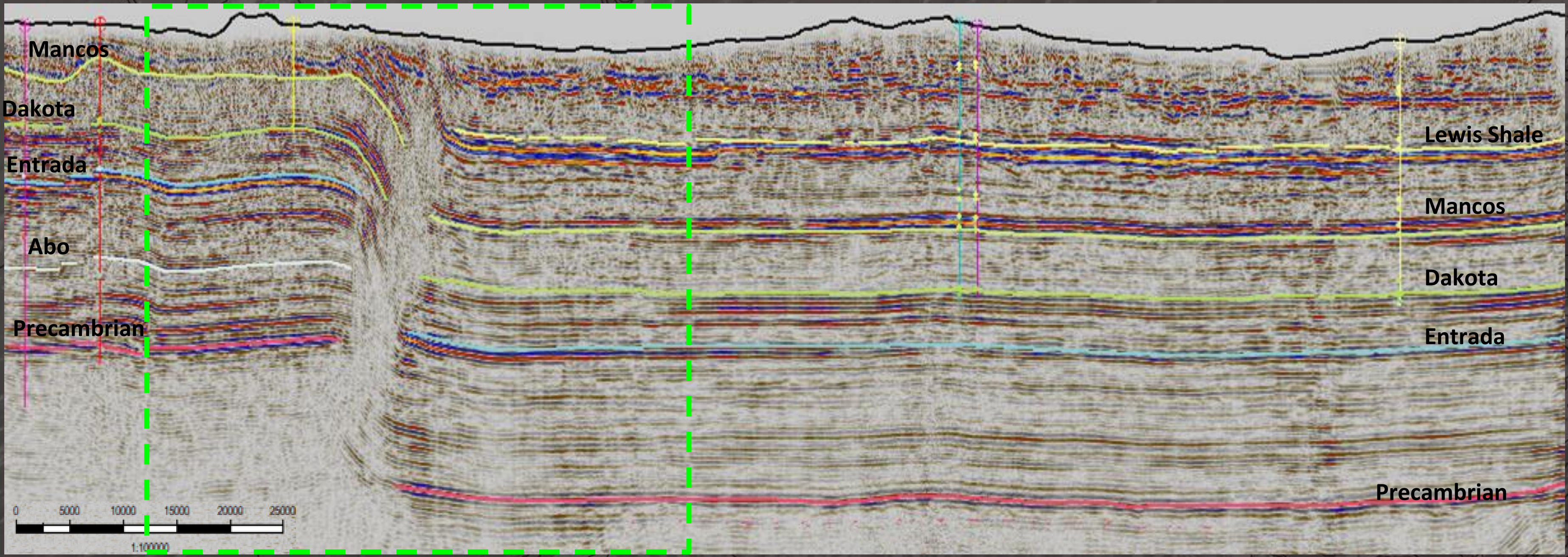
Task 3: Subsurface Data

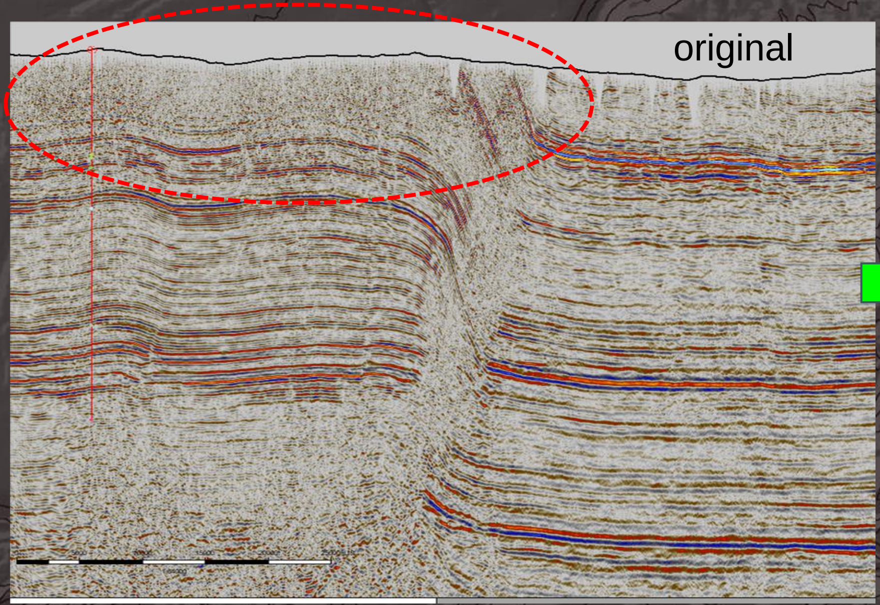
- Subtask 3.2 - Evaluation of Existing Seismic data
- 10 lines, 243 miles
- Subtask 3.3.2-Processing seismic data
- Denoise and depth migrate
- Subtask 3.3.3 - Interpreting seismic data
- Initial time interpretation in progress

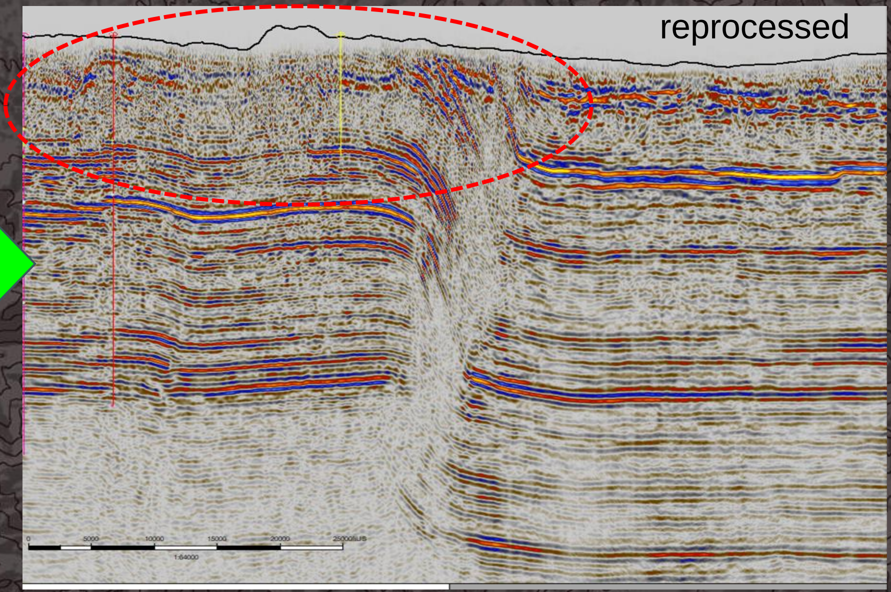




Seismic Reprocessing - progress update







Seismic Reprocessing - *Details in the poster hall*

Multi-2D Reprocessing of Seismic Data for Structural Interpretation in the San Juan Basin

Adewale Amosu[1], Martin Reyes-Correa[2], George El-Kaseeh[1], Luke Martin[2], William Ampomah[1]
1. Petroleum Recovery Research Center, New Mexico Tech
2. New Mexico Bureau of Geology & Mineral Resources, New Mexico Tech

Abstract

- The San Juan Basin in New Mexico is currently undergoing site characterization efforts for carbon sequestration.
- Several 2D seismic are being reprocessed and interpreted to characterize the structure of the northwest corner of the basin including the Hogback monocline, a distinct geological feature which is the surface expression of a deep reverse fault.
- Multi-2D seismic processing is being implemented. Data is processed to ensure that amplitude fidelity is preserved. Novel processing techniques for noise removal are applied.
- The latest processing techniques are applied to the 2D seismic, including the appropriate depth imaging algorithm. Statics correction was applied to the data and the geometry of the data was reconstructed. Velocity analysis was carried out and both pre-stack and post-stack depth imaging were applied.
- The final processing data will be interpreted for improved structural characterization of the northwest San Juan Basin and the Hogback monocline.

Introduction

- The San Juan Basin covers 7,500 mi^2 (square miles) primarily in New Mexico but also extends into Utah, Colorado, and Arizona (Figure 1).
- The region is highly favorable for CO_2 sequestration; sources, storage reservoirs, and confining units coexist.
- The San Juan Basin contains a thick sedimentary section, ranging from Cambrian to Eocene-aged rocks. In the deepest part of the basin, there is over 15,000 feet of sedimentary fill.
- Target formations for carbon sequestration are the Saltwash member of the Morrison Formation, the Bluff Sandstone and the Entrada Sandstone. The primary confining zones are the Brushy Basin member of the Morrison Formation, the Summerville Formation, the Todilto Formation, and Carmel Formation.
- Seismic characterization will help to identify the main risks associated with the feasibility of carbon sequestration.

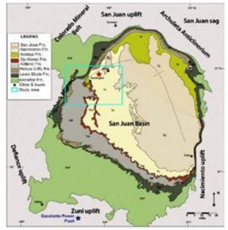


Figure 1. Regional geological map of the San Juan Basin modified from Pecha et al. (2018)

Data and Processing

- Ten 2D seismic lines were licensed for multi-2d seismic processing and interpretation.
- Spherical divergence correction was applied to compensate for loss of amplitudes due to spherical wave front spreading.
- First-break picks associated with the refracted arrival times are used to study the near-surface velocity zones and subsequent determination of static corrections.
- Denoising was conducted using Continuous Time Frequency Domain (CTFD) filter that more effectively removes airblast without removing shallow data was applied.
- The processing steps result in cleaner gathers and helps with subsequent reprocessing steps such as velocity analysis, residual statics and imaging.
- Surface consistent scaling and velocity analysis were implemented.

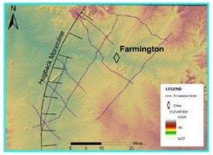


Figure 2. Location of the study area that contains the 10 2D seismic lines licensed for the seismic processing see location in Figure 1.

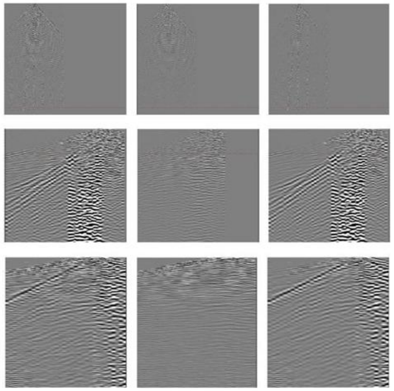


Figure 3. Denoising of seismic gathers. Original seismic (left), denoised seismic (middle), and subtracted noise (right) for lines AYH-1, GDX-7, and GBQ-12 top to bottom respectively.

Seismic Imaging

- Kirchhoff PSTM has been applied and PSTM stacks tied.
- Other processes to be carried out
  - Kirchhoff PSDM
  - Reverse Time Migration (RTM)
  - Gaussian Beam Migration (GBM)
  - AVO Analysis: Offset stacks, Angle stacks, Intercept and Gradient stacks.
  - Creation of Pseudo-3D PSTM, PSDM and RTM stack volumes by 3D interpolation of Multi-2D PSTM, PSDM and RTM stack profiles.

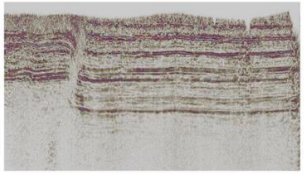


Figure 4. PSTM stack for line AYH-1.

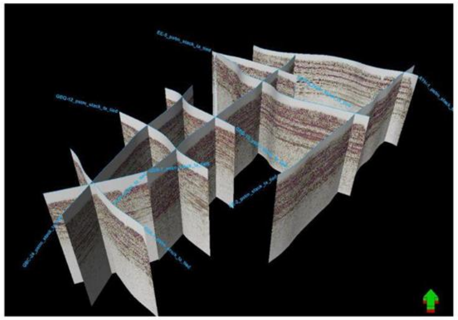


Figure 5. Tied PSTM stacks of the 2D lines.

Acknowledgements

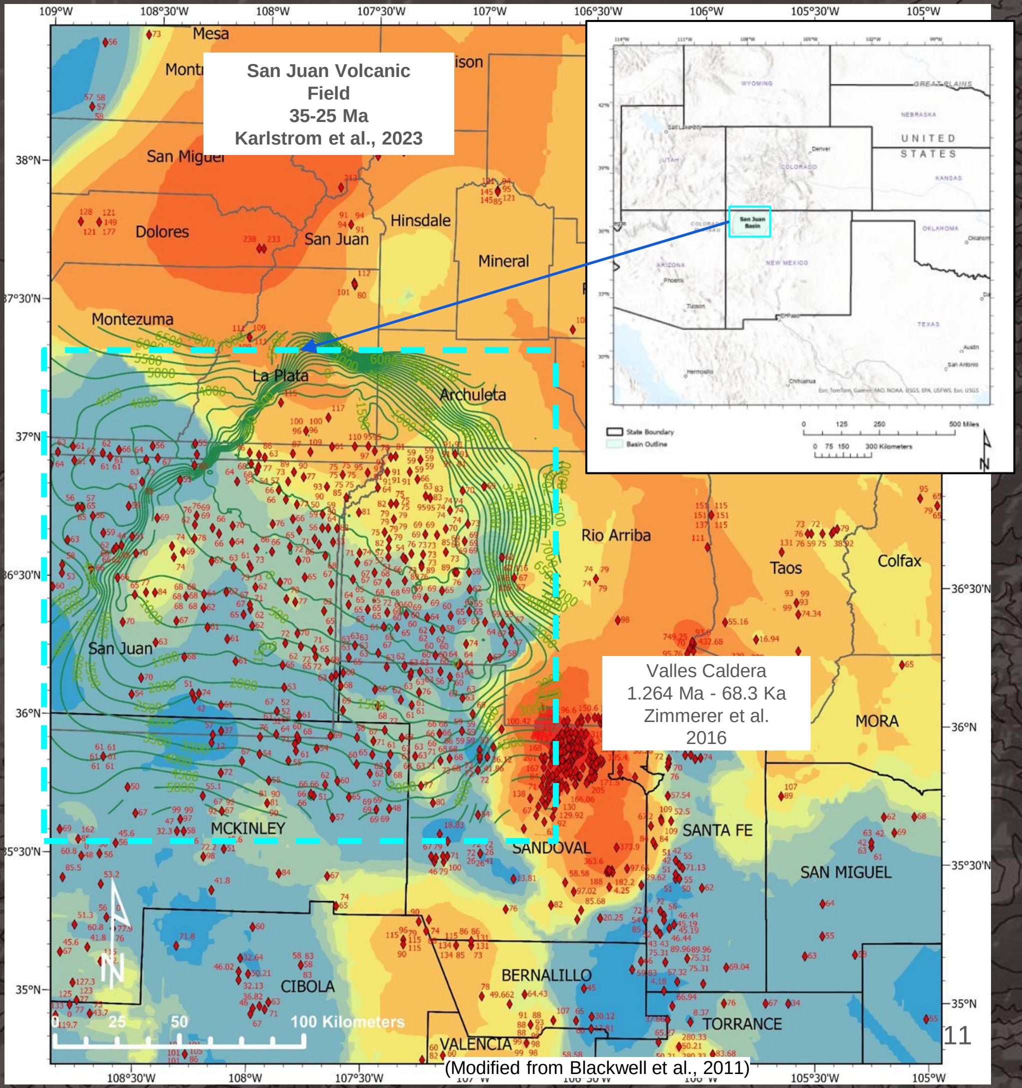
This work was supported by the U.S. Department of Energy (DOE) under award DE-FE0032369.

BUREAU OF GEOLOGY AND MINERAL RESOURCES

Task 3: Thermal Data

- Thermal data input for basin reservoir models

- Relationship between high modern heat flow areas near volcanic centers and potential for resources in those areas?
  - Duration and maximum temperature of thermal events effect on *reservoir properties*?
    - Carbon Sequestration
    - Geothermal Exploration



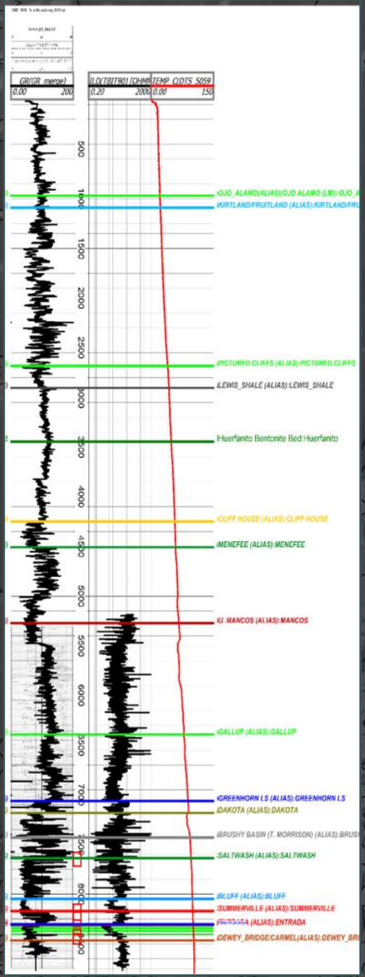
(Modified from Blackwell et al., 2011)

Present Day Heat flow= thermal conductivity x temperature gradient

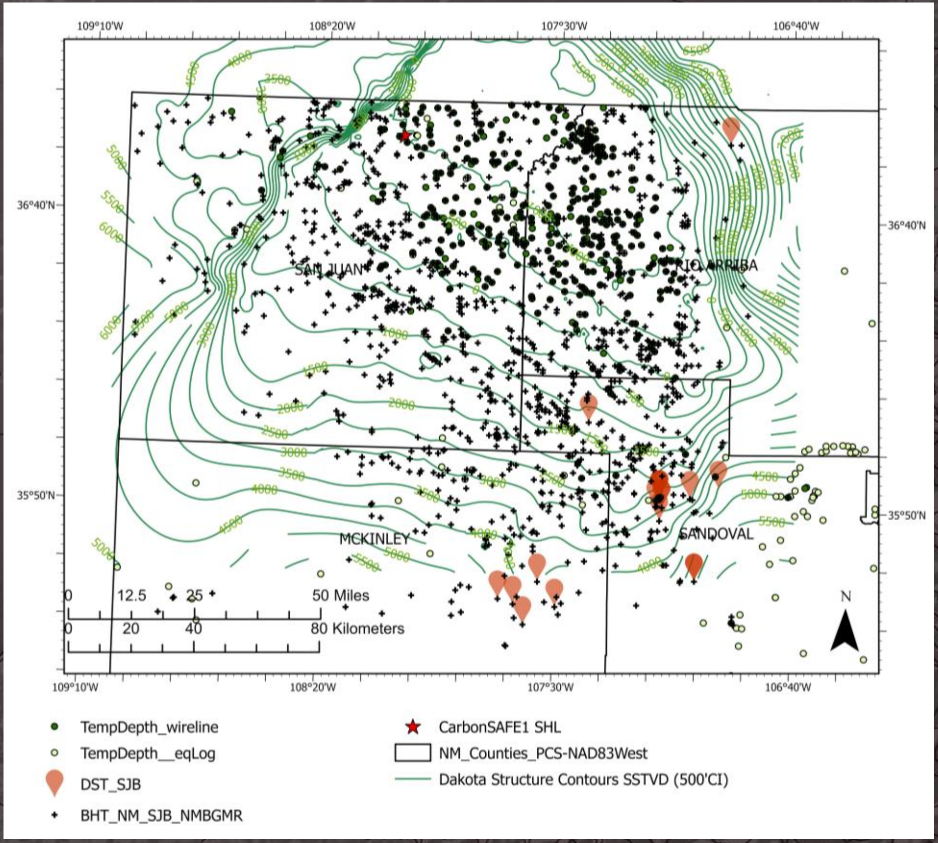
Green contours = SSTVD structure of top Dakota Formation 1000' CI)

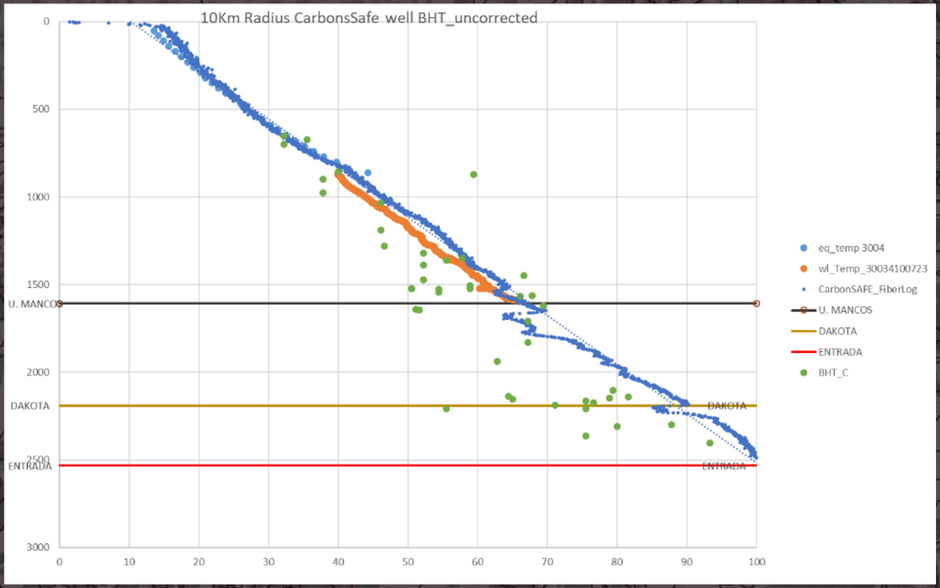
Temperature

- Present Day Temperature
  - Temperature logs
  - Bottom hole temperature
  - DST Formation tests
  - NMBGMR Subsurface Library



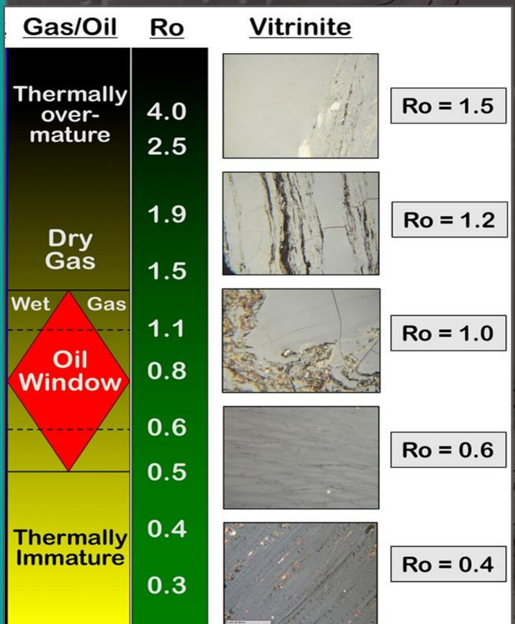
CarbonSAFE 1 - Fiber Optic Temp log
45 days post drilling





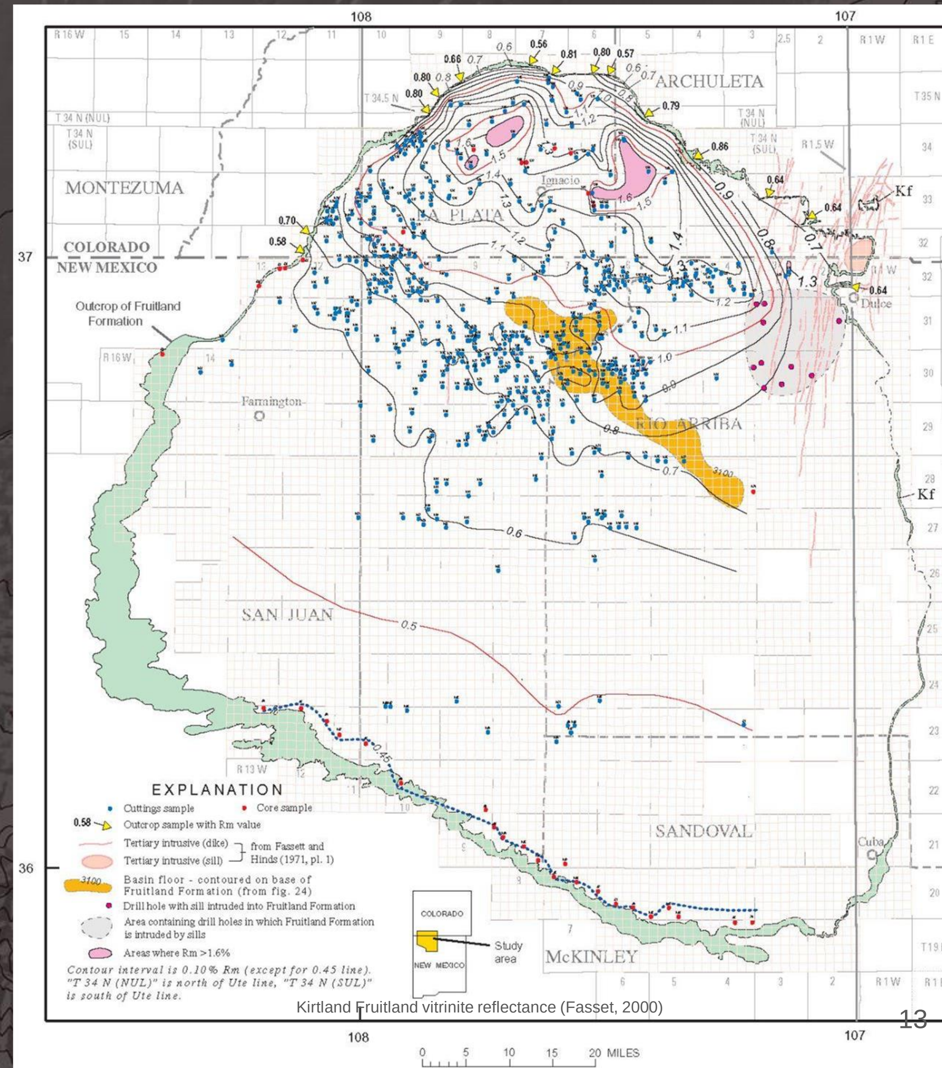
Vitrinite Reflectance

- Peak Temperature
  - *Vitrinite reflectance* (Ro)
    - Thermal alteration of organic matter
  - Internal reports at NMBGMR and publications
    - Subsurface and outcrop



Ro	Barker and Goldstein (1990)	Burnham and Sweeney (1989) 0.5°C/Ma	Burnham and Sweeney (1989) 50°C/Ma
2.4	280	205	>230
2.2	265	200	230
2.0	245	185	215
1.8	235	180	210
1.6	225	170	200
1.4	210	165	190
1.2	180	150	175
1.0	150	130	150
0.8	120	115	130
0.6	85	90	115
0.4	~35	50	80

https://www.uky.edu/KGS/coal/coal-analyses-vitrinite.php



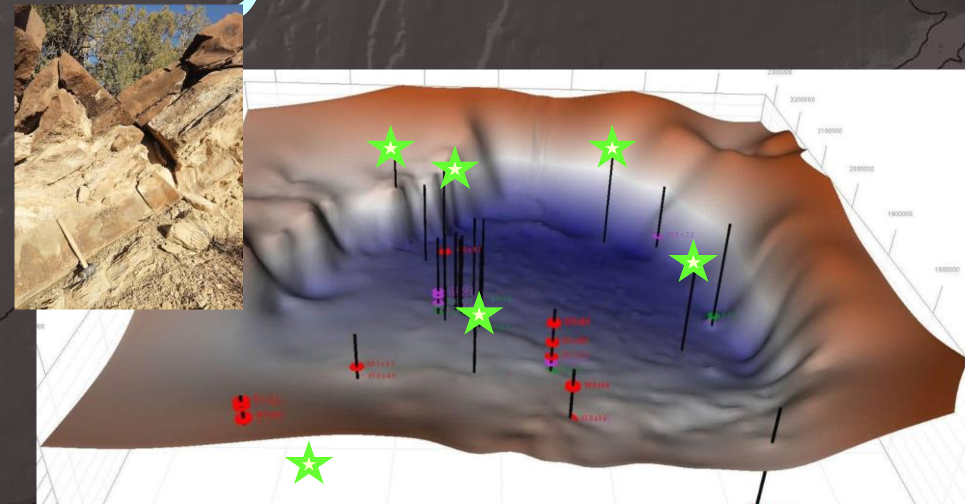
Kirtland Fruitland vitrinite reflectance (Fasset, 2000)

Hansley (1987)

BUREAU OF GEOLOGY AND MINERAL RESOURCES

Thermochronometry

- Timing of thermal events



From Kelley (2019) and Kelley (unpublished)

Apatite or Zircon (U-Th)/He

- Decay of $^{238}U \rightarrow {}^{206}Pb$, $^{235}U \rightarrow {}^{207}Pb$, $^{232}Th \rightarrow {}^{208}Pb$
  - ^{4}He nuclei (alpha particles) at each step

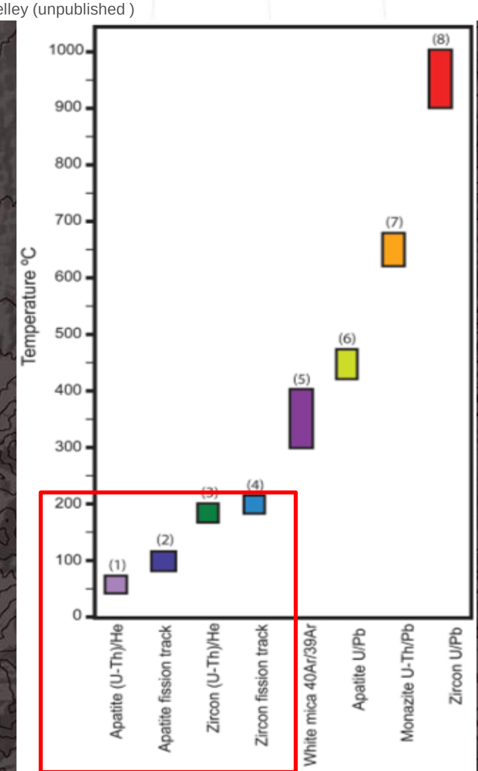
	Closure	Partial Retention	Not Retained (0 age)
Apatite	40 ºC	40-70 ºC	>70 ºC
Zircon	130 ºC	130 - 180 ºC	>180 ºC

Apatite or Zircon Fission Track

- Decay of ^{238}U
  - Damage fission tracks proxy for daughter products

	Closure	Partial Annealing	Annealed (0 age)
Apatite	60 ºC	60-120 ºC	>120 ºC
Zircon	180 ºC	180 - 240 ºC	>240 ºC

(from Peyton and Carrapa, 2013)



(figure from Peyton and Carrapa, 2013)

Hansley (1987)

Paragenetic Analysis

Effect of duration and maximum temperature of thermal events on reservoir properties

- Thin section petrography:
  - Cement Stratigraphy
    - Diagenetic sequence of cementation
  - Packing density and grain deformation
    - Is porosity loss due to compaction or could be related to thermal effects?
  - Dissolution and cementation patterns
  - Cross-cutting relationships
  - Timing of Fluid Migration
    - Hydrocarbon presence or fluid inclusions
  - Diagnostic fabrics and morphologies

Ulmer Scholle et al., 2014

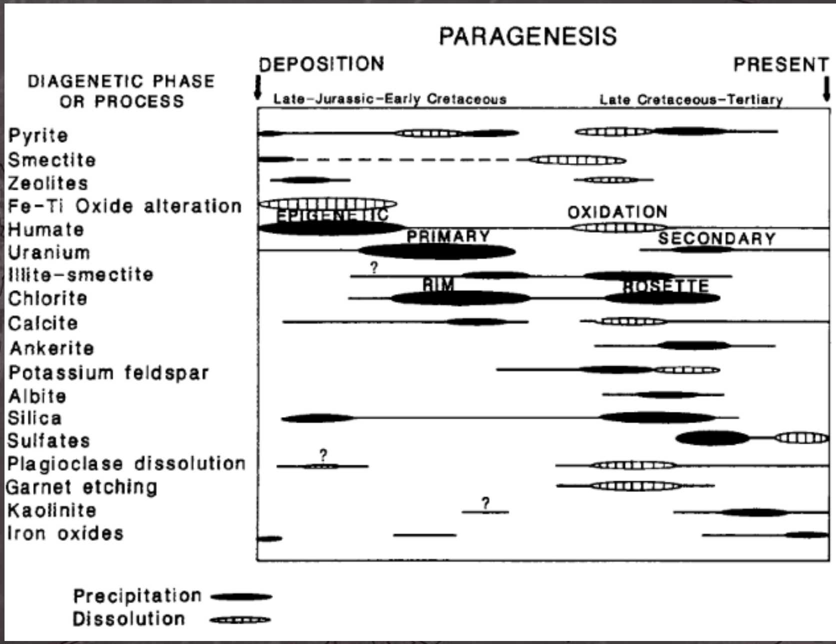
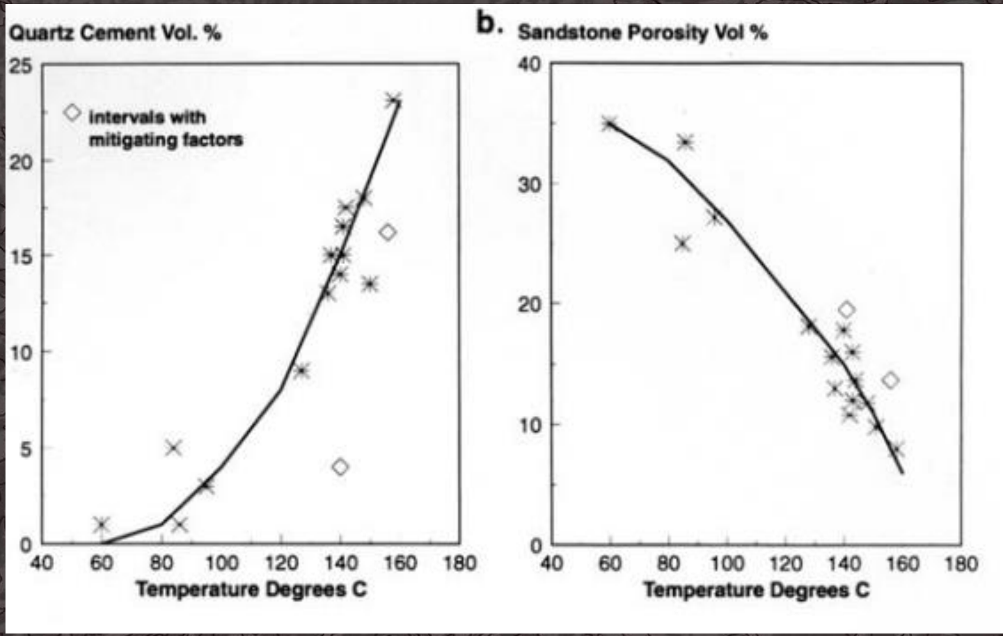


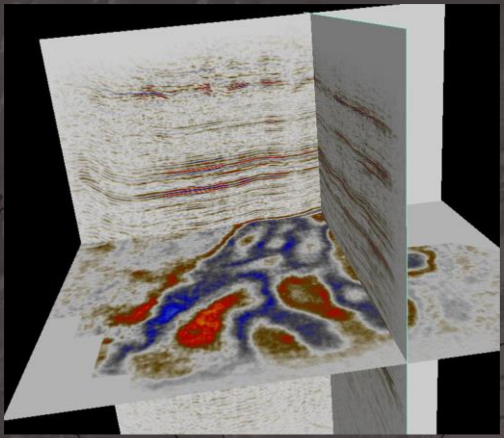
FIG. 7.—Paragenetic diagram of major diagenetic alterations in the Morrison Formation in the southern San Juan Basin. The width of the shaded or patterned area indicates the intensity of the process.

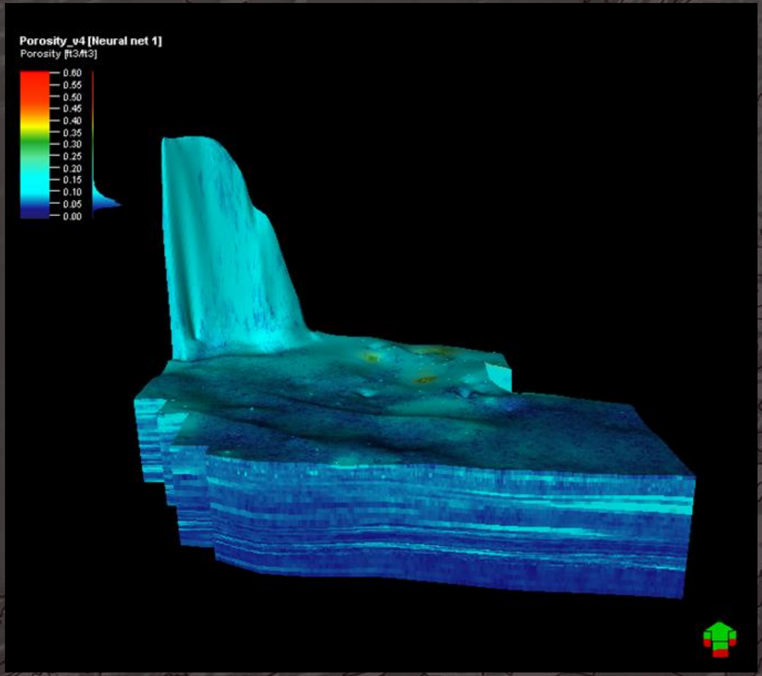
Morrison Formation in the southern San Juan Basin (from Hansley, 1987)

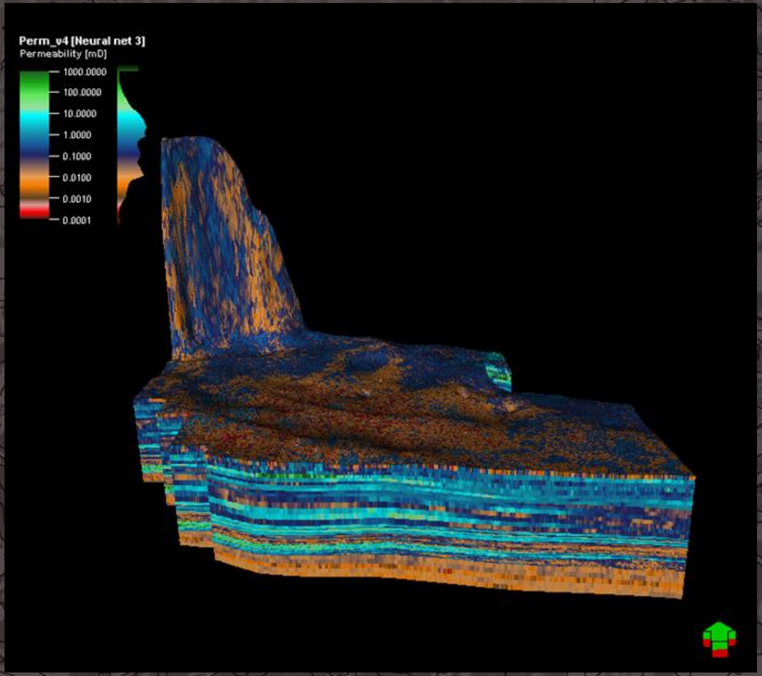


Task 4.0 - Geologic Modeling : Upcoming

Task 4.0 - Geologic Modeling
- Subtask 4.1 - Creation of the model
- Subtask 4.2 - Updating storage models
- Subtask 4.3 - 3D fault model
- Subtask 4.4 - Integration of thermal data, thermochronology data, and vitrinite reflectance data
  - November 30th, 2025
- Subtask 4.5 - Machine learning analysis of basin-wide geological data
- Subtask 4.6 - Resource assessment
  - November 30th, 2025



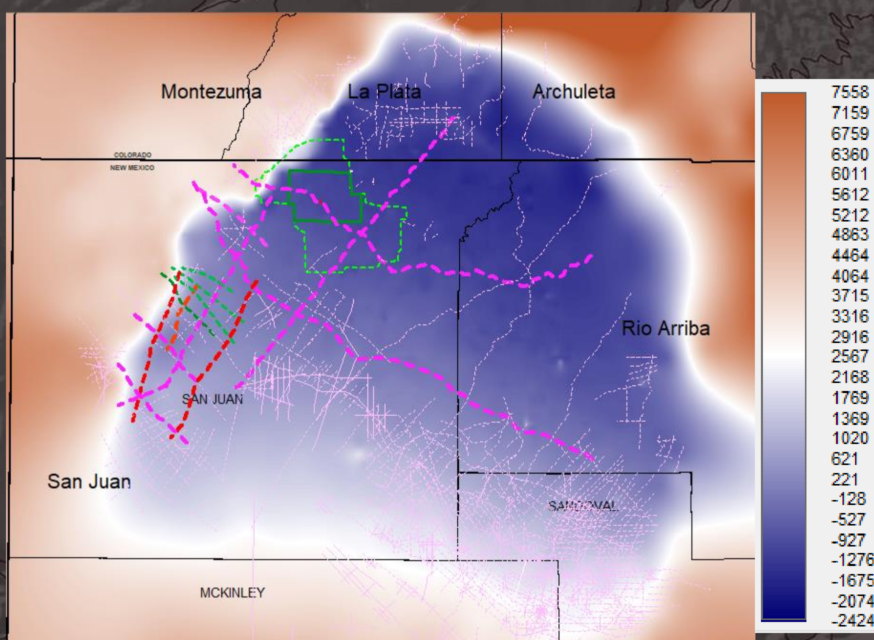


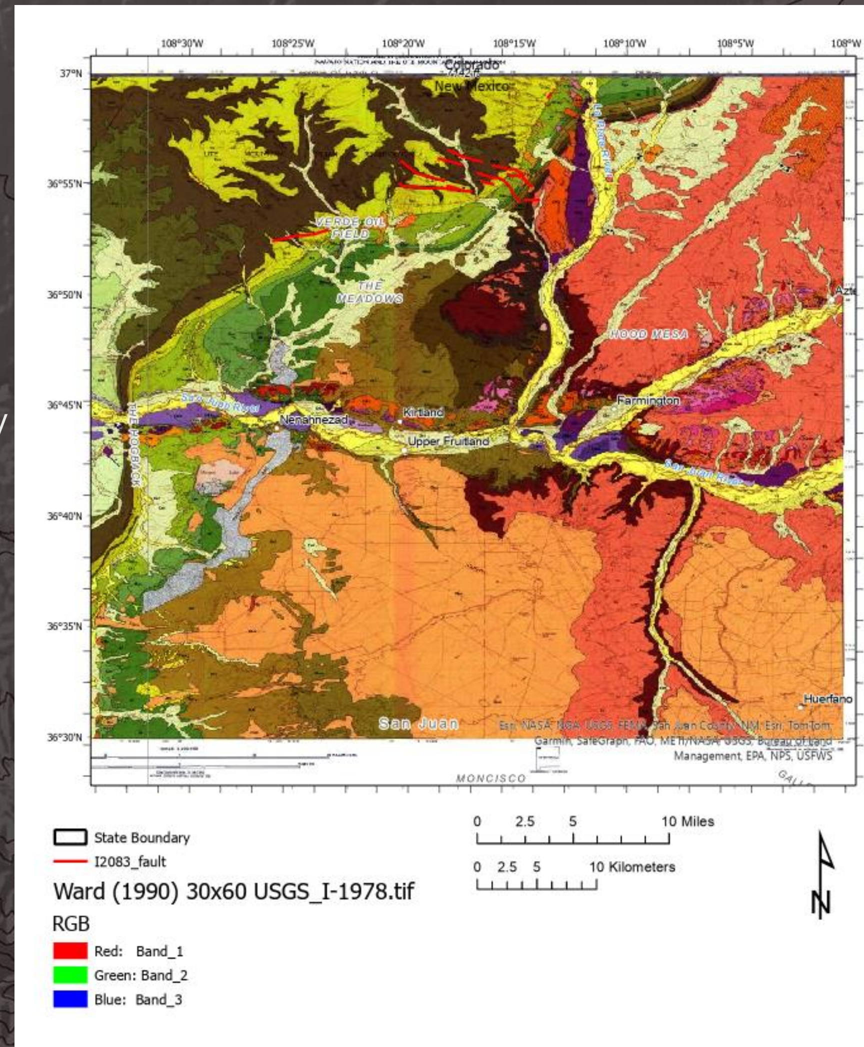


BUREAU OF GEOLOGY AND MINERAL RESOURCES

Next Steps: Project

- After Project/Scale-up potential
  - 3D seismic integration with other DOE projects
  - Eastern side of SJB - fault characterization
  - Integrate subsurface work with detailed *Surface* mapping currently being done by NM Statemap project





Technical - Success Criteria/Outcomes

Objective/ Decision point	Success Criteria
Conduct community outreach and public engagement of identified stakeholders. Assess of environmental Justice & Justice40 and regional economic impact to DACs [Task 2]	Proposed project is well received by the local communities and stakeholders. Positive project environmental and economic impacts to DACs is identified and quantified.
Evaluate, compile, and analyze geological and geophysical data including seismic, well-log, thermal, thermochronological, and paragenetic data [Task 3]	Database is created to host data and analysis products that support CCUS activities in the San Juan Basin.
Geological modeling incorporating 3D fault model [Task 4]	Probabilistic resource assessment of CO_2 sequestration potential in the San Juan Basin is developed.
Coordination with other DOE Projects to host and disseminate geological data and basin characterization results [Task 5]	Data and work products made available to the DOE and other stakeholders, published on the website of the NMBGMR as open file reports, and provided to the NATCARB database.

Technical - High Impact/Probability Project Risks

Perceived Risk	Risk Rating			Mitigation/Response Strategy	
	Probability	Impact	Overall		
	(Low, Med, High)				
Technical/Scope Risks:					
Unsuitable geology in identified area	Low	High	Low	Site location was chosen after a pre-feasibility study by expert geologists with years of experience in the San Juan Basin. This study identified other potential sites in the area that could serve as secondary sites	
Lack of data	Low	High	Low	The project has identified several sources of commercial data and data that will be acquired and potentially shared by our industry partners. The PI is the manager of the NMBGMR Subsurface Library with access to databases and well logs as well as for geological information throughout the San Juan Basin.	