# Advancing Characterization of Faults Through Deployment of Novel Geophysical, Geochemical and Geomechanical Technologies at the San Juan Basin (SJB) CarbonSAFE Site

DE-FE0032064

William Ampomah, PhD
Section Head-Research Engineer/ Assistant Professor
New Mexico Tech

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022

# Project Participants

- **NMT**
- **Dr. William Ampomah**
- Dr. Sai Wang
- Mr. George El-kaseeh
- Mr. Luke Martin
- Dr. Alex Rinehart
- Dr. Jiawei Tu
- Graduate Student

- **University of Utah**
- **Prof. Brian McPherson**
- Dr. Kevin Lynn McCormack

- **Silixa LLC**
- **Mr. Thomas Coleman**
- Dr. Carlos Maldaner
- Dr. David Podrasky

- **LANL**
- **Dr. Lianjie Huang**
- Dr. Jeffrey Hyman
- Dr. Zhou Lei
- Dr. Rajesh Pawar

**Contractors**

- Dr. Tom Bratton

- **AHS**
- **Dr. Michael P. Smith**
- Dr. Christopher Smith
- Mr. Patrick Gordon

# Project Overview

– Funding Profile

– Project Performance Dates:

07/01/2021– 06/30/2024

| | BP1 07/01/21 - 06/30/22 | | BP2 07/01/22 - 06/30/23 | | BP3 07/01/23 - 06/30/24 | | Total | |
|---|---|---|---|---|---|---|---|---|
| | DOE Funds | Cost Share | DOE Funds | Cost Share | DOE Funds | Cost Share | DOE Funds | Cost Share |
| NMIMT | 332,640 | 32,389 | 169,139 | 43,195 | 156,146 | 28,481 | 657,924 | 104,064 |
| University of Utah | 54,419 | 13,608 | 26,449 | 6,612 | 14,132 | 3,530 | 95,000 | 23,750 |
| Silixa LLC | 246,970 | 140,315 | - | 23,800 | - | 23,800 | 246,970 | 187,915 |
| LANL | 79,996 | - | 80,008 | - | 39,996 | - | 200,000 | - |
| Total ($) | 714,025 | 186,312 | 275,596 | 73,607 | 210,274 | 55,811 | 1,199,894 | 315,729 |
| Total Cost Share % | | 20.7% | | 21.1% | | 21.0% | | 20.8% |

# **Project Overview:** Objectives

- The main objective is to carry out field deployment of an integrated suite of cost-effective and novel geophysical, geochemical, and geomechanical technologies for detection and characterization of faults and fractures.

- The project will deploy these technologies at the San Juan Basin (SJB) CarbonSAFE Phase III site

- To permanently deploy an integrated behind casing fiber optic sensing system, including Distributed Strain Sensing (DSS), Distributed Temperature Sensing (DTS), and a high sensitivity Distributed Acoustic Sensing (DAS) system.

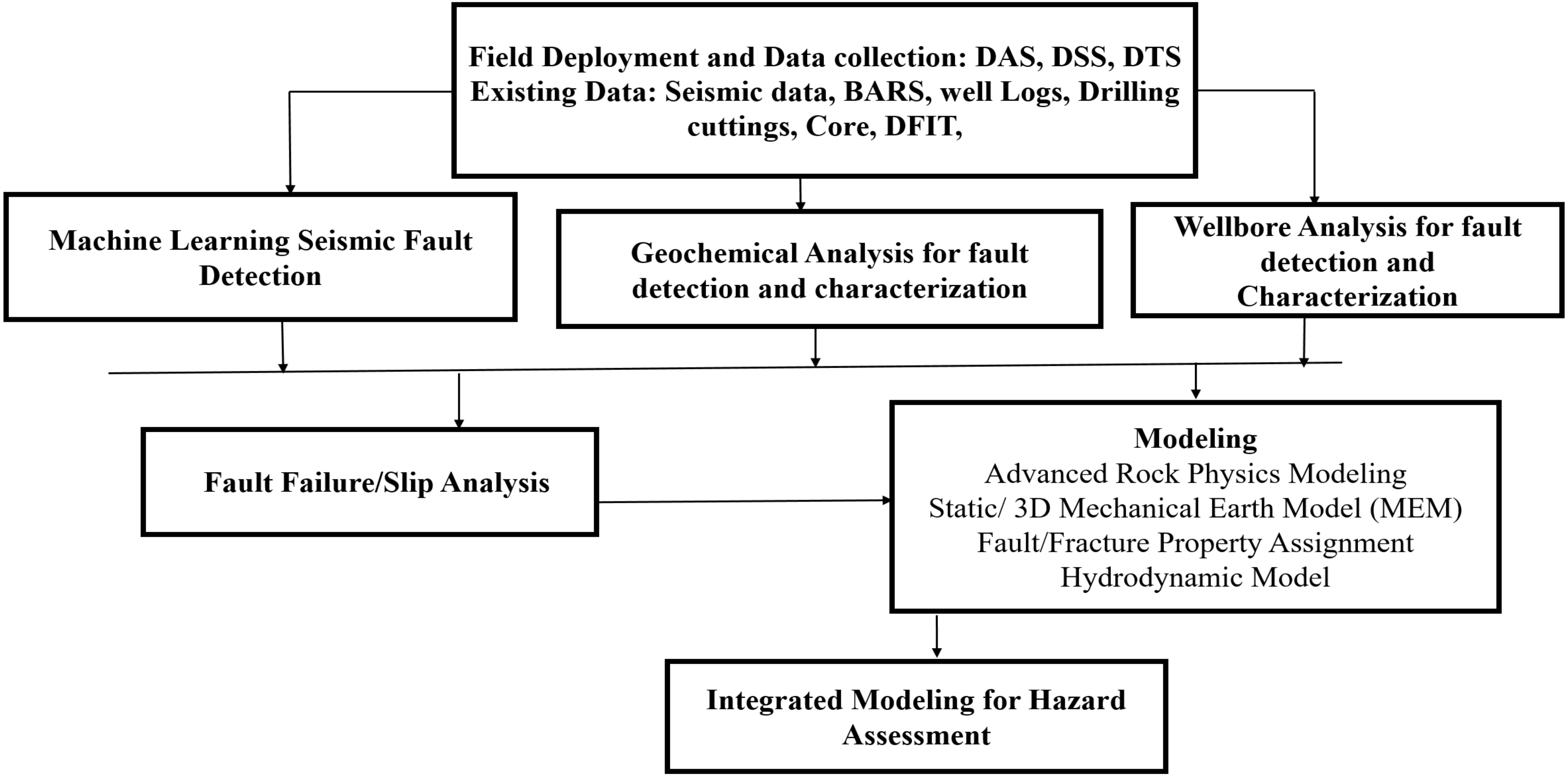
- To employ Rock Volatile Stratigraphy (RVStrat), a novel geochemical technology that uses drill cuttings and core, to locate faults (including aseismic faults) and estimate their sizes and orientations.

# **Project Overview:** Objectives

- To detect faults near and more distant from the well bore, including faults in the crystalline basement rock, using a novel multi-scale U-Net machine learning method to evaluate 3D surface seismic and 3D VSP images.

- To integrate proposed technologies to develop advanced rock physics and coupled thermo-hydrodynamic-mechanical models in combination with the Monte Carlo method, to determine state of stress on each mapped fault and estimate long-term slip potential and/or maximum fault slip potential resulting from large-scale $CO_2$ injection.

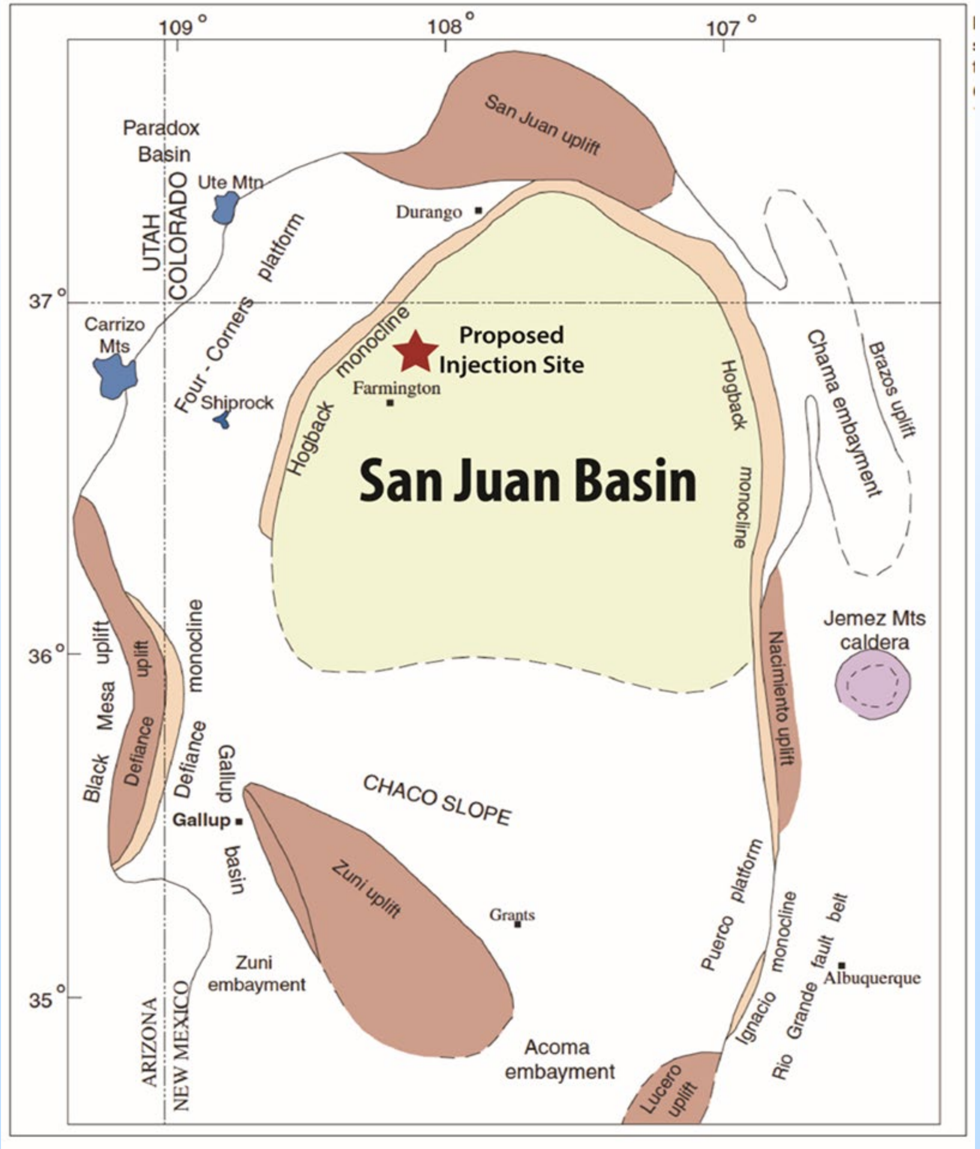
# Our Approach

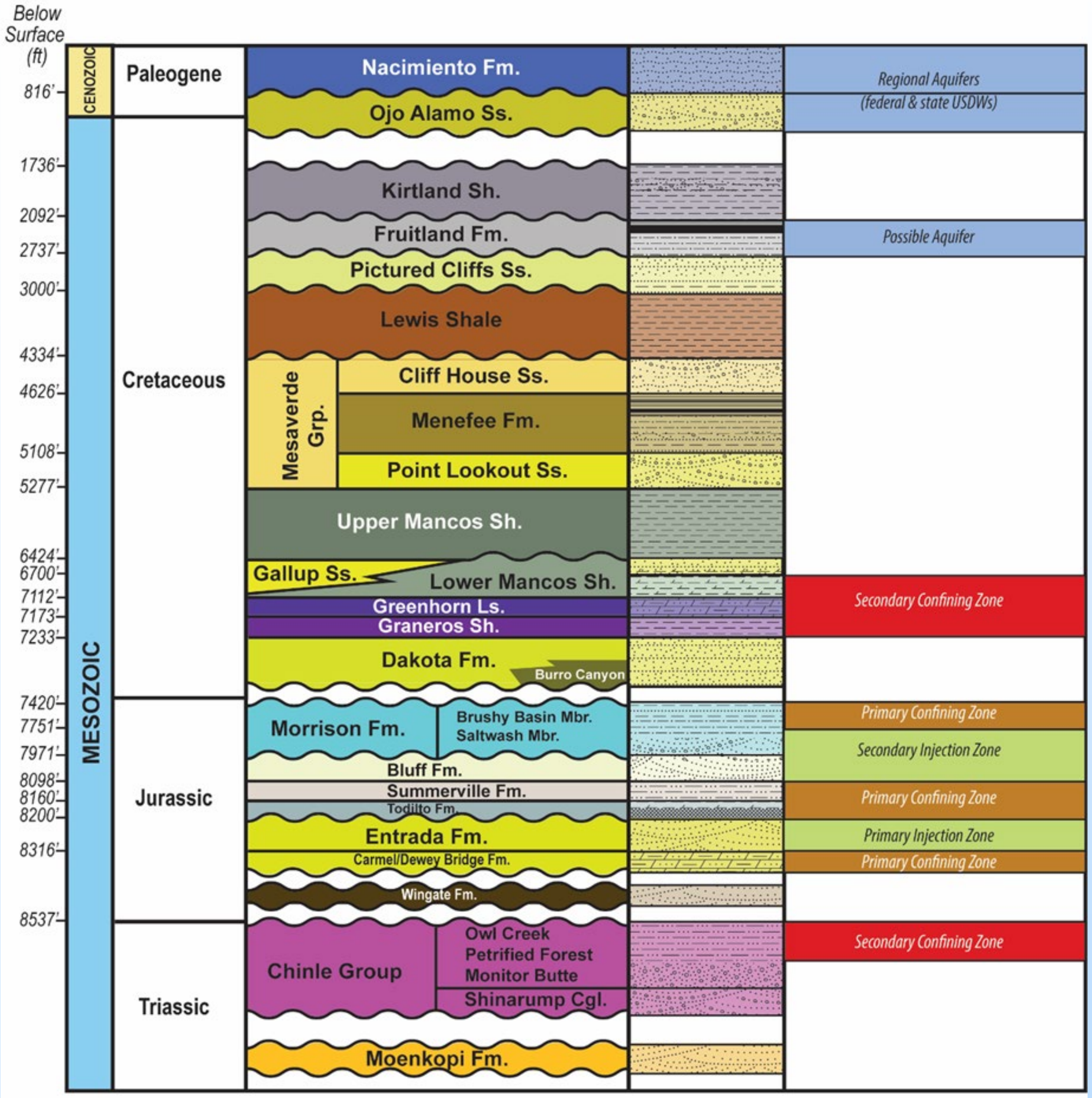


# Milestones

| Task/ Subtask | Milestone Title & Description | Planned Completion Date | Verification method |
|---|---|---|---|
| 1.0 | Project Kick-off meeting | | Attend Meeting |
| 2.2 | Deployment of DAS/DSS/DTS behind casing in the SJB CarbonSAFE stratigraphic well | 12/31/2022 | Report to DOE |
| 2.4 | Drilling cuttings, core and legacy core cuttings assembled | 10/31/2021 | Report to DOE |
| 3 | Seismic analysis detecting aseismic and basement faults | 9/30/2022 | Report to DOE |
| 4 | RVstrat approach detecting and characterizing faults | 7/31/2022 | Report to DOE |
| 5.1/5.2 | Wellbore analysis detecting and characterizing geological features such as faults | 3/31/2022 | Report to DOE |
| 5.3 | Determination of principal stress, pore pressure within storage complex | 1/31/2023 | Report to DOE |
| 6.1/6.2 | Compilation of fault information and baseline seismicity within storage complex and basement | 9/30/2023 | Report to DOE |
| 6.3 | Fault slip analysis | 11/30/2023 | Report to DOE |
| 7.1 | Completion of static model for numerical simulation | 2/28/2023 | Report to DOE |
| 7.3 | Numerical modeling for hazard assessment | 4/30/2024 | Report to DOE |

# Storage Complex @ San Juan Basin



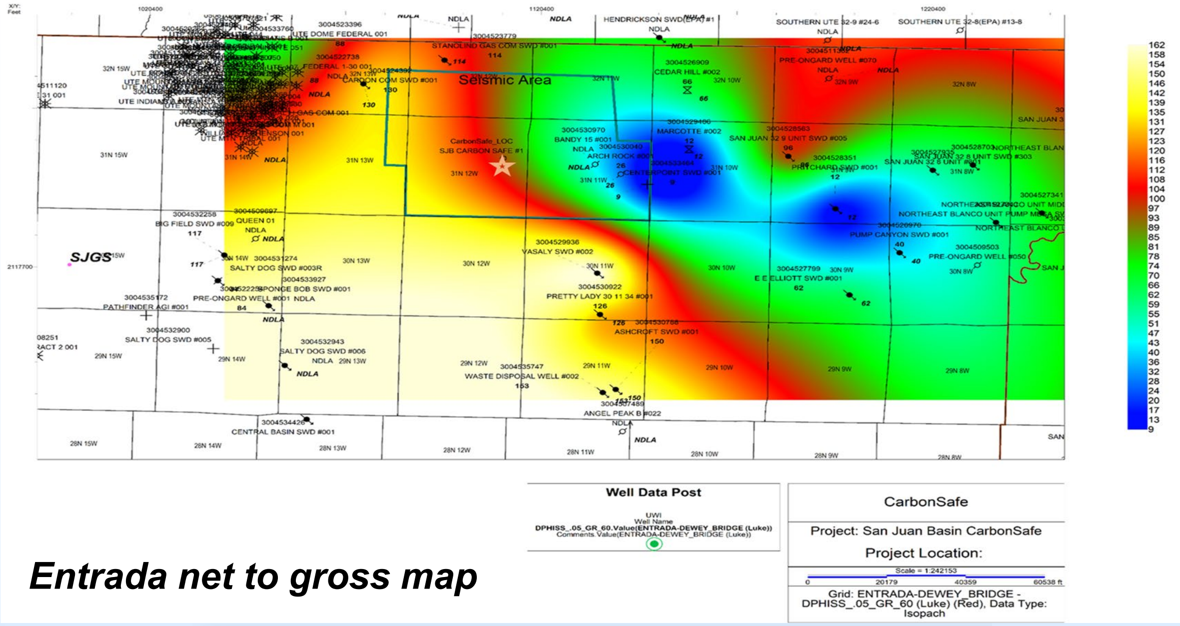
# SJB CarbonSAFE Project Facts

## Key Project Facts

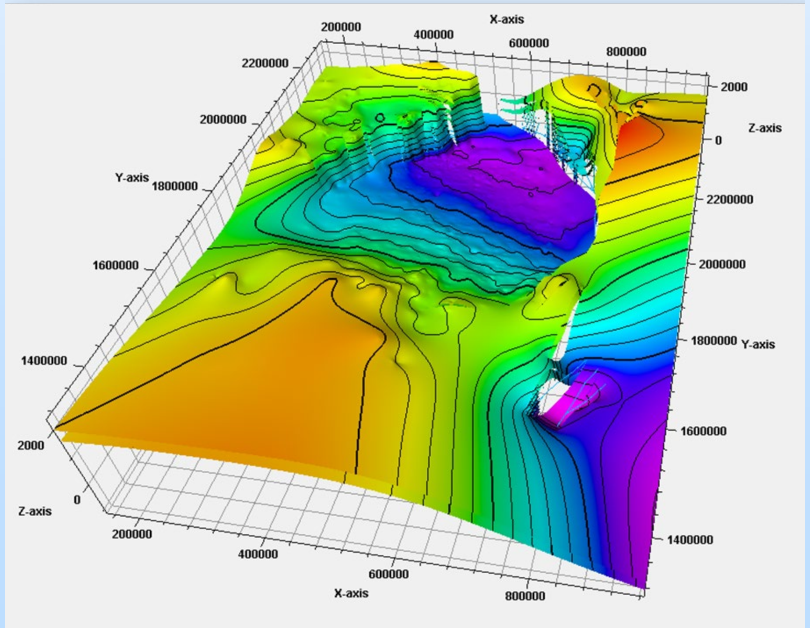
- Retrofit the San Juan Generating Station with 6-7 MMT/yr $CO_2$ capture technology, locally store within San Juan Basin.
- Characterization target located ~17 miles from SJGS

## Characterization Plan

- Drill characterization well, perform injectivity tests on Private land
- Perform suites of laboratory experiments and numerical models
- Purchased 3D seismic, acquire 3D VSP




*Entrada net to gross map*



# SJB CarbonSAFE Stratigraphic Well- Fiber Installation

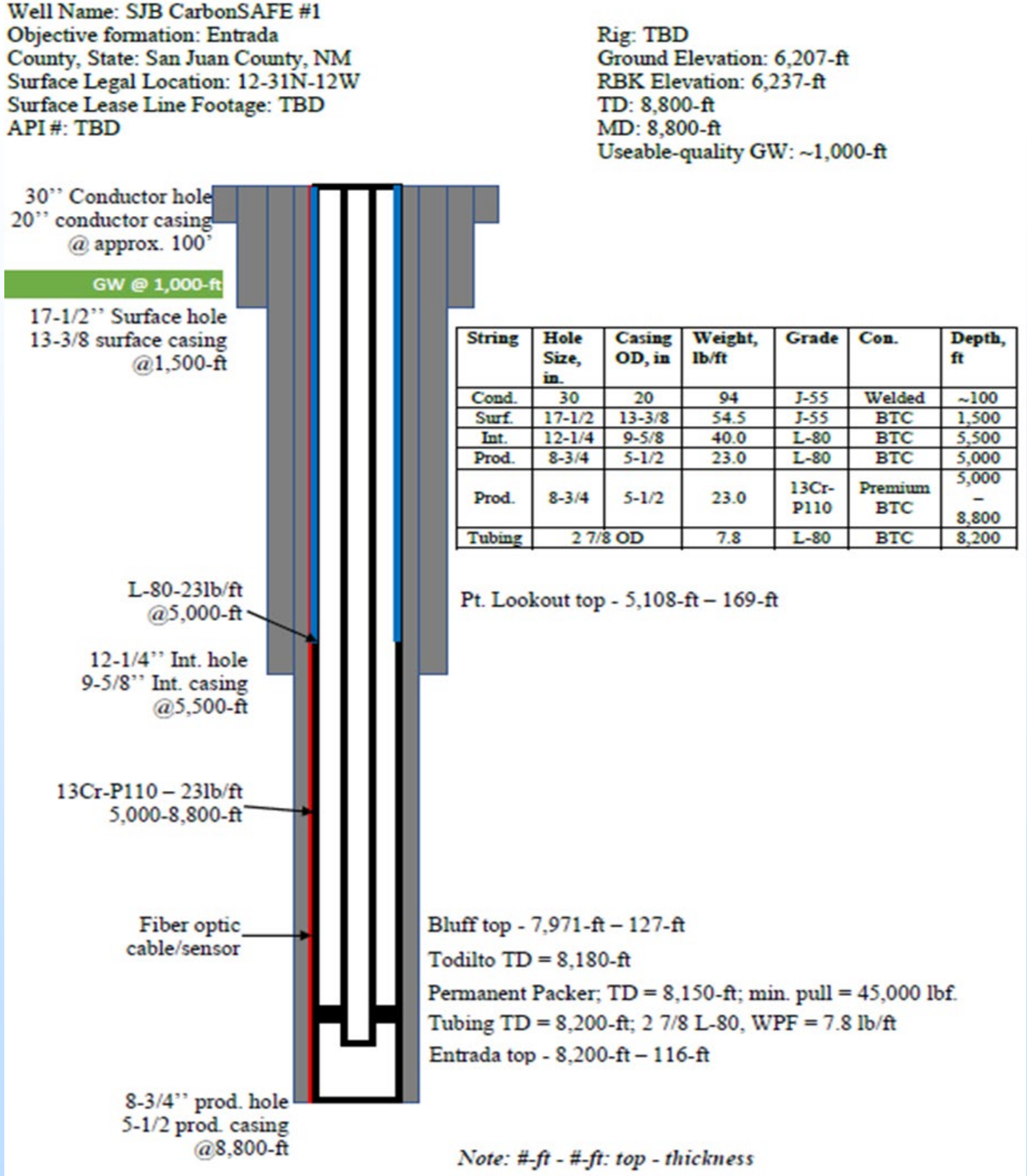
## Key Notes

- **Completion to Class VI Standard**

  The strat well even though permitted as class II, we plan to complete it to a class VI standard for potential future use

- **Fiber Optic Line**

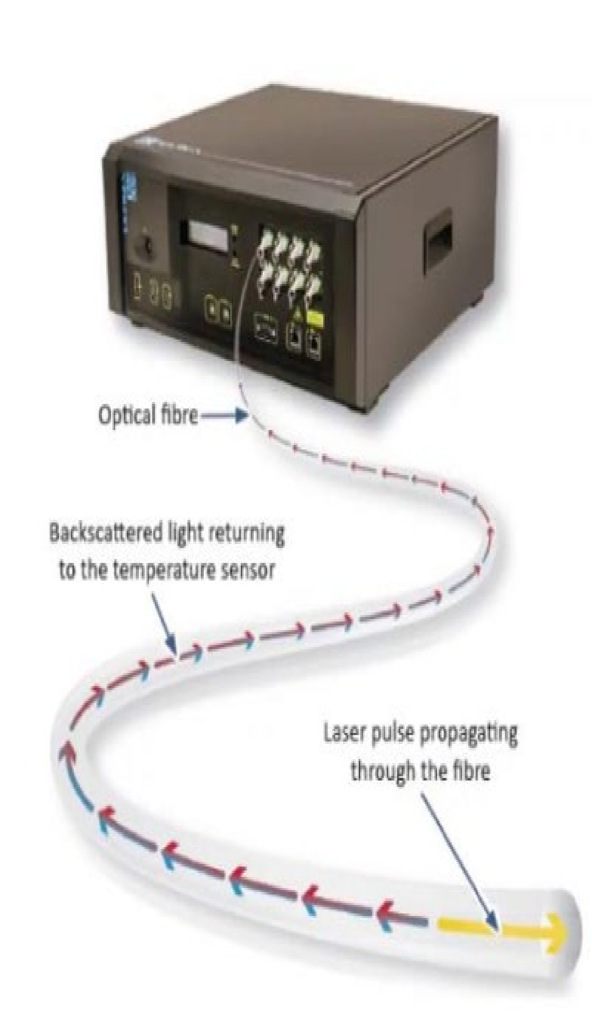
  Fiber optic line will be attached, along with downhole gauges, to the outside of the 5-1/2" casing to monitor the stress, pressure and temperature profiles along the wellbore.



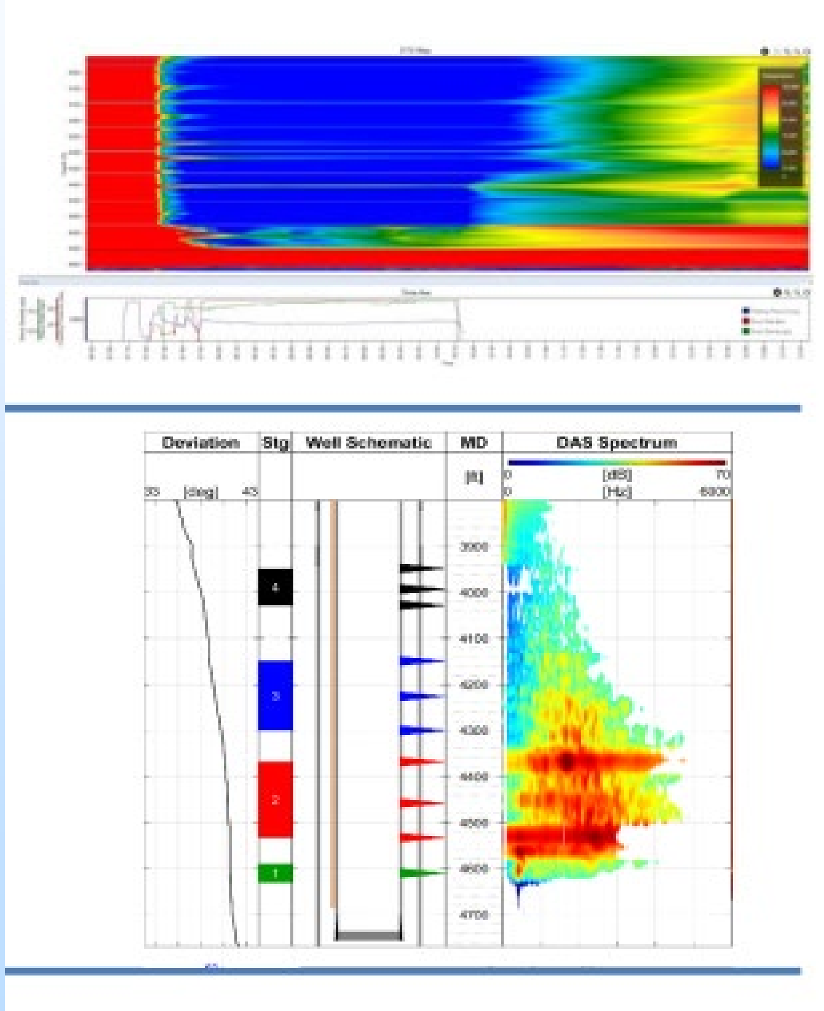

| String | Hole Size, in. | Casing OD, in | Weight, lb/ft | Grade | Con. | Depth, ft |
|---|---|---|---|---|---|---|
| Cond. | 30 | 20 | 94 | J-55 | Welded | ~100 |
| Surf. | 17-1/2 | 13-3/8 | 54.5 | J-55 | BTC | 1,500 |
| Int. | 12-1/4 | 9-5/8 | 40.0 | L-80 | BTC | 5,500 |
| Prod. | 8-3/4 | 5-1/2 | 23.0 | L-80 | BTC | 5,000 |
| Prod. | 8-3/4 | 5-1/2 | 23.0 | 13Cr-P110 | Premium BTC | 5,000 – 8,800 |
| Tubing | 2 7/8 OD | | 7.8 | L-80 | BTC | 8,200 |

# Silixa Distributed Optical Fiber Technology

## Fiber Optics Installation ➜ Monitoring Solutions ➜ Data Interpretation ➜ Assess Risks

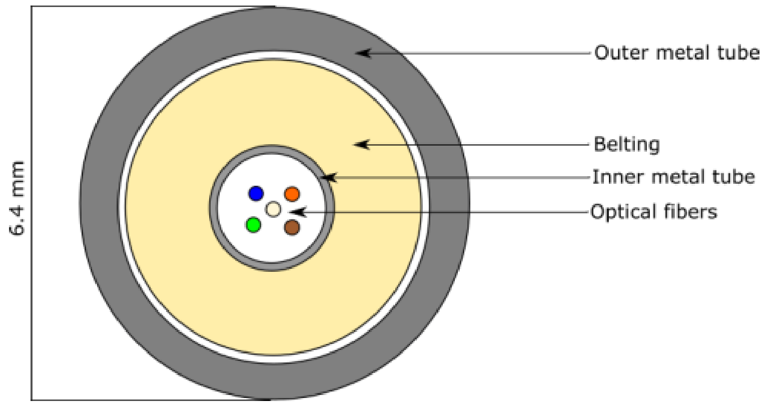







- Faults/Fractures Detection and Characterization
- Matrix/Fractures/ Faults Geomechanical Properties Evaluation
- Micro-seismicity Monitoring

# Downhole Fiber Optic Cable – A825 Outer Sheath




* Drawing not to scale

**Optical Details**

| Fiber Type | Multimode | | Singlemode | | Constellation |
|---|---|---|---|---|---|
| Fiber Count | 2 | | 2 | | 1 |
| Core Diameter | 50 µm | | 9 µm | | 9 µm |
| Cladding Diameter | 125 µm | | 125 µm | | 125 µm |
| Wavelength | 850 nm | 1300 nm | 1310 nm | 1550 nm | NA |
| Maximum Attenuation | 3.2 dB/km | 1.4 dB/Km | 0.72 dB/Km | 0.62 dB/Km | NA |





SILIXA actionable insight

# Scheduled Data Acquisition- Fiber Optic

The DTS, DSS, and DAS data acquisition plan includes:

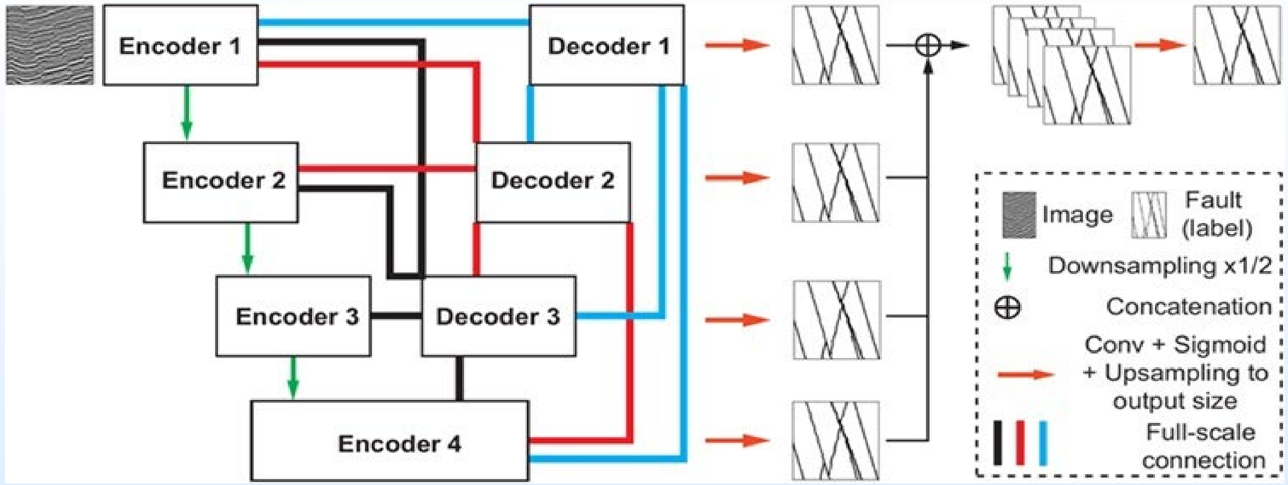
- Mobilization 1 – Fiber optic cable deployment
  - ➢ Measurements during fiber optic cable deployment to assess integrity of optical fibers using a portable optical time-domain reflectometer (OTDR).
  - ➢ DSS and DTS surveys after the cable reaches total depth and before the cementation process to assess the hole temperature profile, which can be used to inform the cement mixture.
  - ➢ DSS and DTS surveys during and after the cementation process to assess the cementation progress, final cement level, and cement curation process, which can be informative about the thermal and hydraulic properties of the formation.

# Scheduled Data Acquisition- Fiber Optic

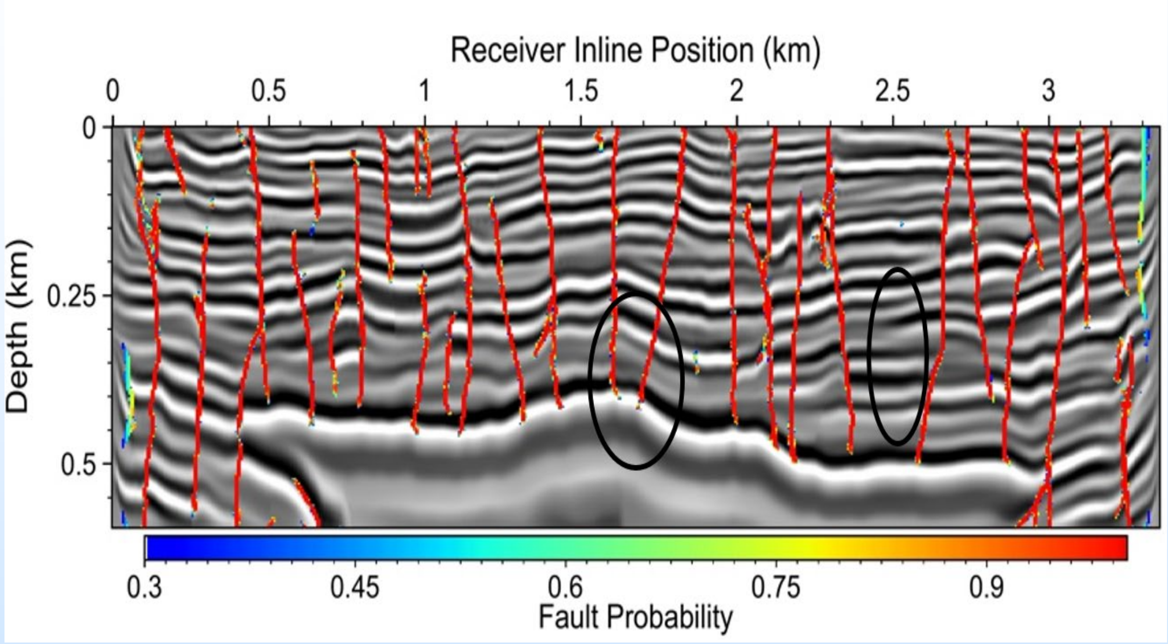
The DTS, DSS, and DAS data acquisition plan includes:

- Mobilization 2 – Baseline
  - Strain (DSS) baseline
  - Temperature (DTS) baseline
  - Acoustic (DAS) baseline (ambient noise log)
  - Seismicity baseline
  - Continuous monitoring during DFIT using DTS, DSS, DAS

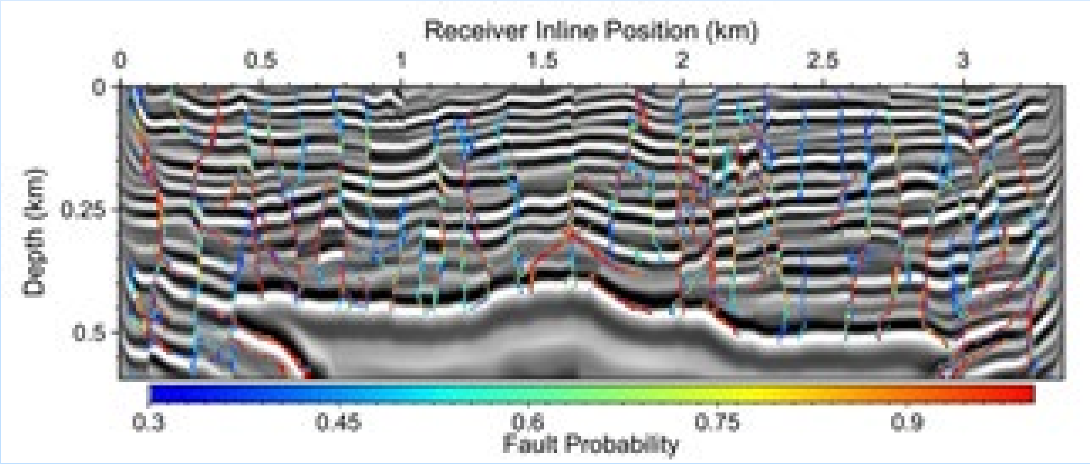
# LANL Multiscale Connection-fusion U-shaped Convolutional Neural Network (MCFU)




Architecture of multiscale connection-fusion convolutional neural network method (MCFU).




Fault Segmentation from Seismic Image via MCFU



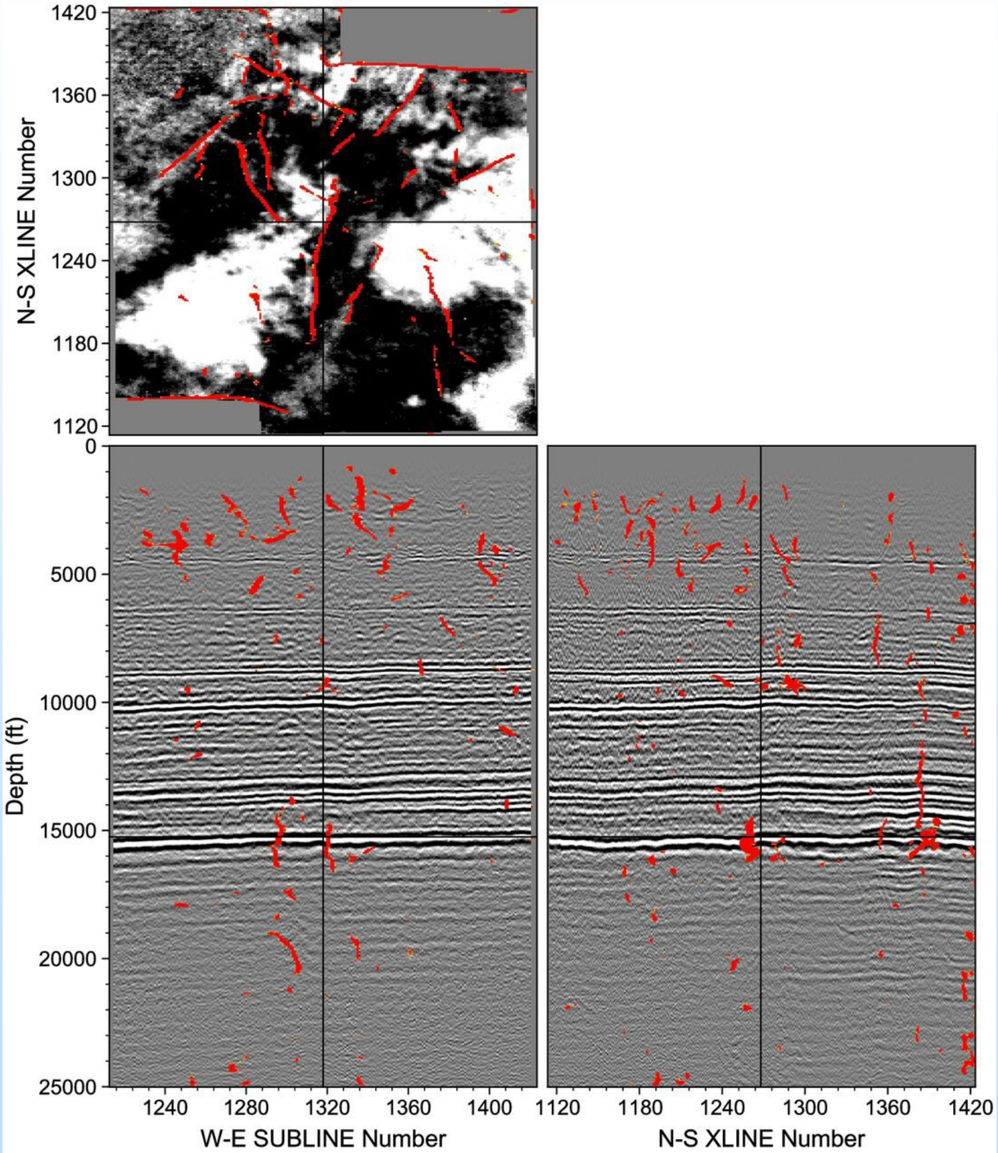

Ant tracking

## Technology Advantages

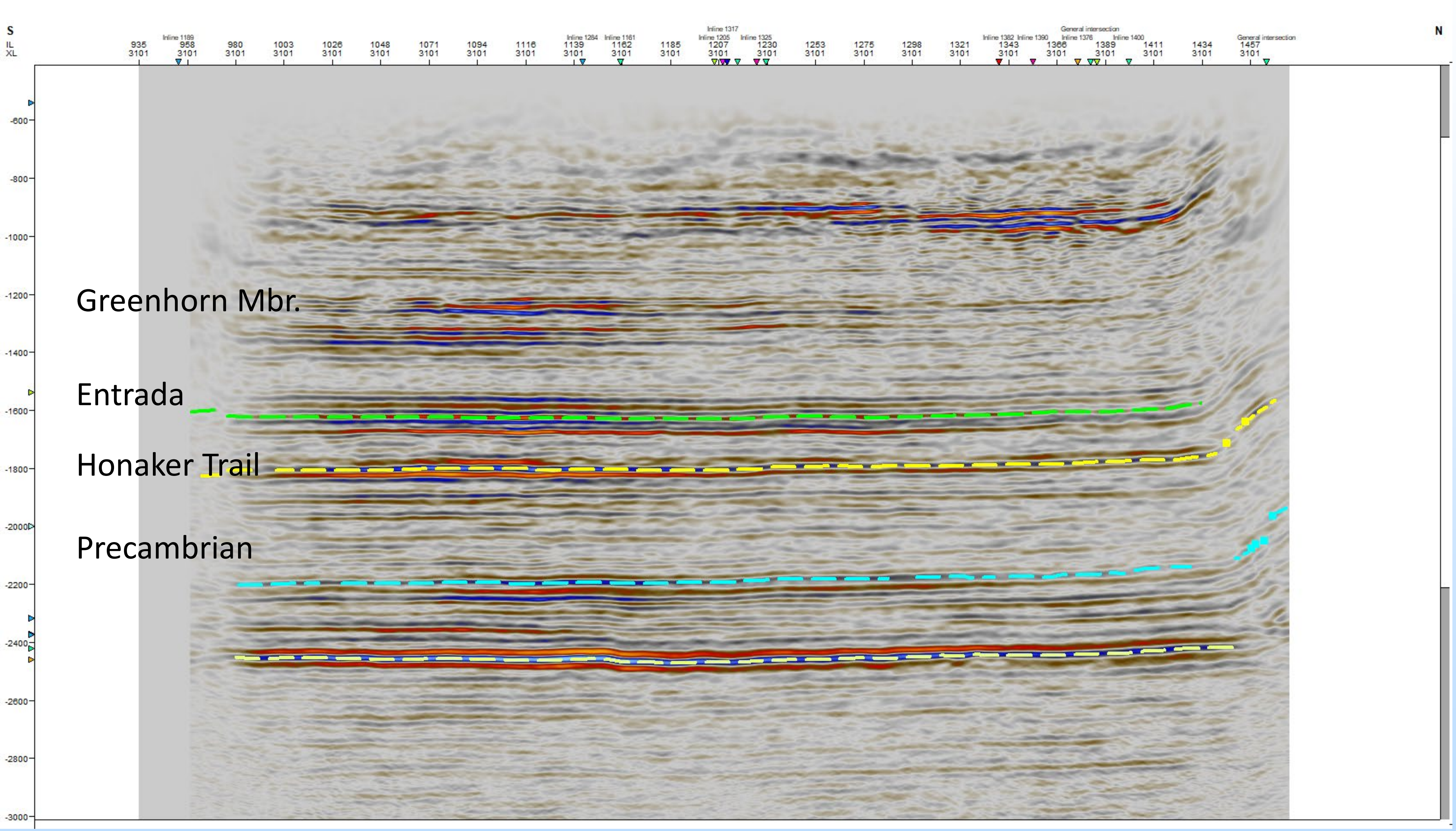
- Improved in Faults Detection
- Reliable Large-scale Fault Mapping
- Enhanced Cost Efficiency

# Machine Learning Fault Detection: Preliminary Result

Machine learning fault detection on a depth-converted 3D volume of a 3D prestack time migration image showing that there is no major fault at the project site.

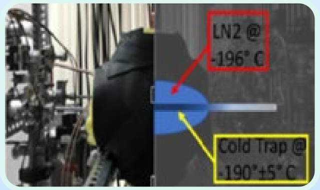


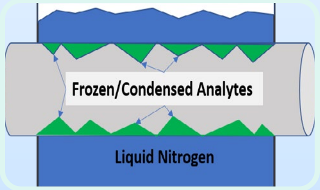
# 3D Surface Seismic, Before and after Reprocessing

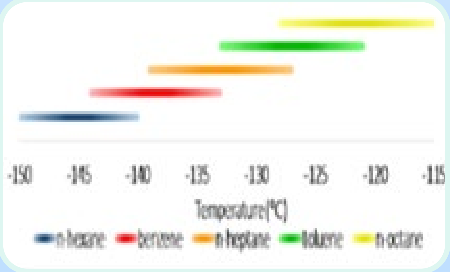


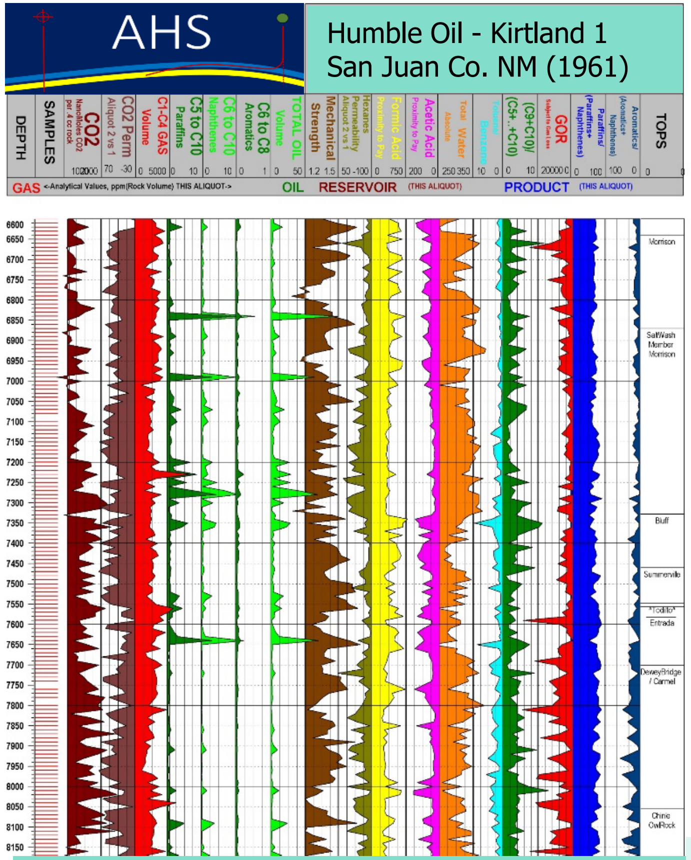
# AHS Rock Volatiles CCS Well Site Evaluation

## Analyze Rock Volatiles → Analyze Nearby Well → Assess Risks



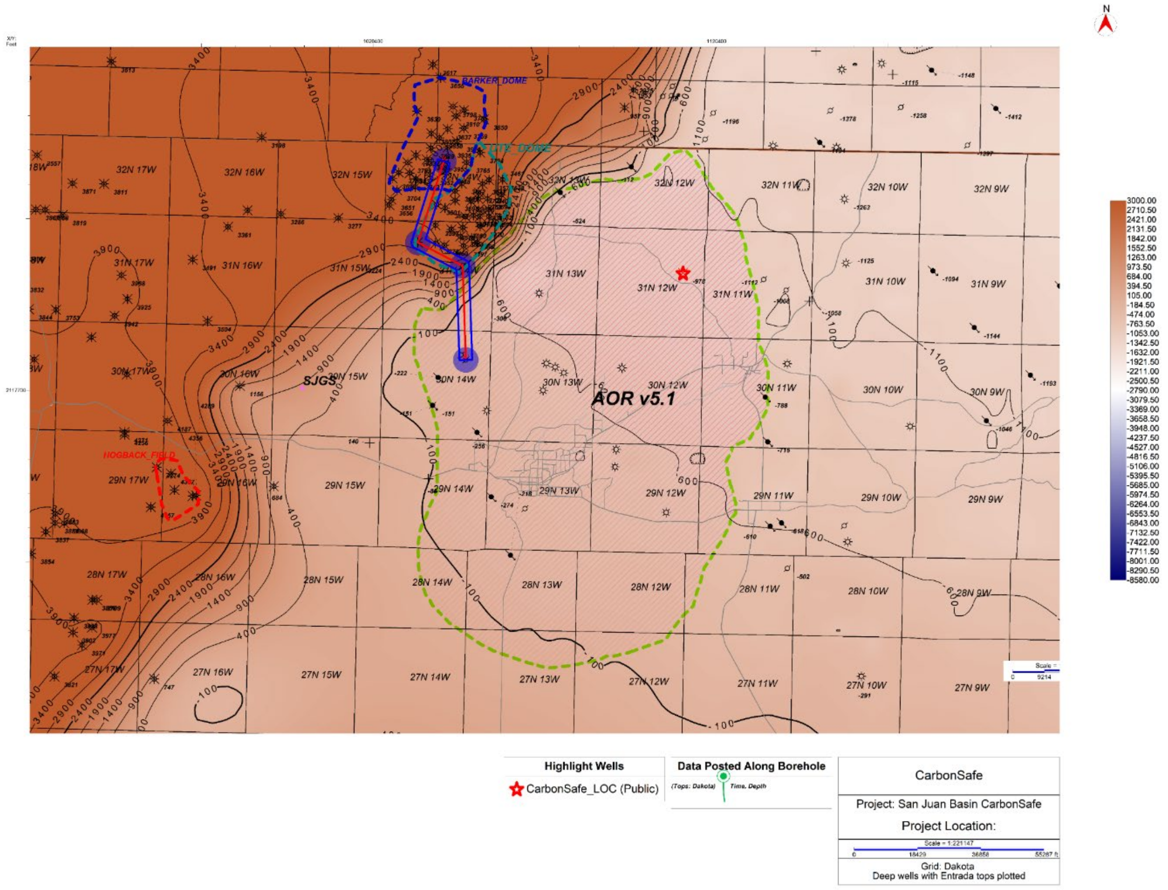



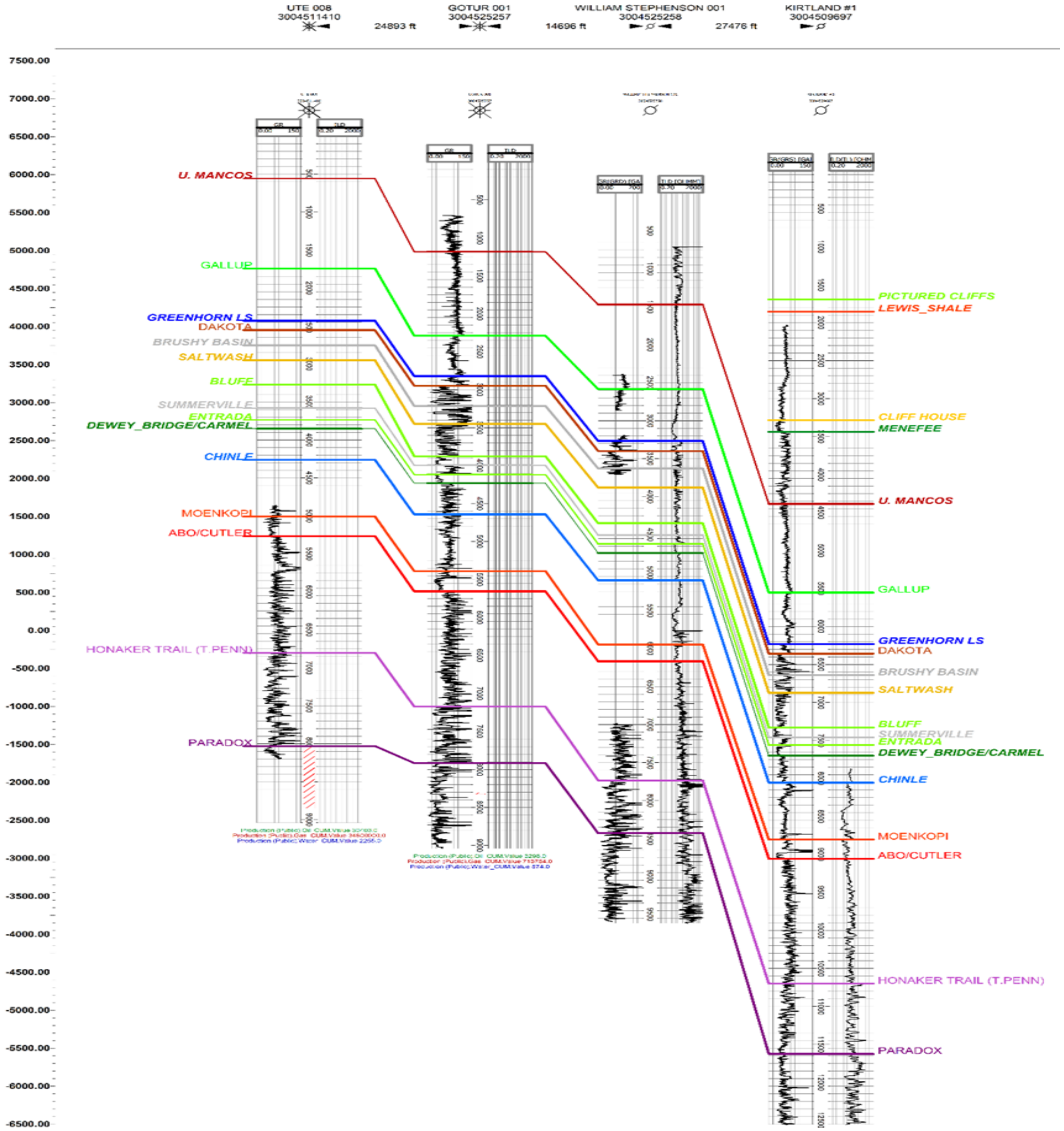




Kirtland 1; 14 miles SSW of CarbonSAFE1 Site

- Faults/Fractures
- Fault Activating
- Fluid Conduits
- $CO_2$ Seals
- $CO_2$ Permeability
- Past $CO_2$ Loss
- Future $CO_2$ Loss

# Cuttings Sampling for AHS Analysis



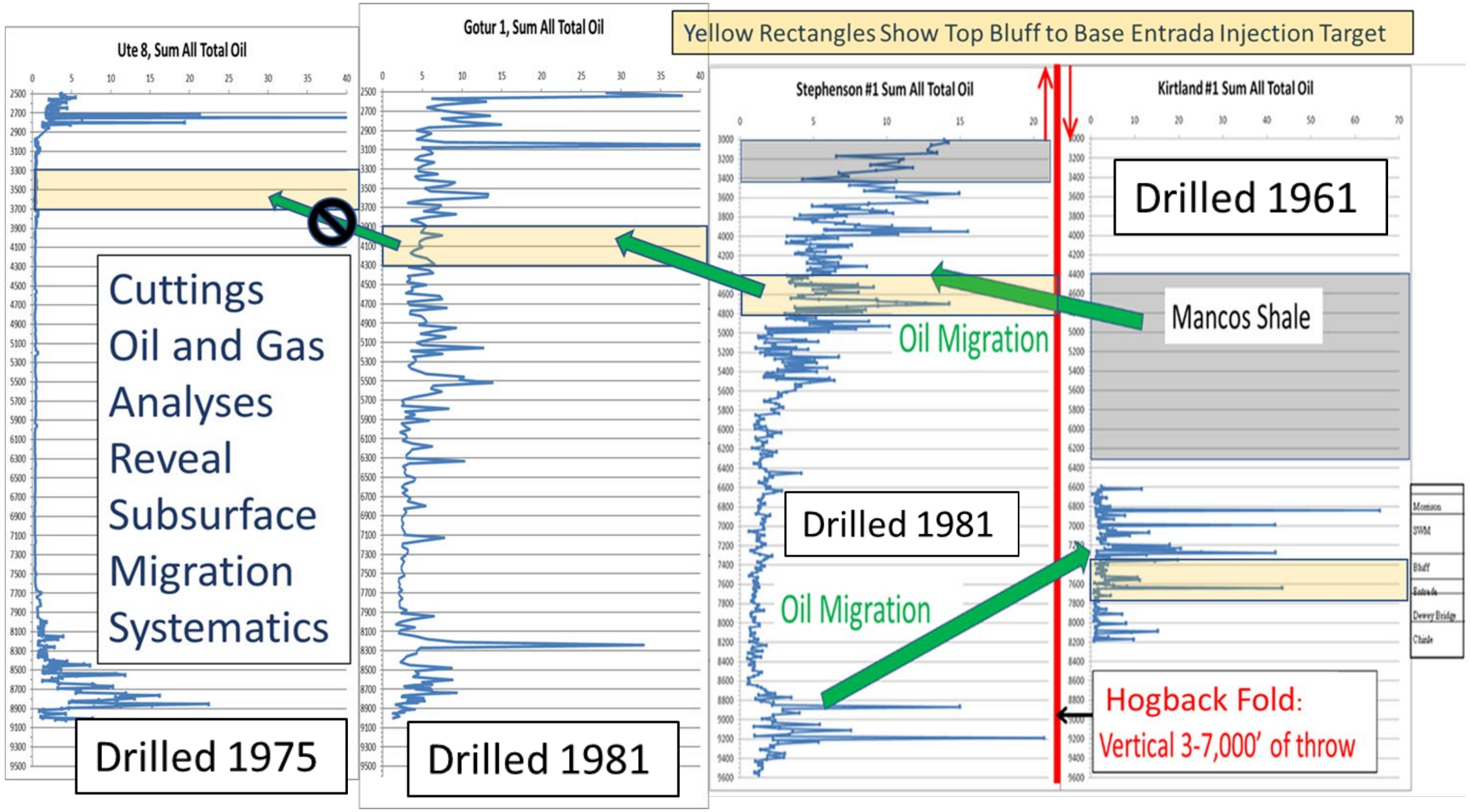




# 4 Legacy Wells’ Cuttings Analyzed

# SJB Fluid Migration from Legacy Cuttings Volatiles

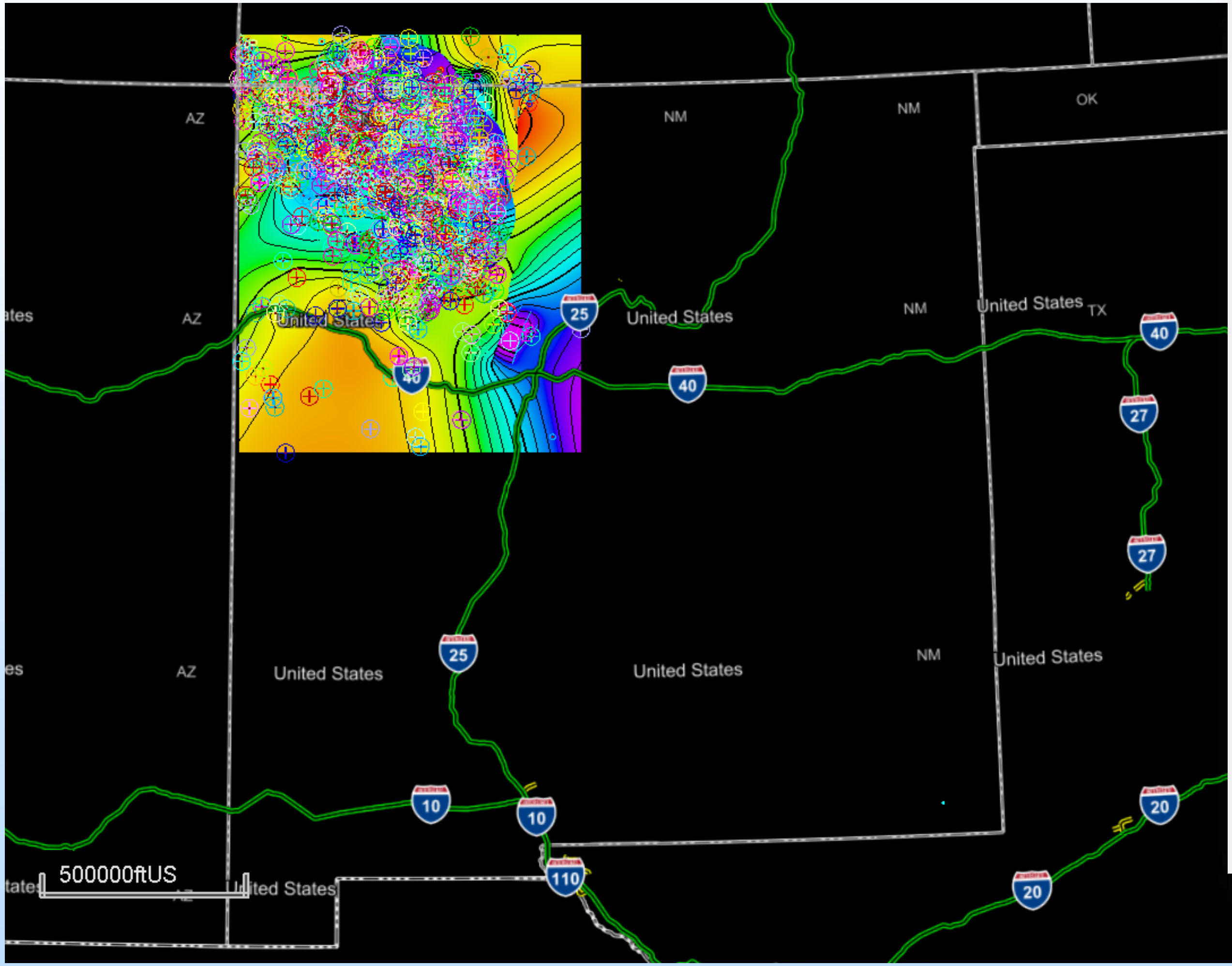
ADVANCED HYDROCARBON STRATIGRAPHY

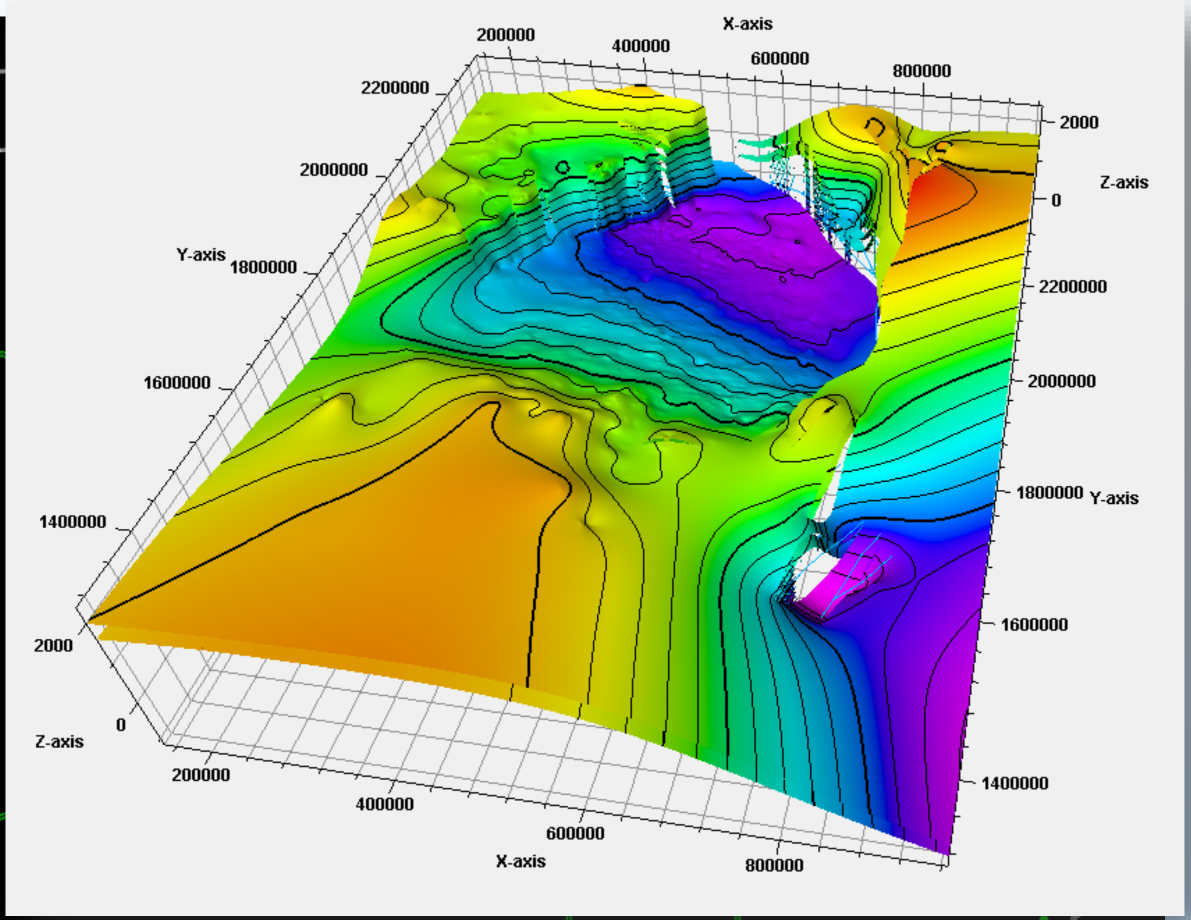
- Gentle Cryo-Trap Volatiles Analyses, Maps Fluid Migration From Legacy Drill Cuttings.
- Migrated Oil and Condensate Occur as Data Spikes
- No Relationship to Stratigraphy or Lithology,
- Potential Fracture Migration.



# San Juan Basin Geological Modeling

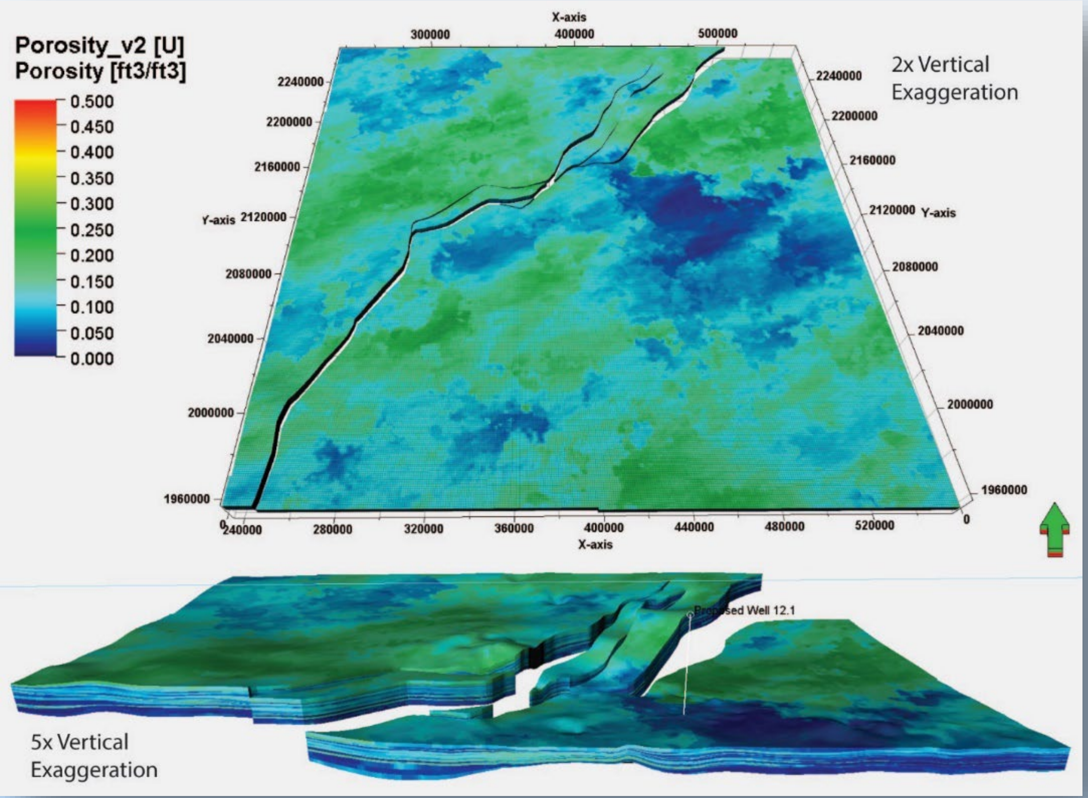
- More than 2200 well tops so far



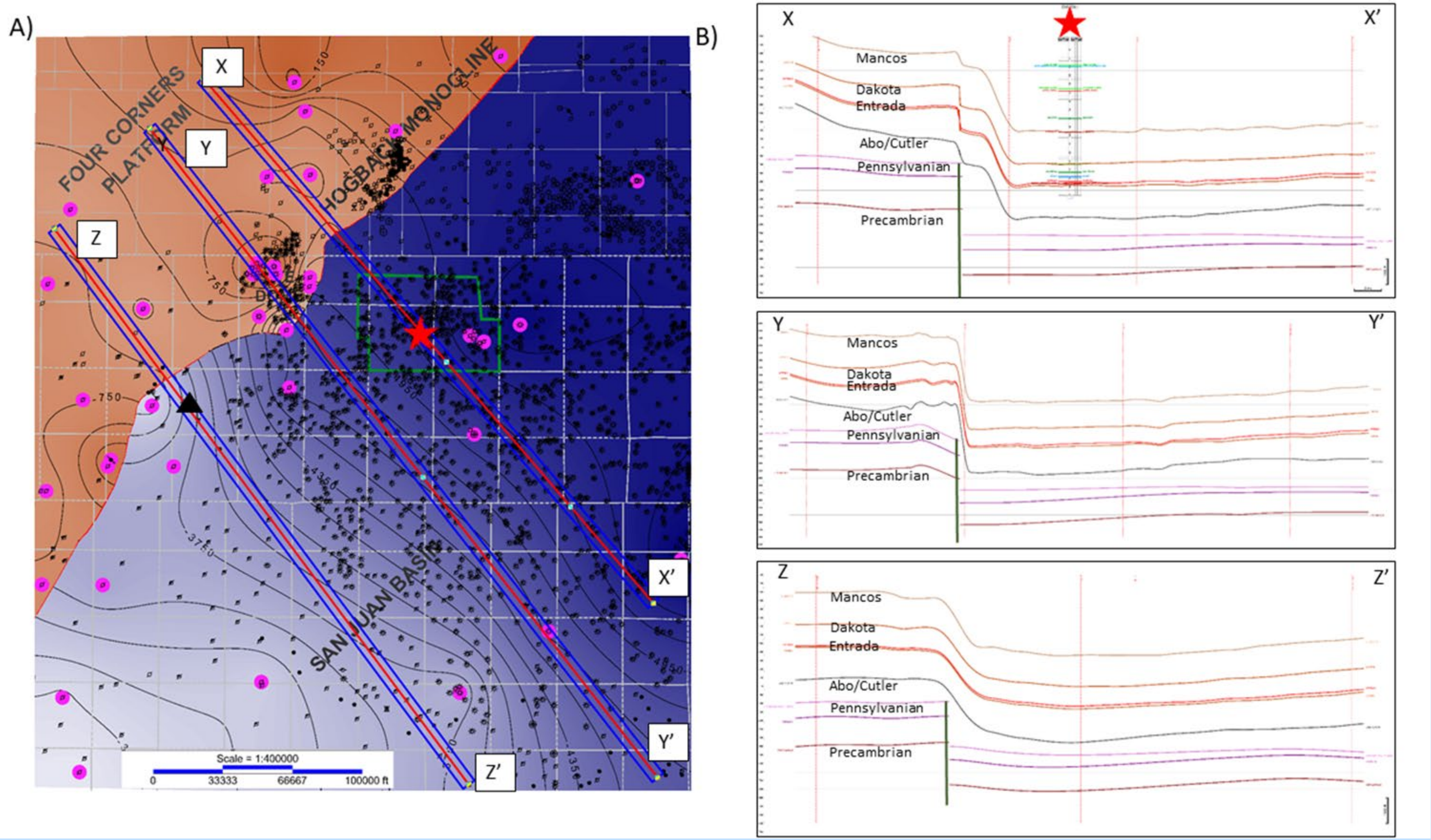
# SJB CarbonSafe Geomodel

- Grid cells (nI x nJ x nK): 322 x 321x 29
- Total number of grid cells: 2,886,660
- X (ft.): 235356.12 ~ 555976.40 ->320620.28 ft. (**60.72** miles)
- Y (ft.): 1957320.33 ~ 2278308.71-> 320988.38 ft. (**60.79** miles)
- CRS: NM-W:NAD27 New Mexico State Planes, Western Zone, US Foot




| Layer No. | Formation |
|---|---|
| 1 | Dakota |
| 2 | Brushy Basin |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | Salt Wash |
| 8 | |
| 9 | |
| 10 | |
| 11 | |
| 12 | Bluff |
| 13 | |
| 14 | |
| 15 | |
| 16 | |
| 17 | Summerville |
| 18 | |
| 19 | |
| 20 | |
| 21 | Todilto |
| 22 | |
| 23 | Entrada |
| 24 | |
| 25 | |
| 26 | |
| 27 | Camel |
| 28 | |
| 29 | |

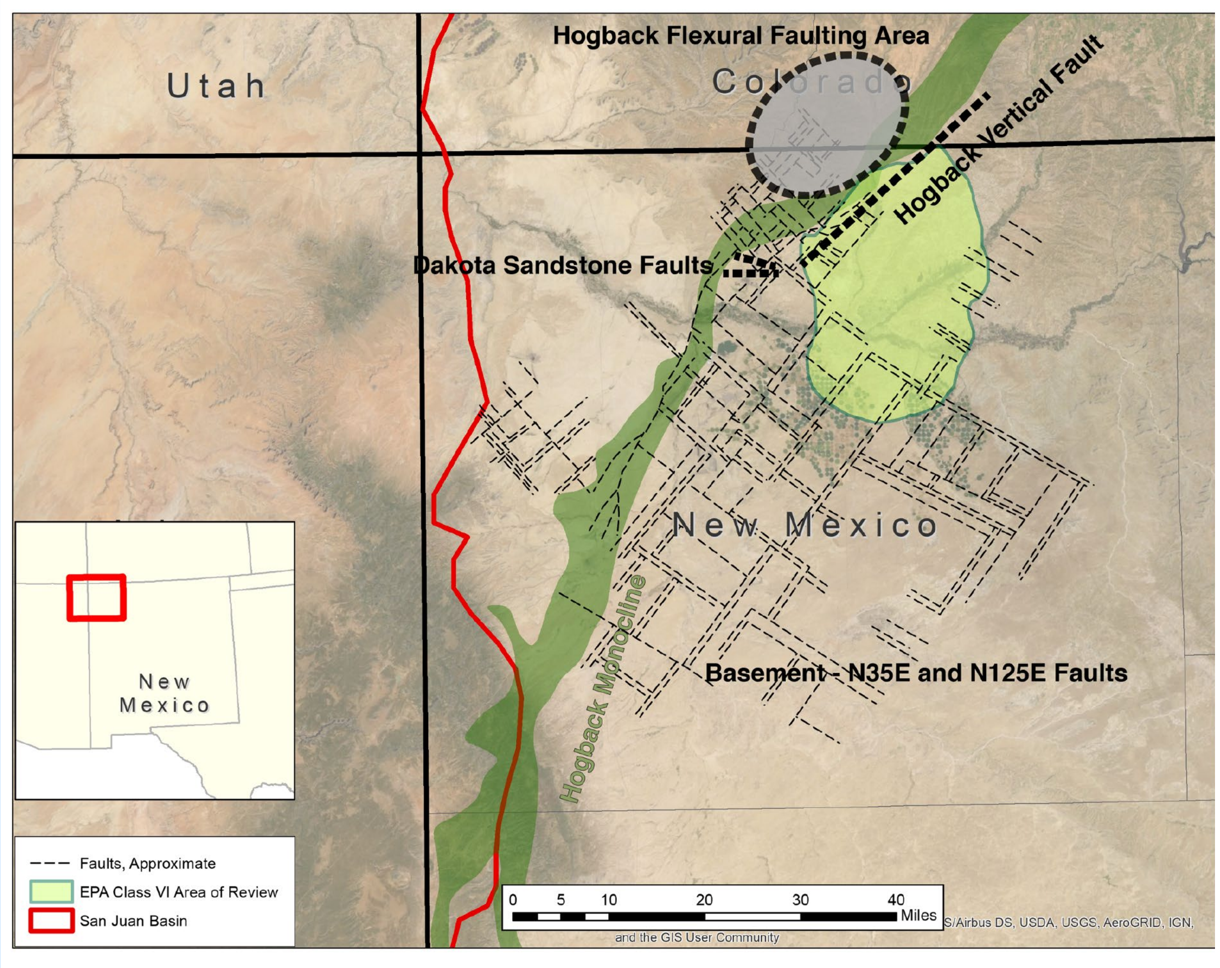
# San Juan Basin Geology

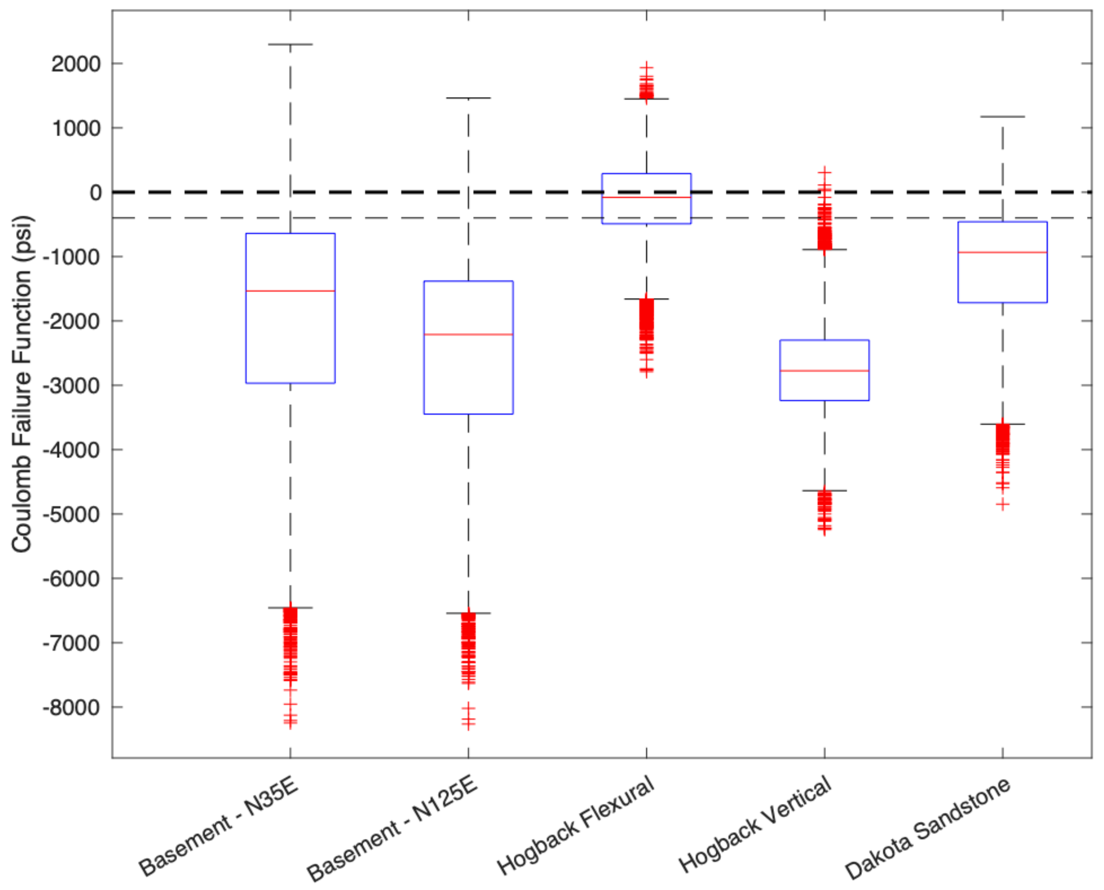



A) SSTVD structure map of the topo of the Honaker Trail Formation with locations of structural sections X, Y, and Z

B) Cross sections X, Y, Z (10x vertical exaggeration) with key formation grids visible

# In previous work, we identified the seismic risk using a single planar model



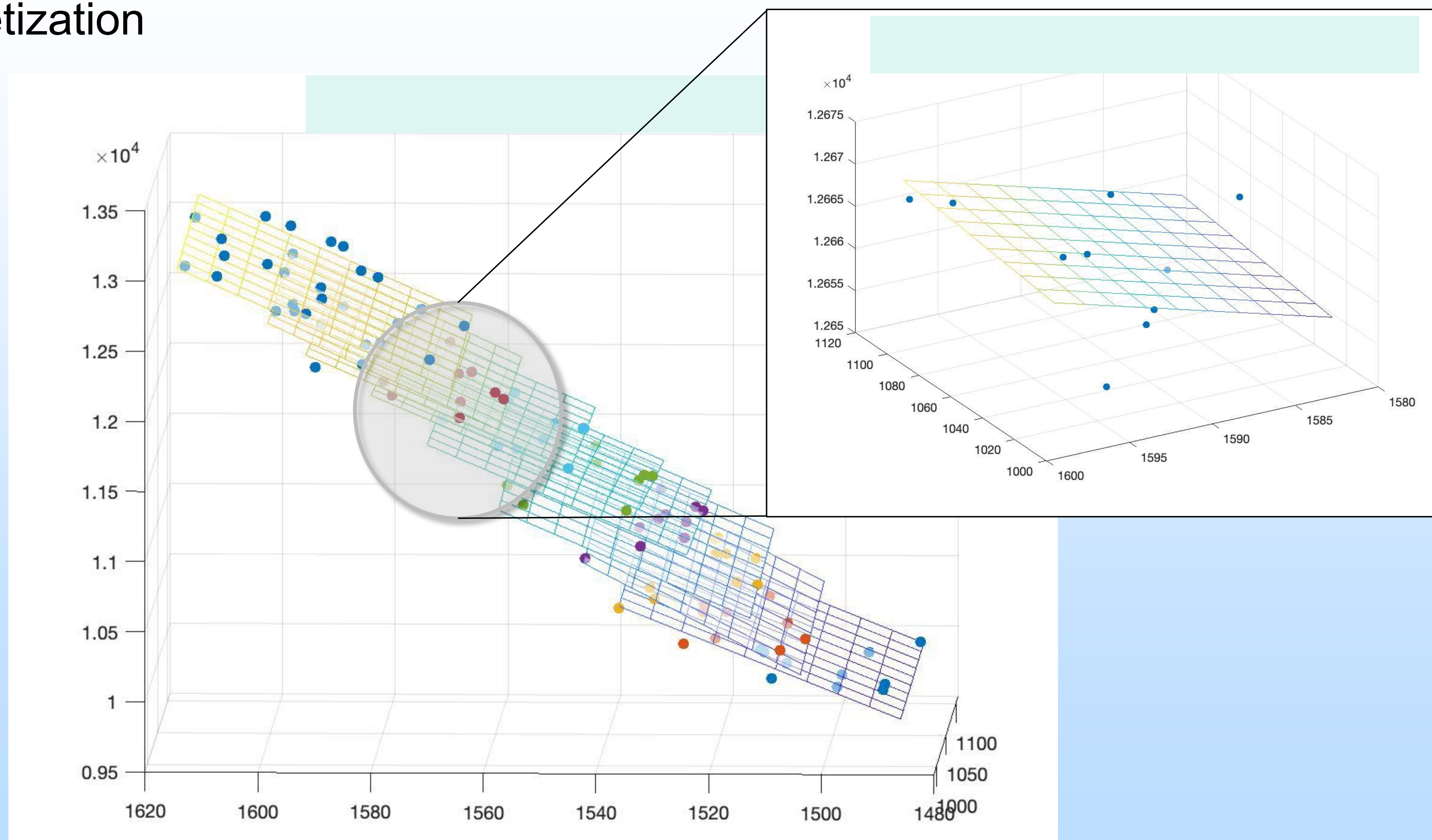




McCormack et al. (2022)

# We are improving our understanding of risk through discretization

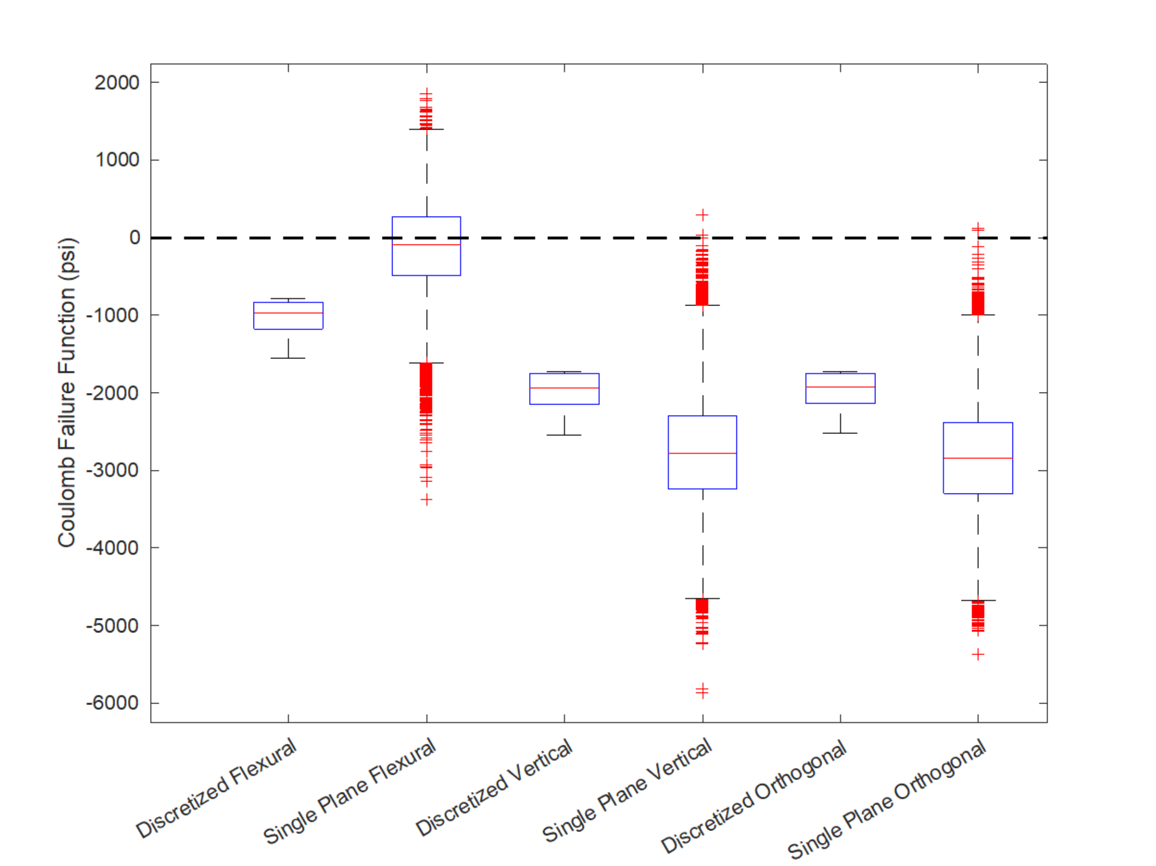
The search radius is placed at many locations

A planar regression elucidates the discrete fault patch

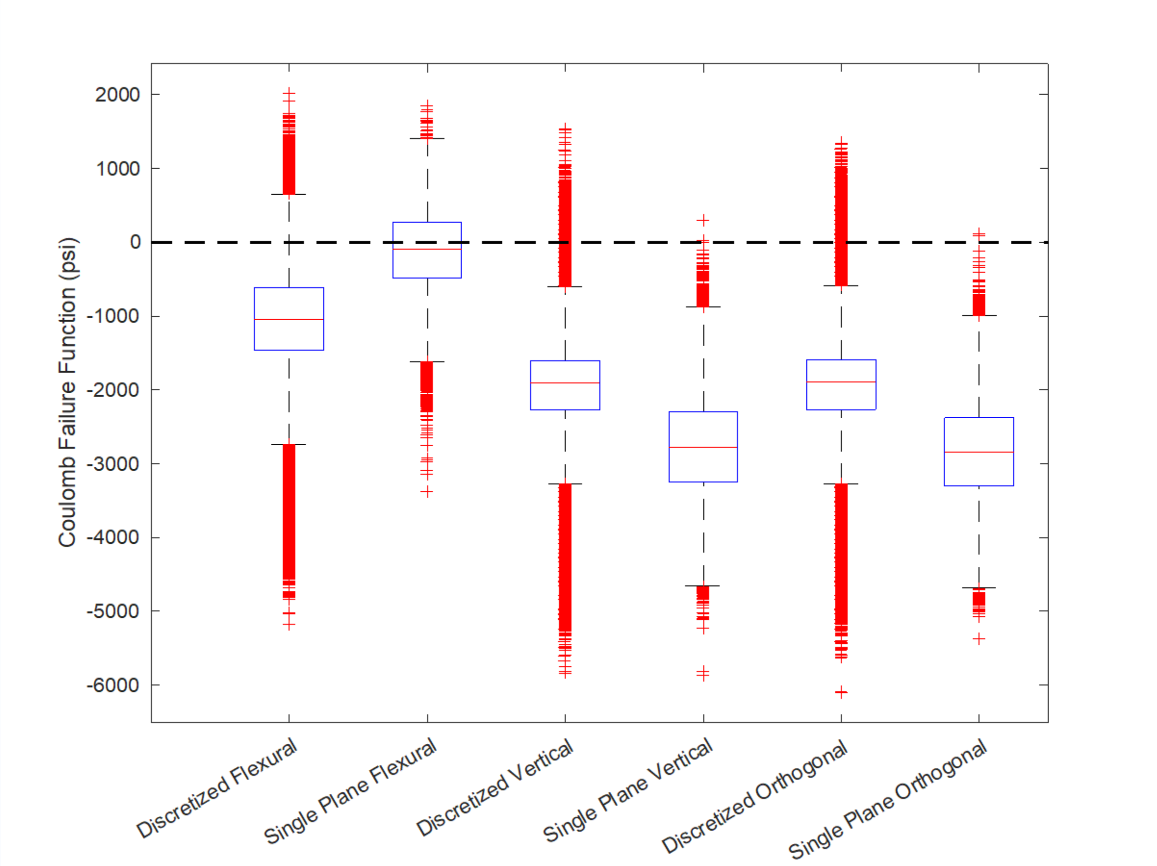


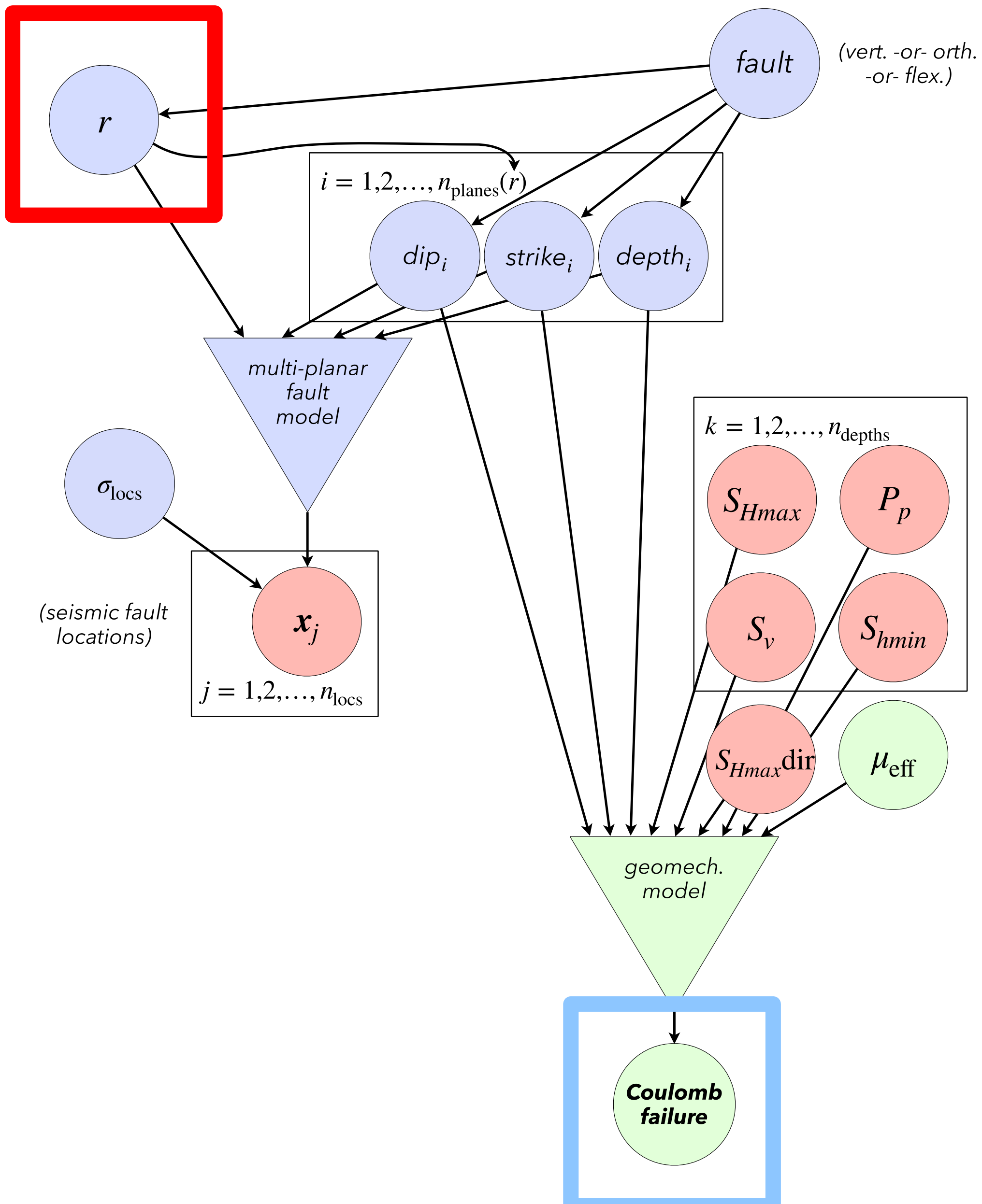
We ran the analysis for three faults in the case of both discretization and a single planar model

Median values for each point in the fault model




All the realizations for each point in each model






We are formulating the problem in a Bayesian framework

We want to understand the Impact discretization (r) has on
Coulomb Failure Function (CFF)

# Summary Slide

- The project management team completed the technology maturation plan and received the approval from the DOE.
- The downhole Fiber Optic cable was successfully manufactured and the clamps utilized during the cable installation was secured.
- Over 1,161 well cuttings from four legacy wells close to the proposed SJB CarbonSAFE III site has been identified and analyzed geochemically through the RVStrat technology.
- The concepts and mathematics involved in viscoplastic stress relaxation theory was constructed to interpret the log data for fault detection and characterization.
- The preliminary analysis using machine learning techniques did not identity any major fault within the current 3D seismic volume.
- The faults orthogonal to the Hogback Fault had been interpreted by the Monte Carlo Mohr-Coulomb simulations.
- The fault polygons for the hogback fault system as well as other basement faulting system in the area has been identified and the static geological and hydrodynamic flow model was completed.
- The training on advanced modeling tools, including dfnWorks, Hoss, and Amanzi, for the hazard assessment have been completed.

# Next Steps- DfnWorks

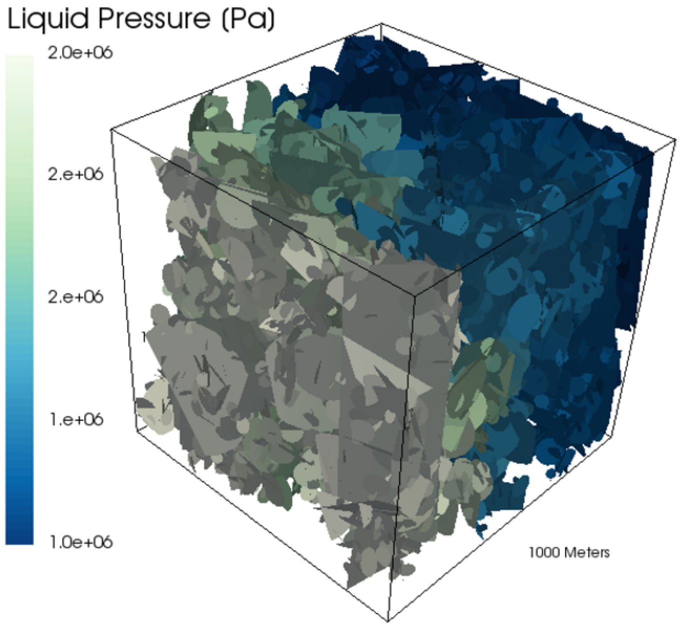
dfnGen → dfnFlow → dfnTrans

dfnFlow:

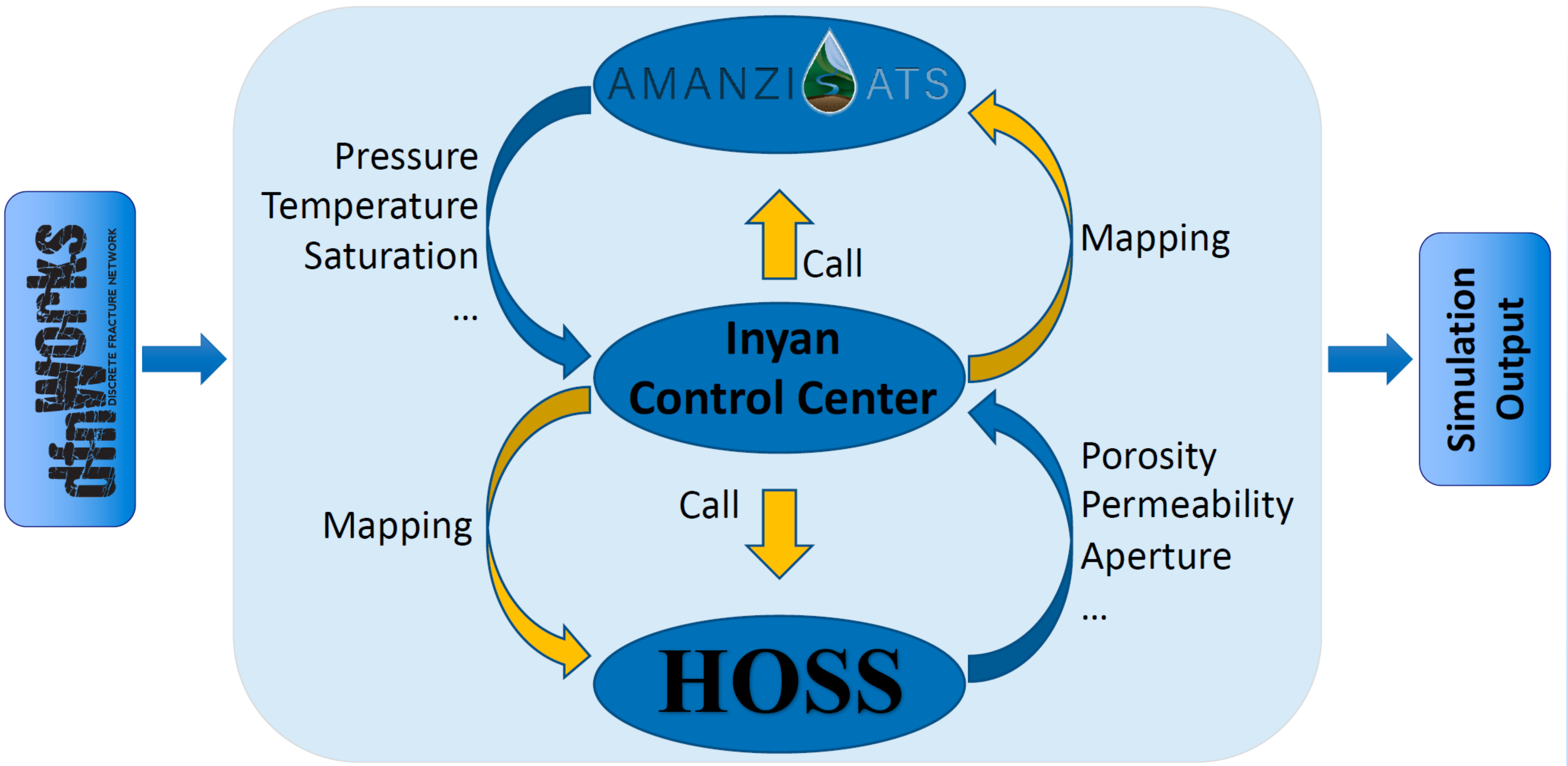
1) PFLOTRAN
2) FEHM
3) AMANZI

dfnTrans:

1) Advection-Dispersion
2) Particles
3) Pipe-Network



# Next Step- Coupled Modeling Workflow



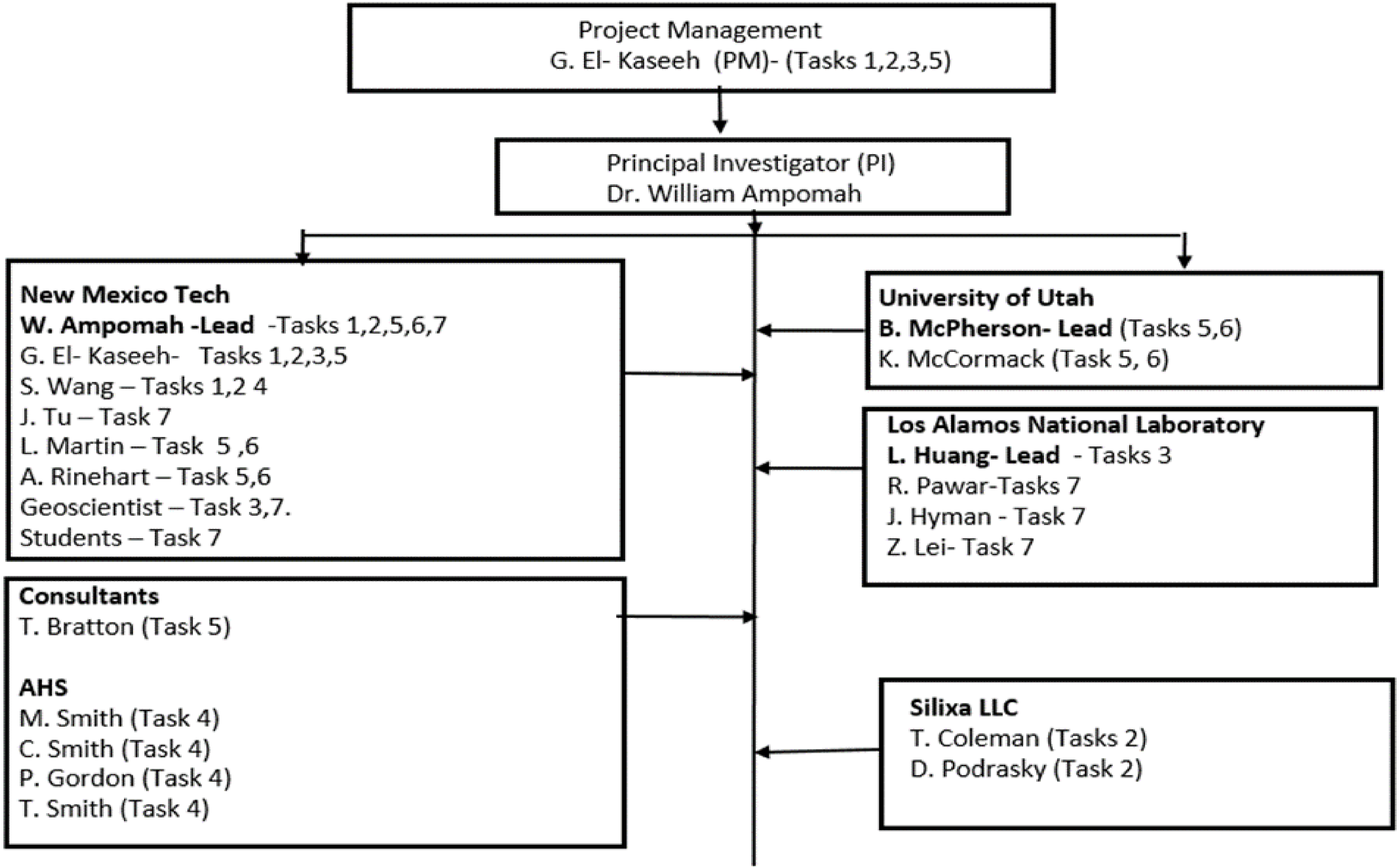
# Acknowledgements

The project would like to thank DOE for the award opportunity through DE-FE0032064 and our partners. We would like to acknowledge additional support from San Juan Basin CarbonSAFE project.

# Appendix

- These slides will not be discussed during the presentation but are mandatory.

# Organization Chart



# Proposed Schedule

| Tasks | | Project Year 1 | | | | | | | | | | | | Project Year 2 | | | | | | | | | | | | Project Year 3 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 |
| **Task 1.0** | **Project Management and Planning** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Subtask 1.2** | **Technology Maturation Plan** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 2.0** | **Deployment of Field Technology/Data Collection** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 2.1* | Review of Well Design | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 2.2* | Deployment of the DSS/DAS/DTS Fiber Optic Cable | | | | | | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 2.3* | Data Acquisition | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 2.4* | Cutting Sample Collection and Pretreatment | | | | | | | M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 3.0** | **Seismic Analysis for Fault Detection** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 3.1* | Machine Learning Fault Detection of Surface Seismic Image | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | | | | | | | | |
| *Subtask 3.2* | Machine Learning Fault Detection of VSP Images and VSP-DAS Images | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 3.3* | Comparison with Industry Standard Seismic Fault Detection | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 4.0** | **Geochemical Analysis for Fault Detection and Characterization** | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | | | | | | | | |
| *Subtask 4.1* | Historical Sample Analysis | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 4.2* | Volatiles Identification and Quantification | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 4.3* | Bulk Mechanical Strength Measurements | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 4.4* | Integration of well log and RVstrat Analysis | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 5.0** | **Wellbore Analysis for Fault Detection and Characterization** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 5.1* | Fault and Fracture Detection using Wellbore Images | | | | | | | | | | | | M | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 5.2* | Fault and Fracture Detection using BARS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 5.3* | DFIT Analysis to Quantify Minimum Horizontal Stress, Pore Pressure, and Matrix Permeability | | | | | | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | | | |
| *Subtask 5.4* | Viscoplastic Minimum Principal Stress Estimation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 5.5* | Strain Modeling with Finite Element Analysis | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 6.0** | **Fault Slip/Activation Analysis** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 6.1* | Compile Stress Information | | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | | | | | | | |
| *Subtask 6.2* | Compile Fault Information | | | | | | | | | | | | | | | | | | | | | | | | | | | | | M | | | | | | | |
| *Subtask 6.3* | Compute Coulomb Failure Function | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Task 7.0** | **Integrated Modeling for Hazard Assessment** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.1* | Geological/Static Modeling | | | | | | | | | | | | | | | | | | | | M | | | | | | | | | | | | | | | | |
| *Subtask 7.1.1* | Geologic Structural and Stratigraphic Framework | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.1.2* | 3D Hydrodynamic and Mechanical Model | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.1.3* | Fracture Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.1.4* | Fault Transmissibility Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.2* | Advanced Rock Physics Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.2.1* | Verify the presence of fractures in caprocks | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.2.2* | Develop combined rock physics model | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.3* | Advanced Numerical Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Subtask 7.3.1* | Hydrodynamic Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | M | | |
| *Subtask 7.3.2* | Coupled Thermo-hydrodynamic-Mechanical Modeling | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Outer Sheath: A825 Alloy Performance in Comparison to 316SS

- Primary protection of fibers provided by outer sheath, 0.25" OD, 0.035" thick A825 Alloy continuous tube (sometimes called Incoloy)

- Developed for **high corrosion resistance** at high T, particularly low/high pH solutions & chloride stress corrosion (*significantly higher performance than 316SS*).

- High performance in high T environment, less than a 5% tensile strength reduction at 500 C. Considerably stronger than 316 SS.

*[data from Sandmeyer Steel Corp & Special Metals Inc.]*

**Resistance to Laboratory Sulfuric Acid Solutions**

| Alloy | Corrosion Rate in Boiling Laboratory Sulfuric Acid Solution Mils/Year (mm/a) | | |
|---|---|---|---|
| | 10% | 40% | 50% |
| 316 | 636 (16.2) | >1000 (>25) | >1000 (>25) |
| 825 | 20 (0.5) | 11 (0.28) | 20 (0.5) |
| 625 | 20 (0.5) | Not Tested | 17 (0.4) |

**Resistance to Chloride Stress Corrosion Cracking**

| Test (U-Bend Samples) | Alloy | | | |
|---|---|---|---|---|
| | 316 | SSC-6MO | 825 | 625 |
| 42% Magnesium Chloride (Boiling) | Fail | Mixed | Mixed | Resist |
| 33% Lithium Chloride (Boiling) | Fail | Resist | Resist | Resist |
| 26% Sodium Chloride (Boiling) | Fail | Resist | Resist | Resist |

Mixed - A portion of the samples tested failed in the 2000 hour of test. This is an indication of a high level of resistance.

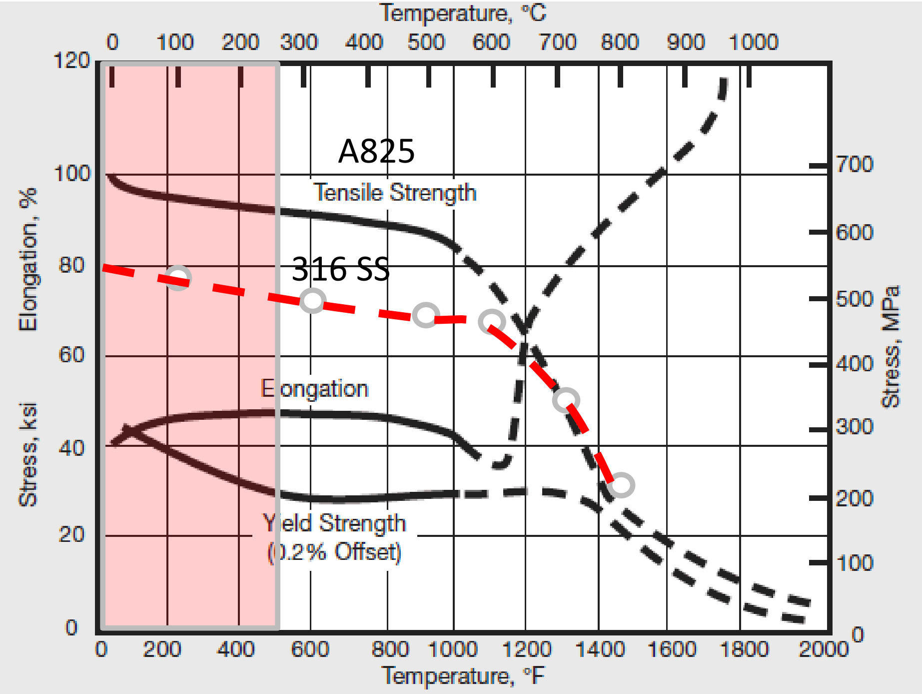



**Figure 1.** High-temperature tensile properties of annealed bar. ▬ Indicates the typical usage range.