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

DE-FE0032064

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 28 – September 1, 2023

Project Participants

- **NMT**
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- Dr. Sai Wang
- Mr. George El-kaseeh
- Mr. Luke Martin
- Dr. Alex Rinehart
- Dr. Jiawei Tu
- Dr. Adewale Amosu
- 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**
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- Dr. Zhou Lei
- Dr. Rajesh Pawar
- Dr. Konstantin Lipnikov

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– 03/30/2025

	BP1 07/01/21 - 03/31/23		BP2 04/01/23 - 03/30/24		BP3 04/01/24 - 03/31/25		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 project will 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.

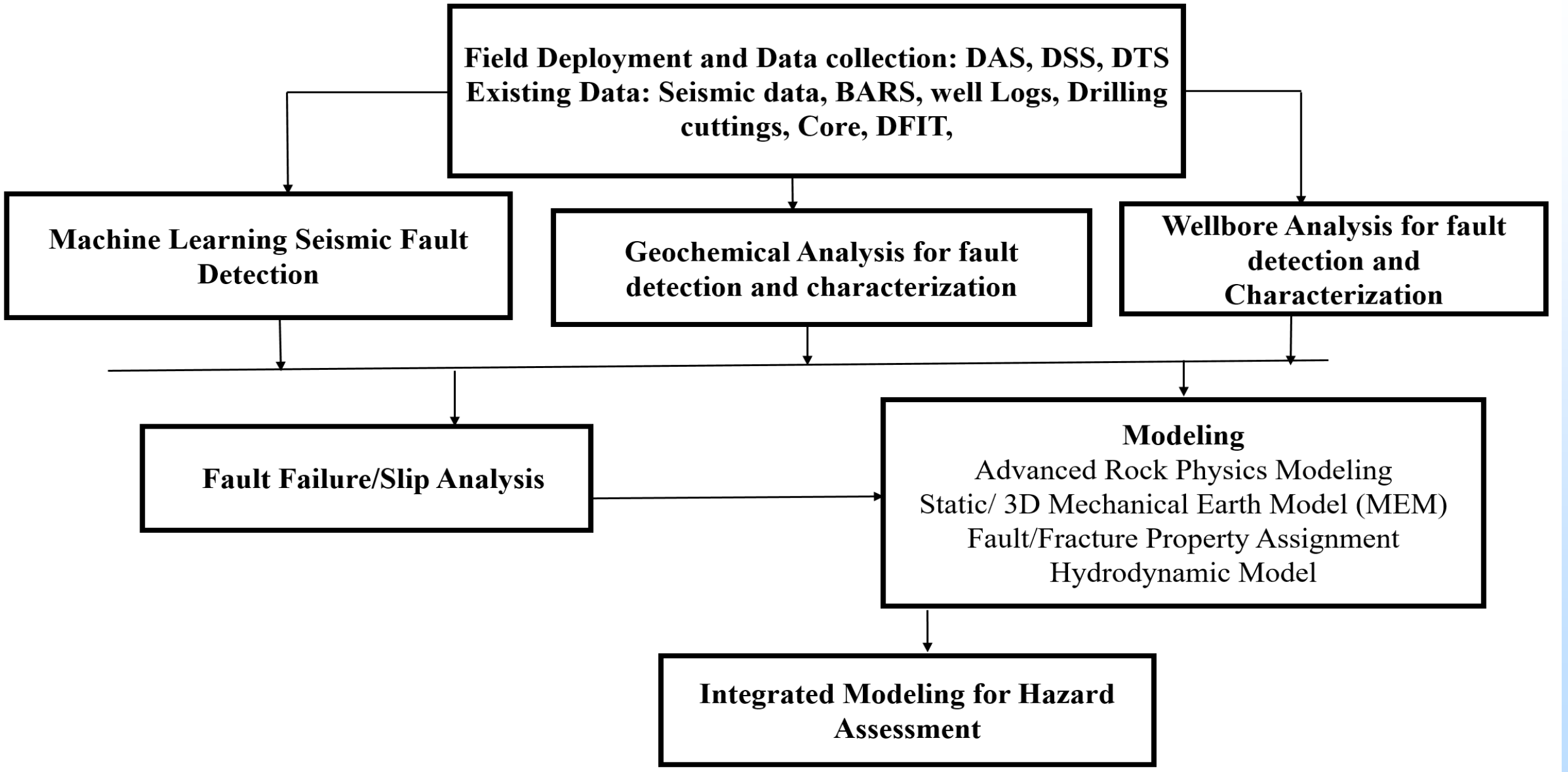
- To employ Rock Volatile Stratigraphy (RVStrat), a novel geochemical technology that uses drill cuttings and core, to locate faults (including aseismic faults) and estimate their sizes and orientations.

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.

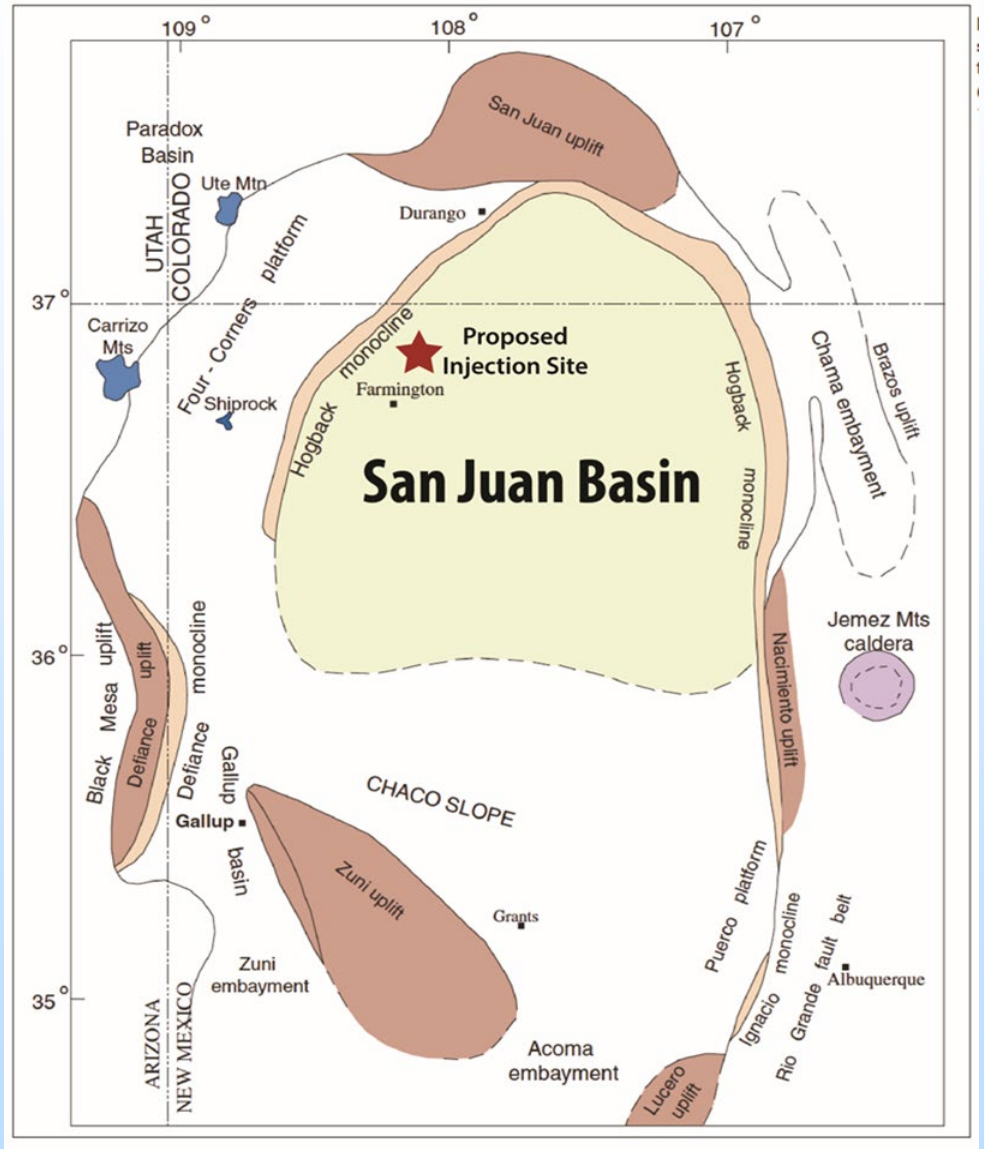
Project Approach

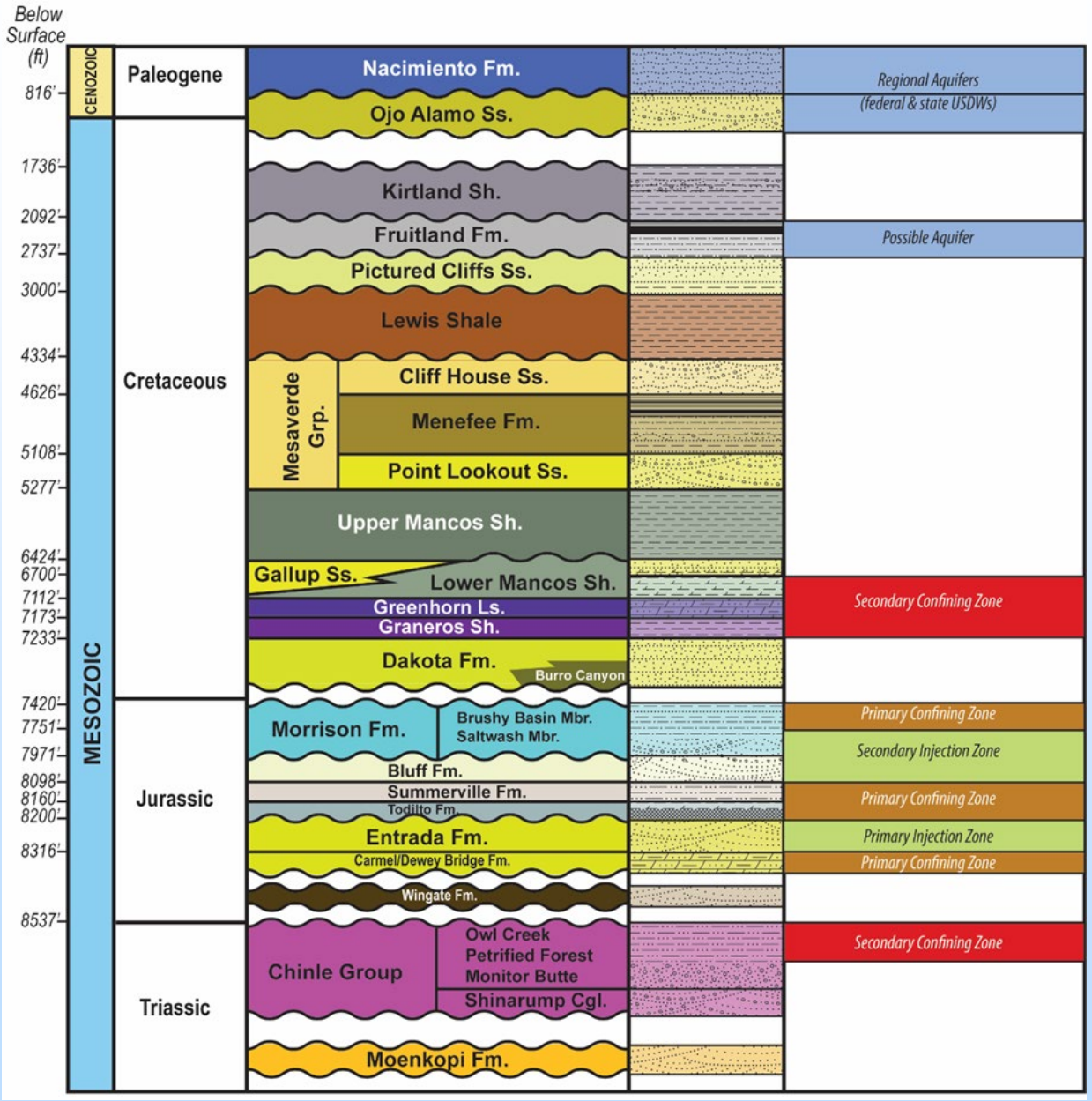


Milestones

Task/ Subtask	Milestone Title & Description	Planned Completion Date	Status
1.0	Project Kick-off meeting		Attend Meeting
2.2	Deployment of DAS/DSS/DTS behind casing in the SJB CarbonSAFE stratigraphic well	02/02/2023	Completed
2.4	Drilling cuttings, core and legacy core cuttings assembled	02/02/2023	Completed
3	Seismic analysis detecting aseismic and basement faults	08/31/2023	Ongoing
4	RVstrat approach detecting and characterizing faults	03/31/2024	Ongoing
5.1/5.2	Wellbore analysis detecting and characterizing geological features such as faults	10/31/2023	Ongoing
5.3	Determination of principal stress, pore pressure within storage complex	03/31/2024	Ongoing
6.1/6.2	Compilation of fault information and baseline seismicity within storage complex and basement	03/31/2025	Ongoing
6.3	Fault slip analysis	09/30/2024	Ongoing
7.1	Completion of static model for numerical simulation	10/30/2023	Ongoing
7.3	Numerical modeling for hazard assessment	02/28/2025	Ongoing

Storage Complex @ San Juan Basin

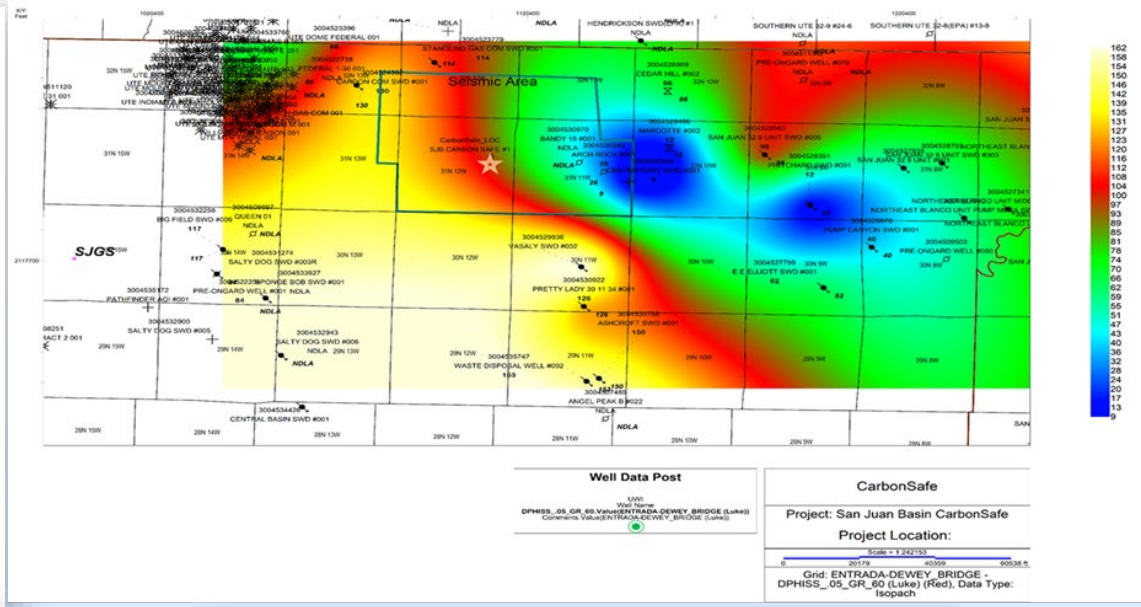




SJB CarbonSAFE Project Facts

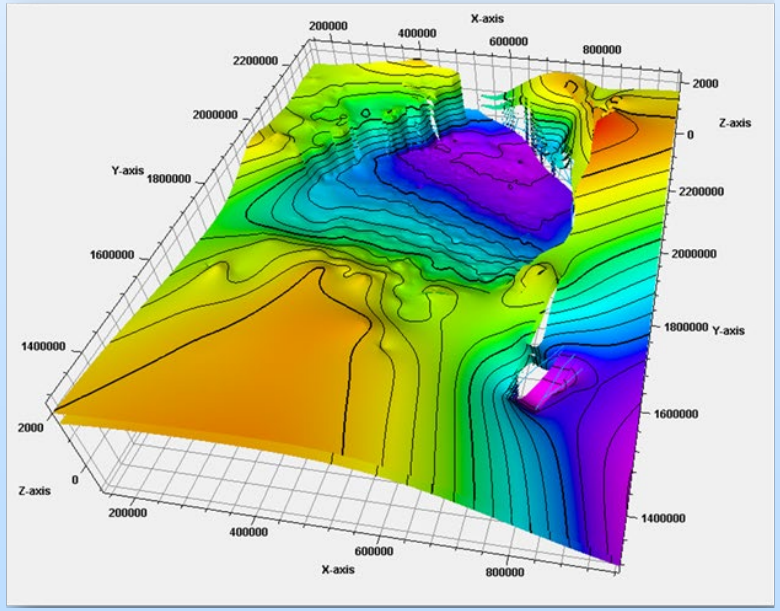
Key Project Facts

- Perform Site Characterization of storage complex within San Juan Basin
- Source CO2 from Escalante H2 plant, located in Prewitt, NM, USA.
- Initial UIC Class VI permit submitted in 2023
- Community and stakeholder outreach on CCS technology and its benefits

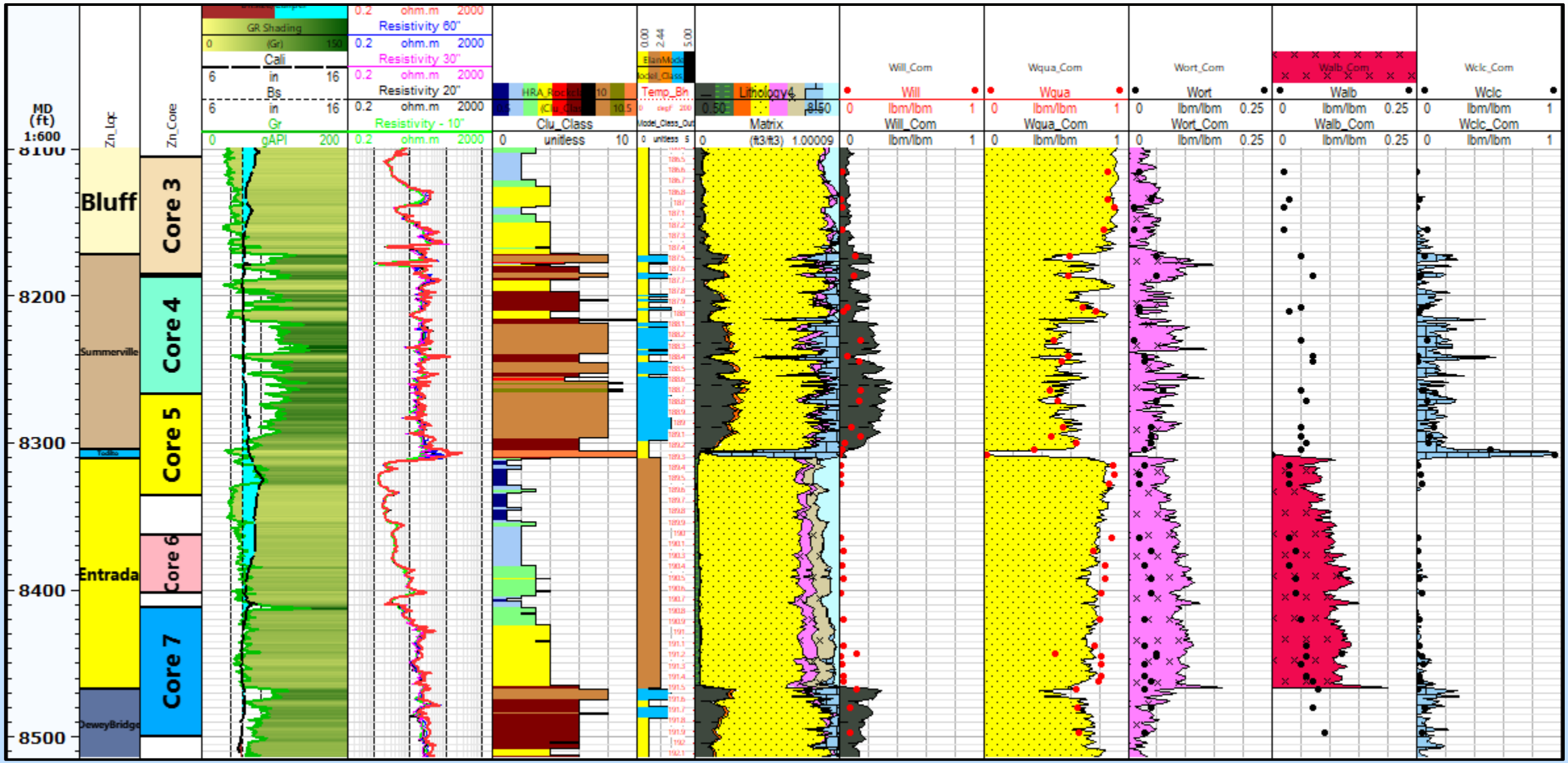


Characterization Plan

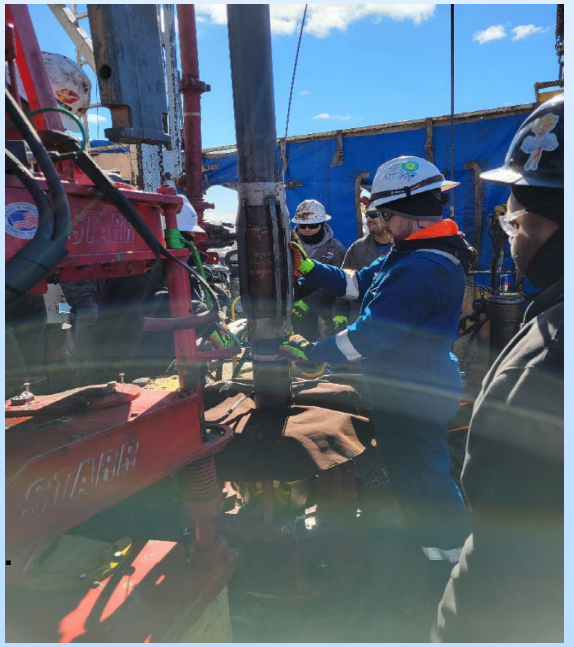
- Drilled characterization well, perform injectivity tests
- Recovered ~ 450 ft of Core, sampled drilling cuttings, advanced log suites measurements
- Perform suites of laboratory experiments and numerical models
- Purchased 100 sq.miles 3D seismic, acquire 3D VSP,
- Installed DAS/DTS/DSS Optical fiber behind casing



SJB CarbonSAFE Well - XRD data



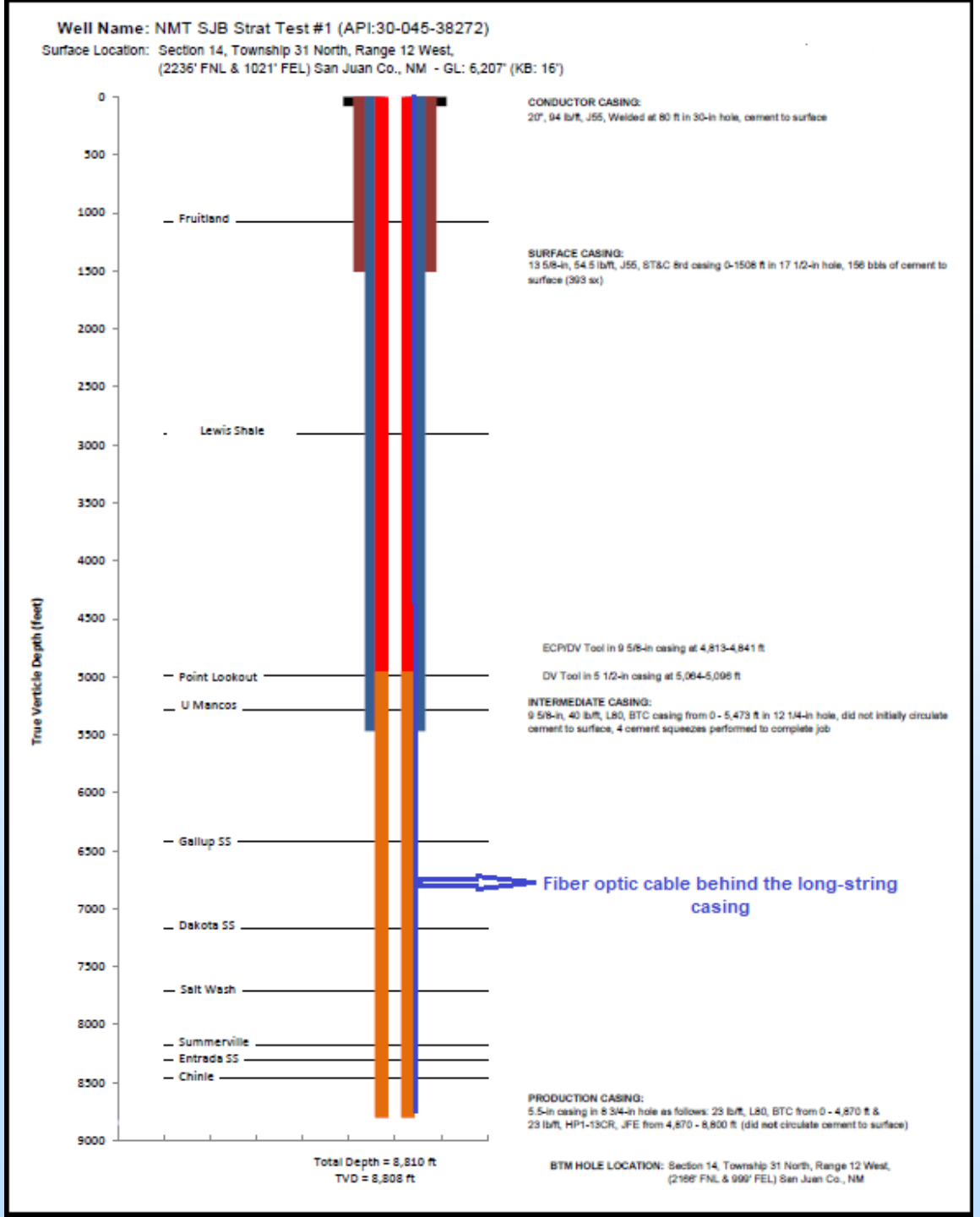
Field Operation - Fiber Installation



Well drilling operations under SJB CarbonSAFE Project (DE-FE0031890).

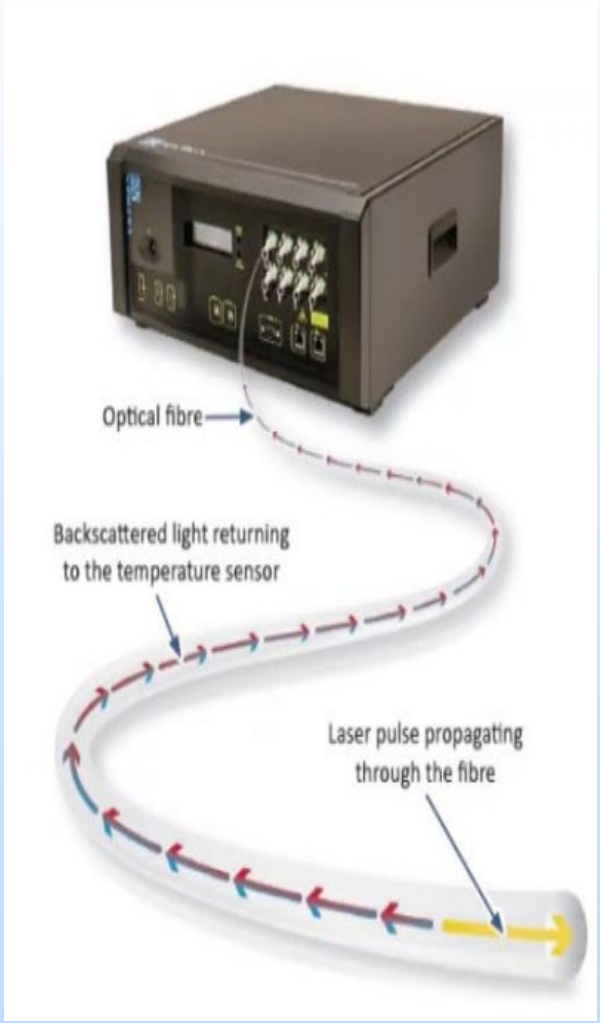
SJB CarbonSAFE Stratigraphic Well- Fiber Installation

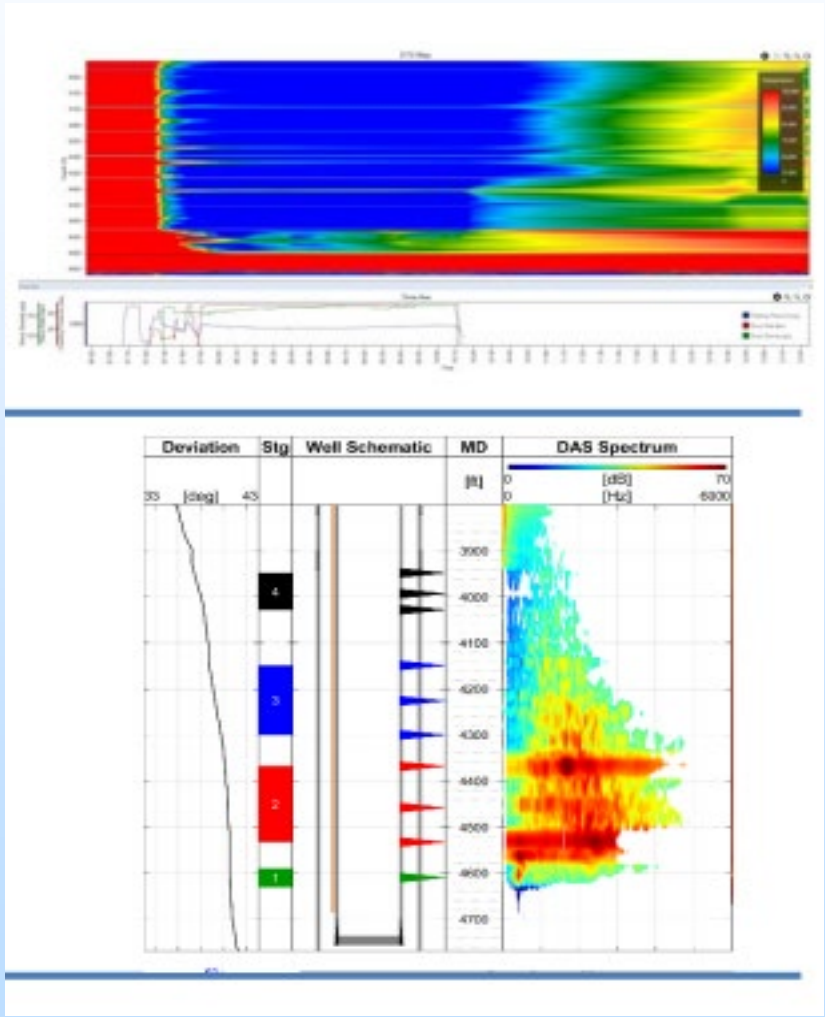
Stratigraphic Well Design



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

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
  - DSS and DTS surveys after the cable reaches total depth
  - DSS and DTS surveys during and after the cementation process

- **Mobilization 2** – Baseline
  - Strain (DSS) baseline
  - Temperature (DTS) baseline
  - Acoustic (DAS) baseline (ambient noise log)
  - Zero-offset and Walk-away VSP
  - Seismicity baseline

- **Mobilization 3** – Injection Test
  - Continuous monitoring during DFIT using DTS, DSS, DAS

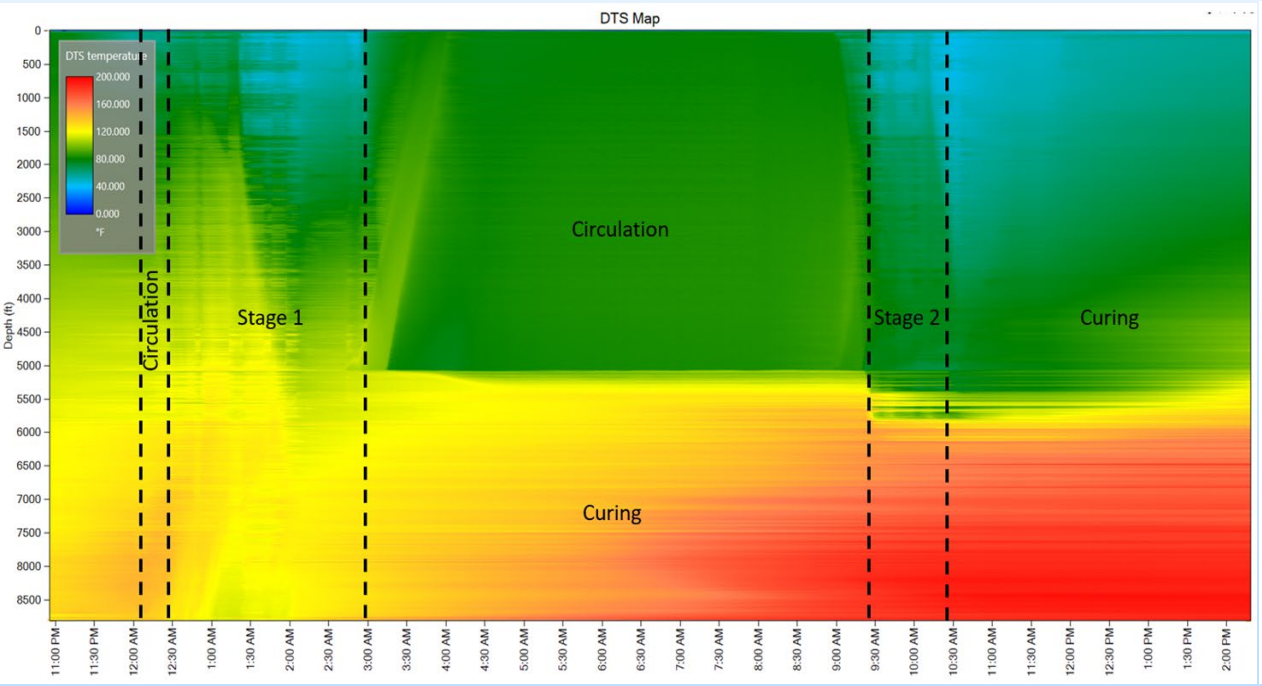
Cementation Results

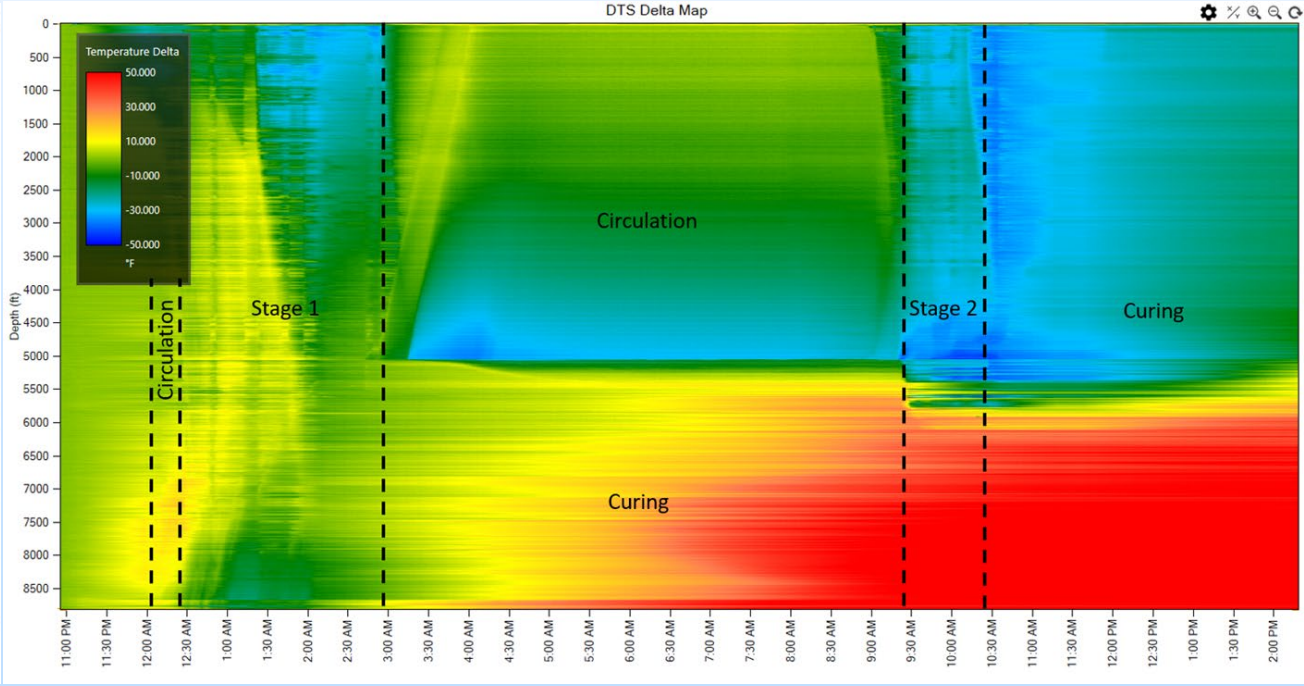
- Two multimode fibers, double-ended in Bottom Hole Assembly
- BHA depth 8686.9 ft KB
- Cementation took place in two stages from 12:01 am to10:23 am on February 2nd, 2023
- A DV tool was utilized to facilitate stage two injection
- DTS Monitoring took place from February 1st ,11pm to February 3rd ,10am

Date	Time	Event
Feburary 2 2023	00:01	Begin pumping Water ahead
Feburary 2 2023	00:27	Stage one Lead Cement
Feburary 2 2023	03:02	Open DV Tool and Circulate
Feburary 2 2023	09:29	Stage Two Lead Cement
Feburary 2 2023	10:23	Shutdown

Cementation Results

- DTS absolute temperature during cementation.
- Top of stage one cement at 5034 ft KB
- Stage two ingress below the DV tool
- Weak exothermic response is apparent in stage 2





Zero Offset VSP

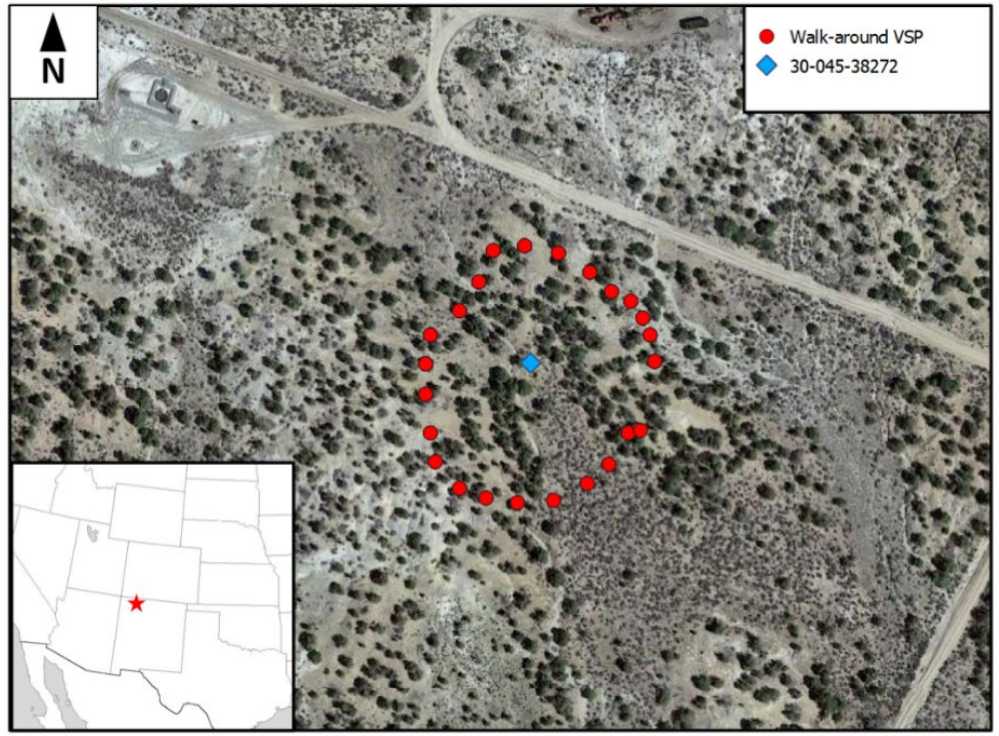
- VSP acquisition took place on February 26-27, 2023
- Acquired with Silixa's Carina DAS
- Vibroseis survey with near offset ring

Setting	Value	Units
Sampling frequency	1	kHz
Time decimation	20	
Spatial sampling	1	m
Gauge length	10	m

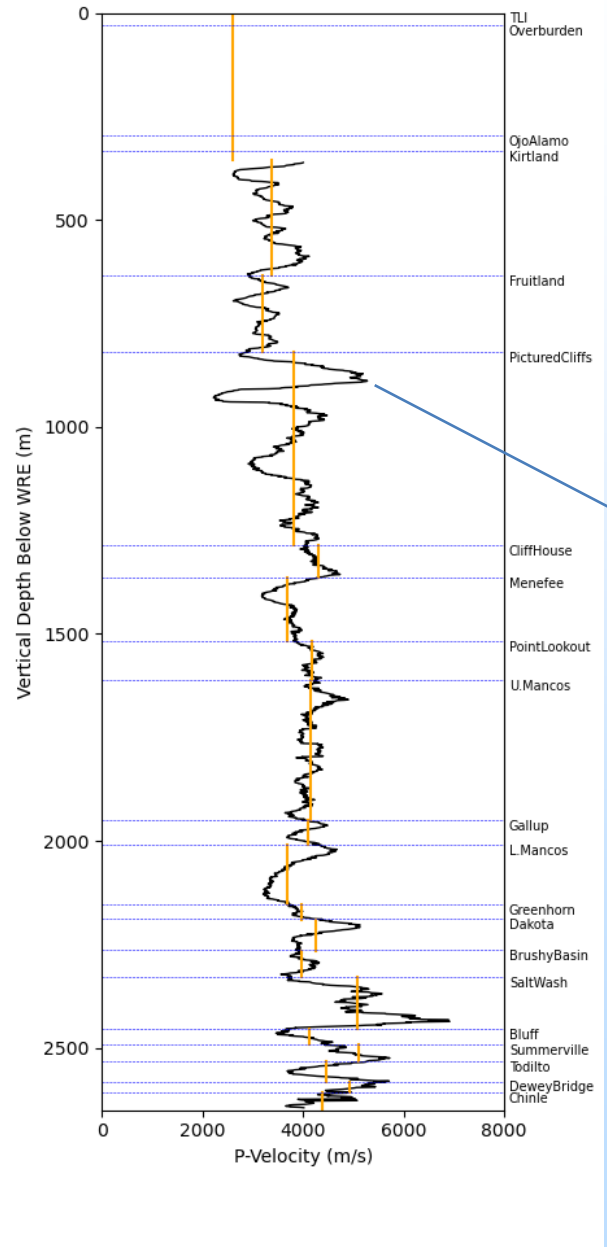
Table 3: Primary Carina settings for the DAS VSP survey.

Settings	Value	Units
Sweep design	Linear	
Sweep frequency range	4-120	Hz
Sweep length	12	s
Sweep tapers	300	ms
Listen time	5	s

Table 4: Vibroseis sweep parameters.



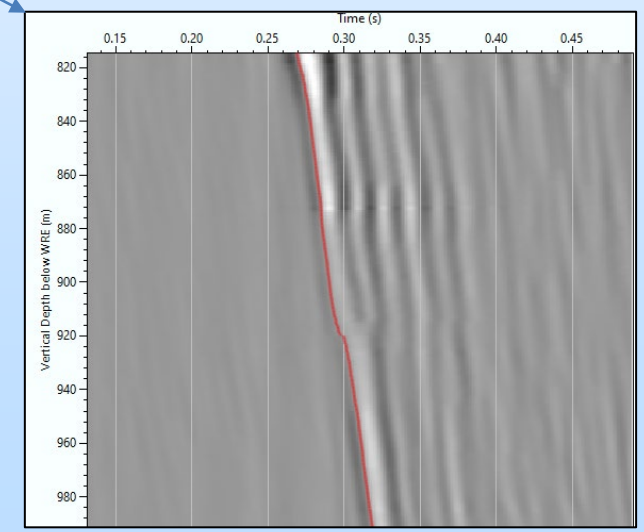
Zero Offset VSP



P-wave Velocity profile and Blocked model

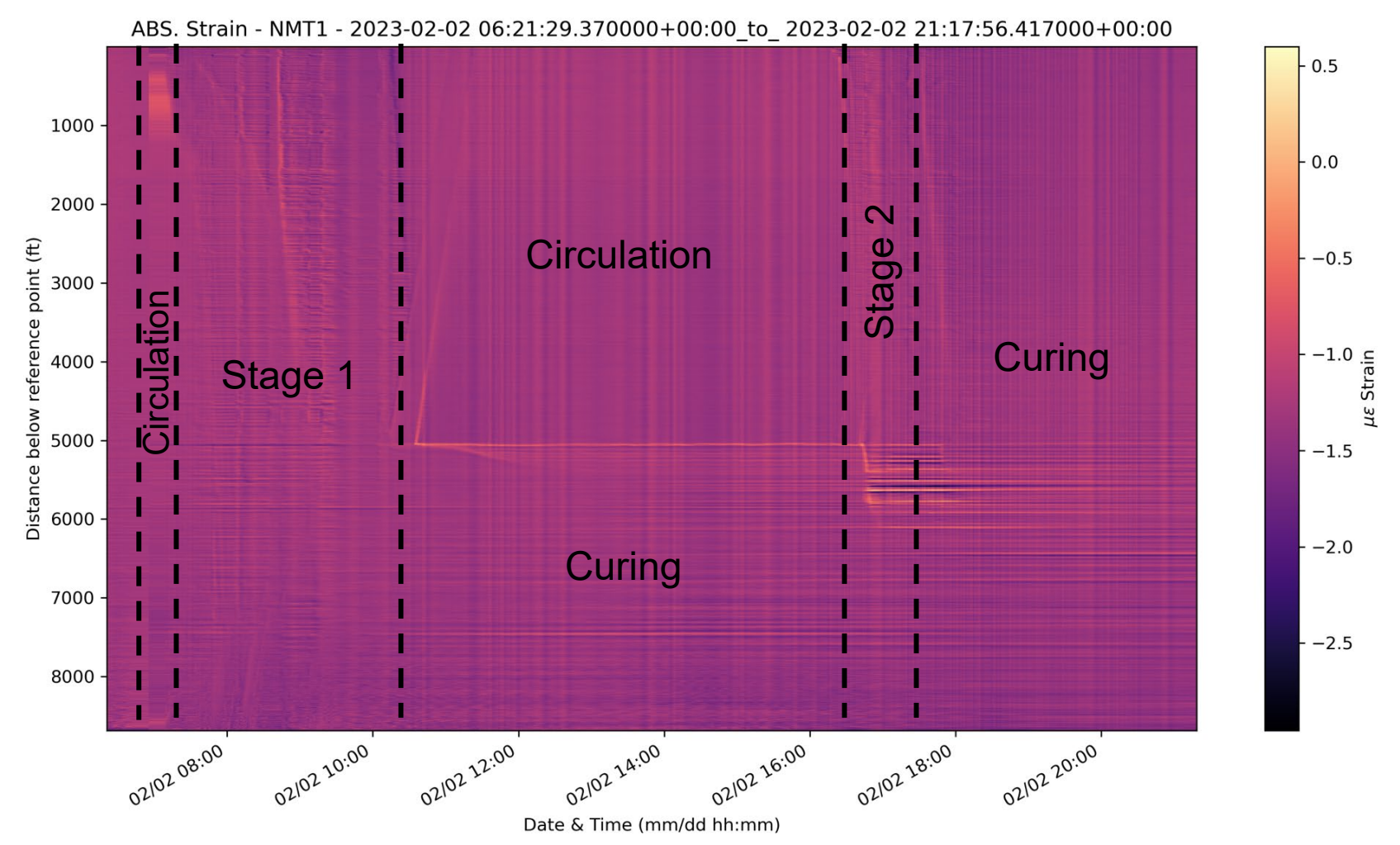
- Good correlation with formation tops (blue)
- Model created by blocking off the mean of the velocities (orange)

- Large velocity contrasts outside of formation boundary's – Top of Pictured Cliffs 2700 ft to 3100 ft
- Large contrast in Velocity correlated with poor cement bonding from VDL logs, and casing ring.



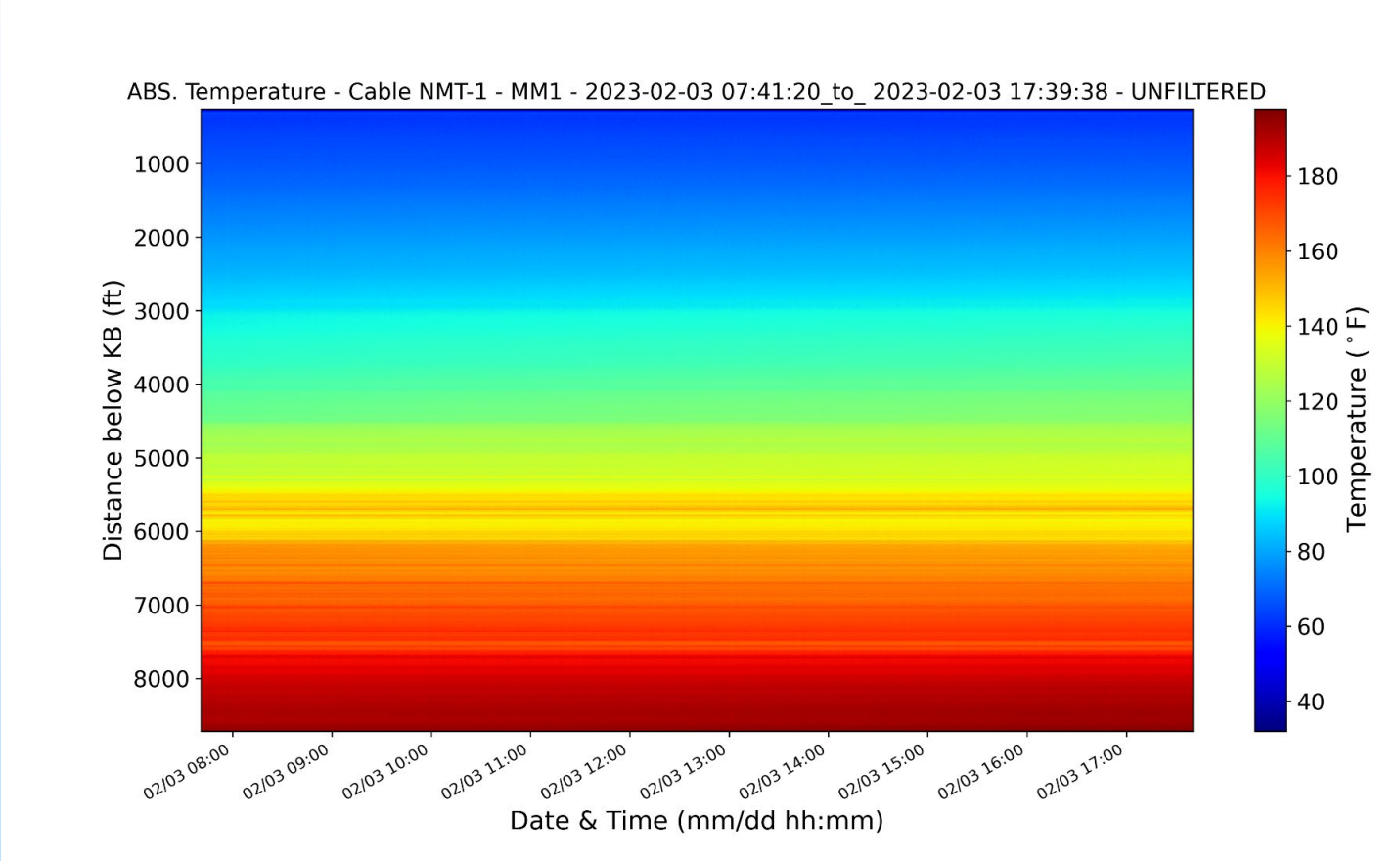
Cementation monitoring

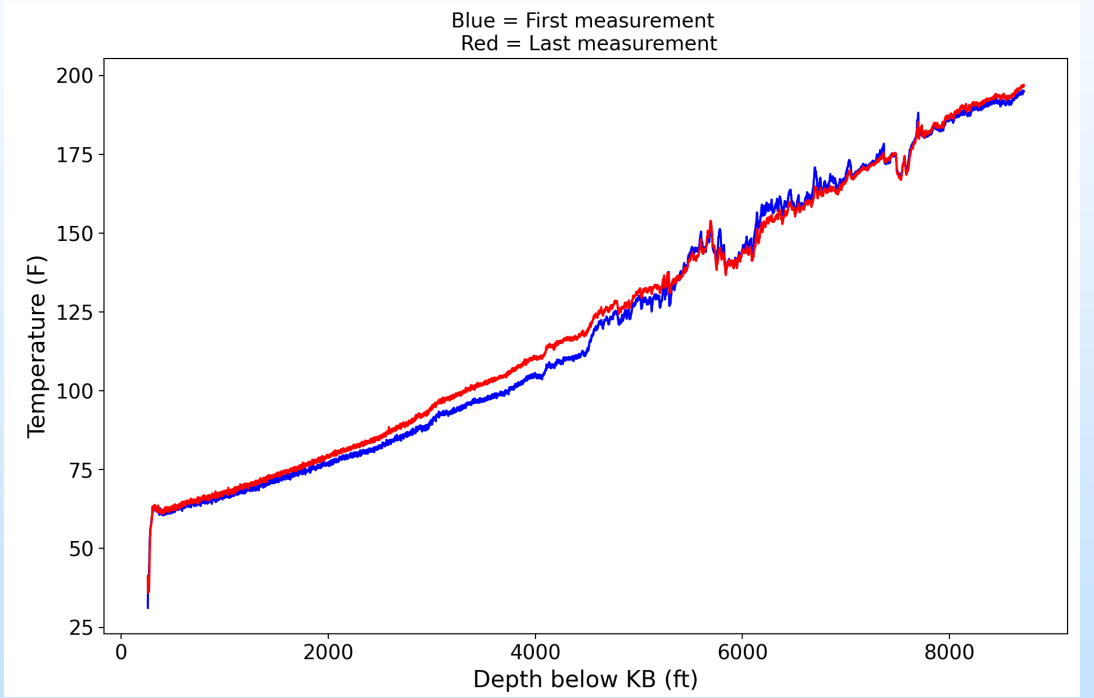
Absolute strain measurements during cementation



Post Wellhead Installation

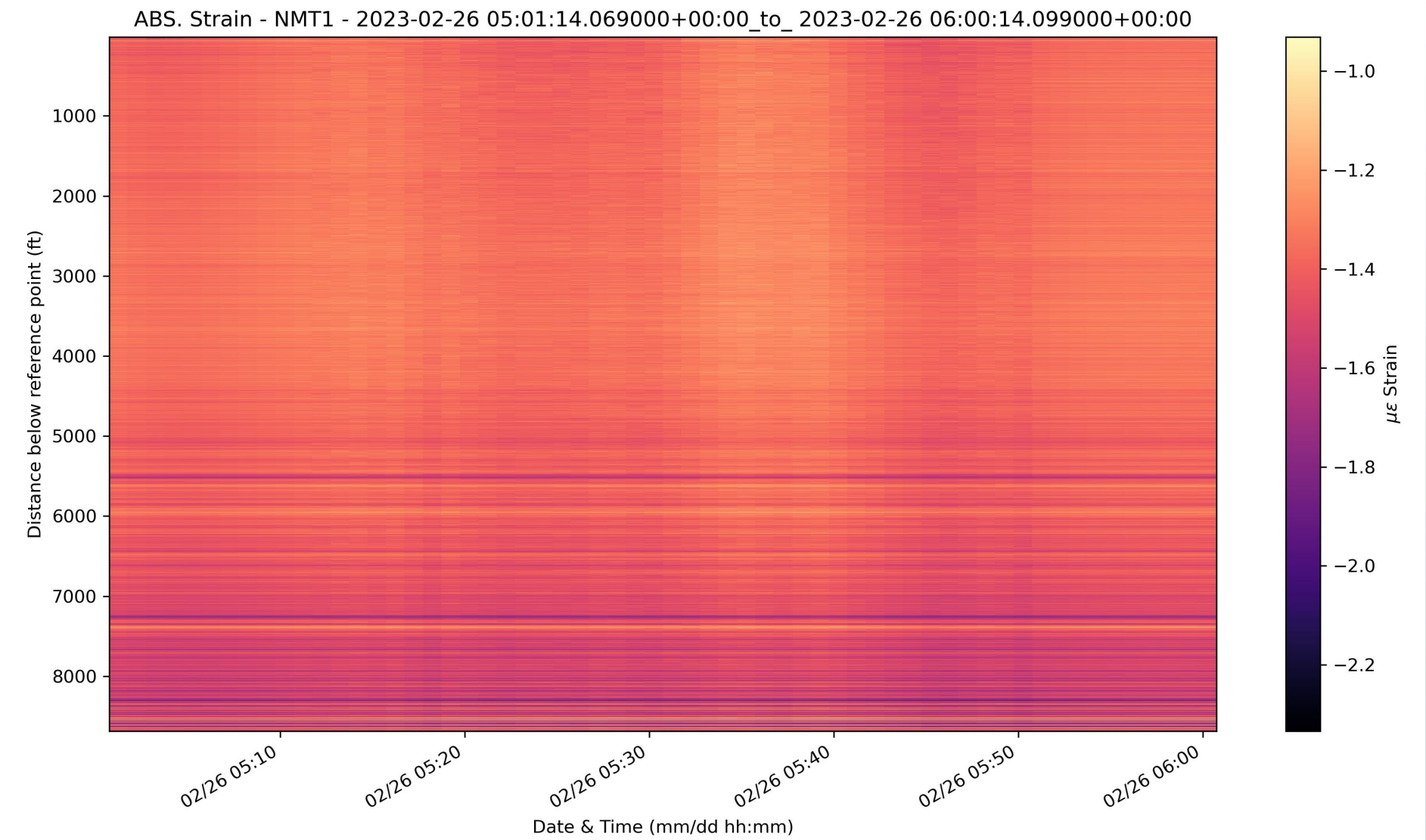
Temperature data, post cementation (2023-02-03) (i.e. warmback)





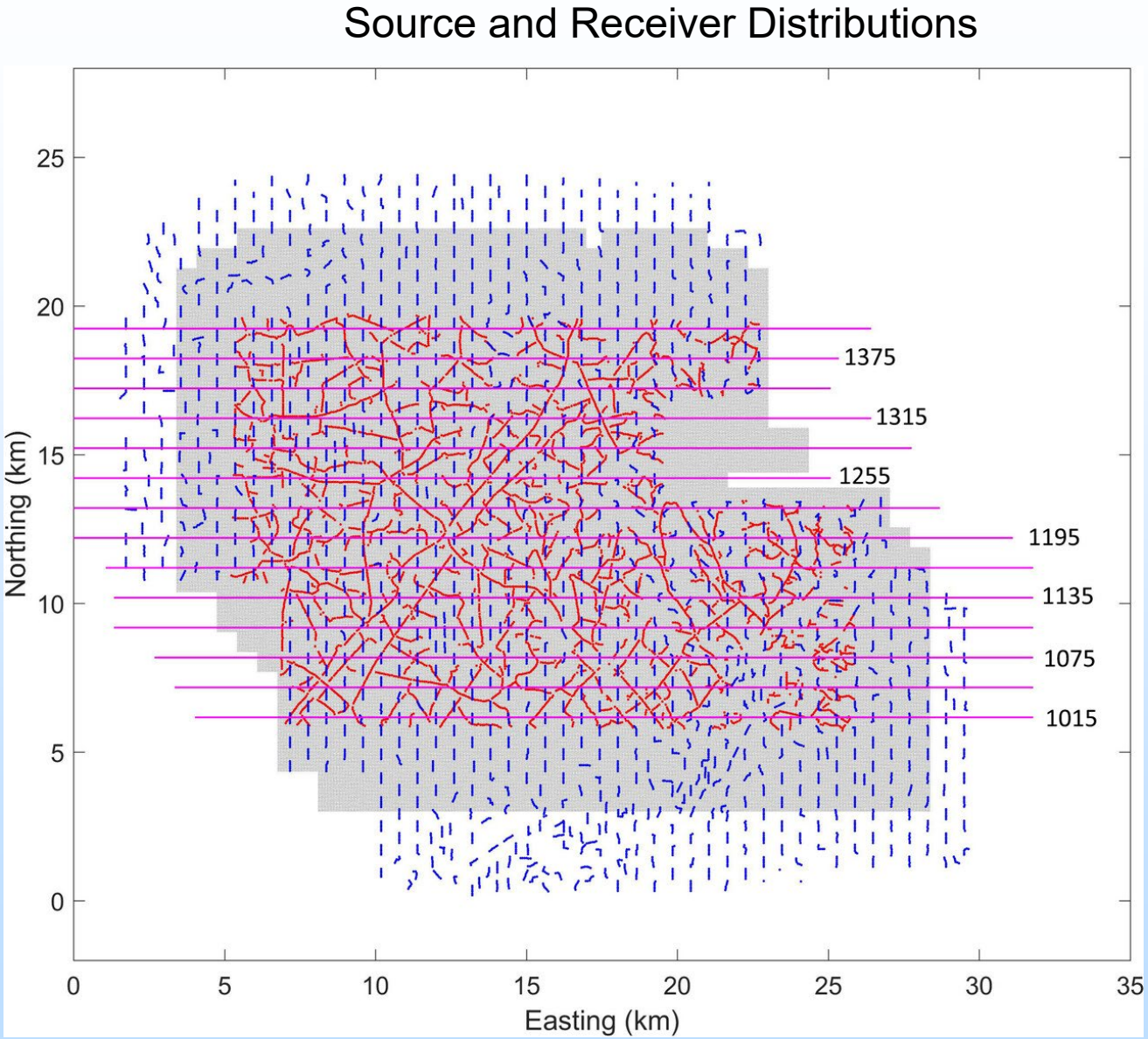
Coincident with VSP

Strain data coincident with VSP survey, temperature corrected (2023-02-26)

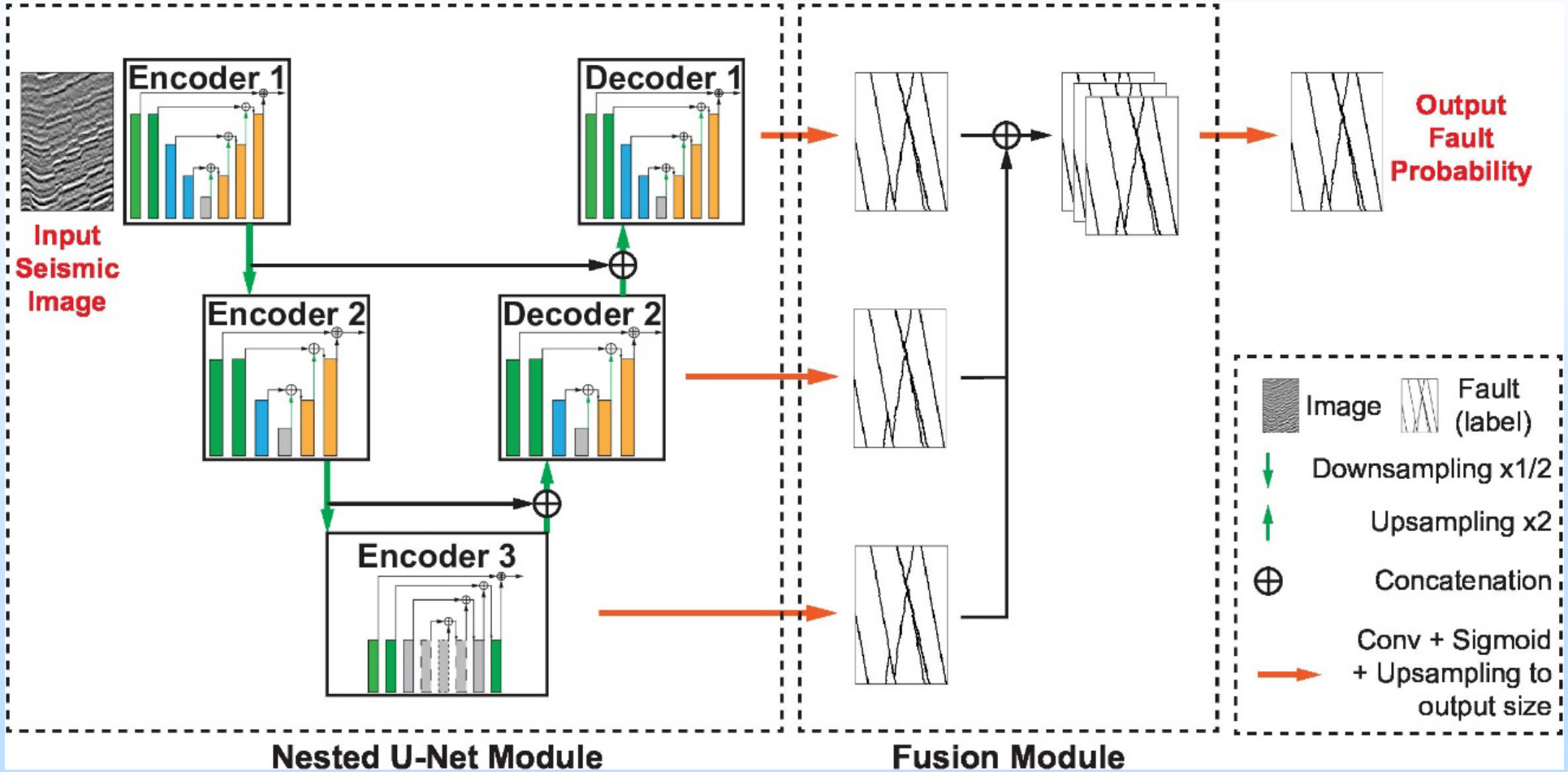


Legacy 3D Surface Seismic Data

- The project procured a legacy 3D surface seismic dataset acquired at the San Juan CarbonSAFE storage site.
- We perform migration velocity analysis and prestack depth migration to obtain improved subsurface structural images.
- We use anisotropic diffusing filtering to reduce image noise and improve the reliability of fault detection.
- We detect faults on migration images using LANL's recently developed machine-learning algorithm (Gao, Huang, Zheng, 2022).

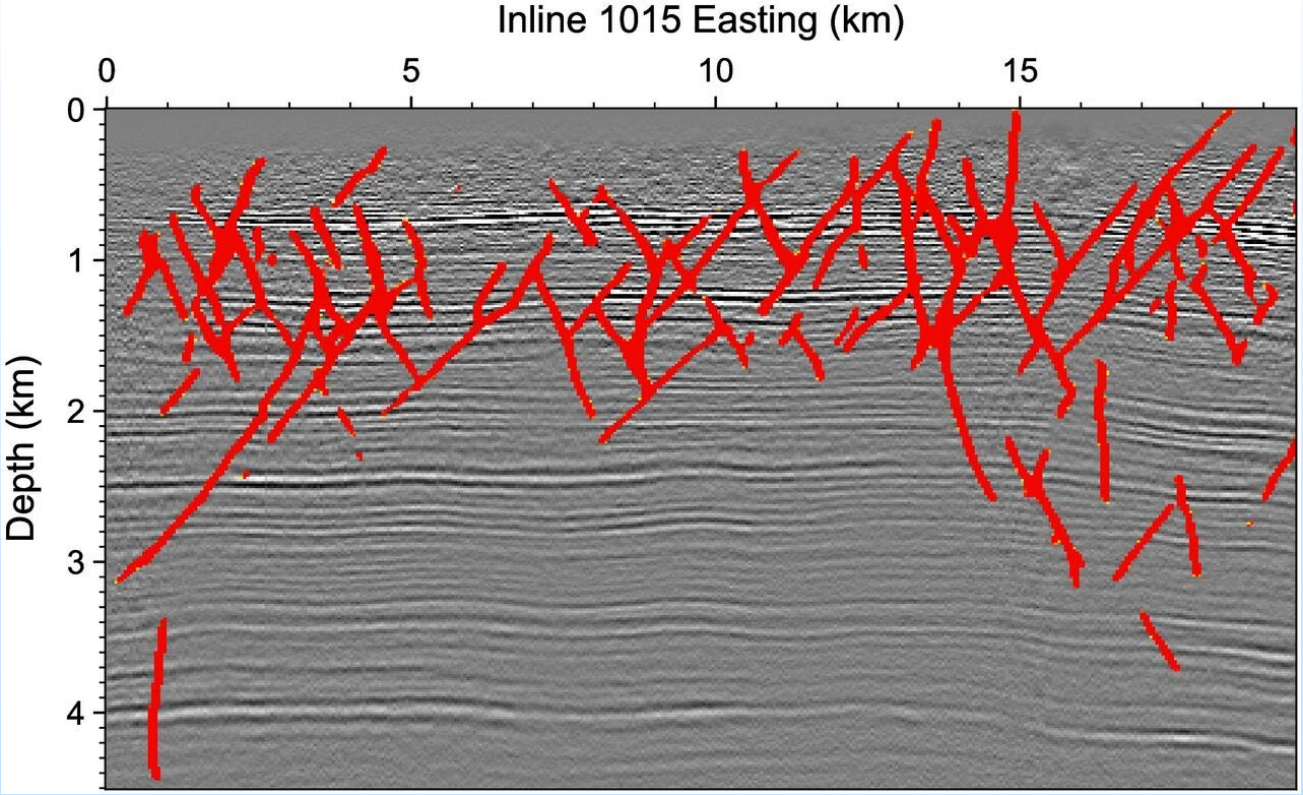


Nested-Residual U-Net (NRU) Fault Detection

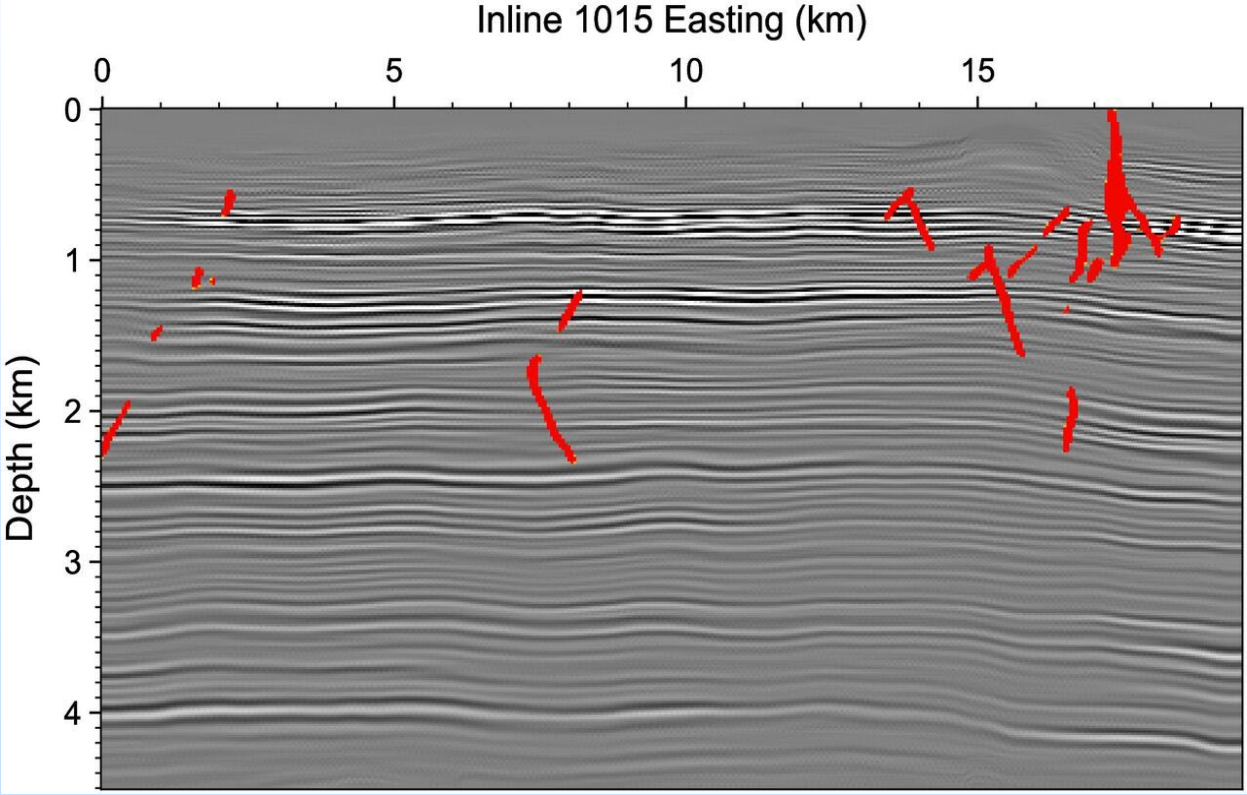


(Gao, Huang, Zheng, 2022)

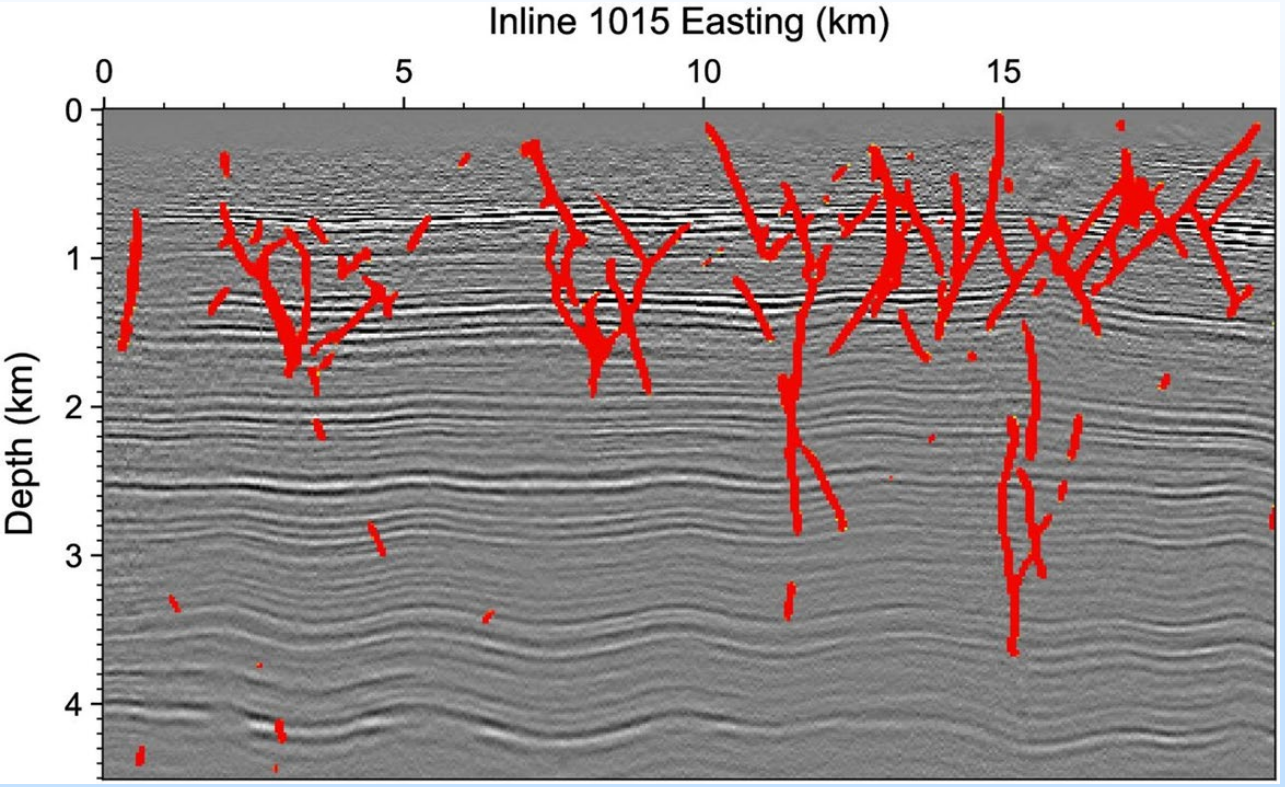
ML-Detected Fault on Original PSTM Image



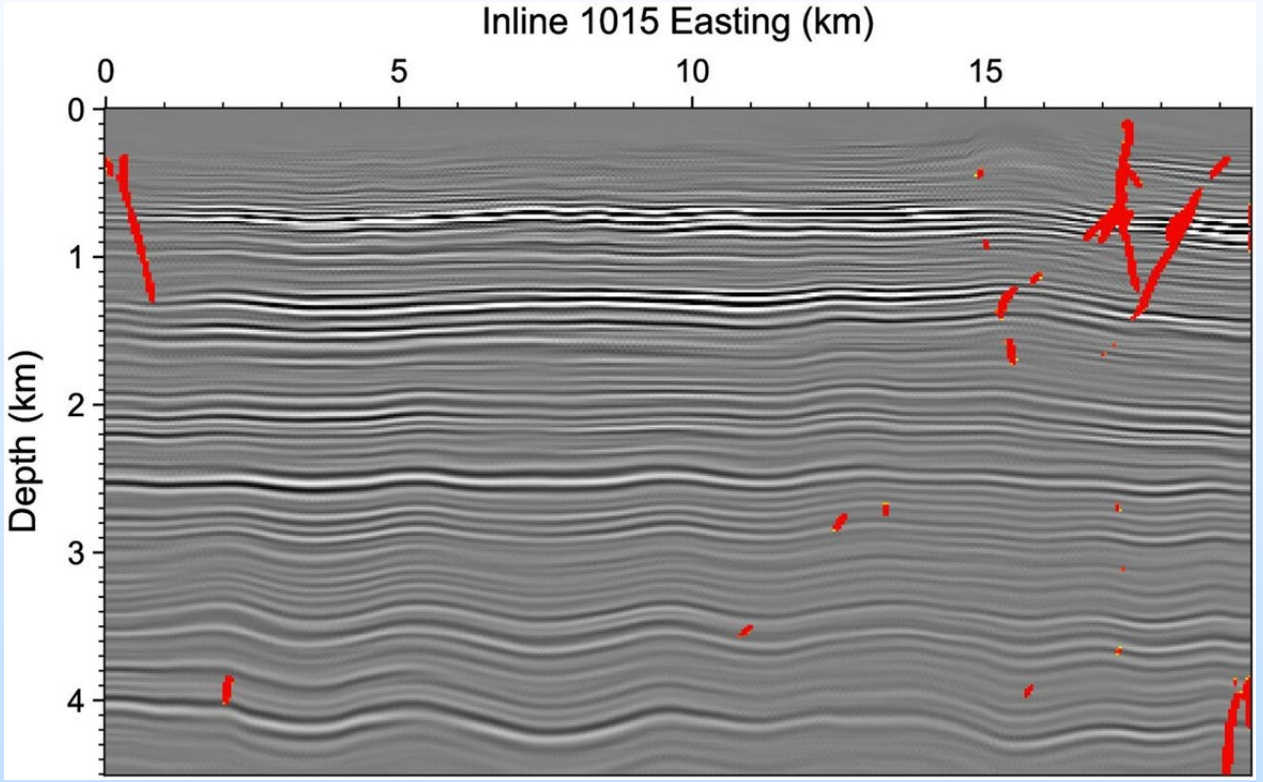
ML-Detected Faults on Denoised PSTM Image



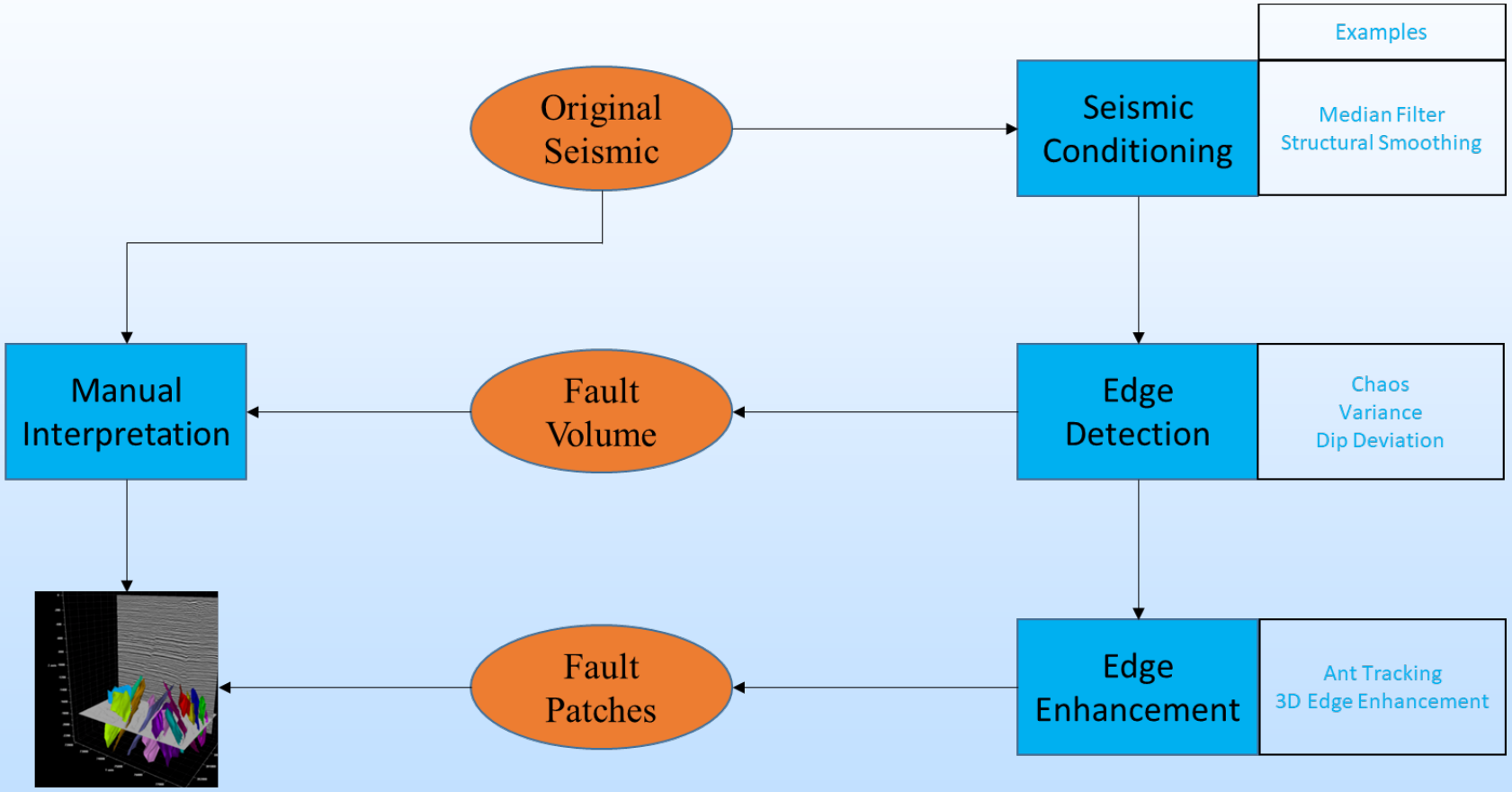
ML-Detected Fault on Original PSDM Image

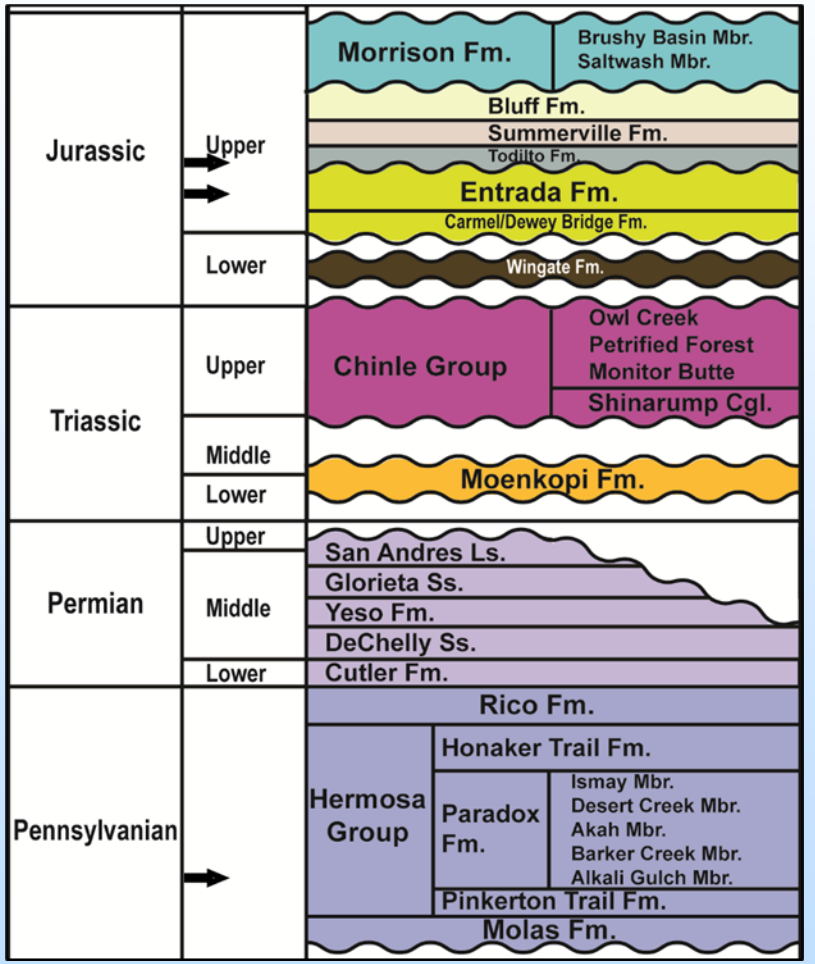


ML-Detected Faults on Denoised PSDM Image

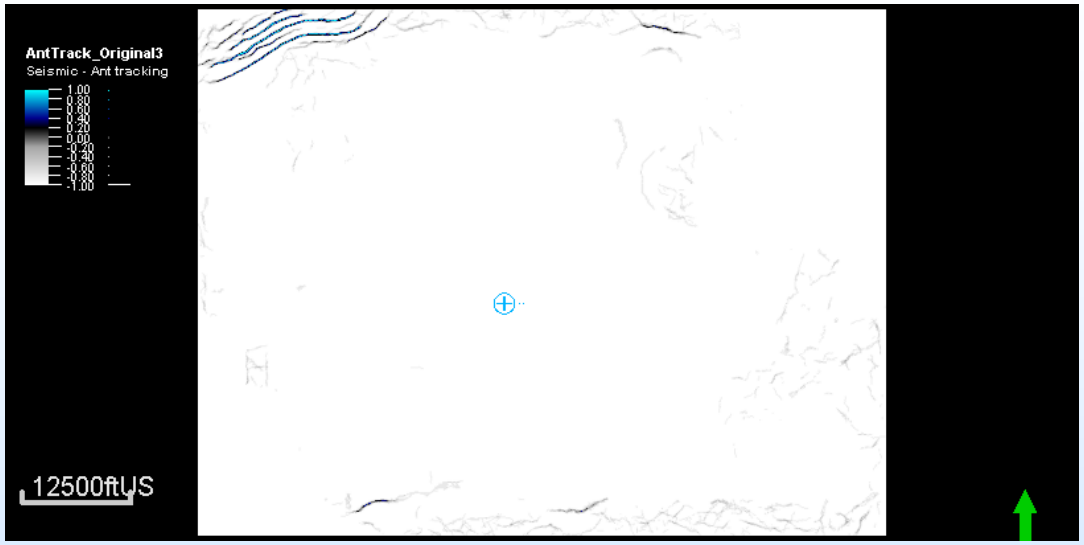


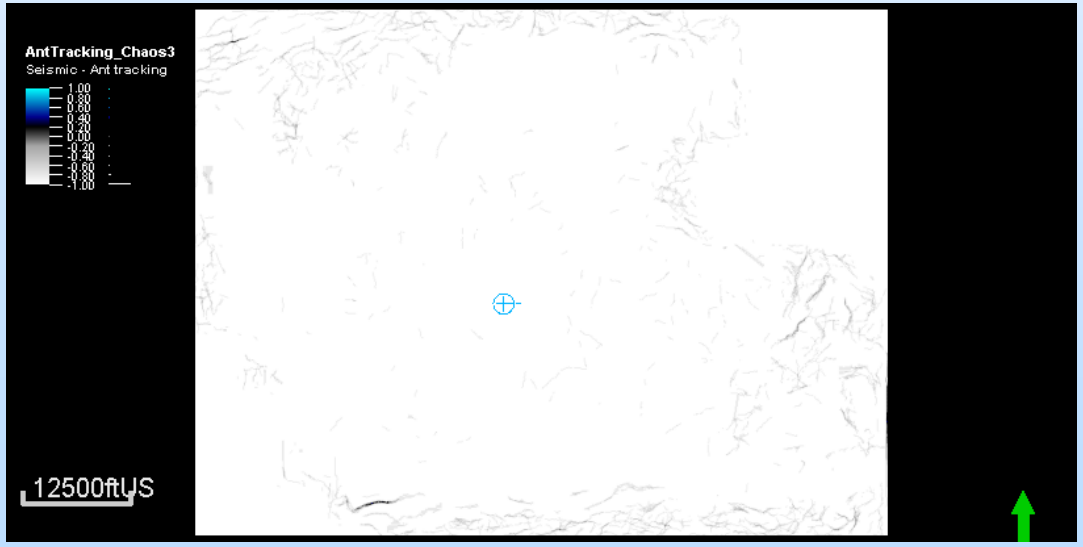
Seismic Attribute based Fault Extraction

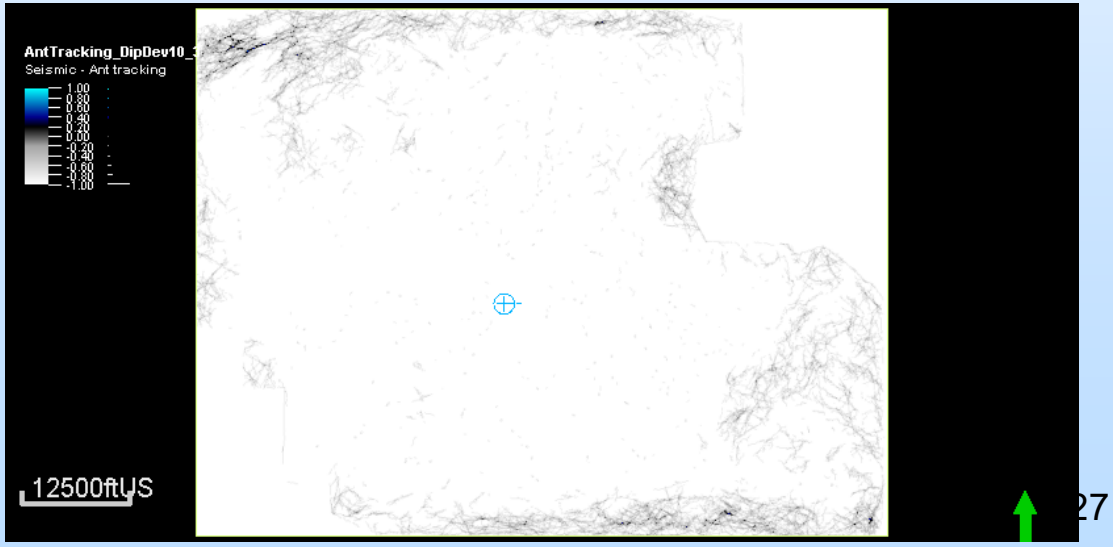




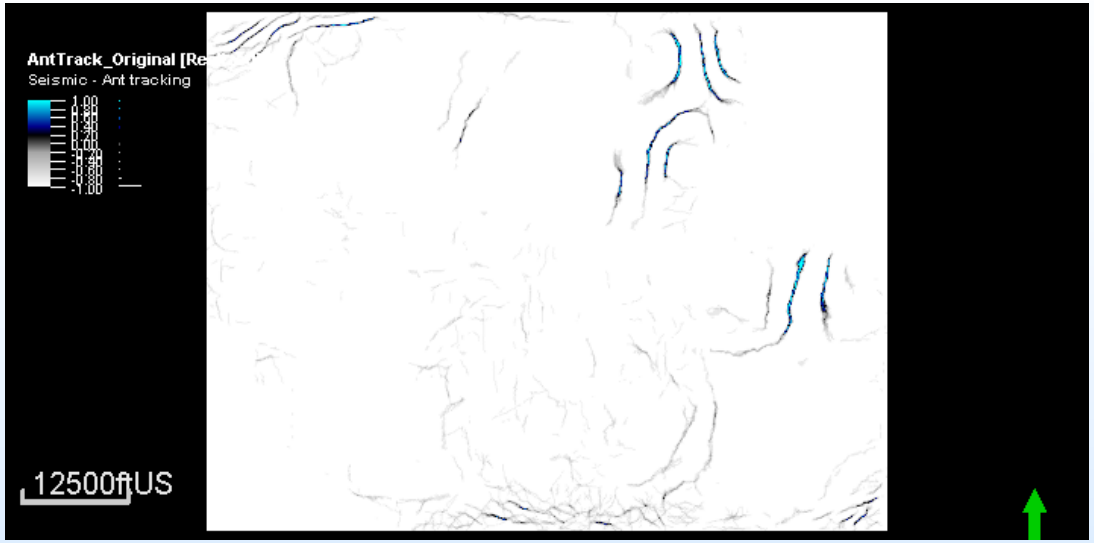
Ant Tracking - Todilto

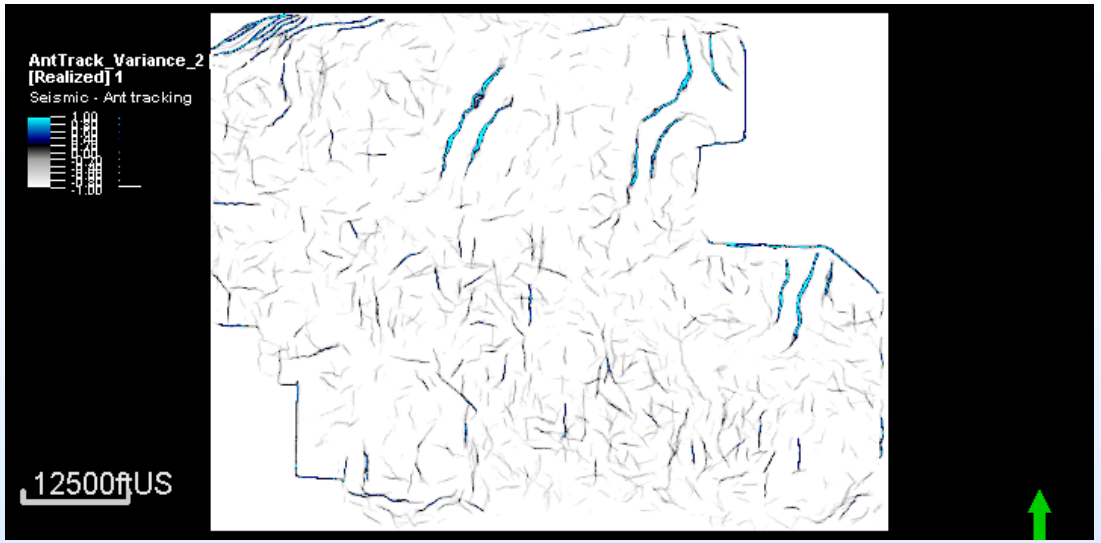


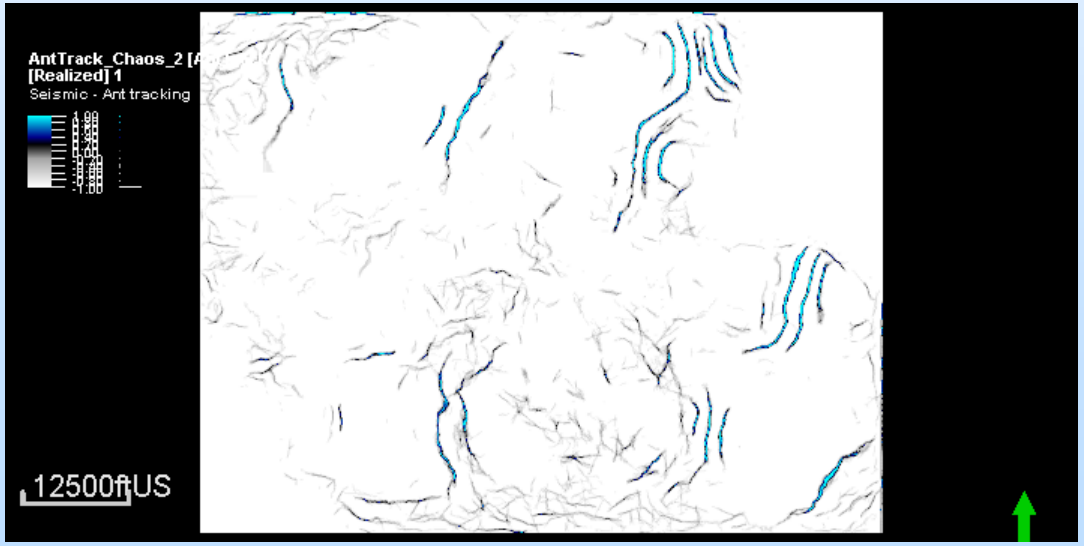


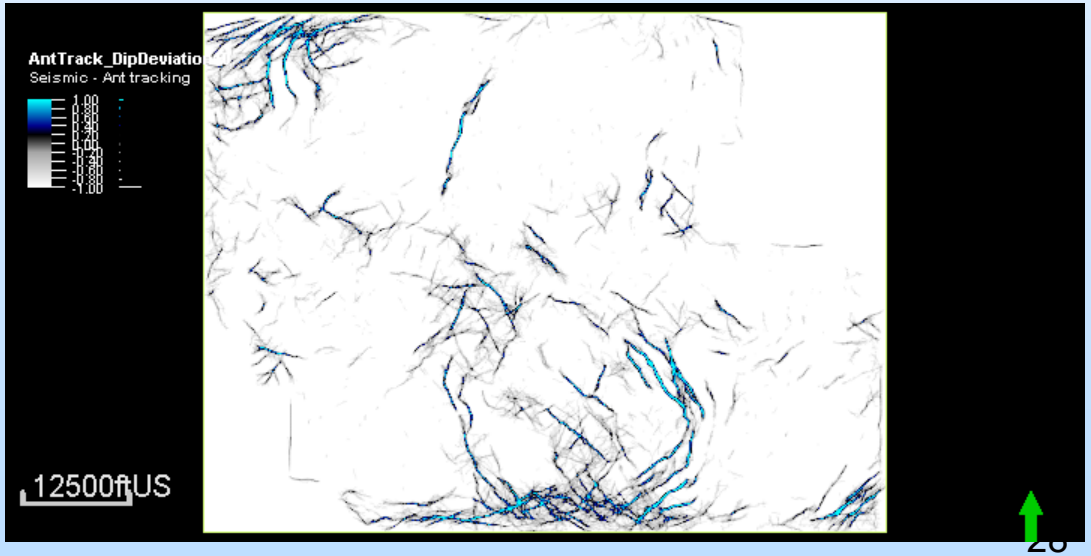


Double Pass Ant Tracking - Alkali Gulch



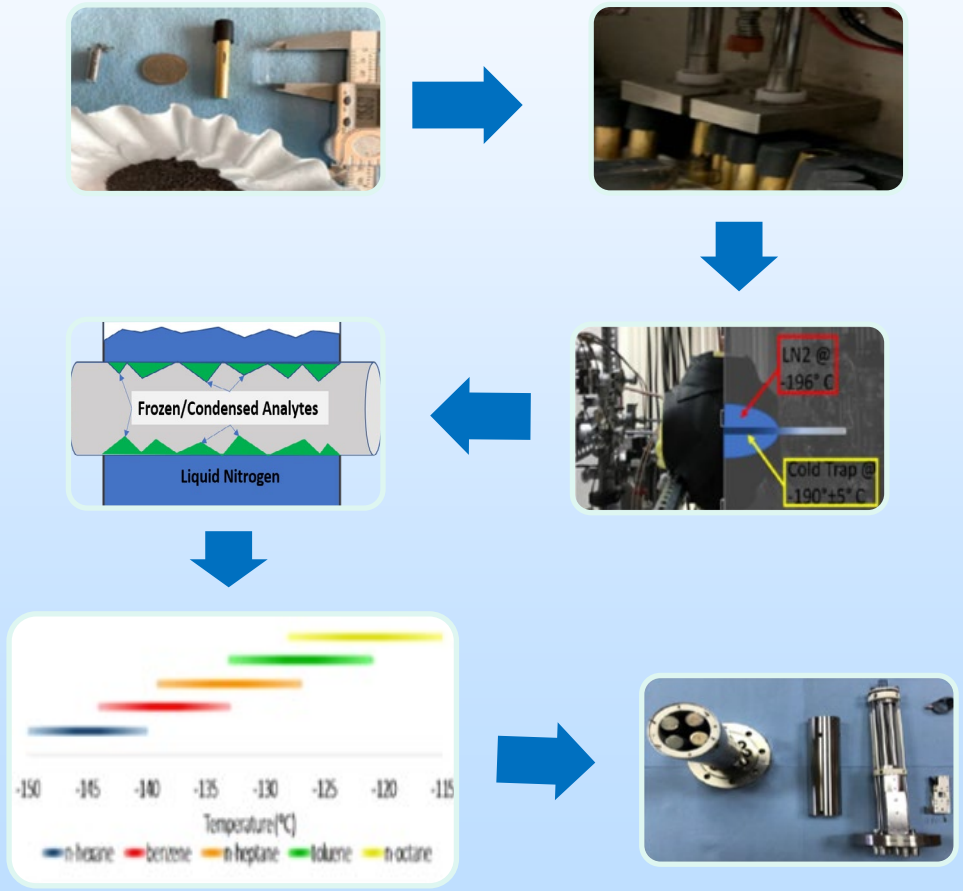


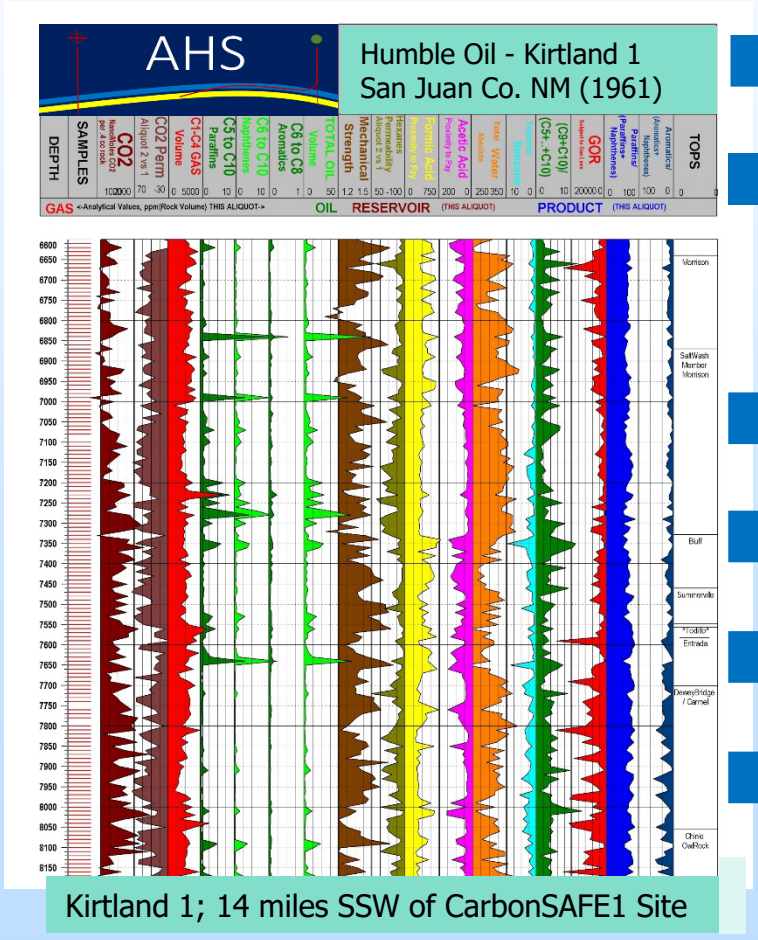




AHS Rock Volatiles CCS Well Site Evaluation

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

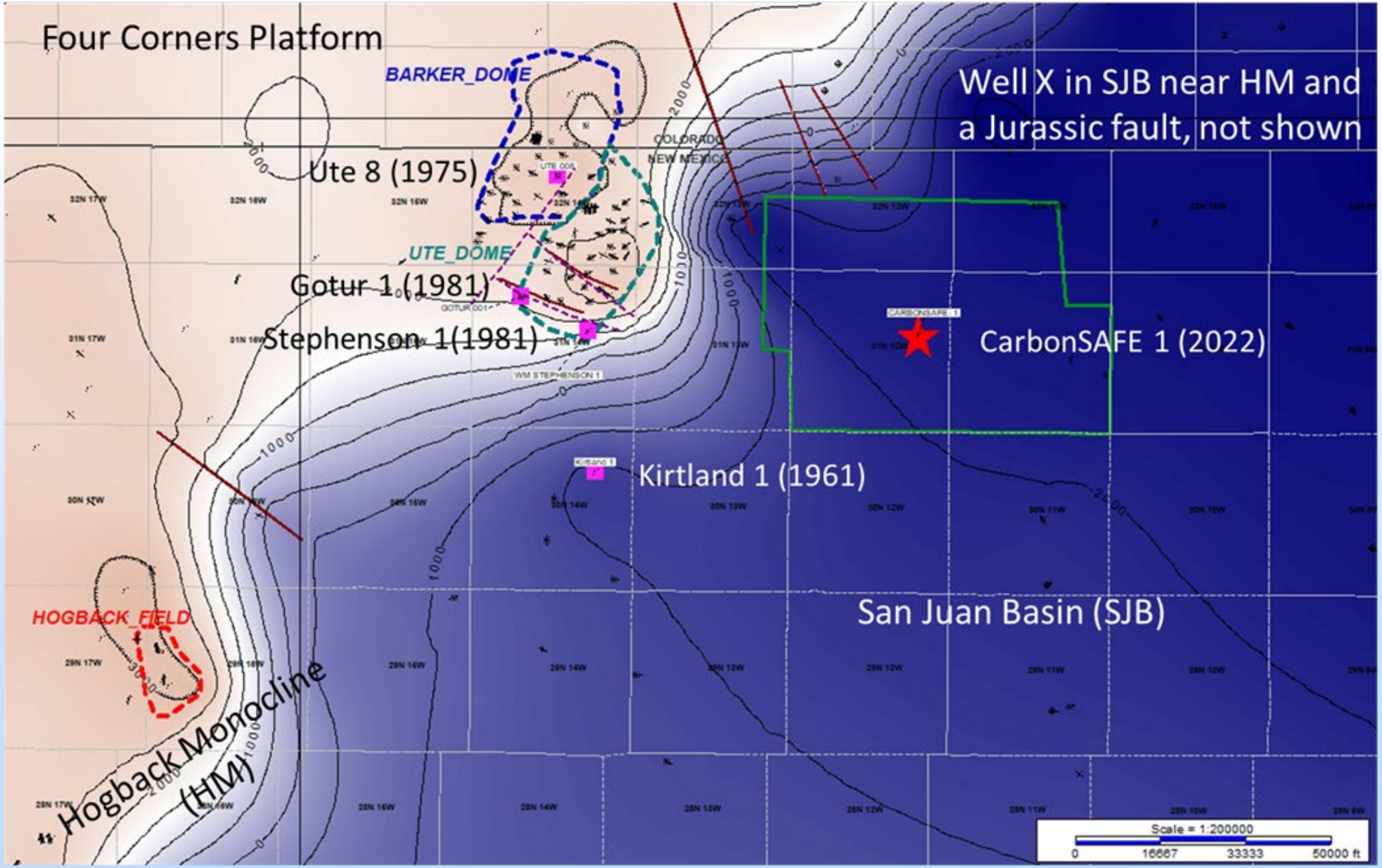
Site Evaluation

- Presently the sealed at the well cuttings samples have been analyzed
- Unsealed cuttings samples and core samples RVS data will be needed for an apples-to-apples comparison to the regional baselines

With the available data, it is possible to begin assessing some of the identified features relating to the Farmington site

Feature of Interest	Status in CarbonSAFE 1 Well
Petroleum System - Lateral Migration	?
Petroleum System - Vertical Migration	?
Carbon Dioxide Regional Baseline	?
Nature of Carbon Dioxide Release	?
Vertical Seals	?

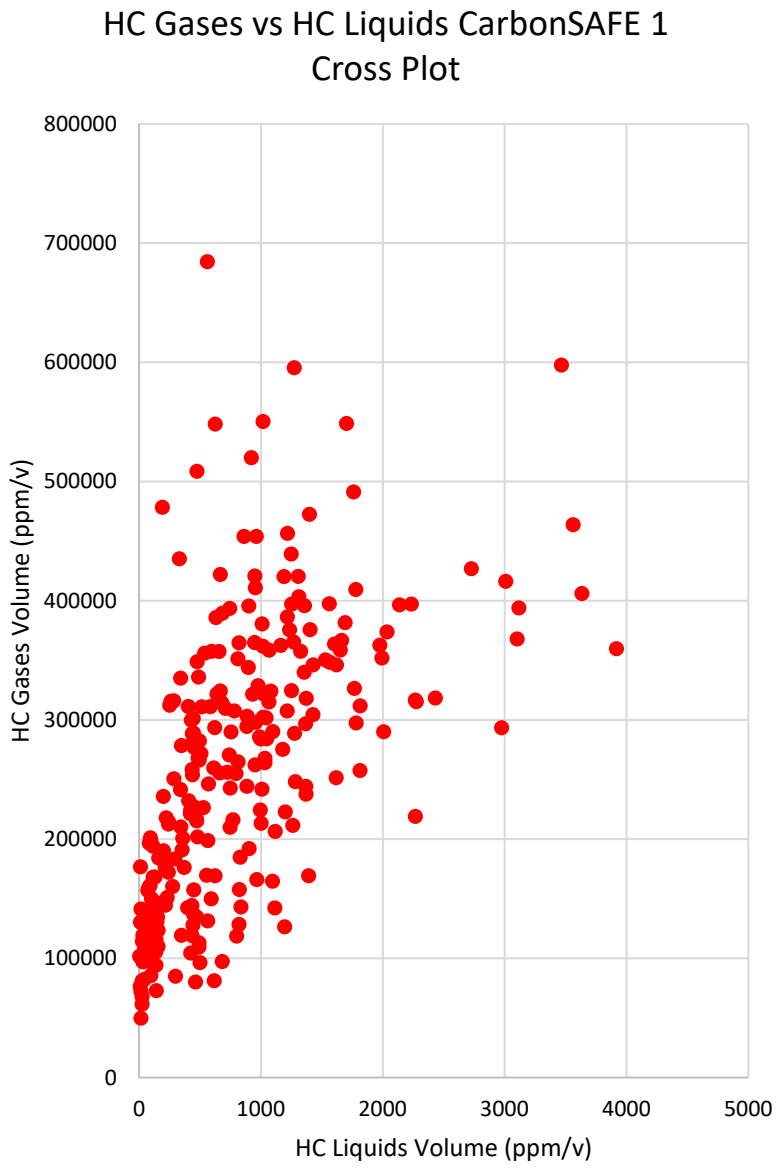
Site Evaluation- Sample Locations

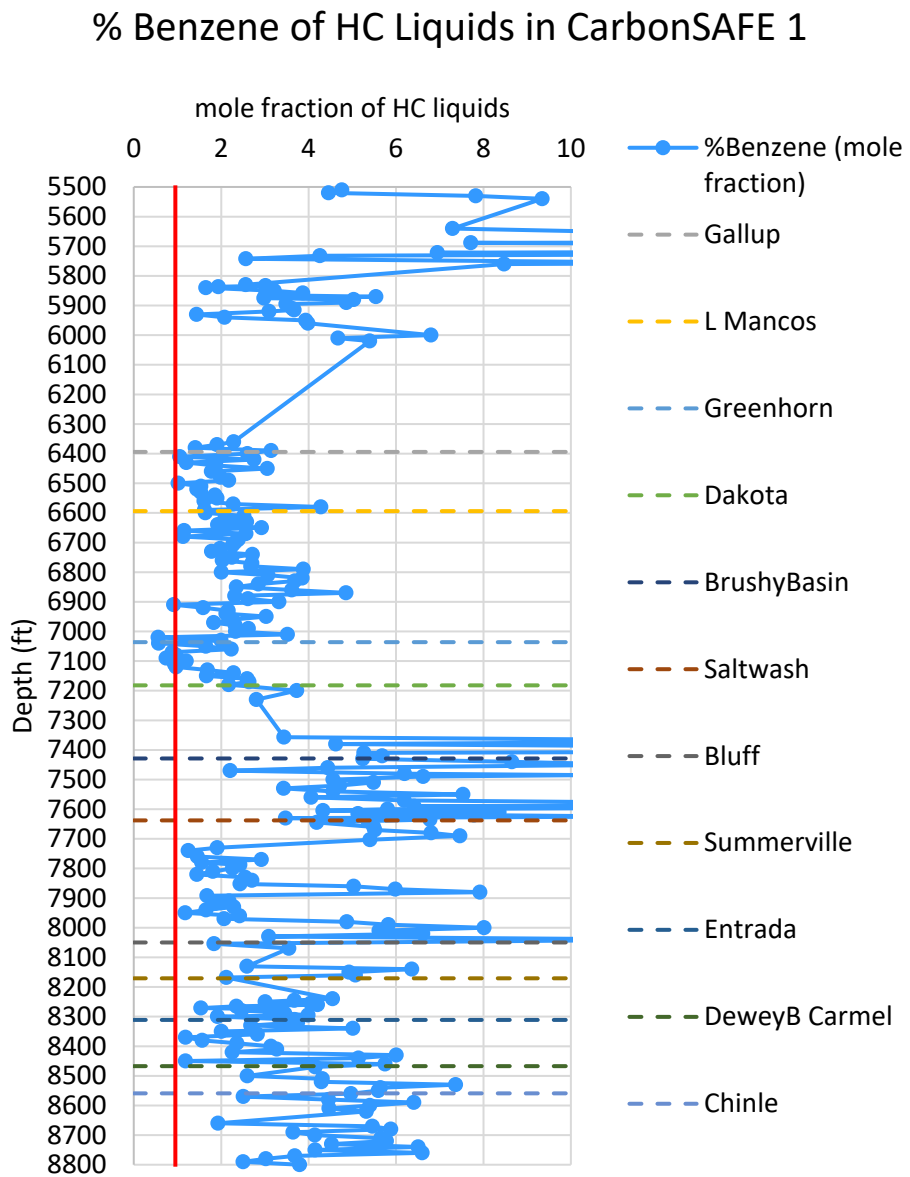


Lateral Migration

- Composition of the HCs reveals additional information
- Positive correlation between HC gases and liquids; HC liquids are likely present as a condensate in the gas
- HC liquids composition across the well is very benzene rich, values of ~1% are consistent for oil, values of a gas will be less because of its low volatility
- The high benzene content means significant water is present across most of the analyzed section due to its solubility

Further investigation is needed to evaluate where these liquids rich gas condensates came from and potential implications

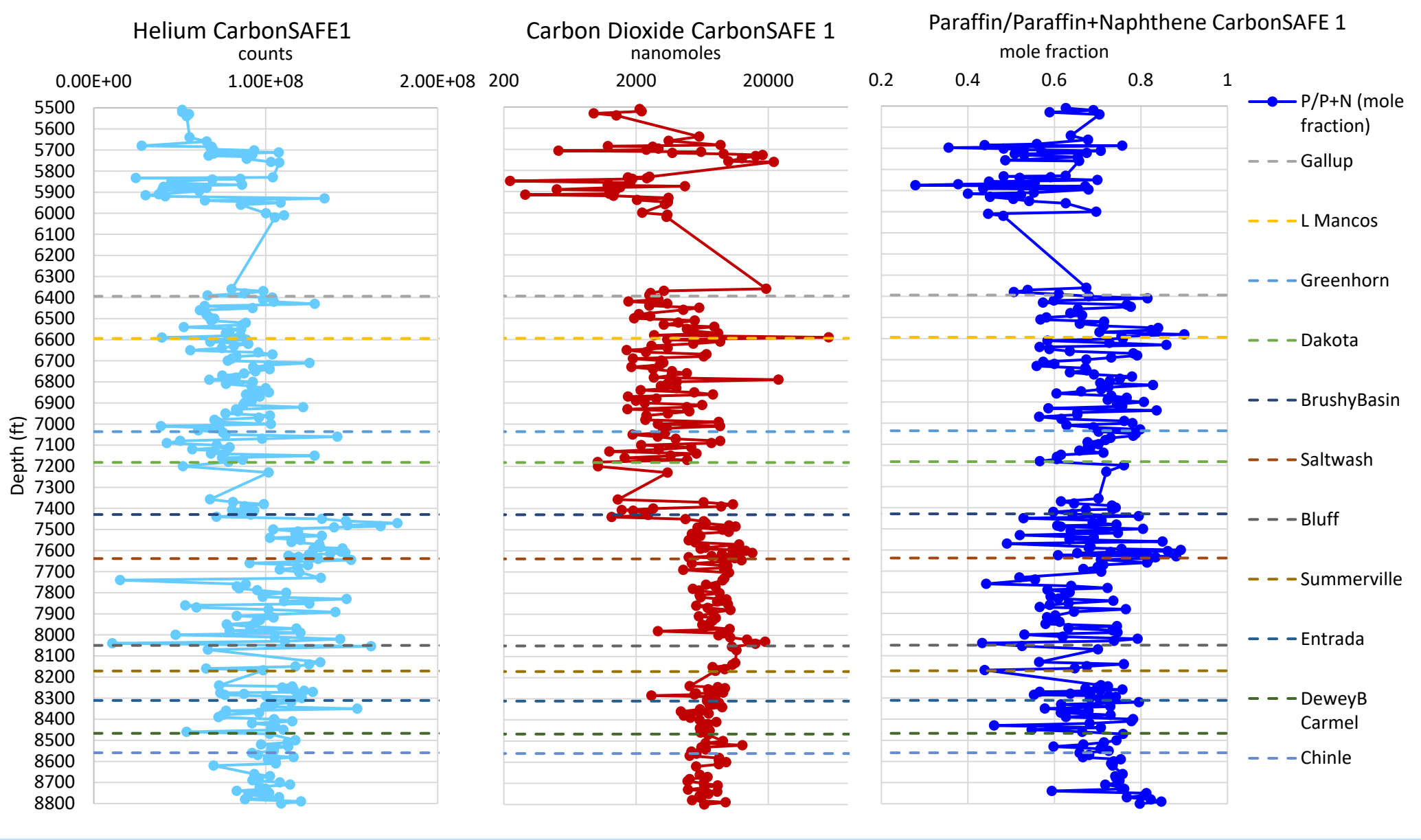




Vertical Seals

- Geochemical evidence of several significant seals in the primary and secondary seals
- CO2 and helium show a stepwise change in the top of the Brushy Basin indicating an excellent seal
- HC composition indicates a potential seal in the U. Mancos and Chinle
- Other seals are possible

Very positive evidence for the existence of good quality seals at CarbonSAFE 1

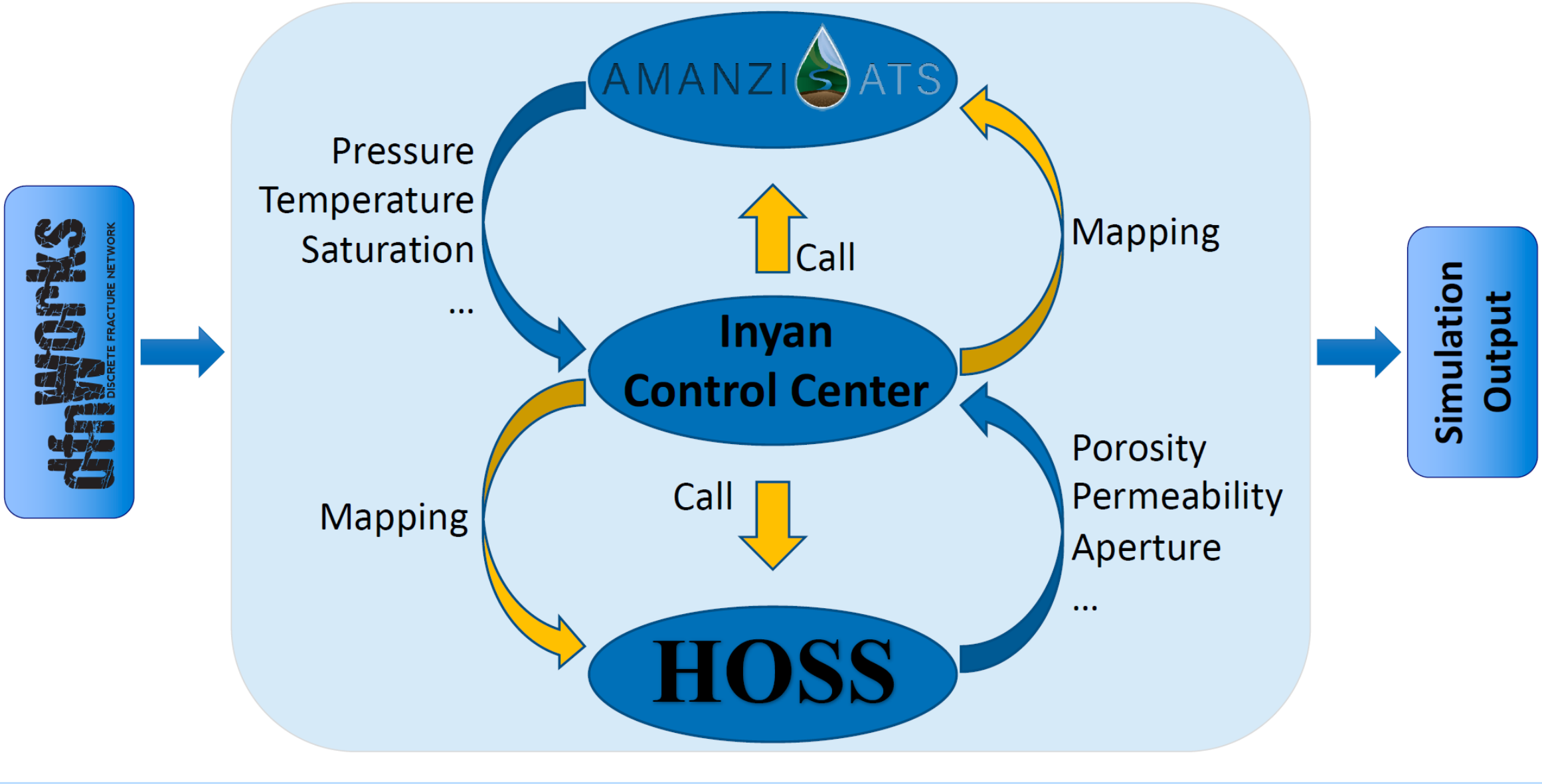


Site Summary

While the question of lateral migration of HCs needs to be evaluated, features of interest based on the evaluation of legacy cuttings samples were identified and the results in relation to the SJB CarbonSAFE Storage site are overall encouraging, especially in relation to a lack of a history of CO2 migration/loss and evidence of strong vertical seals

Feature of Interest	Status in CarbonSAFE 1 Well
Petroleum System - Lateral Migration	Needs Evaluation
Petroleum System - Vertical Migration	Encouraging
Carbon Dioxide Regional Baseline	Encouraging
Nature of Carbon Dioxide Release	?
Vertical Seals	Positive

Next Step- Coupled Modeling Workflow



Summary Slide

- We have preformed machine-learning fault detection on prestack time migration (PSTM) and prestack depth migration (PSDM) images and compare the results.
- Most lines of our machine-learning fault detection results show that there are no major faults around the primary CO2 injection zone
- Successfully utilized Silixa fiber to monitor cementation operations during SJB CarbonSAFE well drilling.
- Successfully acquired a zero-offset and Walk away VSP at the SJB CarbonSAFE site
- Established a baseline for DAS/DTS/DSS responses post-drilling operations.
- Utilized AHS drilling cuttings analysis to establish lateral and vertical storage integrity within the storage complex

Next Steps

a. Complete analysis of unsealed cuttings and core and incorporate into sealing and migration assessment of the San Juan Basin
b. Perform 3D migration and 3D fault detection using ML approach
c. Compare residual U-shaped CNN method to conventional seismic attributes
d. Complete the conversion of existing 3D geological models to a format that LANL numerical tools can use
e. Continue the integrated hazard modeling utilize state-of-the art LANL tools
f. Acquire a time-lapse fiber data during the injection test at the SJB CarbonSAFE site

Acknowledgements

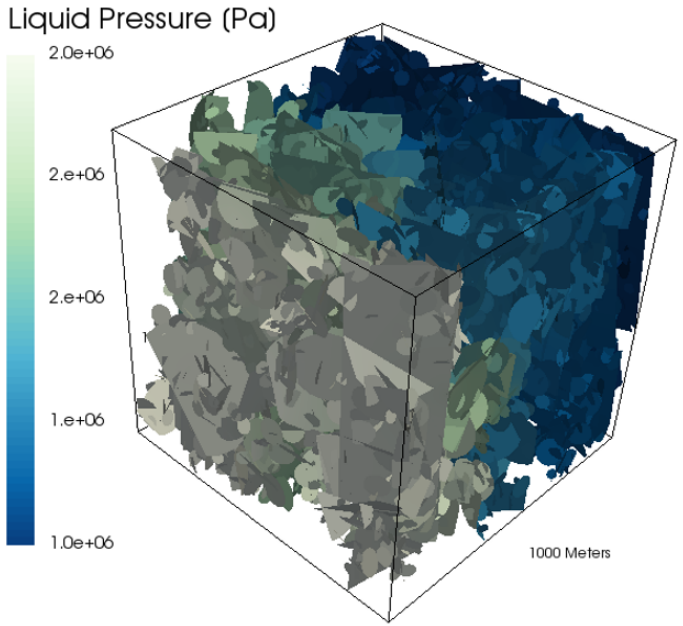
The project would like to thank DOE for the award opportunity through DE-FE0032064 and our partners. We would like to acknowledge additional support from San Juan Basin CarbonSAFE project.

Appendix

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

Next Steps- DfnWorks

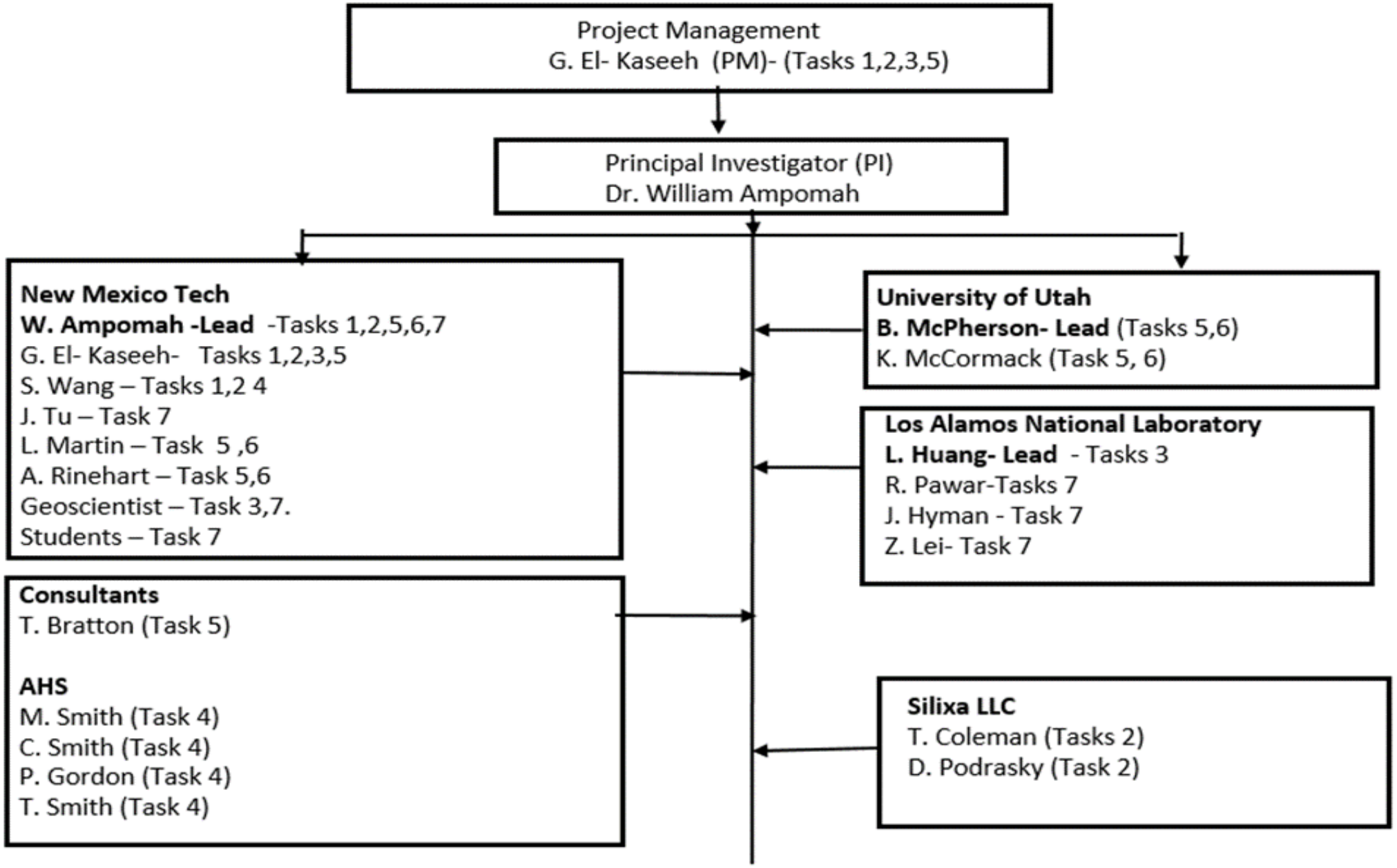
dfnGen → dfnFlow → dfnTrans



1) PFLOTRAN
2) FEHM
3) AMANZI

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

Organization Chart



Proposed Schedule

	Tasks	Budget Period 1-[07/01/2021 to 03/31/2023																								Budget Period 2												Budget Period 3											
		Project Year 1																								Project Year2												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	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
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									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																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																																																	
Subtask 5.4	Viscoplastic Minimum Principal Stress Estimation																																																	
Subtask 5.5	Strain Modeling with Finite Element Analysis																																																	M
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																																																	