# Regional Resource Assessment for $CO_2$ Storage in New Mexico and Surrounding Areas: Identification, Characterization, and Evaluation of In-Situ Mineralization Site/Complex

Carbon Conversion FOA 2614: AOI 4
DE-FE0032257
Project Performance Dates: 09/04/2023 – 09/03/2025

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U.S. Department of Energy
National Energy Technology Laboratory
2024 FECM / NETL Carbon Management Research Project Review Meeting
August 8, 2024

# Project Participants

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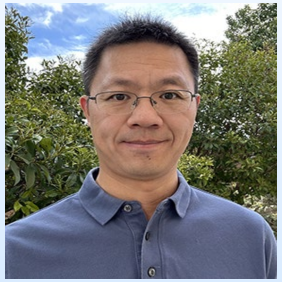
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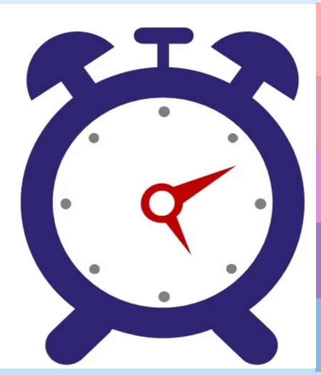
# Project Objective and Goals

- Project Objective: Identify and access statewide resources for potential CO2 storage via mineralization processes, including near surface and subsurface basalt formations and related stratigraphic units, and/or mining wastes in the state of New Mexico, as well as identify and characterize potential targeted storage sites/complexes to provide insights on storage capacity.

- Tasks:



Task 1: Project Management

Task 2: Site Screening and Characterization — Pre-screening and identifying potential CO2 mineralization storage sites/complexes

Task 3: Sample Characterization — Investigating and diagnosing the petrological, mineralogical, geochemical, geophysical and geomechanical properties of resource rock

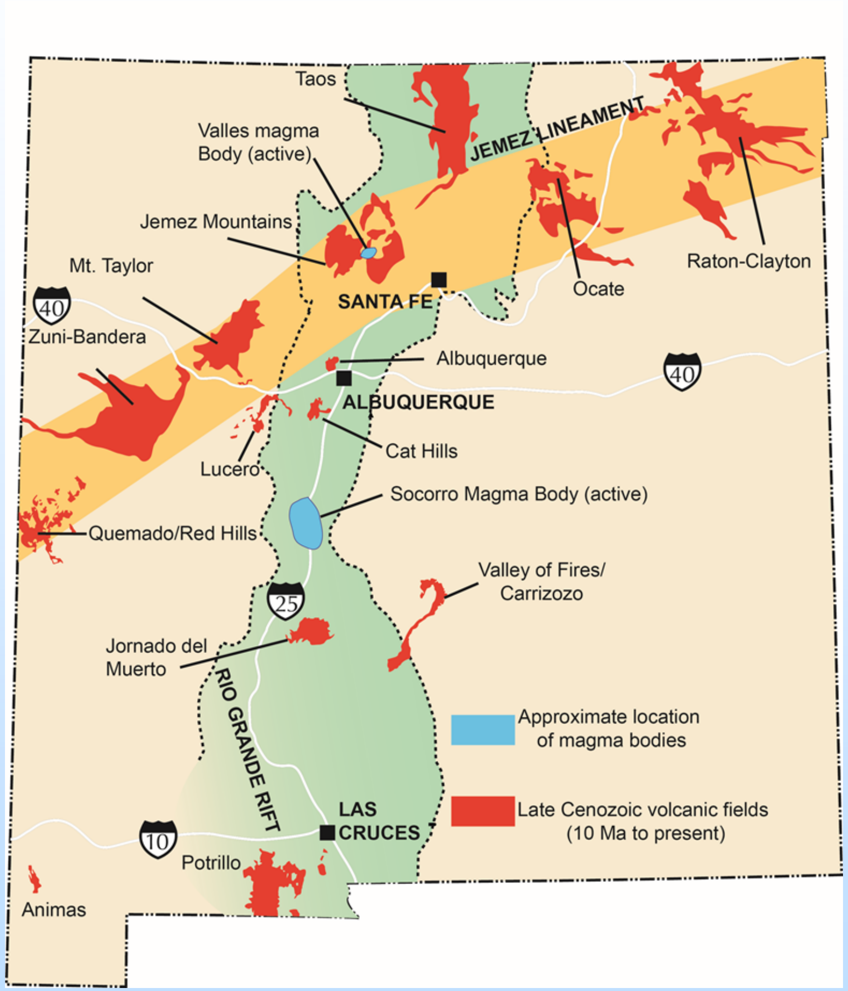
Task 4: Reaction Dynamic — Studying reaction dynamics of the CO2 mineralization process on the localized resource rock to indicate the optimum scenario for CO2 storage

Task 5:Storage Capacity — Understanding the CO2 storage potential through the eservoir-scale simulation and conduct economic analysis

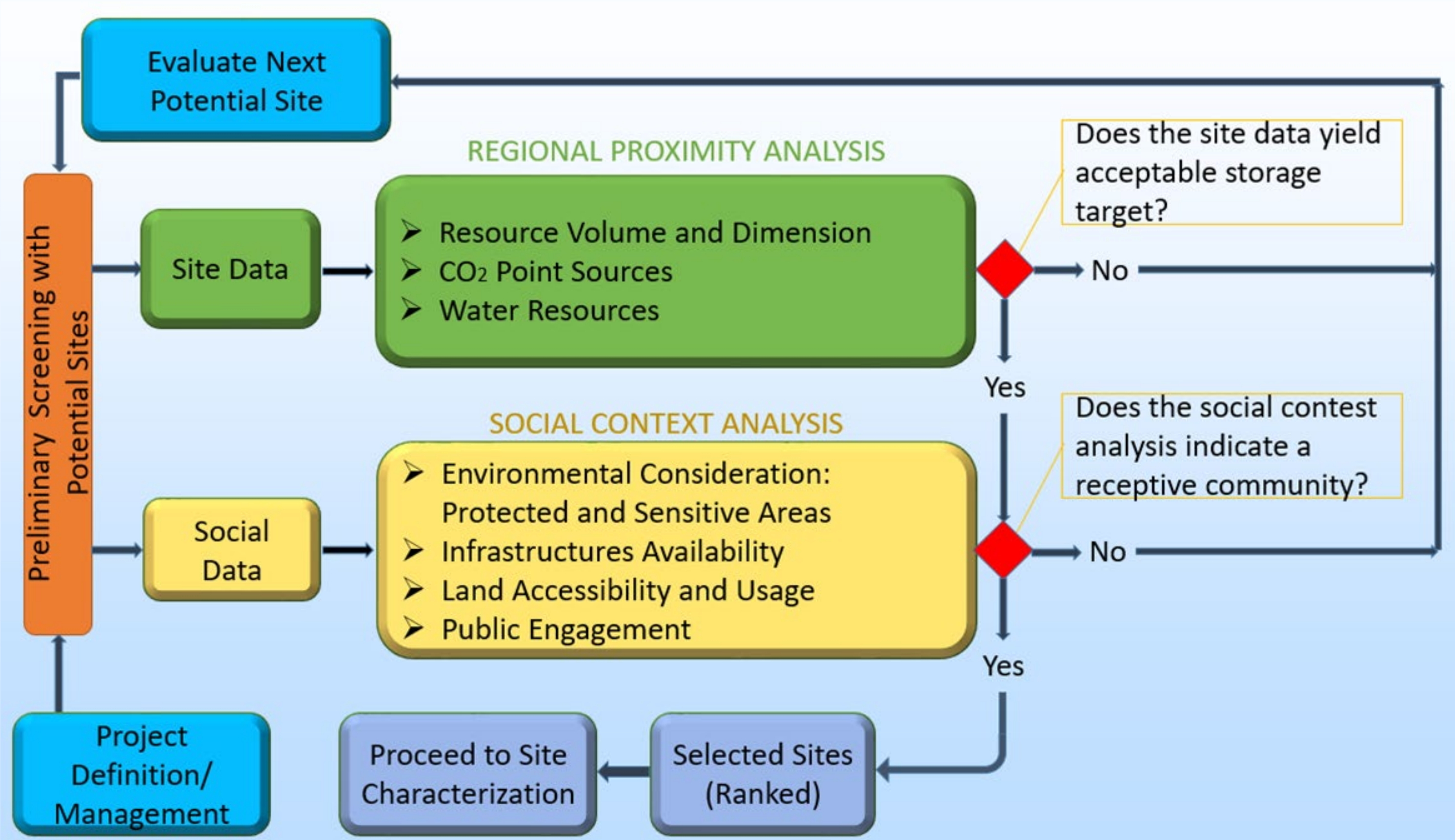
Task 6: Outrea — Provoking the interest in CO2 mineralization to local ommunities and opening the dialog between researchers and identified stakeholders

# Technical Update

## Site Selection-Near-surface Basalt



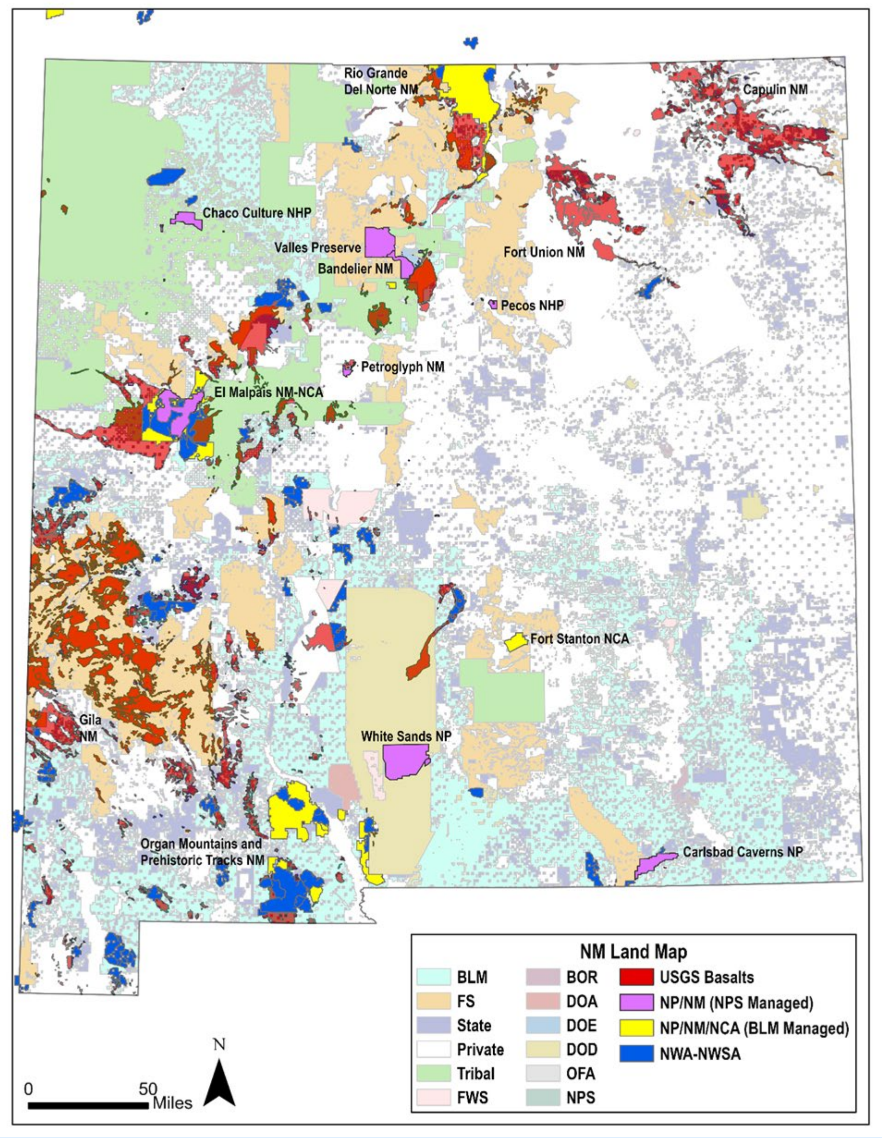

Geographical distribution of the basaltic rock in New Mexico

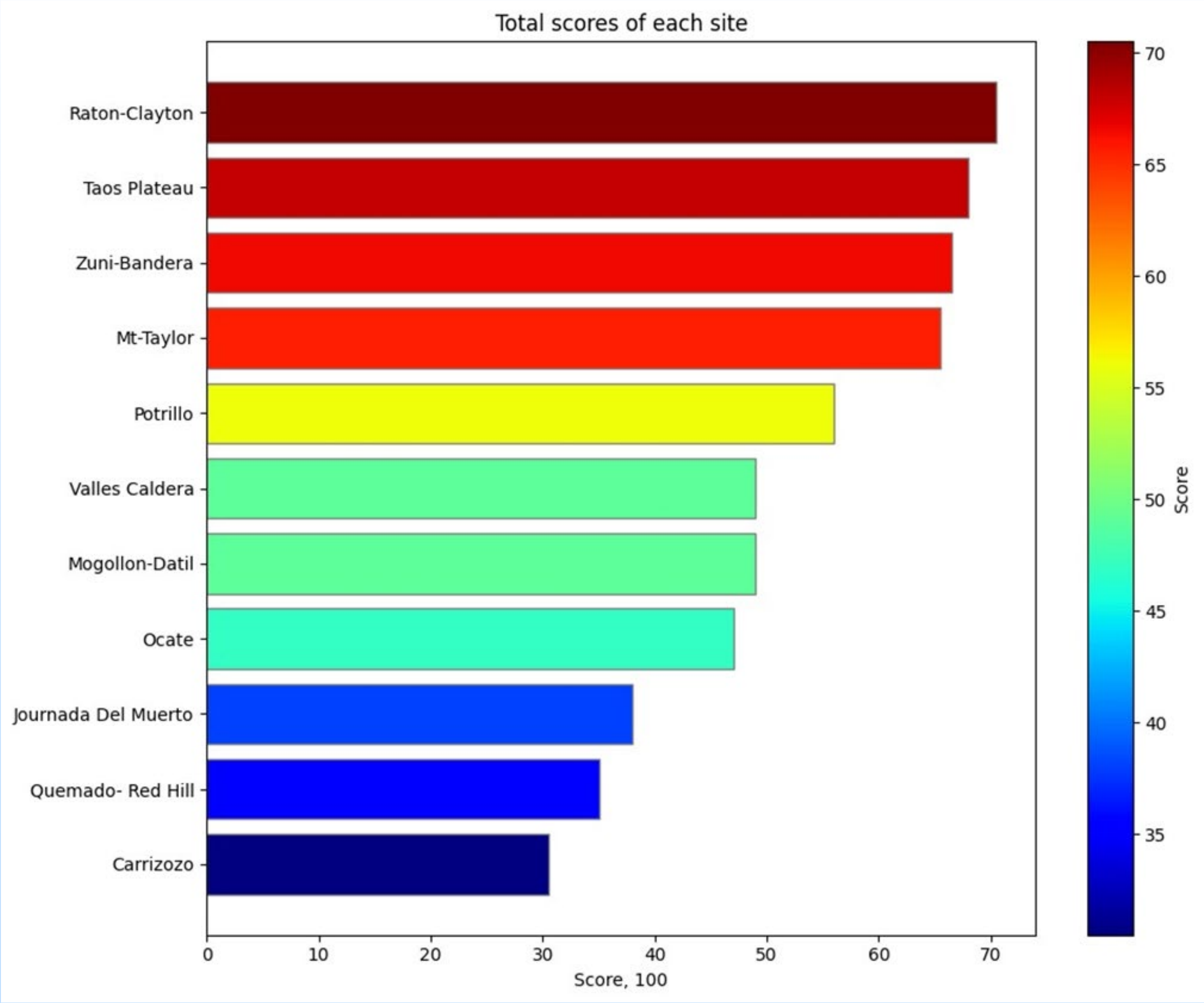



**Site Suitability:** Decision criteria are relevant to the specifics of CCUS via mineralization projects, such as: geologic formation volume, presence of divalent cation, proximity to sensitive areas, land access, CO2 sources, surrounding water resources, infrastructure availability and public engagement, etc.

# Technical Update

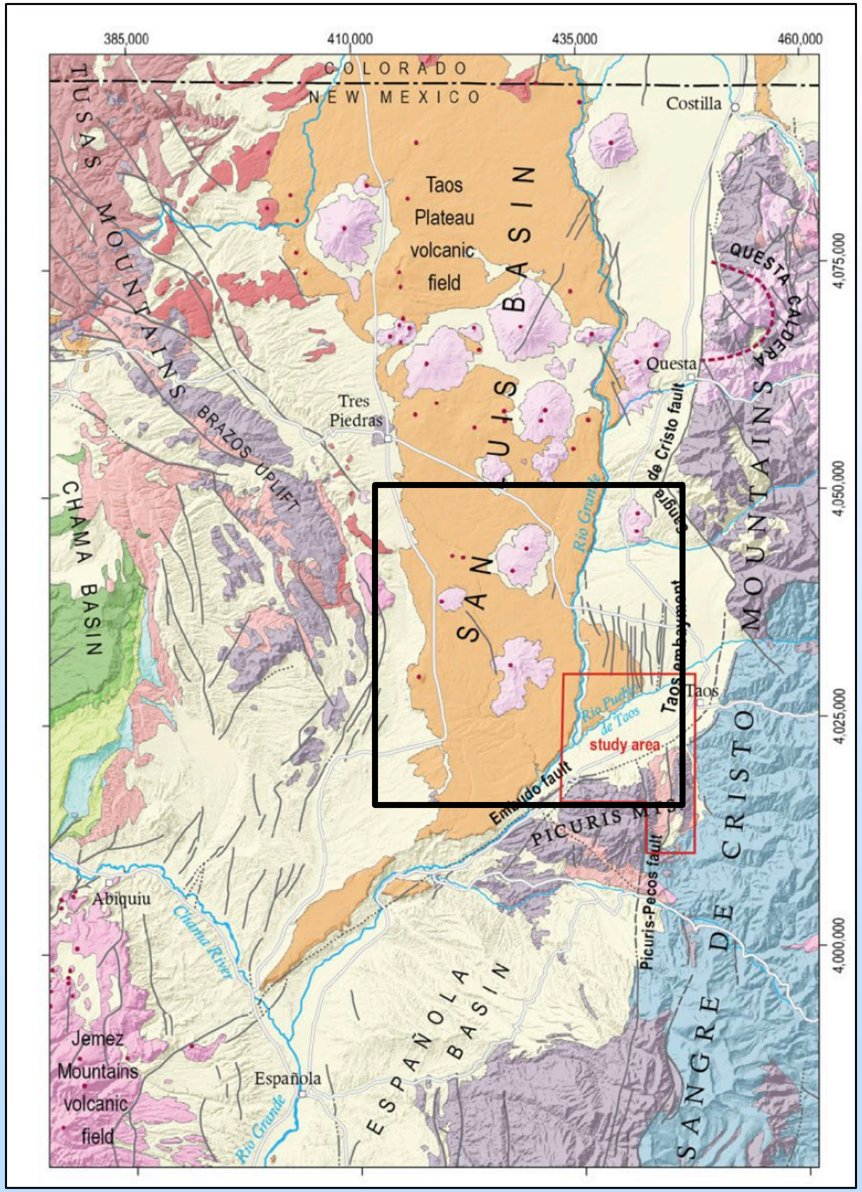
## Site Selection-Near-surface Basalt



# Technical Update

Taos Plateau Volcanic Field - Introduction




>6.0 Ma to 1.0 Ma

~2,500 $km^2$

~250 $km^3$

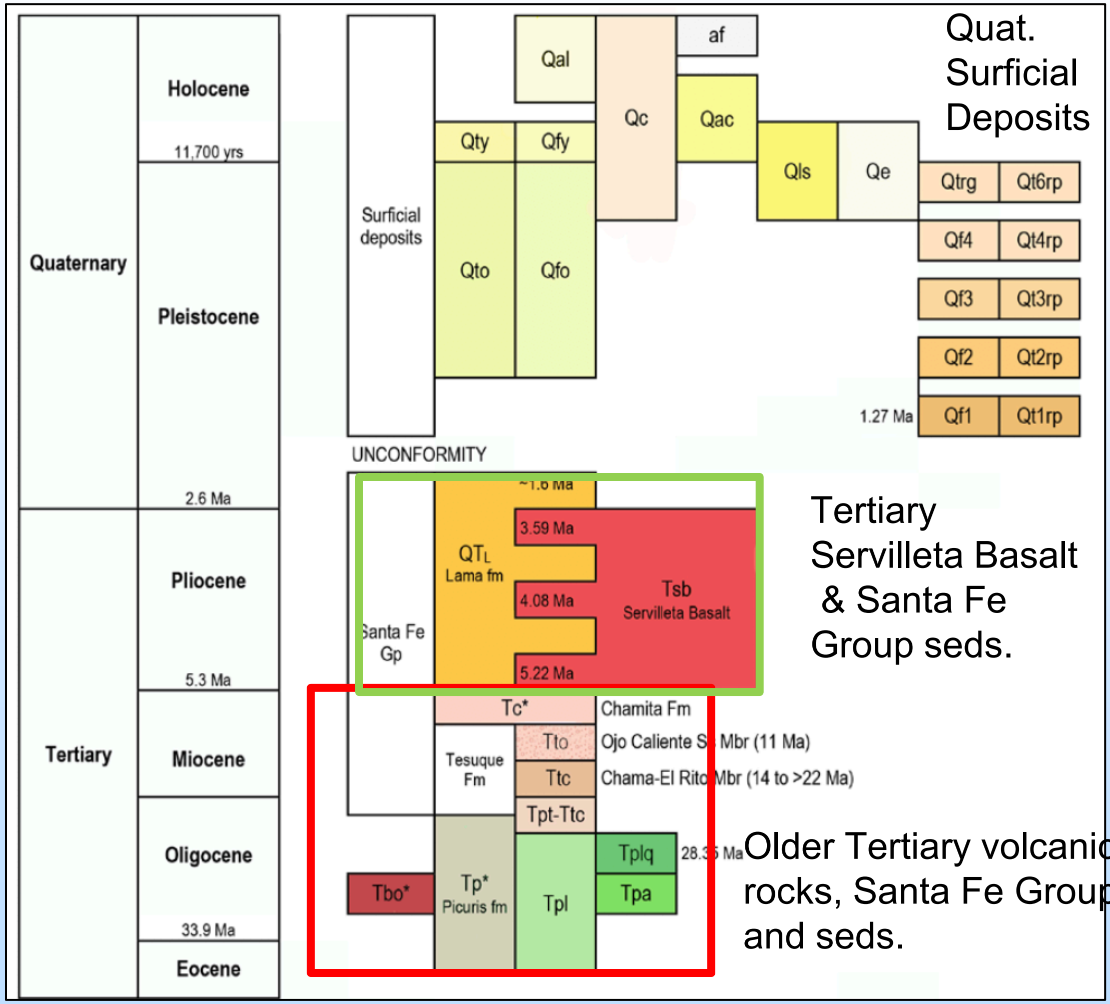
35-50 exposed volcanoes(more buried)

Compositionally diverse

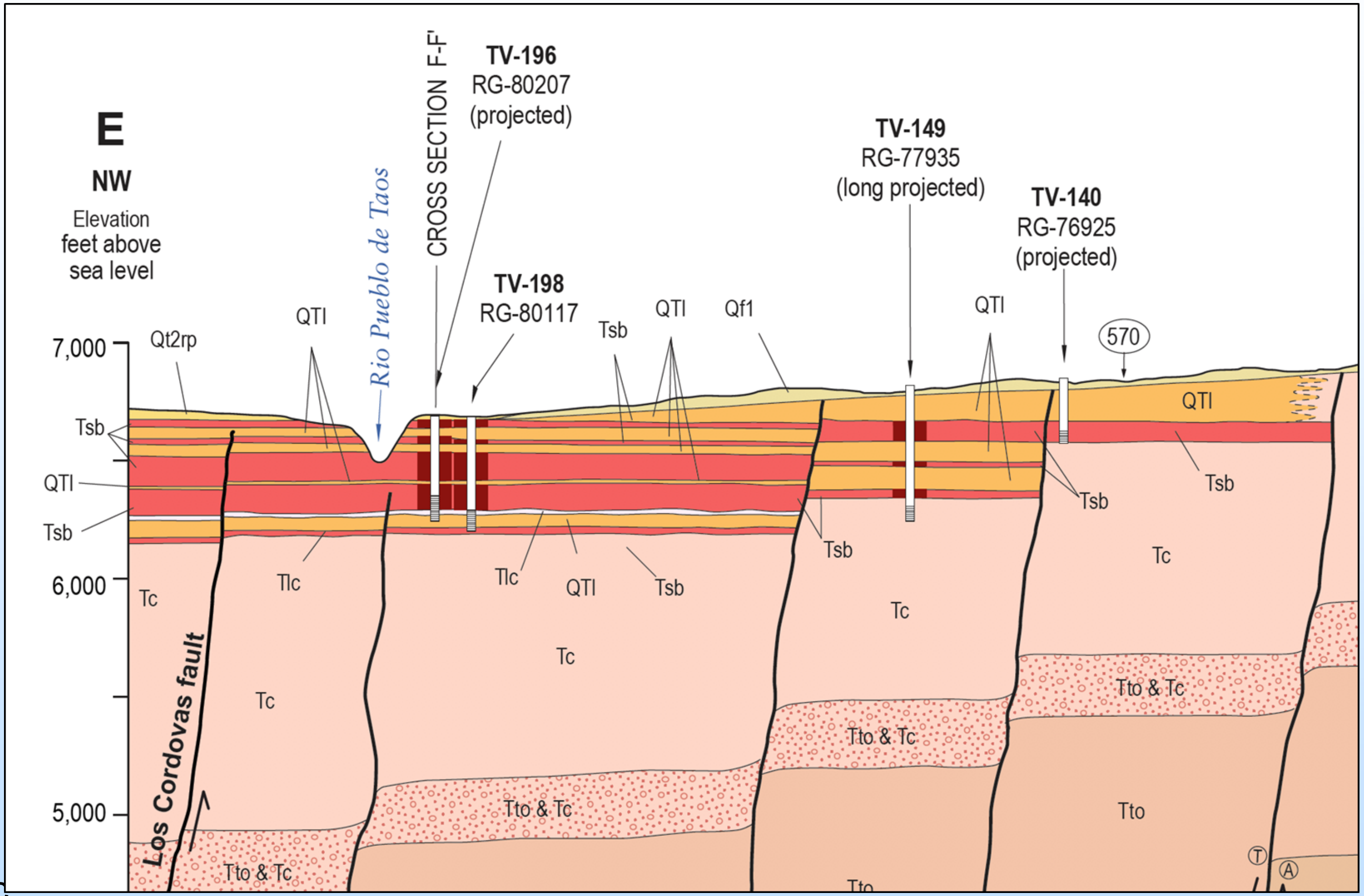
Late Cenozoic field in NM

# Technical Update

## Taos Plateau Volcanic Field - Stratigraphy

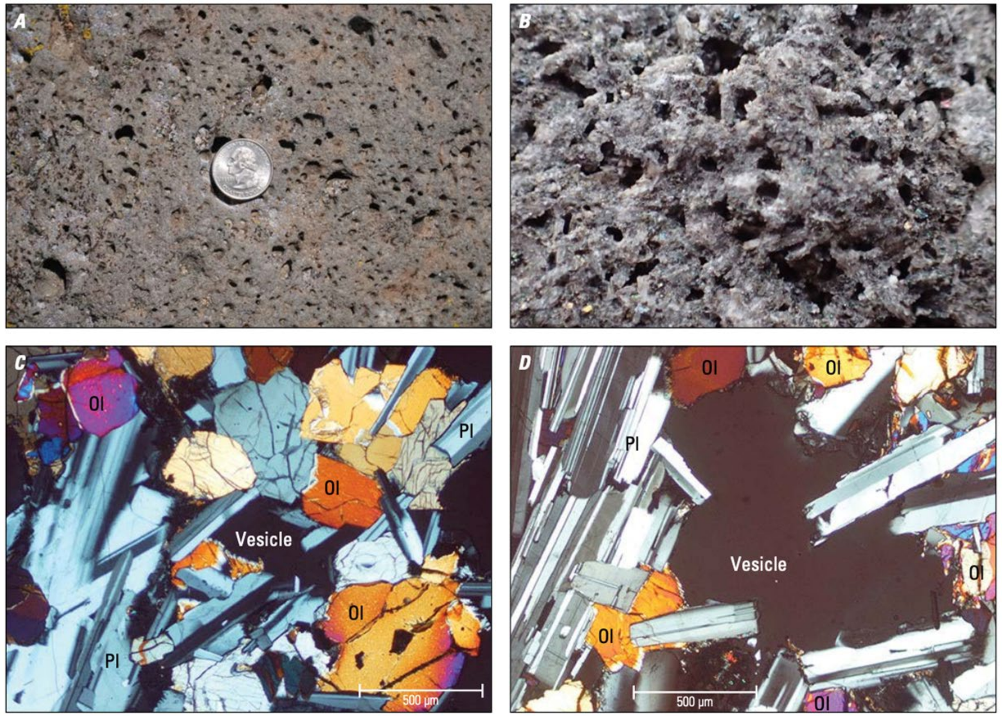


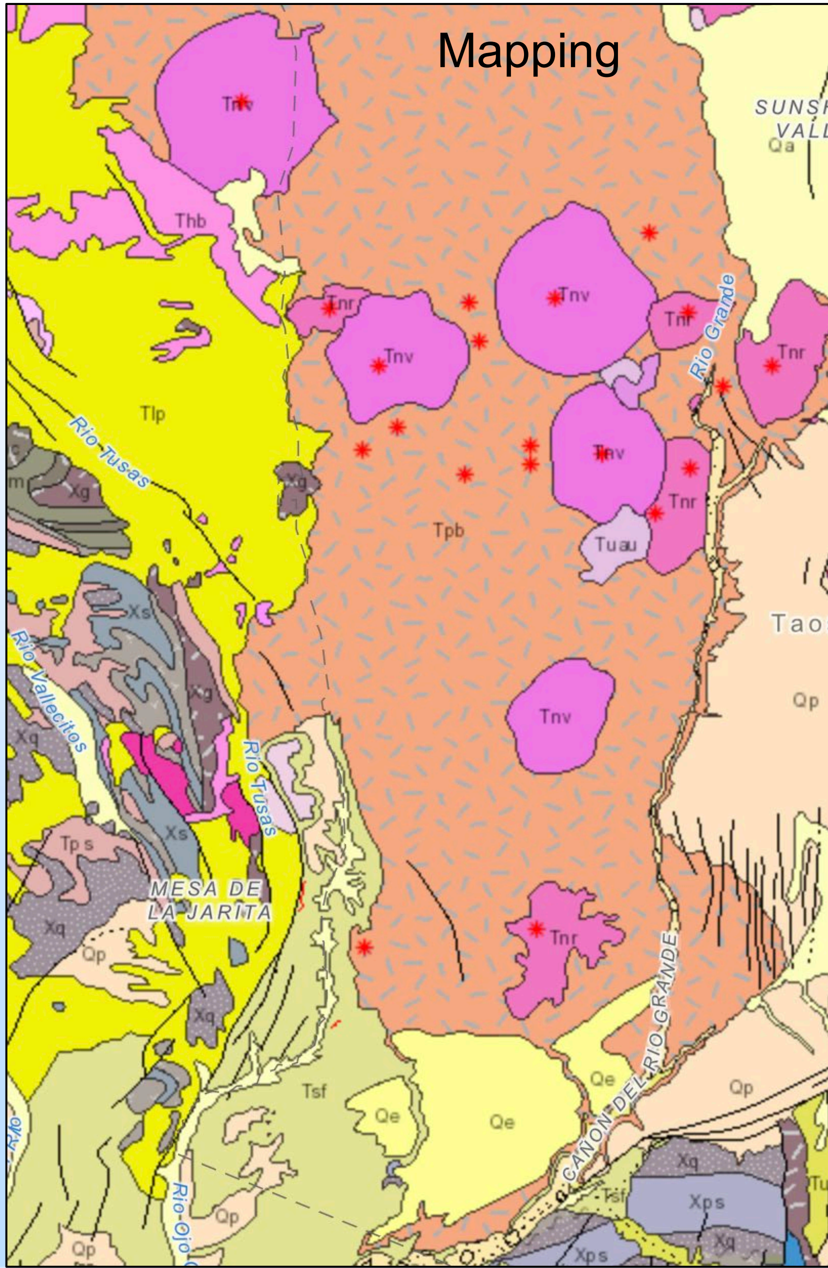

## Servilleta Basalt




Eruptions between ca. 5 and 3 Ma from numerous (≥ 5) shield volcanoes; Volume: ~200 km$^3$; As much as ~ 200 m thick in Taos Gorge; thins to 1-2 m at margins of the field; Three subunits: Lower, Middle, Upper; Composed of thin Pahoehoe flows

# Technical Update

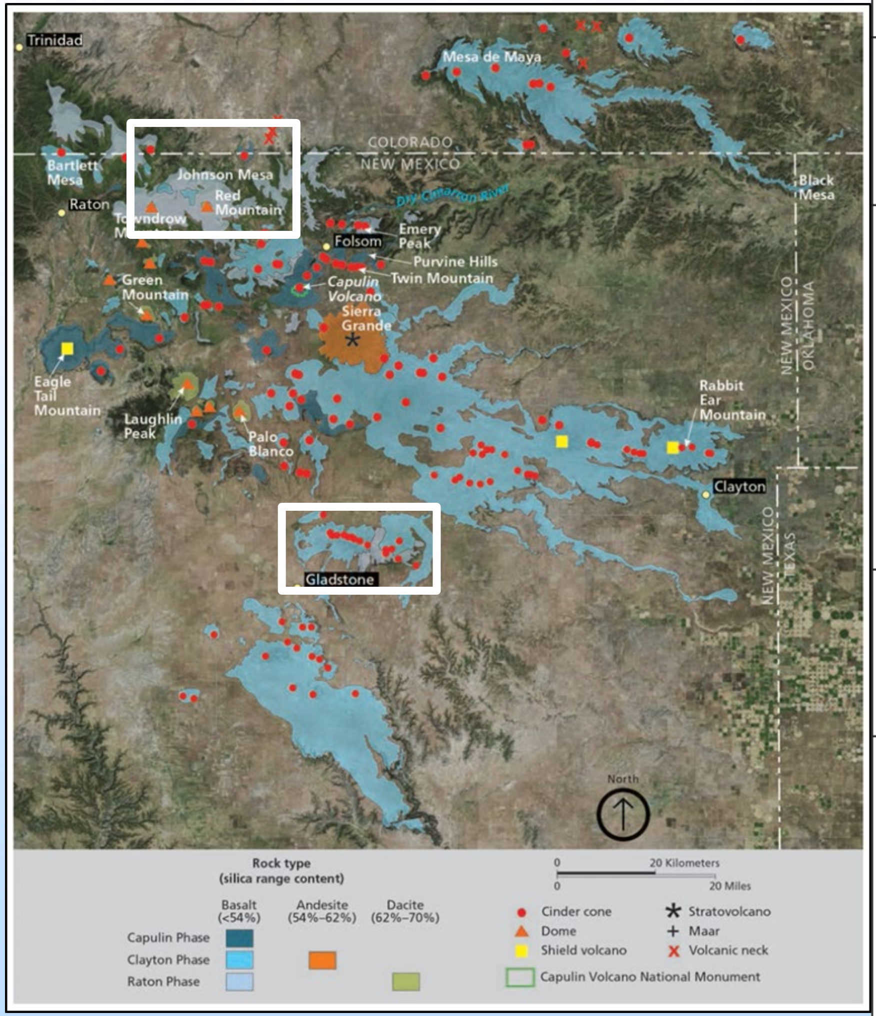



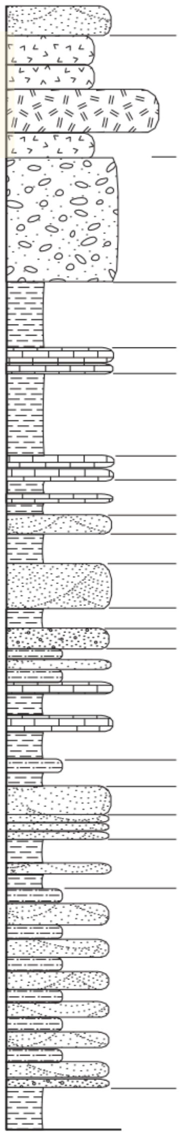

- Porous
- Some extensive clay layers have been identified between the basalt flows. These clays layers act as impermeable zones that appear to be the seal zone candidate.
- Notable features includes variable fractures related to cooling, extensive vesicle pipes, and the diktytaxitic texture of the groundmass

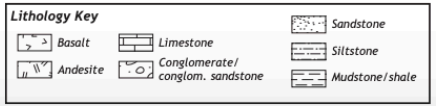
# Technical Update

## Raton-Clayton Stratigraphy




| Geologic Age | Stratigraphic Unit | General Rock Type(s) | Avg. Thickness |
|---|---|---|---|
| Quaternary | | Eolian sand sheets, dune and alluvial deposits. | ~0-30 m |
| Quaternary | Raton-Clayton-Capulin volcanics | Dark gray to black basalts, cinder cones and fissure vents ranging in age from ~ 36 ka - ~ 9 Ma. Incl. Sierra Grande: med. gray andesite, ~2.6-3.8 Ma. | |
| Miocene-Pliocene | Ogallala Fm. | Reddish-brown to tan coarse-grained sand with local lenses of pebble to cobble conglomerate. Heavily bioturbated. Locally capped by well-developed calcrete. | 0 - 200 m |
| Cretaceous | Smoky Hill Marl (Niobrara Fm.) | Dark gray silty to sandy shale with thin beds of limestone and marl. | 305 m |
| Cretaceous | Ft. Hays Ls. | Pale gray medium bedded limestone | 15 m |
| Cretaceous | Carlile Shale | Dark gray shale with thin limestone beds in upper section. | 61 m |
| Cretaceous | Greenhorn Ls. | Gray shale and pale gray medium-bedded micrite beds. | 9 m |
| Cretaceous | Graneros Shale | Medium gray shale with thin fossiliferous limestone beds. | 38 m |
| Cretaceous | Dakota Group: Romeroville Ss. | Yellowish-gray medium-grained, locally pebbly sandstone. | 0-8 m |
| Cretaceous | Dakota Group: Pajarito Shale | Medium gray shale. | 10-20 m |
| Cretaceous | Dakota Group: Mesa Rica Ss. | Brownish-yellow persistent medium grained, cross-bedded sandstone. | 33 m |
| Cretaceous | Glencairn Fm. | Gray to dark gray shale, siltstone and sandstone. | 22 m |
| Cretaceous | Lytle Ss. | Light gray conglomeratic cross-bedded sandstone. | 10-20 m |
| Jurassic | Morrison Fm. | Gray-green and red mudstone with locally thick medium to coarse-grained sandstone and thin micrite beds. | 52-168 m |
| Jurassic | Bell Ranch Fm. | Dark brown mudstone with nodules of alabaster. | 0-8 m |
| Jurassic | Exeter Sandst. | White to pale pink cross-bedded sandstone. | 0-24 m |
| Late Triassic | Dockum Group: Sheep Pen Ss. | Light-brown, thin-bedded sandstone. | 0-33 m |
| Late Triassic | Dockum Group: Sloan Canyon Fm. | Red and pale gray-green mudstone with lenses of medium-grained sandstone. | 0-46 m |
| Late Triassic | Dockum Group: Travesser Fm. | Reddish-brown siltstone and sandstone with local intraformational conglomerate lenses. | 75-168 m |
| Late Triassic | Dockum Group: Baldy Hill Fm. | Purple, red and green mottled mudstone with lenses of coarse-grained sandstone. Base not exposed. | > 30 m |

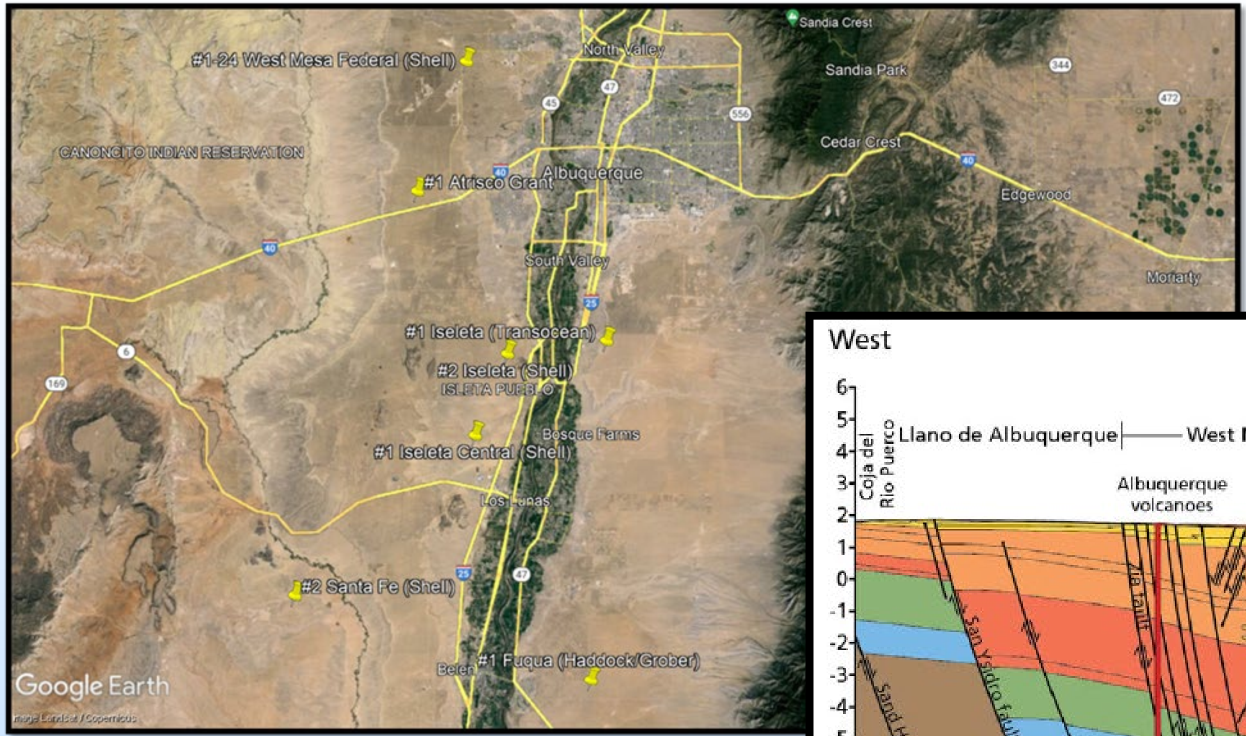


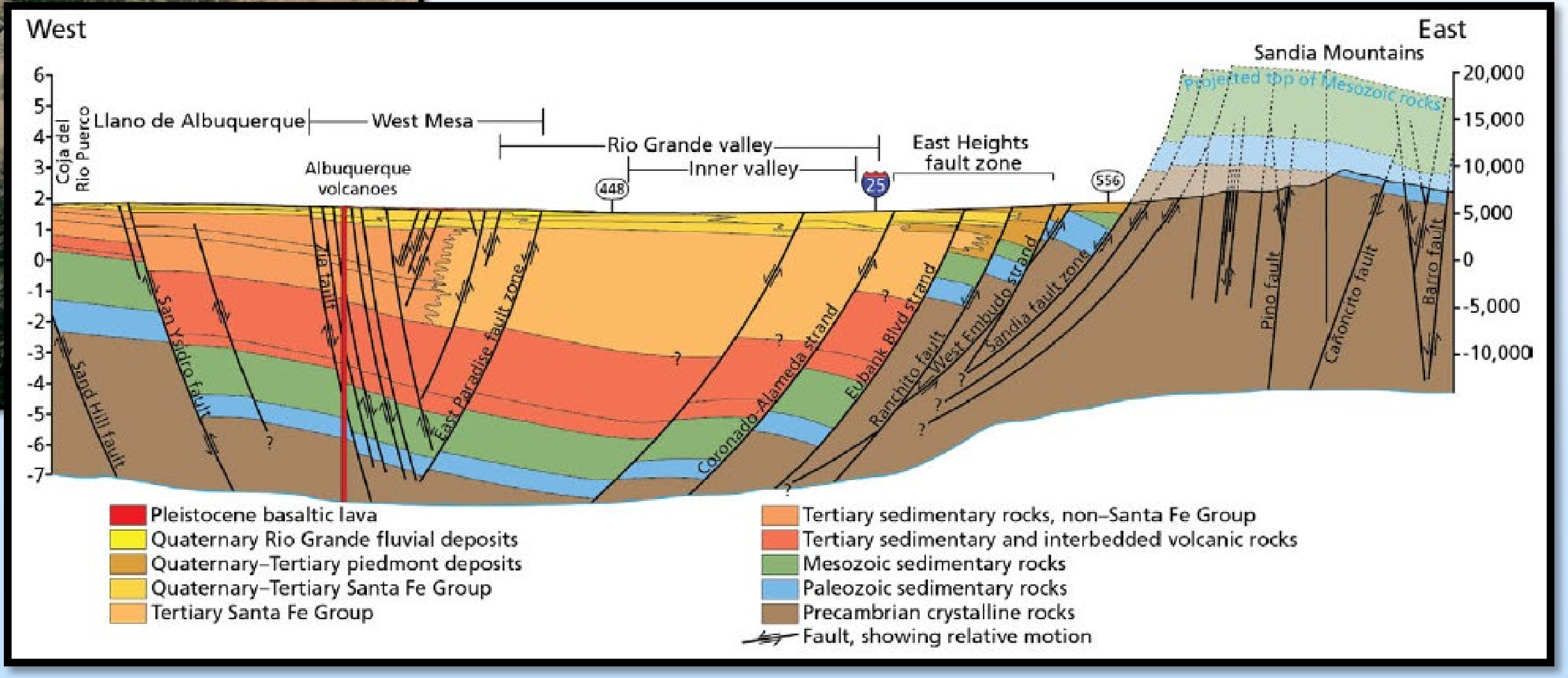



- Eruptions between ca. 9 Ma and 37 ka
- ~140 vents (mostly cinder cones)
- 7,000-10,000 km2
- ~100-200 km3
- Approximately 1,200 feet thick
- Basalt-Andesite-basalt
- Two subregions of interest: Johnson Mesa & Don Carlos Hills

# Technical Update

## Subsurface Basalt – Albuquerque Basin

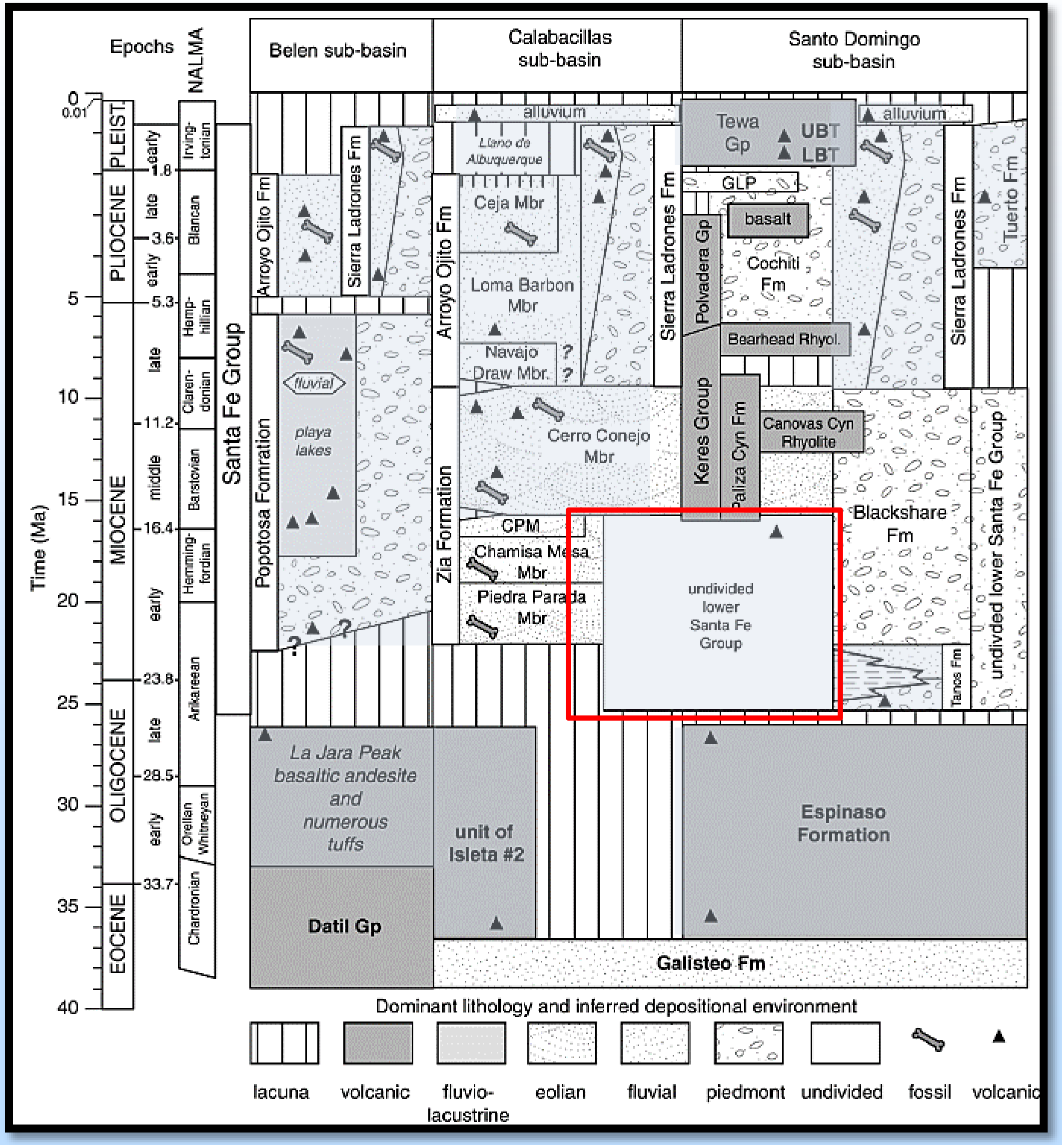



- Albuquerque Basin is a sub-basin in the Rio Grande Rift
- Wells with potential Basalt zones
- Most of the wells have cuttings or core available
- Shell #2 Isleta & Carpenter #1 Atrisco Grant (Arrows) may have the greatest potential

# Technical Update

## Stratigraphic Column

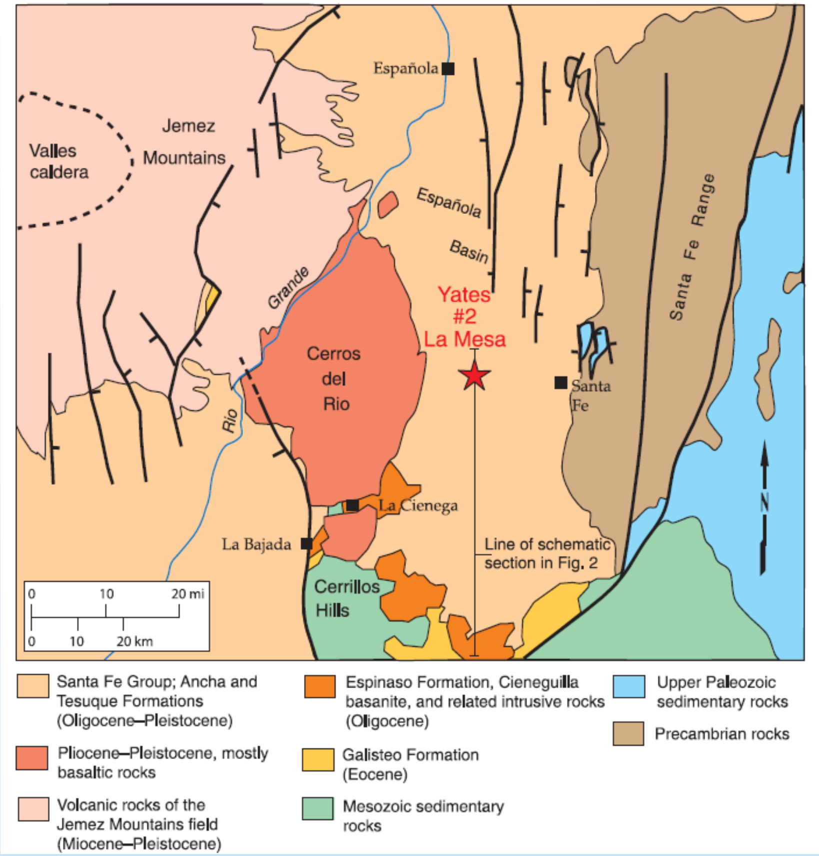



| API | Well | Location | Depth (ft) | Basalts | Depths |
|---|---|---|---|---|---|
| 30-001-05004 | Carpenter #1Atrisco Grant | 28-10N-1E | 6,652 | Basalts | 1,570-1,580;<br>3,350-3,455 sill?;<br>4,130-4,140;<br>4,175-4,185 volcanic cave?;<br>4,560-4,600;<br>4,910-4,970 sill?;<br>5,170-5,210 sill?;<br>5,500-5,670;<br>6,320-6,360 |
| 30-061-20004 | Shell #2 Santa Fe (cutting) | 29-6N-1W | 14,305 | Basalts | 14,700-14,800;<br>14,900-15,200 |
| 30-061-20008 | Shell Isleta Central (cutting) | 7-7N-2E | 16,346 | Basalts | 3,300-3,520;<br>6,950-7,000;<br>7,300 |
| 30-061-20031 | Grober #1 Fuqua | 19-5N-3E | 6,500 | | Not readable |
| 30-001-20002 | Trans Ocean Isleta #1 | 8-8N-3E | 10,378 | | Not readable |
| 30-001-20003 | Shell Isleta #2 (core, cutting) | 16-20N-13W | 21,266 | Basalt | 1,570-1,600 vesicular;<br>4,100-4,200 tuffs;<br>5,500-5,600 scoria |
| 30-001-20004 | Shell West Mesa Federal #1-24 (core) | 24-11N-1E | 19,375 | Basalt | 13,850-13,900;<br>14,700-14,800;<br>14,900-15,200 abundant fragments |

- Santa Fe Group deposits: Basalt flows interbedded with sedimentary basin fills (Sandstones, siltstones, shales, etc). Some volcanic sills as well.
- Strip logs were used initially to identify horizons with basaltic clasts.
- Listed wells that contained basalts, their depths, and there are core and/or cuttings at the NMBGMR.

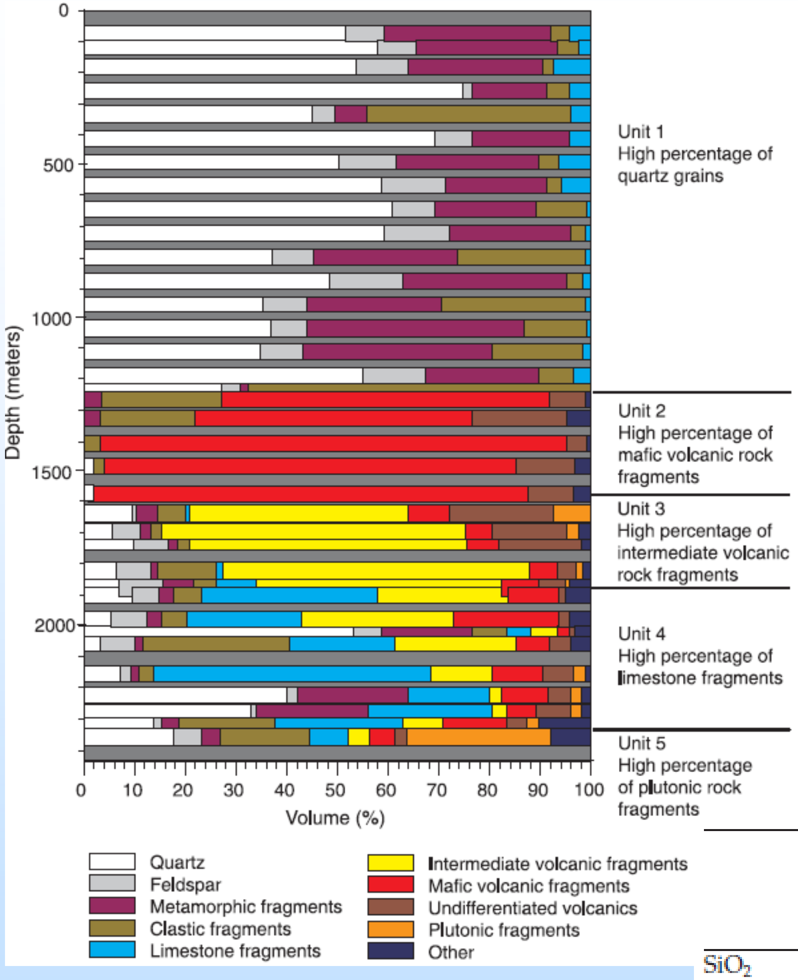
# Technical Update

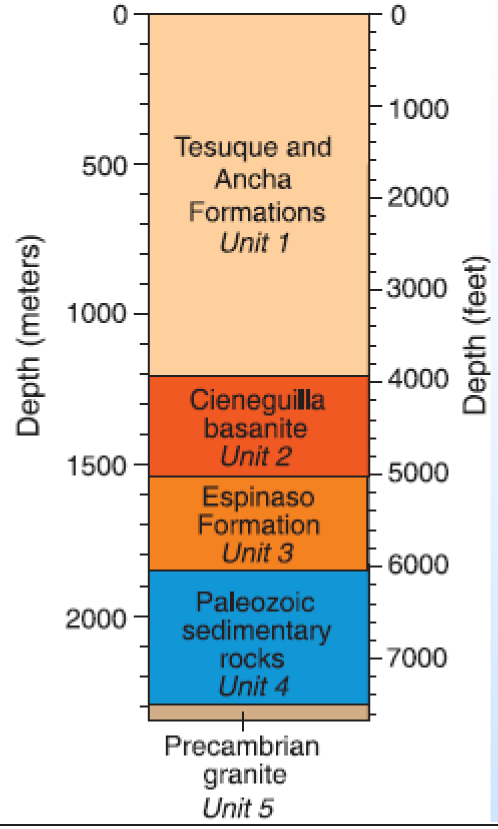
## Other subsurface basalt in NM?




Yates #2 La Mesa well located within the southern Española Basin, west of Santa Fe, New Mexico

CO2 source from Los Alamos



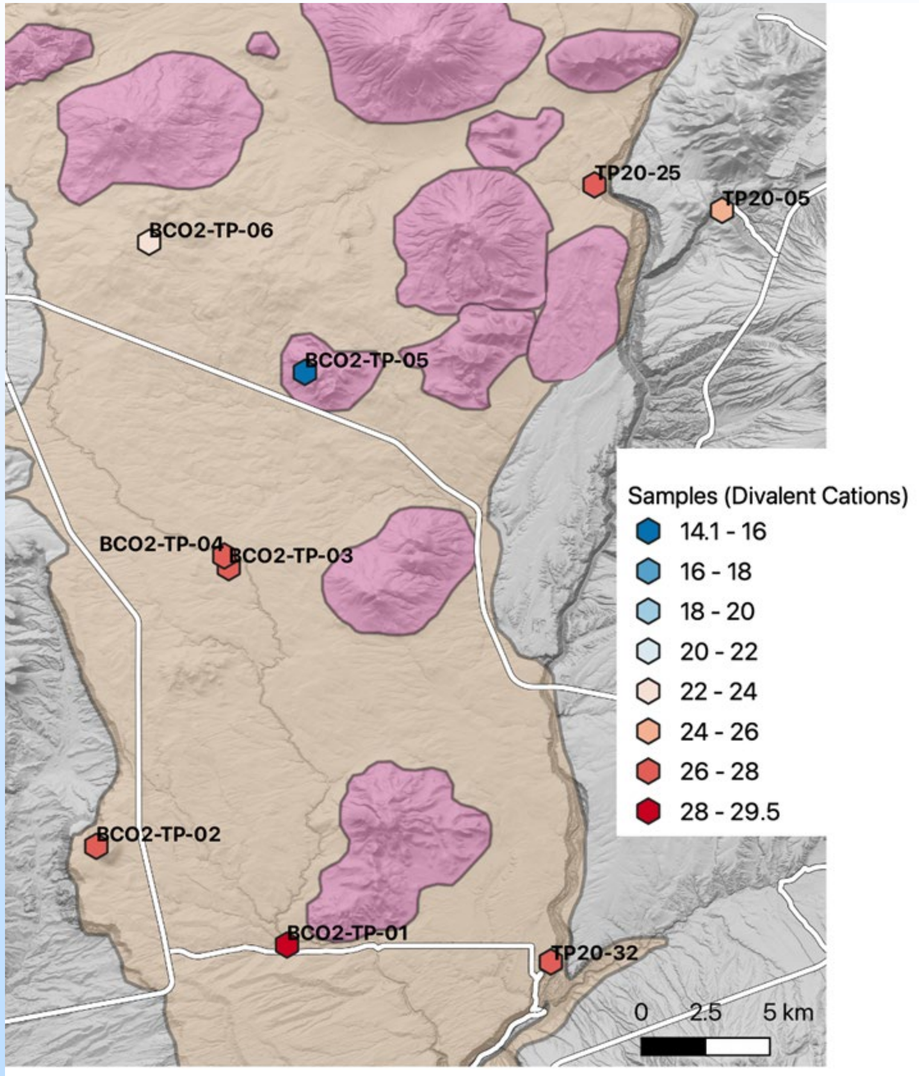



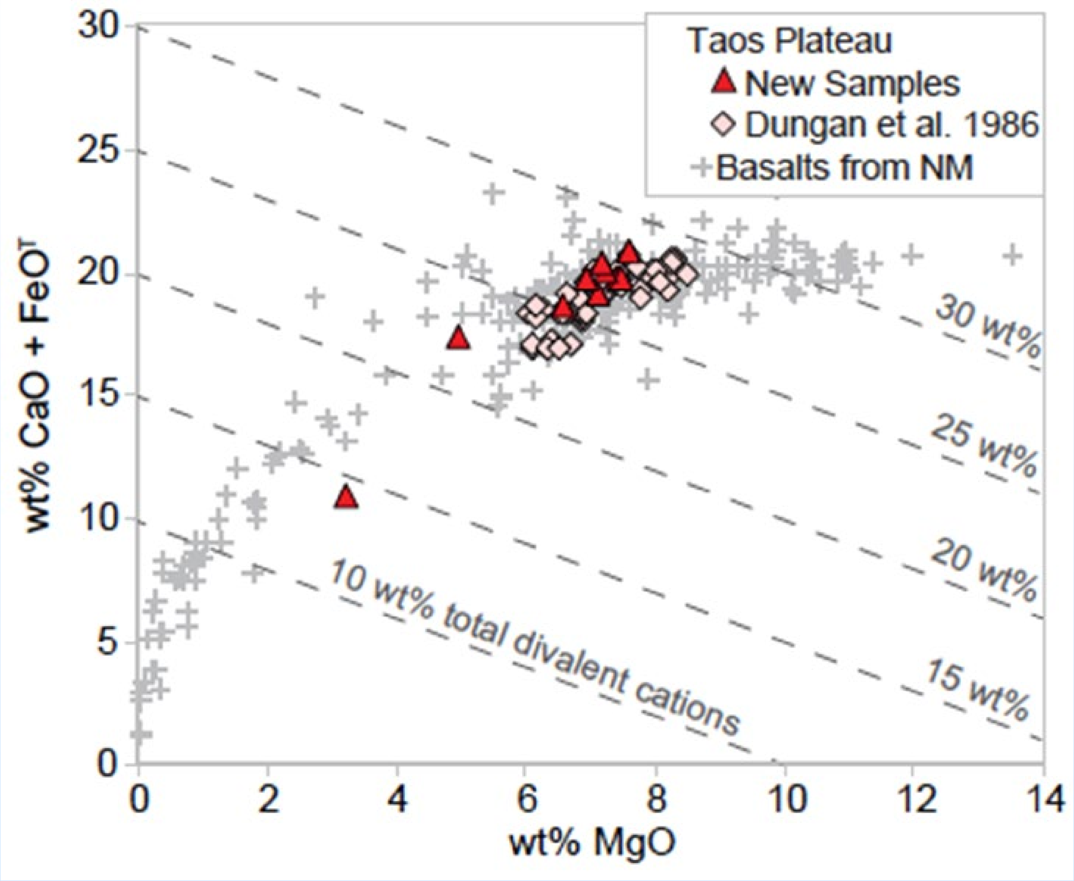

Designation of lithostratigraphic units based on well-cutting compositions

| | Espinaso Formation | | Cieneguilla basanite | |
|---|---|---|---|---|
| | alkaline latite[1] wt % | calc-alkaline latite[1] wt % | basalt[2] wt % | basanite (limburgite)[2] wt % |
| $SiO_2$ | 54.42 ± 5.24 | 59.25 ± 2.74 | 45.81 | 40.18 |
| $Al_2O_3$ | 16.89 ± 1.65 | 17.13 ± 0.85 | 14.08 | 11.7 |
| FeO | 7.12 ± 2.52 | 5.83 ± 1.32 | 7.41 | 6.68 |
| MgO | 2.54 ± 1.23 | 1.95 ± 0.58 | 8.79 | 14.3 |
| CaO | 6.48 ± 2.05 | 5.57 ± 0.64 | 9.45 | 13.28 |
| $Na_2O$ | 3.8 ± 0.73 | 3.97 ± 0.46 | 2.49 | 3.48 |
| **$K_2O$** | **3.97 ± 0.77** | **2.65 ± 0.64** | **0.86** | **0.76** |
| $TiO_2$ | 1.41 ± 1.09 | 0.73 ± 0.18 | 1.63 | 2.66 |
| $P_2O_5$ | 0.42 ± 0.26 | 0.25 ± 0.06 | 0.28 | 0.68 |
| MnO | 0.18 ± 0.03 | 0.15 ± 0.03 | 0.19 | 0.08 |

# Technical Update

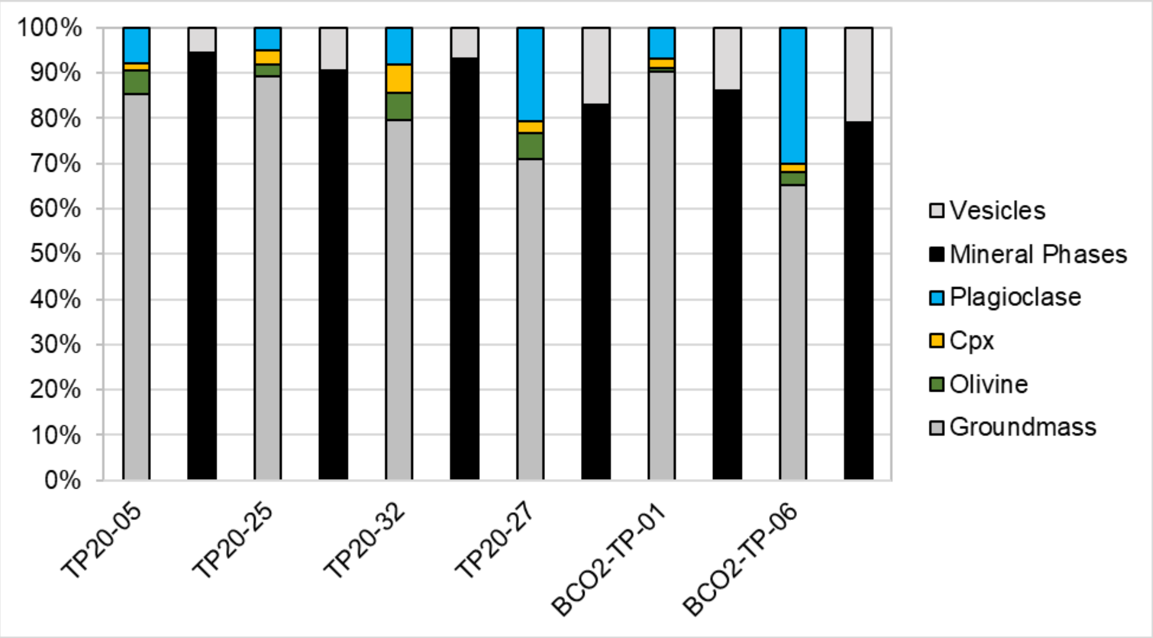
Sample characterization




Current and new samples from Taos Plateau with whole rock compositions

# Technical Update





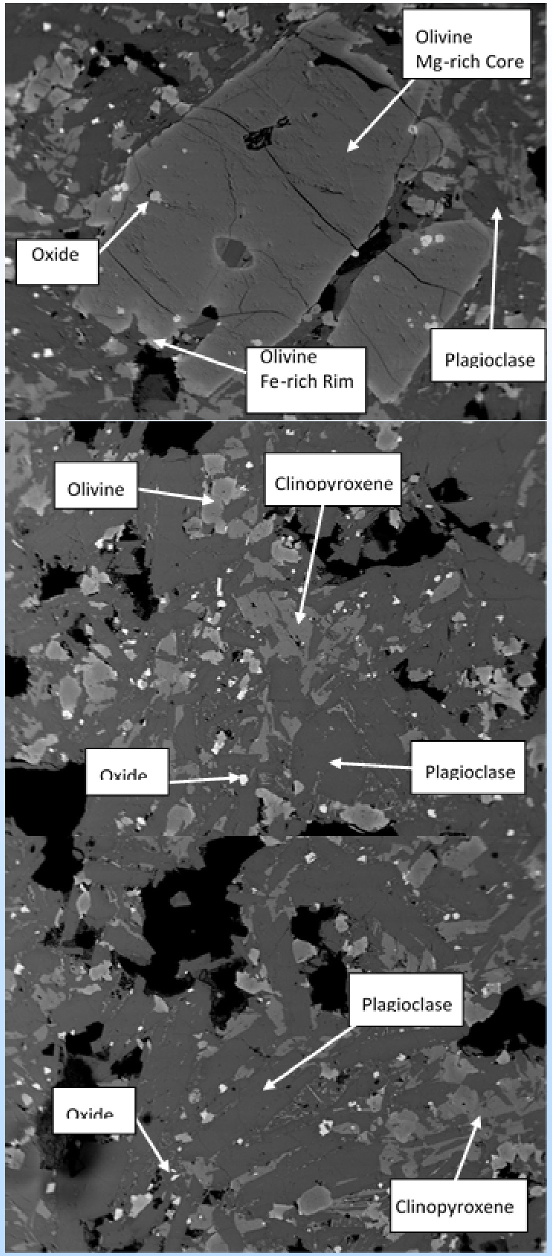
Sample TP20-27. Point counting of this thin section had results of 17.05% vesicles and 82.95% crystalline material. Out of the crystalline material, 70.85% was groundmass, 20.79% was plagioclase, 5.84% was olivine.

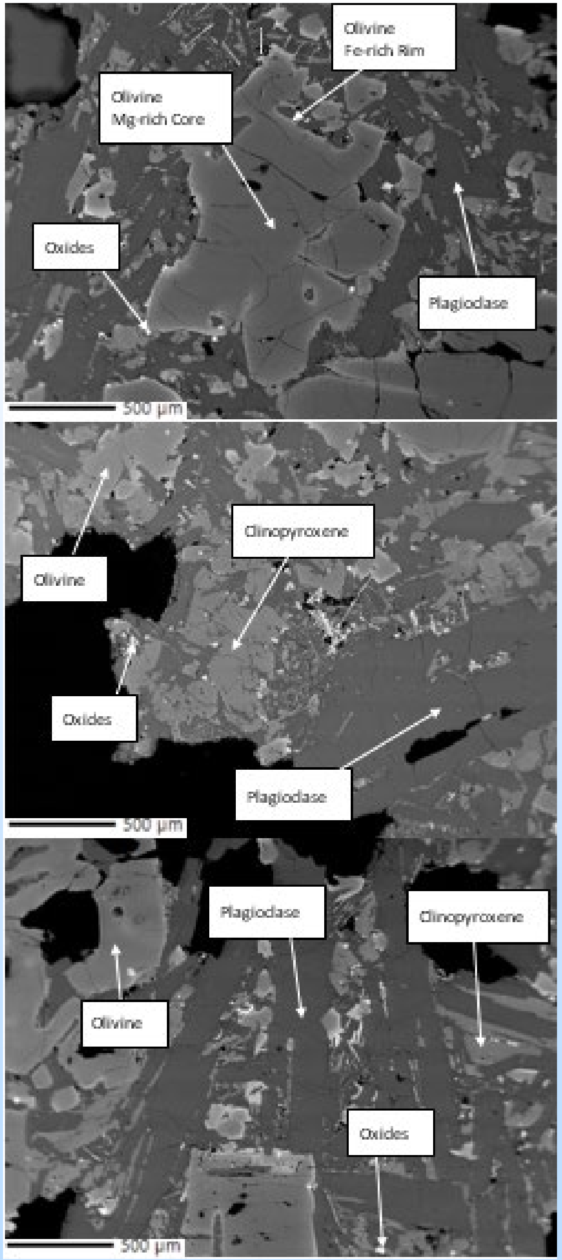
Results of point counts, are shown as bar graphs for mineral and groundmass assemblages (left bar, blue, orange, green and grey) and for the sample vesicularity (right bar, black and grey). bar).

- point counts to describe the overall mineralogy of the samples
- Samples have phenocryst abundances that range from ~10-25%, with assemblages consisting of olivine + clinopyroxene + plagioclase + Fe-Ti oxides. In general, plagioclase is the most abundant mineral in all assemblages followed by either olivine (e.g., TP20-05) or by pyroxene (e.g., TP20-32).
- Samples range in vesicularity from ~6% vesicles to ~20%.

# Technical Update

Petrology




Electron microprobe analyses(EMA) on the mineral phases within samples. The backscatter electron images of major mineral phases for all the samples shows:

- Olivine tends to be normally zoned, where the cores are magnesium rich and the faint rims are iron rich.
- Small olivine crystals also make up portions of the groundmass assemblage in all samples.
- Fe-Ti oxides occur as inclusions in olivine and also occur in the groundmass in all samples.

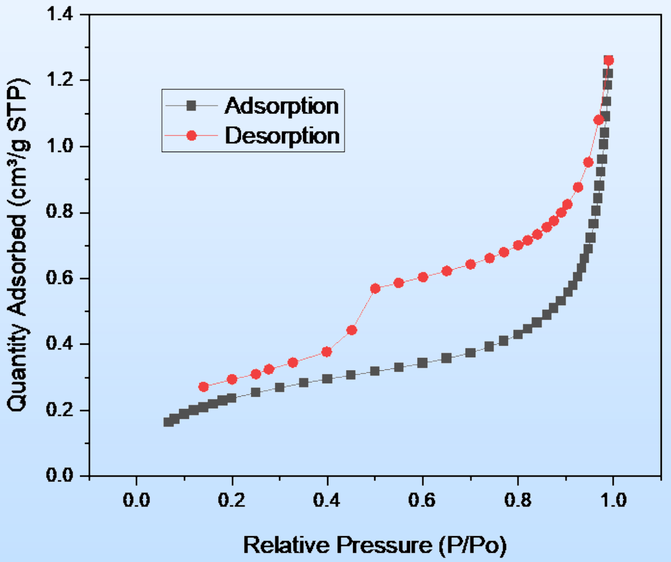
# Technical Update

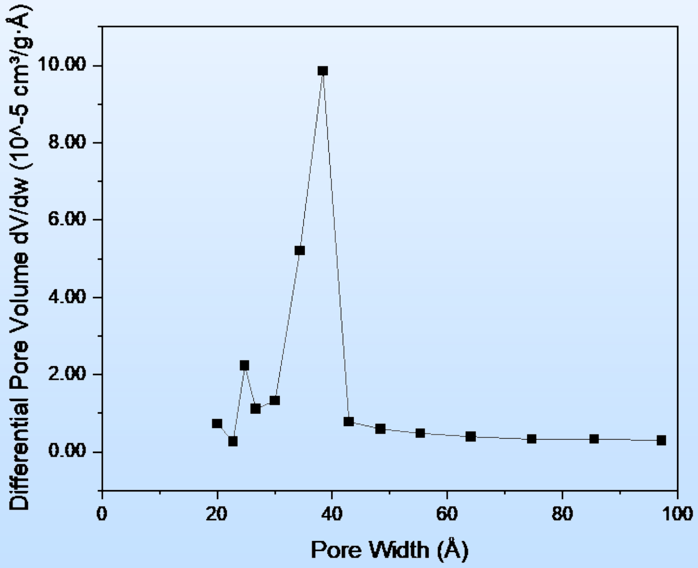
## Geophysical Properties

The BET-specific surface area was analyzed for basaltic rock samples from Taos using Micrometrics ASAP 2020 Plus 2.0.

**Method:**

- Adsorbs gas molecules (e.g., nitrogen) onto the material's surface.
- Measures gas adsorption at various relative pressures.
- Uses the BET equation to calculate surface area.


- The specific surface area for this study was 0.9178 ± 0.0055 $m^2/g$.
- The hysteresis loop is a type IV isotherm as shown in figure 1.
- The particle size width is 40 nm and corresponds to a mesopore.

# Technical Update

## Geomechanical Properties


**Objective**: Obtain mechanical properties of candidate resource rocks and changes in mechanical properties as a result of $CO_2$ injection.

**Progress**: Experimental test plan is outlined, sample prep in progress

**Planned experiments and mechanical properties:**

| **Planned Experiment** | Triaxial shear* | Uniaxial Compressive Strength (UCS)* | Indirect tension | Triaxial compression | Notched 3-pt.-bend* |
|---|---|---|---|---|---|
| **Measured parameter** | friction at confinement | cohesion, internal friction | tensile strength | internal friction | fracture and material toughness |

**test will be run on reacted and unreacted samples*

# Technical Update

## Reaction Dynamic

- Conduct the batch-type experiments to address dissolution and precipitation kinetics (Ambient T&P, Insitu P&T).
- GEM-Selektor code package based on the Gibbs energy minimization method will be used for thermodynamic and kinetic simulations of fluid-rock reactions during CO2 mineralization.
- Geochemist Workbench to simulate the dissolution and precipitation kinetics

- Multi-element analysis, determine which elements we could reliably detect
- Analyzed for major elements: Ca, Mg, Na, K, Si, Fe, Ba,

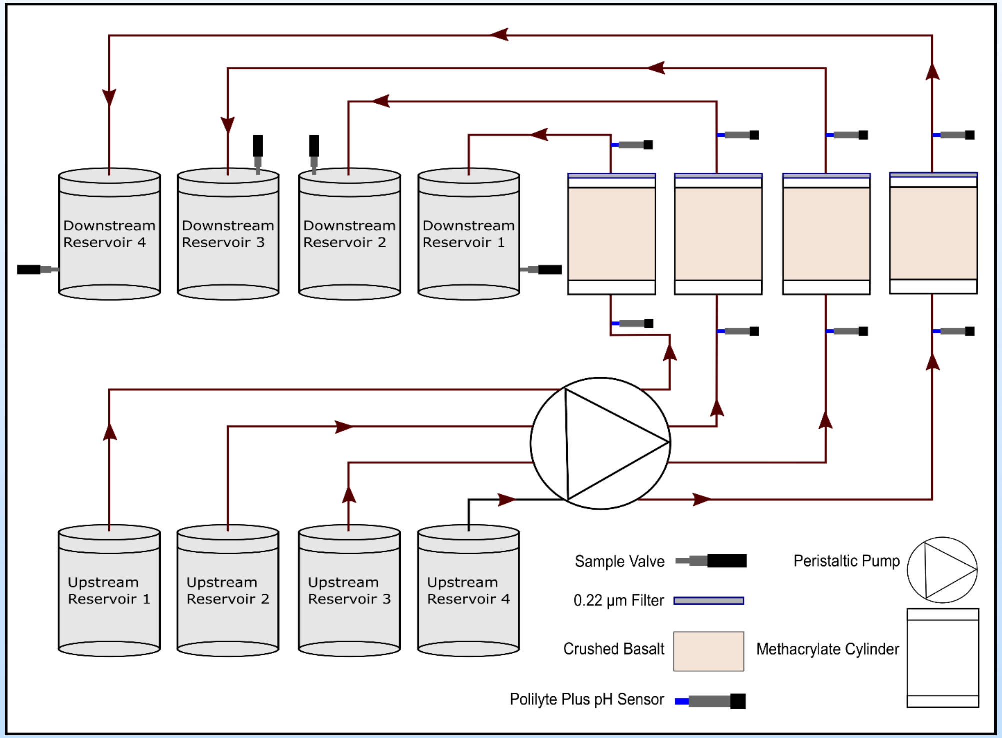
# Technical Update

## Dynamic Flow-through Experiments

**Objective**: Measure rates of chemical reactions of potential reservoirs during continuous exposure of different waters as a function of grain size vs. fracture area, while monitoring for changes in mechanical properties.

Table 1. Proposed Experimental conditions for reactive tests, B.E. is basalt equilibrated.

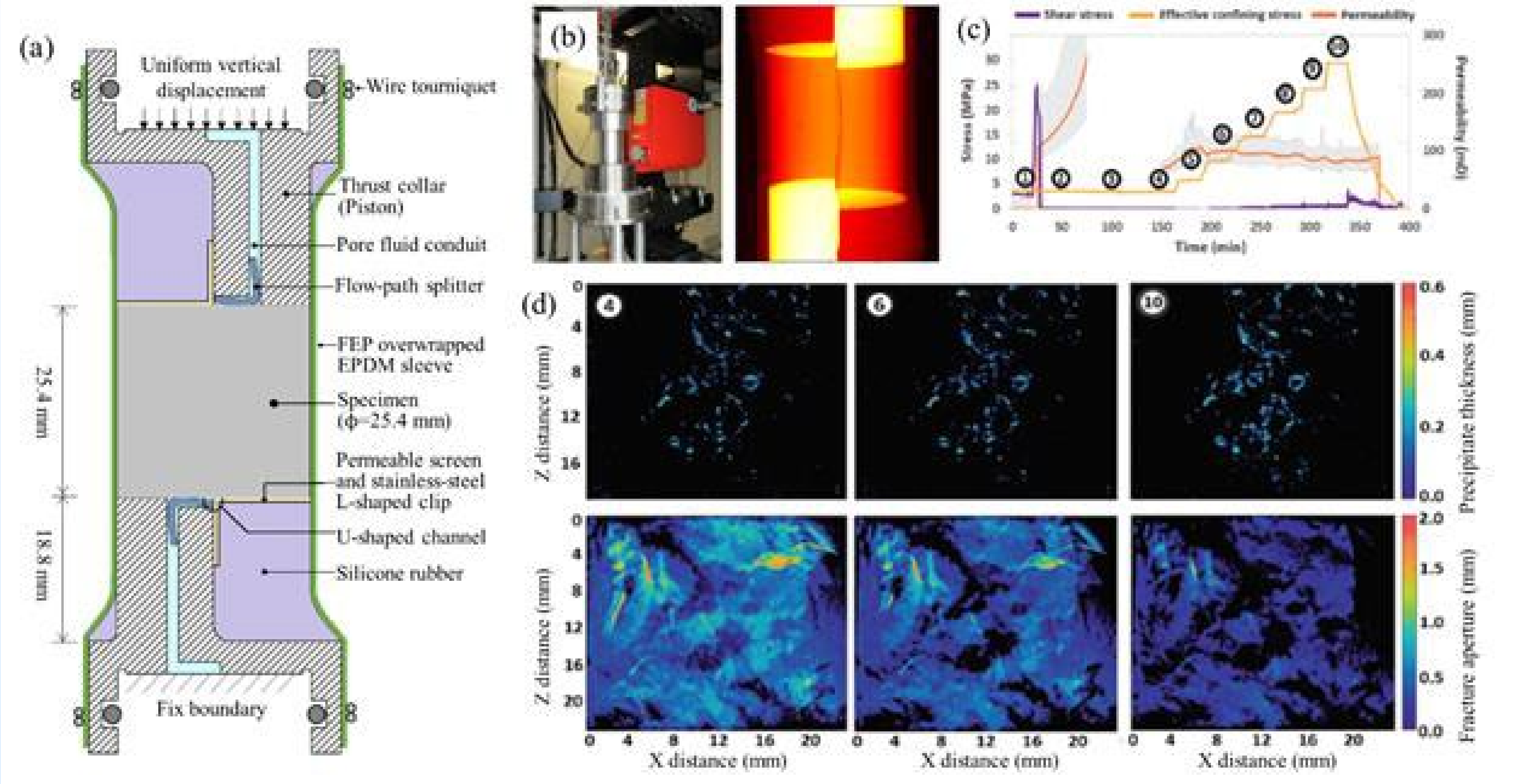
| Test # | Basalt Type | Reactive Mechanism | Experimental Solution | Grain Size (um) |
|---|---|---|---|---|
| 1 | Pristine | Dissolution | GW + CO2(a) | 44 - 125 |
| 2 | Vesicular/Fractured | Dissolution | GW + CO2(a) | 44 - 125 |
| 3 | Pristine | Precipitation | BE GW + CO2(a) | 44 - 125 |
| 4 | Vesicular/Fractured | Precipitation | BE GW + CO2(a) | 44 - 125 |
| 5 | Pristine | Dissolution | GW + CO2(a) | 250 -500 |
| 6 | Vesicular/Fractured | Dissolution | GW + CO2(a) | 250 -500 |
| 7 | Pristine | Precipitation | BE GW + CO2(a) | 250 -500 |
| 8 | Vesicular/Fractured | Precipitation | BE GW + CO2(a) | 250 -500 |
| 9 | Pristine | Dissolution | GW + CO2(a) | 1000 -2000 |
| 10 | Vesicular/Fractured | Dissolution | GW + CO2(a) | 1000 -2000 |
| 11 | Pristine | Precipitation | BE GW + CO2(a) | 1000 -2000 |
| 12 | Vesicular/Fractured | Precipitation | BE GW + CO2(a) | 1000 -2000 |
| 13 | Pristine | Recirculating | GW + CO2 (a) | whole |
| 14 | Vesicular/Fractured | Recirculating | BE GW + CO2(a) | whole |



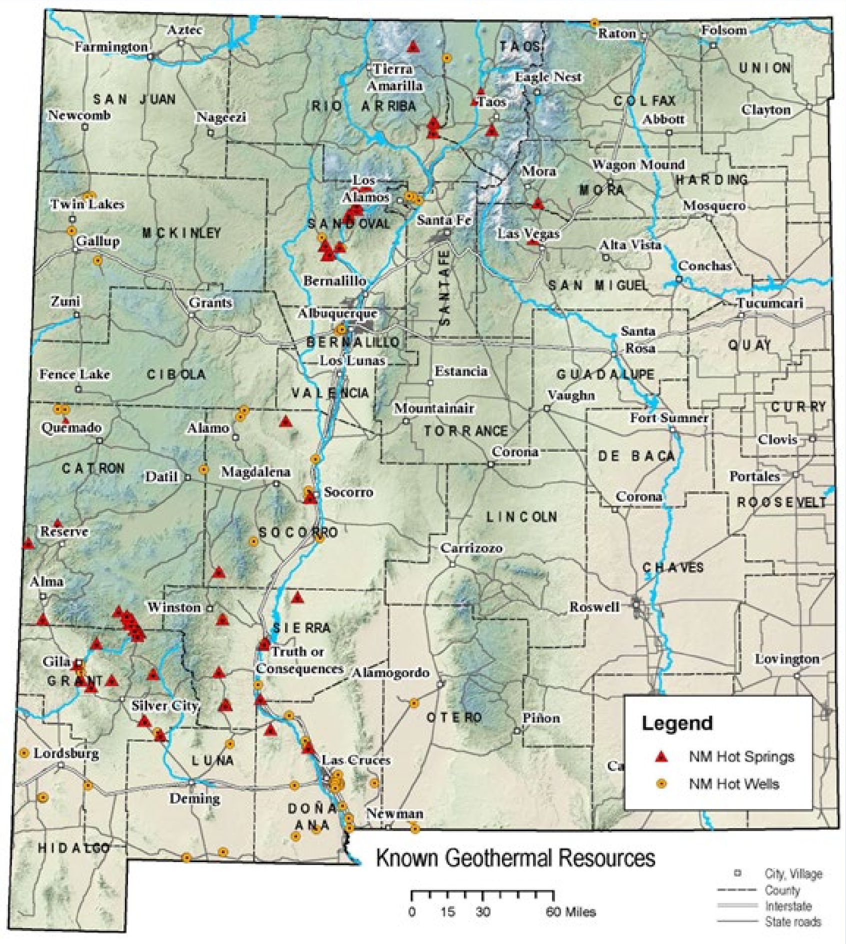

**Progress**: Experimental design is complete. In process of fabrication of flow cells.

# Technical Update

- Perform the flow-through tests integrated with real-time X-ray microtomography to investigate sustainability of CO2 injection into the target basalt samples.
- Using Elevated Heat Flow to Enhance Reaction Rates.




Evolution of fracture geometry and precipitate growth based on a triaxial direct-shear (TDS) experiment integrated with fluid flow and real-time X-ray micro tomography

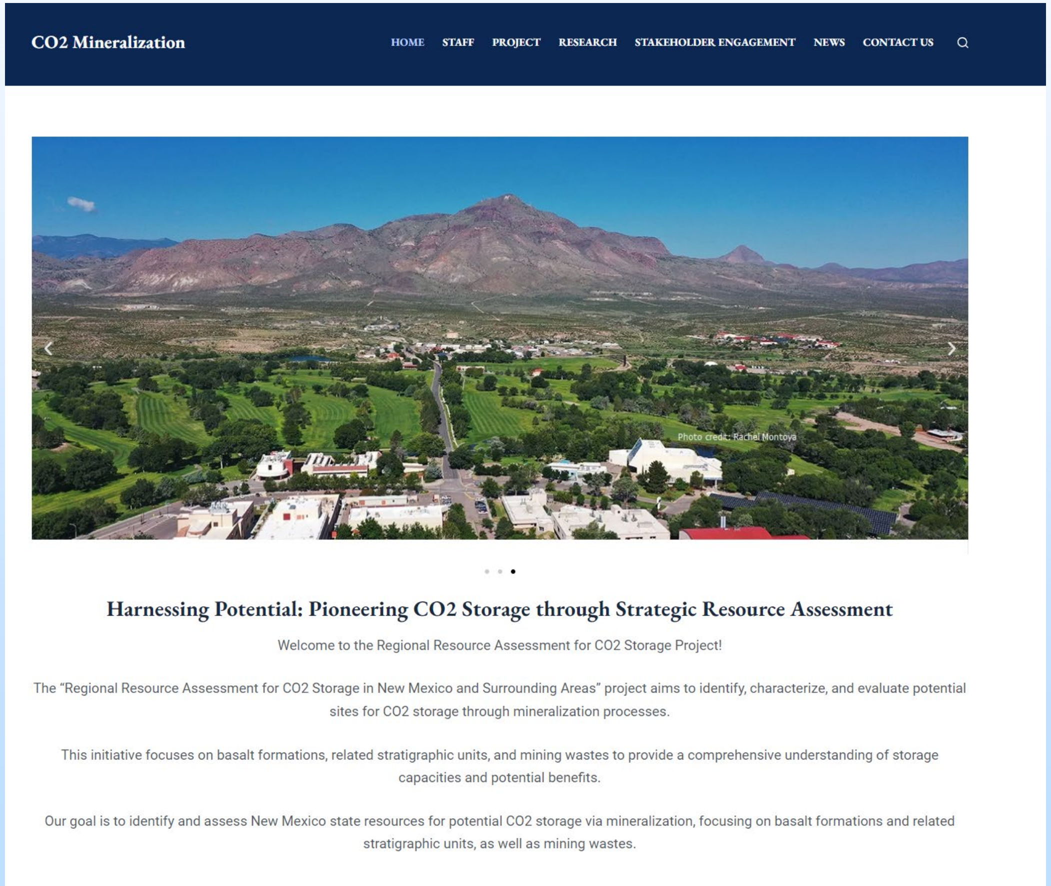


# Outreach Activity

## Website in development

- Collaboration with Arizona Geological Survey to synchronize outreach in the region.
- Share project information
- Share $CO_2$ mineralization research

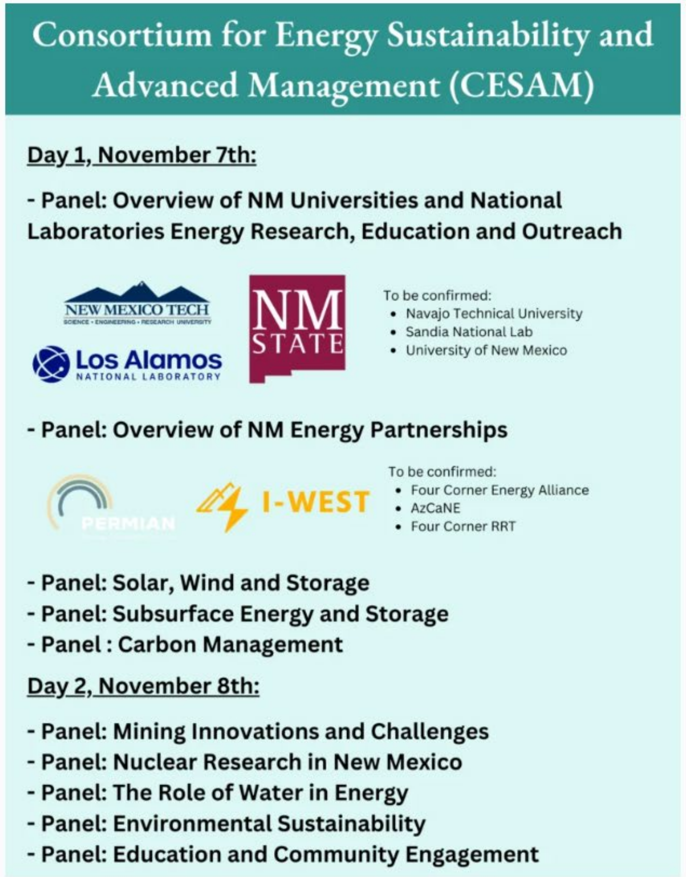
https://co2rocks.net/




## Workshop in preparation

- November 7th-8th, 2024 in Socorro, New Mexico
- The event gather around 100 energy stakeholders from NM
- Collaboration with the Consortium for Sustainable Energy and Advanced Management (CESAM)

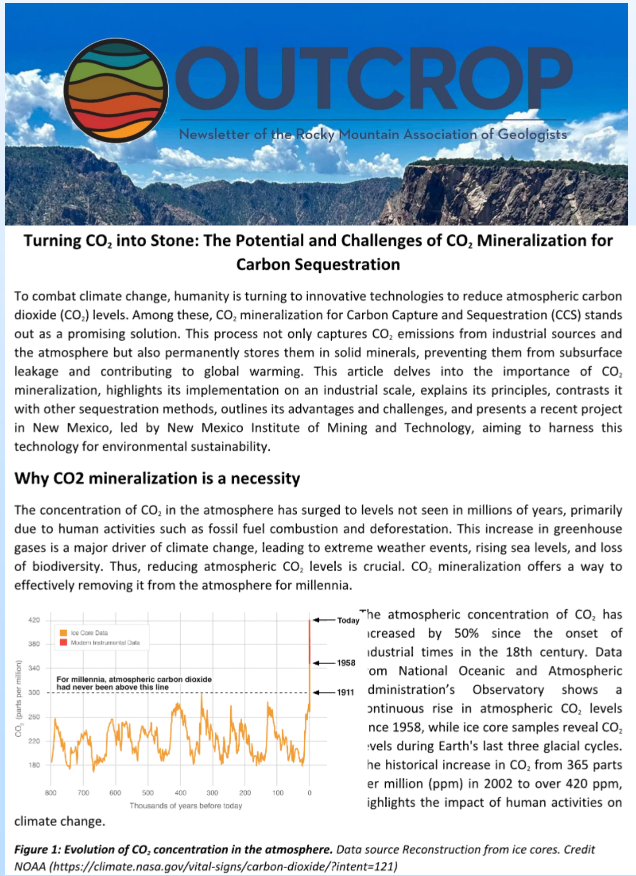
https://nm-secm.org/outreach/

# Outreach Activity

## Article in development

- Will be released in the Outcrop magazine published by the Rocky Mountain Association of Geologist in November 2024. https://www.rmag.org/
- Another in preparation for Spring, 2024 for the Lite Geology Magazine (NMT)



OUTCROP

Newsletter of the Rocky Mountain Association of Geologists

**Turning $CO_2$ into Stone: The Potential and Challenges of $CO_2$ Mineralization for Carbon Sequestration**

To combat climate change, humanity is turning to innovative technologies to reduce atmospheric carbon dioxide ($CO_2$) levels. Among these, $CO_2$ mineralization for Carbon Capture and Sequestration (CCS) stands out as a promising solution. This process not only captures $CO_2$ emissions from industrial sources and the atmosphere but also permanently stores them in solid minerals, preventing them from subsurface leakage and contributing to global warming. This article delves into the importance of $CO_2$ mineralization, highlights its implementation on an industrial scale, explains its principles, contrasts it with other sequestration methods, outlines its advantages and challenges, and presents a recent project in New Mexico, led by New Mexico Institute of Mining and Technology, aiming to harness this technology for environmental sustainability.

**Why CO2 mineralization is a necessity**

The concentration of $CO_2$ in the atmosphere has surged to levels not seen in millions of years, primarily due to human activities such as fossil fuel combustion and deforestation. This increase in greenhouse gases is a major driver of climate change, leading to extreme weather events, rising sea levels, and loss of biodiversity. Thus, reducing atmospheric $CO_2$ levels is crucial. $CO_2$ mineralization offers a way to effectively removing it from the atmosphere for millennia.

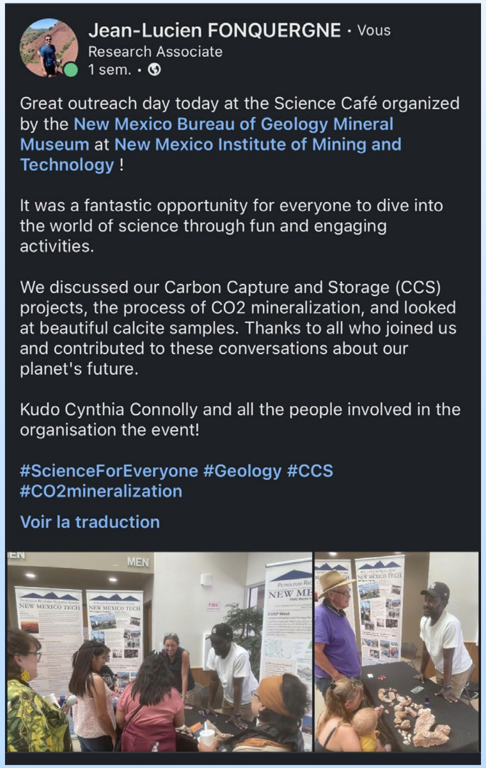


The atmospheric concentration of $CO_2$ has increased by 50% since the onset of industrial times in the 18th century. Data from National Oceanic and Atmospheric Administration's Observatory shows a continuous rise in atmospheric $CO_2$ levels since 1958, while ice core samples reveal $CO_2$ levels during Earth's last three glacial cycles. The historical increase in $CO_2$ from 365 parts per million (ppm) in 2002 to over 420 ppm, highlights the impact of human activities on climate change.

*Figure 1: Evolution of $CO_2$ concentration in the atmosphere.* Data source Reconstruction from ice cores. Credit NOAA (https://climate.nasa.gov/vital-signs/carbon-dioxide/?intent=121)

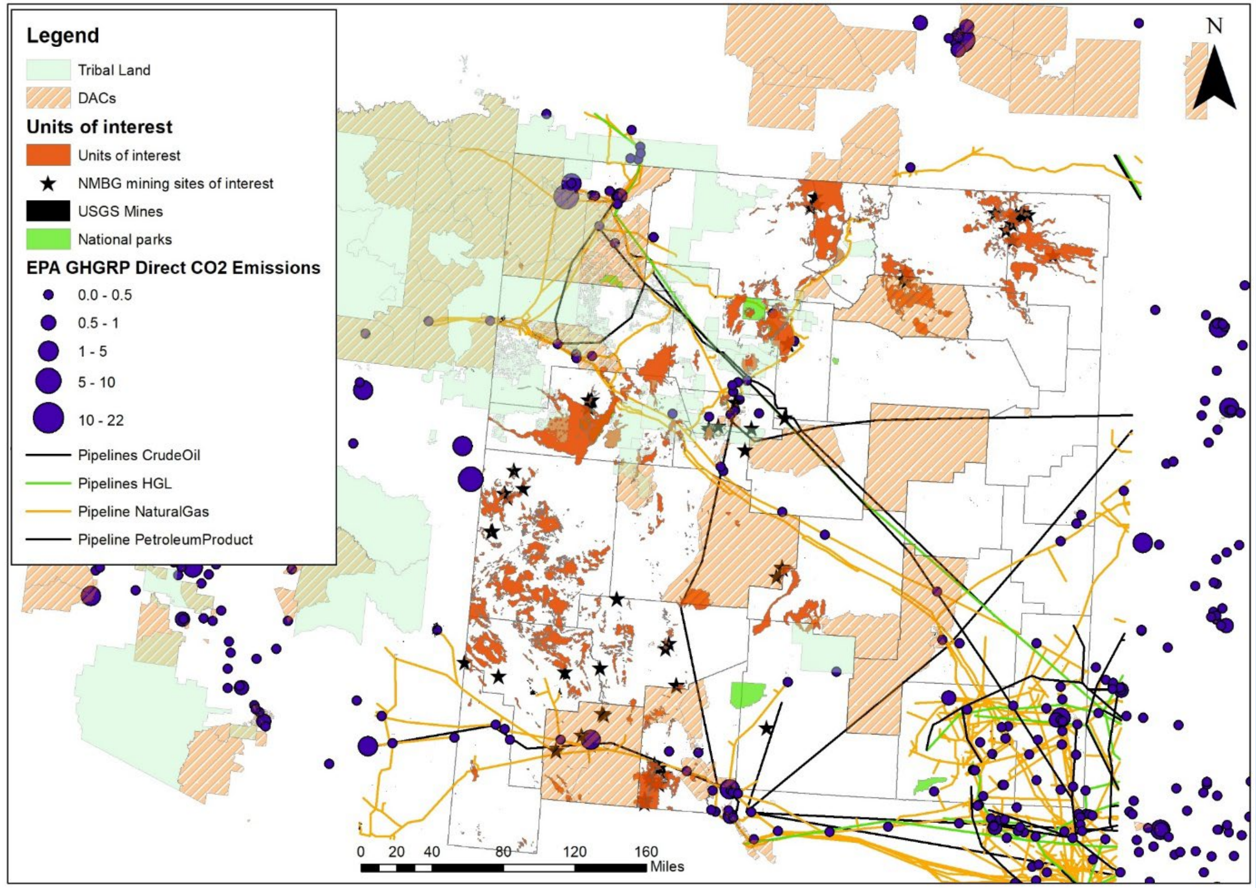
## Community Engagement

- Initial Assistance & Validation Meeting, November 9, 2023
- Outreach and engagement with land owners from the Don Carlos hill and Johnson Mesa, near the sites of interest. More than 15 landowners engaged via meetings, phone calls or mail.
- Engagement with Freeport, mining company.
- Contact with University of Eastern New Mexico for outreach event.
- Engagement with students and New Mexico communities at the Science Café in Socorro, NM.




# Future Plans

- Continue to study the geological and hydrogeological properties on the selected sites.
- Continue to characterize on the petrological, mineralogical, geochemical, geophysical and geomechanical properties of resource rock.
- Study reaction dynamics of the CO2 mineralization process on the localized resource rock in order to indicate the optimum scenario for CO2 storage and upscaling.
- Outreach activities. We will continue our efforts on engagement with Minority Serving Institutions and stakeholders in the project area for outreach event and develop outreach materials (Articles, website, social media, workshops…)



# Acknowledgements

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