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U.S. DEPARTMENT OF ENERGY

Distributed Mafic Rock Resources for CO_2 Mineralization in Arizona

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COI disclosure: CO-PI Lackner is an advisor to CarbonCollect Limited and to Aircela Inc. He has financial stakes in both companies and is on the Board of Aircela. Neither company is involved in mineralization, which is the subject of the work presented.

UA SCIENCE ARIZONA GEOLOGICAL SURVEY
NAU NORTHERN ARIZONA UNIVERSITY
ASU Arizona State University

Project Overview

Carbon Conversion
FOA2614: AOI 4
2 Year Project
6/28/2023 – 6/27/2025
Total Award: $1,169,245

Ex-situ CO_2 reactivity of scoria and basalt

Test the CO2 reaction extent of surficial scoria and basalt flows in Arizona.

Establish parameters for maximum reaction extent ex-situ.

The Mafic Rock Resource Inventory (MMRI); Outreach

Create a public Mafic Rock Resource Inventory (MMRI) to catalog rock properties and reactivity data.

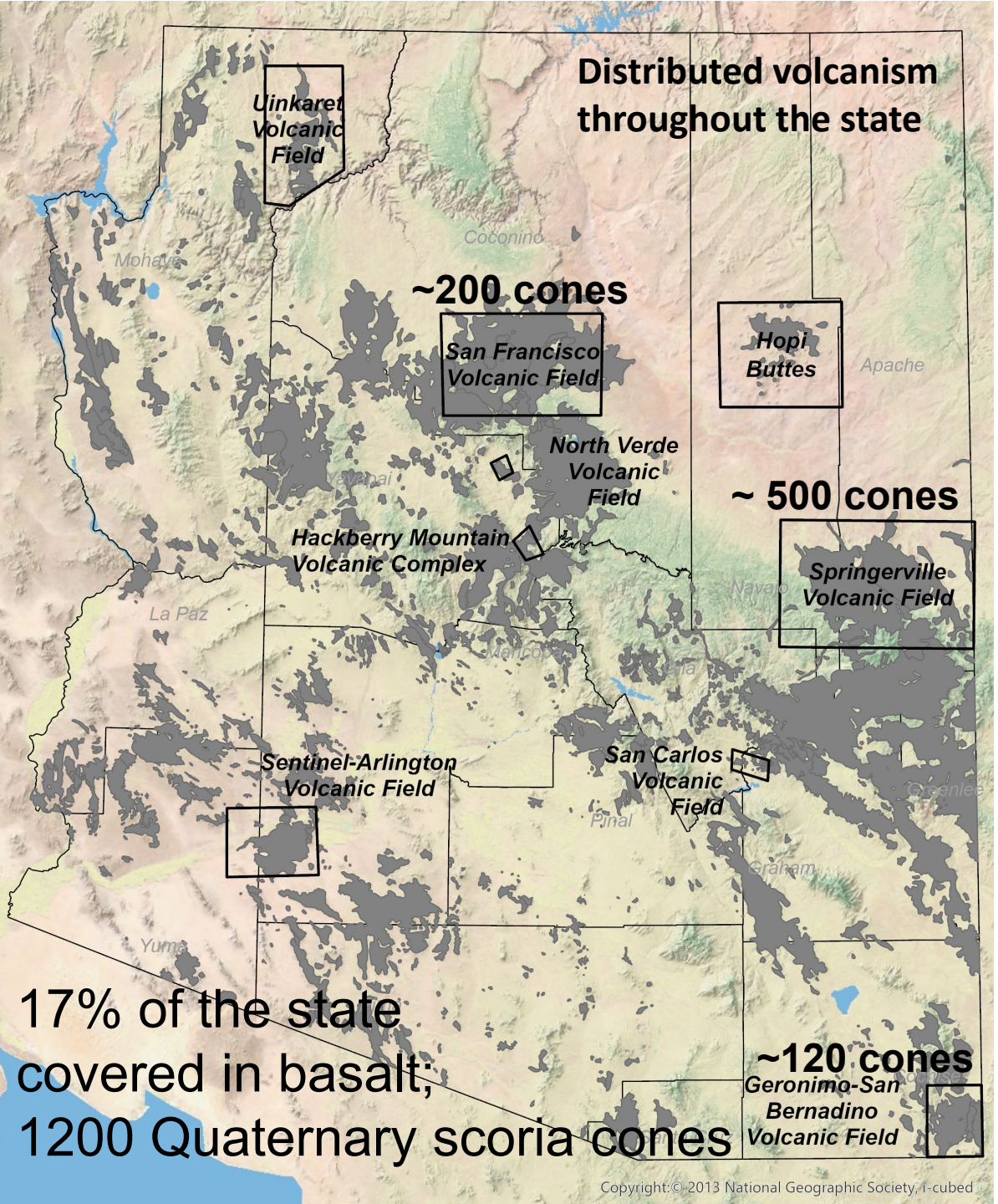
Develop relationships with statewide industry and community stakeholders and educate public on basalt mineralization

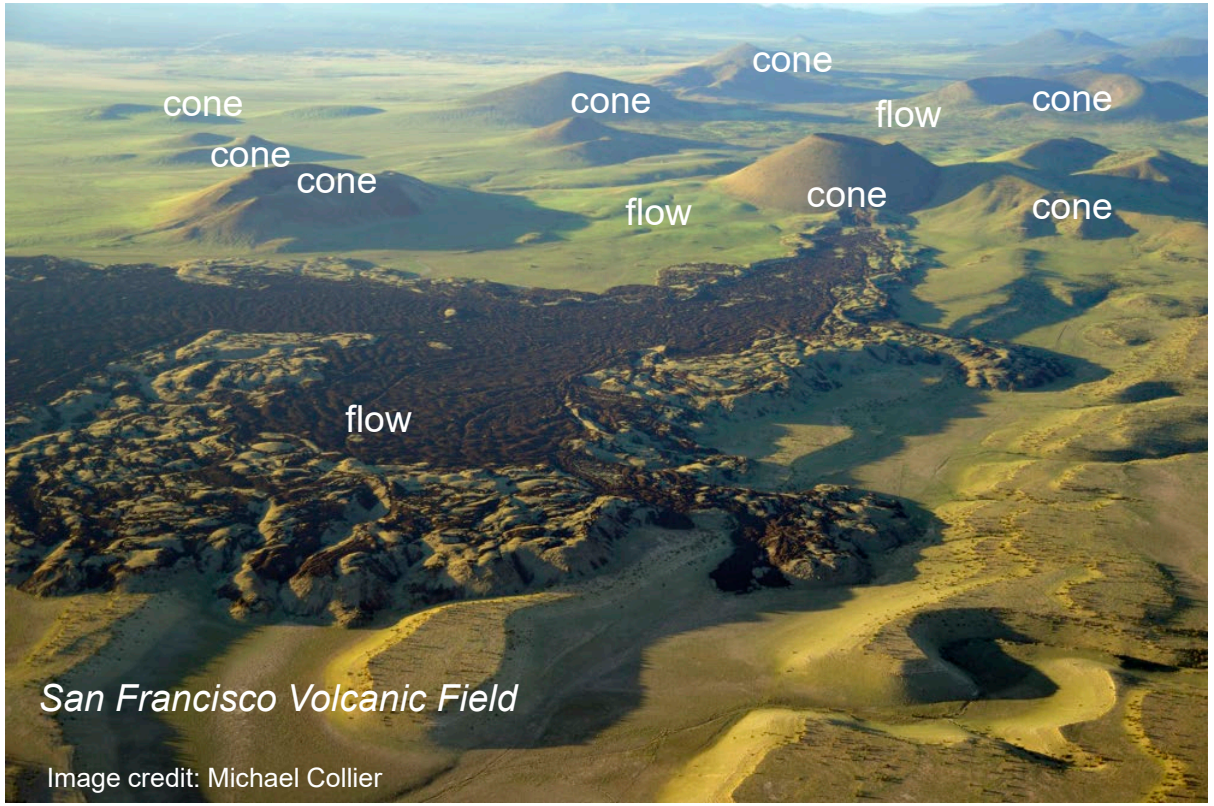
Direct Air Capture to Mineralization (DACM) systems model; TEA/LCA

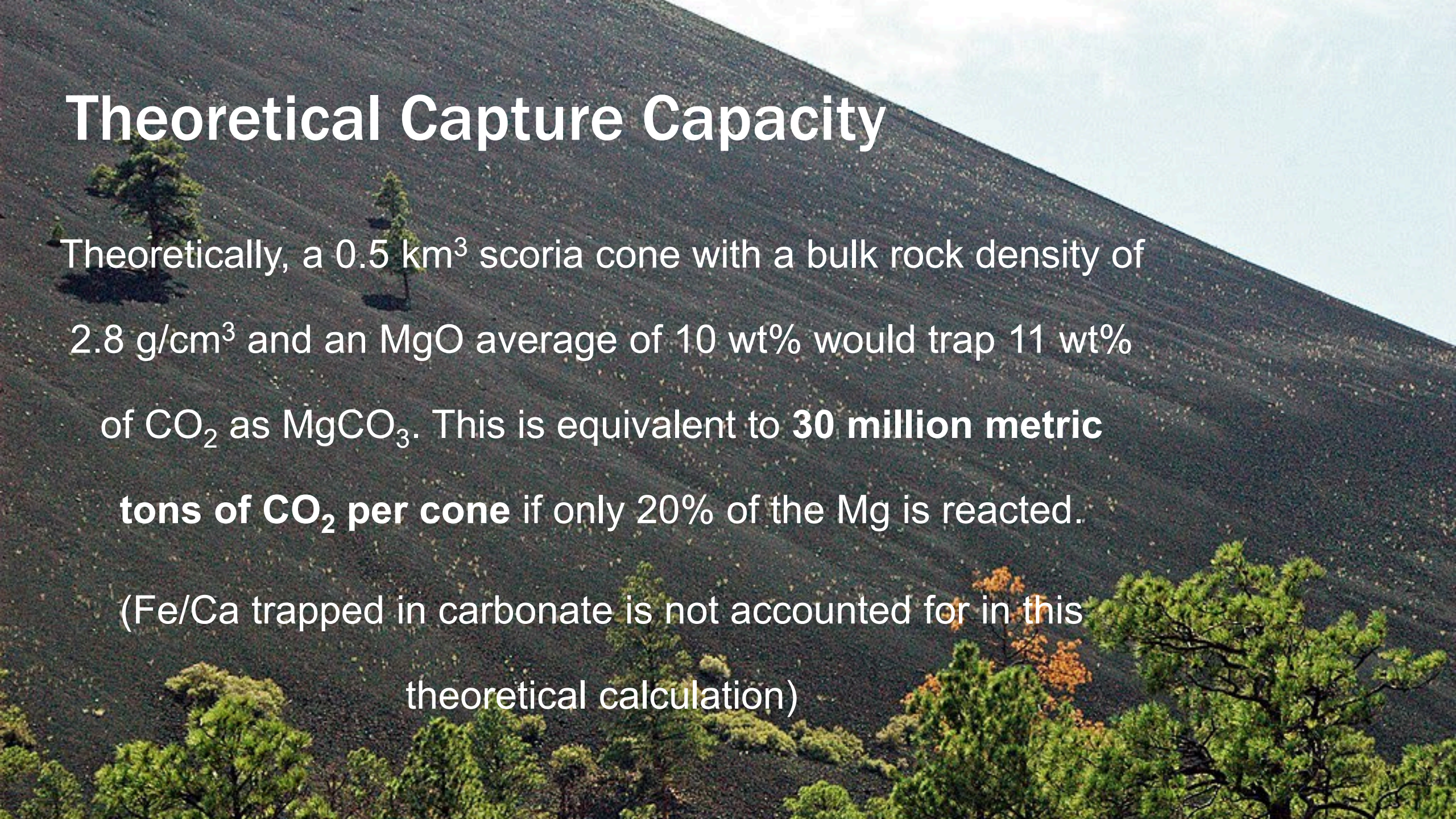
Design a DAC to mineralization systems model to describe implementation at a commercial scale.

Mafic volcanism in Arizona

Geologically young mafic volcanic fields have many eruptive centers (cones) and lava flows







Theoretical Capture Capacity

Theoretically, a 0.5 km^3 scoria cone with a bulk rock density of 2.8 g/cm^3 and an MgO average of 10 wt% would trap 11 wt% of CO_2 as $MgCO_3$. This is equivalent to **30 million metric tons of CO_2 per cone** if only 20% of the Mg is reacted.

(Fe/Ca trapped in carbonate is not accounted for in this theoretical calculation)

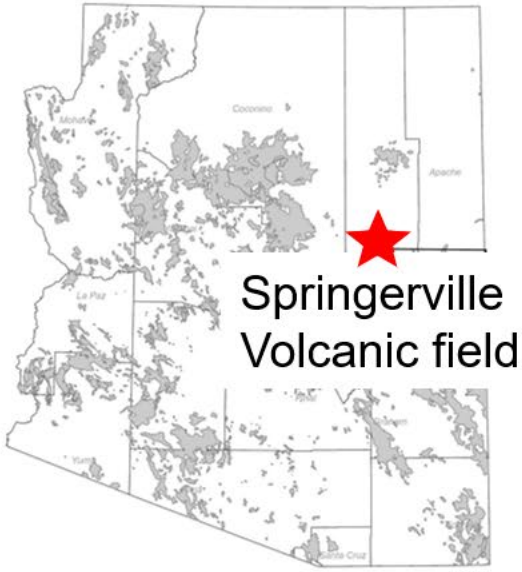
Scoria mine at Sheep Hill, Flagstaff, AZ
San Francisco Volcanic Field

Many cones are already mined

Scoria is mined throughout the state for landscaping and road surfacing material.

Magmatic Mapping:

Cones and flows related to one another by chemistry & ranked by olivine content

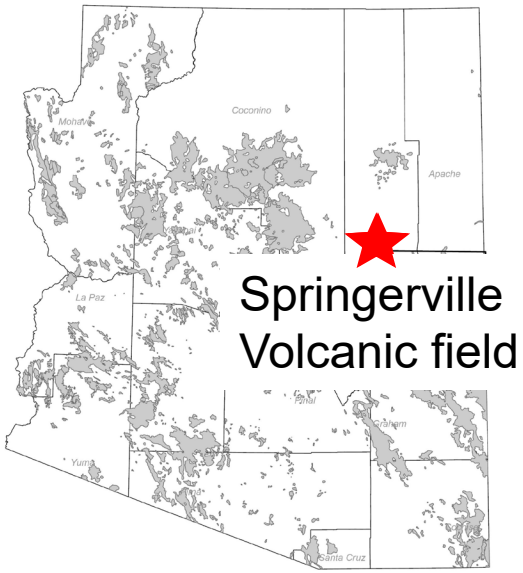


Mnich and Condit (2018); Condit et al.(1999); Condit, 1991

Mapping digitized from Mnich and Condit, 2018 (J Volc Geothermal Energy)

Magmatic Mapping:

Cones and flows related to one another by chemistry & ranked by olivine content



Springerville Volcanic field

Springerville volcanic field

picritic basalt,scoria cone
picritic basalt,lava flow
olivine-pyroxene basalt,scoria cone
olivine-pyroxene basalt,lava flow
olivine basalt,scoria cone
olivine basalt,lava flow
travertine,<Null>

A type

C type

B type

Show Low

Pinetop

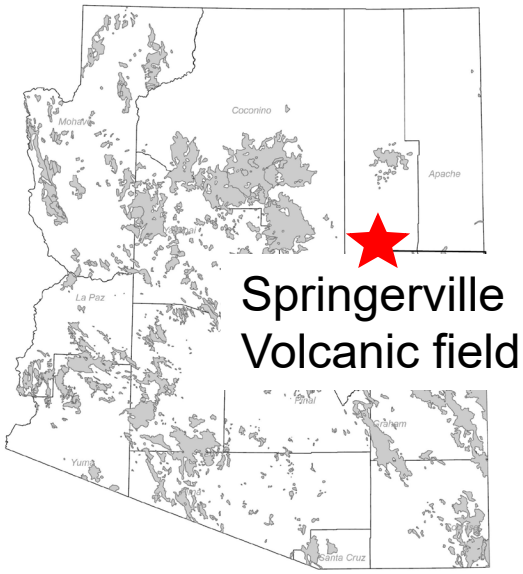
Scale: 1:125,000
0 3 7 10
Kilometers

Mapping digitized from Mnich and Condit, 2018 (J Volc Geothermal Energy)

Whole rock geochemistry

Bulk rock major element analysis

MgO >10% wt% guides sampling strategy



Springerville volcanic field

OBJECTID	41
SamID	216L
Unit	Qbb2
SiO2	46.1
TiO2	1.56
Al2O3	11.8
Fe_2O_3	13.1
	0.17
MgO	17.6
CaO	7.99
2O	2.16
K2O	0.67
P2O5	0.26
Total	101.44
LAT	34.132117
LONG	-109.881182
LOI	<0.01
Rank	priority 1

Show Low

Pinetop

Scale: 1:125,000

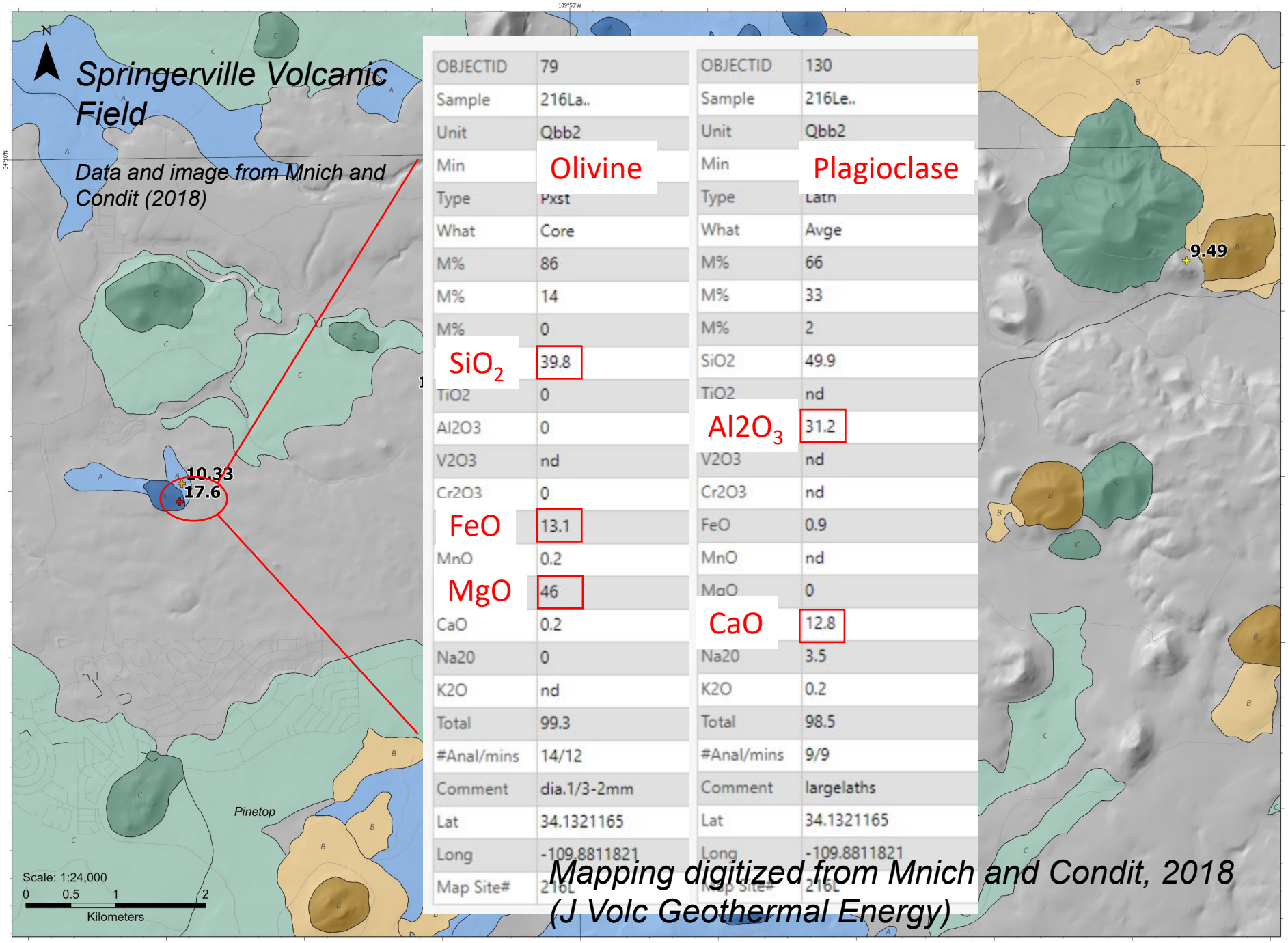
0 3 7 10

Kilometers

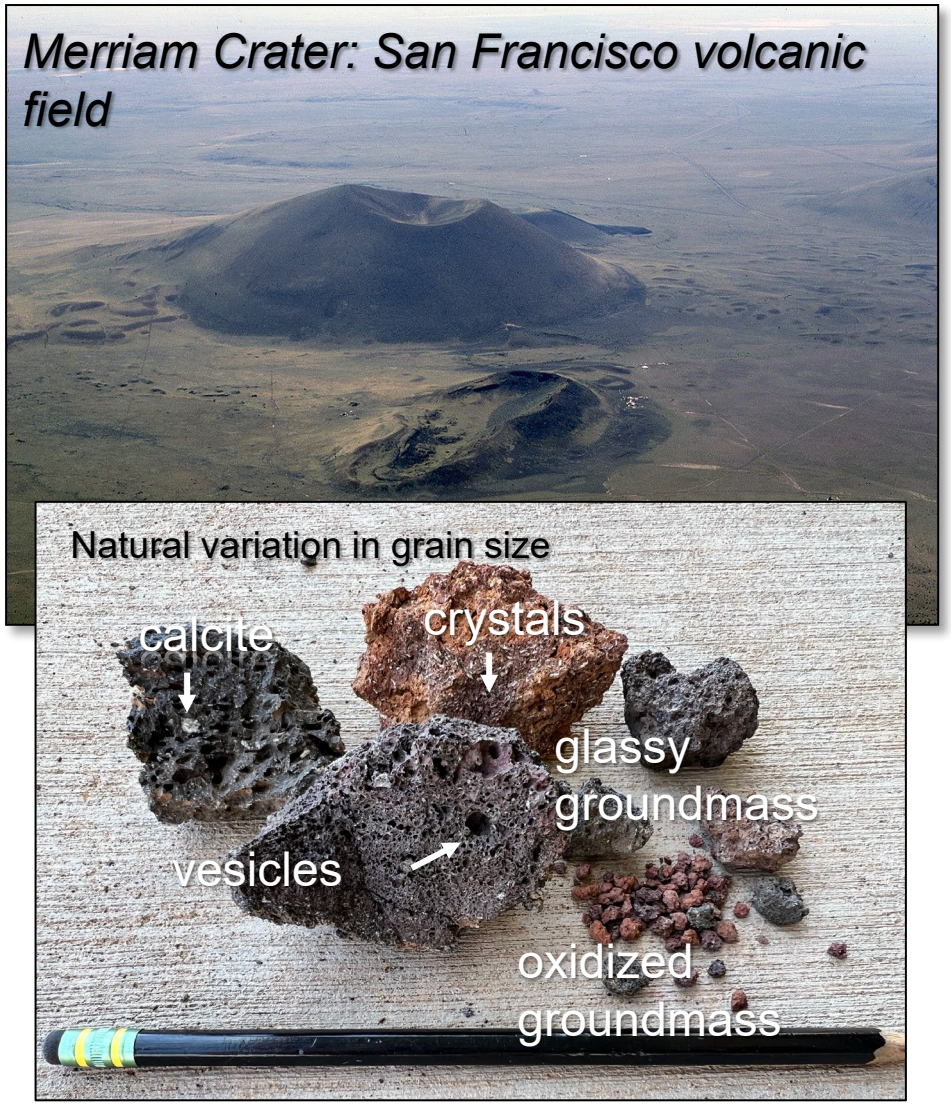
Mapping digitized from Mnich and Condit, 2018 (J Volc Geothermal Energy)

Mineral chemistry

Mineral major element analysis contextualizes reactivity rates and products. Data available for Springerville but not for all volcanic fields.

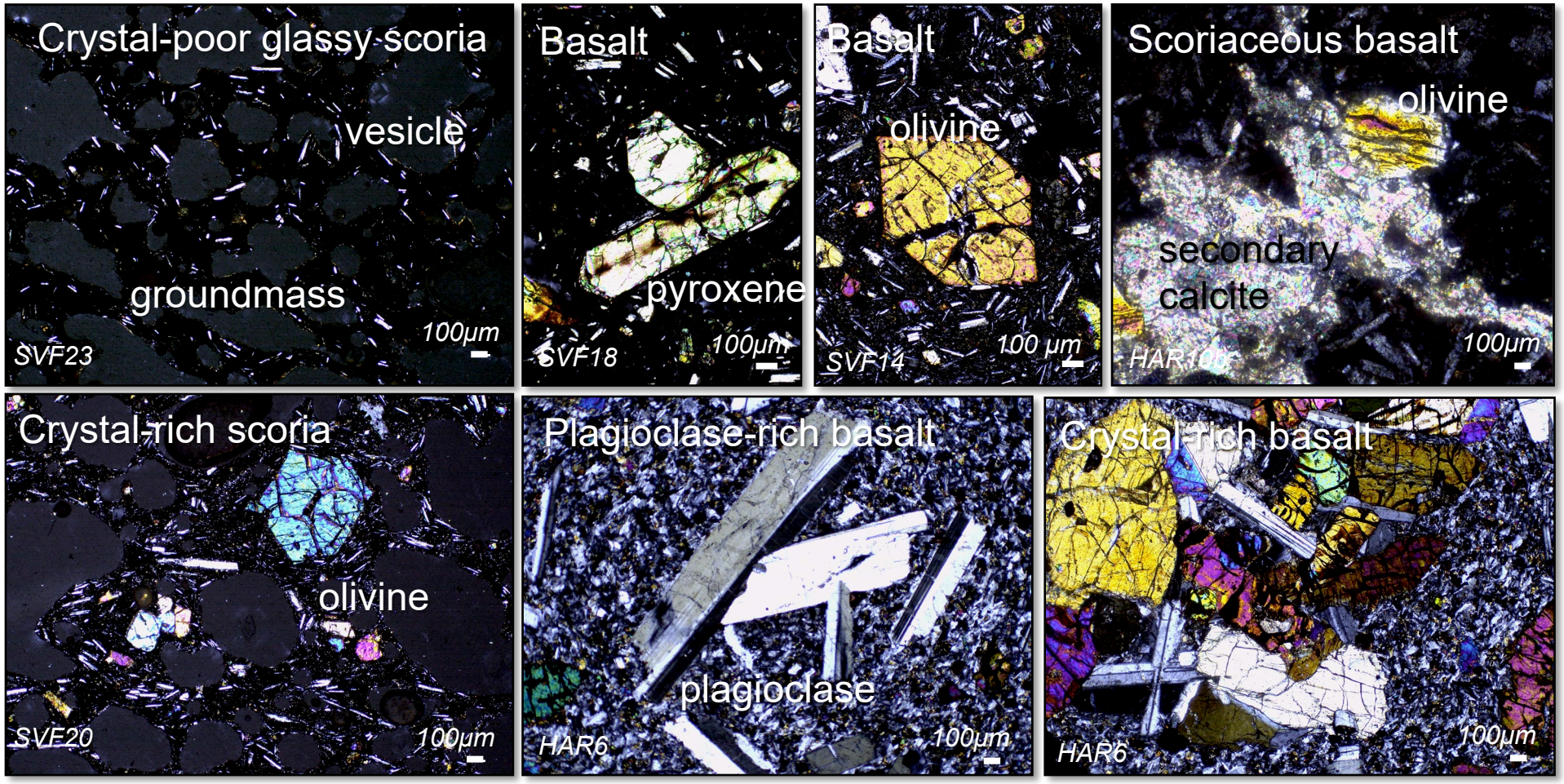


Sample collection: capturing rock heterogeneity



Sampling targets resources on State Trust Land, BLM, National Forest, and private land including existing scoria mines.

Scoria and basalt mineralogical variability



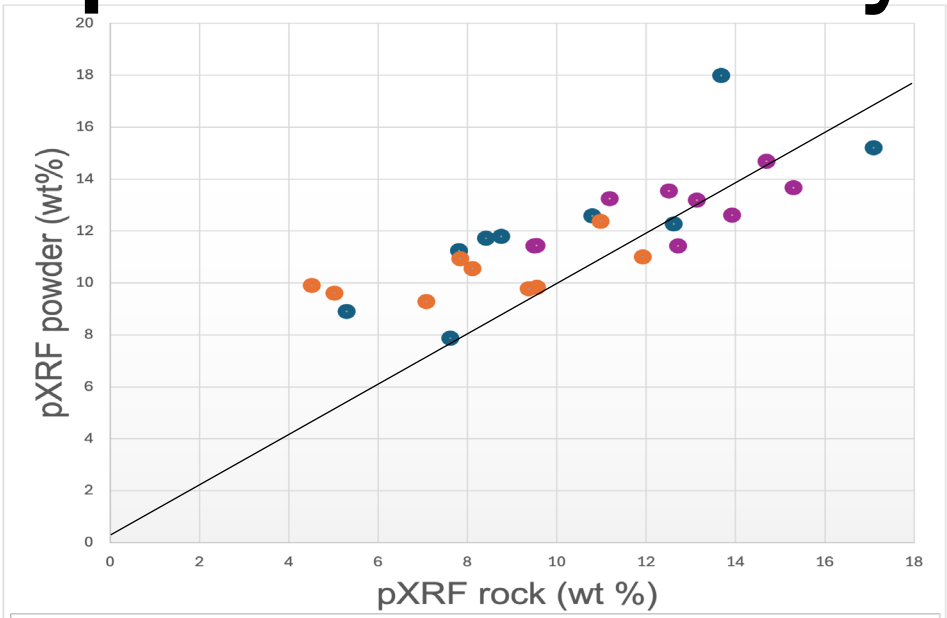
Crystal components (e.g. olivine, pyroxene, plagioclase); **groundmass** components (e.g plagioclase; glass; iron oxides) vary in size and concentration significantly from sample to sample – even from within the same deposit.

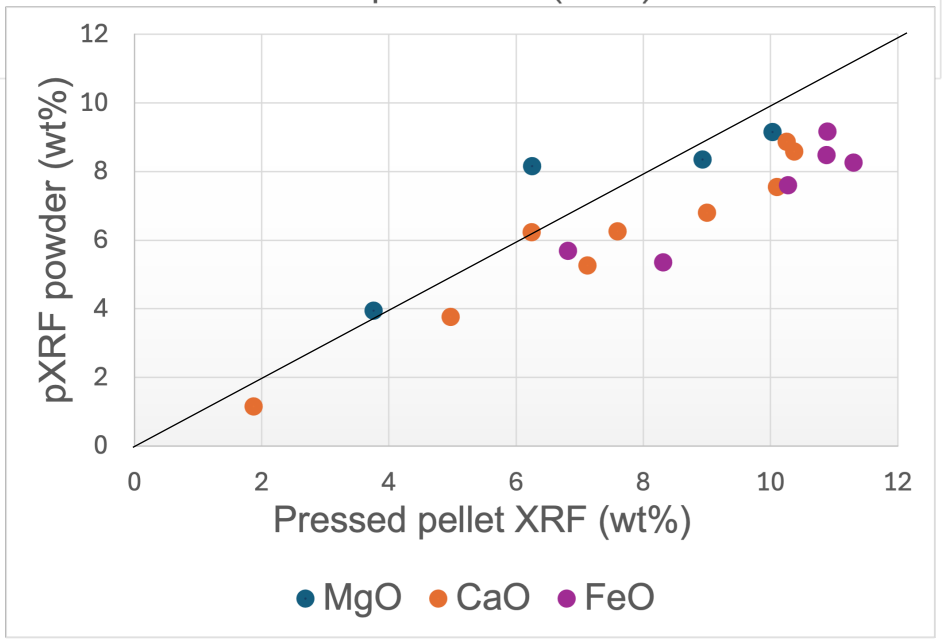
Pre-reacted sample preparation & analyses

(1) Samples split for reactivity, whole rock geochemistry, thin section

(2) Reactivity samples crushed, powdered, homogenized, & sieved to <63 microns

(3) Rock and powdered samples analyzed with Niton XL5 portable XRF (pXRF) then sent to a lab for pressed pellet XRF/ ICPMS/ ICPOES





How to determine which samples to react?

Whole rock pXRF analyses shows lowest concentration of oxides, followed by powdered pXRF, and then pressed pellet analyses

CO_2 Reaction Conditions

Low Intensity:

- pH = 6.5 (NaHCO3 buffer)
- PCO2 = 80 kPa
- T = 20 degrees Celsius
- Time = 160 days
- Solid Loading: 15 wt%
- San Carlos olivine and scoria from San Francisco volcanic field

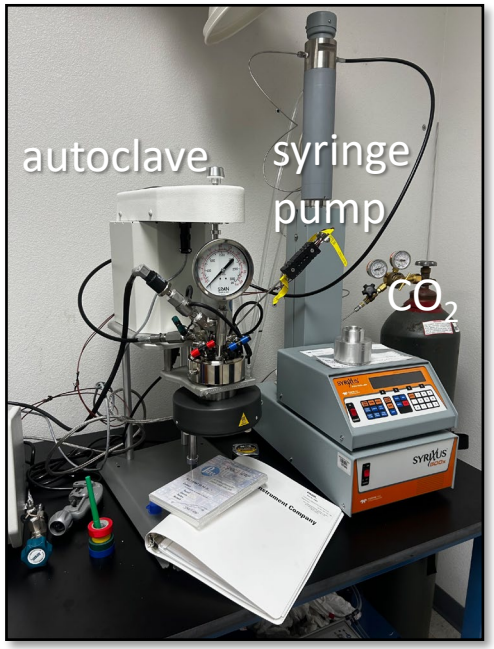
High Intensity:

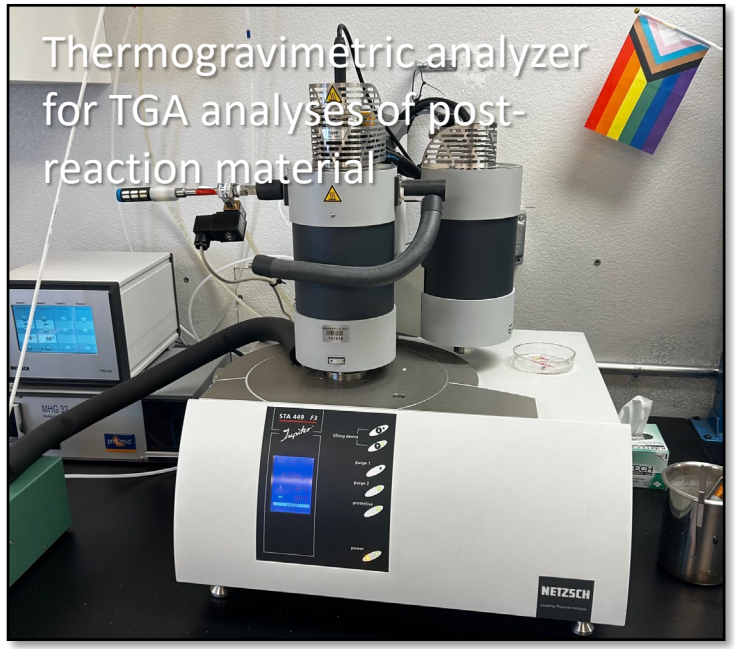
Benchmarked Direct Aqueous Mineralization [1]

- pH = 6.5 ($NaHCO_3$ buffer)
- PCO2 = 150 bar
- T = 185 degrees Celsius
- Time ≤ 24 hours
- Mineral size = 34-100 microns
- Solid Loading: 15 wt%
- San Carlos olivine as benchmark

Low intensity:

High intensity:





[1] *Gerdemann et al., 2007 (Environ Sci Tech)*

Preliminary results: San Carlos olivine vs. picritic (alkaline) basalt

Theoretical capture capacity:

	$MgCO_2$	$FeCO_2$	$CaCO_2$	**Total (g CO_2 / g rock)**
	wt%	wt%	wt%	
SCO	47.58	5.09	1.47	**54.14**
SVF1	23.73	7.80	4.90	**36.43**

Major oxide composition by weight %:

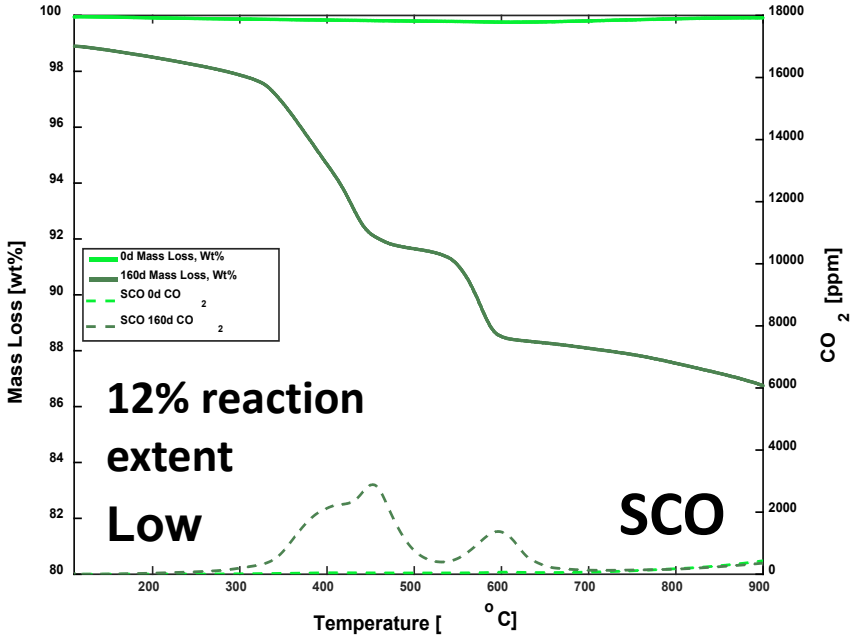
	SiO_2	TiO_2	Al_2O_3	FeO^1	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
SCO	43.96	0.08	1.80	8.31	0.13	43.58	1.87	0.22	0.02	0.03	100.00
SVF1	44.92	1.42	10.46	12.74	0.19	21.73	6.24	1.58	0.48	0.23	100.00

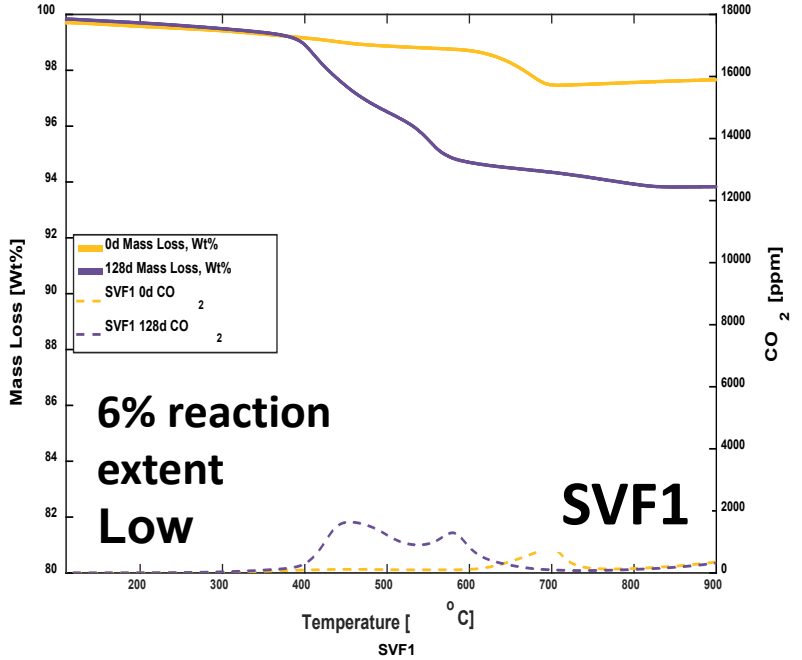
Low intensity vs. high intensity reaction extent (TGA)

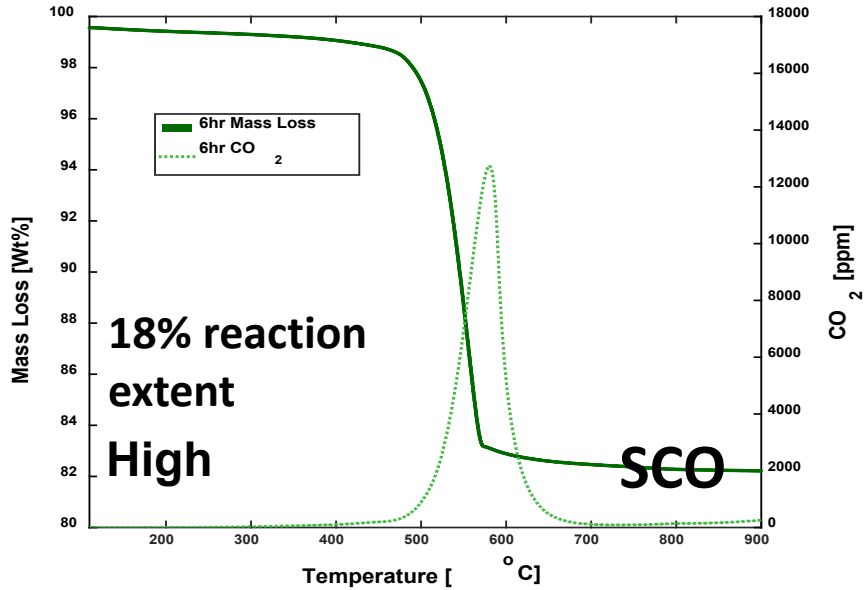
Low intensity success has applications to CDR through enhanced weathering

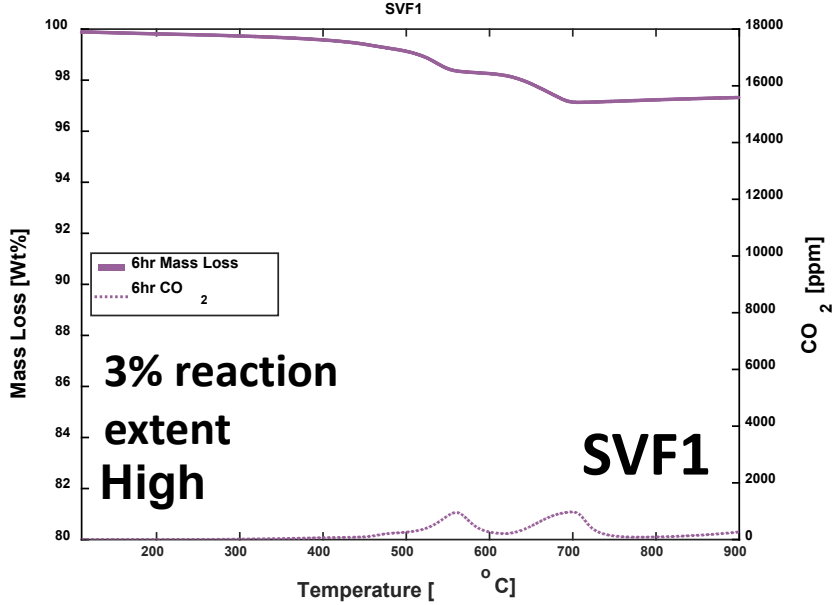
SCO high intensity reactions result in a **6% greater** reaction extent than low intensity.

SVF1 high intensity reactions result in a **3% lower** reaction extent than low intensity.

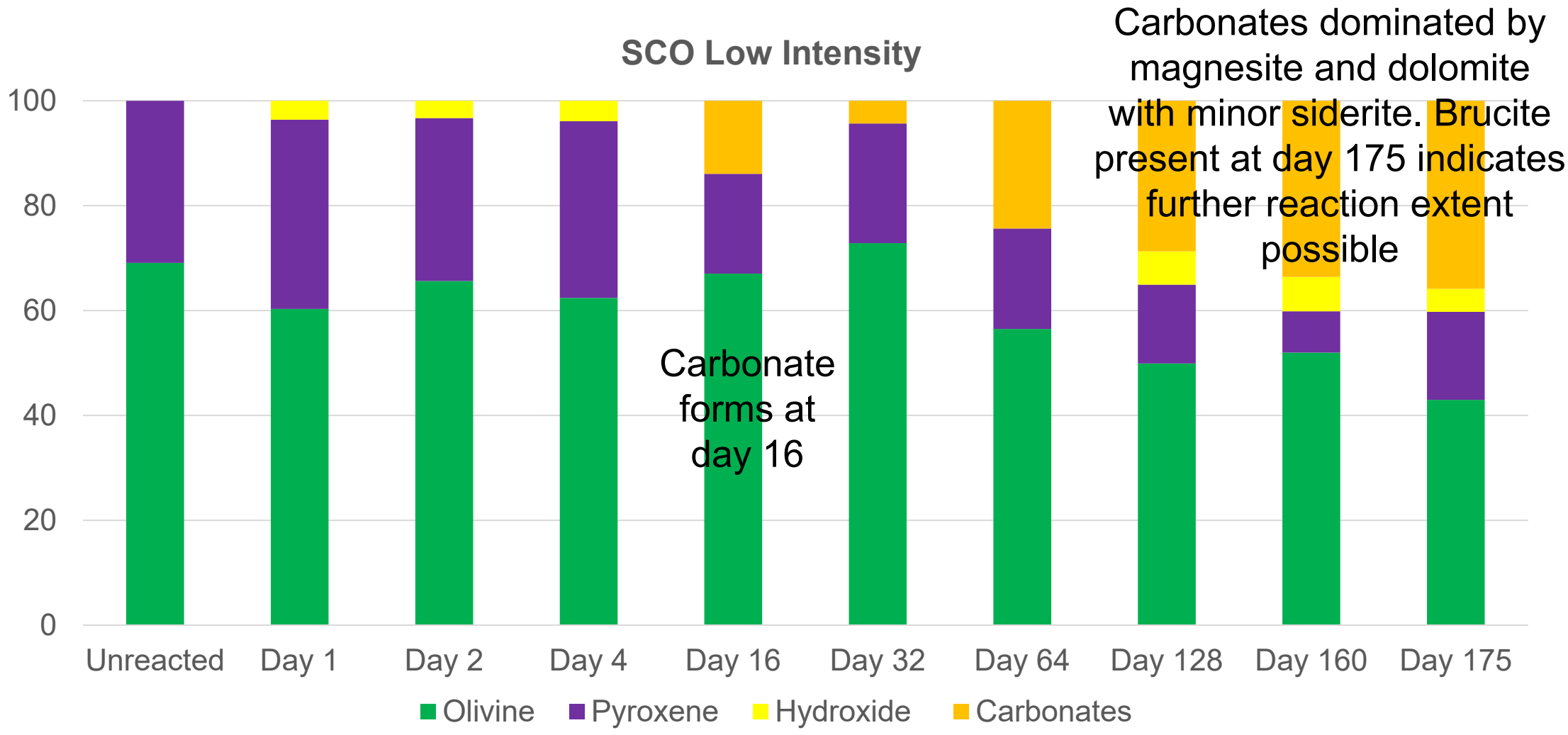




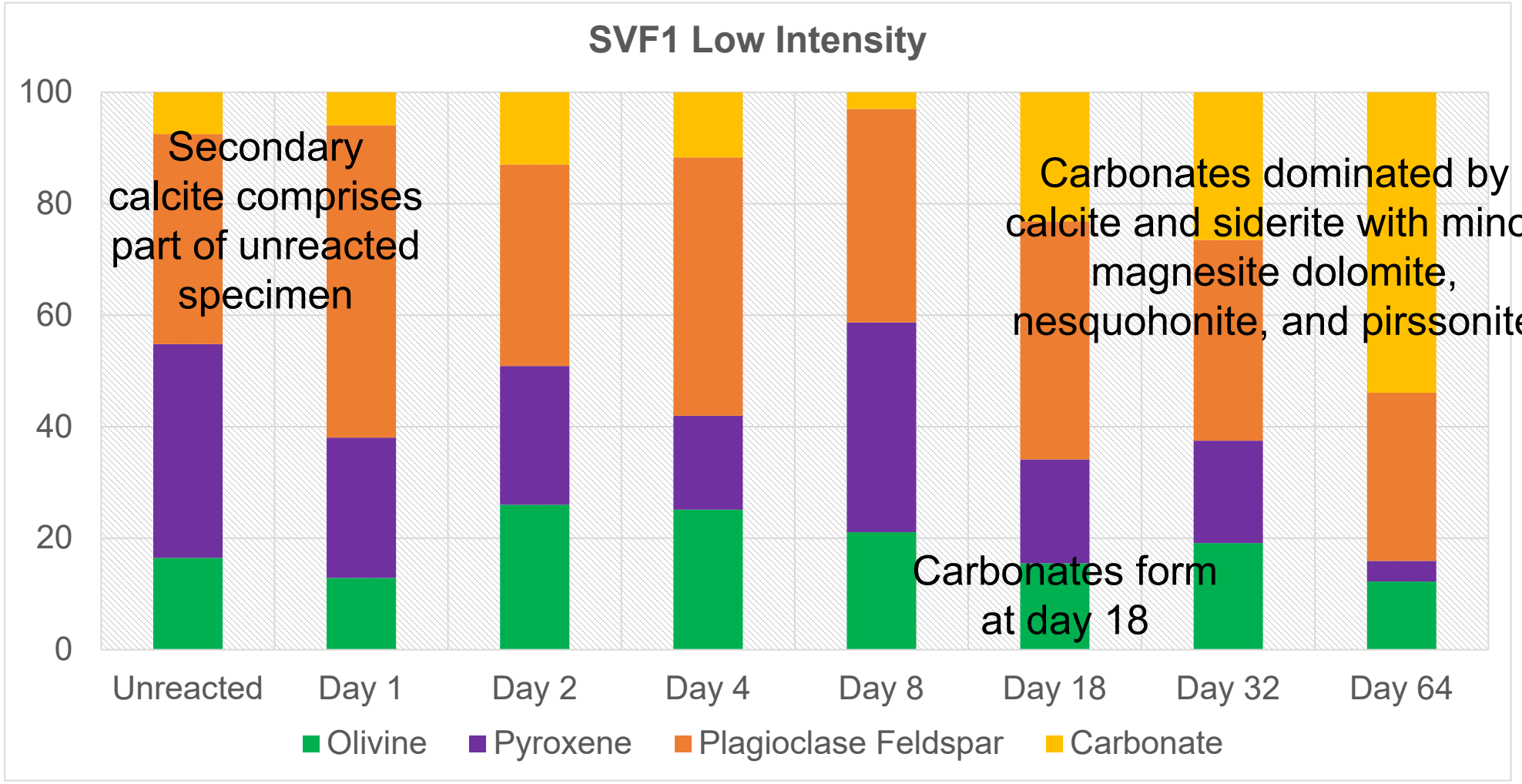




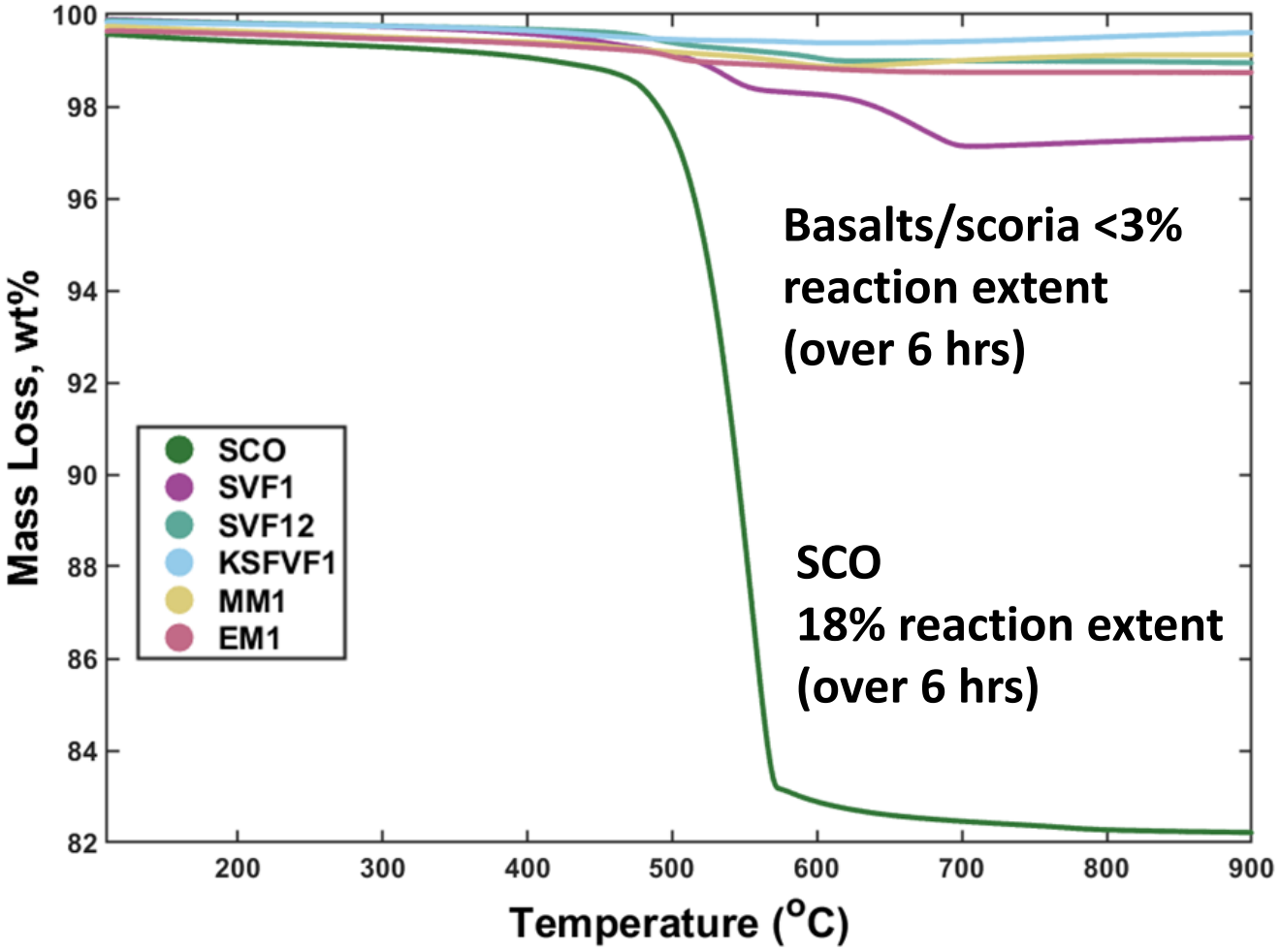
San Carlos olivine (SCO): Low intensity disappearance and emergence of mineral phases over time



Olivine-rich basalt (SVF1): Low intensity disappearance and emergence of mineral phases over time



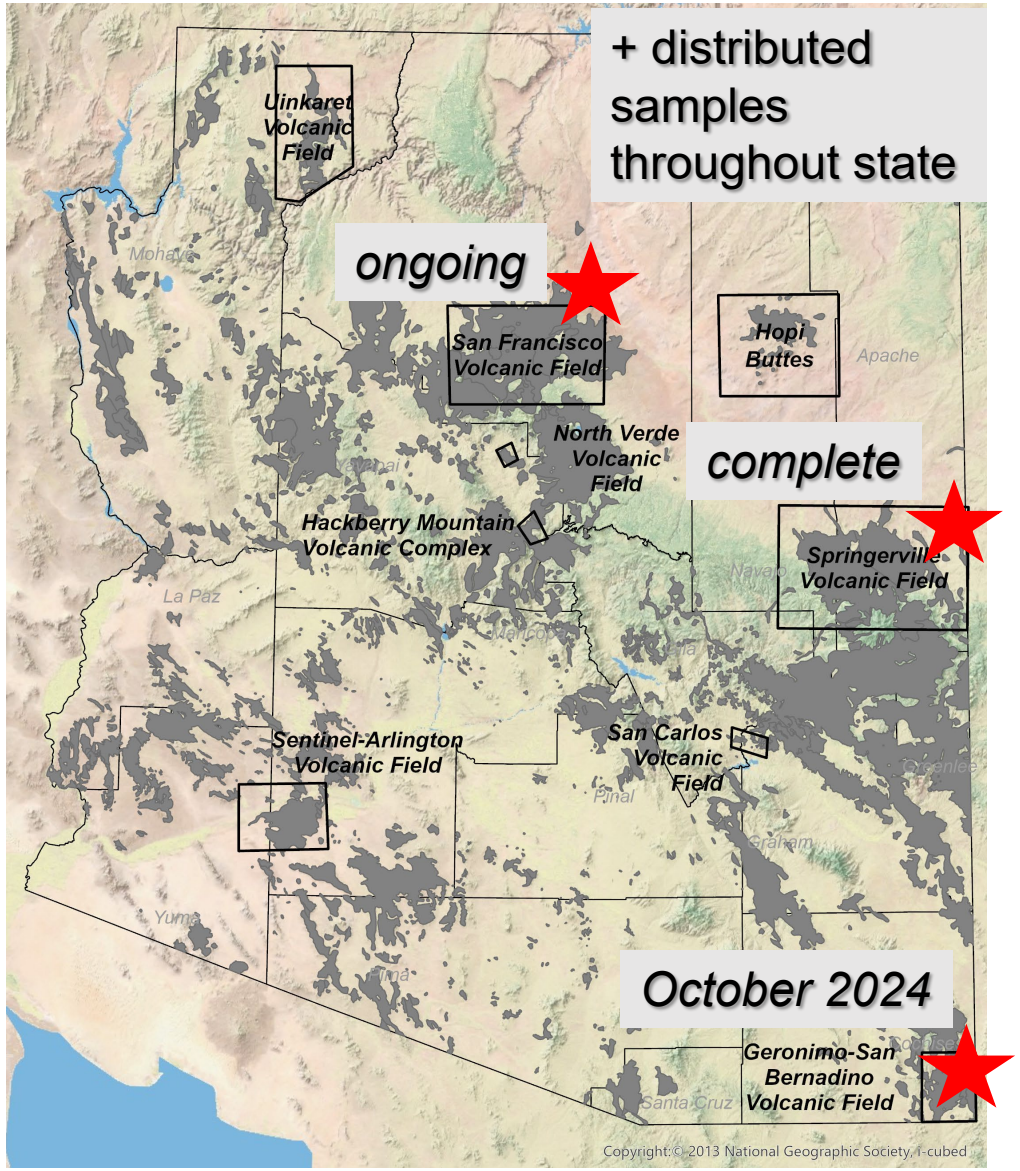
Why is SCO reacting so well at high intensity while SVF1 is not?



Mg is not mineralizing

- Hydration of volcanic glass to form silica gels that coat minerals in the short term?
- Cations trapped in non-carbonate minerals – such as smectites or saponite-type clays?

We will be parameterizing temperature, pressure, pH, and wt% solid content over the coming weeks



Mafic Rock Resource Inventory (MMRI)

Published data	• geochemistry • mapping
New 1:24K geologic mapping	• Cinder cone facies • Fill in data gaps
Physical rock properties	• Description; grain size/crystallinity variations
Whole rock geochemistry	• pXRF; pressed pellet XRF
Thin section analysis	• Pre-reaction mineral ID and abundance
Porosity/permeability	• Pre- and post reaction physical properties
TGA/XRF/XRD/SEM	• Post-reaction mineral ID
Reaction kinetics	• Parameters and reaction extent • Kinetics
Land use/ water quality/rock volume	• Economize ex-situ reactions • Systems model development

MMRI geodatabase design

- MMRI.sde ← geodatabase
  - MMRI.DBO.GSBVF
  - MMRI.DBO.SFVF
  - MMRI.DBO.Statewide
  - MMRI.DBO.SVF ← feature dataset
    - MMRI.DBO.SVF_CinderPit ← feature class point vector
    - MMRI.DBO.SVF_Contacts ← feature class line vector
    - MMRI.DBO.SVF_LandOwnership
    - MMRI.DBO.SVF_Springs
    - MMRI.DBO.SVF_Streets
    - MMRI.DBO.SVF_WRG
    - MMRI.DBO.SVF_WRG_DataSources ← relationship class
    - MMRI.DBO.SVF_WRG_MineralChemistry
    - MMRI.DBO.SVFMapUnits ← feature class polygon vector
    - MMRI.DBO.SVFMapUnits_DataSources
    - MMRI.DBO.SVFOilGasWells
    - MMRI.DBO.SVfSamples
    - MMRI.DBO.SVfSamples_Geochem_Lab
    - MMRI.DBO.SVfSamples_Geochem_PXRF
    - MMRI.DBO.SVFWaterWells
  - MMRI.DBO.DataSources ← tabulated data
  - MMRI.DBO.Geochem_Lab
  - MMRI.DBO.Geochem_PXRF
  - MMRI.DBO.MineralChemistry

Magmatic mapping

Pop-up **Relationship Classes**

- MMRI.DBO.SVfSamples (1)
  - Stations 2
    - MMRI.DBO.Geochem_PXRF
    - MMRI.DBO.Geochem_Lab
    - MMRI.DBO.LowIntensityReactivity

Tabulated Data

OBJECTID	8
SampleID	SVF2
Analysis	PXRF
Form	powder
Rock type	spatter
Location	Springerville
Date	4/12/2024
Main	0
Low	44.67
High	44.93
Light	44.7
Reading No	84
Sigma Value	1.5
Ag	<LOD
Ag 2-Sigma	1.877
Al	153063.25
Al 2-Sigma	1398.2913
As	<LOD
As 2-Sigma	1.9106

Direct Air Capture to Mineralization Systems Model

DAC
Mechanical
Trees capture
1 T CO_2/day

+

Mine, sieve, mill,
& react scoria on site

+

Renewable
Energy

CO_2
delivered in
bicarbonate
brine using
saline
groundwater

Turning technology into impact

Provide a quantifiable model that describes generic implementation

TEA & LCA analysis

What amount of capital, equipment, energy, water, and disposal are required?
What are the environmental impacts?
Environmental Justice considerations?
What uses are there for the reacted material?

Outreach

- Scheduled social media campaign (post ~ once a quarter)
  - 100% increase in follower engagement
- ARPA Board of Directors Meeting (August 21)
  - Solicit samples from mine operators
  - Solicit feedback on industry needs
- Collaborate with PNNL on CDR outreach culminating in AZ-based community benefit meetings (Spring 2025)

ARIZONA ROCK PRODUCTS ASSOCIATION

Trade Organization that represents companies producing all aggregate materials in AZ.

Researchers from NAU, AZGS-UA, and ASU are testing how a volcanic rock called scoria can be used to...

Published by Chad Kwiatkowski

· April 30 ·

Recent Facebook Post Analytics

Post Impressions	Post reach	Engagement
62,166	60,365	3,910

Interactions

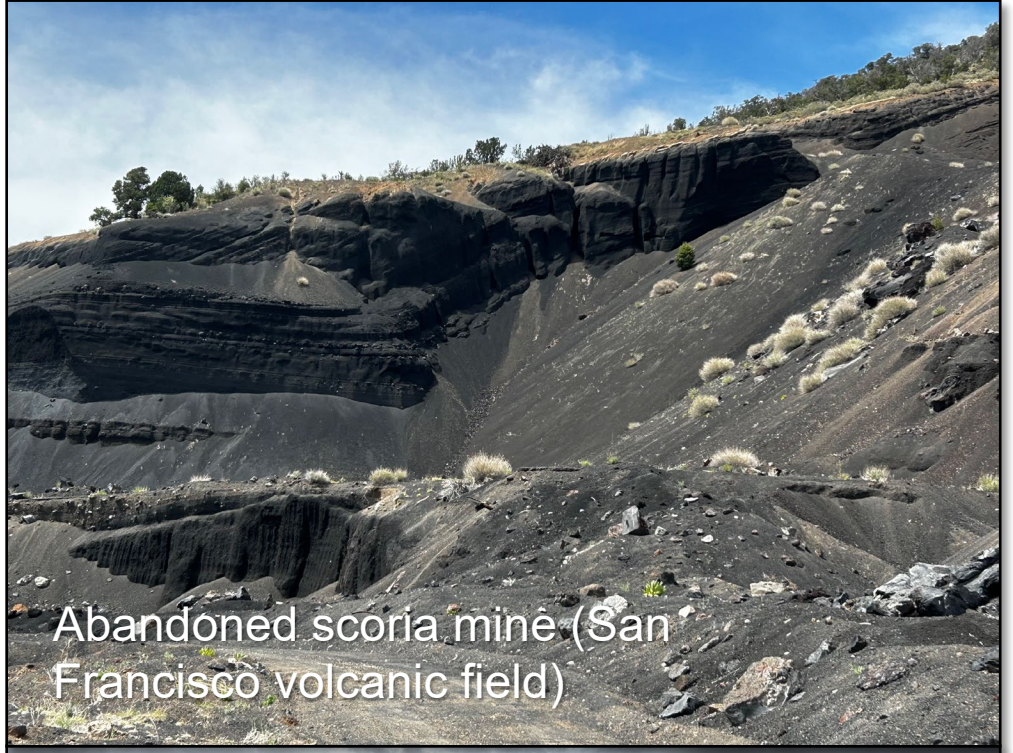
1.1K	111	7	46	0	2

Reactions	617
Comments	171
Shares	236
Other Clicks	1,034

Of the 171 comments, 47 of them were on a false statement about climate change illustrating continued need to counter the spread of mis- and disinformation

Summary

1. Sampling lessons: rock heterogeneity is important (particularly naturally weathered basalts)
2. Low intensity reactions:
    1. San Carlos olivine: 12% over 160 days
    2. Basalt: 6% over 64 days
3. High intensity:
    1. San Carlos olivine: 18% over 6 hours
    2. Basalt/scoria: <3% over 6 hours
4. Successful low intensity reaction of basalt has implications for mineralization through enhanced weathering
5. Disappointing reaction results of basalt at benchmark conditions gives us the opportunity to parameterize conditions for optimal reaction extent
6. Mafic Rock Resource Inventory is ~35% complete. Map-based product that will pair rock properties with reaction kinetic data
7. Direct Air Capture to Mineralization model (DACM) is dependent on reaction results – to be completed in this final year
8. Stakeholder outreach is a collaborative effort between PNNL & AZGS


Abandoned scoria mine (San Francisco volcanic field)

Scoria cone (Springerville volcanic field)

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Arizona Geological Survey
at the University of Arizona

Acknowledgements:

Pictured – Adam Sjolund: CO_2 reactivity; Andrea Wrenn: XRD; Thomas Sasser: Sample prep; Riva: field assistant

Not pictured – Connor Grayson: DACM; Tawnya Wilson – MMRI

Program Manager Ashley Urosek

Randi Bellassai (Associate Director and Business Manager at AZGS)

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