Subsurface mafic and ultramafic rock mapping and analysis for carbon mineralization in the US (SubMAP-CO2)

DE-FE0032249

7/1/23 through 5/31/25

Govt. Share: $989,655.00; Cost Share : $280,488.00; Total : $1,270,143.00

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Bureau of Economic Geology

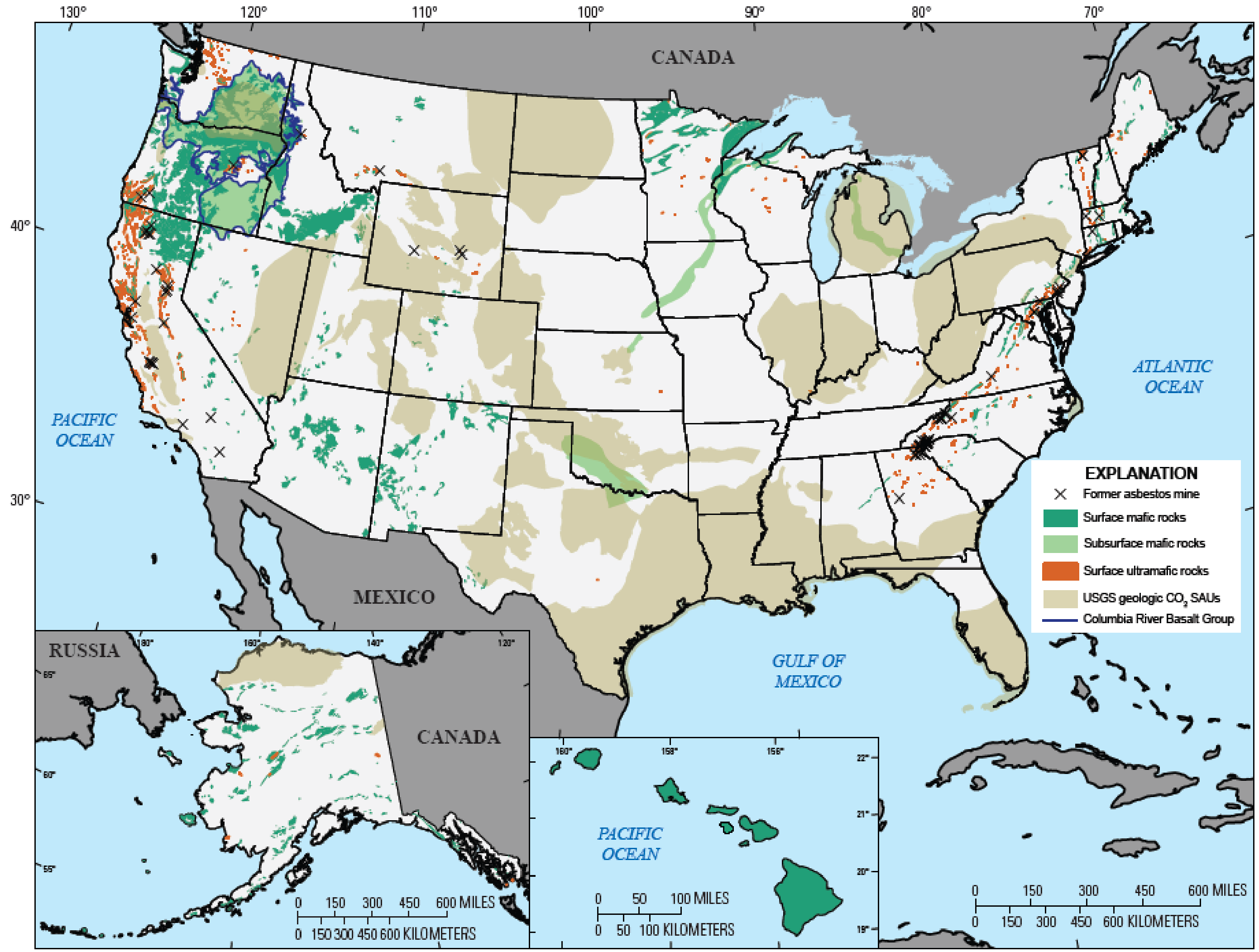
Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

Columbia University
in the City of New York

Key Participants

- The University of Texas at Austin
  - Esti Ukar (PI)
  - Shuvajit Bhattacharya (Co-PI) (Geophysics, Petrophysics)
  - Nicolas Espinoza (Co-PI) (Geomechanics, Carbonation experiments)
  - Lily Horne (3D model and database)
  - Julia Gale (Bedrock geology, Database)
  - Andras Fall (Carbonation experiments)
  - Ramon Gil-Egui (Economics, source-to-sink assessment)
  - Brent Elliott (Economic geology)
  - Lorena Moscardelli* (Texas)
  - Mert Ugurhan (GIS)
  - Sue Hovorka* (CCUS)
  - Rama Arasada (3D models)
  - Yuntian Teng (experiments)
- Lamont-Doherty Earth Observatory/Columbia University
  - Peter Kelemen* (Carbon mineralization, sampling)
  - Jakob Tielke (Carbon mineralization experiments)
  - Christine McCarthy (Carbon mineralization experiments)

Knowledge gap: subsurface ultramafic rocks



Blondes, M.S., Merrill, M.D., Anderson, S.T., and DeVera, C.A., 2019, Carbon dioxide mineralization feasibility in the United States: U.S. Geological Survey Scientific Investigations Report 2018–5079, 29 p., https://doi.org/10.3133/sir20185079

Project Objective

- Characterize and document:
  - Location
  - Volumetric extent
  - Mineralogy (including critical minerals, asbestiforms)
  - Petrophysical characteristics (grain size, grain density, porosity, permeability)
  - Carbonation potential

…of **mafic and ultramafic rocks in the subsurface** of the USA where large amounts of CO_2 can be stored via *in-situ* carbon mineralization

Goals

- Subsurface 3D mapping of mafic/ultramafic bodies
- Rock characterization and analysis
- Carbonation reaction rates and carbonation capacity
- Identification of subsurface CO_2 storage opportunities in the US

Deliverables

- ➢ Subsurface 3D map and core database (Y1Q4)
- ➢ Metadata of subsurface mafic and ultramafic rocks linked to the 3D subsurface model (Y2Q3)
- ➢ Source-to-sink assessment and ranking of sites across the USA for in-situ mineralization (Y2Q4)

6 Tasks schedule

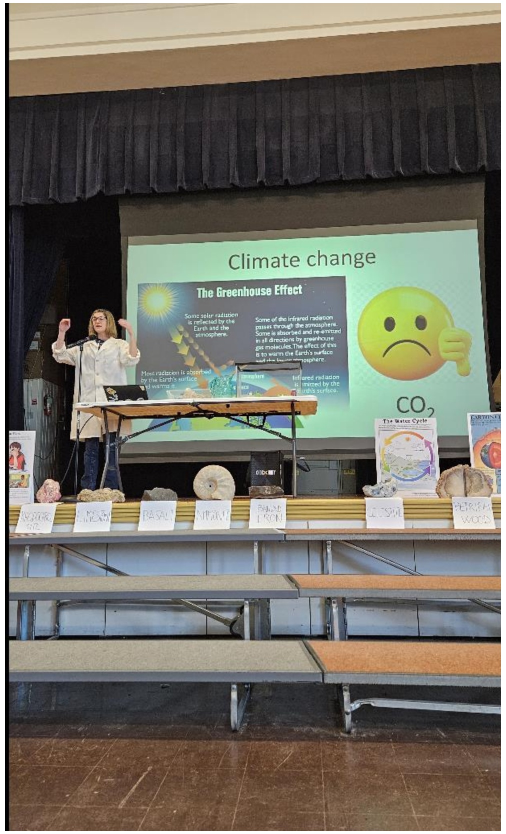
		Year 1				Year 2			
Task name	**Assigned Resources**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**
Task 1.0 -Project Management and Planning	Ukar, Bhattacharya, Espinoza								
M1: Project Kickoff Meeting	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Subtask 1.1.- Management	Ukar, Battacharya, Espinoza								
Subtask 1.2. -Meetings	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Subtask 1.3. -Reporting	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Task 2.0 -Subsurface 3D mapping of mafic and ultramafic bodies	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Subtask 2.1. -Literature and database review and curation	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Subtask 2.2. -Gravity and magnetic anomaly survey analysis	Horne, Bhattacharya, Smye, postdoc								
Subtask 2.3. -Non-public data sources	Ukar, Horne, Smye, Elliott, Fall, Bhattacharya, Postdoc								
Subtask 2.4. -Petrophysical log and core data compilation	Smye, Bhattacharya								
Subtask 2.5 -Data synthesis and subsurface map and 3D model construction	Horne, Bhattacharya, Smye, postdoc								
M2: Summarize subsurface map and core database construction									
Decision point #1: Do we have enough data and samples to proceed?									
Task 3.0 - Subsurface rock characterization	Ukar, Fall, Elliott, Smye, Bhattacharya, postdoc								
Subtask 3.1. -Core sampling and description	Ukar, Fall, Elliott, postdoc								
Subtask 3.2. - Field sampling and description	Ukar, Elliott, Kelemen, Tielke, postdoc								
M3: Summarize core and field sample dataset									
Subtask 3.3. -Rock petrologic characterization and analytical measurements	Ukar, Fall, Elliott, Espinoza, postdoc								
Subtask 3.4. -Integrated petrophysical analysis	Bhattachrya, Smye								
M4: Summarize subsurface rock characterization dataset									

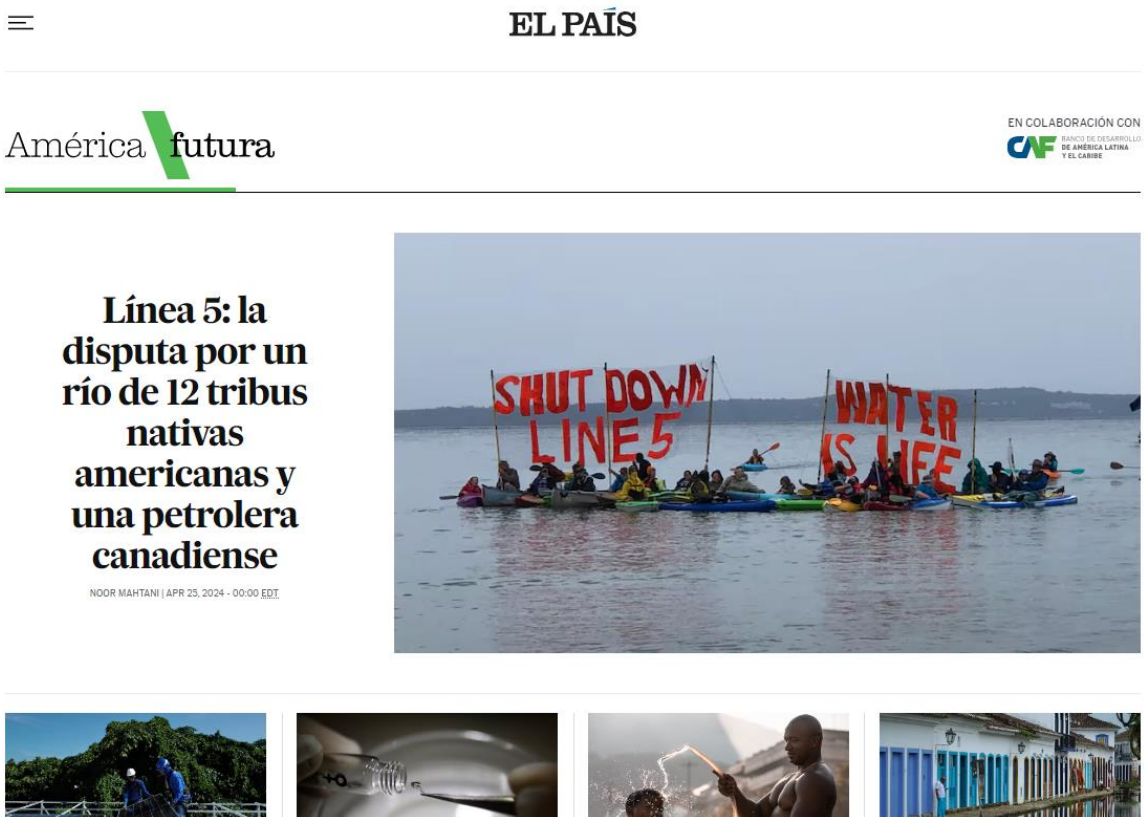
		Year 1				Year 2			
Task name	**Assigned Resources**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**	**Qtr 1**	**Qtr 2**	**Qtr 3**	**Qtr 4**
Task 4.0. -Kinetics and carbonation reaction experiments	Espinoza, Fall, Kelemen, Tielke, McCarthy, postdoc								
Subtask 4.1. -Autoclave experiments	Espinoza, postdoc								
Subtask 4.2. -Flow-through experiments	Espinoza, Kelemen, Tielke, McCarthy, postdoc								
M5: Assess success and scalability of autoclave and flow-through experiments									
Subtask 4.3. -Pressure vessel and synthetic CO_2-rich fluid inclusions experiments	Fall								
M6: Assess success and scalability of pressure vessel experiments									
M7: Identify challenges that can affect upscaling									
Decision point #2: Can experimental results be used for a realistic CO_2 source-to-sink assessment									
Task 5.0. -CO_2 source-to-sink site assessment	Ramon Gil-Egui, Horne, Smye, Elliott, Battacharya, Ukar, Postdoc								
Subtask 5.1. -Sites with highest potential as CO_2 sinks	Ramon Gil-Egui, Horne, Smye, Elliott, Battacharya, Ukar, Postdoc								
Subtask 5.2. -Community impact and land use	Ramon Gil-Egui								
M8: Deliver final assessment of potential CO_2 sink sites and reccomendations for further site-specific assessment									
Task 6.0. -Public database population and web portal construction	GIS and web design specialist								
M9: Launch publicaly accessivle web portal									
M10: Final meeting and report									

Task 1: Project Management and Planning

- 1.1 Project Management
- 1.2 Community Benefits Plan

Outreach and dissemination





EL PAÍS

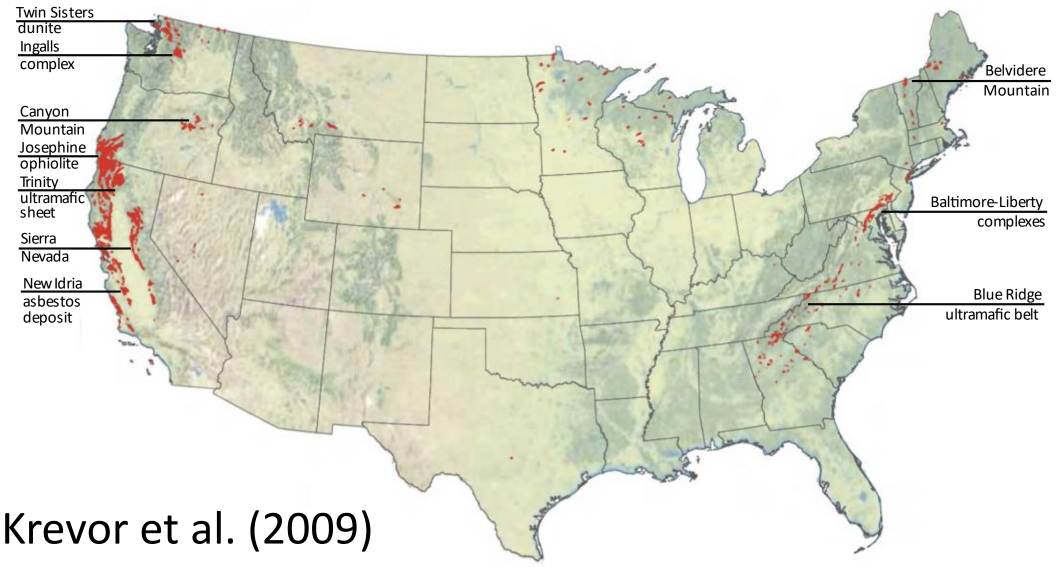
América futura

EN COLABORACIÓN CON CAF

Línea 5: la disputa por un río de 12 tribus nativas americanas y una petrolera canadiense

NOOR MAHTANI | APR 25, 2024 - 00:00 EDT

Task 2: Subsurface mapping

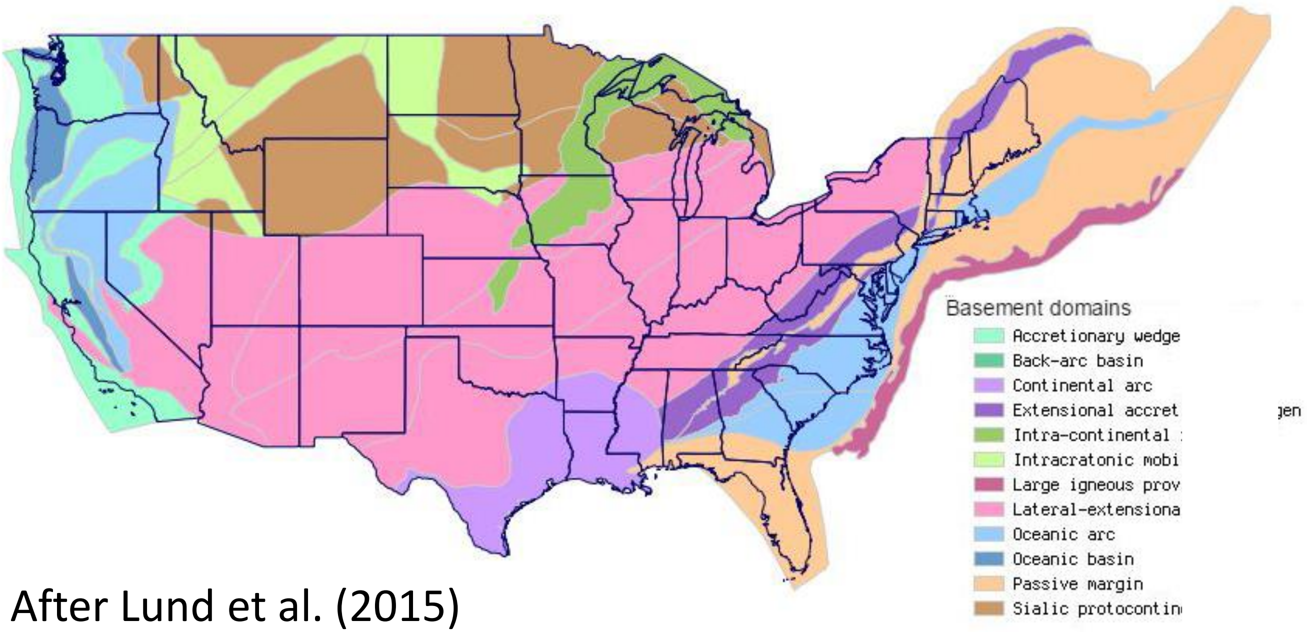


Krevor et al. (2009)

- Eastern states
- Western states
- Mid Continental Rift

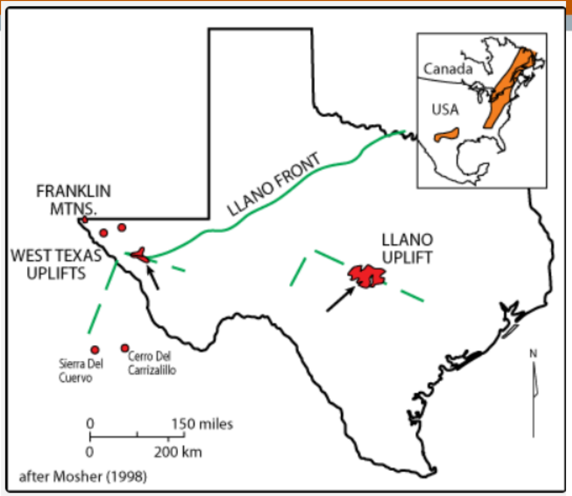
- 2.1 Database/literature review

Basement domains



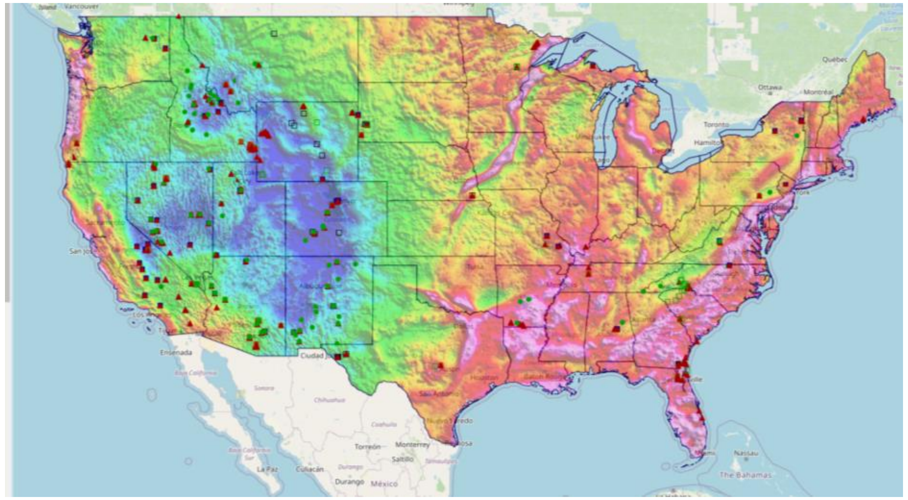
After Lund et al. (2015)

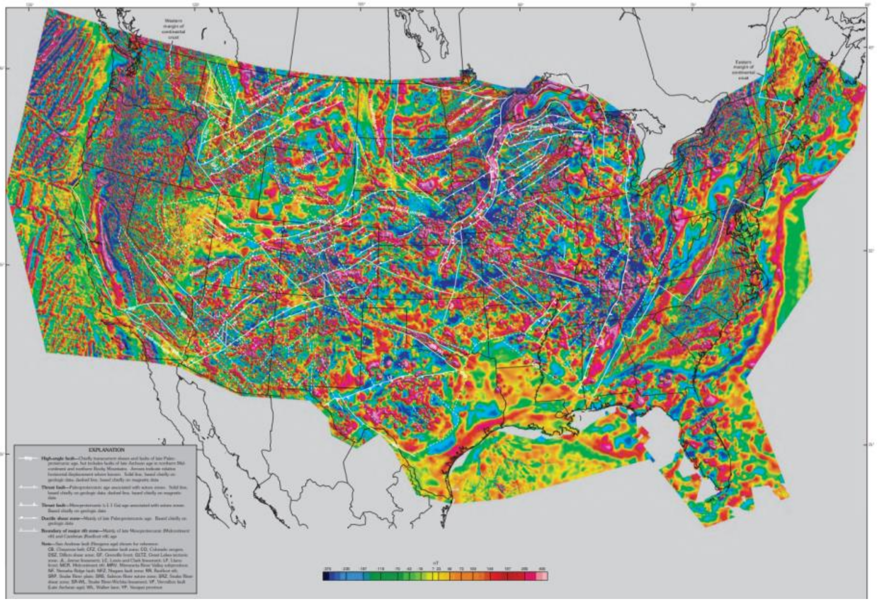
- 2.2 Gravity and magnetic surveys

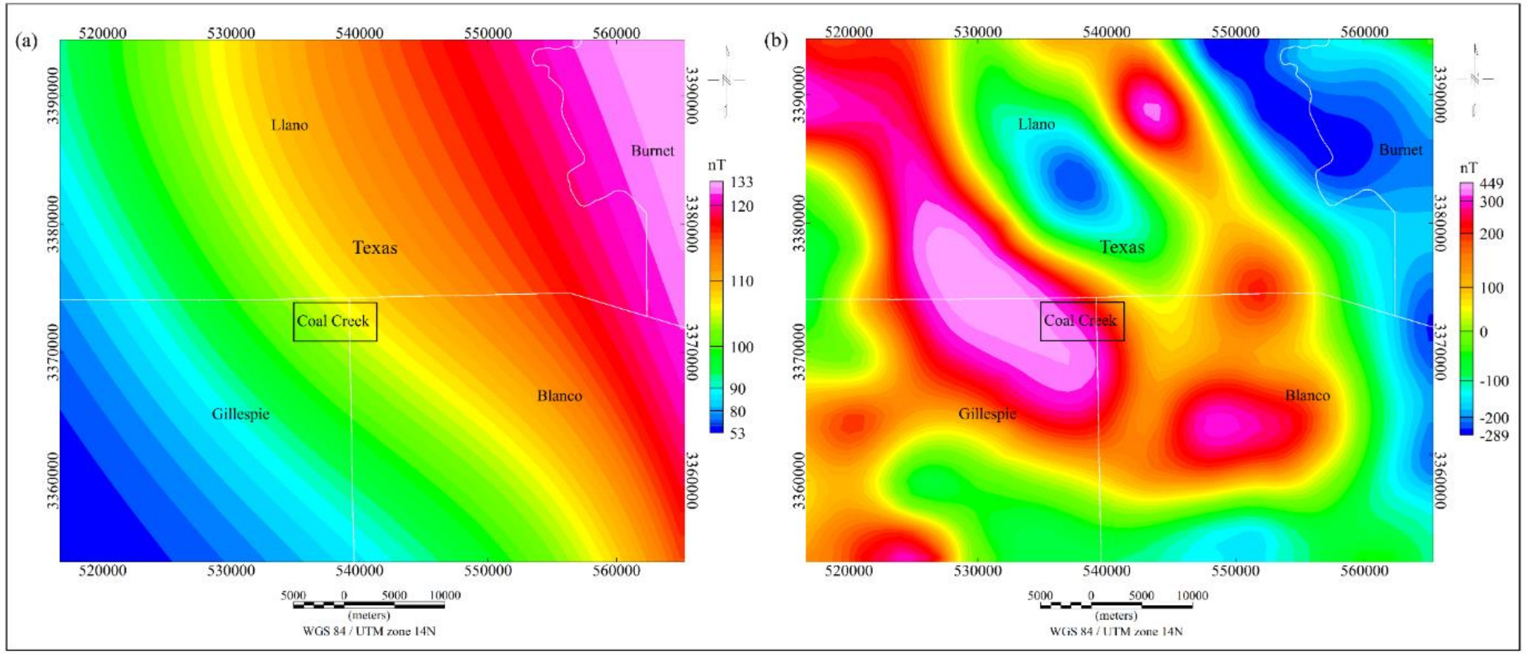


Public data sources (USGS)

- Geobodies with high magnetic anomalies



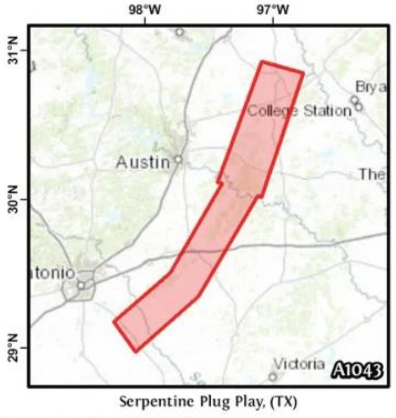




Upward continued map of magnetic anomalies to 20 km height

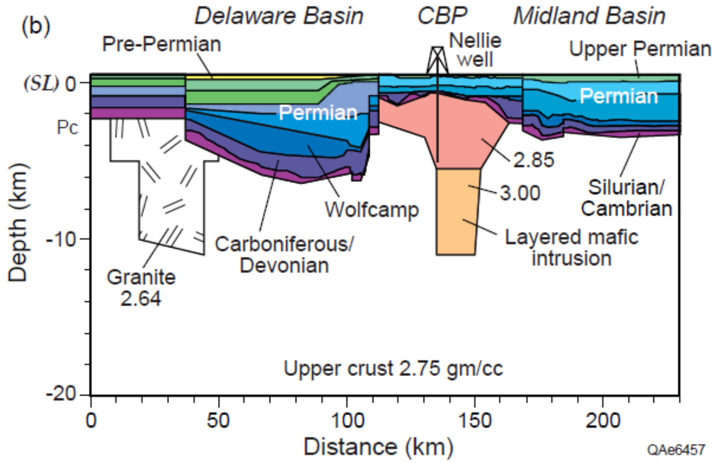
Residual magnetic anomaly map based on USGS map

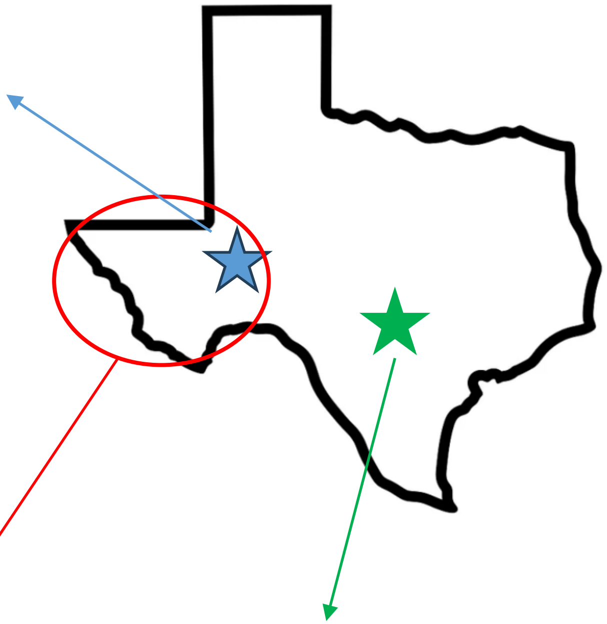
- 2.3 Non-public data sources
  - Texas

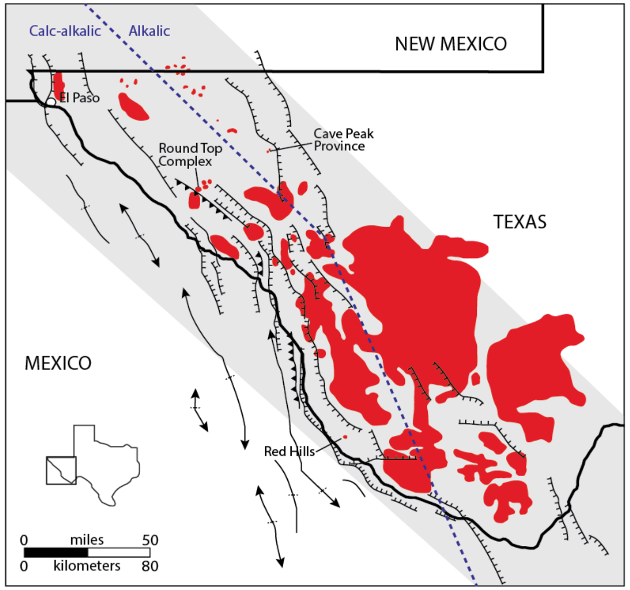


Serpentine Plug Play, (TX)

Rio Grande Embayment, (TX)







Pecos Mafic Intrusive Complex (Barnes et al., 1999)

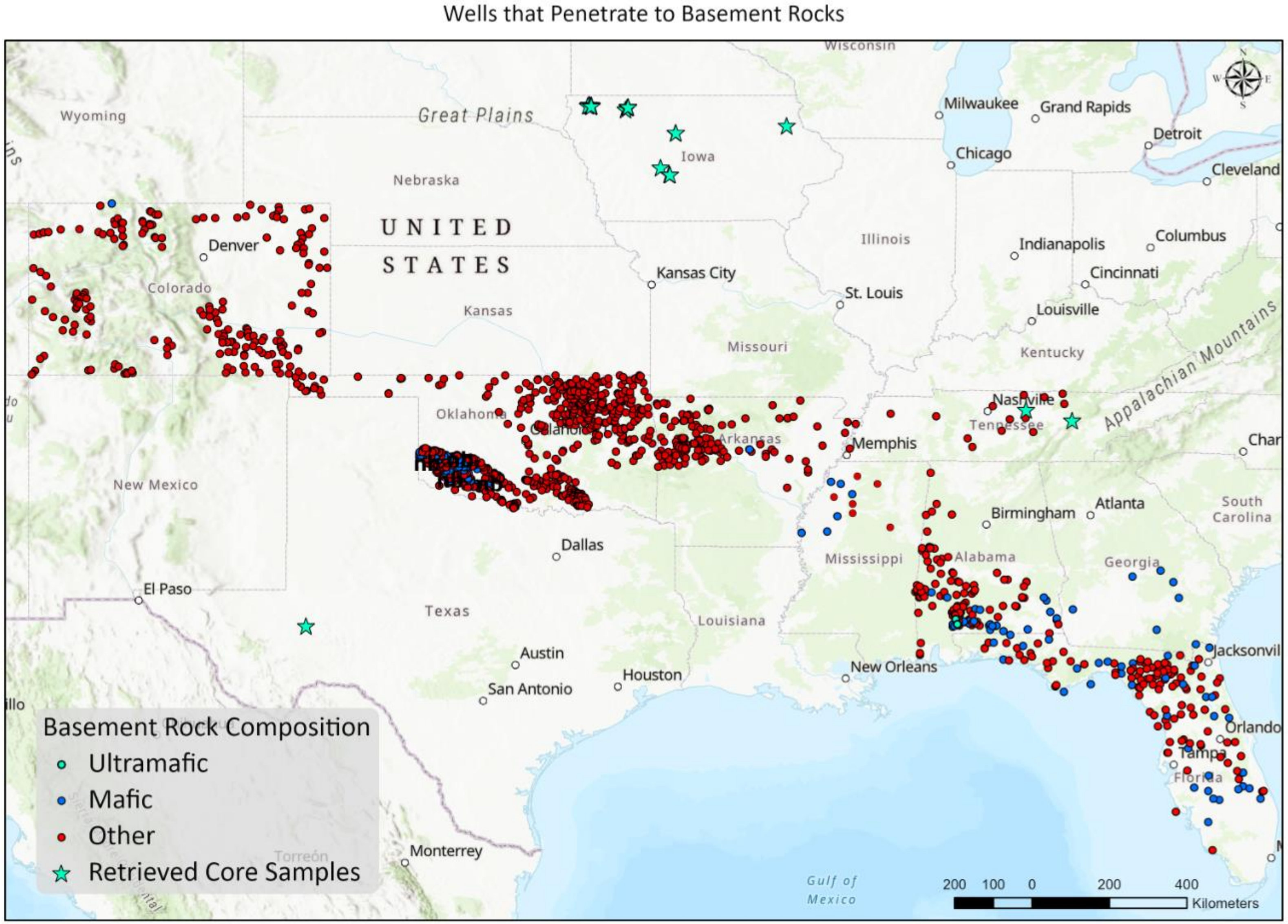
Coal Creek serpentinite (serpentinized harzburgite)(Mosher et al., 2008)

Bureau of Economic Geology

• 2.4 Well penetrations

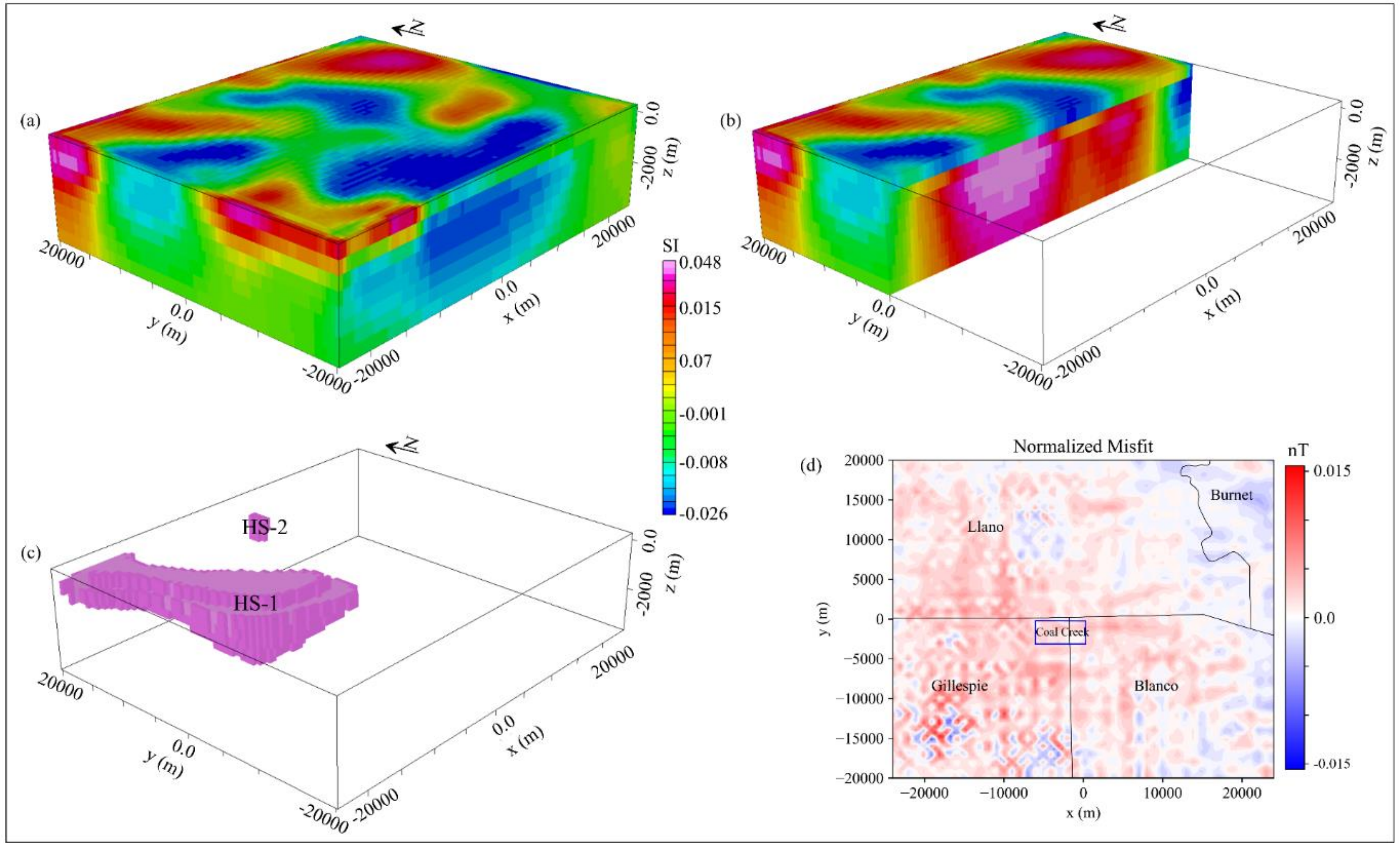
- Wells/cores that have penetrated basement

- Mafic/ultramafic basement

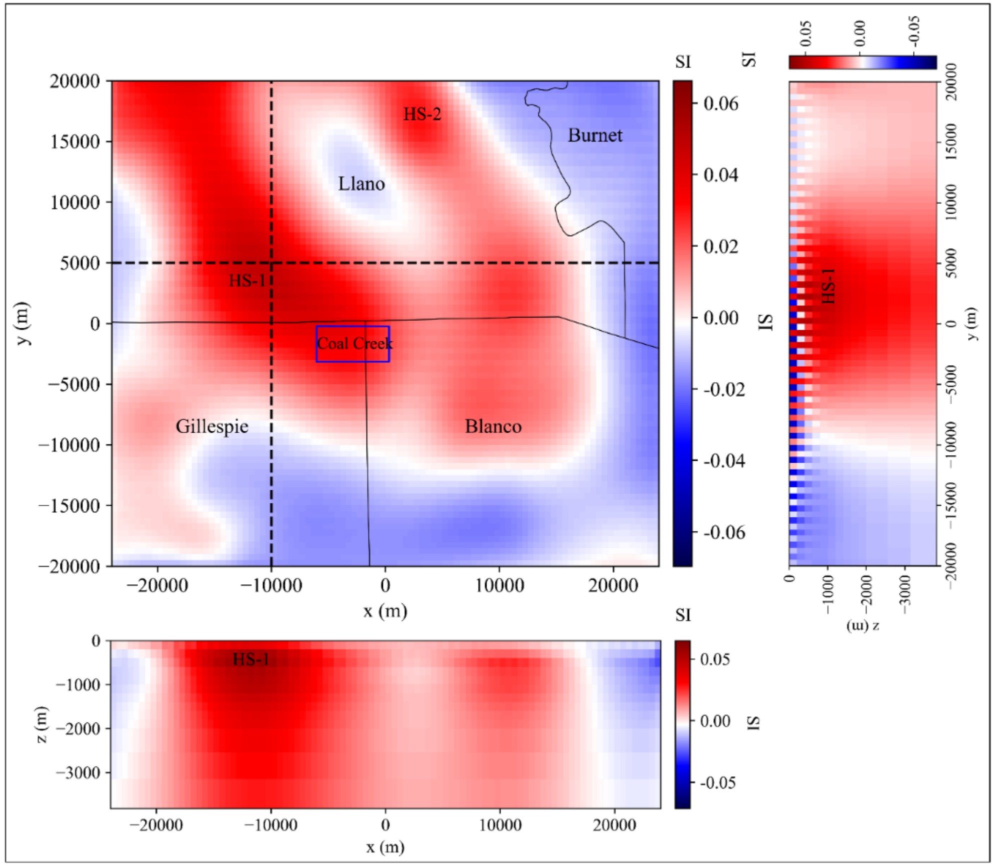


- 2.5 Subsurface 3D model and volume calculation

Inversion of residual total field (RTF) magnetic data using a Magnetic Vector Inversion (MVI) code (SimPEG Python open-source package; Cockett et al., 2015).



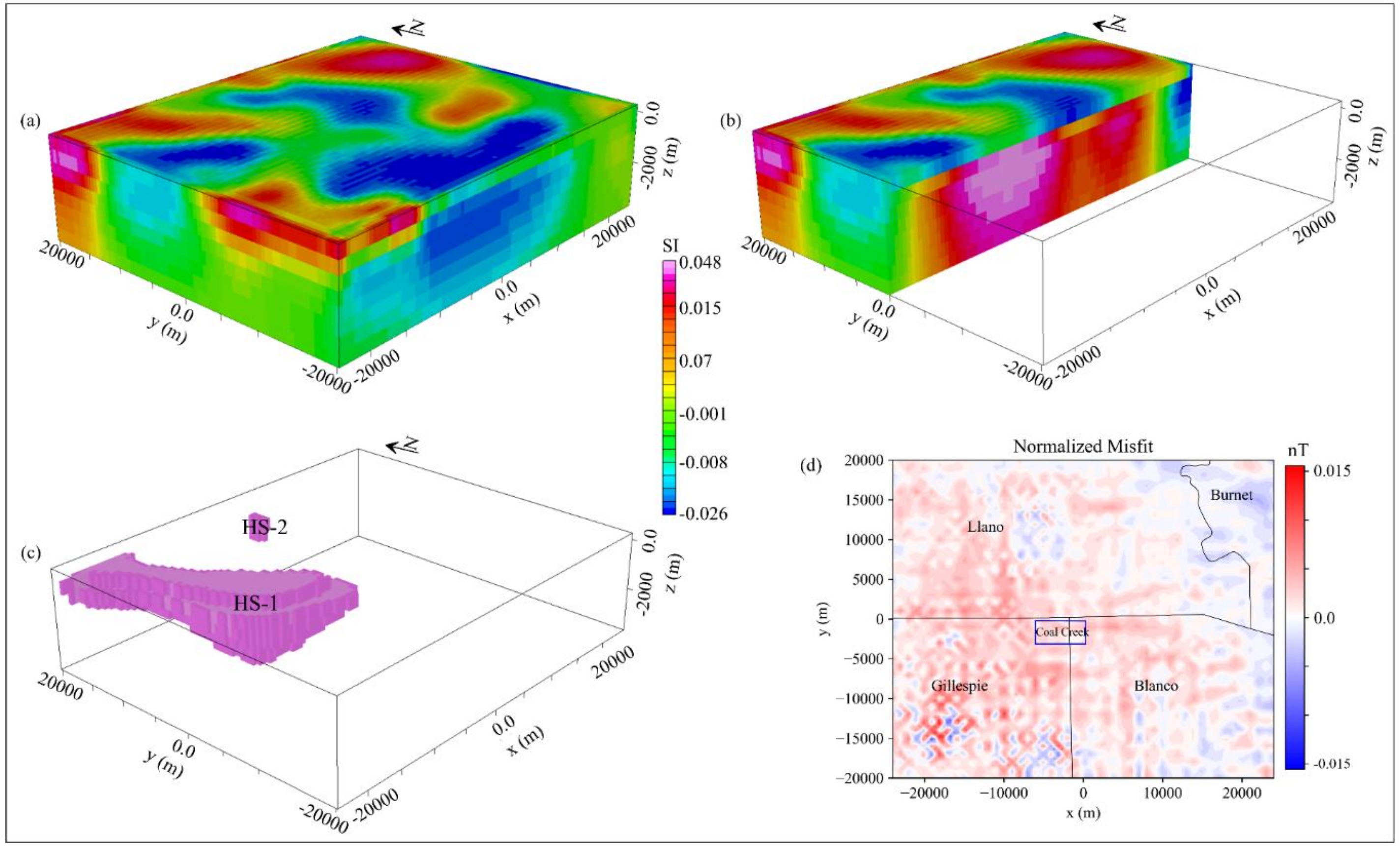
3D magnetic inversion showing magnetic susceptibility distribution beneath Coal Creek



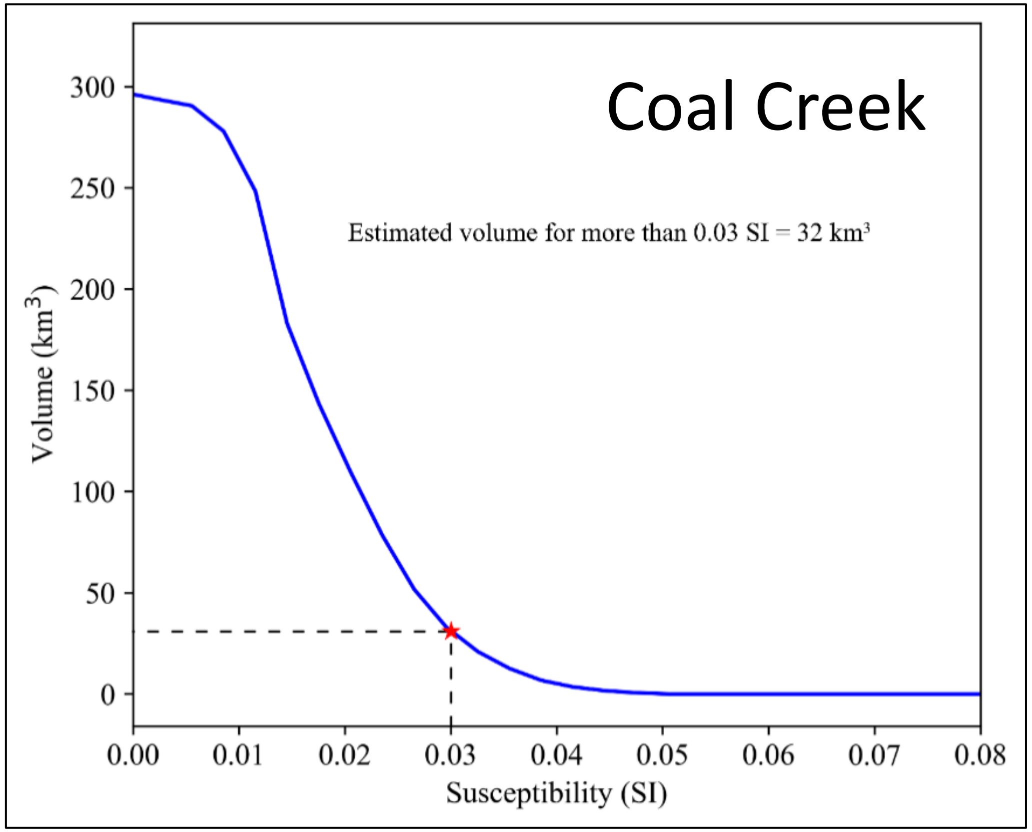
Depth slice of the magnetic susceptibility model at depth -1.11 km

• 2.5 Subsurface 3D model and volume calculation

Inversion of residual total field (RTF) magnetic data using a Magnetic Vector Inversion (MVI) code (SimPEG Python open-source package; Cockett et al., 2015).



3D magnetic inversion showing magnetic susceptibility distribution beneath Coal Creek



If SI <0.03 = 32 km³

Task 3: Rock sampling and characterization

- 3.1. Subsurface samples
  - Challenge: Scarce and difficult to obtain

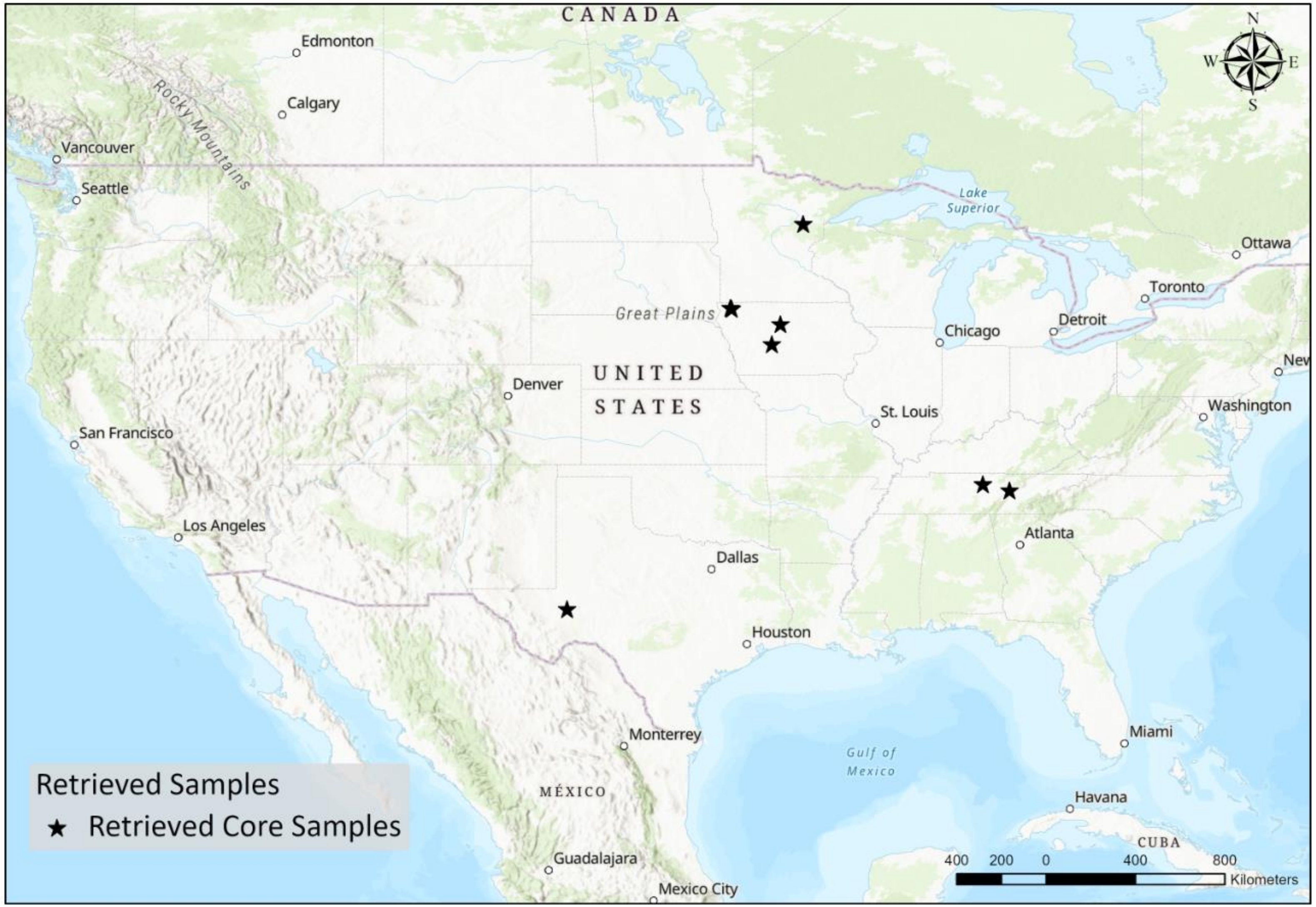
- 3.2 Field sampling

- 3.3 Rock characterization

- 3.4 Integrated petrophysics

• 3.1 Core sampling

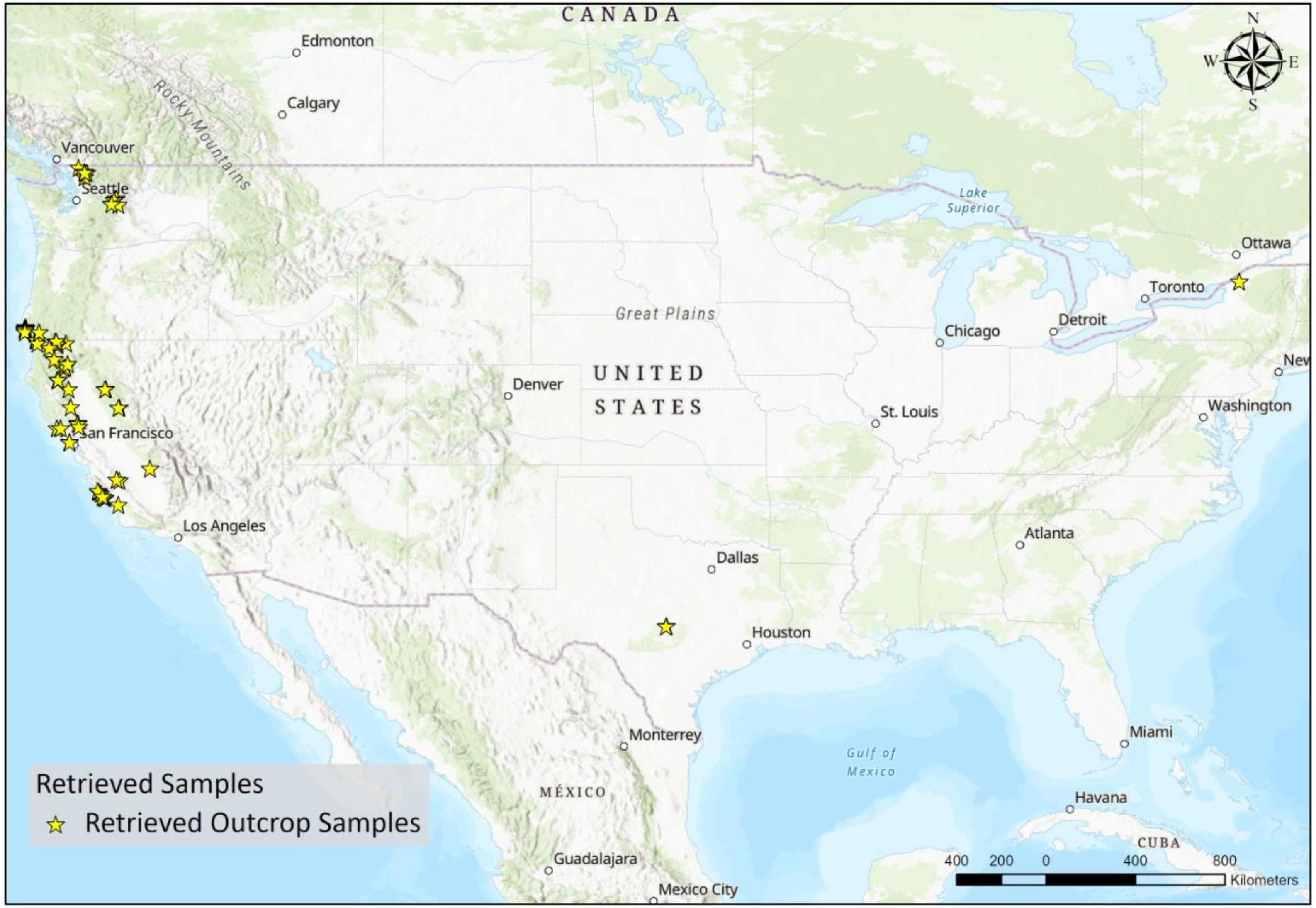
- Thor complex (IA): 14 samples
- Tennessee (TN): 2 samples
- Tamarack (MN): 1 sample
- Nellie Well (TX): 265 thin sections



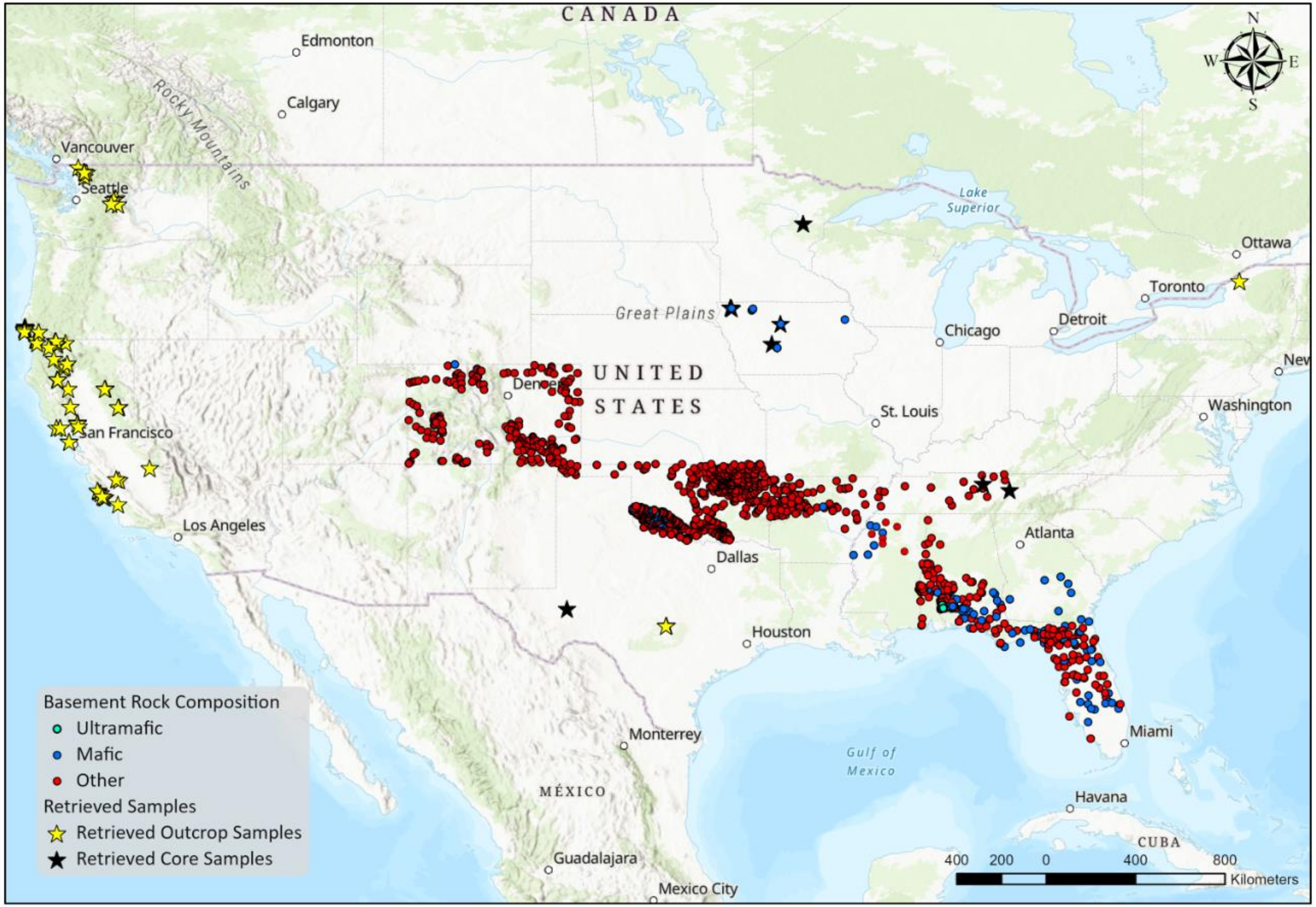
• 3.2 Field sampling

- Twin Sisters dunite (WA)
- Ingalls complex (WA)
- Josephine peridotite (OR)
- Coal Creak serpentinite (TX)
- Yellow Lake serpentinite (NY)
- Franciscan, Trinity, Coast Range ophiolite, The Geysers… (CA)

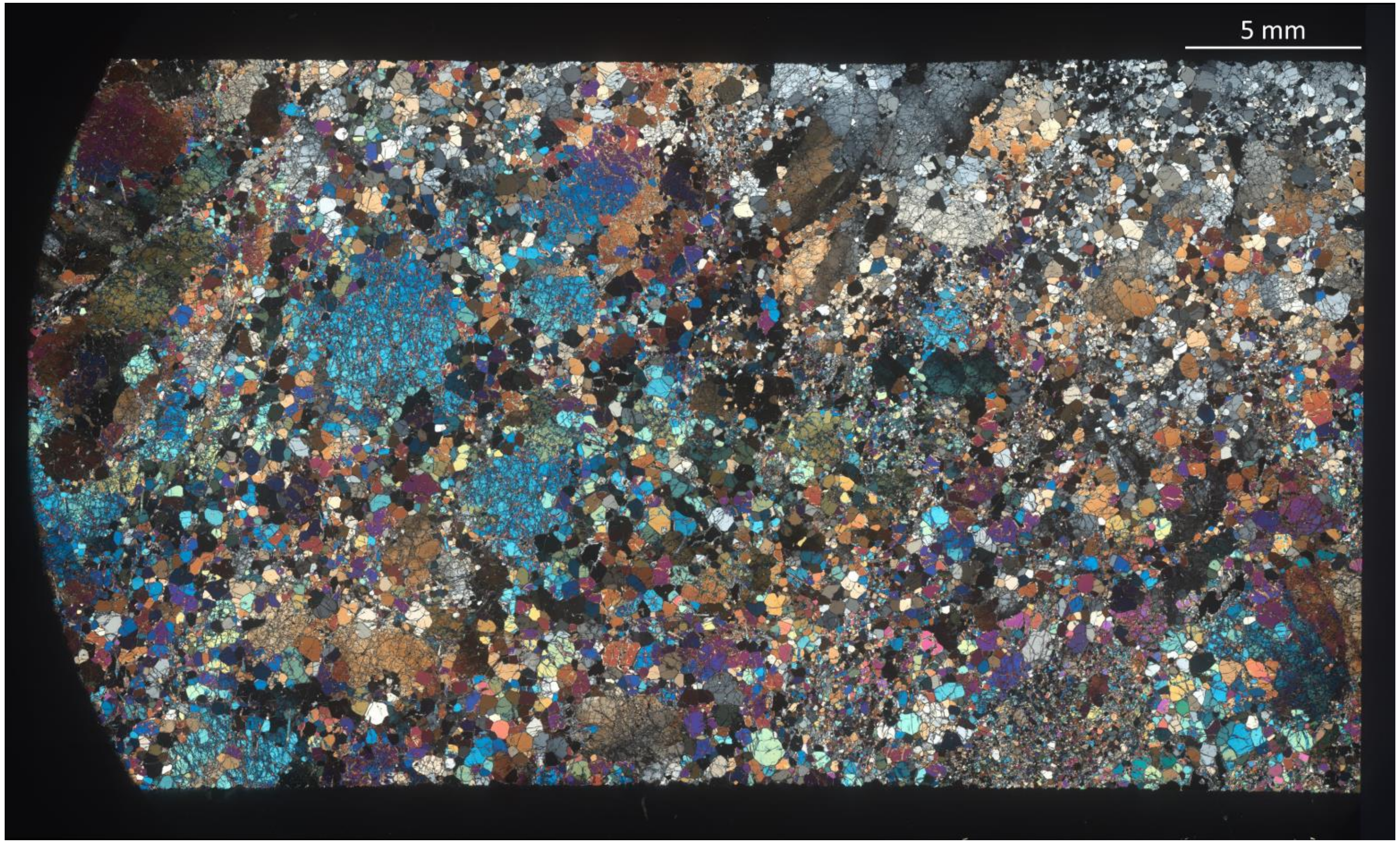
~100 samples



Core database + retrieved samples

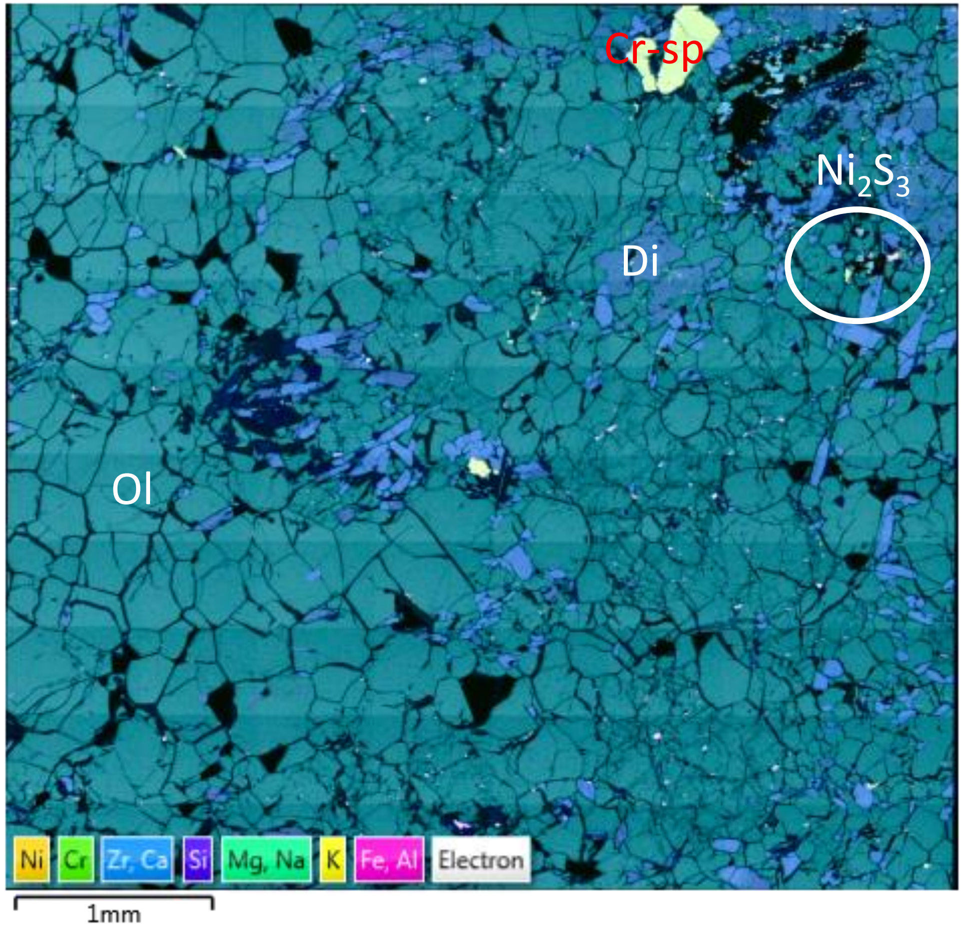


- 3.3 Rock characterization



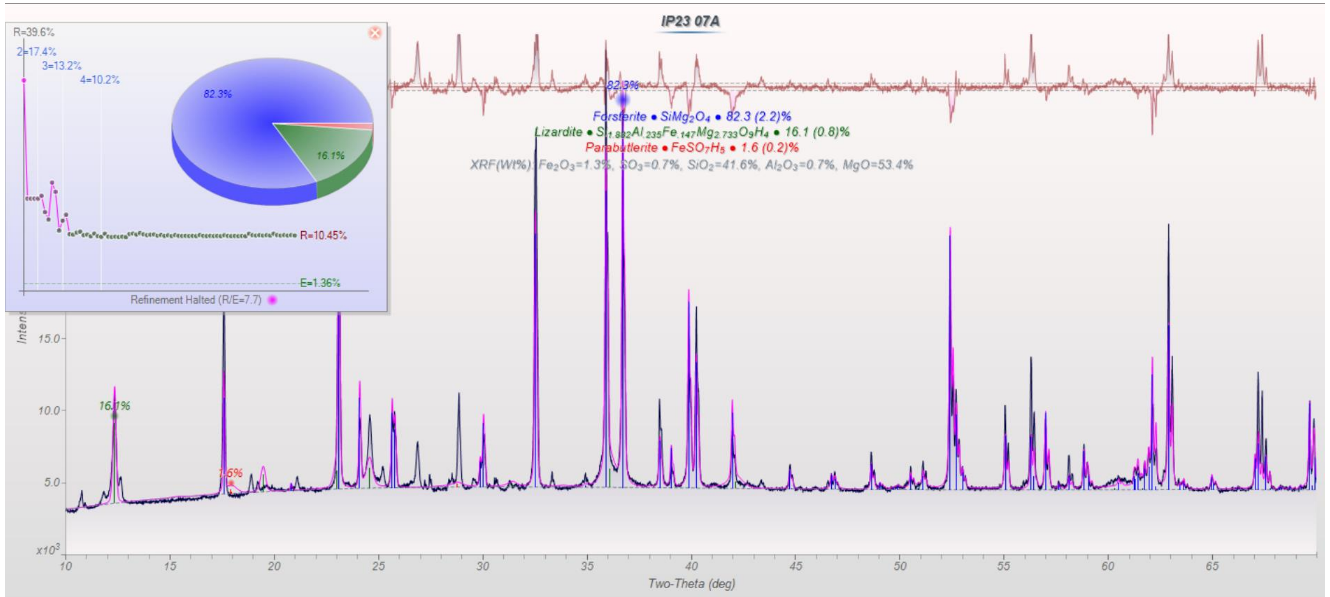
Optical microscopy

IP23-07A



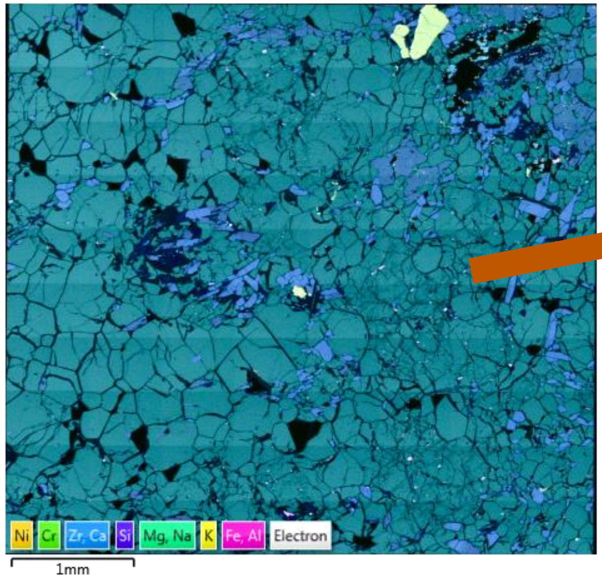
SEM-EDS

XRD (>5%)

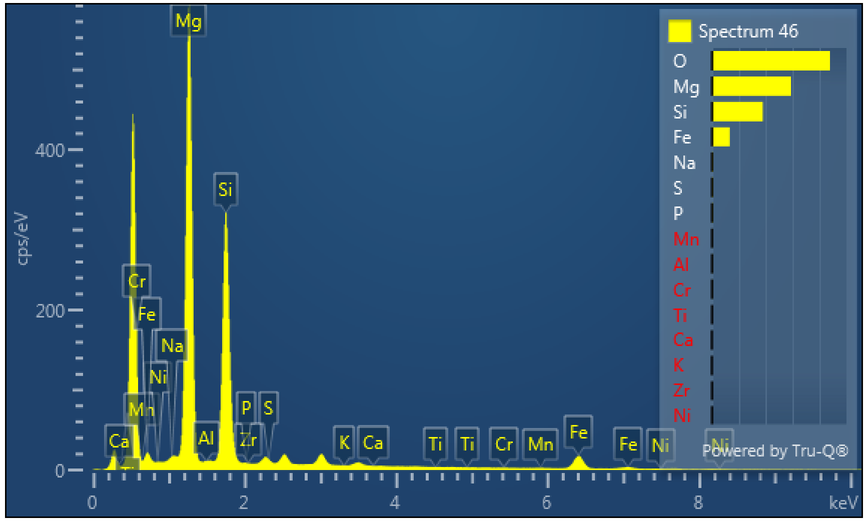


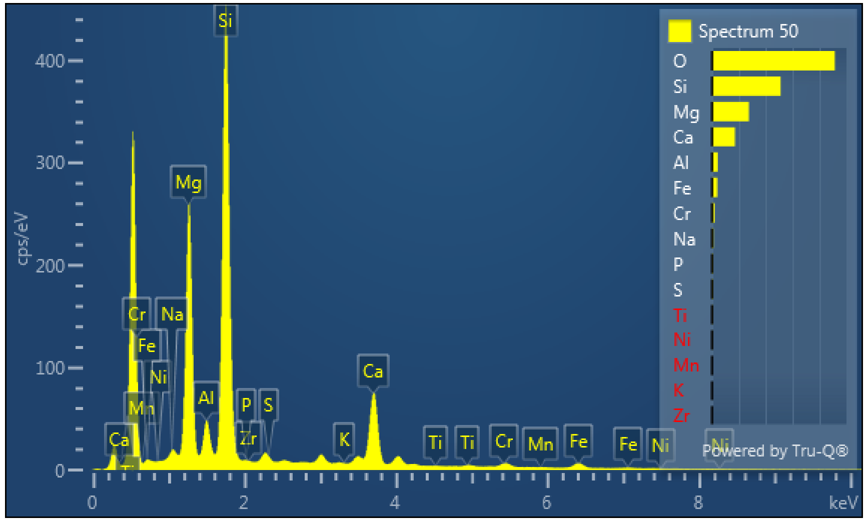
Semi-quantitative elemental composition of minerals

Label	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Ni	Zr	Total
Map Sum Spectrum	40.12	0.45	15.49	2.88	15.82	0.28	0.96	0	3.62	0.08	0.36	0.13	19.34	0.46	0	100
Spectrum 1	43.77	0.32	9.93	1.57	23.83	0.24	0.25	0	15.58	0.28	1.53	0	2.61	0.08	0	100
Spectrum 2	43.73	0.34	9.79	1.7	23.73	0.29	0.21	0	15.55	0.33	1.51	0	2.73	0.08	0	100
Spectrum 3	46.38	0.29	24.39	0.8	23.74	0.54	0.54	0	0.09	0	0.06	0.15	3.02	0.01	0	100
Spectrum 4	43.78	0.3	10.02	1.33	24.03	0.25	0.23	0	15.72	0.27	1.43	0	2.54	0.12	0	100
Spectrum 5	23.94	0.58	1.32	0.35	1.07	0	0.4	0.01	0.07	0.02	0.03	0.09	71.9	0.17	0.05	100
Spectrum 6	43.07	0.59	16.69	9.91	15.94	0.63	0.25	0	0.02	0.02	0.05	0.32	12.51	0	0	100
Spectrum 7	44.04	0.55	19.18	7.32	18.2	0.53	0.3	0	0.03	0.02	0.01	0.28	9.54	0	0	100
Spectrum 8	45.95	0.45	23.53	1.97	22.91	0.3	0.51	0	0	0.05	0.17	0.18	3.97	0	0	100
Spectrum 9	44.14	0.56	17.12	11.41	16.15	0.74	0.28	0	0	0	0	0.27	9.32	0	0	100
Spectrum 10	42.41	0.59	13.56	12.45	14.43	0.71	0.24	0	0	0.01	0.01	1.59	13.98	0	0	100
Spectrum 11	42.72	0.61	13.14	14.54	13.51	0.84	0.21	0	0	0	0.01	1.54	12.88	0	0	100
Spectrum 12	43.82	0.32	10.03	1.37	24.01	0.26	0.23	0	15.6	0.29	1.53	0	2.48	0.07	0	100
Spectrum 13	22.53	0.54	0.24	0.06	0.09	0.01	0.06	0	0	0	0.01	0.09	76.05	0.31	0	100
Spectrum 14	45.13	0.15	22.11	2.48	22.17	0.19	0.48	0	0	0	0	0.19	7.07	0	0	100
Spectrum 15	46.11	0.49	24.46	0.78	23.82	0.25	0.42	0	0	0	0	0.14	3.54	0	0	100
Spectrum 16	45.29	0.47	22.87	5.16	20.09	0.4	0.36	0	0	0.02	0	0.13	5.21	0	0	100
Spectrum 17	45.48	0.35	22.57	2.52	22.5	0.29	0.37	0	0.01	0.02	0.03	0.2	5.67	0	0	100
Spectrum 18	43.77	0.29	10.07	1.25	24.03	0.26	0.22	0	15.77	0.26	1.42	0	2.57	0.09	0	100
Spectrum 19	43.8	0.3	9.97	1.39	24.02	0.26	0.21	0	15.75	0.27	1.43	0	2.56	0.03	0	100
Spectrum 20	45.83	0.38	23.61	1.02	23.67	0.23	0.38	0	0	0.01	0.13	0.2	4.54	0	0	100
Spectrum 21	44.06	0.52	19.18	7.54	17.98	0.52	0.37	0	0	0.03	0.01	0.34	9.45	0	0	100

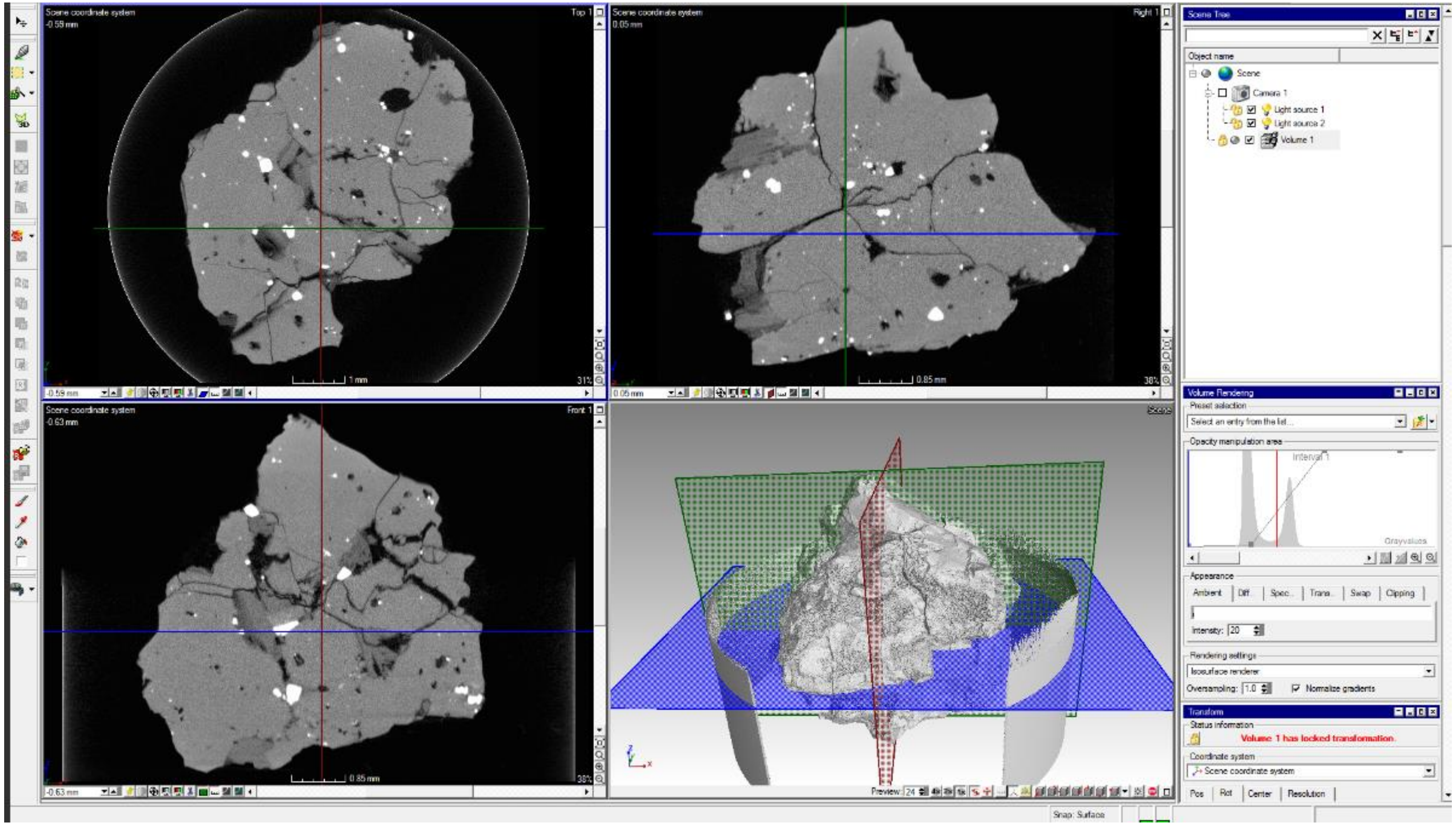


EDS spectra





- 3.4 Petrophysics
  - Porosity, permeability, magnetic susceptibility



Micro-CT

Task 4: Carbon mineralization experiments

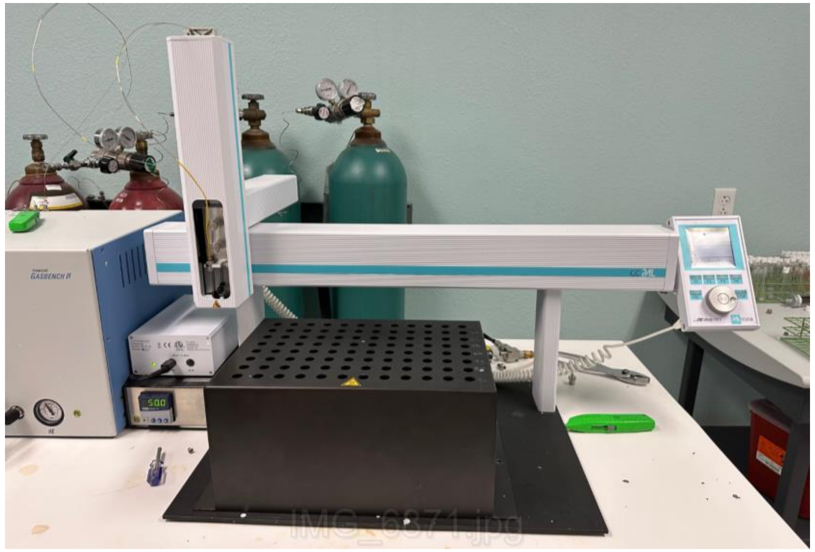
- 4.1. Batch reactions, autoclave
- 4.2. Flow-through experiments
- 4.3. Pressure vessels and synthetic fluid inclusions

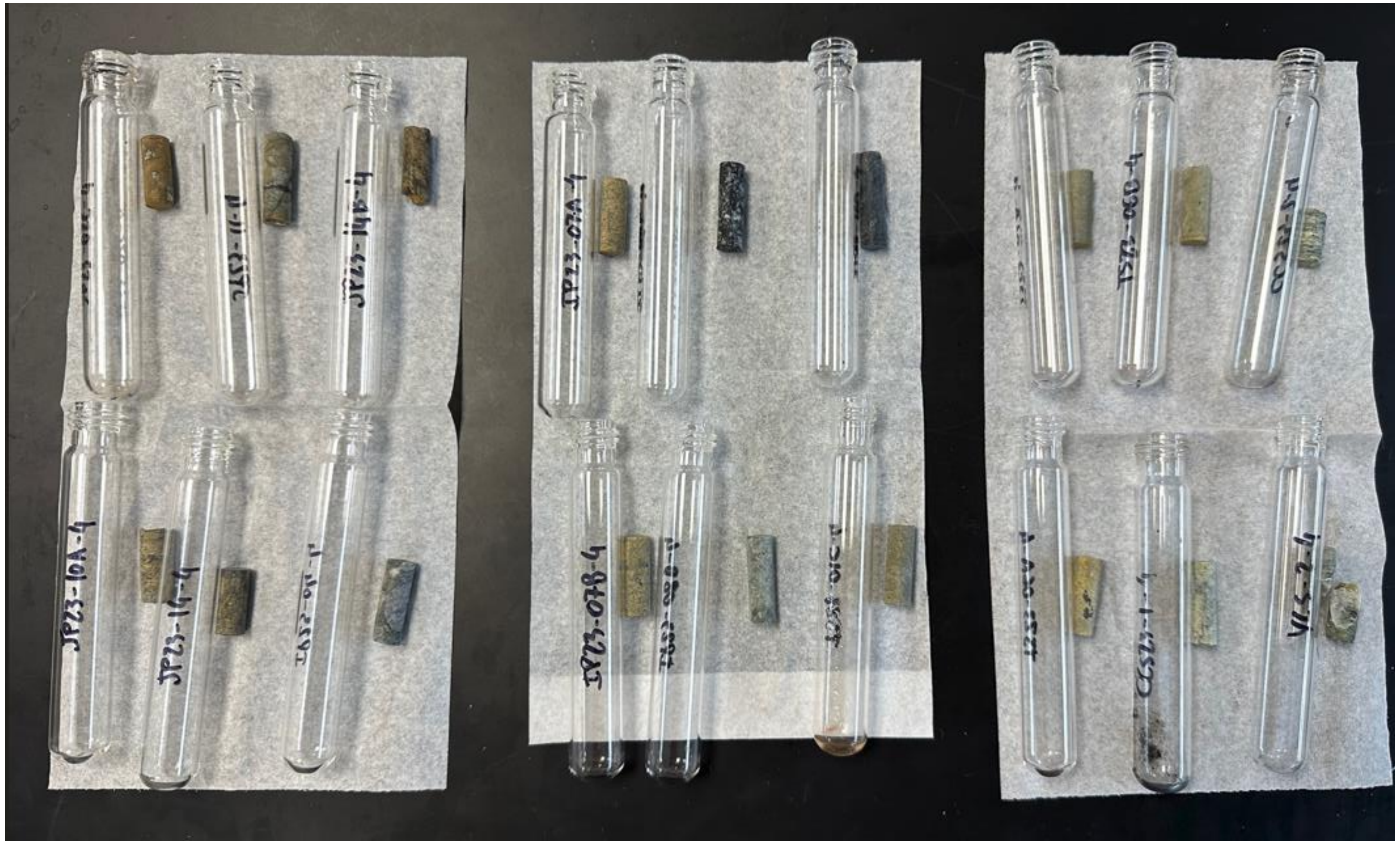
- Array of UT Austin and Lamont labs

- Reaction Screening Experiment Platform (RSEP)
  - Batch Reactions

8 mm

- 18 rock types
- 1, 4, 12, 19, 27 days at 90ºC and 1-2 atm
- Sample fluids, solids, pH, carbonation
- Use to define reaction conditions for autoclave experiments



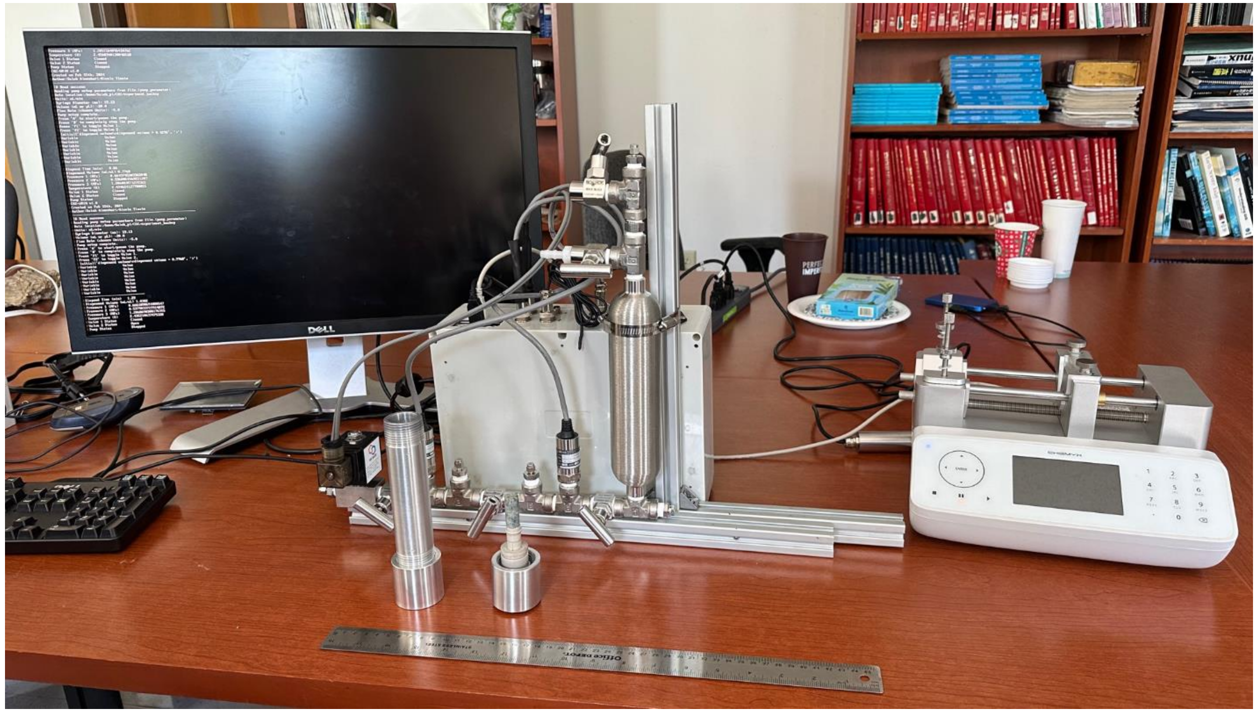


19d

• CT-transparent compact flow-through system

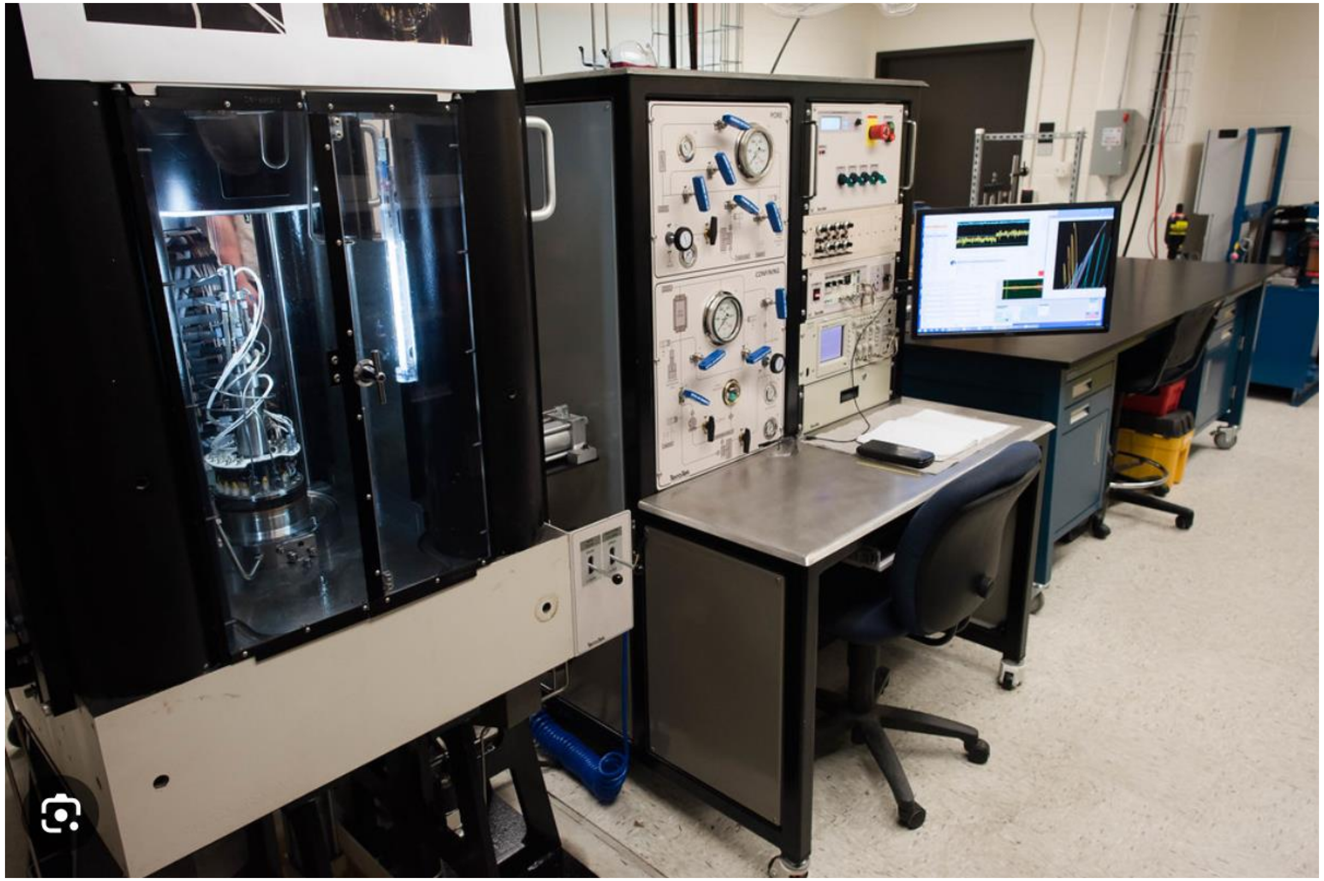
- Conduct experiments inside CT scanner
- Undisturbed for 1-2 months
- Periodic, systematic scans

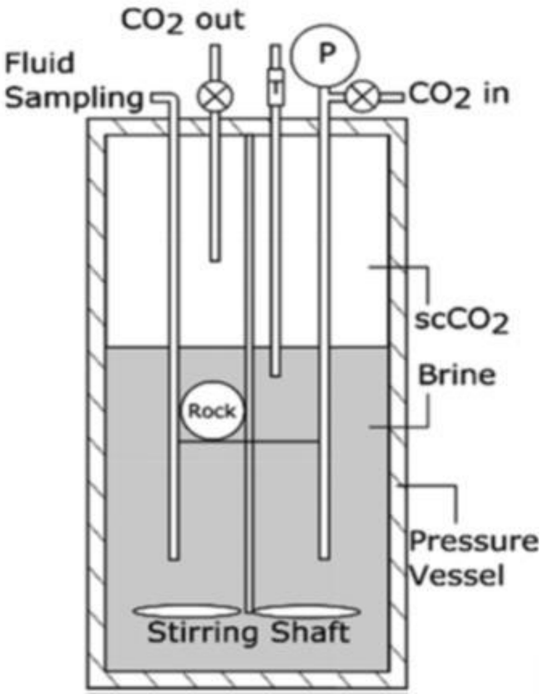
1-inch core plugs from Coal Creek Serpentinite

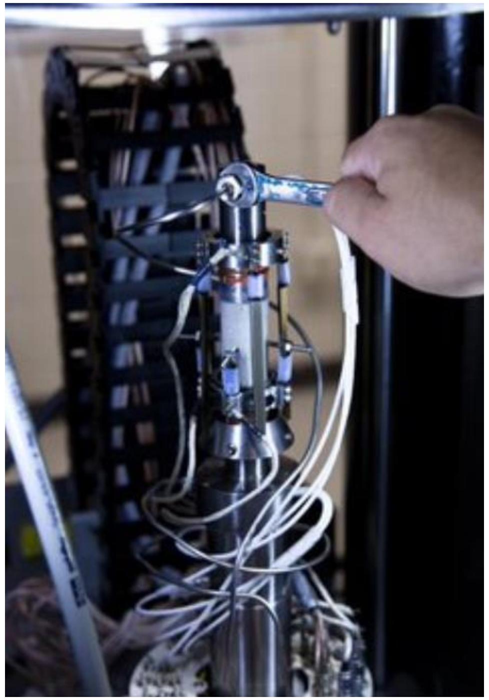


- Flow-through experiments (UT Austin)
  - Simulate P, T conditions at depth

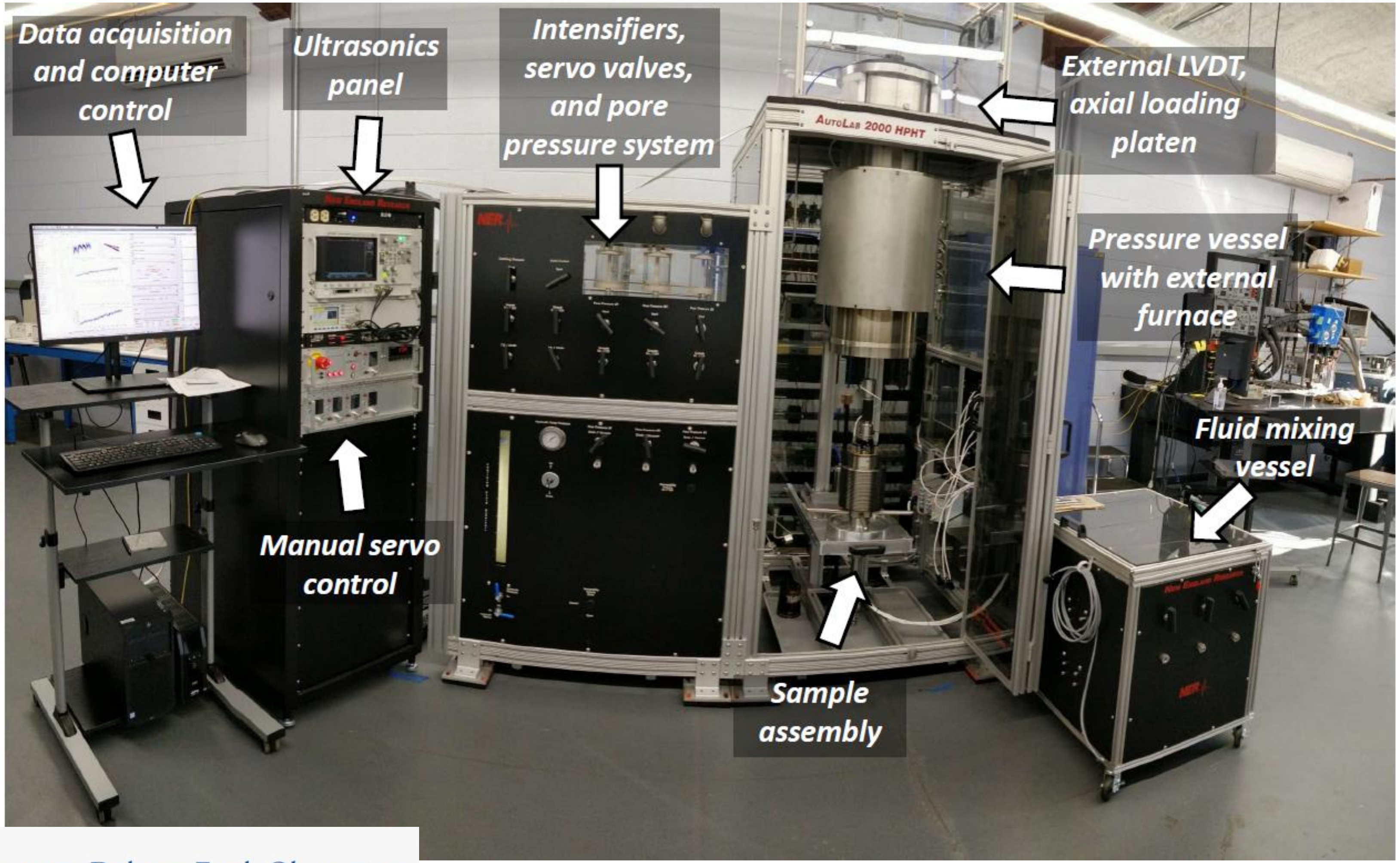
- Design new apparatus for <1 cm diameter core plugs





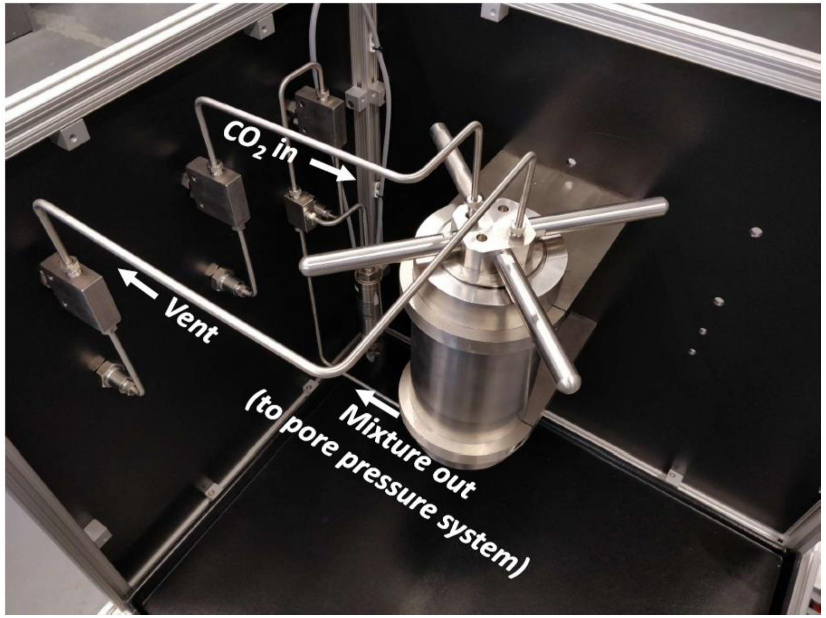


- Autolab 2000 triaxial deformation apparatus (LDEO)



- Simulate P, T conditions at depth
- Measure sample's response to CO_2

Pore Pressure Fluid Mixing Vessel



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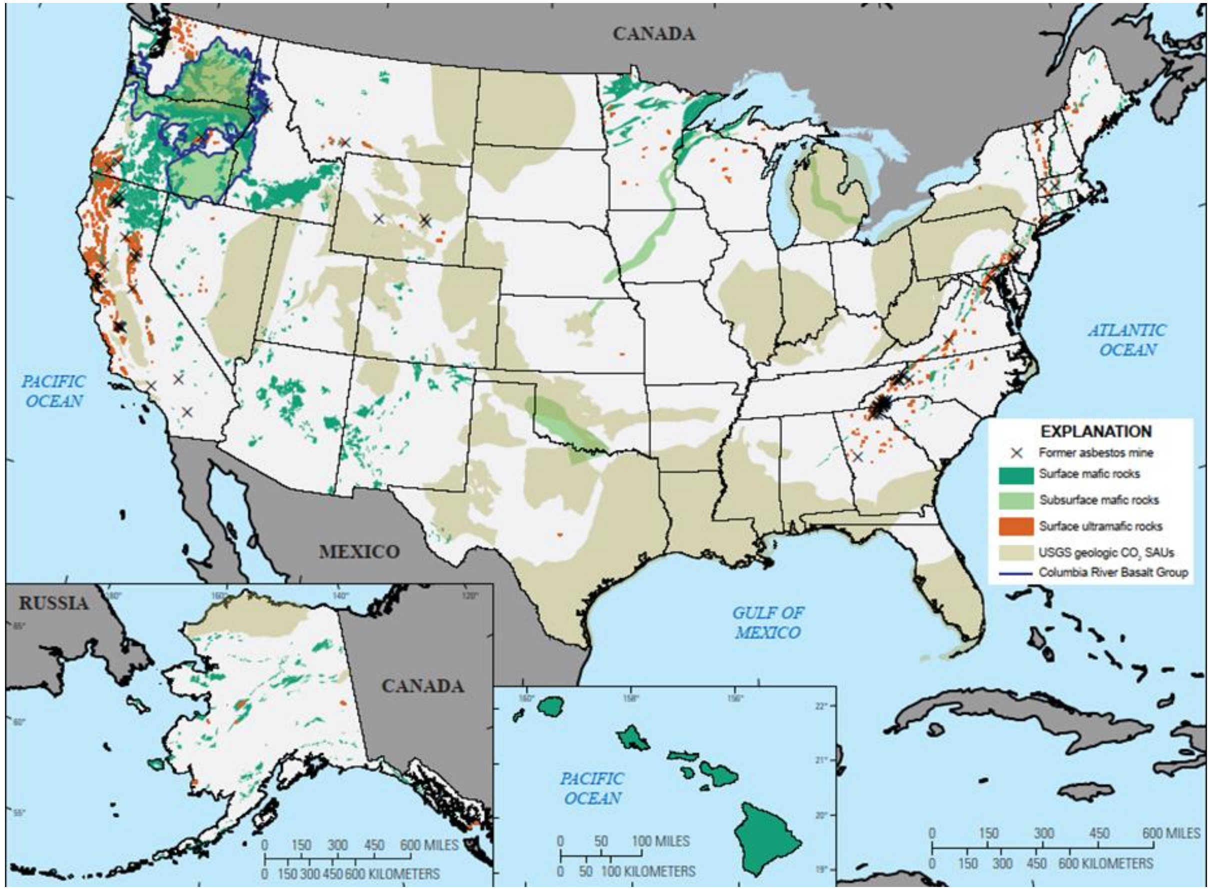
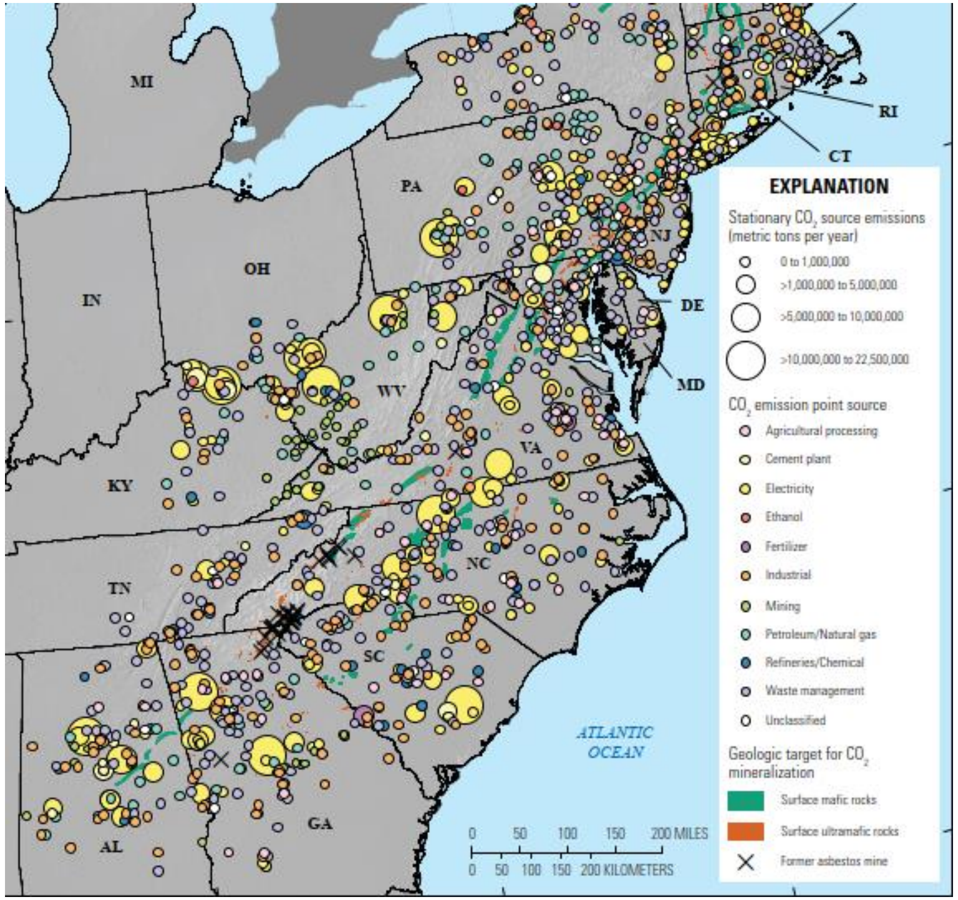
Task 5: Source-to-sink assessment

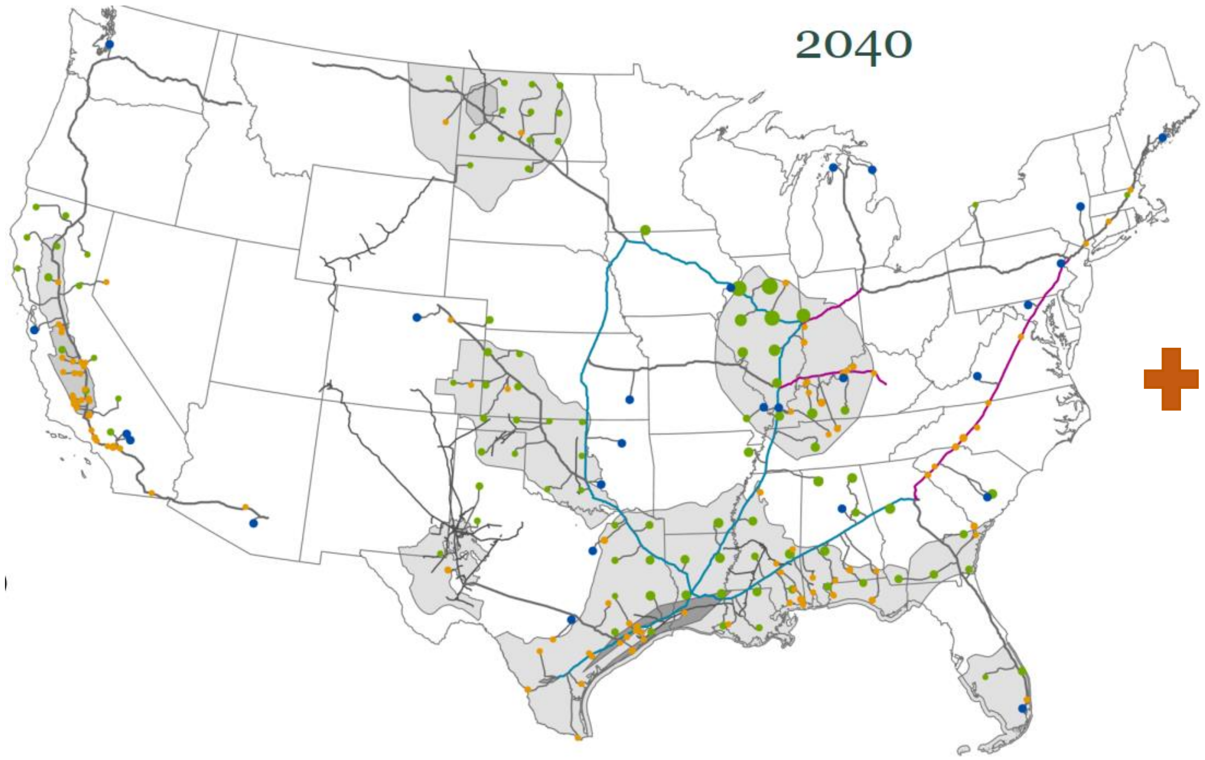


1) Updated 3D model of subsurface rock volumes
- Carbonation potential based on mineralogy etc.



2) Nearby CO_2 (~100miles) sources
- EPA's Flight GHG tool

- Rank potential sites for in-situ carbon mineralization



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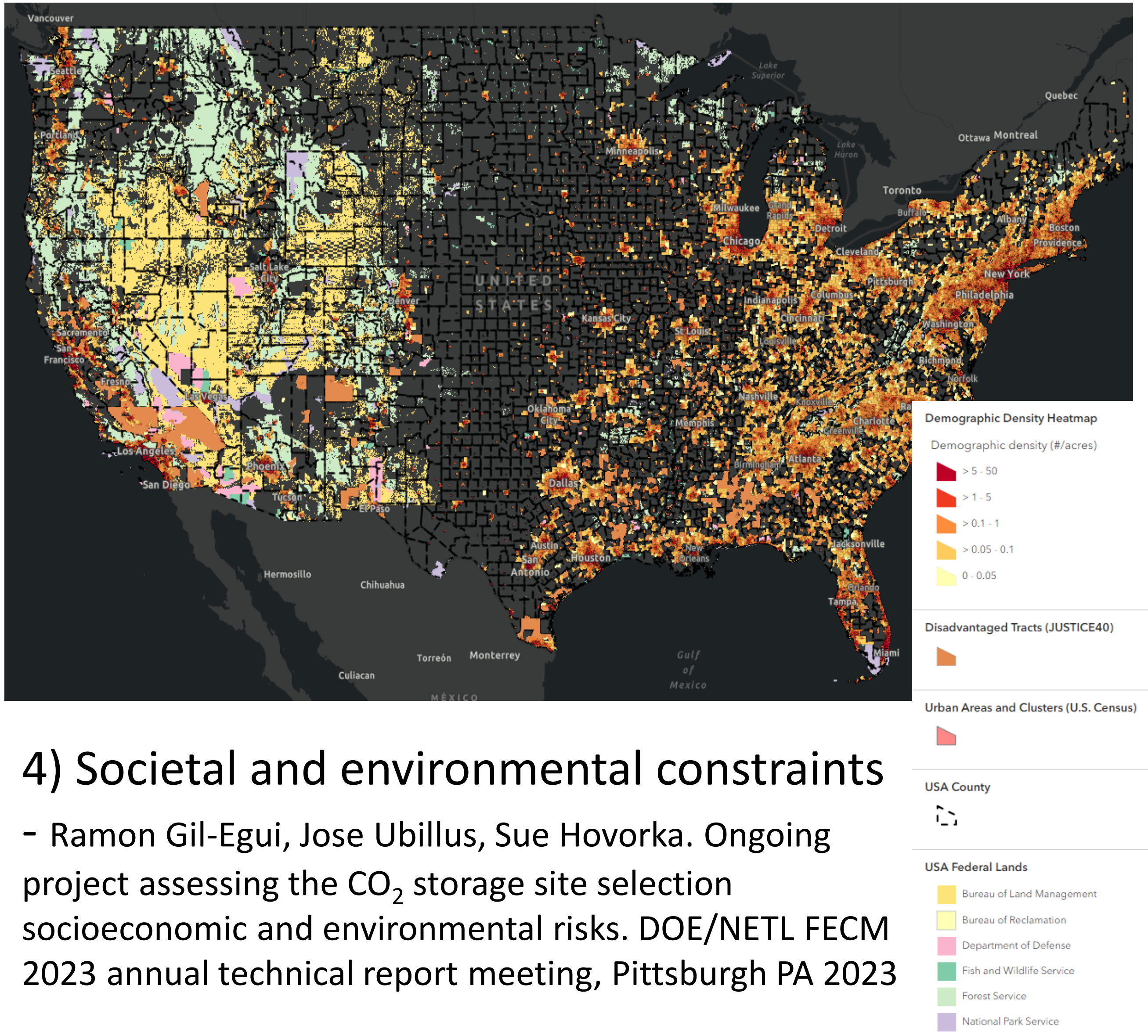

3) CO_2 transport (pipeline) network

- Princeton Study Proposed Trunk CO_2 Pipeline Network (Larson et al., Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Final report, Princeton University, Princeton, NJ, 29 October 2021)

4) Societal and environmental constraints

- Ramon Gil-Egui, Jose Ubillus, Sue Hovorka. Ongoing project assessing the CO_2 storage site selection socioeconomic and environmental risks. DOE/NETL FECM 2023 annual technical report meeting, Pittsburgh PA 2023

Task 6: Public data sharing

- Results from tasks 2-5 will be integrated into public databases:
  - DOE NETL Energy Data Exchange (EDX)
  - USGS Minerals Database (USMIN)
  - Geological Survey's Earth Mapping Resources Initiative (Earth MRI) by site- site-specific characterization of resources.
  - Database systems managed by the State Geologic Surveys

- Construct a web portal for easy access to the data generated in this study

Next steps

- Task 2: Continue subsurface mapping, core sampling, and volumetric estimates
- Task 3: Continue rock characterization of old and new samples
  - Add geochemical analyses
- Task 4: Kinetics and carbonation reaction rate experiments
  - Batch experiments of new samples at same conditions
  - Select a few for flow-through experiments
  - Analyze fluids, solids, carbonation capacity
- Task 5: Source-to-sink assessment
  - Rank sites
- Task 6: Data sharing and accessibility

Lessons learnt to date

- We have a very poor understanding/sampling of US mafic/ultramafic basement rocks   - drill more cores!
    - Samples difficult to obtain, small in size
    - Cross-project sample sharing

- Drill well/core documentation is poor in most geo state surveys
    - More resources

- Large ultramafic bodies exist within upper 2 km

- Rapid carbonation reactions even at T <100ºC