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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TEXAS Geosciences
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

The University of Texas at Austin
Cockrell School of Engineering

Bureau of Economic Geology

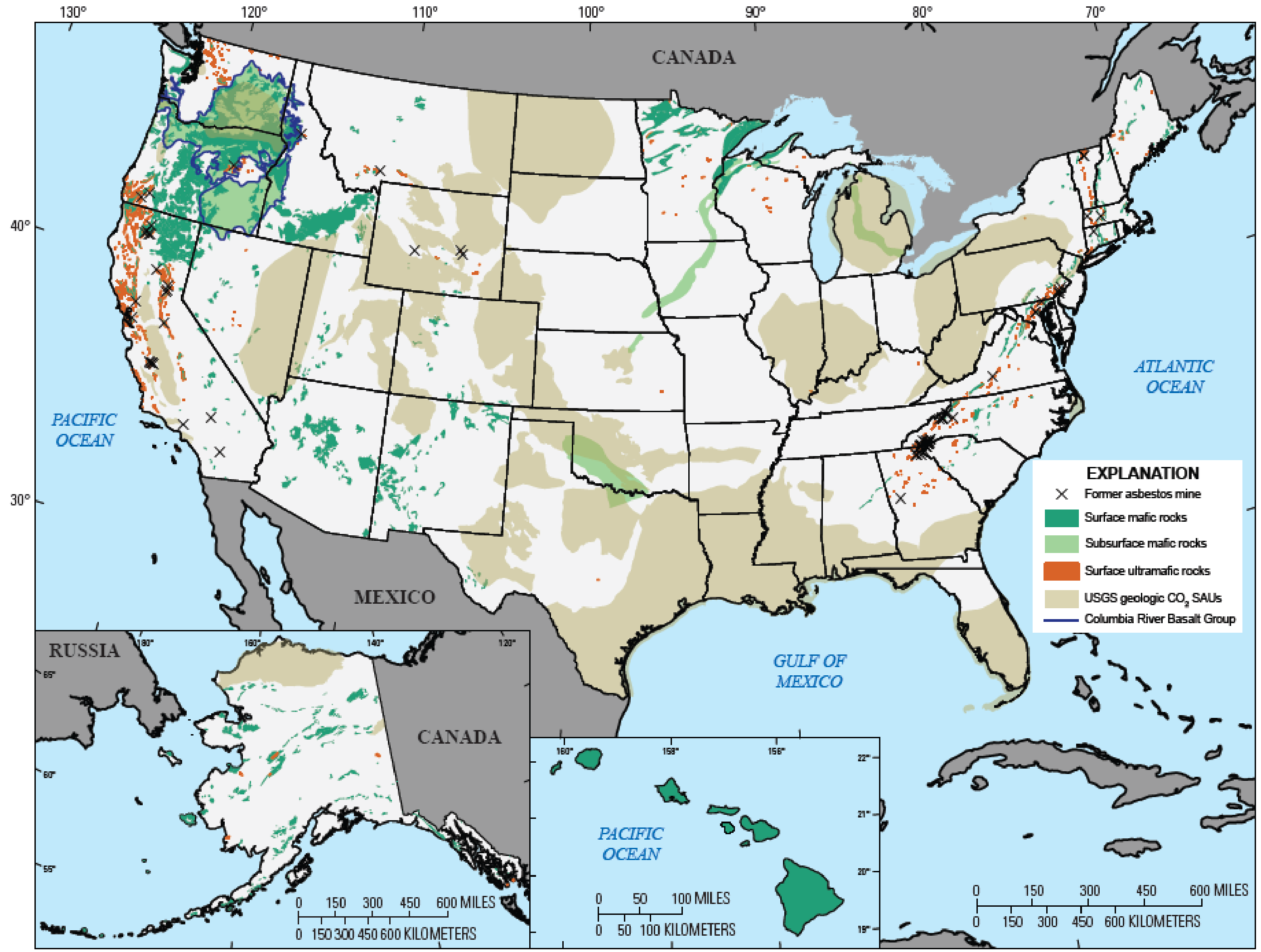
Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

Columbia University
In the City of New York

Key Participants

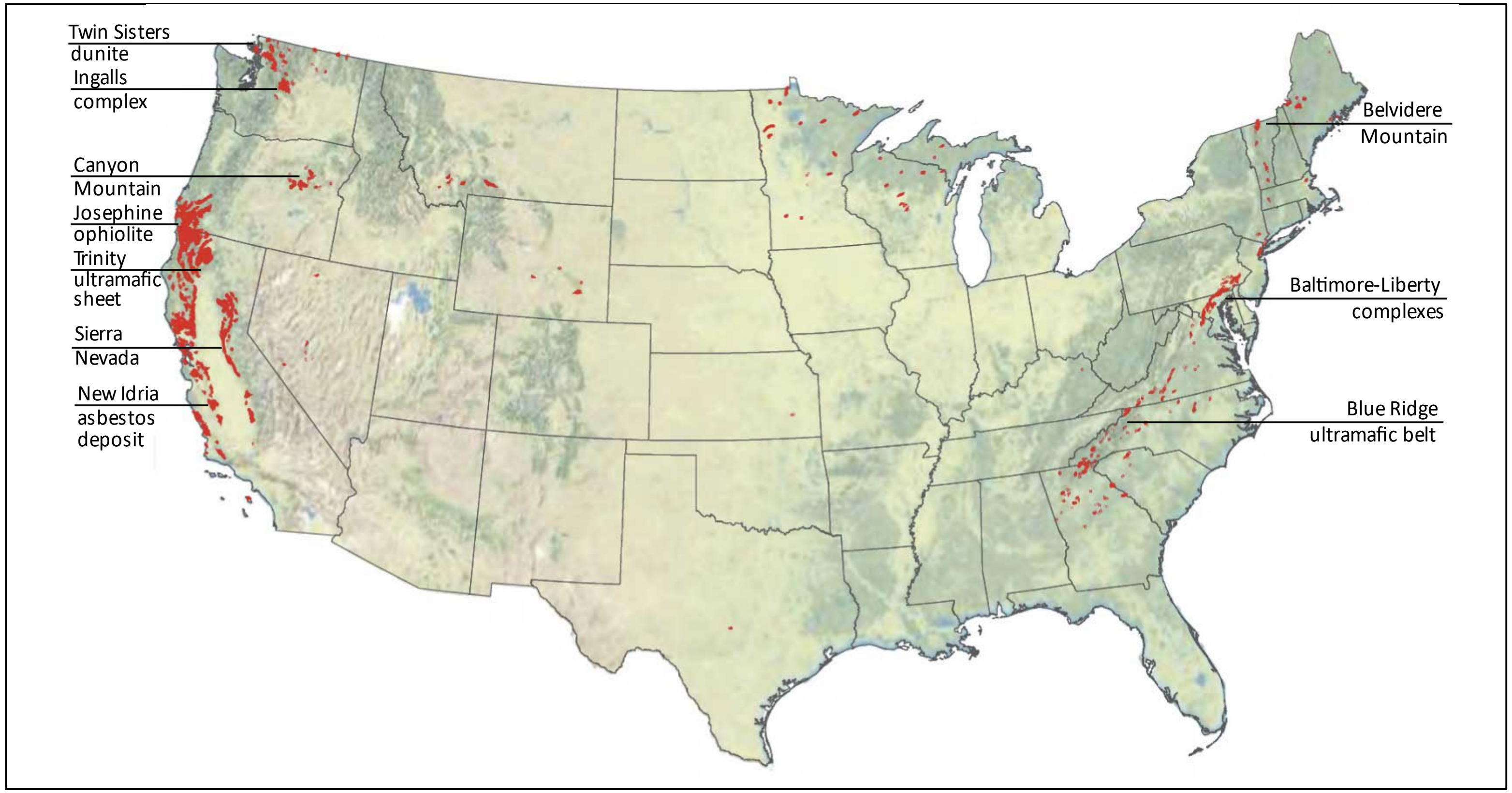
- The University of Texas at Austin
  - Esti Ukar (PI)
  - Shuvajit Bhattacharya (Co-PI) (Geophysics, Petrophysics)
  - Nicolas Espinoza (Co-PI) (Geomechanics, Carbonation experiments)
  - Lily Horne (3D model and database)
  - Katie Smye (Database, Petrophysics)
  - Andras Fall (Carbonation experiments)
  - Ramon Gil-Egui (Economics, source-to-sink assessment)
  - Brent Elliott (Economic geology)
  - Lorena Moscardelli* (Texas)
  - Mert Ugurhan (GIS)
  - Sue Hovorka* (CCUS)
  - Postdoctoral Fellow (3D model and experiments; currently conducting interviews)
- 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

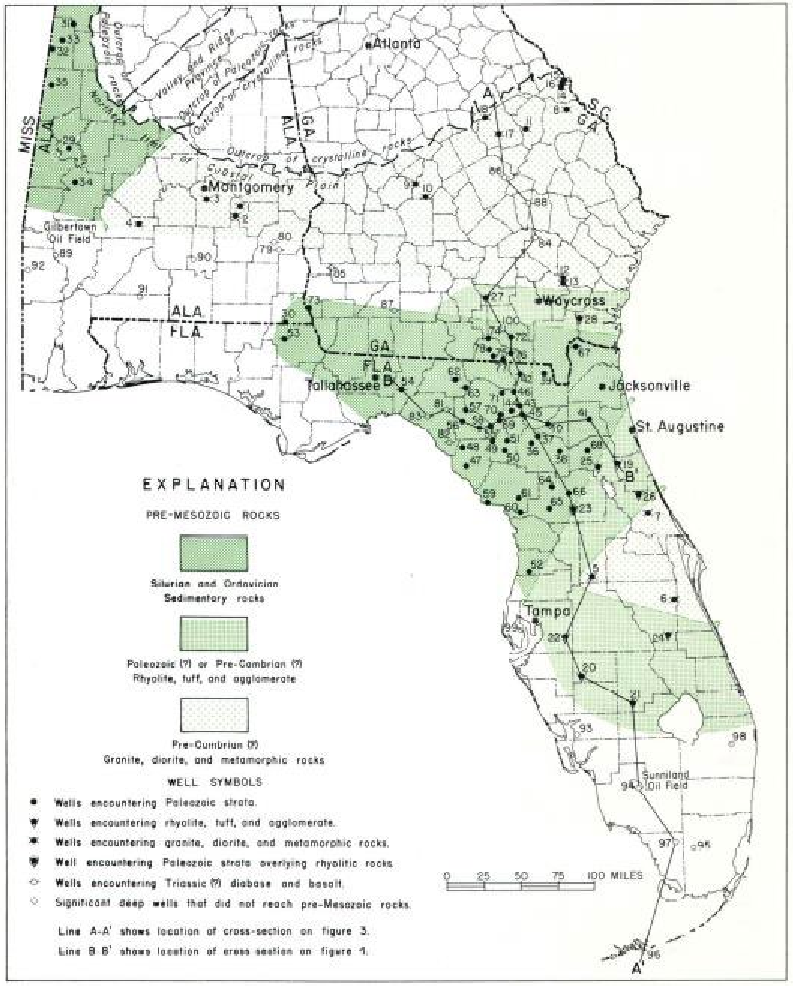


Blondes, M.S., Merrill, M.D., Anderson, S.T., and DeVera, C.A., 2019, Carbon dioxide mineralization feasibility in the United States: U.S. Geological Survey Scientific Investigations Report 2018–5079, 29 p., https://doi.org/10.3133/sir20185079

Knowledge gap: subsurface ultramafics



Krevor et al. (2009)



Map Includes peridotite, dunite, picrite and their altered form, serpentinite

Aplin (1951)

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 where large amounts of CO_2 can be permanently stored (Y2Q4)

Benefits

- Support large-scale CO_2 storage via mineralization leading to widespread deployment

- Identification of mineralization-based storage opportunities across the U.S. for long-term, safe, economical, and scalable storage
- Assessment of the quantity, quality, availability, accessibility, volume, and CO_2 storage potential and costs associated with different sites
- Quantitative assessment of the distribution and quantity of CO_2-reactive minerals
- Measurement of relevant reaction kinetics and reaction rates at field conditions
- Assessment of likely mineralization processes and selection of locations for future, detailed site evaluations

Tasks

- Task 1: Project Management and Planning
  - 1.1 Project Management Plan
  - 1.2 Diversity, Equity, and Inclusion Plan
- Task 2: Subsurface 3D mapping of mafic and ultramafic bodies
  - 2.1 Literature/database review and curation
  - 2.2 Gravity and magnetic anomaly survey analysis
  - 2.3 Non-public data sources
  - 2.4 Basement well penetration –petrophysical and core data compilation
  - 2.5 Data synthesis and subsurface map and 3D map/model construction
- Task 3: Subsurface rock characterization
  - 3.1 Core sampling and description
  - 3.2 Field sampling and description
  - 3.3 Petrologic characterization and petrophysical measurements
  - 3.4 Integrated petrophysical analysis
- Task 4: Kinetics and carbonation reaction rate experiments
  - 4.1 Autoclave experiments
  - 4.2 Flow-through experiments
  - 4.3 Pressure vessel and synthetic CO_2-rich fluid inclusions
- Task 5: CO_2 source-to-sink site assessment
  - 5.1 Sites of highest potential as CO_2 sinks
  - 5.2 Community impact and land use
- Task 6: Public database population and web portal construction

		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 CO2-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 CO2 source-to-sink assessment									
Task 5.0. -CO2 source-to-sink site assessment	Ramon Gil-Egui, Horne, Smye, Elliott, Battacharya, Ukar, Postdoc								
Subtask 5.1. -Sites with highest potential as CO2 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 CO2 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									

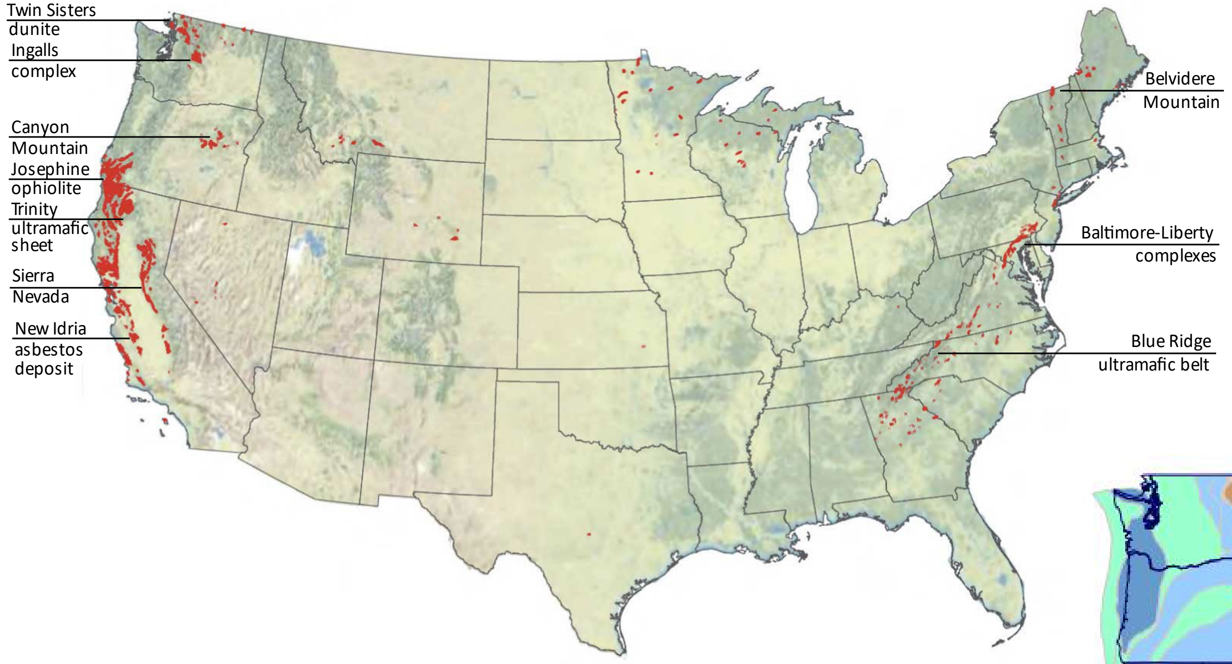
Task	Milestone Title and Description	Planned completion date	Verification Method
1	M1: Project Kickoff Meeting	Y1 Q1	Meeting attendance; Presentation file
2	M2: Summarize subsurface map and core database construction	Y1 Q4	Submit written report to DOE summarizing subsurface map and core database
2	Decision point #1: Do we have enough data and samples to proceed?	Y1 Q4	
3	M3: Summarize core and field sample dataset	Y1 Q4	Submit written report to DOE summarizing subsurface sample dataset
3	M4: Summarize subsurface rock characterization dataset	Y2 Q3	Submit written report to DOE summarizing subsurface rock characterization dataset
4	M5: Assess success and scalability of autoclave and flow-through experiments	Y2 Q3	Submit written report to DOE assessing the success and scalability of autoclave and flow-through experiments
4	M6: Assess success and scalability of pressure vessel experiments	Y2 Q3	Submit written report to DOE assessing the success and scalability of pressure vessel experiments
4	M7: Identify challenges that can affect upscaling	Y2 Q3	Quick look report identifiying challenges for upscaling
4	Decision point #2: Can experimental results be used for a realistic CO2 source-to-sink assessment	Y2 Q3	
5	M8: Deliver final assessment of potential CO2 sink sites and reccomendations for further assessment	Y2 Q4	Submit written report to DOE assessing potential CO2 sinks; submit recommentdation of sites for further assessment
6	M9: Launch publicly accessible web portal	Y2 Q4	Inauguration of fully operative, interactive web portal
All	M10: Final meeting and report	Y2 Q4	Submit to DOE letter report of final meeting of team members

Task 1: Project Management and Planning

- Management
  - PI/Co-PI, Senior advisors
    - Esti Ukar (PI)
    - Shuvajit Bhattacharya: Geophysics/petrophysics
    - Nicolas Espinoza: Carbonation experiments
    - Peter Kelemen: Columbia (sampling, characterization, experiments)
  - Advisors: Peter Kelemen, Sue Hovorka, Lorena Moscardelli
- Meetings
  - Monthly
  - Weekly/daily as needed depending on task
- Reporting

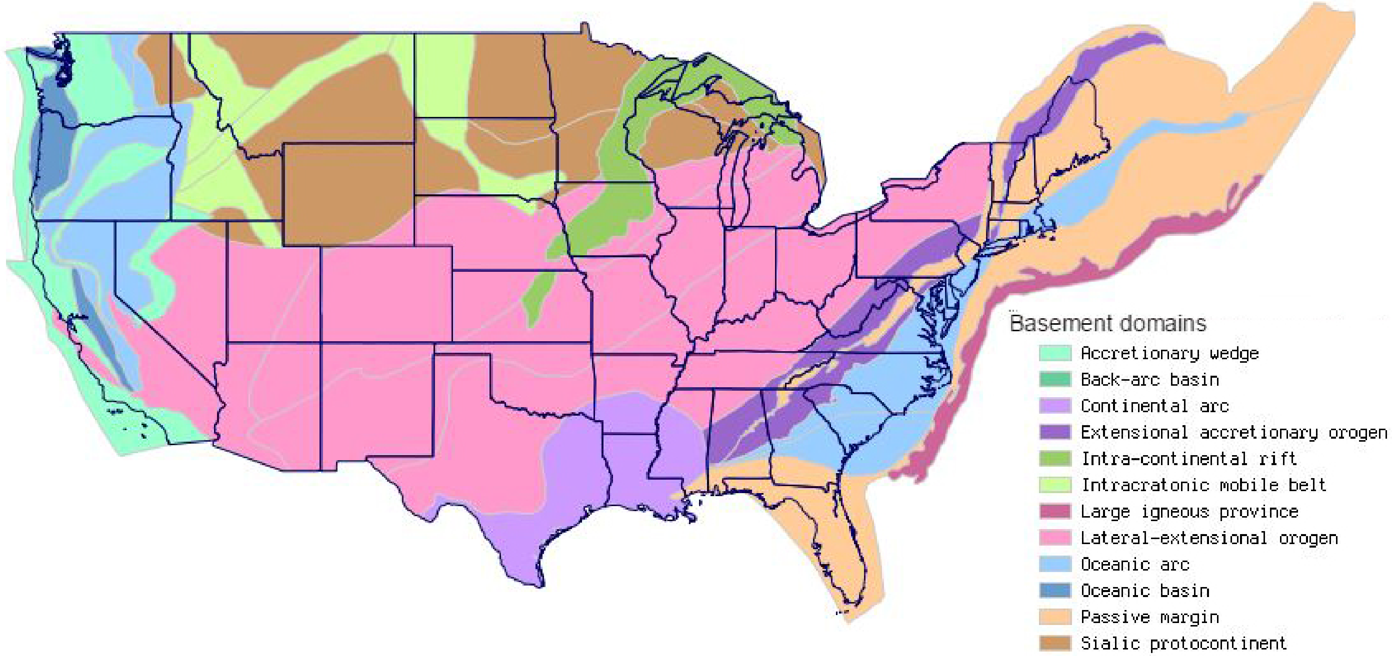
- DEI: Diverse group

Task 2: Subsurface mapping



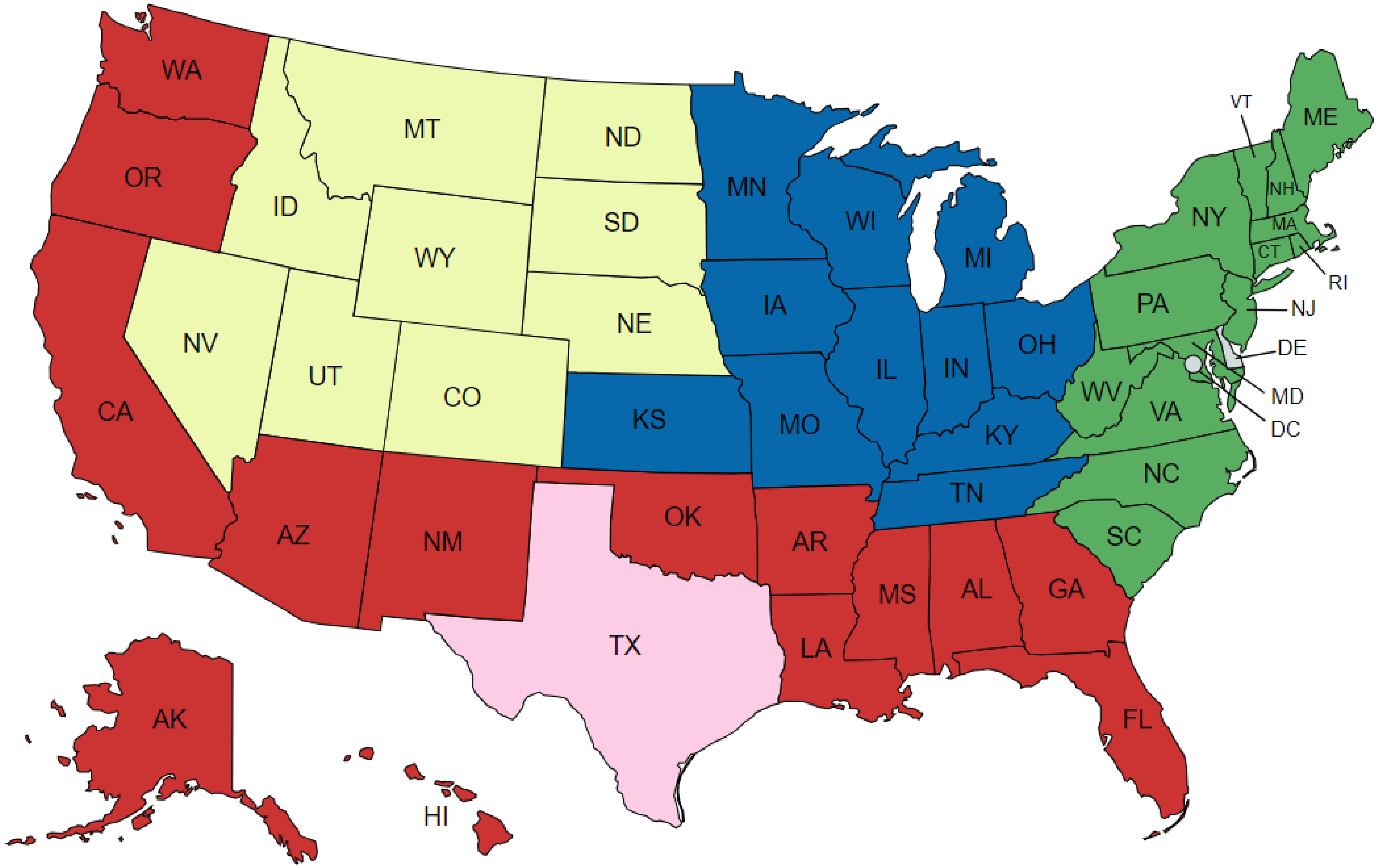
Krevor et al. (2009)

After Lund et al. (2015); USGS



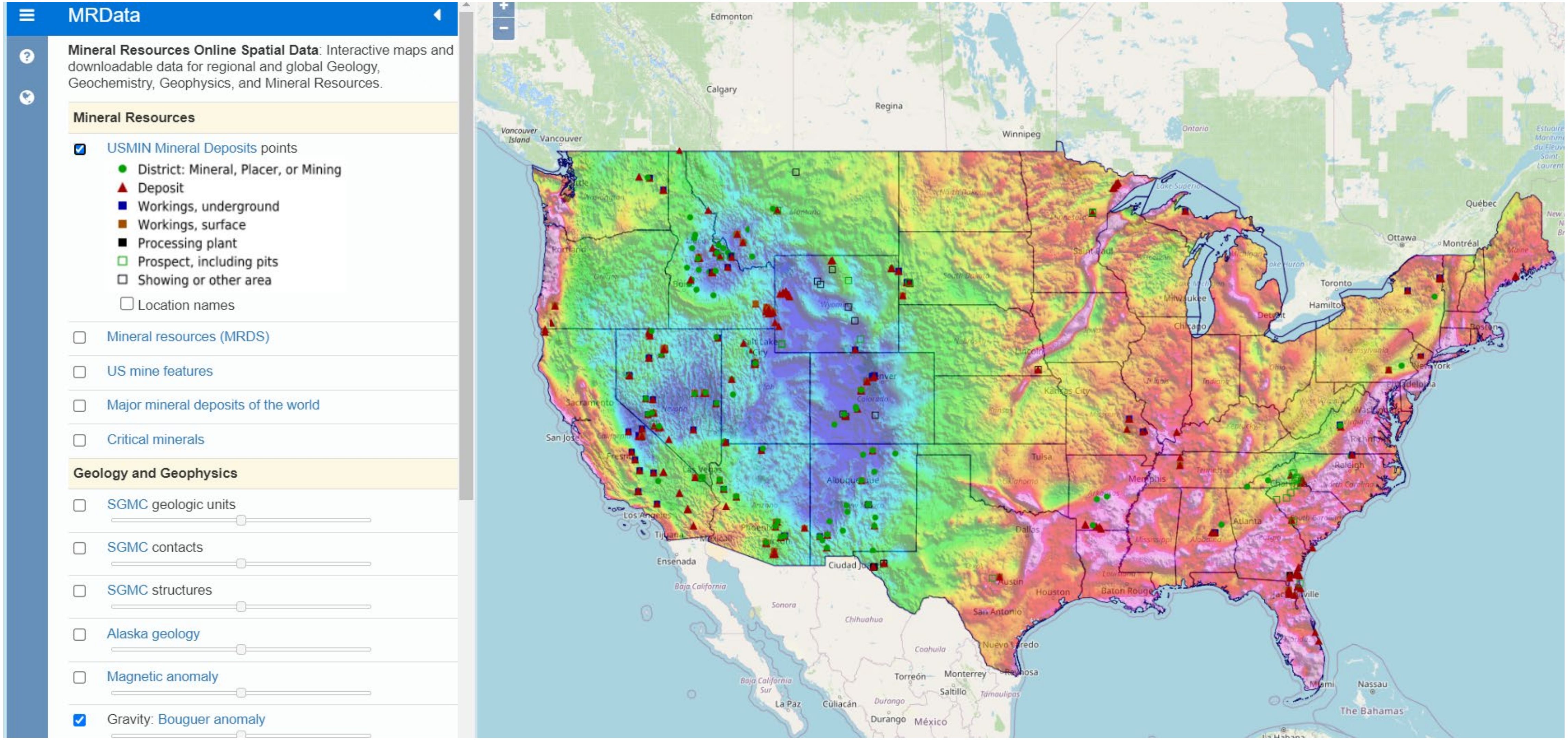
- Eastern states
- Western states
- Mid Continental Rift

- 2.1 Database/literature review

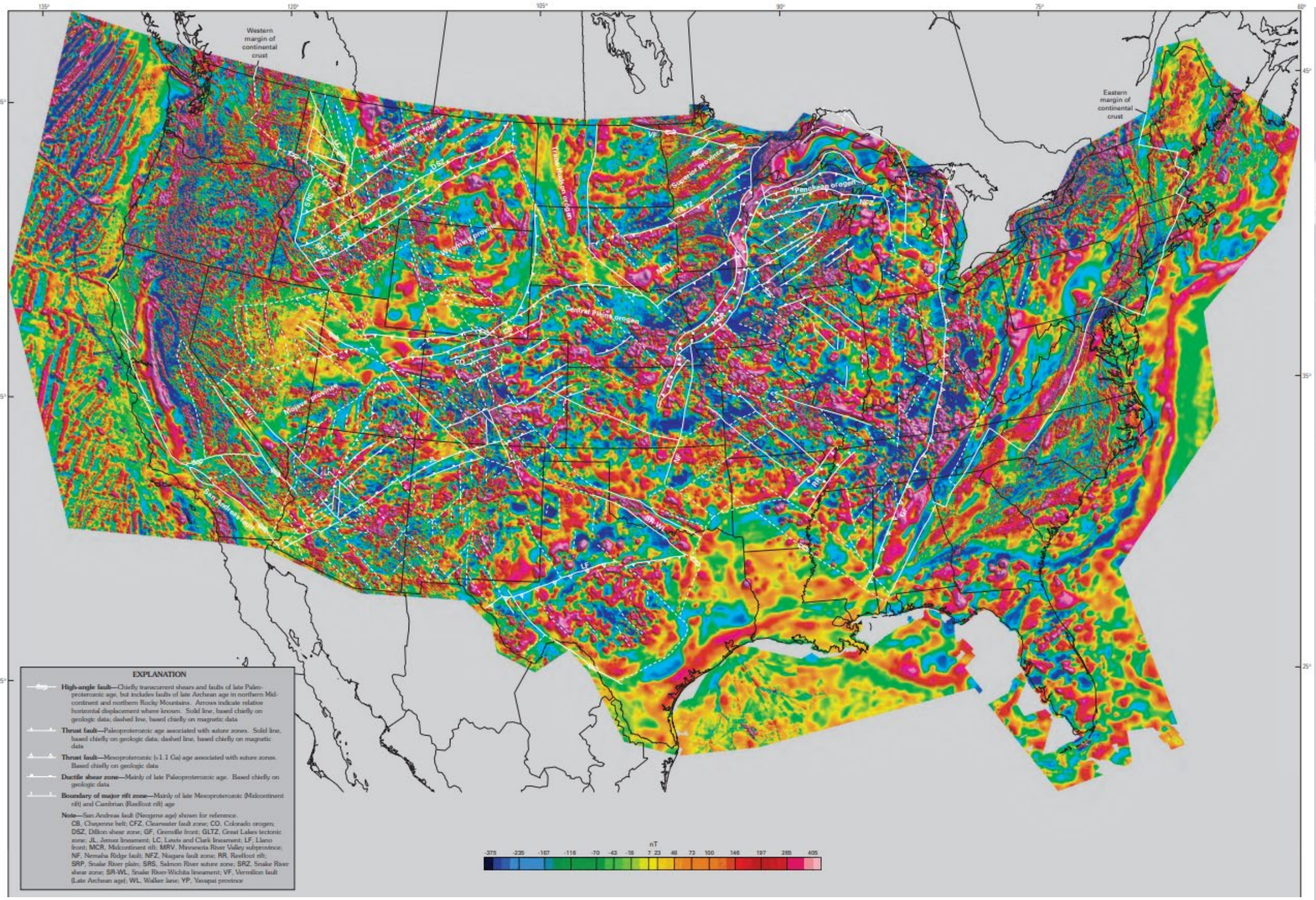


- 4 Regional subdivisions
- State Geological Surveys
- Started from the southern states

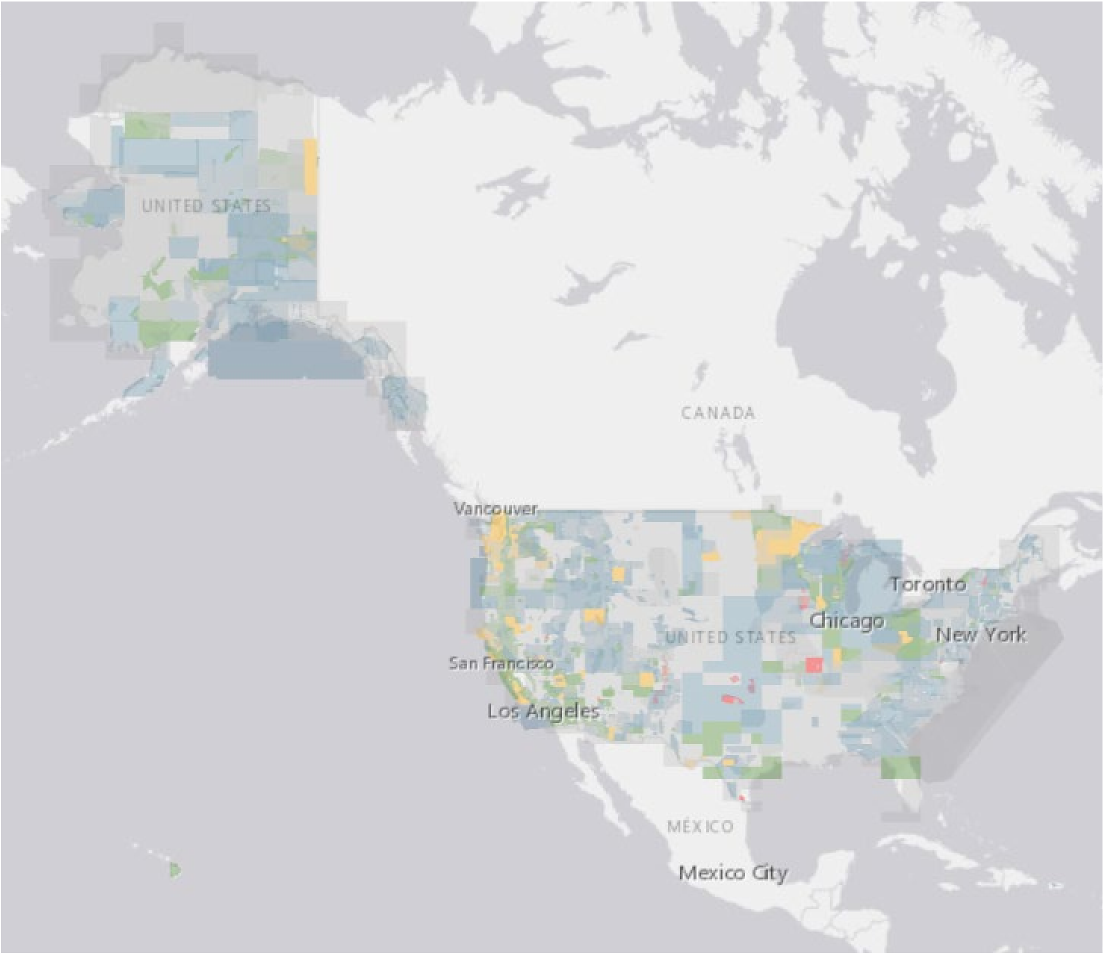
• 2.2 Gravity and magnetic surveys (public data sources)



• 2.2 Gravity and magnetic surveys (public data sources)

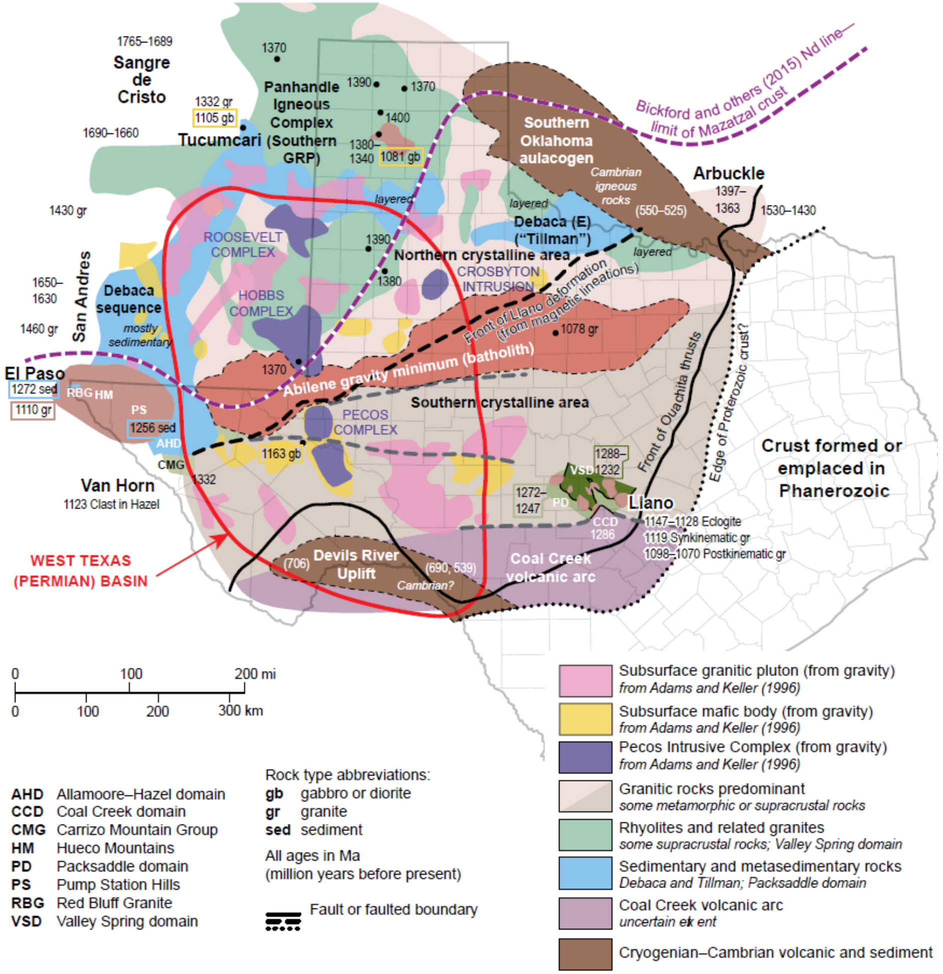


Magnetic anomaly map of USA (Sims et al. 2008, USGS)



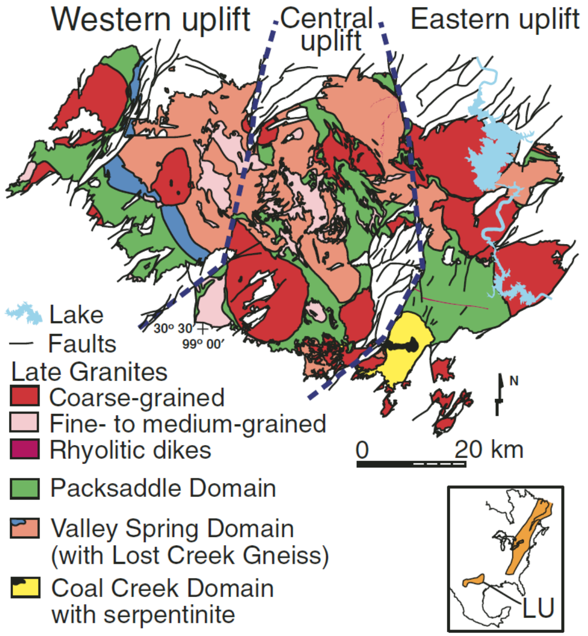
Airborne Geophysical Survey Inventory (USGS)

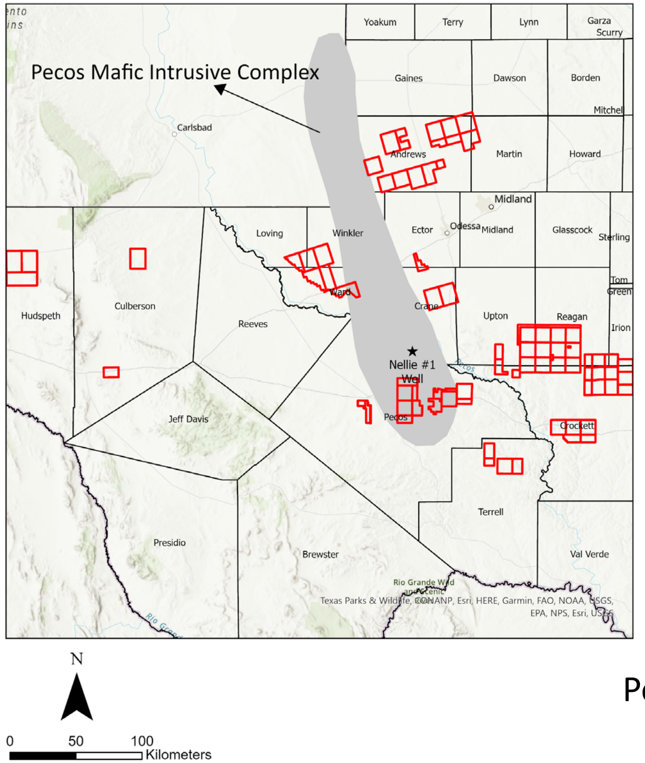
- 2.3 Non-public data sources
  - Texas

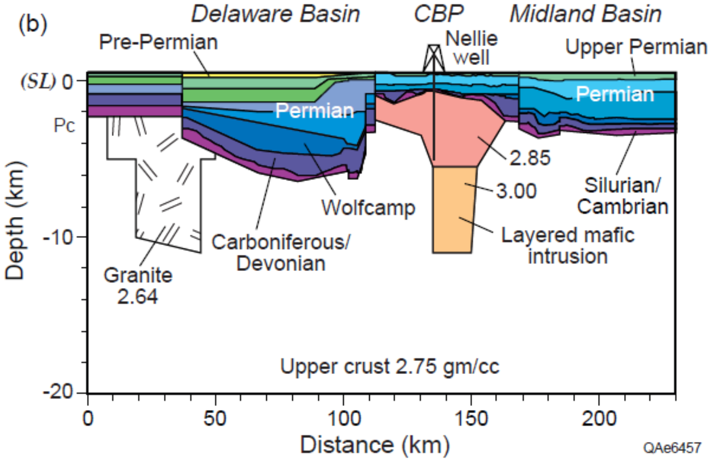


Keller (2019)

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



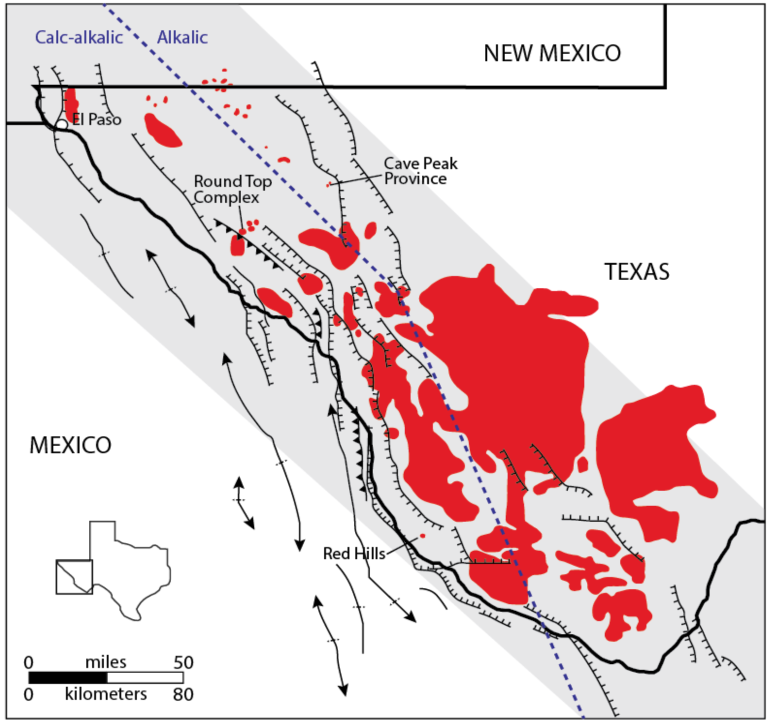




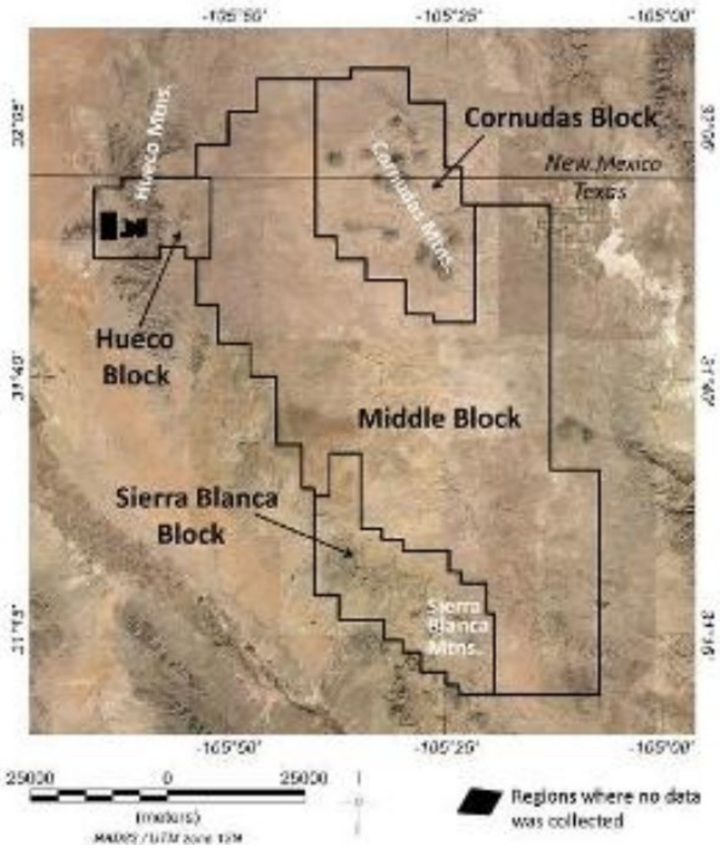
Pecos Mafic Intrusive Complex (Barnes et al., 1999)
Location of Nellie # 1 Well

2.3 Non-public data sources

- Texas

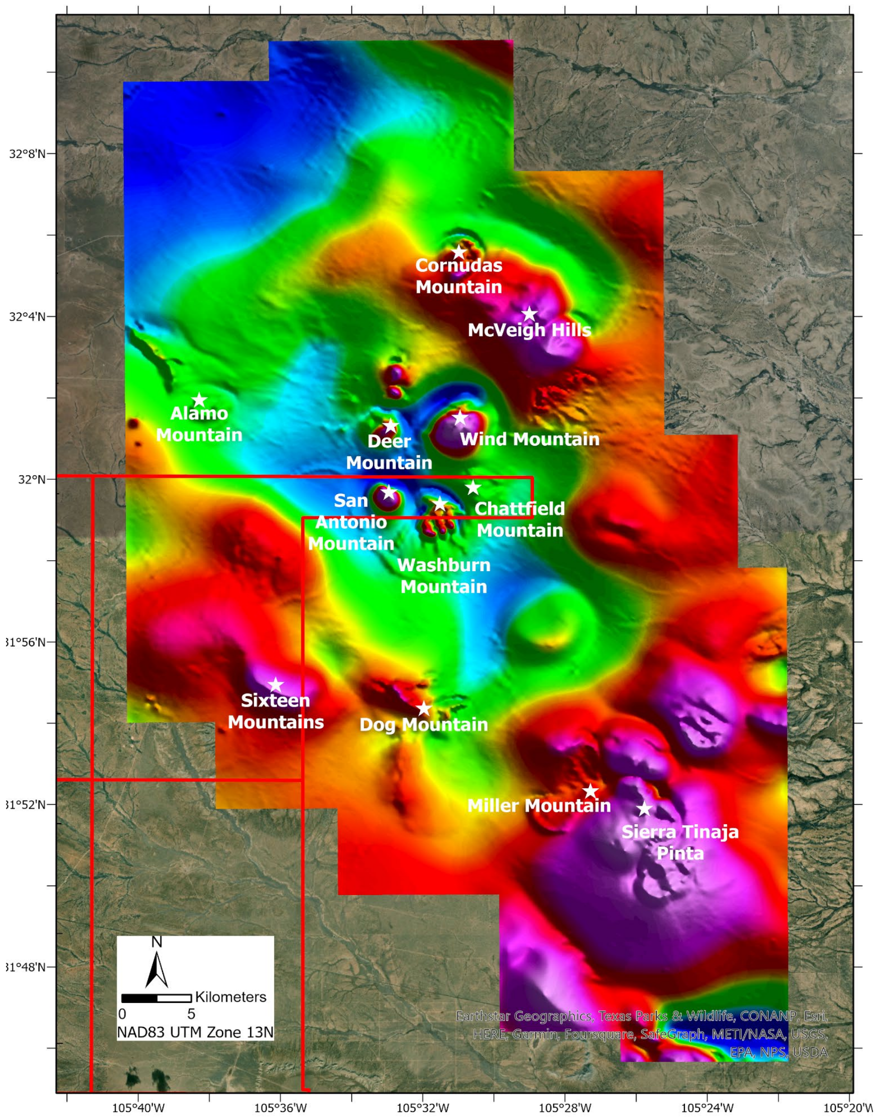


Trans-Pecos Magmatic Province, Cenozoic igneous rocks. Piccione et al. (2019)



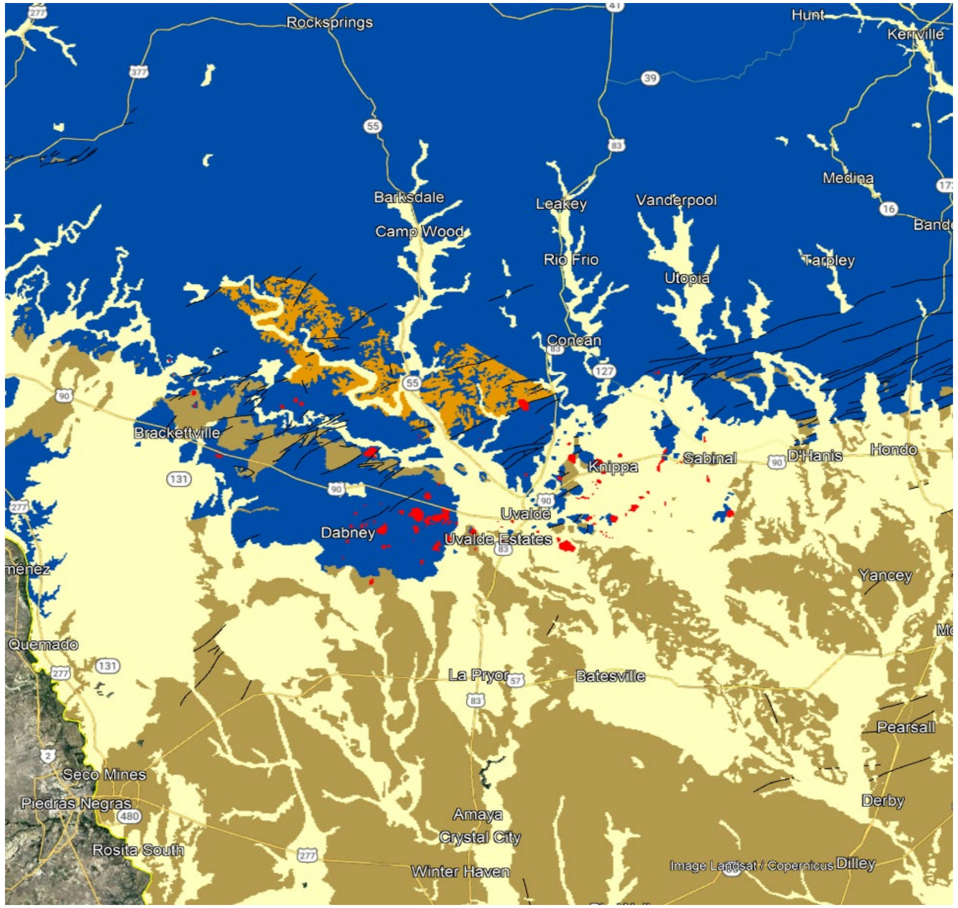
Trans-Pecos aeromagnetic/aeroradiometric survey (USGS). Bultmann (2021)

USGS Aeromagnetic Survey Map, Cornudas Block

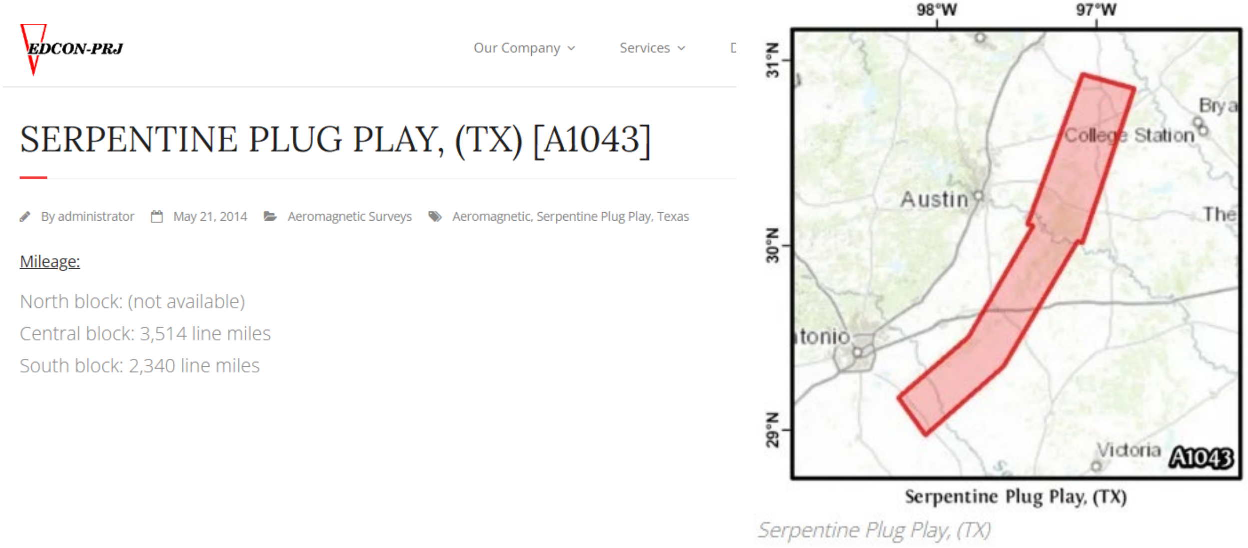


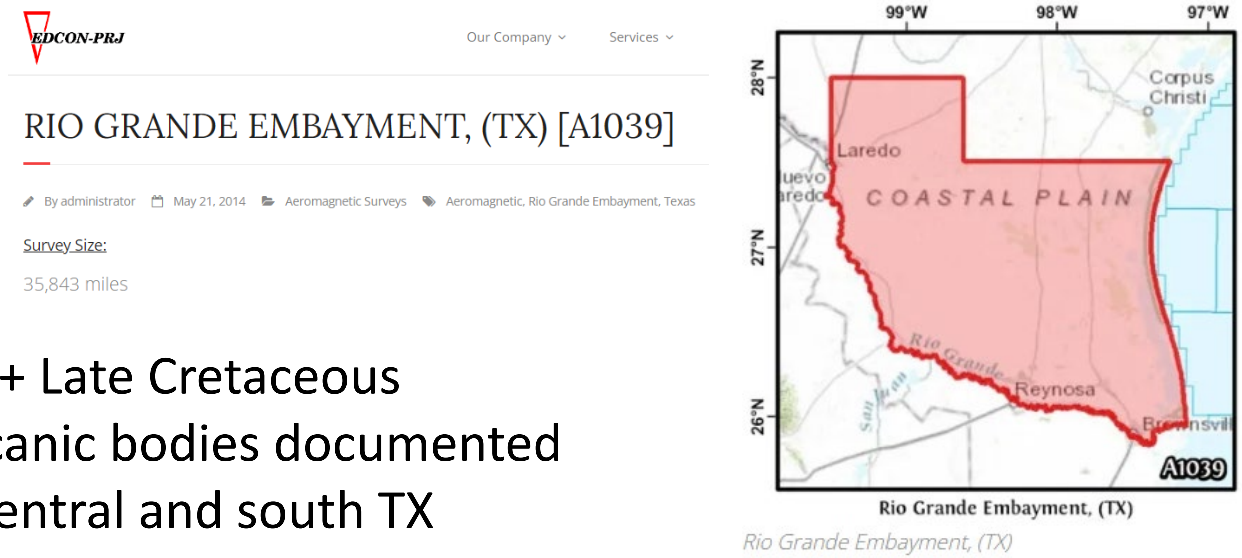
Concealed intrusions with magnetic properties

- 2.3 Non-public data sources
    - Texas



50 km





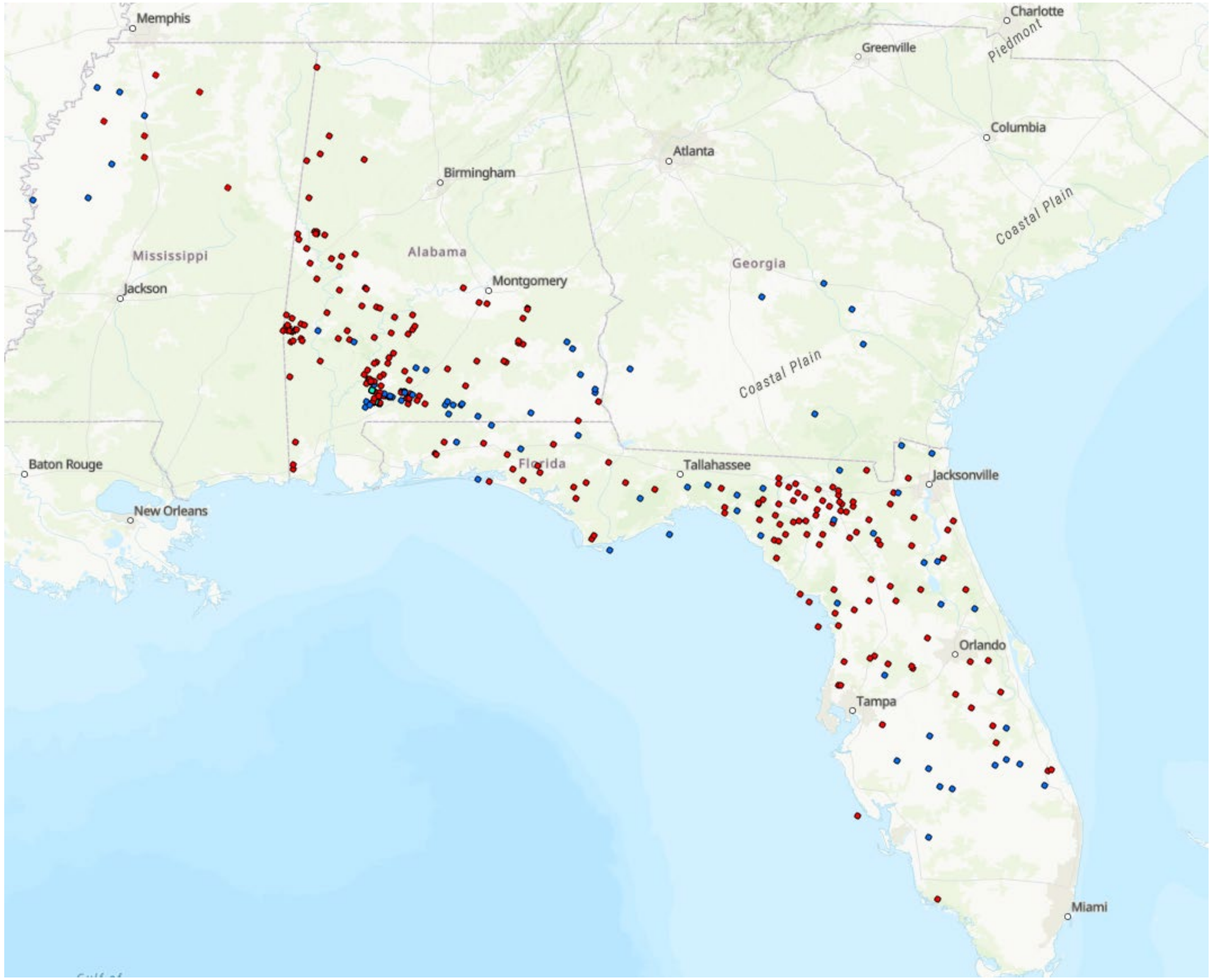
200+ Late Cretaceous volcanic bodies documented in central and south TX

- 2.4 Well penetrations

  - Petrophysical logs
  - Cores

- Summary of location and metadata of wells that have penetrated mafic/ultramafic basement throughout the US

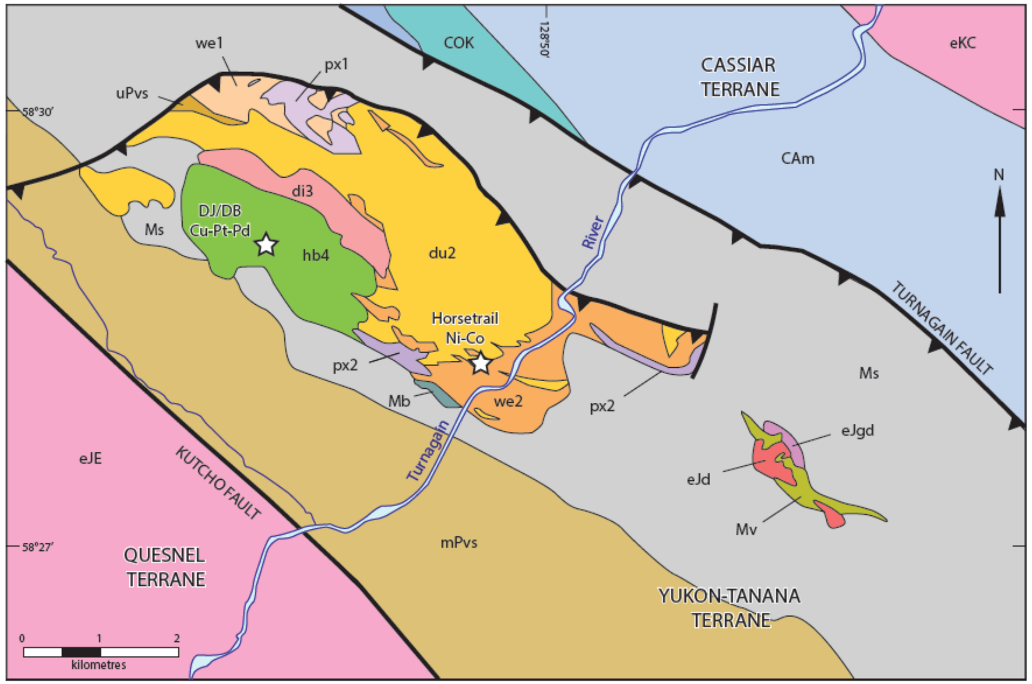
- ArcGIS map



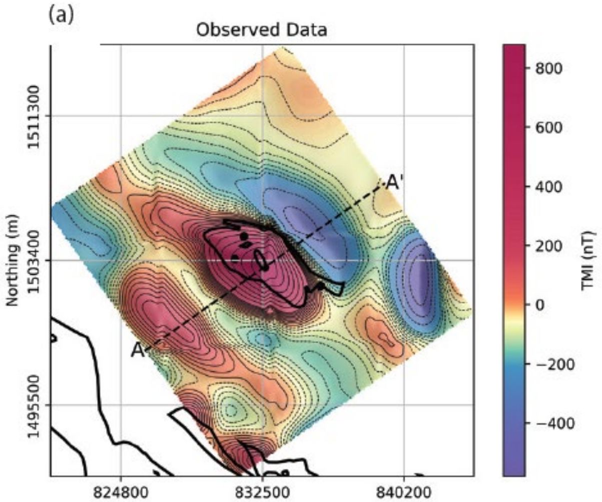
• 2.5 Subsurface 3D model and volume calculation

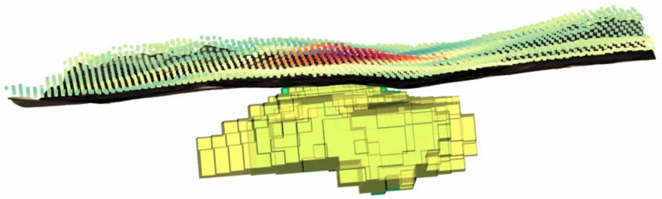
- Inversion of residual total field (RTF) magnetic data using a Magnetic Vector Inversion (MVI) code (SimPEG Python open-source package; Cockett et al., 2015).

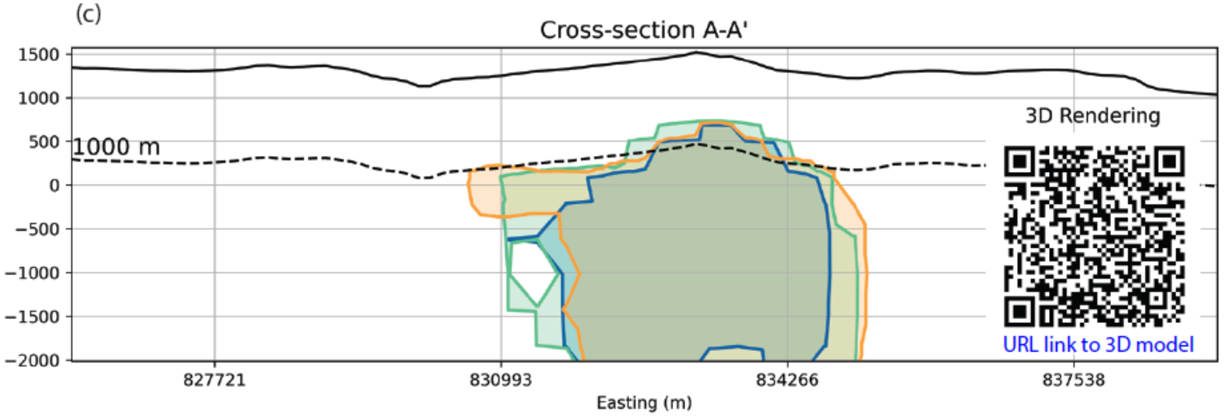
Turnagain Alaskan-type ultramafic intrusion (BC)



Ol-rich dunite and wehrlite core, Ol-poor clinopyroxenite and hornblendite margins







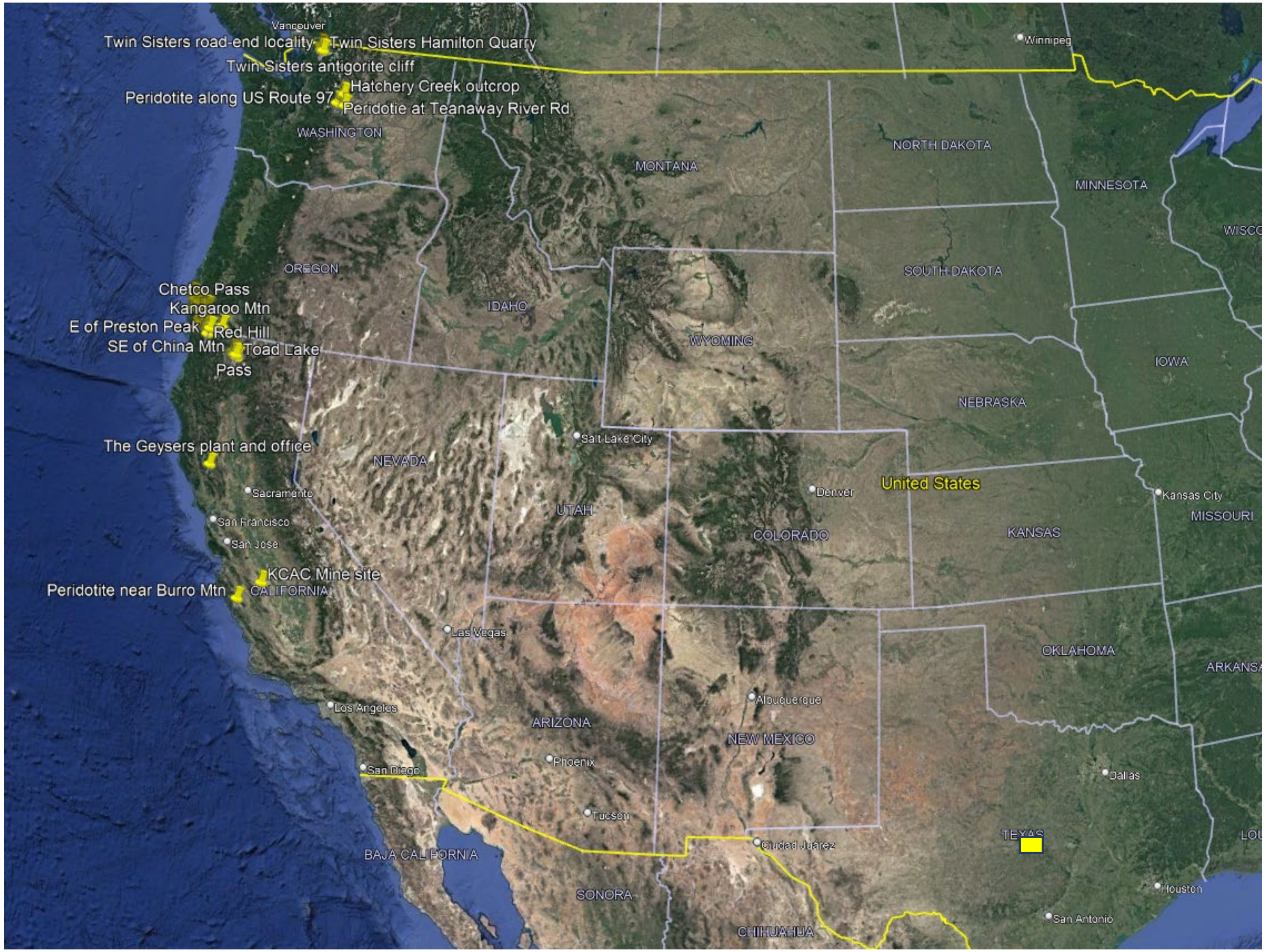
Mitchinson et al. (2020)

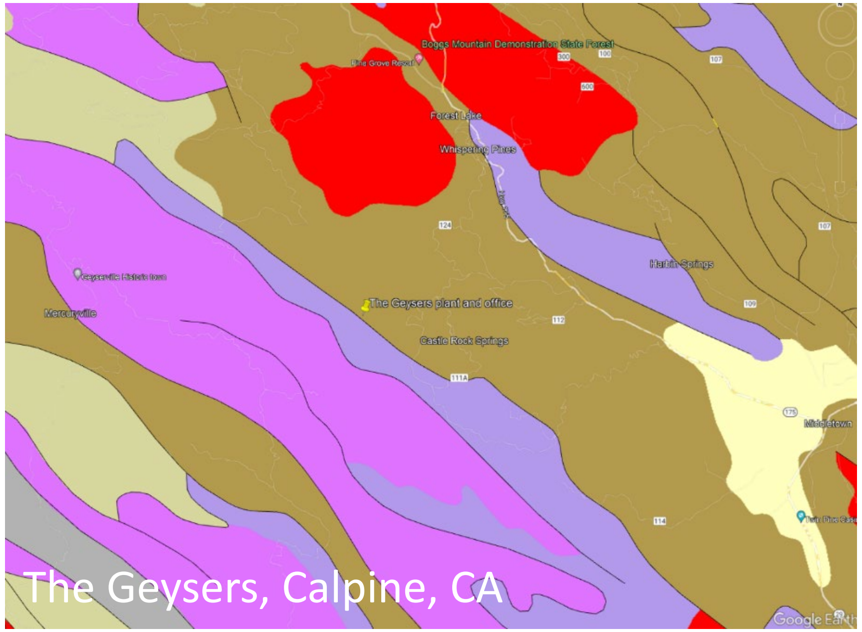
Task 3: Rock sampling and characterization

- 3.1. Subsurface samples. Challenge: difficult to obtain
  - State Geological Survey contacts to provide thin sections, chips, and (hopefully) core
  - Mining companies:
    - Minnesota: Tamarack Mine (Talon Metals/Rio Tinto)
    - Stillwater (Montana)
  - Collaborations/sharing with other DOE-funded groups
- 3.2 Field sampling

- 3.3 Rock characterization
- 3.4 Integrated petrophysics

- 2.3 Field sampling



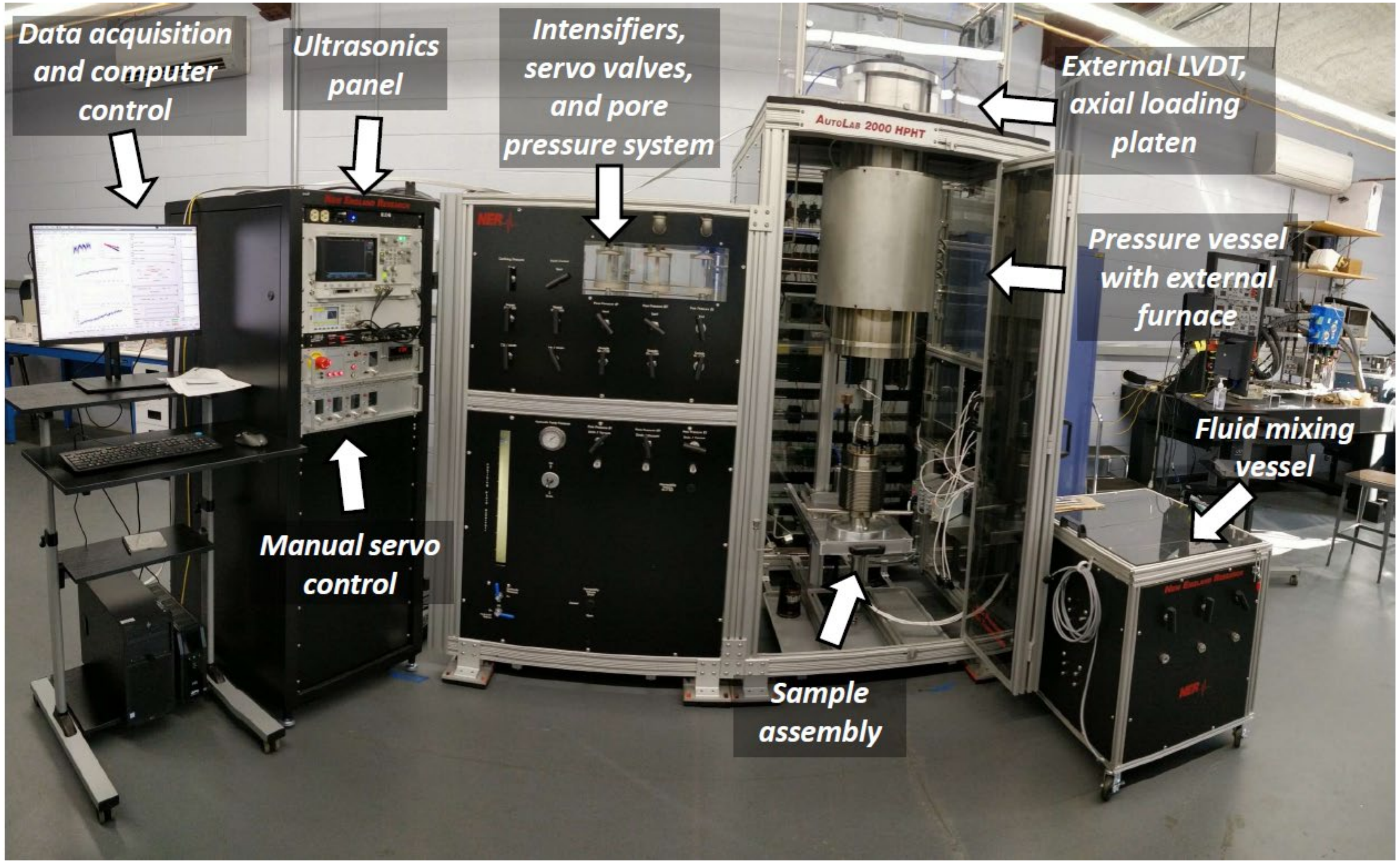


Task 4: Carbon mineralization experiments

- 4.1. Autoclaves
- 4.2. Flow-through experiments
- 4.3. Pressure vessels and synthetic fluid inclusions

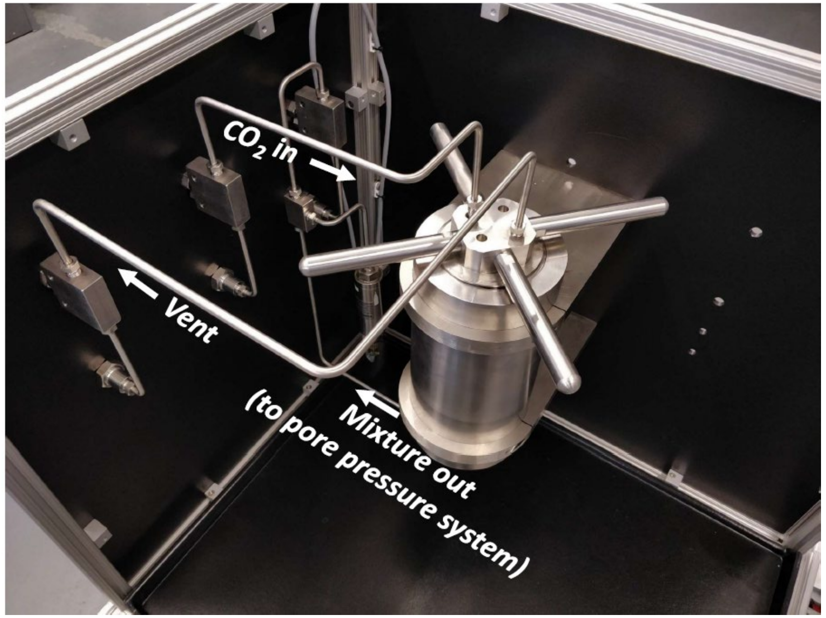
- Array of UT Austin and Lamont labs

• Triaxial deformation apparatus (Lamont; McCarthy, Tielke lab)

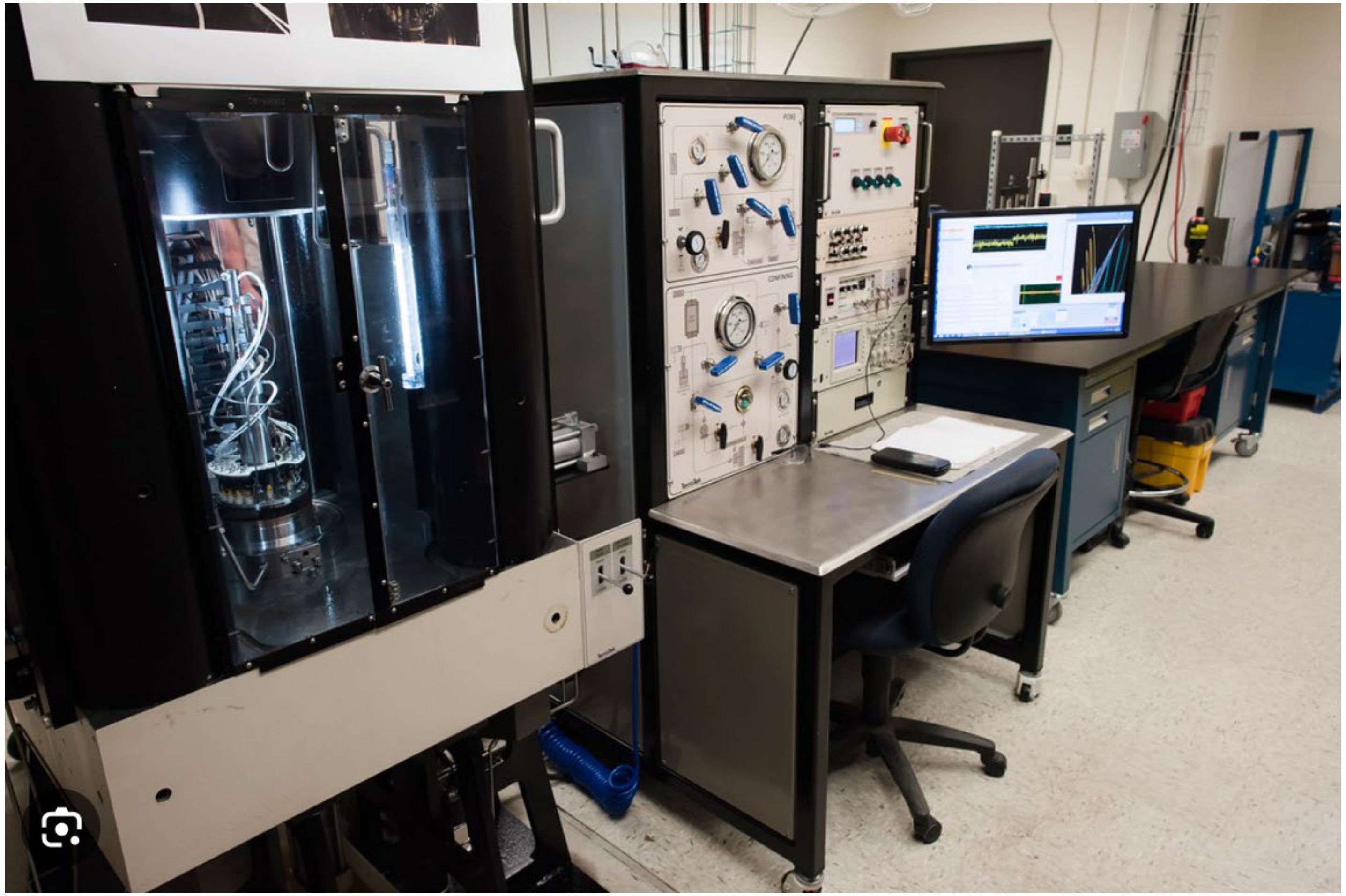


- Simulate P, T conditions at depth
- Measure sample's response to CO_2

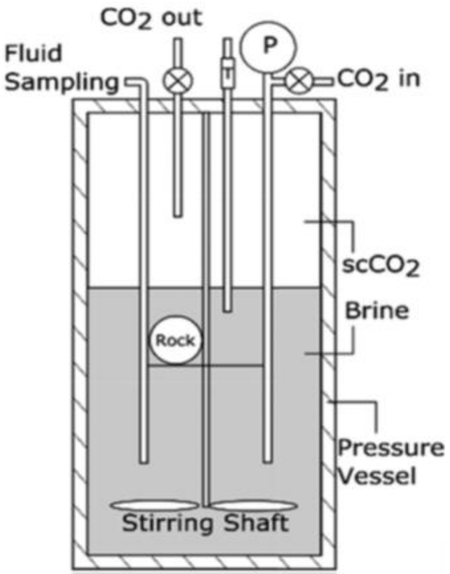
Pore Pressure Fluid Mixing Vessel

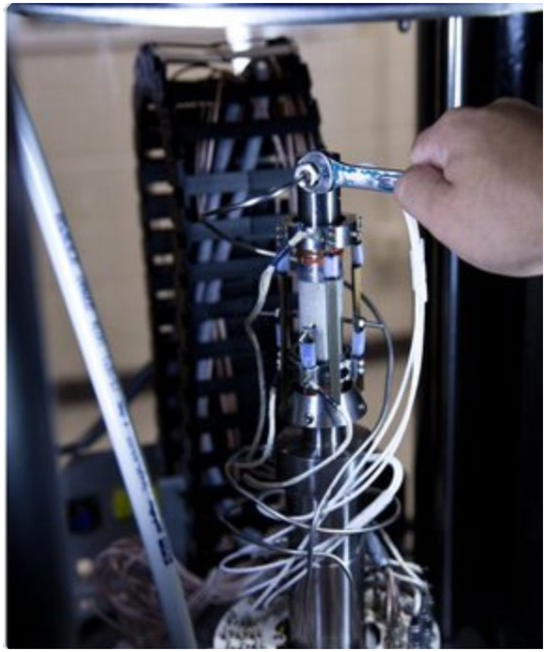


• Autoclave and flow-through experiments (UT Austin, Espinoza lab)



- Simulate P, T conditions at depth
- Measure sample's response to CO_2 injection
- Autoclave, flow-through



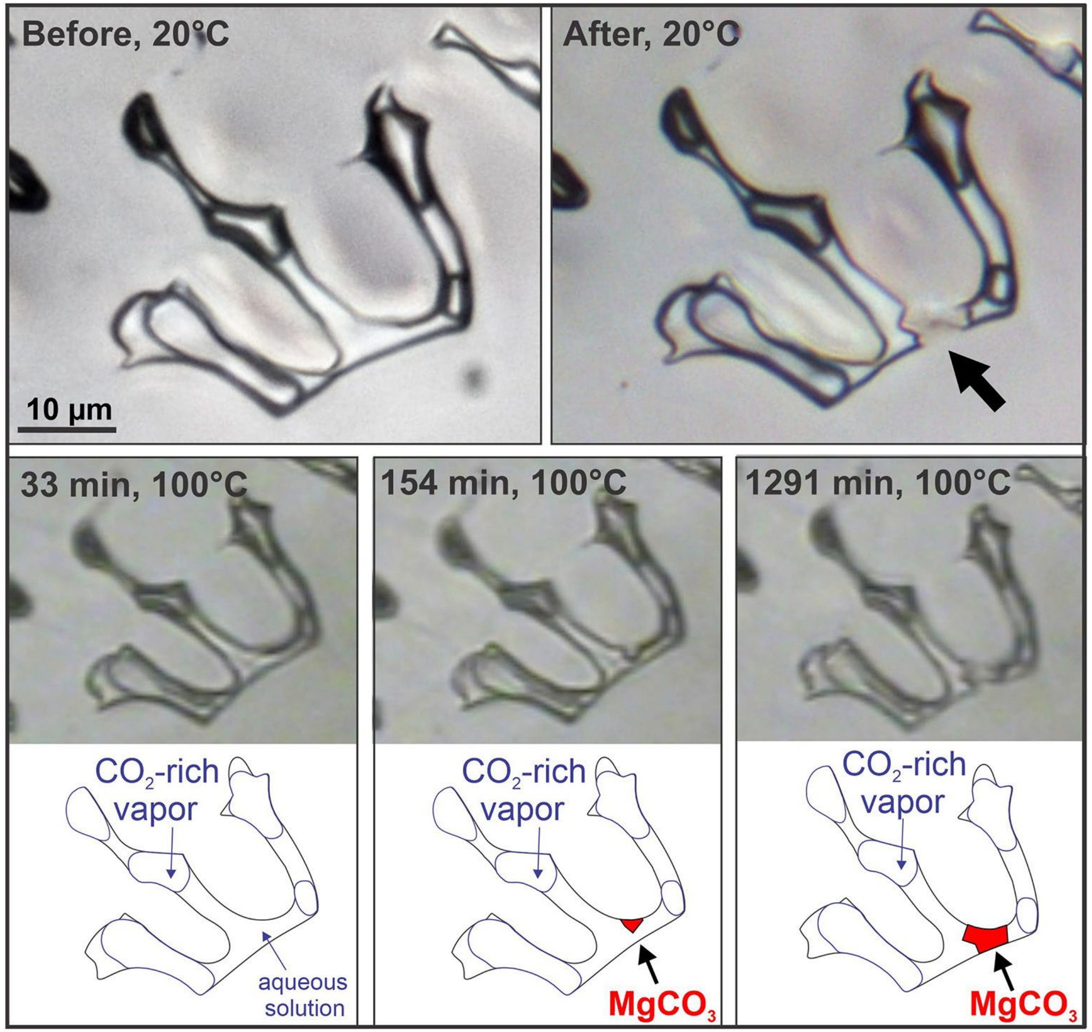


- Reaction Screening Experiment Platform (RSEP)
  - Quick screening, Batch Reactions

- 92 reaction vials
- 10 ml rubber-septum vials at <100°C and atmospheric pressures
- Automated gas headspace sampling for concentration and stable isotope compositions
- Rapid testing of multiple batches of experiments
- Use to define reaction conditions for the more elaborate, expensive, and time-consuming experiments

- Hydrothermal vessels and fluid inclusions as micro-reactors (Fall lab)
  - Olivine/pyroxene + H_2O-CO_2(±NaCl-$MgCl_2$)

$$Mg_2SiO_4(Ol) + 2CO_2 \leftrightarrow 2MgCO_3\ (Mag) + SiO_2(Qtz)$$

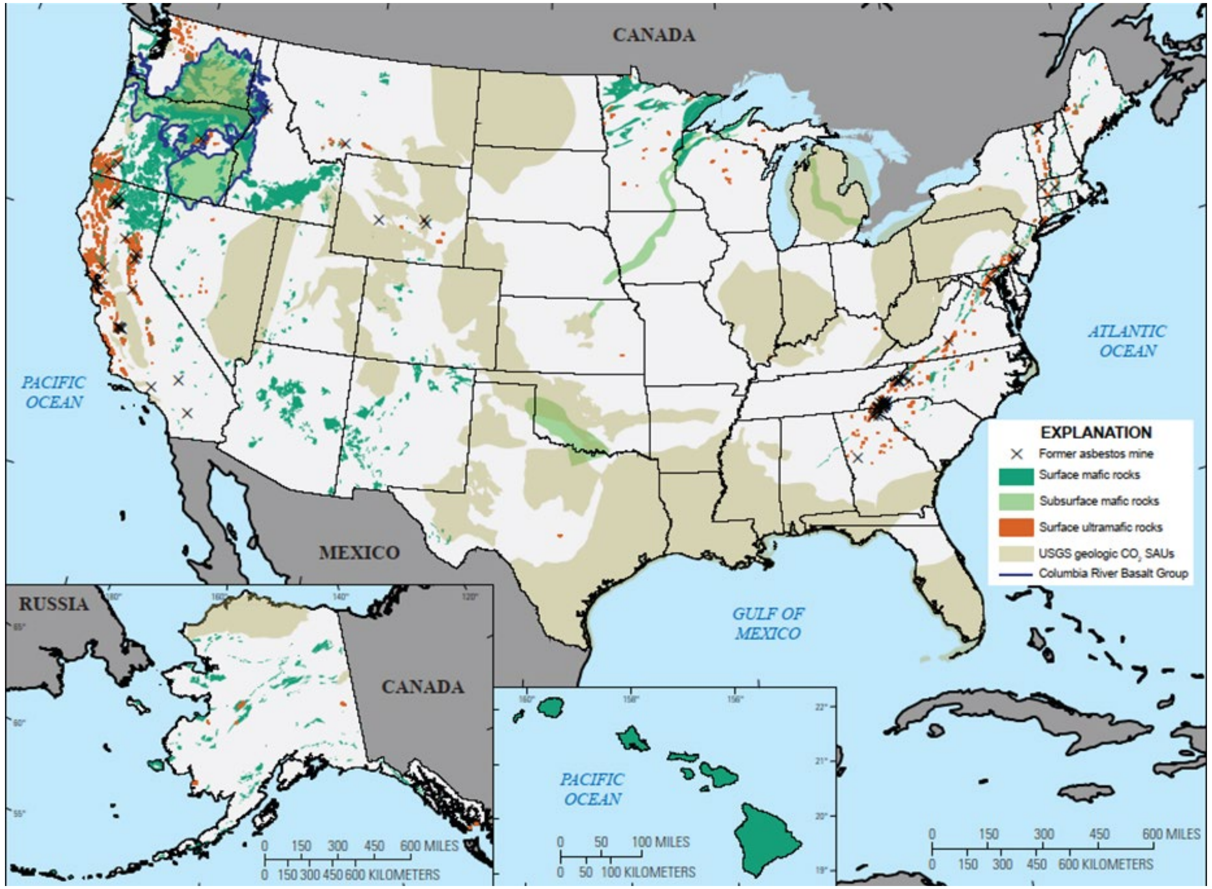


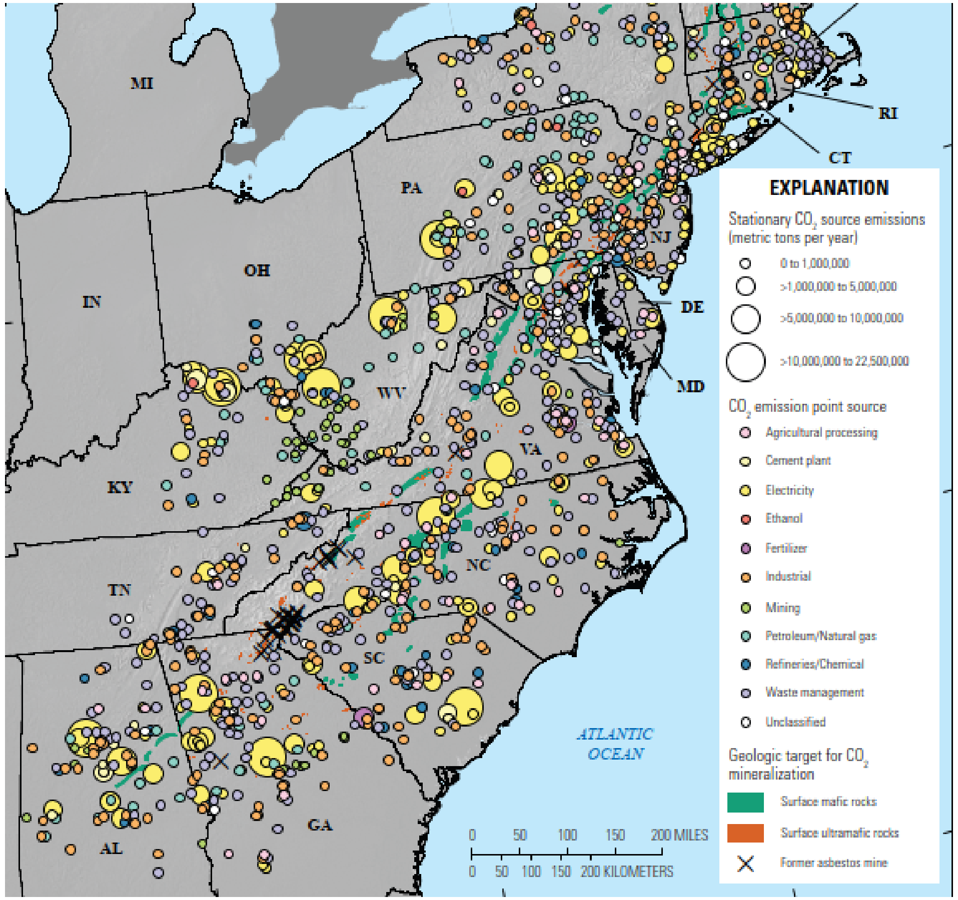
- Reactions monitored by optical microscopy, SEM, Raman

➢ Reaction rates at 50°C to 200°C → hours to weeks

Sendula et al. (2021)

Task 5: Source-to-sink assessment

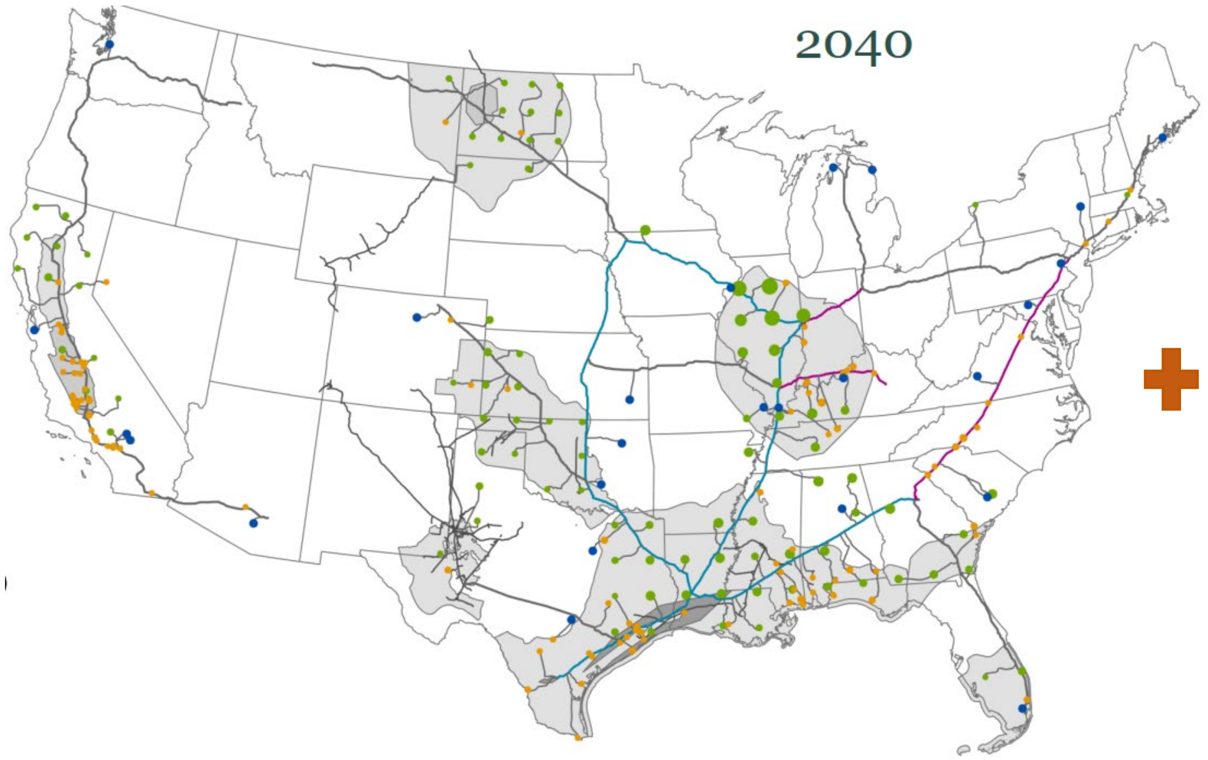




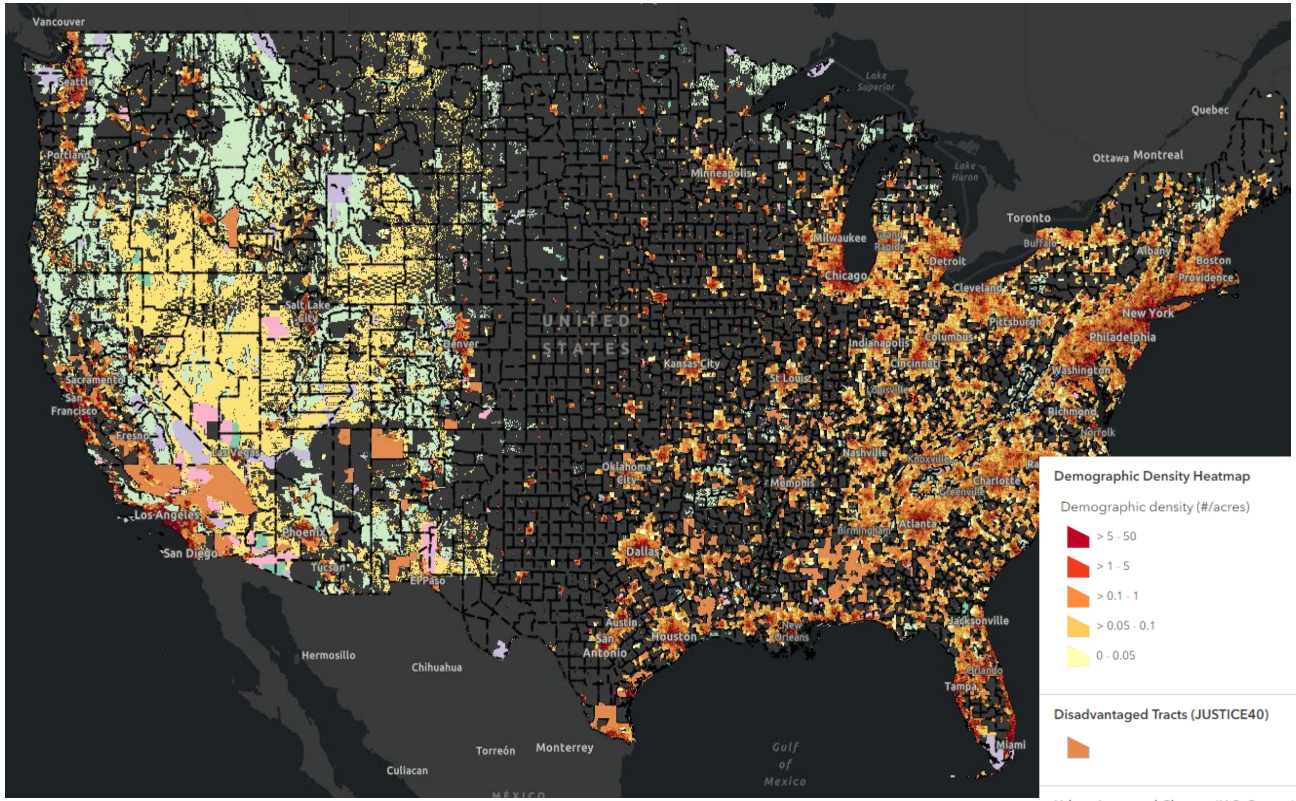
1) Updated 3D model of subsurface rock volumes
- Carbonation potential based on mineralogy etc.

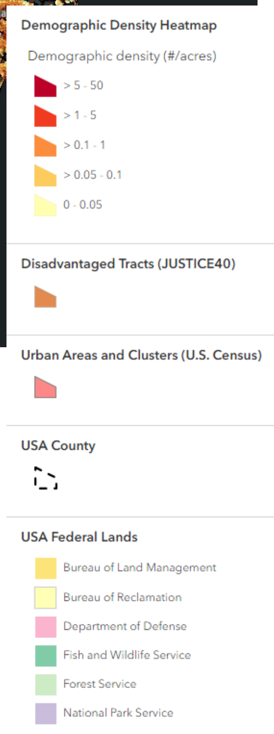
2) Nearby CO_2 (~100miles) sources
- EPA's Flight GHG tool

- Rank potential sites for in-situ carbon mineralization



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 1: Project Management
  - Finalize hiring postdoctoral fellow
- Task 2: Subsurface 3D mapping of mafic and ultramafic bodies
  - Continue literature/database review and curation
  - Seek petrophysical data and well locations from State Geologic Surveys/companies
  - Seek subsurface core samples from State Geologic Surveys/companies/DOE-funded groups
  - Seek non-public geophysical data
  - With postdoctoral fellow in place (expected September-October 2023) begin volumetric calculations and subsurface 3D model construction
- Task 3: Subsurface rock characterization
  - Begin field sample characterization and petrophysical measurements
  - Begin available subsurface thin section characterization
  - Begin petrophysical analysis
- Task 4: Kinetics and carbonation reaction rate experiments
  - Continue single-mineral experiments
    - Forsterite/fayalite
    - Pyroxene
    - Serpentine
  - Begin testing full rock, field samples

Summary of lessons to date

- Early stages of study
  - Subsurface well/core data more disseminated and more poorly characterized than expected
    - Lithologic description of wells/core not always available
  - Core samples scarce and difficult to get
  - Cross-project sample sharing
  - Field samples for experiments/testing
  - Recent algorithms and open-source code allow for rock volumetric calculations
  - RSEP useful for rapid batches, reaction kinetics
  - Autoclave/flow-through to test full rock and reaction-driven cracking
  - Simultaneous progress on other DOE-sponsored projects (e.g. socieconomic/environmental risks) will allow for a better source-to-sink assessment