EARTH MRI AND OTHER CRITICAL MINERAL PROJECTS IN NEW MEXICO

Virginia T. McLemore and the NMBGMR Economic Geology Group

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
Earth Science for the 21st Century

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

National Geological and Geophysical Data Preservation Program (NGGDPP)—Critical Minerals

- 5th year we have received funding
- Funds graduate and undergraduate students
  - Published papers on some of this work (with extra funding from other sources)
- Some of our accomplishments
  - State-wide geochemical database of rocks and mineralized deposits containing critical minerals
  - Depth to Precambrian basement
  - Long range plan to evaluate critical minerals in New Mexico
  - Comprehensive database of critical minerals and other minerals deposits (New Mexico Mines Database)
  - Photograph and describe drill core with critical minerals potential
  - Inventory and storage of samples from areas containing critical minerals
  - Identify districts with critical minerals in New Mexico

Depth to Precambrian basement

In the United States, a critical mineral is a nonfuel mineral commodity that is essential to the economic and national security of the United States, and is from a supply chain that is vulnerable to global and national disruption.

Critical Minerals in New Mexico

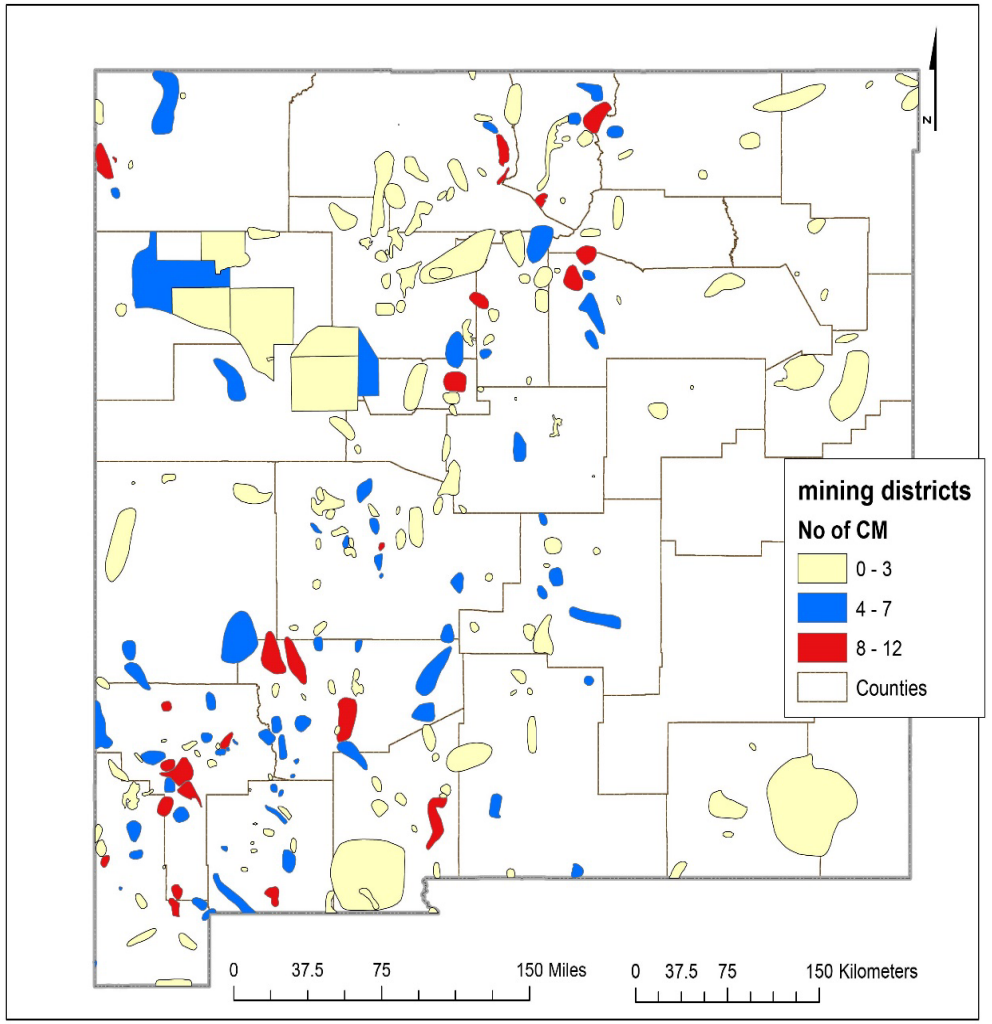
Element currently producing in NM
Element once produced from NM
Element found in NM
Element not found in NM

H																	He
Li	Be												B	C	N	O	F	Ne
Na	Mg												Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn		Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd		In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg		Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac																
			Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
			Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

C=graphite
F=fluorite
Ba=barite

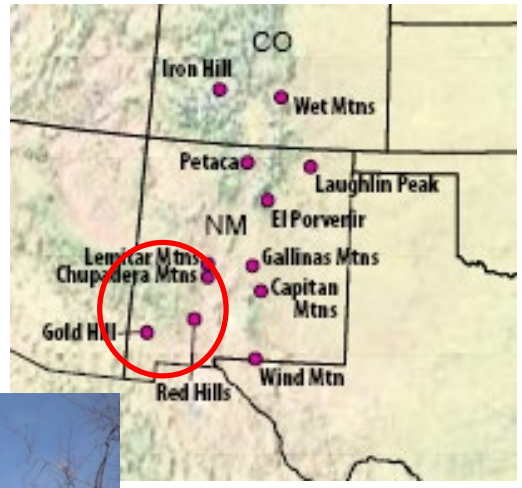
Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

U, Re, He, and K (potash) were removed from the critical minerals list in 2022 and Zn and Ni were added.

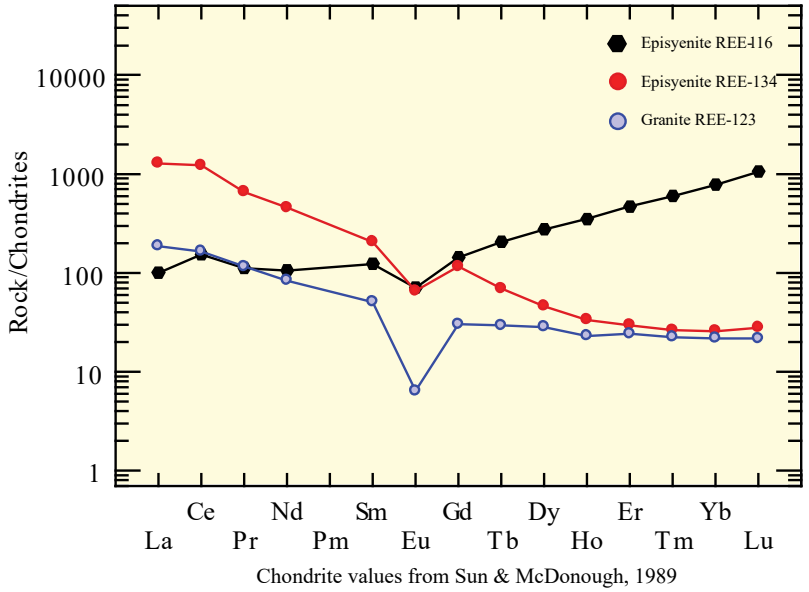


USGS MRERP
Mapping and origin of REE in Cambrian-Ordovician Episyenites in the Caballo and Burro Mountains, southern NM (2012-2022, continuing)

Virginia McLemore, Nelia Dunbar, Matthew T. Heizler, O. Tapani Rämö and many students



- Brick-red episyenites are metasomatic in origin, possibly related to alkaline or carbonatite intrusions at depth
- REE minerals are associated with altered amphiboles, magnetite, secondary chlorite, hematite, zircon, and fluorite
- Samples have low-moderate TREE, Th, and U; but some samples have relatively high HREE

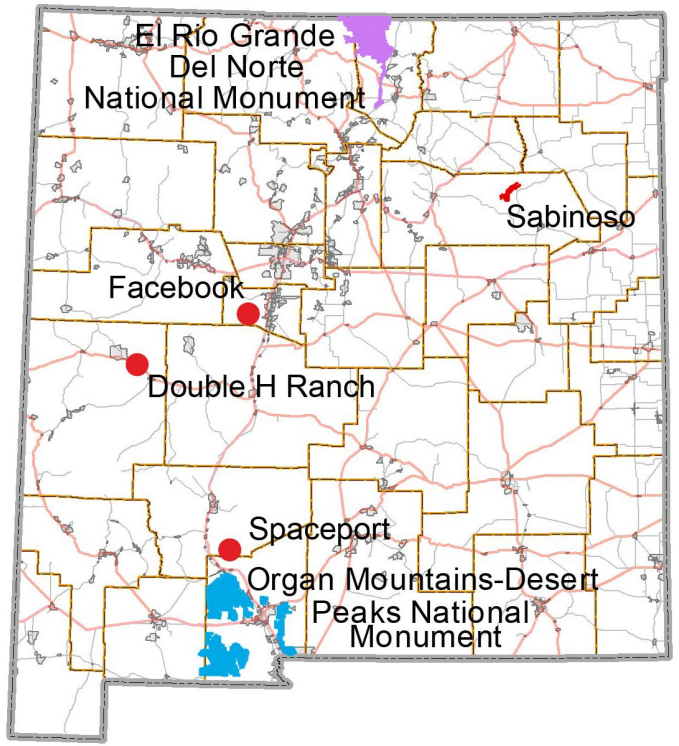


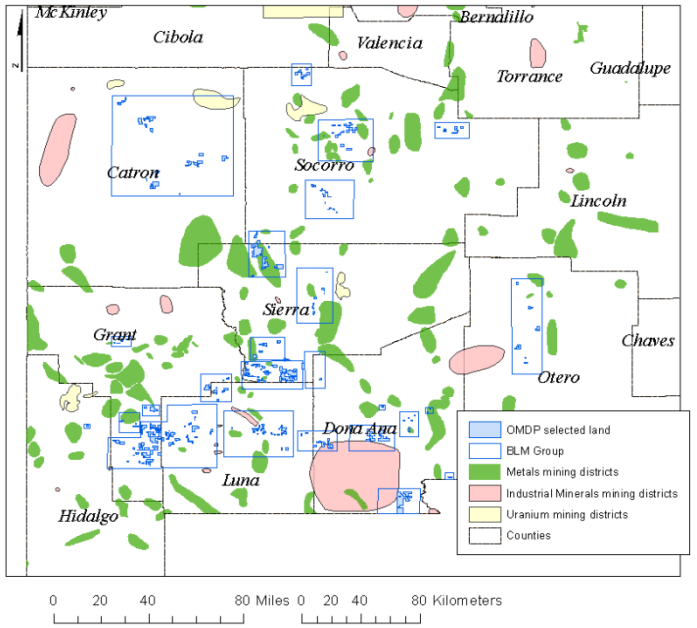
Contact between granitic gneiss and episyenite in Caballo Mtns

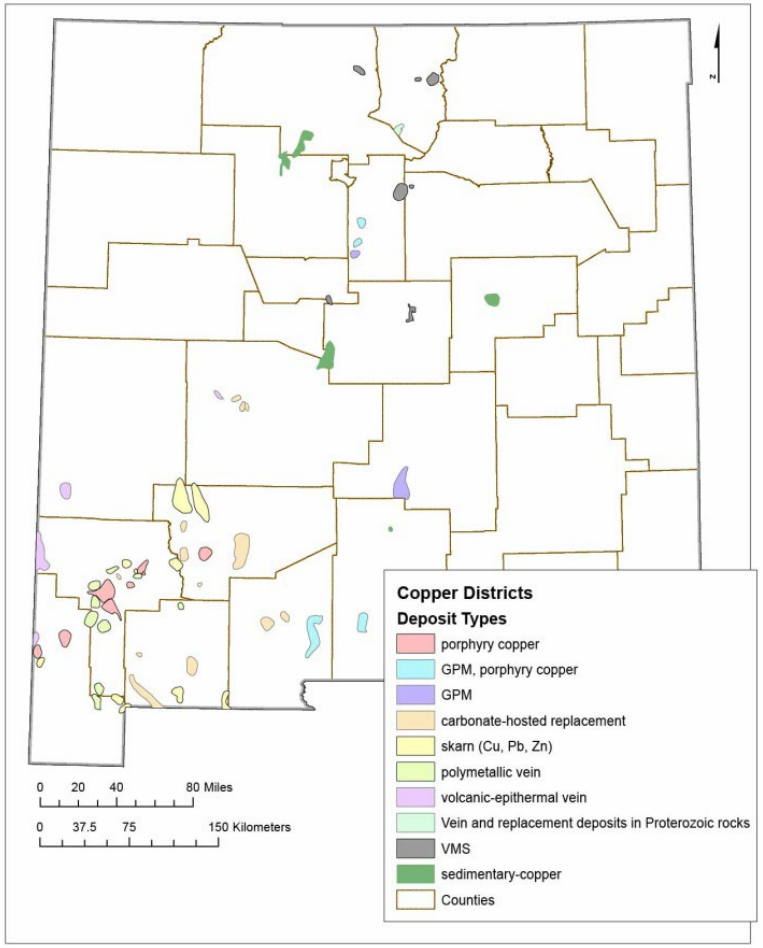
Mineral-Resource Potential of New Mexico, including critical minerals BLM contract 140L0321P0009-FE (June 2021-Feb 2022)

Virginia McLemore, Kyle Stafford, Luke Martin, Shari Kelley, Joseph Grigg, and Ron Broadhead

- Determine the mineral-resource potential for land exchanges
- Generally to transfer state land within wilderness or national monuments
- Transfer Federal land into other beneficial uses

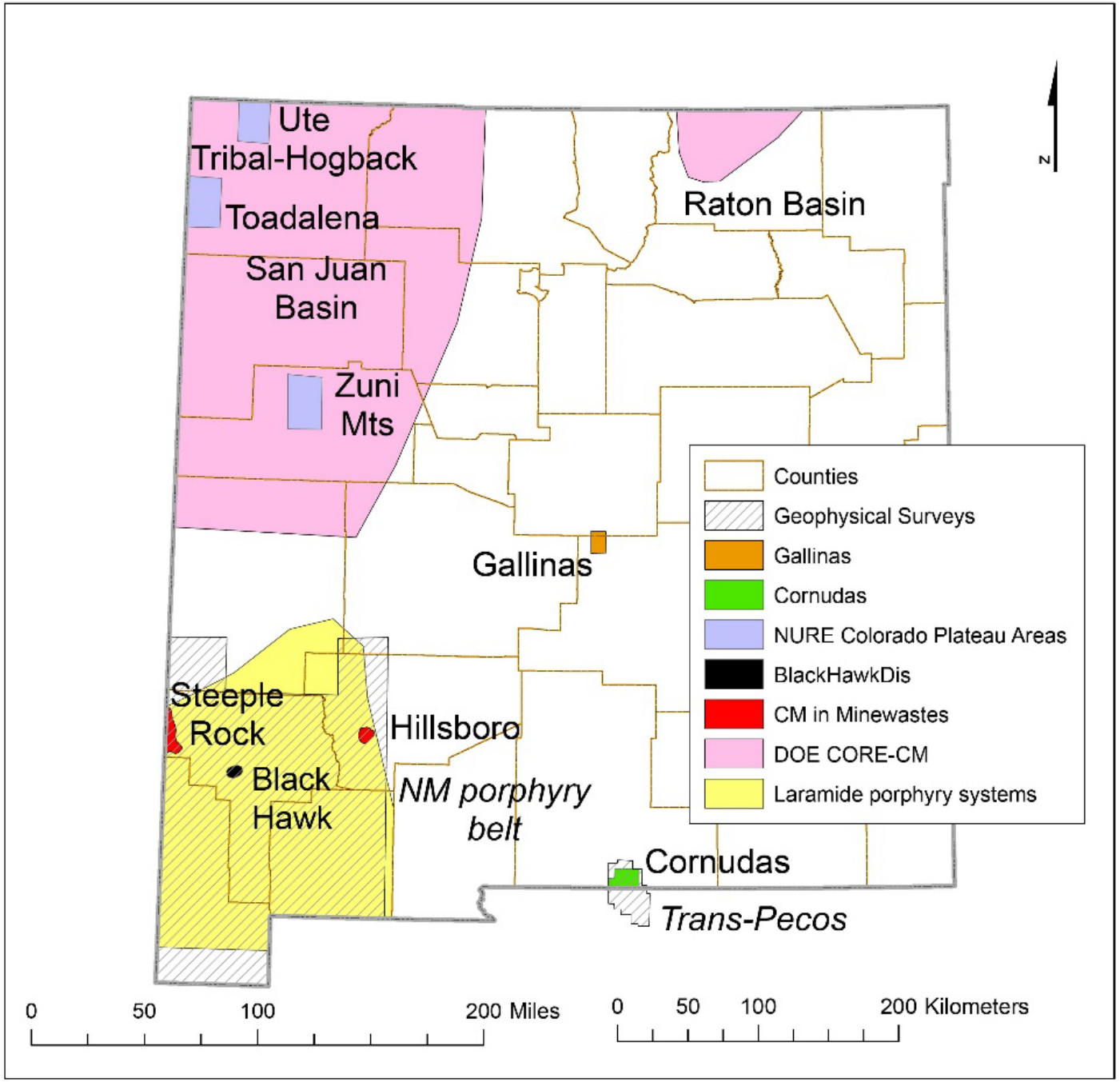






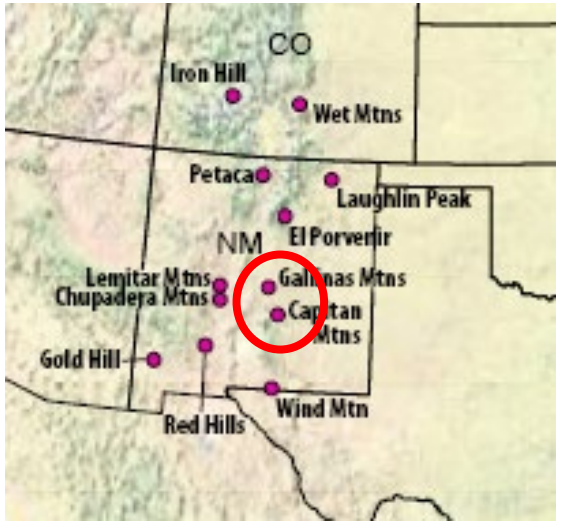
Copper potential

Earth MRI and DOE CORE-CM projects in New Mexico

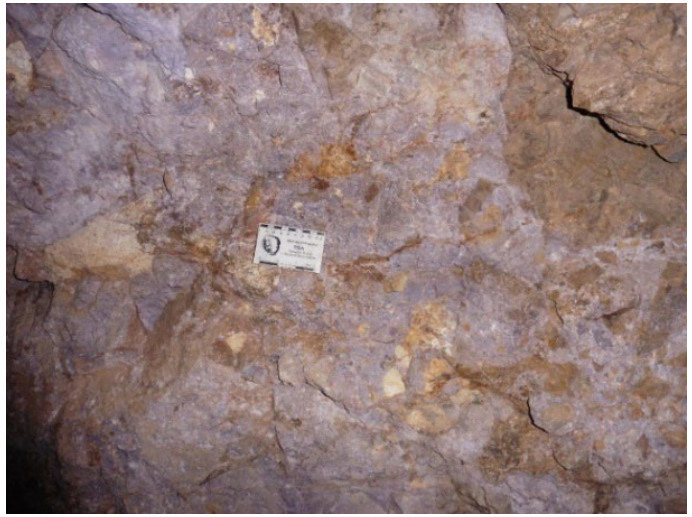


USGS Earth MRI Project Mapping REE in Gallinas Mountains, Lincoln County, NM (2019-2021, continuing)

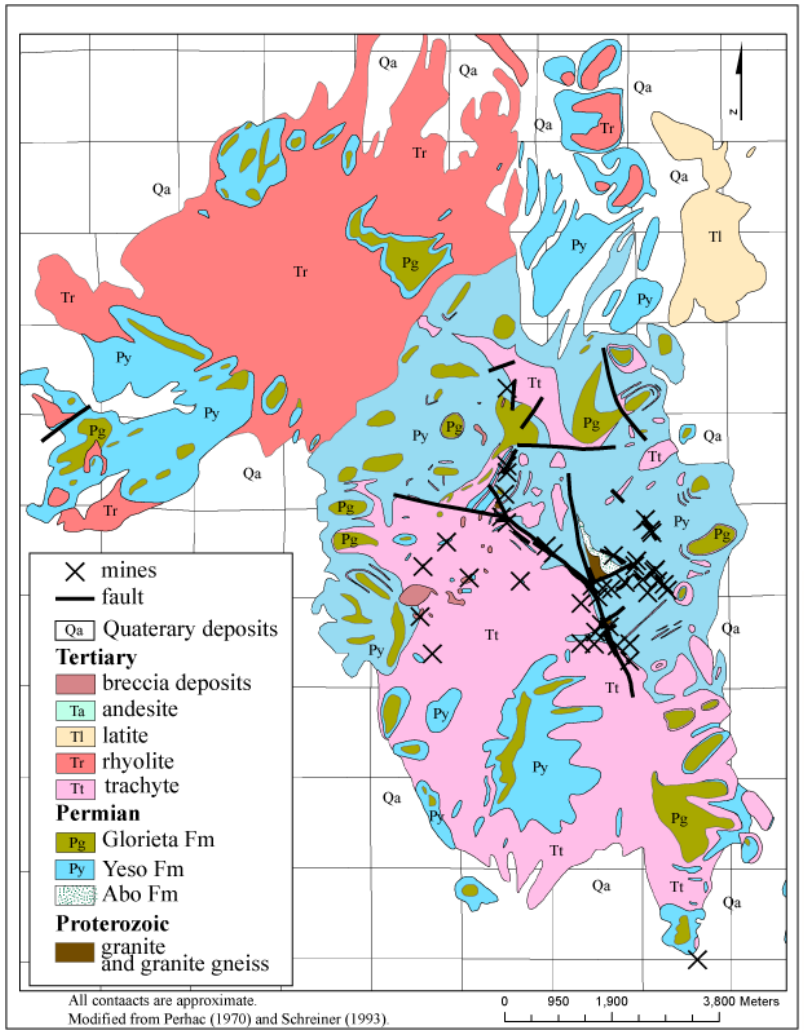
Virginia McLemore, Shari Kelley, Matt Zimmerer, Evan Owen, Alex Gysi and many students



- REE breccia and vein deposits are mostly along minor faults with small displacements and short lengths, and fracture zones, as much as 8% TREE
- Positive correlation between TREE, F, Ba, and Sr
- Possible carbonatite at depth
- Industry provided chemical analyses

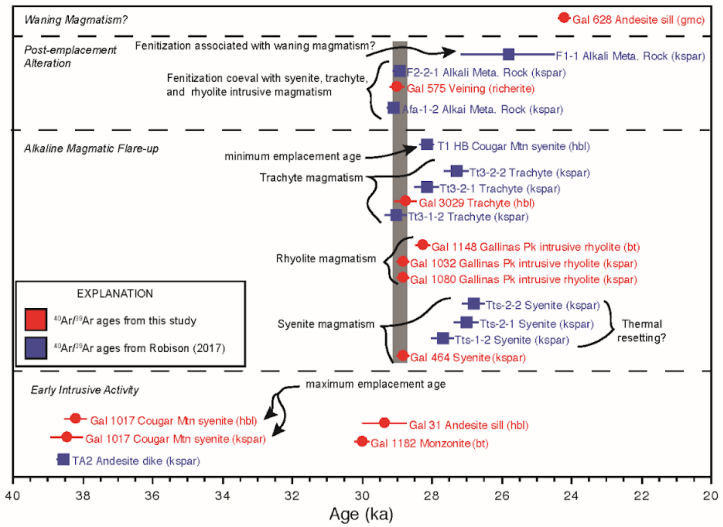


Yellow bastnäsite [(Ce,La)(CO_3)F] in purple fluorite breccia from the Red Cloud mine (length is ~8 mm). Bastnäsite is the most common REE mineral mined in the world today.

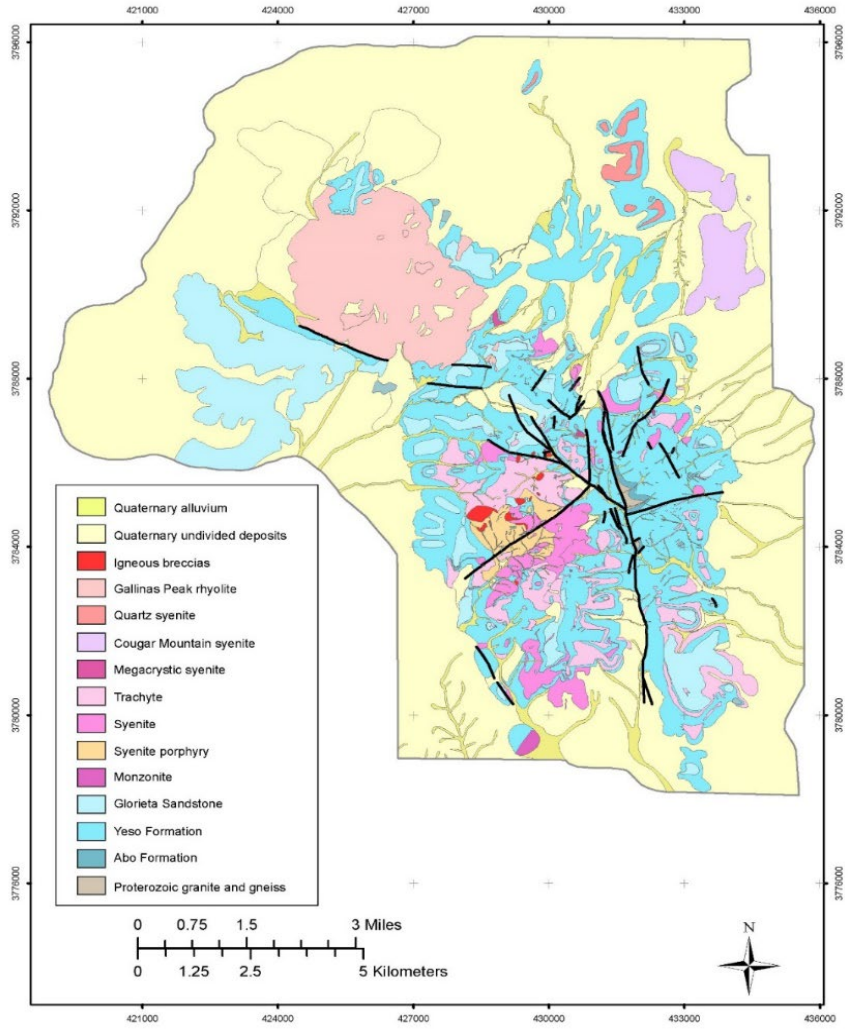


Historic geologic map of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico (Perhac, 1970)

New mapping identified numerous mines and prospects, veins, faults, and subdivided the igneous intrusions



Summary of new (red) and published (blue; from Robison 2017) $^{40}Ar/^{39}Ar$ ages.

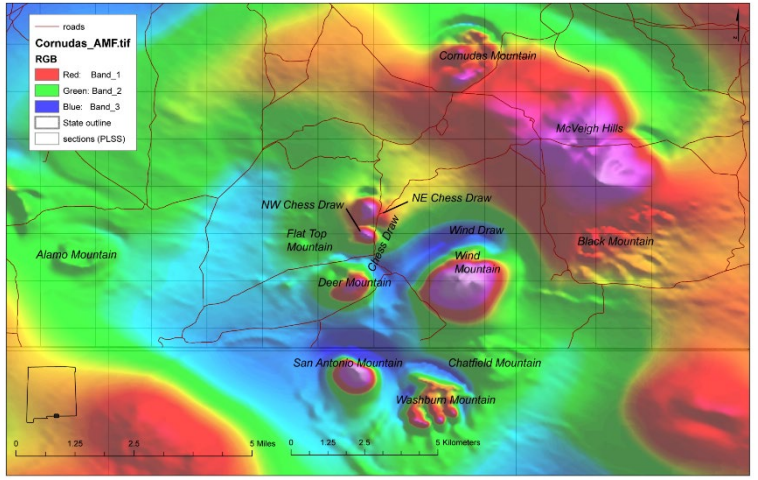


New geologic map of the Gallinas Mountains, Lincoln and Torrance Counties, New Mexico

USGS Earth MRI Project Mapping REE in Cornudas Mountains, Otero County, NM (2020-2023)

Virginia T. McLemore, Nels Iverson, Evan Owen, Snir Attir, and several students

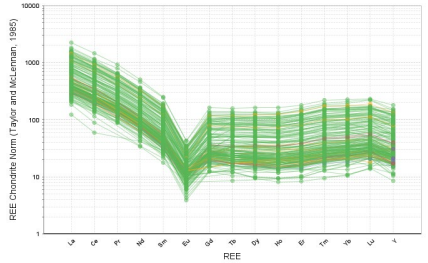
IN COOPERATION WITH TEXAS



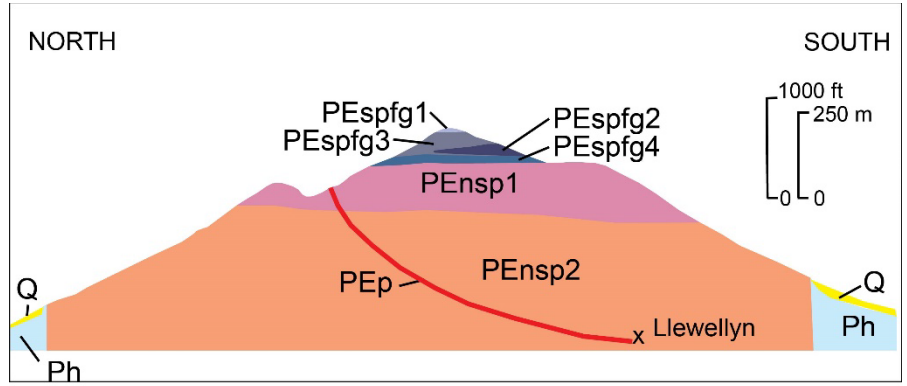
- Finishing up the GIS geologic map
- Differential cooling of the magma resulted in the textural variations at Wind Mountain
  - 36.32±0.15 Ma
- Eudialyte is primary REE mineral
- Chemical analyses—3790 ppm total REE, 2332 ppm Nb, 92 ppm Be, and 3137 ppm F
- Industry provided core, chemistry

Pink eudialyte in black phonolite dike in contact with skarn

Map of the anomalous magnetic field (AMF) of the Cornudas Mountains (Bultman, 2021, 2022) showing intrusive laccoliths and plugs (red anomalies) that extend deep into the subsurface, with additional intrusions potentially buried in the subsurface.



Wind Mountain laccolith

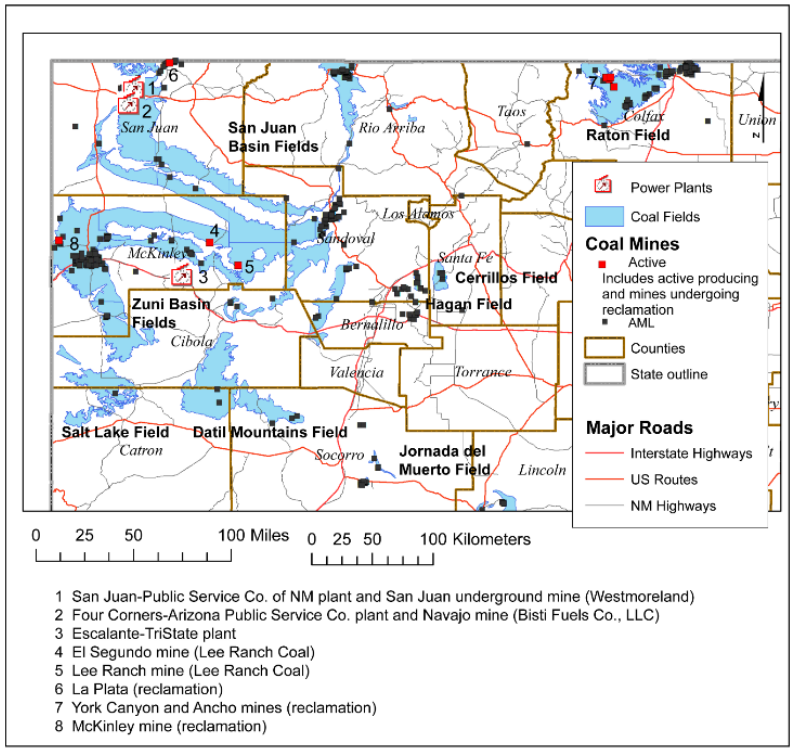


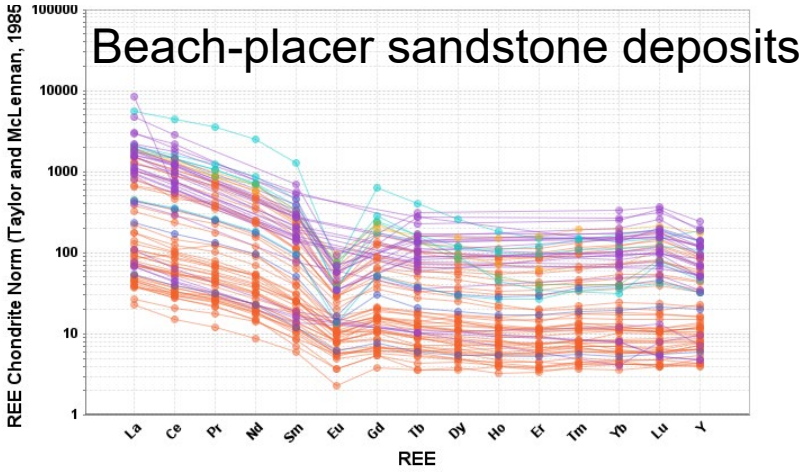
DOE CORE-CM project—San Juan River-Raton Basin, New Mexico DOE contract (Oct 2021-Sept 2023, extension requested)

Virginia T. McLemore, Navid Mojabai, Shari Kelley, Evan Owen, many students and staff

- **CORE-CM=Carbon Ore, Rare Earth and Critical Minerals**
- Identify and quantify the distribution of REE and CM in coal beds and related stratigraphic units in the San Juan and Raton basins
- Identify, sample, and characterize coal waste stream products
- Sandia: Microscale characterization techniques to identify where REEs and critical metals are hosted
- LANL: Field-portable, in situ LIBS/RAMAN analysis

Industry provided access to mines





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New Mexico Tech

Sandia National Laboratories

Los Alamos National Laboratory EST. 1943

SAN JUAN COLLEGE

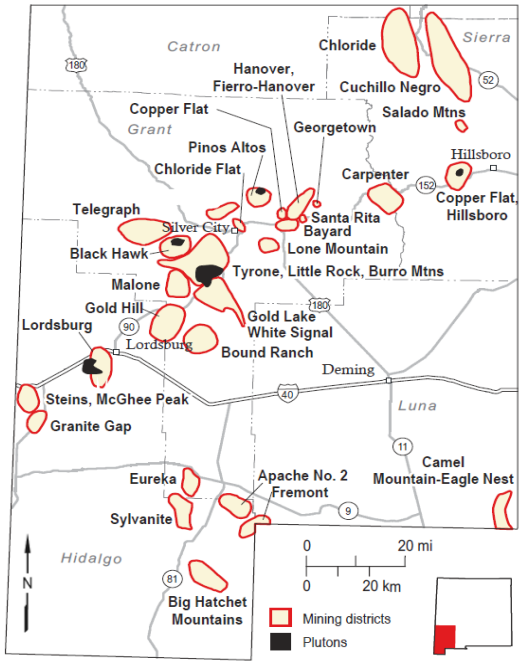
SonoAsh

USGS Earth MRI Project Critical minerals in Laramide porphyry copper deposits (Aug 2022—July 2025)

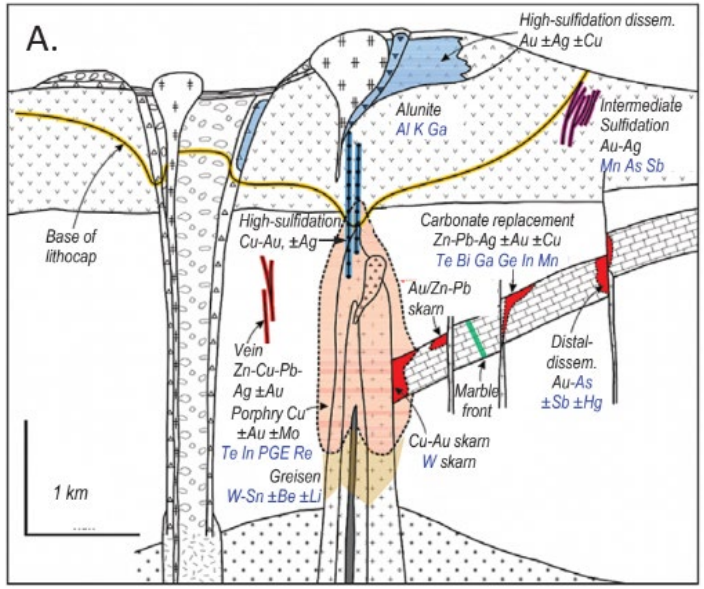
Virginia T. McLemore, Evan Owen, Nels Iverson, Shari Kelley, and many students

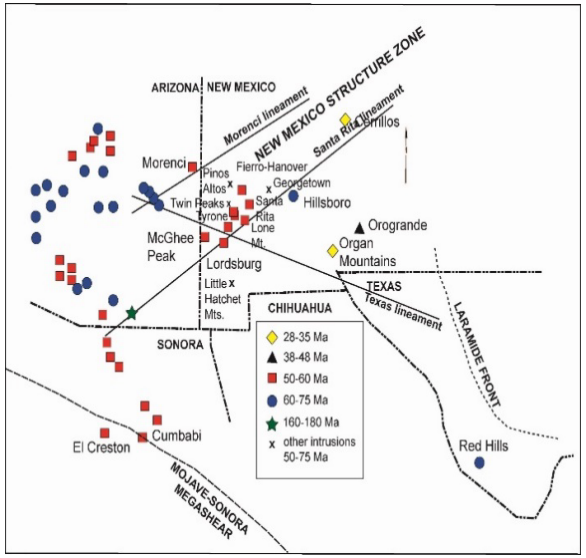
IN COOPERATION WITH ARIZONA GEOLOGICAL SURVEY

- What are the ages
- Where in the porphyry copper deposits are there critical minerals
- Cooperate with industry

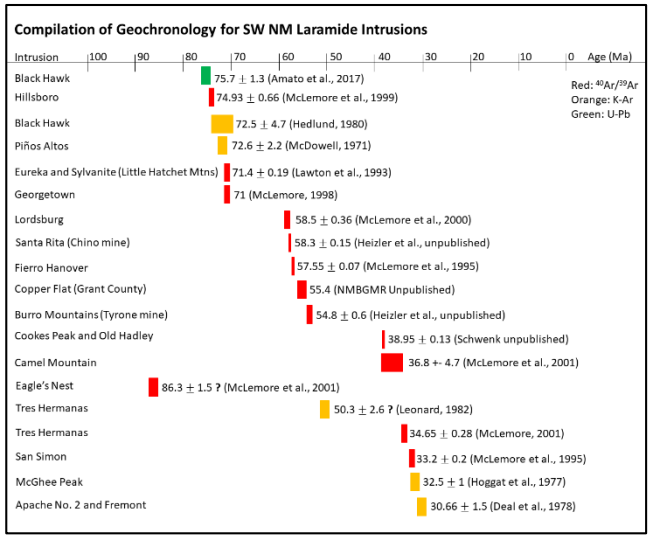


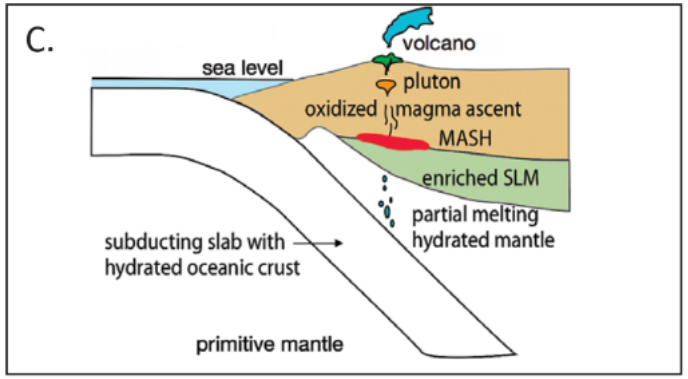
Districts with Laramide deposits and plutons (black) in southwestern New Mexico





Laramide porphyry copper deposits in southwestern United States and northern Mexico. The Copper Flat porphyry copper deposit is in the Hillsboro district.



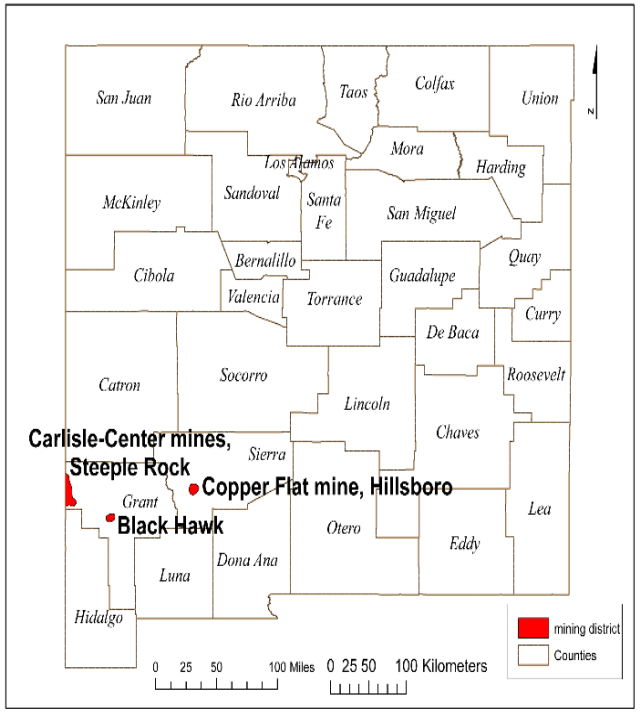


Simplified settings of porphyry copper and associated deposit types Hofstra and Kreiner (2020), top image modified from Sillitoe (2010), bottom from Tosdal et al. (2009)

USGS Earth MRI Project Critical minerals from mine wastes (August 2022-July 2024)

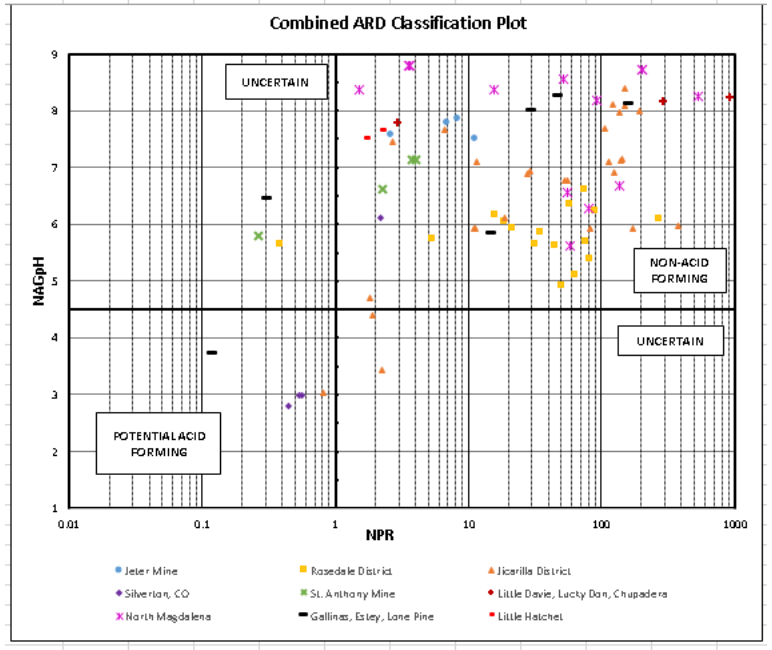
Virginia T. McLemore, Bonnie Frey, Evan Owen, Dan Jones, and students

- Test USGS protocols for sampling mine wastes
- Characterize mine wastes for critical minerals potential
- Includes tailings, mine waste rock piles, stockpiles, pit lakes
- Acid-base accounting to determine acid generating potential
- Industry provided access to sites



Sampling stockpile at Copper Flat

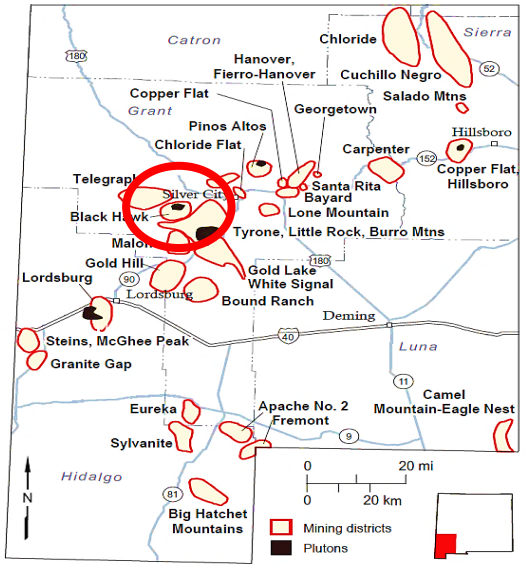
Pit in Copper Flat tailings



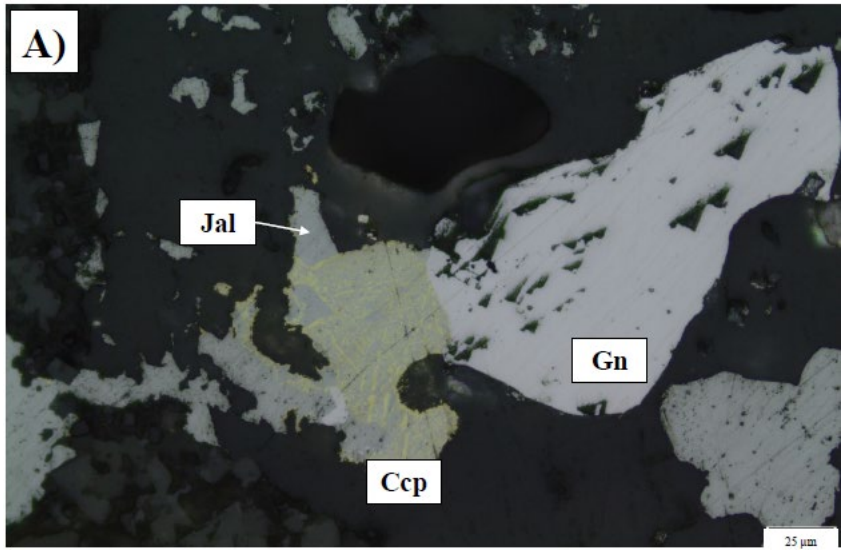
Acid rock diagram for mine waste rock piles in NM

USGS Earth MRI Project Geochemistry and detailed mapping of the Black Hawk arsenide-5 element vein system

Virginia T. McLemore, Evan Owen, Nels Iverson, and several students



- Five-element vein deposits contain Ag, As, Bi, Ni, and Co ± U, Sb, Zn, Cu, Pb
- These deposits are unusual and not well understood
- Like other worldwide example of five-element veins, the Black Hawk district contains silver (Ag) and various critical minerals including nickel (Ni), cobalt (Co), bismuth (Bi), arsenic (As) and local uranium (U), zinc (Zn), and antimony (Sb)
- Industry provided access



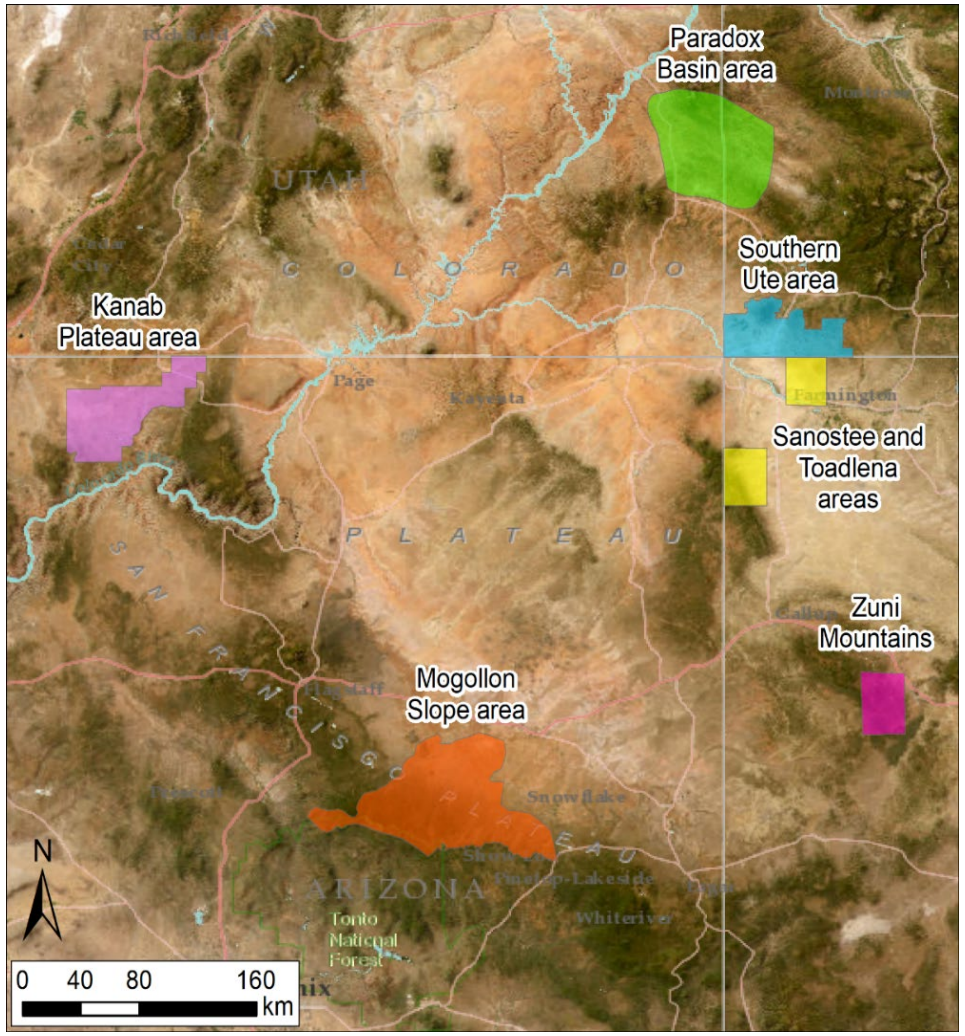
Colloform growths of native Ag, Ni-Co arsenides, anduraninite

USGS Earth MRI Project GEOCHEMICAL REANALYSIS OF NURE SAMPLES FROM THE COLORADO PLATEAU, NEW MEXICO, UTAH, COLORADO, AND ARIZONA (August 2023-July 2026)

Virginia T. McLemore, Evan Owen, and several students

IN COOPERATION WITH ARIZONA, UTAH, AND COLORADO GEOLOGICAL SURVEYS

Stephanie Mills, Jake Alexander, Taylor Boden, Mike O'Keeffe, Andrew Giebel, and Carson Richardson



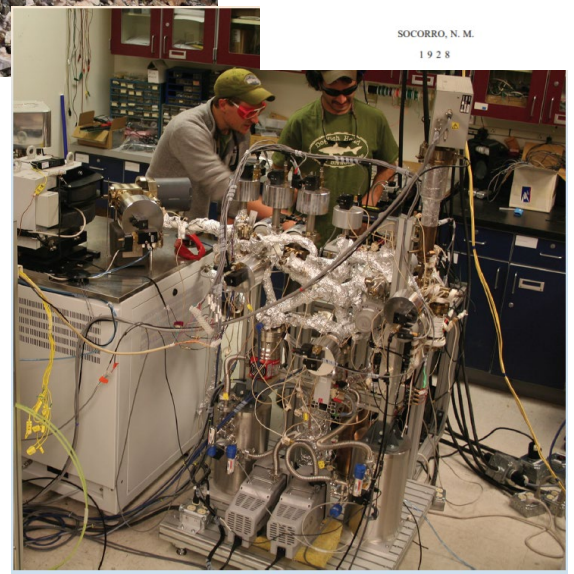
- Reanalysis of a select group of existing NURE sediment pulps by the USGS using modern geochemical methods where critical minerals are found
- Resample additional areas
- New Mexico will use this as part of a graduate course (Exploration Geochemistry)

NURE=National Uranium Resource Evaluation

Summary

- This funding has and will increase our knowledge of where in NM critical minerals are found
  - Land use decisions, including land exchanges
  - Potential for mining=economic benefits to NM
  - Training the work force
  - Outreach components help educate society on the importance of critical minerals
  - Increase our knowledge of geologic processes and models of these deposits=more effective exploration
- Projects are built upon decades of research at NMBGMR and NM Tech
  - Data preservation funding is important to preserve these historic data, records, and drill core
- Cooperation with adjacent states and industry is important
- These projects takes many students and staff, which requires this level of funding
  - Teams are very important, but expensive

NMBGMR ECONOMIC GEOLOGY GROUP RESEARCH



NEW MEXICO SCHOOL OF MINES

STATE BUREAU OF MINES AND MINERAL RESOURCES

E. H. WELLS, PRESIDENT AND DIRECTOR

BULLETIN NO. 4

Fluorspar In New Mexico

BY

WILLIAM DRUMM JOHNSTON, JR.

SOCORRO, N. M.

1928

Questions

Summary of M.Sc. Research in the Gallinas Mountains, NM

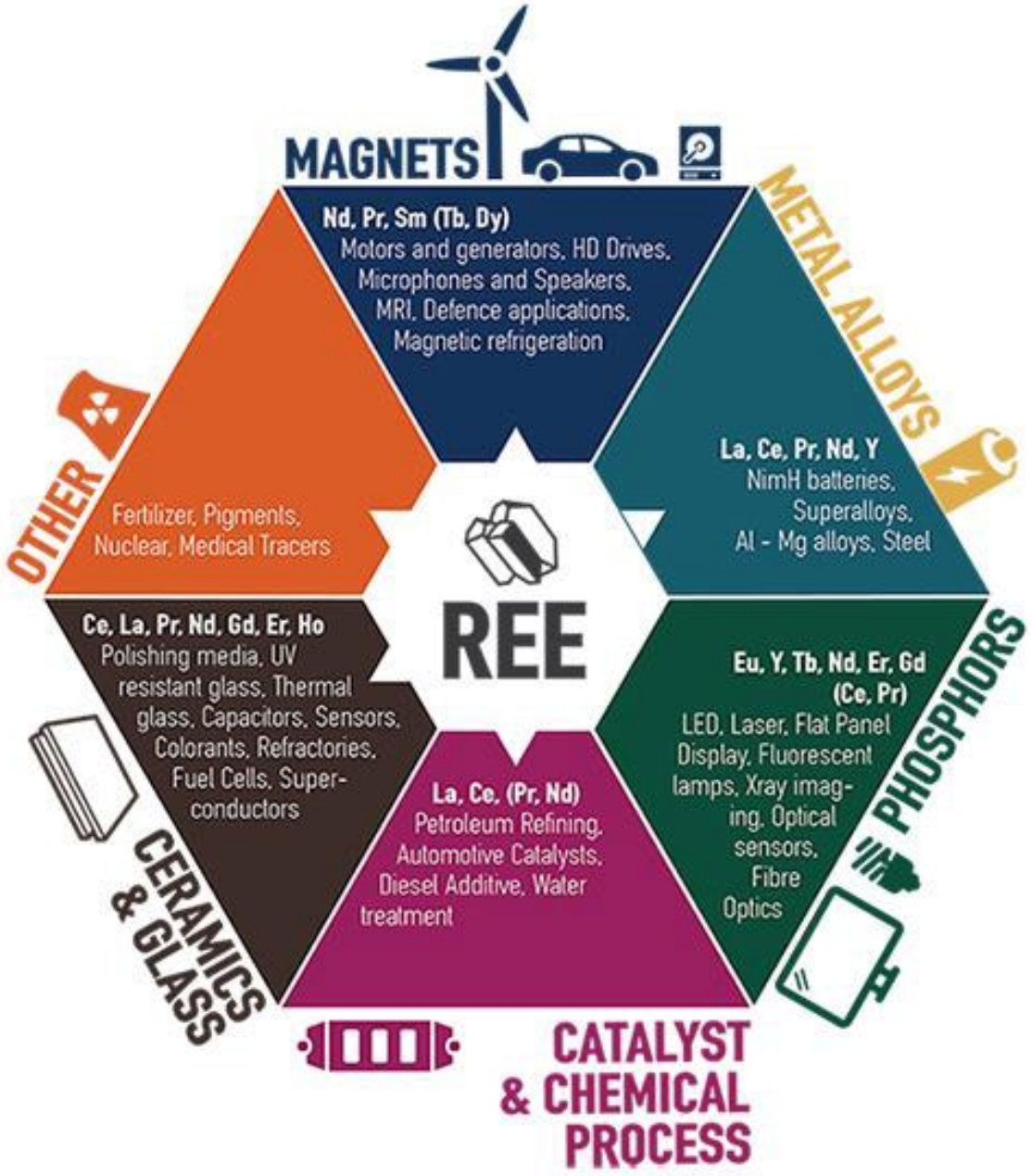
Evan Owen, M.Sc. student, Economic Geologist [1,2]

Advisor: Alex Gysi, Ph.D., Economic Geologist [1,2]

[1]New Mexico Bureau of Geology and Mineral Resources
[2]Dept. of Earth and Environmental Science, New Mexico Tech

Background and significance

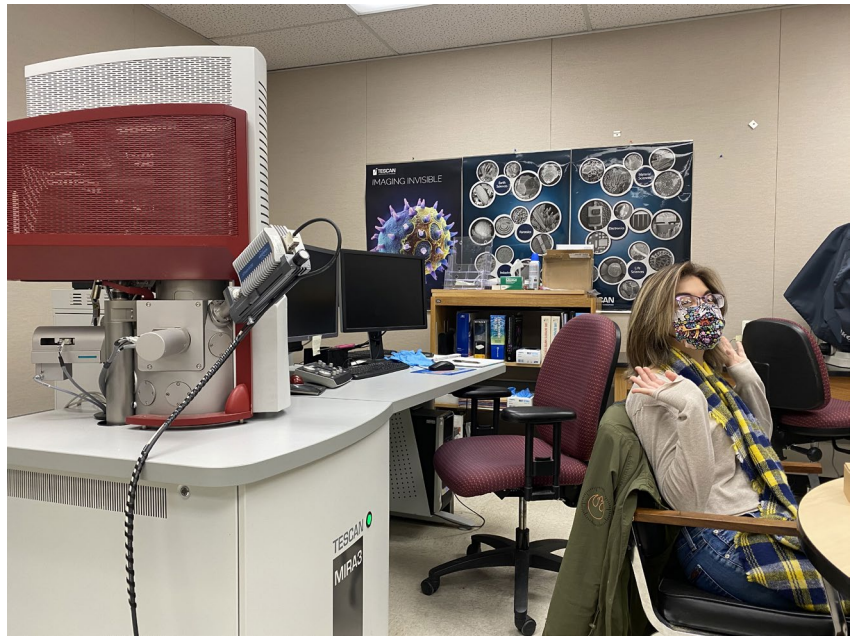
- The Gallinas Mountains host **fluorite veins and breccias** related to **alkaline rocks**
- These veins and breccias contain **bastnäsite**, a mineral with significant (64% by mass) **rare earth elements (REE)**, usually Ce and La dominant
- REE are **critical minerals**, with uses in **green energy** and other high tech applications
- The deposits in the Gallinas Mountains are still not very well understood, but share similarities with **world-class REE deposits**, such as **Mountain Pass** in California, and **Bayan Obo** in China
- Understanding this district can help us more **efficiently explore** for other related deposits in other regions
- Characterizing sub-economic deposits is important, as economics may change in the future

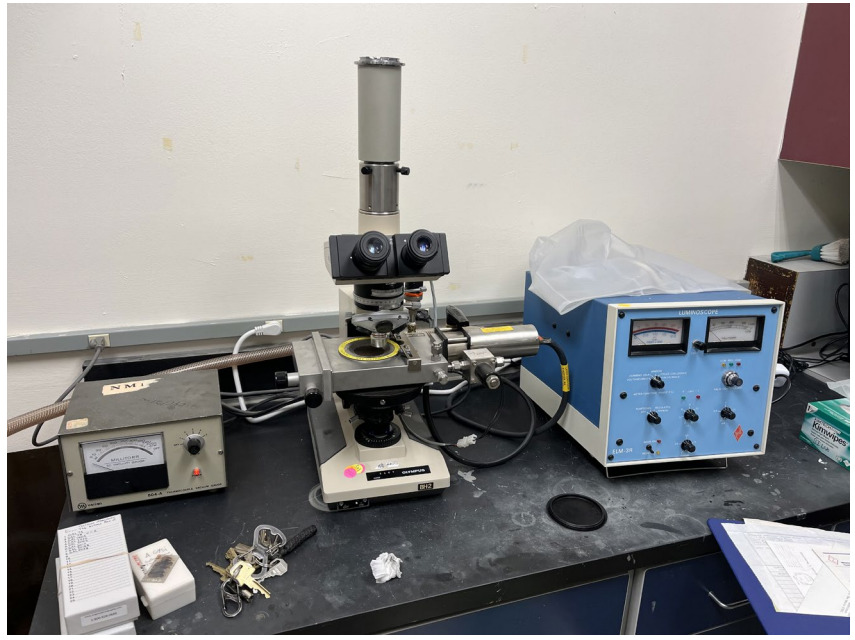


http://www.eurare.org/RareEarthElements.html

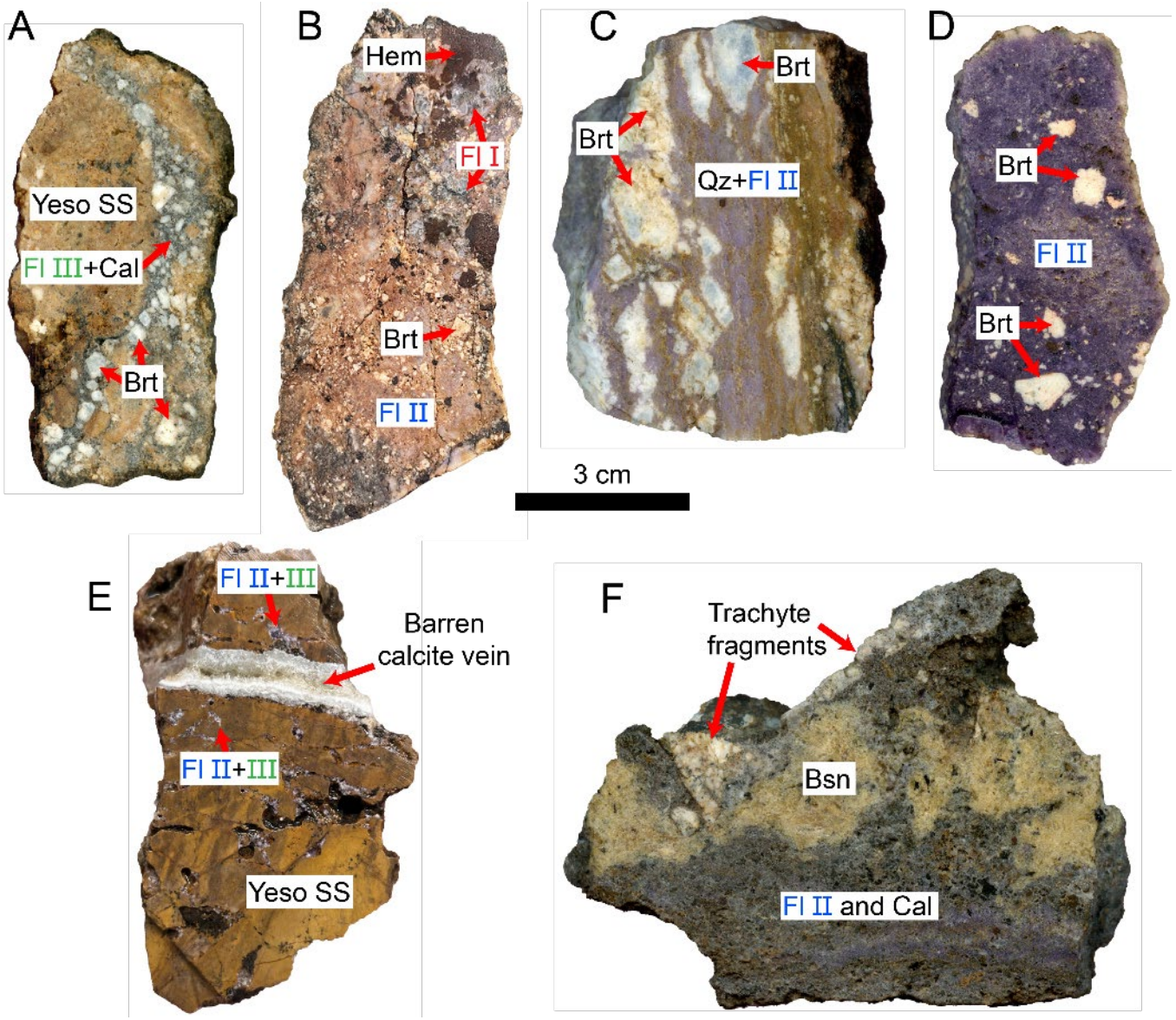
Objectives and Methods

- Characterize the different types of fluorite veins found in the district
  - Optical microscopy, BSE-SEM imaging, automated mineralogy, cathodoluminescence microscopy, LA-ICP-MS
  - Examine microtextures, crosscutting relationships, distinguish mineral generations, mineral chemistry
- Establish a revised mineral paragenesis based on new findings
- Examine whole rock geochemical data to determine if vectors toward REE can be developed

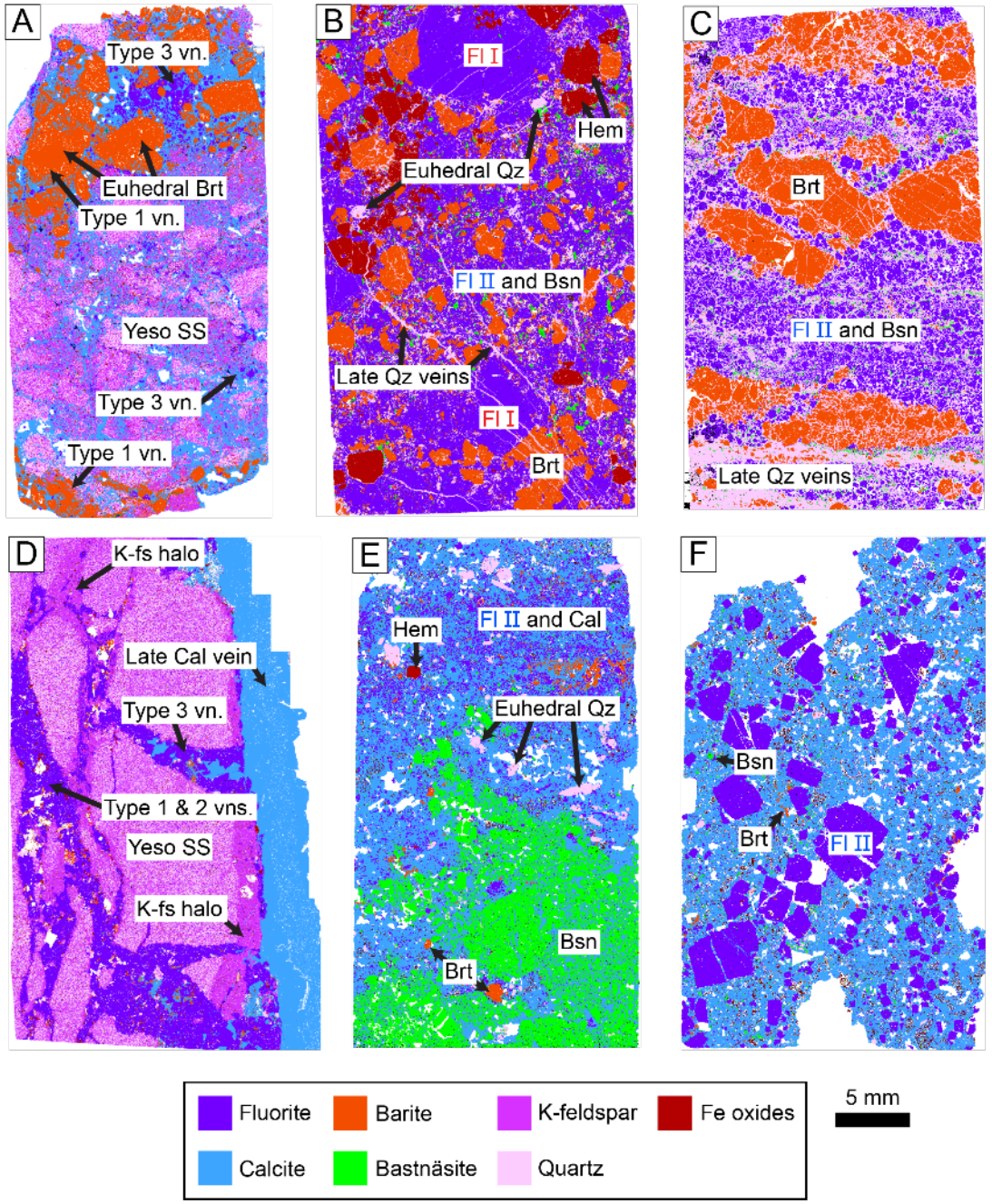




Hand samples of fluorite veins and breccias

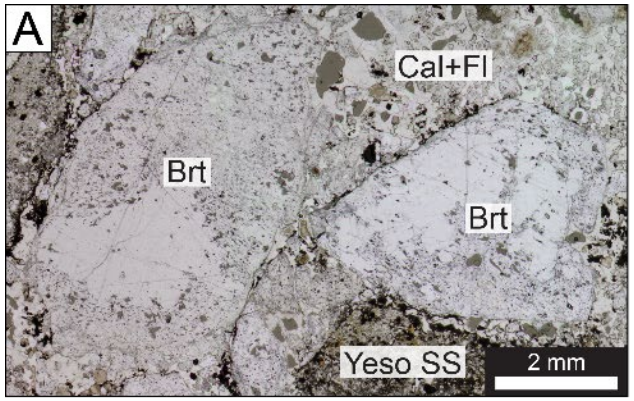


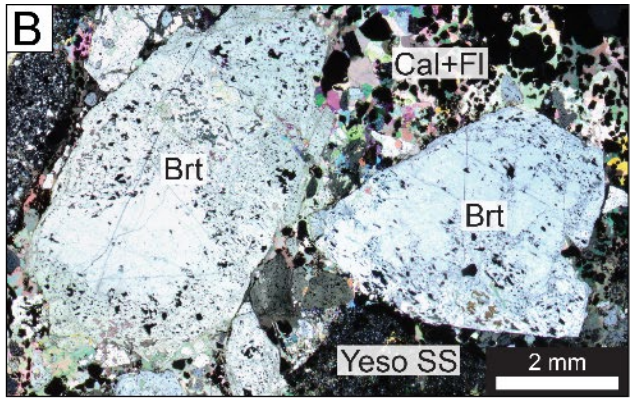
Automated mineralogy maps of thin sections

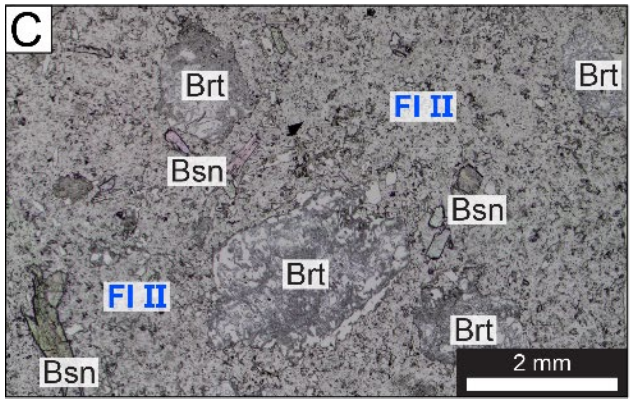


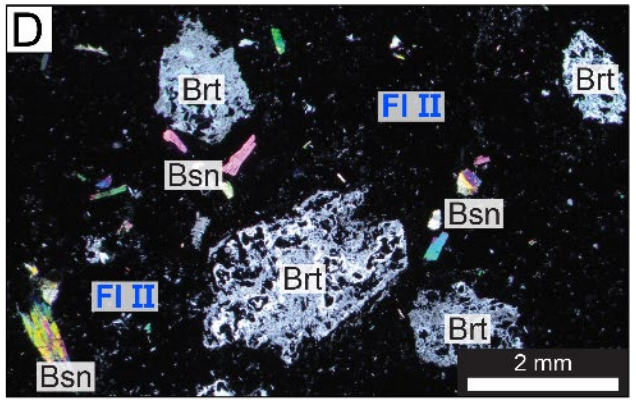
Microtextures and crosscutting relationships

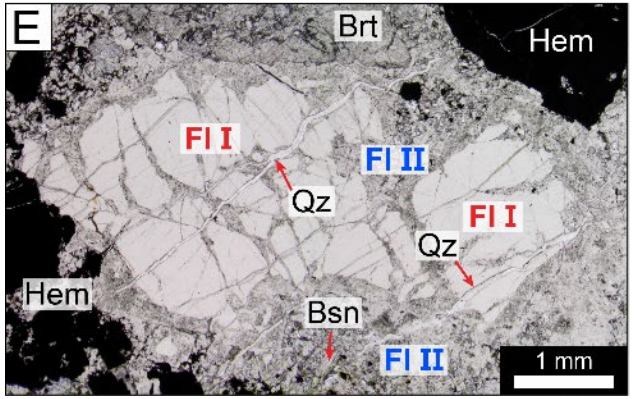
Optical petrography

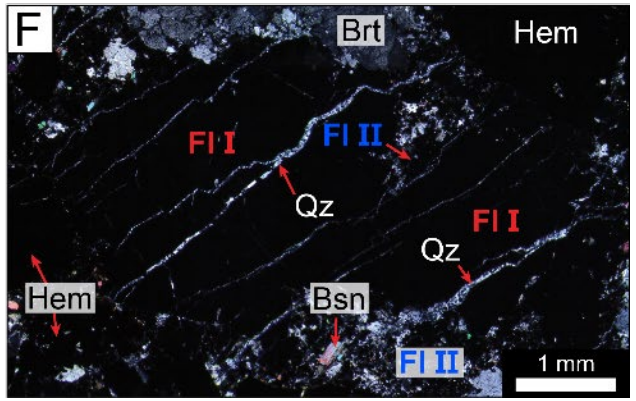




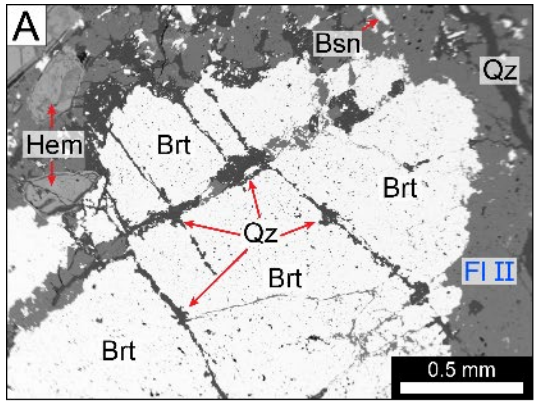


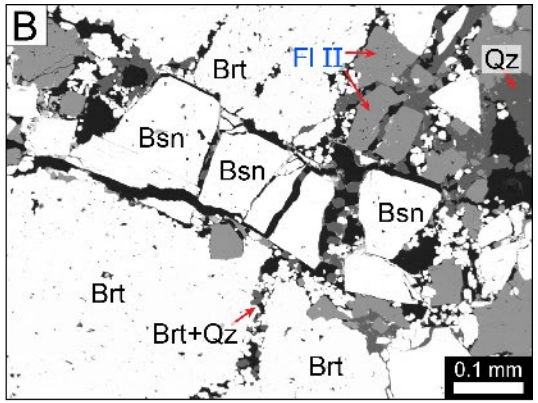


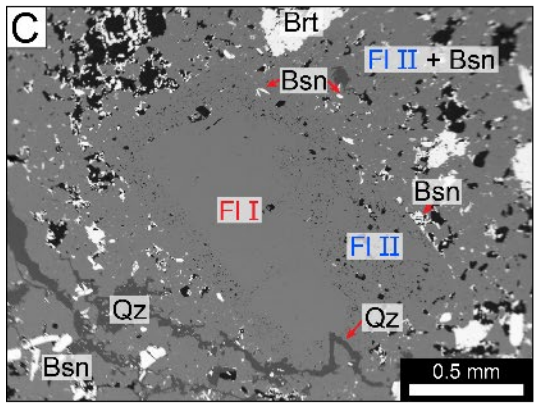


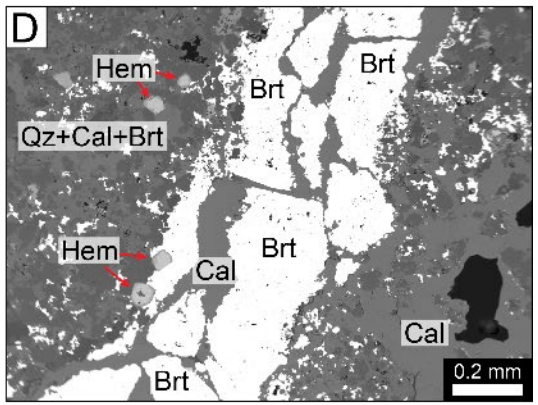


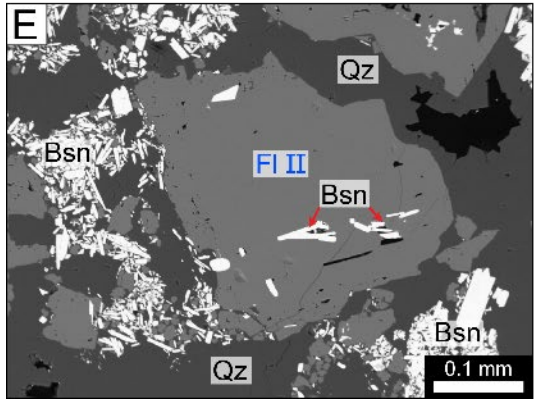
BSE-SEM imaging

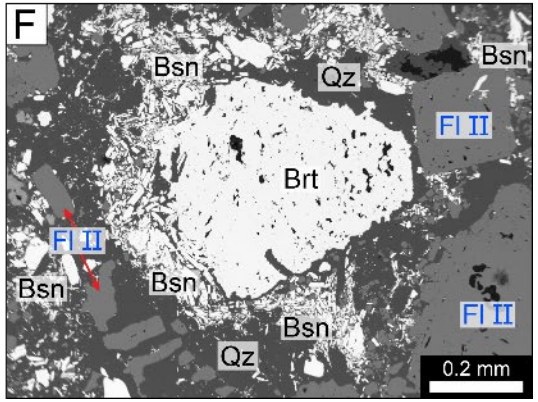




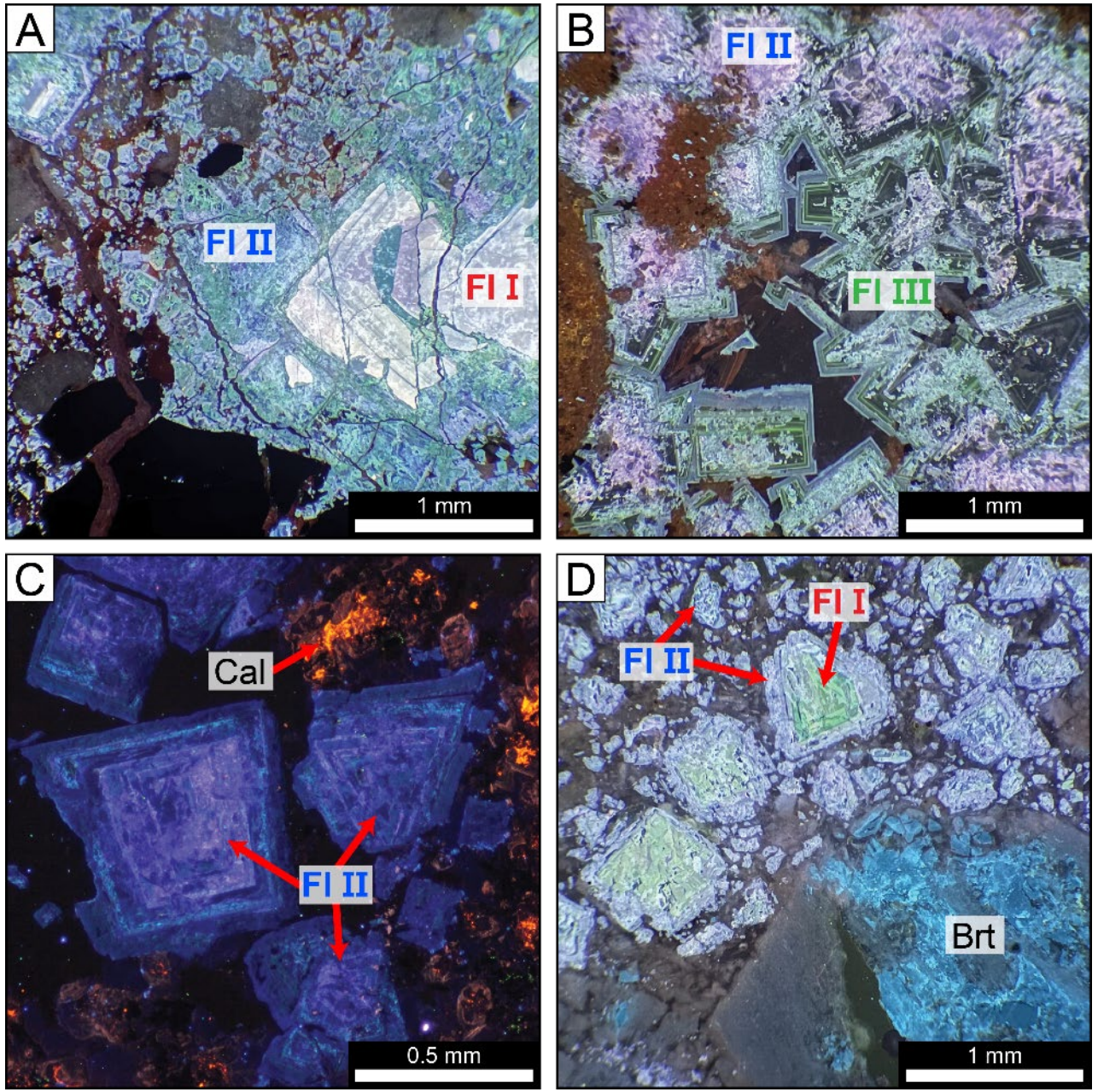




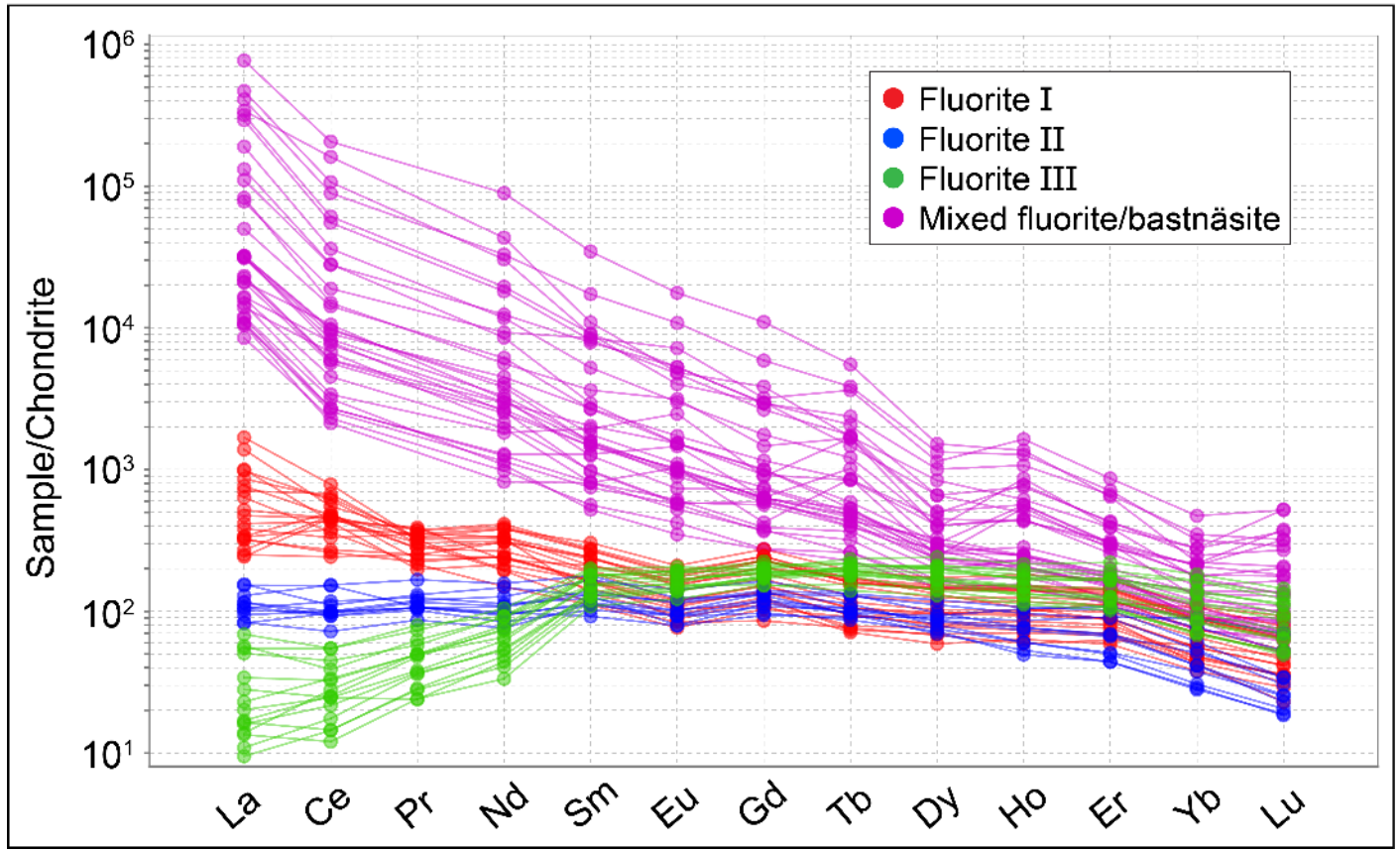




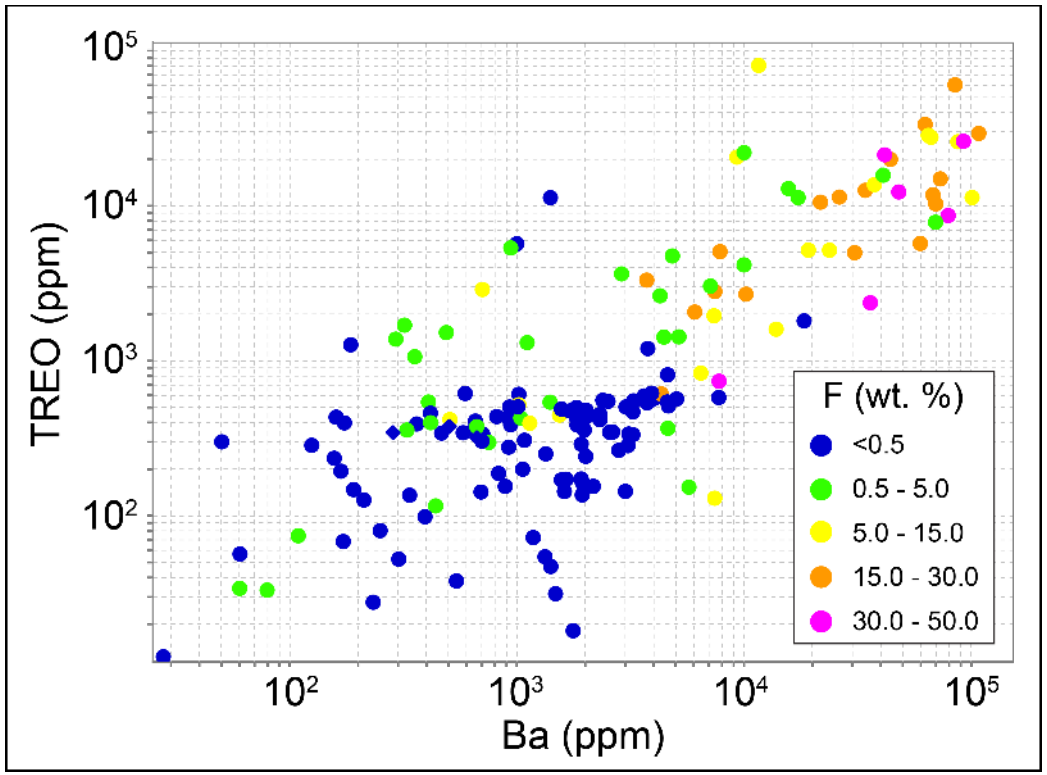
Identifying fluorite generations with cathodoluminescence microscopy



Fluorite trace element chemistry



Whole rock geochemistry



Generalized mineral paragenesis of fluorite veins and breccias