UPDATE ON CRITICAL MINERALS RESEARCH IN NEW MEXICO 2023

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New Mexico Tech

ACKNOWLEDGEMENTS

- Funding from
  - USGS EARTH MRI projects
  - DOE CORE-CM project
  - U.S. Bureau of Land Management (BLM) and New Mexico State Land Office (SLO) mineral resource assessment projects
- New Mexico Energy, Minerals and Natural Resource Department data
- Company annual reports
- Personal visits to mines and exploration sites
- Historical production statistics from U.S. Bureau of Mines, U.S. Geological Survey, N.M. Energy, Minerals and Natural Resource Department (NM MMD), company annual reports
- Students and staff at NM Tech

OUTLINE

- What are critical minerals?
- What critical minerals are found in New Mexico?
  - Where are potential future resources?
  - Briefly describe some of the ongoing research
- What are the challenges in producing critical minerals?

New Mexico Bureau of Geology and Mineral Resources

- A non-regulatory governmental agency (the state's geological survey) that conducts scientific investigations leading to responsible economic development of the state's mineral, water, and energy resources.
- We are a research division of New Mexico Tech.
- Founded in 1927 through state legislation.
- Currently 66 full and part time staff with a range of expertise. We have a number of active emeritus staff and mentor and employ a total of around 40 graduate and undergraduate students.

What are critical minerals?

Critical Minerals

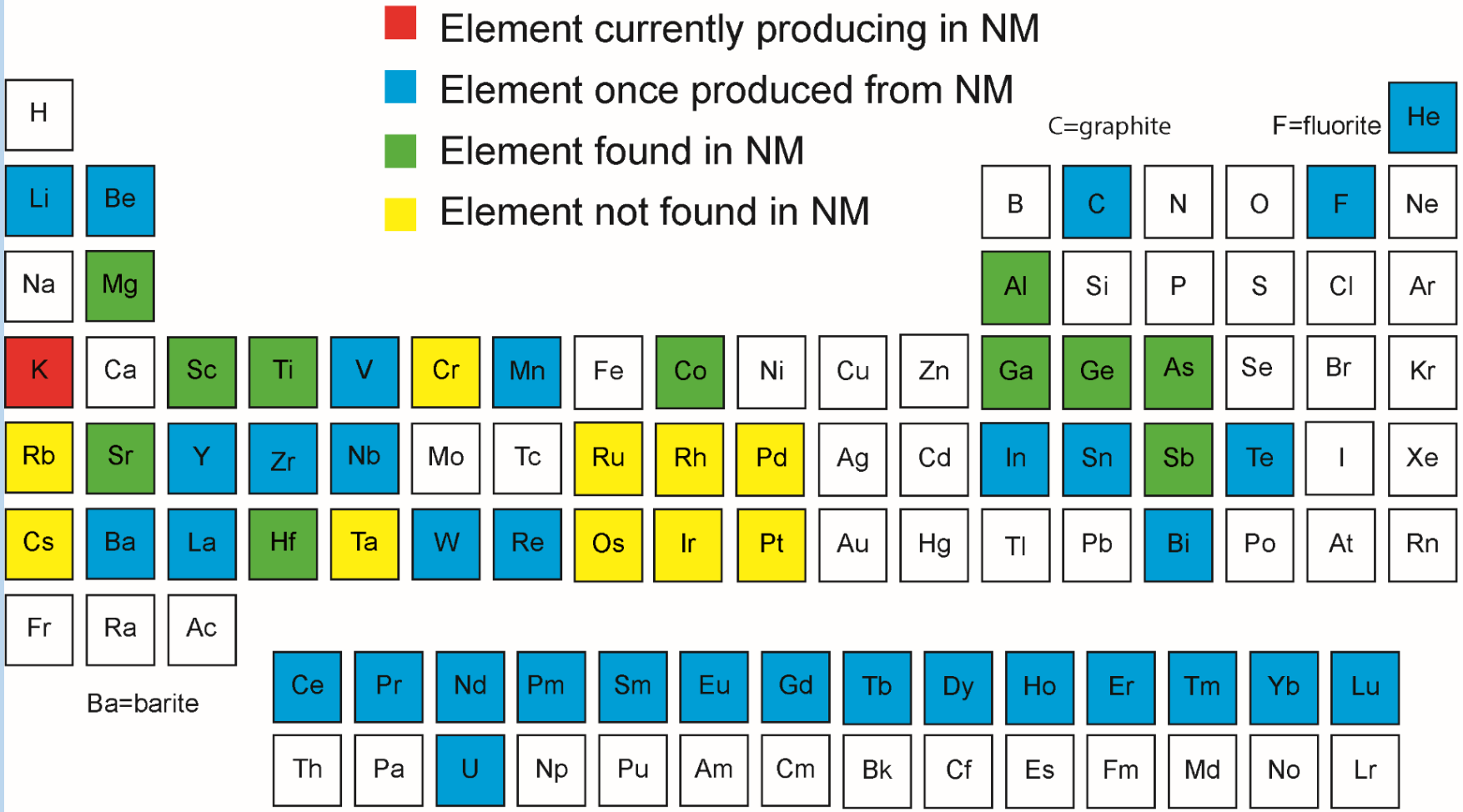
- *is a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security*
- The Departments of Interior, Energy, and Defense developed a list of critical minerals in 2019
- In 2021, the critical minerals list was modified by deleting uranium, helium, rhenium, and potash and adding nickel and zinc
- In 2023, Department of Energy added copper as a critical material

Critical Minerals are defined by

- Economic vulnerability
  - Essential to economic, strategic or national defense
  - Especially needed for the transition to non-CO_2 producing technologies
- High risk of supply disruption
  - Difficulty of permitting new mines
- Trade exposure
  - Dependency on foreign supplies (including refining)
  - Net import reliance of >50%

Critical Minerals in New Mexico

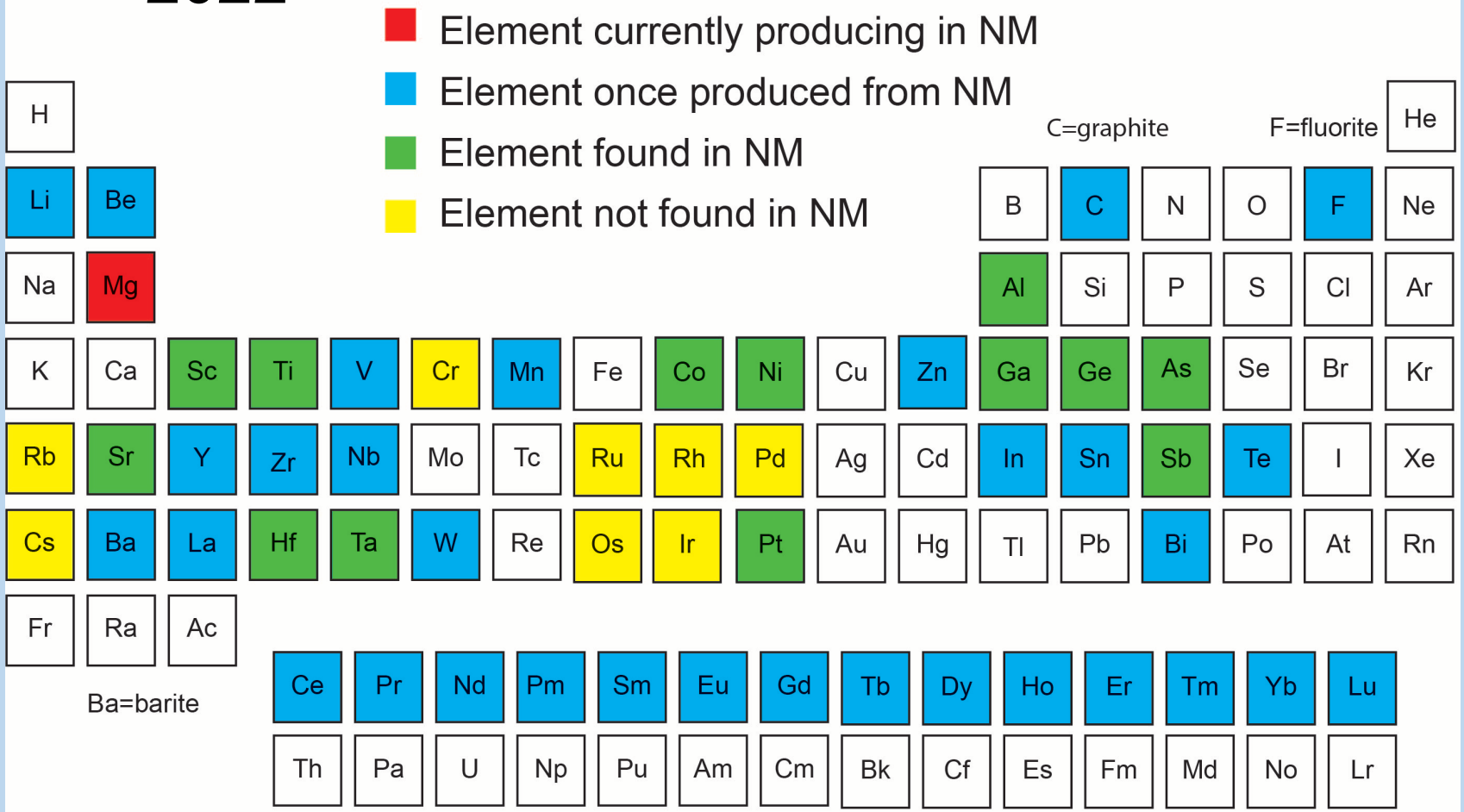
2020



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.

Critical Minerals in New Mexico

2022



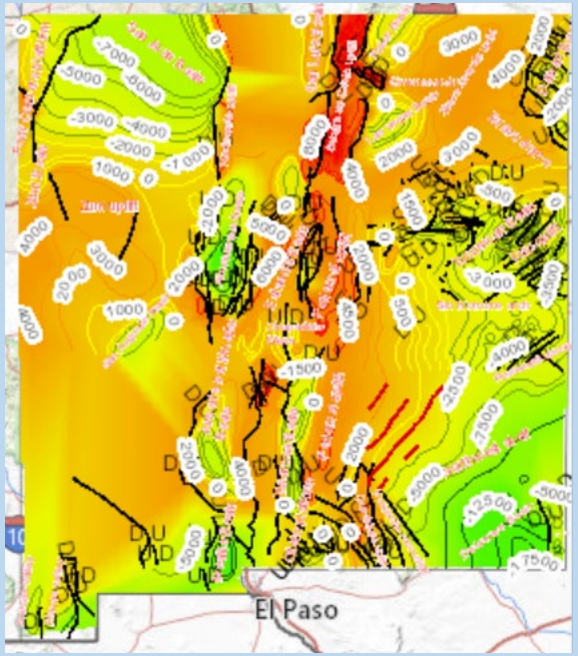
Note that any element or commodity can be considered critical in the future depending upon use and availability. Coal contains several of these critical elements.

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

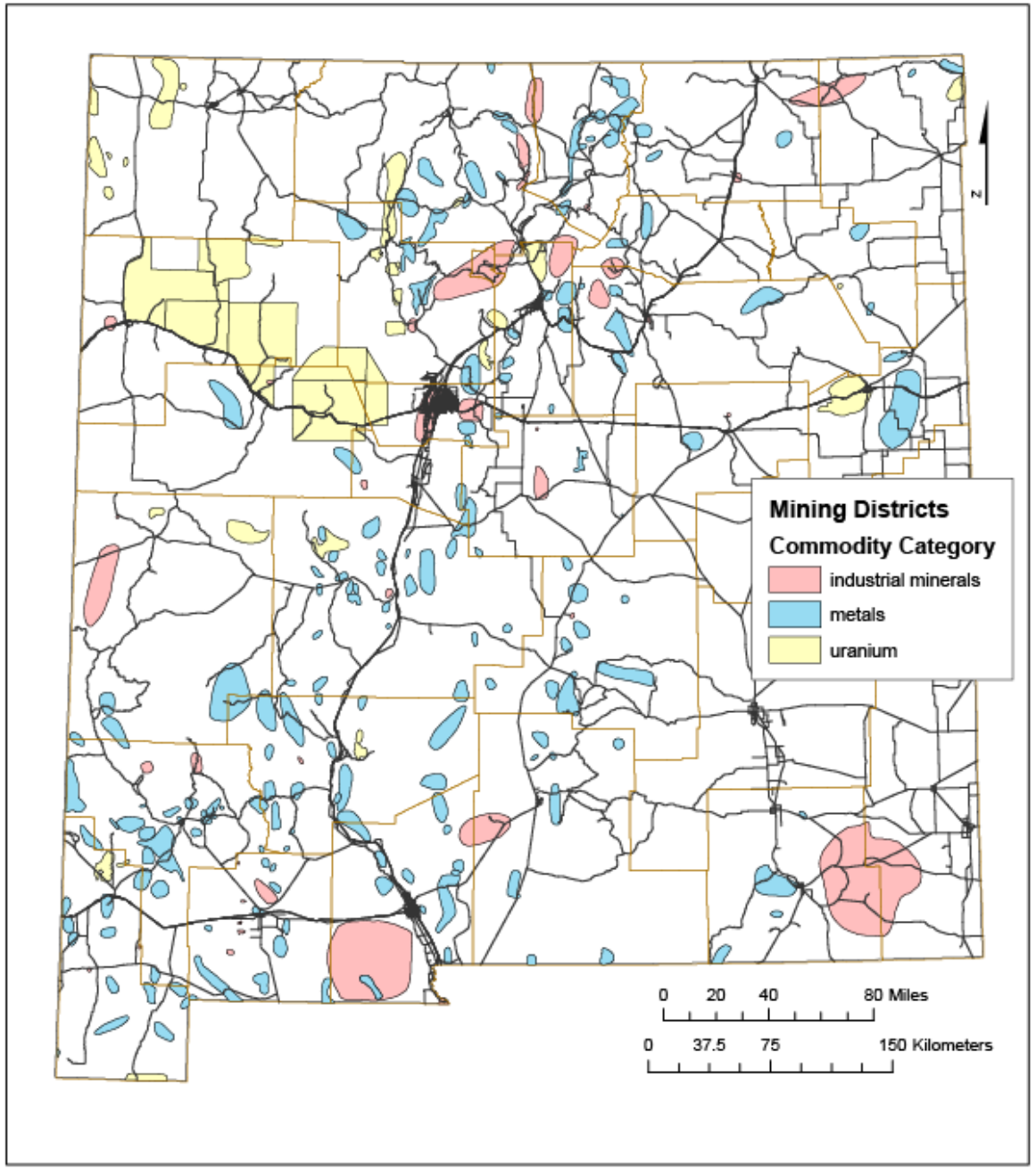
What critical minerals are found in New Mexico?

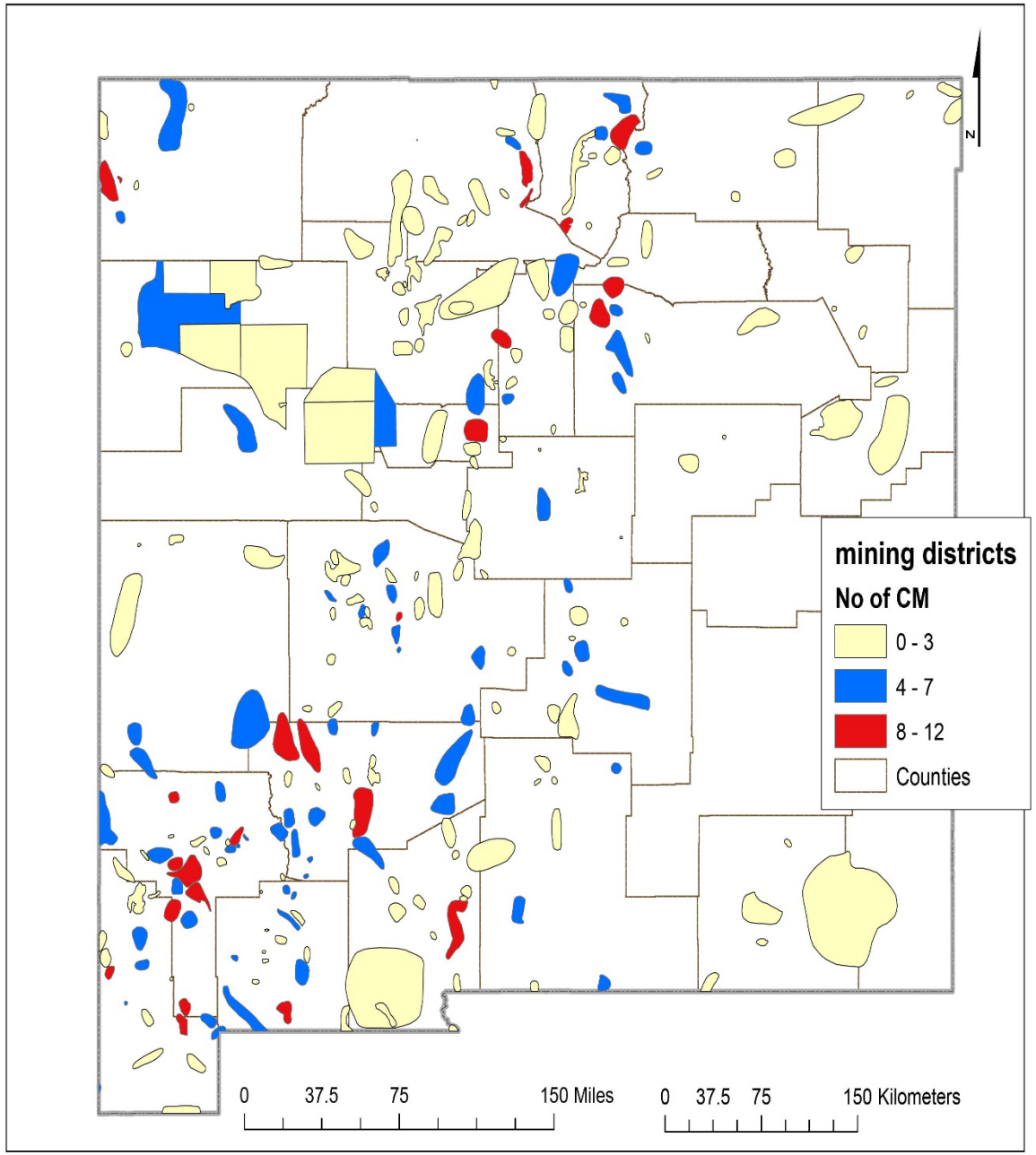
National Geological and Geophysical Data Preservation Program (NGGDPP)—Critical Minerals

- 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



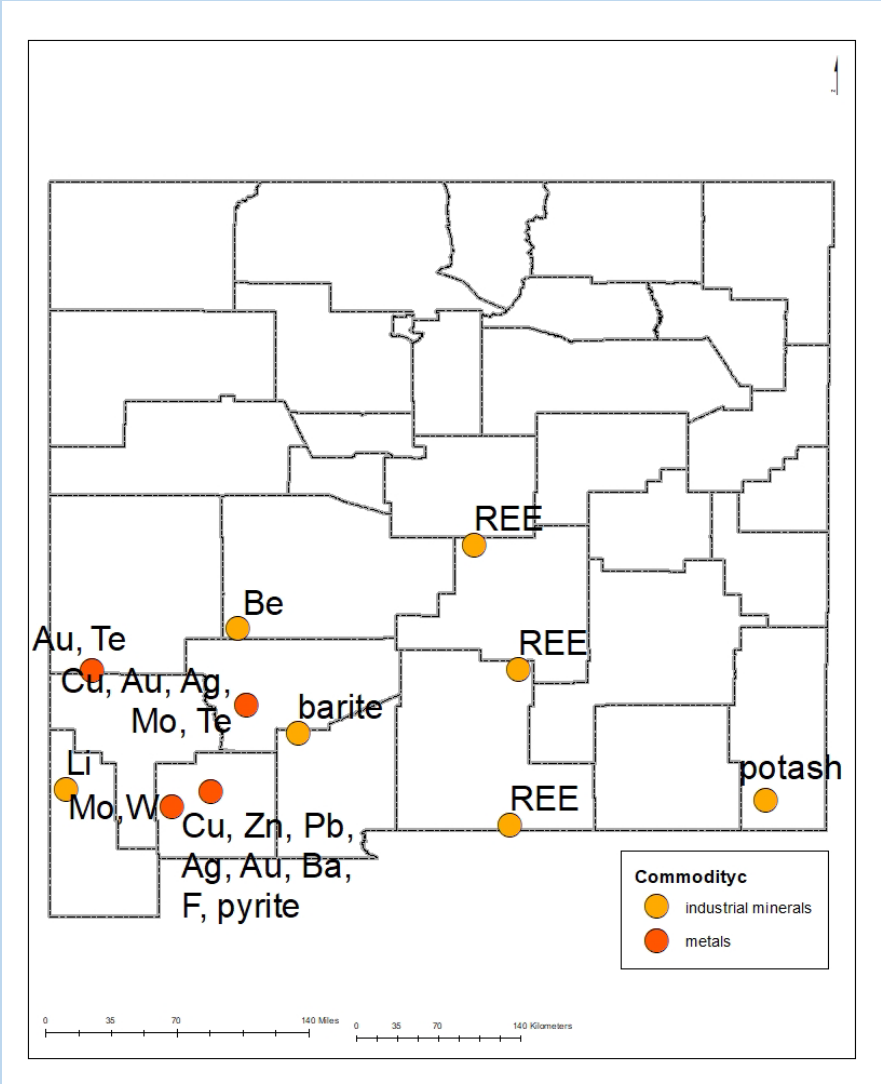
Depth to Precambrian basement


N
Mining Districts
Commodity Category
industrial minerals
metals
uranium
0 20 40 80 Miles
0 37.5 75 150 Kilometers


N
mining districts
No of CM
0 - 3
4 - 7
8 - 12
Counties
0 37.5 75 150 Miles
0 37.5 75 150 Kilometers

Selected exploration sites of critical minerals in New Mexico

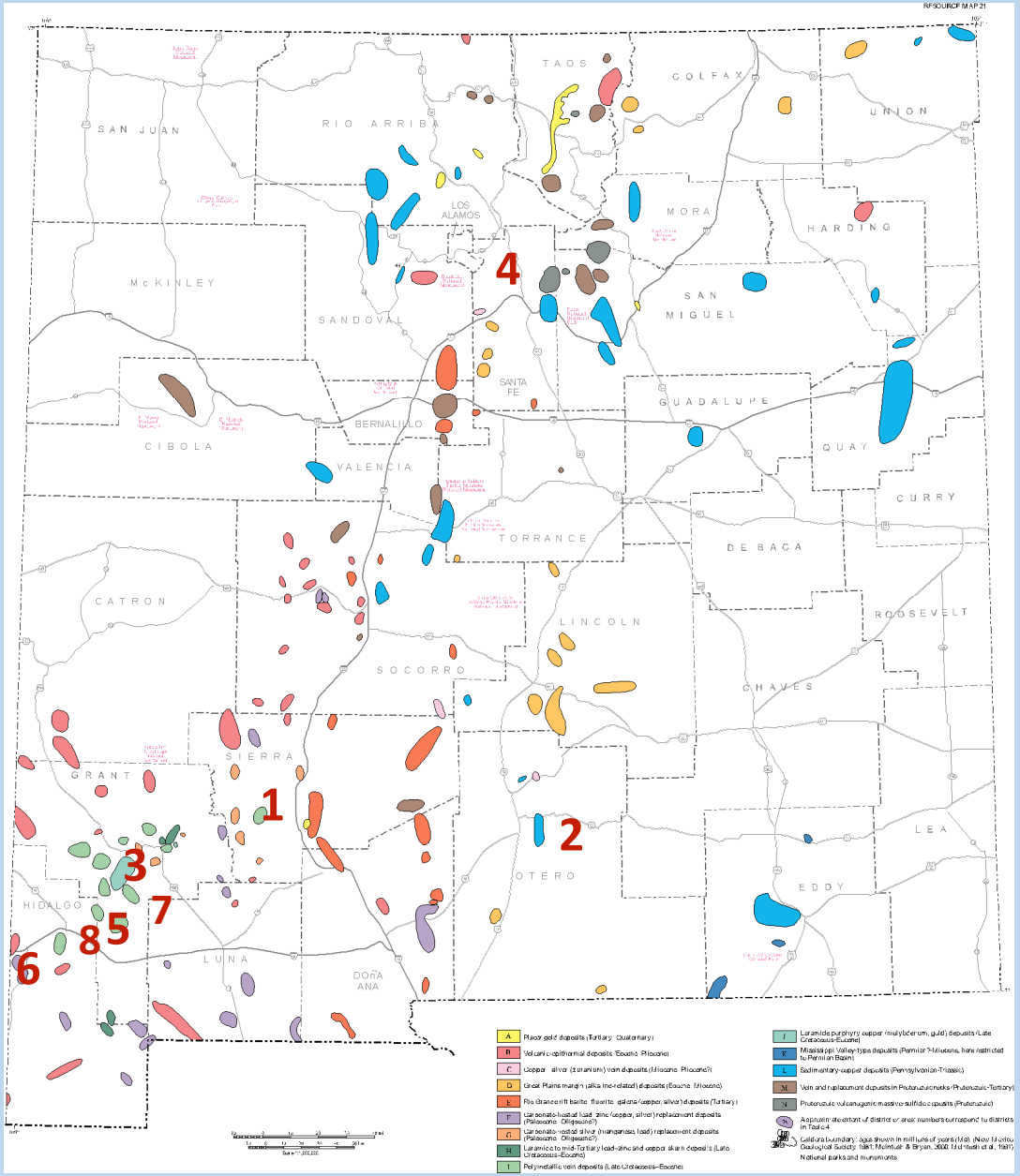
- Copper deposits can contain tellurium, vanadium, REE, rhenium, gallium, indium, germanium, zinc
- Uranium deposits in the Grants district contain vanadium, molybdenum with potential rhenium, potential REE
- Exploration for other critical minerals include REE, tellurium, lithium, beryllium, cobalt
- Other critical minerals were once produced from New Mexico (tin, vanadium, manganese, fluorspar, barite, graphite, zinc)



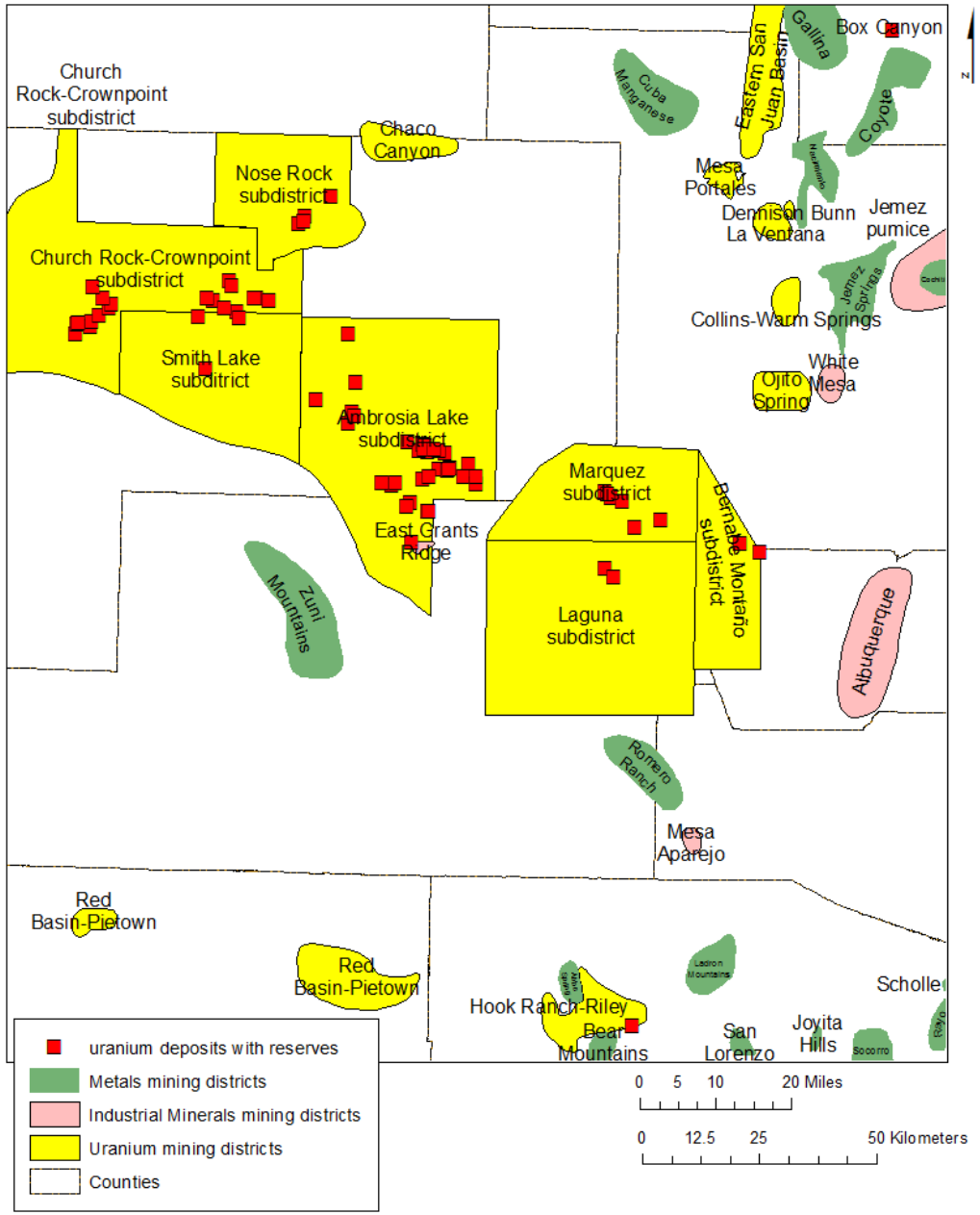
From NM Mining and Minerals Div. and NMBGMR databases, company web sites

Potential Copper Deposits

1. Copper Flat (98.1 million short tons at 0.31% Cu, 0.009% Mo, 0.003 oz/short ton Au, and 0.07 oz/ short ton Ag)
2. Orogrande
3. Hanover Mountain (80 mill st reserves at 0.38% Cu)
4. Copper Hill, Picuris district (46.5 mill st of ore at 0.42% Cu)
5. Lone Mountain (7.5 mill st at 2-3% Cu, 1.2% Pb, 4-5% Zn, 203 opt Ag, .01-.02 opt Au)
6. McGhee Peak, Pelloncillo Mountains
7. Mimbres, Grant Co
8. Oak Grove, Grant Co



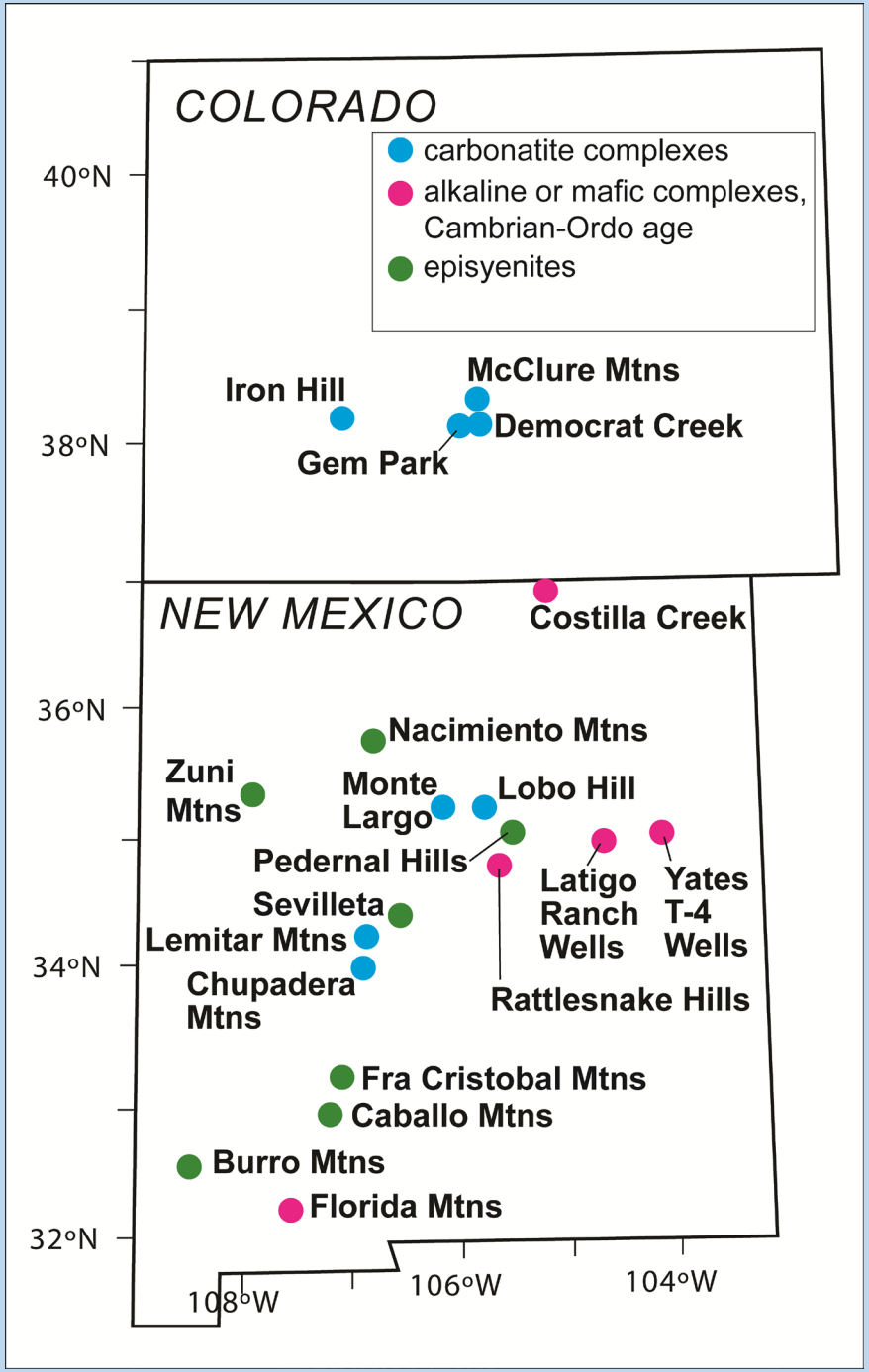
Potential critical minerals include tellurium, vanadium, REE, rhenium, gallium, indium, germanium, zinc



Deposits with uranium resources in New Mexico (McLemore and Chenoweth, 2019). Only major mines and deposits are included here.

Uranium deposits contain vanadium, molybdenum with potential rhenium, potential REE

Summary of critical minerals research in New Mexico



Cambrian Carbonatites and Episyenites (or metasomatic rocks) in New Mexico and Colorado

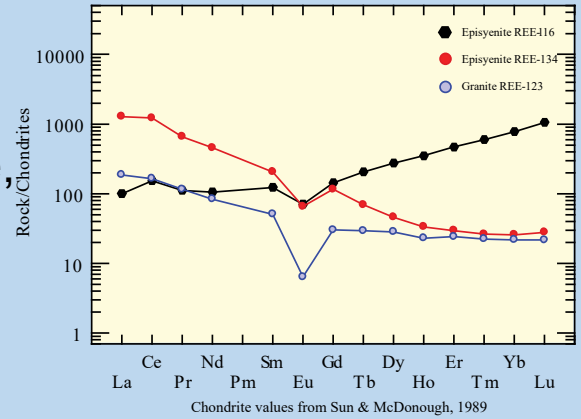
Episyenite is a term used to describe altered rocks that were desilicated and metasomatized by alkali-rich fluids solutions

Episyenites in Longbottom Canyon, Caballo Mountains

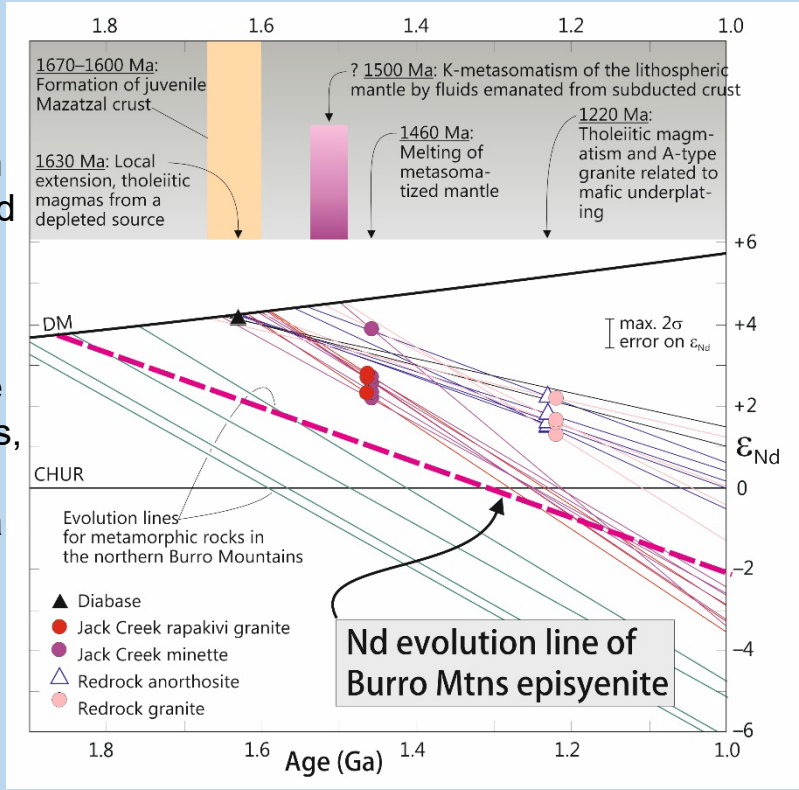
USGS MRERP
Mapping and origin of REE in Cambrian-Ordovician Episyenites in the Caballo and Burro Mountains, southern NM (2012-2023)

Virginia McLemore, Annelise Riggins, Nelia Dunbar, Matthew Heizler, William McIntosh, Kwame Frempong, Adam Smith, Tapani Ramo (Univ Helsinki)

- 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



Epsilon Nd versus age diagram showing evolution line of episyenite compared to Redrock gr, Jack Creek gr and metamorphics. The line is between the time-intergrated evolution of the granites and metamorphics, suggesting that the episyenite may comprise a magmatic source and a fluid component from the upper crust Matzazal metamorphics.

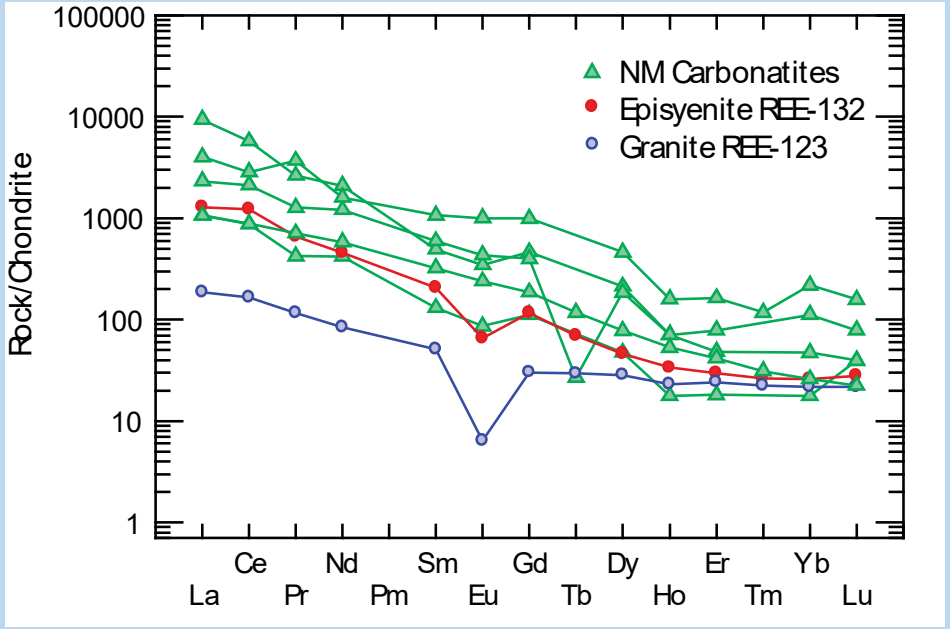


Conclusions

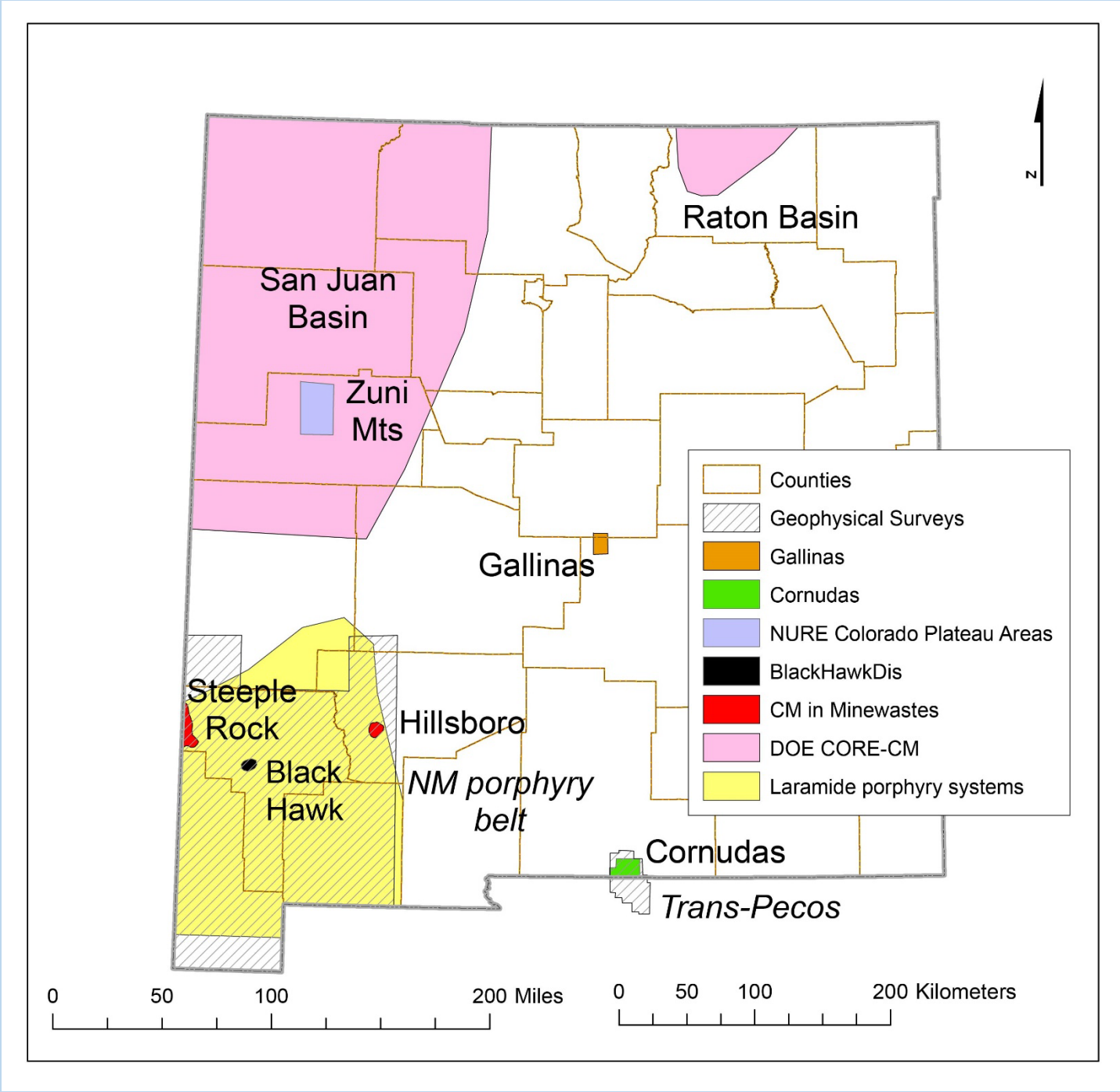
- Field relationships and whole-rock chemistry (>15% K_2O) suggest episyenites are metasomatic in origin
- Fracture-filling episyenites indicates fluid flow along fractures
- Feldspar compositions suggest low temperature formation

Contact between granitic gneiss and episyenite in Caballo Mtns

Clasts of episyenite in the basal transgressive conglomerate of the Bliss Formation

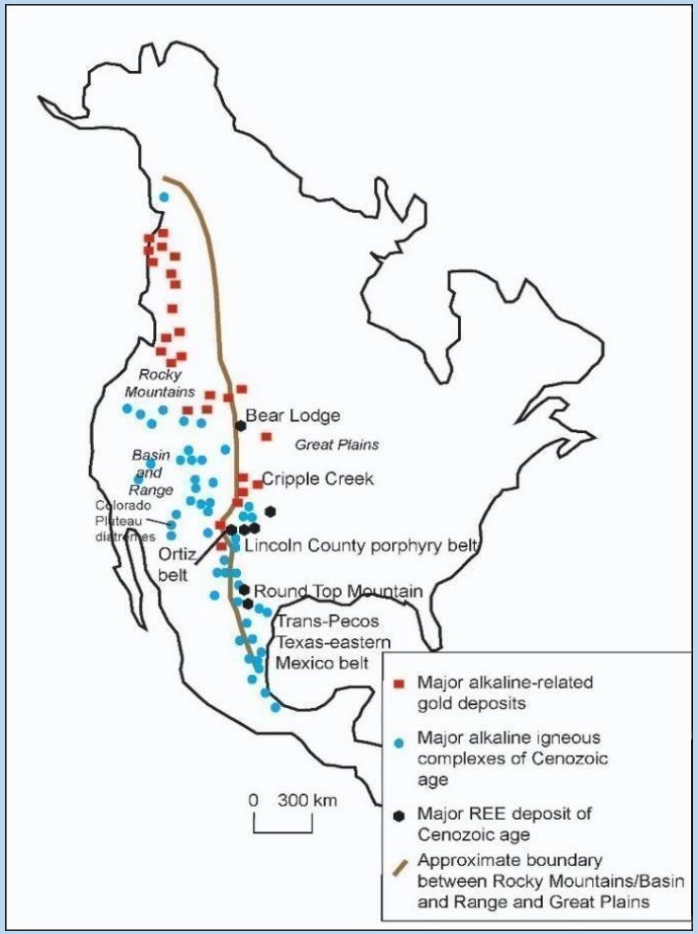


USGS EARTH MRI and DOE CORE-CM projects in New Mexico



Tertiary alkaline igneous-related REE deposits in New Mexico

- Part of a belt of alkaline-igneous rocks
- Extends along the eastern edge of the Rocky Mountains and Basin And Range Provinces
- From Alaska And British Columbia southward into New Mexico, Trans-Pecos Texas, And Eastern Mexico
- These alkaline rocks contain relatively large quantities of important commodities such as, gold, fluorine, zirconium, rare earth elements (REE), tellurium, gallium, and other critical minerals

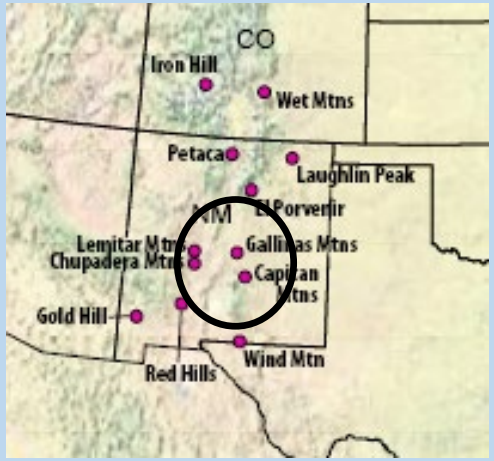


Extent of the North American Cordilleran alkaline-igneous belt (Woolley, 1987; Mutschler et al., 1991; McLemore, 1996, 2018).

Tertiary carbonatites are found in the North American Cordilleran alkaline-igneous belt in Bear Lodge (WY), Laughlin Peaks (NM), and eastern Mexico

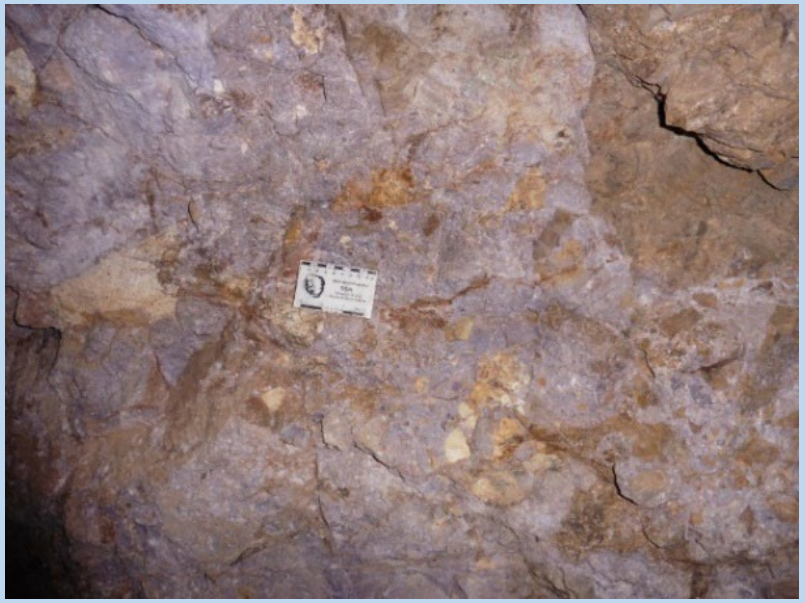
USGS Earth MRI Project Mapping REE in Gallinas Mountains, Lincoln County, NM (2019-2021)

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

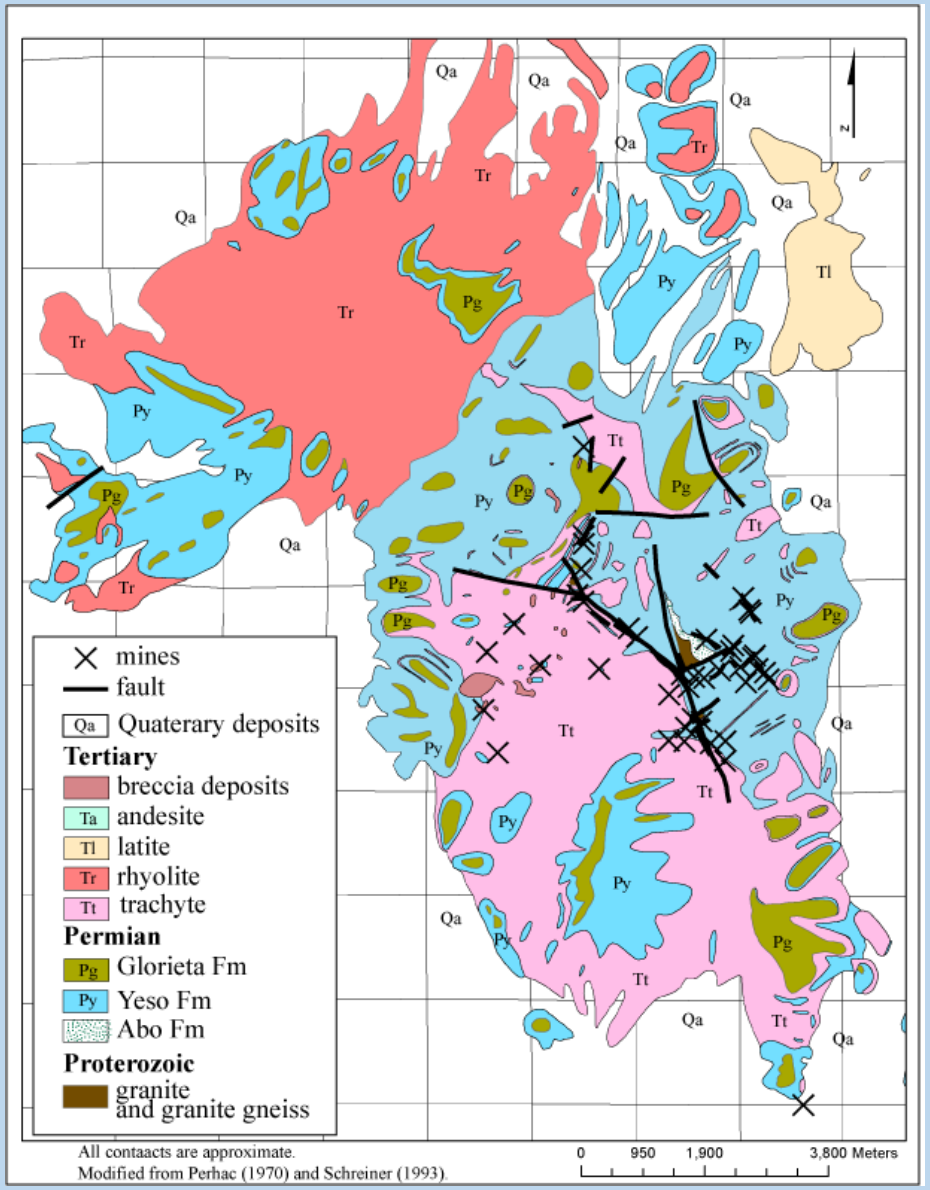


$^{40}Ar/^{39}Ar$ Geochronology Results

- Early magmatic activity (38.5-29.3 Ma)
- Alkaline intrusive flare-up (28.8-28.0 Ma)
- Alteration and younger intrusions (25.8-24.4 Ma)

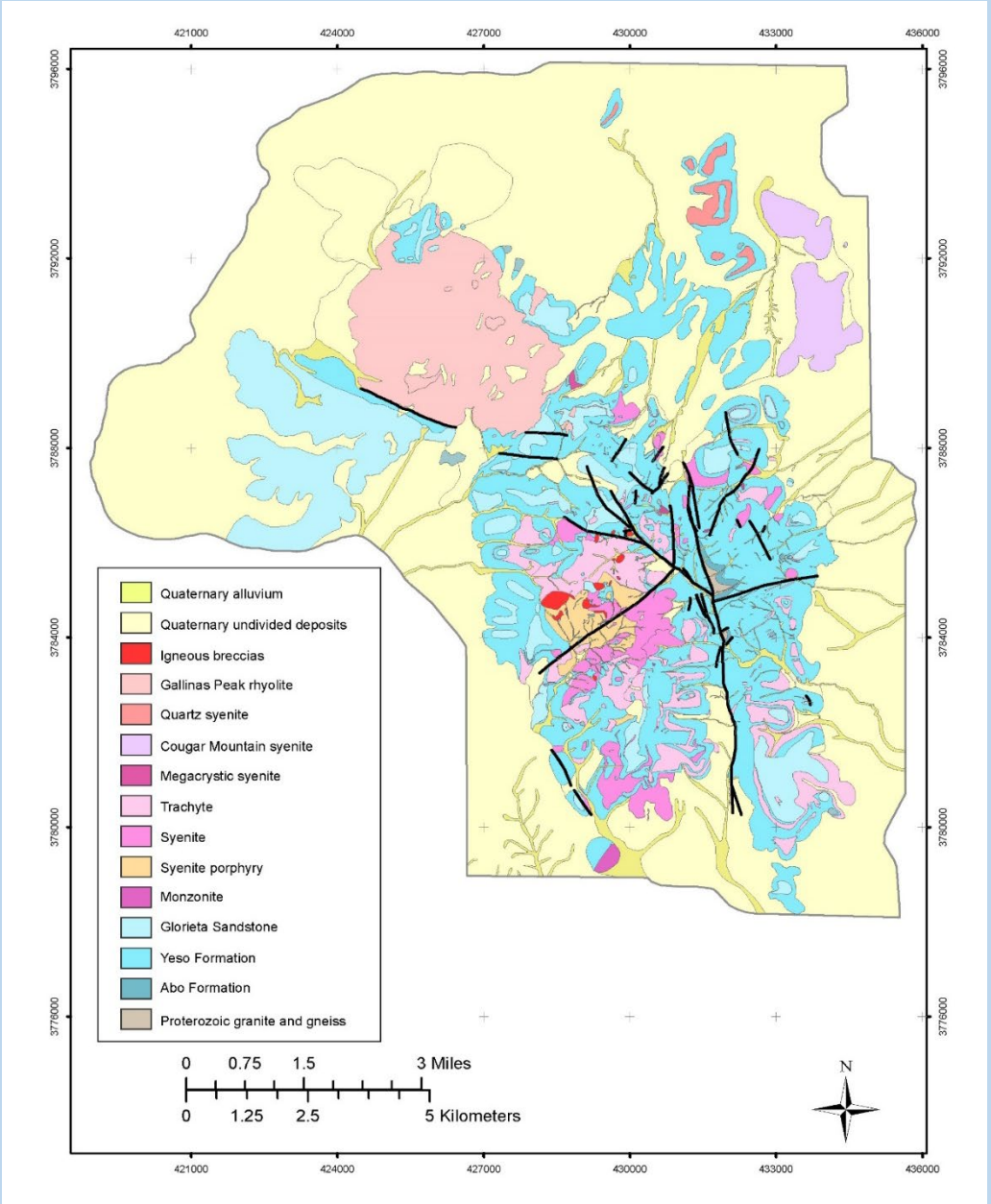


Yellow bastnäsite [$(Ce,La)(CO_3)F$] in purple fluorite breccia from the Red Cloud mine (length is ~8 mm). Bastnaesite is the most common REE mineral mined in the world today.



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



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

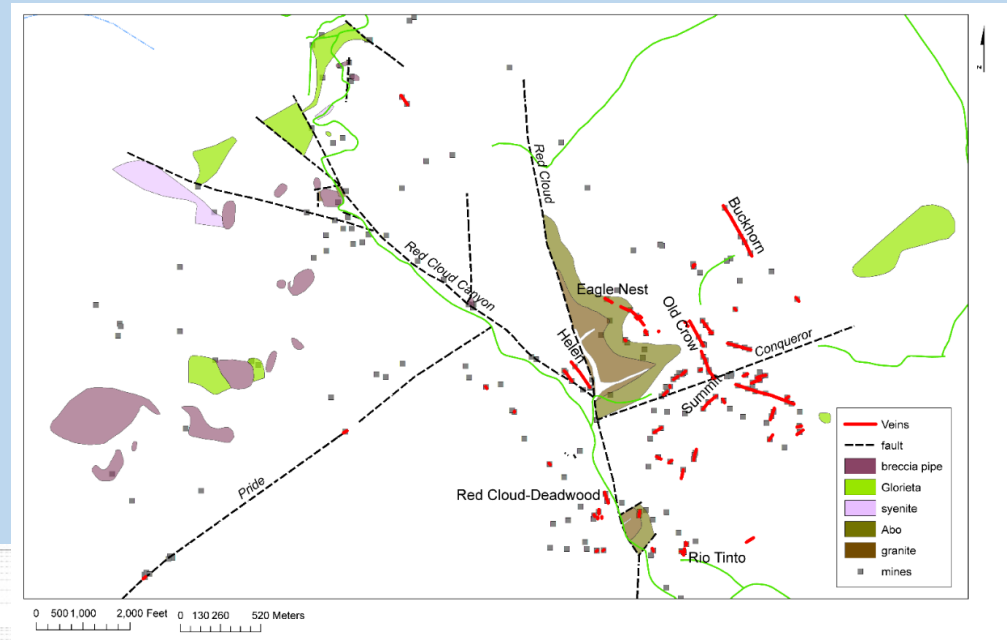
Conclusions

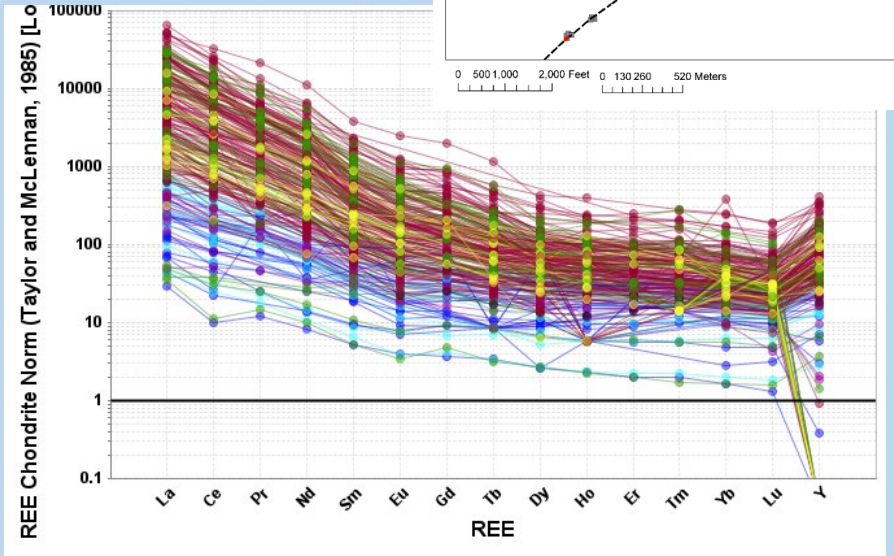
Seven types of mineral deposits (* past production)

- *Hydrothermal breccia and fissure veins (red)
- F replacements/disseminations
- Magamtic intrusive breccia pipes (maroon)
- *Fe skarn-contact replacement deposits
- Carbonate breccias
- Hypogene oxidation
- Supergene oxidation

Mapping, mineralogy, geochemistry suggest a carbonatite at depth

Major faults are not mineralized with the exception of the Pride and Buckhorn faults

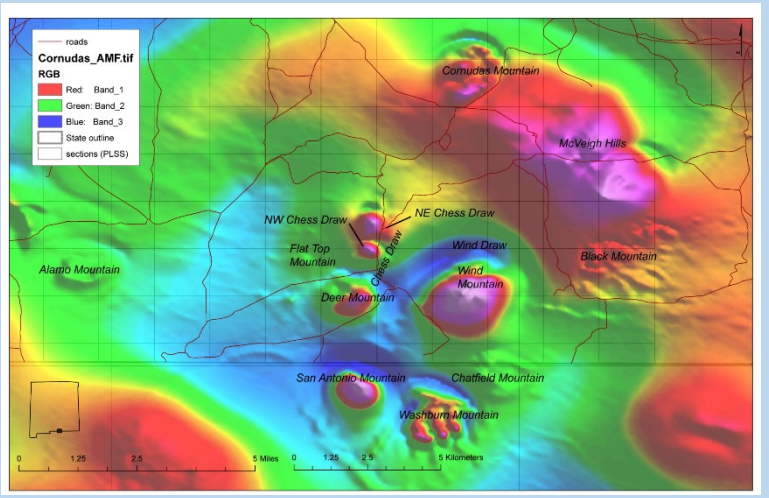




USGS Earth MRI Project Mapping REE in Cornudas Mountains, Otero County, NM (2020-2023)

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

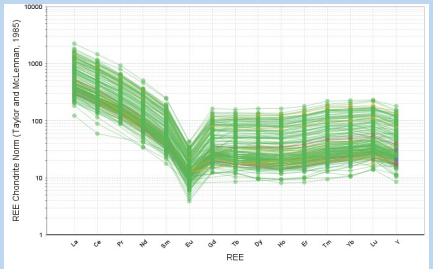
IN COOPERATION WITH TEXAS



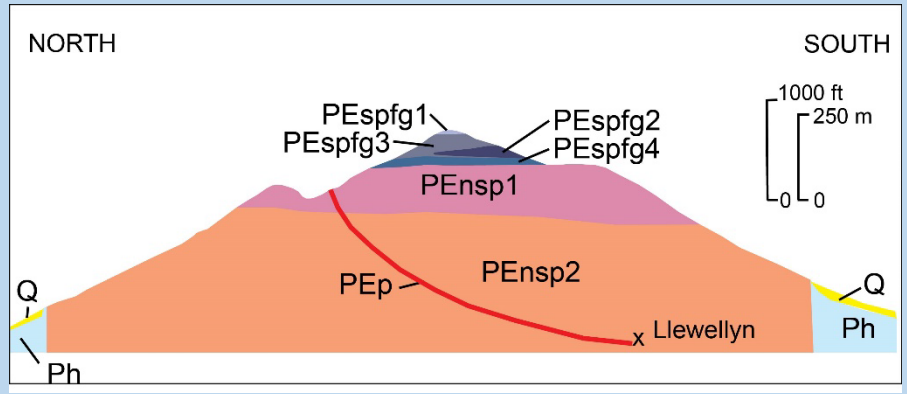
- Finishing up the GIS geologic map
- Differential cooling of the magma resulted in the textural variations at Wind Mountain
  - 36.32±0.15 Ma
- Eudialyte is primary REE mineral
- Chemical analyses—3790 ppm total REE, 2332 ppm Nb, 92 ppm Be, and 3137 ppm F
- Industry provided core, chemistry

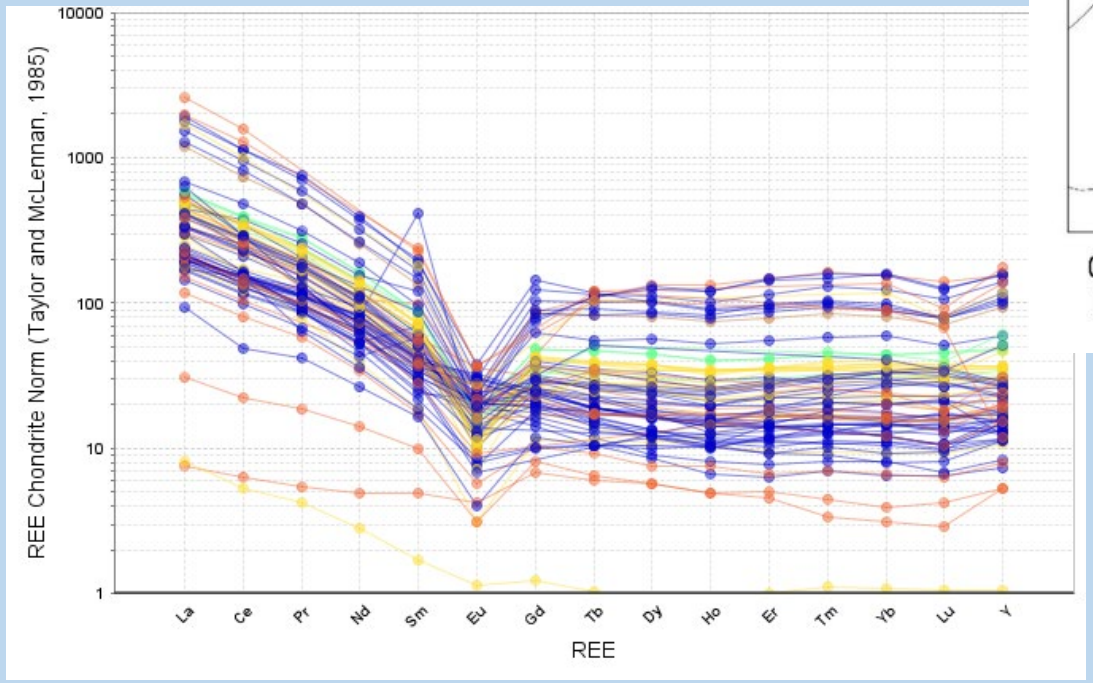
Pink eudialyte in black phonolite dike in contact with skarn

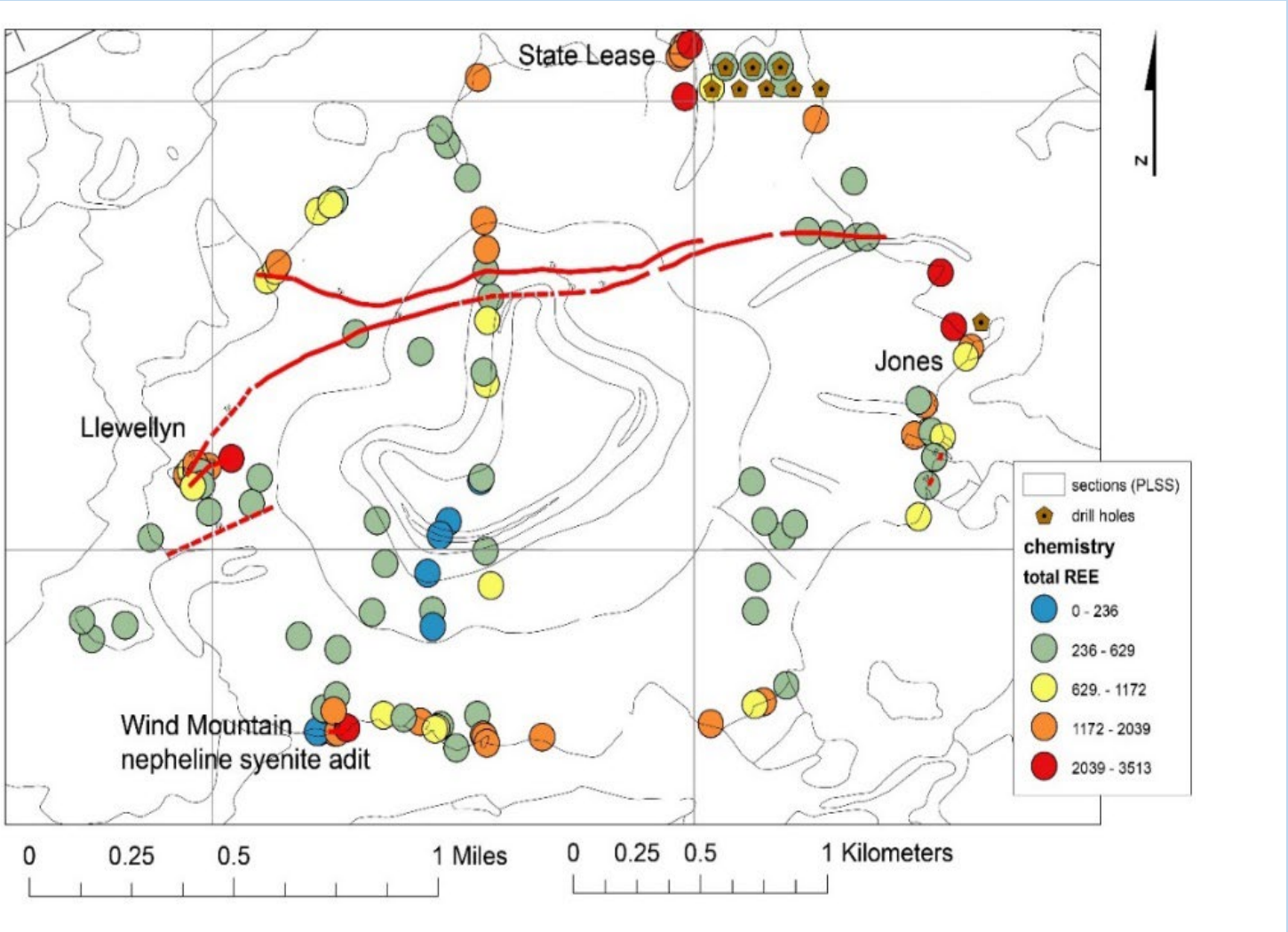
Map of the anomalous magnetic field (AMF) of the Cornudas Mountains (Bultman, 2021, 2022) showing intrusive laccoliths and plugs (red anomalies) that extend deep into the subsurface, with additional intrusions potentially buried in the subsurface.



Wind Mountain laccolith







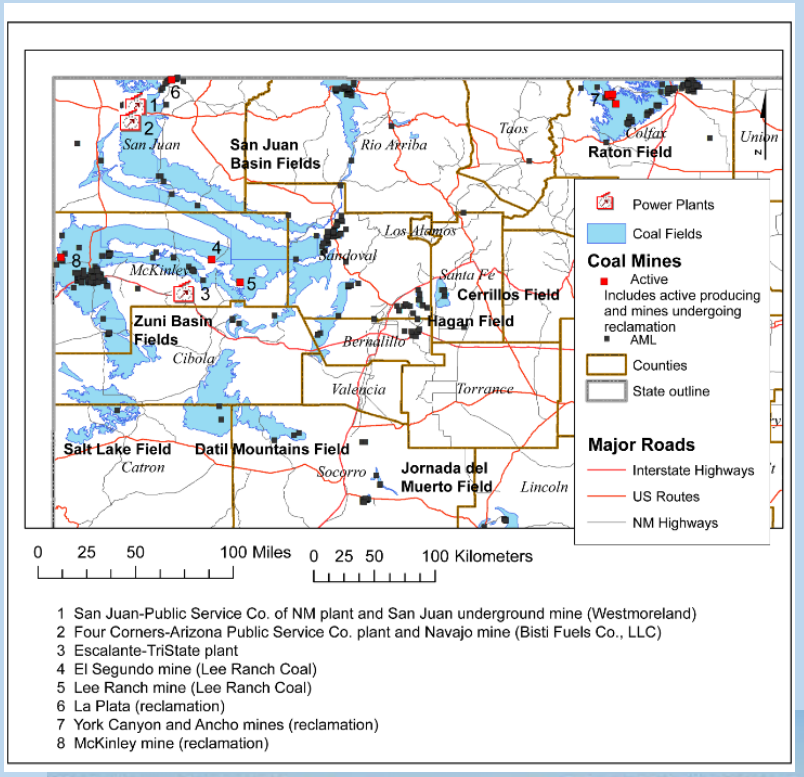
Samples from Wind Mountain

DOE CORE-CM project—San Juan River-Raton Basin, New Mexico DOE contract (Oct 2021-Sept 2024)

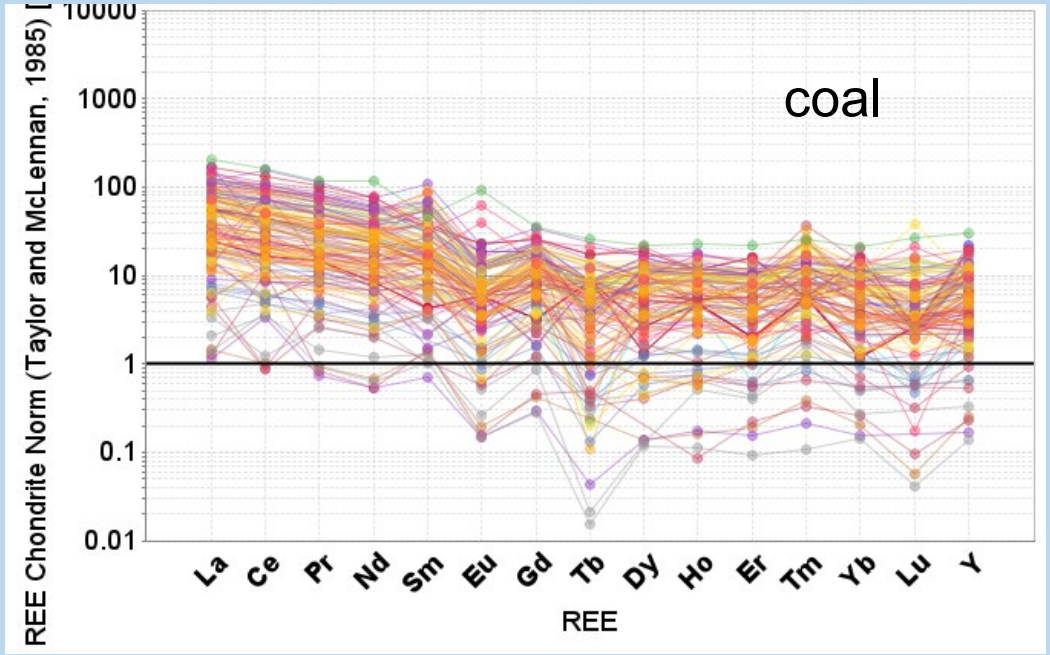
Virginia T. McLemore, Evan Owen, Navid Mojabai, Shari Kelley, many students and staff

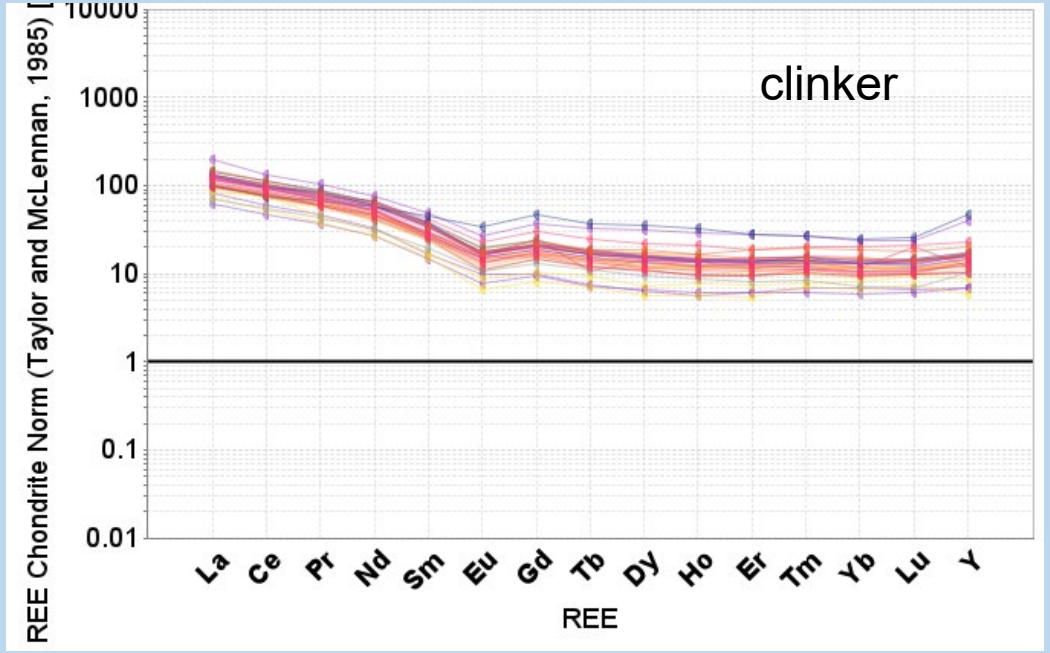
- **CORE-CM=Carbon Ore, Rare Earth and Critical Minerals**
- Identify and quantify the distribution of REE and CM in coal beds and related stratigraphic units in the San Juan and Raton basins
- Identify, sample, and characterize coal waste stream products
- Sandia: Microscale characterization techniques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

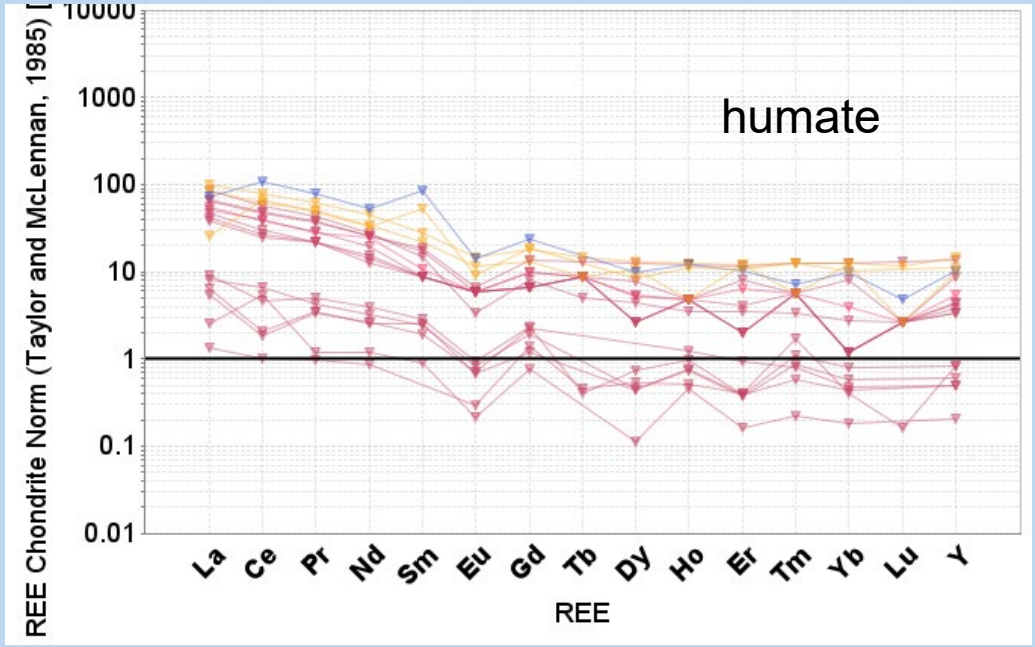
Industry provided access to mines

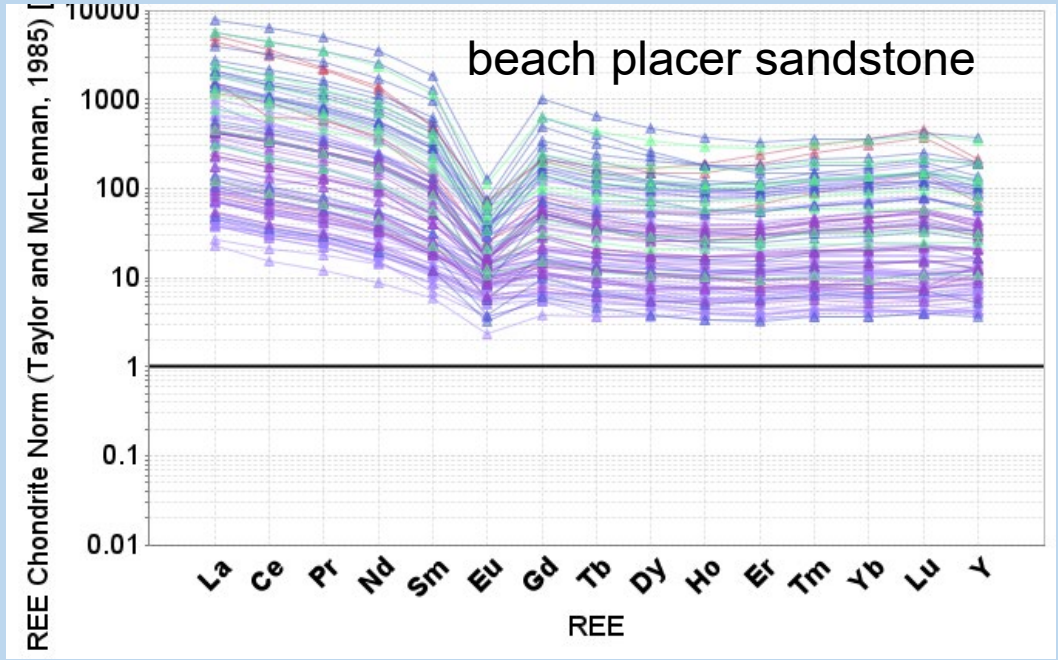


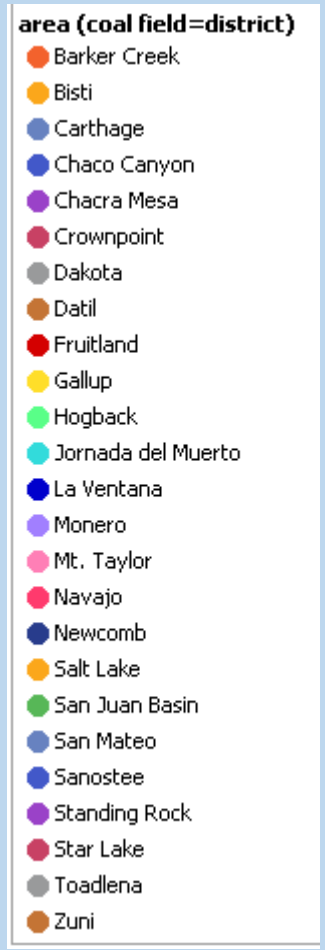
REE chondrite-normalized REE of samples by coal fields in the San Juan Basin









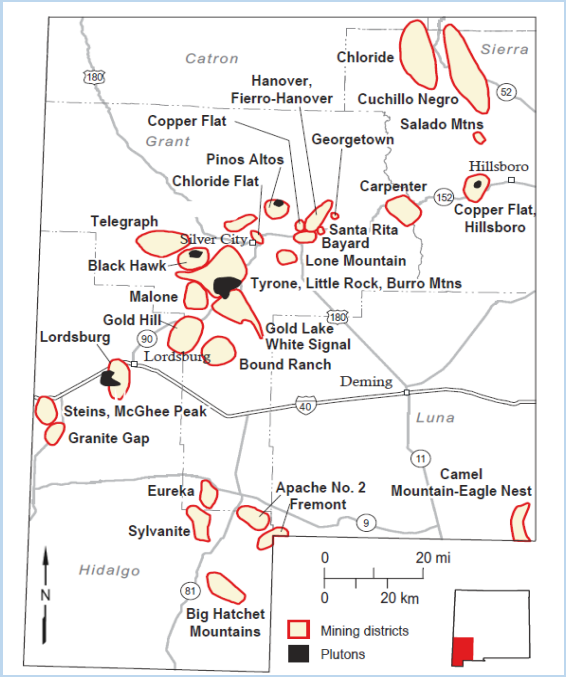


USGS Earth MRI Project Critical minerals in Laramide porphyry copper deposits (Jan 2023—Dec 2025)

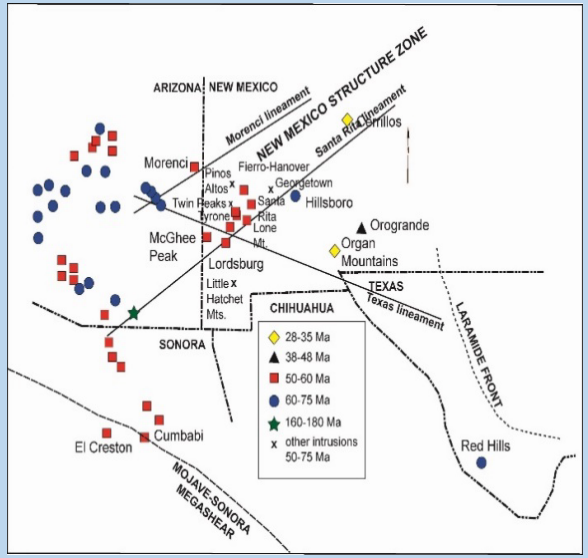
Virginia T. McLemore, Evan Owen, Nels Iverson, Shari Kelley, and many students

IN COOPERATION WITH ARIZONA GEOLOGICAL SURVEY

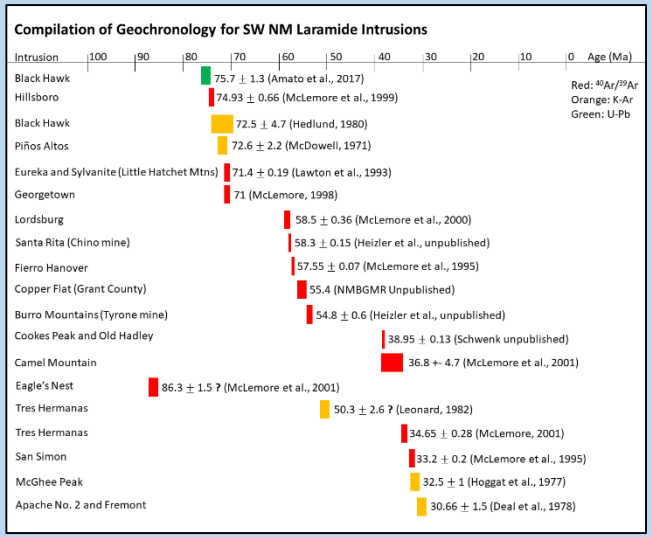
- What are the ages
- Where in the porphyry copper deposits are there critical minerals
- Cooperate with industry

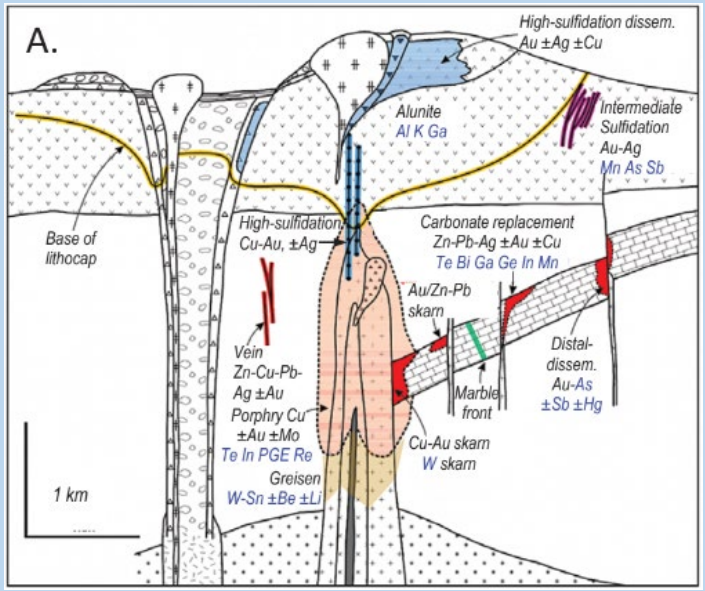


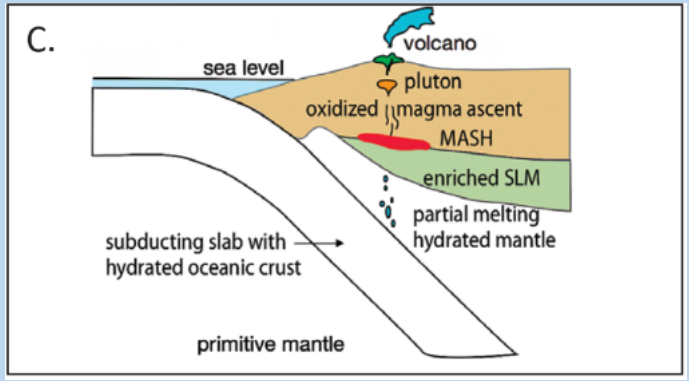
Districts with Laramide deposits and plutons (black) in southwestern New Mexico



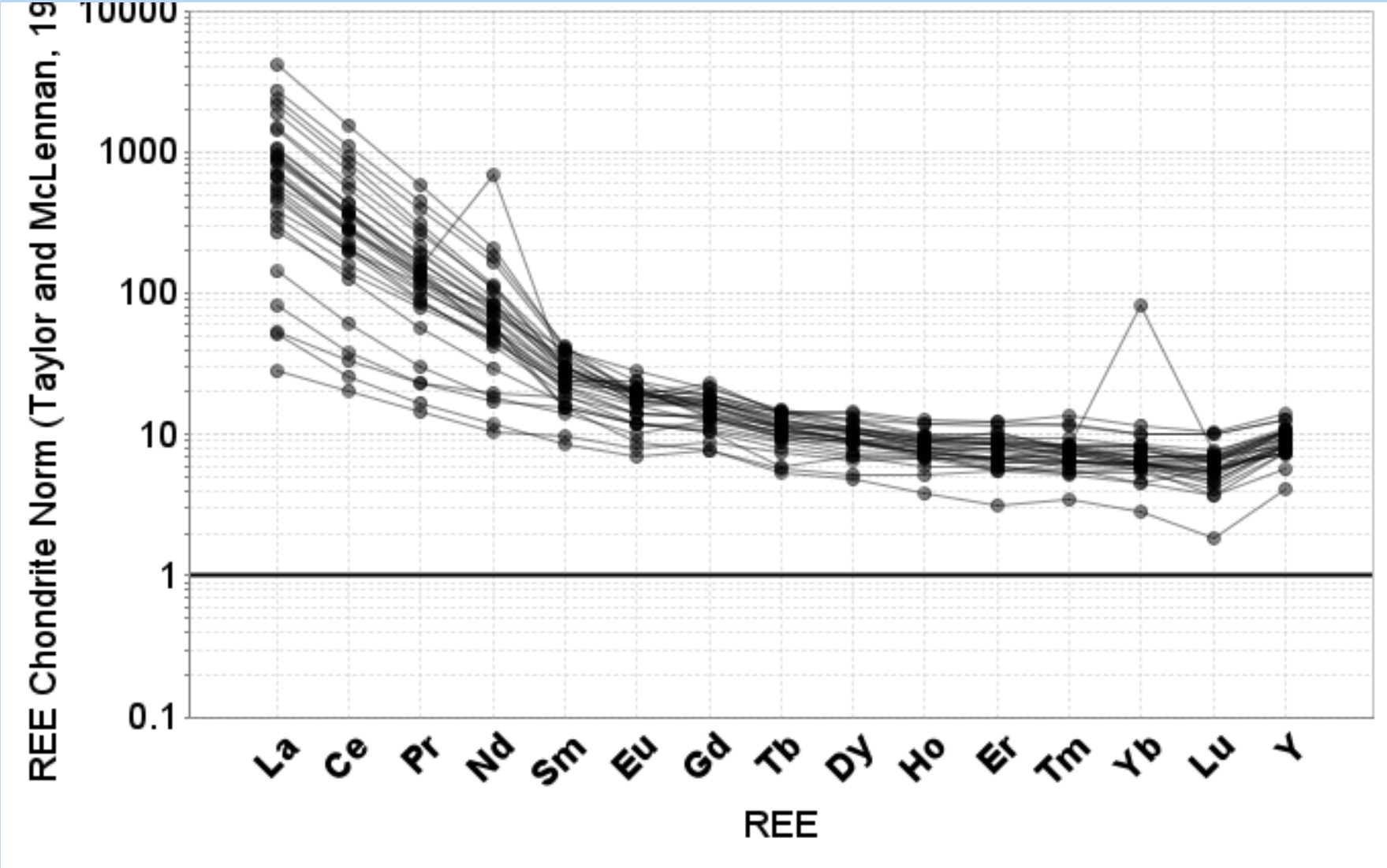
Laramide porphyry copper deposits in southwestern United States and northern Mexico. The Copper Flat porphyry copper deposit is in the Hillsboro district.







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)

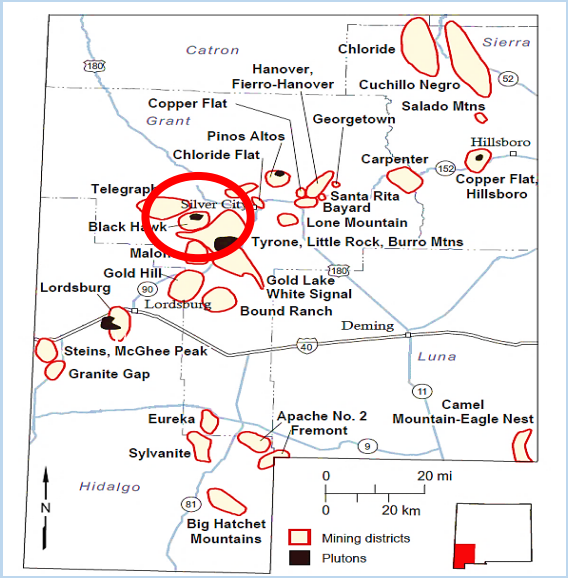


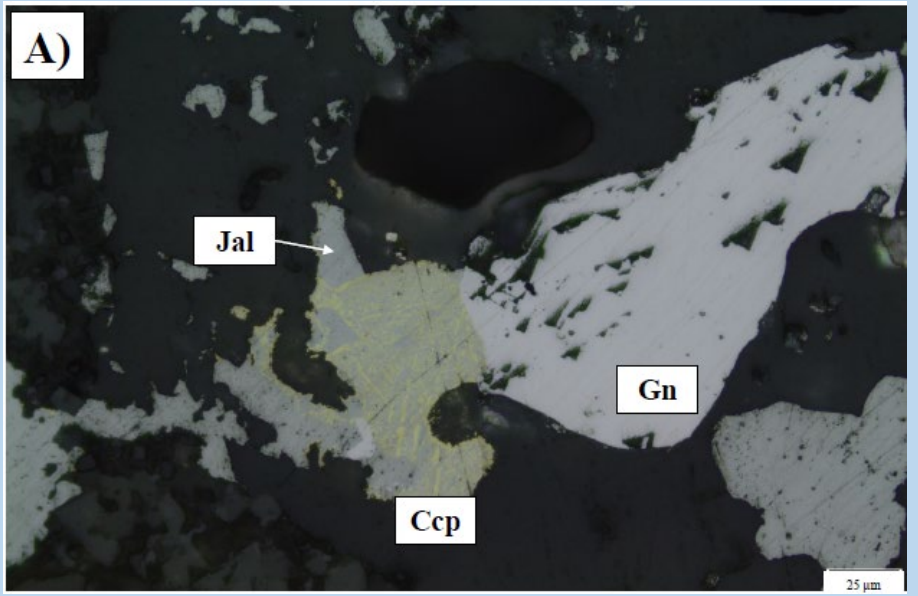
Southern Silver Oro Project, Eureka district, Little Hatchet Mountains
https://southernsilverexploration.com/news/2023/southern-silver-reports-enriched-rare-earth-elements-in-hole-or22-012-extends-claims-to-cover-new-copper-and-ree-skarn-crd/

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



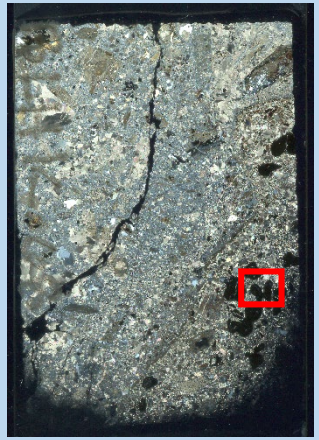


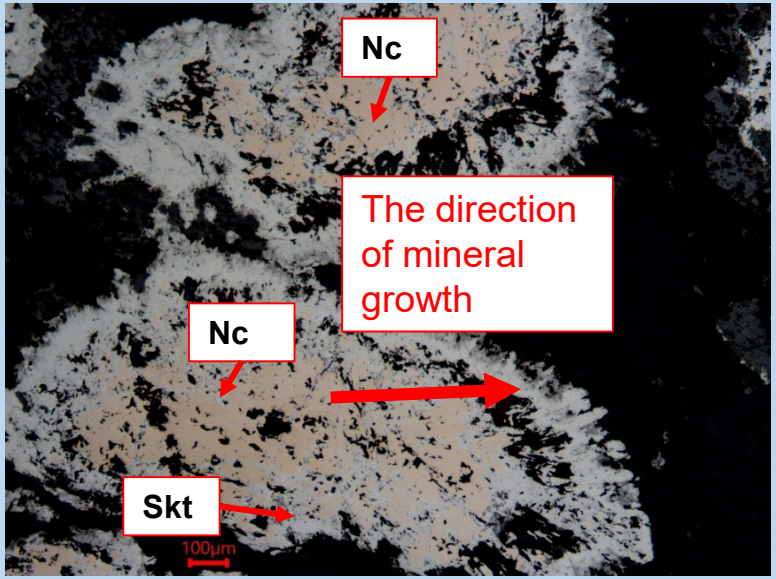
Colloform growths of native Ag, Ni-Co arsenides, anduraninite

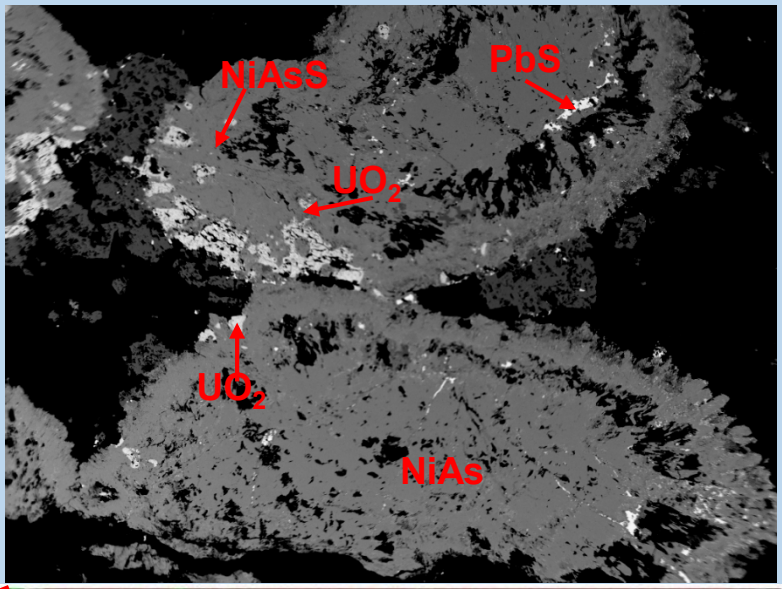
Preliminary Results

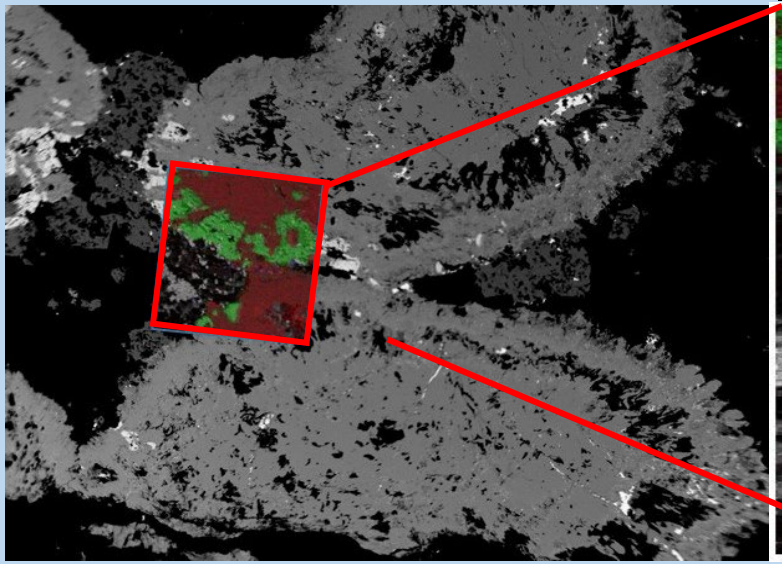
Sample of Arsenides

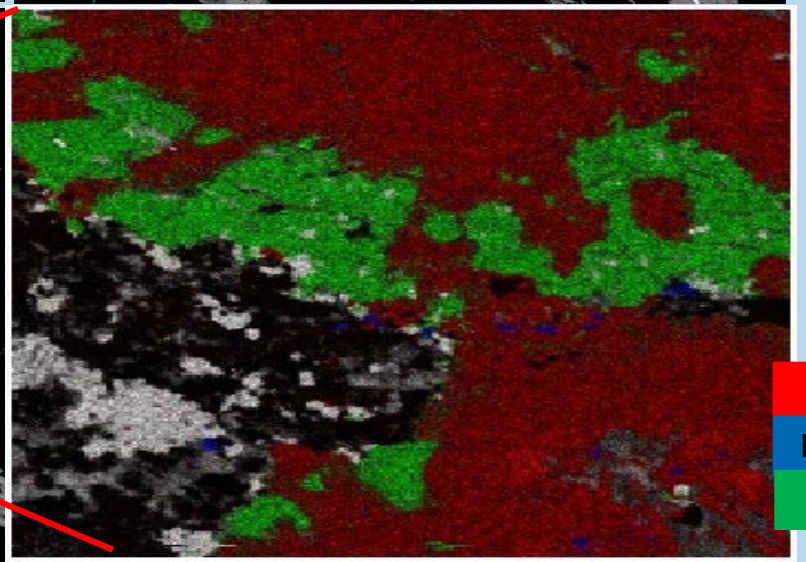
Sample: BLHK68











Paragenesis:

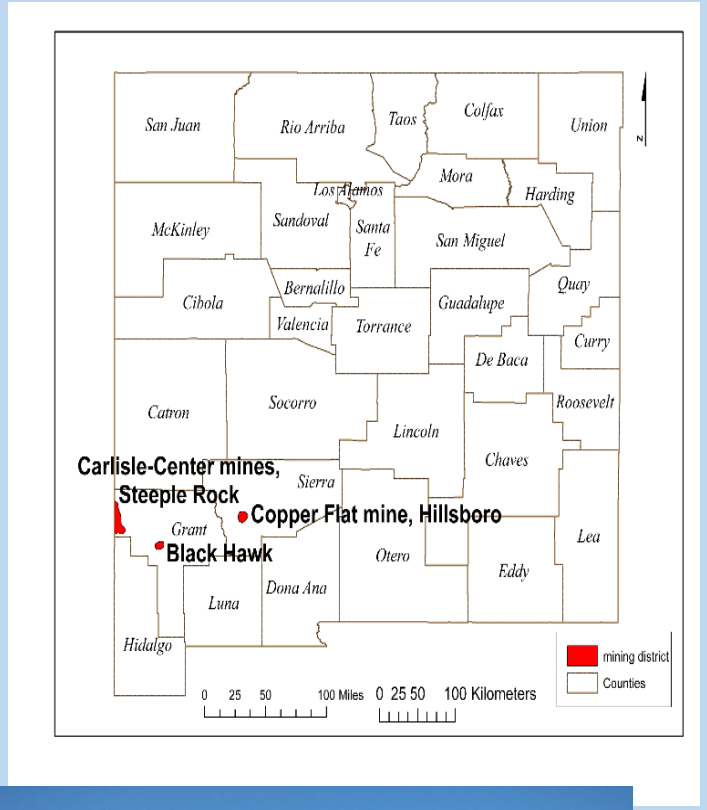
Nc → Skt → Urn

Abbreviations:
Skt: skutterudite;
Sp: sphalerite;
Nc: nickeline

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

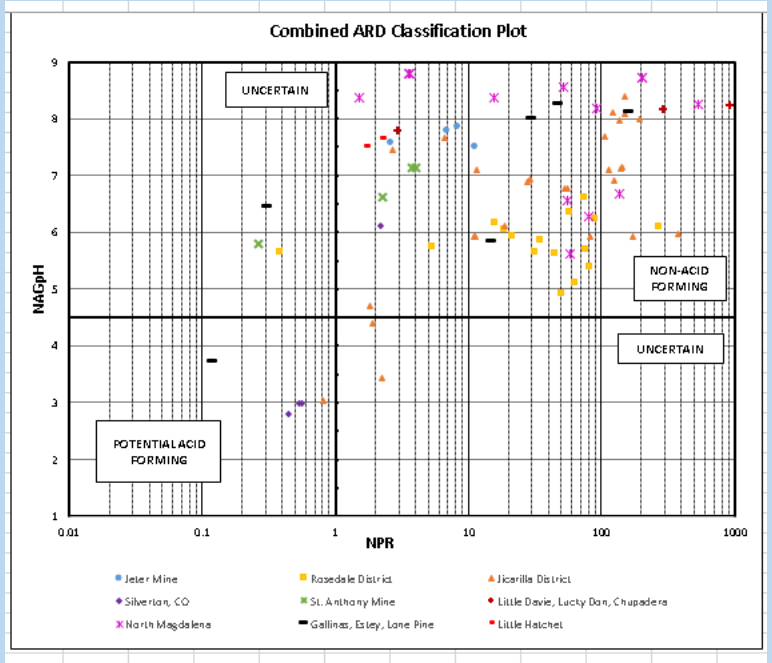
Virginia T. McLemore, Bonnie Frey, Evan Owen, Dan Jones, and students

- 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



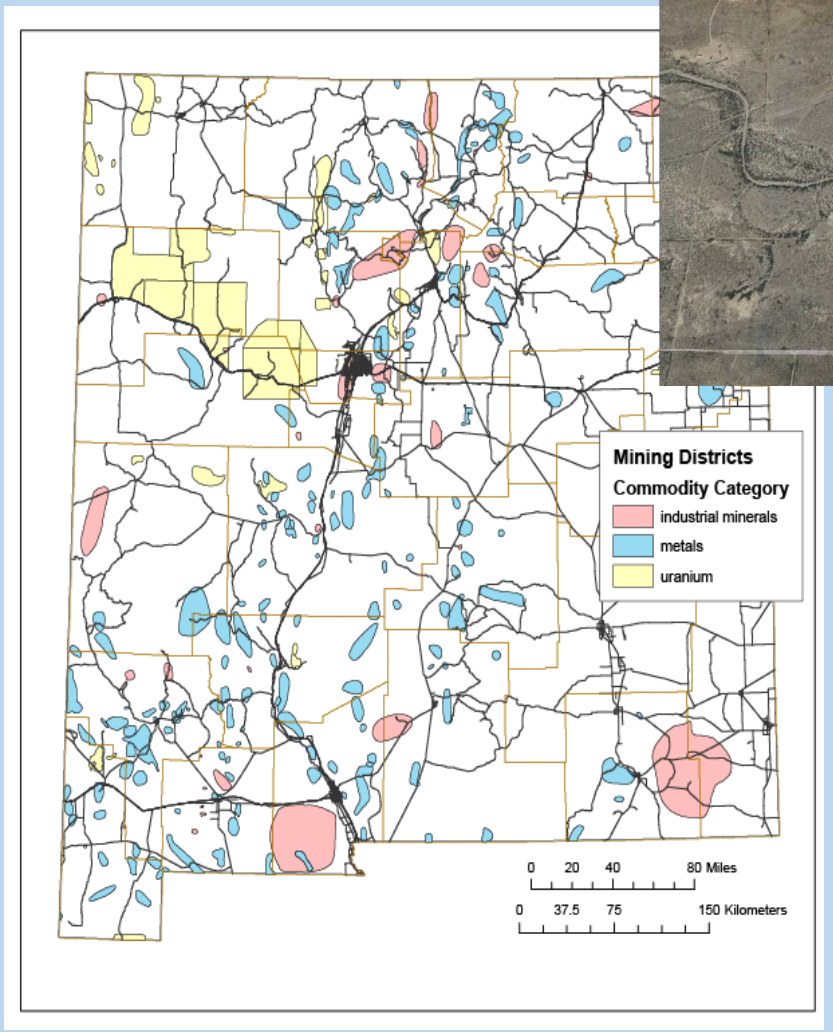
Acid rock diagram for mine waste rock piles in NM

USGS Earth MRI Project
Mine wastes inventory
(September 2023-August 2025)

Virginia T. McLemore, Amy Trivett, Evan Owen, and students

- Inventory mills, smelters, and tailings
- Map tailings and slag piles using ArcGIS
- Evaluate mine wastes for further study of critical minerals potential

Magdalena smelter slag (black) with covered mill tailings (green) in background.



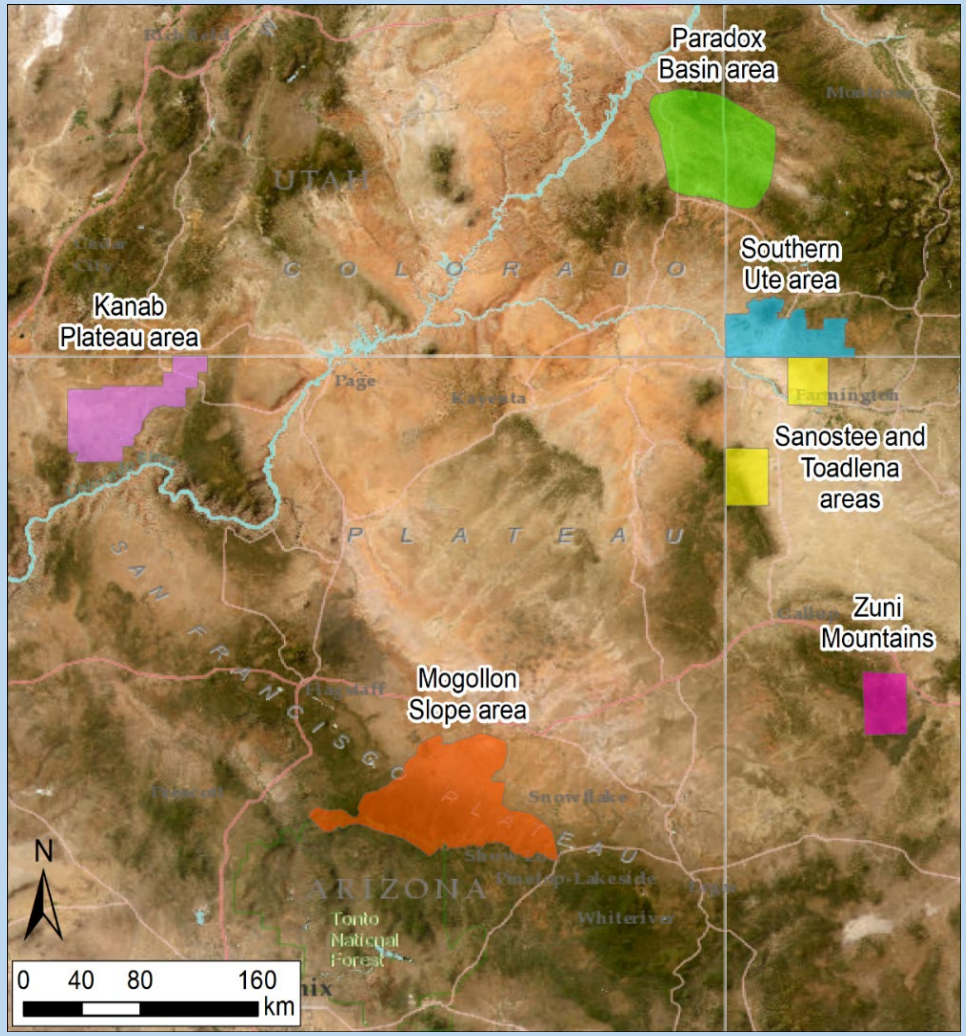
Deming mill sites, Luna County

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

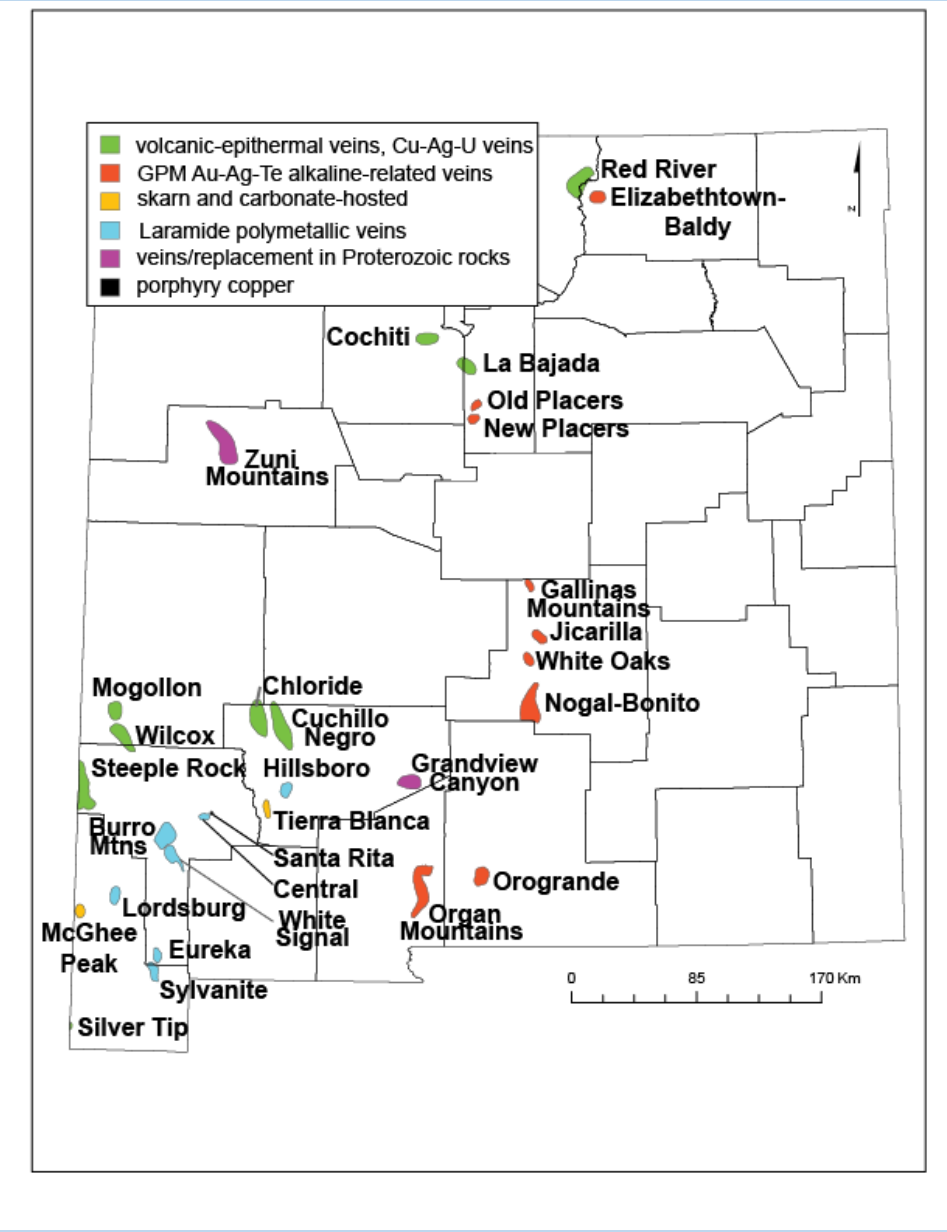


- Reanalysis of a select group of existing NURE sediment pulps by the USGS using modern geochemical methods where critical minerals are found
- Resample additional areas—Zuni Mountains
- New Mexico will use this as part of a graduate course (Exploration Geochemistry)

NURE=National Uranium Resource Evaluation

Tellurium in New Mexico

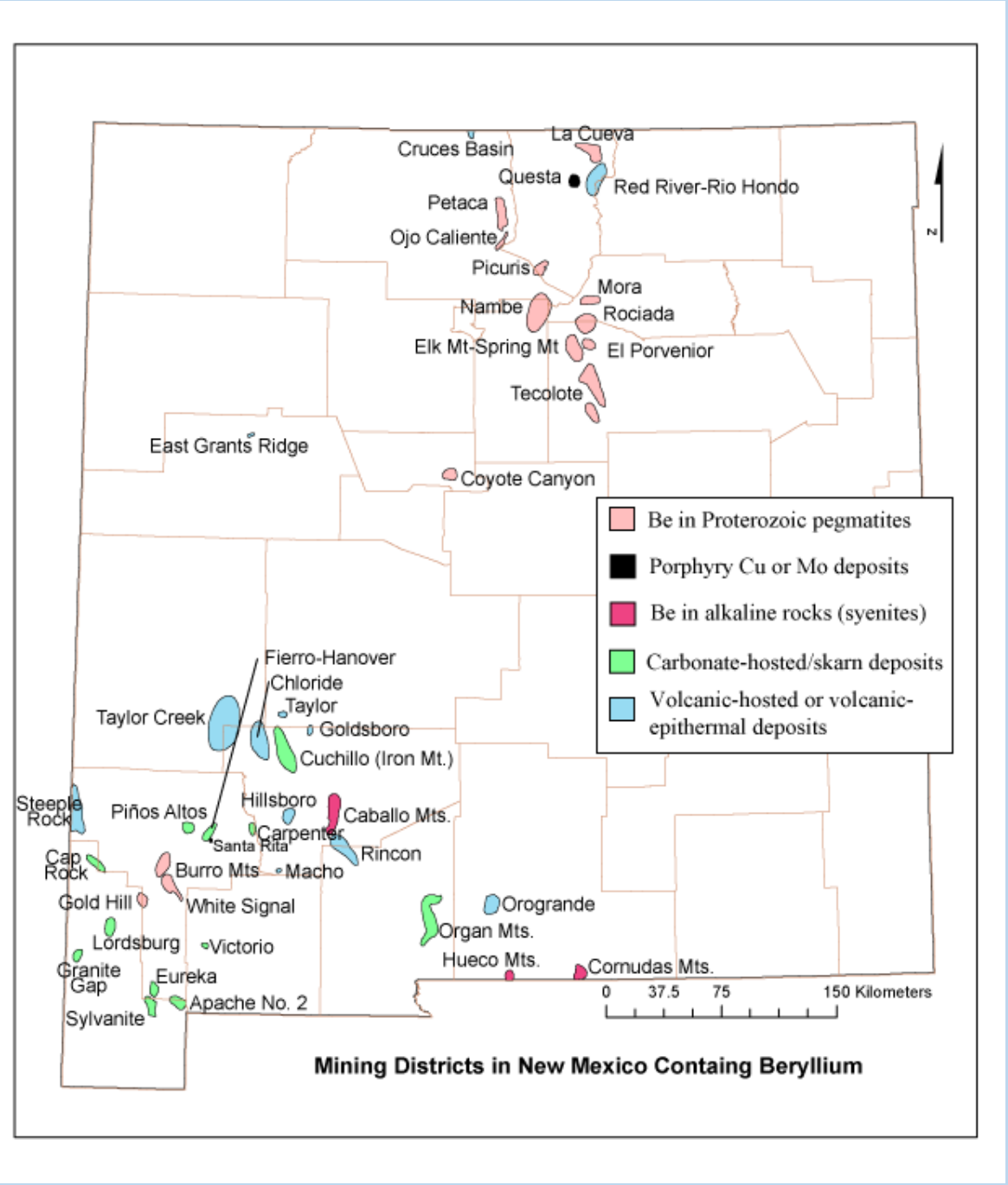
- Alloying additive in steel to improve machining characteristics
- Processing of rubber
- As a component of catalysts for synthetic fiber production
- As pigments to produce various colors in glass and ceramics
- **Thermal imaging devices**
- Thermoelectric cooling devices, such as summertime beverage coolers
- Thermoelectronics
- **Solar panels/cells**



Mining districts in New Mexico with tellurium minerals or chemical assays >20 ppm Te

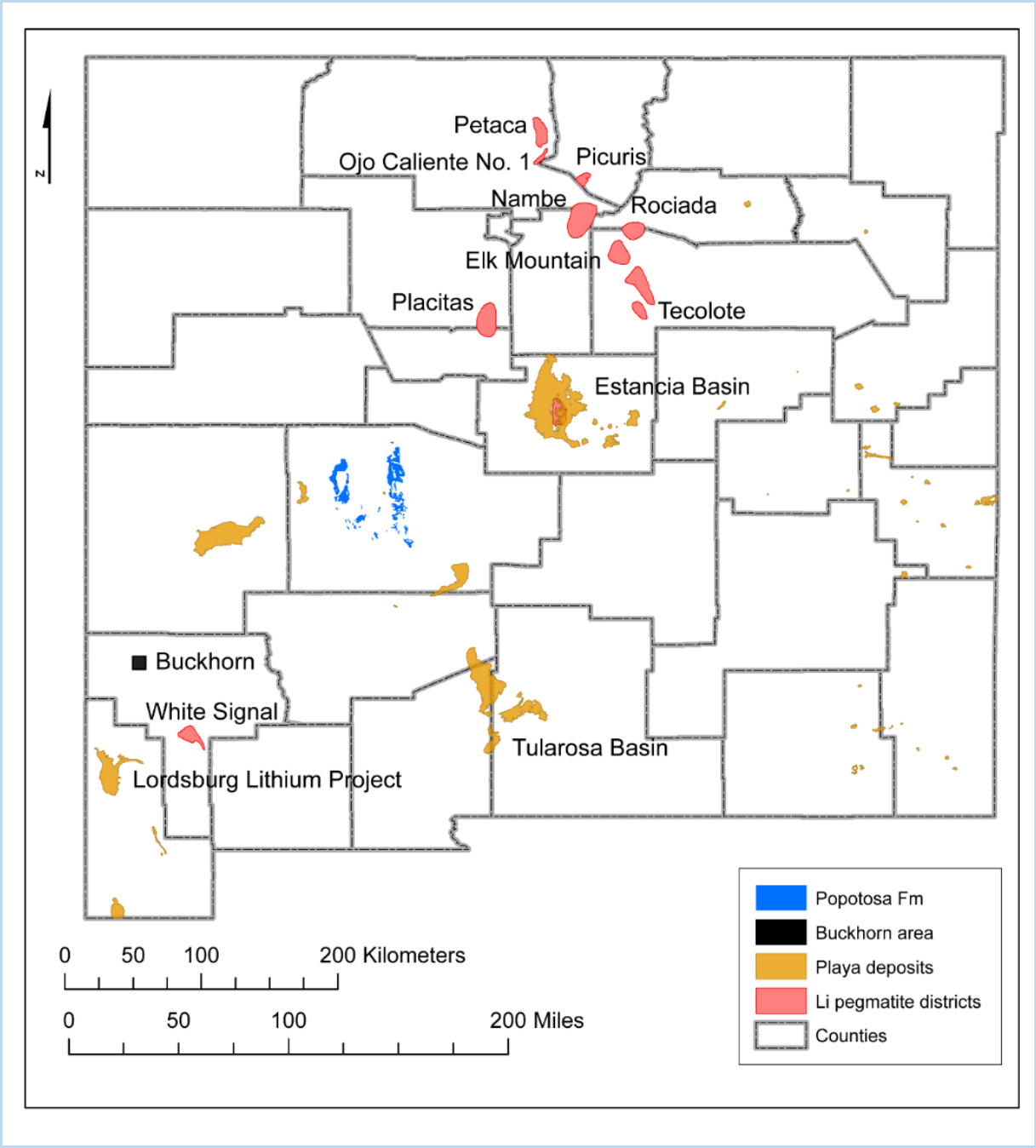
Beryllium In New Mexico

- Defense
- Telecommunications
- Nuclear energy industries
- Shielding in some of our nuclear, medical, and other equipment
- Many of our electronic devices



Lithium in New Mexico

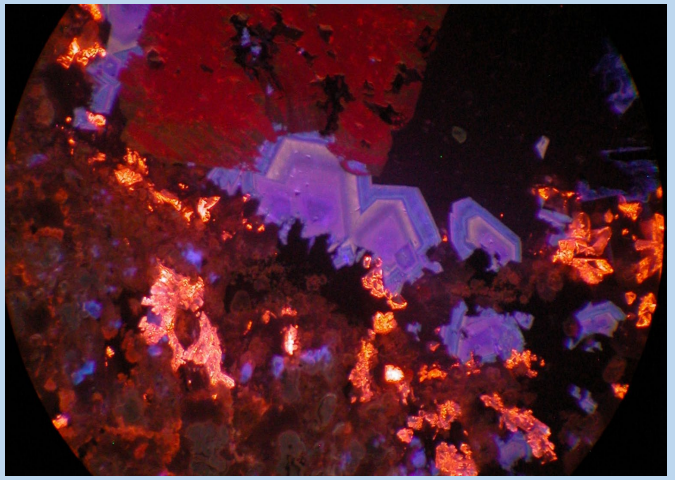
- More than 13,000 short tons of lepidolite ore and several hundred short tons of spodumene ore have been produced from pegmatites in New Mexico in 1920-1950
- Lithium in brine, hydrothermal (geothermal), and playa deposits derived from weathering of lithium-enriched rhyolite and other volcanic rocks
- Lithium is used in batteries, lubricants, pharmacials, glass, chemical industry



Ore Deposits and Critical Minerals Research Group

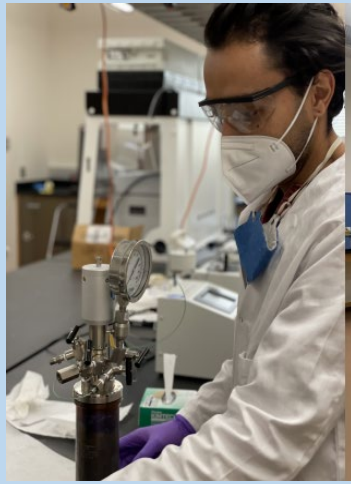
Alexander Gysi
NM Bureau of Geology and Mineral Resources
Department of Earth and Environmental Science, NMIMT

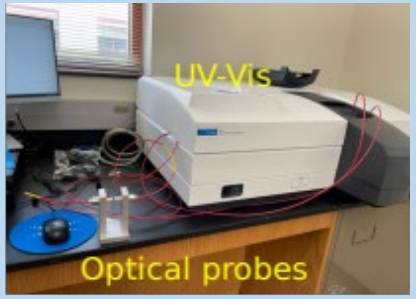
- Research
  - Ore deposits and critical minerals experimental laboratory
  - Development of the MINES thermodynamic database
  - Field observations in critical mineral deposits
- Funding of ~ $3M from DOE and NSF-EAR/-CAREER
- Team: 3 PhD and 2 MS students, 1 undergraduate students and 2 Postdoctoral Fellows
- New U.S. geoscience critical minerals experimental – thermodynamic research hub NMT-LANL-IUB plus search for 3 new PhD and 3 Postdocs

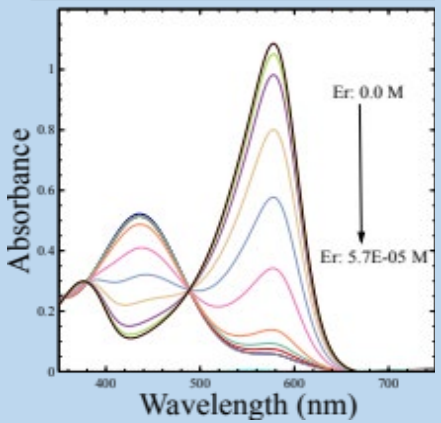


Ore Deposits and Critical Minerals Experimental Lab

- Hydrothermal fluid-mineral experiments
  - Synthesis/dissolution of REE minerals (xenotime, monazite)
  - REE incorporation into calcite, fluorite, apatite
- **Thermodynamic properties of critical minerals and their solid solutions**
  - Hydrothermal solution calorimetry (enthalpy of mixing), heat capacity measurements, and mineral stability
- UV-vis spectrophotometry
  - High temperature complexation of aqueous REE species
  - Flow-through experiments
- NEW Raman laser – hydrothermal diamond anvil cell facility – NSF MRI/DOE research hub

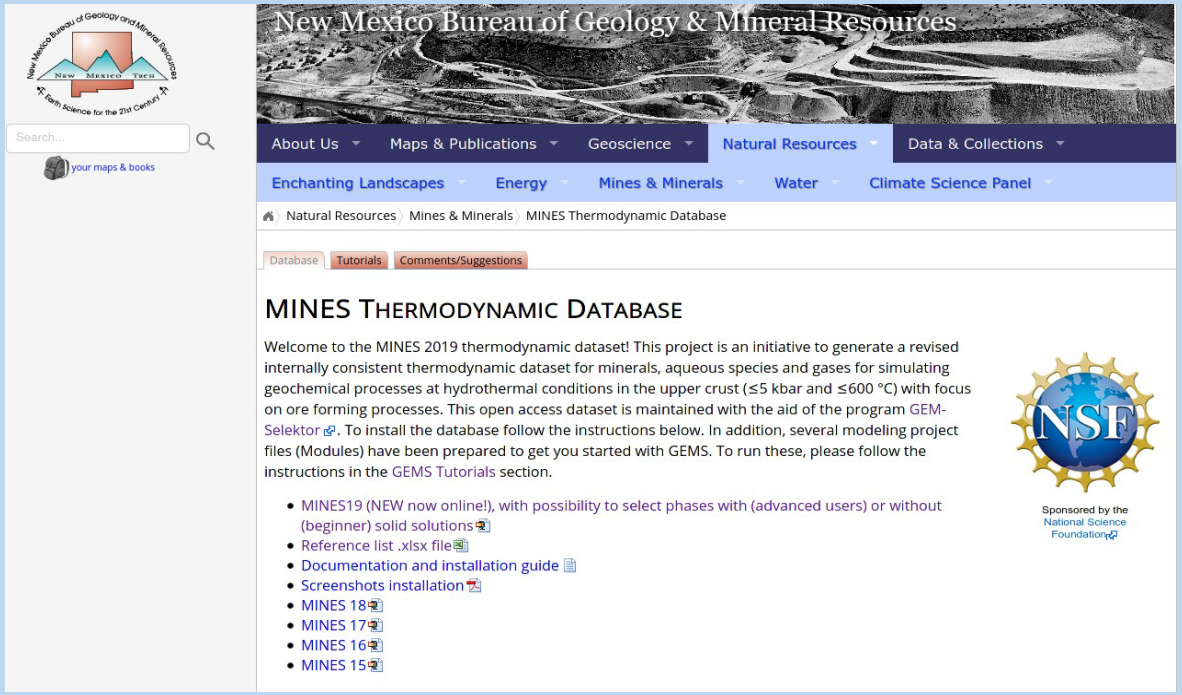






MINES thermodynamic database

- Project goal:
  - Simulate fluid-rock interaction and evaluate mineralization/alteration in a variety of mineral deposits
- Features:
  - Free and open access thermodynamic database
  - Rock-forming minerals, aqueous species, and gases
  - Focus on critical elements, comprehensive database on REE
  - Includes base and precious metals
- Workshops:
  - Annually either online or conferences
  - Gitbook tutorial https://apgysi.github.io/gems-mines-tutorial/



https://geoinfo.nmt.edu/mines-tdb

IMPORTANCE OF MINING REE AND CRITICAL MINERALS IN NEW MEXICO

- Future mining of REE and Critical Minerals will directly benefit the economy of New Mexico and the U.S.
- Mineral resources must be identified before land use decisions are made by government officials
- Crucial to re-establish a domestic source of REE and Critical Minerals minerals in the U.S. to help secure the nation's clean energy future, reducing the vulnerability of the U.S. to material shortages related to national defense, and to maintain our global technical and economic competitiveness
- Training of the future workforce because students at New Mexico Tech and San Juan College will be hired to work on this project and outreach activities train high and middle school students as well as their teachers

What are the challenges in producing critical minerals?

The main challenge is provide society with its needs, protect future resources, limit alteration of the landscape, and affect local communities as little as possible (i.e. sustainable development).

General Mining Issues Facing New Mexico

- Mining requires water and their environmental effects must not impact water supplies
- Legacy issues of past mining activities form negative public perceptions of mining
  - Abandoned or legacy mines, especially Grants uranium district and Questa mine
  - Gold King spill
  - Not in my backyard!!!!!!

General Mining Issues Facing New Mexico—continued

- Exploration for new deposits often results in drill targets based upon regulatory minimal impact regulations rather than optimum geological criteria
- Permitting for exploration can take longer than exploration funds are available
- In some areas conflicts arise between mining and other activities
  - Grants uranium district
  - Otero Mesa
  - Pecos/Tererro mine
  - **Water, don't want a mine in their backyard**
- Shortage of young geologists and engineers to explore for, develop, mine, permit these commodities and evaluate their effect on the environment—math, science skills critical

What are the additional challenges in producing critical minerals?

- Meeting the demand (quick change in supply and demand difficult for mines to meet)
- Permitting
- Fear that producing a byproduct could jeopardize production of major commodity
- Environmental issues
  - Many are associated with U/Th (radioactivity)
- Financing for both exploration/mining and development of new products
- Social license to operate
- Local infrastructure challenges

SUMMARY

- New Mexico has a wealth of mineral resources, including critical minerals
- The New Mexico Bureau of Geology and Mineral Resources has a long history in critical minerals research
  - We have a number of ongoing research projects in the broad field of critical minerals, with strong field and laboratory components
- 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

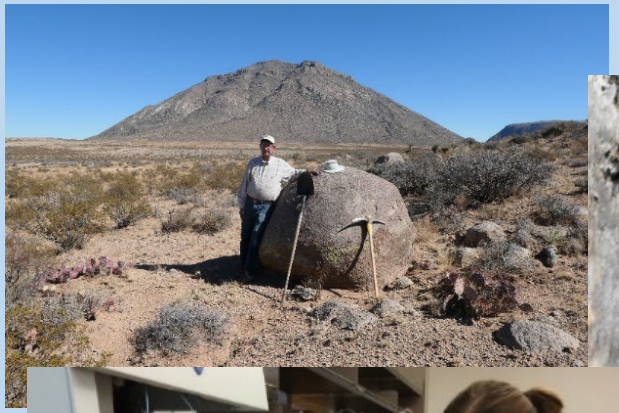
SUMMARY—continued

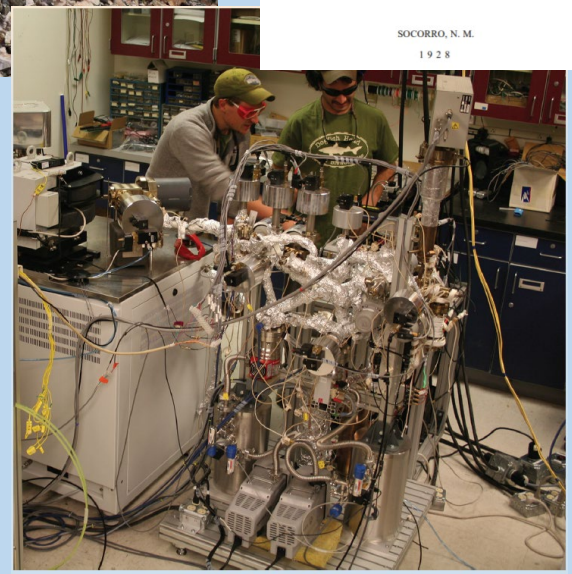
- Projects are built upon decades of research at NMBGMR and NM Tech
  - Data preservation funding is important to preserve these historic data, records, and drill core
- Provides topics of interest for more advanced laboratory and thermodynamics studies
- Cooperation with adjacent states and industry is important
- Exploration and permitting takes many years before a deposit can be mined in NM, >10 yrs
- Negative public perceptions are major issue as is funding

SUMMARY—continued

- NMBGMR/NMT research is addressing some of these issues, as well as actively training future geologists and engineers
- These projects takes many students and staff, which requires this level of funding
  - Teams are very important, but expensive
  - Training of students and younger Bureau staff members

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

More Information

Virginia McLemore web page
http://geoinfo.nmt.edu/staff/mclemore/home.html

New Mexico Bureau of Geology and Mineral Resources
http://geoinfo.nmt.edu/

QUESTIONS?