RARE EARTH ELEMENTS (REE) AND OTHER CRITICAL MINERALS IN LATE CRETACEOUS COAL AND RELATED STRATA IN THE SAN JUAN AND RATON BASINS, NEW MEXICO: PRELIMINARY OBSERVATIONS—DE-FE0032051

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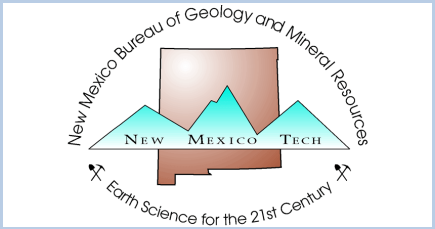

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- Students and staff at NM Tech
- Partners at Los Alamos and Sandia National Labs, Sonoash, San Juan College

Any persons wishing to conduct geologic investigations on the Navajo Nation must first apply for and receive a permit from the Minerals Department, P.O. Box 1910, Window Rock, Arizona 6515 and telephone no. 928-871-6588

Project Overview

CORE-CM project—Rare Earth Elements and Critical Minerals in the San Juan and Raton Basins, northern New Mexico (DOE project)—DE-FE0032051

- CORE-CM=Carbon Ore, Rare Earth and Critical Minerals
- Project Performance Period: 10/01/2021 to 12/31/2024

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Objectives

- Identify and quantify the distribution of critical minerals (CM), including rare earth elements (REE), in coal beds **and related stratigraphic units** in the San Juan and Raton Basins in New Mexico
- Identify possible sources of CM and REE in the basins
- Identify the coal mine and nonfuel carbon-based waste products that could contain CM and REE
- Characterize the CM and REE in these materials
- Determine the economic viability of extracting CM and REE from these materials

Types of strata/samples examined

- Late Cretaceous heavy-mineral beach placer sandstone deposits
- Late Cretaceous coal deposits
- Late Cretaceous humates deposits
- Late Cretaceous clinker deposits
- Late Cretaceous clay deposits
- Permian and Triassic sediment-hosted stratabound copper deposits
- Coal mine and nonfuel carbon-based waste products
  - Coal and copper mine dumps
  - Copper tailings
  - Ash from power plants
  - Waste water

Introduction

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 in 2024

- Element currently producing in NM
- Element once produced from NM
- Element found in NM
- Element not found in NM (except in trace amounts)
- Formerly a critical mineral (He, K are being produced in NM, U was once produced from NM)

Graphite, fluorite, and barite are listed as critical minerals instead of the element because of their specific industrial uses.

C=graphite F=fluorite

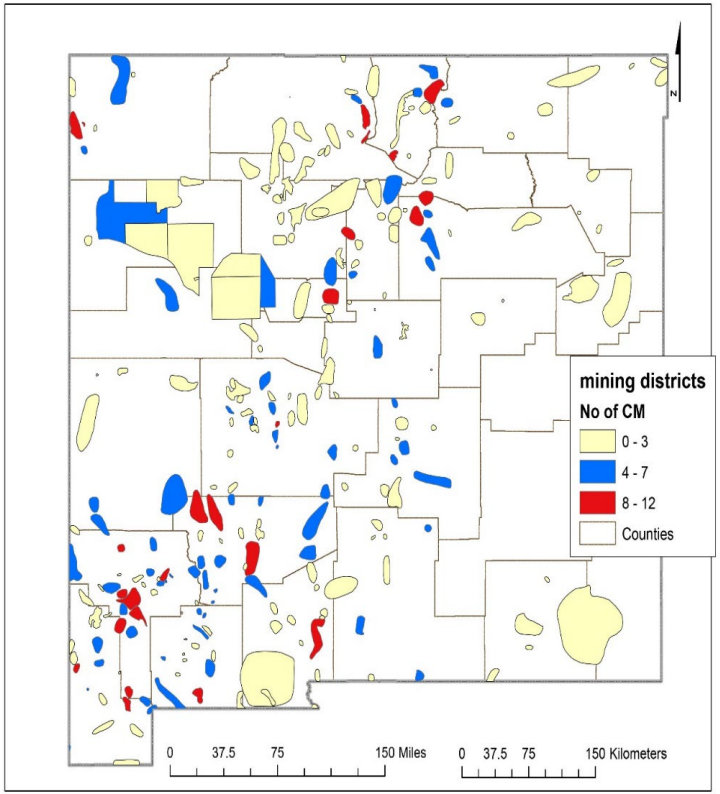
Ba=barite

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															

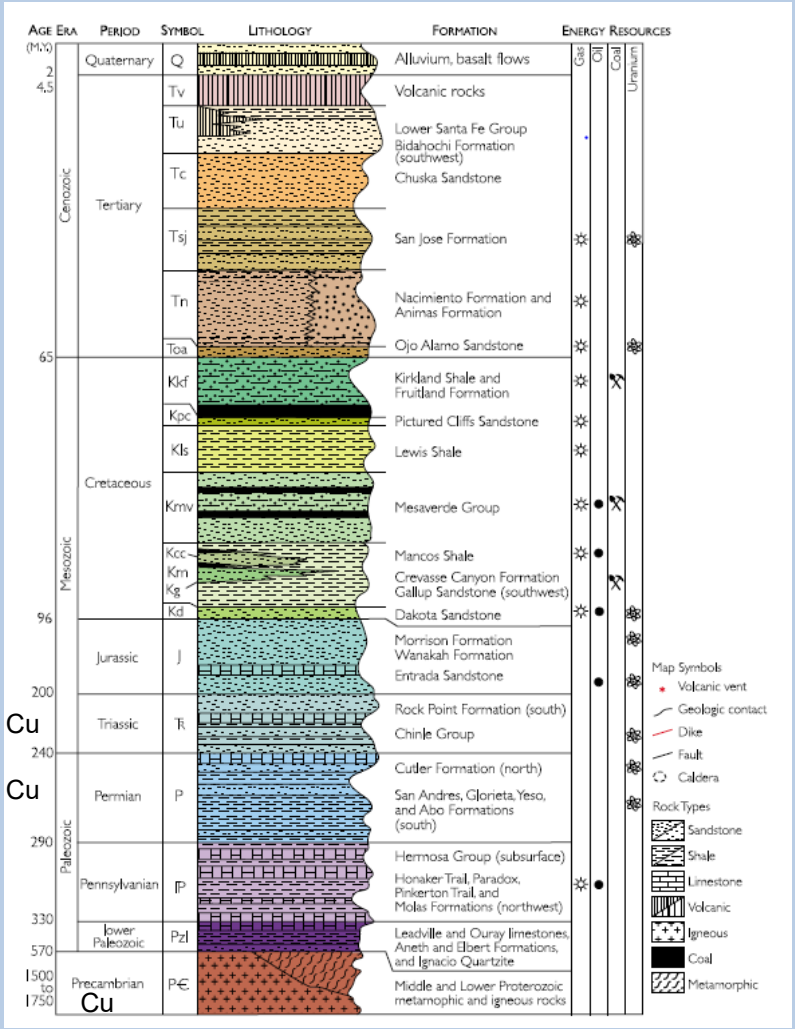
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

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

U, Re, He, Sr, and K (potash) were removed from the critical minerals list in 2022 and Zn and Ni were added. In 2023, the Department of Energy added Cu to the critical materials list.

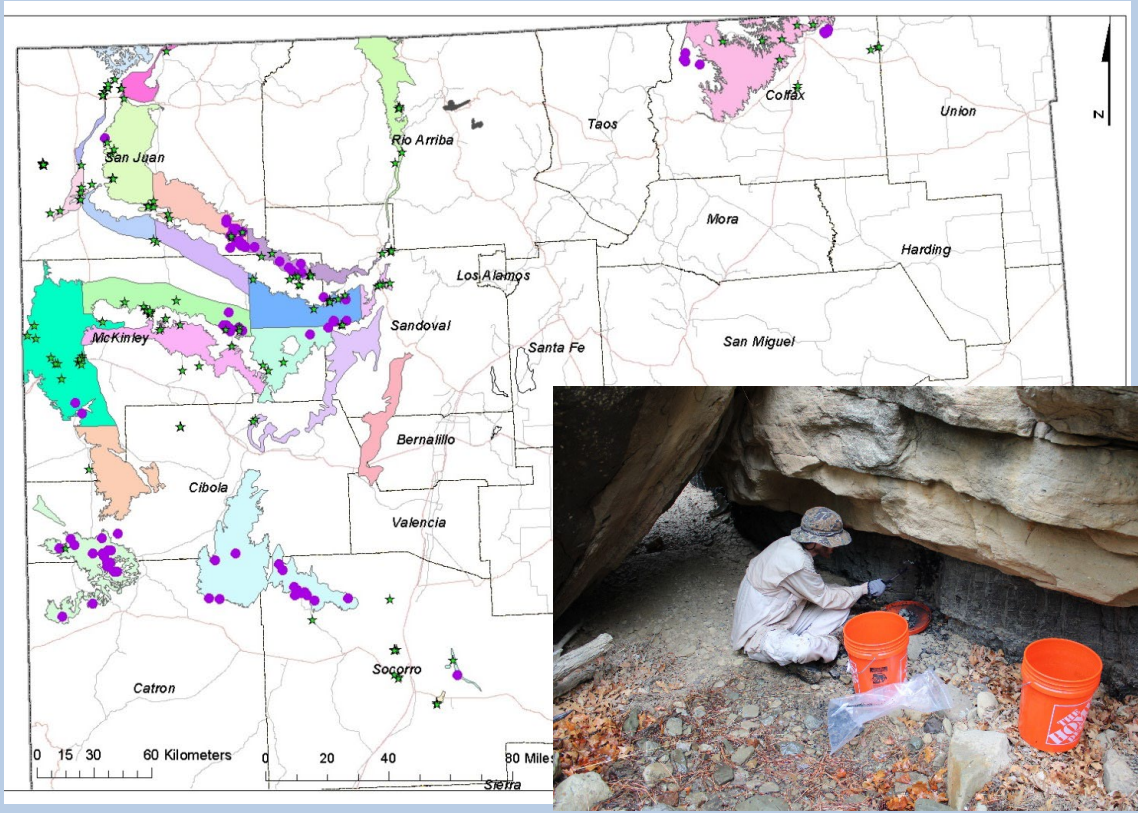


Stratigraphy of the San Juan Basin, New Mexico. Note the stratigraphic units that have gas, petroleum, coal, copper, and uranium potential



New Mexico Coal Fields

- Coal/shale deposits are in the San Juan, Raton Basins
- Are restricted to Late Cretaceous rocks belonging to the Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones



Locations of samples (green) and drill holes (purple) in New Mexico coal fields

This coal has 900-1000 ppm TREE on ash basis

Coal in New Mexico

- Fuels electrical generating plants (1 in NM and 2-3 Arizona plants)
- Surface mines in San Juan Basin
  - El Segundo
  - Lee Ranch (soon to reopen)
  - Navajo
- Resources at Raton, Sierra Blanca fields
- 12th coal in production in U.S. in 2020
  - 10,249,000 short tons
  - Production decreasing because of mine closure
- 15th in estimated recoverable coal reserves in U.S.
  - 65 million short tons of recoverable reserves at mines
  - 6,719 million short tons estimated recoverable reserves

Humates in New Mexico

- Weathered coal and organic material
- Leonardite, weathered lignite
- Transitions to coal at depth
- Humic acids
- Coal burns, high quality humates dissolves in water
- Mining began in New Mexico in 1980s and continues today
- Used as a soil conditioner, medicinal uses, dispersant and viscosity control in oil-well drilling muds, stabilizer for ion-exchange resins in water treatment, source of water-soluble brown stain for wood finishing
- Possibly REE from water soluble products

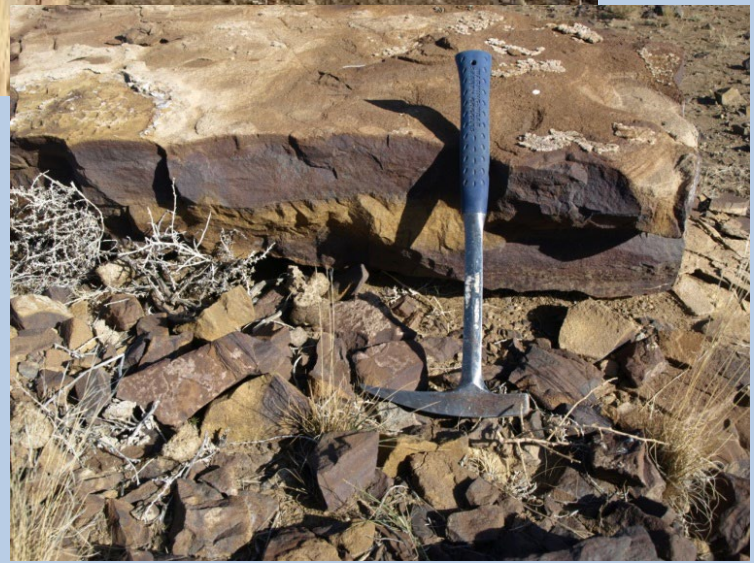
Clinkers in New Mexico

- Clinkers (red) are sedimentary rocks pyrometamorphosed by fire
- Coal seam fires can start from multiple causes at the surface
  - Wildfires
  - Lightning strikes
  - Spontaneous combustion by the oxidation of pyrite
- Coal seam fires can spread extensively underground
- Temperatures can reach 1000F, baking surrounding rocks
- Clinkers can be indicators of coal resources that aren't exposed
  - Resistant to erosion

- Aggregate for roads
- Decorative stone
- Naturally burned coal
- Metal working
- Glass manufacture

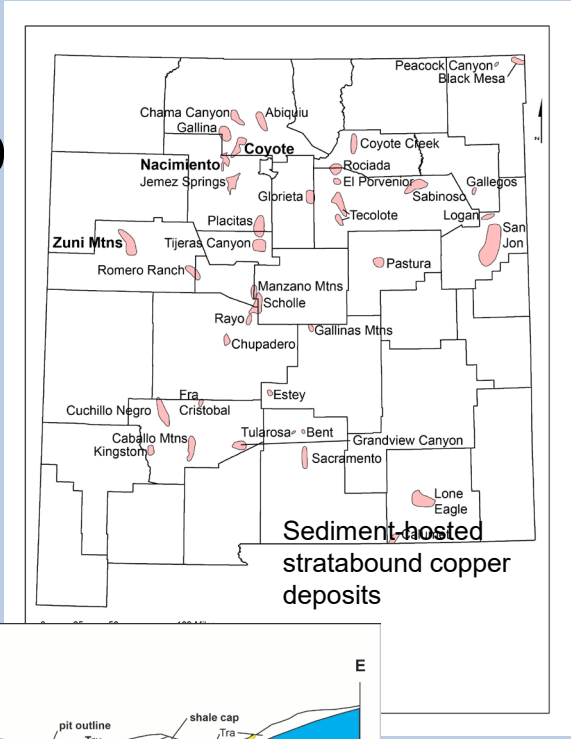
Beach-placer sandstone deposits

- Beach-placer sandstone deposits in the San Juan Basin are restricted to Late Cretaceous rocks and contain high REE
  - Includes NM REE database
- Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones

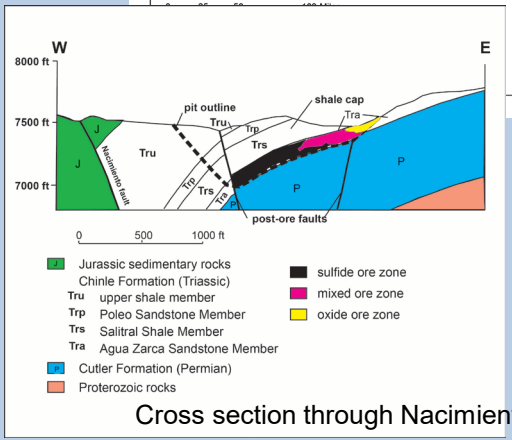


Sediment-hosted stratabound copper deposits in the Nacimiento and Zuni Mountains

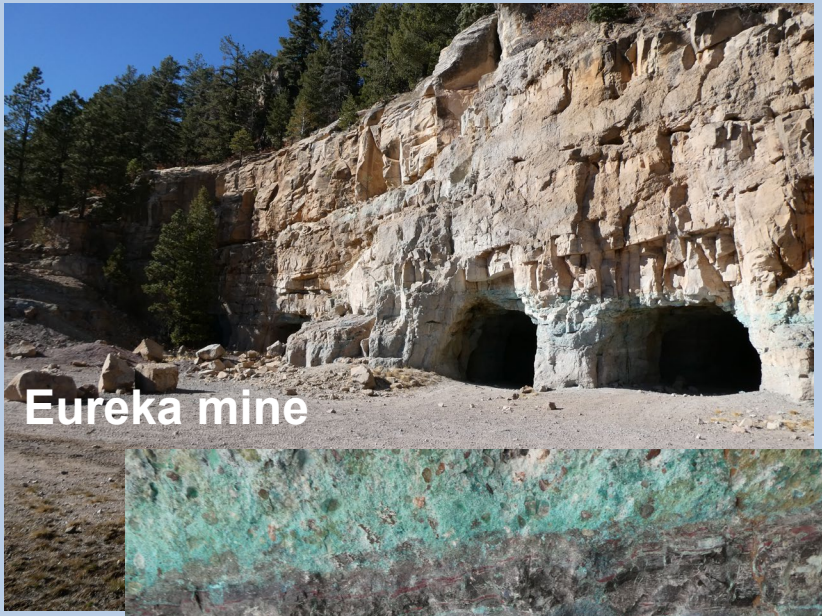
- Copper minerals found as disseminations, cement, and veinlets
- In bleached sandstones, siltstones, shales, and limestones within or marginal to typical thick clastic red-bed sequences
- Also known as sandstone-hosted copper deposits



Sediment-hosted stratabound copper deposits



Cross section through Nacimiento open pit mine


Eureka mine


Copper in sandstone

Copper in sandstone

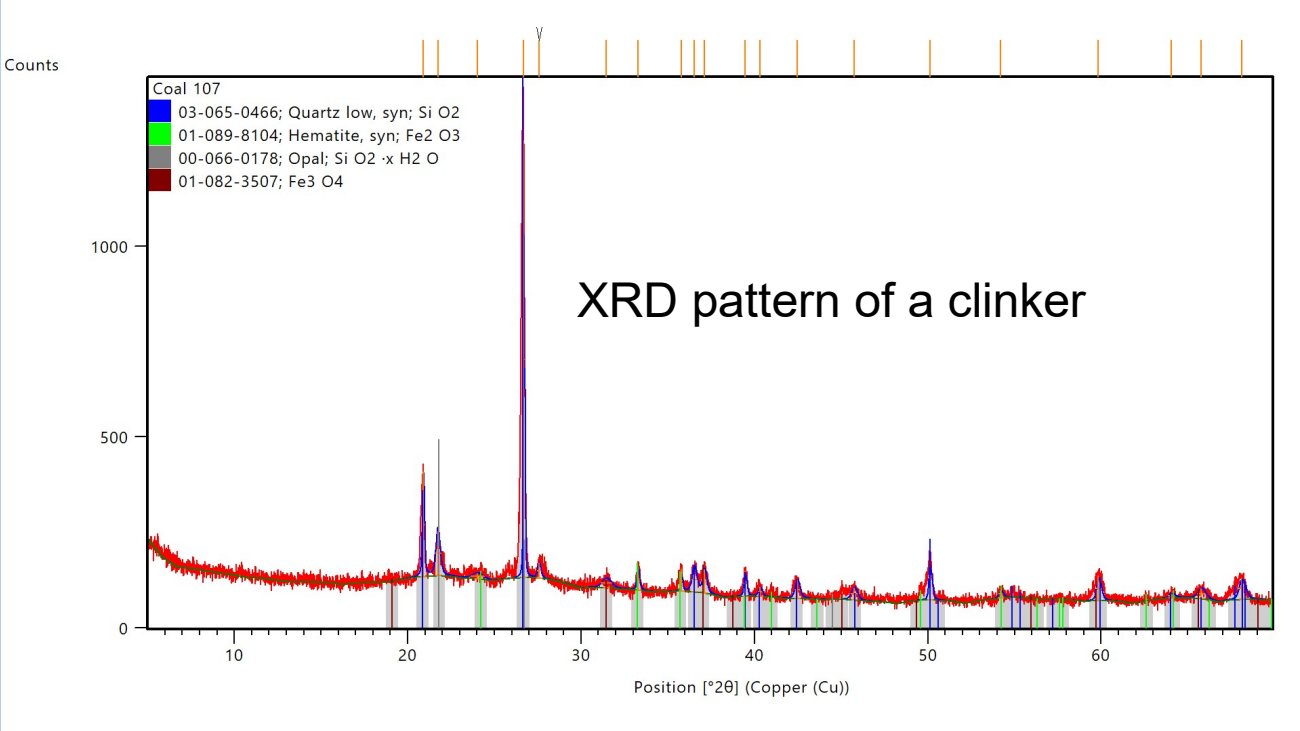

Nacimiento mine

5.4 million metric tons of ore, grade of 0.56% Cu

Results and Current Status

Preliminary mineralogy of coals, humates, and clinkers (XRD, probe, thin section analysis)

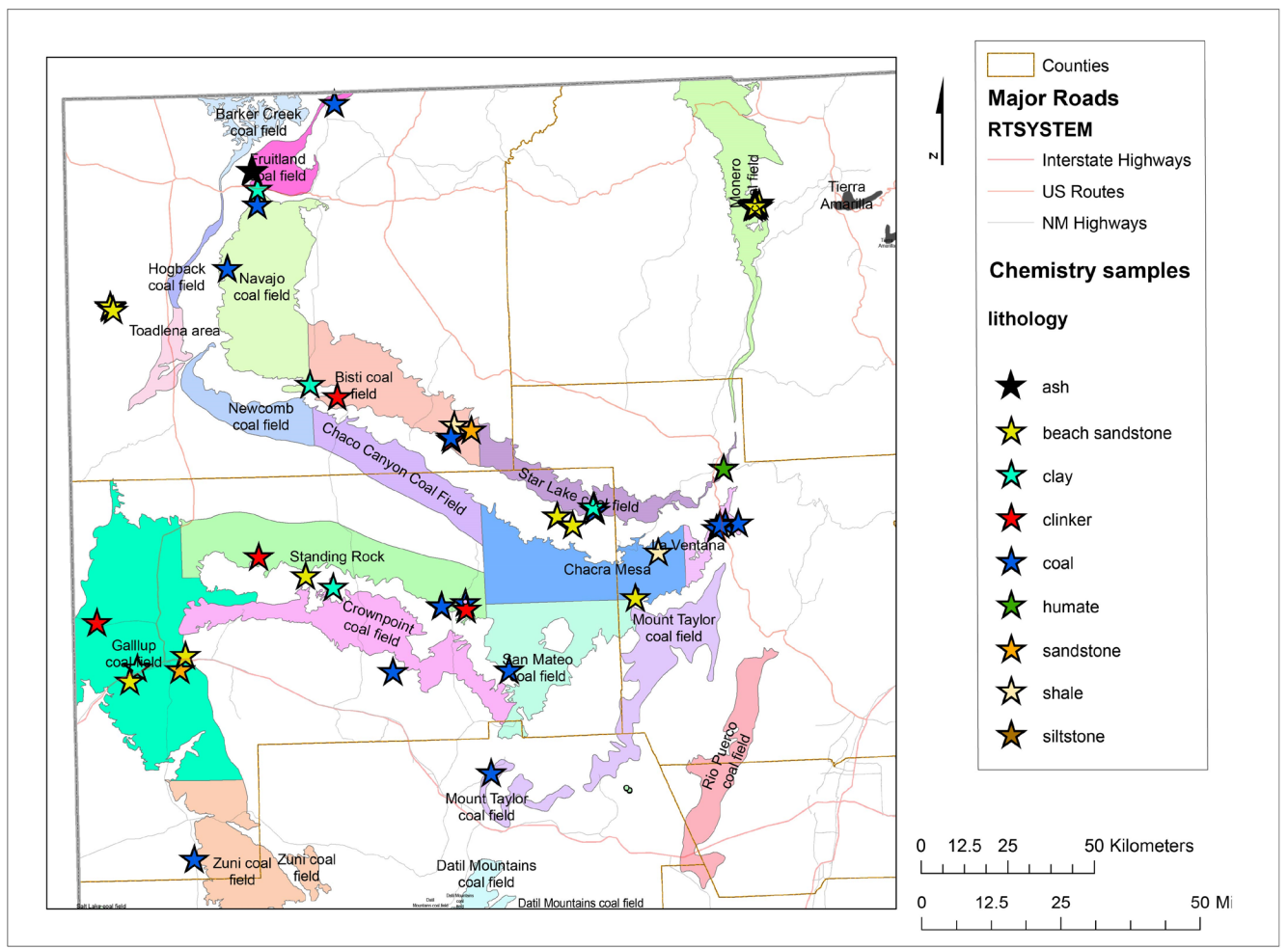
- Quartz
- Clay minerals
- **Zircon**
- Ilmenite
- Rutile/anatase
- Hematite
- **Monazite**
- **Xenotime**



Chemistry samples from 22 fields

(total 26 fields)

- 148 coal, 5 ash, 18 humate, 34 clinker samples
- 119 igneous rocks, shale, sandstone, clay, other
- 93 beach placer
- 22 stratabound Cu



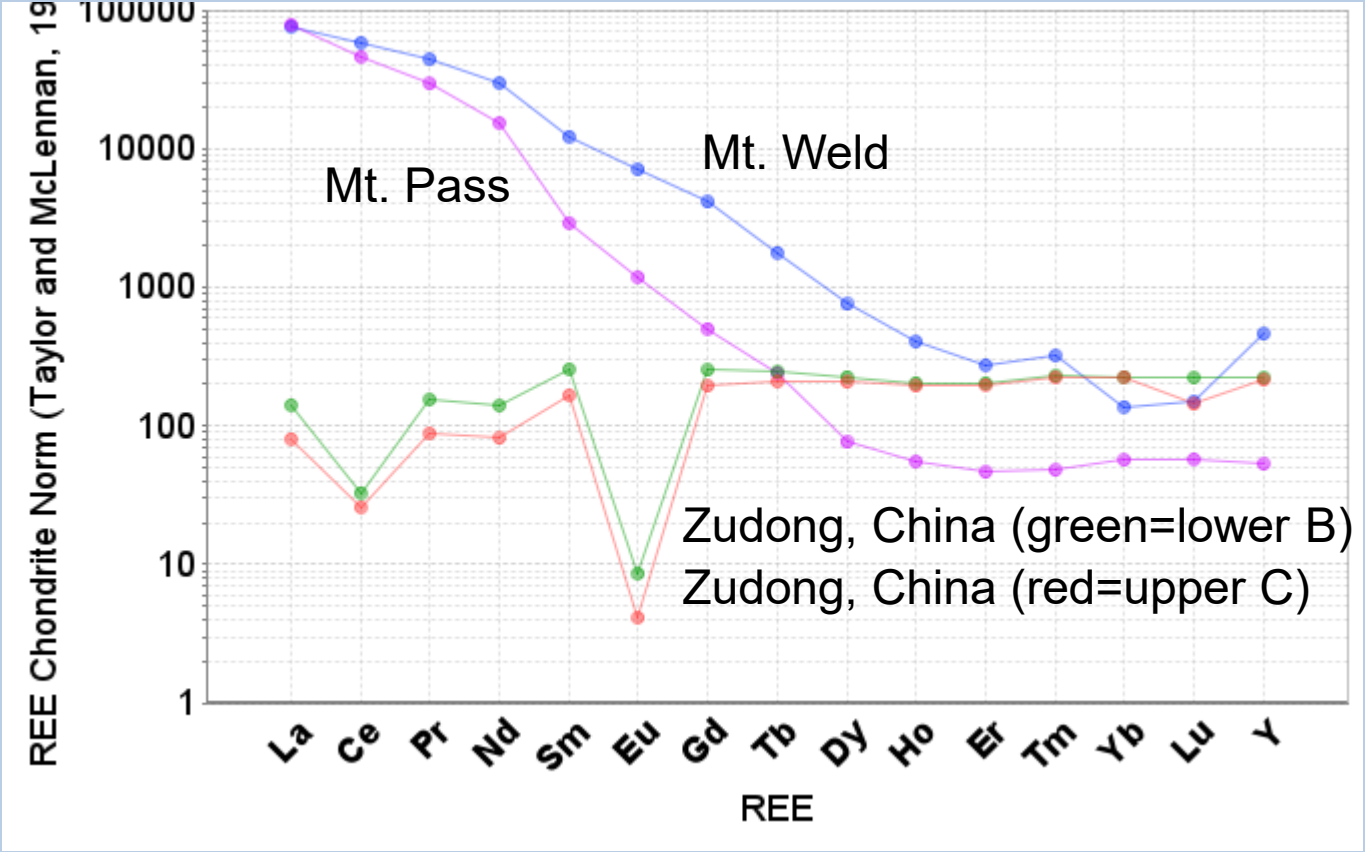
REE for economic deposits currently in production in the world

Total REE

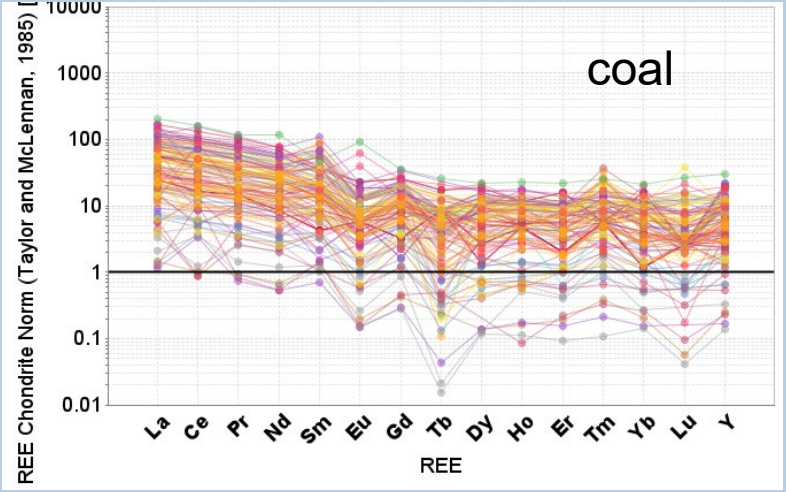
Mt. Pass=8-12% TREE

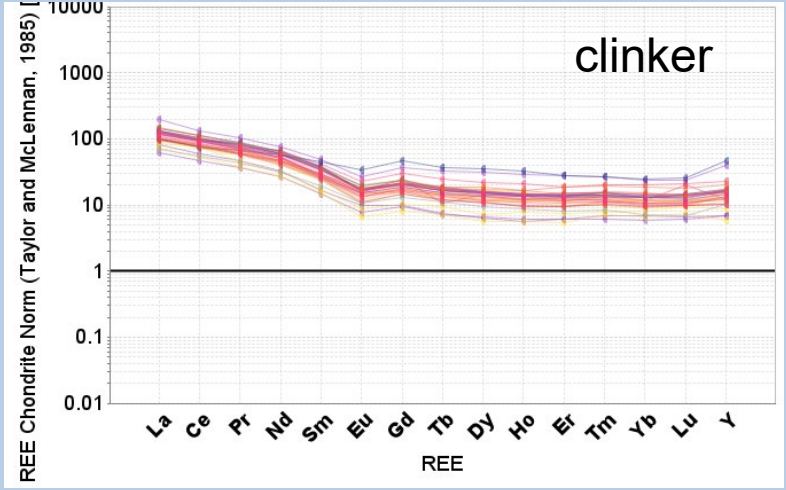
Mt. Weld=8% TREE

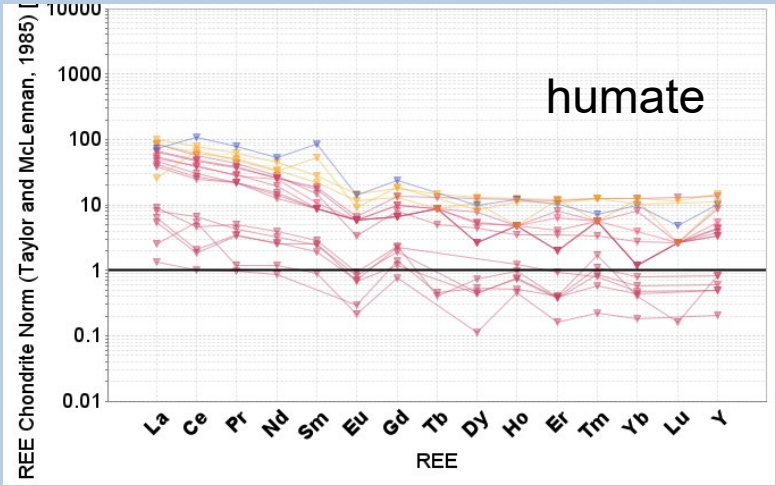
Zudong=400-500 ppm TREE (heavy REE enriched)

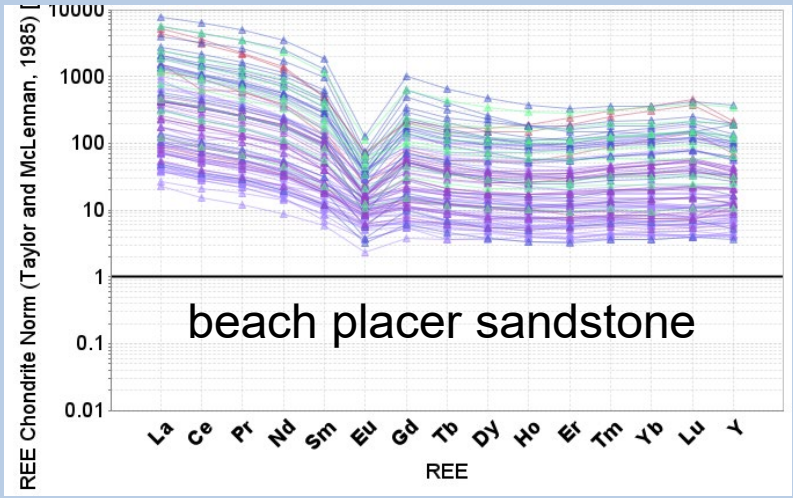


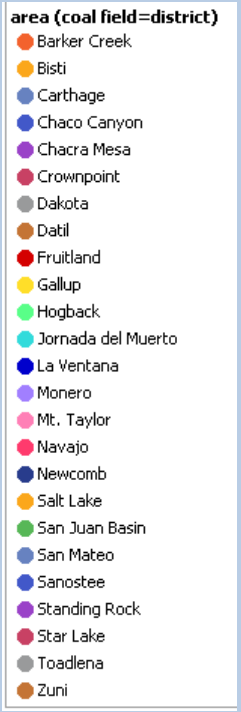
REE chondrite-normalized REE of samples by coal fields in the San Juan Basin





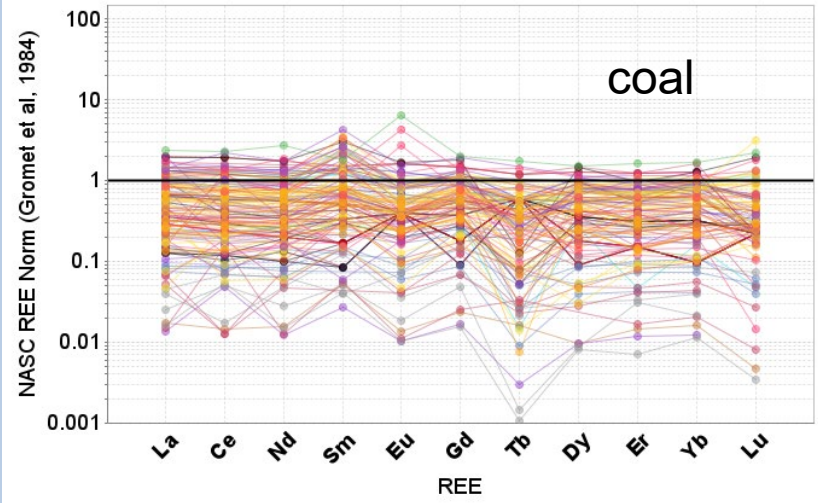


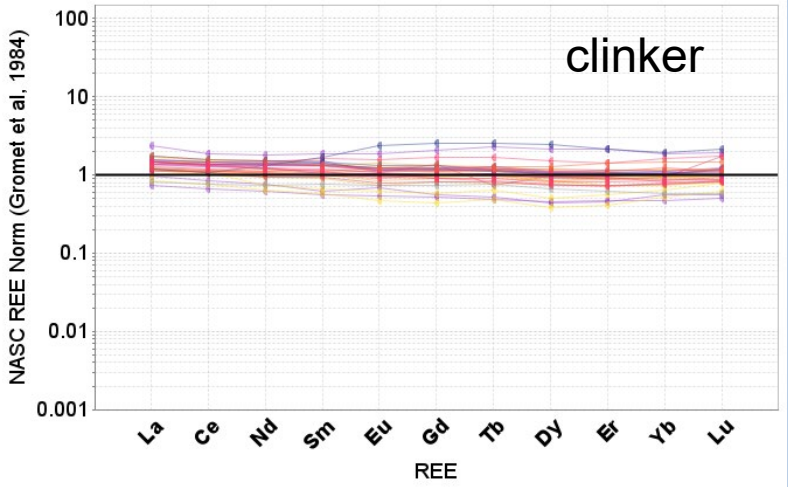


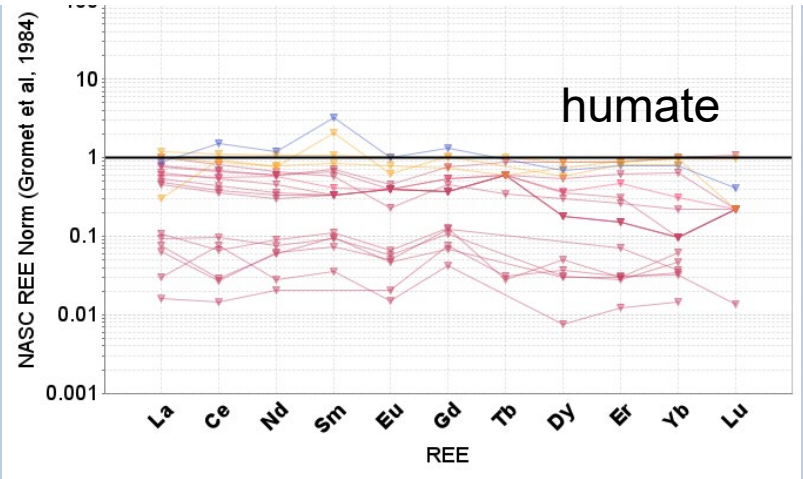


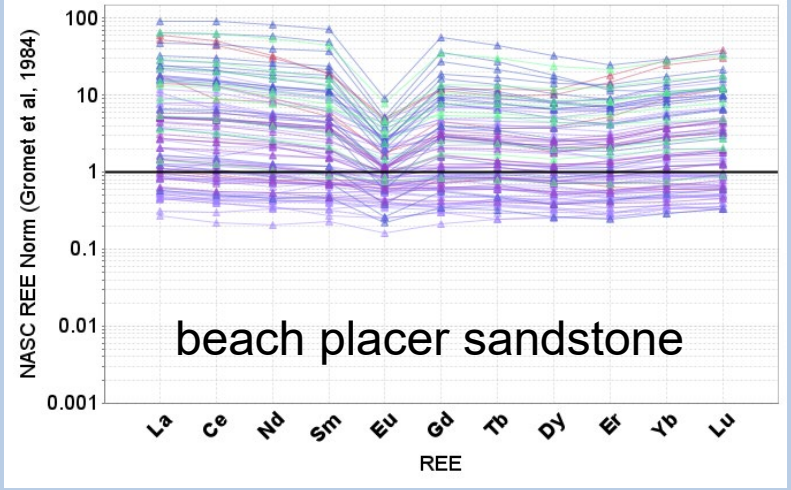
REE calc as whole rock in coals

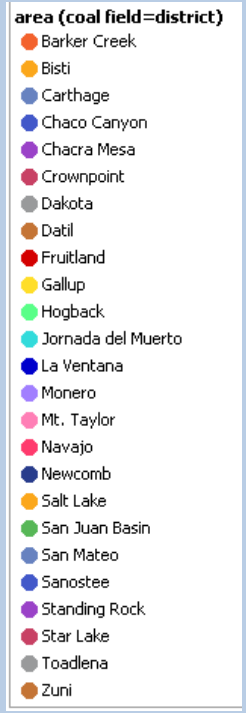
REE NASC-normalized REE of samples by coal fields in the San Juan Basin



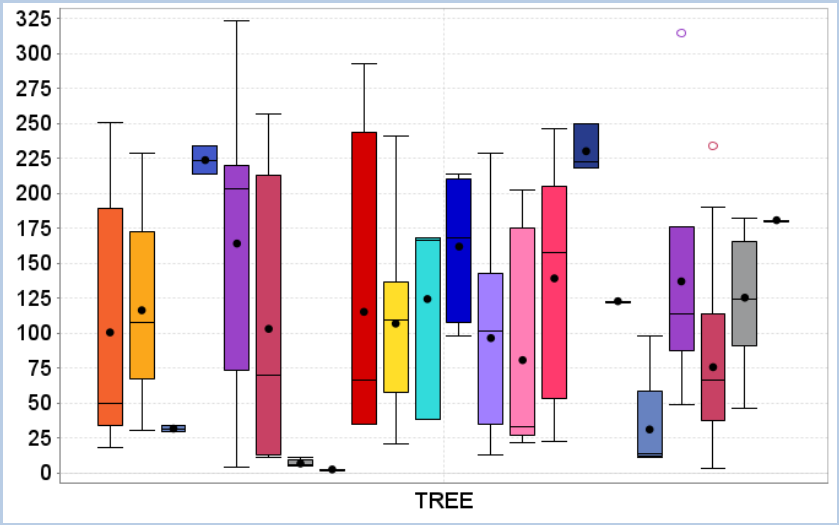








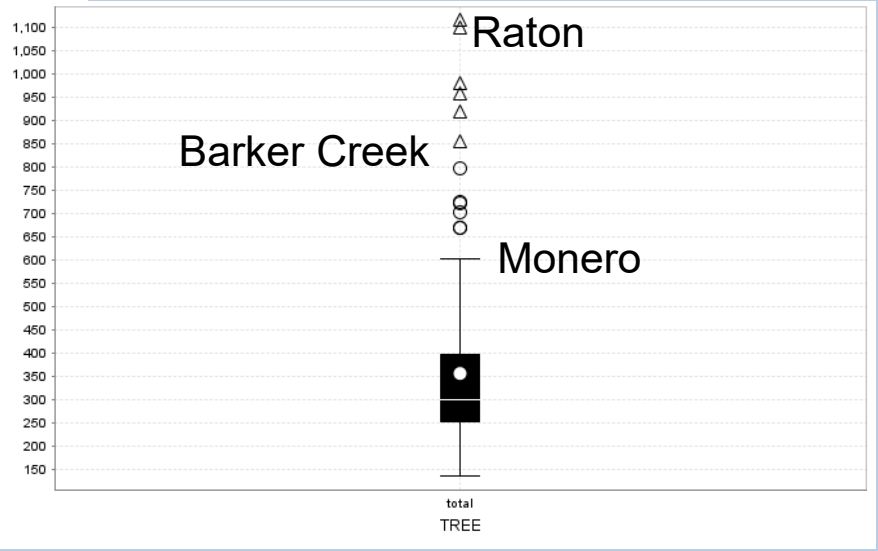
REE calc as whole rock in coals



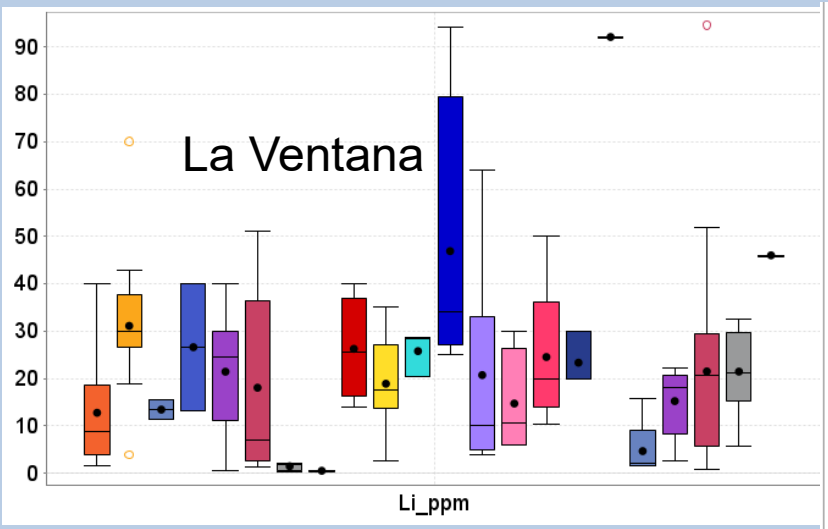
Whole rock basis

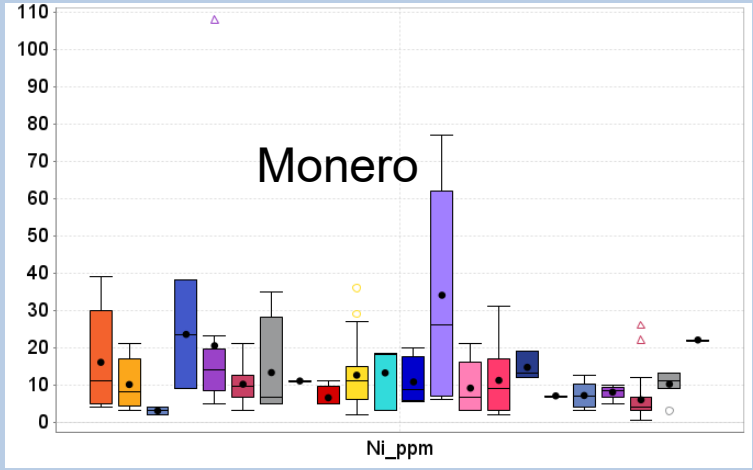
area (coal field=district)
Barker Creek
Bisti
Carthage
Chaco Canyon
Chacra Mesa
Crownpoint
Dakota
Datil
Fruitland
Gallup
Hogback
Jornada del Muerto
La Ventana
Monero
Mt. Taylor
Navajo
Newcomb
Salt Lake
San Juan Basin
San Mateo
Sanostee
Standing Rock
Star Lake
Toadlena
Zuni

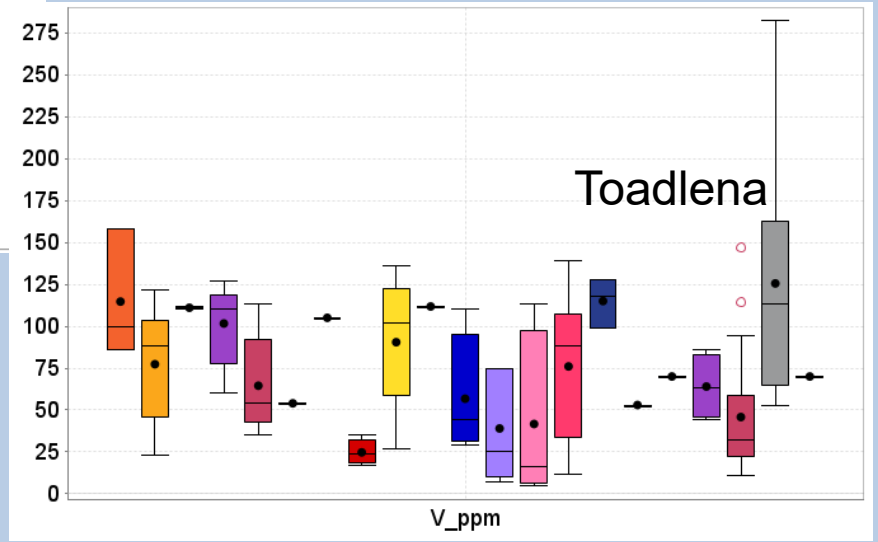
Ash basis



Critical minerals in coal, clinker, humates







Average crustal abundance

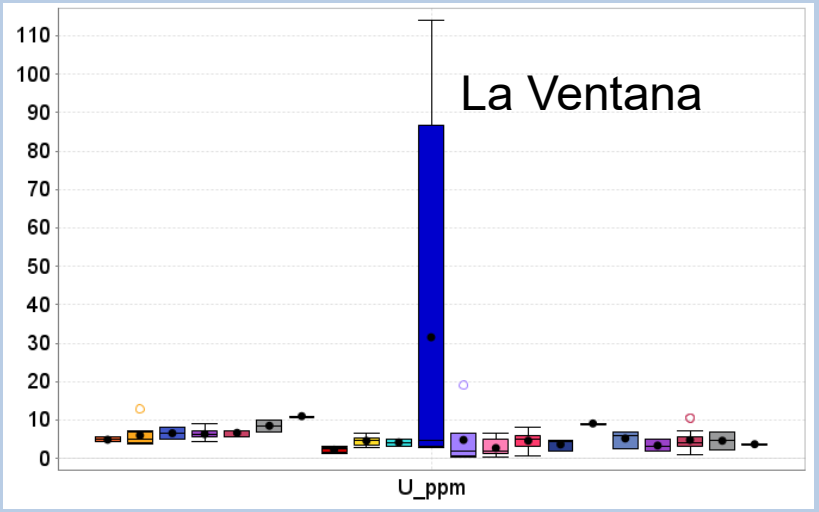
- Li=20 ppm
- Ni=25 ppm
- V=100 ppm

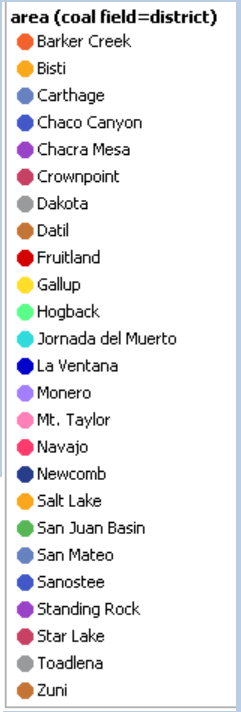
Brines=80 ppm Li

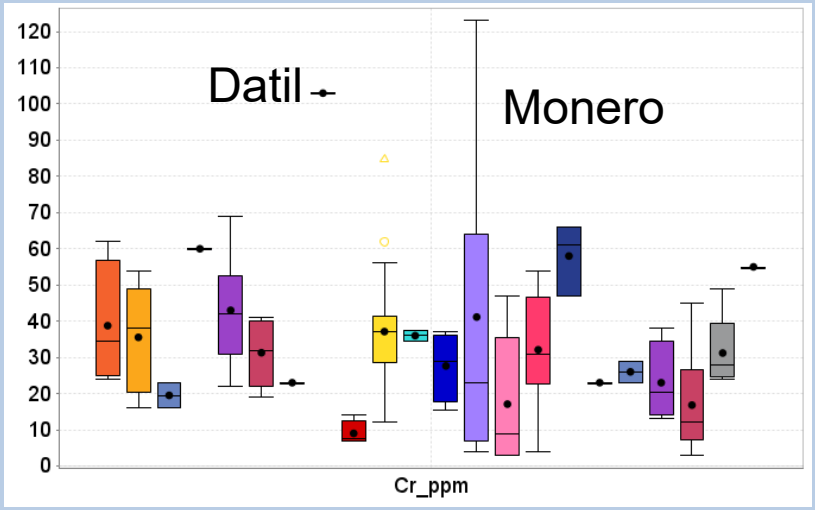
Cut-off grade

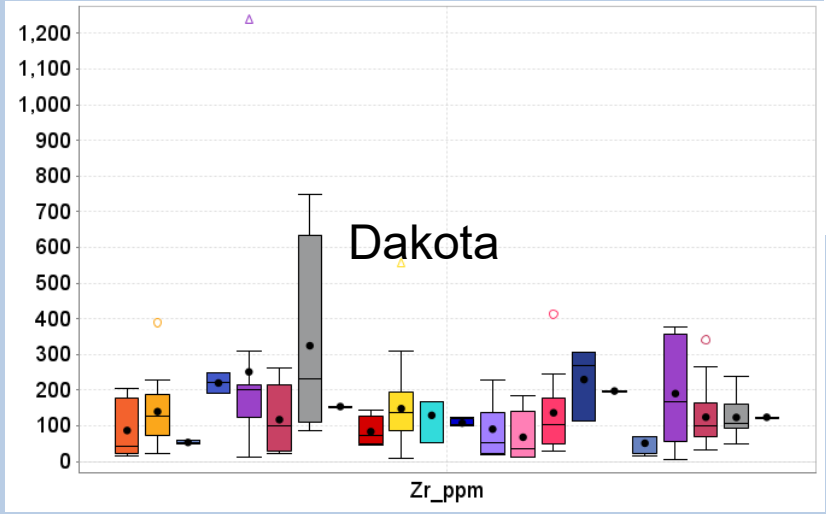
- Ni=0.5%
- V=1000 ppm

Critical minerals in coal, clinker, humates









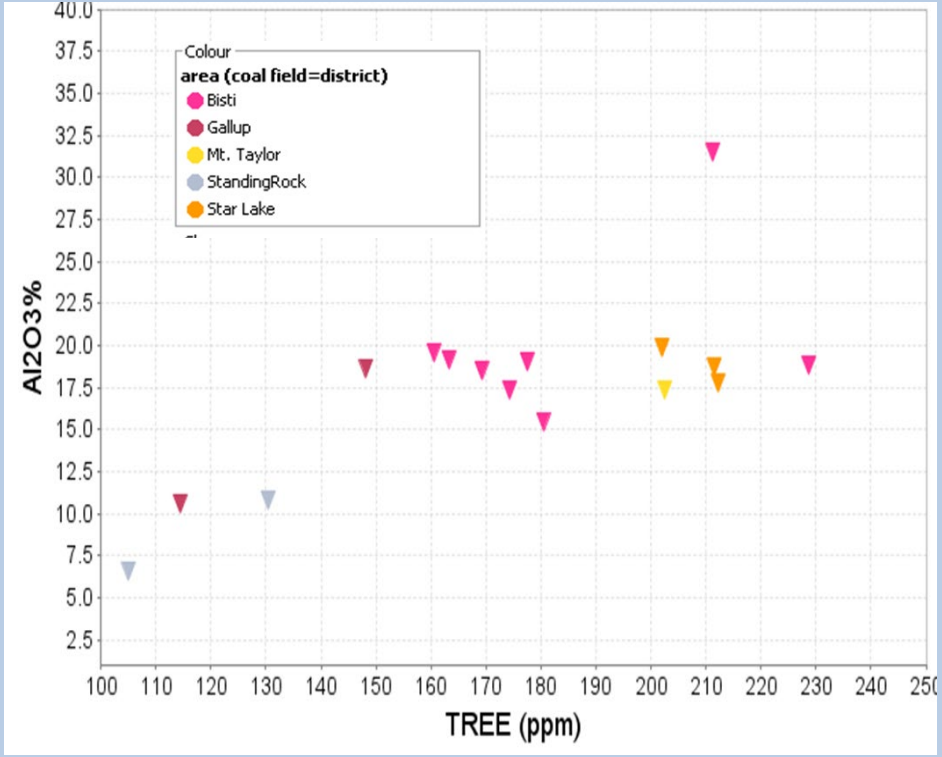
Average crustal abundance

- U=2 ppm
- Zr=250 ppm
- Cr=100 ppm

Cut-off grade

- U=1000 ppm
- 0.5% zircon
- Cr=30%

Clinkers

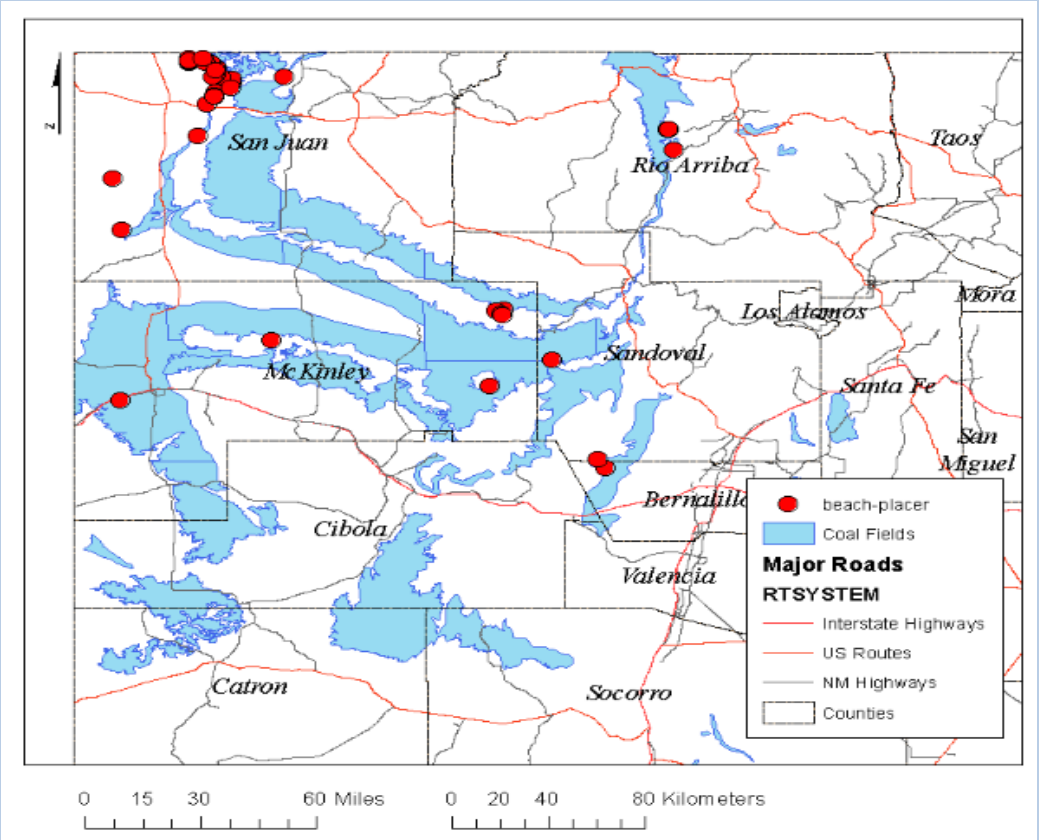


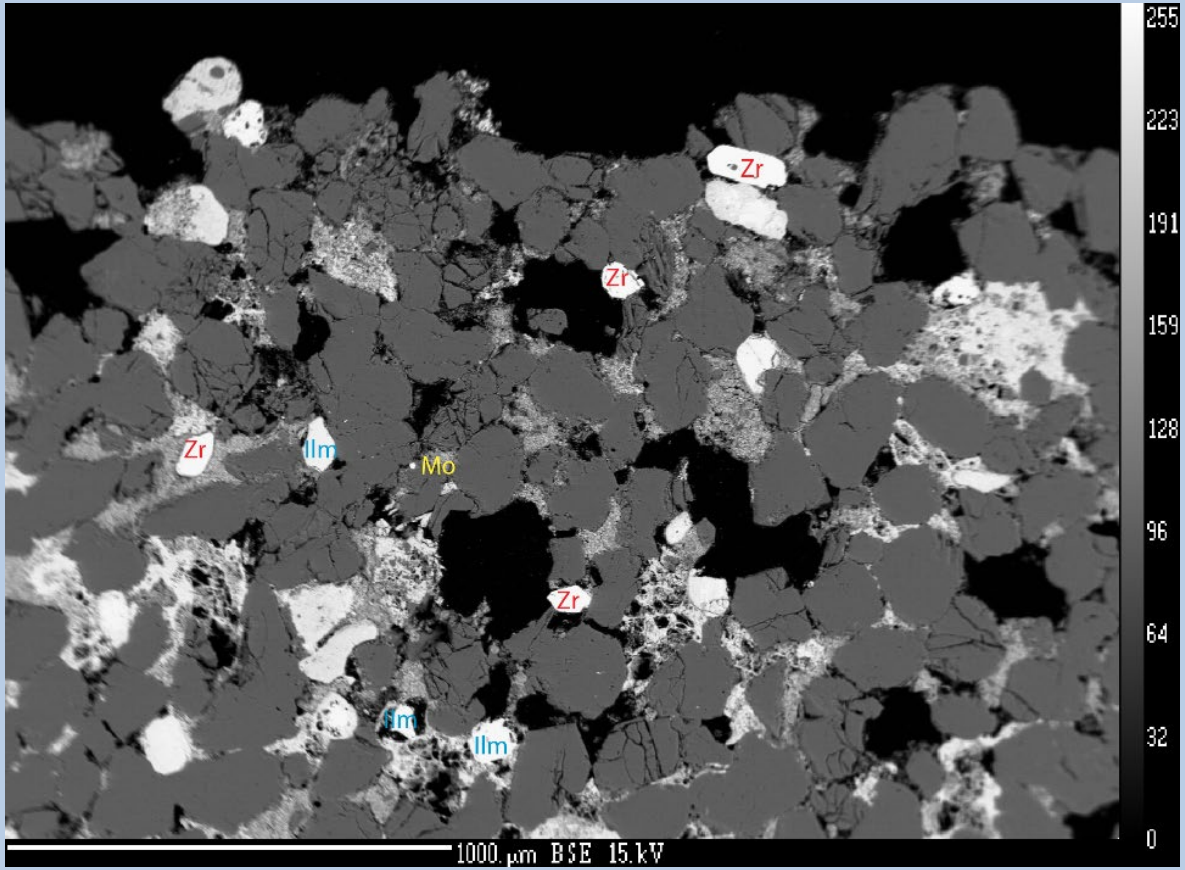
Graduate student testing extraction methods of Al from these rocks

Up to 32% Al_2O_3

Beach-placer sandstone deposits

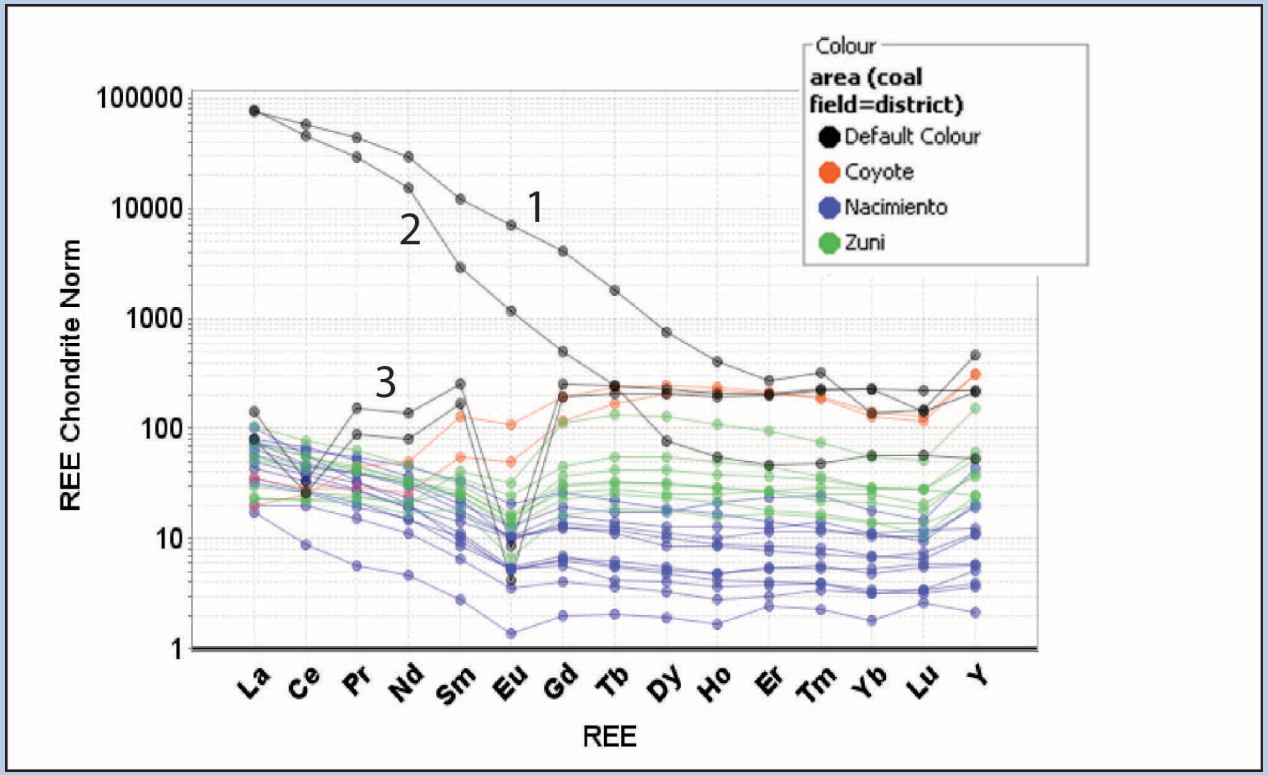
- Are in the vicinity of coal deposits/fields
- Small-intermediate tonnage
- Up to 29.4% TiO_2, 1.4% total REE, >1% Zr





Electron microprobe photo in sample SAN 6 (Sanostee). Zircon grains are labeled in red, ilmenite in blue, and monazite in yellow. Mottled, lighter colored cement is iron oxide (hematite). Dark grey grains are mainly quartz. Black areas are pore spaces.

Sediment-hosted stratabound copper deposits



Chondrite-normalized REE plot. Black lines are representative REE analyses of major deposits in production, for comparison

1=Mt. Weld laterite deposit
2=Mountain Pass, Ca carbonatite deposit
3= Zudong, China ion-adsorption clay deposit

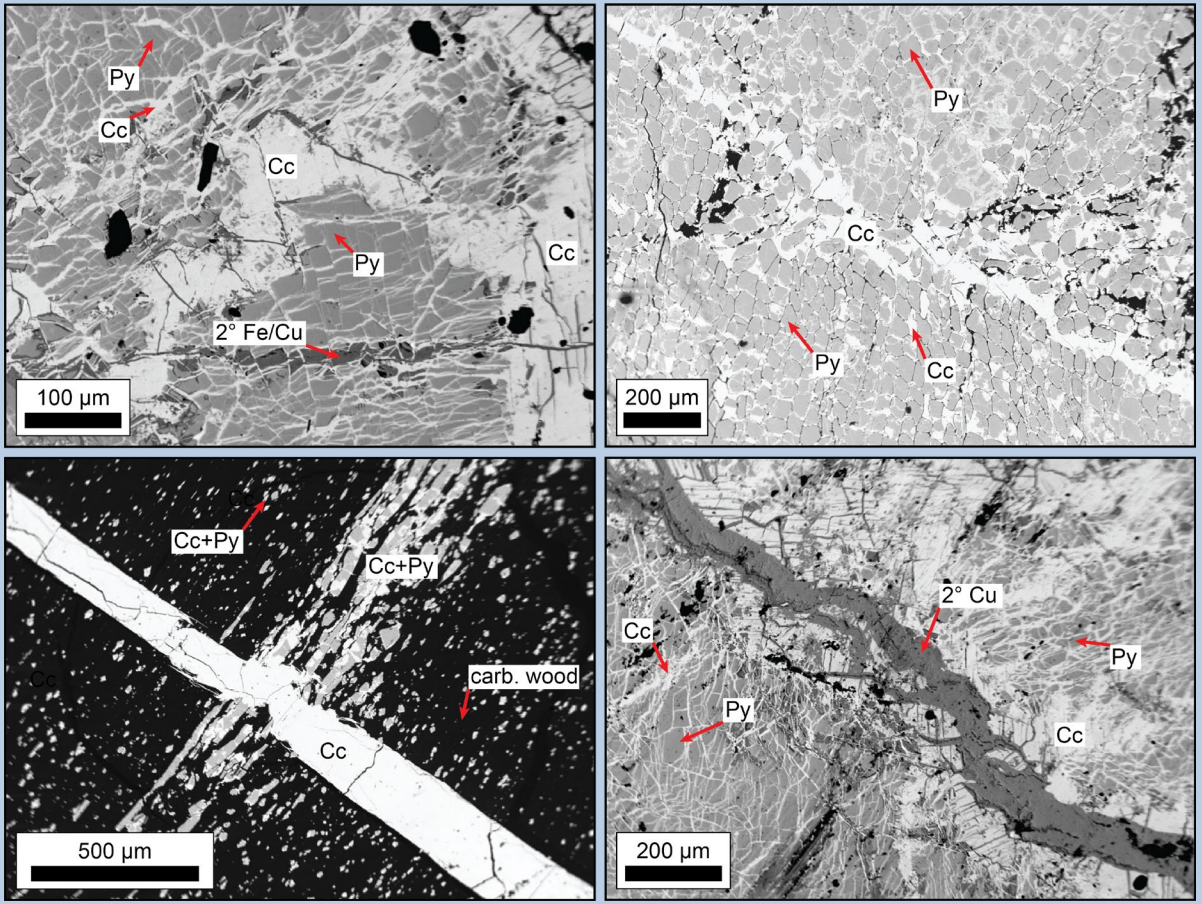
Backscattered electron (BSE) images of chalcocite and pyrite replaced wood from the Nacimiento mine

a) Chalcocite veinlets cutting and replacing pyrite that has replaced wood (NAC4)

b) Chalcocite veinlets cut and replace pyrite showing preserved plant cellular structure (NAC A)

c) Chalcocite and pyrite locally replace carbonized wood cut by a chalcocite vein (NAC B)

d) A late, secondary copper vein (possibly spertiniite) cuts chalcocite replacing pyrite along fractures (NAC4)



Abbreviations: Cc = chalcocite; Py = pyrite; 2° = secondary (iron-copper or copper minerals)

Outreach and Work Force Development

Outreach

- Rockin' Around New Mexico annual 3-day geology workshop for teachers (https://geoinfo.nmt.edu/education/rockin/home.html)
  - Farmington July 5-8, 2022 (visit Navajo coal mine)
  - Socorro July 5-8, 2023
  - Grants July 6-9, 2024 (plan to visit El Segundo coal mine)
- Articles in LITE Geology periodical geared towards earth science teachers in New Mexico (https://geoinfo.nmt.edu/publications/periodicals/litegeology/home.cfml)
- Web page (REE in Coal and associated strata in the San Juan and Raton basins, New Mexico (nmt.edu))

Work Force Development

- Work with the Navajo and Jicarilla Apache Nations
- Undergraduate and graduate students
- Earth Scope (2) students during summer 2023 (community college students)
- San Juan College students (Farmington)

Preliminary conclusions

Preliminary conclusions

- New Mexico is the land of opportunity
  - Deposits incl wastes are available for next stages of exploration
  - Need for industry to take these projects to the development stage
- The New Mexico coal, humates, and clinker deposits are relatively moderate to low in REE (<325 ppm TREE whole rock basis, <1000 ppm TREE ash basis), Li (<90 ppm), V (<168 ppm), Co (<51 ppm), Ni (<108 ppm), Zr (<557 ppm), Hf (<14 ppm), and other critical minerals compared to normal economic deposits
- Beach-placer sandstone deposits are up to 29.4% TiO_2, 1.4% total REE, >1% Zr

Preliminary conclusions—continued

- Sediment-hosted stratabound copper deposits are elevated in TREE (<394 ppm), heavy REE, V, Co, and As
- Potential geologic sources of REE and other critical minerals in New Mexico beach-placer sandstone, coal, humates, and clinker deposits include
  - Proterozoic granitic and metamorphic rocks (such as those found in the Zuni and Nacimiento Mountains)
  - The Jurassic-Cretaceous arc volcanism and magmatism forming the Mogollon Highlands to the south and west
  - Recycling of older sediments
  - Hydrothermal or weathering fluids could concentrate some of the critical minerals

Preliminary conclusions—continued

- More chemical and mineralogical analyses are required to fully understand the distribution and origin of REE and critical minerals in these deposits
- Ultimately, economic potential will depend upon
  - Grade (concentration) and tonnage (size)
  - Access (social license to operate, community) and ability to permit
  - Extraction techniques
  - Production of more than one commodity from beach placer, stratabound copper, coal, humates, and clinker deposits

Future Work

- Examine the REE on an ash basis in NM coals
  - Re-sample areas with high TREE (>500 ppm)
  - Sample additional drill cores
- Examine additional Permian and Triassic sediment-hosted stratabound copper deposits
- Examine Jurassic sandstone uranium deposits
- Examine additional clay deposits
- Continue to examine mine wastes
- Finish characterization
- How do these deposits relate to one another
- What is the source of REE and other critical minerals
- Estimate an endowment (resource) for critical minerals in each type of deposit

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