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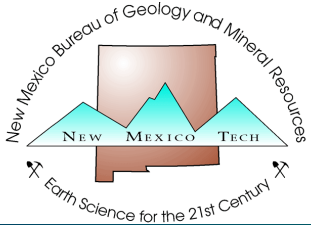
RARE EARTH ELEMENTS (REE) AND OTHER CRITICAL MINERALS IN LATE CRETACEOUS COAL AND RELATED STRATA IN THE SAN JUAN AND RATON BASINS, NEW MEXICO: PRELIMINARY OBSERVATIONS

Virginia T. McLemore, Evan J. Owen, Megan Badonie, Devlon Shaver, and Jakob Newcomer, New Mexico Bureau of Geology and Mineral Resources/NM Tech, Socorro, NM

virginia.mclemore@nmt.edu



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ACKNOWLEDGEMENTS

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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

Purpose—how much critical minerals, including REE, are found in:

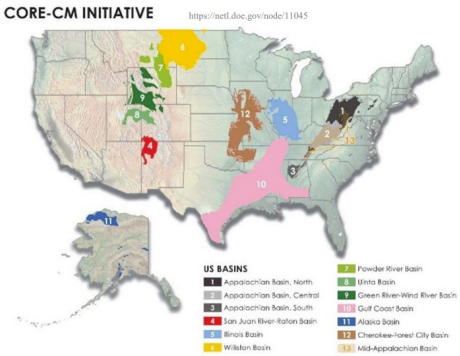
- Late Cretaceous heavy-mineral beach placer sandstone deposits in San Juan Basin
- Late Cretaceous coal deposits
- Late Cretaceous humates deposits
- Late Cretaceous clinker deposits

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

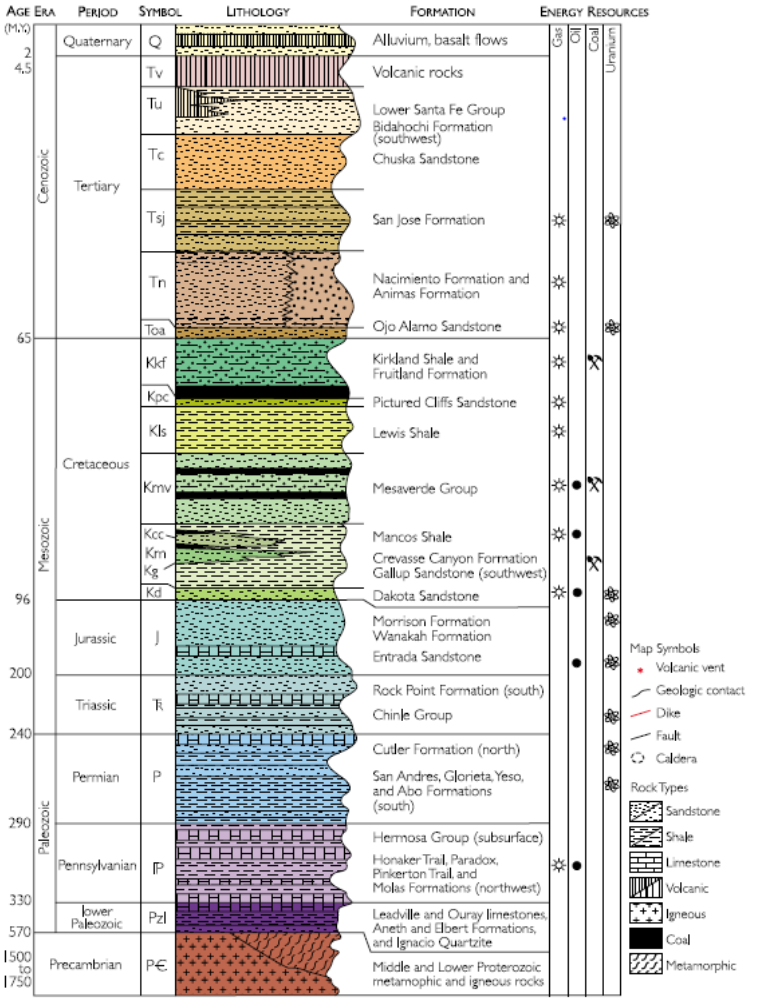
- CORE-CM=Carbon Ore, Rare Earth and Critical Minerals

– Identify and quantify the distribution of REE and CM in **coal beds and related stratigraphic units** in the San Juan and Raton basins

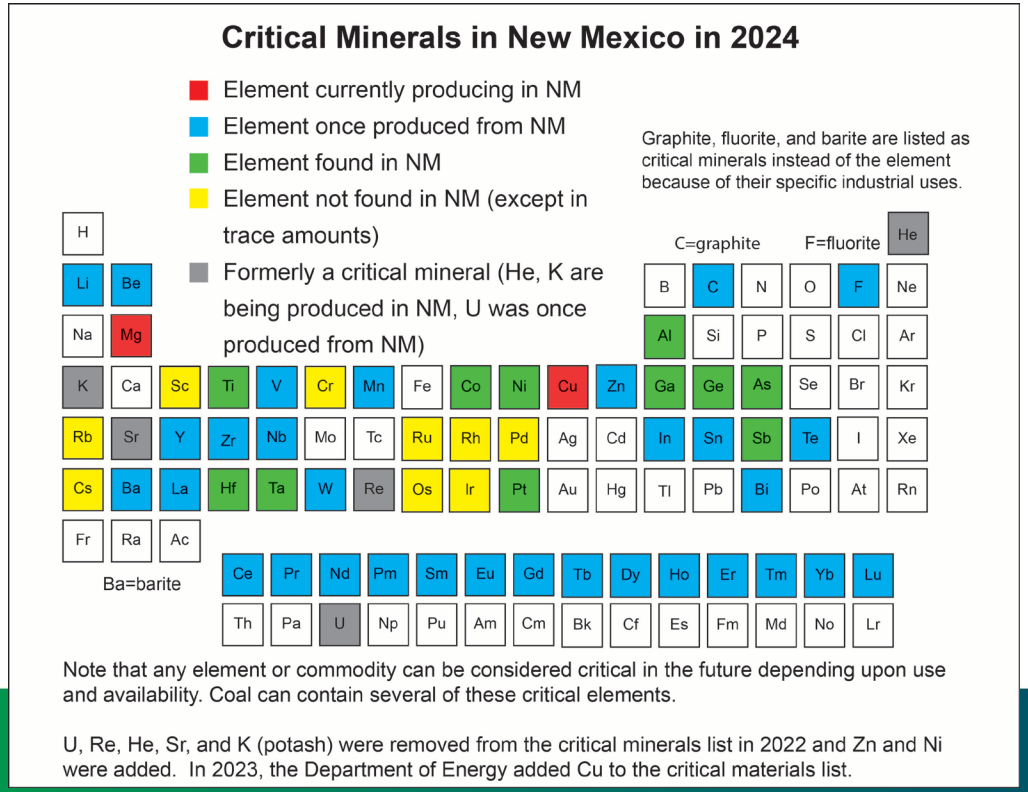
- Identify, sample, and characterize coal waste stream products

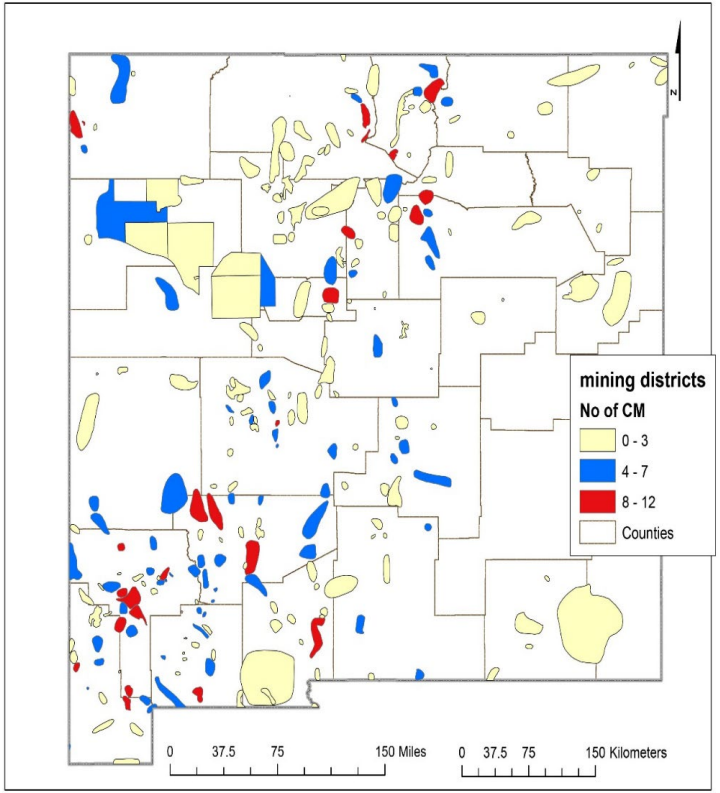


Stratigraphy of the San Juan Basin, New Mexico. Note the stratigraphic units that have gas, petroleum, coal, and uranium potential



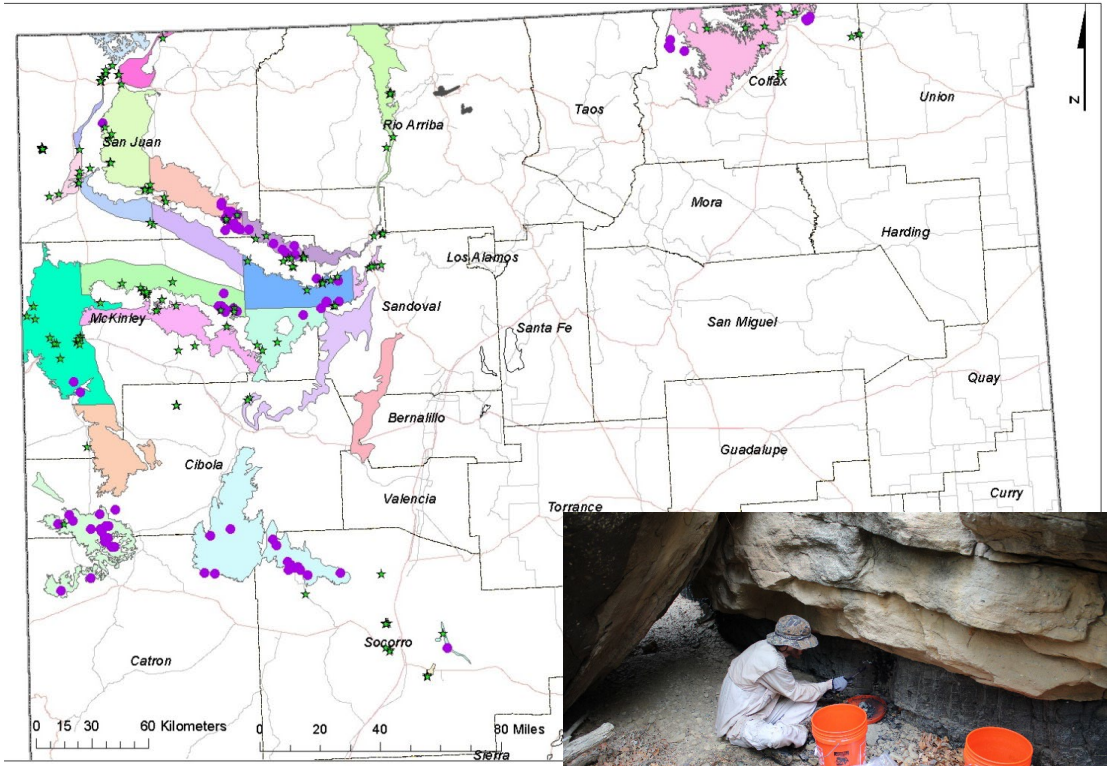
In the United States, a critical mineral is a nonfuel mineral commodity that is essential to the economic and national security of the United States, and is from a supply chain that is vulnerable to global and national disruption





New Mexico Coal Fields

- The coal/shale deposits are in the San Juan Basin
- 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

Coal in New Mexico

- Fuels electrical generating plants (1 in NM and 2-3 Arizona plants)
- 2 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

- 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
- 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

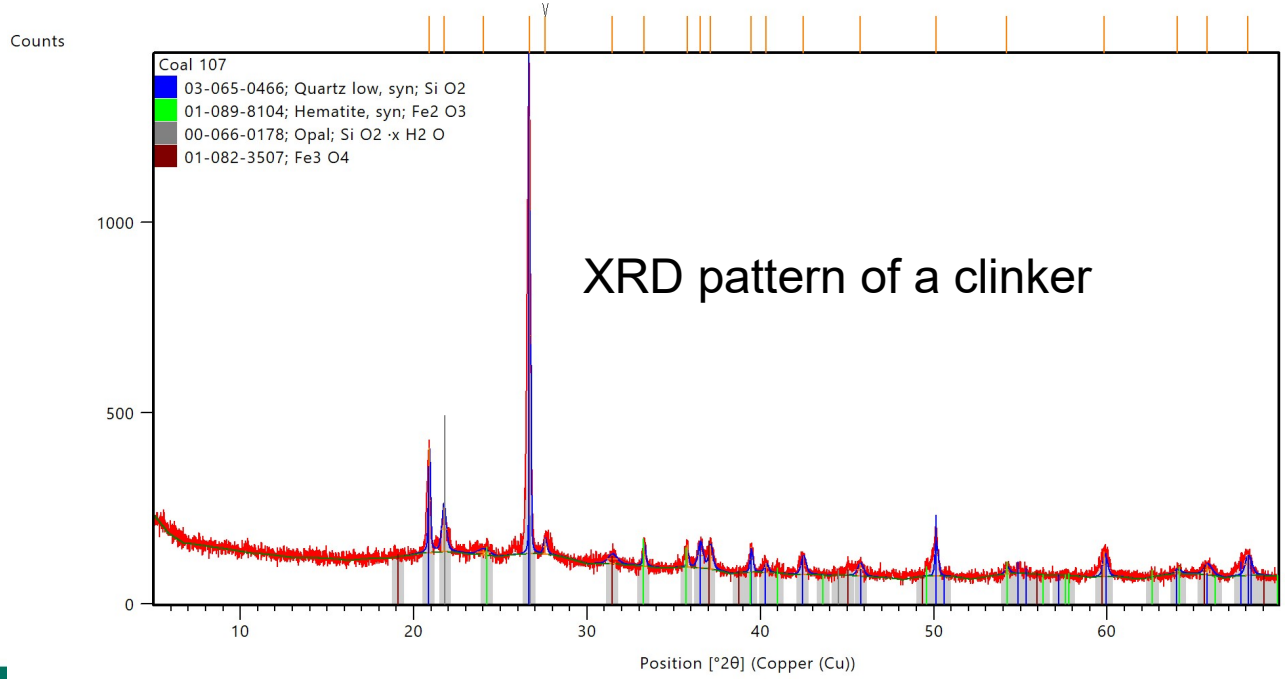
Clinker

- 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

Preliminary mineralogy (XRD, probe, thin section analysis)

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

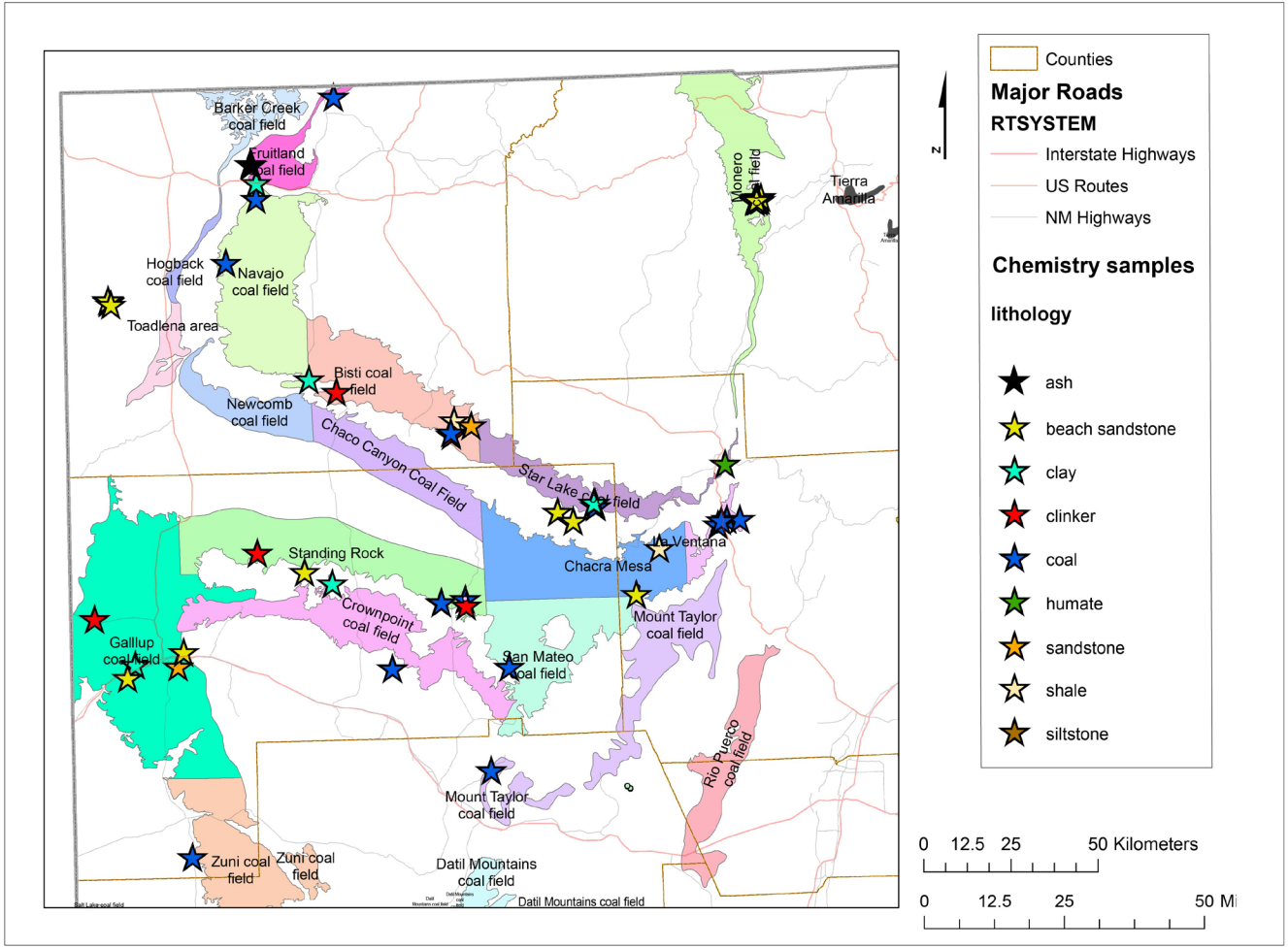


Geochemistry

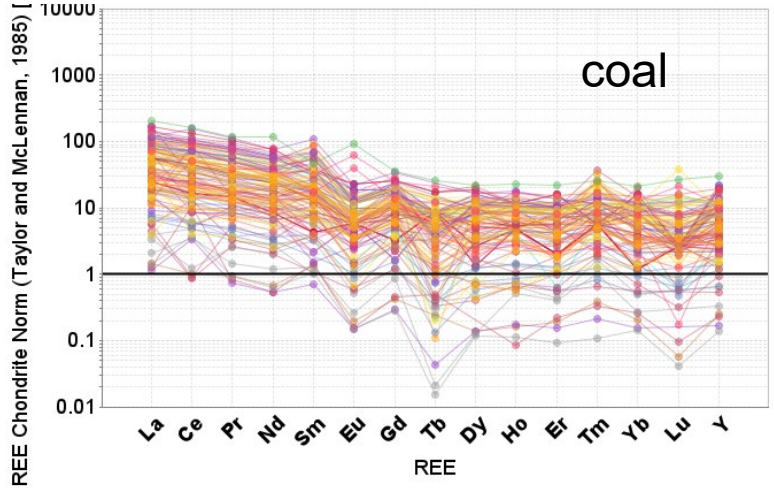
- Geochemical data of the beach-placer sandstone deposits are from a compilation by McLemore et al. (2016) that includes samples collected by McLemore and analyzed in 2010, 2015-2017 and by Zech et al. (1994) (REE by ICP-MS)
- Coal samples are difficult to analyze
  - Preferred ASTM sample preparation methods requires ash coal samples
  - SGS and University of Kentucky
- Legacy geochemical data of the coal deposits are from Baker, 1989; Araya, 1993; Affolter, 2019 [USGS coal quality database]) and new unpublished data collected for the DOE project
  - USGS coal quality data has many issues with the analyses; most REE analyzed by ICP-MS
  - Baker (1989) and Araya (1993) are thesis data analyzed at NM Tech; REE by neutron activation
  - New unpublished data has provided a more consistent data set analyzed by ASTM standards

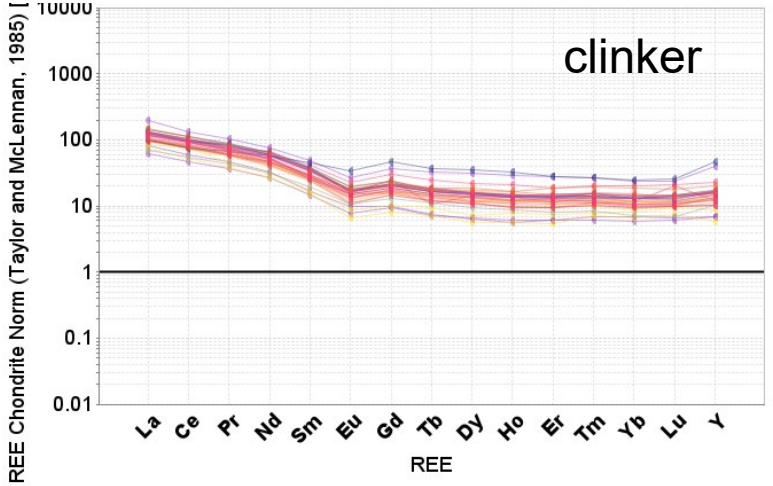
Chemistry samples from 22 fields
(total 26)

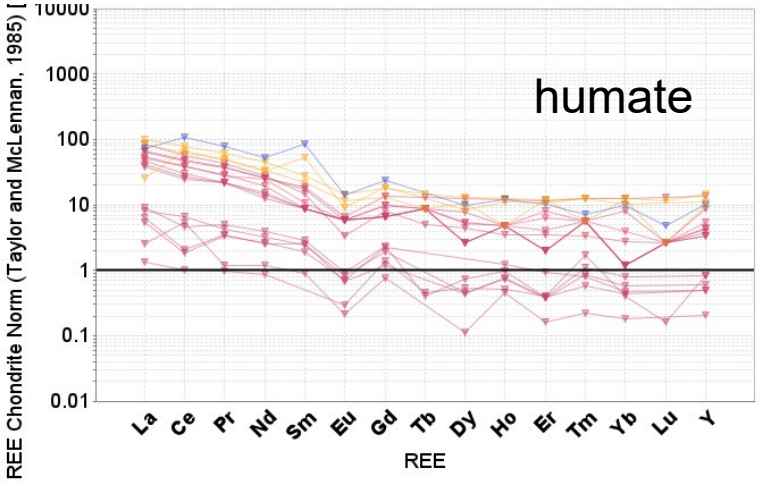
- 148 coal, 5 ash, 18 humate, 34 clinker samples
- 119 igneous rocks, shale, sandstone, clay, other
- 93 beach placer

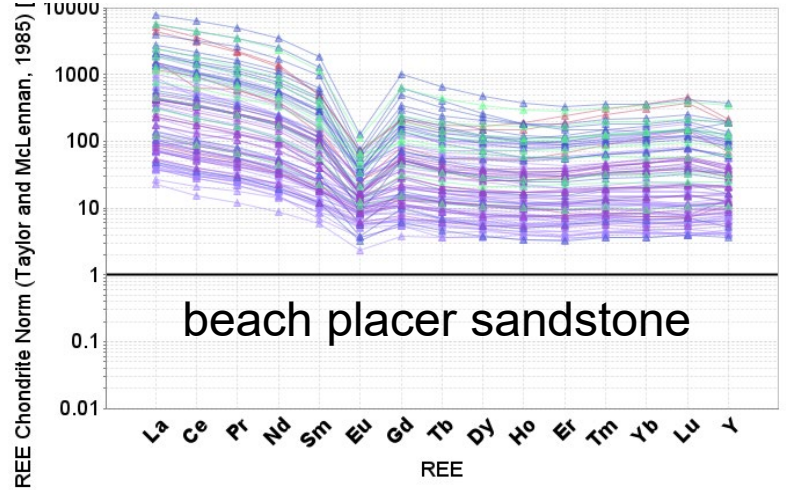


REE chondrite-normalized REE of samples by coal fields in the San Juan Basin

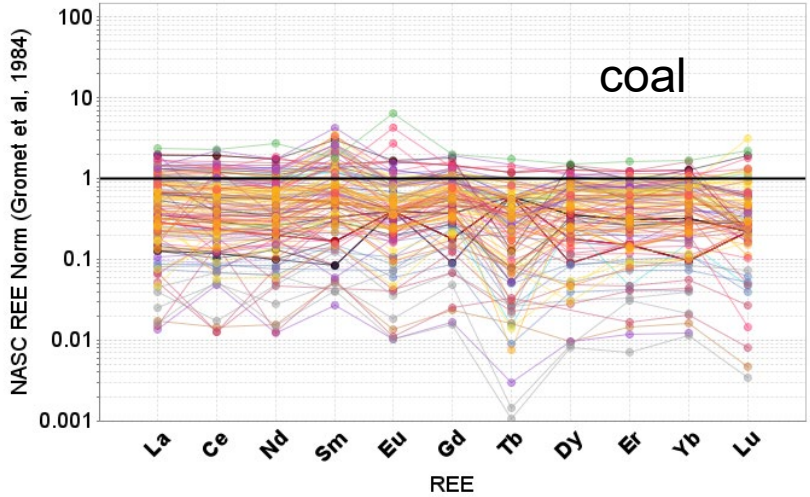


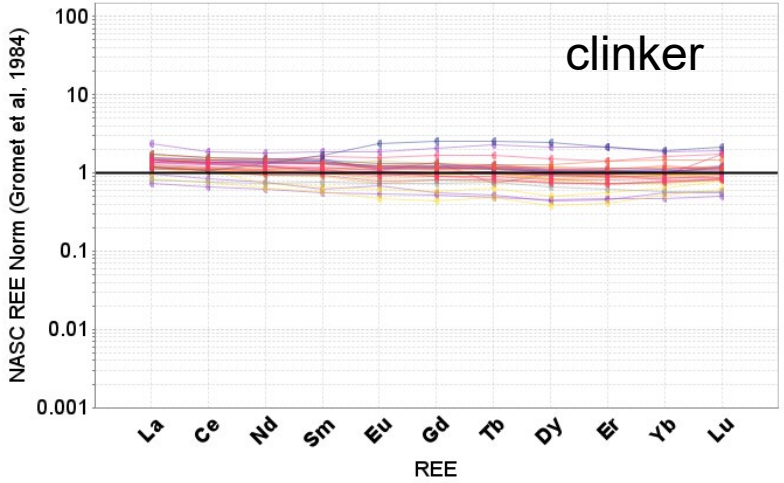


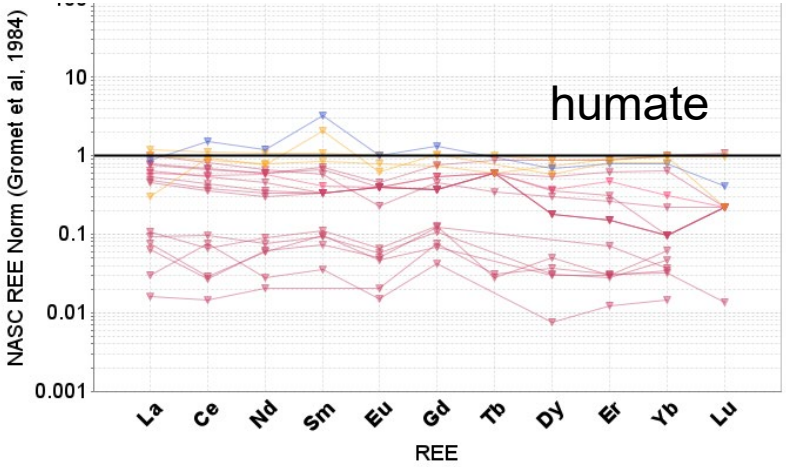


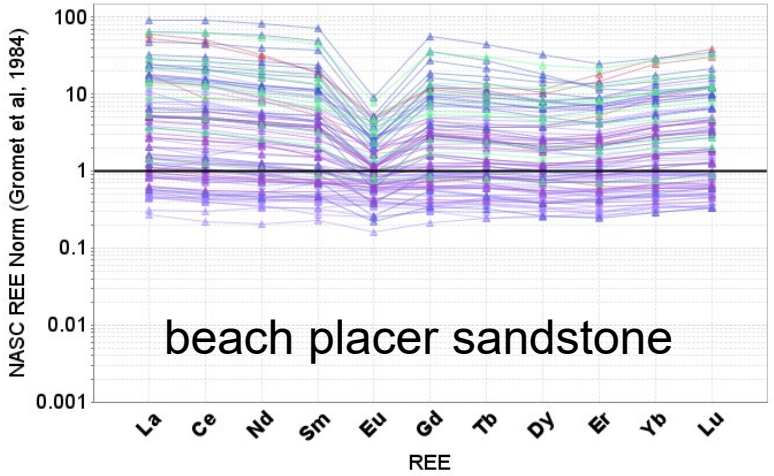


REE NASC-normalized REE of samples by coal fields in the San Juan Basin



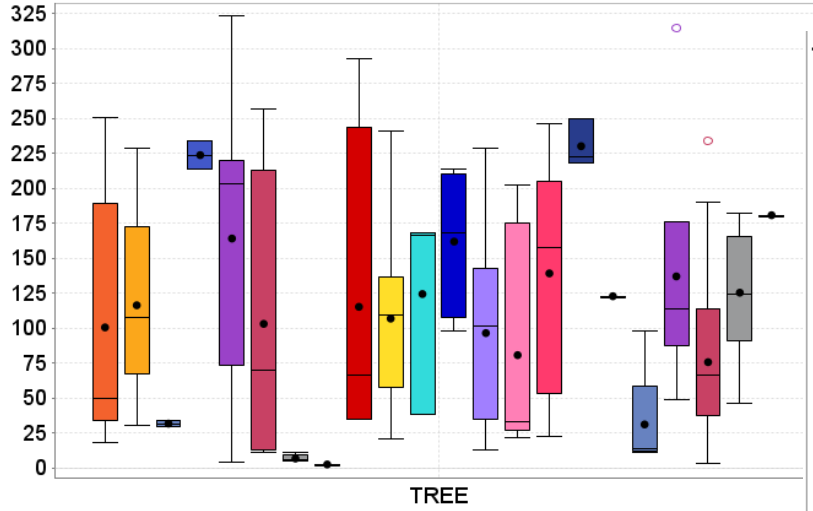


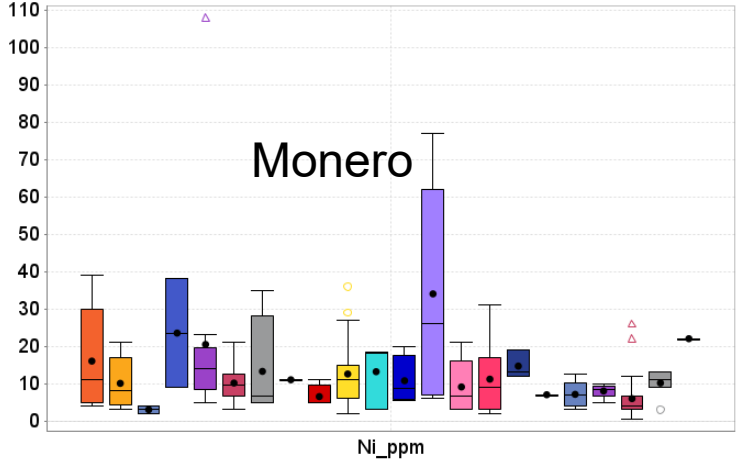


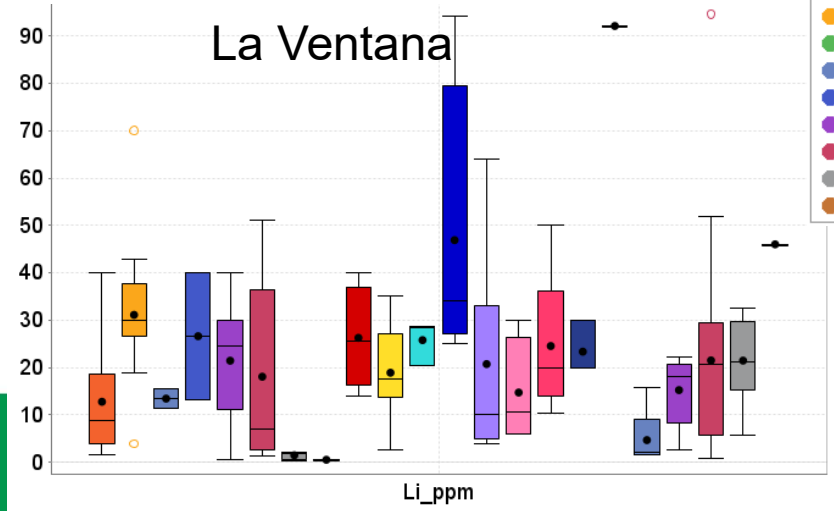


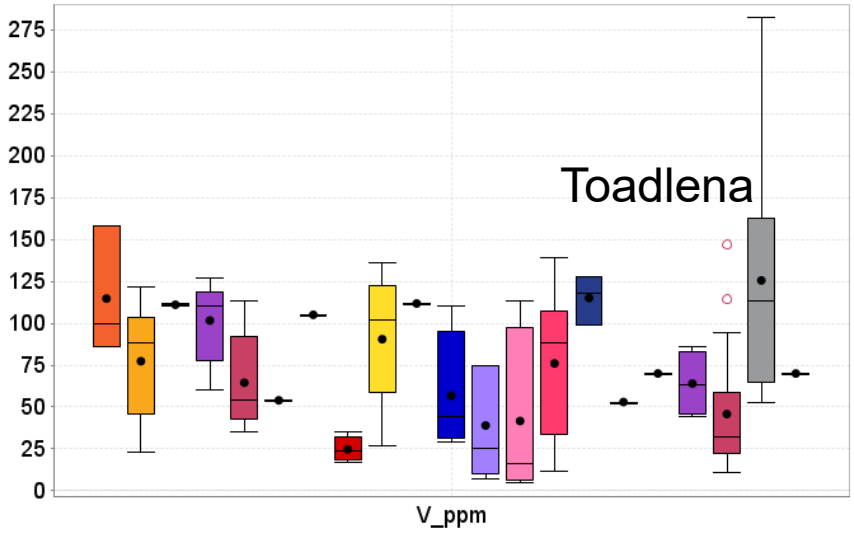
area (coal field=district)
- Barker Creek
- Bisti
- Carthage
- Chaco Canyon
- Chacra Mesa
- Crownpoint
- Dakota
- Datil
- Fruitland
- Gallup
- Hogback
- Jornada del Muerto
- La Ventana
- Monero
- Mt. Taylor
- Navajo
- Newcomb
- Salt Lake
- San Juan Basin
- San Mateo
- Sanostee
- Standing Rock
- Star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

Critical minerals in coal, clinker, humates

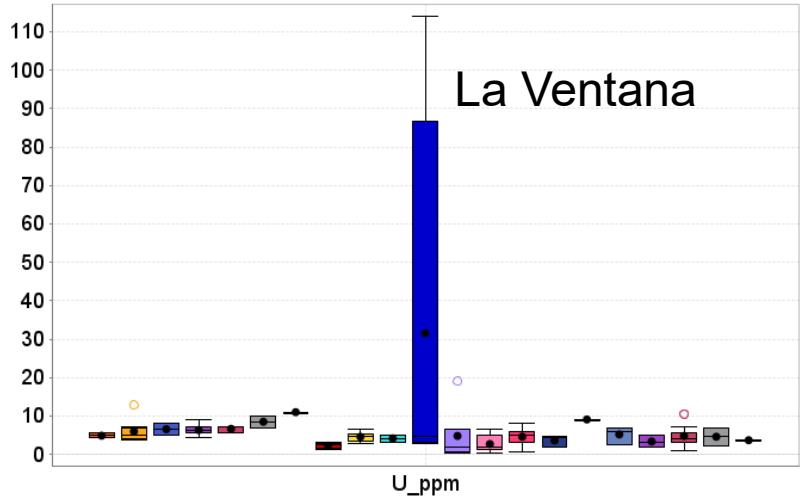


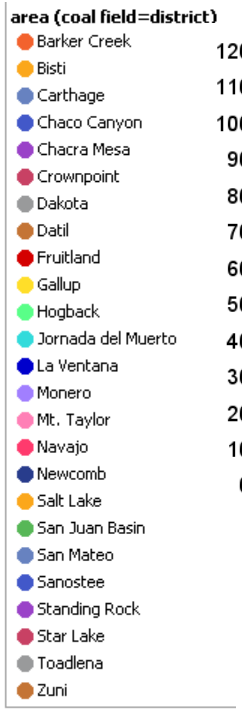


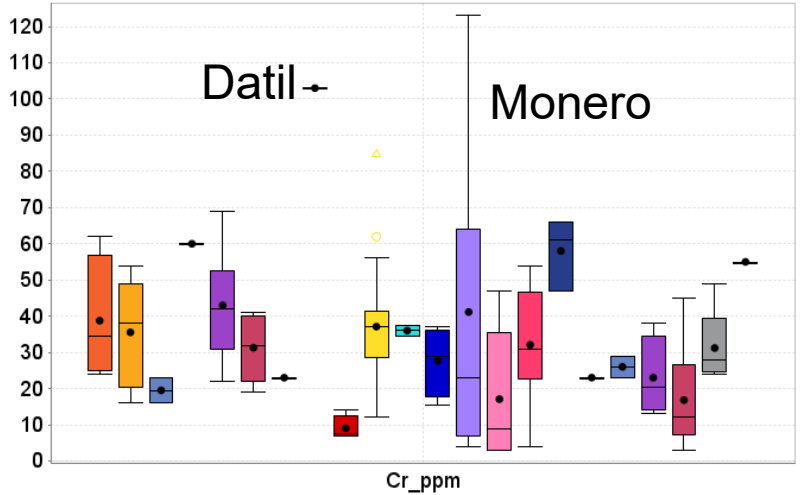


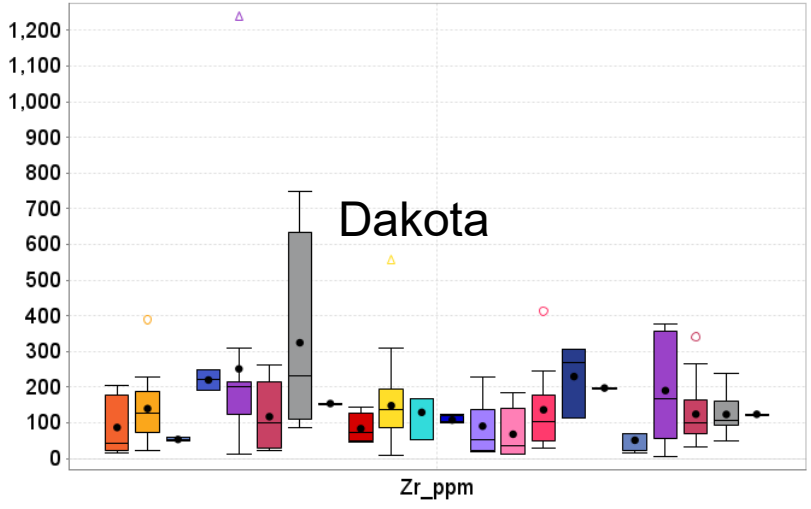


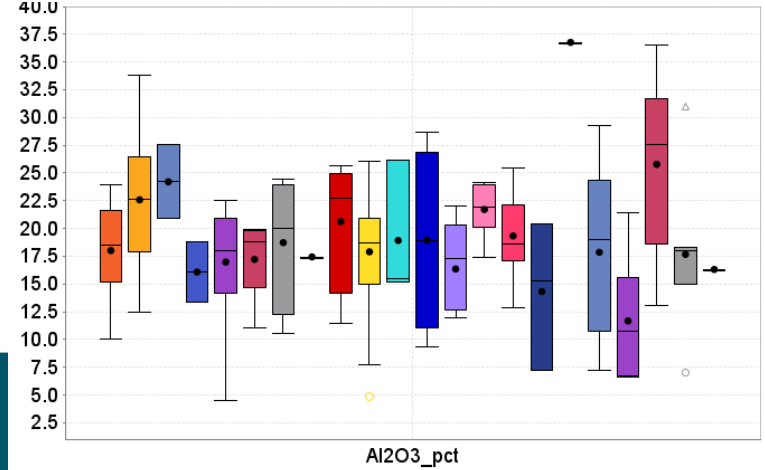
Critical minerals in coal, clinker, humates



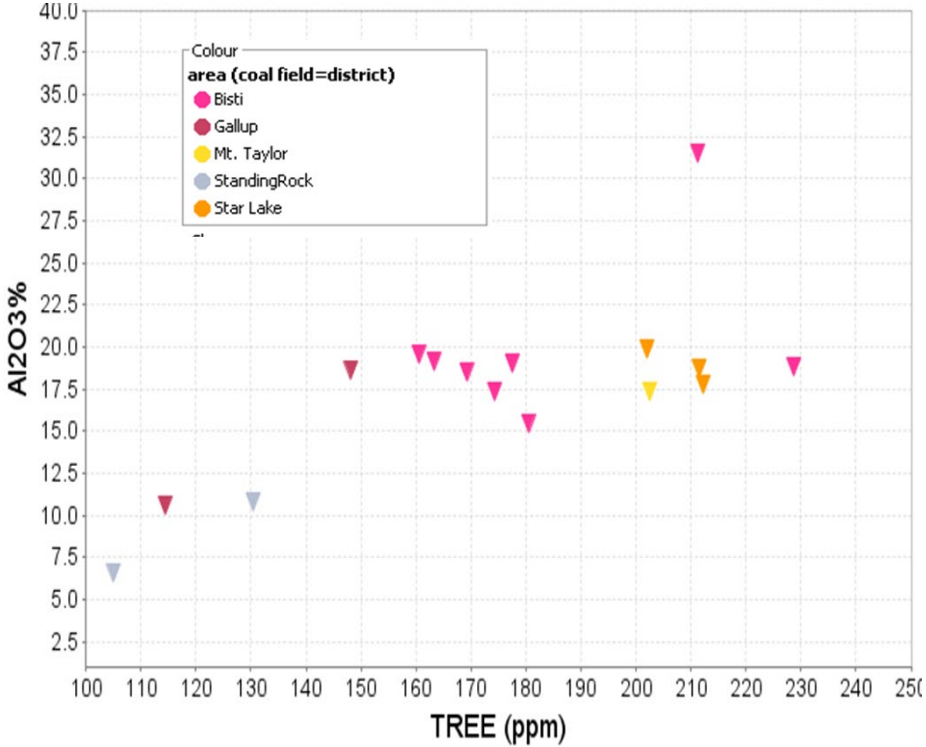








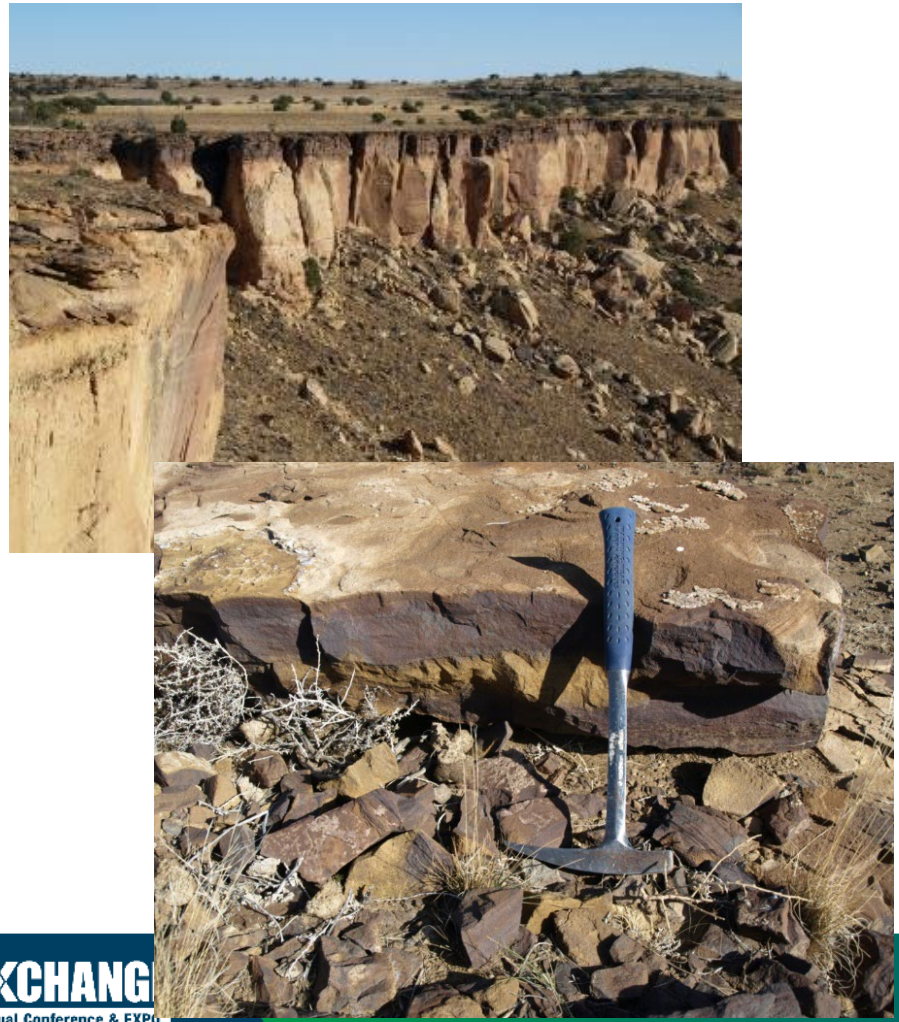
Clinkers



Up to 32% Al_2O_3

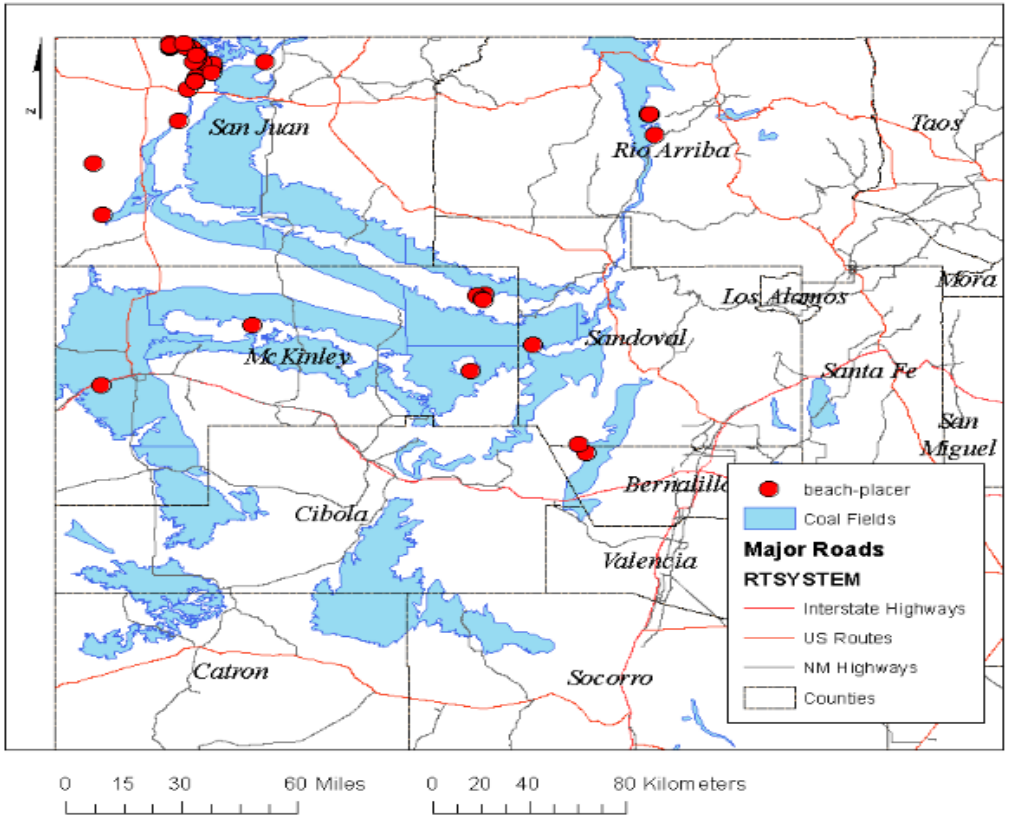
Beach-placer sandstone deposits

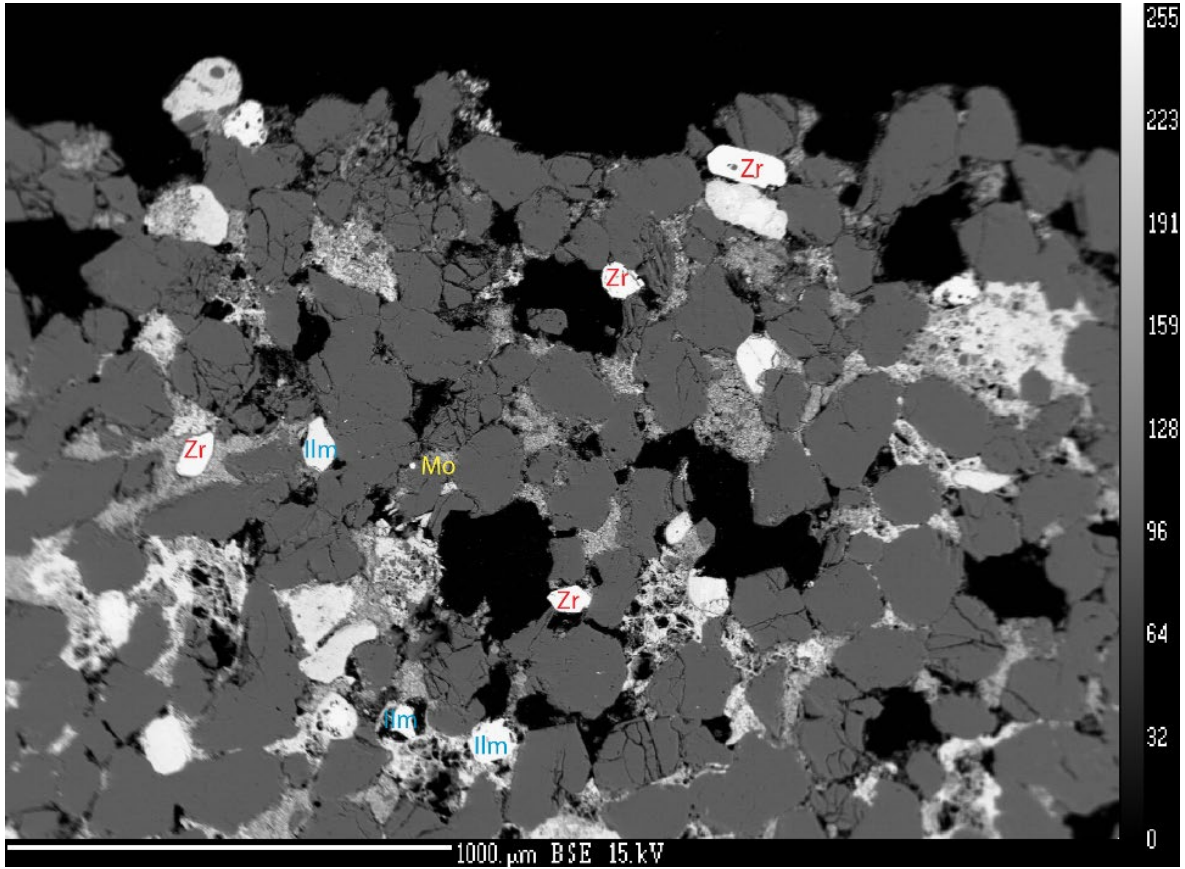
- Beach-placer sandstone deposits in the San Juan Basin are restricted to Late Cretaceous rocks and contain high REE
  - NM REE database
- Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones



Beach-placer sandstone deposits

- Are in the vicinity of coal deposits/fields
- Small-intermediate tonnage





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.

Preliminary conclusions

- The New Mexico coal, humates, and clinker deposits are relatively moderate-low in REE (<325 ppm TREE), Li (<90 ppm), V (<168 ppm), Co (<51 ppm), Ni (<108 ppm), Zr (<557 ppm), Hf (<14 ppm), and many other critical minerals compared to normal economic deposits
- However, some of these rocks are enriched in Al_2O_3 (as much as 40%) and Sr (as much as 3740 ppm), both critical minerals
- Common minerals hosting the critical minerals in these rocks include clay minerals, zircon, and rutile/anatase

Preliminary conclusions—continued

- Potential geologic sources of REE and other critical minerals in New Mexico 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, and recycling of older sediments, although 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
- As the demand for some of these elements increases because of increased need and short supplies, the dollar value per ton of ore rises, enhancing deposit economics
- Ultimately, economic potential will most likely depend upon production of more than one commodity, maybe even from coal, humates, and clinker deposits

Future Work

- Examine Permian and Triassic sediment-hosted stratabound copper deposits
- Examine Jurassic uranium deposits
- 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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