Industrial Minerals in the San Juan Basin area of New Mexico

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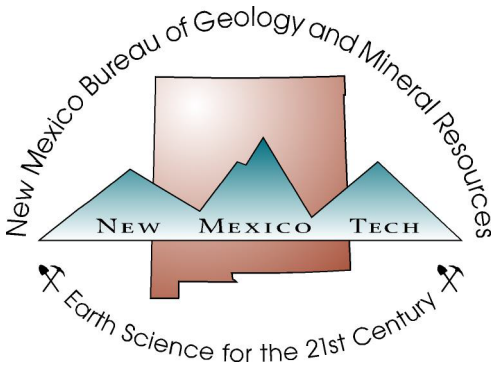


New Mexico Tech

ACKNOWLEDGEMENTS

- Partial funding by USGS National Geological and Geophysical Data Preservation Program (NGGDPP), USGS Earth Mapping Resources Initiative (MRI), DOE CORE-CM, and BLM

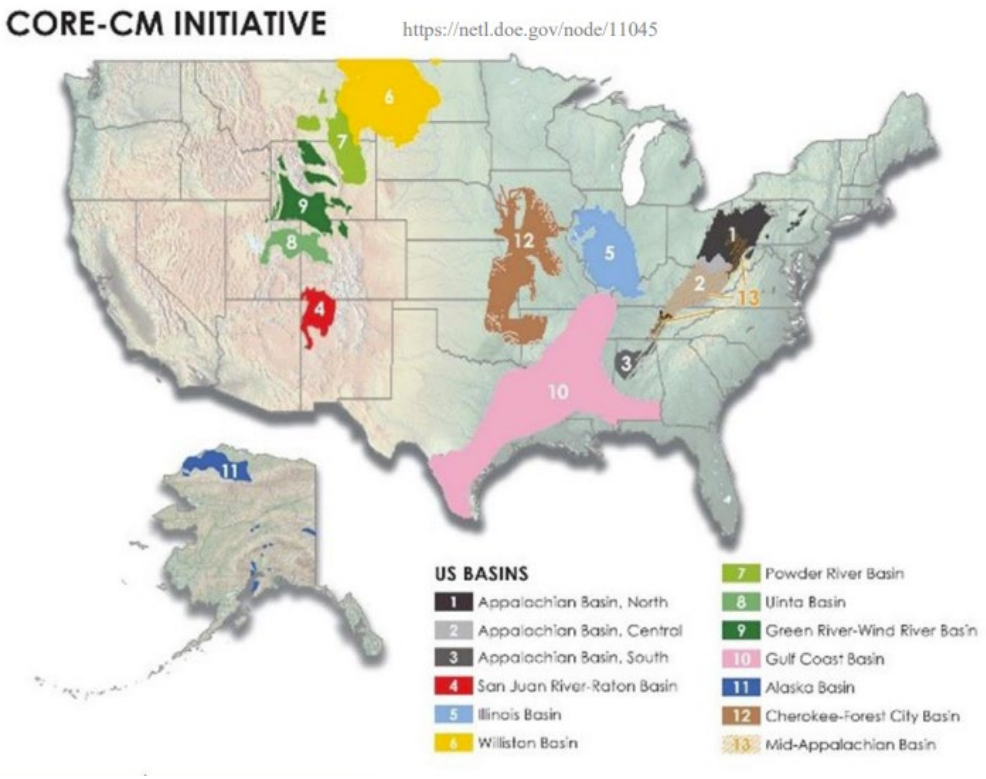
- Any persons wishing to conduct geologic investigations on the Navajo Nation must first apply for and receive a permit from the Minerals Department, P.O. Box 1910, Window Rock, Arizona 6515 and telephone no. 928-871-6588.
- Personal visits to mines
- Current CO-PIs and colleaguesworking on these projects
- Students at NM Tech, many part of the Economic Geology Group

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



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

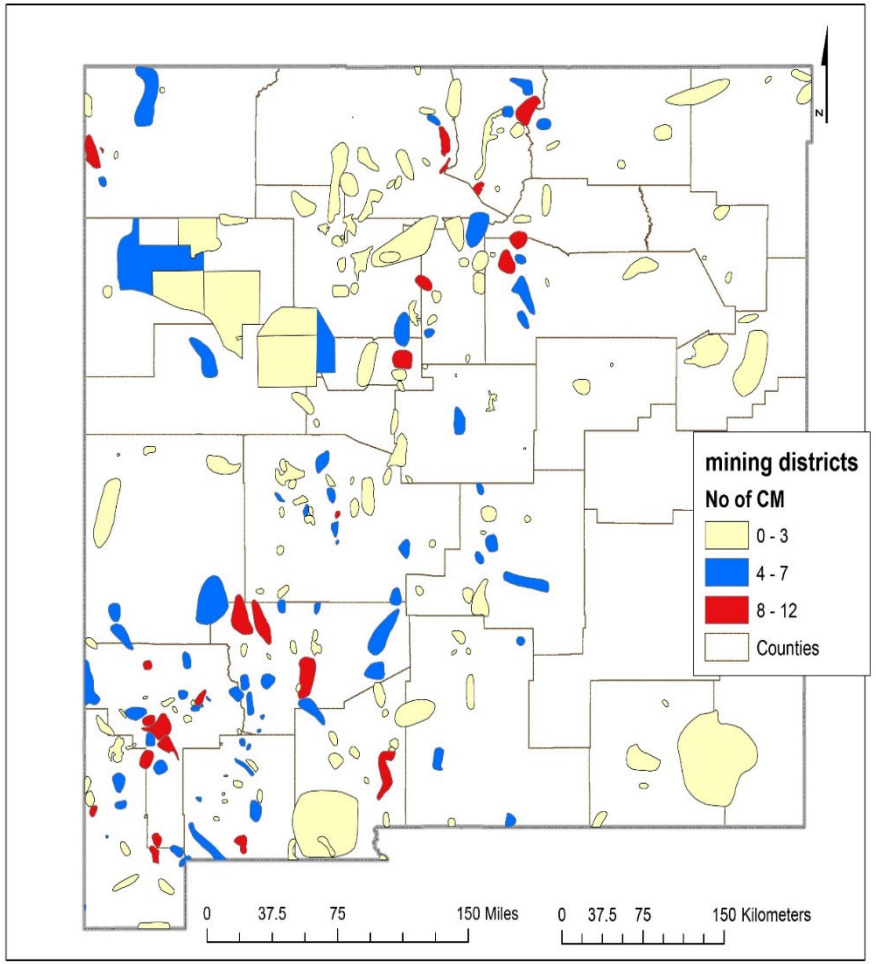
C=graphite
F=fluorite
Ba=barite

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 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.



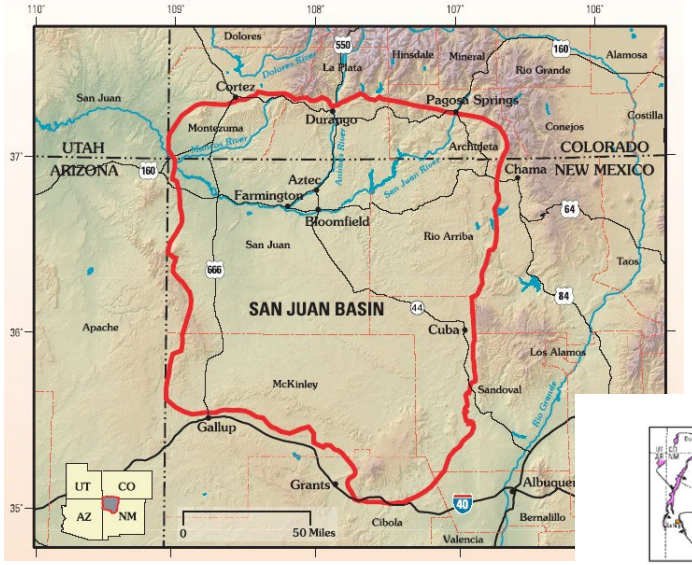
Purpose

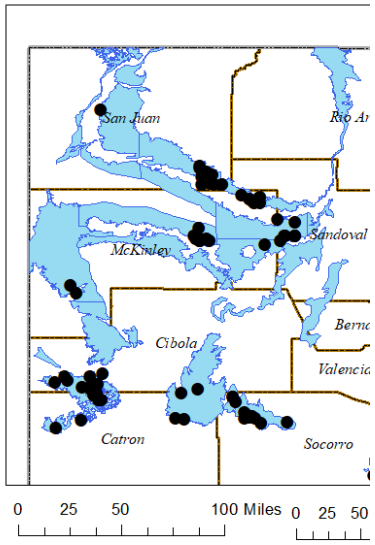
- Identify the industrial minerals currently mined in the San Juan Basin
- Identify potential additional industrial minerals in the basin
- Identify potential critical minerals in the basin

- Provide needed jobs to replace those lost in oil, gas, and coal production as we transition to a carbon-free economy

Geological Background – San Juan Basin

- An asymmetrical structural depression forming southeast margin of the Colorado Plateau
- Upper Cretaceous–Early Tertiary age
- 26,000 + square miles
- San Juan Basin has 3 major coal-bearing units
  - Crevasse Canyon
  - Menefee
  - Fruitland Formations
- ~ 24 coal fields
- Stratigraphy of the San Juan basin dips inward from the highlands towards the center of the basin, creating a “trough-like” feature





Stratigraphic section of the San Juan basin, Northern New Mexico (Hoffman, 2017)

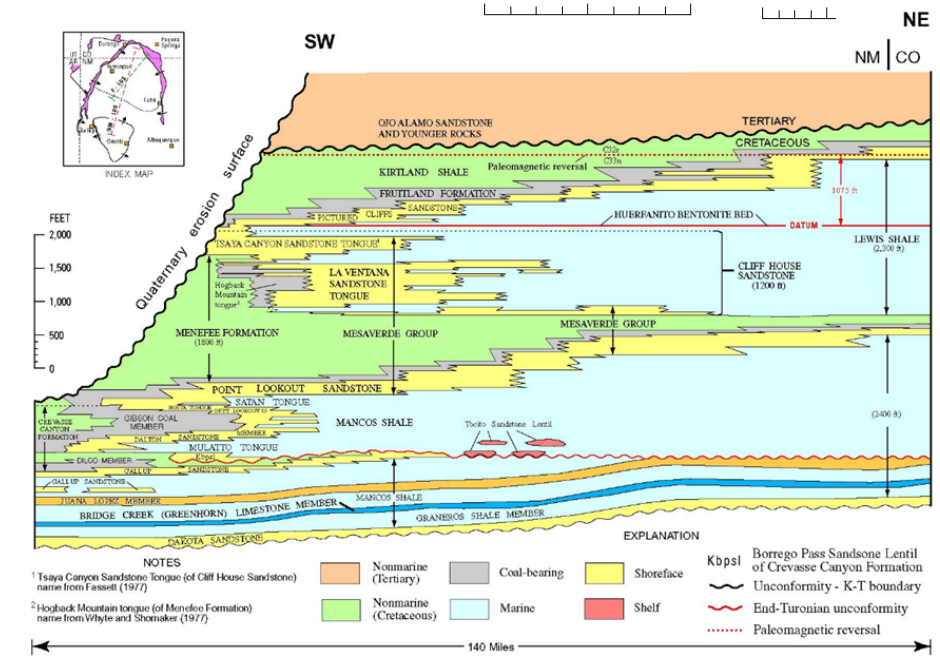
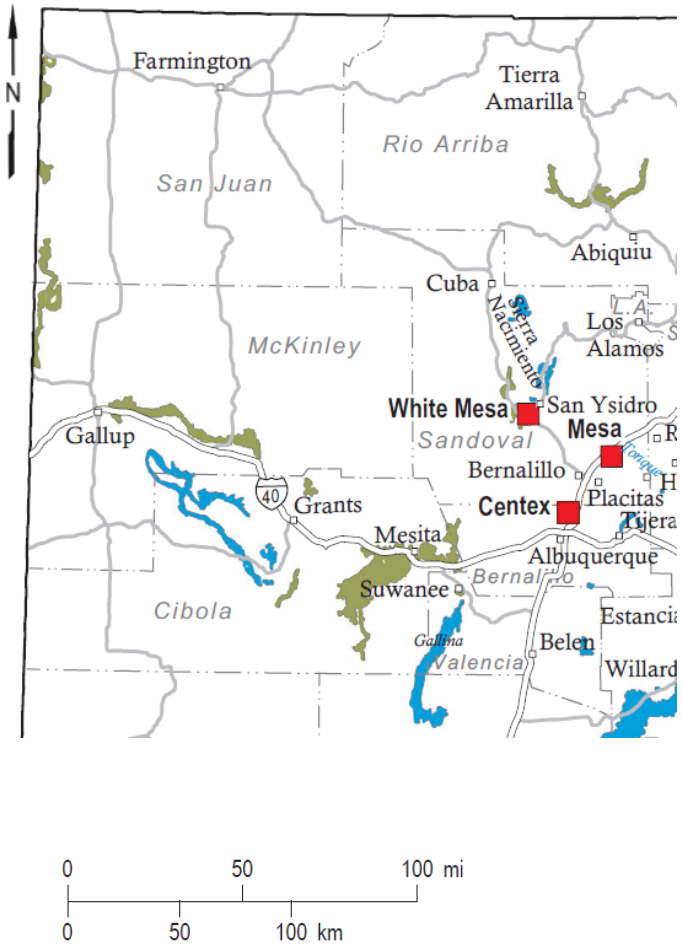
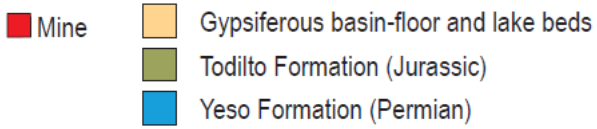


Figure 4. Stratigraphic section showing Upper Cretaceous rocks in the San Juan Basin, New Mexico and Colorado. Tocito Sandstone Lentil and coal-bearing zones are shown diagrammatically. Stratigraphy of rock units from the Point Lookout Sandstone upward is modified from Fassett (1977), stratigraphy for lower part of section is modified from Nummedal and Molenaar (1995). F - LOS on index map is Fassett (1977) line of cross section; NM - LOS is Nummedal and Molenaar (1995) line of cross section. Position of paleomagnetic reversal from chron C33n to C32r is from Fassett and Steiner (1997). Vertical exaggeration x 55.

Gypsum





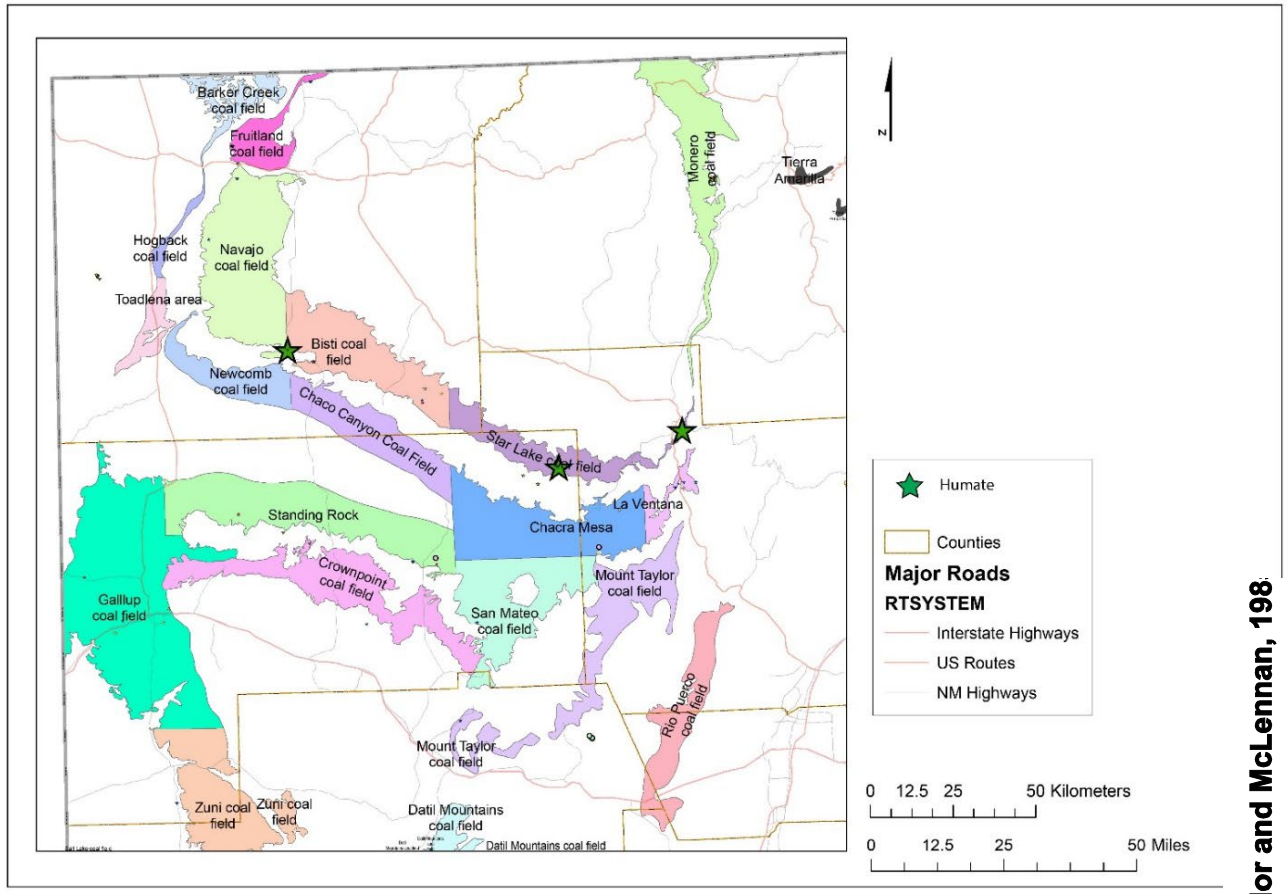
- A soft mineral (hardness of 1.5-2) with the formula $CaSO_4 \cdot 2H_2O$, and is typically formed in sedimentary environments
- Used primarily in the manufacture of wallboard for homes, offices, and commercial buildings; other uses include the manufacture of Portland cement, plaster-of-Paris, and as a soil conditioner
- Eagle Materials (formerly Centex) operates the White Mesa mine near Cuba and 2 wallboard plants in Albuquerque and Bernalillo

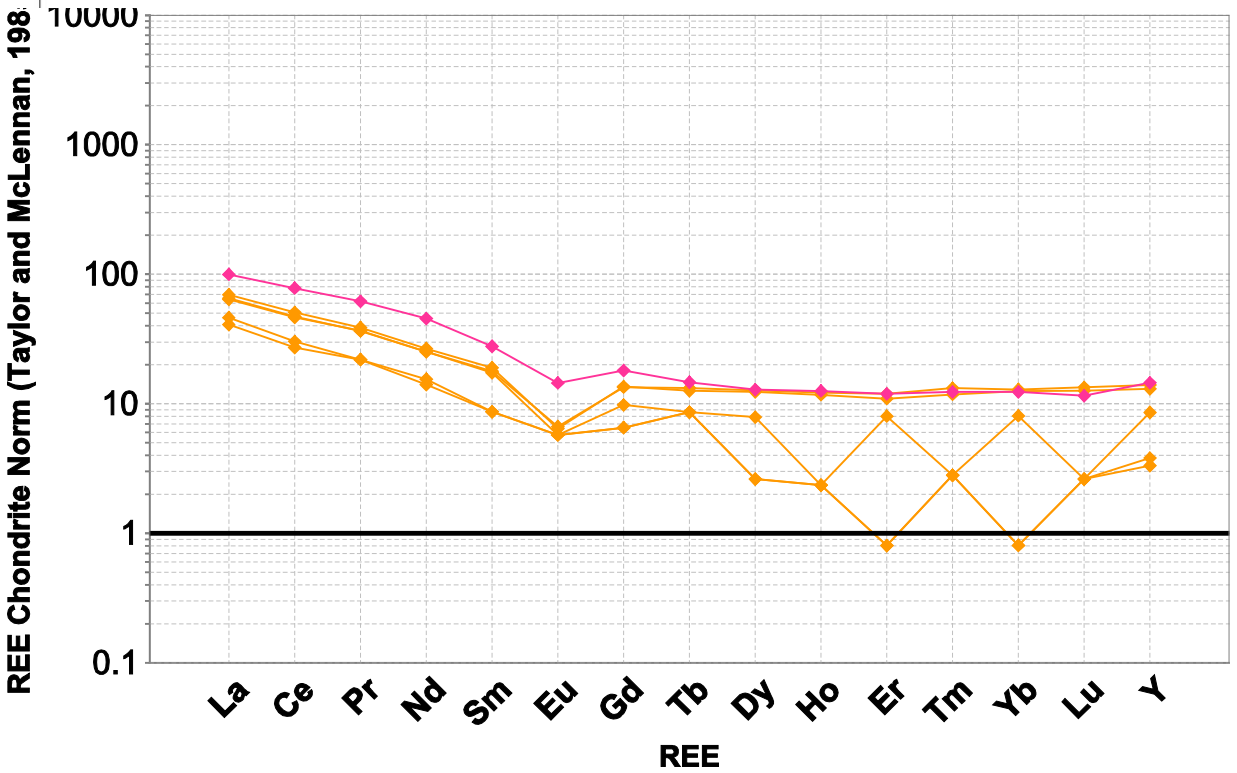
Gypsum is mined at White Mesa, Sandoval County (Eagle Materials) and used to manufacture wallboard

- An average new American home of 2,000-square-foot floor area uses approximately 7.31 metric tons (t) of gypsum in more than 571 square meters (6,144 square feet) of gypsum wallboard
- As a filler in food products the average person eats about 28 pounds of gypsum in a lifetime (National Gypsum Company, 2005)

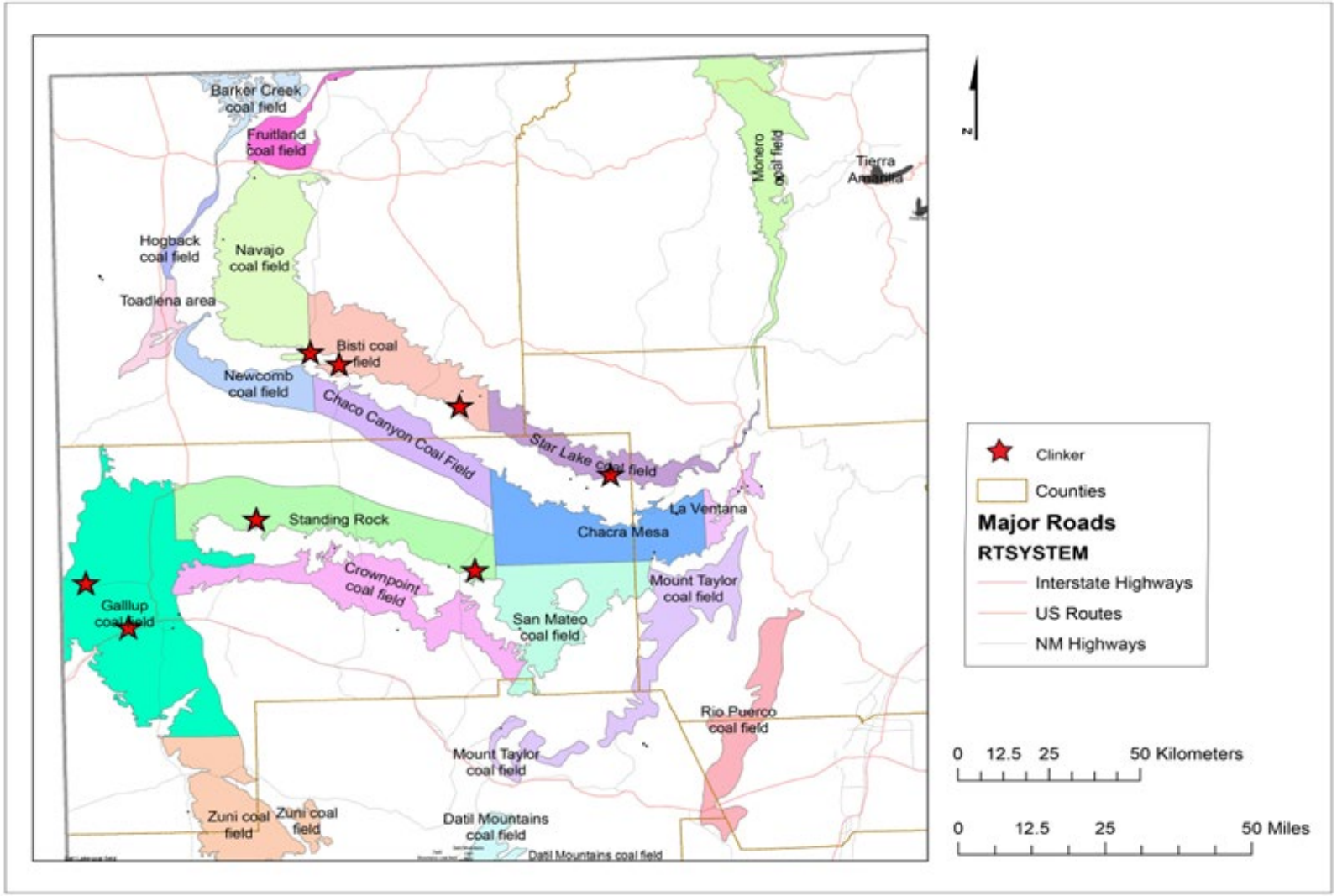
HUMATES

- Weathered coal and organic material
- Leonardite, weathered lignite
- Transitions to coal at depth
- Humic acids
- Coal burns, high quality humate 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


Barker Creek coal field
Fruitland coal field
Monero coal field
Tierra Amarilla
Hogback coal field
Navajo coal field
Toadlena area
Bisti coal field
Newcomb coal field
Chaco Canyon Coal Field
Star Lake coal field
La Ventana
Standing Rock
Chacra Mesa
Crownpoint coal field
Mount Taylor coal field
Gallup coal field
San Mateo coal field
Rio Puerco coal field
Mount Taylor coal field
Zuni coal field
Zuni coal field
Datil Mountains coal field
Datil Mountains coal field
N
Humate
Counties
Major Roads
RTSYSTEM
Interstate Highways
US Routes
NM Highways
0 12.5 25 50 Kilometers
0 12.5 25 50 Miles


REE Chondrite Norm (Taylor and McLennan, 198
10000
1000
100
10
1
0.1
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Y
REE

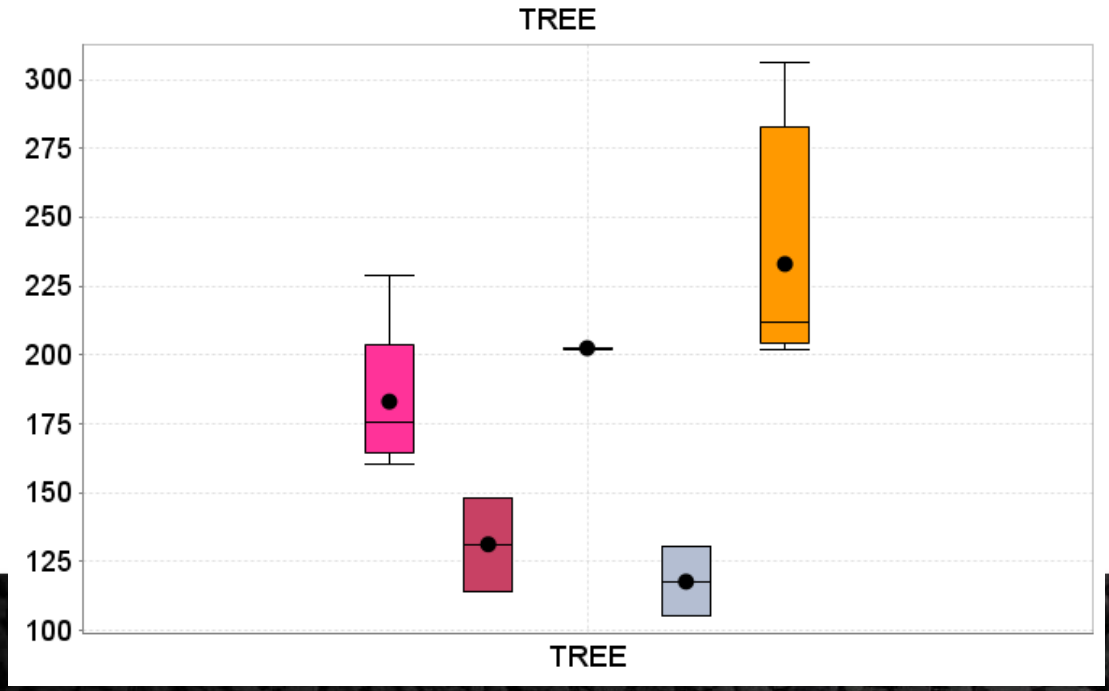
CLINKER (RED DOG, BAKED SHALE, SCORIA, BURNED COAL)

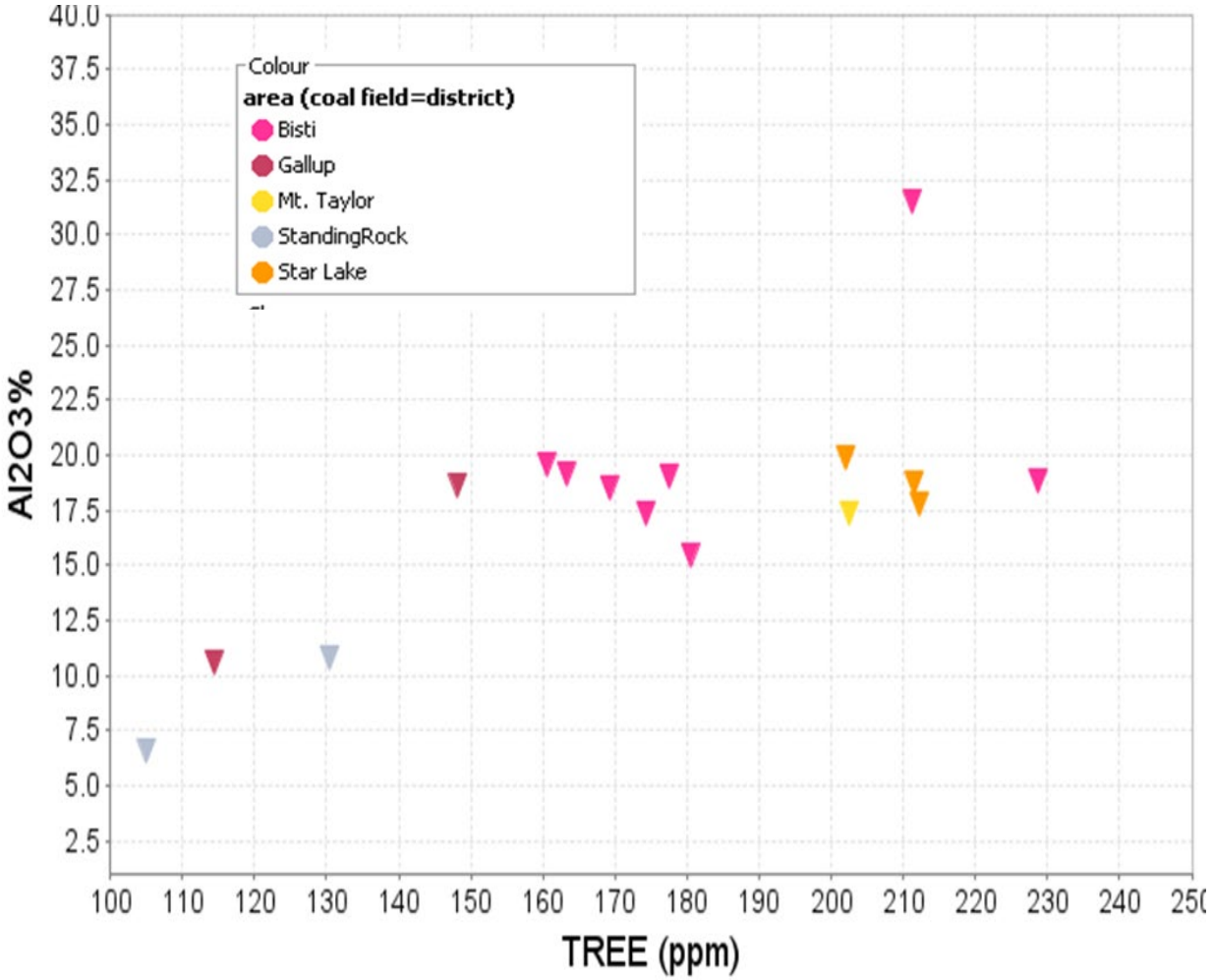


- Aggregate for roads
- Decorative stone
- Naturally burned coal
- Metal working
- Glass manufacture

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 1000°F, baking surrounding rocks
- Clinkers can be indicators of coal resources that aren't exposed
  - Resistant to erosion

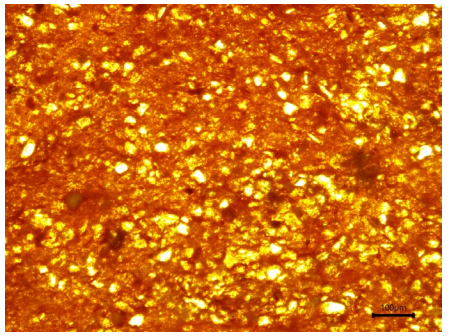



Colour
area (coal field=district)
Bisti
Gallup
Mt. Taylor
StandingRock
Star Lake
Al2O3%
TREE (ppm)
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240

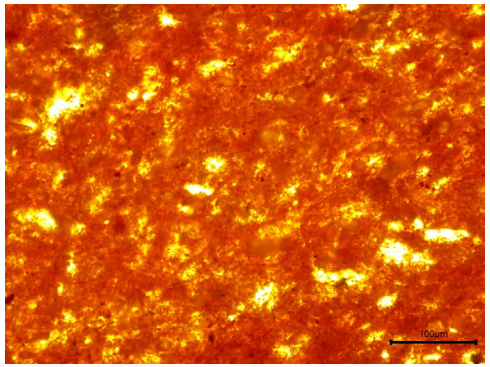
Petrography of Clinkers

Several samples have been examined with transmitted light microscopy

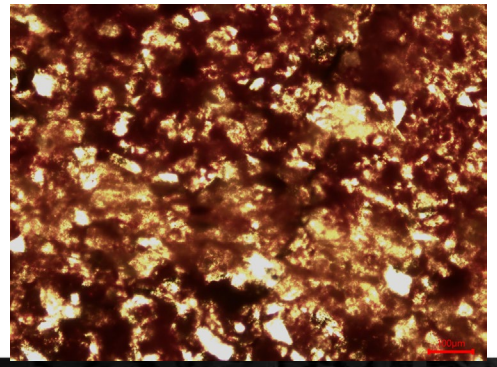
- Dominant minerals through all 3 samples are
  1. Quartz (SiO_2)
  2. Clay minerals (generally high in Al_2O_3)
  3. Hematite (more prevalent in some samples)



Thin section scan and photomicrograph of COAL9, a pyrometamorphosed mudstone with grains of quartz.

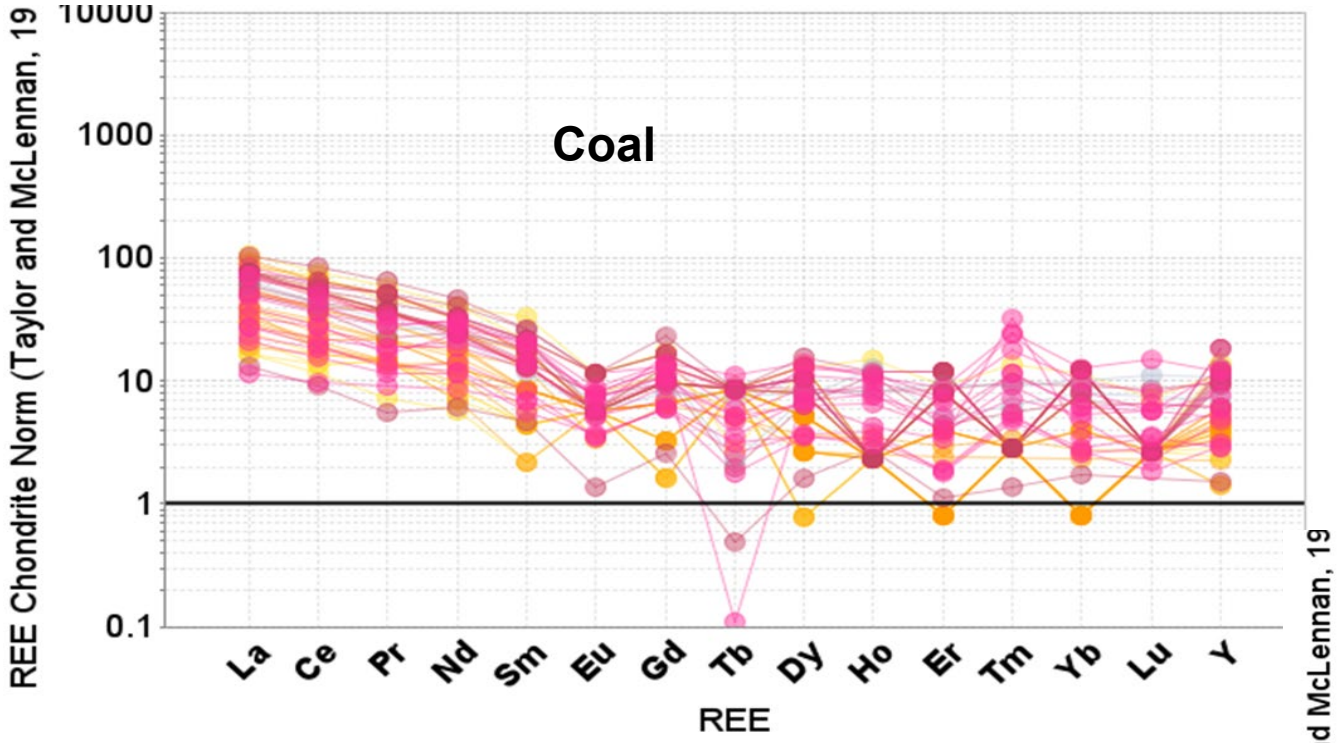


Thin section scan and photomicrograph of COAL28, a claystone/mudstone clinker containing more abundant clay minerals.

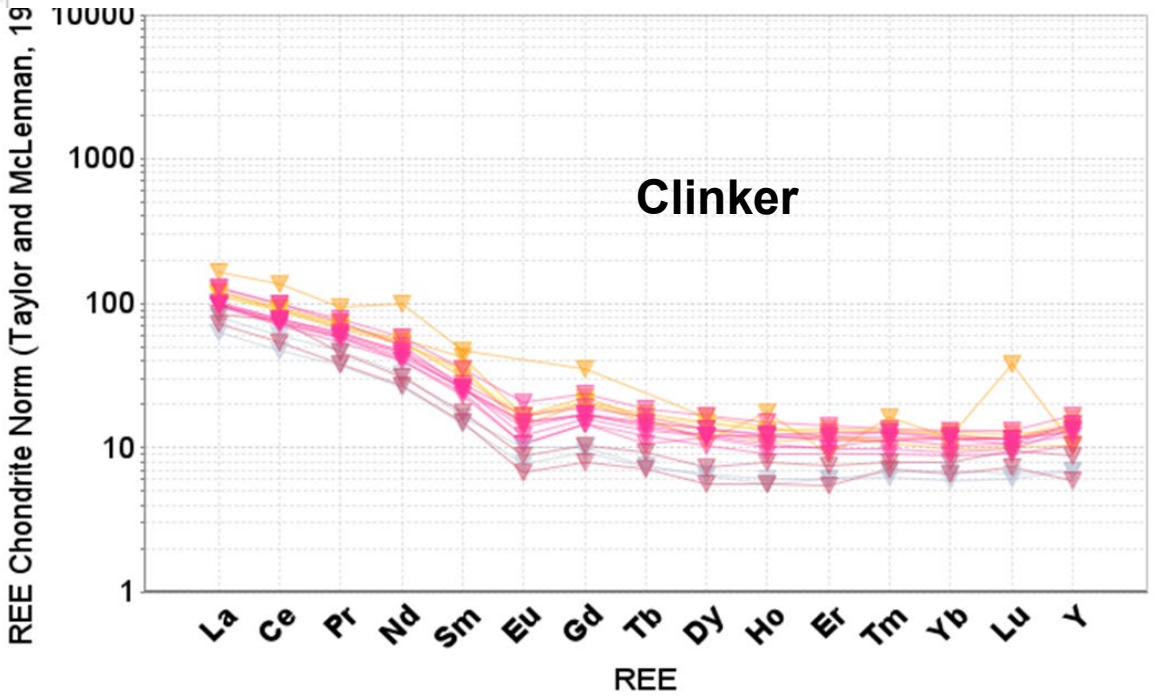


Thin section scan and photomicrograph of COAL36, which is a fine-grained quartz arenite rich in iron oxide. Bedding is defined by variations in grain size and quartz content.

From Devlon Shaver

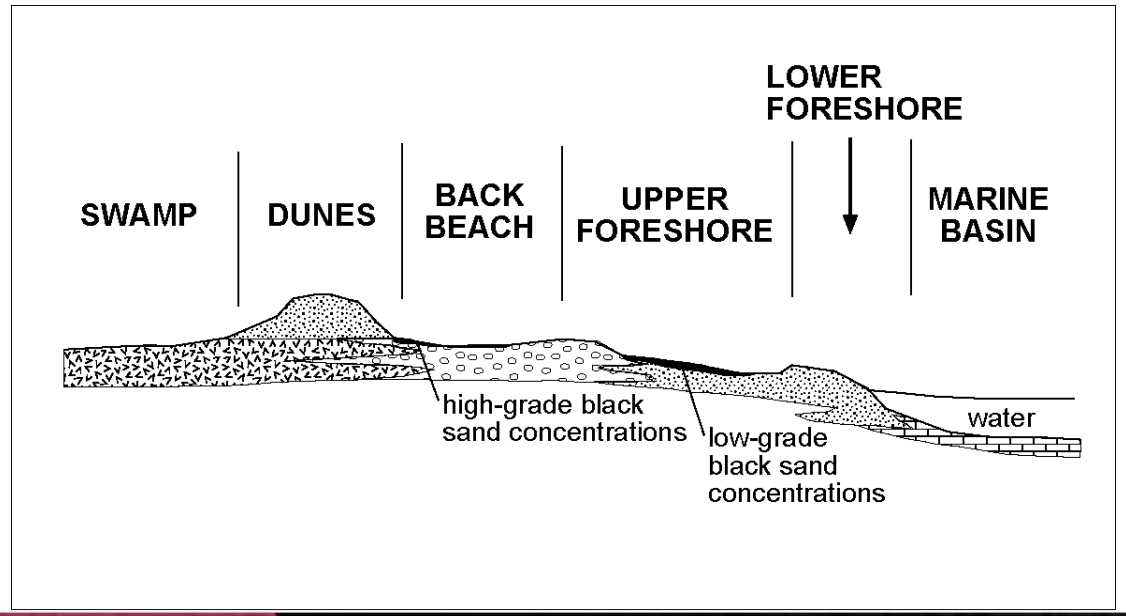

Coal
REE Chondrite Norm (Taylor and McLennan, 19
10000
1000
100
10
1
0.1
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu Y
REE


Colour
area (coal field=district)
Bisti
Gallup
Mt. Taylor
StandingRock
Star Lake


Clinker
REE Chondrite Norm (Taylor and McLennan, 19
10000
1000
100
10
1
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu Y
REE

HEAVY-MINERAL, BEACH-PLACER SANDSTONE DEPOSITS

- In the San Juan Basin
- Restricted to Late Cretaceous rocks
- Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones



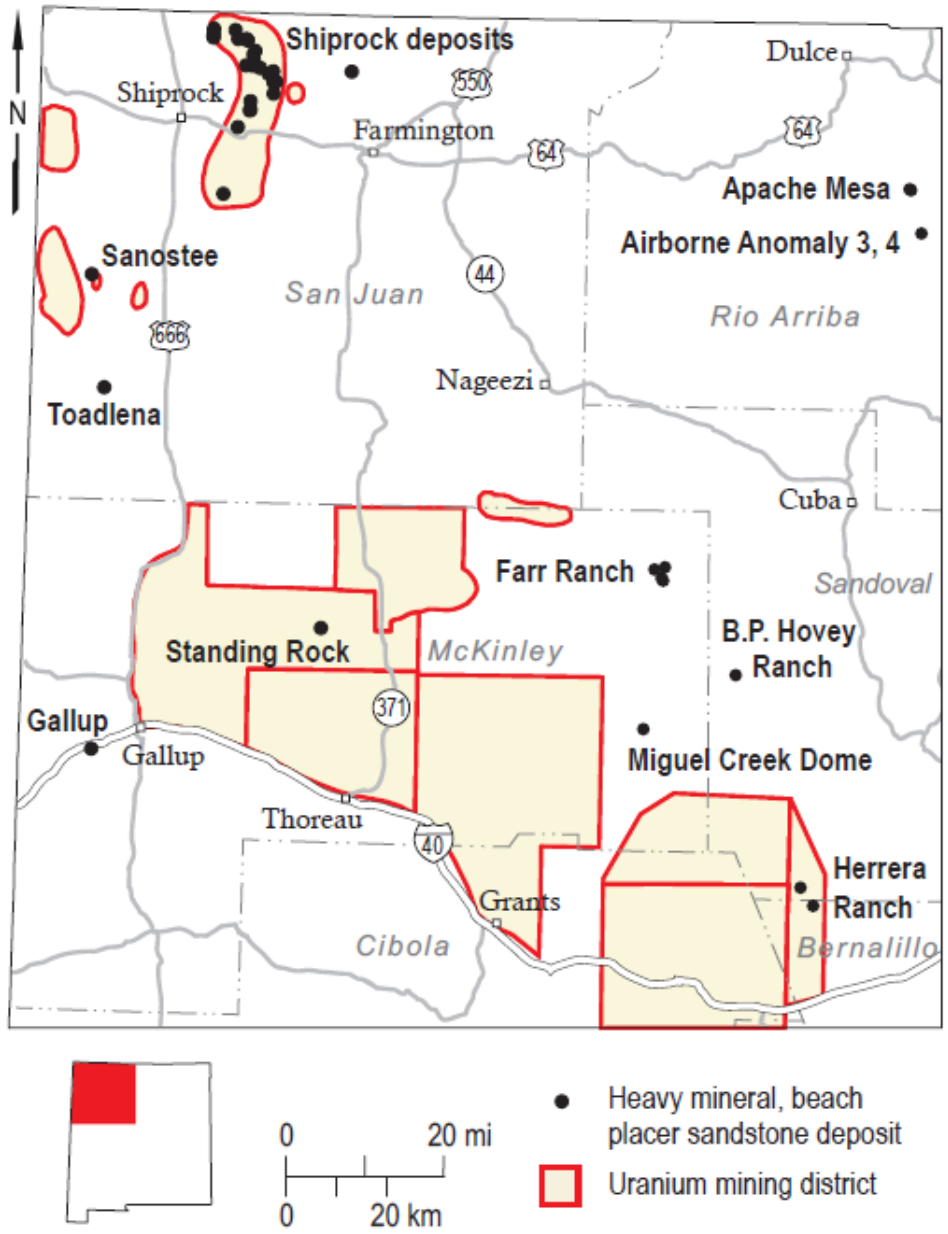
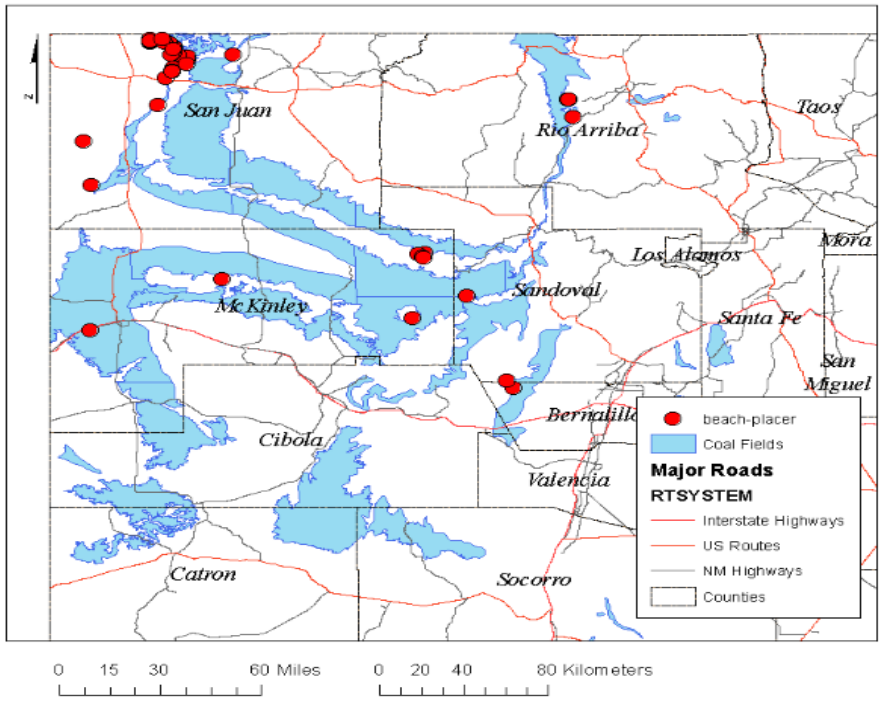


Figure 15. Location of Late Cretaceous heavy mineral, beach-placer sandstone deposits in the north-central San Juan Basin, New Mexico. More detailed location of the deposits are in McLemore (2010a).

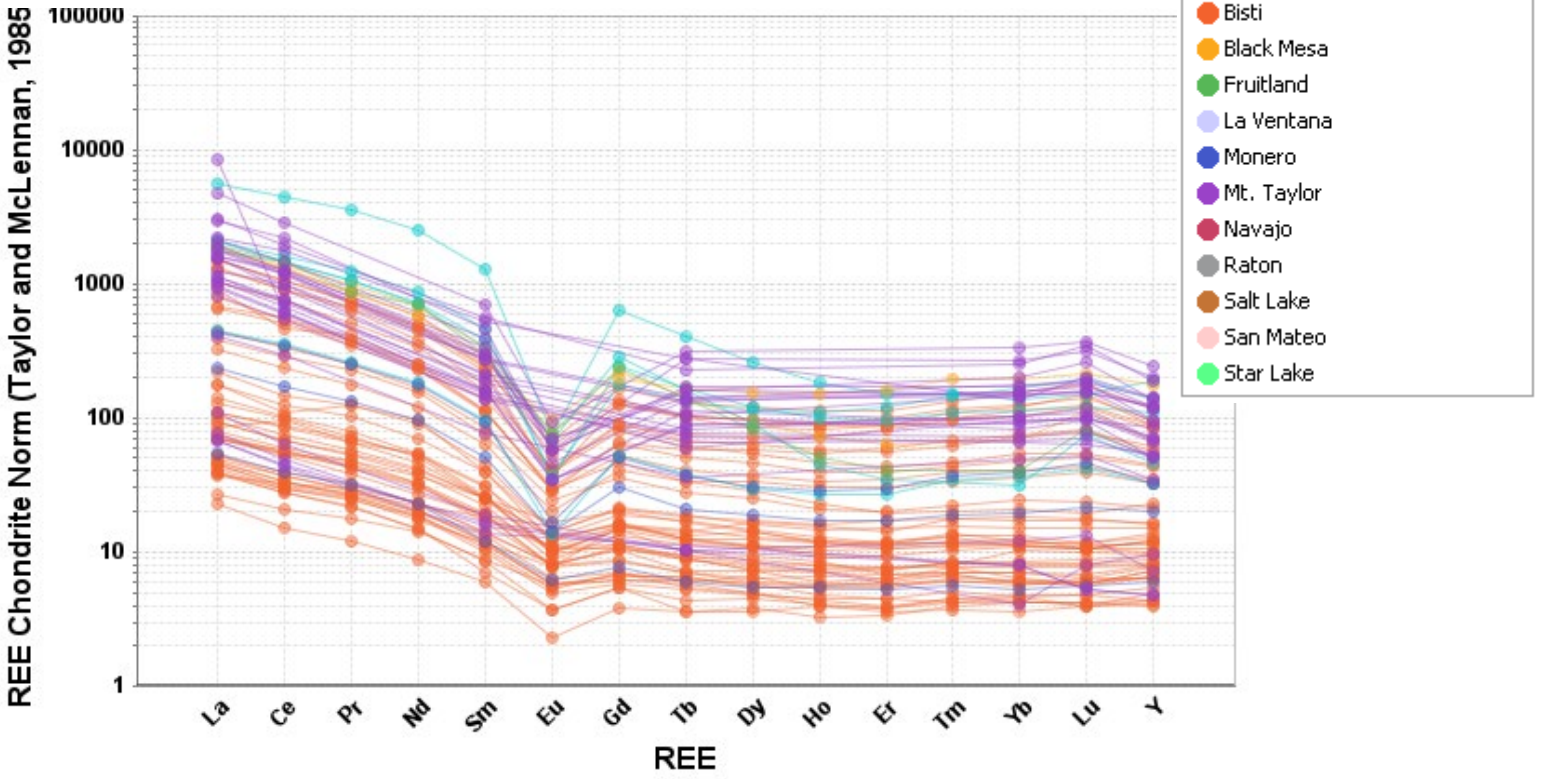
Economics of modern mineral sands

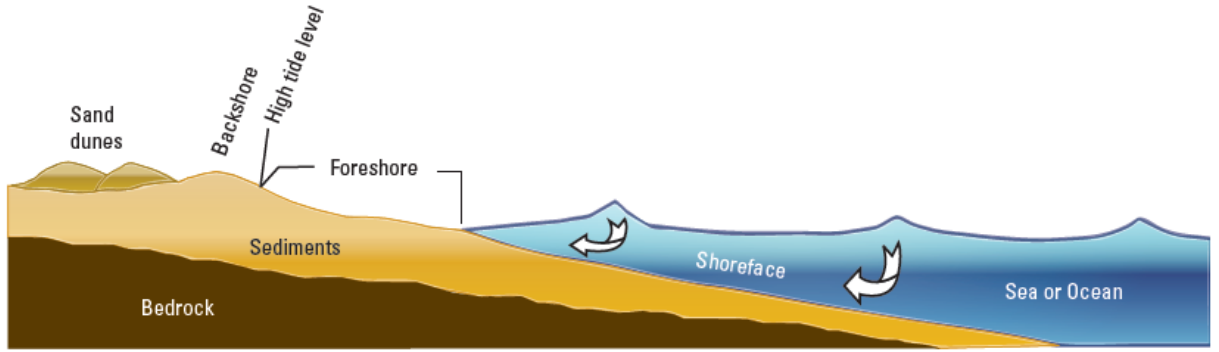
Economic deposits are 10 million tons of >2% heavy minerals

- Zirconium as zircon (1-50%)
  - Ceramic tiles, bricks used to line steel making furnaces, mold and chill sands, alloying agent in steel, laboratory crucibles
- Titanium as ilmenite (10-60%), rutile, leucoxene (titanium, 5-25%)
  - White pigment found in toothpaste, paint, paper, glazes, and some plastics, heat exchangers in desalination plants, alloys in aircraft, welding rods
- REE as monazite $(Ce,La,Y,Th)PO_4$) (<15%)
  - Catalyst, glass, polishing, re-chargeable batteries, magnets, lasers, glass, TV color phosphors
- Other minerals
  - Garnet, starolite, kyanite trace-50%



Are in the vicinity of coal fields (blue)





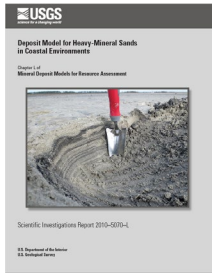
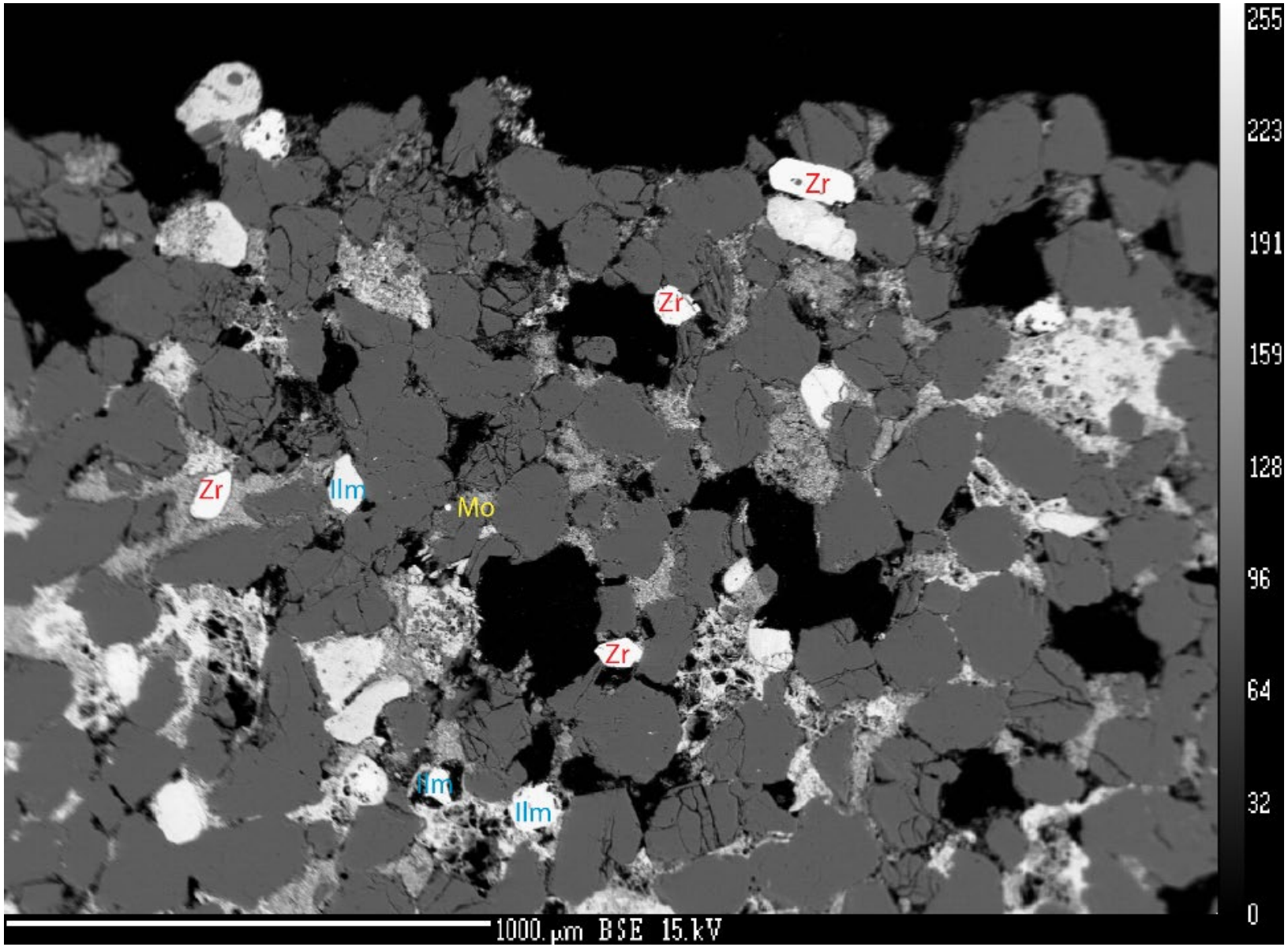


Figure 3. Features commonly used to describe shoreline (strandline) depositional environments associated with deposits of heavy-mineral sands. Not to scale.

Resources are estimated by the USBM as 4,741,200 short tons of ore containing 12.8% TiO_2, 2.1% Zr, 15.5% Fe and less than 0.10 ThO_2 with some REE (USBM files)

Sanostee deposit, San Juan County



Electron microprobe photo of sample SAN 6 (Sanostee). Zircon =red, ilmenite=blue, and monazite=yellow. Mottled, lighter colored cement=iron oxide (hematite). Dark gray grains=quartz. Black areas=pore spaces.

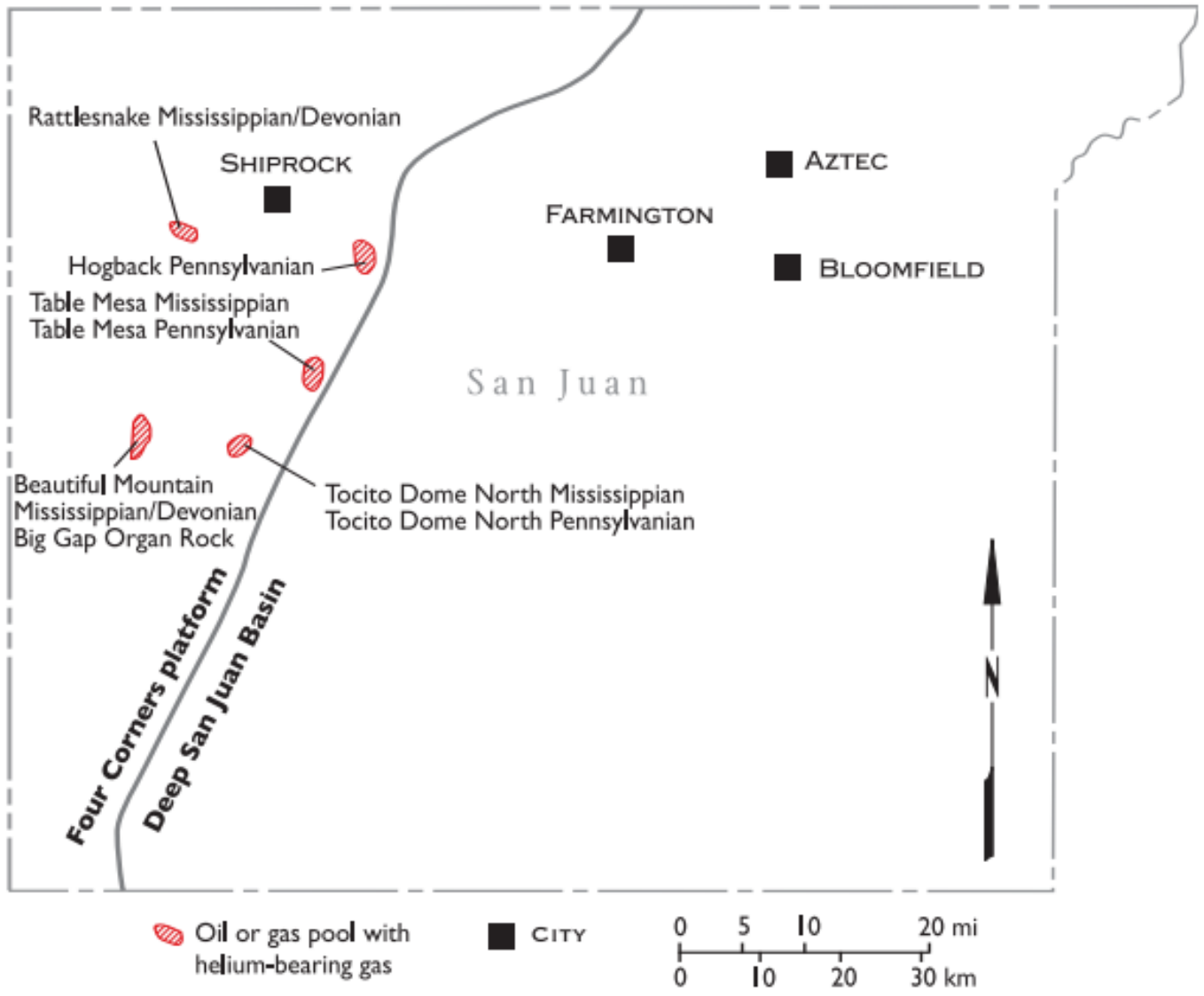
HELIUM

- Cryogenic applications, 24%
  - DEA blimps
  - advertising
- Pressurizing and purging, 20%
- Welding cover gas, 18%
- Controlled atmospheres, 16%
- Leak detection, 6%
- Breathing mixtures, 3%
- Other, 13%

- Helium in the uranium mineral clevite
- Natural gas wells in Texas, Oklahoma, New Mexico, and Kansas

Table 3. Oil and gas pools that have produced commercial helium in New Mexico, percent helium in gas, 2003 annual and cumulative gas production, and estimated cumulative volume of produced helium. MCF, thousand ft^3. See Figure 2 for locations of pools.

Field	Reservoir age	Reservoir units	Location (township, range)	Percent helium in gas	2003 gas production (MCF)	Cumulative gas production (MCF)	Helium produced, estimated (MCF)
Beautiful Mountain	Mississippian, Devonian	Leadville Limestone, Ouray Formation	T27N R19W	7.14	169,568	2,455,230	***175,303***
Big Gap	Permian	Organ Rock member of Cutler Formation	T27N R19W	5.5	212,663	3,260,416	***179,323***
Hogback	Pennsylvanian	Paradox Formation	T29N R16W	7.17	0	666,714	***47,803***
Tocito Dome North	Mississippian	Leadville Limestone	T27N R18W	7.19	0	1,104,668	***79,426***
Tocito Dome North	Pennsylvanian	Paradox Formation	T27N R18W	3.26	0	532,856	***17,371***
Table Mesa	Mississippian	Leadville Limestone	T27N R17W	5.7	0	1,193,006	***68,001***
Table Mesa	Pennsylvanian	Paradox Formation	T27N R17W	5.37	0	7,100,076	***381,274***
Rattlesnake	Mississippian, Devonian	Leadville Limestone, Ouray Formation	T29N R19W	7.5	0	2,000	***150***
TOTALS					**382,231**	**16,314,966**	**948,652**



Broadhead and Gillard, 2004

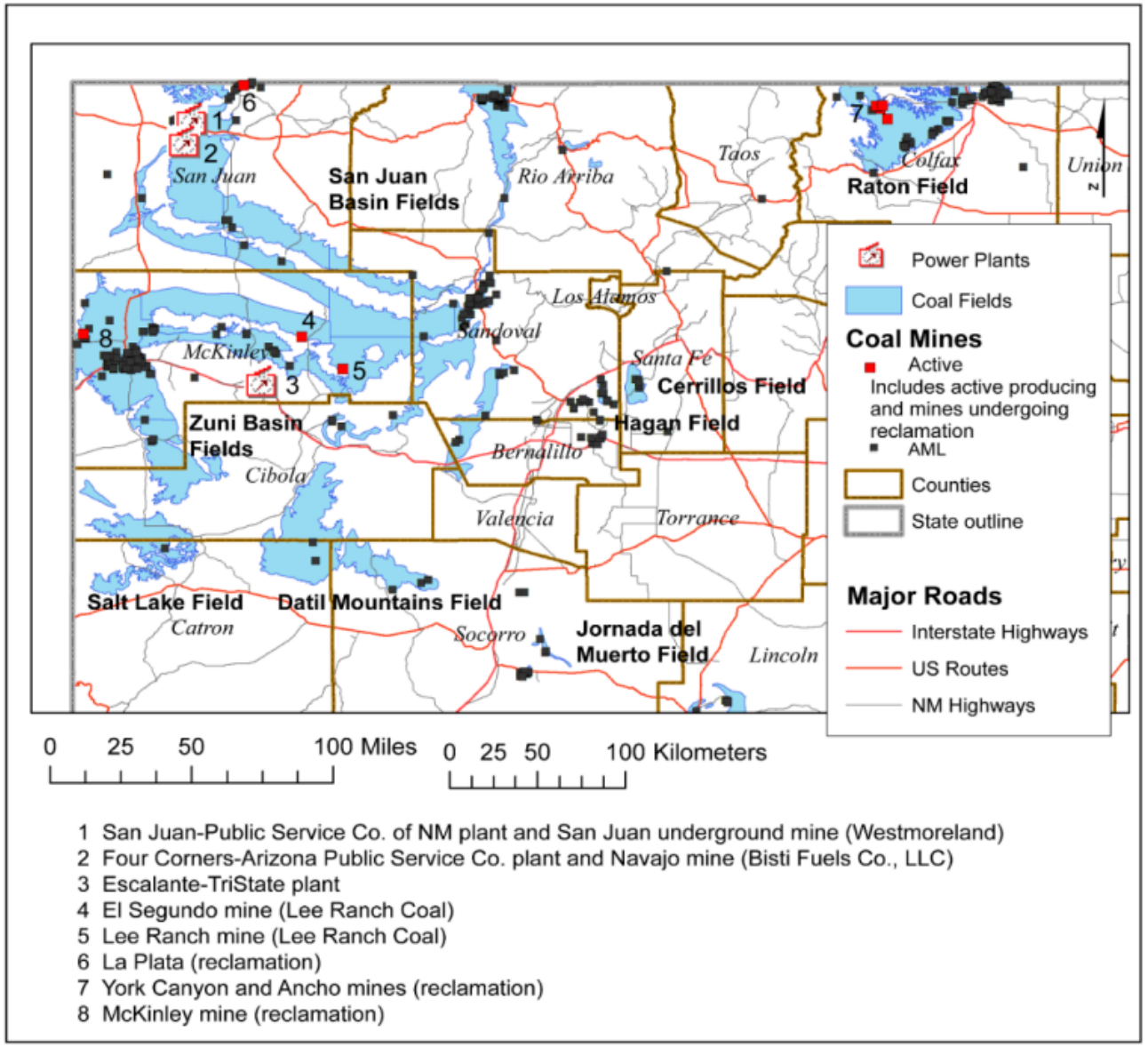
1 plant produced 95% to 99.5% helium in 2022

COAL—Critical minerals

- Fuels 1 electrical generating plant in NM and others in Az
  - Also used in chemical, metallurgical, and pharmaceutical industries
- 2 surface mines in San Juan Basin
- Resources at Raton, Carrizozo
- 12th in production in U.S. in 2021
  - 15th in estimated reserves
  - 65 million short tons of recoverable reserves
- San Juan generating station in the Farmington closed in 2022
- *Coal production is expected to continue to decrease in the near future*

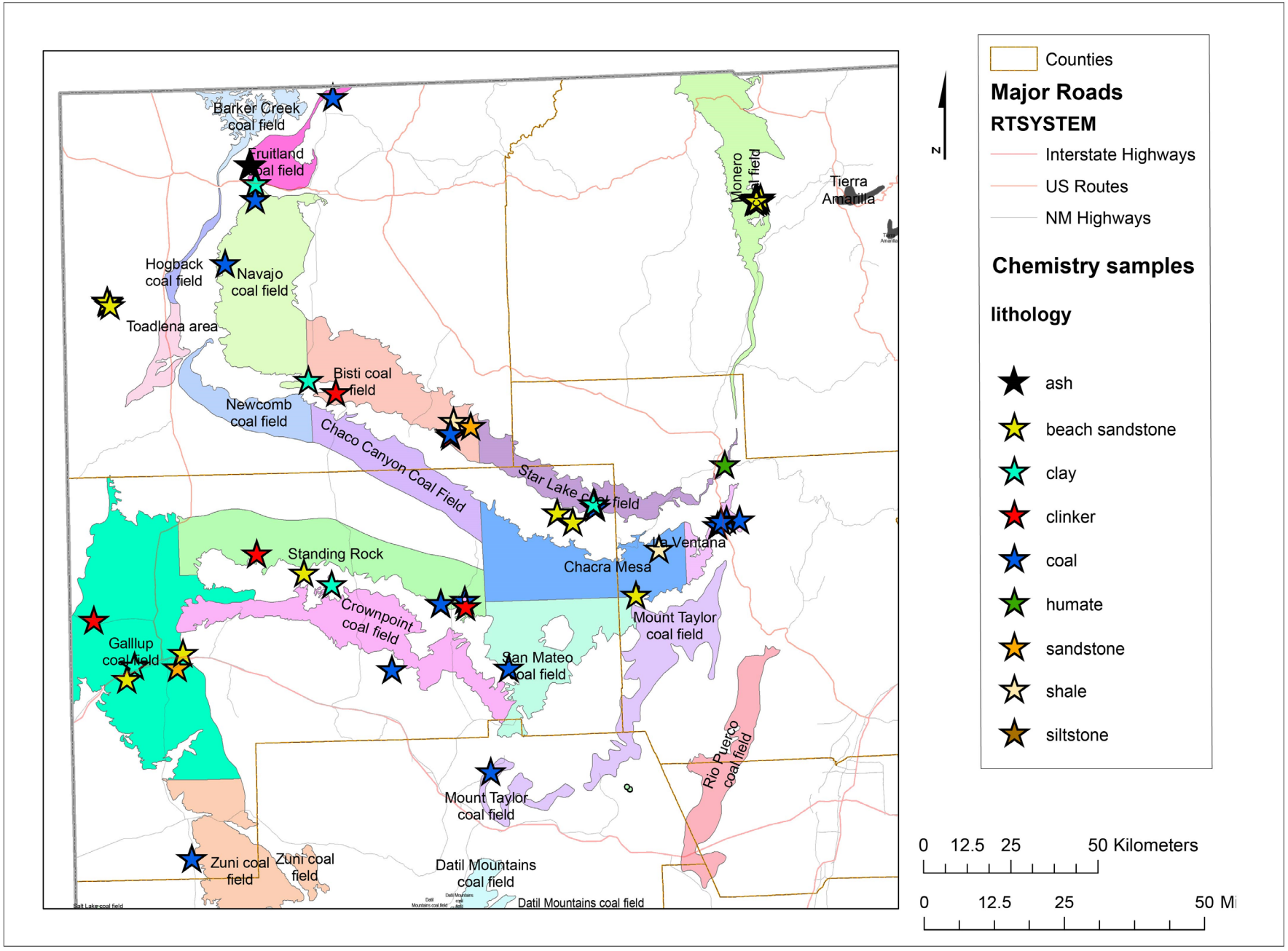
New Mexico Coal Fields

- Coal deposits are in the San Juan Basin
- Restricted to Late Cretaceous rocks belonging to the Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones

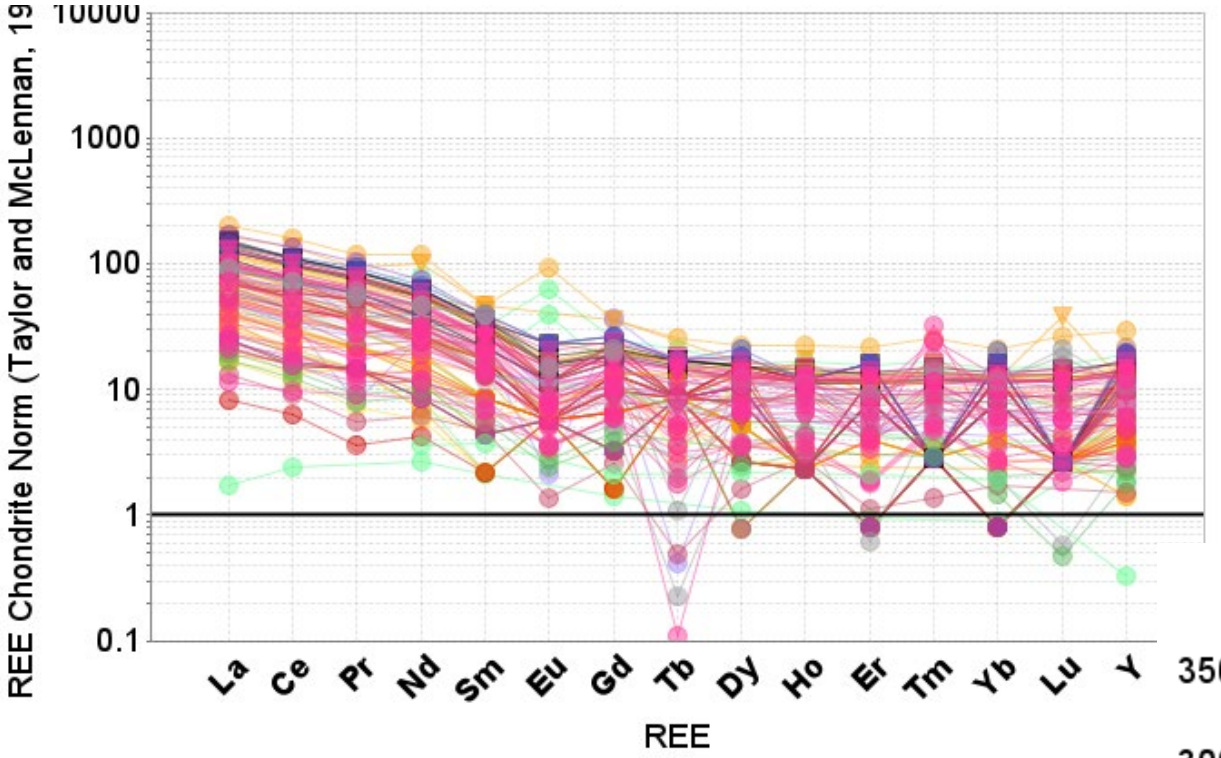


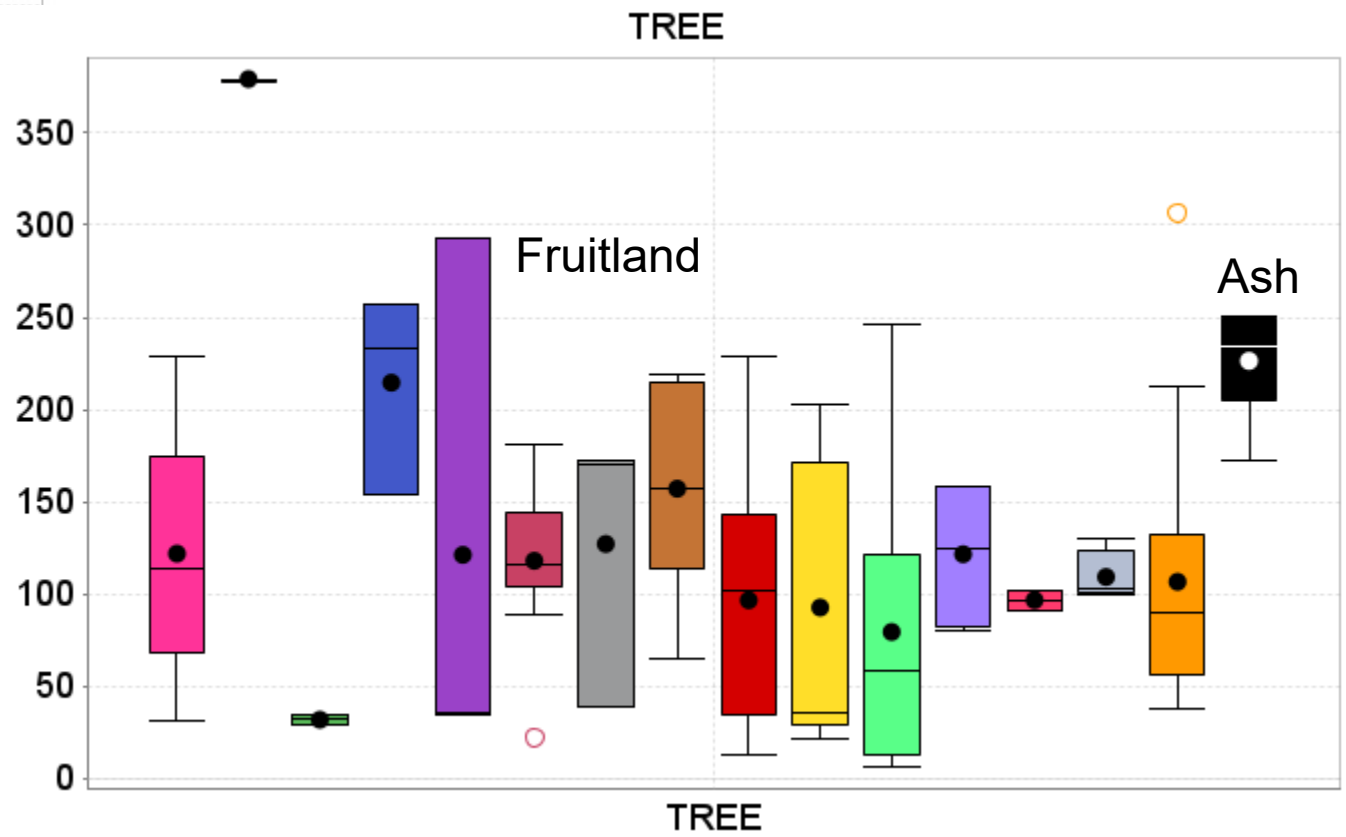
Coal Samples—21 fields (total 26)

- 106 coal, ash, humate, clinker samples
- 105 igneous rocks, shale, sandstone, clay, other
- 125 beach placer

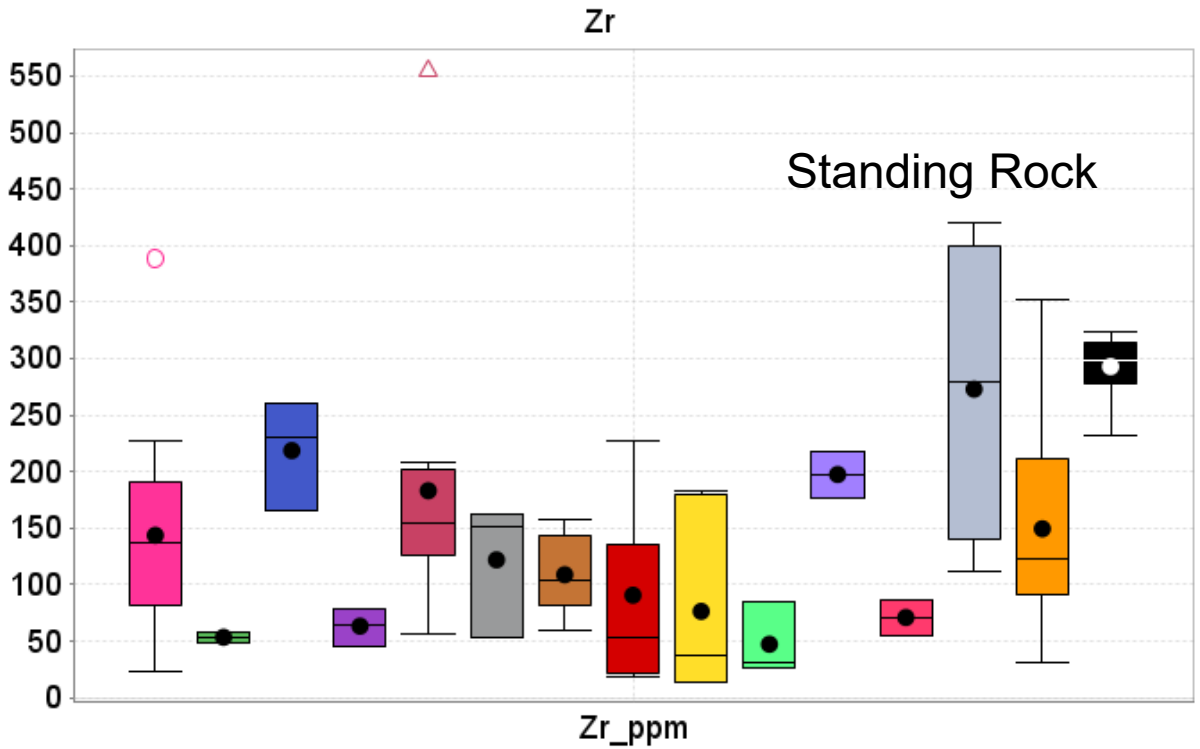


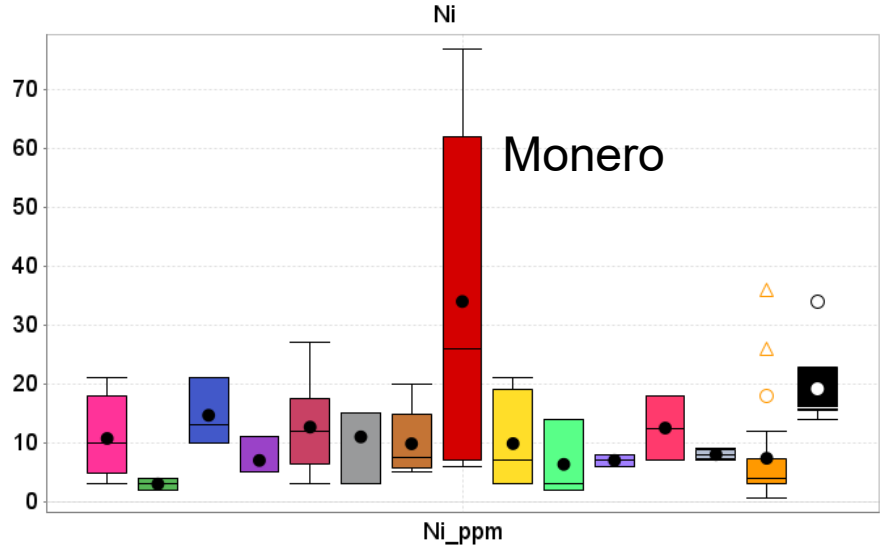
REE in San Juan Basin Coals

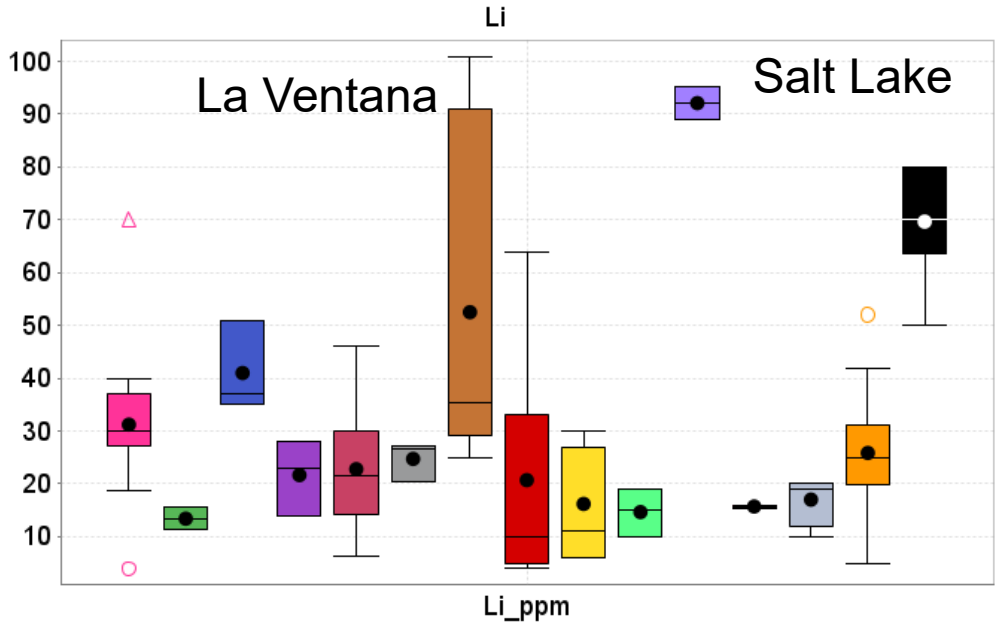


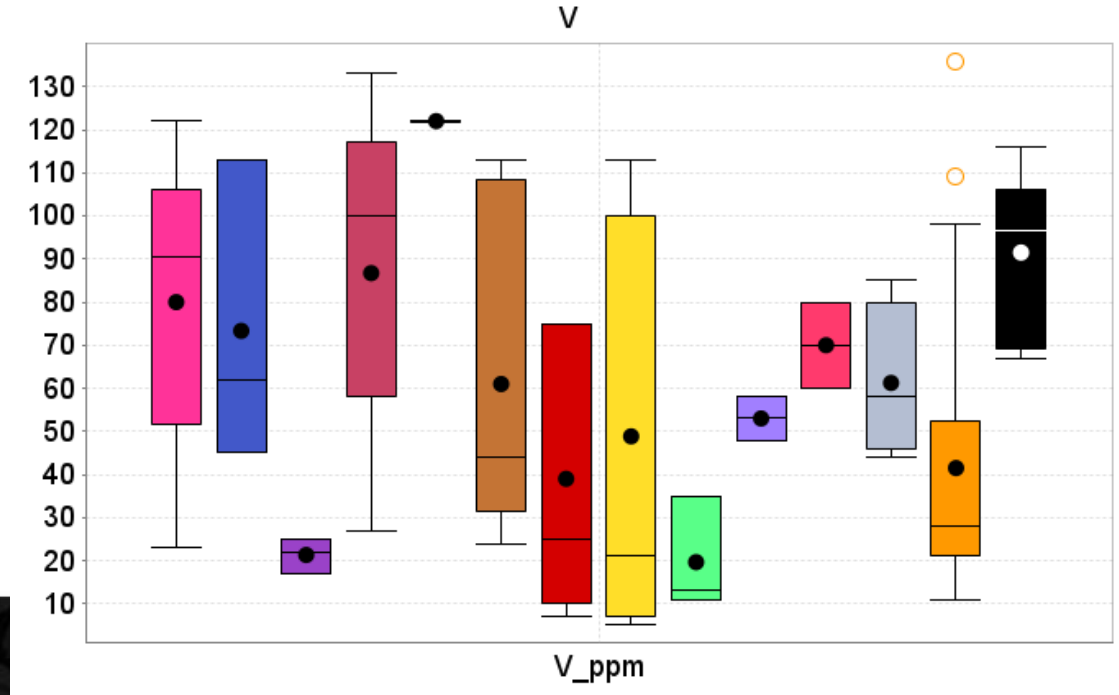


Critical minerals in Coal







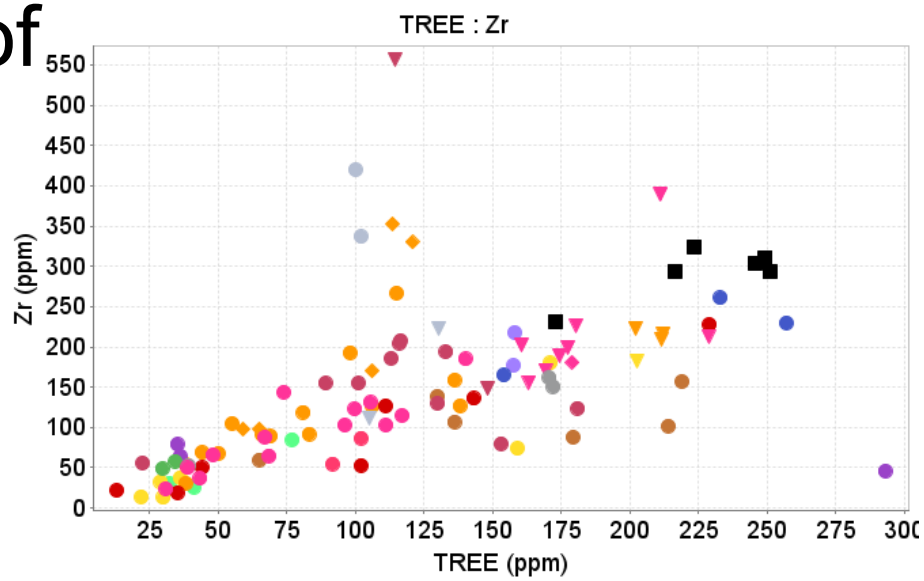


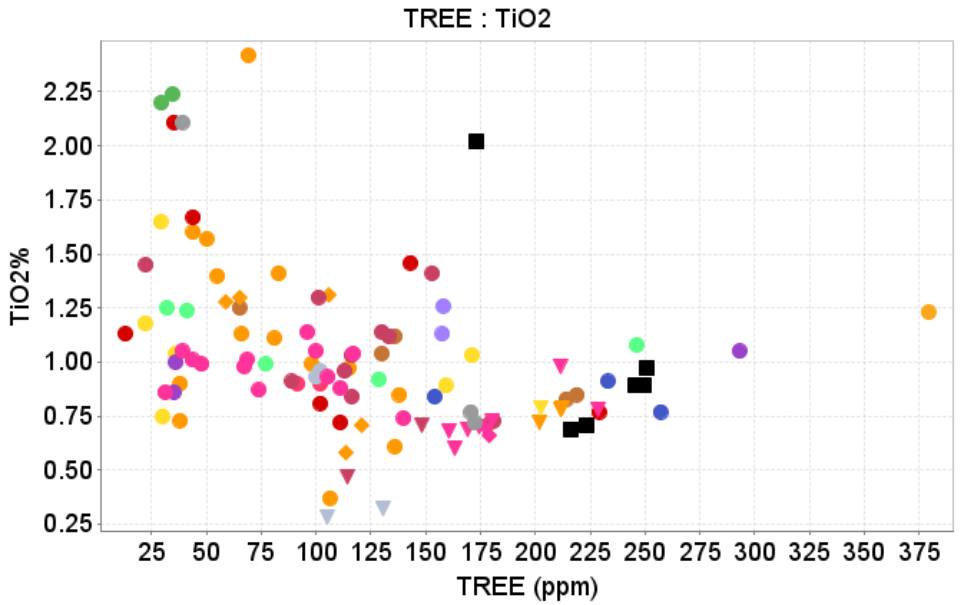
Geochemistry of coal deposits

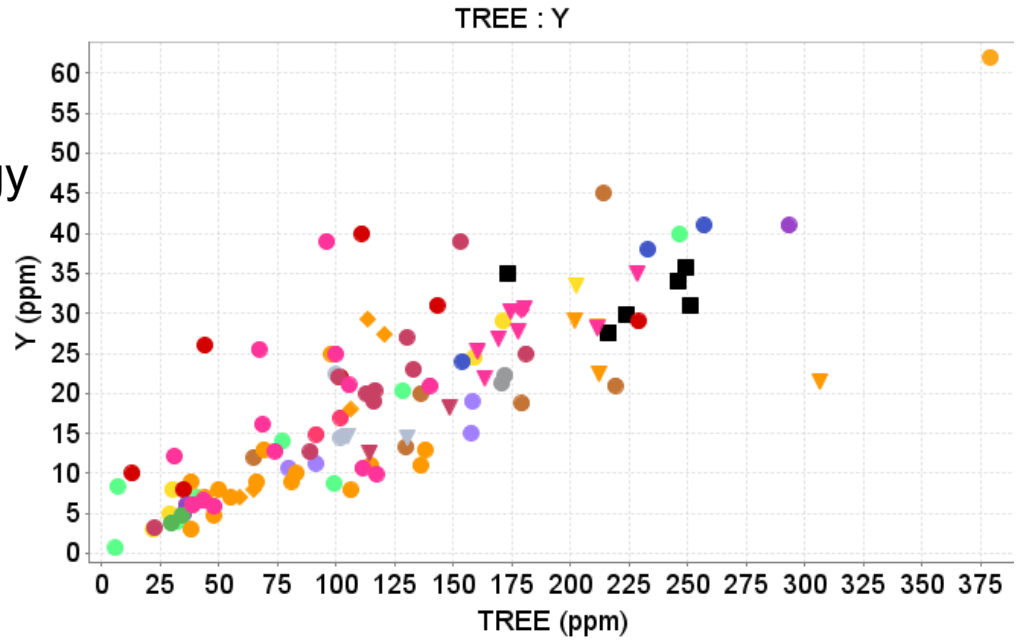
Correlation plots for coal/humate/ash deposits (new unpublished data; Taggart et al. 2016) (note different scales)

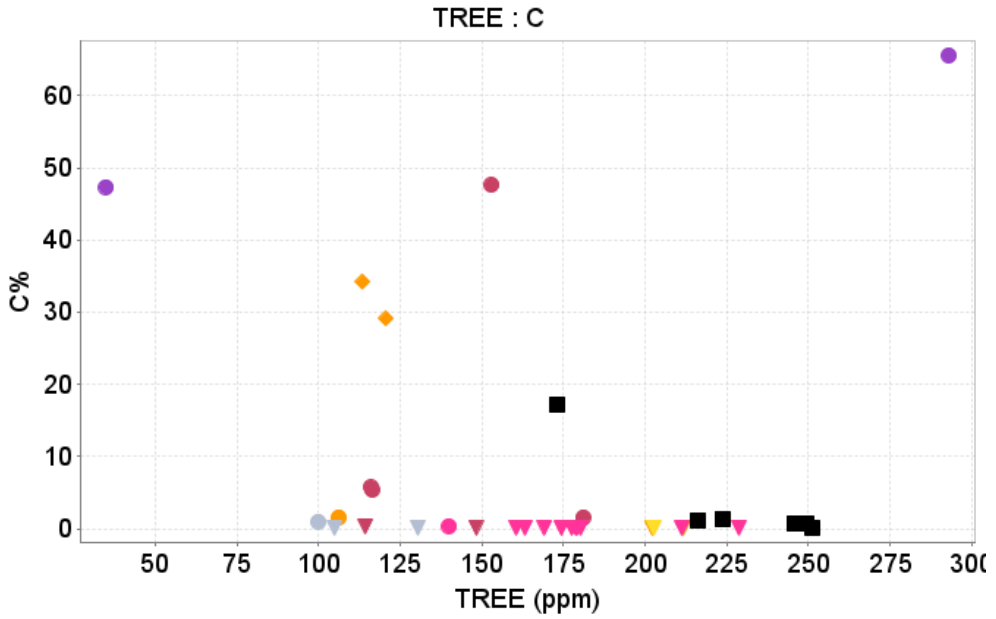
The chemical analyses indicates the predominant mineralogy for that element.

Detailed mineralogical study is underway









Coal ash as an industrial mineral

- Cement/concrete/grout
- Wallboard
- Roofing materials
- Bricks
- Potential recovery of REE and other critical minerals

- The only use of NM coal ash has been for flue gas desulfurization

URANIUM

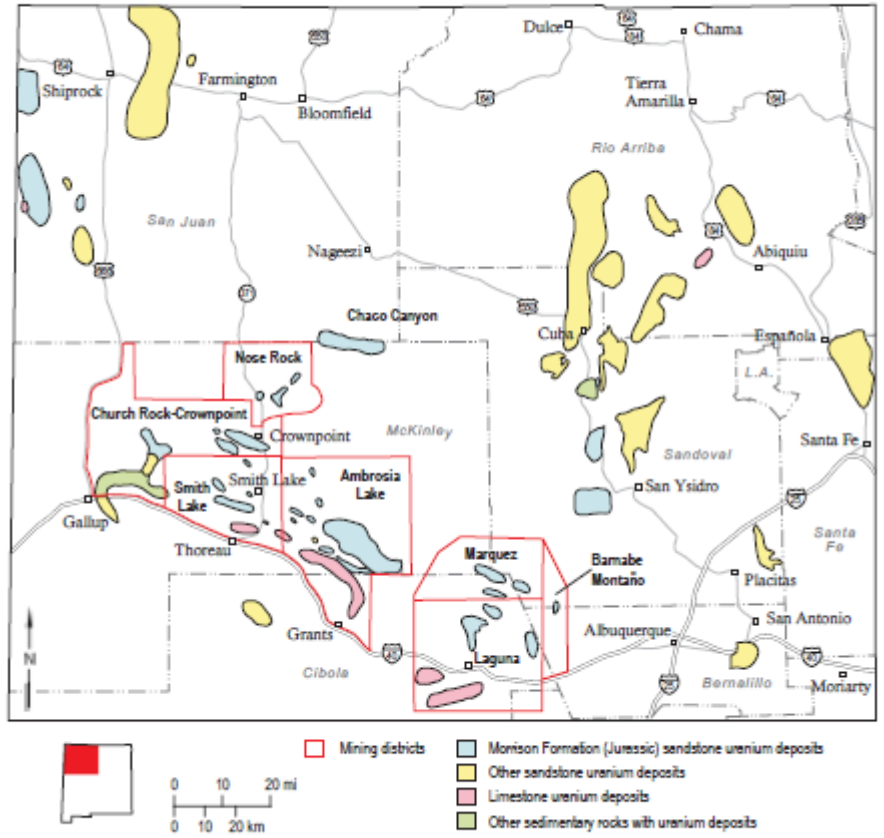


Figure 2. The predominant regions of uranium deposits and production in New Mexico are in the San Juan Basin and include the subdistricts of the Grants district (red outlined regions). Polygons outline approximate areas of known uranium deposits.

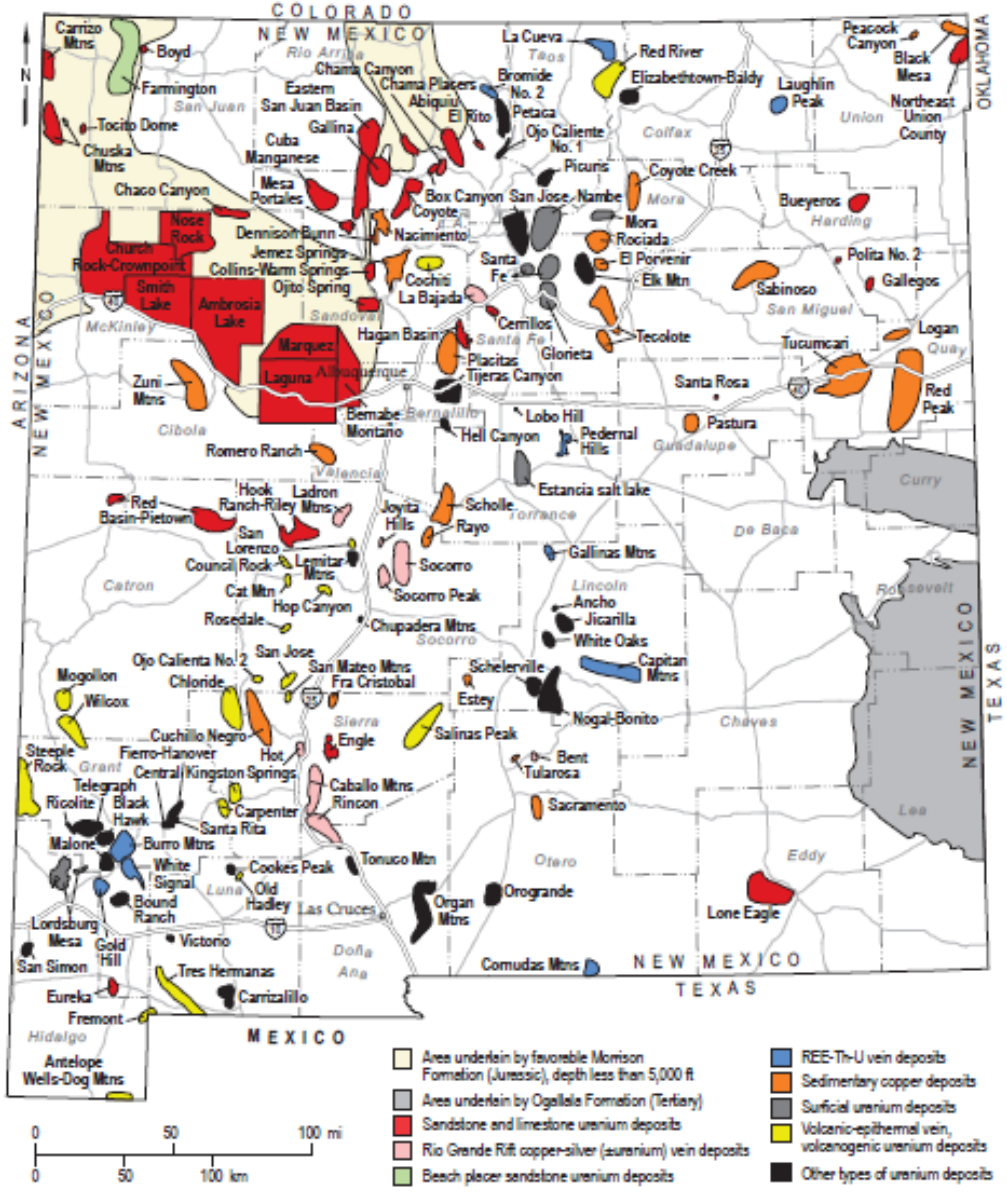
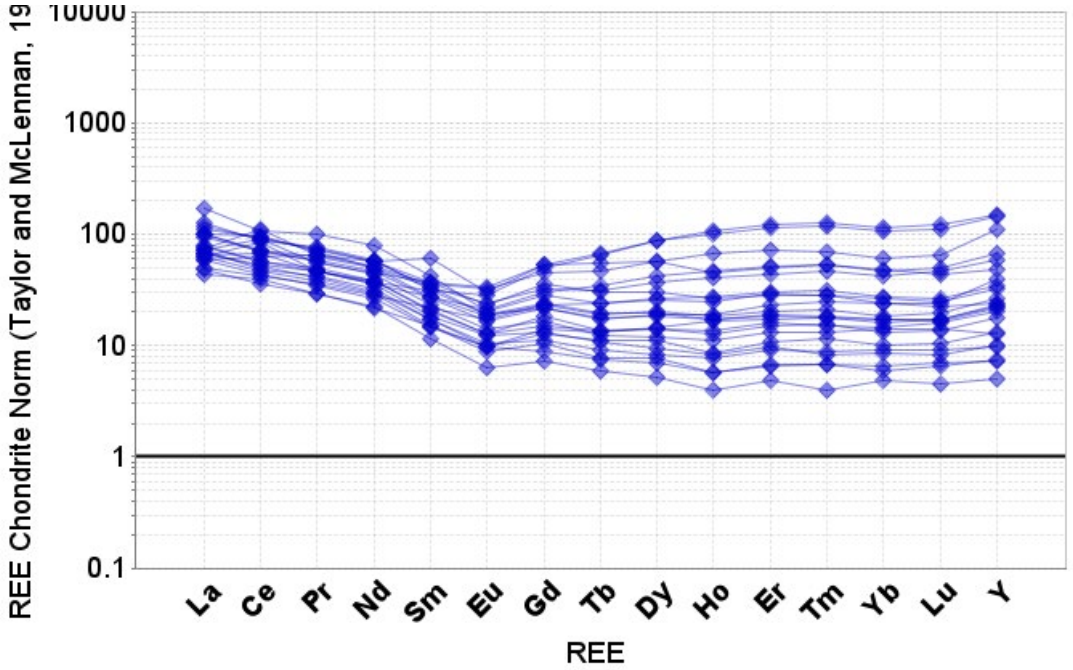
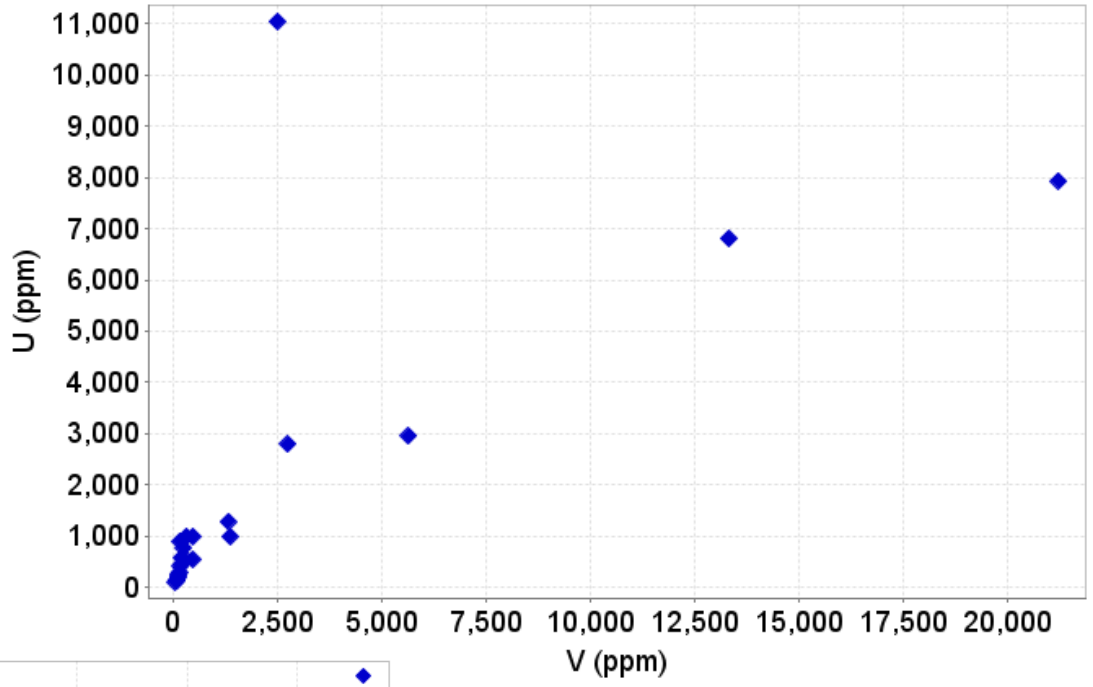
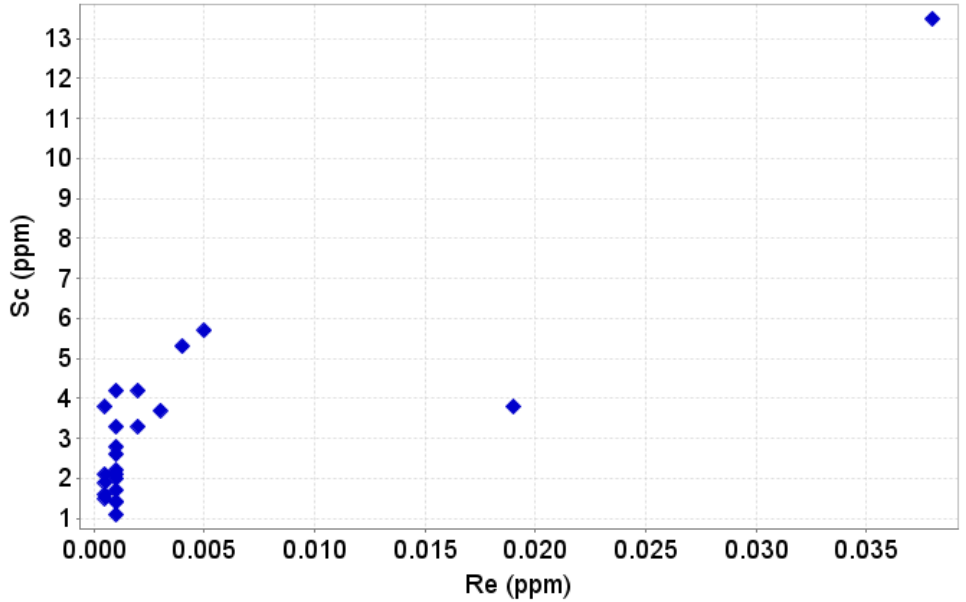


Figure 1. Mining districts that have uranium deposits and other areas favorable for uranium in New Mexico (modified from McLemore and Chenoweth, 1989). Each district is color-coded according to the predominant type of deposit; other types of uranium deposits are found in most districts.





Geochemistry of uranium deposits



Historical Production from the Morrison Formation in Grants District

- 340 million lbs of U_3O_8 from 1948-2002; plus vanadium (critical mineral), molybdenum
  - Additional 450 million lbs in historic resources
- Accounting for 97% of the total uranium production in New Mexico
- More than 30% of the total uranium production in the United States
- 7th largest district in total uranium production in the world

Importance of sandstone uranium deposits in the Grants district

- Major mining companies abandoned the districts after the last cycle leaving advanced uranium projects.
- Inexpensive property acquisition costs includes $$ millions of exploration and development expenditures.
- Availability of data and technical expertise.
- Recent advances in in situ leaching makes sandstone uranium deposits attractive economically.
- Potential critical minerals: rhenium in molybdenum, REE (especially heavy REE), vanadium, scandium

Other industrial minerals

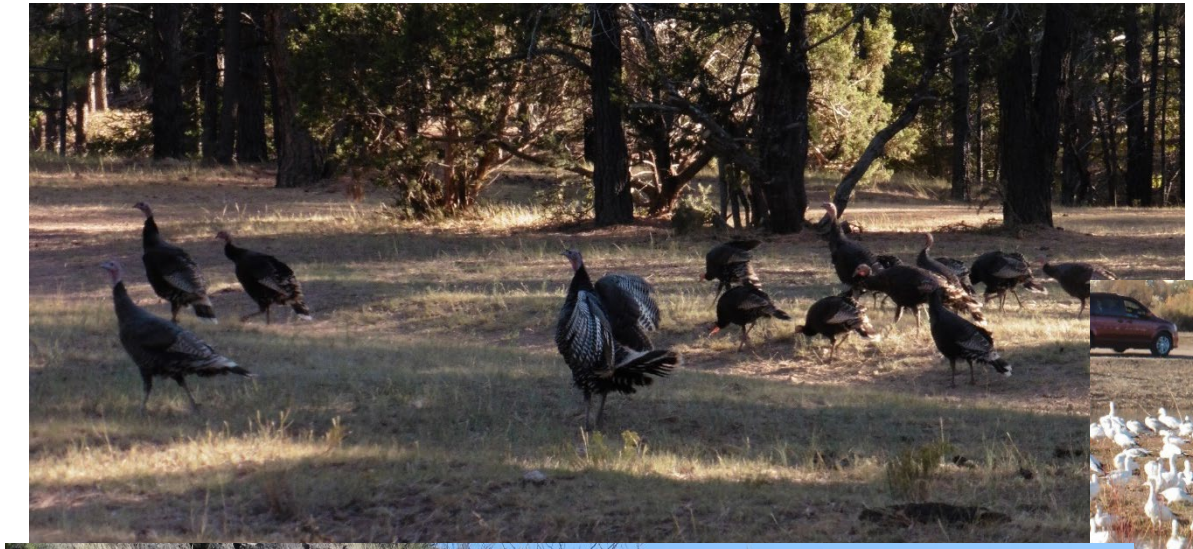
- Fluorite in Zuni Mountains (potential critical minerals?)
- REE in episyenites in Zuni Mountains
- Pumice, scoria, perlite near Grants, southern San Juan Basin
- High Ca limestone (Todilto limestone)
- Sand and gravel operations throughout the basin
- Clay deposits
- Potential sulfur from oil and gas production

SUMMARY

- Gypsum is produced from the Todilto Formation
- Humates (weathered coal) are produced from coal and humate mines—***humate production will continue even though coal mines are closing***
- Clinkers (burned coal deposits) and sand and gravel are used in road construction and decorative stone
- Helium from oil and gas wells
- Potential REE, Ti, Zr from Late Cretaceous heavy-mineral, beach placer sandstones
- Potential REE and other critical minerals from coal and coal ash
- Potential V, Re, REE from sandstone U deposits

QUESTIONS?

See project web page at
https://geoinfo.nmt.edu/staff/mclemore/REEinCoalWeb.html



MINING DISTRICTS (PRODUCTION) AND PROSPECT AREAS (NO PRODUCTION)

- 274 in NM, including coal
  - Pink=predominantly industrial minerals districts
- Mining district, coal field, prospect area, or the geographical area as defined by File and Northrop (1966), Shoemaker et al. (1971), North and McLemore (1986), McLemore and Chenoweth (1989), Hoffman (1996), and McLemore (2001)