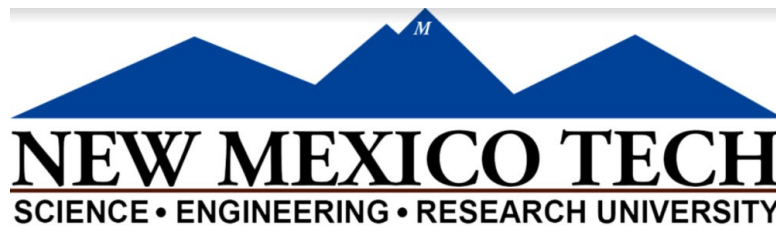
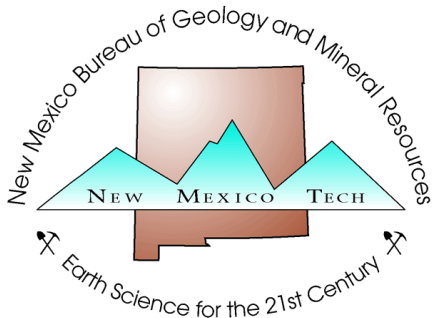


RARE EARTH ELEMENTS (REE) IN LATE CRETACEOUS COAL AND BEACH-PLACER SANDSTONE DEPOSITS IN THE SAN JUAN BASIN, NEW MEXICO: PRELIMINARY OBSERVATIONS

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Purpose

- Importance of critical minerals, including REE
- Summarize the geology, geochemistry, of the Late Cretaceous heavy-mineral beach placer sandstone deposits in San Juan Basin
- Summarize the geology, geochemistry (preliminary) of the Late Cretaceous coal deposits
- How do these deposits relate to one another
- Source of REE and other critical minerals

Working hypothesis—are heavy-mineral, beach-placer sandstone deposits related to coal deposits

ACKNOWLEDGEMENTS

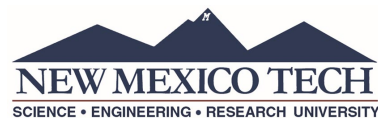
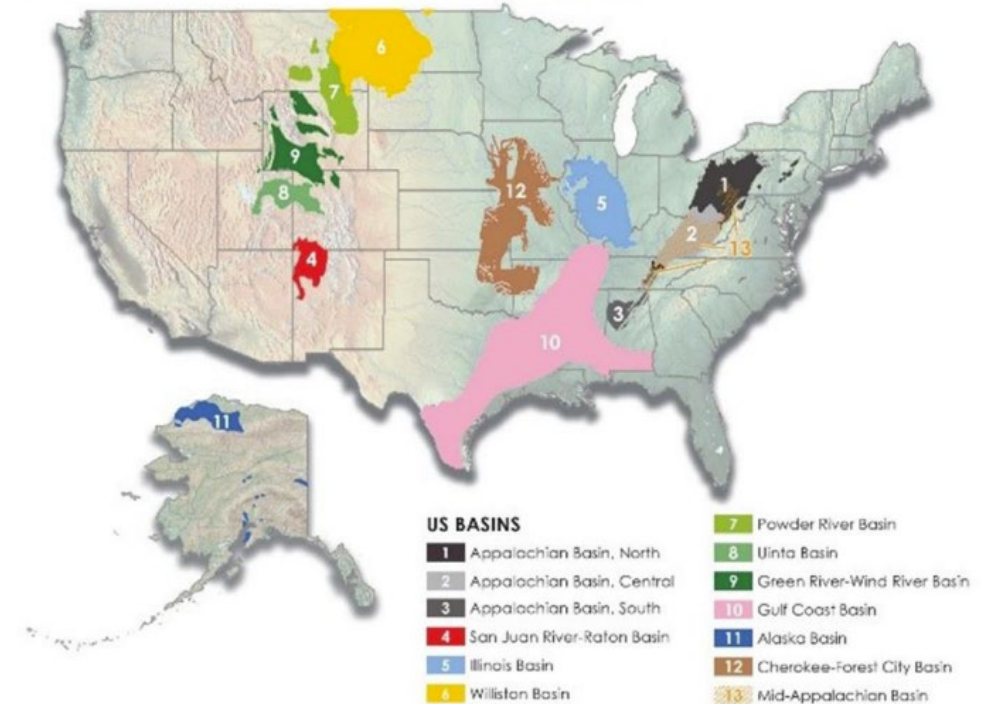
- U.S. Department of Energy, U.S. Bureau of Land Management, U.S. Army Corps of Engineers, and E. I. duPont de Nemours and Co. funded earlier investigations (1980-2010)
- Apache Mesa funded by Grant award A14AP00084 with the Jicarilla Apache Nation (2015-2016)
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- Students and staff at NM Tech

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

CORE-CM INITIATIVE

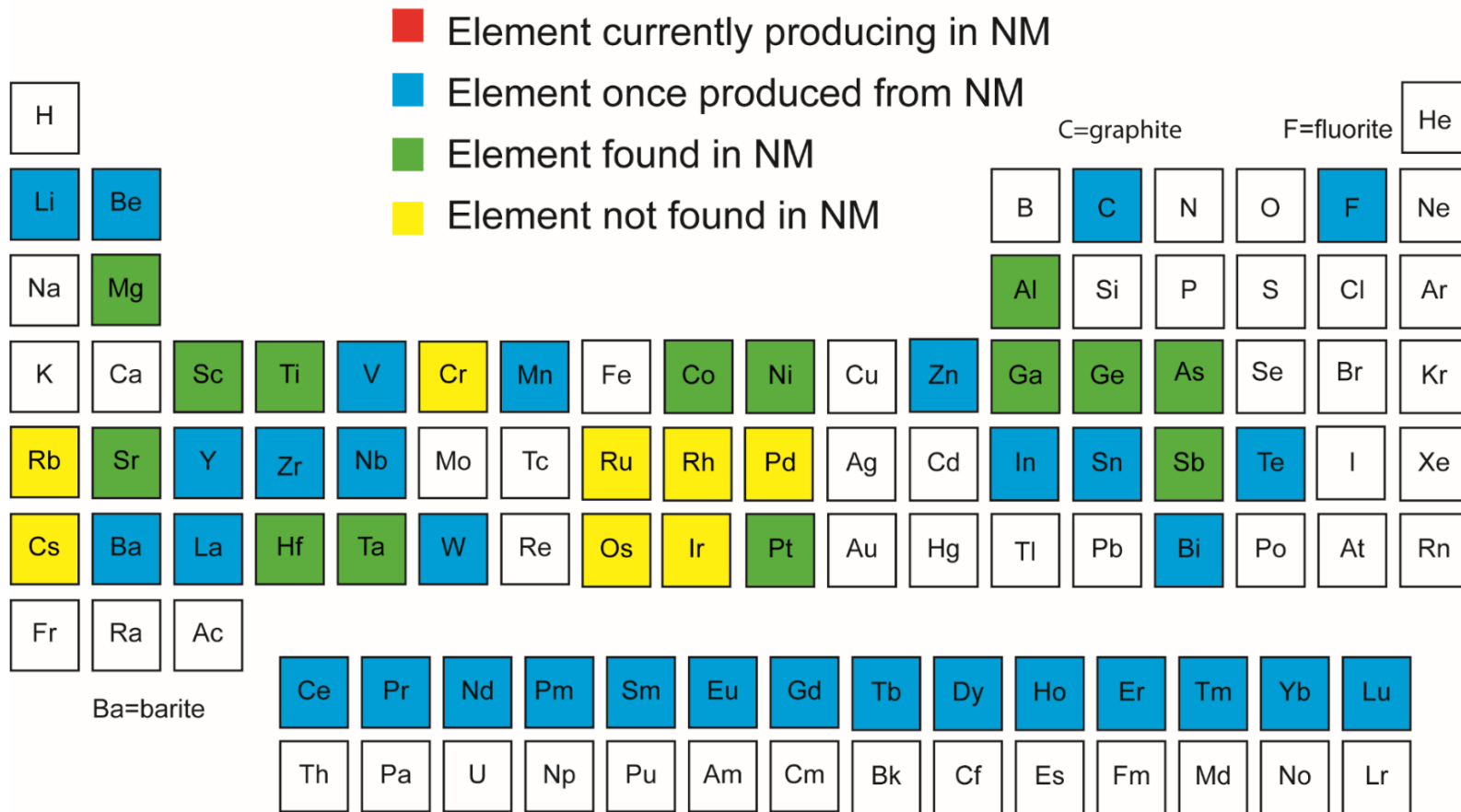
<https://netl.doe.gov/node/11045>



Critical minerals

- Identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States
- From a supply chain that is vulnerable to disruption
 - Disruptions in supply chains may arise for any number of reasons, including natural disasters, labor strife, trade disputes, resource nationalism, conflict, and so on
- That serves an essential function in the manufacturing of a product, the absence of which would have substantial negative consequences for the U.S. economy or national security

Critical Minerals in New Mexico



Coal in general has potential for REE, Co, Ga, Ge, Ni, Zn, and other CM

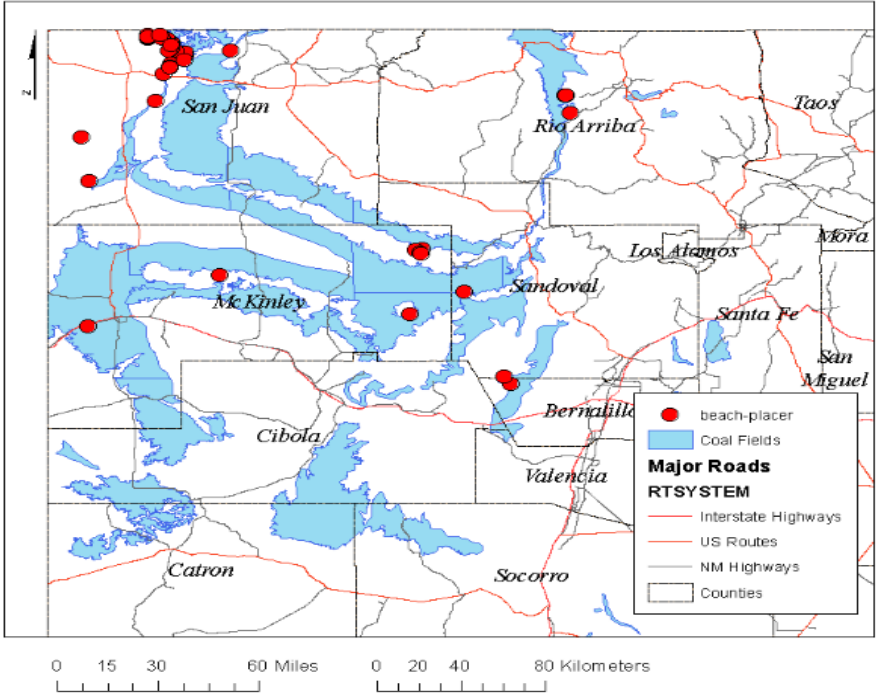
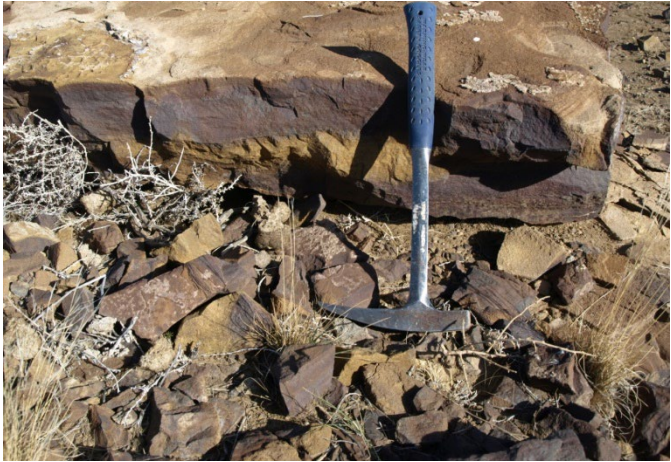
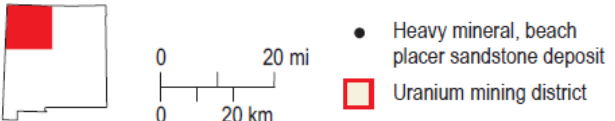
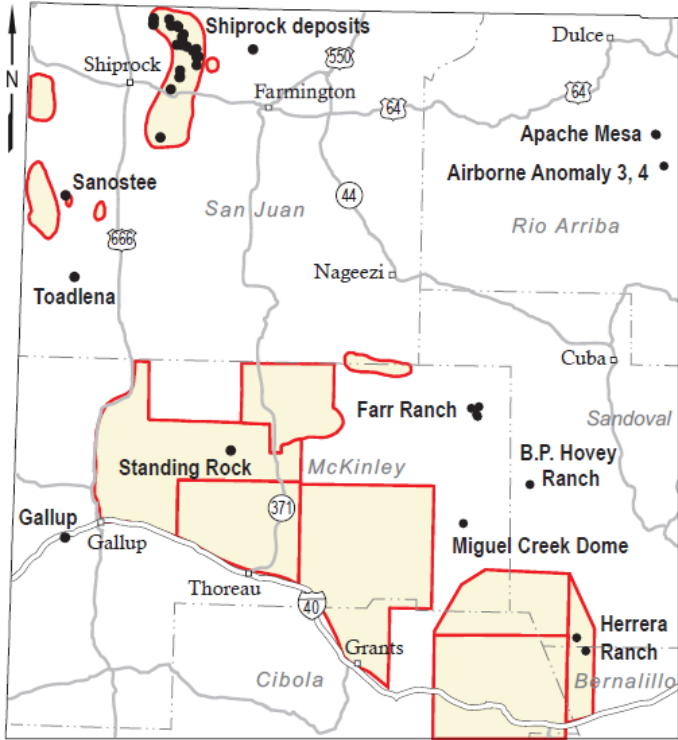
Graphite is found adjacent to some Raton coals that have been intruded by Tertiary igneous dikes

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.

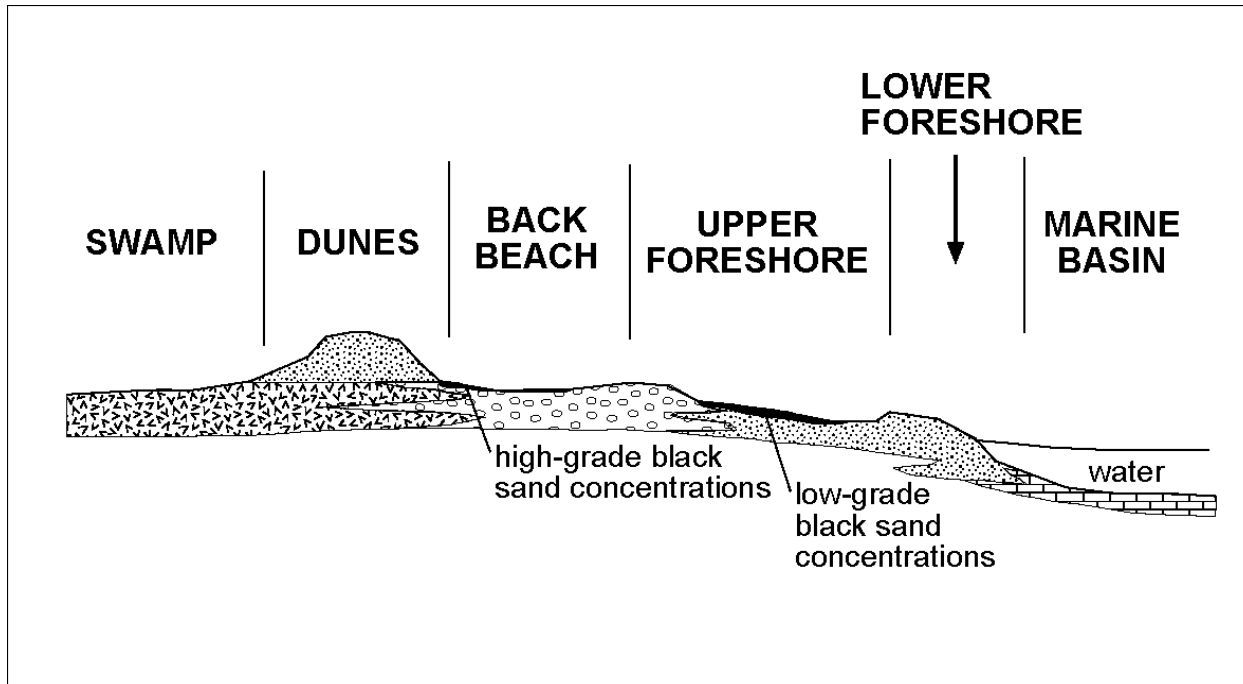
Beach-placer sandstone deposits

- 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
- Are in the vicinity of coal deposits



Beach-placer sandstone deposits

Beach-placer sandstone deposits are accumulations of heavy, resistant minerals (i.e. high specific gravity) that form on upper regions of beaches or in long-shore bars in a marginal-marine environment.



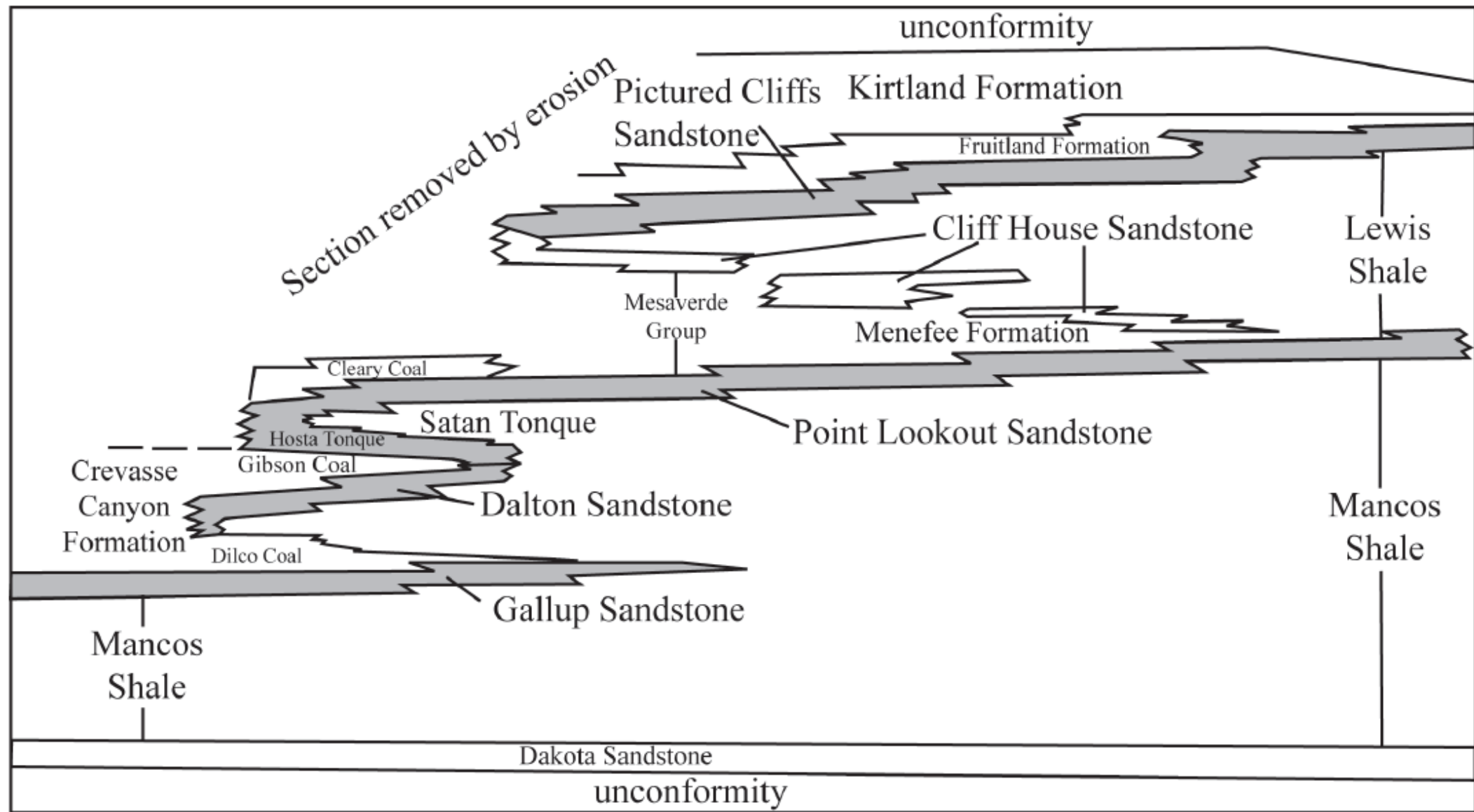
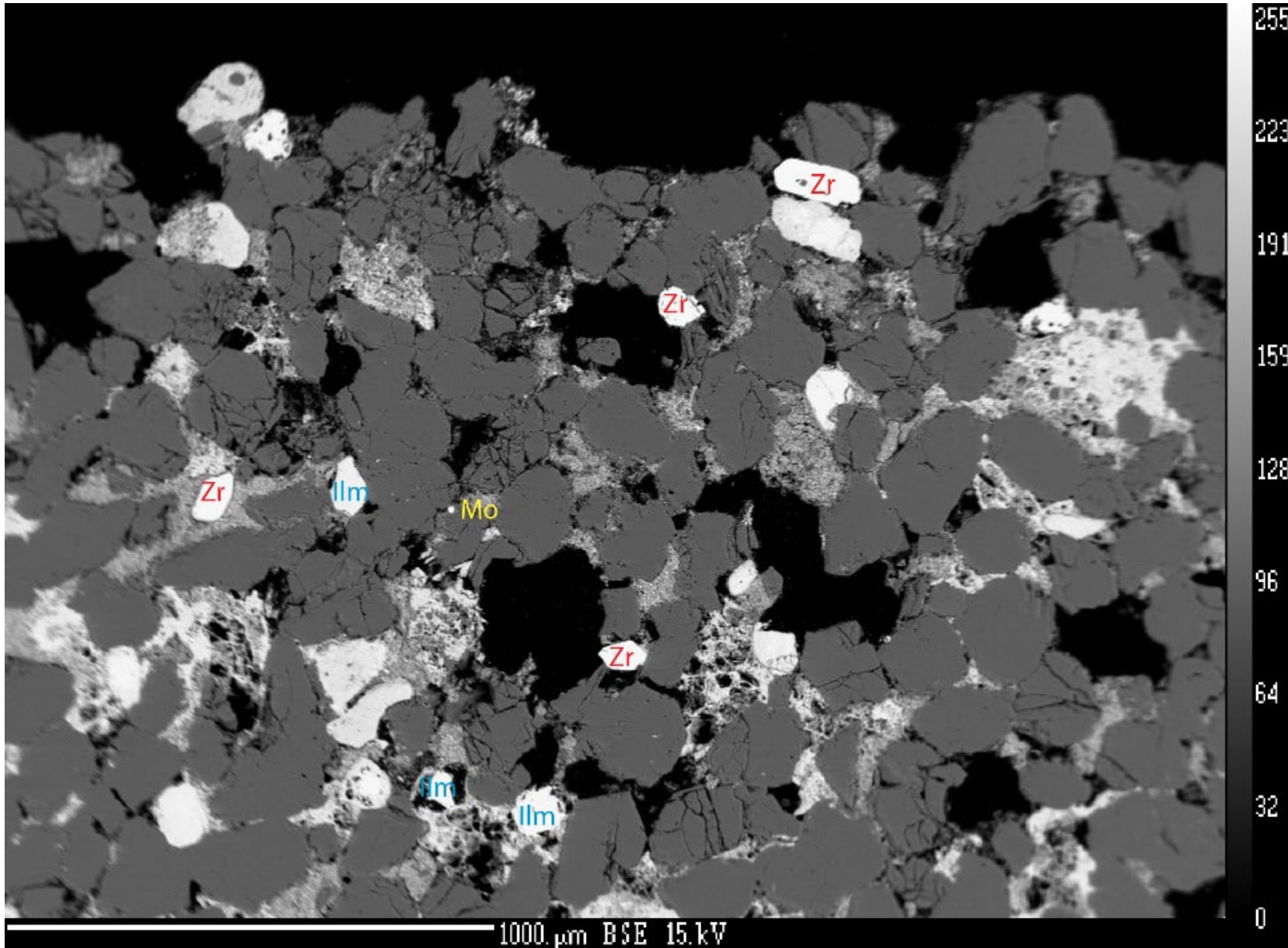


FIGURE 3. Stratigraphic framework and nomenclature of the Late Cretaceous sedimentary rocks in the San Juan Basin (simplified from Molenaar, 1989; Craig et al., 1990). Gray-shaded sandstone units are hosts of known beach-placer sandstone deposits in the San Juan Basin.



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.

Beach-placer sandstone deposits

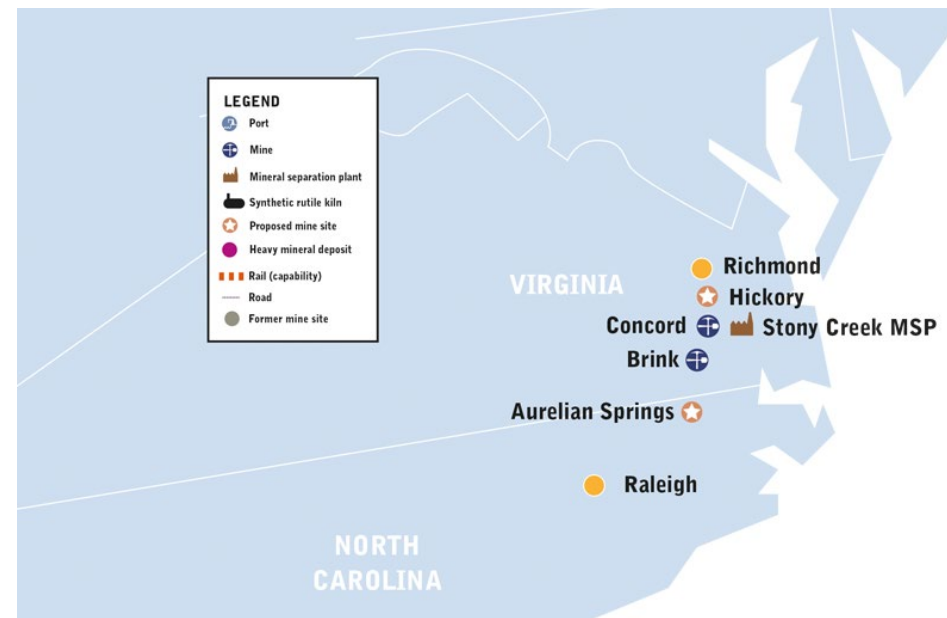
- They form by mechanical concentration (i.e. settling) of heavy minerals by the action of waves, currents, and winds
- Titanite, zircon, magnetite, ilmenite, monazite, apatite, rutile, xenotime, garnet, and allanite, among other minerals
- Ti, Fe, Nb, Th, U, Zr, Sc, Y, and REE also can be economically important



Modern examples

- Atlantic Coast, USA
- southeastern Australia
- Andhra Pradesh, India

- Mined for titanium, zircon, and monazite (a Ce-bearing REE mineral)



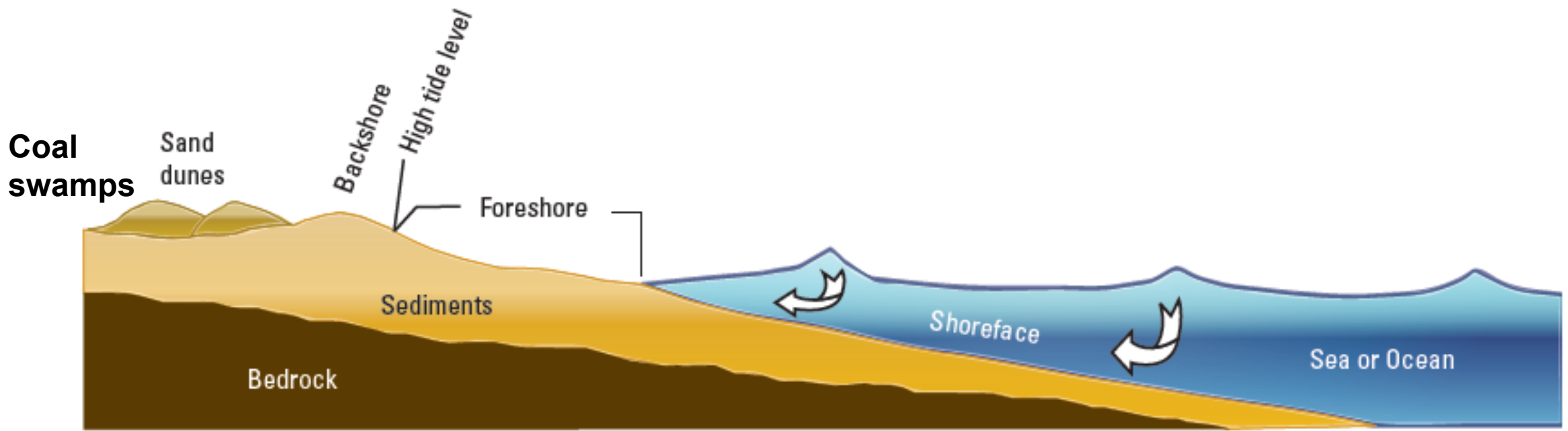


Figure 3. Features commonly used to describe shoreline (strandline) depositional environments associated with deposits of heavy-mineral sands. Not to scale.



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)PO₄ (<15%)
 - Catalyst, glass, polishing, re-chargeable batteries, magnets, lasers, glass, TV color phosphors
- Other minerals
 - Garnet, starolite, kyanite trace-50%

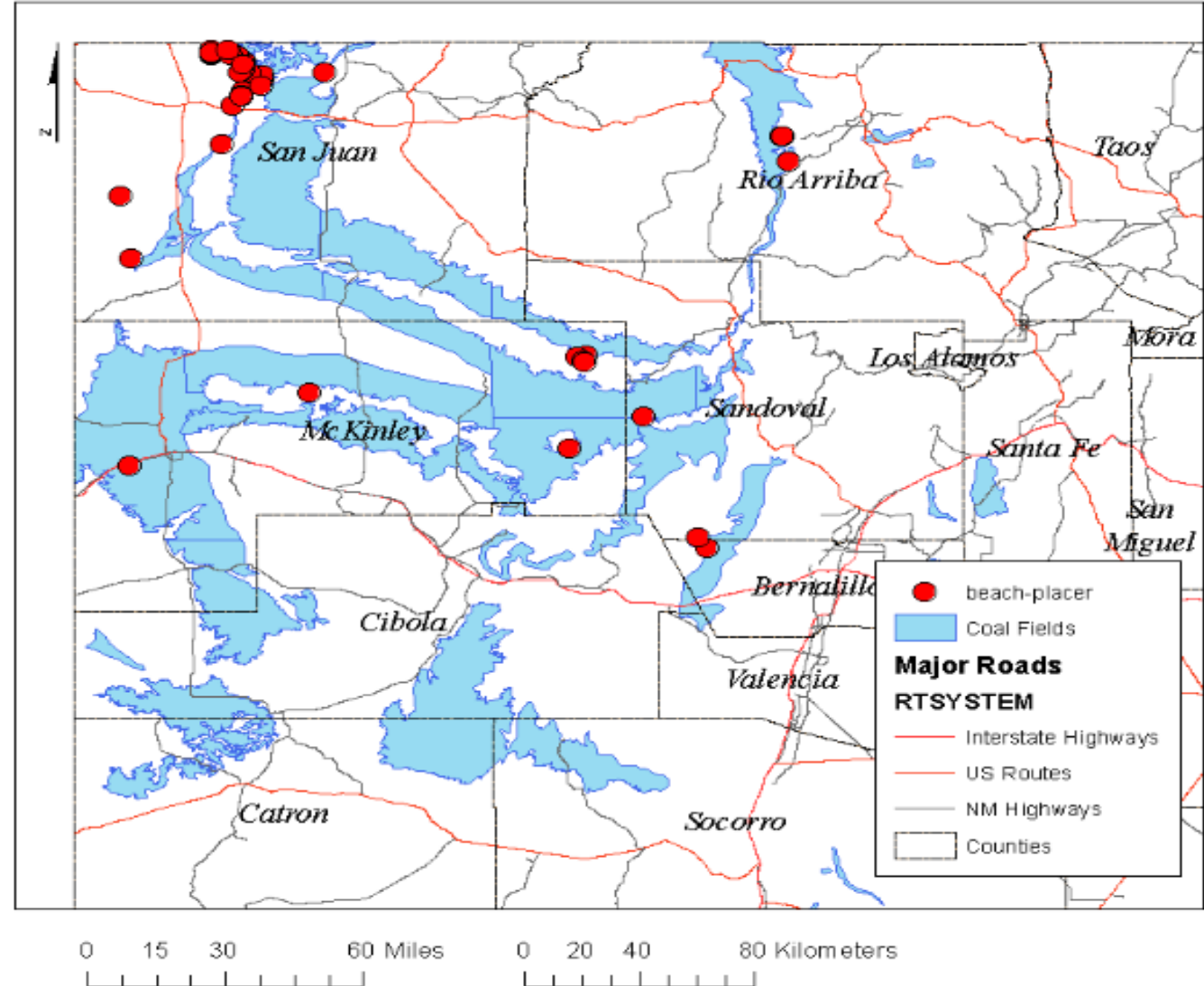
Coal in New Mexico

- Fuels electrical generating plants (1 in NM and fuels Arizona plants)
- 2 surface mines and 1 underground mine in San Juan Basin
 - El Segundo
 - Navajo
 - San Juan (soon to close)
- Resources at Raton, Sierra Blanca fields
- 12th coal in production in U.S. in 2020
 - 10,249,000 short tons
- 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



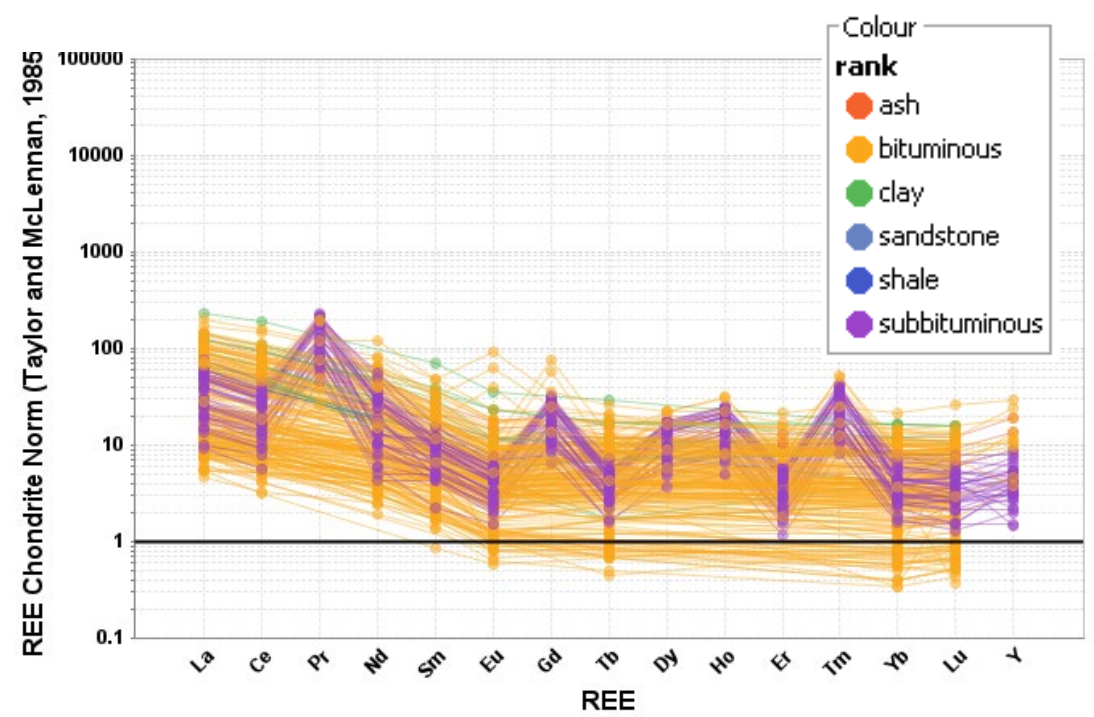
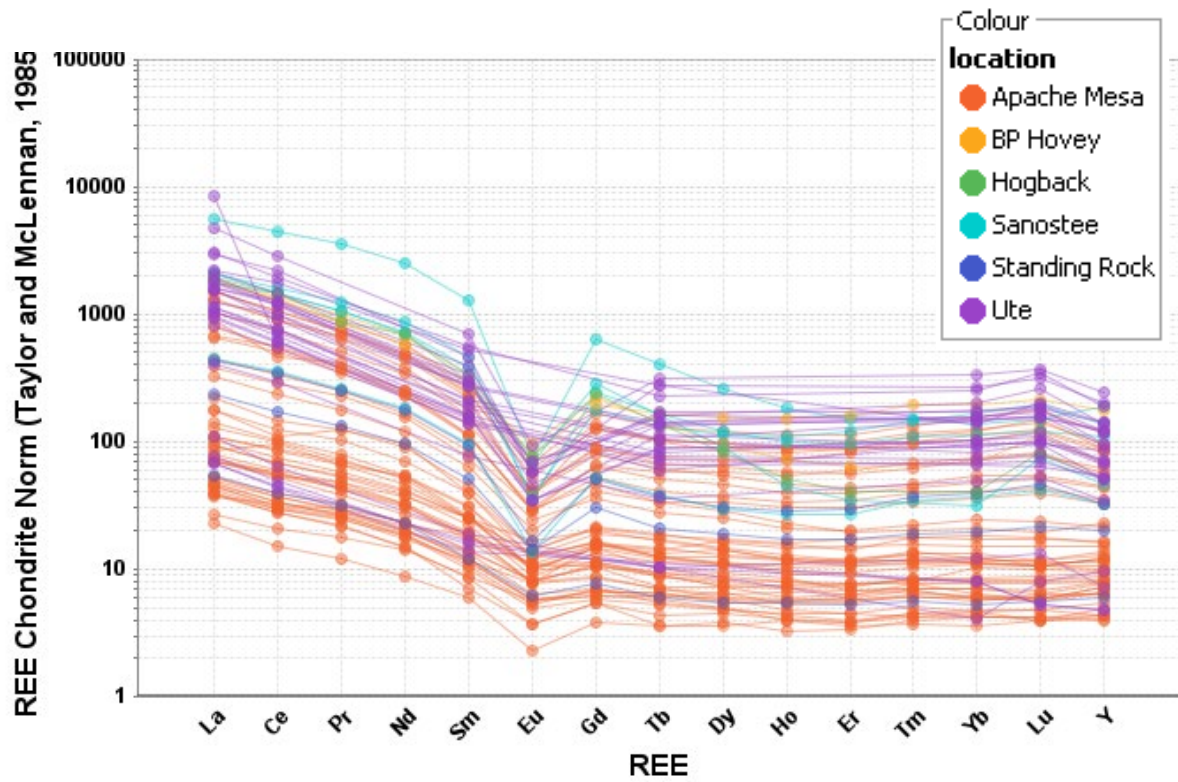
New Mexico Coal Fields

- 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



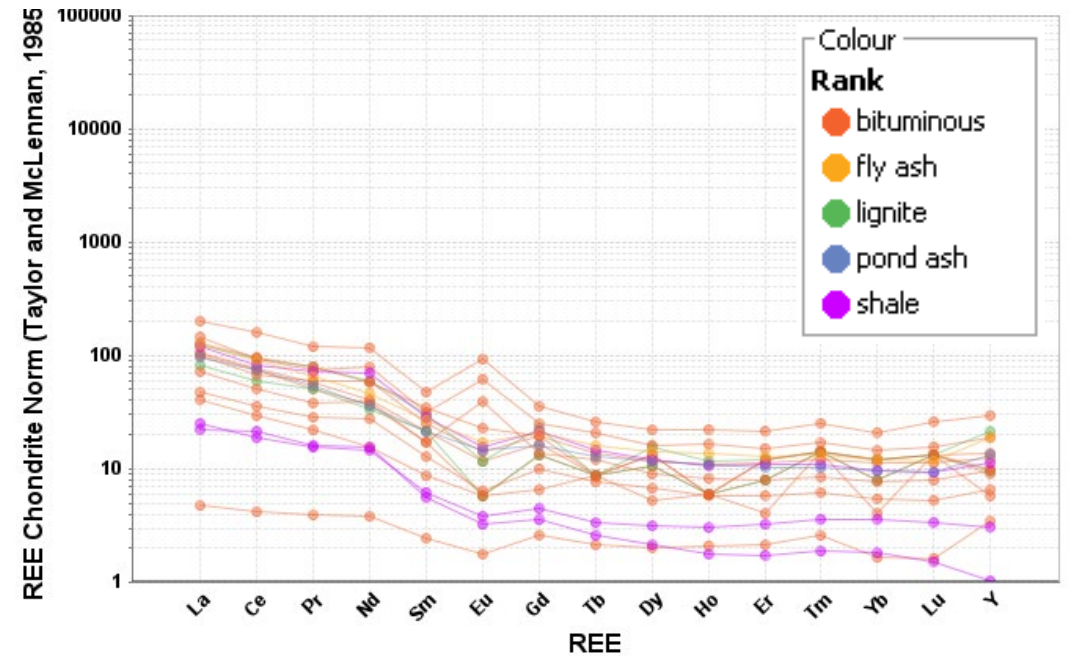
Geochemistry

- 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 ash the coal samples
- 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 is intended to provide a more consistent data set analyzed by ASTM standards

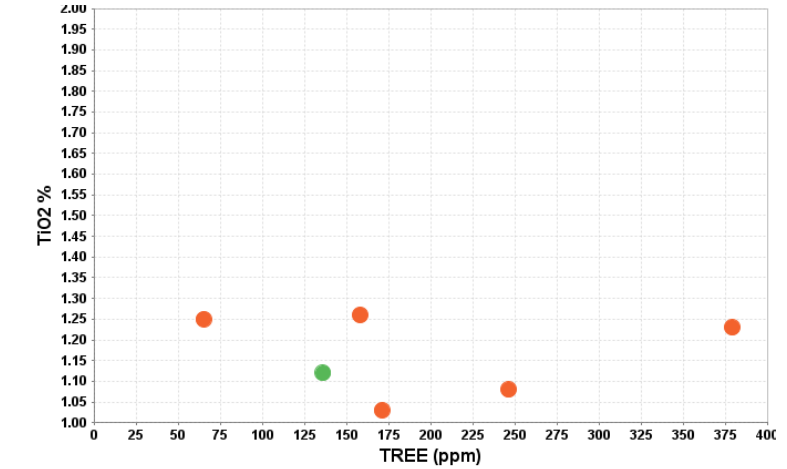
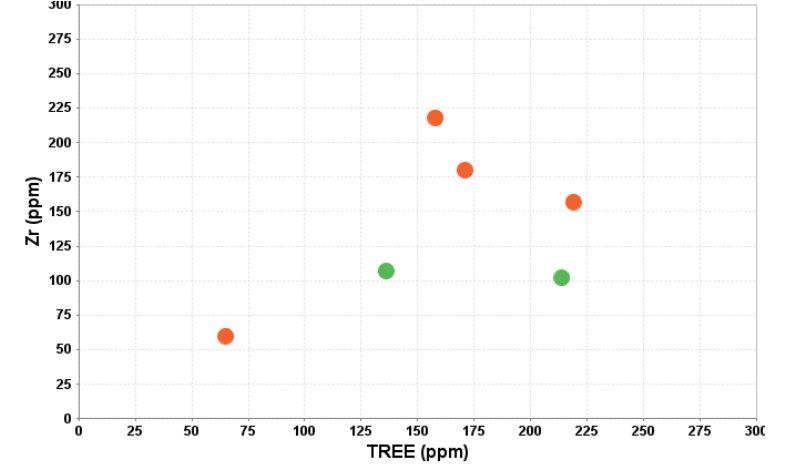
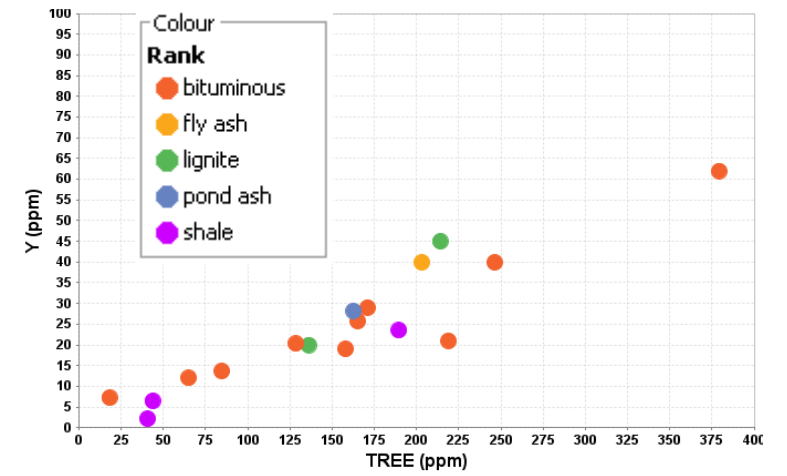
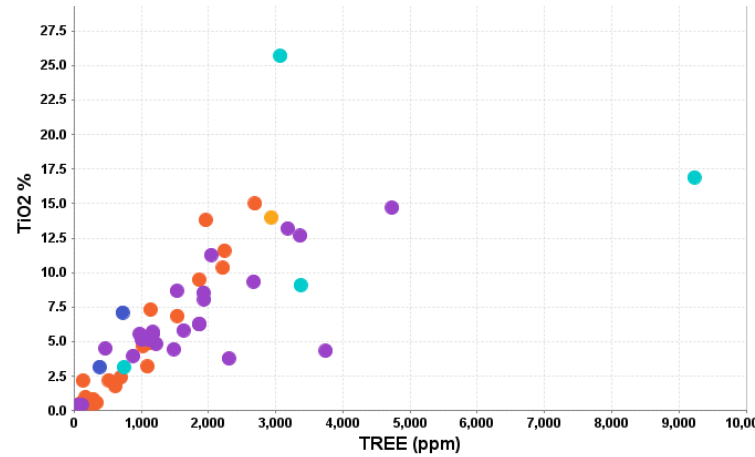
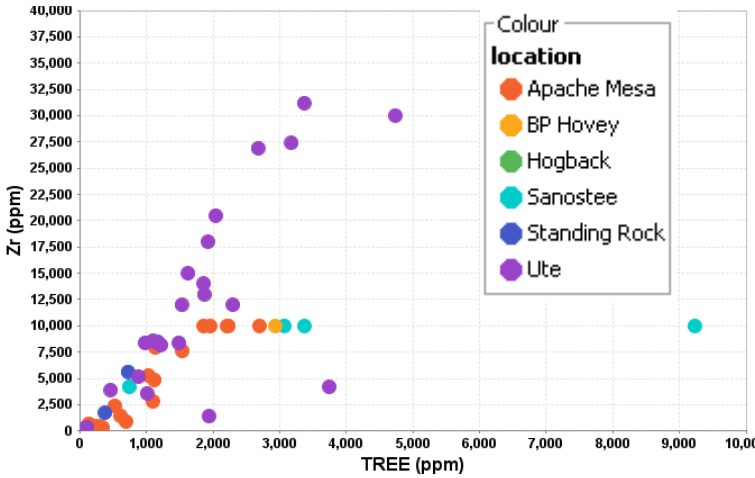
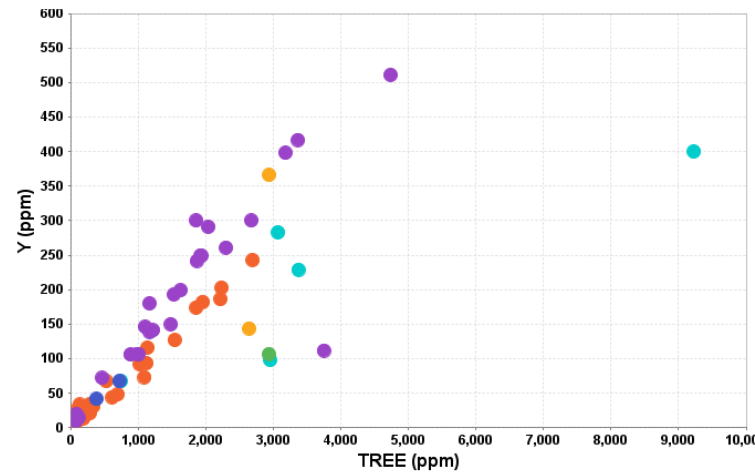


Beach-placer sandstone deposits have high concentrations of TREE, Zr, Ti, Nb (data from McLemore et al., 2016)

Coal/shale/ash deposits have low concentrations of TREE, Zr, Ti, Nb (UPPER RIGHT data from Affolter, 2019; Araya, 1993; Baker, 1989).
 BOTTOM RIGHT new unpublished data; Taggart et al. 2016)



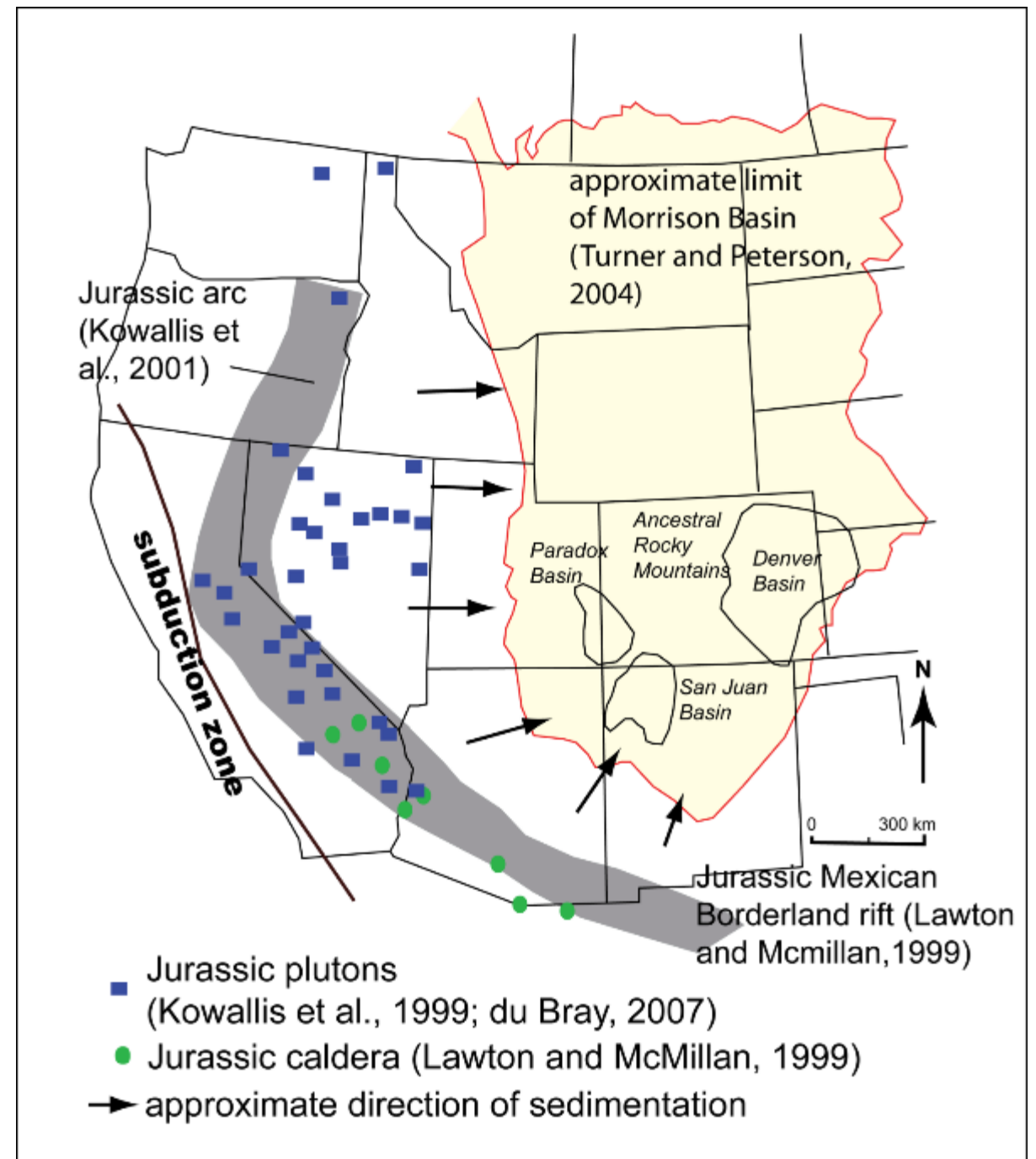
Geochemistry of beach-placer sandstone and coal deposits



Correlation plots of TREE vs Y, Zr, and TiO₂ for beach-placer sandstone deposits (LEFT; data from McLemore et al., 2016) and coal/shale/ash deposits (RIGHT, new unpublished data; Taggart et al. 2016) (note different scales)

Detailed mineralogical study is underway

Test a possible regional source of REE and CM in New Mexico coals and beach-placer sandstones from volcanic ash erupted from the Jurassic-Cretaceous arc in western U.S.



Preliminary Conclusions

- Chemical analyses of coal deposits from the literature (including the USGS coal quality database) are not always accurate and must be used with caution
- However, chemical analyses from the literature do provide guides for interpretations
- New unpublished data is intended to provide a more consistent data set analyzed by ASTM standards
- Chemical analyses can be used to approximate the mineralogy of the deposit

Preliminary Conclusions—continued

- Although, local high concentrations of Ti, Zr, U, Th, and REE are found in some heavy mineral, beach-placer sandstone deposits in the San Juan Basin, it is unlikely that any of these deposits in the San Juan Basin will be mined in the near future because of small tonnage, high degree of cementation through lithification, high iron content, and distance to processing plants and markets
- However, as the demand for some of these elements increases because of increased demand and short supplies, the dollar value per ton of ore may rise, enhancing deposit economics

Preliminary Conclusions—continued

- The TREE and other critical minerals in San Juan Basin coal deposits are low, but since ash is produce from burning coal, REE and perhaps some critical minerals could be recovered from the ash, especially if there are industrial uses for the ash (additional study underway)
- Ultimately, economic potential of both types of deposits will most likely depend upon production of more than one commodity

Future work

- Continue to sample remaining beach-placer sandstone and coal deposits
- Compile geochemical and mineralogical analyses
- Identify possible sources
- Evaluate the mineral-resource potential