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

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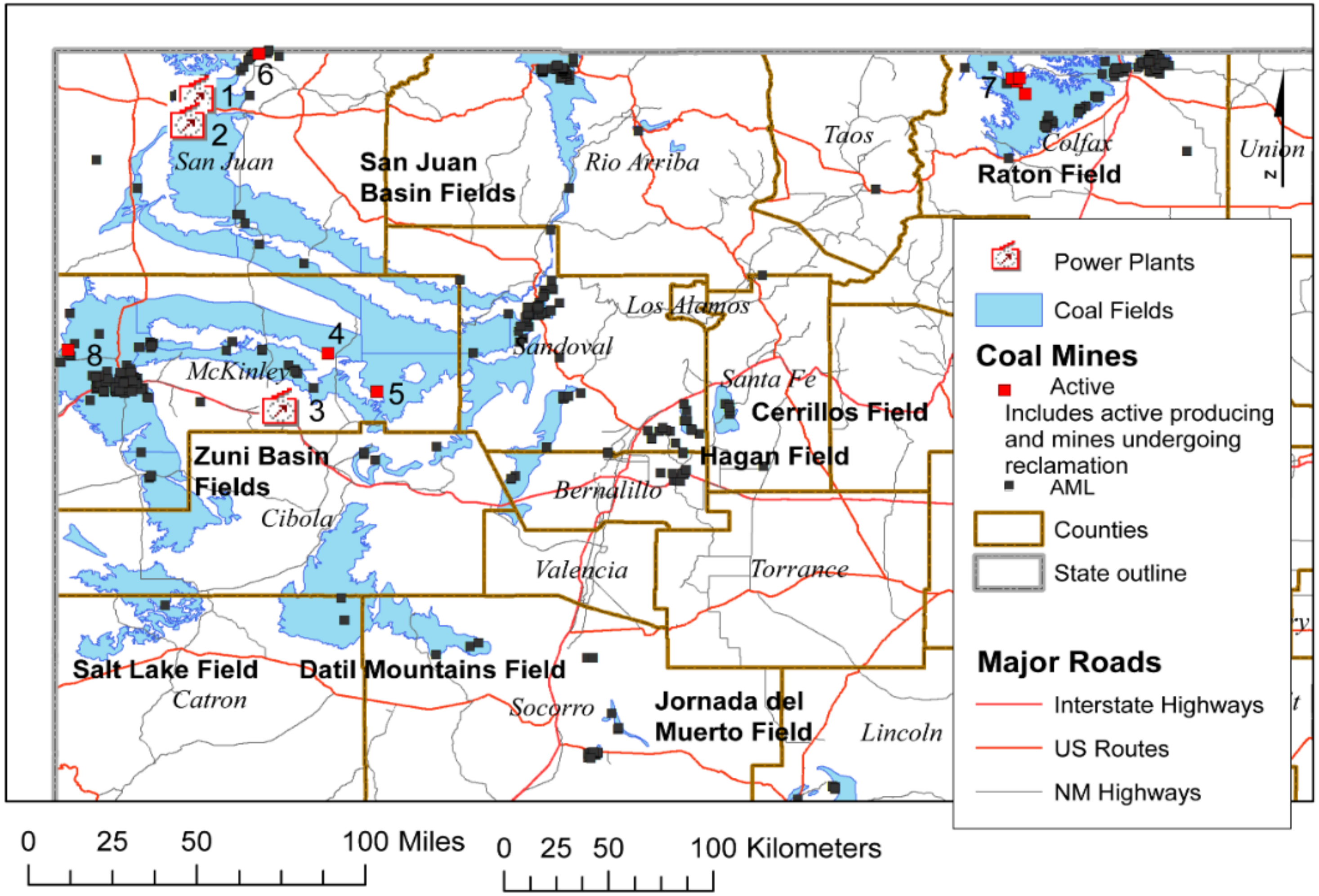
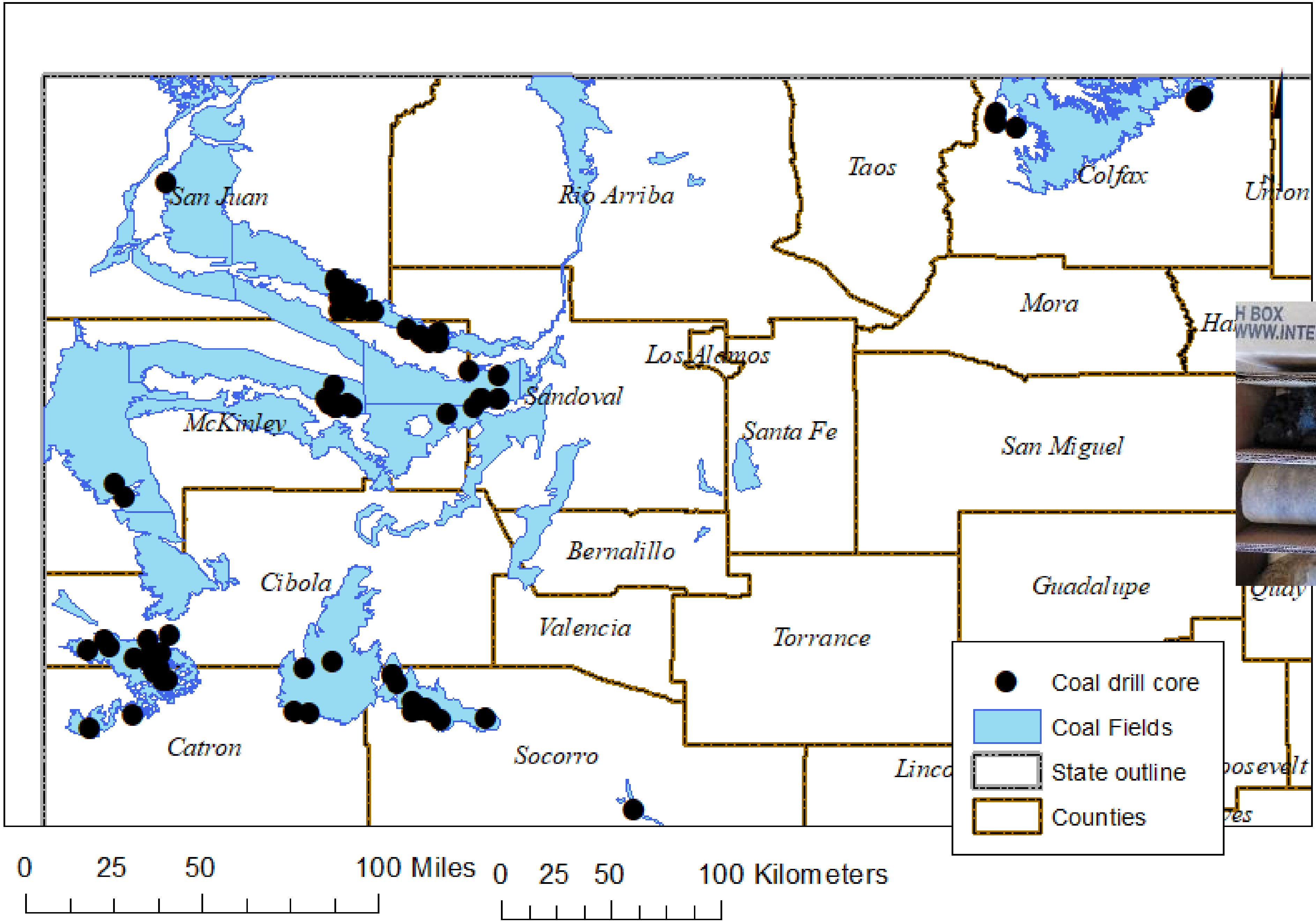
Outline of today's presentation

- Summarize the geology, geochemistry, of the Late Cretaceous coal and heavy-mineral beach placer sandstone deposits in San Juan and Raton basins
- Preliminary conclusions



1 San Juan-Public Service Co. of NM plant and San Juan underground mine (Westmoreland)
2 Four Corners-Arizona Public Service Co. plant and Navajo mine (Bisti Fuels Co., LLC)
3 Escalante-TriState plant
4 El Segundo mine (Lee Ranch Coal)
5 Lee Ranch mine (Lee Ranch Coal)
6 La Plata (reclamation)
7 York Canyon and Ancho mines (reclamation)
8 McKinley mine (reclamation)



San Juan
Rio Arriba
Taos
Colfax
Union
Mora
Los Alamos
Sandoval
McKinley
Santa Fe
San Miguel
Bernalillo
Cibola
Guadalupe
Valencia
Torrance
Catron
Socorro
Quay
Coal drill core
Coal Fields
State outline
Counties
0 25 50 100 Miles
0 25 50 100 Kilometers

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District id	District (coal field)	Year of Discovery	Year of Initial Production	Year of Last Production	Estimated Cumulative Production	Formation	Number of samples collected
DIS257	**Barker Creek**	1882		1905		Menefee	
DIS150	Bisti	1961	1980	1988	$40,075,148.00	Fruitland	2
DIS259	**Chaco Canyon**	1905	1905			Menefee	
DIS260	**Chacra Mesa**	1922		1945		Menefee	
DIS174	La Ventana	1884	1904	1983		Menefee	4
DIS118	**Crownpoint**	1905	1914	1951	$20,758.00	Crevasse Canyon	
DIS155	Fruitland	1889	1889	2001	$3,137,957,050	Fruitland	1
DIS119	**Gallup**	1881	1882	2001	$121,522,629,885	Crevasse Canyon	
DIS156	**Hogback**	1907	1907	1971	$301,237.00	Menefee	
DIS146	**Monero**	1882	1882	1970	$5,277,552.00	Menefee	
DIS016	Mount Taylor	1936	1952	1953	$69,948.00	Crevasse Canyon	8
DIS157	**Navajo**	1933	1963	9999	$4,714,689,147	Fruitland	
DIS258	**Newcomb**	1955				Menefee	
DIS021	Raton	1820	1898	2002	$954,470,032.00	Vermejo, Raton	23
DIS003	**Rio Puerco**	1901	1937	1944	$139,555.00	Crevasse Canyon	
DIS009	Salt Lake	1980	1987	1987	$100,000.00	Moreno Hill	2
DIS121	**San Mateo**	1905	1983	2001	$1,678,742,326	Menefee	
DIS261	**Standing Rock**	1934	1952	1958		Menefee	1
DIS158	Star Lake	1907			$0.00	Fruitland	30
DIS263	**Tierra Amarilla**	1935	1955	1955		Menefee	
DIS159	**Toadlena**	1950			$0.00	Menefee	
DIS124	**Zuni**	1916	1908	1926	$16,010.00	Crevasse Canyon	
	Other samples						8
	Total samples						81

COAL FIELDS

Red bold=no chemical analyses

San Juan Basin

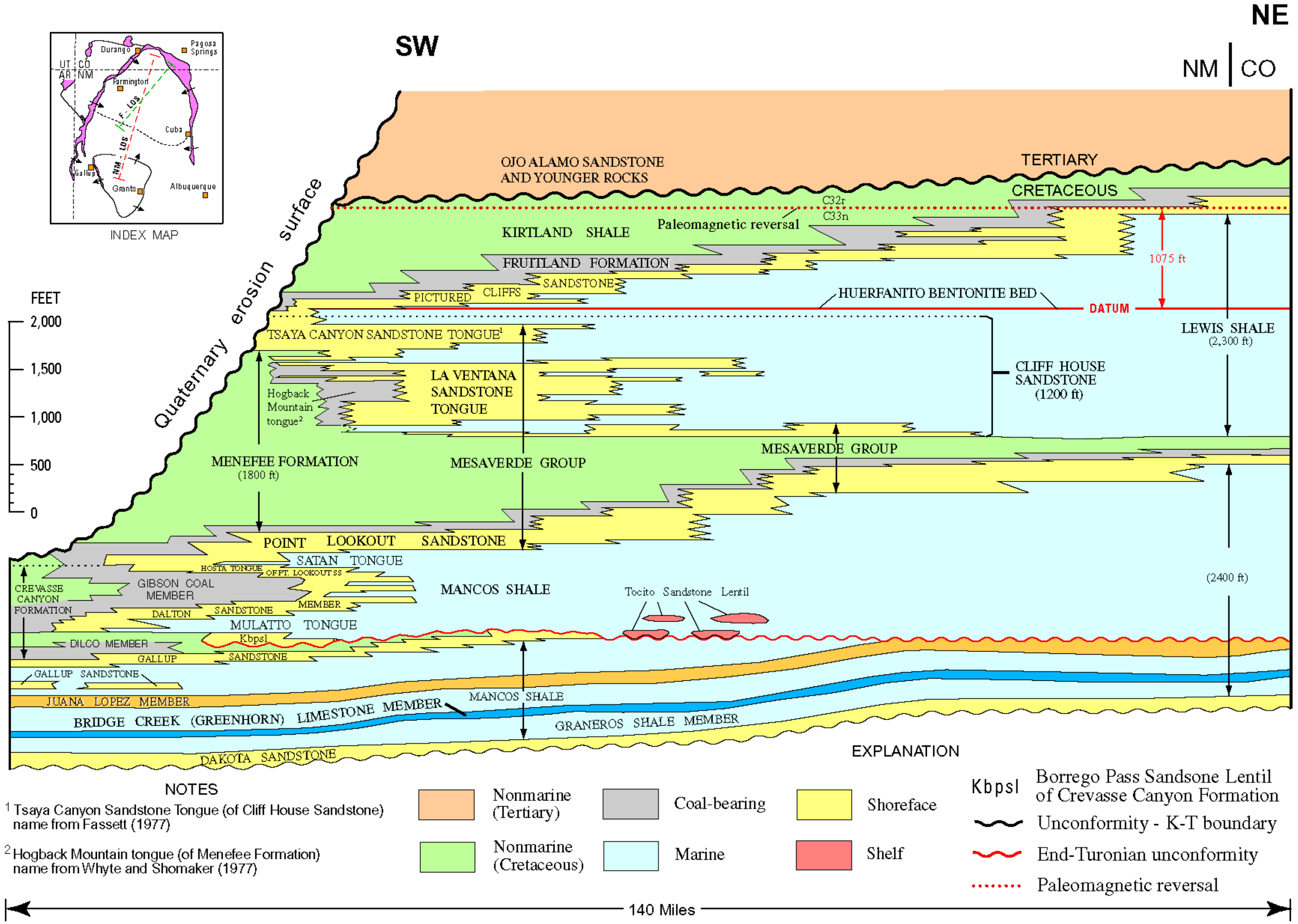
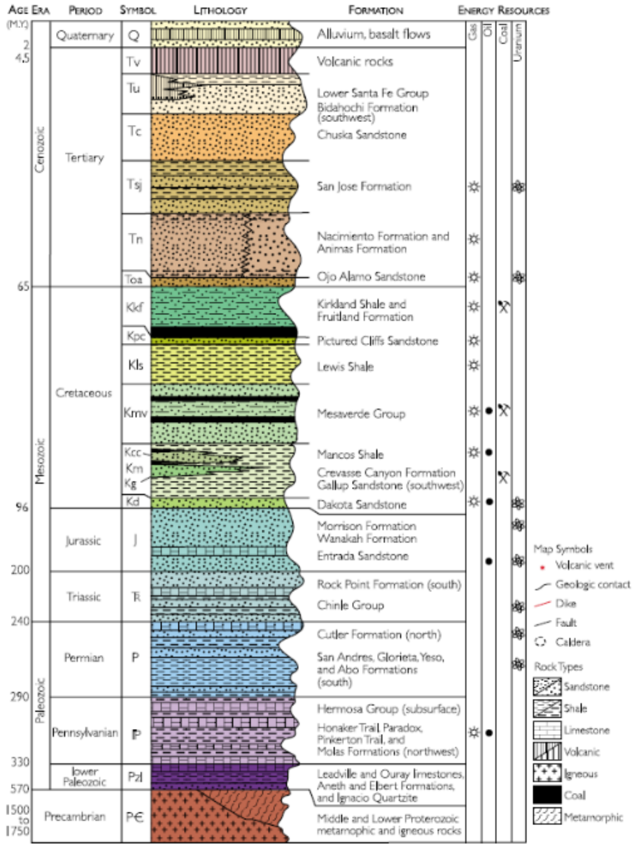


Figure 4. Stratigraphic section showing Upper Cretaceous rocks in the San Juan Basin, New Mexico and Colorado. Tocito Sandstone Lentil and coal-bearing zones are shown diagrammatically. Stratigraphy of rock units from the Point Lookout Sandstone upward is modified from Fassett (1977), stratigraphy for 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.

Geology and Coal Resources of the Upper Cretaceous Fruitland Fm., San Juan Basin, New Mexico and Colorado Q7



Raton Basin

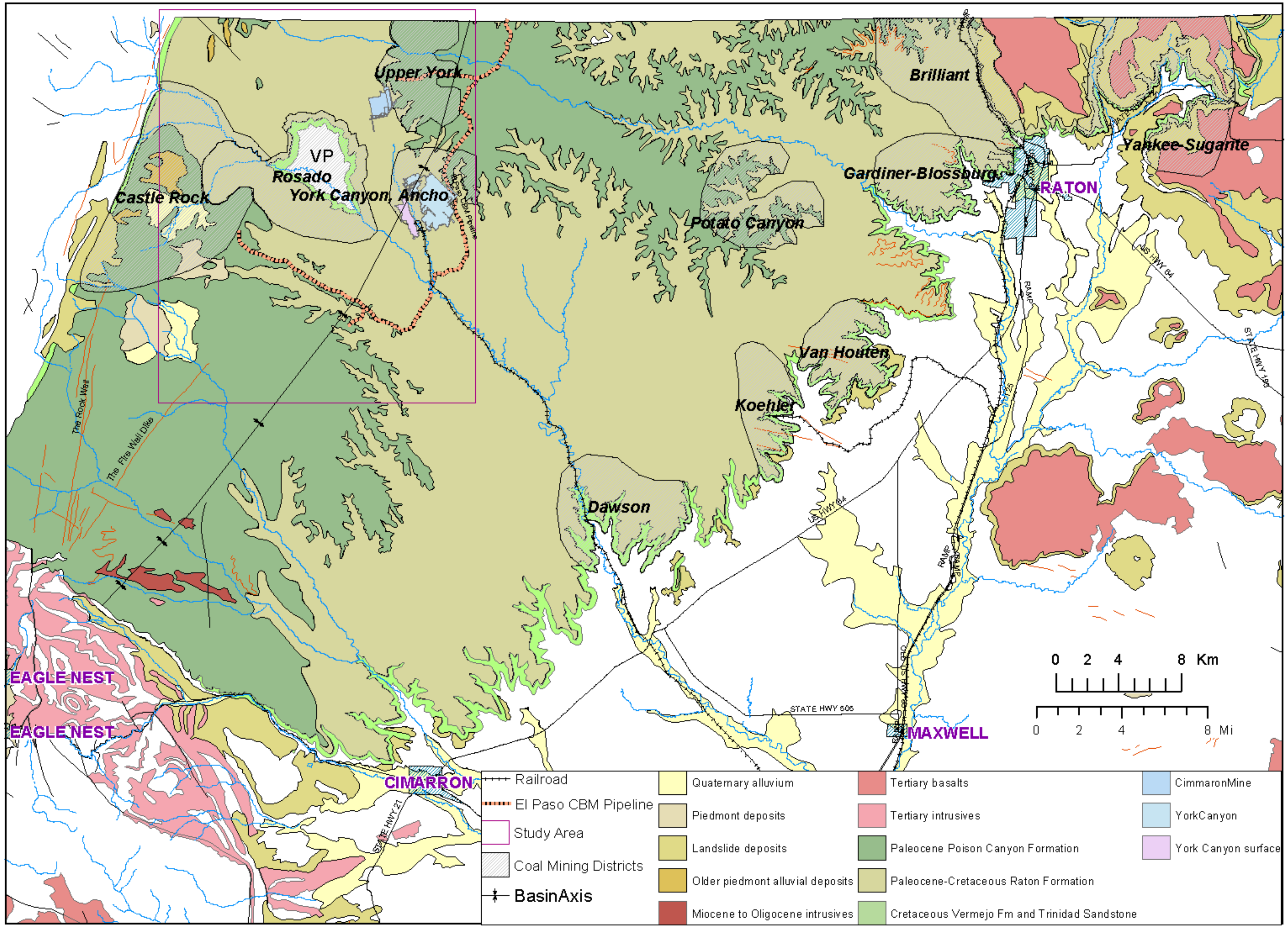
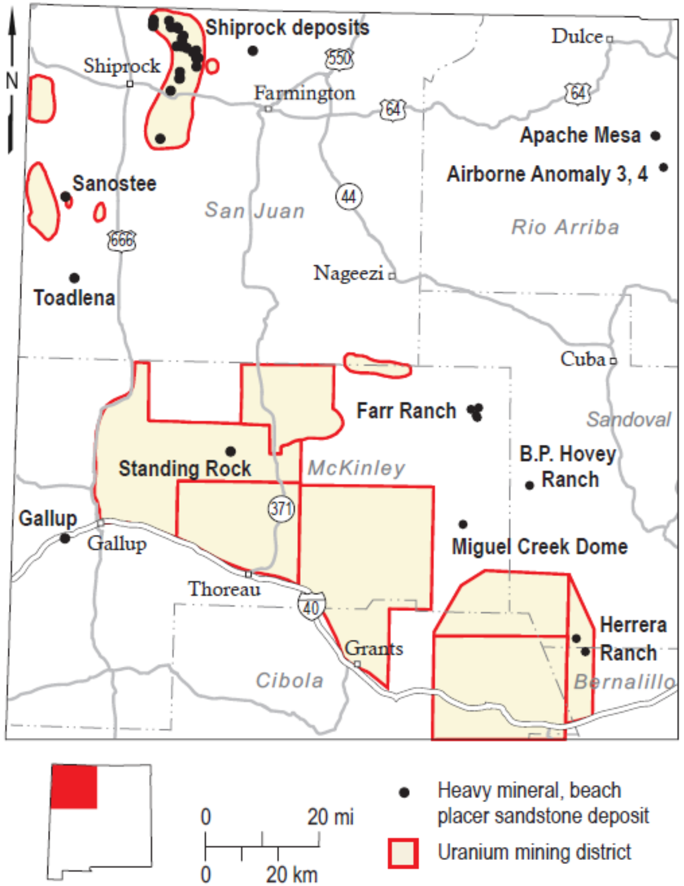


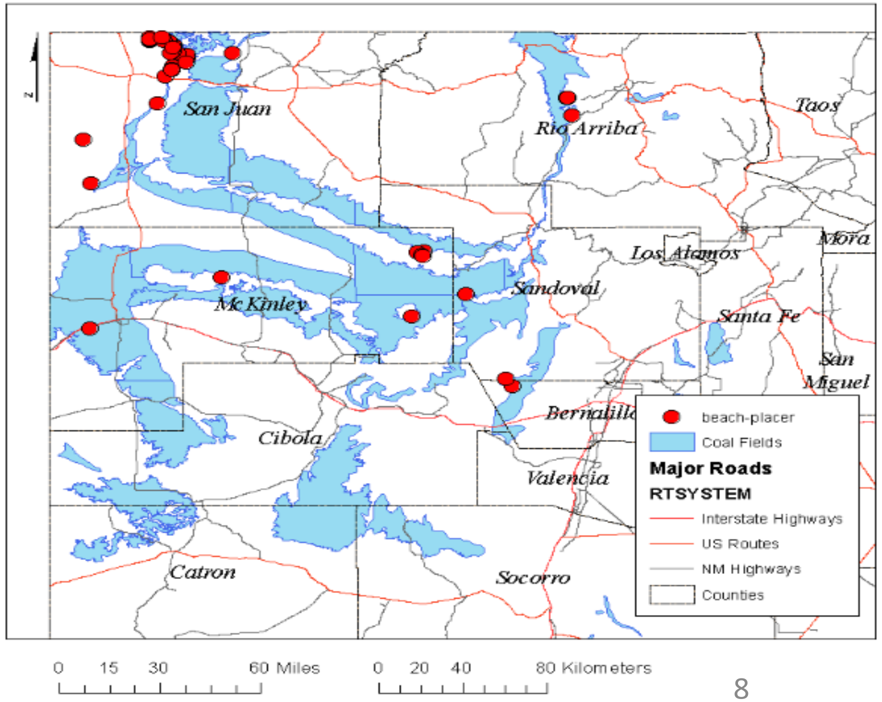
Figure 1.Generalized geologic map of Raton coalfield, New Mexico with mining districts (Pillmore, 1991) and outline of study area. Geology from New Mexico Bureau of Geology, 2003.

2

Beach-placer sandstone deposits

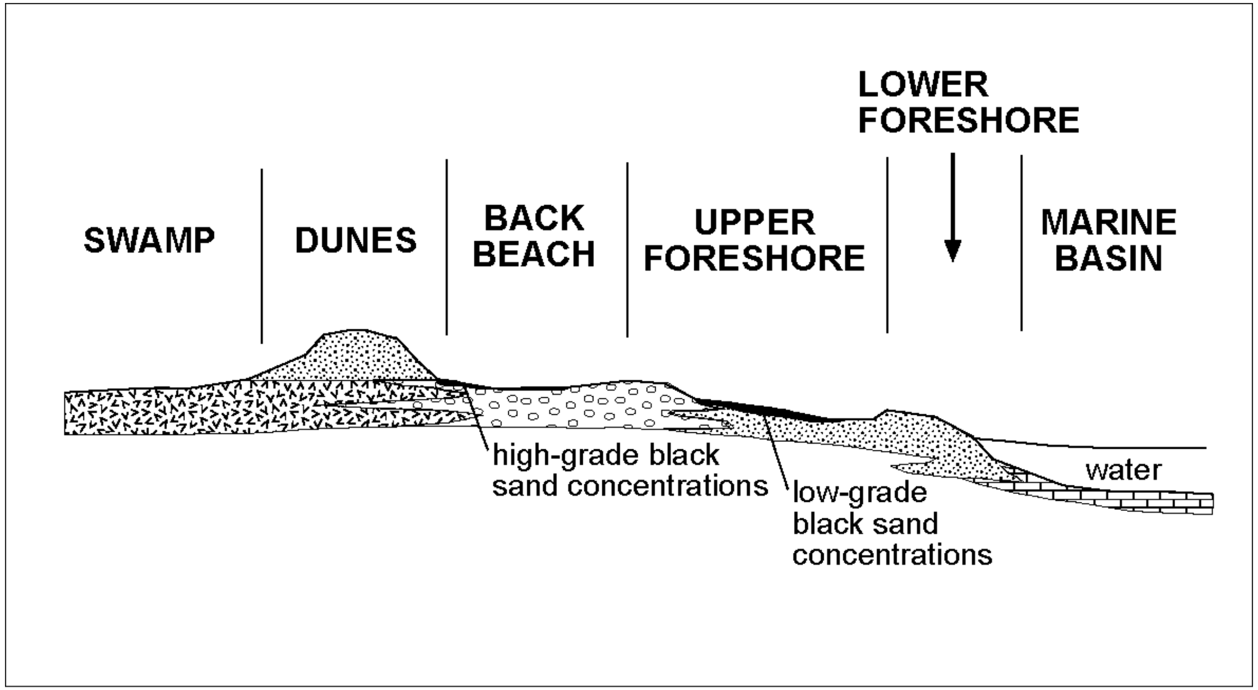
- Beach-placer sandstone deposits in the San Juan Basin are restricted to Late Cretaceous rocks and contain high REE
  - NM REE database
- Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones
- Are in the vicinity of coal deposits





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.



Assateague Island, Md, before and after Hurricane Sandy, where the storm surge redeposited heavy mineral sands (van Gosen et al., 2010)

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)

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%

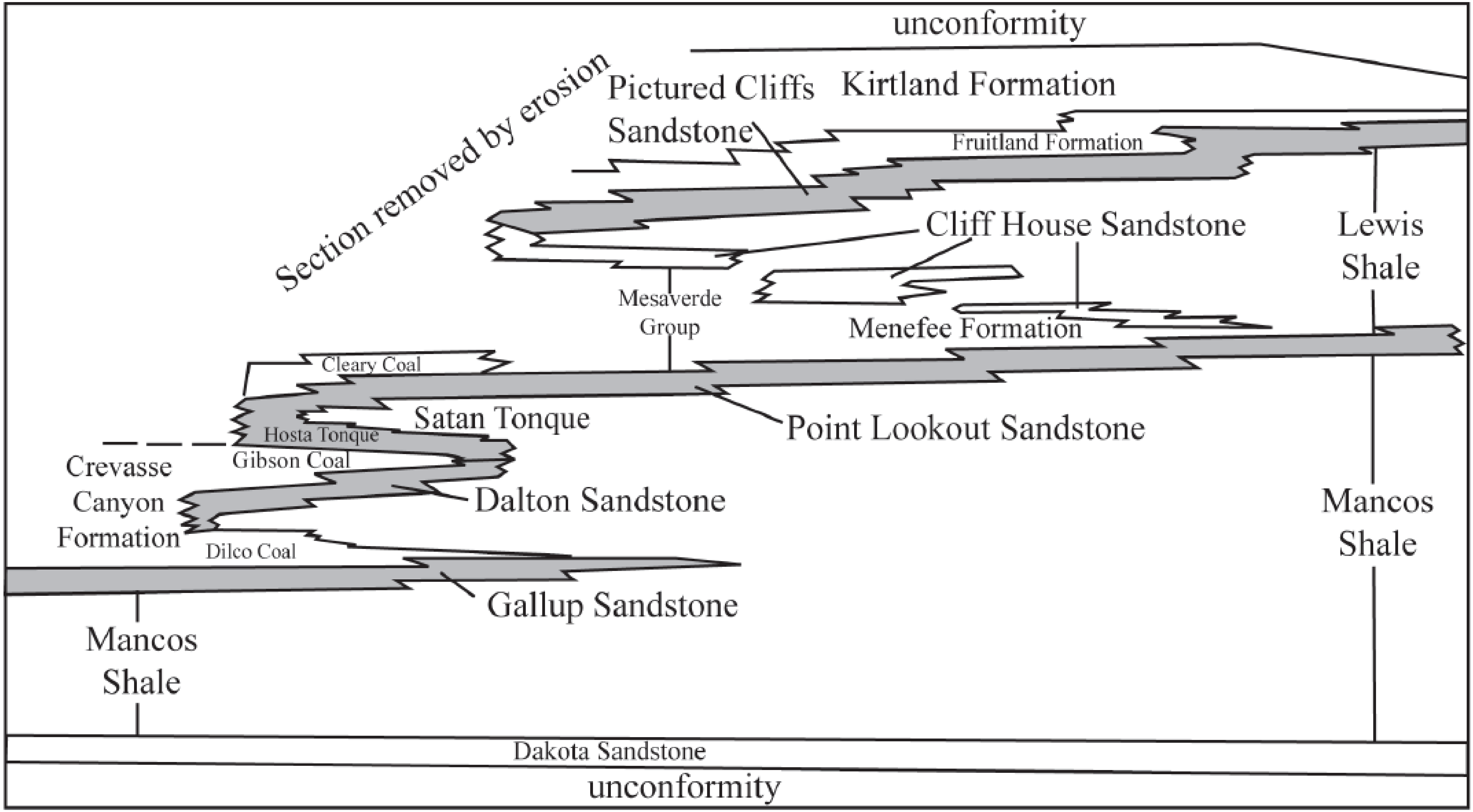
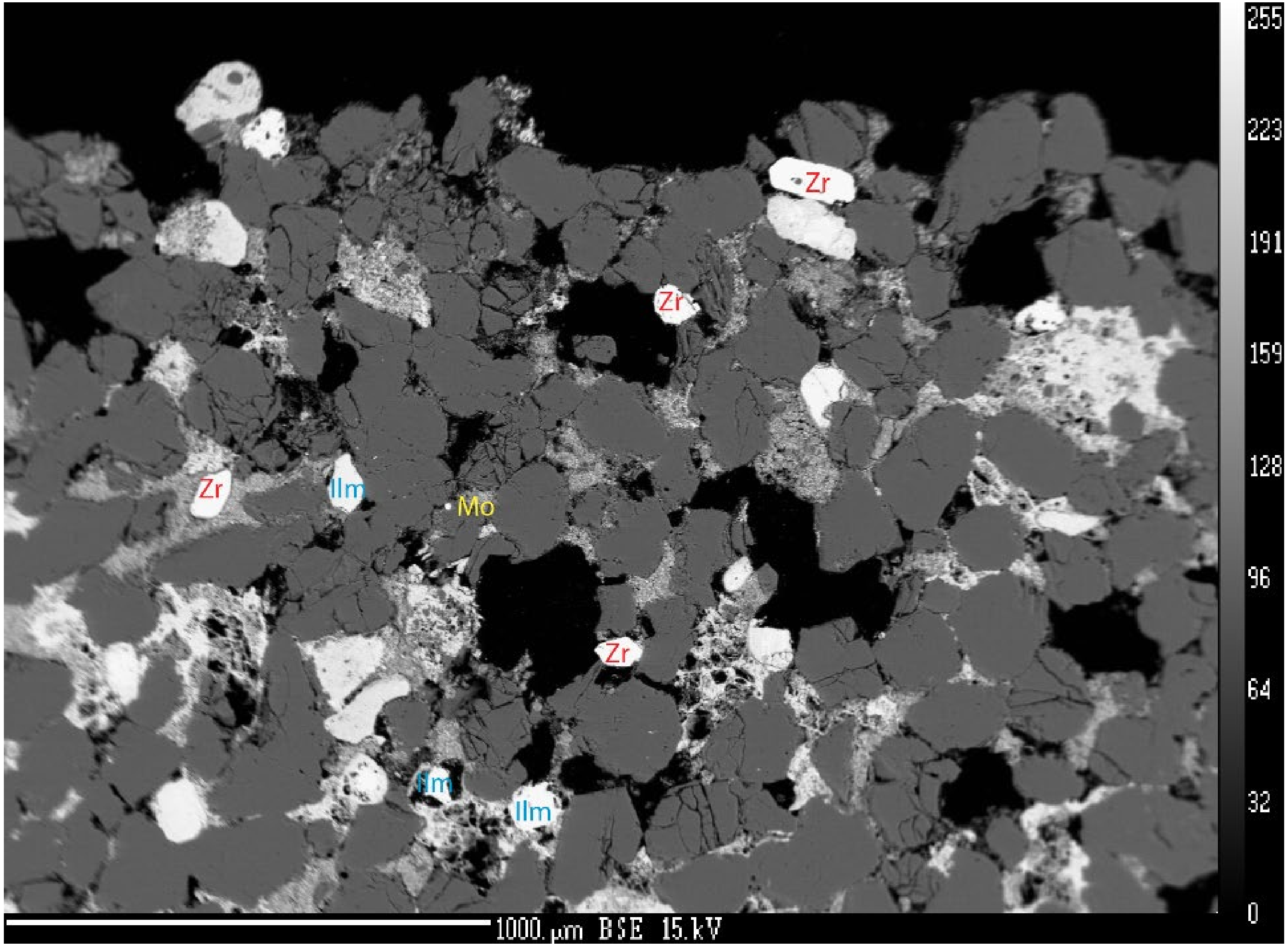


FIGURE 3. Stratigraphic framework and nomenclature of the Late Cretaceous sedimentary rocks in the San Juan Basin (simplified from Molenaar, 1989; Craigg et al., 1990). Gray-shaded sandstone units are hosts of known beach-placer sandstone deposits in the San Juan Basin.



Electron microprobe photo of sample SAN 6 (Sanostee, San Juan Basin). 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.

Coal swamps

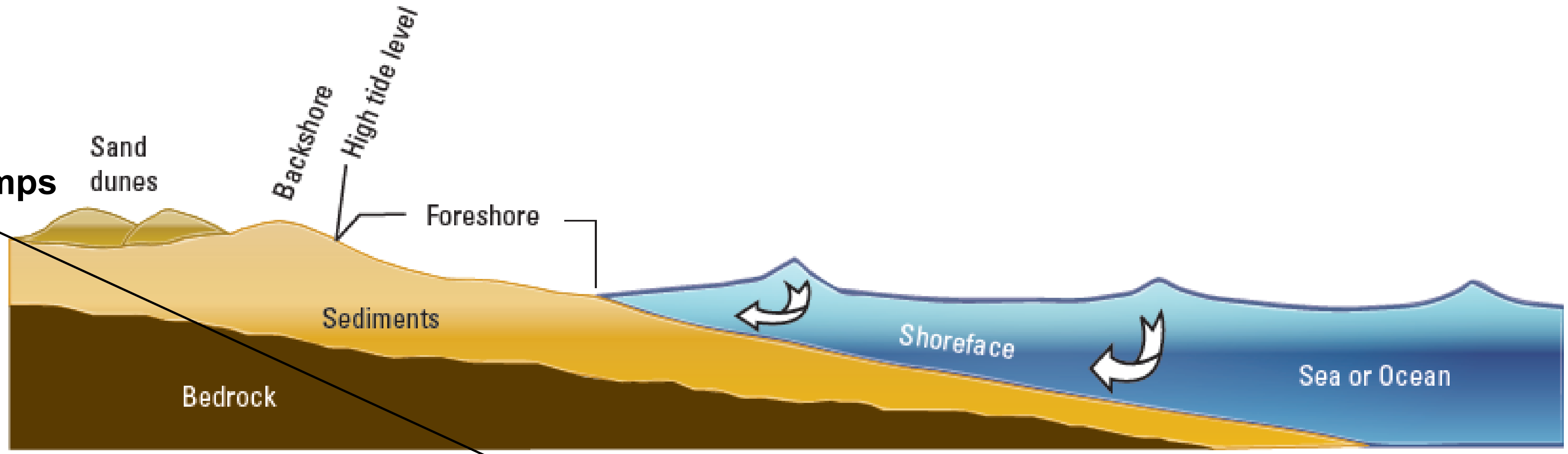
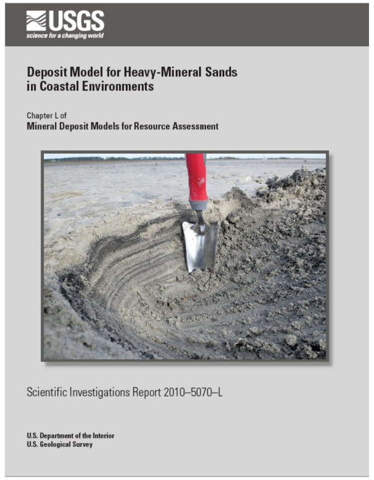
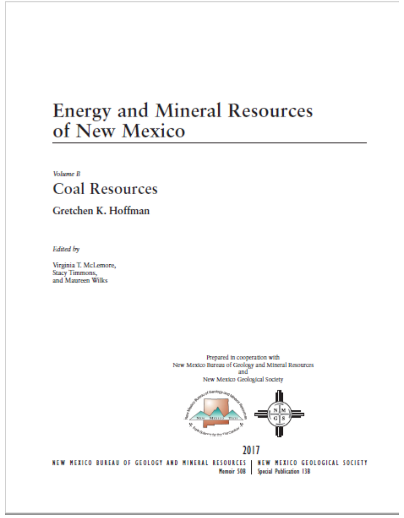
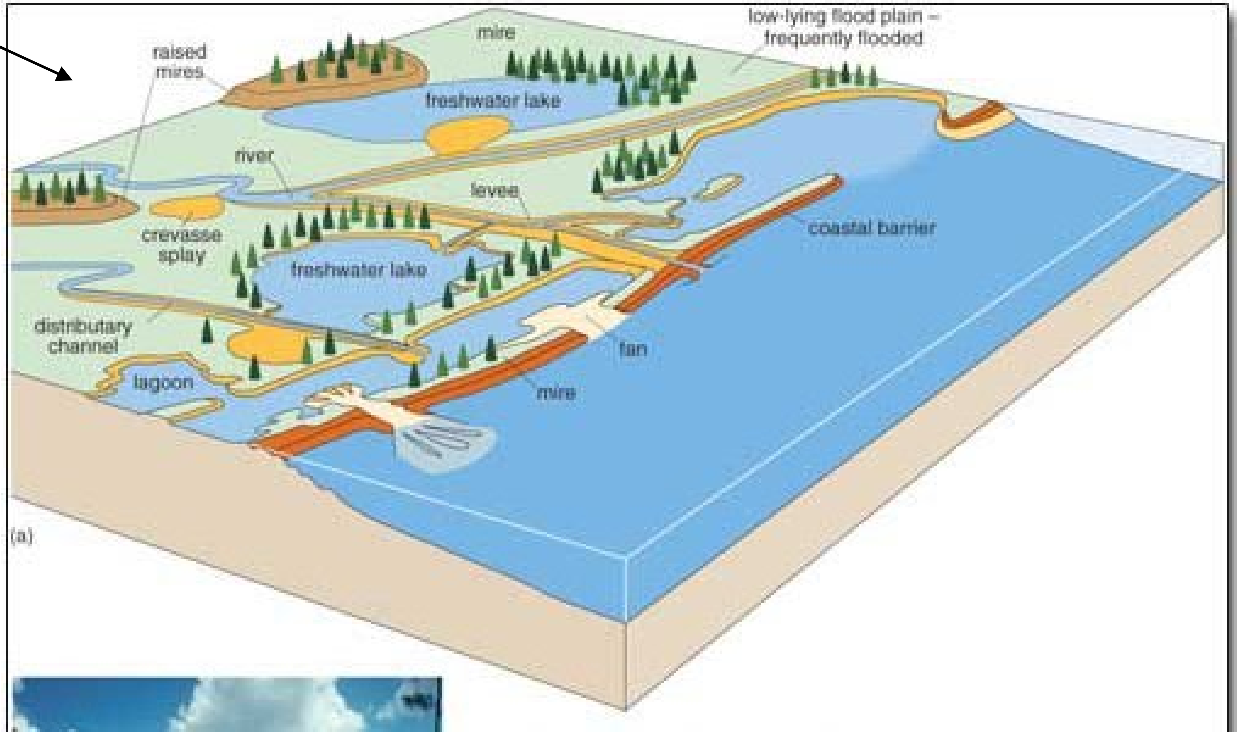


Figure 3. Features commonly used to describe shoreline (strandline) depositional environments associated with deposits of heavy-mineral sands. Not to scale.





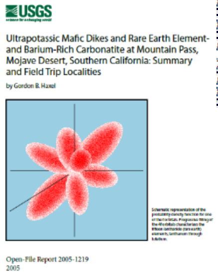


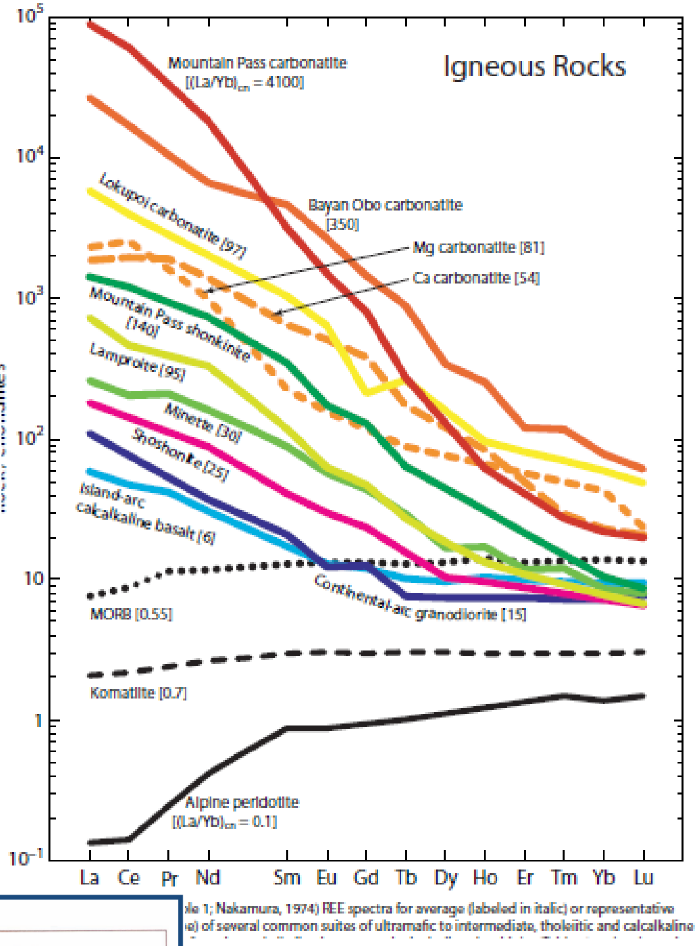
Geochemistry results

Geochemistry data

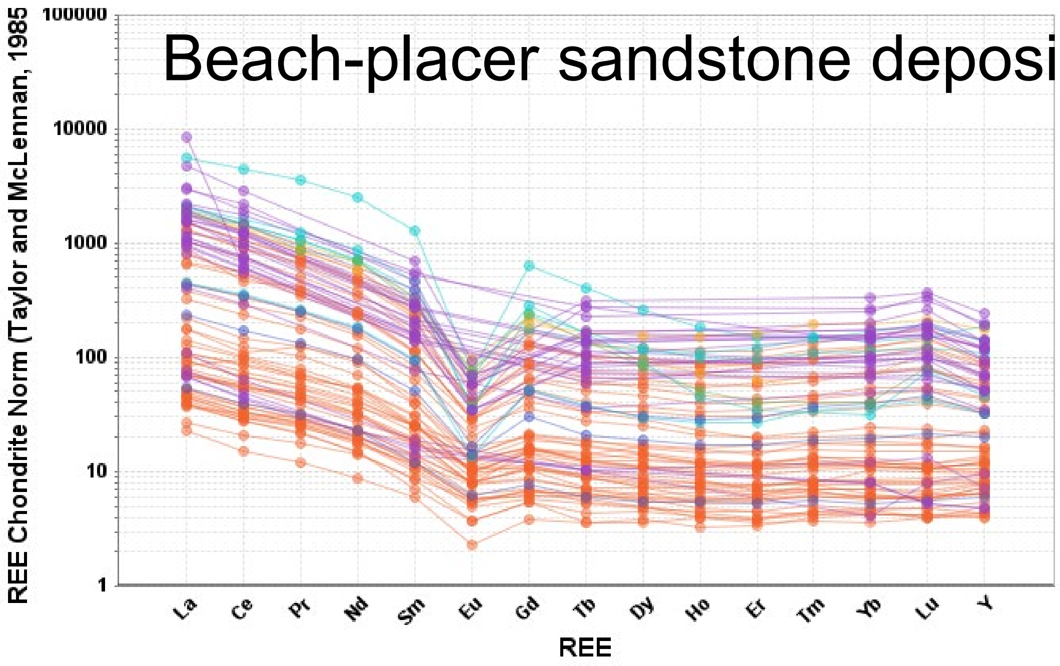
- Geochemical data of the beach-placer sandstone deposits are from a compilation by McLemore et al. (2016) that includes samples collected by McLemore and analyzed in 2010, 2015-2017 and by Zech et al. (1994) (REE by ICP-MS)
- Coal samples are difficult to analyze
  - Preferred ASTM sample preparation 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 instrumental neutron activation analyses (INAA)
  - New unpublished data is intended to provide a more consistent data set analyzed by ASTM standards

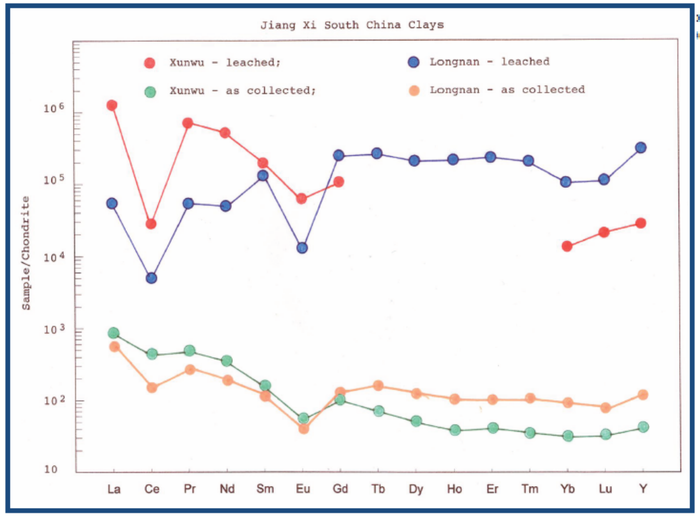
Carbonatites, including producing deposits





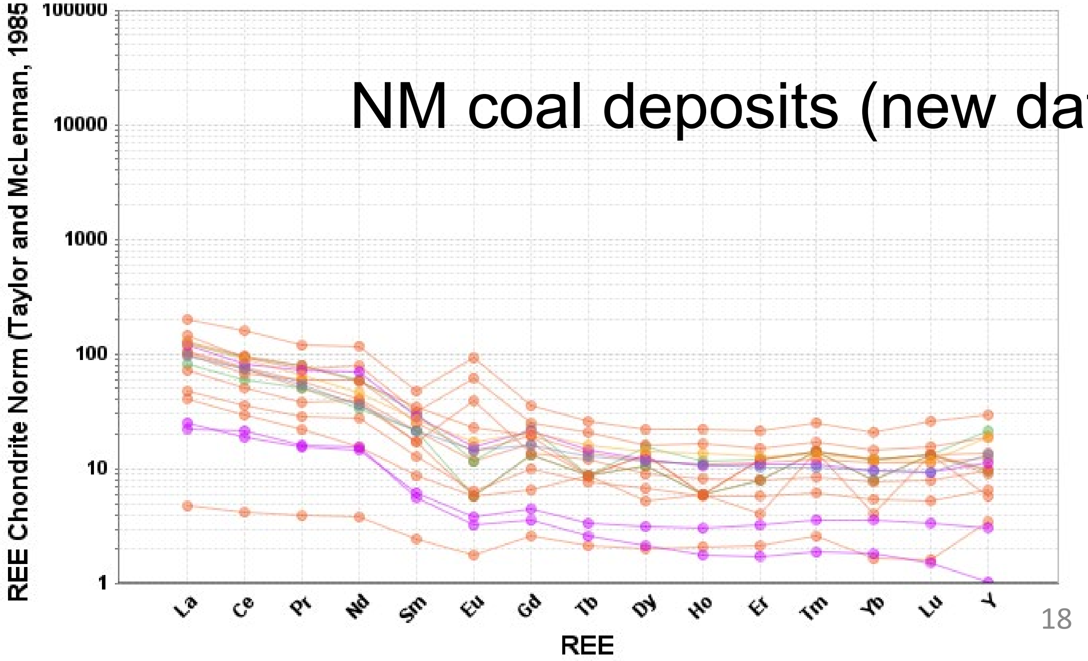
Beach-placer sandstone deposits

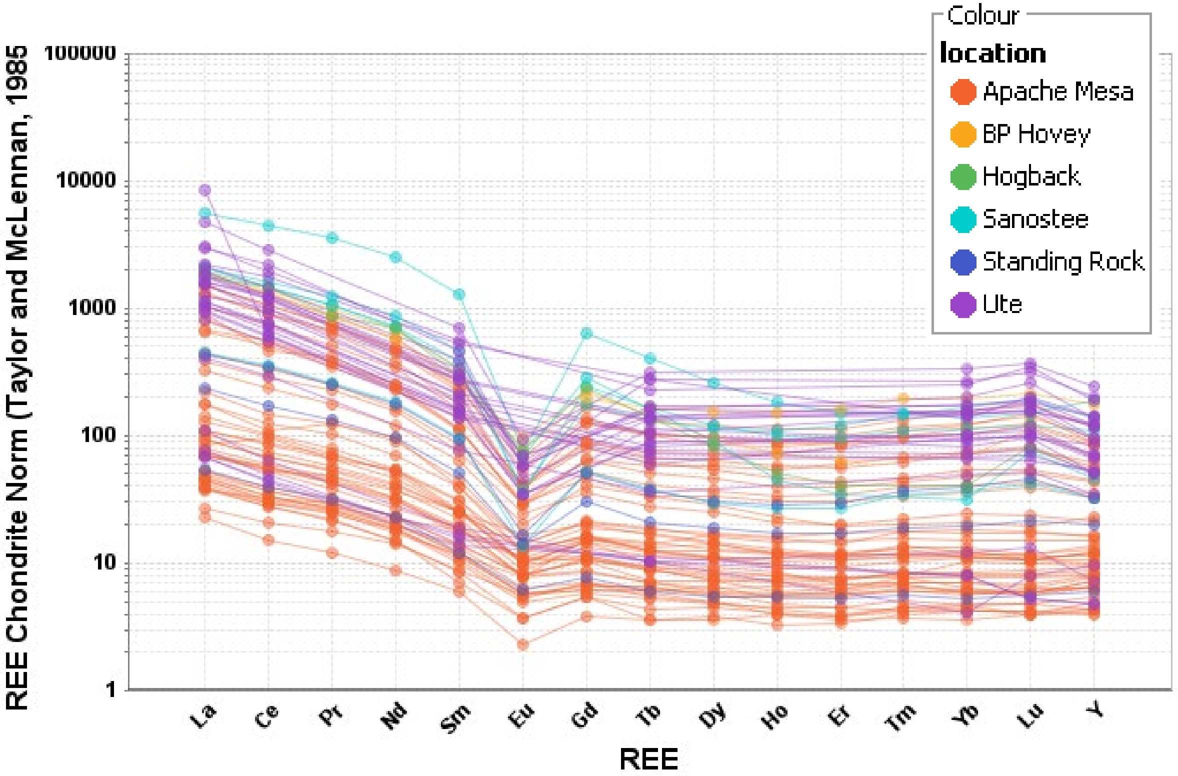


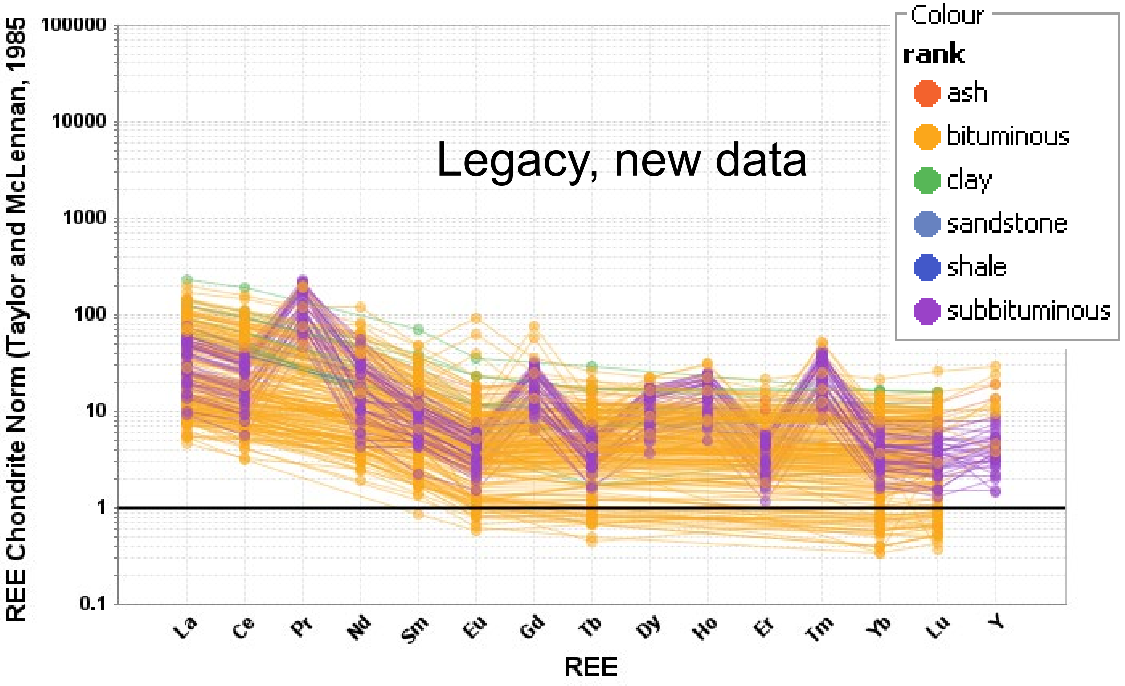


China REE clays

NM coal deposits (new data)

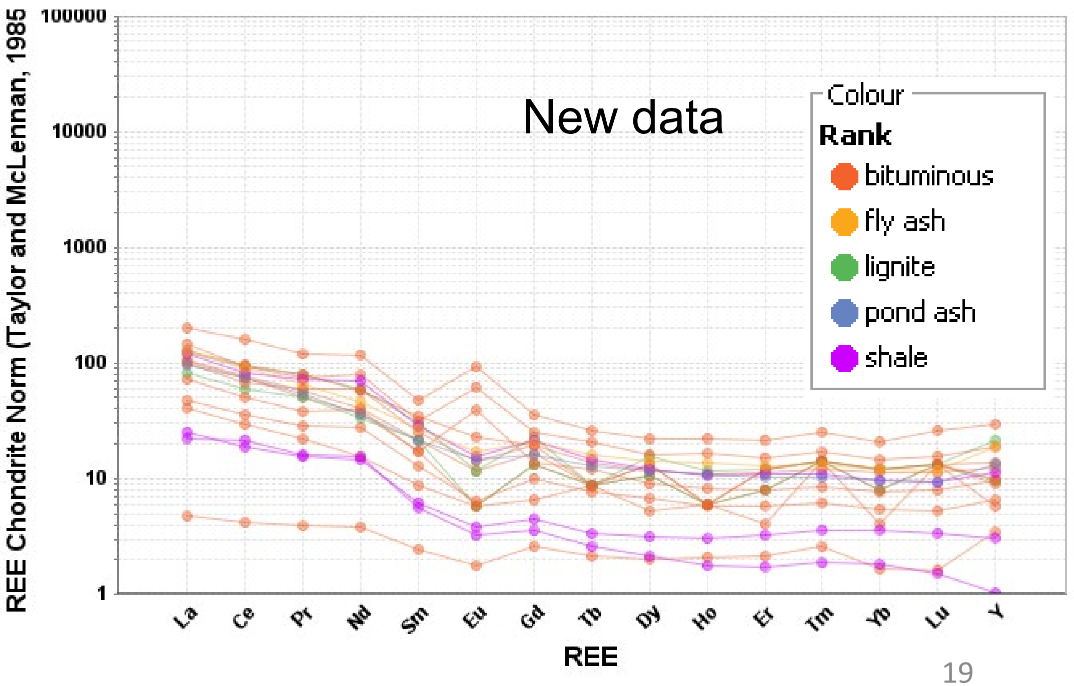


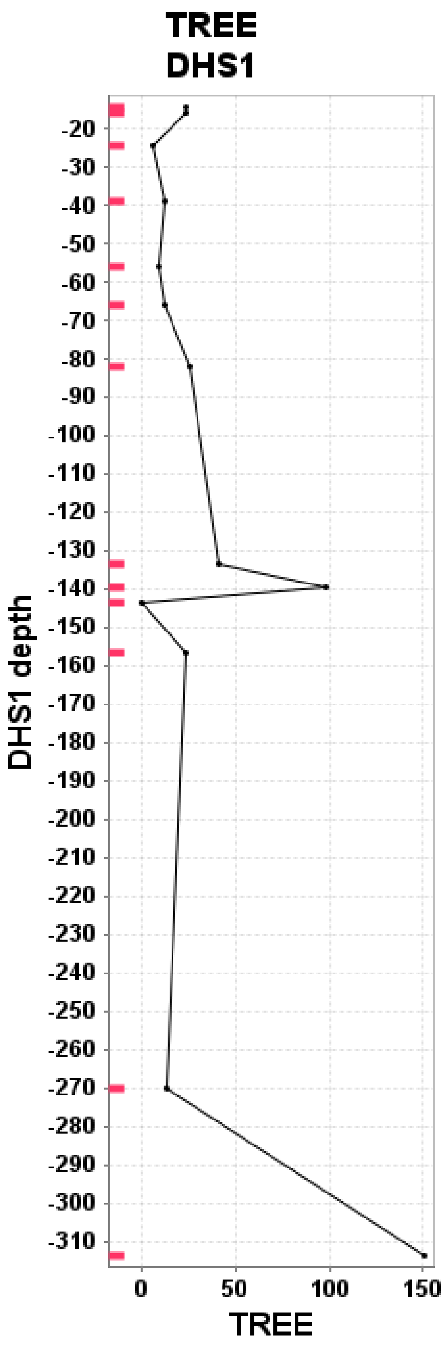




Beach-placer sandstone deposits have high concentrations of TREE, Zr, Ti, Nb (data from McLemore et al., 2016)

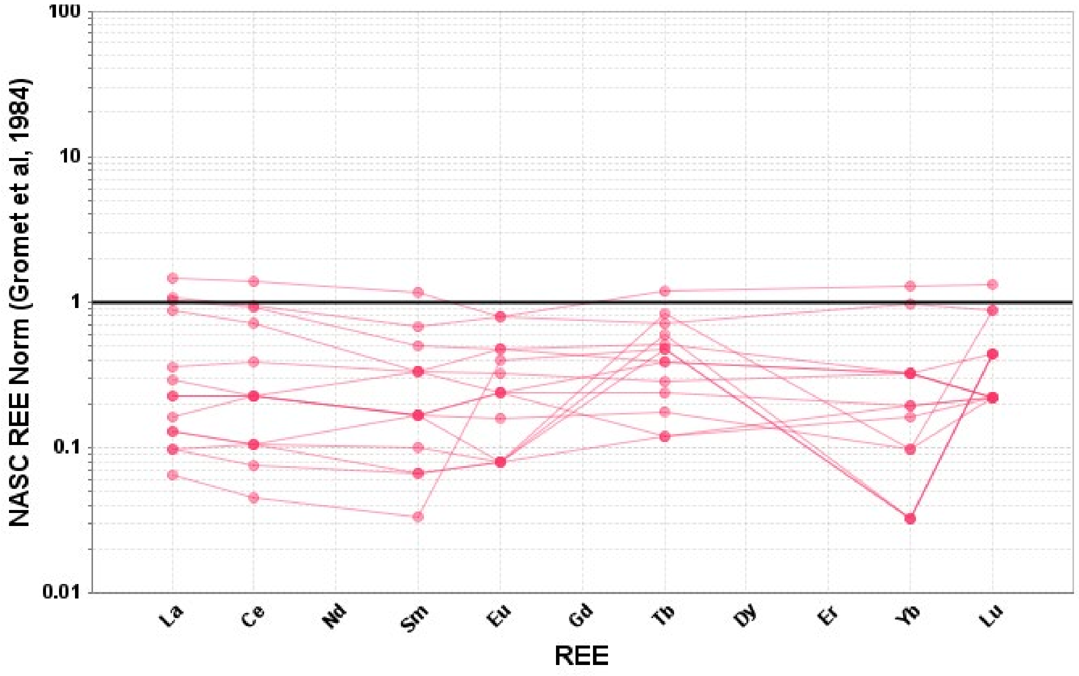
Coal/shale/ash deposits have low concentrations of TREE, Zr, Ti, Nb (UPPER RIGHT data from Affolter, 2019; Araya, 1993; Baker, 1989). BOTOM RIGHT new unpublished data; Taggart et al. 2016)
Note that coal ash samples >200 ppm TREE are significant

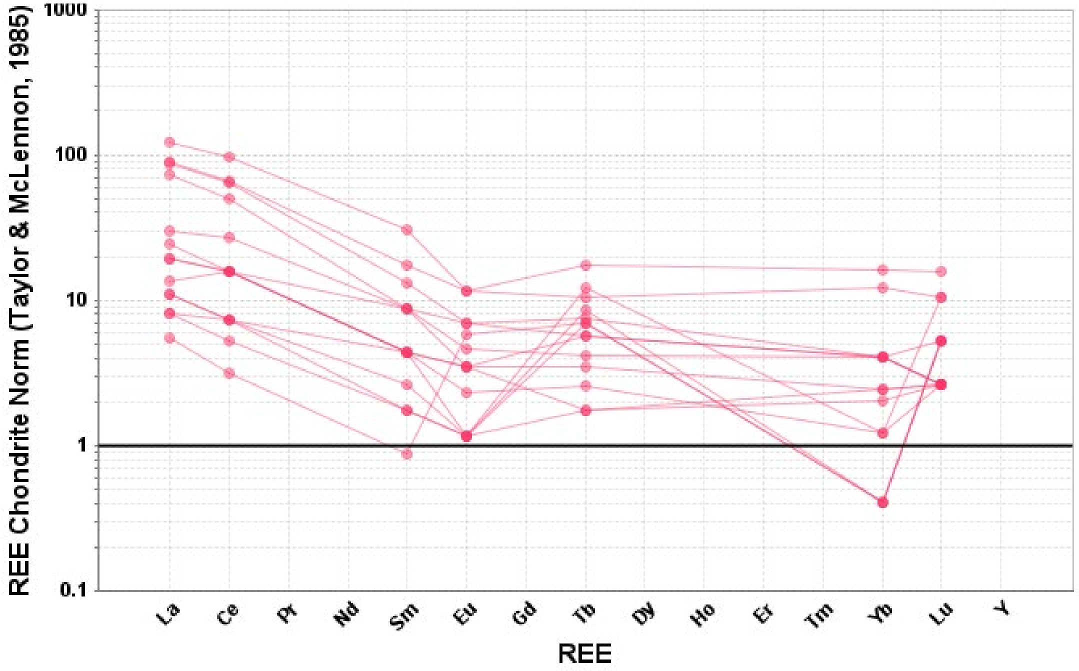


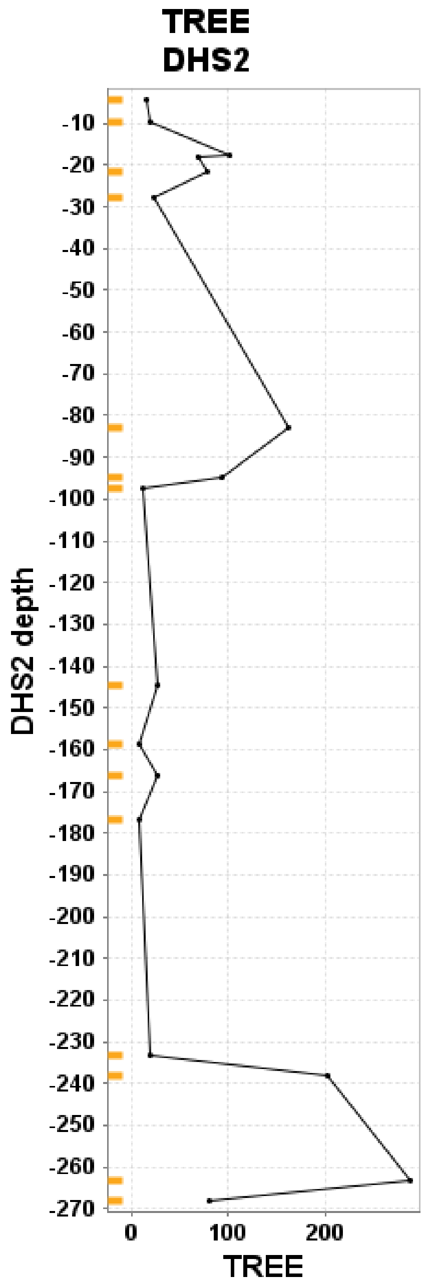


Downhole Variations

DHS1 Lee Ranch coal (Araya, 1993)

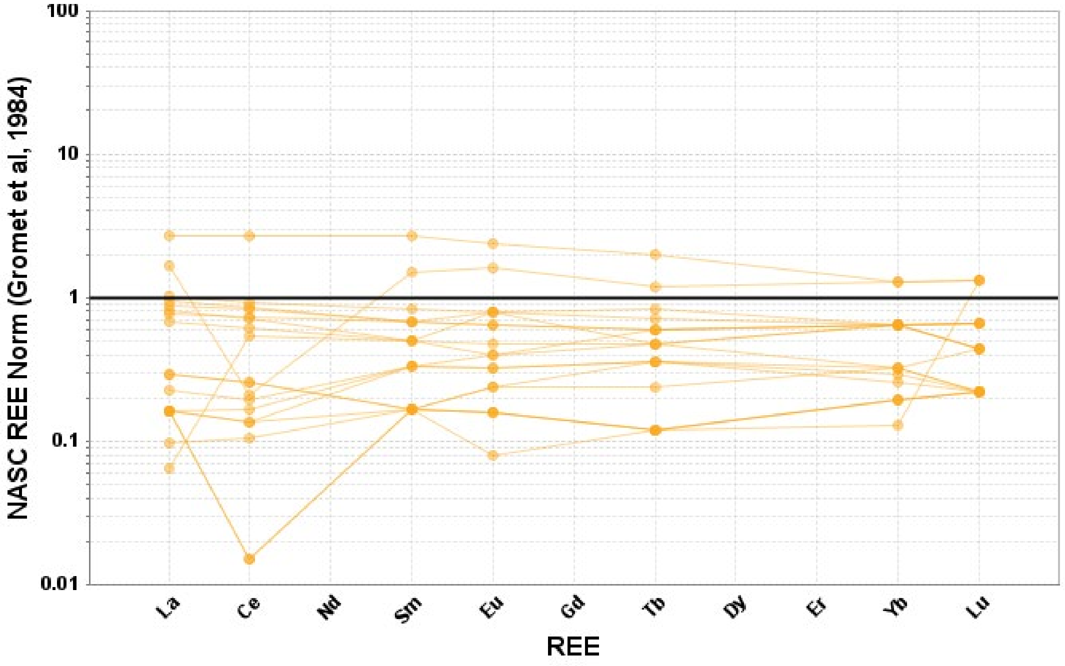


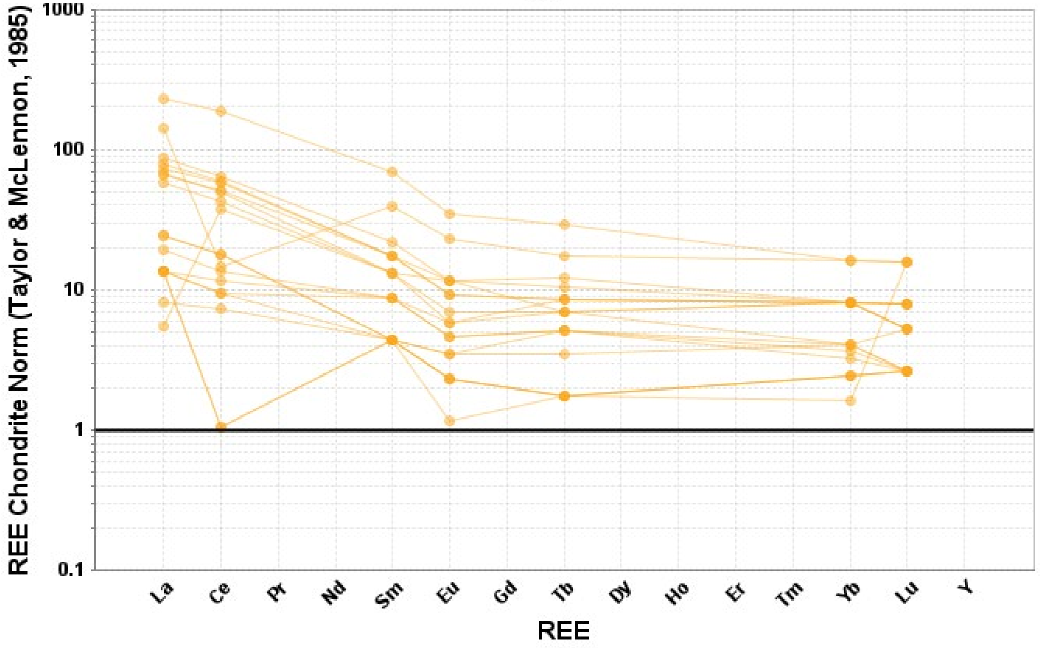


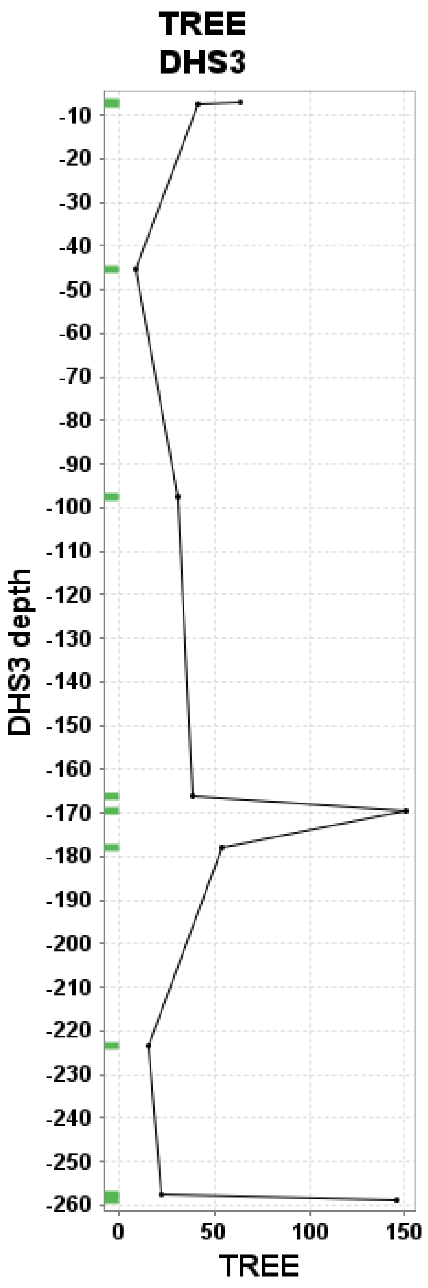


Downhole Variations

DHS2 Lee Ranch coal (Araya, 1993)

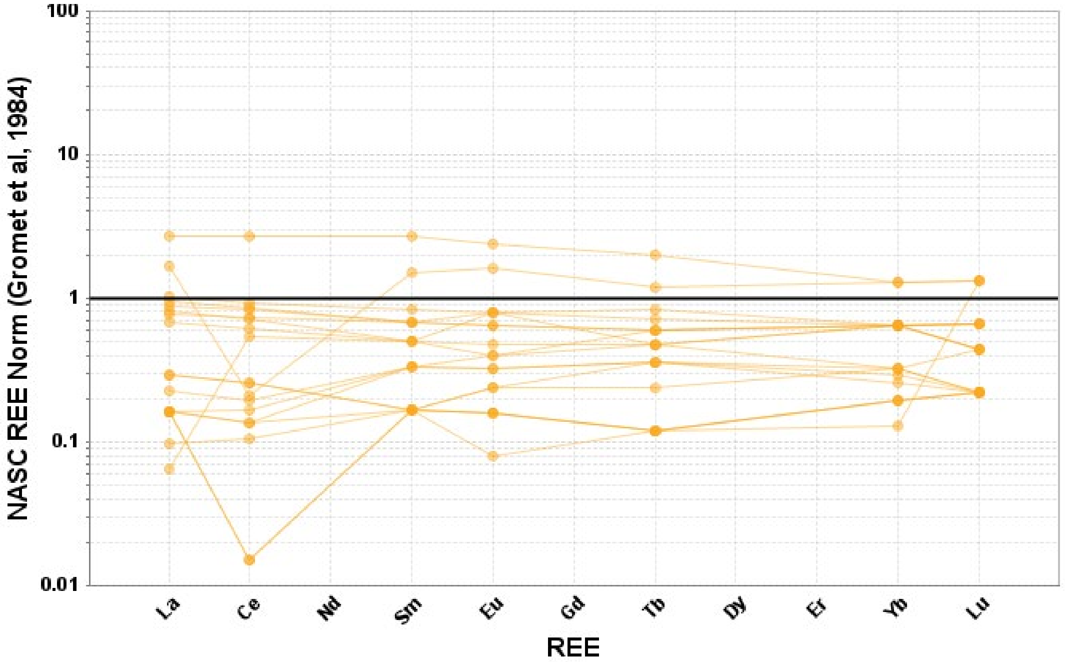


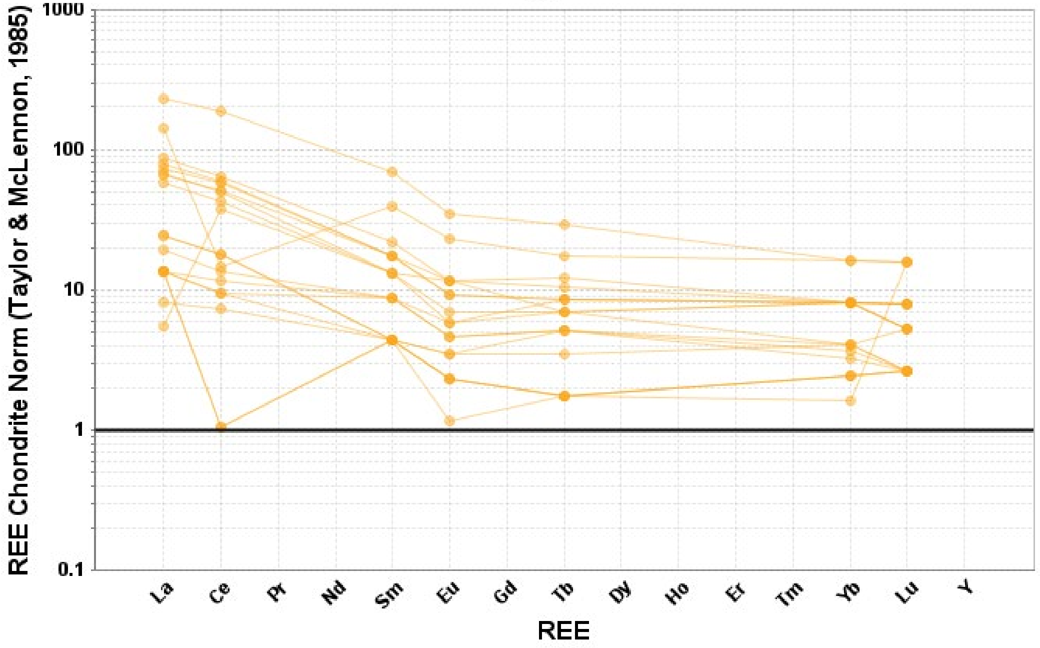


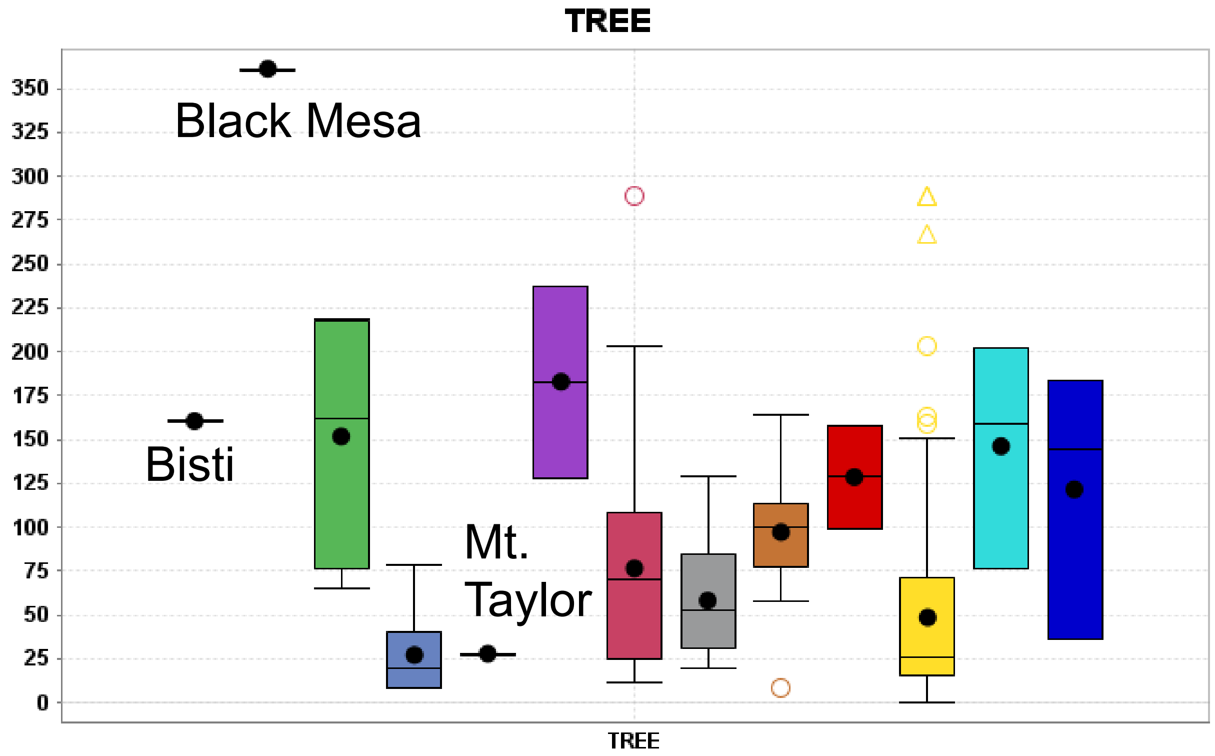


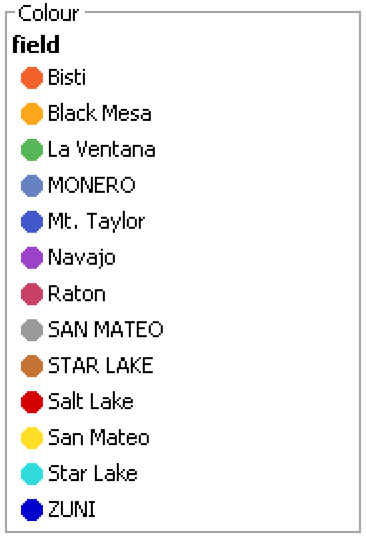
Downhole Variations

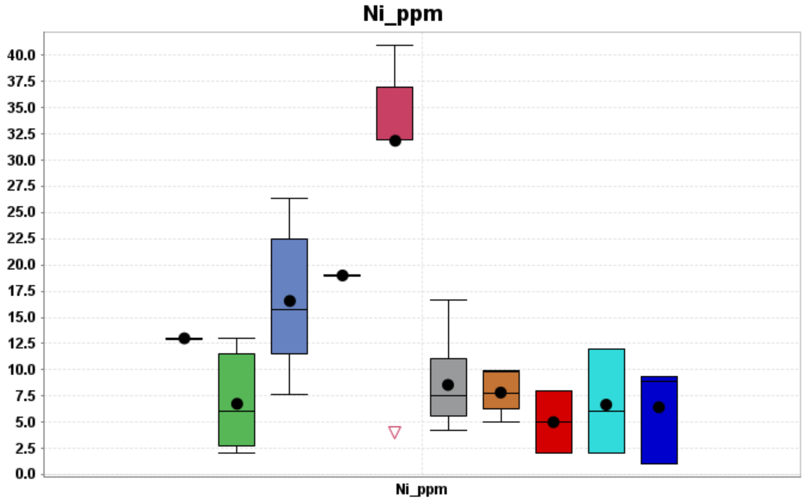
DHS3 Lee Ranch coal (Araya, 1993)

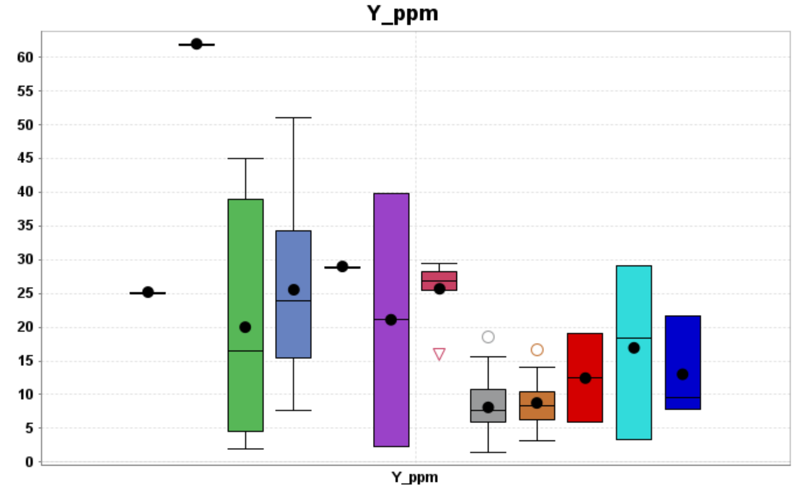


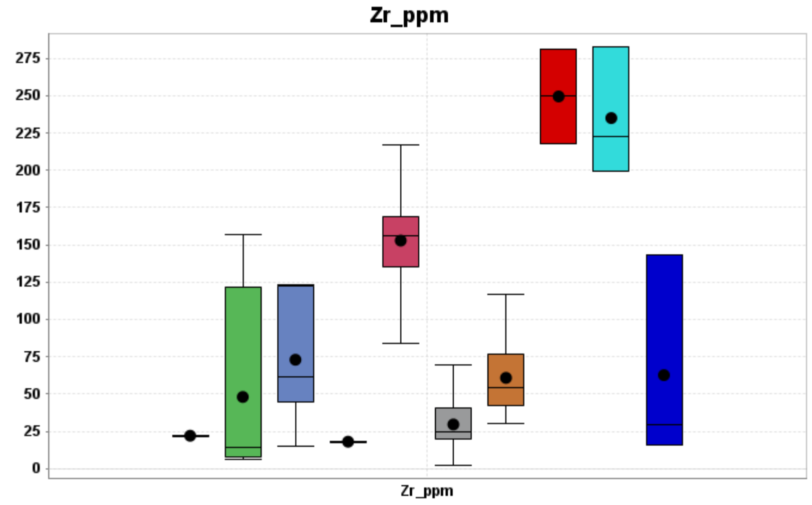


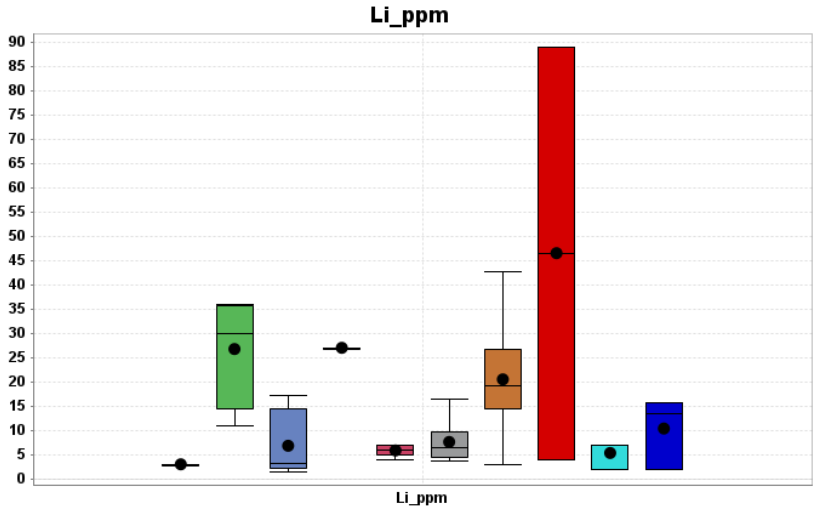






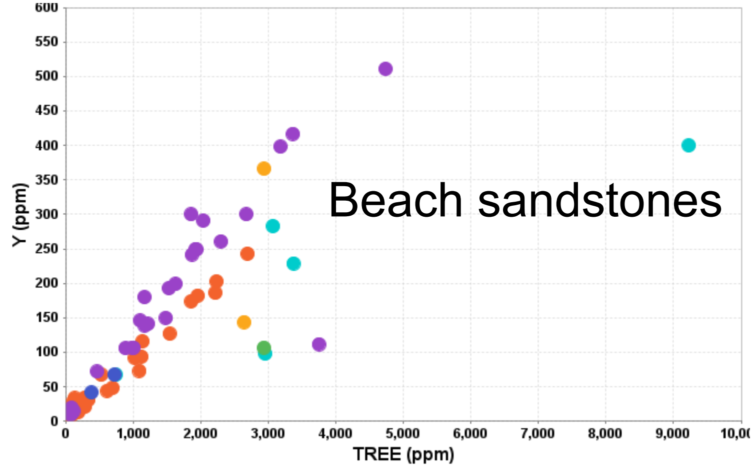


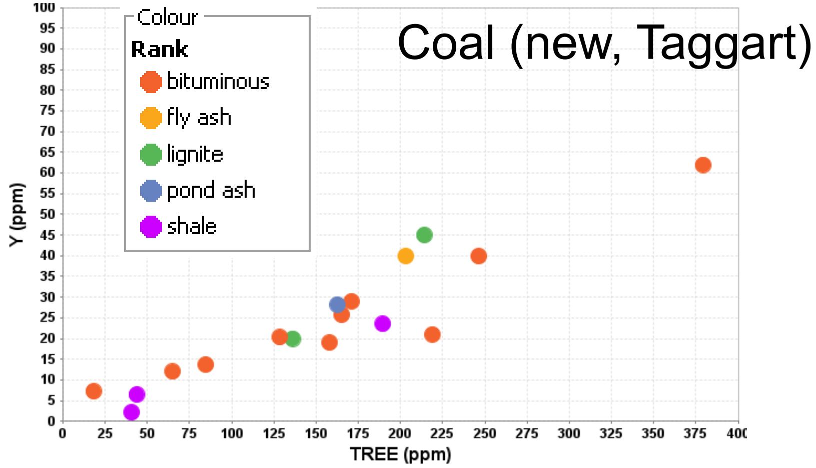


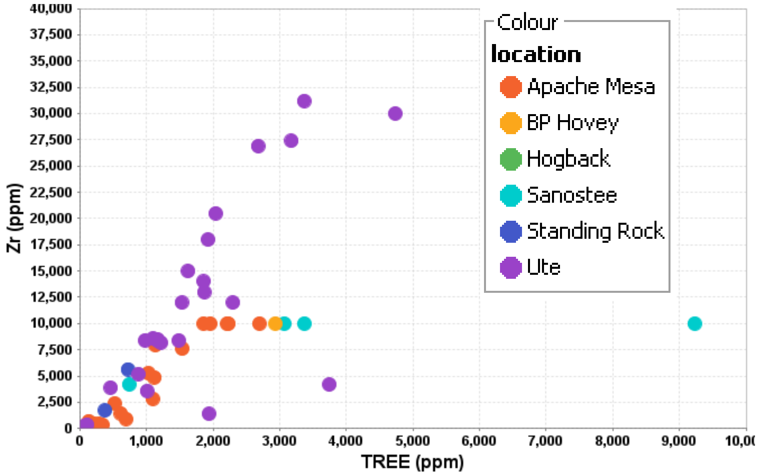


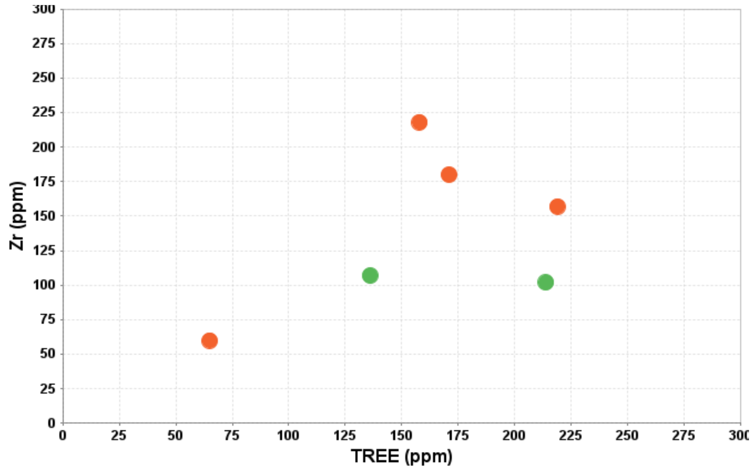
Coal legacy, new

Geochemistry of beach-placer sandstone and coal deposits

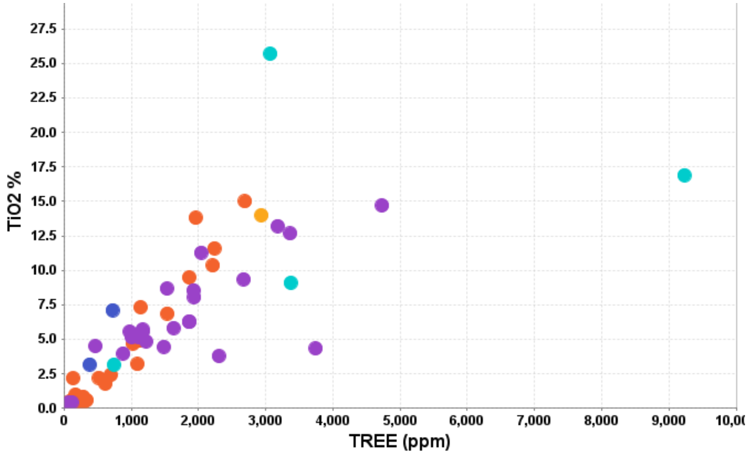


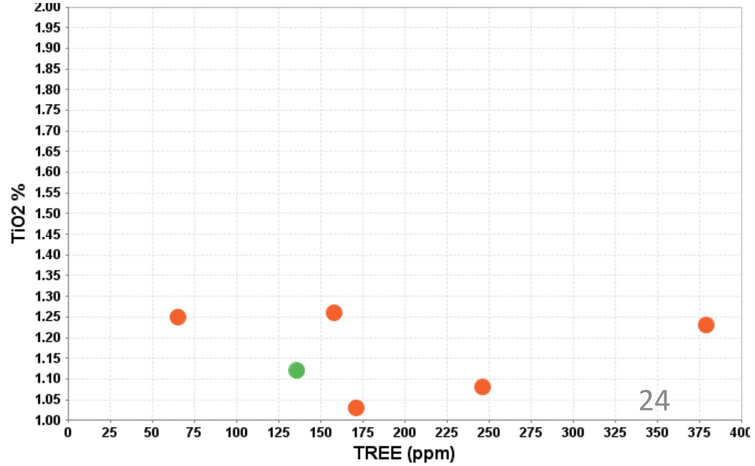






Correlation plots of TREE vs Y, Zr, and TiO2 for beach-placer sandstone deposits (LEFT; data from McLemore et al., 2016) and coal/shale/ash deposits (RIGHT, new unpublished data; Taggart et al. 2016) (note different scales)

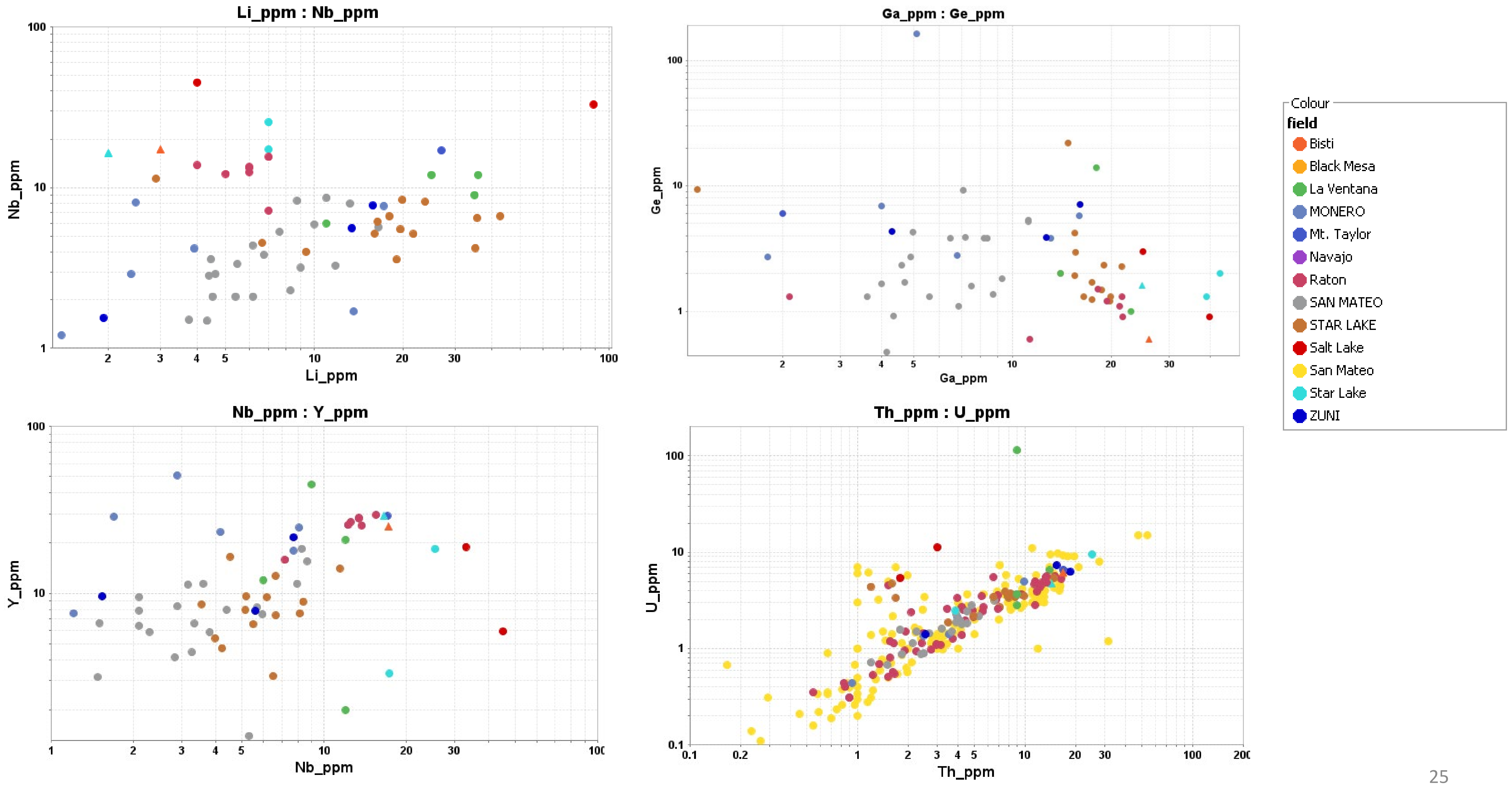




The chemical analyses indicates the predominant mineralogy for that element.

Detailed mineralogical study is underway

Other chemical analyses of San Juan, Raton coals (legacy, new data)



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 sampling and confirming interpretations
- New unpublished data is intended to provide a more consistent data set analyzed by ASTM standards
- Coal chemistry is variable within the same district and between districts

Preliminary Conclusions—continued

- Chemical analyses can be used to approximate the mineralogy of the deposit
- 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 REE and other critical minerals in San Juan and Raton basins coal deposits are low (limited data), 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

- Sample coals and other strata from coal fields with no data
- Continue to sample remaining beach-placer sandstone deposits
- Continue geochemical, mineralogical, and other characterization analyses
- Identify possible sources of REE and other critical minerals
- Evaluate the mineral-resource potential

QUESTIONS?

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