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

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

Virginia T. McLemore

New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, Socorro, NM

U.S. Department of Energy

National Energy Technology Laboratory

Resource Sustainability Project Review Meeting

October 25 - 27, 2022

Outline of today's presentation

- Importance of critical minerals, including REE
- Summarize the CORE-CM project
- Summarize the geology, geochemistry, of the Late Cretaceous coal and heavy-mineral beach placer sandstone deposits in San Juan Basin
- Stakeholder Outreach and Education
- Importance of the CORE-CM project—San Juan River-Raton Basins, New Mexico
- Challenges
- Preliminary conclusions
- Future work

ACKNOWLEDGEMENTS

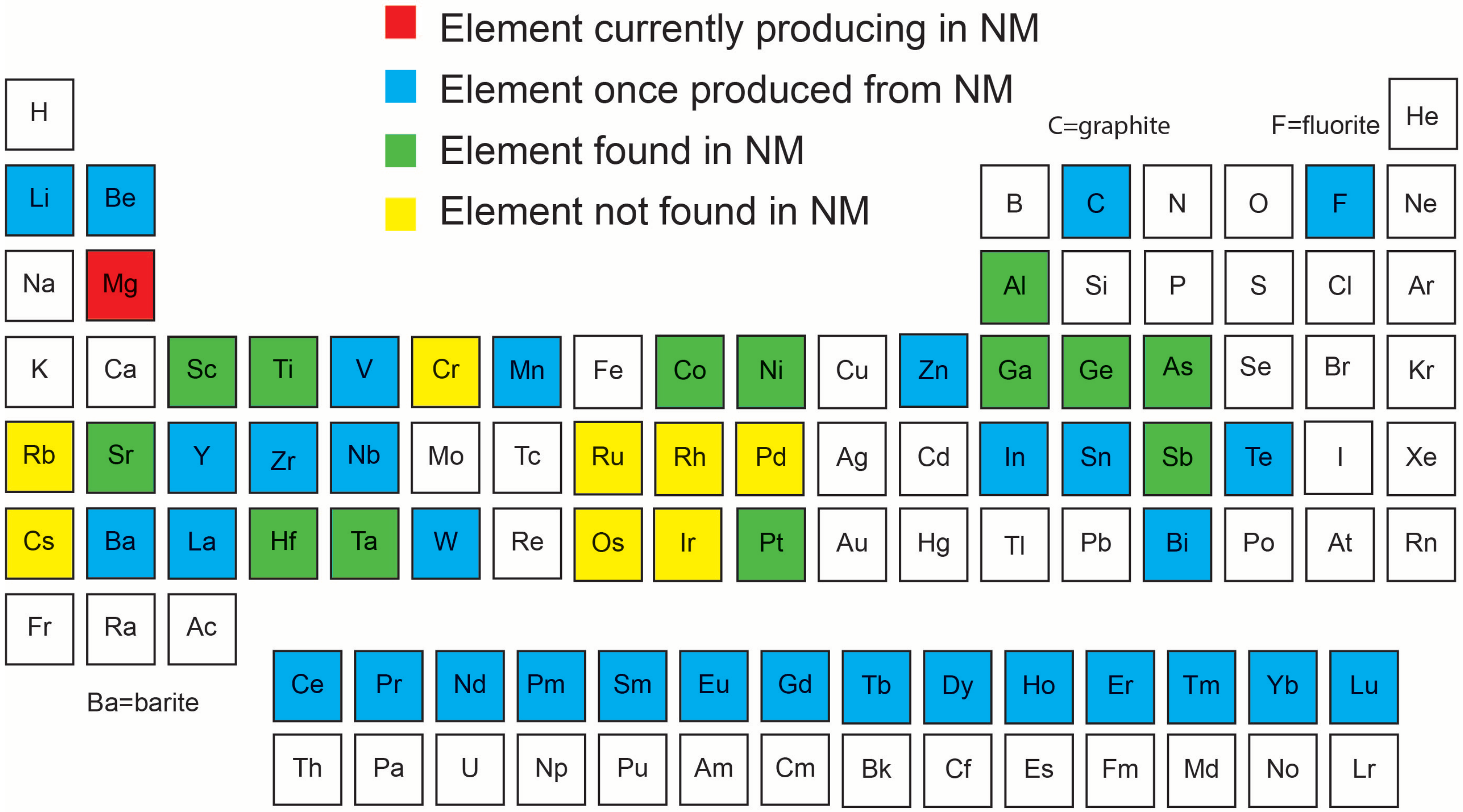
- U.S. Department of Energy, U.S. Bureau of Land Management, U.S. Army Corps of Engineers, and E. I. duPont de Nemours and Co. funded earlier investigations (1980-2010)
- Apache Mesa funded by Grant award A14AP00084 with the Jicarilla Apache Nation (2015-2016)
- U.S. Department of Energy, CORE-CM project DE-FE0032051 (2021-2023)
- Students and staff at NM Tech
- Additional partners on the DOE project

Importance of critical minerals

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



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.

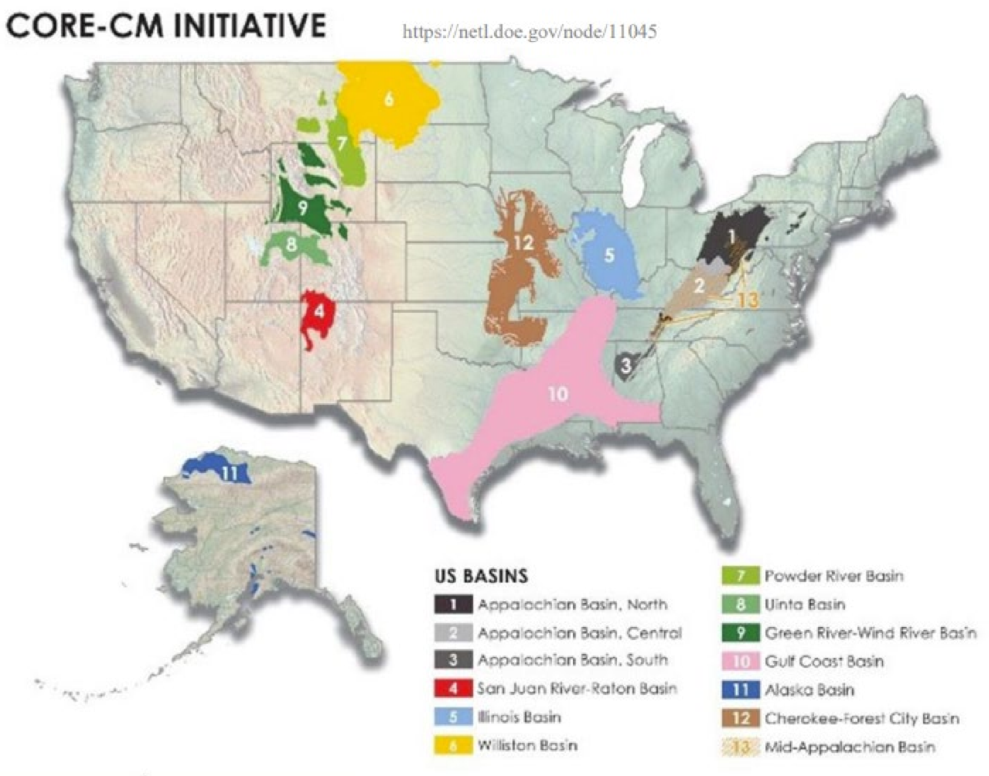
Coal in general has potential for REE, Co, Ga, Ge, Ni, Zn, and other CM

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

Summary of CORE-CM Project

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
- 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



New Mexico Bureau of Geology and Mineral Resources · New Mexico Tech · Sandia National Laboratories · Los Alamos National Laboratory · San Juan College · SonoAsh

Objectives of project

- **Basal Assessment of CORE-CM Resources**
  - **identify and quantify the distribution of REE and CM in coal beds and related stratigraphic units in the San Juan and Raton basins**
  - **identify and characterize the sources of REE and CM**
- Basinal Strategies for Reuse of Waste Streams
- Basinal Strategies for Infrastructure, Industries and Businesses
  - evaluate the basinal industry infrastructure and determine the economic viability of industrial upgrading
  - **Life cycle analysis**
- Technology Assessment, Development, and Field Testing
- Technology Innovation Center
- **Stakeholder Outreach and Education**

Tasks

- **A basinal assessment for CM and REE potential, using state-of-the-art technologies to estimate basin-wide CM and REE resources in coal and related stratigraphic units**
- **Identify, sample, and characterize coal waste stream products**
- Conduct bench tests to develop a basinal reuse of waste strategy
- Illustrate the current status of the feedstock supply of REE and CM to understand the basinal REE industry's capital expenditures and obstacles to expanding REE-related business development
- **Develop a life-cycle analysis to establish pathways, process engineering, and design requirements to upgrade REE processing industry**
- Evaluate technology gaps
- Establish a Center Of Excellence And Training Center (COE) for coal ash beneficiation at San Juan County
- **Create REE research-based activities that can be shared during the NMBGMR summer geology teacher workshop and assemble REE research-related articles for an REE-centered issue of Lite Geology**

Geology, geochemistry, of the Late Cretaceous coal and heavy-mineral beach placer sandstone deposits in San Juan Basin

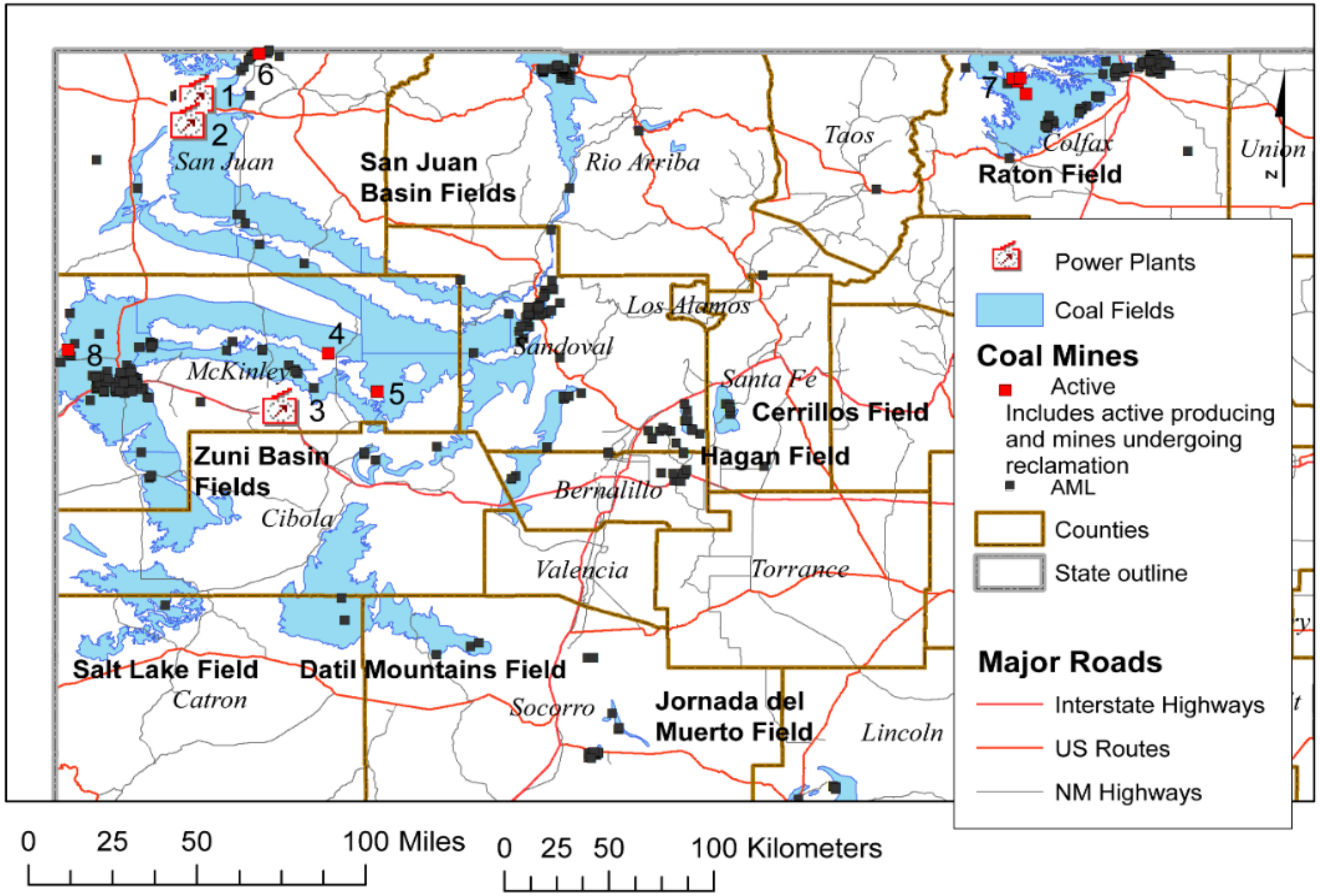
TASKS

1. A basinal assessment for CM and REE potential, using state-of-the-art technologies (such as machine learning, other mineral resource assessment methods, etc.) to estimate basin-wide CM and REE resources in coal and related stratigraphic units

2. Identify, sample, and characterize coal waste stream products

Coal in New Mexico

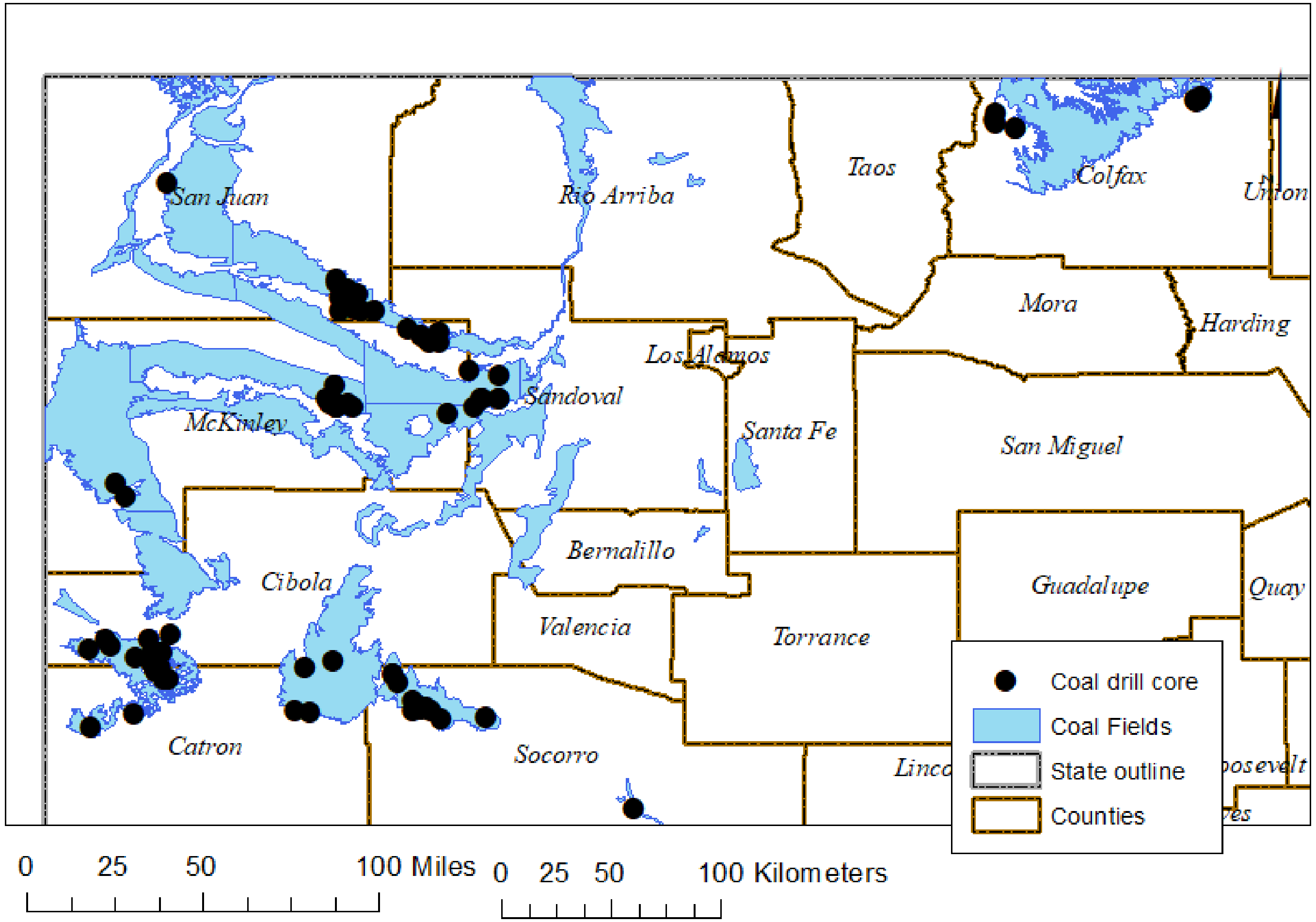
- Fuels electrical generating plants (1 in NM and fuels Arizona plants)
- 2 surface mines and 1 underground mine in San Juan Basin
  - El Segundo
  - Navajo
  - San Juan (closed end of September)
- Resources at Raton, Sierra Blanca fields
- 12th coal in production in U.S. in 2020
  - 10,249,000 short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



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)

New Mexico Coal Fields

- The coal deposits are in the San Juan and Raton Basins
- Are restricted to Late Cretaceous rocks



San Juan Basin

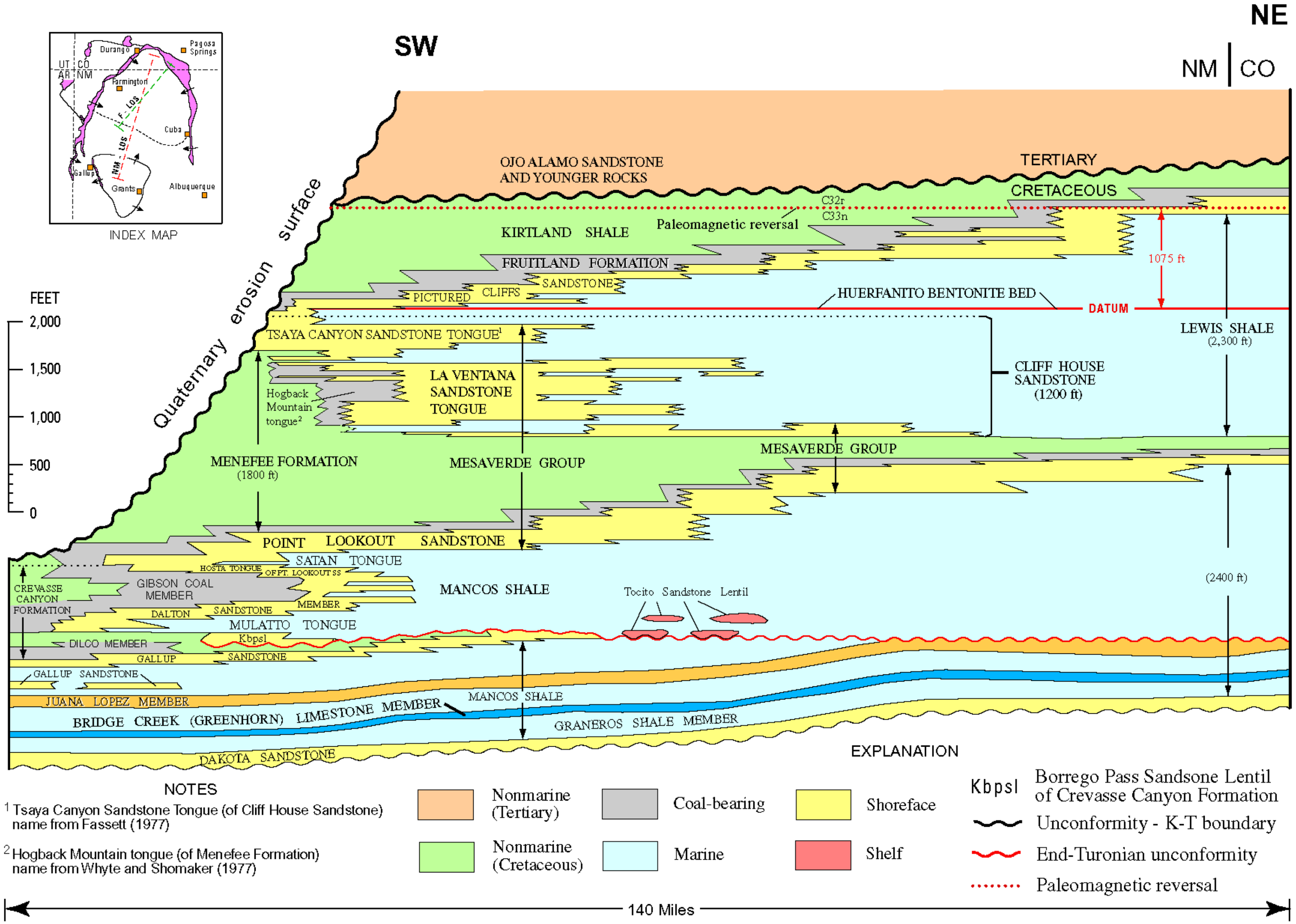
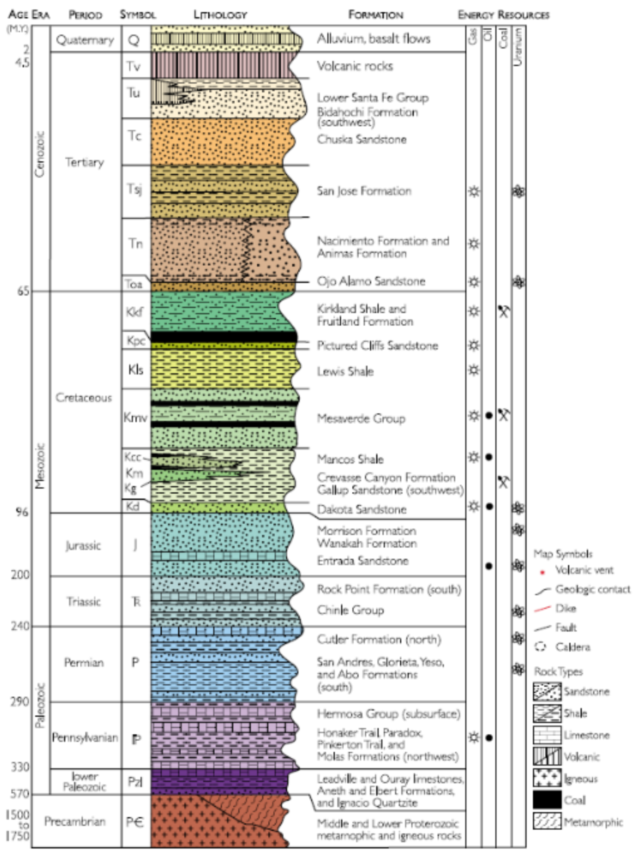


Figure 4. Stratigraphic section showing Upper Cretaceous rocks in the San Juan Basin, New Mexico and Colorado. Tocito Sandstone Lentil and coal-bearing zones are shown diagrammatically. Stratigraphy of rock units from the Point Lookout Sandstone upward is modified from Fassett (1977), stratigraphy for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

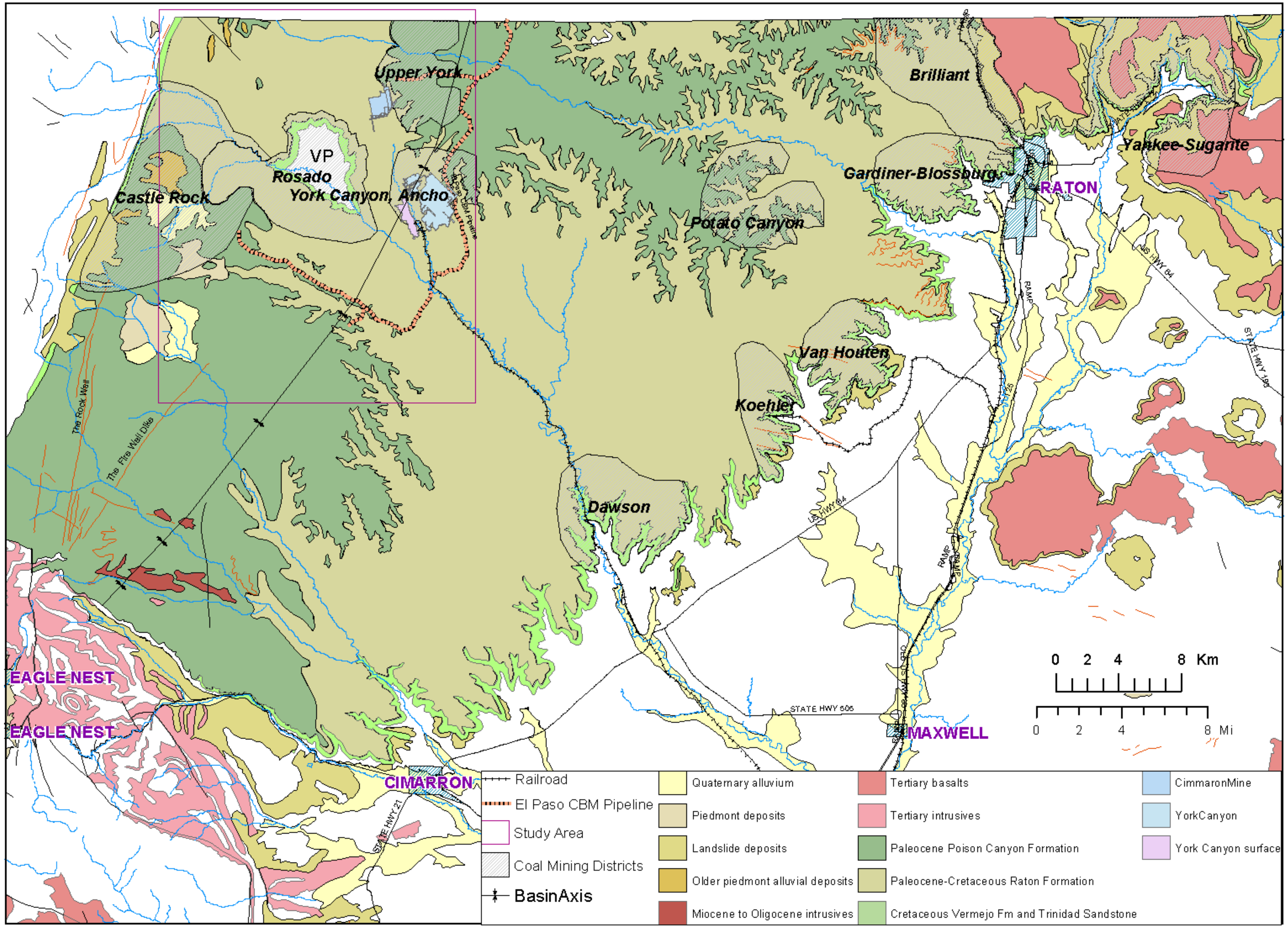
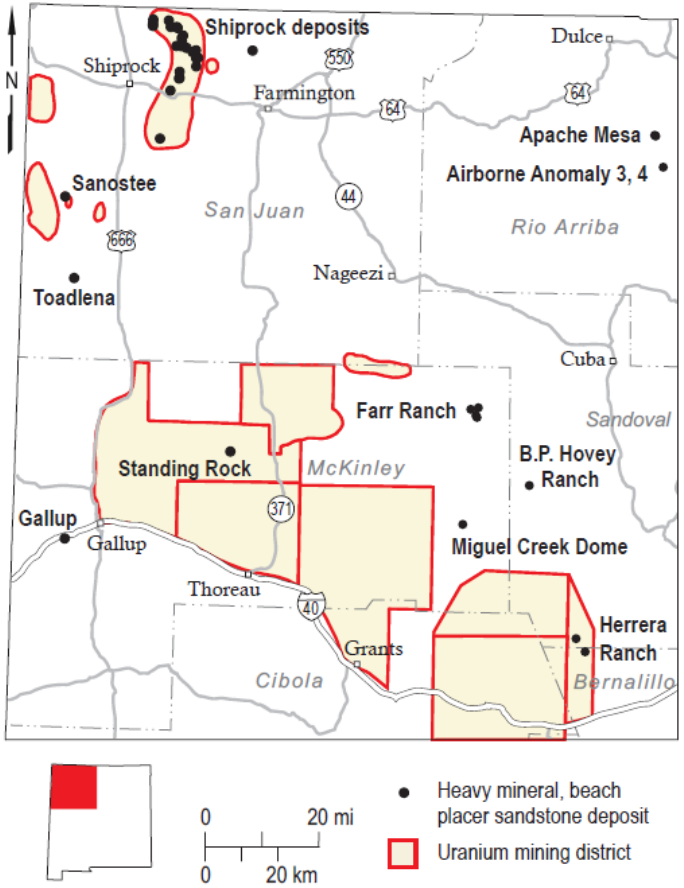


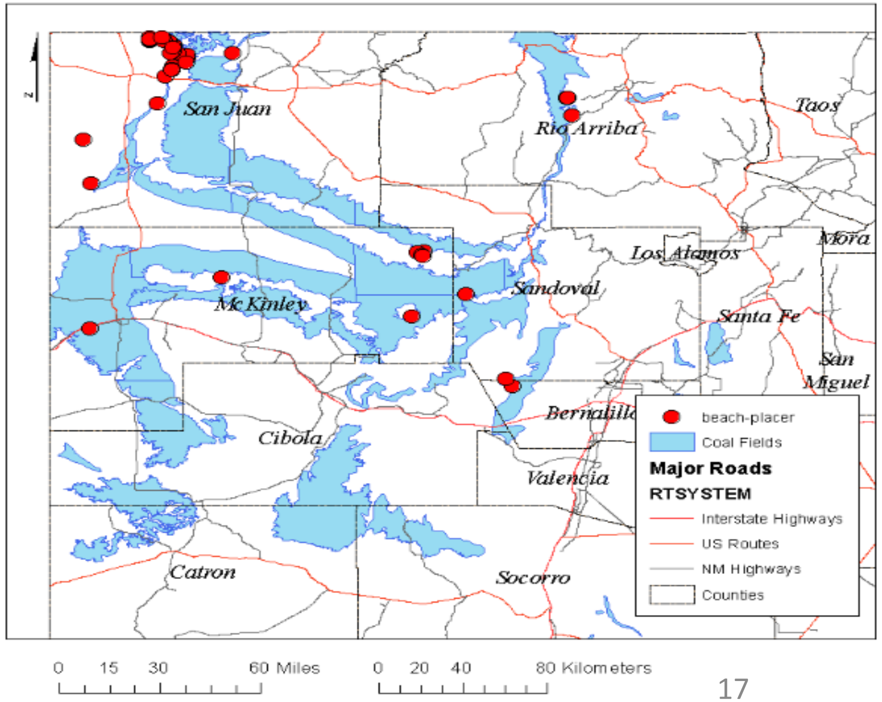
Figure 1.Generalized geologic map of Raton coalfield, New Mexico with mining districts (Pillmore, 1991) and outline of study area. Geology from New Mexico Bureau of Geology, 2003.

2

Beach-placer sandstone deposits

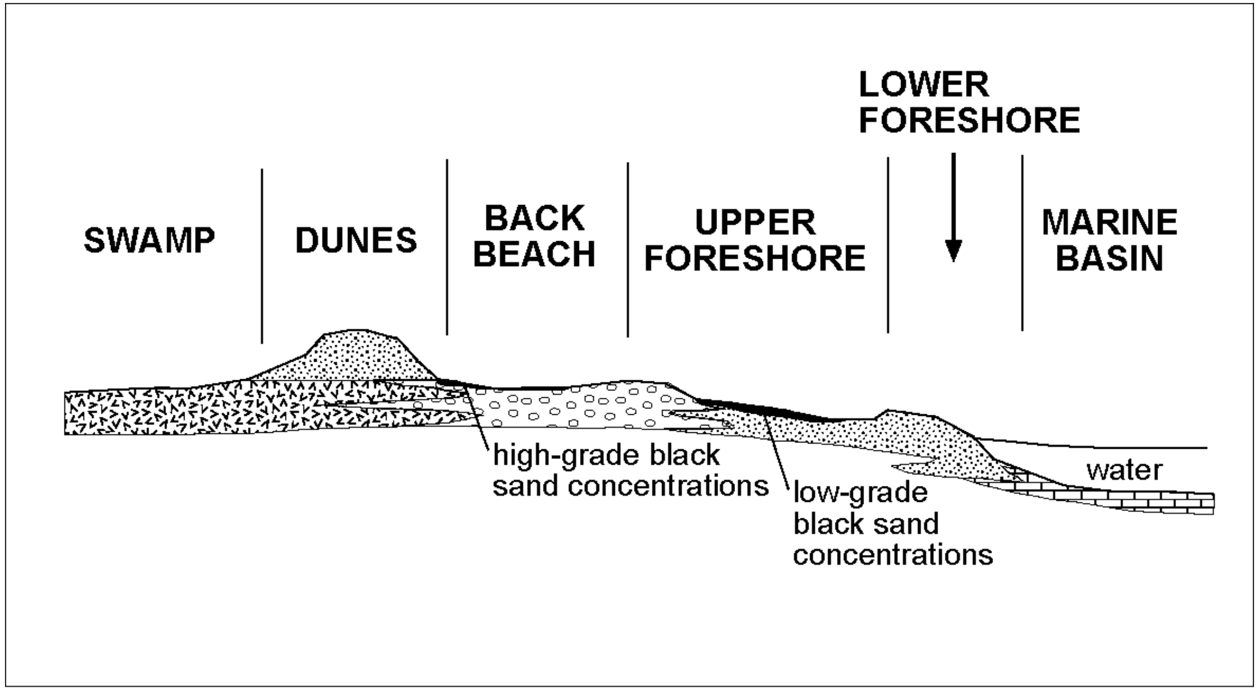
- Beach-placer sandstone deposits in the San Juan Basin are restricted to Late Cretaceous rocks and contain high REE
  - NM REE database
- Gallup, Dalton, Point Lookout, and Pictured Cliffs Sandstones
- Are in the vicinity of coal deposits





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)

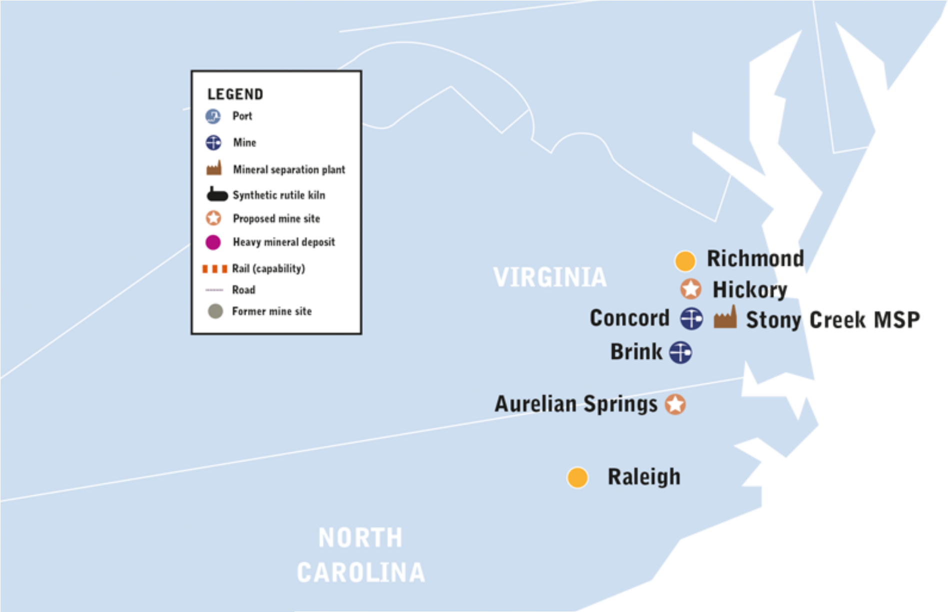
Beach-placer sandstone deposits

- 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%

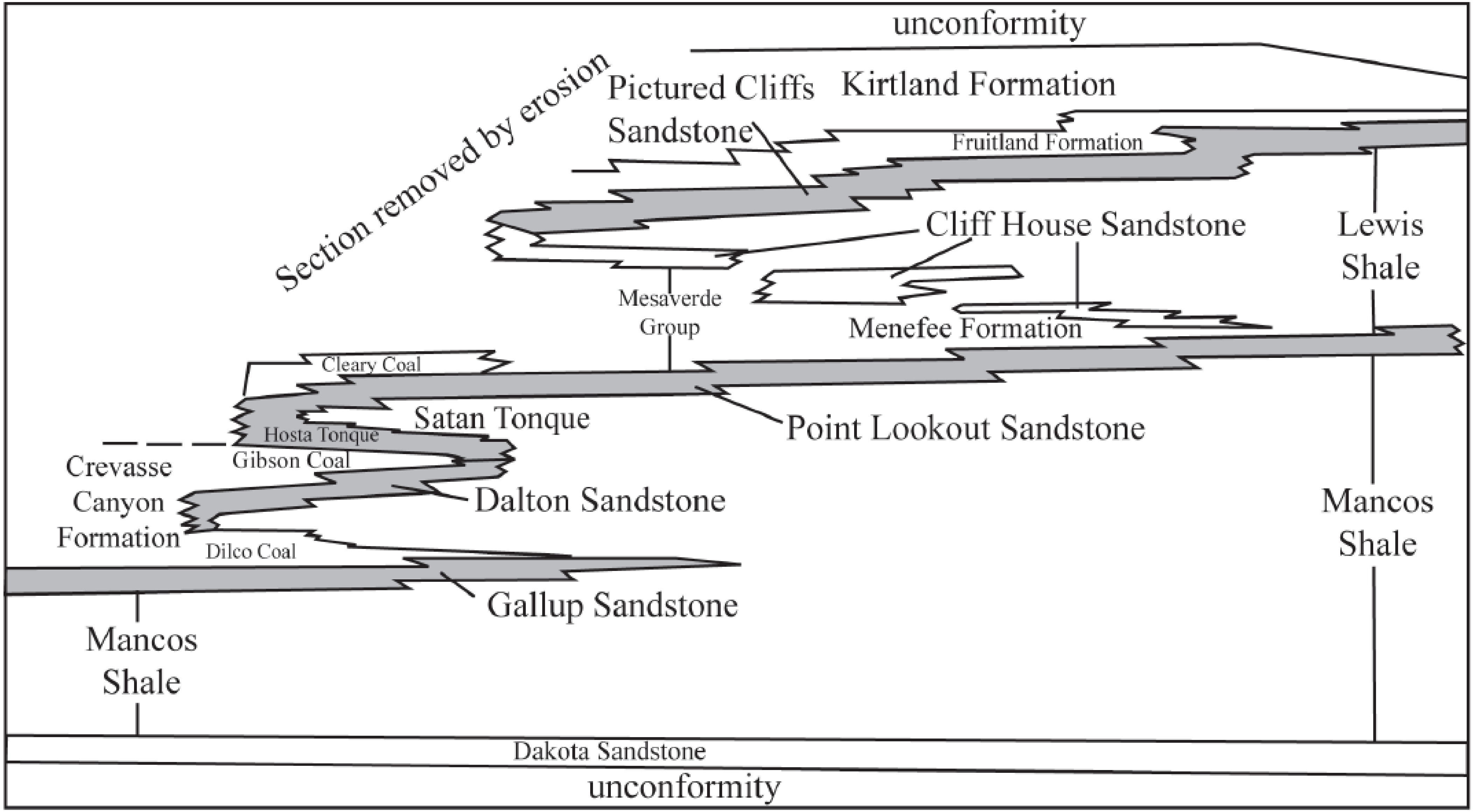
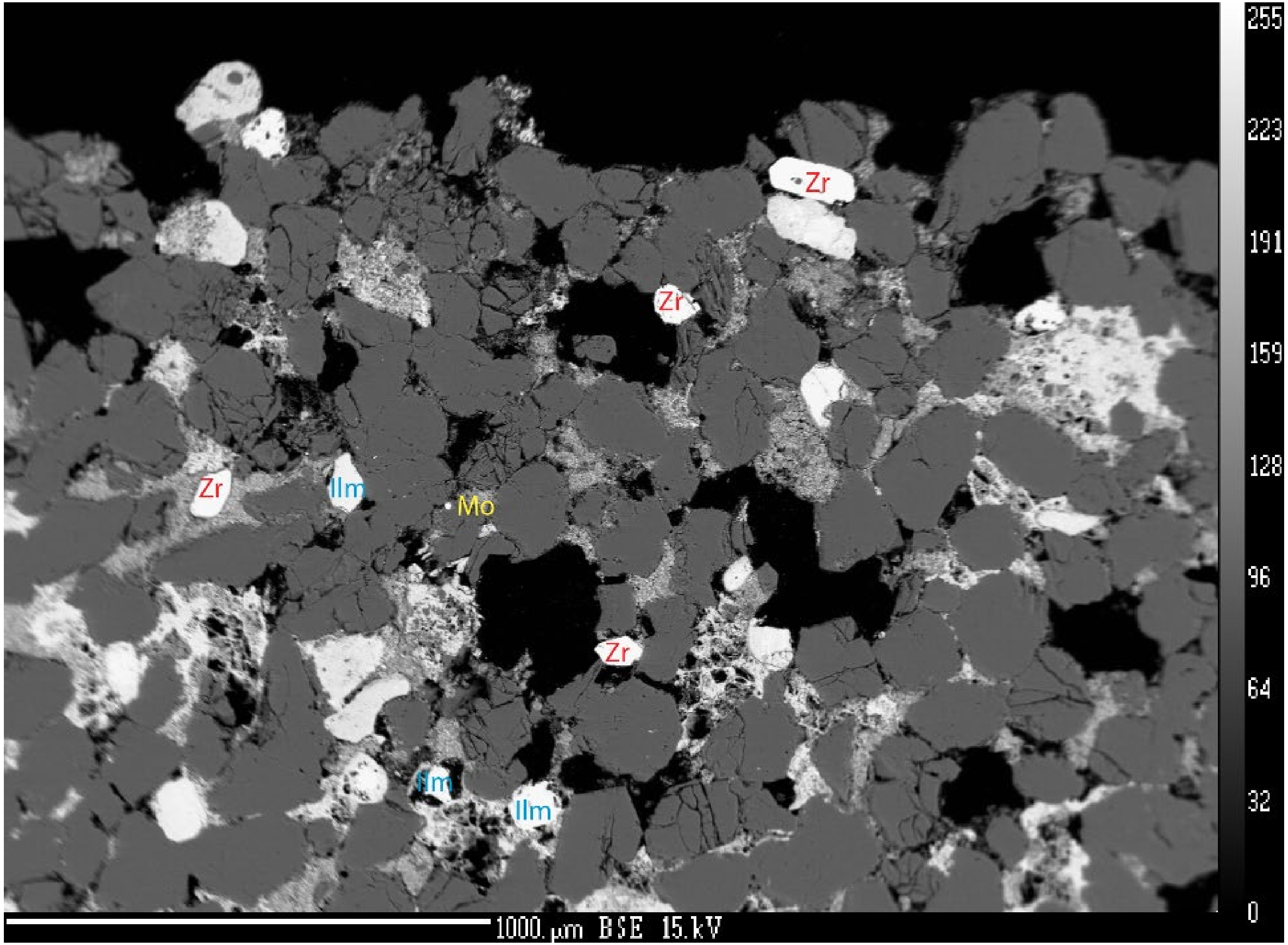


FIGURE 3. Stratigraphic framework and nomenclature of the Late Cretaceous sedimentary rocks in the San Juan Basin (simplified from Molenaar, 1989; Craigg et al., 1990). Gray-shaded sandstone units are hosts of known beach-placer sandstone deposits in the San Juan Basin.



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

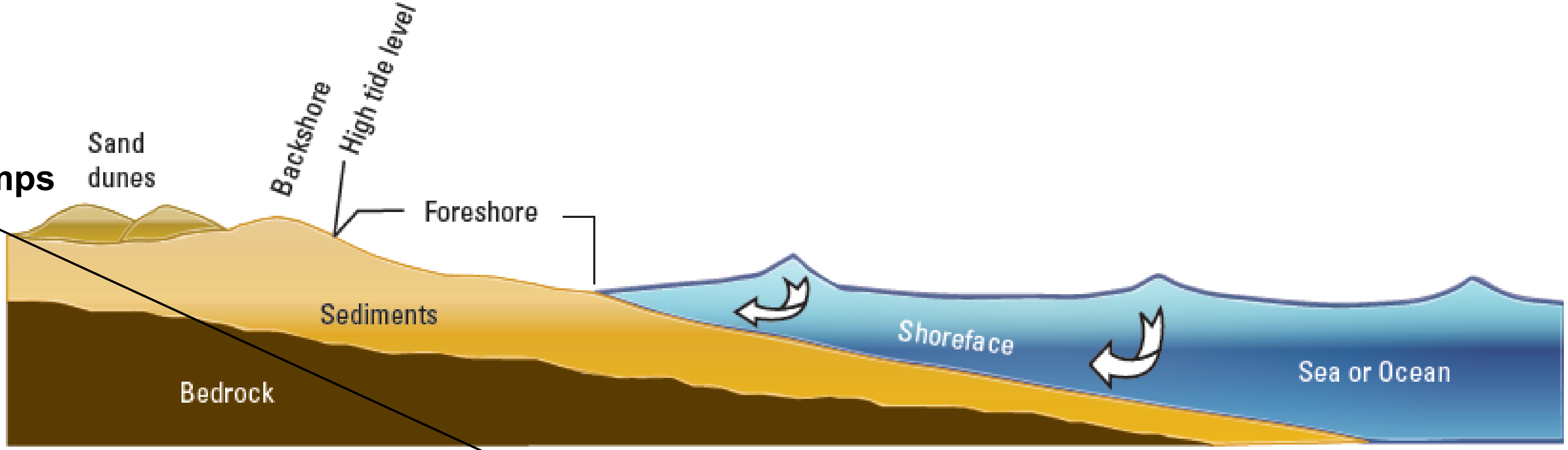
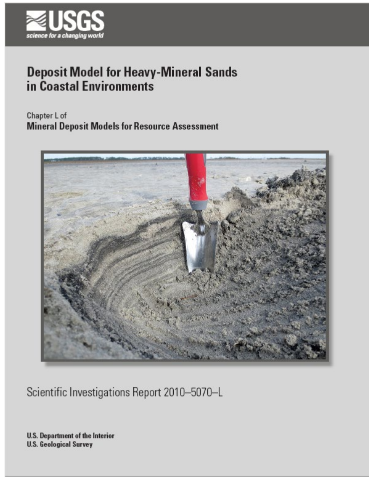


Figure 3. Features commonly used to describe shoreline (strandline) depositional environments associated with deposits of heavy-mineral sands. Not to scale.



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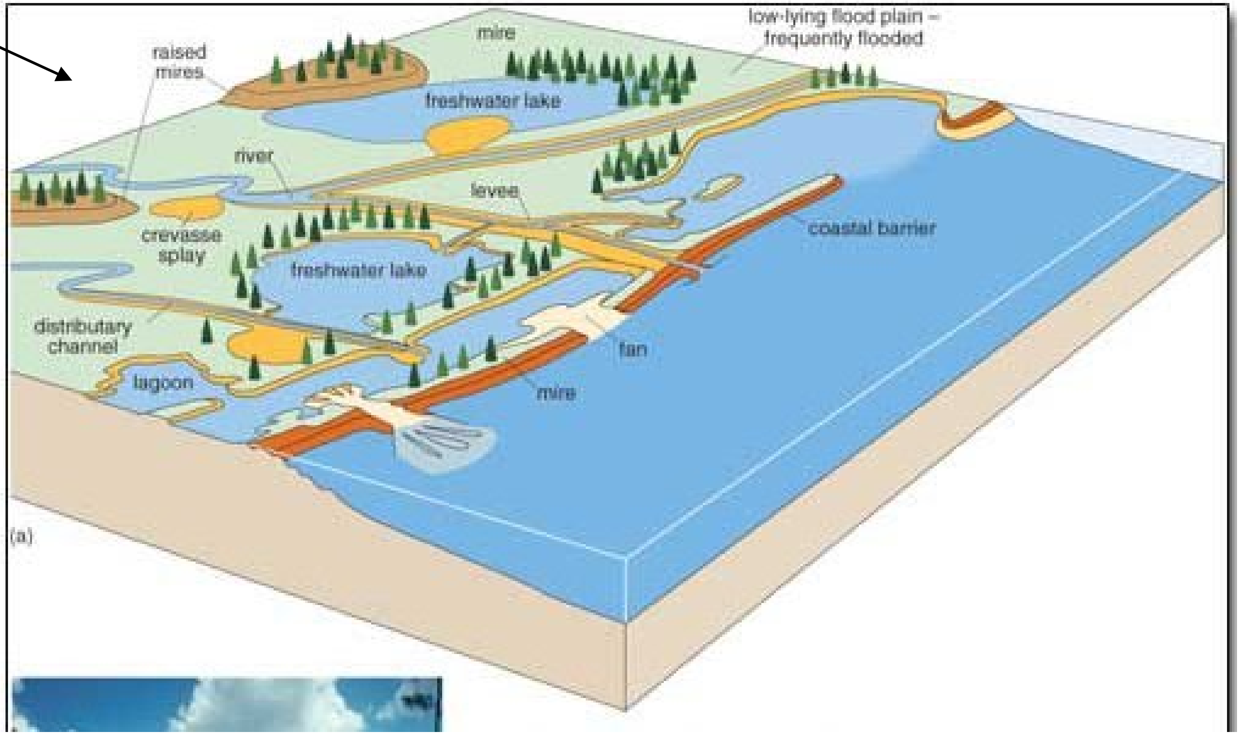
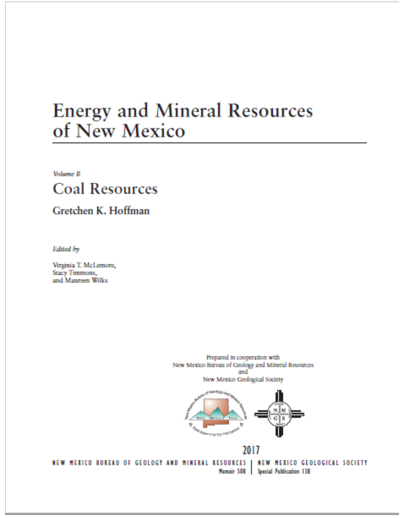
Deposit Model for Heavy-Mineral Sands in Coastal Environments

Chapter L of
Mineral Deposit Models for Resource Assessment

Scientific Investigations Report 2010–5070–L

U.S. Department of the Interior
U.S. Geological Survey





Energy and Mineral Resources of New Mexico

Volume B

Coal Resources

Gretchen K. Hoffman

Edited by

Virginia T. McLemore,
Stacy Timmons,
and Maureen Wilks

Prepared in cooperation with
New Mexico Bureau of Geology and Mineral Resources
and
New Mexico Geological Society

2017

NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES Memoir 50B | NEW MEXICO GEOLOGICAL SOCIETY Special Publication 13B

Geochemistry—Results

Selection of field sample sites

We will have 2 phases of sampling

1st sampling phase

- Obtain representative samples from all coal fields (including drill core, outcrops)
  - Identify coal seams, clay, black shale, graphite (Raton Basin)
- Available field access (accessible roads, Federal land, sites we have permission from private owners, tribes, and State Land Office)
- Field descriptions
- Radioactivity (measure of elevated REE)
- Use of LANL LIBS/RAMAN instrument

2nd sampling phase

Sample sites will be selected using machine learning techniques (LANL) to select sites to “fill in the gaps” for a complete basin assessment

Collect samples

- Outcrops of coal seams
- Stratigraphic units above and below coals (tonsteins, clays, black shales, beach-placer sandstone deposits)

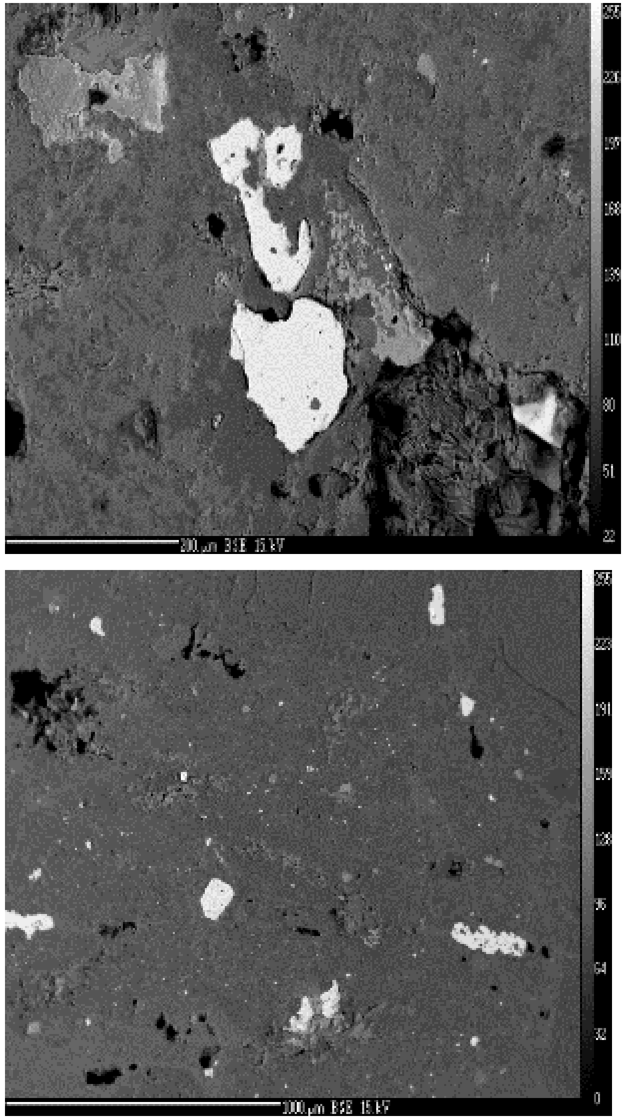
- Drill core of coal deposits (log, photograph, sample core for mineralogical and chemical characterization)

- Coal wastes from active, reclamation, and AML sites
  - Fly ash, bottom ash
  - Waste rock piles (dumps)
  - AMD (acid mine drainage)?
  - Processing waters?

Identify, sample, and characterize coal waste stream products

- Continue to add to the New Mexico Mines Database with additional locations and information of missing inactive coal mines (AML)
- Selected AML sites have been sampled
- Ash from San Juan Generating Plant has been collected
- Characterize the samples
- Interpret data

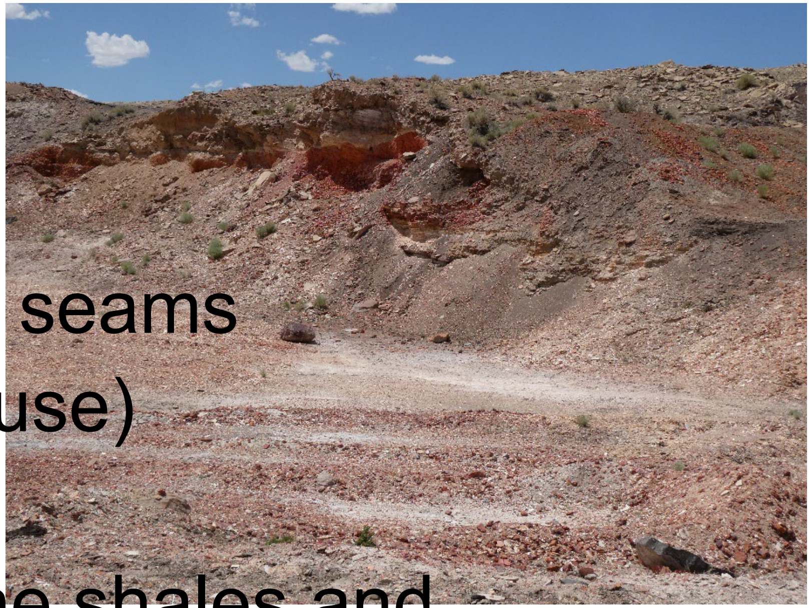
2 mm



Backscattered electron images of pyrite

Other related strata to be analyzed

- Clay beds (above and below coal seams)
- Clinker deposits (burnt coal layers)
- Volcanic ash beds within and adjacent to coal seams
- Humate deposits (top of coal beds, industrial use)
- Black shales
- Igneous rocks (dikes, sills) adjacent/near to the shales and coals
- Uranium deposits (Jurassic age)
- Popotosa Formation (known to contain lithium in clays)
- Produced waters????

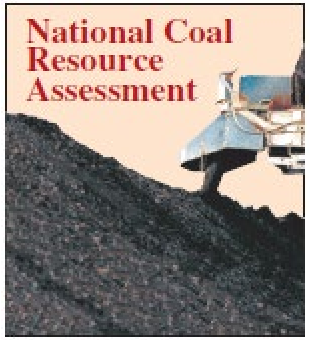


Geochemistry results

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

Compile existing data



USGS PP1625B

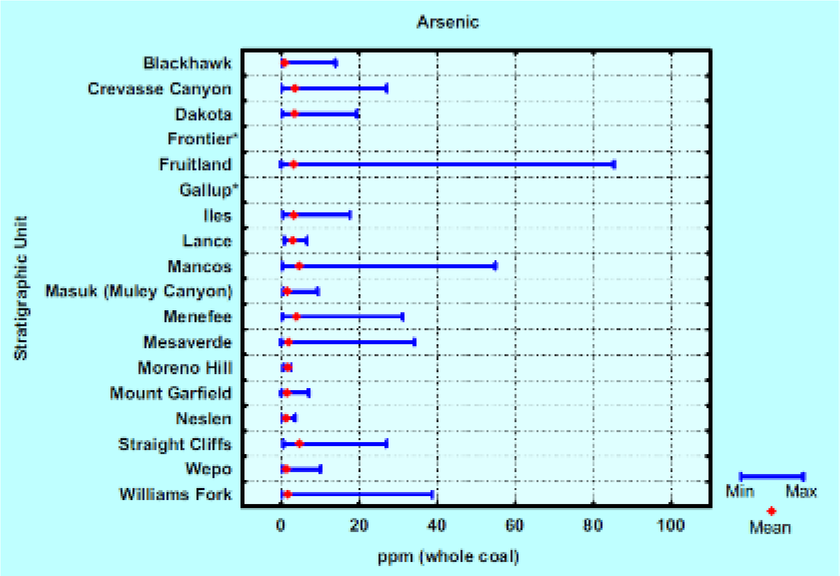


Figure A7-15. Minimum, maximum, and mean content of arsenic for coal from all stratigraphic units in the Colorado Plateau coal assessment area (* indicates insufficient data).

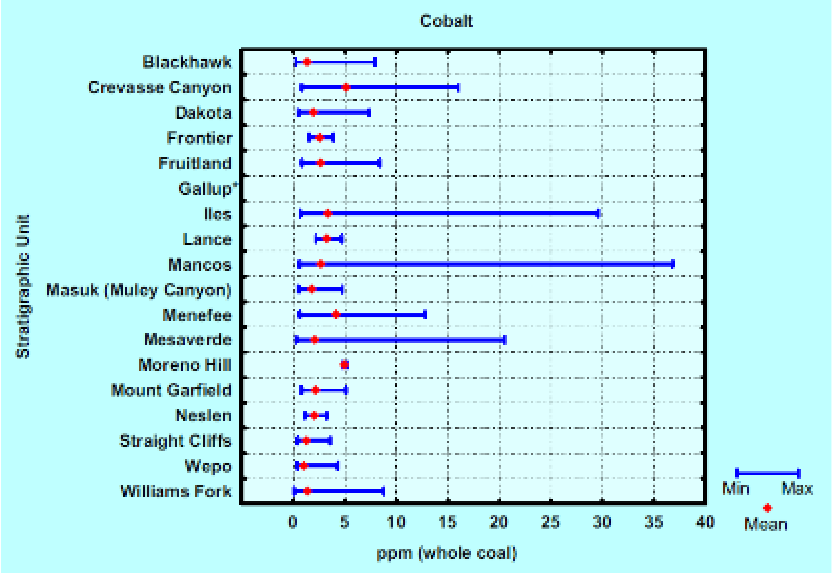


Figure A7-19. Minimum, maximum, and mean content of cobalt for coal from all stratigraphic units in the Colorado Plateau coal assessment area.

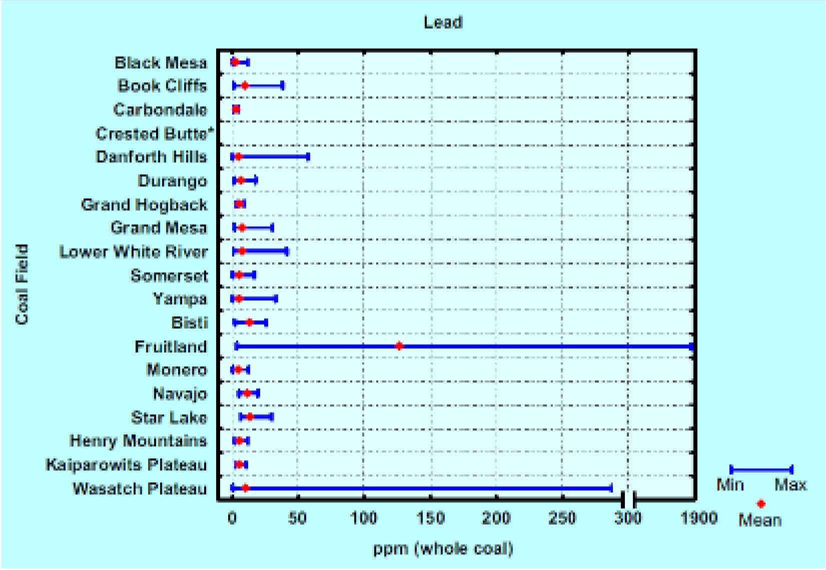


Figure A7-8. Minimum, maximum, and mean content of lead for coal from high-priority coal fields in the Colorado Plateau coal assessment area (* indicates insufficient data).

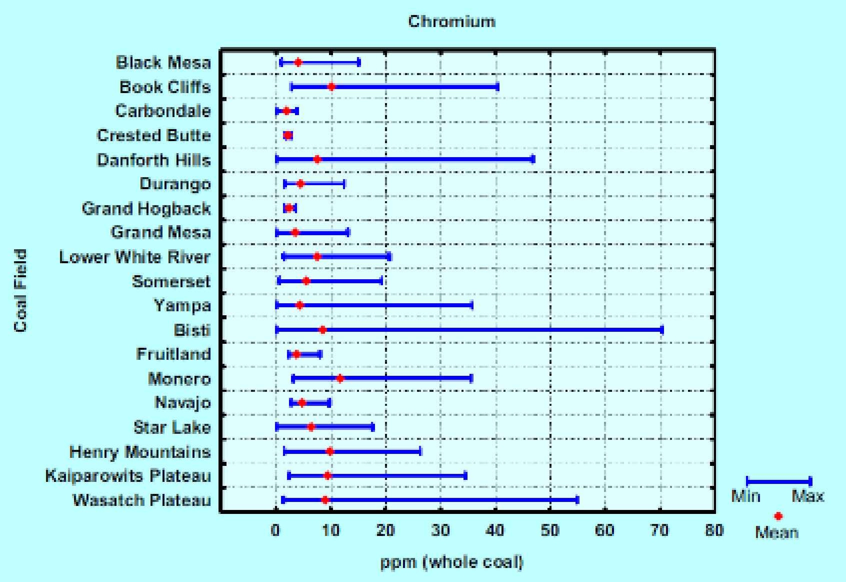


Figure A7-5. Minimum, maximum, and mean content of chromium for coal from high-priority coal fields in the Colorado Plateau coal assessment area.

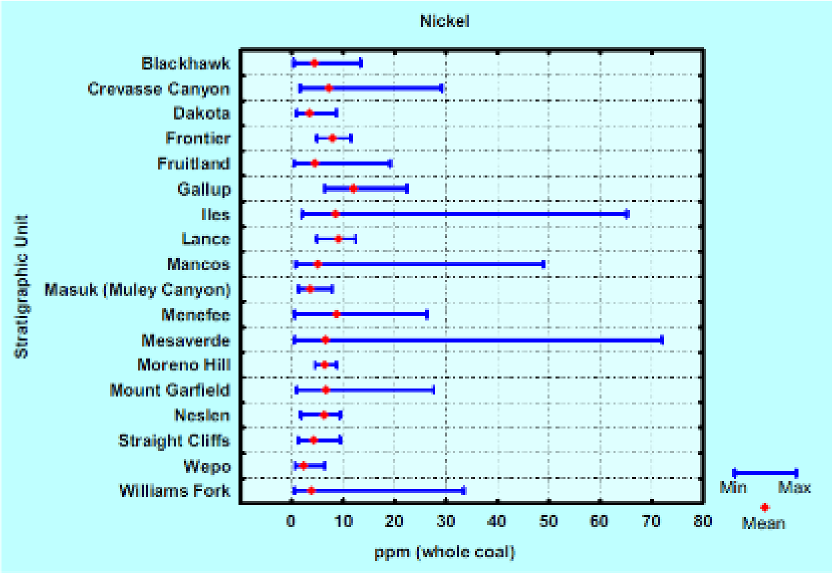
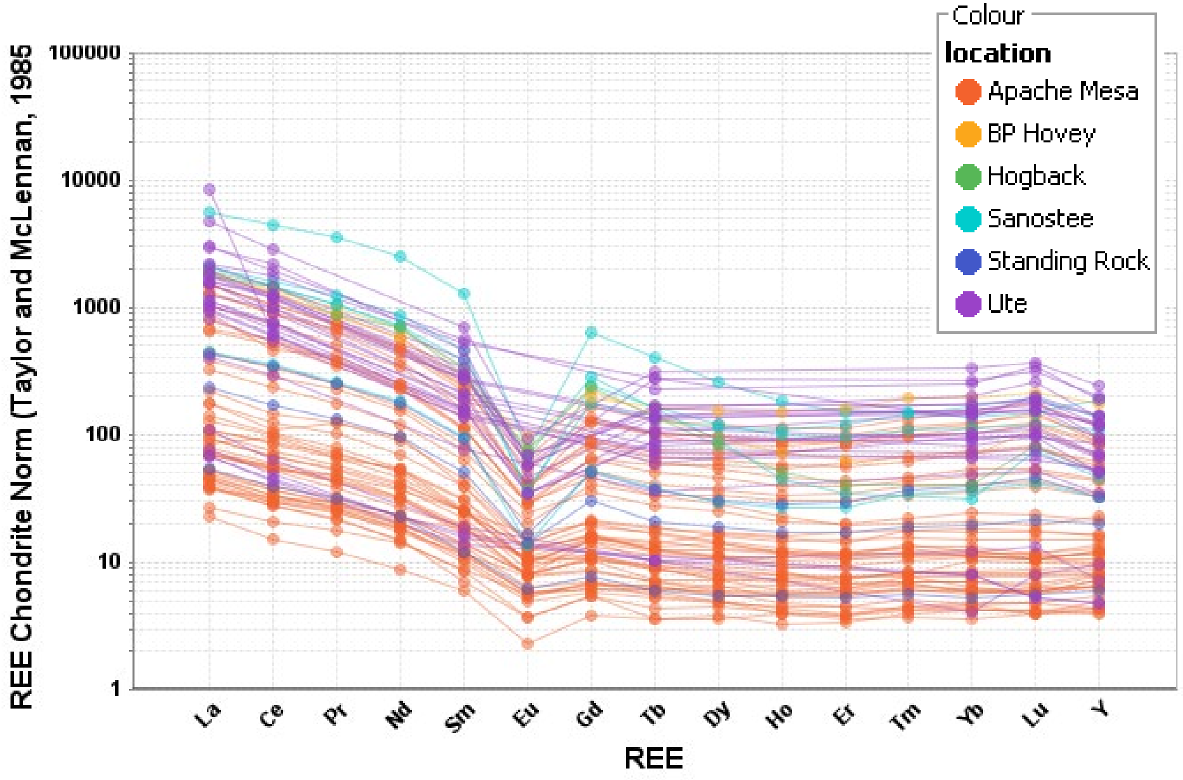
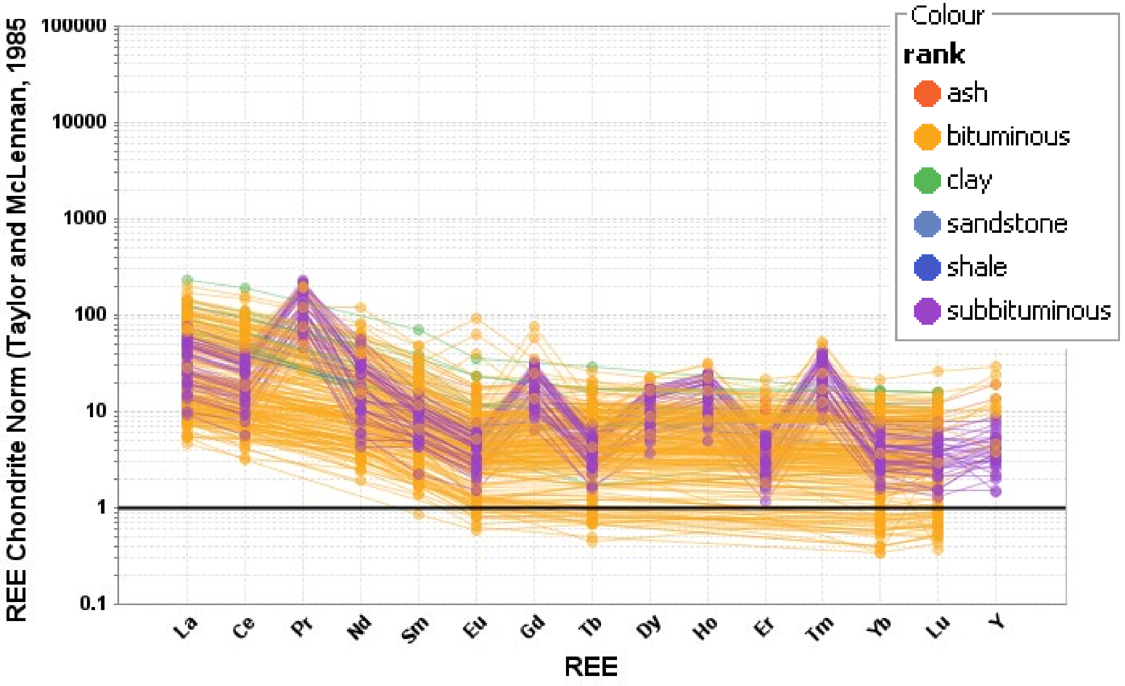


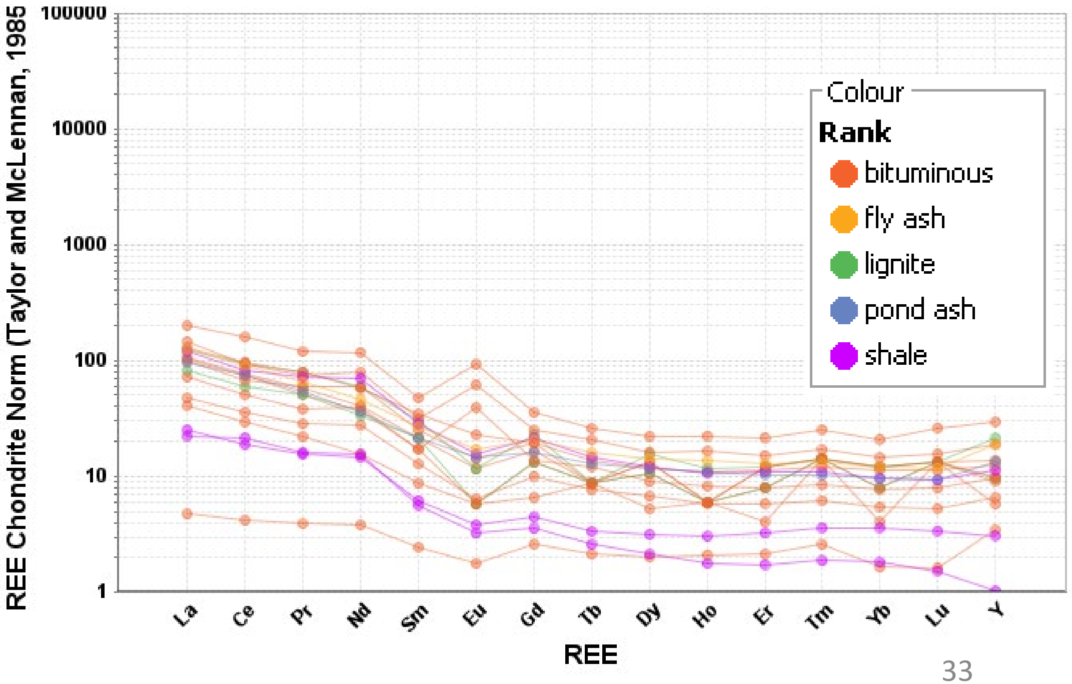
Figure A7-24. Minimum, maximum, and mean content of nickel for coal from all stratigraphic units in the Colorado Plateau coal assessment area.



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





Carbonatites, including producing deposits

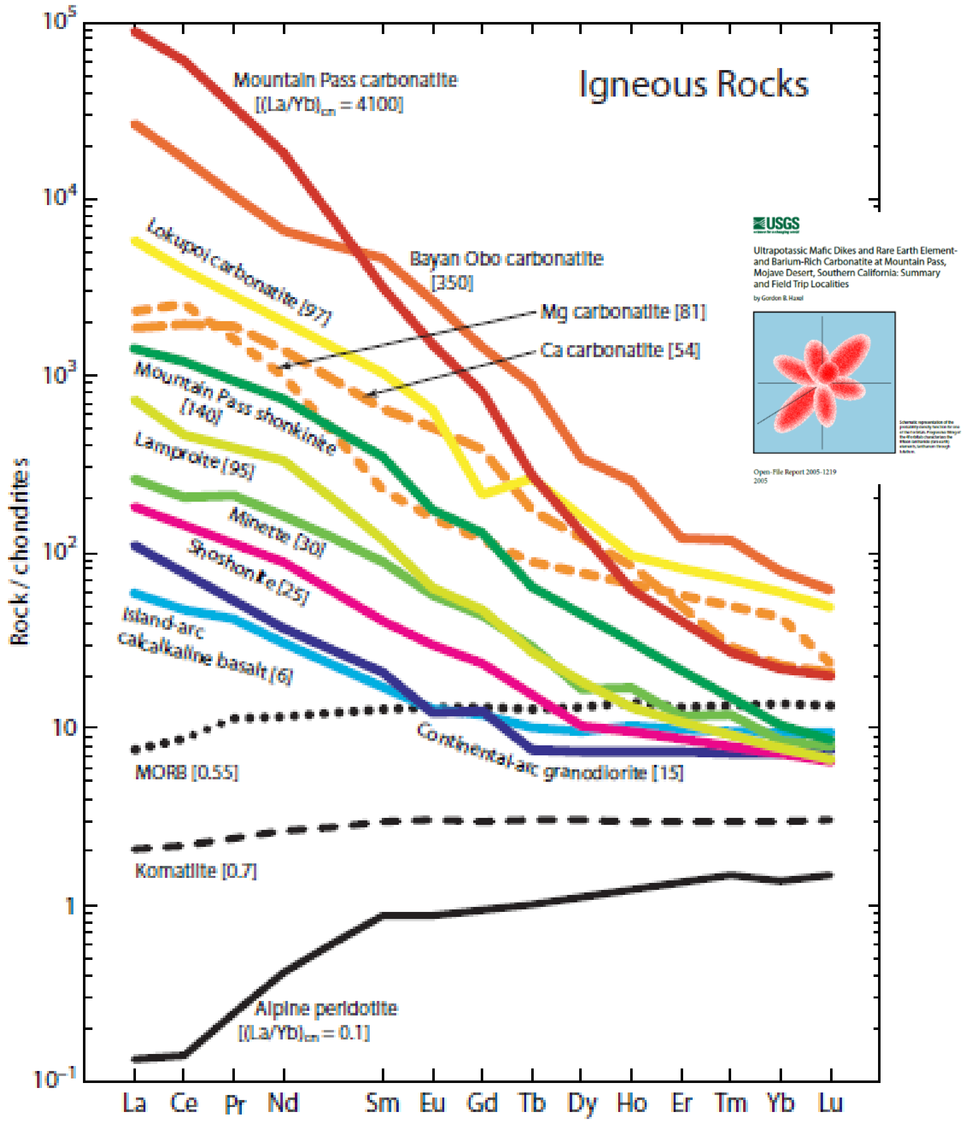
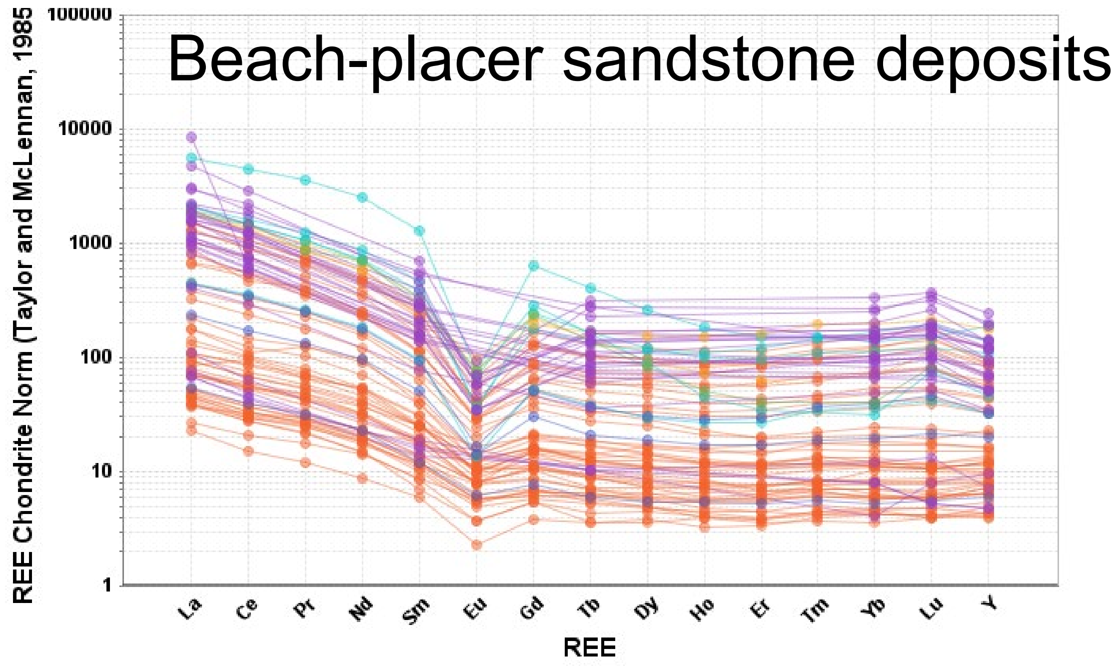
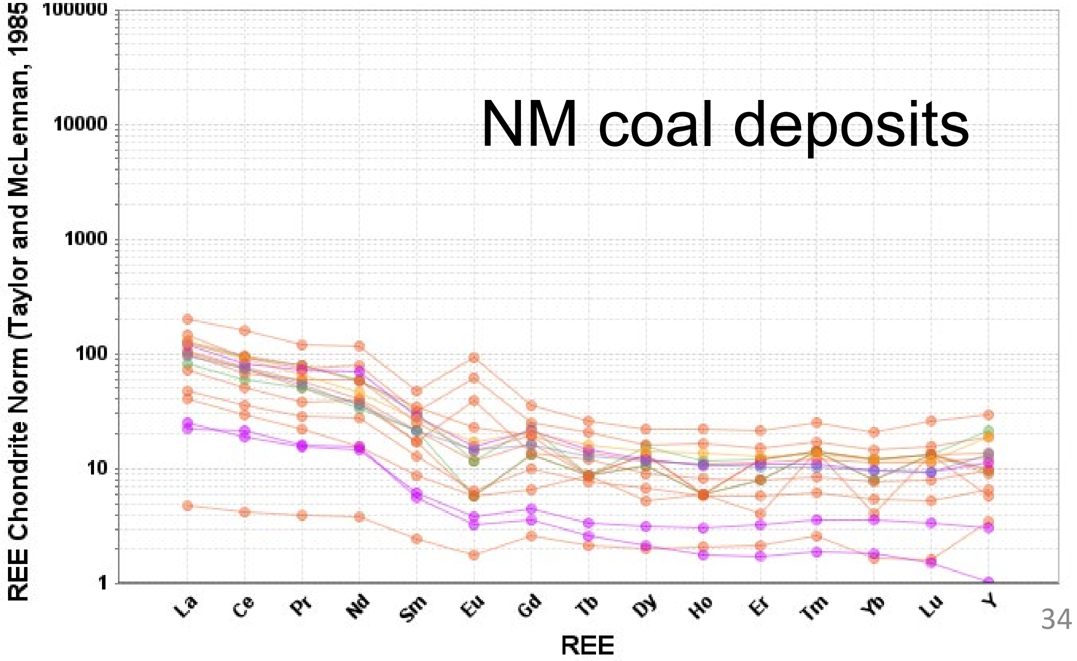
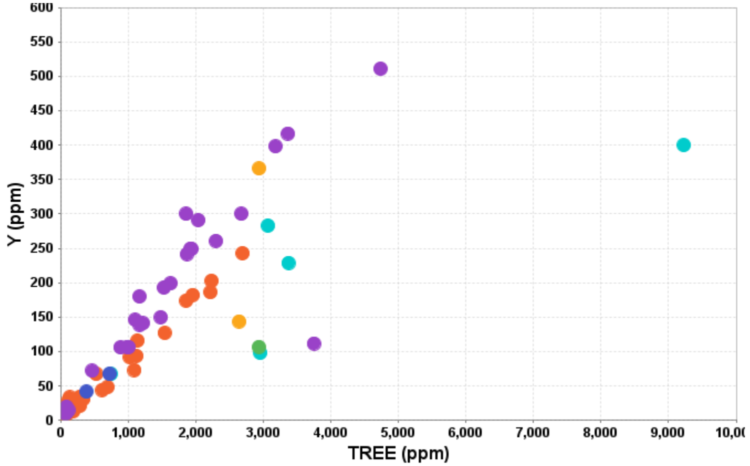


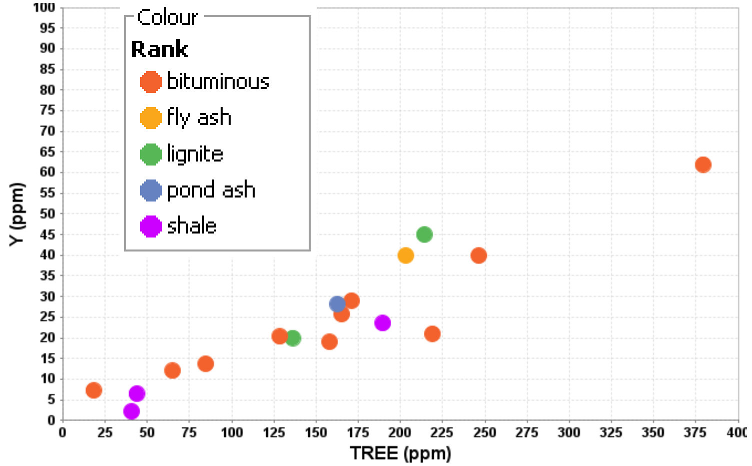
Figure 3. Chondrite-normalized (Table 1; Nakamura, 1974) REE spectra for average (labeled in italic) or representative compositions (labeled in upright type) of several common suites of ultramafic to intermediate, tholeiitic and calcalkaline

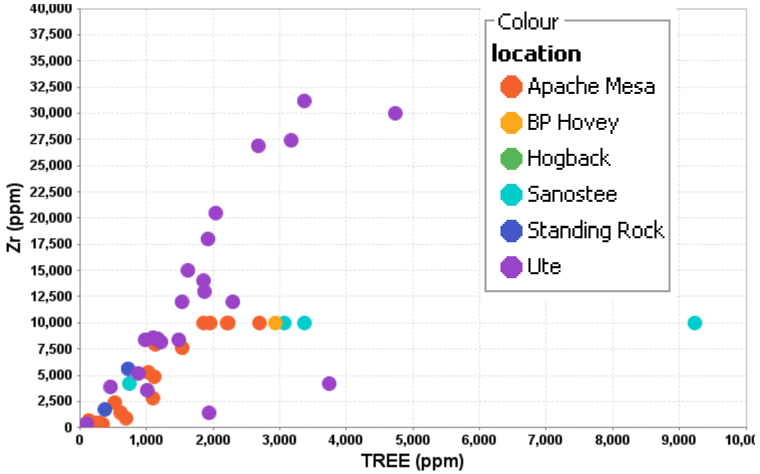




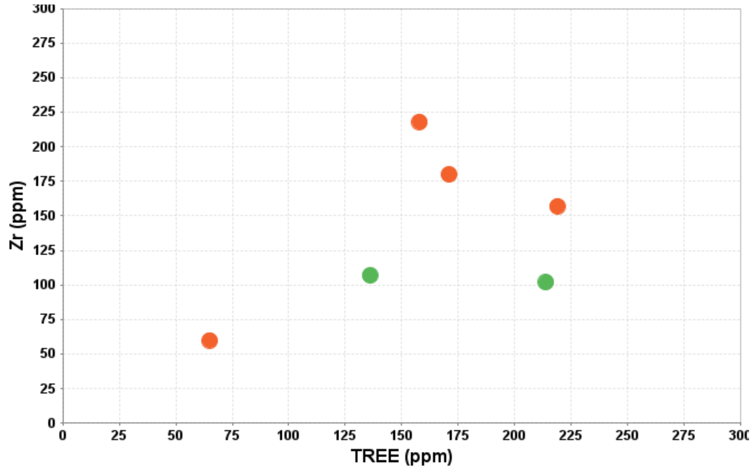


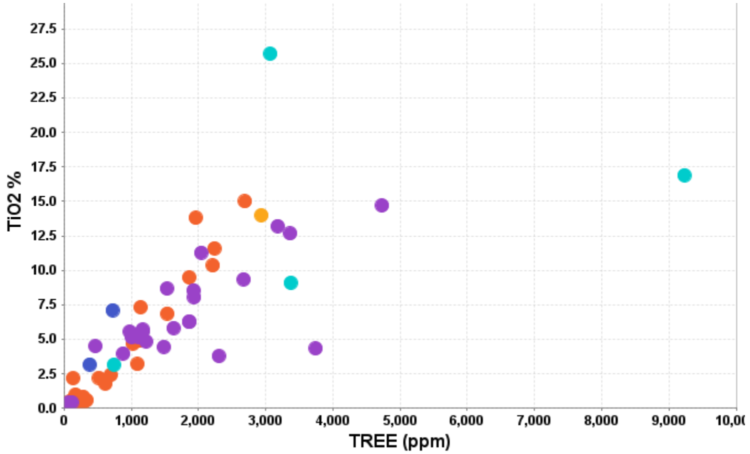
Geochemistry of beach-placer sandstone and coal deposits





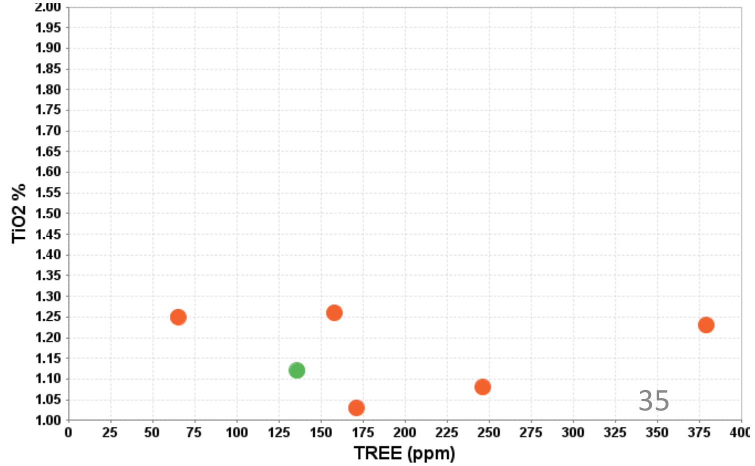
Correlation plots of TREE vs Y, Zr, and TiO2 for beach-placer sandstone deposits (LEFT; data from McLemore et al., 2016) and coal/shale/ash deposits (RIGHT, new unpublished data; Taggart et al. 2016) (note different scales)



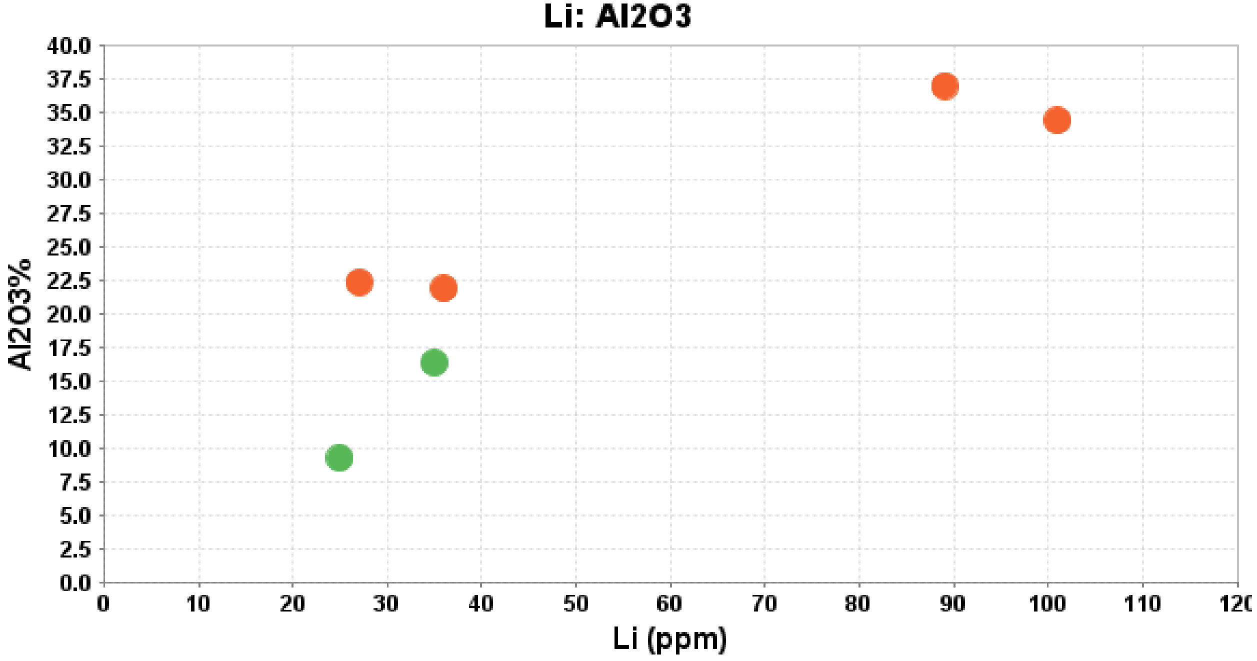


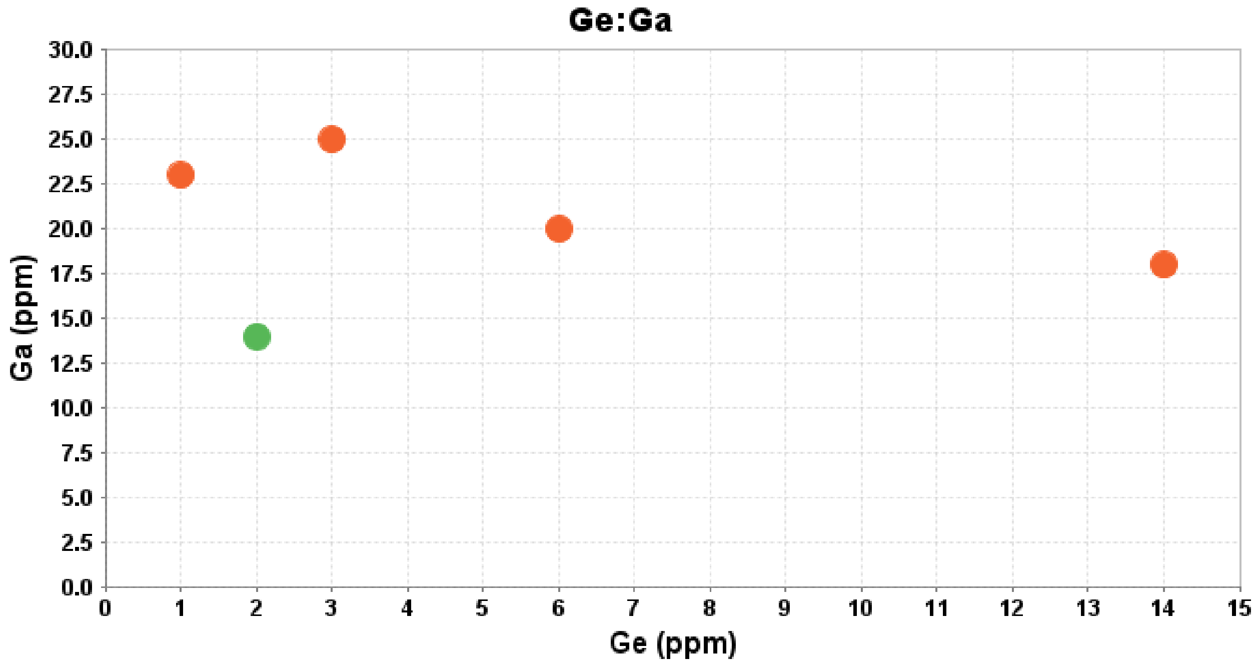
The chemical analyses indicates the predominant mineralogy for that element.

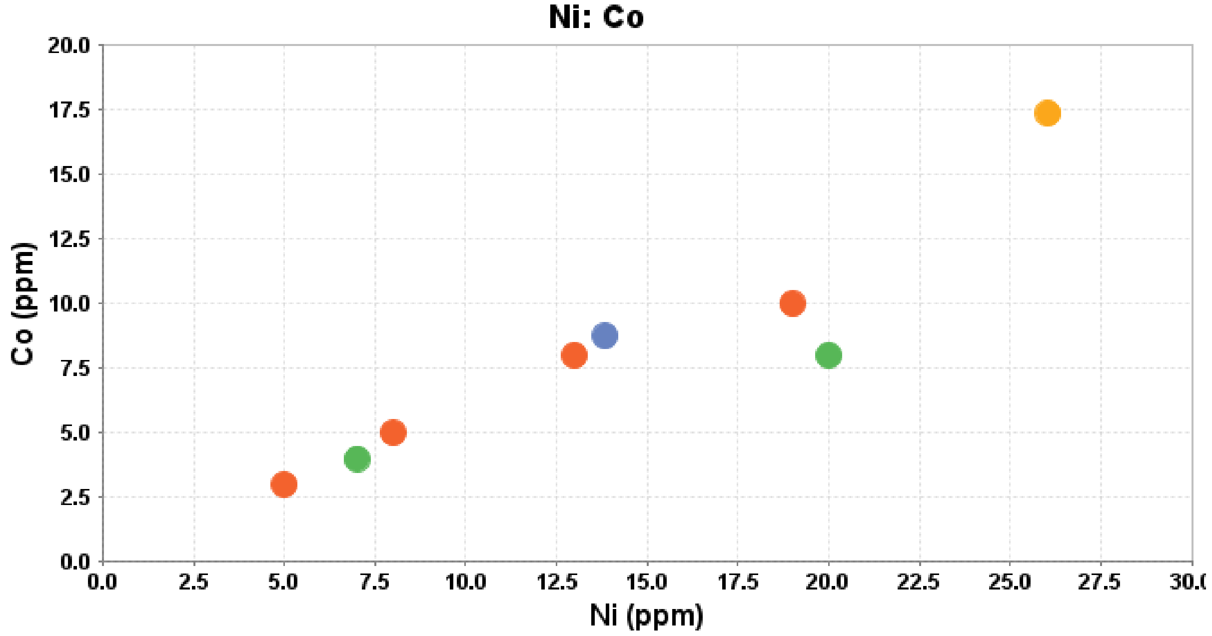
Detailed mineralogical study is underway

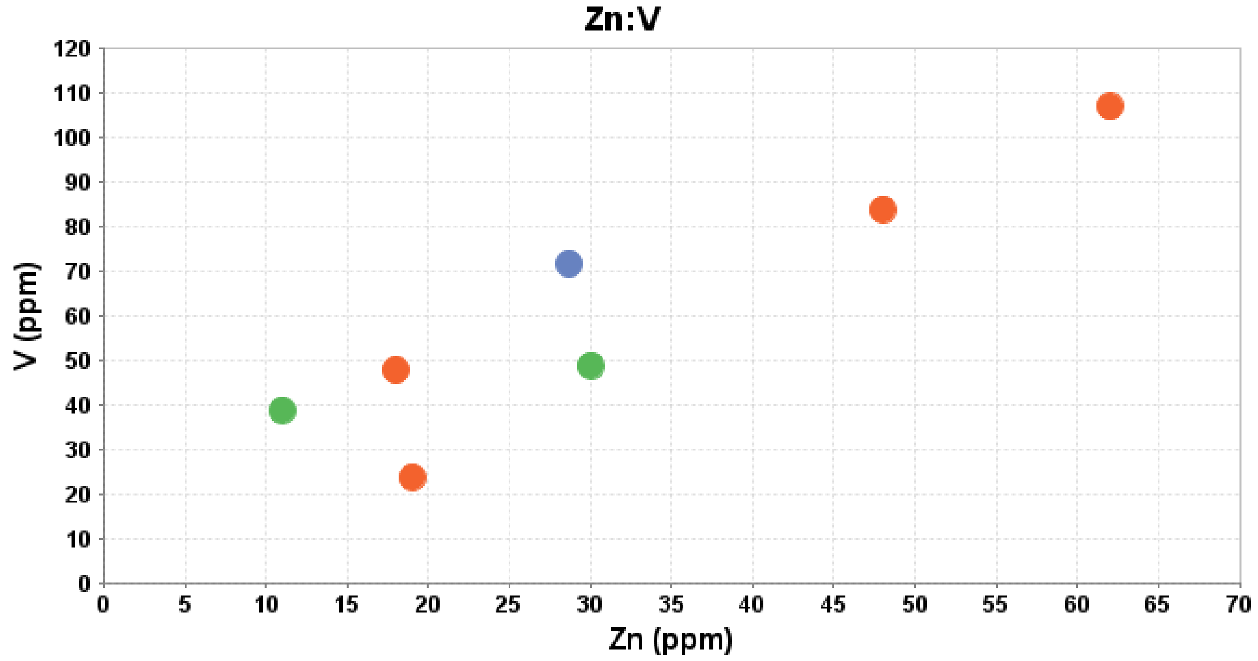


Other chemical analyses of San Juan coals







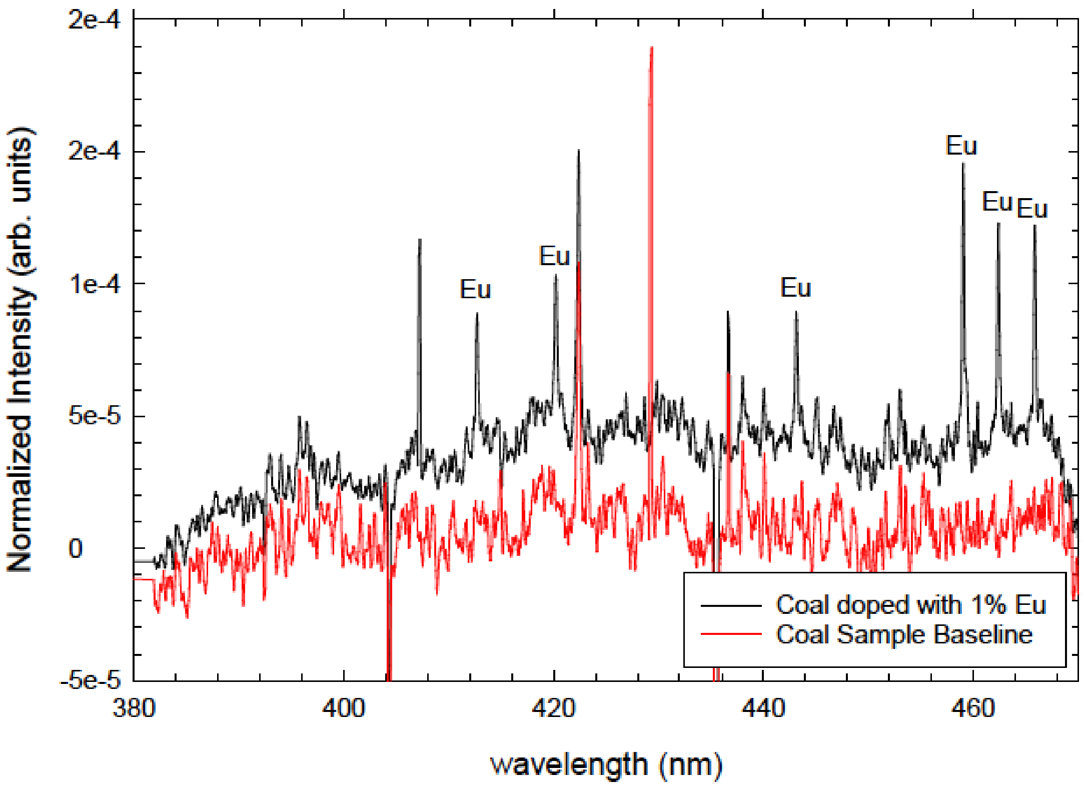


Characterization methods

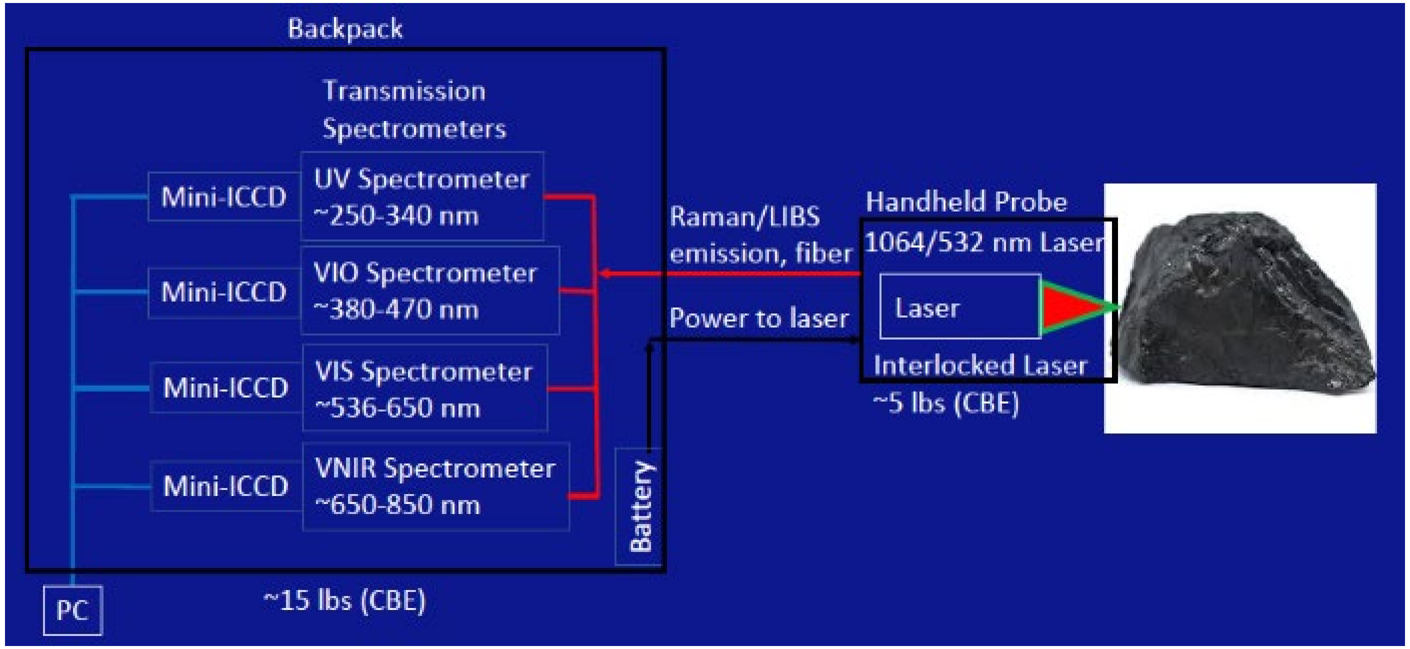
- Field characterization (location, lithology, description of units, radioactivity, thickness)
- Paste pH, S, C, acid base accounting of mine wastes (ARD diagram)
- Mineralogy (petrography, XRD)
- Whole-rock chemical analyses (ALS)
- Electron microscopy (mineral chemistry, texture, identification and location of REE and other CM)
- Particle size analyses of mine wastes
- Field-portable, in situ LIBS/RAMAN analysis
- Micro X-ray CT (μ-XRCT)
- Focused ion beam–scanning electron microscopy (FIB-SEM)

LANL: Field-portable, in situ LIBS/RAMAN analysis

- Field-portable Laser Induced Breakdown Spectroscopy (LIBS) and Raman spectroscopy instrument
- Collects geochemical and mineralogical data from the same sample volume
- Calibrated to detect all REE in coal and coal by-product samples



Above: example of LIBS data showing detection of Eu in a doped sample [Clegg et al. 2019]



Left: diagram of LIBS/RAMAN instrument [Clegg 2021]

Sandia: Task and Approach

Microscale characterization techniques to identify where REEs and critical metals are hosted

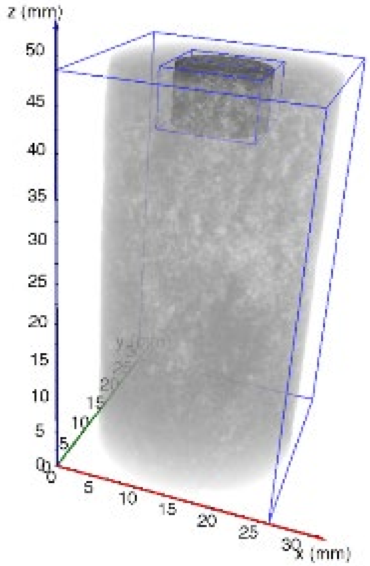
- 3D spatial petrography:
  - Micro X-Ray CT (μ-XRCT) to obtain nested 3D image volumes – use imaging and post-processing to quantify locations & geometry of specific mineral components
  - Focused ion beam–scanning electron microscopy (FIB-SEM) with energy dispersive spectroscopy or electron backscatter diffraction; can be registered with μ-XRCT – 3D micron to nano-scale quantification of geometry and composition
- Estimate/characterize the maturity of coal using infrared and Raman microscopy
- Conduct lab analysis (ICP-MS) to assist assessment of the potential reserve in acid drainage and abandoned mines as needed

Development of regionally optimized extraction technique

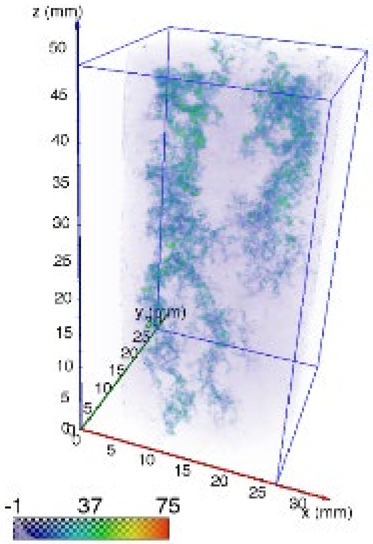
- Develop an optimized extraction technique from coal and various waste streams for the San Juan Basin using chelating agents, supercritical CO_2, and H_2O

Micro X-Ray CT example on sandstone plug

- *Example of registered 11 μm and 27 μm datasets*

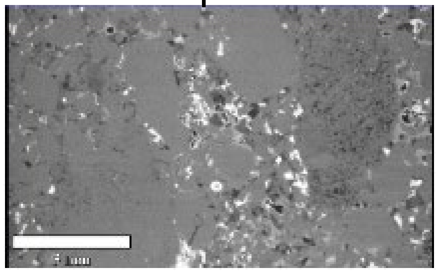


3D rendering of dissolved regions from pre-post reacted samples

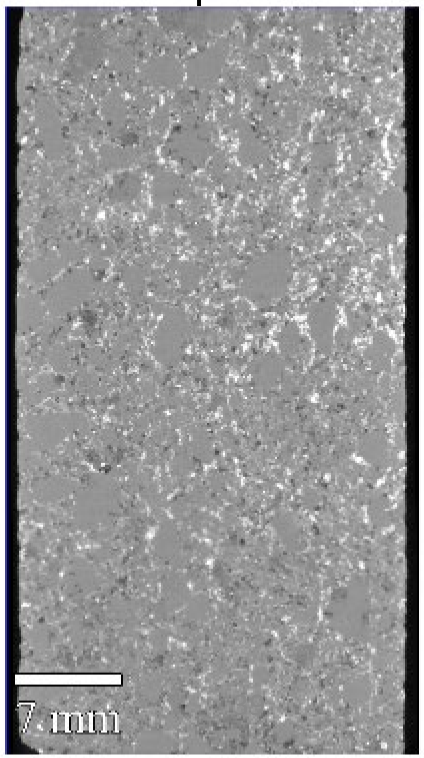


Vertical images from 3D datasets

11 μm

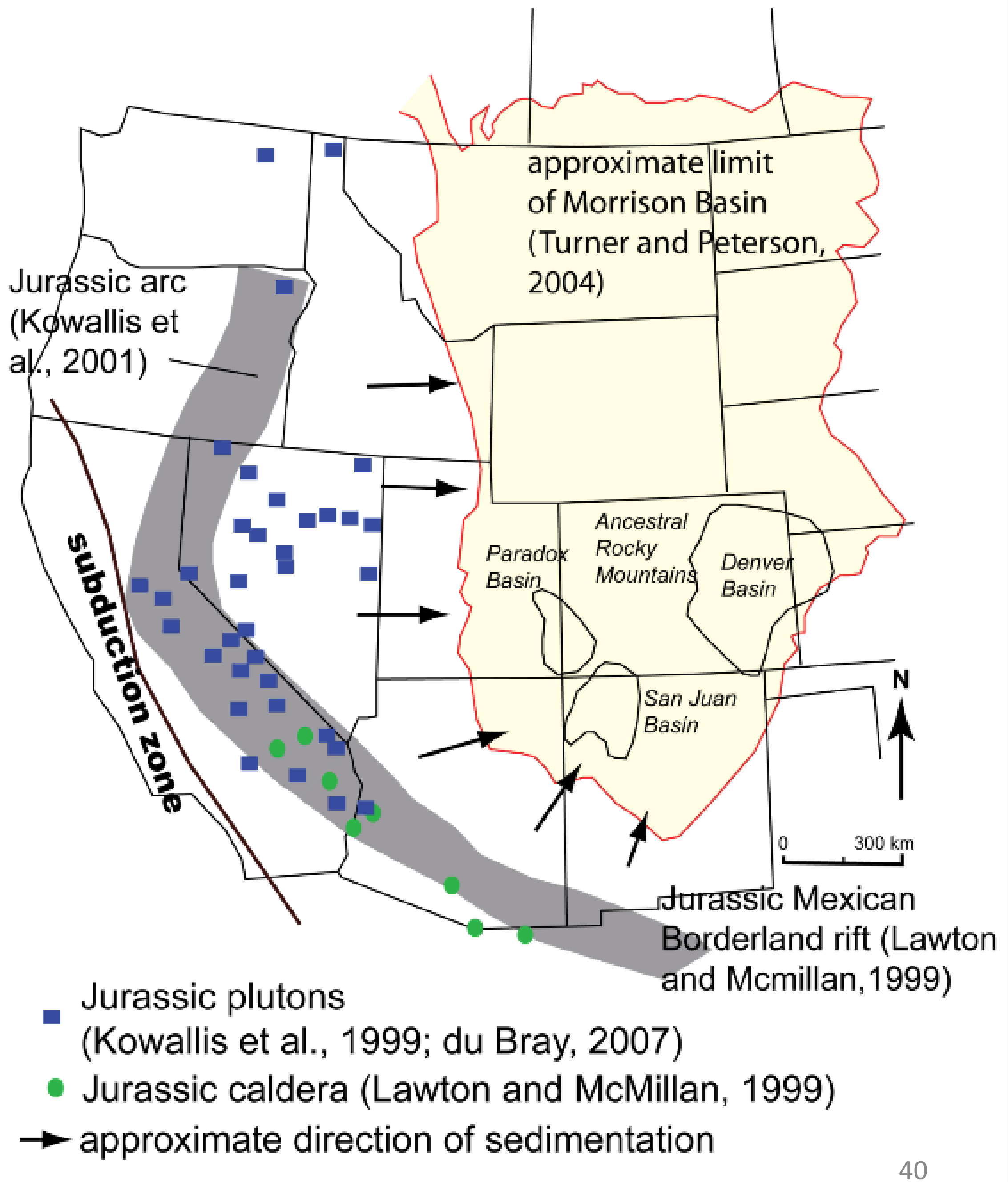


27 μm



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.

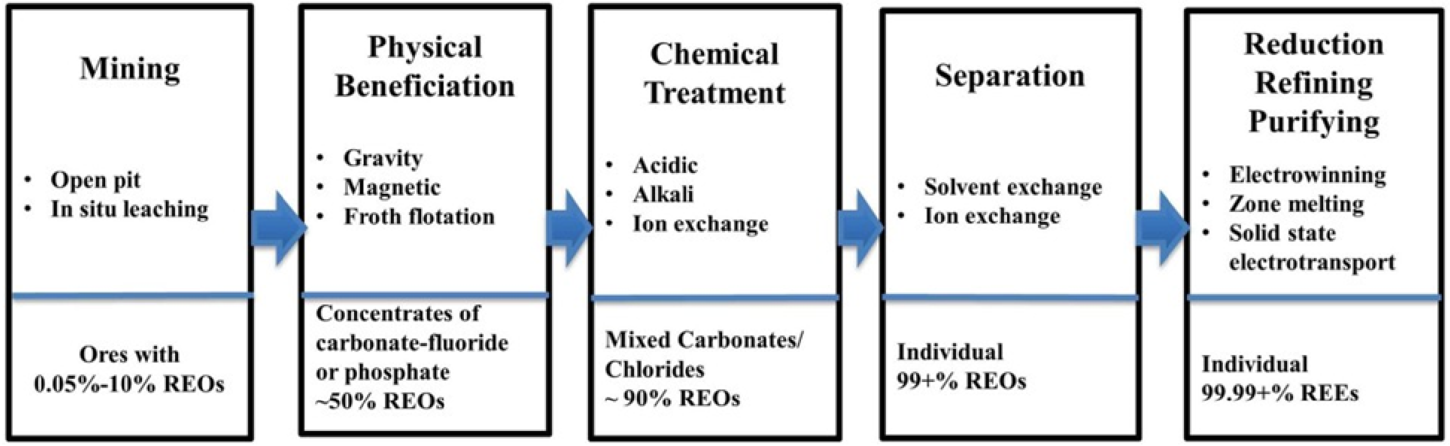
Both detrital and ash fall



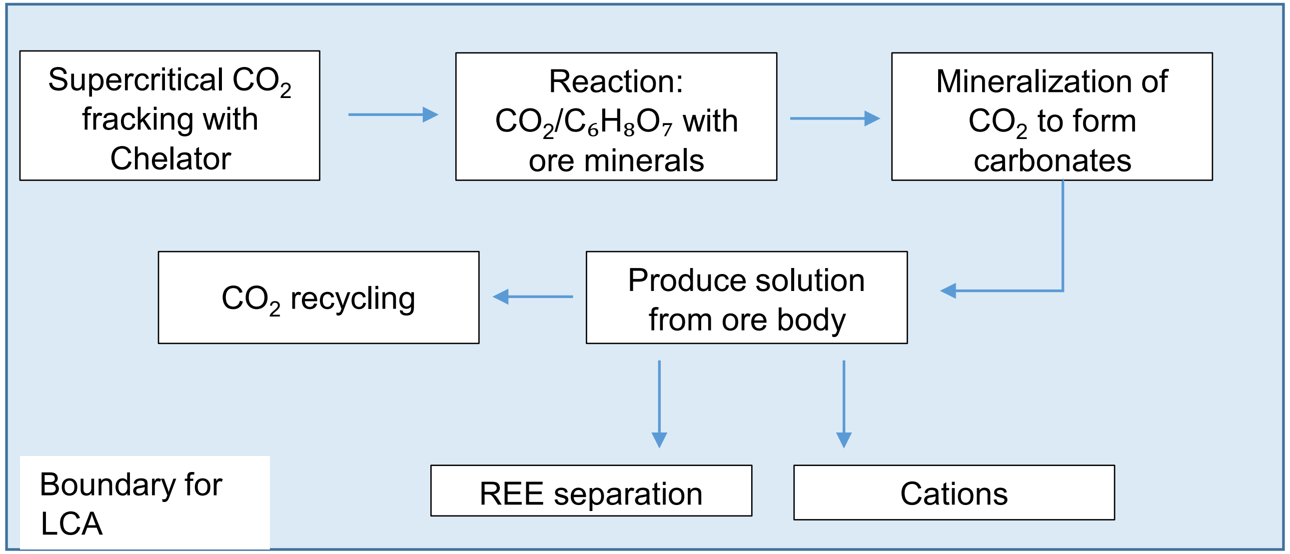
Life-Cycle Analysis (LCA)

Life-Cycle Analysis (LCA)

- Utilize the cradle-to-grave concept to set the boundary of energy and material flows for all the processes involved in the REE industry
- LCA includes energy and material analysis, environmental impact assessment, scalability assessment and detailed economic analysis



REE production route



- ➢ Currently, the focus extraction technology is the utilization of supercritical CO_2 Chelator fluids to mine these minerals (Sandia National Laboratories)
- ➢ The Life Cycle Impact Assessment (LCIA) step of an LCA study is used to evaluate the significance of potential environmental impacts using inventory data, and providing information for the interpretation step

Stakeholder Outreach and Education

Stakeholder Outreach and Education

- A short summary of the project was written for Gold Pan (https://nmt.edu/advancement/goldpan_archives/2022_Summer_GoldPan_Digital2.pdf), NMIMT Alumni Newsletter
- Another short summary of the project written for Lite Geology
- The NMBGMR Rockin' Around New Mexico was in Farmington, NM July 6-8, 2022 (https://geoinfo.nmt.edu/education/rockin/home.html). Lectures on critical minerals and a tour of the Navajo coal mine were included (https://geoinfo.nmt.edu/staff/mclemore/home.html)

Rockin' Around New Mexico

This program has served teachers for **25** years!

The location of RANM changes annually

Each year up to 30 K-12 teachers attend

All costs for workshop materials and fees for K-12 teacher professional development are covered by our Rockin' DHSEM (Division of Homeland Security and Emergency Management) grant

Rockin' was in Farmington in July 2022

Rockin' Around New Mexico, Farmington, July 2022

Students from New Mexico Tech are trained to perform field sampling and laboratory work

Presentations

- New Mexico Geological Society abstract: Badonie, M.N. and McLemore, V.T., 2022, REE in coalbeds in the San Juan-Raton coal basins (abstr.): New Mexico Geological Society, Spring Meeting, https://nmgs.nmt.edu/meeting/abstracts/view.cfm?aid=2838. Poster at https://geoinfo.nmt.edu/staff/mclemore/documents/NMSG.Poster2022COPY2.pdf
- New Mexico Mining Association abstract and presentation: REE in the coal and associated strata in the San Juan and Raton Basins, New Mexico, 2022, Megan Badonie, Jakob Newcomer, Devlon Shaver Advised by: Dr. Virginia T. McLemore, https://geoinfo.nmt.edu/staff/mclemore/documents/NMAAPresentationNMMAFINAL2022.pdf
- McLemore, V.T., 2022, Rare Earth Elements (REE) in Late Cretaceous coal and beach-placer sandstone deposits in the San Juan Basin, New Mexico: Preliminary Observations (abstr.): Geological Society of America, Annual Conference, October, https://gsa.confex.com/gsa/2022AM/meetingapp.cgi/Paper/378264, presentation https://geoinfo.nmt.edu/staff/mclemore/documents/McLemoreGSA22Wed10-12-22.pdf

Challenges

- Sampling was delayed due to COVID restrictions, poor weather, vacation schedules, **closures of Federal land because of fire danger**, and students not available because of school schedules
- We started sampling in April
- Chemical analyses were delayed in order to locate laboratories that would ash and analyze coal samples

- What certified standards are recommended for chemical analyses?

Importance of the CORE-CM project—San Juan River-Raton Basins, New Mexico

- Select and archive samples to achieve project objectives, esp in the future
- Delineate favorable geologic terranes and priority areas containing potential REE and CM deposits
- REE and CM resources must be identified before land use decisions are made by government officials
- Future mining of REE and CM will directly benefit the economy of NM
- Develop Technology Innovation Center
- Crucial to re-establish a domestic source of REE and CM minerals in the U.S. to help secure the nation's clean energy future, reducing the vulnerability of the U.S. to material shortages related to national defense, and to maintain our global technical and economic competitiveness
- Training of the future workforce because students at New Mexico Tech and San Juan College will be hired to work on this project and outreach activities train high and middle school students as well as their teachers

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
- 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 REE and other critical minerals in San Juan Basin 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

- Continue to sample remaining beach-placer sandstone and coal deposits
- Continue geochemical, mineralogical, and other characterization analyses
- Identify possible sources of REE and other critical minerals
- Evaluate the mineral-resource potential

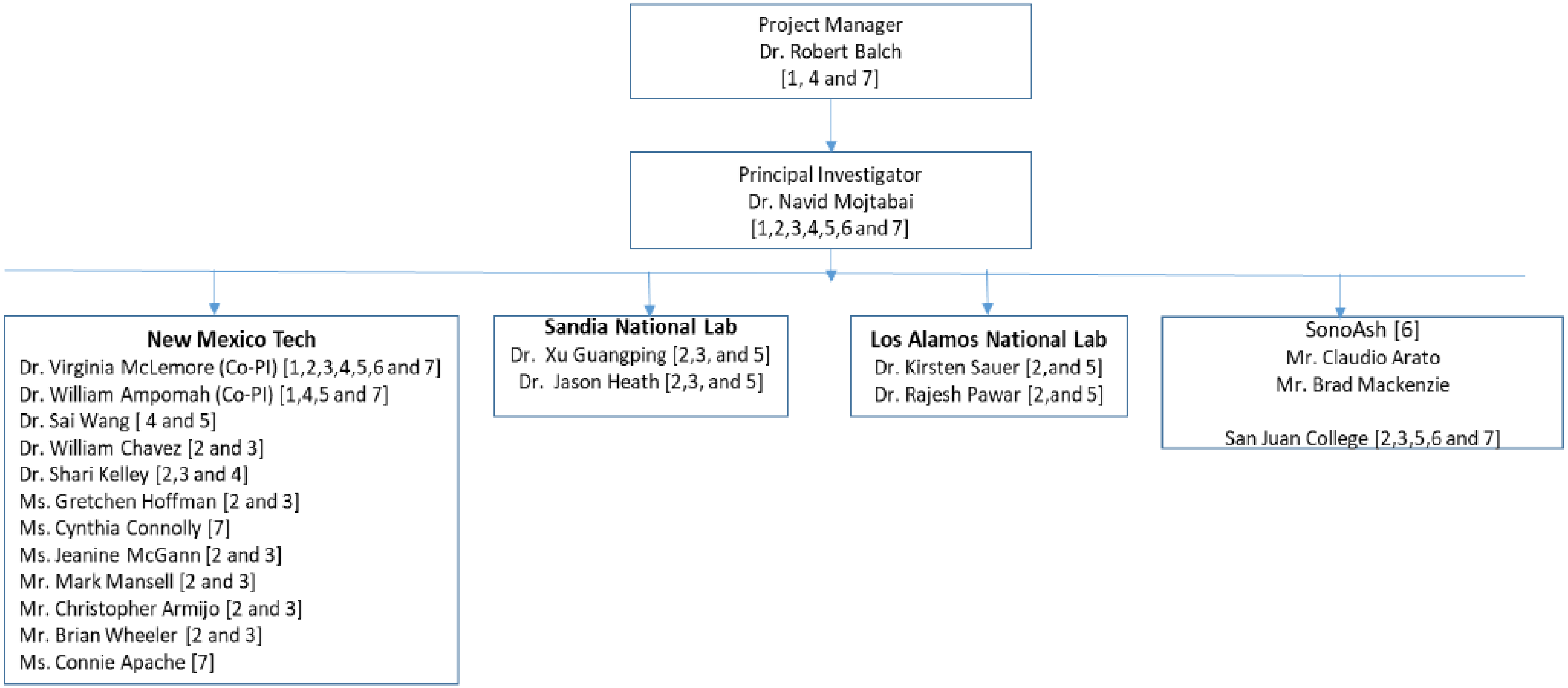
QUESTIONS?

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

Appendix

Organization Chart

Figure 1 below shows the organizational chart for the proposed project.



Gantt Chart

Project Timeline (Gantt Chart) Example

		7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
		Project Year 1												Project Year 2											
	Tasks																								
Task 1.0	**Project Management and Planning**																								
Task 2.0	**Basinal Assessment of REE and Other CM in the San Juan and Raton Basins**	M																							
Subtask 2.1	**Identification of Sampling Sites**																								
Subtask 2.2	**Collection and Review of Existing Data**																								
Subtask 2.3	**Develop a Sampling Plan**																								
Subtask 2.4	**Collect Samples**																								
Subtask 2.5	**Sample Characterization**				M				M				M				M				M				
Subtask 2.5.1	Bulk rock characterization																								
Subtask 2.5.2	Micro-scale characterization																								
Subtask 2.5.3	3D multiscale petrography																								
Subtask 2.5.4	*in situ* LIBS/RAMAN analyses																								
Subtask 2.6	Application of Machine Learning techniques for basin-wide resource assessment																M								
Task 3.0	**Basinal Strategies for Reuse of Waste Streams**				M				M				M				M				M				
Subtask 3.1	Waste streams sampling and characterization																								
Subtask 3.2	Coal Ash																								
Subtask 3.3	Technology development of basinal reuse strategy																								
Task 4.0	**Basinal Strategies for Infrastructure, Industries and Businesses**																	M							
Subtask 4.1	**Infrastructure Investigation**																								
Subtask 4.2	**Competitiveness and Challenge**																								
Subtask 4.3	**Life Cycle Analysis**																								
Task 5.0	**Technology Assessment, Development and Field Testing**																		M						
Subtask 5.1	**Identify and Assess Existing and Novel Technologies Specific to the Resource**																								
Subtask 5.2	**Develop Plan for Field Testing**																								
Task 6.0	**Technology Innovation Centers**																								
Subtask 6.1	**SonoAsh Center of Excellence**												M												
Task 7.0	**Stakeholder Outreach and Education**				M				M				M				M				M				
Subtask 7.1	**New Mexico State and Regional Education**																								
Subtask 7.2	**Lessons learned and narratives constructed**																								
Subtask 7.3	**Publications**																								
Subtask 7.4	**Training and Conferencing with SJC and Sonoash COE**																								