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Alteration and Geochemistry of Clinkers in the San Juan Basin, New Mexico

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Purpose of the study

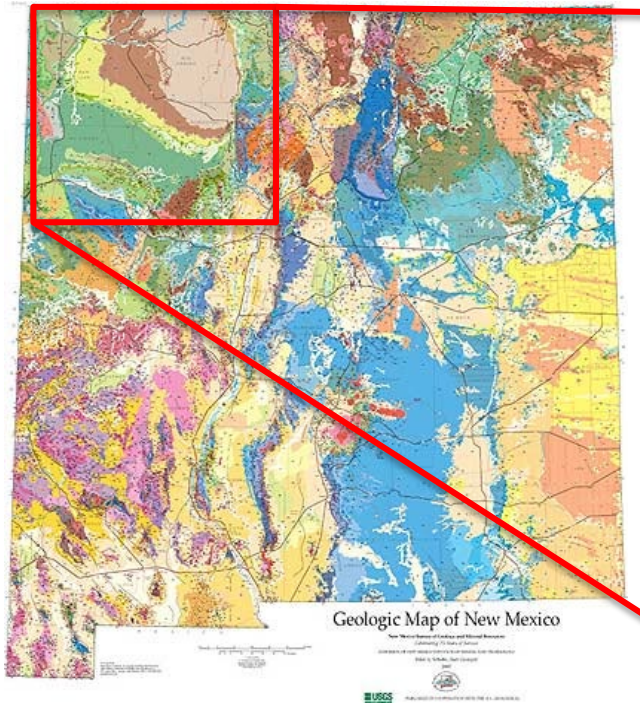
- To determine the mineralogy and chemistry of clinkers from coal fields
- To examine clinkers for potentially recoverable critical minerals
- Some clinkers have been shown to have moderate levels of REE's and critical minerals, up to 200 and higher ppm of total REE

Introduction

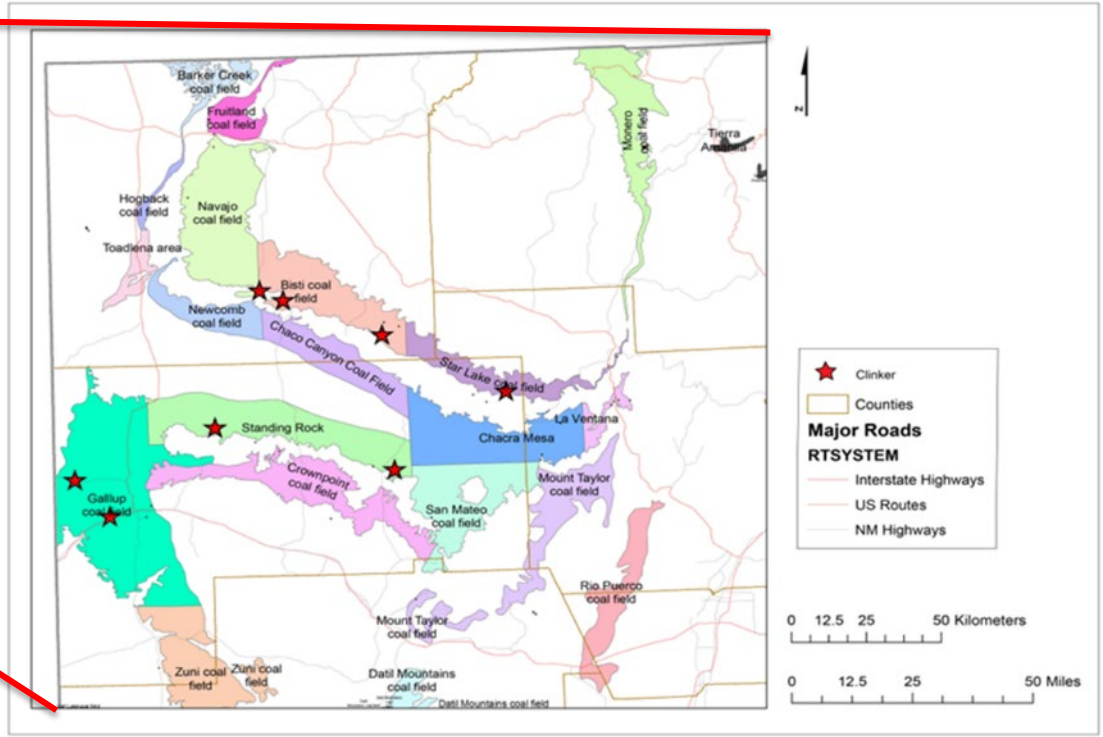
- San Juan Basin contains 24 coal fields
- Coal has been mined since the late 1800s
- Late Cretaceous geology
  - Menefee Fm. of the Mesa Verde Fm.
  - Crevasse Canyon Fm. of the Fruitland Fm.
- Humates and clinkers are formed through erosion and pyrometamorphism, respectively

Red Dog Fm clinker, El Segundo Mine

San Juan Basin in NM

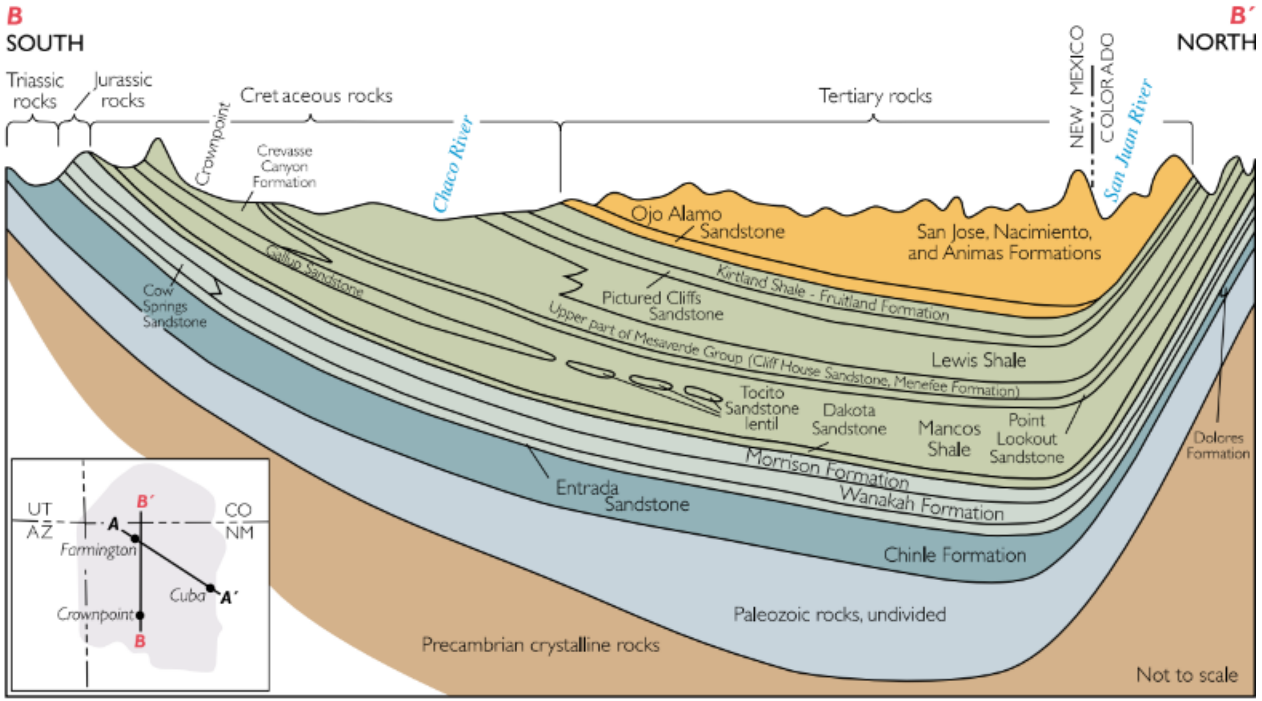


1:500k geologic map of NM, credit to NMBGMR



Map of San Juan Basin showing clinker deposits (stars) and coal fields (colored polygons) in northwestern New Mexico.

Stratigraphy



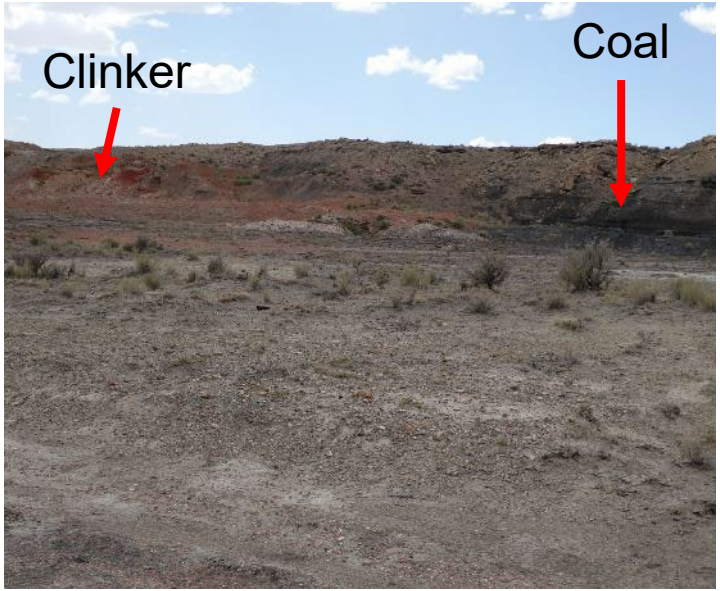
SE-NW cross section of the San Juan basin.
Credit to NMBGMR, Craigg 2001

Fruitland formation: Coal 8, Coal 28,Coal 36, Coal 88, Coal 89,Coal 107, Coal 108

Mesa Verde Formation: Coal 140

What is clinker?

- Clinkers are sedimentary rocks pyrometamorphosed by intense heat
- Coal seam fires can start from multiple causes at the surface
  - Wildfires
  - Spontaneous combustion by the oxidation of pyrite
  - Lightning strikes
- Temperatures can reach 1000ºF, baking the surrounding rocks
- Clinkers can be indicators of coal resources that aren't exposed
  - Resistant to erosion, commonly forms buttes



Coal 11C, Virginia T. McLemore photo

Industrial uses of clinker

- Clinker is a cheap and readily available resource in coal fields, which makes it ideal for construction as an aggregate
- Some forms of clinker can be used in metal working and glass manufacture after being crushed to fine powders

Clinker aggregate road, credit to North Dakota DoMR

Coal 28E, San Juan Basin Clinker outcrop, Virginia T. McLemore photo

Methods of Study

- Sample collection
- Whole-rock and trace element chemistry
- Petrography
- Electron microprobe analysis (EMPA)
- X-Ray diffraction (XRD)

Coal/Humate profile collection. Photo credit to Virginia T. McLemore

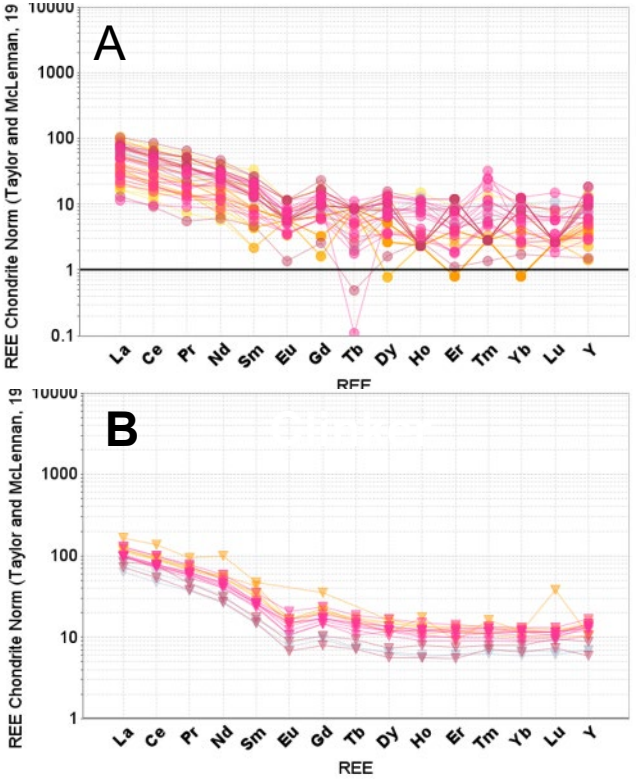
Work Done so Far

Petrography in progress, Devlon R. Shaver

- Samples collected
- Whole-rock and trace element chemistry completed
- XRD completed on clinkers
- Most clinkers ready for thin sectioning for petrographic study, more being prepared

Chemistry: Clinker vs Coal

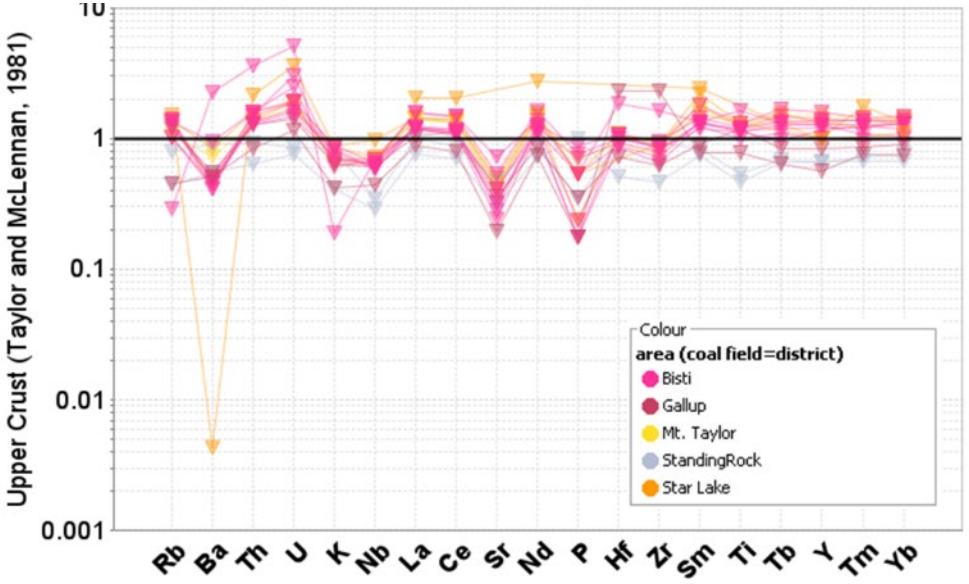
- Clinkers are very similar in chemistry compared to coals
- Both coal (A) and clinker (B) are slightly enriched in LREE and average/slightly depleted in HREE in comparison to chondrite



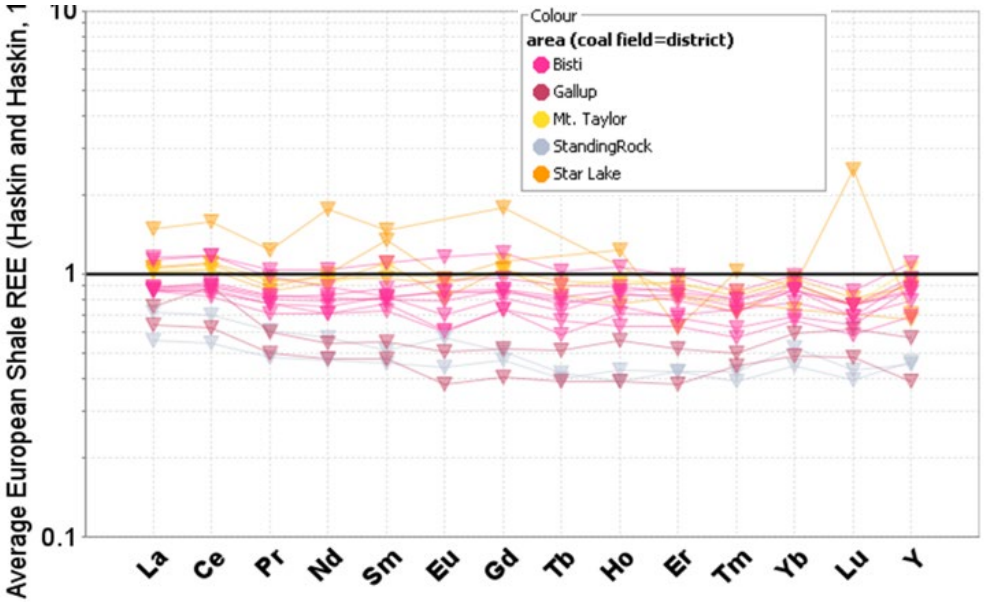
Clinker geochemical comparisons: Average Upper Crust

Compared to Average Upper Crust, clinkers are:

- Slightly enriched in uranium (U)
- Depleted in barium (Ba), potassium (K), niobium (Nb), and strontium (Sr)
- Average for other elements



Clinker Chemistry: Average European Shale



Compared to Average European Shale, clinker are:

- Generally average to slightly depleted for REE
- Heavy REE values may show more depletion than LREE

Clinker Chemistry

- Chemistry has shown that NM clinkers are relatively low in REE with the highest concentration being 323 ppm TREE
- Some clinkers exhibit high levels of Al_2O_3, possible aluminum resource?

- Highest values for REE and selected critical minerals
- TREE: 323 ppm (Coal 140)
- Li: 70 ppm (Coal 106)
- V: 114 ppm (Coal 9)
- Ni: 108 ppm (Coal 140)
- Zr: 557 ppm (Coal 117)

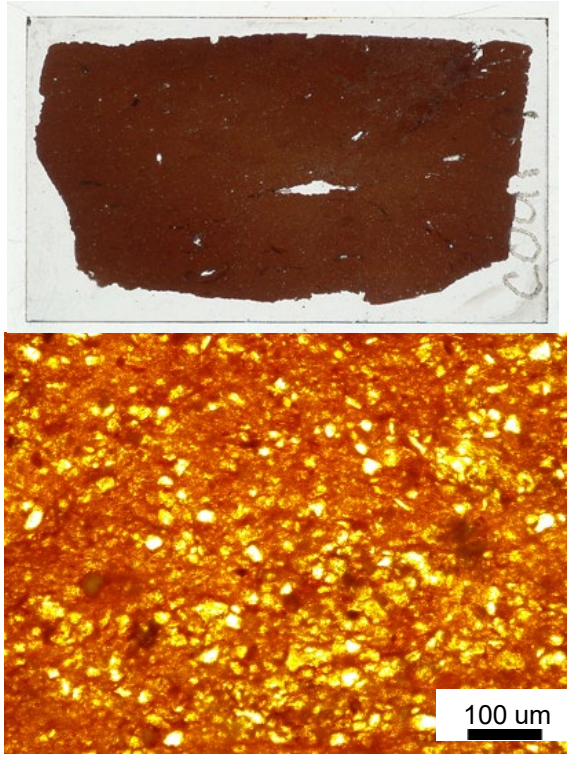
X-ray Diffraction data

As of now, XRD has been completed on 16 samples

- Quartz is the dominant mineral in many of these samples
- Hematite (Fe_2O_3) is the dominant iron mineral, present in minor values
  - Goethite (FeO(OH)) present in some samples
- Various other minerals can be present such as opal, albite, and others
- Some minerals are present due to high temperature alteration of silica (>1000ºF), such as cristobalite (SiO_2)

Petrography

- Seven samples have been examined with transmitted light microscopy
- Dominant mineral species from XRD confirmed through petrography
  - Some minerals identified in petrography not seen in XRD



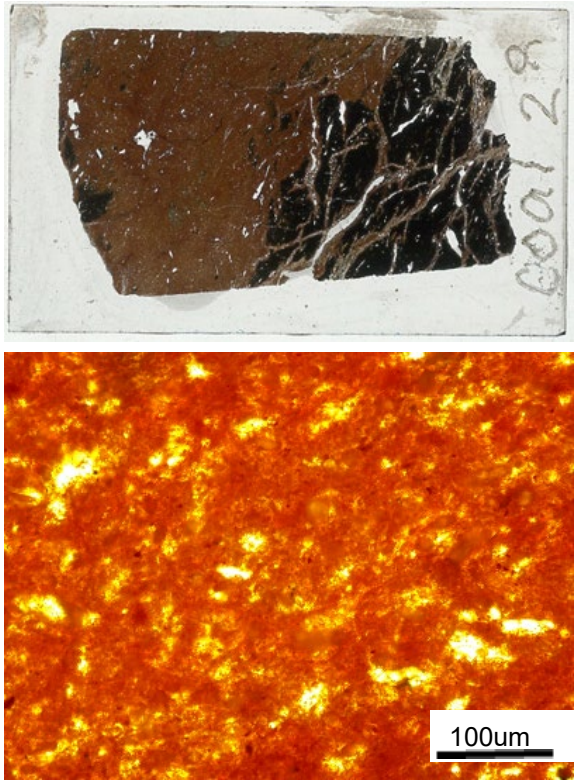
Thin section scan and photomicrograph of COAL9, pyrometamorphosed mudstone, Fruitland Formation

- Large quartz grain clusters present
- Dull orange color
- Organic sourced hematite
- Metallic hematite crystals present
- Small rutile crystals present

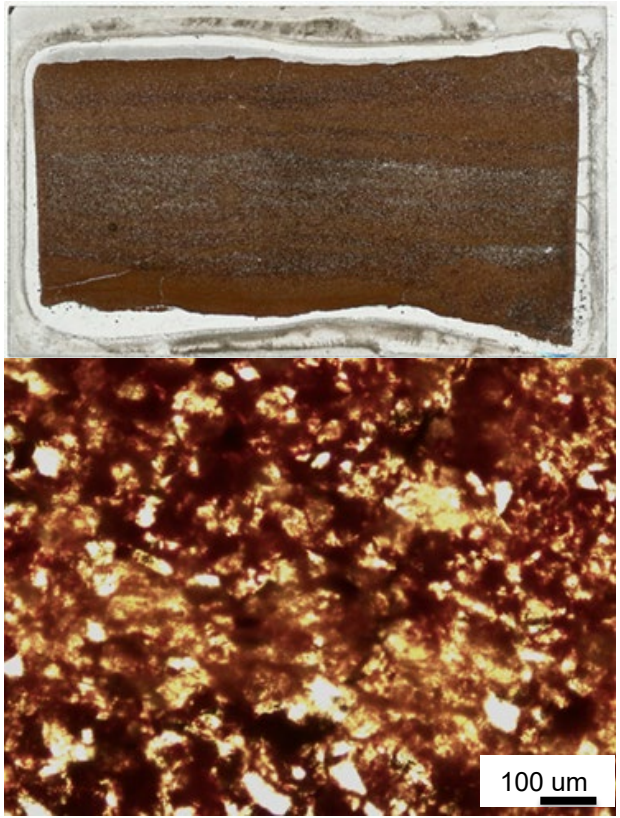
Petrography

Thin section scan and photomicrograph of COAL28, a claystone/mudstone clinker, Fruitland formation

- Abundant clay minerals present
- Uniquely presenting pyrobitumen
- Rutile also present as small red crystals
- Quartz is dominated by clay matrix



Petrography



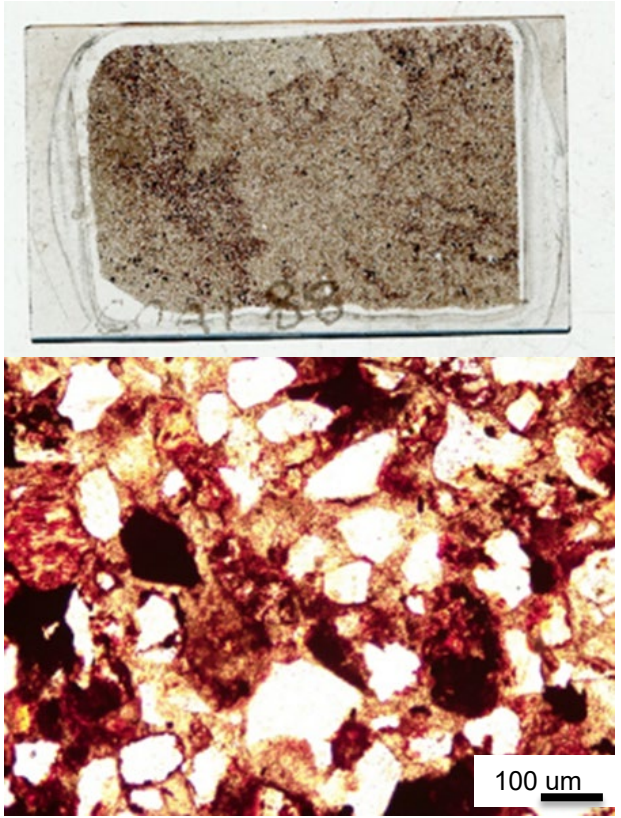
Thin section scan and photomicrograph of COAL36, a fine-grained quartz arenite rich in iron oxide, Fruitland Formation

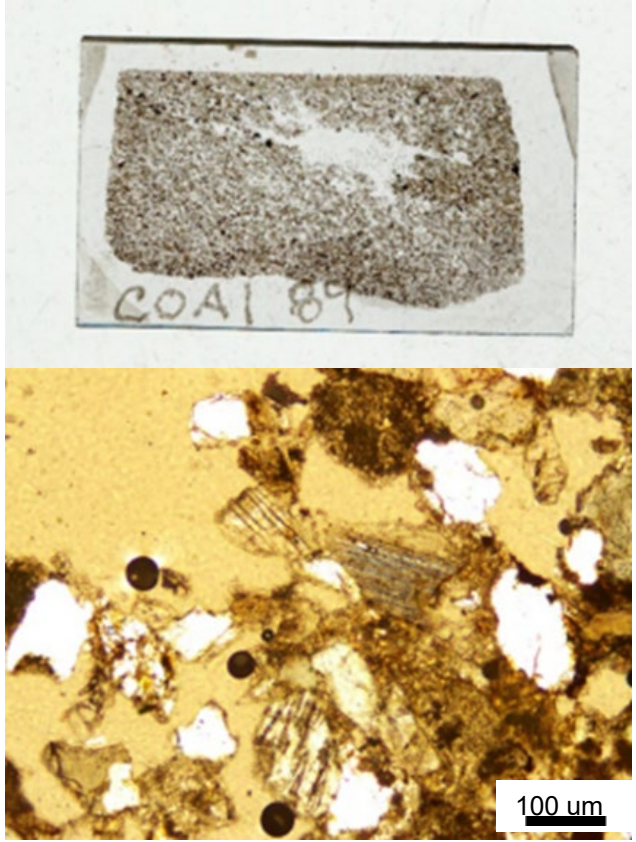
- Bedding layered defined by quartz content and grain size
- Low mineral species environment

Petrography

Thin section scan and photomicrograph of COAL 88

- Moderately sorted sandstone full of angular/subangular quartz grains
- Kaolinite seen in matrix as well
- Fruitland Formation





Petrography

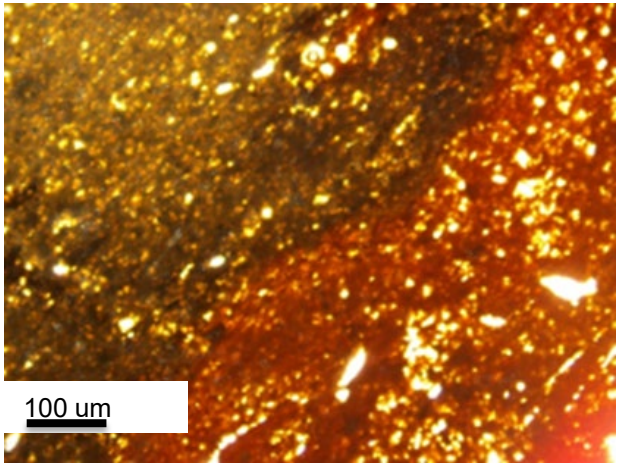
Thin section scan and photomicrograph of COAL 89, a mature arkose sandstone, with granitic source

- Feldspars like microcline and albite are present, exhibiting distinct twinning
- Biotite present as small brown clusters
- Low temperature compared to other clinkers, very little glass
- Fruitland Formation

Petrography

Thin section scan and photomicrograph of COAL 107. Interbedded shale, siltstone and sandstone beds, Fruitland Formation

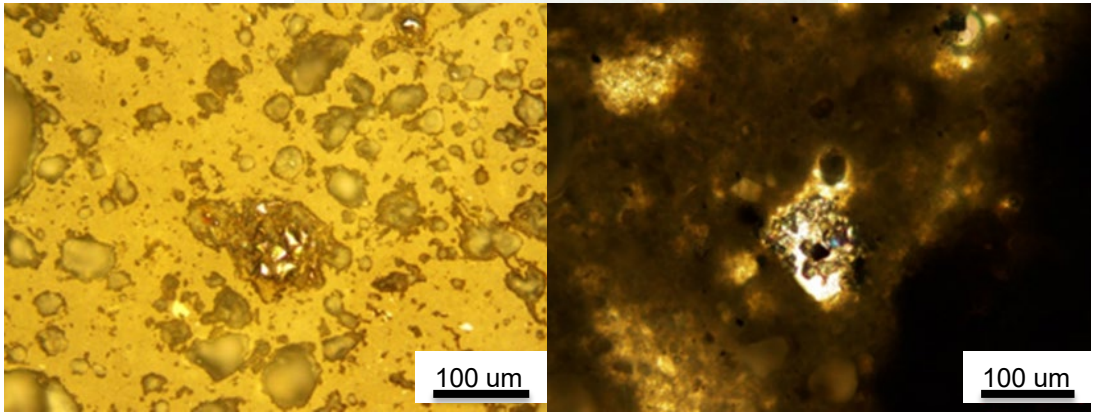
- Hematite rich
- High temperature exposure with high glass content present
- Distinctive bedding layers defined by their grain size, shape, and color



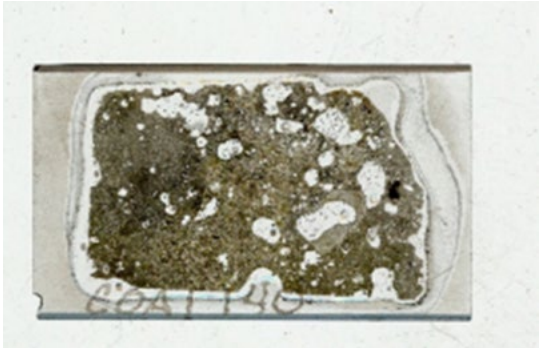
Petrography

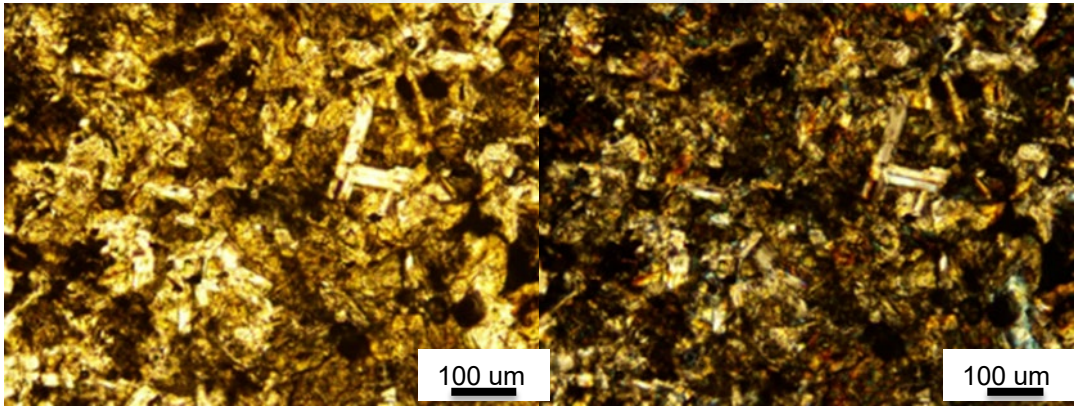
Thin section scan and photomicrograph of COAL 108. A highly altered sedimentary rock, Fruitland Formation

- Mullite, cristobalite and high glass content shows it was exposed to high temperatures
- Glass and hi-temp minerals are most likely an effect of pyro-metamorphism that made the clinker
- Possibly pyrometamorphosed coal



Petrography





Thin section scan and photomicrograph of COAL 140. High temp clinker with relatively low iron percentage, Mesa Verde Formation

- Feldspars present in sample, with enriched amphibole content
- Cummingtonite ($(Mg,Fe)_2(Mg,Fe)_5Si_8O_{22}(OH)_2$) is present as dominant amphibole
- Source is speculated to be a potassium enriched protolith

Mineralogy

Mineralogy of all XRD and Petrographically identified minerals in Clinkers has been catalogued

More samples to be catalogued after further sample analysis and comparison to other specimens

Sample Name	Mineral
Coal9	Quartz (SiO_2), Hematite (Fe_2O_3), Rutile (TiO_2)
Coal 28	Quartz (SiO_2), Goethite (a-FeO(OH)), Rutile (TiO_2)
Coal 36	Quartz (SiO_2), Hematite (Fe_2O_3), Kaolinite ($Al_2Si_2O_5(OH)$)
Coal 88	Quartz (SiO_2), Hematite (Fe_2O_3), Calcite ($MgCa(CO_3)_2$), Kaolinite ($Al_2Si_2O_5(OH)$, Unidentified iron mineral
Coal 89	Quartz (SiO_2), Albite ($NaAlSi_3O_8$)
Coal 102	Quartz (SiO_2), Hematite (Fe_2O_3)
Coal 104	Quartz (SiO_2)
Coal 106	Quartz (SiO_2)
Coal 107	Quartz (SiO_2), Hematite (Fe_2O_3), Opal (SiO_2 -H_2O), Iron Oxide (Fe_3O_4)
Coal 108	Quartz (SiO_2), Cristobalite (SiO_2), Mullite ($3Al_2O_3SiO_2$), Cordierite ($Mg_2Al_4Si_5O_{18}$), high glass content
Coal 110	Quartz (SiO_2), Hematite (Fe_2O_3)
Coal 117	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)$
Coal 138	Quartz (SiO2)
Coal 140	Orthoclase($KAlSi_3O_8$), Albite ($NaAlSi_3O_8$) Cummingtonite
Coal 146	Quartz, (SiO_2), Illite $((K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10})(OH)_2,(H_2O)$
Coal 167	Quartz (SiO_2)

Preliminary Conclusions

- Most clinkers were sandstone, siltstones, and shales formed by the natural burning of the adjacent coal seams
- The pyrometamorphism that formed clinker has not caused any significant variation in the concentrations of REE
- Clinkers do not show potentially economic levels of REE and other critical minerals to date, with only low to moderate levels detected
- Light REE chondrite normalized pattern suggests that REE present may be hosted by clay minerals or very fine grained REE minerals
- Potential resource for Al_2O_3 due to enrichment of aluminum oxides

Acknowledgements

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- 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
- Thanks to the graduate students who helped in sample collection and fieldwork, Special thanks in particular to Zohreh Kazemi Motlagh, Jakob Newcomer, Kyle Stafford, and Megan Badonie, in the collection of field samples and assistance in analytical work.
- Thanks to Dr. William Chavez for help with petrography.

Questions?