COLORADO GEOLOGICAL SURVEY

Research Notes RN-05
Reconnaissance of Critical Minerals in Denver Formation Coal-bearing Strata, Denver Coal Region, Ramah-Fondis Coal Field, Colorado

Citation

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ABOUT THIS REPORT

From the abstract:
"Coal and coal-related stratigraphy may contain elevated concentrations of critical minerals and/or materials as defined by the U.S. Geological Survey and U.S. Department of Energy. Based on recent limited sampling results, Late Cretaceous-Paleocene Denver Formation coal in the Denver Basin contains elevated concentrations of rare earth elements (REEs) ranging from 359 to 1,026 parts per million total REEs. Elevated concentrations of REEs occur in lignite dominated beds of the Upper Paleocene portion of the Denver Formation within the Ramah-Fondis coal field located in the Denver Coal Region. These REE concentrations are higher than most of the concentrations reported for coals and coal-related stratigraphy in the Uinta and Greater Green River coal regions in western Colorado. Shallow (<150-feet of overburden) Denver Formation lignite occurs in a wide area (> 660 square miles), in four informal coal zones from ~1 to 30 feet thick, and contain abundant partings including tonstein, clay (especially kaolinite), and other lithologies."

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RESEARCH NOTES 05

Reconnaissance of critical minerals in Denver Formation coal-bearing strata, Denver Coal Region, Ramah-Fondis coal field, Colorado

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2026

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DISCLAIMER AND ACKNOWLEDGEMENTS

The material presented here is from a limited study and intended for general information purposes only. Those making use of or relying upon the material, previous exploration results, results of this investigation, and any other information provided herein assume all risks and liability arising from such use or reliance. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the Colorado Geological Survey and Colorado School of Mines.

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ABSTRACT

Coal and coal-related stratigraphy may contain elevated concentrations of critical minerals and/or materials as defined by the U.S. Geological Survey and U.S. Department of Energy. Based on recent limited sampling results, Late Cretaceous-Paleocene Denver Formation coal in the Denver Basin contains elevated concentrations of rare earth elements (REEs) ranging from 359 to 1,026 parts per million total REEs. Elevated concentrations of REEs occur in lignite-dominated beds of the Upper Paleocene portion of the Denver Formation within the Ramah-Fondis coal field located in the Denver Coal Region. These REE concentrations are higher than most of the concentrations reported for coals and coal-related stratigraphy in the Uinta and Greater Green River coal regions in western Colorado. Shallow (<150-feet of overburden) Denver Formation lignite occurs in a wide area (>660 square miles), in four informal coal zones from ~1 to 30 feet thick, and contain abundant partings including tonstein, clay (especially kaolinite), and other lithologies. Although the lignite might not be a resource with regards to electricity generation, it could be a potential resource with regards to REEs - the deposits are widespread, at a relatively shallow depth, and may contain sufficient tonnage to be a resource albeit at a lower concentration than other conventional economic REE deposits. In order to better determine the potential for REE resources in the Denver Coal Region, future investigations should include: additional sampling and analysis of available coal seams in the Denver Formation as well as the Upper Cretaceous Laramie Formation coals; mineralogical studies to determine the mode of REE occurrence; extraction/recovery tests to determine the recovery potential of REEs; and additional assessment of other potential REE-bearing formations in the region including the Fox Hills Sandstone and the Denver Basin Group D1/D2 regional paleosol.

INTRODUCTION AND BACKGROUND

Coal and coal-related stratigraphy may contain elevated concentrations of critical minerals especially with regards to the rare earth elements (REEs) (Nassar and Fortier, 2021; Nassar and others, 2025; DOE, 2023). The U.S. Department of Energy (DOE) determined that relatively large potential resources of REEs may exist in some U.S. coal deposits, and/or in the byproducts of coal combustion (e.g., fly ash), but these potential resources likely vary significantly by location (DOE, 2017; DOE, 2022). With the assistance of the Colorado Geological Survey (CGS), the University of Wyoming and University of Utah each conducted DOE funded carbon ore, rare earth, and critical mineral (CORE-CM) investigations in select coal regions in Colorado to determine if coal, and related deposits, contain elevated concentrations of critical minerals. These investigations were mainly conducted within the Greater Green River Coal Region (Sand Wash Basin) and Uinta Coal Region (Piceance Basin), Colorado (**Figure 1**), and the results are provided in University of Wyoming (2024) and Coe and others (2024).

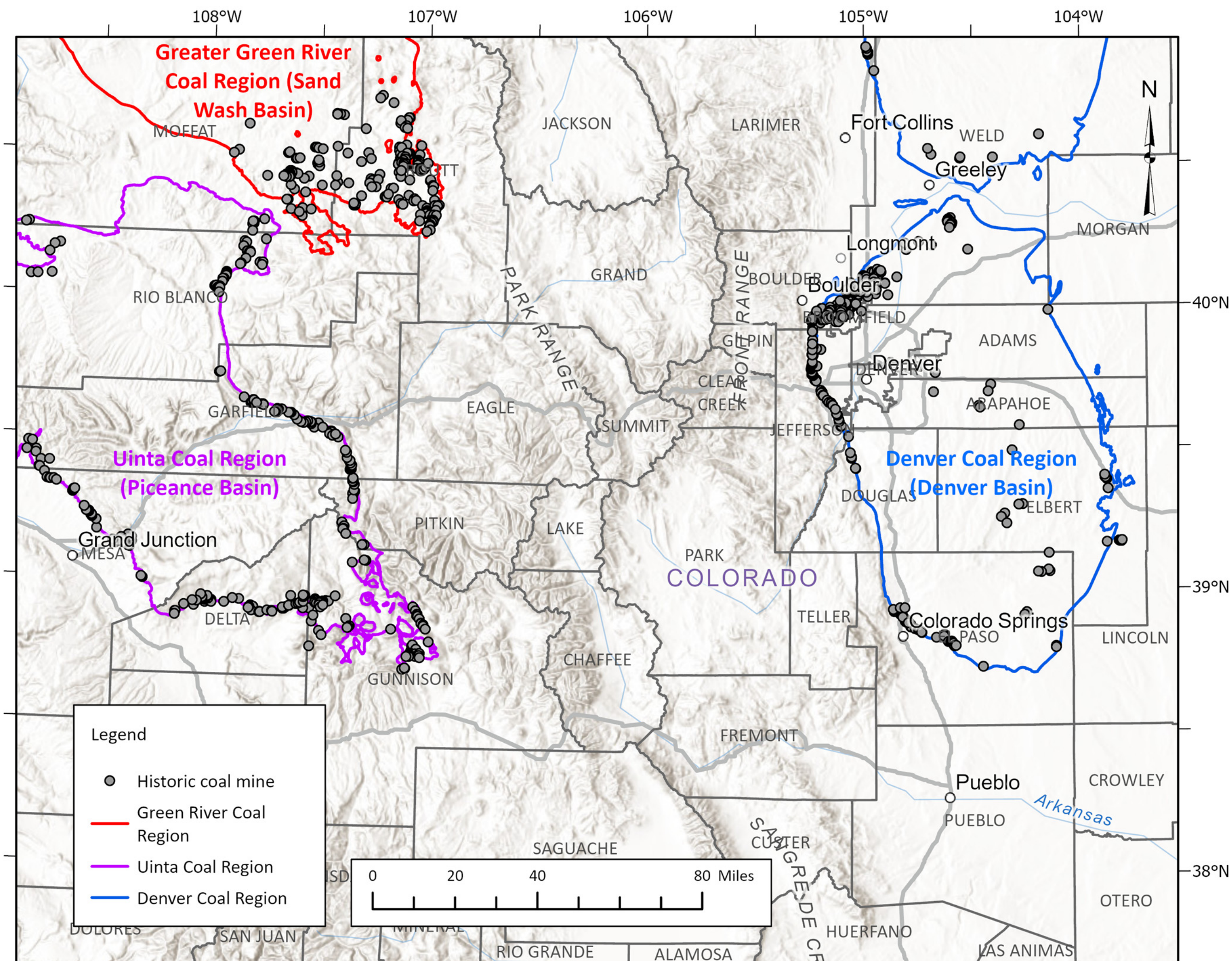


__Figure 1__ – Location of select Colorado coal regions where recent CORE-CM projects were completed. These investigations concentrated on coal fields in northwest and western Colorado. Historic coal mines (Carroll and Bauer, 2001) are also shown.

A limited investigation (10 samples from one exposure) was also conducted on the Late Cretaceous-Paleocene Denver Formation coal deposits in the Denver Basin (**Figure 2**) by the CGS. Although the Denver Formation coals are dominantly lignite and are not currently economic coal targets (nor have they been extensively mined in the past), these deposits contain other characteristics (e.g., mudstones, altered volcanic ash/kaolinite, partings) associated with elevated critical minerals (e.g., REEs) observed in other coal regions. For example, lignite deposits below kaolinitic zones in the Bear Den Member of the Paleocene Golden Valley Formation in North Dakota contain elevated concentrations of REEs well over the DOE proposed commercial viability benchmark of ~300 parts per million (ppm) total REEs (Moxness and others, 2023; 2025). Additionally, the Denver Formation coal seams may be relatively accessible to mining operations as they occur at the surface to <150 feet deep in a relatively large area as shown on **Figure 3**.

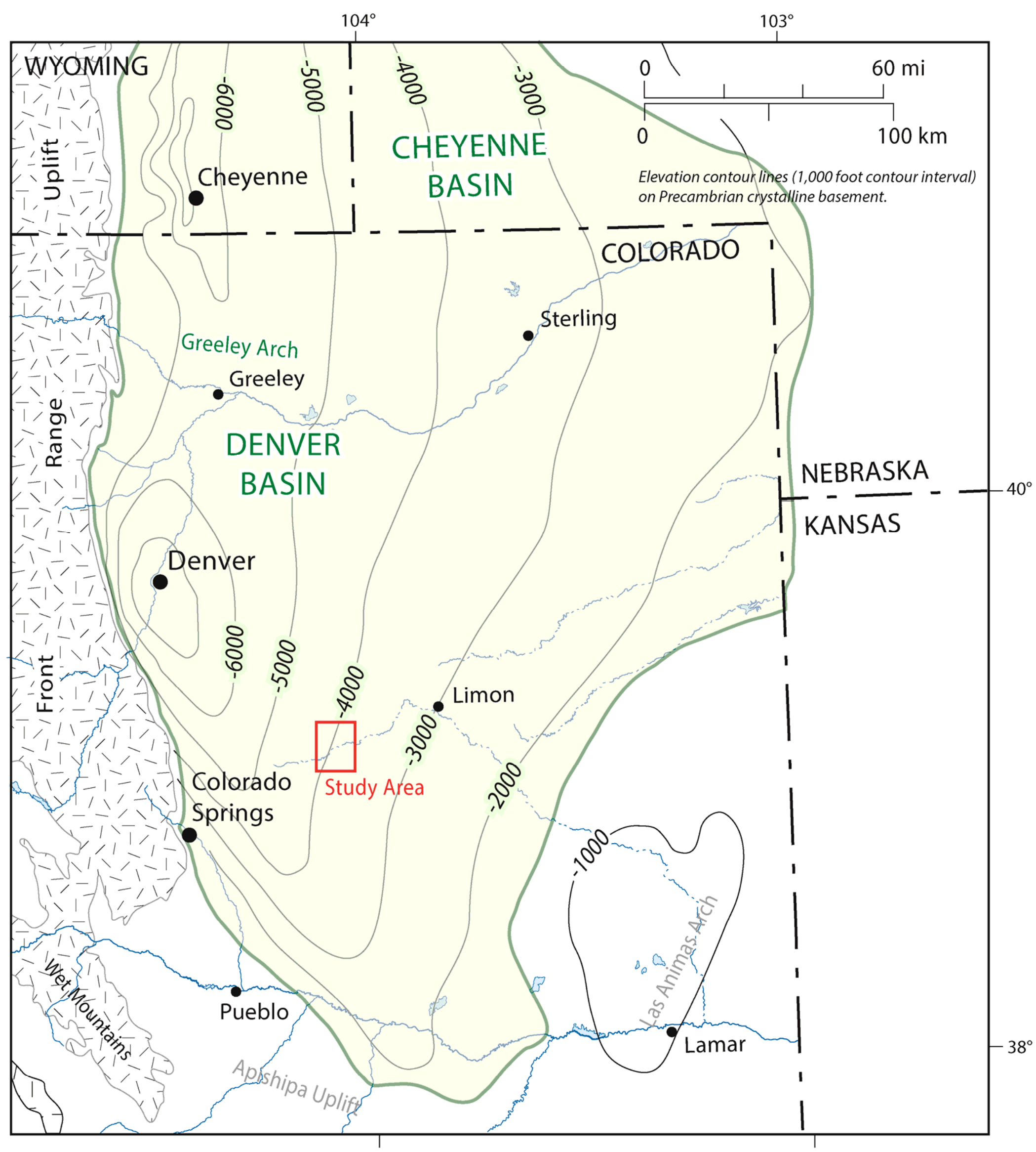


Figure 2 – *Location of the Ramah-Fondis coal field (study area) within the Denver Basin (modified from O'Keeffe and others, 2020).*

The CGS collected samples from an exposure of these deposits in the Ramah-Fondis (Ramah) coal field, Denver Coal Region, in the Denver Basin (**Figure 2** and **3**). The results of the CORE-CM investigation in the Greater Green River and Denver coal regions are included in the final report submitted by the University of Wyoming (2024) to the DOE. Of the >420 sample results, four of the top ten total REE concentrations (ranging from ~580 to 1,026 ppm) were detected in samples collected from the Denver Formation lignite (the highest total REE concentration detected was ~1,313 ppm from an area in Wyoming). Although a summary of the results is provided in the University of Wyoming (2024) report, this document includes more details associated with the Denver Formation sampling, a detailed presentation of the results, and recommendations for future work.

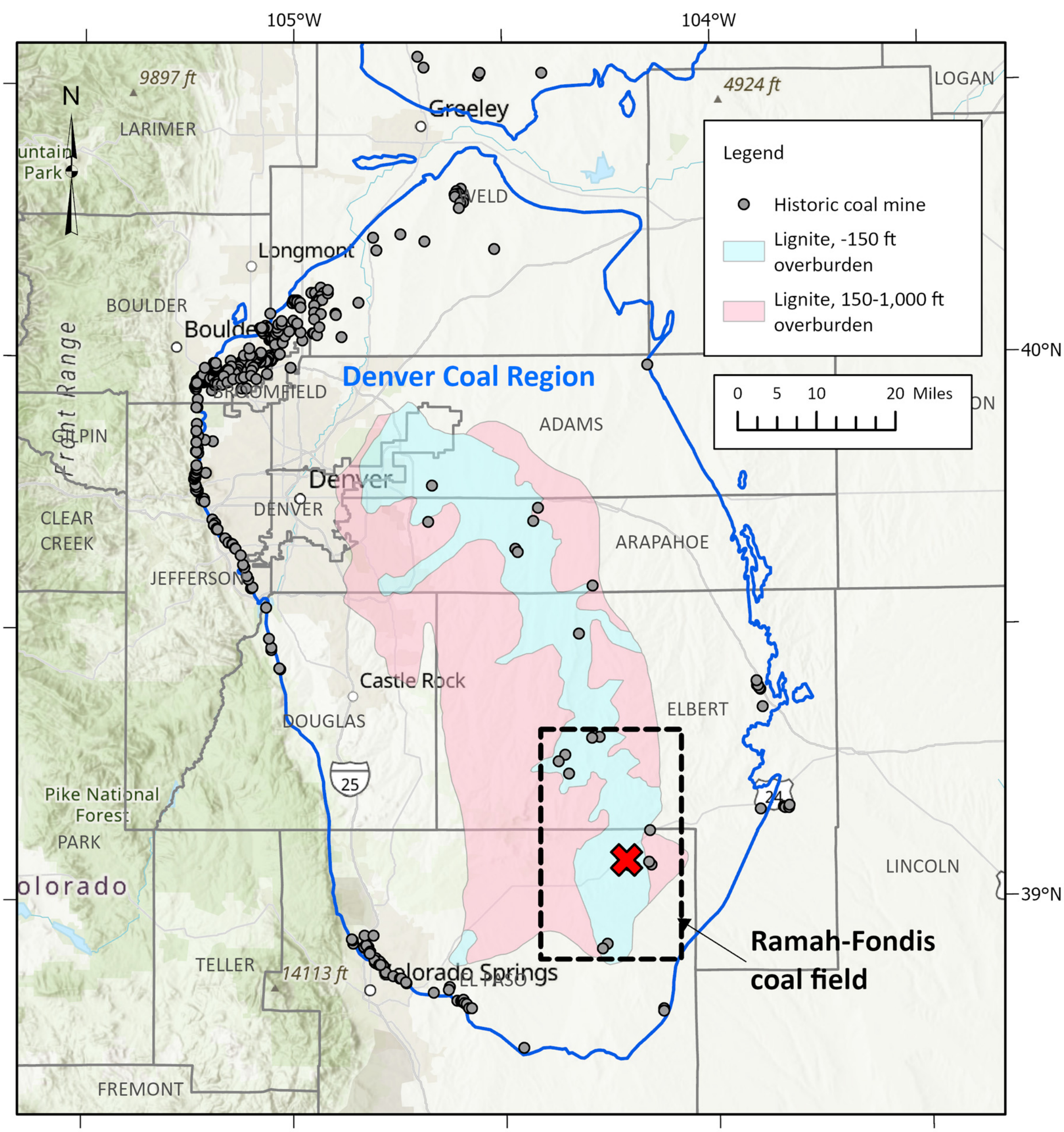


Figure 3 – Ramah-Fondis coal field and sampling location map (red X) showing the general extent of Denver Formation lignite at depth (Carroll, 2006). The historic mines shown on the western edge of the region are associated with the Laramie Formation.

Background

The Denver Coal Region extends into Wyoming and includes the Denver and Cheyenne basins which are separated by the Greeley arch where the coal-bearing formations have been eroded (Carrol, 2004) (**Figure 2**). The Denver Basin (or Denver-Julesburg Basin, DJ Basin) is an asymmetric foreland basin that formed during the Laramide uplift of the Front Range between the Late Cretaceous and the middle Eocene (**Figure 2**) (Deschesne and others, 2011). Coal deposits in the Denver Basin occur in the Denver Formation, Denver Basin Group, and the lower portion of the underlying Cretaceous Laramie Formation. Although no coal mining currently occurs in this coal region, about 135 million tons of coal were produced from ~385 primarily underground mines between 1864 and 1988 (Carroll, 2004). Most of the coal was produced from the Laramie Formation due to its better quality and, to a much lesser extent (likely less than 0.1% according to Soister [1974]), the Denver Formation.

Coal seams occur in the Upper Paleocene portion of the Denver Formation within the Denver Basin Group (**Figure 4**). Denver Basin Group deposits represent a change from a "*low-relief coastal plain (Upper Cretaceous Laramie Formation) to a more dynamic fluvial plain dominated by the Front Range immediately to the west*" (Dechesne and others, 2011; page 8) within the Denver Basin. The Denver Formation spans the K/Pg boundary, is associated with the D1 sequence of the Denver Basin Group (Raynolds, 2002; Deschesne and others, 2011) (**Figure 4**), and ranges in thickness between 600 to 1,580 feet. In the southern portion of the Denver Basin, in the Ramah-Fondis coal field and beyond, a regional paleosol occurs between the upper Denver Formation (D1 sequence) and the Eocene Dawson Formation (D2 sequence) within the Denver Basin Group (Raynolds, 2002; Deschesne and others, 2011) (**Figure 4**).

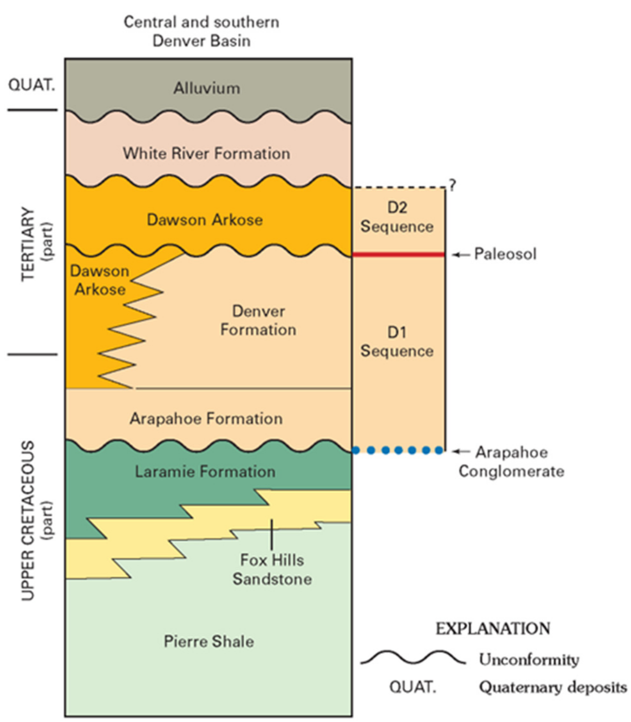


Figure 4 *– General stratigraphy of the central and southern Denver Basin, Colorado from Roberts (2007). The Denver Group includes the D1 and D2 sequence. Coal occurs in both the Laramie and Denver Formation.*

The Denver Formation consists primary of claystone, siltstone, and fine-grained sandstone but also contains minor conglomerates as well as local lava flows along the Front Range (Nichols, 1999). Coal beds and carbonaceous shale occur in the upper 300 to 500 feet (Upper Paleocene) portion of the Denver Formation east of the basin axis (Kirkham and Ladwig, 1979; Tremain and others, 1996; Nichols, 1999). A portion of the coal lies within 200 feet of the surface, with a few outcrops at the surface, however, overburden thicknesses are variable in the area due to local stream erosion (Nichols, 1999). Carrol (2006) indicates that a portion of the Denver Formation occurs <150-feet from the surface in an area extending from El Paso to Adams County as shown in **Figure 3**.

As reported by Eakins and Ellis (1987), thicknesses of the coal zones within the Ramah field are variable, lenticular, and range from 1 to 30 feet thick although most have much lower average thicknesses. Four informal coal zones were identified in this area including, from bottom to top, the Bijou, Kiowa, Comanche, and Wolf (**Figure 5**) based on drill hole data and their thicknesses range from 1-19, 1-26, 1-30, and 1-19 feet, respectively (Eakins and Ellis, 1987). Nichols (1999) indicates the principal beds range in thickness from 5 to 10 feet while the Wolf bed is the thickest and ranges between 18 and 28 feet thick. Thinner lignite beds also occur.

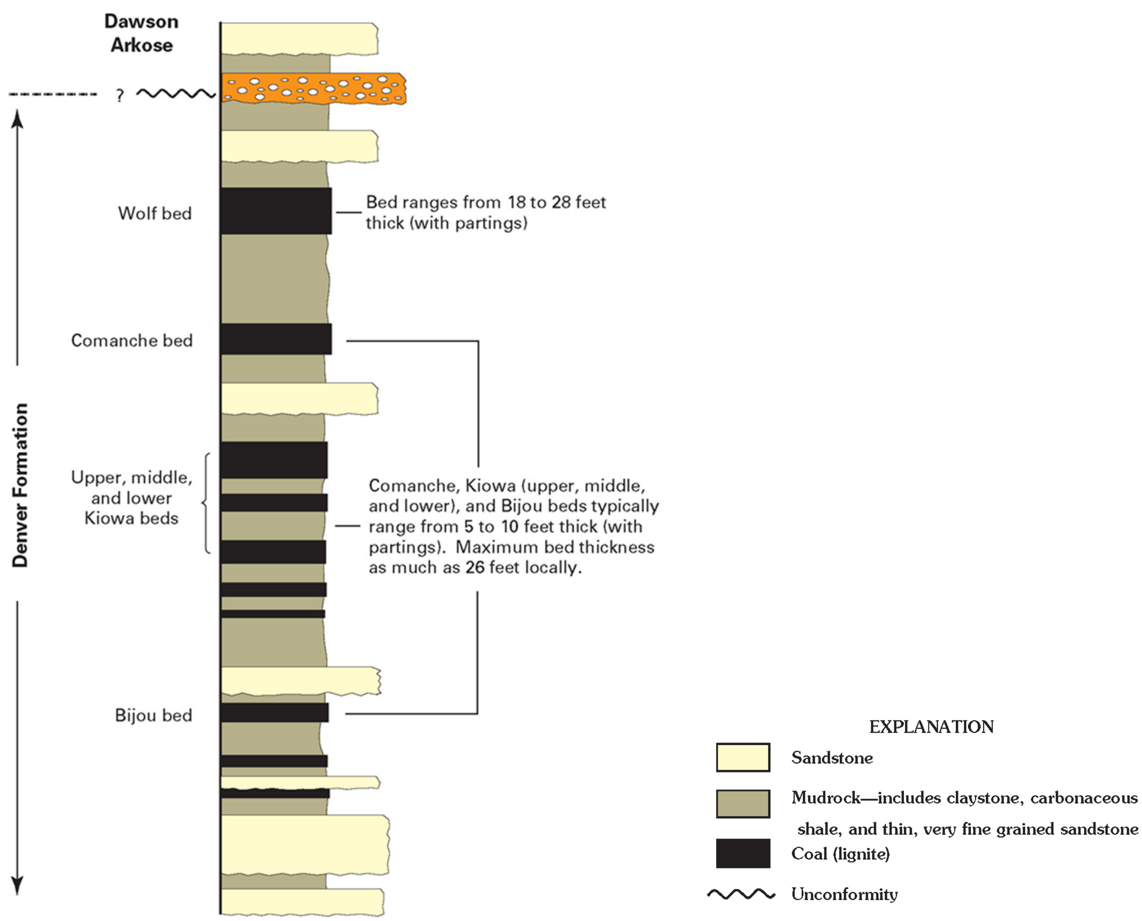


Figure 5 *– General stratigraphy and coal bed nomenclature of the Denver Formation, Ramah-Fondis coal field, Denver Basin Coal Region, Colorado (from Roberts, 2007).*

As reported by several authors (Soister, 1974; Kirkham and Ladwig, 1979; Nichols, 1999), the Denver Formation coal beds are primarily lignite with less subbituminous coal. The lignite beds contain abundant partings between < 1 inch to more than 2 feet, which are primarily clay but also include volcanic ash, clay, claystone, siltstone, or clayey/silty sandstone (Kirkham and Ladwig, 1979; Nichols, 1999). The number of partings varies from a couple to dozens and can vary laterally (Kirkham and Ladwig, 1979). Reportedly, the clay partings range from 3 to 4-inches thick and are primarily kaolinite, a potential source of aluminum. Partings can range from 5 to 30% of the total thickness of a bed. As described by Kirkham and Ladwig (1979; page 58):

> "*Denver Formation lignite is brownish-black to black, and weathers, slacks, and disintegrates rapidly. Quality of the lignite varies dure to the number and thickness of non-coal partings and the physical character and rank of pure lignite. Most analyses indicate the lignite ranks as lignite A, however, thin intervals within thick lignite beds may rank as high as subbituminous C coal. The Comanche bed of the southern lignite area appears to be the highest quality lignite bed in the entire Denver Formation.*"

Analyses of lignite beds from the Denver Formation across the Denver Basin generally indicate (as-received basis): heat values between 4,000-7,500 British thermal units (btu) per pound (lb), 22-40% moisture, 8-30% ash, and 0.2-0.6% sulfur (Kirkham and Ladwig, 1979). Historic coal mines in the Ramah coal field (**Figure 3**) produced a small amount (3,047 tons) of coal from the Denver Formation between around 1909 to 1940 (Kirkham and Ladwig, 1979). About nine mines operated during this time. Lignite reserves in the Ramah area were estimated at 474 million tons (Soister, 1974; Landis, 1959). Kirkham and Ladwig (1979), based on a comparison of previous estimates, indicate that there is potentially 10 to 15 billion tons of Denver Formation lignite within the entire Denver Basin (includes the Ramah and several other coal fields) within beds >4 feet thick and <1,000 feet deep.

Samples were collected and analyzed from a Denver Formation coal seam within the Ramah-Fondis coal field to determine if elevated concentrations of critical minerals occur within these coals and related stratigraphy. Ten samples were collected from a coal bed at an exposure (**Figure 3** and **6**) located between Calhan and Ramah, El Paso County, Colorado. Based on Eakins and Ellis (1987; Plate 12B), the outcrop likely contains a portion of the Kiowa coal bed (**Figure 5**) and is near the historic Purdon Coal Mine (Soister, 1974). A detailed geologic log of the outcrop is provided in **Appendix A**.

About 12.5 feet of Denver Formation is exposed at this location and capped by sandy soil and interbedded mudstone, siltstone and eroded Denver Formation lignite (**Figure 6**). Samples were collected along a ~9.4-foot-long channel excavated exposing the less weathered material at depth. The upper ~3 feet of the outcrop was not sampled as only minor beds of lignite occurred in this interval. Two- to 23-inch-long channel samples were collected from the outcrop based on field observations. Lignite seams appeared to extend below the exposure but were not sampled.

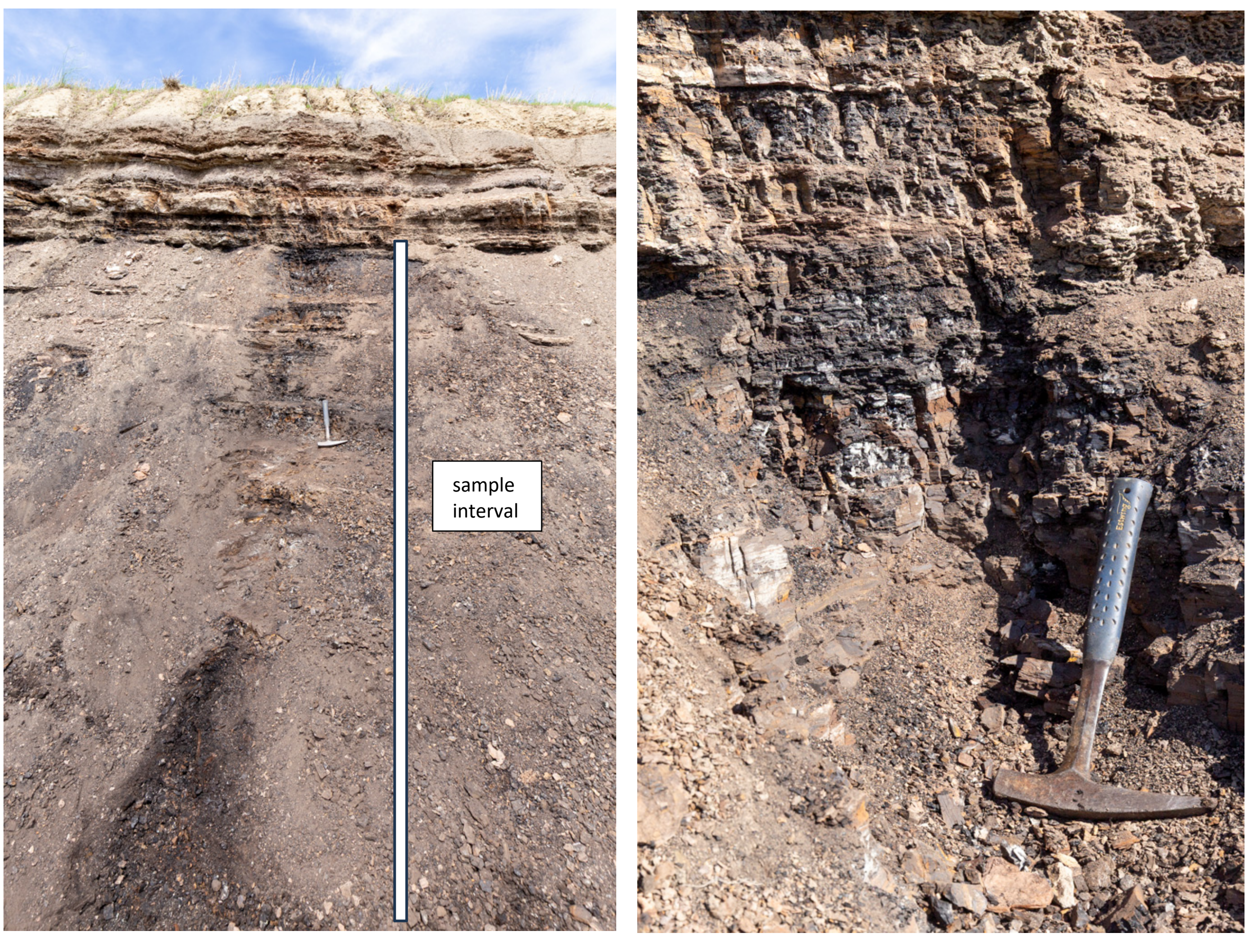


Figure 6 *– Photos of the Denver Formation coal sampling location in the Ramah-Fondis coal field. Hammer is ~13-inches long. Left: Channel samples collected from the area mostly below the ledge in the upper portion of the photo (first sample collected at the ledge base in carbonaceous mudstone, see Figure 5 sample GRCO-OC-23-DB-01). Right: Close-up of the Denver Formation lignite showing fractures, numerous partings, iron oxides, and weathered nature of the outcrop.*

Due to the numerous partings, some of the samples included multiple lithologies. The coal exposure is mostly weathered, fractured, and friable lignite with abundant partings (**Appendix A**). Partings include mudstone, carbonaceous mudstone, silty mudstone, tonstein and/or clay. Abundant secondary iron oxides and/or gypsum were frequently observed in fractures (**Figures 7** through **9**). Some partings appeared to be tonstein (**Figure 8** and **9**) but it was difficult to confirm if these layers were altered volcanic ash in the field. A summary of the geologic log is included in **Table 1**.

Location	Formation	Sample ID	Interval (inches)	Thickness (inches)	Graphic Log	Rock Type	Description
Denver Coal Region, Ramah/Fondis coal field, Colorado (39.08362, -104.22093)	Denver Formation	GRCO-OC-23-DB-01	73-80	7		Carbonaceous mudstone	Mudstone, brown to gray, coal laminations, plant debris, iron oxide on fractures, fissle, shaly.
		GRCO-OC-23-DB-02	80-91	11		Carbonaceous mudstone, lignite	Sample includes 4" of carbonaceous mudstone, 3" of lignite, and 4" of carbonaceous mudstone. Carbonaceous mudstone includes coal laminations, gypsum/iron oxide on fractures. Lignite is brown to black, cleats, weathered, gypsum/iron oxide on fractures.
		GRCO-OC-23-DB-03	91-110	19		Lignite	Lignite, brownish black to black, gypsum and yellowish brown iron oxide on fractures, very weathered, cleats, mostly dull with some bright coal.
		GRCO-OC-23-DB-04	110-113	3		Clay (tonstein?), carbonaceous mudstone	Two layers of tonstein? with 1" carbonaceous mudstone in between, tonstein is buff, lensic, iron oxide stained, fissile, platy clay with silt.
		GRCO-OC-23-DB-05	113-122.5	9.5		Lignite, tonstein?	Lignite with 1" layer of buff tonstein.
		GRCO-OC-23-DB-06	122.5-124.5	2		Tonstein?, lignite	Two beds of tonstein? with 1-2" of lignite, buff, lensic, friable, coal laminations, platey clay with little silt.
		GRCO-OC-23-DB-07	124.5-139.5	15		Lignite	Lignite with trace interbed of tonstein?, black to brownish black, interbeds of carbonaceous mudstone, weathered, gypsum and reddish brown iron oxides on fractures.
		GRCO-OC-23-DB-08	139.5-152.5	13		Lignite, carbonaceous mudstone, tonstein?	Mostly lignite with ~1.5 inches total of two or three tonstein? layers and 2" of carbonaceous mudstone. Lignite is brown to dark gray to black, fractured, iron oxides on fractures. Tonstein? layers are light to dark brown to buff to light pinkish, friable, fissle, clay with little silt, iron oxide and gypsum on fractures. Carbonaceous mudstone is black, coal limainations, clayey, with iron oxide and gypsum in fractures.
		GRCO-OC-23-DB-09	152.5-162.5	10		Lignite	Lignite, black to brownish black, cleats, reddish to yelllowish brown iron oxide and gypsum on fractures, mostly dull with little bright, trace reddish brown resin, blocky, conchoidal fractures.
		GRCO-OC-23-DB-10	162.5-185.5	23		Lignite	Lignite, black to brownish black, cleats, reddish to yelllowish brown iron oxide and gypsum on fractures, mostly dull with little bright, trace reddish brown resin, blocky, conchoidal fractures. Small (1-inch) carbonaceous mudstone at base.

NOTE: Channel samples from the top to road grade stratigraphically at the outcrop.

***Table 1** – Sampling and geological summary of the Denver Formation coal seam sampling site, Ramah-Fondis coal field, Denver Basin, Colorado. See **Appendix A** for the detailed geologic log.*

Figure 7 *– Close-up photo of the Denver Formation lignite exposure (scale is in millimeters) showing fractured nature of the lignite, iron oxides, and gypsum (white).*

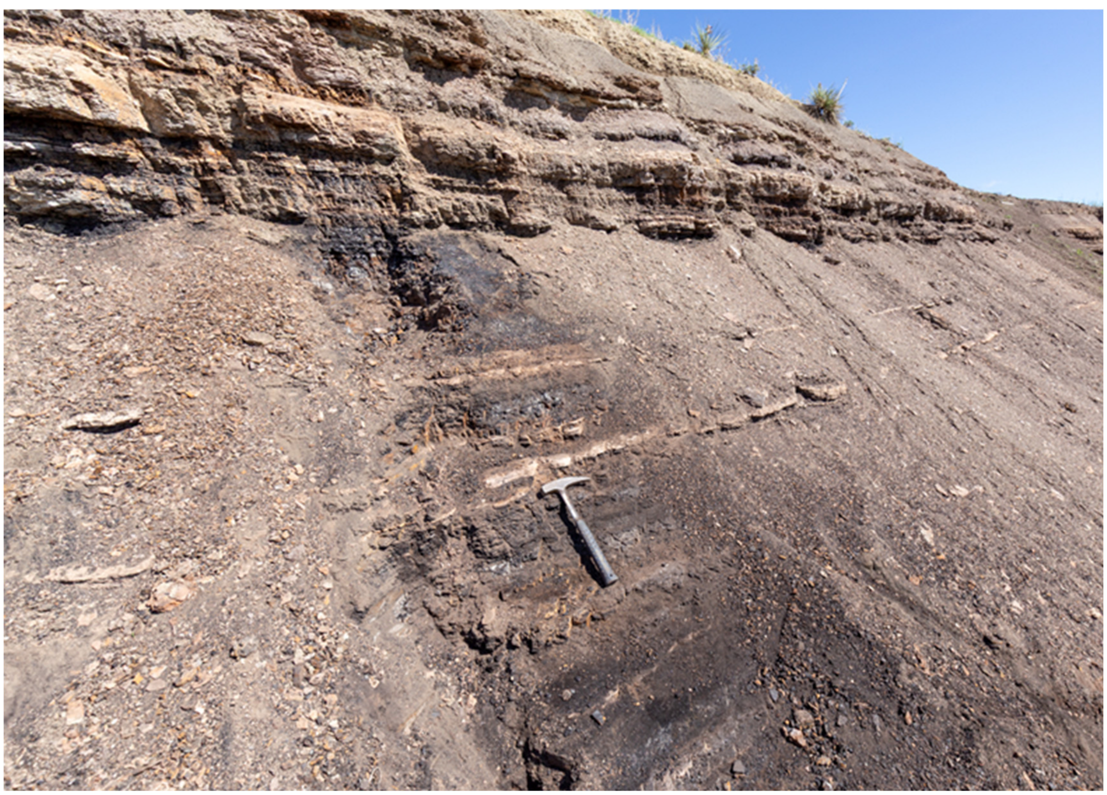


Figure 8 *– Photo of continuous clay and/or tonstein layers (light colored layer above the hammer) in the Denver Formation lignite (hammer is ~13-inches long).*

***Figure 9** – Close-up photo of the clay and/or tonstein layers shown in Figure 6 (hammer is ~13-inches long).*

Samples were collected in clean labeled plastic double bags and provided to the University of Wyoming for analysis. The mass of individual samples collected was at least 100-200 grams of material to generate at least 5 grams of coal ash necessary for major and trace element analyses. Samples were first ashed to drive off volatile matter prior to whole rock and trace element analyses. Most of the ashing was conducted by either ALS Global (ALS) (Brisbane, Australia) or Hazen Research in Golden, CO, following ASTM International standards (University of Wyoming, 2024; see Appendix 2b and 2c). Trace elements were determined by inductively coupled plasma mass spectrometry (ICP-MS) and oxides by ICP-AES (atomic emission spectrometry). Most of the sample analyses were carried out at ALS in Vancouver, British Columbia, Canada, following ashing and further preparation at ALS in Reno, NV (University of Wyoming, 2024).

The major and trace element laboratory results are summarized in **Tables 2, 3**, and **4**. Lignite dominant intervals are high-ash lignite (e.g., ash > 15%; Wood and others, 1983) with ash contents ranging from 13.19 to 21.03%. A few lignite intervals are medium-ash coal (8 to 15% ash) (**Table 2**). The ash contents of the parting-rich beds ranged from 36.42 to 62.17%. Lignite coal classes could not be verified because the calorific value was not measured. However, most of the coal appears to be lignite with interbedded subbituminous C coal in places.

Elevated concentrations of SiO_2 (~44.3-55%) and Al_2O_3 (~32.6-40.1%) in the non-lignite samples indicate the presence of quartz sand, feldspar, and clay in these samples (**Table 2**). Elevated aluminum concentrations may be associated with clay-rich partings, especially kaolinite as determined in past investigations. As reported by Kirkham and Ladwig (1979), the kaolinite-rich partings comprise 5 to 30% of the total lignite bed thickness in places and could potentially be a source of aluminum. Total REE (TREE) concentrations of all the samples ranged from 140.7 to 1,026.3 ppm with mean and median concentrations of 452 and 372 ppm, respectively (**Table 3**). Samples collected from the lignite dominant zones generally had the highest TREE concentrations enriched in light REEs (LREE) ranging from ~384.9 to 1,026.3 ppm. The highest TREE concentration was detected in the 10-inch channel sample located near the base of the outcrop. This interval is dominantly lignite with iron oxide and gypsum filled fractures where traces of reddish-brown resin-like material were observed. The highest concentrations of barium, strontium, and uranium were also observed in this interval (**Table 4**) which may indicate the presence of uranium-bearing celestite ($SrSO_4$) and/or barite ($BaSO_4$) in this interval. Analysis of samples from the lignite-dominant intervals general indicates the presence of high-barium coals >750 ppm (Hao and others, 2022).

The lignite samples containing relatively higher TREE samples are enriched in LREE with several reported concentrations over five times the bulk continental crust concentrations as reported by Taylor and McClennan (2003) (**Table 3**). Analyses of two intervals containing abundant partings detected elevated but relatively lower TREE concentrations (355.8 and 359.1 ppm) when compared to the lignite samples. Additional elevated concentrations of strontium, a critical mineral, were also detected in these samples (**Table 4**). Other critical minerals were detected at five times the bulk continental crust concentration including barium (6 samples), strontium (5 samples), tungsten (3 samples), zirconium (2 samples), and niobium (1 sample). Elevated concentrations of thorium and uranium were also detected in 5-6 samples (**Table 4**).

Sample ID	Interval (inches)	Thickness (inches)	Graphic Log	Rock Type	Ash Content	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	Total	LOI
GRCO-OC-23-DB-01	73-80	7		Carbonaceous mudstone	na	44.3	32.6	0.87	0.59	0.31	0.22	0.39	<0.002	1.04	0.01	0.03	0.01	0.04	101.61	21.2
GRCO-OC-23-DB-02	80-91	11		Carbonaceous mudstone, lignite	46.96	50.8	37	1.53	4.65	0.45	0.44	0.61	0.003	1.66	0.03	0.06	0.06	0.07	99.89	2.53
GRCO-OC-23-DB-03	91-110	19		Lignite	13.19	28.8	21	6.81	25	1.54	1.2	0.22	0.003	1.2	0.11	0.73	0.4	0.54	91.67	4.12
GRCO-OC-23-DB-04	110-113	3		Clay (tonstein?), carbonaceous mudstone	57.14	55	35.5	1.29	1.98	0.29	0.34	1	<0.002	2.04	0.01	0.06	0.03	0.05	99.46	1.87
GRCO-OC-23-DB-05	113-122.5	9.5		Lignite, tonstein?	17.51	40.9	31	3.9	14.9	0.78	0.56	0.37	0.012	1.11	0.06	1.38	0.39	0.47	98.09	2.26
GRCO-OC-23-DB-06	122.5-124.5	2		Tonstein?, lignite	62.17	51.9	40.1	1.6	3.02	0.4	0.22	0.3	<0.002	1.57	0.01	0.06	0.05	0.16	101	1.61
GRCO-OC-23-DB-07	124.5-139.5	15		Lignite	14.29	37.3	29.9	3.32	16.9	1.08	0.69	0.36	0.006	1.69	0.07	0.08	0.21	0.18	94.23	2.49
GRCO-OC-23-DB-08	139.5-152.5	13		Lignite, carbonaceous mudstone, tonstein?	36.42	48.3	37.3	2.14	5.58	0.42	0.41	0.55	0.003	1.49	0.03	0.1	0.07	0.1	98.71	2.22
GRCO-OC-23-DB-09	152.5-162.5	10		Lignite	18.27	28.7	23.9	5.56	22.3	1.08	0.75	0.17	0.002	1.16	0.08	2.52	0.64	0.68	90.01	2.47
GRCO-OC-23-DB-10	162.5-185.5	23		Lignite	21.03	39.3	28.2	4.7	14.4	0.76	0.33	0.31	0.003	1.43	0.05	0.12	0.19	0.28	92.84	2.77

NOTES: Channel samples from the top downward stratigraphically at the outcrop. All results in %. LOI - loss on ignition

Table 2 *– Major element laboratory results (ash basis) by XRF analysis, Ramah-Fondis coal field, Denver Basin, Colorado.*

Sample ID	Interval (inches)	Thickness (inches)	Graphic Log	Rock Type	Total REE	Total LREE	Total HREE	LREE/HREE ratio	LREE							HREE							
									La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
GRCO-OC-23-DB-01	73-80	7		Carbonaceous mudstone	140.7	120.9	19.8	6.1	27.4	54.5	6.58	24	4.19	1	3.23	0.48	2.84	0.55	1.37	0.22	1.5	0.22	12.6
GRCO-OC-23-DB-02	80-91	11		Carbonaceous mudstone, lignite	355.8	297.4	58.5	5.1	65.5	132	16.3	60.3	11.9	2.8	8.66	1.3	7.9	1.53	4.35	0.61	3.84	0.62	38.3
GRCO-OC-23-DB-03	91-110	19		Lignite	582.5	468.9	113.6	4.1	109.5	205	24.1	93.9	17.1	4.37	14.95	2.18	13.2	2.64	7.37	1.13	6.66	1.05	79.4
GRCO-OC-23-DB-04	110-113	3		Clay (tonstein?), carbonaceous mudstone	121.5	96.9	24.6	3.9	18.1	43.2	5.56	21.1	4.6	1.09	3.23	0.53	3.15	0.61	1.89	0.31	2.09	0.31	15.7
GRCO-OC-23-DB-05	113-122.5	9.5		Lignite, tonstein?	762.8	648.7	114.1	5.7	162.5	293	32	118.5	20.6	5.03	17.05	2.49	14.9	2.95	8.13	1.17	7.41	1.13	75.9
GRCO-OC-23-DB-06	122.5-124.5	2		Tonstein?, lignite	207.4	175.3	32.1	5.5	37.4	79.3	9.71	35.8	6.45	1.68	4.98	0.78	4.38	0.81	2.28	0.36	2.36	0.39	20.7
GRCO-OC-23-DB-07	124.5-139.5	15		Lignite	579.5	472.4	107.1	4.4	101	217	25	93.8	17.5	4.28	13.8	2.09	12.7	2.69	7.71	1.14	7.4	1.22	72.2
GRCO-OC-23-DB-08	139.5-152.5	13		Lignite, carbonaceous mudstone, tonstein?	359.1	307.0	52.1	5.9	70.2	137.5	16.6	60.7	11.1	2.9	8.09	1.24	7.18	1.36	3.78	0.61	3.66	0.56	33.7
GRCO-OC-23-DB-09	152.5-162.5	10		Lignite	1026.3	904.0	122.4	7.4	277	393	41.5	145.5	22	5.62	19.35	2.62	15.7	3.01	7.97	1.2	7.38	1.13	83.4
GRCO-OC-23-DB-10	162.5-185.5	23		Lignite	384.9	317.1	67.9	4.7	69.6	142	17.1	64.3	11.7	2.85	9.56	1.43	8.56	1.68	4.76	0.72	4.66	0.74	45.3
Bulk continental crust (Taylor and McLennan, 2003, see Table 4)									16	33	3.9	16	3.5	1.1	3.3	0.6	3.7	0.78	2.2	0.32	2.2	0.3	20

NOTES: Channel samples from the top downward stratigraphically at the outcrop. All results in ppm. HREE - heavy REEs, LREE - light REEs, TREE - total REEs.
Gray highlighted results indicate results equal to or greater than 5x the bulk continental crust concentrations reported by Taylor and McLennan (2003).

***Table 3** – REE trace element laboratory results (ash basis) by ICP-MS analysis, Ramah-Fondis coal field, Denver Basin, Colorado.*

Sample ID	Interval (inches)	Thickness (inches)	Graphic Log	Rock Type	Other elements (light blue = critical minerals)																								
					Ba	Co	Cr	Cs	Cu	Ga	Ge	Hf	Mo	Nb	Ni	Pb	Rb	Sb	Sc	Sn	Sr	Ta	Te	Th	Ti	U	V	W	Zn	Zr
GRCO-OC-23-DB-01	73-80	7		Carbonaceous mudstone	365	na	7	0.59	na	41.3	na	6.19	na	28.2	na	na	10.4	na	8	1.8	114	1.6	na	12.7	0.71	2.98	69	1.6	na	236
GRCO-OC-23-DB-02	80-91	11		Carbonaceous mudstone, lignite	617	na	25	0.51	na	54.1	na	12.2	na	41.5	na	na	14.4	na	18.3	4.1	535	2.4	na	22.8	1.12	5.14	157	3.1	na	487
GRCO-OC-23-DB-03	91-110	19		Lignite	4860	na	37	0.18	na	51.2	na	10.6	na	40.6	na	na	6.1	na	20.7	3.5	3490	1.8	na	19.3	0.81	5.48	170	11.2	na	432
GRCO-OC-23-DB-04	110-113	3		Clay (tonstein?), carbonaceous mudstone	473	na	11	0.59	na	52.6	na	10.5	na	41.4	na	na	20.9	na	13.2	4.6	275	2.4	na	17.3	1.33	4.13	100	2.5	na	434
GRCO-OC-23-DB-05	113-122.5	9.5		Lignite, tonstein?	4390	na	90	0.38	na	48.3	na	11.4	na	41.2	na	na	9.7	na	31.8	3.3	3490	1.9	na	21.6	0.76	6.06	223	4.3	na	455
GRCO-OC-23-DB-06	122.5-124.5	2		Tonstein?, lignite	1380	na	16	0.45	na	53.5	na	11.3	na	34.9	na	na	9.8	na	14.2	3.4	444	1.7	na	19.9	1.05	4.89	154	3.6	na	464
GRCO-OC-23-DB-07	124.5-139.5	15		Lignite	1580	na	47	0.35	na	48.3	na	13.9	na	60.9	na	na	8.2	na	19.7	4	1875	3.2	na	26.4	1.14	7.16	225	2.8	na	543
GRCO-OC-23-DB-08	139.5-152.5	13		Lignite, carbonaceous mudstone, tonstein?	836	na	19	0.59	na	48.7	na	12.9	na	41.1	na	na	13.4	na	16	4.1	619	2.5	na	21.4	1	5.86	137	2.3	na	545
GRCO-OC-23-DB-09	152.5-162.5	10		Lignite	6140	na	28	0.23	na	55.4	na	10.4	na	39	na	na	4.7	na	23.9	3.3	5480	1.7	na	22.1	0.8	18.7	226	5.1	na	409
GRCO-OC-23-DB-10	162.5-185.5	23		Lignite	2440	na	34	1.41	na	47.1	na	11	na	52.2	na	na	12.6	na	18.8	4.7	1660	2.9	na	27.3	0.97	8.83	205	5	na	439
Bulk continental crust (Taylor and McLennan, 2003, see Table 4)					250	29	185	1.5	75	18	1.6	3	1	11	128	8	37	0.2	30	2.5	260	1	na	4.2	5400	1.1	230	1	80	100

NOTES: Channel samples from the top downward stratigraphically at the outcrop. All results in ppm. na - not available.
Gray highlighted results indicate results equal to or greater than 5x the bulk continental crust concentrations reported by Taylor and McLennan (2003).

***Table 4** – Other trace element laboratory results (ash basis) by ICP-MS analysis, Ramah-Fondis coal field, Denver Basin, Colorado.*

Photo of the eroded Denver Formation lignite roadcut prior to sampling. Interbedded sandstone, claystone, carbonaceous shale, and smaller lignite beds cap the slope-forming lignite. More resistant and relatively thin (2- to 3-inch thick) tonstein/clay layers form continuous ledges on the slope (e.g. center of photo, above the hammer) within the eroded lignite.

DISCUSSION AND RECOMMENDATIONS

Most of the TREE concentrations detected in the lignite and other rock types analyzed during this investigation are over the proposed DOE's commercial viability benchmark of ~300 parts per million (**Table 3**) (University of Wyoming, 2014; Moxness and others, 2025). The Denver Formation lignite deposits are not currently exploited for power generation and have not been mined since at least the 1940s. However, portions of these deposits are relatively shallow in the Ramah coal field and beyond where they occur at the surface with <150 feet of overburden in a relatively large area (Carroll, 2006) (**Figure 3**). Based on Carroll (2006), the Denver Formation lignites with less than 150-feet of overburden occur in an estimated area exceeding 660 square miles. Additionally, other Denver Formation potential lignite resources occur over 1,170 square miles between 150 and 1,000 feet deep in the Denver Basin (Carroll, 2006). Although the lignite might not be a resource with regards to electricity generation, it could be a potential resource with regards to REEs - the deposits are widespread, at a relatively shallow depth, and may contain sufficient tonnage to be a resource albeit at a lower concentration (e.g., maximum detected concentration of ~1,026 ppm TREE) than other conventional economic REE deposits (e.g., >10,000-20,000 ppm).

TREE concentrations detected in the Denver Formation lignite were similar to, but a bit less (North Dakota lignites can have significant TREE enrichment over 1,820 ppm; Moxness, 2025), than some of the more recent sampling results associated with Paleocene lignites in North Dakota (Moxness and others, 2023; Moxness and others, 2025). However, additional sampling of the Denver Formation coals and associated strata, both horizontally and vertically, may provide better results as this investigation was very limited (one roadcut, n = 10). Other outcrops, and potentially core, may exist in other, or nearby, areas of this coal field as well as others in the Denver Basin (e.g., Scranton coal field). Furthermore, most of the coal historically mined in the Denver Coal Region, including both the Denver and Cheyenne basins, was sourced from the Upper Cretaceous Laramie Formation, and was not sampled during this investigation. These coals may contain elevated concentrations of materials deemed critical by the USGS and the DOE as well.

Future work in the Denver Coal Region should include the following recommended tasks:

- Identify and sample additional Denver Formation and Laramie Formation outcrop locations and/or existing core in the Denver Coal Region including areas within the Ramah, Scranton, and other coal fields. If accessible, the well-known Kiowa core (Raynolds and others, 2001) likely contains coal from the Denver and Laramie formations. Outcrop sampling may be difficult as most exposures are on private land. A few cores containing Laramie Formation coal are at the USGS core repository (USGS, 2026; core library number R944, R945, and 948).
- Determine the mode of REE occurrence (e.g., mineralogy) in the coal-bearing and associated strata and conduct extraction/recovery tests to determine if and how REEs could be recovered from the matrix.
- Identify and sample additional potential sources of REE in the Denver Coal Region including the Upper Cretaceous Fox Hills Formation (O'Keeffe and others, 2020) and the paleosol, as well as the Denver Formation coal below these lignites, within the Paleocene portion of the Denver Basin Group. Elevated concentrations of REEs in

lignites may be associated with the leaching of these paleosols and redistribution of REEs within coal beds (Murphy and others, 2023). These formations may provide additional feedstock and/or potential resources that should be considered when determining the overall resource potential for REEs in the Denver Basin.

REFERENCES

Carroll, C.J., 2004, 2003 Summary of coal resources in Colorado: Colorado Geological Survey Publication 54, 25 p., https://doi.org/10.58783/cgs.sp54.hppp3354.

Carroll, C.J., 2006, Coal resource maps of Colorado: Colorado Geological Survey Map Series 43, https://coloradogeologicalsurvey.org/publications/coal-resource-maps-colorado.

Carroll, C.J., and Bauer, M.A., 2001, Historic coal mines of Colorado: Colorado Geological Survey Information Series 64, https://coloradogeologicalsurvey.org/publications/historic-coal-mines-colorado.

Coe, H.H., Birgenheier, L.P., Fernandez, D.P., Gall, R.D., Vanden Berg, M.D., and Giebel, A., 2024, Rare earth element enrichment in coal and coal-adjacent strata of the Uinta Region, Utah and Colorado: Frontiers in Earth Science, 26 April 2024, 17 p., https://doi.org/10.3389/feart.2024.1381152.

Deschesne, M., Raynolds, R.G., Barkman, P., and Johnson, K.R., 2011, Notes on the Denver Basin geologic maps: bedrock geology, structure, and isopach maps of the Upper Cretaceous to Paleogene strata between Greeley and Colorado Springs, Colorado: Colorado Geological Survey Open-File Report 11-01, 35 p., https://doi.org/10.58783/cgs.of1101.twrm7264.

DOE (U.S. Department of Energy), 2017, Report on rare earth elements from coal and coal byproducts: U.S. Department of Energy, Report to Congress, January 2017, 43 p., https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442%20-%20for%20Conrad%20Regis%202.2.17.pdf.

DOE, 2022, Recovery of rare earth elements and critical materials from coal and coal byproducts: U.S. Department of Energy, Report to Congress, May 2022, 85 p., https://www.energy.gov/sites/default/files/2022-05/Report%20to%20Congress%20on%20Recovery%20of%20Rare%20Earth%20Elements%20and%20Critical%20Minerals%20from%20Coal%20and%20Coal%20By-Products.pdf.

DOE, 2023, Critical materials assessment: U.S. Department of Energy, July 2023, https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals.

Eakins, W. and Ellis, M.S., 1987, Coal resources of the Castle Rock ½ degree by 1 degree quadrangle and adjacent area, Colorado: Colorado Geological Survey Resource Series 25, 135 p., https://coloradogeologicalsurvey.org/publications/coal-resources-castle-rock-quadrangle-colorado/.

Hao, H., Zhang, M., Wang, J., Fu, Z., Balaji, P., and Jiang, S., 2022, Barium in coal and coal combustion products: Distribution, enrichment and migration: Energy Exploration and Exploitation, 40 (3), p. 889-907., https://doi.org/10.1177/01445987221086981.

Kirkham, R.M. and Ladwig, L.R., 1979, Coal resources of the Denver and Cheyenne Basins, Colorado: Colorado Geological Survey Resource Series 5, 70 p., https://doi.org/10.58783/cgs.rs05.skcc9990.

Landis, E.R., 1959, Coal resources of Colorado: U.S. Geological Survey Bulletin 1072-C, 232 p., https://doi.org/10.3133/b1072C.

Moxness, L.D., Murphy, E.C., and Kruger, N.W., 2023, Critical mineral enrichment in lignites beneath the Rhame Bed (Paleocene) of the Slope Formation in the Williston Basin of North Dakota: North Dakota Geological Survey, Report of Investigation No. 134, 267 p., https://www.dmr.nd.gov/dmr/sites/www/files/documents/Survey/RI134/RI-134-Critical-Mineral-Enrichment-in-Lignites.pdf.

Moxness, L.D., Murphy, E.C., Kruger, N.W., and Chumley, A.S., 2025, Exploratory drilling for rare earth elements and other critical minerals in lignites across southwestern North Dakota: North Dakota Geological Survey, Report of Investigation No. 137, 286 p., https://www.dmr.nd.gov/dmr/sites/www/files/documents/Survey/Publications/Report_of_Investigation/RI-137.pdf.

Murphy, E.C., Moxness, L.D., and Kruger, N.W., 2023, Elevated critical mineral concentrations associated with the Paleocene-Eocene thermal maximum, Golden Valley Formation, North Dakota: North Dakota Geological Survey, Report of Investigation No. 133, 89 p., https://www.dmr.nd.gov/ndgs/documents/Publication_List/pdf/RISeries/RI-133.pdf.

Nassar, N.T. and Fortier, S.M., 2021, Methodology and technical input for the 2021 review and revision of the U.S. critical minerals list: U.S. Geological Survey, Open-file Report 2021-1045, 21 p., https://pubs.er.usgs.gov/publication/ofr20211045.

Nassar, N.T., Pineault, D., Allen, S.M., McCaffrey, D.M., Padilla, A.J., Brainard, J.L., Bayani, M., Shojaeddini, E. Ryter, J.W., Lincoln, S., and Alonso, E., 2025, Methodology and technical input for the 2025 U.S. list of critical minerals – Assessing the potential effects of mineral commodity supply chain disruptions on the U.S. economy: U.S. Geological Survey Open-File Report 2025-1047, https://pubs.usgs.gov/of/2025/1047/ofr20251047.pdf.

Nichols, D.J., 1999, Summary of Tertiary coal resources of the Denver Basin, Colorado: in 1999 resource assessment of selected Tertiary coal beds and zones in the Northern Rocky Mountains and Great Plains Region by Flores, R.M. and Nichols, D.J.: Chapter SD, U.S. Geological Survey Professional Paper 1625A, 38 p., https://pubs.usgs.gov/pp/p1625a/Chapters/SR.pdf.

O'Keeffe, M.K., Dechesne, M., Morgan, M.L., Keller, S.M., Pfaff, K., Mahatma, A., and Peretyatko, A.I., 2020, Beach placer mineral deposits along localized paleoshorelines of the Western Interior Seaway, Upper Cretaceous Fox Hills Sandstone, Eastern Denver Basin, Colorado: Colorado Geological Survey Resource Series 48, 45 p., https://doi.org/10.58783/cgs.rs48.kzgr9849.

Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado: Rocky Mountain Geology, v. 37, no. 2, p. 111–134, https://doi.org/10.2113/gsrocky.37.2.111.

Raynolds, R.G., Johnson, K.R., Arnold, L.R., Farnham, T.M., Fleming, R.F., Hicks, J.F., Kelley, S.A., Lapey, L.A., Nichols, D.J., Obradovich, J.D., and Wilson, M.D., 2001, The Kiowa core, a continuous drill core through the Denver Basin bedrock aquifers at Kiowa, Elbert County, Colorado: U.S. Geological Survey open-file report 2001-185, 27 p., https://doi.org/10.3133/ofr01185.

Roberts, S.B., 2007, Coal in the front range urban corridor—An overview of coal geology, coal production, and coal-bed methane potential in selected areas of the Denver Basin, Colorado, and the potential effects of historical coal mining on development and land-use planning, in *Higley, D.K., compiler, Petroleum systems and assessment of undiscovered oil and gas in the Denver Basin Province, Colorado, Kansas, Nebraska, South Dakota, and Wyoming—USGS Province 39*: U.S. Geological Survey Digital Data Series DDS–69–P, ch. 3, 45 p., https://pubs.usgs.gov/dds/dds-069/dds-069-p/REPORTS/69_P_CH_3.pdf.

Soister, P.E., 1974, Preliminary report on a zone containing thick lignite beds, Denver Basin, Colorado: U.S. Geological Survey Open-File Report 74-27, 62 p., https://pubs.usgs.gov/of/1974/0027/report.pdf.

Taylor, S.R. and McLennan, S.M., 2003, Chemical composition and element distribution in the Earth's Crust: Encyclopedia of Physical Science and Technology, Academic Press, p. 697-719.

Tremain, C.M., Hornbaker, A.L., Hold, R.D, Murray, D.K., and Ladwig, L.R., 1996, 1996 summary of coal resources in Colorado: Colorado Geological Survey Special Publication 41, 19 p., https://doi.org/10.58783/cgs.sp41.ncxz2155.

University of Wyoming, 2024, CORE-CM in the Greater Green River and Wind River Basins – transforming and advancing a national coal asset: University of Wyoming, Center for Economic Geology Research, School of Energy Resources, submitted under DOE funding announcement DE-FE0032047, DOE–UWYO/SER-0032047, 31 August 2024, 399 p., https://doi.org/10.2172/2440364.

USGS, 2026, Core research center website: U.S. Geological Survey website, https://www.usgs.gov/core-research-center/wells.

Wood, Jr., G.H., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, Second Printing 1992, 65 p., https://doi.org/10.3133/cir891.

APPENDIX A

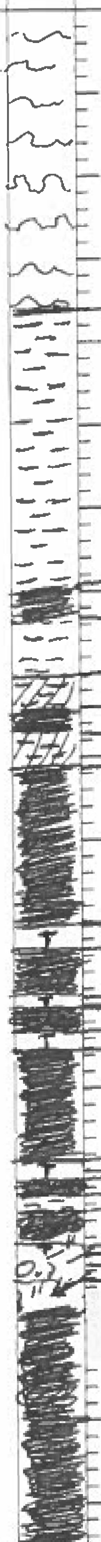
Geologic log - coal seam in the Denver Formation, Ramah-Fondis coal field, CO.

Project: DENVER BASIN COAL **State:** CO **Mine/Region:** RAMAH/FONDIS COAL **Sample Site Number:**

GPS Coordinates and elevation: N. 39.08362, W. 104.22093, ELEV. ±6260 **Date:** 6/6/23

Sample Type (Outcrop/Core/Mine/Channel/Point): DENVER FORMATION OUTCROP, CHANNEL SAMPLES **Geologist:** M. O'KEEFE, A. PAPP, N. ROGERS.

Graphic Log:



Depth (inches)	Lithology Interval	Thick	Lithology Code
0–36		36"	SOIL
36–69		33"	MUDSTONE
69–73		4"	COAL
73–80		7"	MUDSTONE
80–84		4"	CARB MUDSTONE
84–87		3"	COAL
87–91		4"	CARB. MUDSTONE
91–110		19"	COAL
110–113		3"	ASH
113–119		6"	COAL
119–119.5		0.5"	ASH
119.5–122.5		3"	COAL
122.5–124.5		2"	ASH
			COAL
		.5"	ASH
		1"	COAL
		1"	MUDSTONE
	7"	1"	COAL
		1.5"	ASH
		1"	COAL
			MUDSTONE
		33"	COAL
BASE	BASE		

Lithologic Description (e.g., rock type, grain size, rounding, mineral percents, size percents, secondary minerals, color, bedding, etc.)

0-36": SANDY SOIL, ERODED DENVER FORMATION LIGNITE.

36-69": MUDSTONE, GRAY TO BROWNISH GRAY, ABUNDANT GYPSUM ON FRXS, VERY WEATHERED ABUNDANT PLANT REMAINS, REDDISH BROWN FEOX.

69-73": LIGNITE, SOME CARB. MUDSTONE, VERY WEATHERED FEOX ON FRXS CLEATS, 1/4" BUFF TONSTEIN LAYER.

73-80", MUDSTONE, BROWN TO GRAY, SILTY, COAL LAMINATIONS, PLANT DEBRIS, FEOX ON FRXS, FISSILE, SHALY.

80-84": CARB. MUDSTONE, COAL LAMS, GYPSUM ON FRXS, FEOX ON FRXS.

84-87": COAL, LIGNITE, BROWN TO BLACK, WEATHERED, CLEATS, GYPSUM/FEOX ON FRXS.

87-91": CARB. MUDSTONE, COAL LAMS, GYPSUM/FEOX ON FRXS.

91-110": COAL, LIGNITE, BROWNISH BLACK TO BLACK, GYPSUM + YELLOWISH BROWN FEOX ON FRXS, VERY WEATHERED, CLEATS, MAINLY DULL WITH SOME BRIGHT COAL.

110-113": TWO TONSTEIN LAYERS WITH 1" CARB MUDSTONE IN BETWEEN, TONSTEIN IS BUFF, LENSIC, FEOX STAINED, BREAKS EASILY, COAL LAMS, RECRYSTALLIZED? PLATY CLAY WITH SILT.

113-119": COAL, LIGNITE.

119-119.5": TONSTEIN, BUFF, AS ABOVE.

119.5-122.5": COAL, LIGNITE.

122.5-124.5": TONSTEIN, TWO BEDS WITH 1-2" OF LIGNITE IN BETWEEN, BUFF, LENSIC, FEOX STAINS, FRIABLE, COAL LAMS., CLAY APPEARS PLATY, LITTLE SILT.

124.5-139.5": COAL, LIGNITE, BLACK TO BROWNISH BLACK, TRACE INTERBEDS OF TONSTEIN, AND CARB. MUDSTONE WEATHERED GYPSUM AND FEOX (REDDISH BROWN) ON FRXS.

~~140.5~~ 139.5-140.5": TONSTEIN, LIGHT TO DARK BROWN, FRIABLE.

140.5-141.5": COAL, LIGNITE, BROWN TO BLACK, WEATHERED.

141.5-142.5": CARB. MUDSTONE, BLACK, GYPSUM ON FRXS, COAL LAMS., CLAY, FRXS.

142.5-149.5": COAL, LIGNITE AS BELOW.

Sample Interval	Thick	Sample Number
	7"	DB-OC-01
	11"	DB-OC-02
	19"	DB-OC-03
	3"	DB-OC-04
	9.5"	DB-OC-05
	2"	DB-OC-06
	15"	DB-OC-07
	13"	DB-OC-08
	10"	DB-OC-09
	23"	DB-OC-10
BASE		

Project: DENVER BASIN COAL	State: CO	Mine/Region: RAMAH/FONDIS COAL	Sample Site Number:
GPS Coordinates and elevation: N. 39.08362, W. 104.22093, ELEV. ± 6260			Date: 6/6/23
Sample Type (Outcrop/Core/Mine/Channel/Point): DENVER FORMATION OUTCROP, CHANNEL SAMPLES			Geologist: M. [illegible] A. PAPP, N. ROGERS

Depth (~~ft~~) inch	Graphic Log	Lithology Interval	Thick	Lithology Code	Lithologic Description (e.g., rock type, grain size, rounding, mineral percents, size percents, secondary minerals, color, bedding, etc.)	Sample Interval	Thick	Sample Number
					149.5"-150.0": TONSTEIN, BUFF, FISSILE, WEATHERED, FEOX ON FRXS, CLAY W/ LITTLE SILT			
					150.0-151.5": COAL, LIGNITE, DARK GRAY TO BLACK, WEATHERED, FRACTURED FEOX ON FRXS.			
					151.5-152.5": CARB. MUDSTONE WITH LENSES OF TONSTEIN?, DARK GRAY TO TAN (PINKISH IN PLACES), LAMINATED, GYPSUM + FEOX ON FRX).			
					152.5-185.5": LIGNITE, COAL, WEATHERED, BLACK TO BROWNISH BLACK, CLEATS, GYPSUM ON FRXS, FEOX (reddish brown to yellowish brown) ON FRXS, MOSTLY DULL W/ LITTLE BRIGHT, TR. REDDISH BROWN RESIN, BLOCKY, CONCHOIDAL BREAKS IN PLACES, SMALL (1") CARB. MUDSTONE AT BASE. COAL LIKELY EXTENDS BELOW BUT IS COVERED.			