Rare Earth and Other Critical Element Concentrations in the Sentinel Butte and Bullion Creek Formations (Paleocene), Billings, McKenzie, and Golden Valley Counties, North Dakota

by

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On the cover: The color change of the rocks from bright yellow to more somber browns marks the contact between the Bullion Creek Formation and the overlying Sentinel Butte Formation. The HT Butte lignite has burned along the eastern edge of the photo turning the basal Sentinel Butte Formation to clinker. Photograph taken looking north along East River Road in central Billings County. Photo by Ed Murphy.

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Abstract

This report integrates new and previously reported findings of rare earth and other critical element concentrations with three main areas of focus: 1) the lateral extent of REE enrichment in beds where isolated samples contained unique REE enrichment, most notably site 17 at Crooked Creek in Billings County, 2) the co-occurrence of other critical minerals with uranium in coals near the White River unconformity at Sentinel Butte in Golden Valley County, and 3) critical mineral concentrations in carbonaceous beds around the prominent "blue bed" volcanic ash in the Sentinel Butte Formation of McKenzie County. In total, 18 new geologic sections were measured, and 163 new rock samples were submitted for critical element ICP-MS analysis. Of the 240 sample analyses included in this report, 77 were previously reported from 10 sites of interest, and 89 additional samples and six measured sections are reported here to further contextualize the critical mineral enrichment at those sites. Twelve new measured sections and 74 new samples are also reported from across Billings, McKenzie, and Golden Valley Counties. Most samples (215) were lignites and carbonaceous claystones or mudstones. The samples were analyzed for the rare earth elements, including yttrium and scandium, 26 additional elements deemed critical to the economic security of the United States, and noncritical elements molybdenum and thorium. Between 16 and 163 new analyses of each element were acquired, with the more economically promising elements receiving more focus. In samples with all rare earth elements analyzed and total concentrations >300 ppm, the high-demand elements dysprosium, neodymium, scandium, and terbium make up 23.0% of the total rare earth elements. Lateral samples of a one-foot-thick lignite at the Crooked Creek site in western Billings County showed consistent REE enrichment (>300 ppm) occurring over an area of one square mile (2.6 km^2), however lateral sampling of carbonaceous beds at most other sites failed to match the REE contents of the original sample. Laboratory analysis of samples exhibiting elevated radioactivity via field measurement at Sentinel Butte confirmed enrichment in uranium as well as other elements (molybdenum, arsenic, hafnium, tungsten, zirconium), but did not show a directly corresponding enrichment of REE in the same samples. Sampling of a known Paleocene volcanic ash, associated bentonites, and adjacent lignites and carbonaceous mudstones across McKenzie County did not show REE enrichment.

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Introduction

The rare earth element (REE) group is the most prominent example of mineral commodities that are vital components of modern technology and strategic defense, but the market is controlled by a few foreign sources and supply chains are vulnerable to geopolitical disruptions. These commodities, referred to as critical minerals by the U.S. Department of the Interior, include the REEs (lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium), aluminum, antimony, arsenic, barite, beryllium, bismuth, cesium, chromium, cobalt, fluorspar, gallium, germanium, graphite, hafnium, helium, indium, lithium, magnesium, manganese, niobium, platinum group metals (platinum, palladium, rhodium, ruthenium, iridium, and osmium), potash, rhenium, rubidium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium (DOI, 2018). The DOI defines these minerals (mostly listed as elements) as commodities "that serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for our economy or our national security." Copper, silver, nickel, gold, zinc, molybdenum, and lead also received strong consideration. Subsequent versions of the U.S. critical minerals list (DOI, 2022) added nickel and zinc and removed helium, potash, rhenium, uranium, and strontium. These lists were published during heightened international trade tensions and global supply chain constraints, in part as guidance for developing U.S. sources of these elements, which has led to a new wave of domestic critical mineral exploration.

Coal and coal ash have received interest as possible alternative sources of critical mineral commodities, especially the REEs (Seredin and Dai, 2012). Rare earths, like many of the other elements on the critical minerals list, are traditionally extracted from hard rock ores, but soft sedimentary sources like coal, which is already mined as part of thermal power operations, could prove attractive at much lower levels of enrichment. Concentrated accumulations of the REEs are notoriously uncommon, which is why the U.S. Department of Energy considers 300 ppm REE in coal promising despite it being less than twice the average crustal abundance (182 ppm including Y and Sc; McLennan, 2001). REE extraction from coal ash has received much of the research focus, as burning coal is a simple method of concentrating the non-volatile mineral matter 20-fold or more in very low-ash coals. Seredin and Dai (2012) proposed that coal ashes containing 0.1% rare earth oxide (REO; $[REE]_2O_3$) content be considered promising, as that is roughly twice the world average (72 ppm in whole dry coal and 427 ppm in the average world coal ash; including Y and Sc; Ketris and Yudovich, 2009). Unfortunately, a significant portion of the REE content in coal ash is "locked" in aluminosilicate glasses that form during high temperature coal combustion (Scott and Kolker, 2019). Mobilization of the REEs from the glass requires aggressive and costly acid digestion, offsetting much, if not all, of the advantage of its higher overall REE concentrations. Research at the University of North Dakota has shown that much of the REE content of North Dakota lignites is loosely bound to the organics and can be easily extracted from unburnt lignite using a one-step acid leaching process (Laudal et al., 2018). Thus, it is useful to look at samples which contain over 300 ppm REE in dry whole coal and those which contain over 0.1% REO content in the ash, as many samples reach one threshold and not the other, and the ultimate optimal feedstock type is not yet clear.

There are fewer generally accepted economic thresholds for the 28 non-rare earth elements investigated in this study. These elements are produced from a wide variety of ores, have supply/demand dynamics controlled by multiple industries, and are economic at concentrations of different orders of magnitude. Dai and Finkelman (2018) examined concentrations of traditional ore sources vs. those reported from coals and attempted to classify the prospects for each element to be competitively produced from coal. Several mineral commodities are already commercially produced from coal or coal ash, including aluminum, gallium, germanium, magnesium, silicon, selenium, and vanadium. Extraction methods are being developed for additional highly promising elements like gold, silver, platinum, palladium, molybdenum, niobium, rhenium, and zirconium. Elevated concentrations of antimony, beryllium, chromium, cesium, iridium, iron, hafnium, lithium, osmium, rhodium, ruthenium, tantalum, titanium, and tungsten occur in coal or coal ash that could be competitive with conventional ores.

Project Background

The North Dakota Geological Survey (NDGS) began the first detailed investigation of rare earth element concentrations in North Dakota coals in 2015. The initial results of this study (Kruger et al., 2017) contained analyses of 352 lignites and associated lithologies systematically collected from outcrops across southwestern North Dakota. Sampling was broadly distributed, both geographically and stratigraphically, targeting strata from the Sentinel Butte, Bullion Creek, Slope, Ludlow, and Hell Creek Formations across McKenzie, Golden Valley, Billings, Slope, Bowman, and Morton counties. Of those initial 352 samples, 251 (71%) were above the average REE concentration in world coals (72 ppm; Ketris and Yudovich, 2009) and 22 (6.3%) were above the 300 ppm DOE benchmark for economically promising concentrations. The first 169 sample analyses did not include scandium, which some authors do not consider as part of the REEs as it is not a significant component of conventional ores. In coal, however, it may be the single most valuable rare earth element (Moxness et al., 2021) and has been a part of every subsequent NDGS analysis. Most samples in the 2017 report were collected from the Sentinel Butte (158 samples) and Bullion Creek (161 samples) Formations, as outcrops of these units comprise the majority of the Little Missouri Badlands study area. Average REE concentrations, some without scandium, were very similar between the two formations (124 ppm in the Sentinel Butte Fm. and 122 ppm in the Bullion Creek Fm.) with concentrations generally highest in the top few inches of the bed.

Coal has historically been a source of mineral commodities in North Dakota. Uraniferous lignites in Billings, Golden Valley, Slope, and Stark counties were mined, burned down, and shipped out of state for processing when demand for uranium was high in the 1950's and 60's (Murphy, 2015). The original source rocks for these uranium deposits are considered to be the volcanic-rich White River and Arikaree strata, which exist today in North Dakota only as isolated erosional remnants, often on butte tops (Hager, 1954; Denson et al., 1959; Denson and Gill, 1965). These rocks are believed to have been leached and the uranium transported downward by groundwater, where it was deposited when it came into contact with carbonaceous material or in sandstones as roll-front deposits. Rare earth elements are also known to be enriched in volcanic rocks, and Kruger and others (2017) examined whether REEs may be enriched in similar infiltrational pathways. Lignites from old uranium mines and beds near the White River contact were sampled, but the REEs did not appear uniquely enriched in these beds, including those with elevated radioactivity as identified in the field with a scintillometer. Kruger and others also investigated whether the lithology of the overlying strata played a role in enrichment (i.e., if the REEs in coal are primarily allogenic, then hypothetically coals beneath permeable strata such as sandstone would have more exposure to descending REE-enriched fluids than those beneath impermeable lithologies like mudstone). Lignites beneath sandstones contained slightly higher average REE concentrations, but no significant correlation was found.

Subsequent characterization work focused on Logging Camp Ranch in Slope County, where 7 of the 22 original coal samples over 300 ppm REE were collected, including the highest (603 ppm, dry whole coal basis) from the H bed and second highest (555 ppm) from the Harmon lignite bed. These lignites are positioned in the lower Bullion Creek Formation, hundreds of feet (m) lower stratigraphically than the initially hypothesized source beds at the White River contact and with no measurable elevated radioactivity levels. Murphy and others (2018) reported the REE concentrations in 113 additional samples collected during extensive lateral sampling of the Harmon, H, and other lignite beds within a few miles of the initial sample sites from Kruger and others (2017). By performing concentrated lateral sampling, the authors hoped to identify whether the elevated REE concentrations were continuous across particular stratigraphic horizons, which would suggest REE enrichment during lignite deposition, or, if the high concentrations were more isolated, it would more likely indicate enrichment was the product of localized vertical groundwater flows.

Results on the lateral variability of the REE enrichment within the beds at Logging Camp were mixed. The H bed contained elevated REE concentrations in two separate outcrops over one mile apart, but this thin coal (18-inch (46 cm) maximum thickness) pinches out over short distances, preventing thorough lateral sampling. The overlying lithology again did not appear to play a role in enrichment, as the H bed was overlain by sandstone at one site and mudstone at another, both with similar REE enrichment. The much thicker Harmon bed provided more consistent lateral sampling opportunities. The upper few inches (5-8 cm) of the bed were consistently enriched where exposed within a few hundred feet (61-91 m) of Kruger and others (2017) site 56, but samples from the same portion of the bed were not enriched along extensive exposures on the south face of Tepee Buttes one mile to the north (sites 67-83 of Murphy et al., 2018). The 2018 study also examined REE enrichment relative to terraces in the area, which are capped with Pliocene or Quaternary gravels with distinct volcanic pebbles, but no significant increase in REE concentrations was identified in lignites below these gravels. In all, 92 of the 113 samples in Murphy and others (2018) were above 72 ppm REE and 10 were over 300 ppm, with a new high of 1,026 ppm from the H bed.

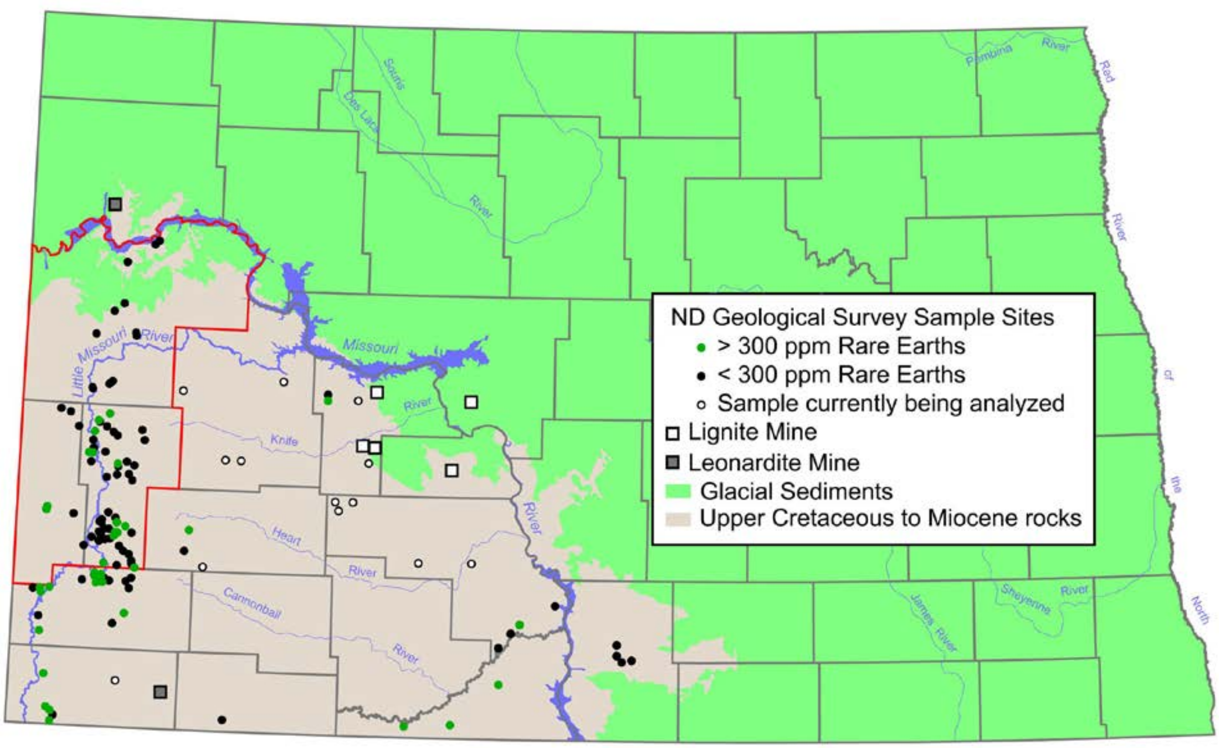
One of the other locations identified in initial work by Kruger and others (2017; sites 37 & 38) did provide a better opportunity to laterally trace lignites and carbonaceous mudstones which were more consistently enriched. Moxness and others (2021) reported the REE concentrations of 160 new samples from the Tracy Mountain area in Billings County. In addition to the rare earth elements, the report published analyses from 28 other elements; 26 considered critical minerals: antimony, arsenic, barium, beryllium, bismuth, cesium, chromium, cobalt, gallium, germanium, hafnium, indium, lithium, magnesium, manganese, niobium, rubidium, strontium, tantalum, tellurium, tin, titanium, tungsten, uranium, vanadium, and zirconium, along with the noncritical elements molybdenum and thorium. Although molybdenum is not considered a critical element in the United States, it is a potential value-added product from coal and has been the subject of recent commercial exploration in North Dakota lignites, along with uranium and germanium (Murphy, 2015). Conversely, thorium is a contaminant which is expensive to separate from the REEs during refinement and is relevant in the economic assessment of REE ores. Some elements do not tend to accumulate in coals, while others are known to become enriched, but are still not competitive with exceptionally-enriched conventional ores. The NDGS has taken Dai and Finkelman's (2018) classification of each element's unique economic prospects into account when allocating its analytical budget, focusing more on elements believed to be more promising in coal.

At Tracy Mountain, over 300 feet (90 m) of outcrop is well exposed around the perimeter of the main butte. Samples from all six of the uppermost continuous to semi-continuous carbonaceous beds (A, B, E, F, G, and I; Moxness et al., 2021) contained REE concentrations in excess of 400 ppm and enrichment was relatively consistent around the butte. Although these beds are generally thin (a few inches to a foot (<0.3m) thick), these results show that high REE concentrations in North Dakota lignites can occur over a more widespread area than would be expected if enrichment were the product of localized vertical groundwater flows. An alternative enrichment model, however, remained unclear. Samples from two beds, B and I, were over 1,000 ppm REE. The I bed is present directly below a presumed bentonite (weathered volcanic ash). Volcanic ash is a known source of the REEs, but carbonaceous beds lower in the section beneath bentonites were not enriched, and the higher portions of the butte contained multiple consistently enriched beds with no associated bentonites. A white, siliceous Paleocene weathering zone is present in the enriched interval on the west side of the butte, but REE concentrations were similarly high on the east side where no bleached zone was present, so again a direct link between the REE concentrations and the adjacent lithologies was not apparent.

Rare earth enrichment at Tracy Mountain was mostly limited to a 60-foot (18m) vertical zone at the top of the butte, with samples from carbonaceous beds in the lower 200 feet (60m) of section containing markedly lower concentrations. It is possible that the upper interval captures a period of Paleocene time where REE-enriched waters were entering the swamps as the peats formed. Another possibility is that these beds were enriched as the overlying strata eroded away during the Pliocene or Quaternary, and/or weathering of the stable surface in the intervening time, potentially millions of years. The authors attempted to establish whether the REE enrichment was related to the stratigraphic interval or the topographic position by sampling surrounding buttes. Results of this sampling were also mixed. Because of the isolation of Tracy Mountain, the nearest comparative butte was often several miles away and the equivalent stratigraphic intervals were either not present (due to structural dip) or lacking in comparable carbonaceous beds. The uppermost carbonaceous beds were sometimes enriched, although none to the degree seen at the main butte of Tracy Mountain, perhaps because the upper surfaces of these surrounding topographic highs are not as ancient.

An analogue to Tracy Mountain was also initially identified in Kruger and others (2017), this time in the Ludlow and Hell Creek Formations at Mud Buttes in Bowman County. Here, another tall, flat-topped butte preserves an ancient upland surface with multiple REE-enriched beds immediately below it, but in the lower 300 feet (90m) of section REE concentrations were rarely enriched. Moxness and others (2022) reported new REE analyses of 219 new samples from Fox Hills, Hell Creek, and Ludlow Formations across Bowman, Emmons, Morton, Sioux, and Slope counties, with additional critical element data for 212 samples, including six added to samples with REE analyses first reported in Kruger and others (2017). Another focus of the report was to investigate the Marmarth, Breien, and Linton volcanic ashes, bentonites, and their underlying carbonaceous beds, as volcanic sediment can be a source of REEs and other critical minerals and the most enriched lignite at Tracy Mountain was immediately below a bentonite. A dozen assorted concretions and nodules were also collected and analyzed to investigate if critical minerals precipitate with the cementing agents in other lithologies.

Moxness and others (2022) found that only lignites and carbonaceous mudstone samples were enriched over 300 ppm REE, and none of the 32 enriched samples were directly beneath volcanic ash beds, direct samples of which were low in REE content. Instead, enrichment was found in the topographically higher Ludlow coals. Like Tracy Mountain in Billings County, far southwestern North Dakota contains many flat-topped buttes and mesas which preserve remnants of long-lived upland surfaces occurring at many different positions stratigraphically. Enrichment observed in the Ludlow Formation offered further chances to investigate whether high REE concentrations in this setting are restricted within a correlated stratigraphic interval or controlled by topographic position. Sites 64 and 257, three miles (5km) apart, both contained lignite samples over 660 ppm REE within 20 to 30 feet (6-9m) of a stable upland surface, and both exhibited mostly non-enriched underlying beds. The enriched beds at site 64 were approximately 145 feet (44m) further above the Cretaceous-Paleogene boundary than the enriched uppermost lignite at site 257. The stratigraphic position of the topographic enrichment was similarly variable across other sites in Moxness and others (2022), leading the authors to conclude that 1) REE enrichment is generally not controlled by the permeability or volcanic content of adjacent lithologies, and 2) there was no evidence of specific periods of late Cretaceous/early Paleocene time when REE-enriched waters were entering Williston basin peat bogs. Figure 1 contains a complete map of sites from existing reports as well as ongoing critical mineral characterization work.



▲ **Figure 1.** NDGS critical mineral study sample sites. The study areas of this report are outlined in red.

Moxness and others (2021 and 2022) demonstrated that other critical elements were enriched in North Dakota bedrock beyond just the rare earths. Results from the Fox Hills, Cretaceous, and Ludlow Formations also included non-REE critical element analyses. A full account of analyses of each element in each report is presented in Table 1. Because these elements occur at different orders of magnitude (e.g., the average concentration of titanium in world coals is 800 ppm, but for indium it is 0.031 ppm (Ketris and

▼ **Table 1.** NDGS analyses by stratigraphic formation and report. Abbreviations Tsb - Sentinel Butte Fm., Tbc – Bullion Creek Fm., Ts – Slope Fm., Tl – Ludlow Fm., Khc – Hell Creek Fm., Kfh – Fox Hills Fm.

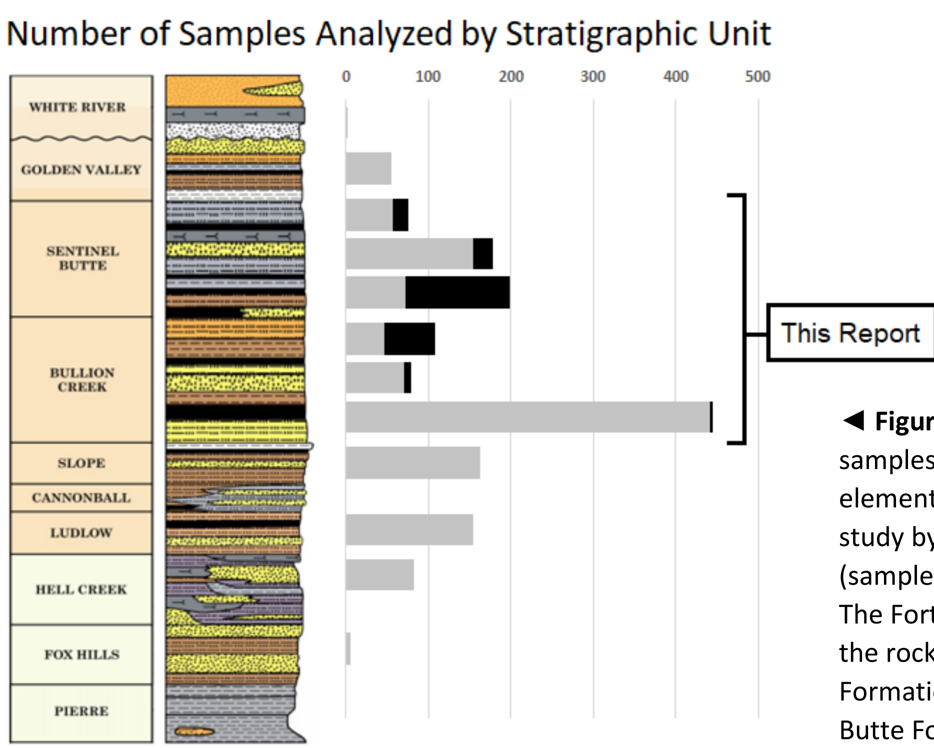
Number of NDGS analyses of North Dakota lignites and associated lithologies

			RI-117 Kruger and others (2017)					RI-119 Murphy and others (2018)	RI-128 Moxness and others (2021)	RI-130 Moxness and others (2022)			RI-131 This Report (2022)		
	Element		Tsb	Tbc	Ts	Tl	Khc	Tbc	Tsb	Tl	Khc	Kfh	Tsb	Tbc	Total
Rare Earth Elements (REE)	Cerium	Ce	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Dysprosium	Dy	176	143	10	15	8	113	63	49	4		88	22	**691**
	Erbium	Er	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Europium	Eu	176	143	10	15	8	113	63	49	4		88	22	**691**
	Gadolinium	Gd	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Holmium	Ho	176	143	10	15	8	113	63	49	4		88	22	**691**
	Lanthanum	La	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Lutetium	Lu	176	143	10	15	8	113	63	49	4		88	22	**691**
	Neodymium	Nd	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Praseodymium	Pr	176	143	10	15	8	113	63	49	4		88	22	**691**
	Samarium	Sm	176	143	10	15	8	113	63	49	4		88	22	**691**
	Scandium	Sc	86	64	10	15	8	113	160	139	76	6	108	55	**840**
	Terbium	Tb	176	143	10	15	8	113	63	49	4		88	22	**691**
	Thulium	Tm	176	143	10	15	8	113	63	49	4		88	22	**691**
	Ytterbium	Yb	176	143	10	15	8	113	63	49	4		88	22	**691**
	Yttrium	Y	176	143	10	15	8	113	160	139	76	6	108	55	**1009**
	Antimony	Sb							81	38	30	6	28	35	**218**
	Arsenic	As							73	8	23	6	19	33	**162**
	Barium	Ba							81	37	25	6	29	5	**183**
	Beryllium	Be							34	59	50	6	31	43	**223**
	Bismuth	Bi							21	8	23	6	14	3	**75**
	Cesium	Cs							34	38	33	6	28	11	**150**
	Chromium	Cr							108	72	50	6	41	7	**284**
	Cobalt	Co							55	18	23	6	40	34	**176**
	Gallium	Ga							128	121	76	6	43	37	**411**
	Germanium	Ge							128	127	76	6	49	25	**411**
	Hafnium	Hf							137	103	56	6	31	13	**346**
	Indium	In							21	8	23	6	14	3	**75**
	Lithium	Li							34	51	30	6	28	11	**160**
	Magnesium	Mg							157	121	76	6	45	43	**448**
	Manganese	Mn							24	8	24	6	26	3	**91**
	Molybdenum	Mo							157	127	74	6	48	37	**449**
	Niobium	Nb							126	121	74	6	44	19	**390**
	Rubidium	Rb							24	8	25	6	16	9	**88**
	Strontium	Sr							34	20	23	6	17	4	**104**
	Tantalum	Ta							108	38	30	6	26	5	**213**
	Tellerium	Te							21	8	23	6	13	3	**74**
	Thorium	Th							24	8	25	6	28	9	**100**
	Tin	Sn							21	8	23	6	13	3	**74**
	Titanium	Ti							34	116	65	6	44	13	**278**
	Tungsten	W							154	38	30	6	28	35	**291**
	Uranium	U							157	121	76	6	46	43	**449**
	Vanadium	V							126	121	74	6	44	7	**378**
	Zirconium	Zr							157	121	74	6	46	43	**447**

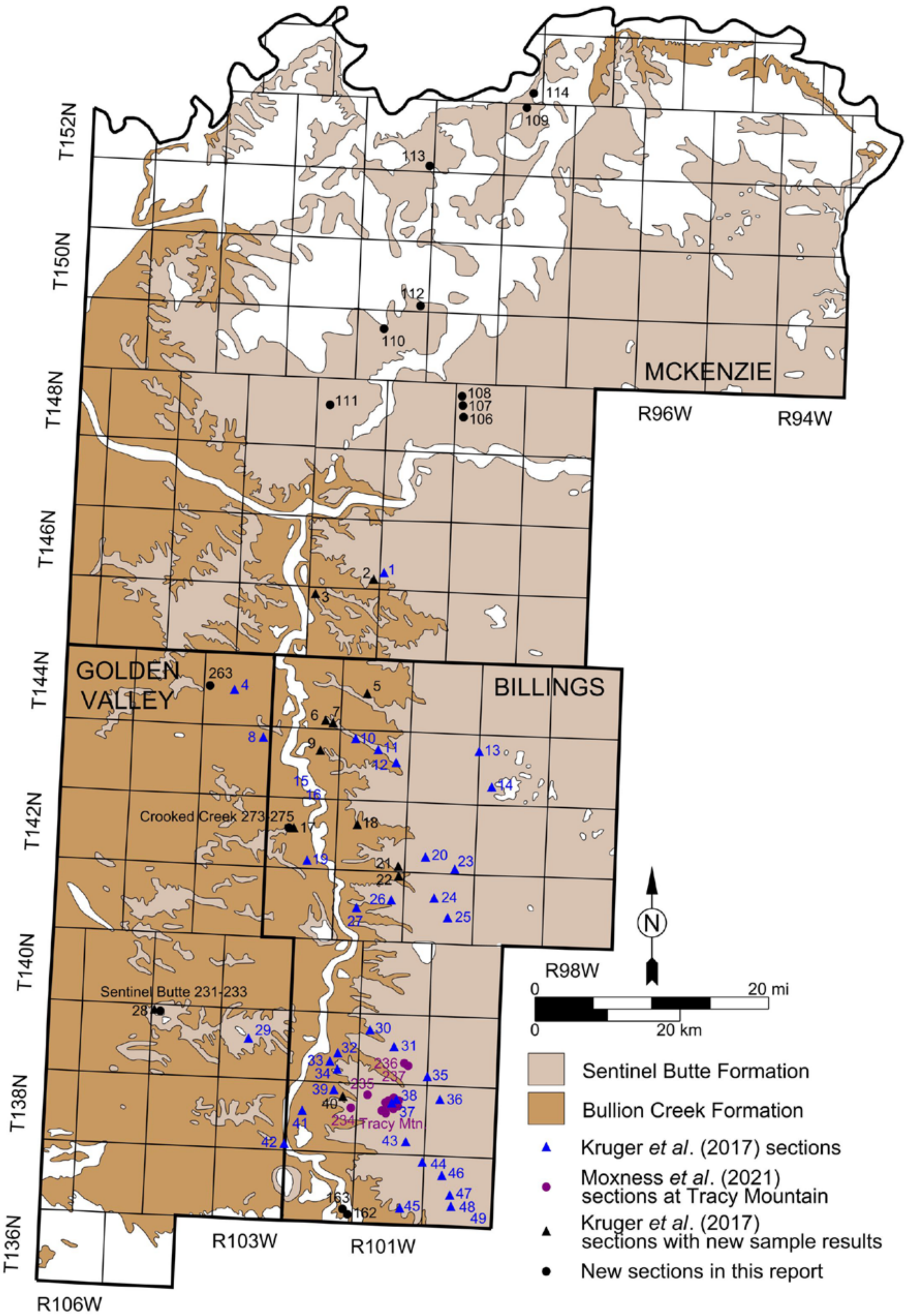
Yudovich, 2009), it is more useful to discuss these concentrations in terms of enrichment over background. Many authors normalize concentrations in coal to upper continental crust (UCC; values from Taylor and McLennan, 1985 with updates in McLennan, 2001), including Dai et al., (2016), who classified concentrations of trace elements in coal from "unusually enriched" to "depleted" based on their ratio to UCC. Based on these criteria, lignites at Tracy Mountain contain unusually high enrichment (>100 times UCC) of antimony, arsenic, and molybdenum, and significant enrichment (10 to 100 times UCC) in barium, cobalt, germanium, tungsten, and uranium. Lignites in samples from the Ludlow Fm. contained significant enrichment of antimony, arsenic, barium, germanium, molybdenum, and uranium. Lignites and carbonaceous mudstones from the Hell Creek Formation contained unusual enrichment of germanium, and significant enrichment in antimony and molybdenum. Volcanic ashes and bentonites were significantly enriched in antimony and arsenic, while samples of nodules and concretions occasionally contained unusual enrichment of antimony, arsenic, and tungsten, and significant enrichment of barium, manganese, and molybdenum.

Sampling Strategy of this Report

This report expands on a number of interesting critical mineral occurrences identified in Kruger and others (2017), broadly grouped: 1) REE and other critical mineral concentrations in carbonaceous beds around the prominent “blue bed” volcanic ash and bentonites in the Sentinel Butte Formation of McKenzie County, 2) the lateral extent of REE enrichment in beds where isolated samples contained unique REE enrichment, most notably site 17 at Crooked Creek in Billings County, and 3) the co-occurrence of other critical minerals with uranium in coals near the White River unconformity at Sentinel Butte in Golden Valley County. Here we present the results of 163 additional sample analyses: 89 additional samples from 10 sites identified in Kruger and others (2017; sites 2, 3, 5, 6, 9, 17, 18, 21, 28, and 40), including three new measured sections at Sentinel Butte (28; 231-233) and three at Crooked Creek (17; 273-275), and 74 additional samples from 12 new measured sections (106-114, 162, 163, and 263) spread across the three counties (figs. 1-3). The total REE concentrations of 53 of the 163 new samples in this report were modeled using concentrations of the major seven rare earth elements using methodologies outlined by Kruger (2020). In addition to the REEs, 86 samples have additional critical element analyses, including five with REE concentrations reported in Kruger and others (2017) that were re-analyzed for additional elements (samples 2AA, 7G, 9A, 9E, and 22C).



◄ **Figure 2.** The number of samples analyzed for critical elements for the entire NDGS study by stratigraphic position (samples in this report in black). The Fort Union Group consists of the rocks from the Ludlow Formation through the Sentinel Butte Formation.



▲ **Figure 3.** The locations of measured sections in McKenzie, Golden Valley, and Billings counties from the NDGS critical minerals project. Sites with new data in this report are in black (new measured sections as circles and revisited sections from Kruger et al., 2017 as triangles).

Analytical Results

The lithologies of the samples in this report include 215 lignites and carbonaceous mudstones (collectively referred to as coal in this report), six bentonites, five volcanic ashes, four presumed tonsteins, four sandstones (two of which contained organic stringers), three non-carbonaceous claystones, two concretions, and a natural coal ash (Table 2). A complete summary of ICP-MS results for all 240 samples in this report is presented in Table 3, including 77 samples with REE analyses first reported in Kruger and others (2017). The highest concentrations for each element were from a sample of coal or carbonaceous mudstone with the following exceptions: manganese in two concretions, magnesium in a natural coal ash, tantalum from a tonstein, and titanium from a claystone parting. The highest whole dry coal and ash basis concentrations of those elements from a carbonaceous bed in this study were 19,400/57,000 ppm Mg, 648/1,410 ppm Mn, 1.02/1.76 ppm Ta, and 6,410/11,300 ppm Ti.

▼ **Table 2.** The number of samples in this report analyzed for REE and other critical elements by lithology.

Entire Project (2015-2022)	This Report	Lithology
1,089	185	Lignites
292	30	Carbonaceous clay/mudstones
25	3	Claystones and mudstones
25	6	Bentonites
22	4	Tonsteins
22	2	Nodules or concretions
20	5	Volcanic ashes
12	1	Natural coal ash
11	4	Sandstones and Siltstones
3		K/Pg ejecta
1,521	**240**	**Total**

Of the 77 samples from selected sections from Kruger and others (2017) included in this report, 54 were above the world average for REE in coals (72 ppm for samples including scandium and 68 ppm for those without, Ketris and Yudovich, 2009) and six were above 300 ppm REE, with a high of 521 ppm. New sampling at these sites (2, 3, 5, 6, 9, 17, 18, 21, 28, and 40), including new lateral sections (231-233, 273-275), added 85 of 89 samples over the world average REE concentrations in coal. Thirteen of these samples were over 300 ppm REE with a high of 512 ppm. Sections from the uraniferous zone at Sentinel Butte (28, 231-233) contained 3 of 17 samples over 300 ppm REE with a high of 447 ppm, and the Crooked Creek sections (17, 273-275) contained 10 of 44 samples over 300 ppm, with a high of 512 ppm. None of the 59 samples from the new sections containing the "Blue Bed" in McKenzie County (106-114) were over 300 ppm REE, with a high of 298 ppm. Two of 11 samples from the lower Bullion Creek Fm in southernmost Billings County (sites 162 and 163), north of Logging Camp Ranch, contained just over 300 ppm. None of the four samples collected from section 263, a section spanning the Sentinel Butte/Bullion Creek contact in northern Golden Valley County, exceeded 300 ppm.

▼ **Table 3.** Summarized analytical results of this report. Abbreviations: A is the atomic number of the element; n is the number of samples analyzed.

Chemical Group		Element	Symbol	A	n	Analyses (all lithologies, concentrations in ppm) Dry Coal/Rock Basis MAX	Dry Coal/Rock Basis MIN	Dry Coal/Rock Basis MEAN	Dry Ash Basis MAX	Dry Ash Basis MIN	Dry Ash Basis MEAN
Alkali Metals		Lithium	Li	3	39	40.8	1.5	15.6	76.8	8.0	32.9
Alkali Metals		Rubidium	Rb	37	25	106	1	29	149	5	57
Alkali Metals		Cesium	Cs	55	39	9.0	0.05	2.6	12.6	0.23	4.9
Alkaline Earth Metals		Beryllium	Be	4	74	30.5	0.5	5.2	76.7	0.8	12.6
Alkaline Earth Metals		Magnesium	Mg	12	88	28000	1390	8644	57000	1457	18500
Alkaline Earth Metals		Strontium	Sr	38	21	811	62	392	2410	69	1080
Alkaline Earth Metals		Barium	Ba	56	34	8790	24.8	1380	33000	38	3700
Rare Earth Elements	Lanthanides	Lanthanum	La	57	240	72.6	1.6	21.7	224	9.4	49
Rare Earth Elements	Lanthanides	Cerium	Ce	58	240	170	3.1	46	481	19.8	105
Rare Earth Elements	Lanthanides	Praseodymium	Pr	59	187	21.6	0.4	5.4	57.7	2.0	13.0
Rare Earth Elements	Lanthanides	Neodymium	Nd	60	240	86.9	1.9	22.6	236	7.4	53
Rare Earth Elements	Lanthanides	Samarium	Sm	62	187	19.3	0.4	4.5	53.1	1.3	11.5
Rare Earth Elements	Lanthanides	Europium	Eu	63	187	4.29	0.11	1.09	11.8	0.29	2.9
Rare Earth Elements	Lanthanides	Gadolinium	Gd	64	240	21.4	0.5	5.1	58.8	1.1	12.8
Rare Earth Elements	Lanthanides	Terbium	Tb	65	187	3.39	0.08	0.77	9.63	0.14	2.10
Rare Earth Elements	Lanthanides	Dysprosium	Dy	66	187	19.7	0.5	4.8	61.5	0.9	13.3
Rare Earth Elements	Lanthanides	Holmium	Ho	67	187	3.83	0.11	0.99	12.9	0.17	2.8
Rare Earth Elements	Lanthanides	Erbium	Er	68	240	11.4	0.32	3.2	37.2	0.54	8.4
Rare Earth Elements	Lanthanides	Thulium	Tm	69	187	1.64	0.04	0.42	5.09	0.05	1.20
Rare Earth Elements	Lanthanides	Ytterbium	Yb	70	187	10.5	0.26	2.8	31.6	0.48	7.9
Rare Earth Elements	Lanthanides	Lutetium	Lu	71	187	1.67	0.04	0.43	4.92	0.05	1.24
Rare Earth Elements	Transition Metals	Scandium	Sc	21	189	35.3	1.3	11.9	90.2	4.9	27.3
Rare Earth Elements	Transition Metals	Yttrium	Y	39	240	105	4.1	29	369	6.0	78
Transition Metals		Titanium	Ti	22	57	15100	229	2000	15800	1005	3800
Transition Metals		Vanadium	V	23	51	519	3.6	134	1450	5.5	300
Transition Metals		Chromium	Cr	24	48	146	4	47	290	5	98
Transition Metals		Manganese	Mn	25	29	5400	9	510	6420	38	800
Transition Metals		Cobalt	Co	27	74	91.2	2.1	18.9	181	2.4	41
Transition Metals		Zirconium	Zr	40	89	1000	16.7	250	3200	28.0	530
Transition Metals		Niobium	Nb	41	63	80	1.8	14.9	122	4.5	31
Transition Metals		Molybdenum	Mo	42	85	3800	0.8	130.0	8990	0.84	280
Transition Metals		Hafnium	Hf	72	44	33.0	0.5	4.0	50.2	0.9	8.6
Transition Metals		Tantalum	Ta	73	31	1.58	0.12	0.52	1.81	0.29	1.01
Transition Metals		Tungsten	W	74	63	75.1	0.7	7.2	178	0.8	17
Post-Transition Metals		Gallium	Ga	31	80	50.3	2.2	18.8	163	7.6	38
Post-Transition Metals		Indium	In	49	17	9.2	<0.02	0.6	14.0	<0.02	0.9
Post-Transition Metals		Tin	Sn	50	16	2.0	0.2	1.0	4.5	0.7	2.2
Post-Transition Metals		Bismuth	Bi	83	17	3.6	<0.1	N/A	5.5	<0.1	N/A
Metalloids		Germanium	Ge	32	74	63	<1	12	326	<2	31
Metalloids		Arsenic	As	33	52	1860	1.4	130	4400	2.1	290
Metalloids		Antimony	Sb	51	63	29.2	0.65	10.8	99.5	0.96	23.7
Metalloids		Tellerium	Te	52	16	0.39	<0.1	N/A	0.62	<0.3	N/A
Actinides		Thorium	Th	90	37	17.3	1.1	8.3	46.9	3.5	18.9
Actinides		Uranium	U	92	89	1480	1.0	50.0	3500	2.8	100

Using the coal enrichment classification of Dai and others (2016), who selected multiples of 0.5, 2, 5, 10, and 100 times the average concentration of the upper continental crust to define the degree of enrichment in coals, nine coal samples were slightly REE-enriched (>364 ppm; 2 times UCC of 182 ppm, Taylor and McLennan, 1985), 166 samples were normal (91 to 364 ppm), and 65 were depleted (<91 ppm)). On an ash basis, 11 samples are enriched (>910 ppm), 64 are slightly enriched, 123 are normal, and 3 are depleted (39 samples do not have ash yield data). The rare earth elements are considered rare for the infrequency of deposits with high UCC multiples, which is why the U.S. Department of Energy considered 300 ppm, a concentration on the high side of "normal" UCC values, to be promising in coal and coal byproducts.

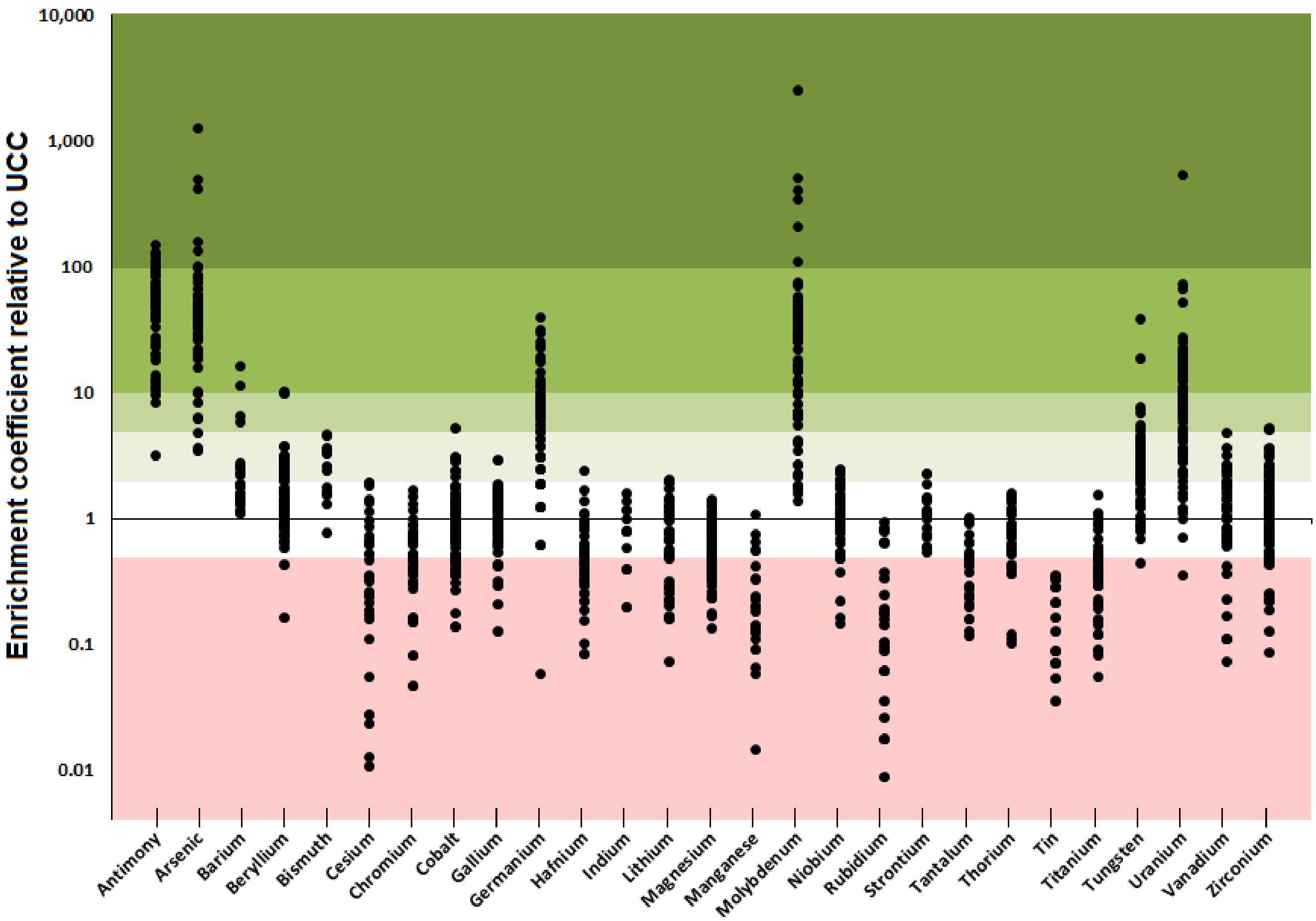
Other elements can be far more enriched relative to average upper continental crust. Dai and others (2016) did not include a category for 1,000 times UCC, but sample 28B contains molybdenum concentrations 2,530 times UCC, arsenic that is 1,240 times UCC, and uranium at 529 times UCC. These are the highest dry whole coal basis enrichment values recorded during the project to date, with the next highest being a carbonaceous claystone from the Hell Creek Formation that contained 453 times the germanium concentrations of the UCC (Moxness et al., 2022). Several samples in this report are also unusually enriched (>100 times UCC) in antimony. Barium, germanium, and tungsten can also be significantly enriched as was seen at Tracy Mountain or samples from the Ludlow and Hell Creek Formations, but this report contains the first instance of significant beryllium enrichment (sample 2AA). On an ash basis, concentrations from lignites were as high as 6,000 (molybdenum), 2,930 (arsenic), 1,250 (uranium), 498 (antimony), 204 (germanium), 88.9 (tungsten), 60.0 (barium), 25.6 (beryllium), 16.9 (zirconium), 15.7 (vanadium), 10.7 (cobalt), 9.61 (gallium), 9.17 (bismuth), 6.89 (strontium), 6.39 (niobium), 5.71 (hafnium), 4.51 (indium), 4.38 (thorium), 4.29 (magnesium), 3.84 (lithium), 3.41 (chromium), 2.76 (titanium), 2.74 (cesium), 2.34 (manganese), 1.76 (tantalum), 1.39 (rubidium), and 0.82 (tin) times the average concentration of the upper continental crust (fig. 4, Table 4).

▼ **Table 4.** The maximum critical mineral enrichment observed in selected groups of lignites and carbonaceous mudstones in North Dakota, relative to upper continental crust. Major non-lignite samples groups are also included below. Abbreviations: Tsb is the Sentinel Butte Formation, Tbc is the Bullion Creek Formation, Tl is the Ludlow Formation, and Khc is the Hell Creek Formation.

Maximum Concentration (dry whole coal/rock basis) vs. Upper Continental Crust (UCC)[5]

Enrichment Classification[4] Ratio to UCC:	Unusually enriched > 100x	Significantly enriched 10x to 100x	Enriched 5x to 10x	Slightly enriched 2x to 5x	Normal 0.5x to 2x	Depleted < 0.5x
Lignites at Sentinel Butte (Tsb)[3]	As,Mo,U	Ge,Sb,W	Ba,Co,Zr	Be,Ga,Hf,V	Bi,Cr,In,Mg,Mn,Nb,Sr,Th,Ti	Cs,Li,Rb,Ta,Sb
Lignites at Tracy Mountain (Tsb)[1]	As,Mo,Sb	Ba,Co,Ge,U,W	Bi,Zr	Be,Cs,Ga,Hf,In,Li,Mn,Nb,Ta,Th,V	Cr,Mg,Rb,Sr,Ti	Sn
Other Tsb lignites [3]	As,Sb	Ba,Be,Ge,Mo,U	W	Bi,Li,Nb,Zr	Cs,Cr,Co,Ga,Hf,In,Mg,Mn,Rb,Ta,Th,Ti	Sn
Tbc lignites [3]	As,Sb	Ge,Mo,U	Ba,W	Be,Bi,Co,Nb,Zr	Cs,Cr,Ga,Hf,In,Li,Mg,Rb,Sr,Ta,Th,Ti,V	Mn,Sn
Tl lignites [2]		As,Ba,Ge,Mo,Sb,U	W	Be,Bi,Cs,Co,Ga,Li,Mg,Nb,Ti,V,Zr	Cr,Hf,In,Mn,Rb,Sr,Ta,Th,	Sn
Khc lignites [2]	Ge	Mo,Sb	As,U,W	Be,Ga,Li,Nb,V,Zr	Ba,Bi,Cs,Cr,Co,Hf,In,Mg,Mn,Rb,Sr,Ta,Th,Ti	Sn
Volcanic ashes & bentonites [1,2,3]		As,Sb	Ba,Mo,W	Bi,Co,Ge,Li,Mn,Th,U	Be,Cs,Cr,Ga,Hf,In,Mg,Nb,Rb,Sr,Ta,Ti,V,Zr	Sb
Concretions & nodules [1,2,3]	As,Sb	Ba,Mn,Mo,W	U	Co,Nb	Be,Bi,Cs,Cr,Ga,Ge,Li,Mg,Sr,Ta,Th,Ti,V,Zr	Hf,In,Rb,Sn

[1] Moxness et al. (2021); [2] Moxness et al. (2022); [3] This report; [4] Dai et al. (2016); [5] Taylor and McLennan (1985), McLennan (2001)



▲ **Figure 4.** Sample concentrations (dry whole basis) in this report relative to average values of the upper continental crust. Colors based on the enrichment classification of Dai et al. (2016), labeled in Table 4.

Results From the Sentinel Butte Ash/Bentonite in McKenzie County

Fisher (1953) referred to a medium grayish-blue, 20-foot-thick bentonite in the Sentinel Butte Formation in central McKenzie County as the "Blue" or the "Blue clay", noting that the color of the bed darkens to almost black when wet. Fisher traced this bed from Sheep Butte in southwestern McKenzie County to the Lost Bridge area in northern Dunn County, a distance of approximately 45 miles (72 km). Although previous workers (Benson, 1954; Laird, 1956; Royse, 1967) had referred to a bluish-gray, 20-foot-thick (6 m), laterally persistent, bentonite near the middle of the Sentinel Butte Formation in south-central McKenzie County, Forsman and Karner (1975) were the first to verify it was a bentonite by documenting the presence of volcanic glass. Forsman (1985) went on to report on the petrography, texture, and geochemistry of the lower, middle, and upper layers of this bed. Forsman noted a 4.9 to 12.1 foot-thick (1.5–3.7 m) lower bentonite layer, a 1.9 to 4.9 foot-thick (0.6-1.5 m) middle layer of grayish/white silt, and a 1.9 to 4.9 foot-thick (0.6-1.5 m) upper bentonite (figs. 5 and 6). The middle unit is typically a laminated siltstone consisting of 75% volcanic glass that is rhyolitic in composition (Forsman,

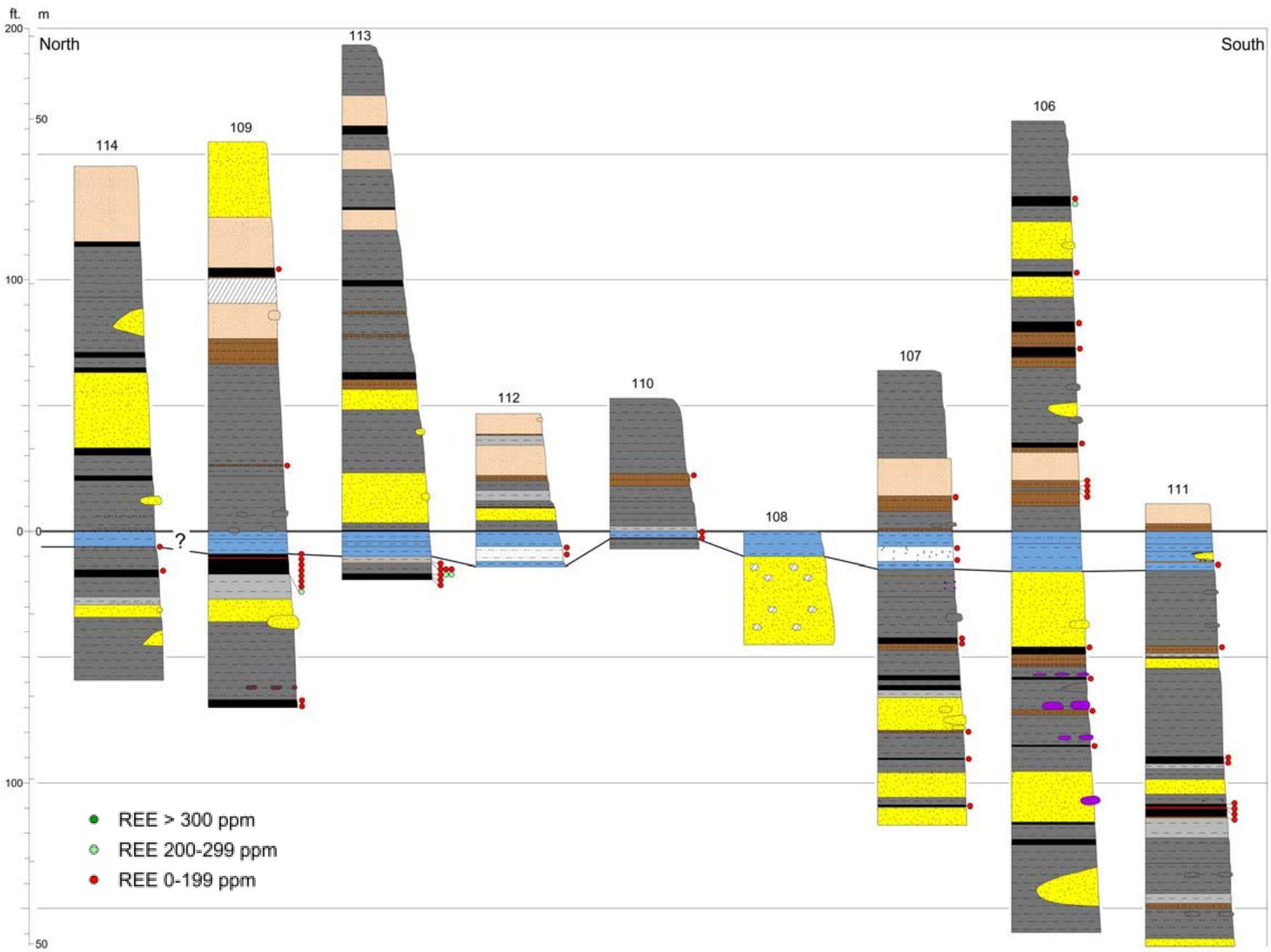
▲ **Figure 5.** The Sentinel Butte ash\bentonite (blue layer) in outcrop just to the north of the North Unit of the Theodore Roosevelt National Park in south-central McKenzie County. The photograph was taken looking to the northwest between measured sections 106 and 107.

▲ **Figure 6.** Six feet (1.8m) of ash (white layer) is exposed between an upper and lower bentonite layer in the Sentinel Butte ash\bentonite at measured section 107. Photo taken looking to the east-southeast.

1985) with the upper and lower bentonites having formed as a result of the alteration of the glass grains.

Forsman (1985) proposed the name Sentinel Butte ash/bentonite and drew a map of the known extent of this ash, extending it 14 miles (23 km) to the northwest from the southeast edge of the North Unit of the Theodore Roosevelt Park, ending the deposit approximately 2.5 miles (4 km) south of the town of Arnegard. This agreed with the extent noted by Carlson (1985). Larsen (1988) roughly doubled the known extent of the ash, extending it primarily to the west, but also to the east and south.

In this study, a series of geologic sections were measured within the known extent of the Sentinel Butte ash/bentonite (sections 106 – 108, 110 – 112). In addition, measured sections 109, 113, and 114 were measured 13 to 18 miles (21-29 km) north of the previously reported extent of this bed. The ash/



▲ **Figure 7.** The rare earth element concentration ranges for rock samples from measured sections of the Sentinel Butte Ash/Bentonite, north to south across McKenzie County. The datum is the top of the Sentinel Butte ash/bentonite.

bentonite ranged in thickness from 3 - 15 feet (0.9-4.6 m). Unaltered ash was only encountered in two measured sections (107 and 112) each of which consisted of six feet (1.8 m) of ash sandwiched between six feet (1.8 m) of upper bentonite and 2-3 feet (0.6-0.9 m) of lower bentonite (fig. 7).

Although unaltered ash is well exposed in outcrops of this bentonite one half mile (0.8 km) to the north of measured section 113, ash or tuff was not exposed where section 113 was measured, nor was it in the vicinity of sections 109 and 114. Sampling at the ash/bentonite locations was focused on the first carbonaceous bed beneath that horizon. At most localities, the first lignite or carbonaceous mudstone was tens of feet (multiple meters) beneath the ash/bentonite layer (fig. 7). However, in measured sections 109 and 114 the bentonite directly overlies a lignite (samples 109C and 114E), samples of which ranged from 33 to 219 ppm REE. At measured section 107 and 113, a thin carbonaceous mudstone (samples 113K, L, and M) was within three feet (1 m) of the base of the ash/bentonite layer. This horizon ranged from 97 to 172 ppm REE. In all, only five of the 59 samples (8.5%) from Sentinel Butte ash/bentonite sites contained dry whole coal concentrations above 189 ppm, the average upper crustal abundance (Taylor and McLennan, 1985). This is notably lower than systematic sampling of Kruger and others (2017), where nearly 21% of samples exceeded that threshold. Thus, it appears the Sentinel Butte ash does not contain significant amounts of rare earths, nor did it contribute significant amounts of REE to adjacent lignites.

Larsen (1983) reported major element oxides and some trace elements from the upper bentonite, middle ash, and lower bentonite. Concentrations of chromium, cobalt, nickel, copper, zinc, gallium, rubidium, strontium, yttrium, zirconium, niobium, barium, and lead were generally within the normal range for upper continental crust (0.5 to 2 times UCC). The highest sample of each of the three horizons was slightly enriched in cobalt (2.4 to 3.2 times UCC), with a high of 54 ppm, and all lead concentrations were slightly enriched at 2.1 to 3.8 times UCC. Nearly all samples were depleted in chromium, and some bentonite samples were also depleted in rubidium, niobium, and barium. The general trends of the critical elements examined by Larsen are consistent with NDGS samples of Cretaceous and Paleocene volcanic ashes and bentonites (Table 4) (Moxness et al., 2021; 2022), which contain normal levels of most elements but can be slightly enriched in cobalt. At Tracy Mountain, a bentonite with carbonaceous stringers is enriched in barium 6.7 times UCC.

Results of lateral sampling of high REE coals identified in RI-117

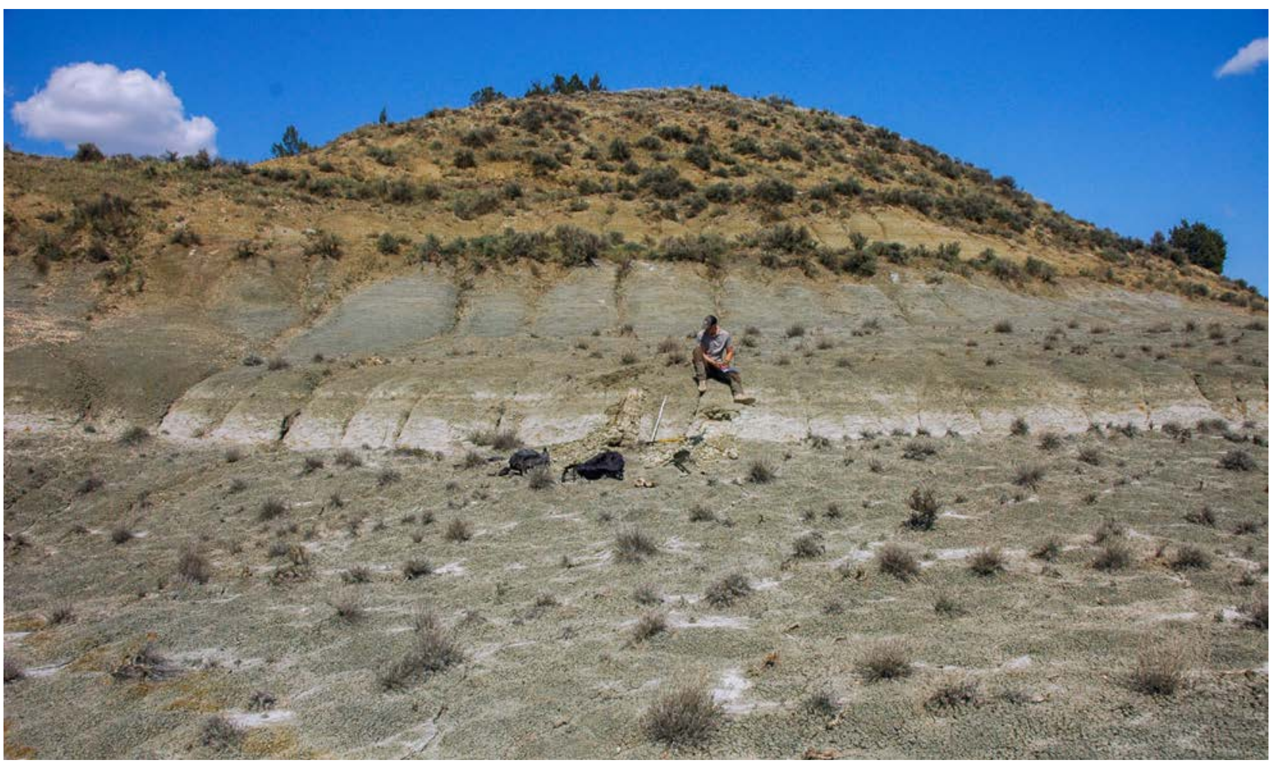
Several of the locations reported in RI-117 were subsequently revisited in order to collect a second or third lateral data point of a coal of interest. These sites include coals (samples 2AA, 3O, and 18C) with elevated outlook coefficients (a measure of the relative abundance of the critical REEs, e.g., neodymium, europium, terbium, dysprosium, erbium, and yttrium; Seredin and Dai, 2012), and coals which had initial REE concentrations exceeding 300 ppm (samples 5A and 21C). Samples of previously unsampled coals were also collected on some return visits as the measured sections were expanded upon by exploring other nearby exposures (measured sections 21 and 40). Sandstone samples were also submitted from measured section 9. Analytical results for these lateral and new samples can be found in Appendices A and B. More extensive lateral sample collection took place on return visits to the locations of measured section 6 in northern Billings County and measured section 17, west of the Little Missouri River in western Billings County.

Kruger and others (2017) reported a sample (6F) in measured section 6 (located in northern Billings County) with a total REE concentration of 333 ppm, not including scandium, collected from one-inch (2.5cm) of fine-grained coaly material near the bottom of a 2.5-foot-(0.8m) thick carbonaceous mudstone. Eleven lateral samples of this coal (fig. 8) were collected, of which seven were analyzed. Spacings intervals were approximately 150 to 500 feet (46-152m) for the samples collected nearest the original sample location, with longer intervals for the two eastern-most laterals (including the eastern-most sample 6F13) which were each approximately 1,800 feet (549m) distant from the next nearest sample. Along the observed outcrops of this bed, the carbonaceous mudstone ranged from slightly more than 1.5-feet (0.5m) thick to just over three-feet (0.9m) thick, generally thinning from west to east with varying amounts of coalified material. None of the seven analyzed lateral samples exceed 300 ppm in total REE concentrations, which for the lateral sample analyses included scandium.

A secondary interest in returning to the measured section 6 site was a thick sequence of bentonitic claystone containing a tuffaceous, clayey sandstone in the middle, roughly 35 feet (11m) below the 6F samples. Although this section occurs in the lower Sentinel Butte Formation, and thus is likely not a southward extension of the Sentinel Butte ash/bentonite in central McKenzie County, a sample (6H8) of the tuffaceous zone and two bentonitic claystones (samples 6G8 and 6I8) were collected (fig. 9). Kruger and others (2017) noted a carbonaceous layer immediately below the lower bentonite, but were unable to sample it due to the steep topography (fig. 10). During a return visit, a safer sampling location was discovered nearby and the coaly top of a carbonaceous layer (sample 6J8) was collected. The bentonites, ash, and underlying coal samples ranged from 160 to 214 ppm REE. The full analytical results from these samples can be found in measured section 6 in Appendices A and B of this report. Measured section 7 of Kruger and others (2017) was roughly one-half mile to the southeast of measured section 6, where multiple samples of lignite and carbonaceous mudstone were collected below the same bentonite. These samples are effectively lateral to sample 6J8 and contained similar REE concentrations (six samples at 81 to 232 ppm).

Also reported in RI-117 was a sample (17B) in measured section 17 at Crooked Creek in western Billings County (fig. 11) with a total REE concentration of 386 ppm (scandium included) collected from the middle of a five-inch-thick coal overlying seven inches (18 cm) of carbonaceous clay. A total of 32 additional samples taken from the tops, middles, and bottoms of this coal (fig. 12) were collected from 19 lateral locations scattered throughout section 16 (T. 142N., R.102W.). The total REE concentrations of these samples ranged from 127 to 512 ppm and averaged 279 ppm. Ten of the samples exceeded 300 ppm REE, five others exceeded 275 ppm. Three new measured sections (273, 274, & 275) were mapped and are shown in cross-section along with measured section 17 in Figure 13.

▲ **Figure 8.** An approximately 30-inch (76 cm)-thick carbonaceous bed underlies a tan mudstone where one of the lateral samples (6F7) was collected.

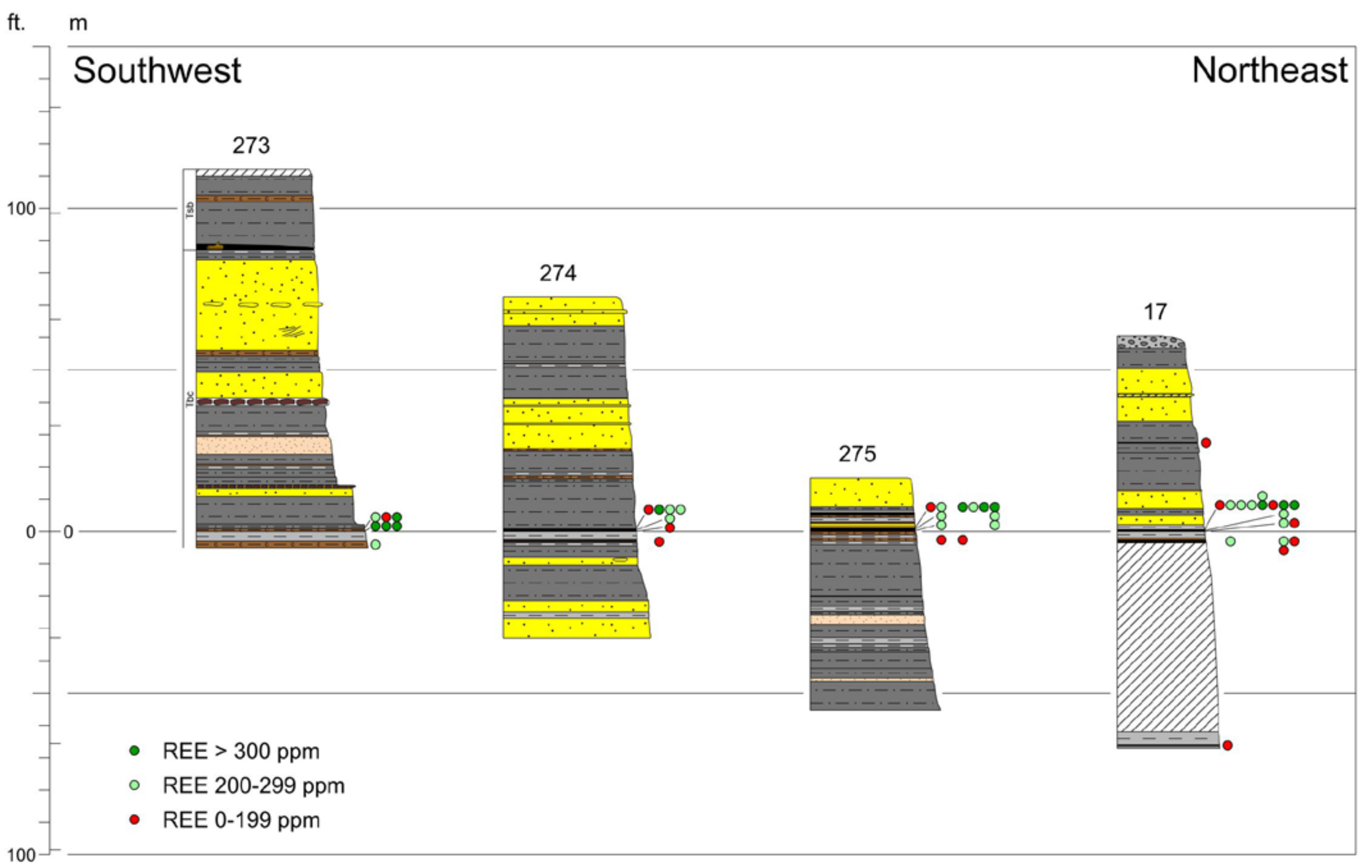


▲ **Figure 9.** Levi Moxness sits atop a white, three-feet (0.9 m)-thick layer of tuffaceous, clayey sandstone sandwiched between bentonitic claystone. Samples of the tuffaceous sandstone (6H8) and overlying and underlying bentonites (6G8 and 6I8, respectively) were collected at this location.

▲ **Figure 10.** The site of measured section 6 from Kruger and others (2017), note the steep cliffs preventing safe sampling of a carbonaceous zone directly under the bentonite. A safer location was found during sampling for this report, as carbonaceous beds below weathered volcanic ashes were of particular interest during this project.

▲ **Figure 11.** North facing view of lateral sampling location (sample 275B4; total REE concentration 454 ppm) where the coaly, carbonaceous claystone is approximately 14-inches (36 cm) thick.

◄ **Figure 12.** Sample 275B6t (NDGS Field ID 17B9A) collected from the upper four inches of a 12-inch (30cm) lignite where it contained 501 ppm REE. Sample 275B6m, taken just below at 4 to 8 inches (10-20cm) in depth, contained 249 ppm REE (estimated), and the bottom of the bed (276B6t) contained 289 ppm REE (estimated). At this sample location, most of the coaly material was observed in the top four inches, though thin coaly intervals can also be seen elsewhere within the carbonaceous mudstone. A nearby top sample (275B4) contained 1,595 ppm REE on a dry ash basis.



▲ **Figure 13.** The rare earth element concentration ranges for lignite and carbonaceous mudstone samples from measured sections at the Crooked Creek site in west-central Billings County (measured sections 17, 273-275). The datum is the top of the enriched "B" coal.

Results from Uranium-enriched coals at Sentinel Butte near the White River Contact

Kruger and others (2017) sampled several uranium-enriched lignites to investigate possible co-enrichment of the REEs with uranium. These samples were analyzed before the NDGS had expanded the project to critical minerals beyond the rare earths, so uraniferous samples were identified via radioactivity levels detected in the field by a scintillometer. They noted no REE enrichment in uraniferous (radioactive) lignites, and further noted no elevated radioactivity in high-REE coals when found at other sites. Thus, uranium and rare earths appeared to enrich somewhat independently of one another, however, analytical data in later phases of the project have since shown a strong correlation. At Tracy Mountain, uranium showed the strongest ranked correlation to total REE of any of the 28 other elements analyzed (ρ of 0.69; Moxness et al., 2021), despite none of the samples exhibiting radioactivity appreciably above background. In 2020, the NDGS returned to one locality where lignites exhibited elevated levels of radioactivity, measured section 28 at Sentinel Butte (fig. 14), to collect samples for additional critical mineral analysis.

▲ **Figure 14.** Measured section 28 at Sentinel Butte. Samples were taken from the uraniferous coal exposed below the yellow sandstone exposed in the center of the photo. Drone photo taken looking southwest.

Samples 28A2 (100 counts per minute), 28B (350 CPM) (fig. 5), 231Eb (70 CPM), and 231F (80 CPM) (fig. 15), were the only samples which exhibited elevated radioactivity in the field, and laboratory analysis confirmed these samples were the four highest of 89 uranium concentrations measured in this report. Lignites an order of magnitude more radioactive (>4,000 CPM) have been identified in the field in North Dakota during this project but were not sampled for the safety of field and laboratory personnel. Sample 28B, at 1,480 ppm U (whole dry coal basis) and 3,500 ppm U (ash basis), is several times more uraniferous than any sample in the project to date. It contains an estimated total REE concentration of just 183 ppm, illustrating with laboratory data the conclusions of Kruger and others (2017) that high REE and high U concentrations do not tend to occur in the same coals.

Other elements do, however, become enriched alongside uranium in coals at Sentinel Butte. Sample 28B contains molybdenum concentrations of 3,800 ppm (dry coal basis) / 8,990 ppm (ash basis), over 16 times higher than any sample from other sites in this project. Arsenic concentrations in this sample (1,860/4,400 ppm dry coal/ash basis) are nearly triple that of any other sample. Sample 28B is also a top five sample in hafnium (14/33 ppm), tungsten (75.1/178 ppm), and zirconium (1,000/2,370 ppm). A sample (28A2) from a few inches above, separated by a thin parting, contains the overall study's highest concentrations for gallium (50.3/163 ppm) in coal and coal ash and zirconium (3,200 ppm) in coal ash. Sample 231F contains the project's highest concentrations of vanadium (519/1,460 ppm), and sample 233T, a 2-inch white claystone parting, is the project's highest titanium (15,100/15,800 ppm) concentration to date, although the latter sample was not especially uraniferous at 11.7 ppm uranium.

▲ **Figure 15.** The locations of two uraniferous coals sampled below a prominent oxidized sandstone in measured section 231 on a northwestern ridge of Sentinel Butte. The outcrop had collapsed sometime prior to the site being sampled. Photo taken looking south, 3-foot-(0.9m) long pick for scale.

Conclusions

The Sentinel Butte ash, the most prominent Paleocene volcanic deposit in North Dakota, does not appear to be enriched in rare earth elements, based on sampling across McKenzie County. Samples of the adjacent bentonites, lignites, and carbonaceous mudstones did not show REE enrichment, which further suggests this deposit was not REE enriched at one time and later depleted by leaching. This conclusion agrees with the findings from volcanic ashes and associated carbonaceous beds in the Hell Creek and Fox Hills Formations of Moxness and others (2022), in that the major late Cretaceous and Paleocene volcanogenic deposits do not appear to play a role in the REE-enrichment seen in lignites present in southwestern North Dakota.

Kruger and others (2017) systematically sampled carbonaceous horizons across Billings, Golden Valley, and McKenzie counties. Subsequent sampling aimed to provide further context of the lateral extent of enrichment by targeting the high-REE beds. Tracy Mountain (Moxness et al., 2022) was the most extensive investigation of any of these original enrichment sites, which showed carbonaceous beds can be continuously REE-enriched over an area of 25 acres (100,000 m^2), and that other critical minerals are enriched in the same beds. This report illustrates that consistent enrichment is fairly rare, as resampling of high to moderate-REE lignites at sites 5, 6, 18, and 21 did not produce a higher sample than the original, although one of three laterals of sample 21C was over 300 ppm REE, some 600 feet (180m) away. Sandstone samples below a 521 ppm REE carbonaceous bed at site 9 contained low REE concentrations. New samples of the HT Butte bed, a high quality nine-foot-thick (2.7m) coal at site 40, were low to very low. Lateral samples of low-REE coals with high proportions of the critical REEs (2AA2, 3O2) did not appear uniquely enriched in any of the non-rare earth critical elements.

The Crooked Creek site in western Billings County did provide higher REE concentrations in lateral samples. An approximately one-foot-(0.3m)-thick lignite in the upper Bullion Creek Formation was relatively consistently enriched around 300 ppm REE (up to 512 ppm REE) over an area of one square mile (2.6 km2). While the concentrations were not as high as Tracy Mountain, where seven of the eight uppermost carbonaceous beds contained REE concentrations over 400 ppm, the enrichment is noteworthy in that it occurs even where overlain by 100 ft (30m) of rock. Results from Tracy Mountain (Moxness et al., 2021) and buttes in the Ludlow Formation across southwestern and south-central ND (Moxness et al., 2022) showed REE enrichment is not uncommon in carbonaceous beds in the topographically highest 60 feet (18m), especially below flat upland surfaces. These upper beds likely became enriched by downward-flowing groundwater during the Pliocene or Quaternary erosive event which created the upland surface, or weathering of the uplands in the intervening time. The consistently high REE concentrations lower in section at Crooked Creek, and the H bed at Logging Camp Ranch (Murphy et al., 2018), supports a second enrichment model where lignites occasionally received high-REE waters during or shortly after deposition.

It was initially hypothesized that rare earths have followed the same enrichment patterns as have been well documented for uranium in North Dakota, and while a positive correlation is apparent across the broader sample dataset, this relationship does not appear to hold in significantly enriched samples. The most uraniferous lignite analyzed in this study, a dry coal sample with 1,480 ppm uranium and 3,800 ppm molybdenum (both over five times higher than the next highest sample), had an estimated total REE concentration of just 183 ppm. The dry coal sample with the highest REE concentration identified during the overall study (an H bed sample containing 1,598 ppm REE) had a uranium concentration of just 25.7 ppm and 17.6 ppm of molybdenum, concentrations that are still roughly ten times the average world coal, but orders of magnitude lower than what would be expected if these elements were tightly correlated (e.g., uranium and molybdenum).

Critical element concentrations are largely consistent with those reported previously from the Sentinel Butte Formation at Tracy Mountain (Moxness et al., 2021) and the Ludlow, Hell Creek, and Fox Hills Formations (Moxness et al., 2022). Low-REE, high-U coals at Sentinel Butte in this report showed molybdenum and arsenic closely co-enrich with uranium, as do hafnium, tungsten, and zirconium to lesser degrees. Relative to the average upper crustal abundance, North Dakota lignites appear to commonly be significantly enriched in antimony, arsenic, germanium, molybdenum, and uranium. Occasionally barium, beryllium, cobalt, and tungsten can also be significantly enriched, and unusually high enrichment of antimony, arsenic, germanium, molybdenum, and uranium have been found. Enriched levels of zirconium have also been identified at Sentinel Butte and Tracy Mountain.

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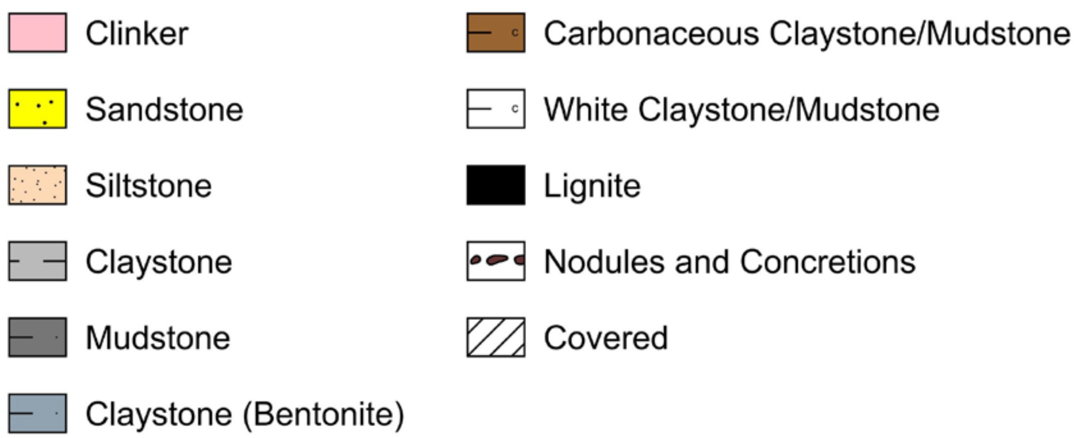
Appendices

Appendix A

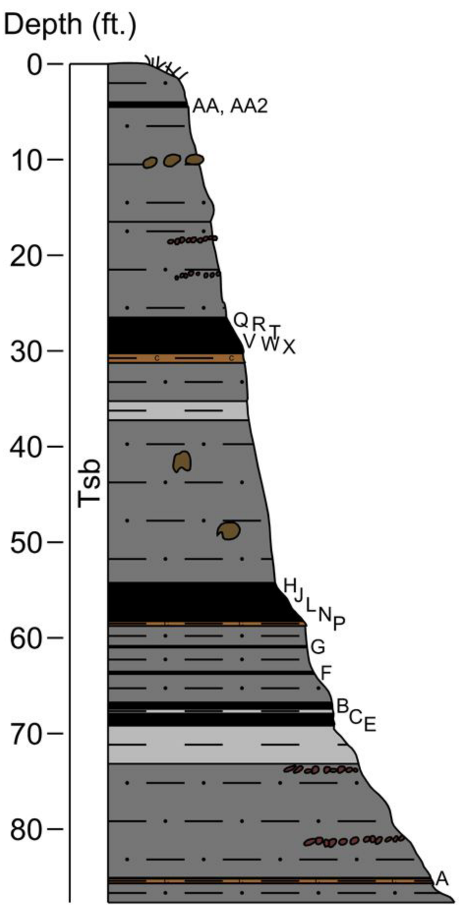
Legend for lithologies of measured sections



Total REE concentrations (dry whole coal and dry ash basis) in *italics* where estimated using the methodology outlined in Kruger (2020).

REE Section 2

T.146N., R.101W., Sec.36, NW1/4
Elevation at top 2,372 ft.

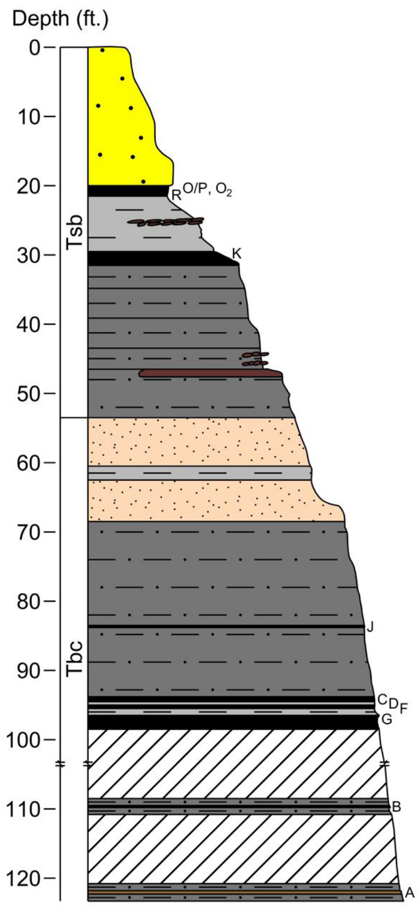


Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
	Lab Analysis (in µg/g)																	
2AA	23.5	8.9	8.38	1.40	5.2	2.39	13.5	1.62	13.3	3.2	3.6		1.10	1.34	9.55	72	169	389
2AA2	31.1	3.7	2.76	0.87	3.4	0.82	15.6	0.46	14.9	3.8	3.2	14.7	0.54	0.39	2.92	24.4	124	249
2Q	15.5	3.3	2.54	0.71	2.4	0.78	10.2	0.40	7.2	1.8	1.7		0.46	0.37	2.50	25	75	
2R	4.5	0.9	0.77	0.18	0.7	0.24	2.7	0.13	2.1	0.5	0.5		0.13	0.12	0.76	8	22	269
2T	8.8	1.0	0.69	0.24	1.1	0.23	4.5	0.09	4.5	1.1	1.0		0.17	0.10	0.59	9	33	
2V	13.1	1.9	1.20	0.34	1.8	0.40	6.5	0.18	7.1	1.7	1.7		0.30	0.17	1.14	13	51	254
2W	76.8	2.4	0.90	0.54	4.1	0.36	33.6	0.09	32.9	9.1	5.8		0.50	0.11	0.63	8	176	
2X	7.8	0.7	0.50	0.11	0.6	0.16	6.2	0.08	2.6	0.7	0.5		0.10	0.08	0.51	5	26	
2H	17.8	3.1	2.17	0.74	2.6	0.70	9.0	0.36	9.8	2.3	2.3		0.47	0.33	2.23	19	73	
2J	3.1	0.5	0.37	0.13	0.5	0.12	1.6	0.05	1.9	0.4	0.4		0.08	0.05	0.32	5	15	191
2L	6.5	0.7	0.44	0.23	0.8	0.15	3.2	0.06	3.8	0.9	0.8		0.13	0.06	0.38	5	23	
2N	13.2	1.2	0.69	0.37	1.3	0.24	7.5	0.10	6.3	1.6	1.4		0.20	0.10	0.64	7	42	169
2P	41.1	2.0	1.34	0.52	2.1	0.45	29.0	0.19	11.7	3.8	1.9		0.33	0.19	1.18	14	110	
2G	22.7	4.5	3.59	0.79	3.3	1.09	11.3	0.68	11.8	2.9	2.8		0.63	0.57	4.10	27	98	
2F	8.4	1.7	1.38	0.28	1.2	0.41	4.2	0.26	4.3	1.0	1.0		0.24	0.22	1.58	11	37	155
2B	10.8	3.5	2.81	0.53	2.3	0.87	5.4	0.46	5.9	1.4	1.6		0.48	0.43	2.89	25	64	366
2C	28.5	3.5	2.04	0.90	3.7	0.72	12.8	0.28	15.4	3.7	3.5		0.60	0.29	1.84	19	97	
2E	26.5	3.0	2.22	0.65	2.7	0.68	13.7	0.37	12.6	3.2	2.6		0.45	0.34	2.39	18	89	
2A	27.1	3.6	2.67	0.64	2.8	0.84	15.0	0.43	12.0	3.1	2.5		0.52	0.40	2.69	23	97	

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
2AA	3.88		1050	30.5		1.49	58		25.0	28	5.4		30.0	19400		2.6	29.7		802	0.55				1930	6.8	29.4	186	514
2AA2	5.52		786	7.3		2.45	114		25.9	37	4.8		15.8	10400		18.6	29.6		523	0.50				2510	11.3	12.3	259	508

REE Section 3

T.145N., R.101W., Sec.6, S1/2
Elevation at top 2,380 ft.

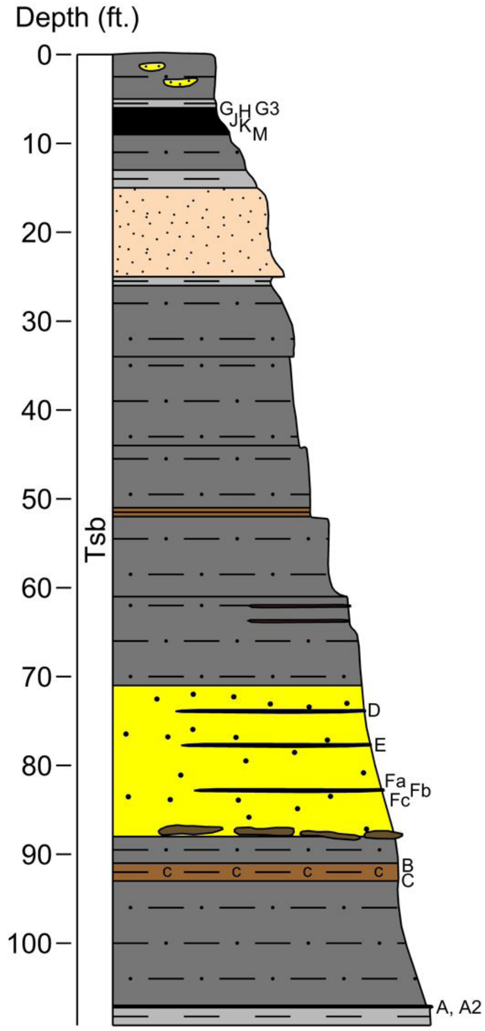


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
3O	13.4	3.2	2.57	0.79	2.4	0.78	7.6	0.45	7.0	1.7	1.7		0.44	0.39	2.72	24	69	469
3O2	15.9	4.7	3.61	0.84	3.4	1.12	8.5	0.60	8.7	2.0	2.3	11.3	0.63	0.54	3.62	34.5	102	727
3P	13.4	2.6	1.97	0.67	2.1	0.61	7.3	0.33	7.3	1.7	1.7		0.37	0.30	2.01	19	61	
3R	11.5	2.4	1.63	0.47	2.1	0.55	6.3	0.22	6.2	1.5	1.5	3.6	0.37	0.23	1.38	19	59	343
3K	13.6	3.0	2.08	0.51	2.4	0.68	6.8	0.32	7.4	1.7	1.8		0.44	0.30	2.00	20	63	200
3J	27.1	5.9	4.29	1.01	4.5	1.37	14.0	0.67	14.5	3.5	3.5		0.85	0.63	4.34	38	124	
3C	54.0	4.5	2.63	0.92	4.7	0.89	24.6	0.38	23.7	6.4	4.9		0.75	0.37	2.46	23	154	
3D	54.8	2.1	0.92	0.70	3.1	0.35	23.9	0.11	21.8	6.2	4.1		0.43	0.11	0.74	9	128	
3F	30.6	4.6	2.92	0.73	3.9	0.98	17.2	0.43	13.8	3.5	3.2		0.70	0.42	2.77	26	112	
3G	31.2	4.7	2.79	0.83	4.4	0.95	15.5	0.39	15.5	3.8	3.7		0.75	0.39	2.53	24	111	
3B	31.8	3.0	2.10	0.64	2.7	0.66	16.4	0.34	14.2	3.8	2.8		0.46	0.31	2.17	17	98	
3A	54.1	3.2	2.16	0.84	3.7	0.69	27.3	0.35	24.1	6.4	4.4		0.53	0.32	2.26	17	147	

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
3O2	2.50	5.5	862	11.3	<0.10	0.13	31	12.4	9.2	48	1.7	<0.02	3.3	3950	207	2.4	11.3	3	355	0.16	<0.10	1.3	0.2	636	2.5	3.1	135	196

REE Section 5

T.144N., R.101W., Sec.16, SW1/4
Elevation at top 2,448 ft.

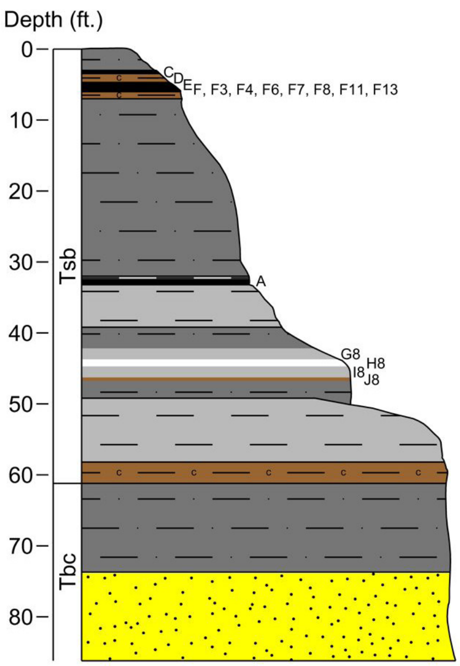


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
5G3	13.3	2.4	1.96	0.55	2.0	0.58	6.9	0.31	6.8	1.6	1.5	8.4	0.34	0.28	1.92	20.4	69	250
5G	16.4	3.6	2.88	0.72	2.7	0.87	8.9	0.48	8.6	2.1	2.1		0.51	0.43	2.83	27	80	
5H	8.9	1.8	1.24	0.34	1.5	0.41	4.0	0.17	5.0	1.2	1.2		0.27	0.17	1.06	15	42	327
5J	10.4	1.8	1.12	0.31	1.7	0.39	4.7	0.16	5.9	1.4	1.5		0.29	0.16	1.00	13	44	
5K	9.7	2.0	1.37	0.34	1.8	0.46	4.4	0.20	5.6	1.3	1.4		0.31	0.20	1.23	14	44	338
5M	8.1	2.4	1.73	0.34	1.6	0.55	3.8	0.29	4.6	1.1	1.2		0.33	0.27	1.79	14	42	
5D	57.5	3.7	2.05	1.22	4.3	0.70	30.0	0.28	25.6	6.7	4.8		0.66	0.29	1.84	17	157	
5E	57.3	3.7	2.08	1.16	4.5	0.71	29.6	0.29	25.5	6.7	4.9		0.66	0.29	1.89	17	156	
5Fa	46.9	2.7	1.43	0.95	3.5	0.50	23.9	0.18	21.0	5.5	4.0		0.49	0.20	1.24	13	125	
5Fb	59.4	3.4	1.78	1.13	4.3	0.62	30.5	0.24	26.2	6.9	5.0		0.63	0.25	1.58	15	157	
5Fc	42.9	2.9	1.65	1.00	3.5	0.55	22.2	0.24	19.6	5.1	3.8		0.50	0.24	1.58	14	120	
5B	73.3	4.9	3.13	1.29	5.4	1.01	35.9	0.51	31.8	8.5	6.0		0.83	0.47	3.16	26	202	
5C	33.6	5.1	3.93	0.88	4.0	1.19	17.5	0.65	16.1	4.1	3.4		0.73	0.59	3.99	34	130	
5A	90.9	16.8	11.40	2.90	14.3	3.75	42.7	1.67	47.1	11.4	11.0		2.57	1.64	10.50	91	360	927
5A2	68.4	8.8	5.80	1.95	8.4	1.89	32.0	0.88	34.7	8.7	7.7	24.1	1.35	0.82	5.6	49.1	260	408

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
5A2	29.2	148	1550	4.2	0.58	6.59	69	27.5	30.0	36	6.3	0.05	24.8	8280	138	44.8	27.8	74	521	0.66	0.17	9.6	1.6	2160	5.6	41.1	217	677

REE Section 6

T.144N., R.102W., Sec.36, NW1/4
Elevation at top 2,510 ft.

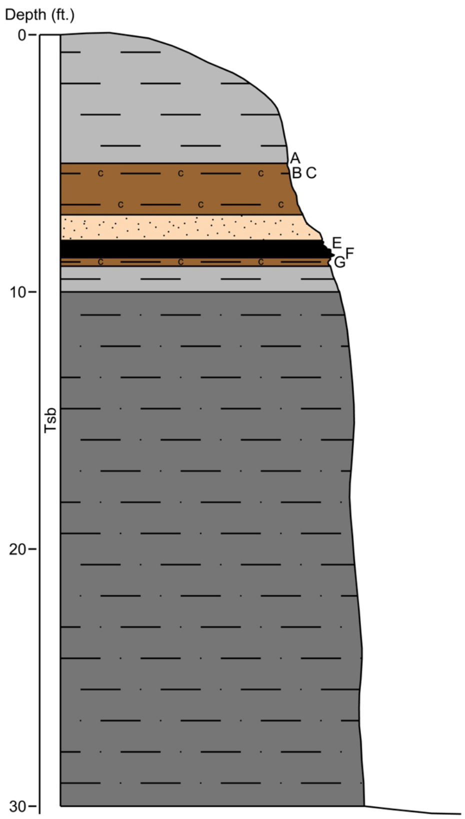


	Lab Analysis (in µg/g)																
																Total REE	
Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
6C	58.7	4.3	2.60	1.23	4.8	0.87	28.4	0.36	26.0	6.8	5.1		0.72	0.37	2.44	25	168	
6D	42.9	2.6	1.61	0.74	2.8	0.53	21.6	0.25	18.5	5.0	3.3	10.9	0.43	0.24	1.57	16	129	168
6E	39.0	3.5	2.12	0.90	3.7	0.73	19.6	0.30	17.7	4.6	3.6	11.2	0.59	0.31	1.97	21	131	213
6F	105	11.8	6.52	3.13	13.0	2.27	44.1	0.84	57.0	13.8	12.8		2.02	0.89	5.49	54	333	
6F3	49.8	4.9	2.79	1.39	5.4	0.96	21.6	0.42	25.8	6.4	5.7	15.6	0.84	0.41	2.66	23.1	168	338
6F4	43.4	4.7	2.67	1.50	5.5	0.90	15.8	0.42	27.1	6.3	6.5	20.3	0.81	0.39	2.70	17.2	156	380
6F6	66.7	5.4	3.33	1.38	5.7	1.12	32.1	0.49	30.3	7.9	6.1	13.7	0.90	0.50	3.15	31.7	210	316
6F7	40.3	3.7	2.19	0.98	4.0	0.75	18.9	0.32	19.0	4.9	4.0	12.0	0.62	0.31	2.04	19.5	134	240
6F8	73.2	8.8	5.14	2.56	9.4	1.72	27.2	0.79	44.1	10.5	10.5	35.3	1.48	0.74	5.07	35.5	272	695
6F11	66.6	8.3	4.41	2.68	10.0	1.54	23.5	0.66	47.9	11.0	11.8	27.8	1.47	0.64	4.32	31.4	254	538
6F13	37.8	3.9	2.26	1.19	4.4	0.77	17.2	0.35	21.2	5.2	4.9	17.0	0.67	0.33	2.24	17.3	137	221
6A	21.0	2.7	2.09	0.55	2.3	0.61	10.5	0.39	10.4	2.6	2.2		0.39	0.34	2.40	17	75	
6G8	64.5	4.3	2.42	1.08	5.1	0.83	31.6	0.34	29.5	7.7	5.9	12.3	0.77	0.34	2.25	21.3	190	207
6H8	54.7	3.6	2.10	1.07	4.3	0.71	27.6	0.30	24.8	6.4	4.7	8.1	0.62	0.30	1.95	18.8	160	169
6I8	73.6	4.6	2.45	1.07	5.6	0.85	36.7	0.34	32.8	8.7	6.4	13.9	0.80	0.34	2.29	23.4	214	231
6J8	63.8	4.0	2.61	0.98	4.5	0.84	31.6	0.42	27.7	7.3	5.3	11.7	0.66	0.39	2.61	25.8	190	242

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
6F6	2.10	12.6	611	3.9	0.44	5.26	65	19.1	15.2	3	3.0	0.06	19.4	4750	36	3.5	14.6	73	211	0.99	0.27	9.4	1.8	4090	2.6	4.2	107	128

REE Section 7

T.144N., R.102W., Sec.36, NW1/4
Elevation at top 2,465 ft.

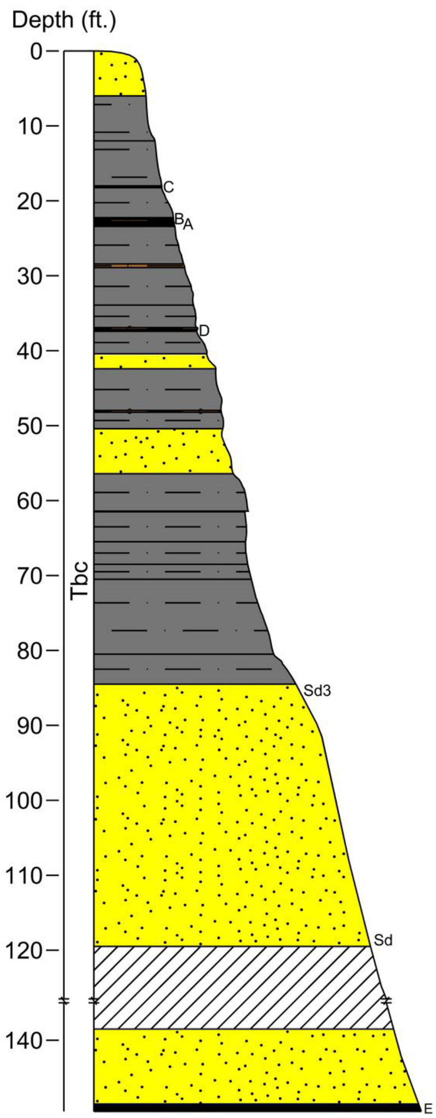


Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
	Lab Analysis (in µg/g)																	
7A	66.2	4.5	2.69	1.21	5.2	0.94	31.3	0.38	29.3	7.7	5.7	15.4	0.79	0.38	2.41	26	200	212
7B	46.0	3.1	2.07	0.76	3.4	0.68	22.8	0.33	19.7	5.2	3.8	8.5	0.53	0.32	2.07	19	138	174
7C	70.0	4.9	2.97	1.22	5.7	1.02	31.1	0.42	31.2	8.1	6.1	13.4	0.87	0.42	2.67	27	207	269
7E	59.1	6.6	4.15	1.23	6.4	1.43	27.9	0.59	27.6	7.0	5.7	13.9	1.07	0.59	3.72	42	209	551
7F	18.7	3.2	2.36	0.44	2.5	0.77	9.4	0.38	8.8	2.2	1.9	3.8	0.47	0.35	2.28	23	81	
7G	76.0	6.1	3.54	1.51	6.7	1.25	36.9	0.49	34.7	9.1	6.9	11.1	1.05	0.50	3.15	33	232	362

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
7G	2.75	9.4	1050	5.0	0.34	8.40	40	18.9	15.1	13	3.0	0.04	23.3	5200	55	9.6	11.4	89	263	0.64	<0.10	6.0	1.6	1920	4.4	8.0	76	207

REE Section 9

T.134N., R.102W., Sec.14, NW1/4
Elevation at top 2,439 ft.

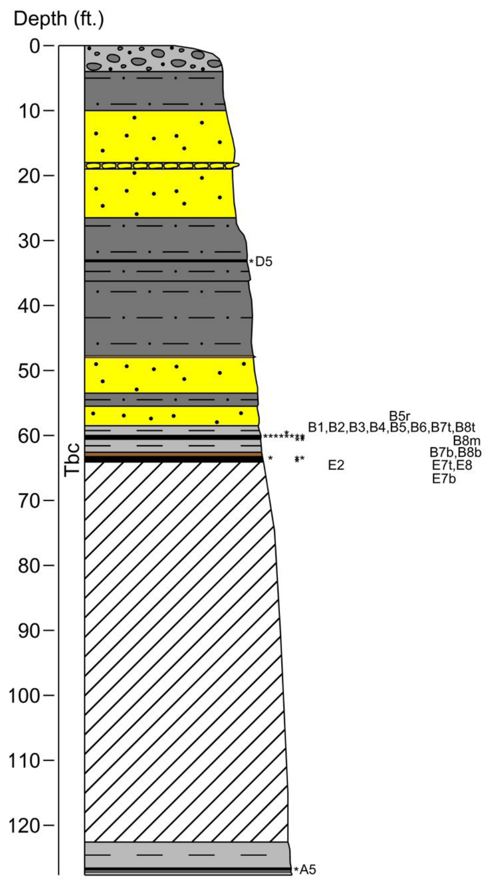


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
9C	27.8	4.8	3.46	0.89	4.0	1.09	14.3	0.59	13.8	3.5	3.2	11.9	0.69	0.52	3.57	30	124	314
9B	76.0	11.7	8.04	1.83	10.1	2.66	54.8	1.14	33.0	8.5	7.0	15.4	1.74	1.14	7.24	95	335	709
9A	170	16.7	8.60	4.17	18.9	3.12	72.6	1.10	86.9	21.6	18.6	18	2.94	1.17	7.46	69	521	850
9D	36.3	5.4	3.65	1.05	4.8	1.20	17.8	0.57	18.7	4.6	4.2	17.4	0.84	0.53	3.59	31	152	349
9Sd3	41.9	2.3	1.36	0.69	3.1	0.43	20.6	0.18	18.8	5.0	3.6	5.0	0.39	0.17	1.30	12.3	117	129
9Sd	35.1	2.2	1.35	0.60	2.8	0.43	17.5	0.19	15.7	4.1	3.1	5.2	0.37	0.18	1.37	12.6	103	114
9E	18.2	3.0	1.96	0.60	2.8	0.66	14.0	0.28	8.4	2.1	2.1	6.8	0.47	0.28	1.80	19	82	262

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
9A	25.0	56.9	3260	5.3	0.47	6.19	61	18.4	30.1	18	8.2	0.07	28.0	8450	67	72.7	29.6	94	367	0.76	0.10	12.8	1.9	1930	10.4	63.7	192	443
9E	1.97	60.9	1400	2.0	<0.10	0.11	4	6.1	3.6	1	0.6	<0.02	3.2	5030	40	9.6	1.8	2	668	0.12	<0.10	1.1	0.3	376	1.8	10.3	12	24.5

REE Section 17

T.142N., R.102W., Sec.16, SE/SW/NE
Elevation at top 2,525 ft.

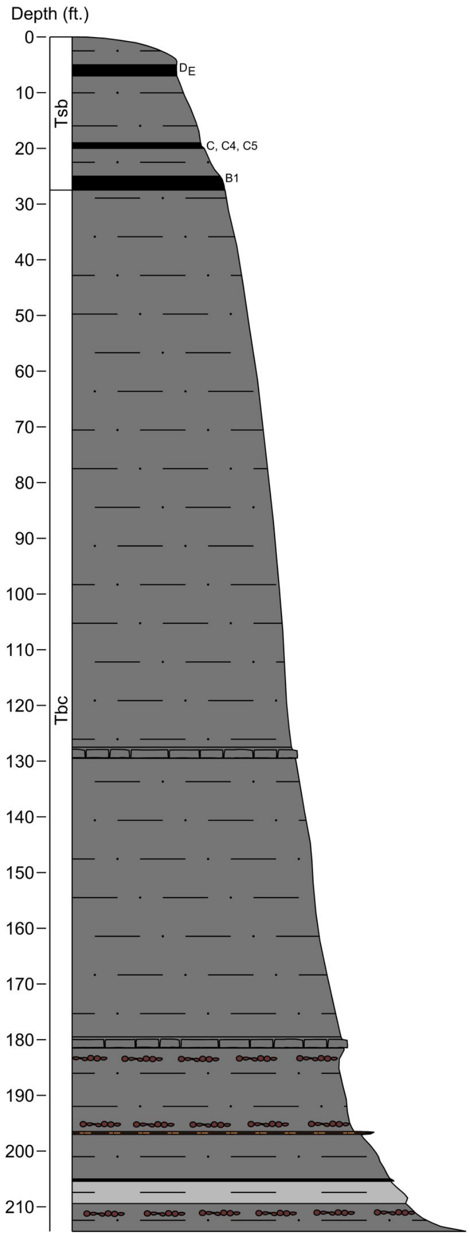


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
17D5	34.3	3.9	2.77	0.85	3.8	0.88	16.7	0.46	16.9	4.3	3.5	11.5	0.63	0.41	2.88	22	126	202
17B5r	70.8	8.3	5.08	1.42	7.8	1.77	35.2	0.63	29.9	7.9	5.9	11.7	1.32	0.69	4.23	52	245	416
17B1	34.0	6.9	5.00	1.02	5.5	1.59	18.4	0.77	17.0	4.1	4.1	13.7	0.99	0.72	4.73	49.3	168	575
17B2	76.4	10.4	6.38	1.91	10.0	2.15	34.6	0.93	37.4	9.3	8.1	15.1	1.63	0.89	5.82	56.1	277	647
17B3	96.8	7.0	3.81	1.87	8.3	1.33	45.8	0.52	44.6	11.4	9.0	14.4	1.22	0.53	3.48	36.7	287	348
17B4	87.6	7.0	3.48	2.19	9.2	1.25	32.9	0.48	48.5	11.9	10.7	14.4	1.30	0.48	3.19	30.5	265	402
17B5	113	14.6	7.85	3.05	15.2	2.82	48.6	1.03	62.4	15.5	13.2	14	2.47	1.07	6.85	64	386	793
17B6	64.1	4.0	2.33	1.21	5.2	0.78	29.8	0.34	31.3	7.9	6.2	12.2	0.73	0.33	2.28	20.1	189	220
17B7t	151	18.9	10.3	4.12	20.2	3.64	61.2	1.33	81.1	19.7	18.0	15.3	3.26	1.40	8.75	91.2	509	1084
17B8t	100	11.9	6.29	2.93	13.8	2.23	36.3	0.83	59.9	14.3	13.4	12.6	2.14	0.86	5.45	52.3	335	615
17B8m	85.3		4.38		10.2		31.7		50.8			16.5				35.2	*275*	*416*
17B7b	92.6	8.8	4.81	2.31	10.4	1.69	39.5	0.66	50.0	12.1	11.0	14.6	1.60	0.67	4.33	41.3	296	424
17B8b	65.6		2.21		5.5		30.1		32.7			11.3				18.9	*190*	*226*
17E2	65.5	9.2	5.85	1.62	8.4	1.96	35.3	0.78	31.3	8.0	6.8	11.1	1.40	0.81	5.08	71.4	265	650
17E7t	66.3		5.43		8.9		30.9		33.4			12.1				56.1	*251*	*594*
17E8	53.3		2.54		5.8		22.3		29.9			10.6				22.7	*171*	*292*
17E7b	42.3		4.76		6.8		22.7		23.5			14.4				46.9	*191*	*423*
17A5	45.4	4.7	3.10	1.02	4.3	1.00	22.5	0.52	21.6	5.6	4.4	15.2	0.72	0.48	3.28	22	156	225

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
17B7t	14.6	152		6.4				53.5	23.3					6680		70.4									7.3	54.4		210
17B8t	11.9	99.3		3.5				31.2	20.6					10100		53.1									4.2	45.4		222
17B8m	11.3	63.4		3.0				11.7	17.6					8690		43.3									2.0	34.8		209
17B7b	13.9	87.5		3.5				13.5	20.3					6800		45.4									2.7	29.6		191
17B8b	4.58	27.8		2.0				6.4	21.8					8320		14.5									1.8	13.7		125
17E7t	5.04	66.8		4.3				14.3	11.5					6860		38.3									4.0	16.4		85.5
17E8	16.5	617		2.5				8.3	14.4					5610		58.8									3.4	17.9		161
17E7b	9.58	85.3		3.2				15.8	12.5					8410		65.9									6.3	26.8		210

REE Section 18

T.142N., R.101W., Sec.17, NE1/4
Elevation at top 2,489 ft.

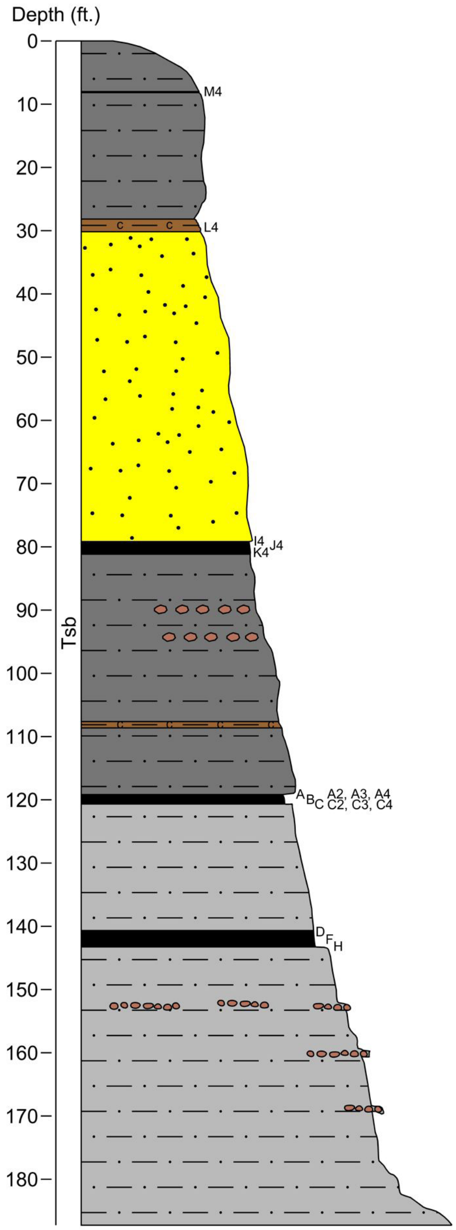


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
18D	14.5	2.4	1.49	0.53	2.3	0.52	6.9	0.19	7.8	1.9	1.9	5.0	0.38	0.20	1.22	18	65	264
18E	13.7	2.5	1.61	0.54	2.2	0.53	6.5	0.21	7.6	1.8	1.8	6.1	0.38	0.22	1.40	18	65	269
18C	47.3	9.6	6.22	1.83	8.1	2.13	24.1	0.85	25.8	6.3	6.2	15.5	1.44	0.88	5.63	61	223	630
18C4	32.0	4.7	2.85	1.03	4.8	0.98	15.4	0.40	16.7	4.0	3.8	9.8	0.75	0.39	2.51	27.5	128	903
18C5	29.9	4.5	2.91	0.95	4.4	0.97	16.2	0.41	15.8	3.9	3.4	9.4	0.70	0.40	2.59	32.9	129	565
18B1	17.6	3.5	2.29	0.62	3.0	0.77	8.8	0.32	9.2	2.2	2.2	6.9	0.54	0.32	2.05	21	81	283

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium

REE Section 21

T.142N., R.101W., Sec.36, NE1/4
Elevation at top 2,640 ft.

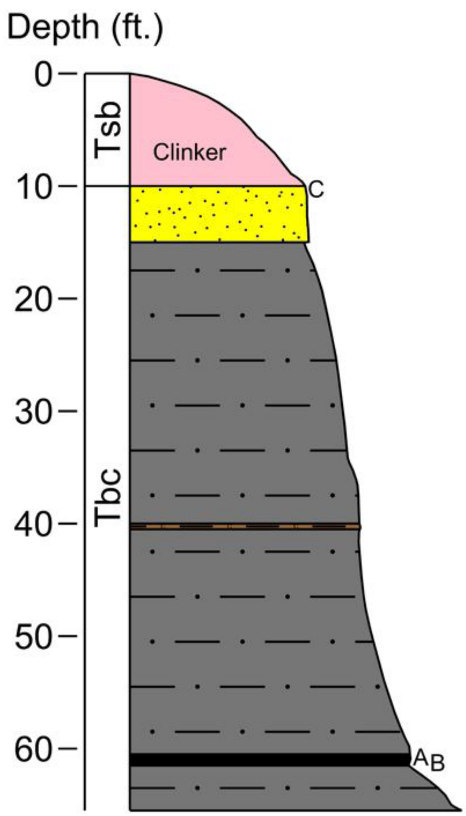


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
21M4	14.1	2.4	1.93	0.44	1.9	0.57	7.6	0.37	7.2	1.8	1.6	13.9	0.33	0.31	2.20	18.3	75	242
21L4	47.4	8.3	5.90	1.64	7.6	1.84	22.1	1.01	27.1	6.4	6.6	18.9	1.28	0.90	5.99	59.4	222	1010
21I4	29.8	6.5	4.38	1.23	5.4	1.40	12.1	0.69	18.3	4.3	4.9	18.8	0.97	0.65	4.30	37.3	151	427
21J4	12.1	3.6	2.77	0.51	2.6	0.86	6.3	0.46	6.8	1.6	1.8	5.2	0.49	0.42	2.76	29.7	78	426
21K4	29.2	4.9	3.37	0.93	4.1	1.09	15.1	0.49	14.9	3.7	3.4	11.7	0.72	0.48	3.15	38.3	136	621
21A2	54.5		4.03		7.2		22.1		30.6			19.2				31.8	*200*	*458*
21A3	46.5	5.5	3.03	1.58	6.2	1.05	16.7	0.42	26.5	6.4	6.3	15.5	0.95	0.42	2.70	25.6	165	420
21A4	11.4	4.8	3.61	0.72	3.3	1.13	6.1	0.55	6.8	1.5	2.1	12.1	0.65	0.53	3.37	36.8	95	398
21A	43.9	6.0	3.54	1.57	6.4	1.23	15.0	0.50	25.7	6.0	6.0		1.04	0.50	3.19	29	150	
21B	17.8	4.8	3.47	0.81	3.7	1.11	9.4	0.53	9.9	2.3	2.7		0.69	0.51	3.28	32	93	
21C	109	7.4	3.94	2.55	9.5	1.40	51.4	0.54	51.2	12.9	10.6		1.39	0.55	3.54	35	301	
21C2	34.8		5.08		5.4		19.5		17.2			16.2				50.2	*174*	*728*
21C3	27.1	4.2	2.88	0.83	3.6	0.93	14.0	0.43	13.0	3.3	3.0	14.1	0.62	0.42	2.70	29.6	121	320
21C4	92.7	8.2	5.14	2.17	8.6	1.67	45.0	0.77	42.1	11.1	8.8	26.8	1.32	0.74	4.84	46.6	307	443
21D	11.5	1.7	1.24	0.31	1.4	0.39	6.3	0.21	5.2	1.3	1.2		0.25	0.19	1.28	10	42	
21F	4.7	1.0	0.74	0.20	0.9	0.24	2.0	0.09	3.0	0.7	0.7		0.16	0.10	0.55	10	25	
21H	3.6	0.6	0.49	0.16	0.6	0.15	1.9	0.08	2.0	0.5	0.5		0.10	0.07	0.48	5	16	

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
21K4	2.17	7.4	622	4.0	0.10	0.05	13	7.9	5.0	8	1.5	0.02	4.5	4550	9	2.7	7.7	1	249	0.28	0.10	4.0	0.4	1520	2.0	6.4	25	156
21A2				3.5		1.14				30	3.7		16.1	9520				18				8.8		1200		19.1		316
21C2				9.1		0.87				14	1.9		11.6	8360				7				6.6		866		6.3		83.6
21C4	9.35	50.2	805	8.8	0.61	4.46	101	19.5	25.4	18	5.1	0.08	40.8	8100	457	22.2	28.8	43	208	1.02	0.39	15.7	2.0	3770	6.1	30.3	209	506

REE Section 22

T.141N., R.101W., Sec.1, NE1/4
Elevation at top 2,449 ft.

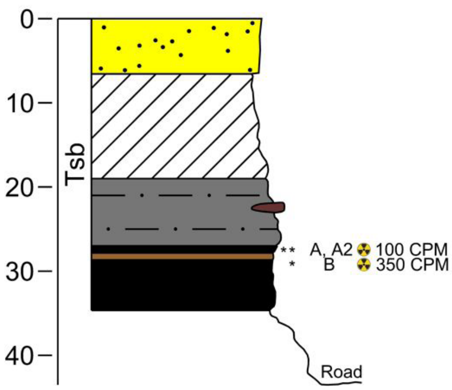


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
22C	46.0	3.3	1.87	0.89	3.8	0.64	22.9	0.28	21.6	5.6	4.3	7.7	0.56	0.27	1.83	16	138	156
22A	12.1	3.0	2.07	0.51	2.4	0.68	5.5	0.30	6.9	1.6	1.8	6.2	0.44	0.29	1.88	20	66	259
22B	11.9	3.3	2.19	0.55	2.6	0.74	5.9	0.30	7.1	1.6	1.9	6.6	0.48	0.31	1.95	22	69	439

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
22C	0.83		417	1.1		4.45	36		10.8	2	2.3		24.5	28000		0.9	10.1		107	0.85				2510	1.4	2.7	62	71.4

REE Section 28

T.139N., R.104W., Sec.6, SE/NE/SW
Elevation at top 3,310 ft.

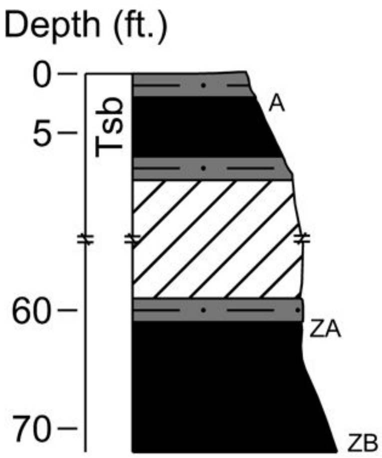


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
28A	70.9	10.4	5.39	2.20	9.6	2.02	38.6	0.69	31.3	8.1	7.6	24.5	1.71	0.73	4.62	58	276	493
28A2	148.0	10.5	5.29	3.06	12.7	1.93	68.9	0.58	62.8	16.3	12.9	12.6	1.92	0.66	3.90	51.3	413	1343
28B	42.0		4.79		6.7		18.9		24.9			16.1				40.1	*183*	*432*

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
28A2							35	36.7	50.3	11				6470	199	512	5.8					8.9		951		145	295	986
28B	10.3	1860	3630	1.3	0.17	0.51	43	19.2	24.5	8	14.0	0.04	3.4	2280	110	3800	5.8	7	299	0.16	0.26	17.3	0.5	796	75.1	1480	137	1000

REE Section 40

T.138N., R.102W., Sec.14, NE1/4
Elevation at top 2,724 ft.

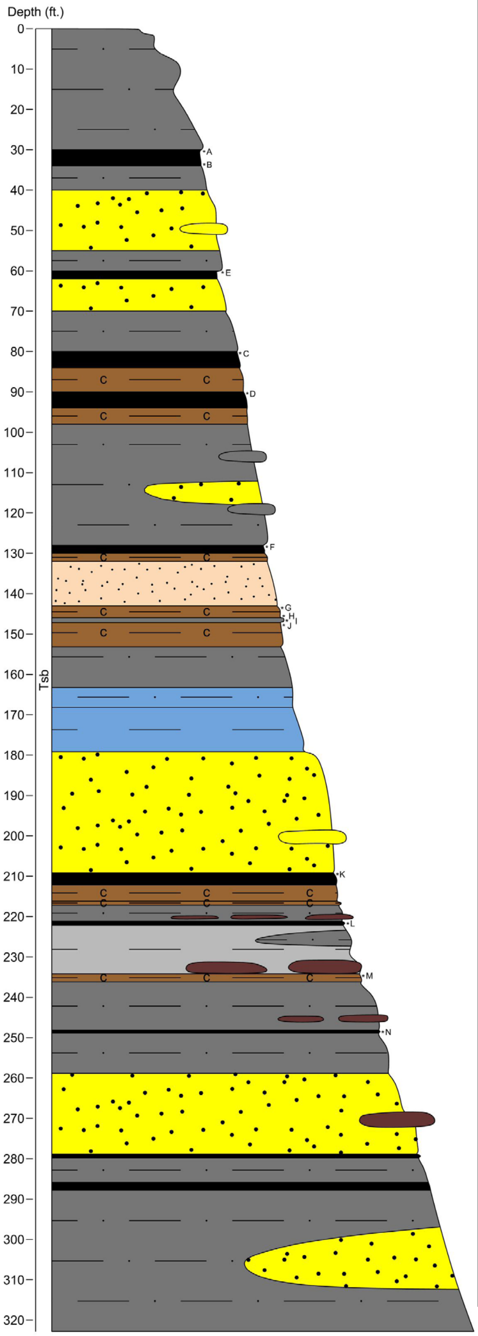


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
40A	27.0	2.4	1.39	0.85	2.8	0.47	12.7	0.22	15.7	3.8	3.3		0.39	0.21	1.41	11	84	
40ZA	31.9		3.65		5.1		14.6		22.8			28.5				25.3	*154*	*379*
40ZB	6.7		0.58		0.9		3.1		3.8			2.5				5.2	*27*	*171*

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
40ZA	4.02	23.7	736						15.7	13				9700		23.1	16.2								3.2	28.9	208	707
40ZB	0.65	9.6	774						2.2	1				5250		10.9	2.0								1.7	2.8	18	47.7

REE Section 106

T.148N., R.99W., Sec.18, NE/SW/SE
Elevation at top 2,375 ft.

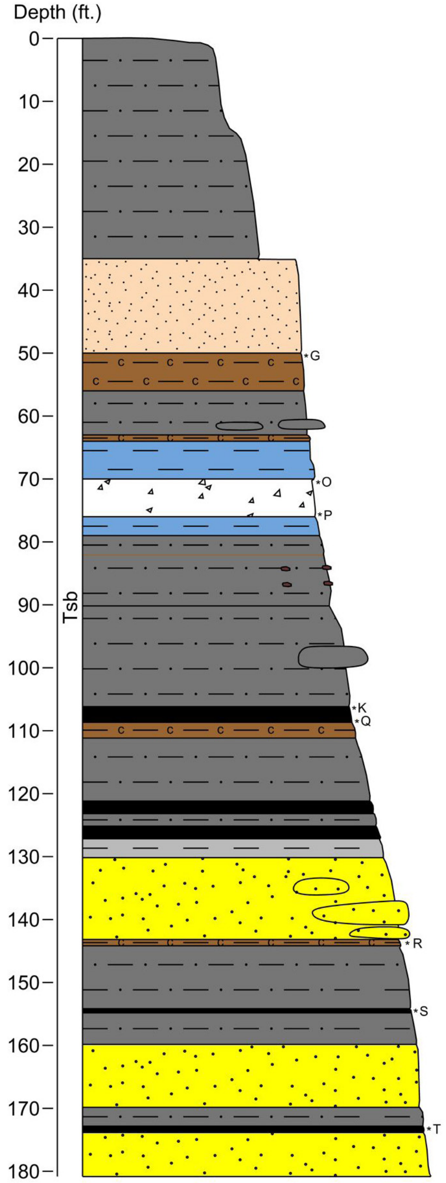


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
106A	11.0	4.2	3.16	0.57	2.7	0.97	5.1	0.48	6.1	1.4	1.7	11.2	0.55	0.45	3.05	30.7	83	496
106B	71.5	10.1	6.11	2.20	10.1	2.06	28.6	0.84	36.3	8.7	8.2	17.7	1.62	0.83	5.47	59.6	270	742
106E	11.7	2.5	1.72	0.48	2.0	0.55	5.5	0.25	6.3	1.5	1.5	11.0	0.35	0.23	1.59	18.3	65	203
106C	46.8	3.5	2.12	0.87	3.9	0.66	22.4	0.29	21.0	5.5	4.1	13.0	0.56	0.27	2.06	18.1	145	233
106D	21.1	3.3	2.37	0.59	2.7	0.73	10.3	0.36	9.8	2.5	2.2	11.0	0.47	0.33	2.32	21.9	92	233
106F	13.0	2.6	1.64	0.53	2.2	0.54	6.3	0.22	6.9	1.7	1.8	8.2	0.39	0.22	1.49	17.6	65	264
106G	55.8	3.6	2.16	0.90	4.2	0.69	27.4	0.29	24.0	6.4	4.7	12.2	0.59	0.29	2.07	20.3	166	212
106H	66.4	3.8	2.26	0.98	4.6	0.73	32.8	0.33	27.7	7.5	5.2	11.4	0.63	0.31	2.25	20.8	188	232
106I	66.1	2.6	1.64	0.76	3.6	0.48	32.9	0.25	27.5	7.4	4.7	5.8	0.45	0.23	1.75	14.4	171	177
106J	53.1	2.6	1.73	0.67	3.1	0.52	27.1	0.26	21.8	6.0	3.9	9.3	0.42	0.23	1.82	15.2	148	163
106K	18.9	3.3	2.54	0.59	2.6	0.77	9.4	0.42	9.5	2.4	2.2	7.9	0.46	0.37	2.56	24.3	88	286
106L	31.7	3.1	2.28	0.73	2.9	0.67	16.3	0.37	14.4	3.8	2.9	13.9	0.45	0.32	2.3	20.7	117	214
106M	21.6	1.9	1.38	0.50	1.8	0.41	10.8	0.21	9.5	2.5	1.8	7.8	0.29	0.19	1.42	13.3	75	197
106N	28.4	4.1	2.71	0.92	3.8	0.89	13.9	0.37	14.1	3.4	3.2	10.7	0.63	0.35	2.35	31.9	122	445

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
106A	1.71		730	5.0		0.06	4	3.1	5.4	3	0.5		1.5	9590		2.1	2.7			0.13				337	0.9	2.0	8	36.2
106K	11.7	66.7	978	4.0	0.21	1.60	14	8.8	7.4	9	0.9	0.02	5.2	6890	56	45.0	4.6	16	488	0.20	<0.10	4.0	0.4	497	7.5	18.3	45	44.1

REE Section 107

T.148N., R.99W., Sec.18, NE/NE/NW
Elevation at top 2,297 ft.

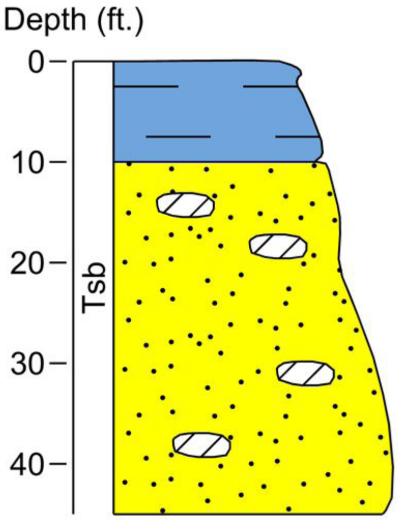


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
107G	55.0	3.8	2.37	0.93	4.3	0.74	26.9	0.32	23.7	6.3	4.6	12.9	0.62	0.30	2.26	23.1	168	216
107O	46.5	2.2	1.27	0.71	2.8	0.41	25.8	0.17	18.2	5.1	3.1	5.9	0.36	0.16	1.25	12.5	126	138
107P	46.0	2.1	1.22	0.68	2.7	0.39	25.1	0.16	17.8	5.1	3.1	6.4	0.34	0.14	1.21	12.2	125	136
107K	20.0	1.9	1.23	0.47	1.9	0.38	10.1	0.18	9.1	2.4	1.9	8.1	0.28	0.16	1.25	10.8	70	160
107Q	24.6	3.0	2.11	0.63	2.7	0.65	13.9	0.30	10.8	2.8	2.2	10.8	0.43	0.28	1.97	22.5	100	257
107R	25.5	2.0	1.35	0.57	2.1	0.40	13.0	0.18	11.3	3.0	2.2	10.6	0.28	0.16	1.32	12.3	86	143
107S	14.0	2.4	1.98	0.47	1.8	0.57	7.1	0.34	6.7	1.7	1.5	9.1	0.32	0.28	2.05	19.1	69	206
107T	42.5	3.6	1.97	0.89	4.2	0.69	19.1	0.23	19.4	4.9	4.1	10.3	0.61	0.25	1.64	20.2	135	720

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
107P	1.22		814	1.7		5.33	26	3.7	15.8	2	2.9		12.2	8120		2.9	8.7			0.90				1280	1.2	4.7	29	80.7

REEE Section 108

T.148N., R.99W., Sec.7, SW/NW/NW
Elevation at top 2,207 ft.

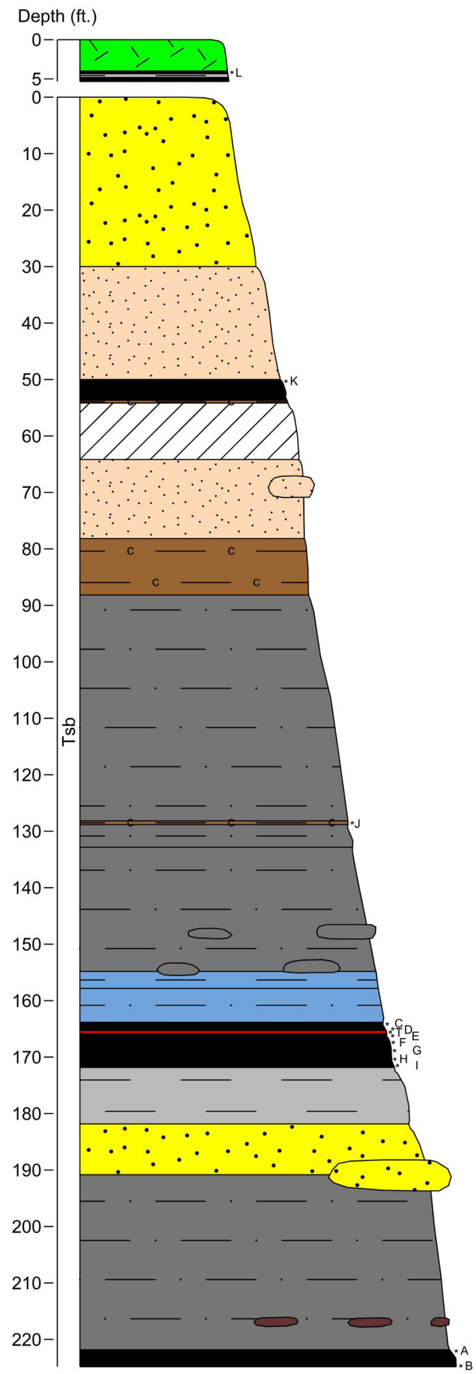


Sample ID	Lab Analysis (in µg/g)																
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE	
																	Whole Coal	Ash

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium

REE Section 109

T.152N., R.98W., Sec.5, NW/NE/SW
Elevation at top 2,180 ft. and 2,250 ft.

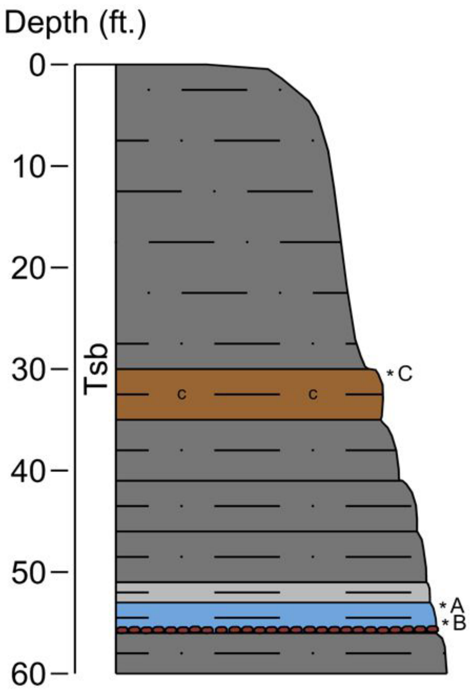


Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
	Lab Analysis (in µg/g)																	
109L	42.7	5.7	3.44	1.42	5.8	1.18	21.0	0.42	22.2	5.3	5.1	7.7	0.92	0.45	2.91	40.6	167	259
109K	18.8	2.8	1.88	0.55	2.4	0.58	9.4	0.29	9.6	2.4	2.2	8.9	0.40	0.27	1.90	17.1	79	160
109J	16.3	3.3	2.48	0.80	2.4	0.75	8.2	0.43	8.0	2.0	1.9	14.5	0.46	0.38	2.58	21.7	86	230
109C	25.6	3.2	1.88	0.86	3.5	0.63	11.5	0.30	14.7	3.5	3.6	6.4	0.53	0.27	1.84	15.8	94	206
109T	45.5	1.5	0.66	0.51	2.1	0.24	23.4	0.09	16.3	4.8	2.8	5.3	0.29	0.09	0.61	5.8	110	126
109D	44.8	2.1	1.16	0.75	2.8	0.40	21.3	0.20	19.6	5.2	3.8	10.8	0.39	0.18	1.21	9.8	124	199
109E	63.3	3.8	2.11	0.84	4.3	0.74	29.0	0.31	24.8	7.0	4.8	3.9	0.66	0.31	2.03	22.2	170	552
109F	14.1	0.6	0.32	0.17	0.8	0.11	9.6	0.04	4.8	1.4	0.8	1.3	0.10	0.04	0.26	4.1	39	250
109G	9.1	1.0	0.58	0.27	1.1	0.20	4.8	0.08	4.6	1.1	1.0	1.8	0.17	0.08	0.49	6.5	33	175
109H	36.0	1.5	1.01	0.52	1.9	0.31	19.7	0.17	14.4	4.0	2.4	14.0	0.26	0.16	1.10	8.7	106	114
109I	59.6	8.0	4.18	2.08	8.8	1.51	25.5	0.55	33.2	7.8	8.3	17.5	1.38	0.56	3.59	36.6	219	823
109A	7.5	1.7	1.33	0.30	1.2	0.41	3.7	0.23	3.9	1.0	1.0	10.9	0.24	0.21	1.39	11.3	46	222
109B	12.4	0.8	0.43	0.28	1.0	0.15	6.4	0.05	5.2	1.4	1.0	2.2	0.14	0.06	0.36	4.1	36	308

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
109L	2.35		6250	6.2		2.45	33	10.0	11.0	3	1.5		16.2	12700		41.9	6.0			0.52				1580	6.0	59.6	65	49.2
109T	1.62		426	0.7		1.14	4	2.1	23.7	2	5.0		21.5	13000		4.4	3.9			1.58				1100	0.7	5.1	12	86.6
109I	7.70	42.8	8790	6.4	0.31	1.64	54	14.1	11.6	23	2.2	0.06	13.7	6790	257	22.4	13.5	22	370	0.47	0.16	6.0	1.2	1930	5.4	9.7	108	148

REE Section 110

T.149N., R.100W., Sec.16, NE/NW/NE
Elevation at top 2,322 ft.

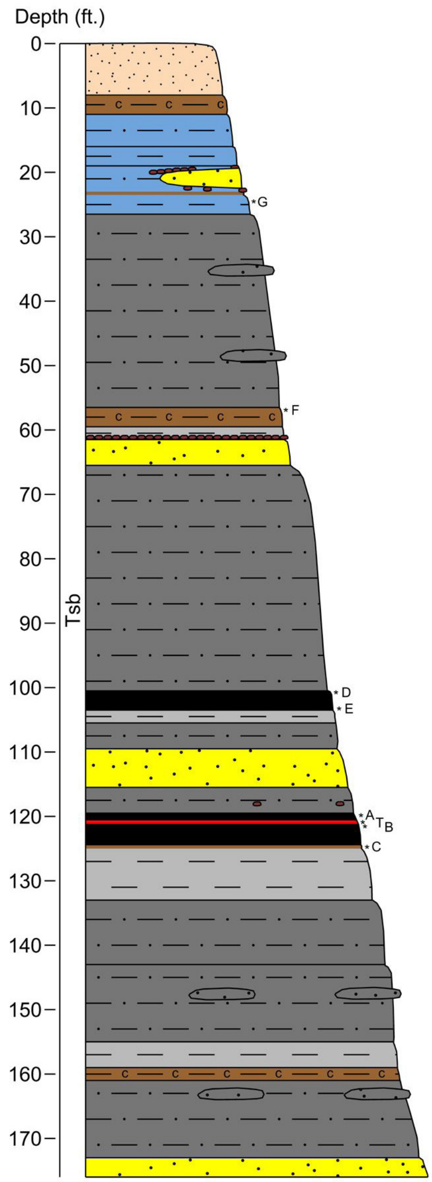


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
110C	28.7	4.0	2.73	0.83	3.6	0.85	14.7	0.46	14.3	3.5	3.1	11.4	0.60	0.40	2.90	23.6	116	288
110A	38.6	1.9	1.06	0.70	2.5	0.35	19.1	0.13	16.7	4.5	3.0	7.8	0.34	0.13	0.99	10.0	108	116
110B	40.6	1.9	1.02	0.71	2.6	0.33	19.6	0.13	17.1	4.7	3.1	7.0	0.33	0.13	1.00	9.6	110	117

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
110B	1.75		258	1.5		1.78	40	8.5	21.6	1	3.3		25.7	18700		2.5	6.9			0.63				2220	0.9	3.8	53	93.1

REE Section 111

T.148N., R.101W., Sec.18, SW/SE
Elevation at top 2,400 ft.

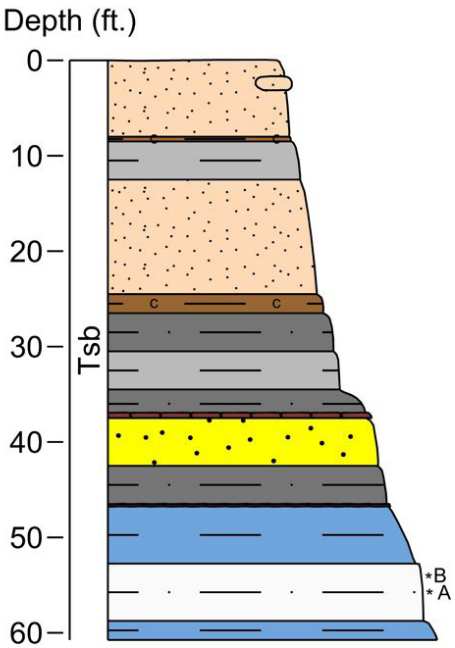


Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
	Lab Analysis (in µg/g)																	
111G	60.1	3.4	1.89	1.05	4.1	0.64	31.1	0.28	25.1	6.9	4.7	11.8	0.60	0.27	1.81	16.4	170	185
111F	49.5	2.5	1.45	0.90	3.3	0.49	25.0	0.21	21.3	5.7	3.9	9.4	0.45	0.21	1.41	12.7	138	146
111D	18.0	1.8	1.33	0.37	1.6	0.41	9.6	0.24	7.5	2.1	1.5	6.7	0.27	0.21	1.48	11.8	65	155
111E	23.6	3.3	2.53	0.65	2.7	0.78	11.7	0.41	10.9	2.9	2.4	11.7	0.48	0.38	2.53	24.8	102	220
111A	24.6	2.6	1.51	0.81	2.9	0.51	10.2	0.22	13.0	3.2	3.0	9.4	0.45	0.21	1.48	12.5	87	213
111T	15.5	0.7	0.42	0.23	0.9	0.13	7.4	0.04	5.8	1.6	1.0	4.5	0.11	0.04	0.38	4.7	43	55
111B	24.8	2.7	1.71	0.54	2.5	0.57	12.8	0.23	10.3	2.8	2.1	3.5	0.41	0.23	1.51	18.8	86	468
111C	11.7	1.8	1.41	0.37	1.5	0.43	6.0	0.24	5.8	1.5	1.3	4.0	0.27	0.21	1.37	16.5	54	302

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium

REE Section 112

T.150N., R.100W., Sec.36, SW/NE/SW
Elevation at top 2,290 ft.

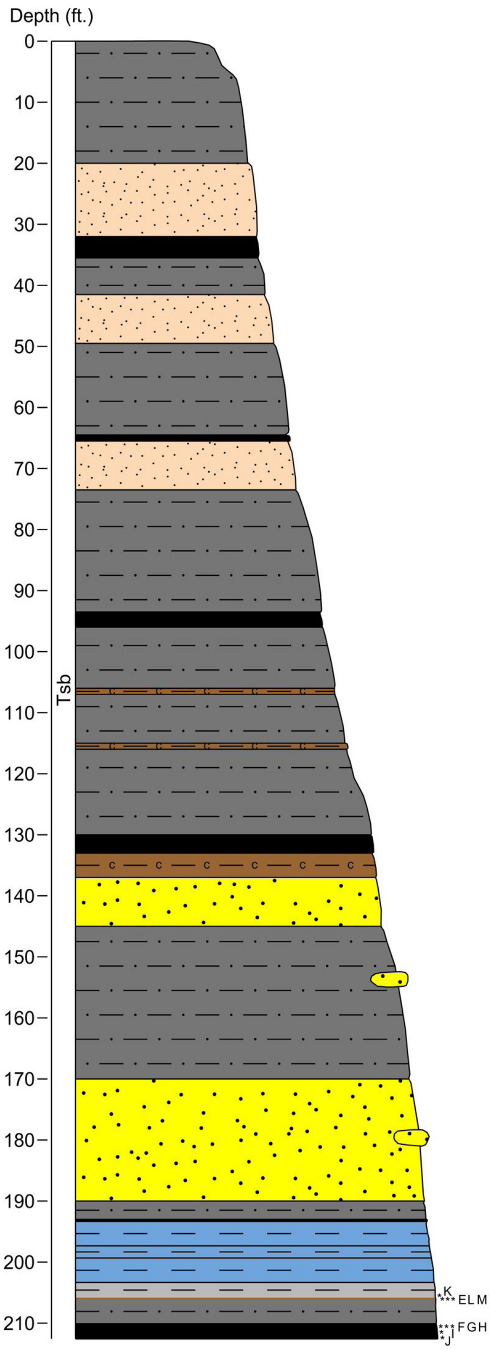


Sample ID	Lab Analysis (in µg/g)																
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
112B	48.8	2.5	1.48	0.80	3.1	0.49	26.3	0.23	19.5	5.3	3.5	9.1	0.43	0.21	1.49	13.7	137	148
112A	45.2	2.2	1.28	0.70	2.6	0.42	24.5	0.20	17.4	4.9	3.1	6.0	0.37	0.18	1.24	12.4	123	137

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium

REE Section 113

T.152N., R.100W., Sec.36, SE/SE To NW/SE
Elevation at top 2,314 ft.



Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
113K	54.8	3.7	2.19	1.12	4.3	0.74	28.0	0.32	24.6	6.5	4.8	17.3	0.62	0.32	2.15	20.1	172	180
113E	25.8	4.4	3.80	0.73	3.1	1.10	13.3	0.70	11.8	3.0	2.6	13.2	0.59	0.59	4.17	30.9	120	274
113L	16.9	4.0	3.60	0.57	2.5	1.01	8.9	0.71	8.2	2.1	2.0	11.0	0.51	0.59	4.14	29.9	97	289
113M	20.9	3.9	3.56	0.65	2.7	1.01	10.9	0.70	10.1	2.5	2.2	11.7	0.51	0.58	4.09	28.8	105	282
113F	8.4	1.3	1.01	0.21	1.1	0.31	4.5	0.17	3.9	1.0	0.9	1.9	0.18	0.15	1.02	10.8	37	186
113G	82.2	7.9	4.82	1.76	8.2	1.61	39.9	0.75	36.6	9.6	7.6	10.8	1.31	0.69	4.70	41.5	260	753
113H	98.8	9.2	4.86	2.54	10.7	1.76	40.9	0.66	47.4	12.3	10.5	8.0	1.63	0.68	4.34	43.6	298	1154
113I	47.4	1.9	0.96	0.49	2.4	0.34	25.3	0.13	16.5	4.9	2.9	5.2	0.34	0.14	0.86	9.0	119	136
113J	22.3	2.0	1.17	0.54	2.1	0.41	15.5	0.15	8.4	2.3	1.8	4.3	0.33	0.16	0.97	13.8	76	322

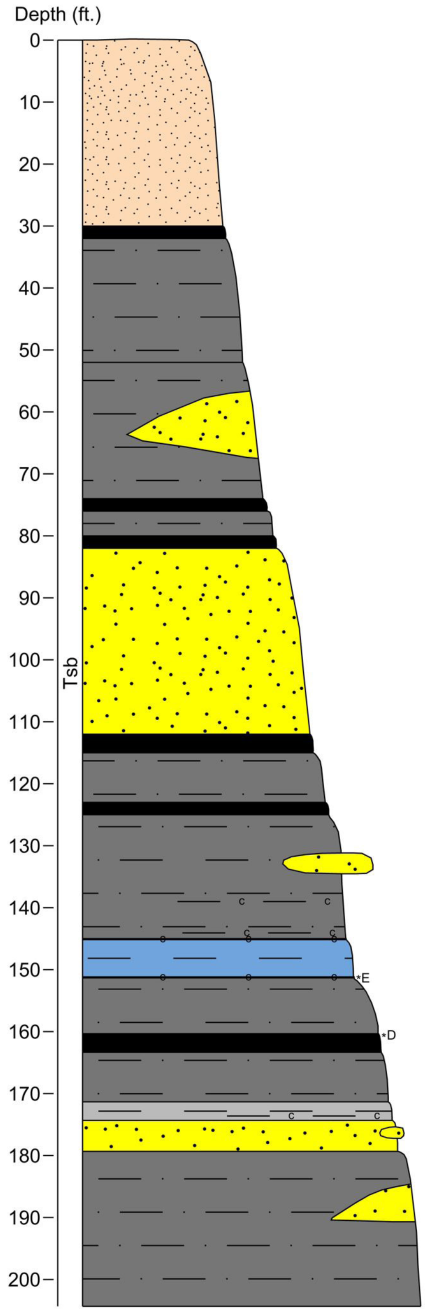
Lab Analysis (in µg/g)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium
113K								12.4		2				
113E	19.9	15.2	780	8.2		3.13	64	23.4	15.2	51	2.6		10.4	9860
113L	19.2		661	7.0		2.85	77	30.3	15.5	63	2.5		9.9	14200
113M	13.8		1040	7.0		3.99	77	12.0	13.5	40	2.7		11.0	15100
113F		5.2						8.1		5				
113G	17.9	236	865	2.7		1.23	27	21.8	10.5	6	1.9		5.6	3530
113H	25.7	199	1290	2.2	<0.10	0.74	26	16.1	10.6	15	1.8	0.02	4.6	4260
113I								4.7		3				
113J								6.2		1				

Sample ID	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
113K		0.8												
113E		42.3	20.7			0.51				1660	13.9	5.0	136	174
113L		15.0	25.1			0.42				1360	9.1	9.7	158	221
113M		8.5	23.0			0.49				1900	10.3	4.5	174	247
113F		6.0												
113G		49.5	15.8		811	0.21				649	9.1	21.3	83	101
113H	85	33.0	18.3	10	523	0.24	<0.10	5.7	0.5	496	15.6	25.6	77	118
113I		4.1												
113J		3.3												

REE Section 114

T.136N., R.102W., Sec.5, NW
Elevation at top 2,210 ft.

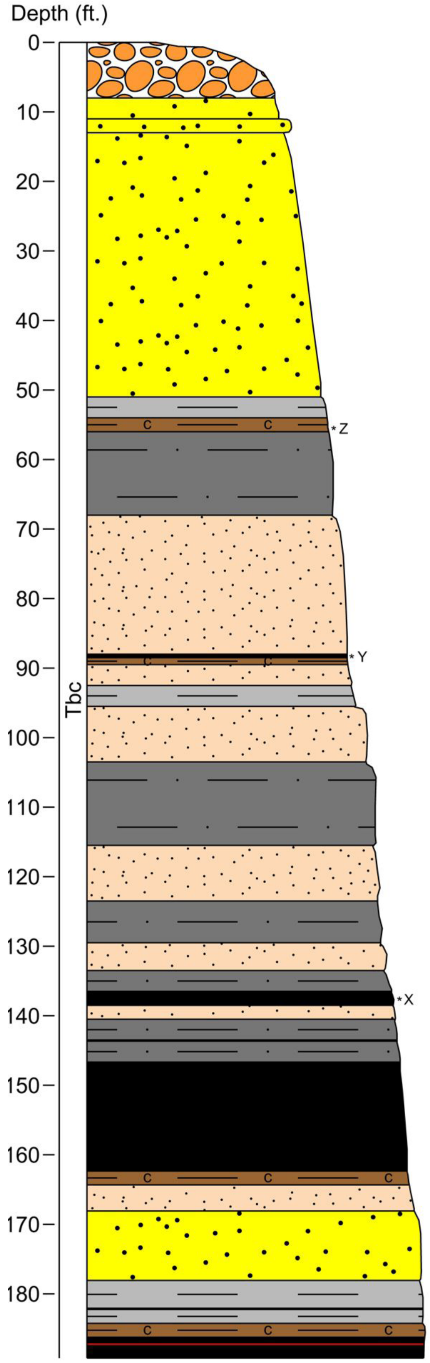


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
114E	51.6	3.9	2.37	1.26	4.5	0.77	25.0	0.35	24.1	6.1	5.0	18.8	0.67	0.33	2.30	18.8	166	185
114D	29.2	4.1	2.41	1.08	4.4	0.81	11.1	0.34	17.5	4.1	4.2	9.6	0.67	0.33	2.18	23.1	115	363

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
114E	8.49		897	1.8		8.88	130	18.7	22.9	5	3.2		35.0	11700		17.7	11.1			0.93				4590	1.4	9.3	242	252

REE Section 162

T.137N., R.102W., Sec.36, NE 1/4
Elevation at top 2,620 ft.

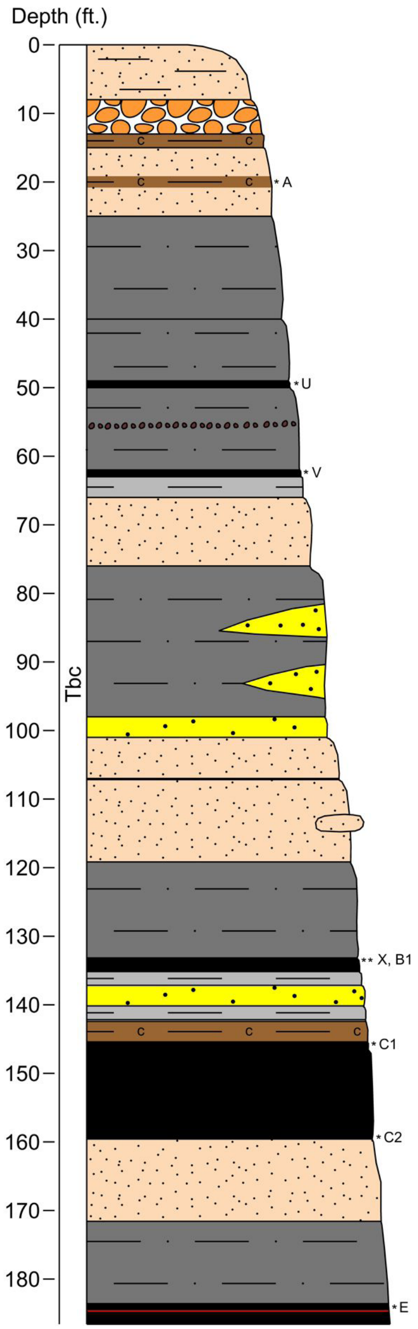


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
162Z	55.0	6.4	3.91	1.33	6.3	1.28	24.2	0.51	25.7	6.5	5.7	11.7	1.01	0.50	3.45	35.9	189	478
162Y	92.9	11.1	6.35	2.5	11.5	2.19	41.3	0.83	47	11.4	10.8	19.1	1.85	0.86	5.67	53.7	319	672
162X	34.6	3.9	2.41	0.82	3.9	0.8	16.5	0.34	16.6	4.2	3.6	7.9	0.63	0.33	2.26	23.1	122	233

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
162Y	12.2		805	7.6		2.93	45		17.1	19	3.3		25.6	6130		27.0	13.2		398	0.44				1390	4.8	28.4	92	203

REE Section 163

T.137N., R.102W., Sec.36, SW/NE
Elevation at top 2,618 ft.

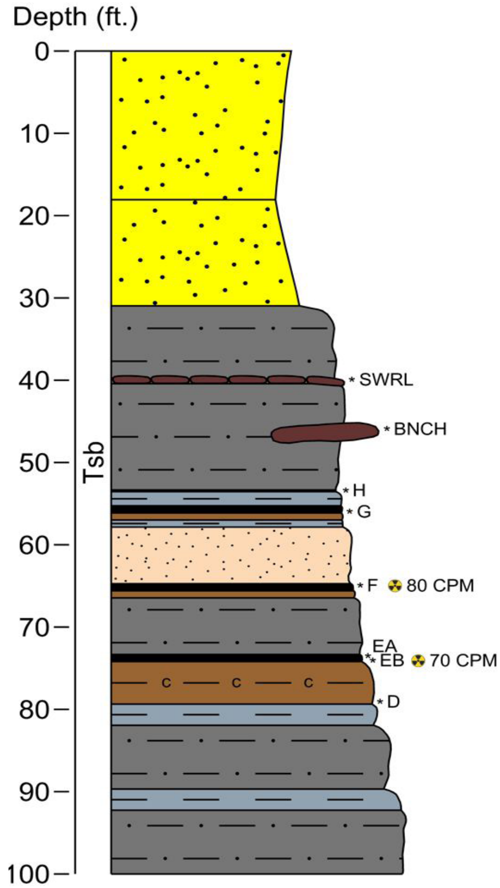


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
163A	80.4	8.8	5.28	2.05	9.6	1.75	35.4	0.67	45.1	11.0	9.4	18.9	1.45	0.68	4.61	51.5	287	355
163U	52.0		2.58		4.2		25.4		23.2			11.9				20.7	*160*	*225*
163V	17.5	2.6	1.58	0.58	2.8	0.53	6.6	0.2	10.7	2.5	2.4	3.1	0.43	0.21	1.34	16.6	70	293
163X	16.0		1.52		2.3		8.0		8.2			4.2				15.1	*65*	*223*
163B1	52.2		4.04		7.8		21.5		29.0			12.6				38.5	*197*	*495*
163C1	50.5		3.66		6.2		21.7		24.8			11.8				33.2	*178*	*714*
163C2	9.3		0.49		0.9		4.4		4.5			1.7				4.7	*30*	*162*
163E	105	8.9	5.21	1.97	9.2	1.78	44.1	0.72	43.5	11.6	9.1	16.6	1.49	0.75	4.88	46.1	311	1047

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
163U				3.3		8.97				7	2.9		38.8	7470				106				10.0		2280		9.0		108
163X				2.8		1.01				10	1.3		10.2	6360				12				4.5		880		5.7		42.6
163B1				4.1		2.17				4	3.1		21.0	3130				28				12.8		1220		8.1		142
163C1				3.7		0.26				2	1.1		13.6	3210				4				11.7		583		6.7		43.0
163C2				0.5		0.13				<1	0.5		4.1	3170				2				1.2		229		1.0		16.7

REE Section 231

T.139N., R.104W., Sec.6
Elevation at top 3,352 ft.

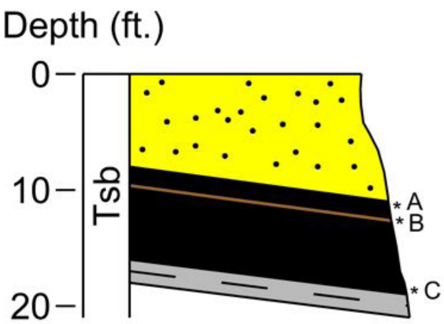


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
231SWRL	22.6		1.49		2.4		13.1		10.1			4.4				15.2	*80*	*89*
231BNCH	36.7		1.96		3.7		18.1		17.0			6.5				19.3	*119*	*152*
231H	37.2		2.37		3.6		14.9		15.5			10.6				18.5	*119*	*137*
231G	121.0	16.7	9.06	3.77	16.0	3.29	62.7	1.14	59.1	14.7	13.8	27.8	2.76	1.20	7.52	84.5	445	884
231F	41.6		5.65		7.8		19.7		24.3			12.9				52.2	*197*	*552*
231EA	45.4		4.59		6.6		21.1		24.9			9.3				39.0	*180*	*384*
231EB	74.5		4.5		8.9		35.9		35.3			14.1				47.3	*257*	*711*
231D	55.9		3.79		6.7		28.1		28.6			16.2				34.0	*202*	*358*

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
231SWRL	4.18	644.0	255	2.4	0.22	1.54	22	68.2	6.8	3	0.8	0.02	9.5	4970	5400	11.4	4.6	28	62	0.26	<0.1	4.1	0.6	901	22.1	5.7	122	25
231BNCH							25	9.8	10.1	2				14600	5050	1.4	7.9					7.1		1720		2.2	39	42
231H							67	22.9	22.3	2				9450	333	4.1	14.2					6.9		4500		8.7	133	90
231G							146	91.2	32.1	9				5940	648	44.6	12.3					11.9		2900		50.7	344	633.0
231F							42	12.3	13.2	4				17500	125	309.0	6.1					8.4		1680		187.0	519	460.0
231EA							33	20.9	7.4	5				6440	80	79.7	11.4					5.8		3360		29.4	261	145
231EB							36	15.0	24.9	3				6700	121	743.0	9.8					4.7		1490		201.0	91	355
231D							63	11.2	17.1	3				7370	81	58.8	9.3					15.2		2070		27.1	115	316

REE Section 232

T.139N., R.104W., Sec.6, SW/SE/NW
Elevation at top 3,090 ft.

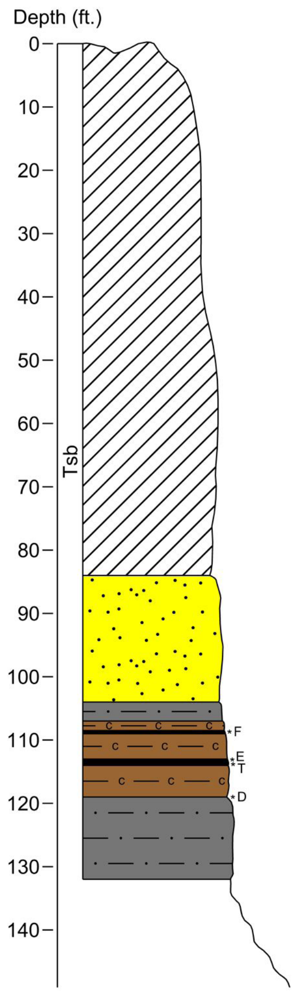


	Lab Analysis (in µg/g)																
																Total REE	
Sample ID	**Cerium**	**Dysprosium**	**Erbium**	**Europium**	**Gadolinium**	**Holmium**	**Lanthanum**	**Lutetium**	**Neodymium**	**Praseodymium**	**Samarium**	**Scandium**	**Terbium**	**Thulium**	**Ytterbium**	**Yttrium**	**Whole Coal**	**Ash**
232A	26.0		2.3		3.1		13.7		12.6			12.3				19.5	*104*	*241*
232B	19.9		1.09		1.6		10.3		8.1			3.7				10.4	*63*	*115*
232C	16.0		0.67		1.1		8.6		7.2			5.6				5.4	*50*	*76*

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
232A							33	8.0	11.1	20				5700	76	12.4	13.6					4.3		1250		13.9	70	426
232B							7	2.4	20.5	2				6050	85	2.8	6.6					16.2		1430		3.4	12	141
232C							33	1.4	9.2	3				2320	80	24.8	5.6					3.6		1610		3.6	83	97

REE Section 233

T.139N., R.104W., Sec.6, NW/SE/SE
Elevation at top 3,388 ft.

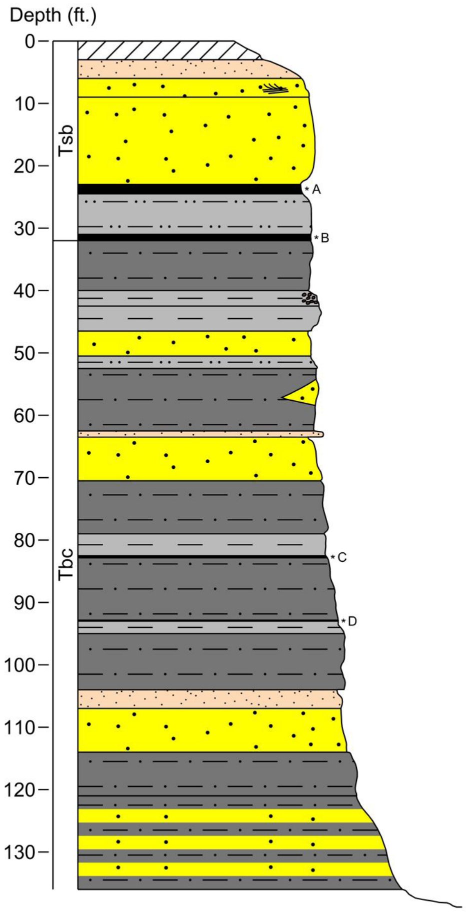


Sample ID	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Total REE Whole Coal	Total REE Ash
	Lab Analysis (in µg/g)																	
233F	72.0		5.93		8.9		39.6		33.0			13.3				61.2	*273*	*684*
233E	95.4	11.6	6.78	2.98	12.5	2.29	44.3	0.95	51.7	12.2	12.0	16.2	1.99	0.95	6.13	59.1	337	595
233T	50.7		4.32		3.9		28.3		20.4			9.7				34.4	*174*	*183*
233D	69.9		3.52		8.2		32.0		37.2			15.0				30.4	*229*	*364*

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
233F	10.10	741.0	1230	6.3	0.20	1.57	45	41.0	28.4	6	10.0	0.04	5.9	5030	396	165.0	10.0	20	405	0.38	0.13	7.7	1.2	2130	37.4	55.4	284	600
233E							86	24.1	16.9	8				2370	86	106.0	18.2					14.4		6410		41.8	396	346
233T							49	3.9	19.8	5				1390	36	52.2	44.9					11.2		15100		11.6	118	293
233D							57	9.0	17.0	4				4570	80	605.0	9.7					13.1		1740		60.2	128	376

REE Section 263

T.144N., R.103W., Sec.18, NW/NE
Elevation at top 2,524 ft.

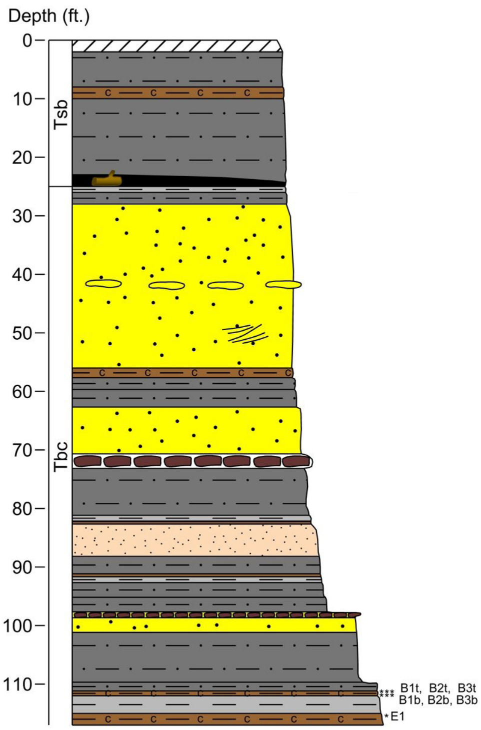


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
263A	35.2		4.21		4.6		19.6		17.3			22.0				37.4	*163*	*313*
263B	12.9		3.12		2.9		6.5		7.4			8.5				26.3	*82*	*343*
263C	25.1		5.05		5.0		13.7		13.6			17.9				40.7	*145*	*363*
263D	40.6		3.57		4.2		21.6		19.3			14.5				28.5	*153*	*227*

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
263A				8.4			62		11.2	14	3.2			11100		5.2	13.3							2140		14.8	207	286
263B				4.8			14		7.3	2	1.3			12200		57.4	8.4							495		12.9	40	91.6
263C				9.6			39		22.2	29	5.7			13700		24.0	25.1							1710		34.4	156	355
263D				6.3			61		25.8	15	6.5			11500		2.7	22.1							3730		22.6	139	432

REE Section 273

T.142N., R.102W., Sec.16, SE/SW/SW
Elevation at top 2,587 ft.

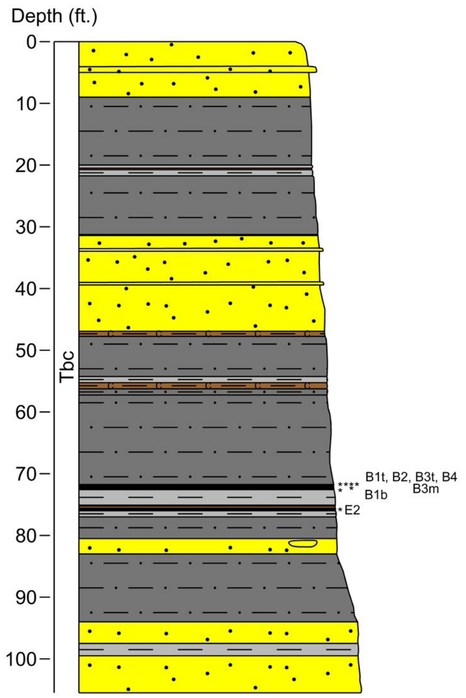


Sample ID	Lab Analysis (in µg/g)															Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
273B1t	56.3		5.33		7.1		29.5		26.0			11.2				44.8	*213*	*459*
273B2t	53.8		4.20		6.7		24.5		28.8			10.9				35.0	*193*	*417*
273B3t	106		7.81		17.4		33.7		74.7			14.8				60.1	*381*	*728*
273B1b	69.4		2.65		5.9		33.5		34.8			12.5				19.3	*204*	*260*
273B2b	104		7.25		15.6		36.0		68.5			14.4				51.4	*358*	*1093*
273B3b	87.8		5.75		13.8		28.5		62.5			17.3				43.3	*312*	*548*
273E1	81.8		4.37		8.3		42.6		40.1			13.4				41.0	*268*	*294*

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
273B1t	22.20	88.2		4.3				20.1	23.1	16				8790		63.1	13.1								8.1	35.3		197
273B2t	13.8	55.3		4.3				13.6	19.0	13				7500		40.8	10.6								5.1	27.2		162
273B3t	12.5	61.2		7.2				30.6	23.4	15				5640		38.8	16.8								5.0	38.4		382
273B1b	7.51	49.2		2.3				5.3	20.6	3				7070		24.8	11.6								2.1	19.9		166
273B2b	24.70	70.0		3.9				19.2	22.6	11				5380		57.3	17.1								8.1	45.5		264
273B3b	14.4	58.1		3.9				12.2	21.5	12				4350		44.8	13.9								4.2	43.8		212
273E1	3.59	32.5		4.9				16.9	25.0	3				15200		6.3	13.4								2.0	6.2		127

REE Section 274

T.142N., R.102W., Sec.16, NW/NE/SW
Elevation at top 2,528 ft.

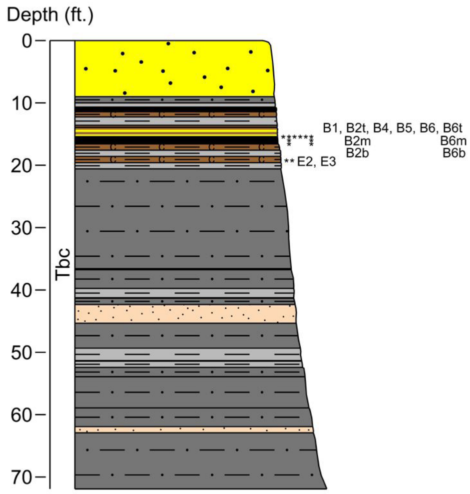


Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
274B1t	39.2		3.86		5.2		20.4		20.1			11.7				35.5	*159*	*305*
274B2	92.5	11.6	6.81	2.18	11.5	2.32	41.7	0.86	43.9	11	9.6	13.6	1.89	0.9	5.72	63	319	795
274B3t	72.4		6.35		9.4		36.2		35.0			13.3				50.9	*265*	*578*
274B4	73.5		5.22		7.9		38.5		34.0			13.5				46.1	*255*	*405*
274B3m	66.9		3.26		6.9		30.8		35.8			13.9				23.2	*210*	*312*
274B1b	46.3		3.09		4.2		24.2		21.9			14.0				23.0	*157*	*208*
274E2	47.8	5.7	3.87	1.14	5.2	1.22	18.3	0.60	22.3	5.5	5.1	17.1	0.88	0.55	3.91	31.2	170	279

Sample ID	Lab Analysis (in µg/g)																										
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
274B1t	10.6	58.1		8.7				18.3	22.8	18				18800		39.3	18.7								8.3	27.1		418
274B3t	17.5	80.4		5.2				23.5	21.3	11				9820		63.8	11.7								9.2	46.2		161
274B4	12.9	56.9		6.0				18.1	25.4	11				12500		46.2	16.1								6.5	27.2		265
274B3m	13.7	121.0		2.7				6.6	19.8	4				7640		41.4	12.8								2.5	21.4		229
274B1b	14.2	75.6		3.7				11.1	22.1	7				9250		39.9	17.2								3.4	24.4		362

REE Section 275

T.142N., R.102W., Sec.16, SE/NE/NE
Elevation at top 2,505 ft.



Sample ID	Lab Analysis (in µg/g)																Total REE	
	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Whole Coal	Ash
275B1	26.4		3.71		4.2		13.1		14.4			10.8				34.4	*127*	*363*
275B2t	72.8		5.99		8.3		40.3		30.5			12.5				57.9	*266*	*636*
275B4	127	17.5	10.6	2.88	16.3	3.68	61.9	1.40	56.0	14.5	11.9	12.1	2.74	1.45	8.98	105	454	1595
275B5	56.9		5.39		6.7		30.7		27.1			17.9				47.6	*224*	*312*
275B6	151	19.7	10.8	4.29	21.4	3.83	50.4	1.43	85.9	21.0	19.3	18.1	3.39	1.45	9.30	88.6	510	1402
275B6t	149	19.0	10.7	3.91	19.7	3.74	56.0	1.39	77.7	19.2	17.0	14.7	3.21	1.45	9.06	92.2	498	1073
275B2m	77.2		2.86		6.4		34.3		37.3			12.3				23.0	*222*	*281*
275B6m	79.7		4.05		8.3		33.7		41.2			12.5				33.8	*249*	*336*
275B2b	89.7		2.77		8.0		37.8		46.6			12.6				21.0	*252*	*316*
275B6b	89.2		4.57		10.6		34.5		52.1			16.8				38.3	*289*	*445*
275E2	52.1		3.02		4.5		27.8		23.1			13.2				25.9	*171*	*242*
275E3	47.1		2.76		4.2		25.0		21.7			11.4				24.7	*157*	*231*

Sample ID	Lab Analysis (in µg/g)																											
	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellurium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
275B1	17.9	60		9.1				23.6	16.8					10200		38.1									6.6	41.7		199
275B2t	18.2	67.3		8.5				25.9	23.2					9200		58.5									8.5	52.7		325
275B4	21.0		1020	7.5		1.11	13	48.7	25.4	5	2.1		6.4	8530		110.0	9.6			0.30				370	15.2	37.1	71	154
275B5	14.1	53.6		8.3				13.5	26.7					17300		45.4									4.6	48.7		317
275B6	13.7	111	787	5.3	0.42	1.58	24	42.0	21.7	10	3.5	0.04	15.4	7830	146	85.4	13.1	20	190	0.25	0.10	8.0	0.7	667	8.5	75.6	82	273
275B6t	17.2	129		6.2				52.3	26.3					8620		79.6									7.3	70.6		427
275B2m	8.23	41.1		2.6				7.4	23.3					8500		22.3									2.9	23.3		232
275B6m	13.5	74.3		3.1				14.0	20.9					8260		65.1									2.7	26.8		149
275B2b	4.6	29.8		2.8				6.8	22.5					7100		10.5									1.6	21.4		173
275B6b	10.1	56.1		3.6				18.8	17.1					7240		38.4									1.8	38.8		212
275E2	7.64	39		4.4				12.7	26.9					10700		9.8									3.8	11.6		249
275E3	12.9	50.3		4.2				19.1	25.6					16900		17.1									5.4	18.7		274

Appendix B - Analytical Results

Concentrations are reported on a whole rock basis (dry) as ug/g or parts per million

Sample ID	NDGS Field ID	Ash (wt%)	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellerium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
2A	2A		27.1	3.6	2.67	0.64	2.8	0.84	15.0	0.43	12.0	3.1	2.5		0.52	0.40	2.69	23																												
2AA	2AA	43.49%	23.5	8.9	8.38	1.40	5.2	2.39	13.5	1.62	13.3	3.2	3.6		1.10	1.34	9.55	72	3.88		1050	30.5		1.49	58		25.0	28	5.4		30.0	19400		2.6	29.7		802	0.55				1930	6.8	29.4	186	514
2AA2	2AA2	49.72%	31.1	3.7	2.76	0.87	3.4	0.82	15.6	0.46	14.9	3.8	3.2	14.7	0.54	0.39	2.92	24.4	5.52		786	7.3		2.45	114		25.9	37	4.8		15.8	10400		18.6	29.6		523	0.50				2510	11.3	12.3	259	508
2B	2B	17.61%	10.8	3.5	2.81	0.53	2.3	0.87	5.4	0.46	5.9	1.4	1.6		0.48	0.43	2.89	25																												
2C	2C		28.5	3.5	2.04	0.90	3.7	0.72	12.8	0.28	15.4	3.7	3.5		0.60	0.29	1.84	19																												
2E	2E		26.5	3.0	2.22	0.65	2.7	0.68	13.7	0.37	12.6	3.2	2.6		0.45	0.34	2.39	18																												
2F	2F	23.95%	8.4	1.7	1.38	0.28	1.2	0.41	4.2	0.26	4.3	1.0	1.0		0.24	0.22	1.58	11																												
2G	2G		22.7	4.5	3.59	0.79	3.3	1.09	11.3	0.68	11.8	2.9	2.8		0.63	0.57	4.10	27																												
2H	2H		17.8	3.1	2.17	0.74	2.6	0.70	9.0	0.36	9.8	2.3	2.3		0.47	0.33	2.23	19																												
2J	2J	7.61%	3.1	0.5	0.37	0.13	0.5	0.12	1.6	0.05	1.9	0.4	0.4		0.08	0.05	0.32	5																												
2L	2L		6.5	0.7	0.44	0.23	0.8	0.15	3.2	0.06	3.8	0.9	0.8		0.13	0.06	0.38	5																												
2N	2N	24.83%	13.2	1.2	0.69	0.37	1.3	0.24	7.5	0.10	6.3	1.6	1.4		0.20	0.10	0.64	7																												
2P	2P		41.1	2.0	1.34	0.52	2.1	0.45	29.0	0.19	11.7	3.8	1.9		0.33	0.19	1.18	14																												
2Q	2Q		15.5	3.3	2.54	0.71	2.4	0.78	10.2	0.40	7.2	1.8	1.7		0.46	0.37	2.50	25																												
2R	2R	8.26%	4.5	0.9	0.77	0.18	0.7	0.24	2.7	0.13	2.1	0.5	0.5		0.13	0.12	0.76	8																												
2T	2T		8.8	1.0	0.69	0.24	1.1	0.23	4.5	0.09	4.5	1.1	1.0		0.17	0.10	0.59	9																												
2V	2V	19.91%	13.1	1.9	1.20	0.34	1.8	0.40	6.5	0.18	7.1	1.7	1.7		0.30	0.17	1.14	13																												
2W	2W		76.8	2.4	0.90	0.54	4.1	0.36	33.6	0.09	32.9	9.1	5.8		0.50	0.11	0.63	8																												
2X	2X		7.8	0.7	0.50	0.11	0.6	0.16	6.2	0.08	2.6	0.7	0.5		0.10	0.08	0.51	5																												
3A	3A		54.1	3.2	2.16	0.84	3.7	0.69	27.3	0.35	24.1	6.4	4.4		0.53	0.32	2.26	17																												
3B	3B		31.8	3.0	2.10	0.64	2.7	0.66	16.4	0.34	14.2	3.8	2.8		0.46	0.31	2.17	17																												
3C	3C		54.0	4.5	2.63	0.92	4.7	0.89	24.6	0.38	23.7	6.4	4.9		0.75	0.37	2.46	23																												
3D	3D		54.8	2.1	0.92	0.70	3.1	0.35	23.9	0.11	21.8	6.2	4.1		0.43	0.11	0.74	9																												
3F	3F		30.6	4.6	2.92	0.73	3.9	0.98	17.2	0.43	13.8	3.5	3.2		0.70	0.42	2.77	26																												
3G	3G		31.2	4.7	2.79	0.83	4.4	0.95	15.5	0.39	15.5	3.8	3.7		0.75	0.39	2.53	24																												
3J	3J		27.1	5.9	4.29	1.01	4.5	1.37	14.0	0.67	14.5	3.5	3.5		0.85	0.63	4.34	38																												
3K	3K	31.53%	13.6	3.0	2.08	0.51	2.4	0.68	6.8	0.32	7.4	1.7	1.8		0.44	0.30	2.00	20																												
3O	3O	14.73%	13.4	3.2	2.57	0.79	2.4	0.78	7.6	0.45	7.0	1.7	1.7		0.44	0.39	2.72	24																												
3O2	3O2	14.07%	15.9	4.7	3.61	0.84	3.4	1.12	8.5	0.60	8.7	2.0	2.3	11.3	0.63	0.54	3.62	34.5	2.50	5.5	862	11.3	<0.9	0.13	31	12.4	9.2	48	1.7	<0.01	3.3	3950	207	2.4	11.3	3	355	0.16	<0.9	1.3	0.2	636	2.5	3.1	135	196
3P	3P		13.4	2.6	1.97	0.67	2.1	0.61	7.3	0.33	7.3	1.7	1.7		0.37	0.30	2.01	19																												
3R	3R	17.19%	11.5	2.4	1.63	0.47	2.1	0.55	6.3	0.22	6.2	1.5	1.5	3.6	0.37	0.23	1.38	19																												
5A	5A	38.81%	90.9	16.8	11.4	2.90	14.3	3.75	42.7	1.67	47.1	11.4	11.0		2.57	1.64	10.5	91																												
5A2	5A2	63.79%	68.4	8.8	5.80	1.95	8.4	1.89	32.0	0.88	34.7	8.7	7.7	24.1	1.35	0.82	5.60	49.1	29.2	148	1550	4.2	0.58	6.59	69	27.5	30.0	36	6.3	0.05	24.8	8280	138	44.8	27.8	74	521	0.66	0.17	9.6	1.6	2160	5.6	41.1	217	677
5B	5B		73.3	4.9	3.13	1.29	5.4	1.01	35.9	0.51	31.8	8.5	6.0		0.83	0.47	3.16	26																												
5C	5C		33.6	5.1	3.93	0.88	4.0	1.19	17.5	0.65	16.1	4.1	3.4		0.73	0.59	3.99	34																												
5D	5D		57.5	3.7	2.05	1.22	4.3	0.70	30.0	0.28	25.6	6.7	4.8		0.66	0.29	1.84	17																												
5E	5E		57.3	3.7	2.08	1.16	4.5	0.71	29.6	0.29	25.5	6.7	4.9		0.66	0.29	1.89	17																												
5Fa	5Fa		46.9	2.7	1.43	0.95	3.5	0.50	23.9	0.18	21.0	5.5	4.0		0.49	0.20	1.24	13																												
5Fb	5Fb		59.4	3.4	1.78	1.13	4.3	0.62	30.5	0.24	26.2	6.9	5.0		0.63	0.25	1.58	15																												
5Fc	5Fc		42.9	2.9	1.65	1.00	3.5	0.55	22.2	0.24	19.6	5.1	3.8		0.50	0.24	1.58	14																												
5G	5G		16.4	3.6	2.88	0.72	2.7	0.87	8.9	0.48	8.6	2.1	2.1		0.51	0.43	2.83	27																												
5G3	5G3	27.74%	13.3	2.4	1.96	0.55	2.0	0.58	6.9	0.31	6.8	1.6	1.5	8.4	0.34	0.28	1.92	20.4																												
5H	5H	12.91%	8.9	1.8	1.24	0.34	1.5	0.41	4.0	0.17	5.0	1.2	1.2		0.27	0.17	1.06	15																												
5J	5J		10.4	1.8	1.12	0.31	1.7	0.39	4.7	0.16	5.9	1.4	1.5		0.29	0.16	1.00	13																												
5K	5K	13.10%	9.7	2.0	1.37	0.34	1.8	0.46	4.4	0.20	5.6	1.3	1.4		0.31	0.20	1.23	14																												
5M	5M		8.1	2.4	1.73	0.34	1.6	0.55	3.8	0.29	4.6	1.1	1.2		0.33	0.27	1.79	14																												

Sample ID	NDGS Field ID	Ash (wt%)	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellerium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
6A	6A		21.0	2.7	2.09	0.55	2.3	0.61	10.5	0.39	10.4	2.6	2.2		0.39	0.34	2.40	17																												
6C	6C		58.7	4.3	2.60	1.23	4.8	0.87	28.4	0.36	26.0	6.8	5.1		0.72	0.37	2.44	25																												
6D	6D	76.77%	42.9	2.6	1.61	0.74	2.8	0.53	21.6	0.25	18.5	5.0	3.3	10.9	0.43	0.24	1.57	16																												
6E	6E	61.42%	39.0	3.5	2.12	0.90	3.7	0.73	19.6	0.30	17.7	4.6	3.6	11.2	0.59	0.31	1.97	21																												
6F	6F		105	11.8	6.52	3.13	13.0	2.27	44.1	0.84	57.0	13.8	12.8		2.02	0.89	5.49	54																												
6F3	6F3	49.65%	49.8	4.9	2.79	1.39	5.4	0.96	21.6	0.42	25.8	6.4	5.7	15.6	0.84	0.41	2.66	23.1																												
6F4	6F4	41.07%	43.4	4.7	2.67	1.50	5.5	0.90	15.8	0.42	27.1	6.3	6.5	20.3	0.81	0.39	2.70	17.2																												
6F6	6F6	66.64%	66.7	5.4	3.33	1.38	5.7	1.12	32.1	0.49	30.3	7.9	6.1	13.7	0.90	0.50	3.15	31.7	2.10	12.6	611	3.9	0.44	5.26	65	19.1	15.2	3	3.0	0.06	19.4	4750	36	3.5	14.6	73	211	0.99	0.27	9.4	1.8	4090	2.6	4.2	107	128
6F7	6F7	55.69%	40.3	3.7	2.19	0.98	4.0	0.75	18.9	0.32	19.0	4.9	4.0	12.0	0.62	0.31	2.04	19.5																												
6F8	6F8	39.15%	73.2	8.8	5.14	2.56	9.4	1.72	27.2	0.79	44.1	10.5	10.5	35.3	1.48	0.74	5.07	35.5																												
6F11	6F11	47.18%	66.6	8.3	4.41	2.68	10.0	1.54	23.5	0.66	47.9	11.0	11.8	27.8	1.47	0.64	4.32	31.4																												
6F13	6F13	61.77%	37.8	3.9	2.26	1.19	4.4	0.77	17.2	0.35	21.2	5.2	4.9	17.0	0.67	0.33	2.24	17.3																												
6G8	6G8	91.96%	64.5	4.3	2.42	1.08	5.1	0.83	31.6	0.34	29.5	7.7	5.9	12.3	0.77	0.34	2.25	21.3																												
6H8	6H8	94.47%	54.7	3.6	2.10	1.07	4.3	0.71	27.6	0.30	24.8	6.4	4.7	8.1	0.62	0.30	1.95	18.8																												
6I8	6I8	92.47%	73.6	4.6	2.45	1.07	5.6	0.85	36.7	0.34	32.8	8.7	6.4	13.9	0.80	0.34	2.29	23.4																												
6J8	6J8	78.69%	63.8	4.0	2.61	0.98	4.5	0.84	31.6	0.42	27.7	7.3	5.3	11.7	0.66	0.39	2.61	25.8																												
7A	7A	94.39%	66.2	4.5	2.69	1.21	5.2	0.94	31.3	0.38	29.3	7.7	5.7	15.4	0.79	0.38	2.41	26																												
7B	7B	79.46%	46.0	3.1	2.07	0.76	3.4	0.68	22.8	0.33	19.7	5.2	3.8	8.5	0.53	0.32	2.07	19																												
7C	7C	76.99%	70.0	4.9	2.97	1.22	5.7	1.02	31.1	0.42	31.2	8.1	6.1	13.4	0.87	0.42	2.67	27																												
7E	7E	37.96%	59.1	6.6	4.15	1.23	6.4	1.43	27.9	0.59	27.6	7.0	5.7	13.9	1.07	0.59	3.72	42																												
7F	7F	8.68%	18.7	3.2	2.36	0.44	2.5	0.77	9.4	0.38	8.8	2.2	1.9	3.8	0.47	0.35	2.28	23																												
7G	7G	71.16%	76.0	6.1	3.54	1.51	6.7	1.25	36.9	0.49	34.7	9.1	6.9	11.1	1.05	0.50	3.15	33	2.75	9.4	1050	5.0	0.34	8.40	40	18.9	15.1	13	3.0	0.04	23.3	5200	55	9.6	11.4	89	263	0.64	<0.9	6.0	1.6	1920	4.4	8.0	76	207
9A	9A	63.36%	170	16.7	8.60	4.17	18.9	3.12	72.6	1.10	86.9	21.6	18.6	18.0	2.94	1.17	7.46	69	25.0	56.9	3260	5.3	0.47	6.19	61	18.4	30.1	18	8.2	0.07	28.0	8450	67	72.7	29.6	94	367	0.76	0.10	12.8	1.9	1930	10.4	63.7	192	443
9B	9B	47.29%	76.0	11.7	8.04	1.83	10.1	2.66	54.8	1.14	33.0	8.5	7.0	15.4	1.74	1.14	7.24	95																												
9C	9C	39.53%	27.8	4.8	3.46	0.89	4.0	1.09	14.3	0.59	13.8	3.5	3.2	11.9	0.69	0.52	3.57	30																												
9D	9D	43.45%	36.3	5.4	3.65	1.05	4.8	1.20	17.8	0.57	18.7	4.6	4.2	17.4	0.84	0.53	3.59	31																												
9E	9E	31.51%	18.2	3.0	1.96	0.60	2.8	0.66	14.0	0.28	8.4	2.1	2.1	6.8	0.47	0.28	1.80	19	1.97	60.9	1400	2.0	<0.9	0.11	4	6.1	3.6	1	0.6	<0.01	3.2	5030	40	9.6	1.8	2	668	0.12	<0.1	1.1	0.3	376	1.8	10.3	12	25
9Sd	9Sd	89.94%	35.1	2.2	1.35	0.60	2.8	0.43	17.5	0.19	15.7	4.1	3.1	5.2	0.37	0.18	1.37	12.6																												
9Sd3	9Sd3	90.98%	41.9	2.3	1.36	0.69	3.1	0.43	20.6	0.18	18.8	5.0	3.6	5.0	0.39	0.17	1.30	12.3																												
17D5	17A	69.25%	45.4	4.7	3.10	1.02	4.3	1.00	22.5	0.52	21.6	5.6	4.4	15.2	0.72	0.48	3.28	22																												
17B5r	17B	48.63%	113	14.6	7.85	3.05	15.2	2.82	48.6	1.03	62.4	15.5	13.2	14.0	2.47	1.07	6.85	64																												
17B5	17C	58.81%	70.8	8.3	5.08	1.42	7.8	1.77	35.2	0.63	29.9	7.9	5.9	11.7	1.32	0.69	4.23	52																												
17A5	17D	62.27%	34.3	3.9	2.77	0.85	3.8	0.88	16.7	0.46	16.9	4.3	3.5	11.5	0.63	0.41	2.88	22																												
17B1	17B5	29.18%	34.0	6.9	5.00	1.02	5.5	1.59	18.4	0.77	17.0	4.1	4.1	13.7	0.99	0.72	4.73	49.3																												
17B2	17B4	42.83%	76.4	10.4	6.38	1.91	10.0	2.15	34.6	0.93	37.4	9.3	8.1	15.1	1.63	0.89	5.82	56.1																												
17B3	17B3	82.50%	96.8	7.0	3.81	1.87	8.3	1.33	45.8	0.52	44.6	11.4	9.0	14.4	1.22	0.53	3.48	36.7																												
17B4	17B2	65.88%	87.6	7.0	3.48	2.19	9.2	1.25	32.9	0.48	48.5	11.9	10.7	14.4	1.30	0.48	3.19	30.5																												
17B6	17B7	85.74%	64.1	4.0	2.33	1.21	5.2	0.78	29.8	0.34	31.3	7.9	6.2	12.2	0.73	0.33	2.28	20.1																												
17B7t	17B14A	46.99%	151	18.9	10.3	4.12	20.2	3.64	61.2	1.33	81.1	19.7	18.0	15.3	3.26	1.40	8.75	91.2	14.6	152		6.4				53.5	23.3					6680		70.4									7.3	54.4		210
17B7b	17B14B	69.84%	92.6	8.8	4.81	2.31	10.4	1.69	39.5	0.66	50.0	12.1	11.0	14.6	1.60	0.67	4.33	41.3	13.9	87.5		3.5				13.5	20.3					6800		45.4									2.7	29.6		191
17B8t	17B13A	54.54%	100	11.9	6.29	2.93	13.8	2.23	36.3	0.83	59.9	14.3	13.4	12.6	2.14	0.86	5.45	52.3	11.9	99.3		3.5				31.2	20.6					10100		53.1									4.2	45.4		222
17B8m	17B13B	66.10%	85.3		4.38		10.2		31.7		50.8			16.5				35.2	11.3	63.4		3.0				11.7	17.6					8690		43.3									2.0	34.8		209
17B8b	17B13C	84.10%	65.6		2.21		5.5		30.1		32.7			11.3				18.9	4.58	27.8		2.0				6.4	21.8					8320		14.5									1.8	13.7		125
17 E2	17 E4	40.68%	65.5	9.2	5.85	1.62	8.4	1.96	35.3	0.78	31.3	8.0	6.8	11.1	1.40	0.81	5.08	71.4																												
17E7t	17B14Y	42.25%	66.3	8.5	5.43	2.13	8.9	1.88	30.9	0.73	33.4	8.3	9.3	12.1	1.35	0.75	4.84	56.1	5.04	66.8		4.3				14.3	11.5					6860		38.3									4.0	16.4		86
17E7b	17B14Z	45.07%	42.3		4.76		6.8		22.7		23.5			14.4				46.9	9.58	85.3		3.2				15.8	12.5					8410		65.9									6.3	26.8		210
17 E8	17B13Z	58.52%	53.3		2.54		5.8		22.3		29.9			10.6				22.7	16.5	617		2.5				8.3	14.4					5610		58.8									3.4	17.9		161
274B2	17B6	40.11%	92.5	11.6	6.81	2.18	11.5	2.32	41.7	0.86	43.9	11.0	9.6	13.6	1.89	0.90	5.72	63.0																												
275B4	17B8	28.46%	127	17.5	10.6	2.88	16.3	3.68	61.9	1.40	56.0	14.5	11.9	12.1	2.74	1.45	8.98	105	21.0		1020	7.5		1.11	13	48.7	25.4	5	2.1		6.4	8530		110	9.6			0.30				370	15.2	37.1	71	154
275B6	17B9	36.38%	151	19.7	10.8	4.29	21.4	3.83	50.4	1.43	85.9	21.0	19.3	18.1	3.39	1.45	9.30	88.6	13.7	111	787	5.3	0.42	1.58	24	42.0	21.7	10	3.5	0.04	15.4	7830	146	85.4	13.1	20	190	0.25	0.10	8.0	0.7	667	8.5	75.6	82	273
274 E2	17 E6	61.12%	47.8	5.7	3.87	1.14	5.2	1.22	18.3	0.60	22.3	5.5	5.1	17.1	0.88	0.55	3.91	31.2																												
275B6t	17B9A	46.42%	149	19.0	10.7	3.91	19.7	3.74	56.0	1.39	77.7	19.2	17.0	14.7	3.21	1.45	9.06	92.2	17.2	129		6.2				52.3	26.3					8620		79.6									7.3	70.6		427
275B6m	17B9B	73.91%	79.7		4.05		8.3		33.7		41.2			12.5				33.8	13.5	74.3		3.1				14.0	20.9					8260		65.1									2.7	26.8		149
275B6b	17B9C	64.96%	89.2		4.57		10.6		34.5		52.1			16.8				38.3	10.1	56.1		3.6				18.8	17.1					7240		38.4									1.8	38.8		212
275B5	17B10	71.85%	56.9		5.39		6.7		30.7		27.1			17.9				47.6	14.1	53.6		8.3				13.5	26.7					17300		45.4									4.6	48.7		317

Sample ID	NDGS Field ID	Ash (wt%)	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium
275 E3	17 E11	68.03%	47.1		2.76		4.2		25.0		21.7			11.4				24.7
275B2t	17B12A	41.84%	72.8		5.99		8.3		40.3		30.5			12.5				57.9
275B2m	17B12B	78.88%	77.2		2.86		6.4		34.3		37.3			12.3				23.0
275B2b	17B12C	79.81%	89.7		2.77		8.0		37.8		46.6			12.6				21.0
275 E2	17 E12	70.88%	52.1		3.02		4.5		27.8		23.1			13.2				25.9
275B1	17B15A	34.84%	26.4		3.71		4.2		13.1		14.4			10.8				34.4
274B1t	17B21A	52.34%	39.2		3.86		5.2		20.4		20.1			11.7				35.5
274B1b	17B21B	75.51%	46.3		3.09		4.2		24.2		21.9			14.0				23.0
274B3t	17B22A	45.77%	72.4		6.35		9.4		36.2		35.0			13.3				50.9
274B3m	17B22B	67.33%	66.9		3.26		6.9		30.8		35.8			13.9				23.2
274B4	17B23	62.79%	73.5		5.22		7.9		38.5		34.0			13.5				46.1
273B3t	17B24A	52.40%	106		7.81		17.4		33.7		74.7			14.8				60.1
273B3b	17B24B	56.87%	87.8		5.75		13.8		28.5		62.5			17.3				43.3
273B2t	17B25A	46.30%	53.8		4.20		6.7		24.5		28.8			10.9				35.0
273B2b	17B25B	32.79%	104		7.25		15.6		36.0		68.5			14.4				51.4
273B1t	17B26A	46.32%	56.3		5.33		7.1		29.5		26.0			11.2				44.8
273B1b	17B26B	78.63%	69.4		2.65		5.9		33.5		34.8			12.5				19.3
273 E1	17 E26	90.93%	81.8		4.37		8.3		42.6		40.1			13.4				41.0
18B1	18B1	28.73%	17.6	3.5	2.29	0.62	3.0	0.77	8.8	0.32	9.2	2.2	2.2	6.9	0.54	0.32	2.05	21
18C	18C	35.38%	47.3	9.6	6.22	1.83	8.1	2.13	24.1	0.85	25.8	6.3	6.2	15.5	1.44	0.88	5.63	61
18C4	18C4	14.13%	32.0	4.7	2.85	1.03	4.8	0.98	15.4	0.40	16.7	4.0	3.8	9.8	0.75	0.39	2.51	27.5
18C5	18C5	22.91%	29.9	4.5	2.91	0.95	4.4	0.97	16.2	0.41	15.8	3.9	3.4	9.4	0.70	0.40	2.59	32.9
18D	18D	24.71%	14.5	2.4	1.49	0.53	2.3	0.52	6.9	0.19	7.8	1.9	1.9	5.0	0.38	0.20	1.22	18
18E	18E	24.20%	13.7	2.5	1.61	0.54	2.2	0.53	6.5	0.21	7.6	1.8	1.8	6.1	0.38	0.22	1.40	18
21A	21A		43.9	6.0	3.54	1.57	6.4	1.23	15.0	0.50	25.7	6.0	6.0		1.04	0.50	3.19	29
21A2	21A2	43.54%	54.5		4.03		7.2		22.1		30.6			19.2				31.8
21A3	21A3	39.39%	46.5	5.5	3.03	1.58	6.2	1.05	16.7	0.42	26.5	6.4	6.3	15.5	0.95	0.42	2.70	25.6
21A4	21A4	23.99%	11.4	4.8	3.61	0.72	3.3	1.13	6.1	0.55	6.8	1.5	2.1	12.1	0.65	0.53	3.37	36.8
21B	21B		17.8	4.8	3.47	0.81	3.7	1.11	9.4	0.53	9.9	2.3	2.7		0.69	0.51	3.28	32
21C	21C		109	7.4	3.94	2.55	9.5	1.40	51.4	0.54	51.2	12.9	10.6		1.39	0.55	3.54	35
21C2	21C2	23.94%	34.8		5.08		5.4		19.5		17.2			16.2				50.2
21C3	21C3	37.76%	27.1	4.2	2.88	0.83	3.6	0.93	14.0	0.43	13.0	3.3	3.0	14.1	0.62	0.42	2.70	29.6
21C4	21C4	69.23%	92.7	8.2	5.14	2.17	8.6	1.67	45.0	0.77	42.1	11.1	8.8	26.8	1.32	0.74	4.84	46.6
21D	21D		11.5	1.7	1.24	0.31	1.4	0.39	6.3	0.21	5.2	1.3	1.2		0.25	0.19	1.28	10
21F	21F		4.7	1.0	0.74	0.20	0.9	0.24	2.0	0.09	3.0	0.7	0.7		0.16	0.10	0.55	10
21H	21H		3.6	0.6	0.49	0.16	0.6	0.15	1.9	0.08	2.0	0.5	0.5		0.10	0.07	0.48	5
21I4	21I4	35.38%	29.8	6.5	4.38	1.23	5.4	1.40	12.1	0.69	18.3	4.3	4.9	18.8	0.97	0.65	4.30	37.3
21J4	21J4	18.32%	12.1	3.6	2.77	0.51	2.6	0.86	6.3	0.46	6.8	1.6	1.8	5.2	0.49	0.42	2.76	29.7
21K4	21K4	21.83%	29.2	4.9	3.37	0.93	4.1	1.09	15.1	0.49	14.9	3.7	3.4	11.7	0.72	0.48	3.15	38.3
21L4	21L4	22.01%	47.4	8.3	5.90	1.64	7.6	1.84	22.1	1.01	27.1	6.4	6.6	18.9	1.28	0.90	5.99	59.4
21M4	21M4	30.91%	14.1	2.4	1.93	0.44	1.9	0.57	7.6	0.37	7.2	1.8	1.6	13.9	0.33	0.31	2.20	18.3
22A	22A	25.36%	12.1	3.0	2.07	0.51	2.4	0.68	5.5	0.30	6.9	1.6	1.8	6.2	0.44	0.29	1.88	20
22B	22B	15.81%	11.9	3.3	2.19	0.55	2.6	0.74	5.9	0.30	7.1	1.6	1.9	6.6	0.48	0.31	1.95	22
22C	22C	86.50%	46.0	3.3	1.87	0.89	3.8	0.64	22.9	0.28	21.6	5.6	4.3	7.7	0.56	0.27	1.83	16
28A	28A	56.06%	70.9	10.4	5.39	2.20	9.6	2.02	38.6	0.69	31.3	8.1	7.6	24.5	1.71	0.73	4.62	58
40A	40A		27.0	2.4	1.39	0.85	2.8	0.47	12.7	0.22	15.7	3.8	3.3		0.39	0.21	1.41	11
40ZA	40ZA	40.75%	31.9		3.65		5.1		14.6		22.8			28.5				25.3
40ZB	40ZB	15.54%	6.7		0.58		0.9		3.1		3.8			2.5				5.2
106A	106A	16.79%	11.0	4.2	3.16	0.57	2.7	0.97	5.1	0.48	6.1	1.4	1.7	11.2	0.55	0.45	3.05	30.7
106B	106B	36.39%	71.5	10.1	6.11	2.20	10.1	2.06	28.6	0.84	36.3	8.7	8.2	17.7	1.62	0.83	5.47	59.6
106E	106E	32.29%	11.7	2.5	1.72	0.48	2.0	0.55	5.5	0.25	6.3	1.5	1.5	11.0	0.35	0.23	1.59	18.3
106C	106C	62.17%	46.8	3.5	2.12	0.87	3.9	0.66	22.4	0.29	21.0	5.5	4.1	13.0	0.56	0.27	2.06	18.1
106D	106D	39.55%	21.1	3.3	2.37	0.59	2.7	0.73	10.3	0.36	9.8	2.5	2.2	11.0	0.47	0.33	2.32	21.9
106F	106F	24.75%	13.0	2.6	1.64	0.53	2.2	0.54	6.3	0.22	6.9	1.7	1.8	8.2	0.39	0.22	1.49	17.6
106G	106G	78.05%	55.8	3.6	2.16	0.90	4.2	0.69	27.4	0.29	24.0	6.4	4.7	12.2	0.59	0.29	2.07	20.3

Sample ID	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellerium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
275 E3	12.9	50.3		4.2				19.1	25.6					16900		17.1									5.4	18.7		274
275B2t	18.2	67.3		8.5				25.9	23.2					9200		58.5									8.5	52.7		325
275B2m	8.23	41.1		2.6				7.4	23.3					8500		22.3									2.9	23.3		232
275B2b	4.60	29.8		2.8				6.8	22.5					7100		10.5									1.6	21.4		173
275 E2	7.64	39.0		4.4				12.7	26.9					10700		9.8									3.8	11.6		249
275B1	17.9	60.0		9.1				23.6	16.8					10200		38.1									6.6	41.7		199
274B1t	10.6	58.1		8.7				18.3	22.8	18				18800		39.3	18.7								8.3	27.1		418
274B1b	14.2	75.6		3.7				11.1	22.1	7				9250		39.9	17.2								3.4	24.4		362
274B3t	17.5	80.4		5.2				23.5	21.3	11				9820		63.8	11.7								9.2	46.2		161
274B3m	13.7	121		2.7				6.6	19.8	4				7640		41.4	12.8								2.5	21.4		229
274B4	12.9	56.9		6.0				18.1	25.4	11				12500		46.2	16.1								6.5	27.2		265
273B3t	12.5	61.2		7.2				30.6	23.4	15				5640		38.8	16.8								5.0	38.4		382
273B3b	14.4	58.1		3.9				12.2	21.5	12				4350		44.8	13.9								4.2	43.8		212
273B2t	13.8	55.3		4.3				13.6	19.0	13				7500		40.8	10.6								5.1	27.2		162
273B2b	24.7	70.0		3.9				19.2	22.6	11				5380		57.3	17.1								8.1	45.5		264
273B1t	22.2	88.2		4.3				20.1	23.1	16				8790		63.1	13.1								8.1	35.3		197
273B1b	7.51	49.2		2.3				5.3	20.6	3				7070		24.8	11.6								2.1	19.9		166
273 E1	3.59	32.5		4.9				16.9	25.0	3				15200		6.3	13.4								2.0	6.2		127
18B1																												
18C																												
18C4																												
18C5																												
18D																												
18E																												
21A																												
21A2				3.5		1.14				30	3.7		16.1	9520				18				8.8		1200		19.1		316
21A3																												
21A4																												
21B																												
21C																												
21C2				9.1		0.87				14	1.9		11.6	8360				7				6.6		866		6.3		83.6
21C3																												
21C4	9.35	50.2	805	8.8	0.61	4.46	101	19.5	25.4	18	5.1	0.08	40.8	8100	457	22.2	28.8	43	208	1.02	0.39	15.7	2.0	3770	6.1	30.3	209	506
21D																												
21F																												
21H																												
21I4																												
21J4																												
21K4	2.17	7.4	622	4.0	0.10	0.05	13	7.9	5.0	8	1.5	0.02	4.5	4550	9	2.7	7.7	1	249	0.28	0.10	4.0	0.4	1520	2.0	6.4	25	156
21L4																												
21M4																												
22A																												
22B																												
22C	0.83		417	1.1		4.45	36		10.8	2	2.3		24.5	28000		0.9	10.1		107	0.85				2510	1.4	2.7	62	71.4
28A																												
40A																												
40ZA	4.02	23.7	736						15.7	13				9700		23.1	16.2								3.2	28.9	208	707
40ZB	0.65	9.6	774						2.2	1				5250		10.9	2.0								1.7	2.8	18	47.7
106A	1.71		730	5.0		0.06	4	3.1	5.4	3	0.5		1.5	9590		2.1	2.7			0.13				337	0.9	2.0	8	36.2
106B	6.69	44.8	1460	7.6	0.23	3.45	40	30.5	14.9	12	2.3	0.03	14.0	6900	350	10.5	9.8	38	411	0.45	<0.10	5.6	0.9	1410	4.5	6.8	72	95.9
106E																												
106C																												
106D																												
106F																												
106G																												

Sample ID	NDGS Field ID	Ash (wt%)	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellerium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
106H	106H	80.92%	66.4	3.8	2.26	0.98	4.6	0.73	32.8	0.33	27.7	7.5	5.2	11.4	0.63	0.31	2.25	20.8																												
106I	106I	96.14%	66.1	2.6	1.64	0.76	3.6	0.48	32.9	0.25	27.5	7.4	4.7	5.8	0.45	0.23	1.75	14.4																												
106J	106J	90.46%	53.1	2.6	1.73	0.67	3.1	0.52	27.1	0.26	21.8	6.0	3.9	9.3	0.42	0.23	1.82	15.2																												
106K	106K	30.83%	18.9	3.3	2.54	0.59	2.6	0.77	9.4	0.42	9.5	2.4	2.2	7.9	0.46	0.37	2.56	24.3	11.7	66.7	978	4.0	0.21	1.60	14	8.8	7.4	9	0.9	0.02	5.2	6890	56	45.0	4.6	16	488	0.20	<0.10	4.0	0.4	497	7.5	18.3	45	44.1
106L	106L	54.53%	31.7	3.1	2.28	0.73	2.9	0.67	16.3	0.37	14.4	3.8	2.9	13.9	0.45	0.32	2.30	20.7																												
106M	106M	38.33%	21.6	1.9	1.38	0.50	1.8	0.41	10.8	0.21	9.5	2.5	1.8	7.8	0.29	0.19	1.42	13.3																												
106N	106N	27.37%	28.4	4.1	2.71	0.92	3.8	0.89	13.9	0.37	14.1	3.4	3.2	10.7	0.63	0.35	2.35	31.9																												
107G	107G	77.78%	55.0	3.8	2.37	0.93	4.3	0.74	26.9	0.32	23.7	6.3	4.6	12.9	0.62	0.30	2.26	23.1																												
107O	107O	91.45%	46.5	2.2	1.27	0.71	2.8	0.41	25.8	0.17	18.2	5.1	3.1	5.9	0.36	0.16	1.25	12.5																												
107P	107P	91.82%	46.0	2.1	1.22	0.68	2.7	0.39	25.1	0.16	17.8	5.1	3.1	6.4	0.34	0.14	1.21	12.2	1.22		814	1.7		5.33	26	3.7	15.8	2	2.9		12.2	8120		2.9	8.7			0.90				1280	1.2	4.7	29	80.7
107K	107K	43.91%	20.0	1.9	1.23	0.47	1.9	0.38	10.1	0.18	9.1	2.4	1.9	8.1	0.28	0.16	1.25	10.8																												
107Q	107Q	38.84%	24.6	3.0	2.11	0.63	2.7	0.65	13.9	0.30	10.8	2.8	2.2	10.8	0.43	0.28	1.97	22.5																												
107R	107R	60.46%	25.5	2.0	1.35	0.57	2.1	0.40	13.0	0.18	11.3	3.0	2.2	10.6	0.28	0.16	1.32	12.3																												
107S	107S	33.65%	14.0	2.4	1.98	0.47	1.8	0.57	7.1	0.34	6.7	1.7	1.5	9.1	0.32	0.28	2.05	19.1																												
107T	107T	18.69%	42.5	3.6	1.97	0.89	4.2	0.69	19.1	0.23	19.4	4.9	4.1	10.3	0.61	0.25	1.64	20.2																												
109L	109L	64.47%	42.7	5.7	3.44	1.42	5.8	1.18	21.0	0.42	22.2	5.3	5.1	7.7	0.92	0.45	2.91	40.6	2.35		6250	6.2		2.45	33	10.0	11.0	3	1.5		16.2	12700		41.9	6.0			0.52				1580	6.0	59.6	65	49.2
109K	109K	49.60%	18.8	2.8	1.88	0.55	2.4	0.58	9.4	0.29	9.6	2.4	2.2	8.9	0.40	0.27	1.90	17.1																												
109J	109J	37.48%	16.3	3.3	2.48	0.80	2.4	0.75	8.2	0.43	8.0	2.0	1.9	14.5	0.46	0.38	2.58	21.7																												
109C	109C	45.65%	25.6	3.2	1.88	0.86	3.5	0.63	11.5	0.30	14.7	3.5	3.6	6.4	0.53	0.27	1.84	15.8																												
109T	109T	87.47%	45.5	1.5	0.66	0.51	2.1	0.24	23.4	0.09	16.3	4.8	2.8	5.3	0.29	0.09	0.61	5.8	1.62		426	0.7		1.14	4	2.1	23.7	2	5.0		21.5	13000		4.4	3.9			1.58				1100	0.7	5.1	12	86.6
109D	109D	62.67%	44.8	2.1	1.16	0.75	2.8	0.40	21.3	0.20	19.6	5.2	3.8	10.8	0.39	0.18	1.21	9.8																												
109E	109E	30.83%	63.3	3.8	2.11	0.84	4.3	0.74	29.0	0.31	24.8	7.0	4.8	3.9	0.66	0.31	2.03	22.2																												
109F	109F	15.42%	14.1	0.6	0.32	0.17	0.8	0.11	9.6	0.04	4.8	1.4	0.8	1.3	0.10	0.04	0.26	4.1																												
109G	109G	18.74%	9.1	1.0	0.58	0.27	1.1	0.20	4.8	0.08	4.6	1.1	1.0	1.8	0.17	0.08	0.49	6.5																												
109H	109H	93.31%	36.0	1.5	1.01	0.52	1.9	0.31	19.7	0.17	14.4	4.0	2.4	14.0	0.26	0.16	1.10	8.7																												
109I	109I	26.63%	59.6	8.0	4.18	2.08	8.8	1.51	25.5	0.55	33.2	7.8	8.3	17.5	1.38	0.56	3.59	36.6	7.70	42.8	8790	6.4	0.31	1.64	54	14.1	11.6	23	2.2	0.06	13.7	6790	257	22.4	13.5	22	370	0.47	0.16	6.0	1.2	1930	5.4	9.7	108	148
109A	109A	20.84%	7.5	1.7	1.33	0.30	1.2	0.41	3.7	0.23	3.9	1.0	1.0	10.9	0.24	0.21	1.39	11.3																												
109B	109B	11.69%	12.4	0.8	0.43	0.28	1.0	0.15	6.4	0.05	5.2	1.4	1.0	2.2	0.14	0.06	0.36	4.1																												
110C	110C	40.20%	28.7	4.0	2.73	0.83	3.6	0.85	14.7	0.46	14.3	3.5	3.1	11.4	0.60	0.40	2.90	23.6																												
110A	110A	92.95%	38.6	1.9	1.06	0.70	2.5	0.35	19.1	0.13	16.7	4.5	3.0	7.8	0.34	0.13	0.99	10.0																												
110B	110B	93.60%	40.6	1.9	1.02	0.71	2.6	0.33	19.6	0.13	17.1	4.7	3.1	7.0	0.33	0.13	1.00	9.6	1.75		258	1.5		1.78	40	8.5	21.6	1	3.3		25.7	18700		2.5	6.9			0.63				2220	0.9	3.8	53	93.1
111A	111A	40.63%	24.6	2.6	1.51	0.81	2.9	0.51	10.2	0.22	13.0	3.2	3.0	9.4	0.45	0.21	1.48	12.5																												
111B	111B	18.28%	24.8	2.7	1.71	0.54	2.5	0.57	12.8	0.23	10.3	2.8	2.1	3.5	0.41	0.23	1.51	18.8																												
111C	111C	18.02%	11.7	1.8	1.41	0.37	1.5	0.43	6.0	0.24	5.8	1.5	1.3	4.0	0.27	0.21	1.37	16.5																												
111D	111D	41.87%	18.0	1.8	1.33	0.37	1.6	0.41	9.6	0.24	7.5	2.1	1.5	6.7	0.27	0.21	1.48	11.8																												
111E	111E	46.19%	23.6	3.3	2.53	0.65	2.7	0.78	11.7	0.41	10.9	2.9	2.4	11.7	0.48	0.38	2.53	24.8																												
111F	111F	94.55%	49.5	2.5	1.45	0.90	3.3	0.49	25.0	0.21	21.3	5.7	3.9	9.4	0.45	0.21	1.41	12.7																												
111G	111G	92.01%	60.1	3.4	1.89	1.05	4.1	0.64	31.1	0.28	25.1	6.9	4.7	11.8	0.60	0.27	1.81	16.4																												
111T	111T	78.46%	15.5	0.7	0.42	0.23	0.9	0.13	7.4	0.04	5.8	1.6	1.0	4.5	0.11	0.04	0.38	4.7																												
112A	112A	89.71%	45.2	2.2	1.28	0.70	2.6	0.42	24.5	0.20	17.4	4.9	3.1	6.0	0.37	0.18	1.24	12.4																												
112B	112B	92.56%	48.8	2.5	1.48	0.80	3.1	0.49	26.3	0.23	19.5	5.3	3.5	9.1	0.43	0.21	1.49	13.7																												
113E	113E	43.69%	25.8	4.4	3.80	0.73	3.1	1.10	13.3	0.70	11.8	3.0	2.6	13.2	0.59	0.59	4.17	30.9	19.9	15.2	780	8.2		3.13	64	23.4	15.2	50.5	2.6		10.4	9860		42.3	20.7			0.51				1660	13.9	5.0	136	174
113F	113F	19.79%	8.4	1.3	1.01	0.21	1.1	0.31	4.5	0.17	3.9	1.0	0.9	1.9	0.18	0.15	1.02	10.8		5.2						8.1		5						6.0												
113G	113G	34.52%	82.2	7.9	4.82	1.76	8.2	1.61	39.9	0.75	36.6	9.6	7.6	10.8	1.31	0.69	4.70	41.5	17.9	236	865	2.7		1.23	27	21.8	10.5	6	1.9		5.6	3530		49.5	15.8		811	0.21				649	9.1	21.3	83	101
113H	113H	25.82%	98.8	9.2	4.86	2.54	10.7	1.76	40.9	0.66	47.4	12.3	10.5	8.0	1.63	0.68	4.34	43.6	25.7	199	1290	2.2	<0.10	0.74	26	16.1	10.6	15	1.8	0.02	4.6	4260	85	33.0	18.3	10	523	0.24	<0.10	5.7	0.5	496	15.6	25.6	77	118
113I	113I	87.55%	47.4	1.9	0.96	0.49	2.4	0.34	25.3	0.13	16.5	4.9	2.9	5.2	0.34	0.14	0.86	9.0								4.7		3						4.1												
113J	113J	23.68%	22.3	2.0	1.17	0.54	2.1	0.41	15.5	0.15	8.4	2.3	1.8	4.3	0.33	0.16	0.97	13.8								6.2		1						3.3												
113K	113K	95.14%	54.8	3.7	2.19	1.12	4.3	0.74	28.0	0.32	24.6	6.5	4.8	17.3	0.62	0.32	2.15	20.1								12.4		2						0.8												
113L	113L	33.39%	16.9	4.0	3.60	0.57	2.5	1.01	8.9	0.71	8.2	2.1	2.0	11.0	0.51	0.59	4.14	29.9	19.2		661	7.0		2.85	77	30.3	15.5	62.5	2.5		9.9	14200		15.0	25.1			0.42				1360	9.1	9.7	158	221
113M	113M	37.17%	20.9	3.9	3.56	0.65	2.7	1.01	10.9	0.70	10.1	2.5	2.2	11.7	0.51	0.58	4.09	28.8	13.8		1040	7.0		3.99	77	12.0	13.5	40	2.7		11.0	15100		8.5	23.0			0.49				1900	10.3	4.5	174	247
114D	114D	31.73%	29.2	4.1	2.41	1.08	4.4	0.81	11.1	0.34	17.5	4.1	4.2	9.6	0.67	0.33	2.18	23.1																												
114E	114E	89.48%	51.6	3.9	2.37	1.26	4.5	0.77	25.0	0.35	24.1	6.1	5.0	18.8	0.67	0.33	2.30	18.8	8.49		897	1.8		8.88	130	18.7	22.9	5	3.2		35.0	11700		17.7	11.1			0.93				4590	1.4	9.3	242	252
162Z	162Z	39.60%	55.0	6.4	3.91	1.33	6.3	1.28	24.2	0.51	25.7	6.5	5.7	11.7	1.01	0.50	3.45	35.9																												
162Y	162Y	47.49%	92.9	11.1	6.35	2.50	11.5	2.19	41.3	0.83	47.0	11.4	10.8	19.1	1.85	0.86	5.67	53.7	12.2		805	7.6		2.93	45		17.1	19	3.3		25.6	6130		27.0	13.2		398	0.44				1390	4.8	28.4	92	203
162X	162X	52.36%	34.6	3.9	2.41	0.82	3.9	0.80	16.5	0.34	16.6	4.2	3.6	7.9	0.63	0.33	2.26	23.1																												

Sample ID	NDGS Field ID	Ash (wt%)	Cerium	Dysprosium	Erbium	Europium	Gadolinium	Holmium	Lanthanum	Lutetium	Neodymium	Praseodymium	Samarium	Scandium	Terbium	Thulium	Ytterbium	Yttrium
163A	163A	80.79%	80.4	8.8	5.28	2.05	9.6	1.75	35.4	0.67	45.1	11.0	9.4	18.9	1.45	0.68	4.61	51.5
163U	163U	71.29%	52.0		2.58		4.2		25.4		23.2			11.9				20.7
163V	163V	23.82%	17.5	2.6	1.58	0.58	2.8	0.53	6.6	0.20	10.7	2.5	2.4	3.1	0.43	0.21	1.34	16.6
163X	163X	29.15%	16.0		1.52		2.3		8.0		8.2			4.2				15.1
163B1	163B1	39.76%	52.2		4.04		7.8		21.5		29.0			12.6				38.5
163C1	163C1	24.96%	50.5		3.66		6.2		21.7		24.8			11.8				33.2
163C2	163C2	18.47%	9.3		0.49		0.9		4.4		4.5			1.7				4.7
163E	163E	29.69%	105	8.9	5.21	1.97	9.2	1.78	44.1	0.72	43.5	11.6	9.1	16.6	1.49	0.75	4.88	46.1
231SWRL	231SWRL	89.64%	22.6		1.49		2.4		13.1		10.1			4.4				15.2
231BNCH	231BNCH	78.61%	36.7		1.96		3.7		18.1		17.0			6.5				19.3
231H	231H	86.91%	37.2		2.37		3.6		14.9		15.5			10.6				18.5
231G	231G	50.32%	121	16.7	9.06	3.77	16.0	3.29	62.7	1.14	59.1	14.7	13.8	27.8	2.76	1.20	7.52	84.5
231F	231F	35.70%	41.6		5.65		7.8		19.7		24.3			12.9				52.2
231EB	231EB	36.15%	74.5		4.50		8.9		35.9		35.3			14.1				47.3
231EA	231EA	46.84%	45.4		4.59		6.6		21.1		24.9			9.3				39.0
231D	231D	56.39%	55.9		3.79		6.7		28.1		28.6			16.2				34.0
232A	231A	43.09%	26.0		2.30		3.1		13.7		12.6			12.3				19.5
232B	231B	54.73%	19.9		1.09		1.6		10.3		8.1			3.7				10.4
232C	231C	65.69%	16.0		0.67		1.1		8.6		7.2			5.6				5.4
28A2	232G	30.78%	148	10.5	5.29	3.06	12.7	1.93	68.9	0.58	62.8	16.3	12.9	12.6	1.92	0.66	3.90	51.3
28B	232G2	42.25%	42.0		4.79		6.7		18.9		24.9			16.1				40.1
233D	233D	63.03%	69.9		3.52		8.2		32.0		37.2			15.0				30.4
233E	233E	56.68%	95.4	11.6	6.78	2.98	12.5	2.29	44.3	0.95	51.7	12.2	12.0	16.2	1.99	0.95	6.13	59.1
233T	233T	95.41%	50.7		4.32		3.9		28.3		20.4			9.7				34.4
233F	233F	39.92%	72.0		5.93		8.9		39.6		33.0			13.3				61.2
263A	263A	51.94%	35.2		4.21		4.6		19.6		17.3			22.0				37.4
263B	263B	23.79%	12.9		3.12		2.9		6.5		7.4			8.5				26.3
263C	263C	39.88%	25.1		5.05		5.0		13.7		13.6			17.9				40.7
263D	263D	67.43%	40.6		3.57		4.2		21.6		19.3			14.5				28.5

Sample ID	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cesium	Chromium	Cobalt	Gallium	Germanium	Hafnium	Indium	Lithium	Magnesium	Manganese	Molybdenum	Niobium	Rubidium	Strontium	Tantalum	Tellerium	Thorium	Tin	Titanium	Tungsten	Uranium	Vanadium	Zirconium
163A																												
163U				3.3		8.97				7	2.9		38.8	7470				106				10		2280		9.0		108
163V																												
163X				2.8		1.01				10	1.3		10.2	6360				12				4.5		880		5.7		42.6
163B1				4.1		2.17				4	3.1		21.0	3130				28				12.8		1220		8.1		142
163C1				3.7		0.26				2	1.1		13.6	3210				4				11.7		583		6.7		43.0
163C2				0.5		0.13				<1	0.5		4.1	3170				2				1.2		229		1.0		16.7
163E				8.1		0.81				5	4.3		22.8	1820				11				6.4		1210		10.1		189
231SWRL	4.18	644	255	2.4	0.22	1.54	22	68.2	6.8	3	0.8	0.02	9.5	4970	5400	11.4	4.6	28	62	0.26	<0.10	4.1	0.6	901	22.1	5.7	122	25.1
231BNCH							25	9.8	10.1	2				14600	5050	1.4	7.9					7.1		1720		2.2	39	42.1
231H							67	22.9	22.3	2				9450	333	4.1	14.2					6.9		4500		8.7	133	90.0
231G							146	91.2	32.1	9				5940	648	44.6	12.3					11.9		2900		50.7	344	633
231F							42	12.3	13.2	4				17500	125	309	6.1					8.4		1680		187	519	460
231EB							36	15.0	24.9	3				6700	121	743	9.8					4.7		1490		201	91	355
231EA							33	20.9	7.4	5				6440	80	79.7	11.4					5.8		3360		29.4	261	145
231D							63	11.2	17.1	3.0				7370	81	58.8	9.3					15.2		2070		27.1	115	316
232A							33	8.0	11.1	20				5700	76	12.4	13.6					4.3		1250		13.9	70	426
232B							7	2.4	20.5	2				6050	85	2.8	6.6					16.2		1430		3.4	12	141
232C							33	1.4	9.2	3				2320	80	24.8	5.6					3.6		1610		3.6	83	97.3
28A2							35	36.7	50.3	11				6470	199	512	5.8					8.9		951		145	295	986
28B	10.3	1860	3630	1.3	0.17	0.51	43	19.2	24.5	8	14	0.04	3.4	2280	110	3800	5.8	7	299	0.16	0.26	17.3	0.5	796	75.1	1480	137	1000
233D							57	9.0	17.0	4				4570	80	605	9.7					13.1		1740		60.2	128	376
233E							86	24.1	16.9	8				2370	86	106	18.2					14.4		6410		41.8	396	346
233T							49	3.9	19.8	5				1390	36	52.2	44.9					11.2		15100		11.6	118	293
233F	10.1	741	1230	6.3	0.20	1.57	45	41.0	28.4	6	10	0.04	5.9	5030	396	165	10.0	20	405	0.38	0.13	7.7	1.2	2130	37.4	55.4	284	600
263A				8.4			62		11.2	14	3.2			11100		5.2	13.3							2140		14.8	207	286
263B				4.8			14		7.3	2	1.3			12200		57.4	8.4							495		12.9	40	91.6
263C				9.6			39		22.2	29	5.7			13700		24.0	25.1							1710		34.4	156	355
263D				6.3			61		25.8	15	6.5			11500		2.7	22.1							3730		22.6	139	432

Results initially reported in Kruger and others (2017)