# Rare Earth Element Concentrations in Fort Union and Hell Creek Strata in Western North Dakota

*by*

***Ned W. Kruger, Levi D. Moxness, and Edward C. Murphy***

**REPORT OF INVESTIGATION NO. 117**
**North Dakota Geological Survey**
**Edward C. Murphy, State Geologist**
**Lynn D. Helms, Director Dept. of Mineral Resources**
**2017**

## Table of Contents

## Table of Contents

## Tables

Page



## Figures

Page

## Abstract

The North Dakota Geological Survey has completed an initial investigation into the potential use of North Dakota lignite as a source for rare earth metals, which included fourteen of the lanthanide elements, yttrium, and scandium. Over a two-year period from 2015-2017, Survey geologists collected 479 rock samples from outcrops in the badlands of western North Dakota and described the settings where they were collected. The majority of samples were lignites or carbonaceous claystones and mudstones from the Fort Union Group (Paleocene) as well as carbonaceous mudstones from the Hell Creek Formation (Cretaceous). Ultimately, 352 of these samples were analyzed, including 277 samples of coal and 62 carbonaceous mudstones. Laboratory results were reported on a whole-mineral basis. Rare earth concentrations in lignites averaged 128 parts per million (ppm) and ranged from 15 - 603 ppm. Carbonaceous claystones and mudstones averaged 164 ppm with a range of 67 - 426 ppm. Coal samples were found to have a higher proportion of the more valuable heavy rare earths elements than the carbonaceous mudstones and claystones, and compared favorably to the rare earth element composition of the previously mined carbonatite at Mountain Pass, California.

Most often, the highest concentrations of rare earths were found in samples collected near the top of the lignite beds, with some of the highest rare earth concentrations found when lignite was overlain by channel sandstones. In this setting, 29 samples averaged 243 ppm and the highest frequencies of samples (24%) reached concentrations of over 300 ppm. Uraniferous lignites were specifically targeted for sampling. While sample analyses did suggest a relationship to higher concentrations of rare earths, a direct correlation was not observed in all coals with elevated radioactivity levels. Coal ash near the base of clinker deposits and tonsteins were also targeted with mixed results. In comparison to data obtained from the United States Geological Survey's CoalQUAL national database, seven coal samples from this report would rank in the top 20 for total rare earth concentrations out of over 5,500 entries.

## Acknowledgements

We wish to thank those landowners who allowed us to collect samples on their property. Special thanks to Roen Land Trust and Steven Wild, Doug and Duane Pope, Darlene Fritz and the late Rocky Fritz, Sandra Short - McDonald Family Trust and Jay Obrigewitch. The location information was left out of the report when the measured section was on private land. We also wish to thank those landowners who allowed us to cross their property in order to access state or federal lands. The vast majority of the collecting sites for this investigation were on either federal or state land. We obtained a collecting permit from the U.S. Forest Service and operated under an existing collecting permit that our paleontologists had from the U.S. Bureau of Land Management. We also obtained a collecting permit from the ND Department of Trust Lands.

We also wish to thank Joe East and Andy Park (U.S. Geological Survey) for generating a query of the rare earth data in the CoalQUAL database.

## Introduction

Rare earth elements (REE), or rare earths, have been in the news recently, but scientists and government officials have been warning about our dependence upon China for these strategic minerals for at least the last ten years. Most scientific literature has focused on igneous or metamorphic deposits, which are conventional sources of rare earths. In 2012, two papers reported that coals had highly-promising rare earth potential (Ekmann, 2012; Seredin and Dai, 2012).

The rare earth elements consist of 15 elements known as the lanthanides (atomic numbers ranging from 57 to 71) and two chemically similar metallic elements, yttrium (atomic number 39) and scandium (atomic number 21) (IUPAC, 2005). The rare earth element promethium is unstable in nature, and due to its rarity is not discussed further in this report. Rare earths can be categorized chemically as light and heavy and economically as critical, uncritical, and excessive (table 1). In Earth's crust, rare earths are not particularly rare, but owing to their geochemical properties they are seldom found concentrated into economically mineable ores (Taylor and McLennan, 1985; Long et al., 2010).

**Table 1.** A list of rare-earth elements, including yttrium and scandium, by weight class, crustal abundance, and economic class (modified from USGS Fact Sheet 2014-3078); (modified from Jefferson Lab, 2017); (modified from Seredin and Dai, 2012). * In this report, scandium was treated as critical due to its current high price.

| Element | Symbol | Atomic Number | Crustal abundance (ppm) | Economic Class |
|---|---|---|---|---|
| Light Rare Earths | | | | |
| Lanthanum | La | 57 | 39 | Uncritical |
| Cerium | Ce | 58 | 66.5 | Excessive |
| Praseodymium | Pr | 59 | 9.2 | Uncritical |
| Neodymium | Nd | 60 | 41.5 | Critical |
| Promethium | Pm | 61 | <0.001 | Uncritical |
| Samarium | Sm | 62 | 7.05 | Uncritical |
| Europium | Eu | 63 | 2.0 | Critical |
| Heavy Rare Earths | | | | |
| Gadolinium | Gd | 64 | 6.2 | Uncritical |
| Terbium | Tb | 65 | 1.2 | Critical |
| Dysprosium | Dy | 66 | 5.2 | Critical |
| Holmium | Ho | 67 | 1.3 | Excessive |
| Erbium | Er | 68 | 3.5 | Critical |
| Thulium | Tm | 69 | 0.52 | Excessive |
| Ytterbium | Yb | 70 | 3.2 | Excessive |
| Lutetium | Lu | 71 | 0.8 | Excessive |
| Yttrium | Y | 39 | 33 | Critical |
| Non-classified Rare Earth | | | | |
| Scandium | Sc | 21 | 22 | Critical* |

Rare earths have found widespread use because of the powerful magnetism, optical properties, luminescence, and strength they can impart upon the products manufactured with them. These products include many electronic and energy-efficient items found in the typical American home or business such as computers, cell phones, televisions, batteries of electric and hybrid vehicles, and LED and CFL light bulbs. Rare earths are crucial components of super-power permanent magnets used in industrial generators, which transform alternative forms of energy such as wind, tidal, and geothermal into electricity (Seredin et al., 2013). Because of their optical and magnetic properties, rare earths are used in CAT scans, MRIs, PET, and X-ray imaging as well as in a variety of laser treatments including those for skin cancer, kidney stones, and tattoo removal (RETA, 2016). Other rare earth-containing products include superconducting electric power lines, semi-conductors, and lightweight aerospace components. A 2014 report by the American Chemistry Council stated over $329 billion of economic output and 618,000 jobs in North America are supported by rare earth chemistry (Rozelle et al., 2016).

Rare earths are commonly produced as byproducts during the mining of other mineral commodities. When an economical ore is discovered, the rare earth-bearing minerals separated from the ore contain multiple individual rare earth elements. Additional extraction and refining via numerous, complex chemical processes are required to separate the different rare earth elements and remove impurities.

The Mountain Pass mine in California was the leading rare earth producer in the world from the 1960s to 1980s. At peak production, the mine produced 22,000 tons (20,000 metric tons) per year of mostly light rare earths from a massive carbonatite which contains the rare earth-bearing mineral bastnäsite (Long et al., 2010). Production at Mountain Pass decreased substantially in 1998 and halted in 2002 as China began to dominate the rare earth market. From 1990-2000, China's production increased by more than 450% (Tse, 2011). During this time, China's consumption of rare earths remained relatively flat and most of the product was exported. The following decade China's consumption rapidly rose. Currently, 83% of global rare earth production occurs in China (Gambori, 2017). More importantly, China produces almost all of the critical, heavy rare earths, which are mined from weathered clay ion-adsorption deposits in its southern provinces (Gambori, 2014). In 2009, China limited export quotas to 38,500 tons (35,000 metric tons) per year in order to conserve resources and protect the environment (Tse, 2011). China's 2016 production quota was 115,700 tons (105,000 metric tons) and they exported 28,800 tons (35,200 metric tons) (Gambori, 2017). China's policy has also encouraged exports of downstream rare earth materials, thus encouraging foreign manufacturers to relocate to China. The United States identifies import dependence upon a single country as a supply security issue, and initiated studies on rare earths in 2010. Molycorp resumed mining operations at the Mountain Pass facility in 2012 and had an estimated production of 6,500 tons (5,900 metric tons) in 2015 (Gambori, 2017). The elemental composition of bastnäsite ore is dominated by less-favorable elements when compared to the more economic compositions of lateritic ores in China (figure 1), and the Mountain Pass Mine was put on "care and maintenance" during the fourth quarter of

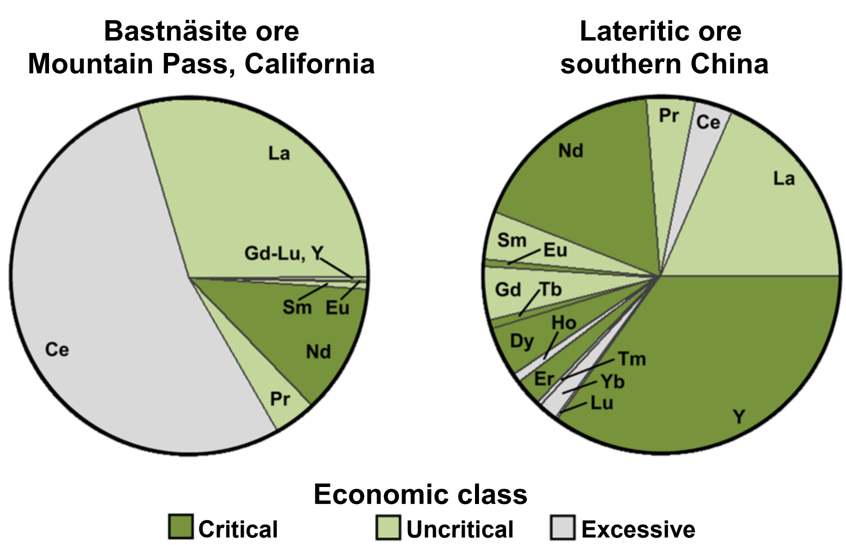



**Figure 1.** Elemental composition of conventional rare earth deposits. Modified from USGS Fact Sheet 087-02 based on economic class after Seredin and Dai (2012).

2015 and did not produce in 2016. As a result, no rare earth elements were mined in the U.S. in 2016 and U.S. imports of rare earths increased by 6% (Gambori, 2017).

Maintaining reliable domestic sources of rare earth-containing raw materials, the vast majority of which are currently produced in China, is critical to each of the industries and manufactured products previously mentioned.  New sources must be identified and developed to ensure an adequate supply of these important metals is available for the technological advances of the future.

**Rare earth elements in coals**

Recent publications indicate the potential of coal deposits for the recovery of rare earths as by-products of mining and combustion (Seredin and Dai, 2012; Seredin et al., 2013; Franus et al., 2015).  In particular, lignite has been highlighted owing to its potential for higher concentrations of rare earths and because there are existing techniques for extracting rare earth metals from this low-ranking coal (Seredin and Dai, 2012).

The average total rare earth content of world coals on a whole mineral basis is estimated to be 68.5 ppm (Ketris and Yudovich, 2009), or 404 ppm on an ash basis, while U.S. coals are estimated to be 62.1 ppm (Finkelman, 1993), or 517 ppm on an ash basis.  Whole-coal based concentrations are roughly 2.5 times lower than average composition of the upper continental crust.  Because rare earths are not combustible, but rather are preserved in the ash, ash-based concentrations are approximately 3 times higher than the upper continental crust (Seredin and Dai, 2012).  This value is close to the content of some conventional sources of rare earths.  Further, abnormally enriched accumulations of rare earths have been documented in coal deposits.  There are four identified means for these accumulations to develop: 1) terrigenous, rare earth input by surface water; 2) tuffaceous, falling and leaching of alkaline volcanic ash; 3) infiltrational, or meteoric ground water-driven; and 4) hydrothermal, connected with ascending flows of thermal mineral water (Seredin and Dai, 2012).  Such enrichment of rare earths is often limited to areas near the contacts of the roof, floor, or partings of coal seams.

Preliminary studies on coal deposits as a source of rare earths indicate that an “unintended production” of 44,000 tons (40,000 metric tons) of rare earths may be occurring annually in the United States from current coal production. An additional important consideration is the coal’s rare earth composition, which ideally should contain higher proportions of critical heavy metals compared to excessive metals. This “unintended production” may include over 11,000 tons (10,000 metric tons) of heavy rare earths (Ekmann, 2012).

In the United States, a study of coal ashes from power plants across the country found the highest rare earth concentrations came from post-combustion ashes of coals from sources in the Appalachian Mountains (591 ppm).  Averages from other major basins include southern and western Illinois (403 ppm) and the Powder River Basin in Wyoming and Montana (337 ppm).  Although the overall concentrations were marginally lower, the study found that greater rare earth extraction was possible from the coal ashes of the Powder River Basin as the lower grade coals found therein more readily allow the acid washes to mobilize rare earths (Taggart et al., 2016). Multiple active projects are examining the larger implementation of extraction techniques and aim to complete bench- and pilot-scale operations to economically produce rare earths from U.S. coal and coal byproducts by 2020 (DOE, 2017a).  Much of the preceding introduction was modified from two articles that appeared in the Department of Mineral Resources Newsletter (Kruger, 2015, 2017).

In the fall of 2014 the North Dakota Geological Survey proposed a rare earth project in their 2015-2017 biennial budget that was subsequently approved during the 2015 legislative session. In September 2015, the Geological Survey began collecting lignite, organic-rich mudstone, and clinker/coal ash samples in western

North Dakota for rare earth element analysis. The Little Missouri River Badlands was targeted because the rocks are easily accessible, negating a costly drilling program. In addition, facies changes that may impact rare earth concentrations can be readily identified in the broad expanse of outcrops. Survey geologists working on this project had more than 50 years of combined experience studying western North Dakota coals in outcrop as well as identifying and correlating coals in more than 25,000 electric logs across the area. This experience saved both time and resources because project staff were able to identify target outcrops based upon previous studies requiring little to no field reconnaissance. Collection permits were obtained from the ND Department of Trust Lands, the US Forest Service, and the US Bureau of Land Management.

In addition to readily accessible outcrops, western North Dakota was also targeted because some lignites in this area are known to contain increased concentrations of uranium, molybdenum, germanium, etc. It was theorized that rare earth elements might be concentrated in these coals by the same processes that concentrated these metals and metalloids. Uranium was first studied in North Dakota approximately 70 years ago. In the summers of 1948 and 1949 Donald Wyant and Ernest Beroni collected rock samples from 69 localities throughout North Dakota. Thirteen rock samples were collected in eastern North Dakota, 18 in north-central North Dakota, one in northwestern North Dakota, and 36 in southwestern North Dakota. Wyant and Beroni speculated that the upper portion of the Sentinel Butte Formation contained the only uraniferous lignites in North Dakota. They also hypothesized that either the uranium was deposited at the same time as the strata or groundwater leached uranium from the overlying rocks and deposited it in "the first carbonaceous material" it encountered. The Chalky Buttes in Slope County was one of the areas they mapped as "the Hot Bed" (containing uraniferous strata). Thirty years later, the Chalky Buttes would become a major area of uranium exploration (Murphy, 2005).

**Sample Procedures**

The North Dakota Geological Survey sampling team ranged from one to three geologists. When alone, the geologist collected coal samples while measuring a geologic section. When there were two or three geologists on site, one measured the section while the other(s) collected the samples. A team of three was found to be the most expedient. Most lithologic thicknesses were approximated to the nearest foot as the intent was to identify lithologies immediately overlying or in close proximity to beds that were sampled, thus bed thicknesses were only of relative importance. As the sections were measured; coals, carbonaceous mudstones, carbonaceous claystones, and occasionally lignite ash at the base of clinkers were identified as targets to be sampled. Small excavations were made with picks and shovels to expose the rock 12 inches (30 cm) back from the outcrop face in order to obtain unweathered rock samples. Photographs were taken of each sample interval and coal quality was noted; i.e., highly cleated, moderately cleated, oxidized, etc. Samples, approximately 1000 grams each, were collected in one gallon Ziploc bags. After the samples were obtained, the excavations were filled back in with waste rock and tamped down with shovels and boots as close as possible to the original contour. Once back in the office, the initial round of samples were air dried in the bag, sealed, and shipped to the laboratory for rare earths analysis. After that first round, samples were typically sent to the laboratory for drying shortly after they were collected, preserving the moisture content at the time of sampling.

During the 2017 field season, scintillometers or Geiger counters were carried in the field and readings were taken of beds prior to sampling. Readings were also taken of the samples within the bags back in the office before they were shipped to the laboratory for testing. Two Arrow-Tech Model no. 3007A survey meters equipped with Ludlum Measurements Model no. 44-9 pancake probes were used. The pancake probe was held one inch (2.5 cm) above the rock outcrop or the collected rock sample and readings were recorded in counts per minute (cpm). It was determined in the field that any readings of 40 cpm or less on North Dakota lignites were equal to background.

**Laboratory Procedures**

Standard Laboratory in Casper, Wyoming prepared all samples and performed analyses on those selected for short proximate testing. Standard Laboratory in Freeburg, Illinois performed the rare earth element analysis. Samples were analyzed using a Perkin Elmer NexION 300x Inductively Coupled Plasma Mass Spectrometry (ICP-MS). American Society for Testing and Materials (ASTM) standards and specifications D6357 does not list rare earth elements, but does note the method is applicable to other elements. Eleven different known value standards were analyzed in order to verify the analytical technique; five NIST known values (1632D, 1633b, 1633c, 2702, and 2711), two SARM known values (18 and 19) and four USGS known values (AGV-2, BHVO-1, MAG-1, and SGR-1). The Freeburg Standard Lab facility has performed trace element analysis on coal and coke combustion residues for more than 45 years. The ASTM D6357 method for rare earth elements has been in use for the last 15 years.

An initial review of literature found that the element scandium, like yttrium, is sometimes included with the rare earths as it is also chemically similar to the lanthanides. However, it was noted that scandium does not generally occur at economic concentrations in the same geological settings as the lanthanides and yttrium (USGS Fact Sheet 2014-3078), and a majority of publications did not include scandium in their discussions. Based on this information, scandium analyses were not requested on the first 175 samples submitted, as a cost saving measure. Subsequently, through discussions with other interested parties, we determined that scandium would add value to this investigation, and was added to the laboratory reports going forward. It should be noted that the total rare earth concentrations provided in the appendices of this report include scandium only when there is a value presented in the scandium column of the table.

Short proximate analyses were conducted on selected samples to determine amongst other things the British thermal units (BTUs). This was done primarily to enable determination of any correlation between coal quality and rare earth concentrations. Short prox was only run on 46 of the coal samples, again as a cost savings measure.

**Fieldwork**

Samples for rare earth analysis were collected from 64 sites along a 25 x 75 mile (40 x 120 km) rectangle centered on the Little Missouri River Valley in Bowman, Slope, Billings, Golden Valley, and McKenzie counties (figure 2). Samples were also collected from a site in Morton County. A total of 479 rock samples were collected from these 65 sites. Initially, samples were collected from coals in 6-inch (15 cm) increments through the depth-thickness of the coal, and at 12-inch (30 cm) increments in the mid-sections of coals exceeding 8 feet (2.5 m)in thickness. When enough samples had been analyzed to confirm an initial hypothesis of the study that the highest rare earth concentrations would typically occur at the very tops of the organic-rich beds, the sampling strategy shifted from including the entire bed to targeting the top, after which samples predominantly represent the top two or three inches (5-8 cm) of the beds. However, since there were instances where the highest concentrations were found at the base of a coal, occasional bottom samples continued to be collected. Of the 479 samples collected under this first sampling phase, 352 were analyzed. Samples were submitted for laboratory analysis in six groupings over a 15-month period from February 2016 to May 2017. As the results were received from Standard Labs, sample submission and field sampling priorities were modified, and 130 samples that were shifted into the low priority category were not submitted to the laboratory for analysis. Many of these were samples collected in six-inch (15 cm) or twelve-inch (30 cm) increments from the middle of a coal. Sampling focused on Fort Union strata since those are the dominant rocks exposed at the surface in western North Dakota.

In 2017, an emphasis was placed on collecting rocks in close proximity to the White River Unconformity and/or areas of known elevated uranium concentrations. As a result, samples were collected from the Sentinel Butte, Bullion Creek, Slope, and Ludlow Formations. Organic-rich mudstone and claystone

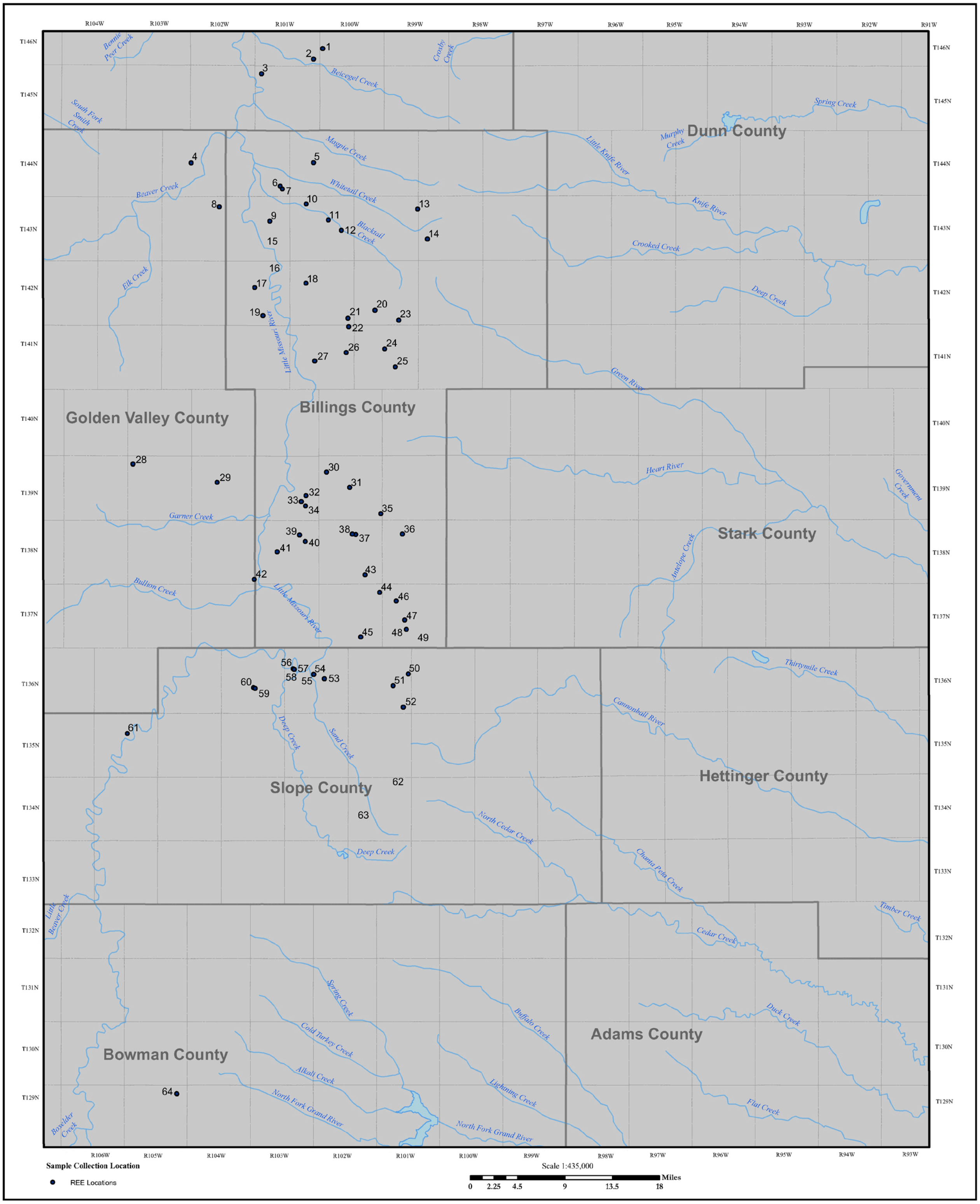



**Figure 2.** The locations of the measured sections in southwestern North Dakota where rare earth sampling activities occurred from the fall to 2015 through the spring of 2017. Measured section 65, not shown, is in Morton County.

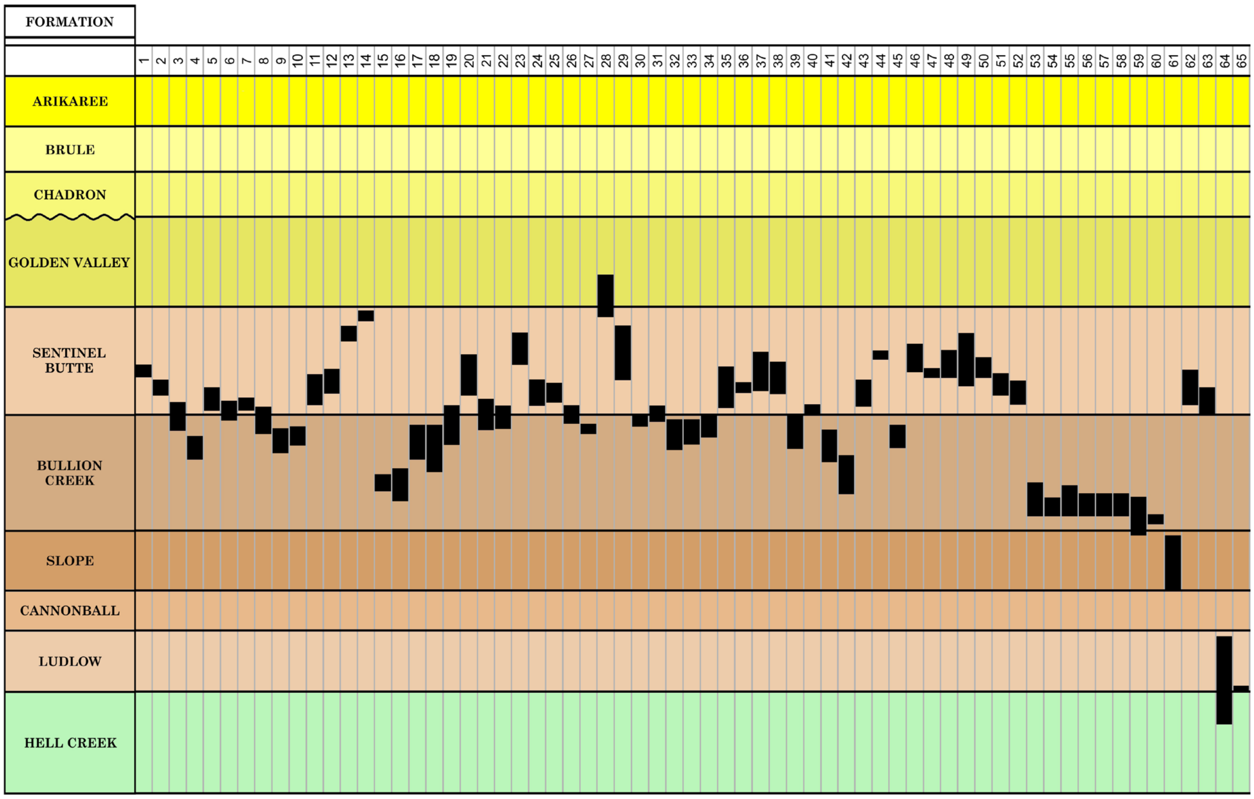



**Figure 3.** The stratigraphic extent of the measured sections in this study. Fort Union Group is shown in shades of brown.

samples were also obtained from the upper Hell Creek Formation at Mud Buttes in Bowman County. In total, 158 samples were analyzed from the Sentinel Butte Formation, 161 samples from the Bullion Creek Formation, eight samples from the Slope Formation, 19 samples from the Ludlow Formation, and six from the Hell Creek Formation (figure 3).

### Rare Earth Element Concentrations

The rare earths are generally divided into two groups, light and heavy, based on atomic weight. Though it has a smaller atomic number, yttrium is classified as heavy, placed between dysprosium and holmium, as its chemical and physical properties more closely resemble this group. While scandium is the lightest rare earth element, it is traditionally considered too chemically and physically dissimilar to be included in either group. Light rare earths as a group are considered less valuable than the heavy rare earths. The lightest lanthanides, lanthanum and cerium, are the two most abundant rare earths found in the upper continental crust and are typically associated with conventional rare earth ores. The heavy rare earths are less abundant and are currently mined primarily from ion-adsorption clay deposits in southern China. Complicating the general truth that light rare earths are less valuable than the heavy rare earths is that authorities sometimes differ on where they place the light/heavy boundary, and in the mid-range of atomic numbers fall several elements currently considered critical by market demand (europium, terbium, dysprosium, and yttrium).

One of the criteria utilized by Seredin and Dai (2012) as a preliminary assessment for coal ashes as a rare earth raw material is an index called outlook coefficient of rare earth ores ($C_{outl}$), which incorporates market trends rather than a simple comparison of light and heavy classifications. This index provides an ore evaluation based on the ratio of the percentage of total rare earths which are critical to the percentage of total rare earths which are excessive. While this approach does provide an additional measure of an ore's potential industrial value, it should be noted that the factors determining the ratio may require adjustment over time as new rare earth sources are discovered, old sources are depleted, or new industries and technologies alter the supply and demand chains for the individual elements. All outlook coefficient figures calculated for this report are based on the formula from Seredin and Dai (2012) as given below.

$$C_{outl} = (Nd+Eu+Tb+Dy+Er+Y/\Sigma REY)/(Ce+Ho+Tm+Yb+Lu/\Sigma REY)$$

The U.S. Department of Energy (DOE) has been using a standard of 300 ppm (on a whole-coal basis) as the minimal threshold sought in project proposals to discover and characterize new potential sources of rare earths, as well as the minimum threshold for the ore utilized in the testing and development of new technologies to extract concentrated solutions of rare earths (DOE, 2017b). Coal samples that exceeded this threshold are emphasized in this report.

## FORT UNION GROUP

### Fort Union Lithologies

Rocks of the Fort Union Group (Paleocene) cover most of southwestern North Dakota. With only a few exceptions, the coal-bearing rocks in the Williston Basin fall within the Fort Union Group (Paleocene). A notable exception is a two-to-three-foot-thick (0.6-0.9 m) coal in the lower Hell Creek Formation (Upper Cretaceous) which appears to extend over much of central North Dakota and was mined by underground methods in at least one locality in Emmons County and by surface methods in Sheridan County. Thin coals are also present in the upper member of the Golden Valley Formation (Murphy, 2006).

The Fort Union Group is a clastic wedge (primarily nonmarine) that extends from the Powder River Basin in Wyoming to the Williston Basin in eastern Montana and western North Dakota. In North Dakota, this group consists of, from oldest to youngest, the Ludlow, Cannonball, Slope, Bullion Creek, and Sentinel Butte Formations (figure 3). The peat, which eventually became coal, was deposited 55-65.5 million years ago in swamps that were adjacent to large fluvial systems. These rivers flowed primarily from west to east, eventually emptying into the Cannonball Sea. Early in Paleocene time, the Cannonball Sea advanced across western North Dakota, at least as far as the Montana line, before retreating eastward to the Missouri River Valley. As a result, the Cannonball Formation thins from east to west while all other formations within the Fort Union Group thin from west to east. Based on the variable thicknesses and lateral extent of lignite beds in North Dakota, the size and duration of swamps within which the peat was deposited were extremely variable. In many cases, swamps lasted for relatively short periods of time as indicated by the presence of numerous, thin, discontinuous coals. Peat production was frequently terminated by fluctuating water levels, either the swamps dried up or were drowned by rising water and peat gave way to the deposition of lake sediments (Murphy, 2006). Typically, coals within the Fort Union Group are bounded by claystone indicating lacustrine deposition both preceded and followed peat deposition. Less frequently, peat production was halted by an influx of clastic sediments as rivers meandered into swamps overwhelming the organic deposits. For large swamps, fluctuating water levels and input of clastic sediments would likely be dampened by the size of the system. In contrast, smaller swamps would have been more sensitive to these changes. Some swamp systems were likely in existence for extended periods of geologic time based on coal beds that are both tens of feet thick and extend for hundreds or thousands of square miles (Murphy, 2006). Volcanism associated with tectonic activity is believed to have been more prevalent during the deposition of the Sentinel Butte Formation (Royce, 1970), which may increase the likelihood of observing remnant deposits of volcanic ash falls, or tonsteins, within the coals deposits of the Sentinel Butte Formation.

The Fort Union Group consists of 60-70% claystone and mudstone, 25-30% sandstone and siltstone, and 5% lignite (Murphy, 2006). The Fort Union Group in North Dakota contains 1.3 trillion tons (1.2 trillion metric tons) of lignite, 25.1 billion tons (22.8 billion metric tons) of which are economically mineable using current surface mining technology (Murphy, 2006; Murphy et al., 2006). The Harmon bed is the thickest and most extensive lignite seam in North Dakota. It reaches a maximum thickness of 53 feet (16.2m) and extends over an area of approximately 3,000 square miles (7,770 square km). There are other North Dakota lignites that are more than 20 feet (6.1m) thick (e.g. T Cross, HT, Alkabo, Coteau), but none extend over an area as vast as the Harmon bed (Murphy, 2012).

It was anticipated that rare earth concentrations might be tied to coal quality. For that reason, as previously noted, general observable qualities were noted in the field. Lignite was found in a variety of quality types including typical coal, hard, powdery, and weathered (figures 4-7). A number of thin lignite lenses in carbonaceous mudstones or sandstones were sampled during this project (figure 8). Carbonaceous claystones and mudstones ranged from slightly carbonaceous to black “paper shale” claystones (figures 9 and 10).


**Figure 4.** A typical North Dakota lignite (categorized as coal in the measured sections), sample 63A.

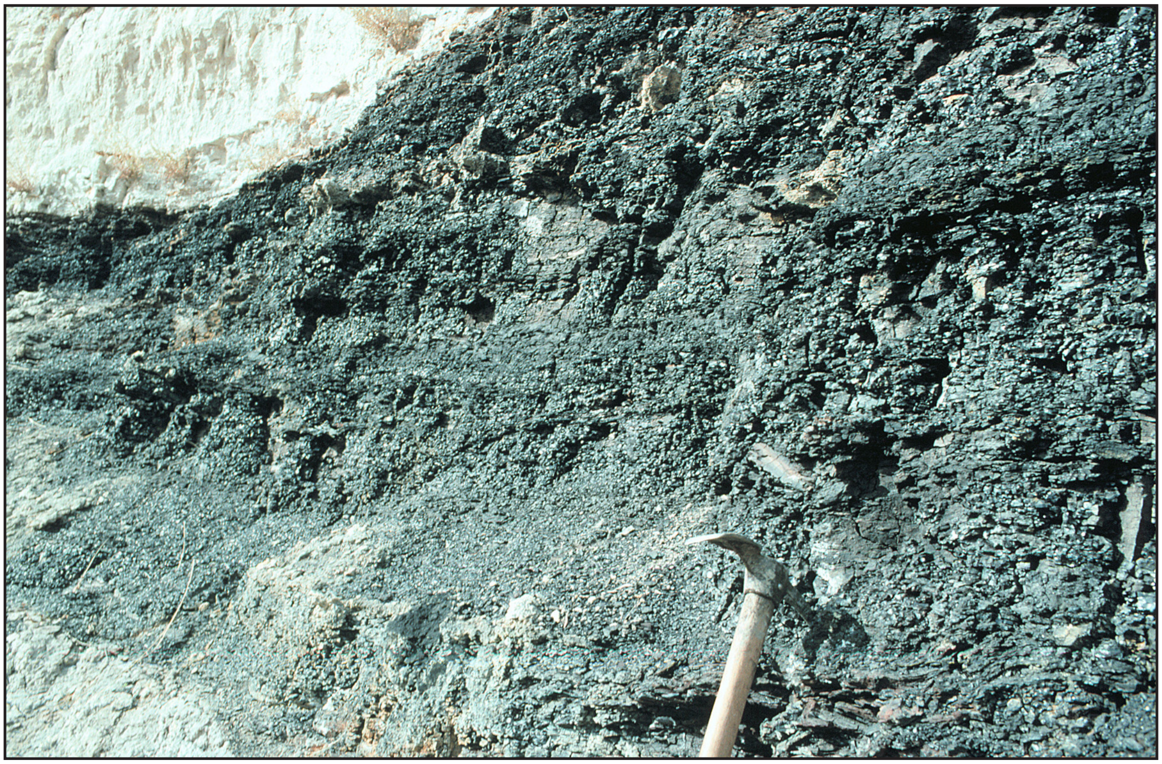


**Figure 5.** The Harmon bed is primarily a hard lignite (hard coal or hcoal in the measured sections) at this locality along East River Road in Slope County.

**Figure 6.** An example of a powder lignite (powder coal or pcoal in the measured sections), sample 55-7.


**Figure 7.** An example of a weathered lignite (wcoal in the measured sections), sample 19I.

**Figure 8.** Lenses of lignite within a carbonaceous mudstone (coal lenses in mudstone or clmdst in the measured sections), samples 9A and 9B.

**Figure 9.** A typical carbonaceous mudstone (cmdst in the measured sections), sample 8B.

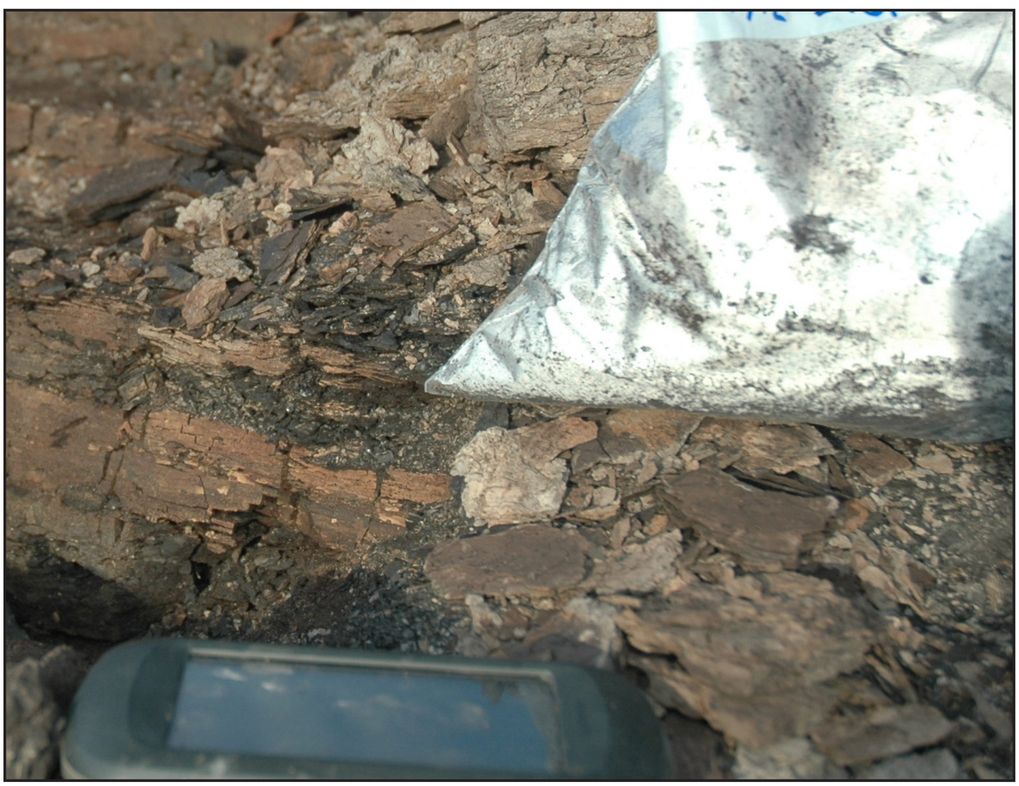


**Figure 10.** Dark brown to black carbonaceous claystone often referred to as “paper shale” (cclst in the measured sections).

**Sentinel Butte Formation**

The Sentinel Butte Formation covers much of the surface of western North Dakota. Sentinel Butte rocks are present throughout the eastern portions of the Little Missouri River Badlands as well as the upper elevations throughout much of the badlands. Sentinel Butte strata was encountered in 38 measured sections. Only nine of these sections included rocks that spanned the upper half of the formation.

There were a total of 158 samples analyzed from the Sentinel Butte Formation (Table 2). Coal accounted for 126 of the samples, while 30 samples were collected from carbonaceous mudstones. Other samples were of bentonite and ash. The total rare earth concentrations of the coal samples ranged from 15 to 408 ppm on a whole-coal basis, with an average concentration of 124 ppm. Analyses for scandium were performed on 54 of the coal samples.

Six of the coal samples exceed 300 ppm. Sample 5A (360 ppm; $C_{outl}$=1.58) was collected from a 3-inch (8 cm), fine-grained coal bound by claystone. Sample 6F (333 ppm; $C_{outl}$=1.17) was collected from the base of a 2.5-foot-coal (0.8 m)with carbonaceous mudstone. Sample 21C (301 ppm; $C_{outl}$=0.88) was collected from the bottom six inches (15 cm) of a 1.5-foot-coal (0.5 m) overlain by mudstone. Sample 35C (318 ppm; $C_{outl}$=1.12) was collected from thin, coal lenses in mudstone. Sample 37L (399 ppm; $C_{outl}$=1.40) was collected from the top three inches (8 cm) of a 1-foot-thick (0.3 m) coal overlain by loosely consolidated claystone. Sample 49B (303 ppm; $C_{outl}$=1.58) was collected from the top two inches (5 cm) of a 4-inch-coal (10 cm) overlain by sandstone. Sample 62F (408 ppm; $C_{outl}$=1.34) was collected from a 2-inch-coal (5 cm) lense within a carbonaceous mudstone. (pages 39, 40, 55, 69, 71, 83, and 95).

One carbonaceous mudstone sample exceeded 300 ppm, sample 38B (426 ppm; $C_{outl}$=1.13). All other samples analyzed from this formation were below 300 ppm.

**Table 2.** Stratigraphic and lithologic distribution of samples.

| | Number of Samples | | | | | Avg Total REE (ppm) | | | Avg $C_{outl}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Formation** | **Total** | **Total Coal** | **Coal Tops** | **Carb/ Mdst** | **Other** | **Total Coal** | **Coal Tops** | **Carb/ Mdst** | **Total Coal** | **Coal Tops** | **Carb/ Mdst** |
| Sentinel Butte | 158 | 126 | 81 | 30 | 2 | 124 | 140 | 158 | 1.49 | 1.48 | 0.96 |
| Bullion Creek | 161 | 133 | 80 | 20 | 8 | 122 | 158 | 157 | 1.37 | 1.45 | 0.88 |
| Slope | 8 | 8 | 8 | 0 | 0 | 166 | 166 | N/A | 1.12 | 1.12 | N/A |
| Ludlow | 19 | 10 | 9 | 6 | 3 | 212 | 233 | 212 | 1.44 | 1.45 | 0.99 |
| Hell Creek | 6 | 0 | 0 | 6 | 0 | N/A | N/A | 163 | N/A | N/A | 0.97 |
| **Total** | **352** | **277** | **178** | **62** | **13** | **128** | **154** | **164** | **1.43** | **1.45** | **1.03** |

**Bullion Creek Formation**

The Little Missouri River Valley and associated badlands consist primarily of Bullion Creek strata from the Slope County/Billings County line north to the North Unit of the Theodore Roosevelt National Park, McKenzie County (figure 1). Bullion Creek rocks were encountered in 31 measured sections. Most sections were measured in the upper portion of the Bullion Creek Formation with only 11 sections incorporating the lower part.

There were a total of 161 samples analyzed from the Bullion Creek Formation. Samples of coal accounted for 133 of the samples, while 20 were collected from carbonaceous mudstones. Other samples were of ash, sandstone, and a tonstein/clay parting. The total rare earth concentrations of the coal samples ranged from 15 to 603 ppm on a whole-coal basis, with an average concentration of 122 ppm (Table 2). Analyses for scandium were performed on 64 of the coal samples.

Nine of the Bullion Creek coal samples exceed 300 ppm. Samples 9A (521 ppm; $C_{outl}$=1.03) and 9B (335 ppm; $C_{outl}$=1.72) were collected from lower and upper coal lenses, respectively, within a 8-inch-carbonaceous (20 cm) mudstone. Sample 17B (386 ppm; $C_{outl}$=1.24) was collected from bottom half of a 5-inch-coal (13 cm) overlying a 7-inch-carbonaceous (18 cm) claystone. Samples 54A (603 ppm; $C_{outl}$=1.03) and 54B (499 ppm; $C_{outl}$=1.15) were collected in sample intervals of 0-4 inches (0-10 cm) and 6-9 inches (15-23 cm), respectively, measured from the top of a 14-inch-coal (36 cm) overlain by sandstone. This coal was identified as the "H bed" of Hares (1928), positioned below the Harmon & Hanson coals beds. Sample 55-2 (365 ppm; $C_{outl}$=0.77) was collected from the top three inches (8 cm) of the "H bed" approximately 125 feet (38 m) to the north of samples 54A&B, where the interval included coal lenses within carbonaceous mudstone overlain by sandstone. Sample 56F (493 ppm; $C_{outl}$=1.15) was collected from the top two inches (5 cm) of the Harmon coal bed which is approximately 16 feet (5 m) thick, including a 2-foot-thick (0.6 m) clay parting, at this location. Sample 56FII (555 ppm; $C_{outl}$=1.24) was collected as a confirmation sample several feet over from sample 56F. Sample 58F (350 ppm; $C_{outl}$=1.13) was also collected from a two-inch (5 cm) interval below two inches (5 cm) of thinly bedded carbonaceous clay at the top of Harmon coal bed approximately 230 feet (70 m) to the southeast. (pages 43, 51, 88, 89, and 91).

Sample 56A (344 ppm; $C_{outl}$=0.82) was the only carbonaceous mudstone sample which exceeded 300 ppm. All other samples analyzed from this formation were below 300 ppm.

**Slope Formation**

The rocks of the Slope Formation make up much of the Little Missouri River Valley and associated badlands topography from the Billings/Slope County line south to the middle of Slope County (figures 2 and 3). Only two measured sections encountered Slope strata. One of these sections was measured at the type section of the Slope Formation in Slope County and encompasses almost the entire formation (Section 61, page 94). The other, (Section 59, page 92), only contains the top 14 feet of the Slope Formation (figure 3).

There were a total of eight samples analyzed from the Slope Formation, all of which were coal (Table 2). The total rare earth concentrations of the samples ranged from 83 to 356 ppm on a whole-coal basis, with an average concentration of 166 ppm. All eight samples included an analysis for scandium. Sample 61H (356 ppm) was collected from the top three inches (8 cm) of a 1-foot-thick (.3 m) coal that is overlain by seven feet (2.1 m) of sandstone and underlain by ten feet (3 m) of sandstone (page 94). All other samples analyzed from this formation were below 300 ppm.

**Cannonball Formation**

The rocks of the Cannonball Formation were deposited in a marine environment. As a result, the Cannonball Formation does not contain lignite. Cannonball strata does occasionally include thin, organic-rich beach or back-beach deposits, generally interpreted as storm deposits. The Cannonball Formation was not sampled during this project.

**Ludlow Formation**

Samples were obtained from coals and carbonaceous mudstones throughout almost the entire Ludlow Formation in Mud Buttes, Bowman County (figures 2 and 3). There were a total of 19 samples analyzed from the Ludlow Formation. Samples of coal accounted for ten of the samples, while six were collected from carbonaceous mudstones (Table 2). Other samples included a tonstein/clay parting and ejecta deposits. The total rare earth concentrations of the coal samples ranged from 32 to 473 ppm on a whole-coal basis, with an average concentration of 212 ppm (Table 2, page 13). Analyses for scandium were performed on all 10 of the coal samples.

Two of the coal samples exceed 300 ppm. Sample 64T (431 ppm; $C_{outl}$=1.17) was collected from the top of a 4-inch-thick (10 cm) coal at the base of a 4-foot-carbonaceous mudstone (1.2 m) overlain by sandstone (page 97). Sample 64U (473 ppm; $C_{outl}$=1.21) was collected from a thin layer of powdery coal within a 1-foot-thick carbonaceous mudstone (10.3 m). Sample 64I (379 ppm; $C_{outl}$=0.90) was the only carbonaceous mudstone sample to exceed 300 ppm. All other samples analyzed from this formation were below 300 ppm. A sample was collected from a possible tonstein in a thin basal coal of the Ludlow Formation in Morton County (page 98).

**MONTANA GROUP**

**Hell Creek Formation**

Samples were obtained from carbonaceous mudstones in the upper part of the Hell Creek Formation in Mud Buttes, Bowman County (figures 2 and 3). The Hell Creek Formation does not generally contain persistent lignite. However, it does contain carbonaceous mudstones and claystones and these were targeted for sampling (figure 11). Hell Creek strata was deposited in an environment rich in volcanic ash

**Figure 11.** A typical carbonaceous mudstone (cmdst in the measured sections) in the Hell Creek Formation.

as evidenced by the abundance of smectitic (swelling) claystones. Hell Creek samples were taken from two measured sections in the Mud Buttes, Bowman County. These sections were then combined into measured section number 64 (page 97). Eight Hell Creek carbonaceous mudstones were sampled at this locality. Seven of these thin, organic-rich mudstones were both overlain and underlain by mudstone. Six samples were submitted for analyses. The rare earth concentrations of these mudstone samples ranged from 118-183 ppm on a whole-mineral basis (Table 2, page 13).

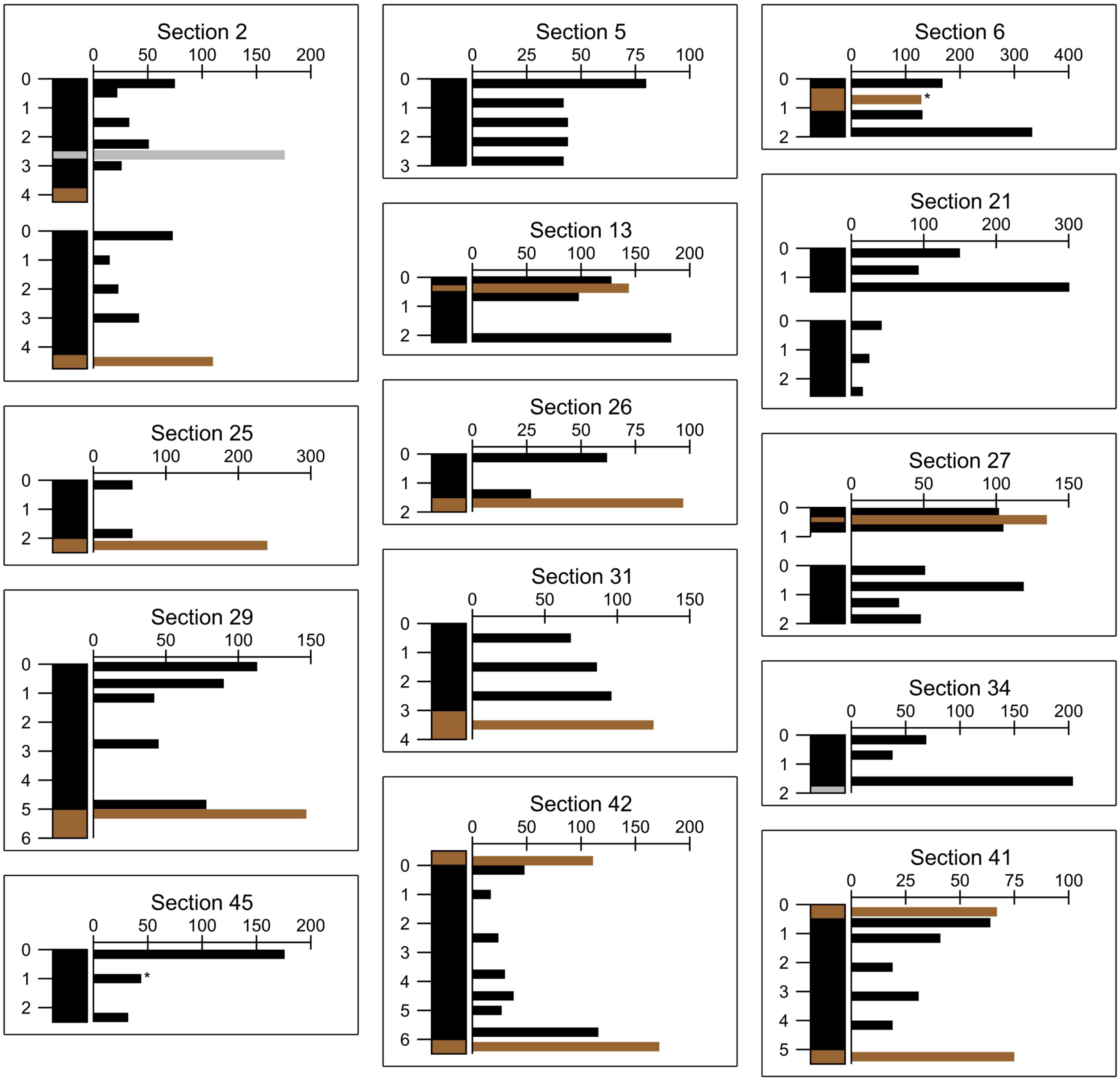
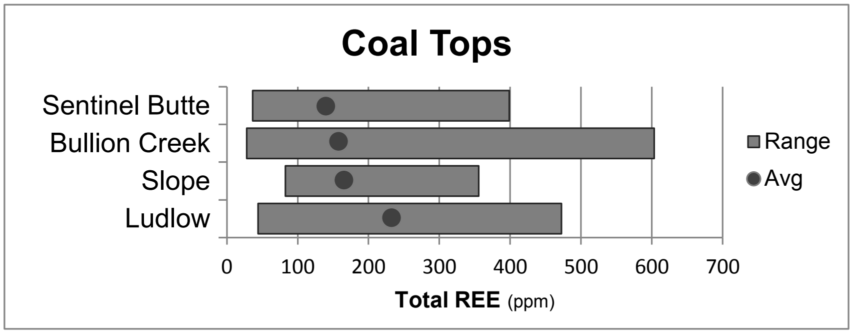



**Figure 12.** Depth profiles of rare earth concentrations in coals. Associated carbonaceous claystones/mudstones along with clay partings are also presented. Concentrations are in part per million (ppm) and the depth is in feet. * Includes scandium.

### Rare Earth Profiles of Individual Beds

Sufficient samples were analyzed from 20 lignites to graphically generate profiles based on rare earth concentrations. Seventeen of these rare earth profiles are depicted in figure 12. Seven of these profiles are of lignites where the highest concentrations of rare earths is at the top of the bed (measured sections 2, 5, 21, 26, 29, 41, 45). In seven of the profiles, the highest concentration is at the base of the profile (measured sections 6, 13, 21, 27, 31, 34, 42). In one of the profiles, the concentrations at the top and bottom of the thin lignite are essentially the same (measured section 25). This same pattern may also hold true for carbonaceous mudstones and claystones, but the vast majority of these were only sampled at the top of the bed (Tables 3 and 4).

**Table 3.** Rare earth concentrations in coal tops (uppermost 1-6 inches of the bed) by formation.




| Formation | Samples | Total REE (ppm) High | Total REE (ppm) Low | Total REE (ppm) Avg | $C_{outl}$ High | $C_{outl}$ Low | $C_{outl}$ Avg |
|---|---|---|---|---|---|---|---|
| Sentinel Butte | 81 | 399 | 36 | 140 | 2.74 | 0.79 | 1.48 |
| Bullion Creek | 80 | 603 | 28 | 158 | 2.59 | 0.69 | 1.45 |
| Slope | 8 | 356 | 83 | 166 | 1.91 | 0.75 | 1.12 |
| Ludlow | 9 | 473 | 44 | 233 | 2.42 | 0.94 | 1.45 |
| Hell Creek | 0 | N/A | N/A | N/A | N/A | N/A | N/A |
| **Total** | **178** | **603** | **28** | **154** | **2.74** | **0.69** | **1.45** |

**Table 4.** Lithologic distributions of rare earth concentrations by sampling position within the bed.

| | Samples | Total REE (% of samples) >100 ppm | >200 ppm | >300 ppm | Avg Total REE | Avg $C_{outl}$ |
|---|---|---|---|---|---|---|
| **Top of Beds** | | | | | | |
| Coal overlain by sandstone | 29 | 79% | 62% | 24% | 243 | 1.25 |
| Coal overlain by siltstone | 3 | 100% | 67% | 0% | 185 | 1.71 |
| Coal overlain by claystone/mudstone | 146 | 58% | 17% | 4% | 136 | 1.48 |
| Carb clyst/mdst overlain by sandstone | 10 | 90% | 20% | 10% | 171 | 0.89 |
| Carb clyst/mdst overlain by siltstone | 2 | 100% | 50% | 50% | 291 | 1.04 |
| Carb clyst/mdst overlain by clyst/mdst | 32 | 94% | 16% | 3% | 160 | 0.97 |
| Carb clyst/mdst overlain by coal | 15 | 87% | 13% | 0% | 155 | 0.86 |
| | **237** | **70%** | **23%** | **8%** | **192** | **1.17** |
| **Middle of Beds** | | | | | | |
| Coal overlain by sandstone | 8 | 25% | 0% | 0% | 61 | 1.18 |
| Coal overlain by siltstone | 1 | 0% | 0% | 0% | 81 | 1.70 |
| Coal overlain by claystone/mudstone | 51 | 8% | 0% | 0% | 51 | 1.34 |
| Carb clyst/mdst overlain by sandstone | 0 | N/A | N/A | N/A | N/A | N/A |
| Carb clyst/mdst overlain by siltstone | 0 | N/A | N/A | N/A | N/A | N/A |
| Carb clyst/mdst overlain by clyst/mdst | 0 | N/A | N/A | N/A | N/A | N/A |
| Carb clyst/mdst overlain by coal | 0 | N/A | N/A | N/A | N/A | N/A |
| | **60** | **10%** | **0%** | **0%** | **64** | **1.41** |
| **Bottom of Beds** | | | | | | |
| Coal overlain by sandstone | 4 | 50% | 50% | 25% | 175 | 1.58 |
| Coal overlain by siltstone | 0 | N/A | N/A | N/A | N/A | N/A |
| Coal overlain by claystone/mudstone | 35 | 46% | 14% | 9% | 117 | 1.42 |
| Carb clyst/mdst overlain by sandstone | 0 | N/A | N/A | N/A | N/A | N/A |
| Carb clyst/mdst overlain by siltstone | 0 | N/A | N/A | N/A | N/A | N/A |
| Carb clyst/mdst overlain by clyst/mdst | 1 | 100% | 0% | 0% | 130 | 1.52 |
| Carb clyst/mdst overlain by coal | 2 | 50% | 0% | 0% | 130 | 0.90 |
| | **42** | **48%** | **17%** | **10%** | **138** | **1.35** |

**Coal and Mudstone Overlain by Sandstone or Siltstone**

Early on in the study, one of the highest rare earth concentrations (603 ppm) was discovered at the top of a thin coal overlain by sandstone (Sample 54A). As a result, emphasis was placed on sampling coals in this geologic setting (figure 13). While this has been shown in past studies, as well as this study, to be a setting where uranium is typically concentrated at the top of a coal, that same level of consistency does not appear to exist with rare earths. Of the 29 lignite beds sampled that were overlain by sandstone, seven (24%) contained rare earth concentrations greater than 300 ppm (sections 49, 54(2), 55, 61 and 64(2), Table 3). Five additional samples had concentrations greater than 275 ppm. Samples were also collected from three coals overlain by siltstone. These samples had an average rare earth concentration of 185 ppm (Table 3).

One of the 10 carbonaceous claystones and mudstones overlain by sandstone had rare earth concentration over 300 ppm (sample 64L, 379 ppm).

Mudstone and claystone account for roughly 60-70% of Fort Union and Hell Creek strata (Murphy, 2006). That is why the vast majority of coals tops that were sampled for this project are overlain by either mudstone or claystone. A total of 146 samples were collected from the tops of coal in this setting and contained an average rare earth concentration of 136 ppm.

**Figure 13.** Coal overlain by a thick channel sandstone at measure section 46.

**Uraniferous Lignites**

Over millions of years, uranium and other metals were leached out of the tuffaceous rocks of the Arikaree, Brule, and Chadron Formations and deposited in the underlying sandstones and coals within the Fort Union Group. Hypothesizing that rare earth elements could also have been leached into the underlying rocks, the stratigraphically highest coals in proximity to the Arikaree/White River unconformity at

Black Butte (Slope County), Chalky Buttes, and Sentinel Butte were specifically sampled. A coal underlies the thick sandstone (Golden Valley Formation) that forms the caprock for Sentinel Butte (Murphy et al., 1993). The top three inches (8 cm) of that coal (Sample 28A) had a scintillometer reading of 500 cpm and a total rare earth concentration of 276 ppm (page 62). Sample 28A is 75 feet (23 m) below the White River unconformity, the closest sample to the unconformity that was collected during this phase of the project. Three samples taken from lignite stringers within a carbonaceous mudstone at the top of a small butte east of Black Butte (Slope County) had rare earth concentrations ranging from 144-201 ppm. The scintillometer readings (< 20 cpm) on this bed were at background levels. This carbonaceous mudstone is approximately 200 feet (61 m) below the White River Unconformity in this area. Forty-three feet (13 m) below this carbonaceous bed, a thin coal had a rare earth concentration of 202 ppm and a scintillometer reading of 200 cpm. The lower bed likely had a higher uranium content than the upper bed, but the rare earth concentrations were essentially the same between the two. A half dozen lignites and carbonaceous mudstones were sampled in a small butte north of the Chalky Buttes. The sandstone caprock of this butte is within 100 feet (30 m) of the White River unconformity and appears to correlate with a highly uraniferous sandstone beneath Chalky Buttes. All of the carbonaceous zones had slightly elevated scintillometer counts (40-50 cpm). The highest rare earth concentration at this site came at the base of an eight-foot (2.4 m) thick carbonaceous mudstone that is sandwiched between two sandstones and is 50 feet (15 m) below the caprock, 150 feet (46 m) below the unconformity. This sample (62F) had a rare earth element concentration of 408 ppm and a scintillometer reading of 45 cpm. It was anticipated that sample 62H, a thin carbonaceous mudstone ten feet (3 m) below the base of the sandstone caprock, would have high uranium and rare earth contents. However, its rare earth element concentration was only 263 ppm and it had a scintillometer count of 40 cpm. It did, however, contain 54 ppm of scandium (page 95).

**Figure 14.** Two thin lignites overlain by sandstone at measured section 49 in Rocky Ridge, Billings County. The lower coal is Bergstrom's (1956) "radioactive lignite bed."

Eight sample sites were located in the Rocky Ridge area where uranium mining took place at the Church and/or Fritz mine as well as the Howie or Schwartz mine in the 1950s and 1960s. An eight-inch-thick (20 cm) carbonaceous mudstone/lignite is overlain by more than 120 feet (36.5 m) of sandstone at one of these sites (figure 14). The sample at the top of this bed (49B) contains rare earth concentrations of 303 ppm and a scintillometer reading of 40cpm. A two-foot (0.6 m) coal, three feet (0.9 m) below (sample 49A the radioactive lignite bed of Bergstrom, 1956) had rare earth concentrations of only 99 ppm and scintillometer readings of 60 ppm. The highest scintillometer reading that was encountered in the field, 3,600 cpm, occurred in the "radioactive lignite bed" 700 feet (213 m) southeast of the Sample 49B locality. Even though dusk masks were worn while sampling rocks with elevated cpm readings, the 3,600 cpm coal was not sampled out of an abundance of caution for our workers safety as well as those in the laboratory. None of the four stratigraphically-lower samples collected at this site contained high rare earth concentrations (page 83).

At measured section 46, a four-foot-thick (1.2 m) lignite is overlain by 90 feet (27.4 m) of sandstone. The top of the coal (Sample 46C2) contains rare earth concentrations of 288 ppm with a scintillometer count of 400 cpm (page 80). Given the thick, laterally continuous nature of the sandstone at this locality, it was anticipated that the rare earth concentrations would be even higher.

**Coal Overlain by Terrace Gravels**

Sample 56F contained 493 ppm of rare earth elements and was collected from the top three inches (8 cm) of the Harmon coal at Logging Camp Ranch (page 89). A confirmation sample ($56F_2$) was collected

**Figure 15.** Terrace gravels deposited by the ancestral Little Missouri River overlie the Harmon coal bed in north-central Slope County.

from the same zone several feet over from the original location and contained 555 ppm of rare earth elements. The Harmon bed consists of 15 feet (4.6 m) of coal at this site; 11 feet (3.4 m) of coal, a two-foot-thick (0.6 m) clay parting, and four feet (1.2 m) of coal at the base (pages 89-91). Sample 56E, taken at the top of the four-foot (1.2 m) basal coal, has a rare earth concentration of 295 ppm. The Harmon bed at this locality is overlain by three feet (0.4 m) of sandy mudstone and nine feet (2.7 m) of gravel that was deposited by the ancestral Little Missouri River (figure 15). This terrace gravel consists of White River and Fort Union concretions, cherts, ironstone, petrified wood, and volcanic pebbles from the Chadron Formation. Ten feet (3.0 m) below the Harmon bed, a sample from the top of a three-foot-thick (0.9 m) carbonaceous claystone (56A) had a rare earth concentration of 344 ppm (page 89).

**Coals and Carbonaceous Mudstones Overlain by Swelling Claystones**

The claystones and mudstones in the Fort Union Group and the underlying Hell Creek Formation consist of a mixture of smectite, illite, and chlorite. The higher the percentage of smectite or swelling claystones, the more pronounced the popcorn surface texture (figure 16). Particular attention was paid to the amount of popcorn texture on claystones and mudstones overlying sampled coals and carbonaceous mudstones. It was hypothesized that in the alteration of volcanic ash deposits to bentonite/smectite, rare earths might be released and attach to the underlying rocks. This did not appear to be the case in sections with swelling claystones.

**Figure 16.** Popcorn claystone overlies lenses of lignite in carbonaceous mudstone.

**Clinker and Coal Ash**

For millions of years, coals have been burning in western North Dakota, baking the overlying rock and creating clinker (known locally as scoria), and reducing the coal to coal ash (figures 17 and 18). Coal ashes were sampled at four localities (measured sections 15, 22, 32, and 53). Many more clinker deposits were investigated in natural settings as well as clinker pits, but the ash layer could not be reached or was poorly

**Figure 17.** A pit dug beneath a prominent layer of coal ash to reach the contact between ash and the unburned Harmon bed at measured section 53.

**Figure 18.** Chunks of clinker within a 7-9 inch ash layer. Note the sharp contact between the ash and the unburned mudstone below (at the base of the rock hammer).

preserved. It was anticipated that the rare earths would be concentrated in the ash layer and a coal with moderate rare earth concentrations might have high concentrations in the ash layer. These coal ash layers had rare earth concentrations ranging from 56 to 236 ppm.

Both the unburned coal and the coal ash were sampled at measured sections 32 and 53 (pages 66 & 87). The lignite at measured section 32 had a rare earth concentration of 74-191 ppm with an average concentration of 157 ppm. The two coal ash samples had an average concentration of only 87 ppm (page 66). At measured section 53, only one sample was obtained from the Harmon bed (53D – rare earth concentration of 103 ppm) and one from the coal ash (53A – rare earth concentration of 236 ppm). There were not enough samples taken at either of these two localities to generate useful results.

**Tonsteins**

Tonsteins are thin, laterally continuous claystone layers within coals. The tonsteins were formed when volcanic ash was deposited in a swamp and the layer of ash was later altered to clay – typically kaolinite. There are a number of thin clay layers in North Dakota lignites that appear to be laterally continuous (figure 19). However, many of these turn out to be common clay partings. Kaolinite has a greasy feel that can be recognized in the field, but microscopic analysis for the presence of zircon is a means of confirming a tonstein. Two potential tonsteins (56C and 65A) were collected in the field, at the same time numerous other thin clay layers were dismissed as clay partings. The rare earth concentrations for 56C were 74 ppm and 261 ppm for 65A (pages 89 and 98).


**Figure 19.** A potential tonstein at measured section 56.

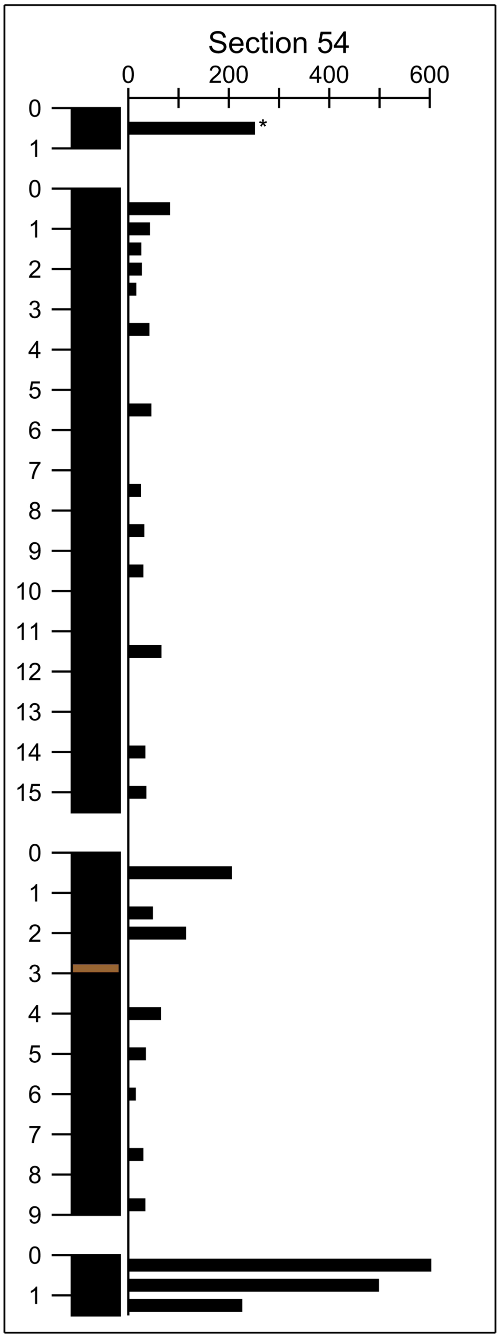



**Figure 20.** Depth profiles of rare earth concentrations in coals at measured section 54. Concentrations are in part per million (ppm). Depth in feet.
* Includes scandium.

**Lateral Extent of Rare Earth Element Concentrations**

As is typical of a phase one sampling project, samples were collected across a wide area of western North Dakota in a variety of geologic settings. Sampling laterally along the same bedding plane to determine the persistence of higher concentrations is typically a phase two task. For that reason, few samples were collected in close proximity to each other during this study. However, two sets of lateral samples were collected in the Logging Camp Ranch area.

Measured sections 54 and 55 (page 88) have the distinction of being the site where the most coal samples (46 samples) were collected at a single locality (figure 20). In addition, samples were collected laterally from the "H bed" coal at two locations. Samples 54A, 54B, and 54C were collected in coal at intervals of 0-4 inches (0-10 cm), 6-9 inches (15-23 cm), and 11-14 inches (28-36 cm), respectively, as measured from the top of a 14-inch-coal (36 cm) overlain by sandstone. Approximately 125 feet (38.1 m) to the north, this bed was observed as an 11-inch-interval (28 cm) of coal lenses in carbonaceous mudstone overlying an 11-inch-coal (28 cm) (Figure 21). Samples collected from this location included the overlying sandstone (55-1), coal lenses in mudstone (55-2), coal (55-4), and underlying carbonaceous mudstone (55-6). The three latter samples were collected at intervals of 0-3 inches (0-8 cm). 12-14 inches (30-36 cm), and 22-26 inches (56-66 cm) from the base of the overlying sandstone. Elevated concentrations of rare earths occur at both locations, with the highest concentrations at the southern location where the coal quality appears to be higher than the carbonaceous mudstone and coal found to the north.

Measured sections 56, 57, and 58 (pages 89-91) are located on the northern, eastern, and southern rims, respectively, of a favine opening to the west (figure 22). These sections included a repeating series of samples (designated F, E, and B) from within the top three-inches (8 cm) of the Harmon, lower Harmon, and Hanson coal beds (figure 23). The distance between measured sections 56 and 57 is approximately 160 feet (48.8 m), between 57 and 58 is 140 feet (42.7 m), and between 56 and 58 is 225 feet (68.8 m). The rare earth concentrations of all three beds were highest at measured section 56. The top of the Harmon bed (F samples) was found to have high rare earth concentrations at all three locations, with a range of 295-555 ppm. The top of the lower Harmon bed (E samples) showed a wide range of concentrations from 36-295 ppm. The samples collected at this interval came from hard coals, and the wide range of concentrations may be due to variations in the coal quality. The tops of the Hanson bed (B samples) ranged from 102-284 ppm.

**Table 5.** Individual element concentrations for laterally equivalent sections. Concentrations are in parts per million. Depth ranges represent the sample collection position relative to the top of the coal bed in inches. Note: a scandium concentration of 13.9 ppm was omitted from section 55-4 in this table to facilitate direct comparison of laterally equivalent samples.

| | H bed | | | |
|---|---|---|---|---|
| | 0-4" | | 11-14" | |
| | 55-2 | 54A | 55-4 | 54C |
| Ce | 139.0 | 206.0 | 94.7 | 65.2 |
| Nd | 64.7 | 136.0 | 45.0 | 48.4 |
| La | 69.1 | 79.2 | 42.7 | 22.7 |
| Y | 29 | 51 | 38 | 29 |
| Pr | 16.7 | 30.3 | 11.9 | 10.1 |
| Sm | 13.5 | 32.9 | 9.0 | 12.4 |
| Gd | 12.0 | 26.1 | 8.9 | 10.9 |
| Sc | N/A | N/A | --- | N/A |
| Dy | 8.3 | 17.9 | 8.2 | 9.2 |
| Er | 3.35 | 7.69 | 4.60 | 5.45 |
| Yb | 2.67 | 6.35 | 3.95 | 5.79 |
| Eu | 3.03 | 7.55 | 2.04 | 2.96 |
| Tb | 1.67 | 3.66 | 1.41 | 1.63 |
| Ho | 1.34 | 3.04 | 1.66 | 1.86 |
| Tm | 0.41 | 1.04 | 0.63 | 0.84 |
| Lu | 0.37 | 0.88 | 0.58 | 0.87 |
| Total REE | 365 | 603 | 273 | 227 |
| $C_{outl}$ | 0.76 | 1.02 | 0.98 | 1.30 |

| | Upper Harmon bed | | | | Lower Harmon bed | | | Hanson bed | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3" | | | | 0-3" | | | 0-3" | | |
| | $56F_2$ | 56F | 57F | 58F | 56E | 57E | 58E | 56B | 57B | 58B |
| Ce | 165.0 | 151.0 | 101.0 | 107.0 | 105.0 | 49.4 | 9.9 | 76.5 | 31.6 | 94.3 |
| Nd | 91.2 | 77.6 | 44.6 | 59.5 | 52.3 | 25.7 | 6.2 | 38.4 | 18.3 | 50.7 |
| La | 68.4 | 64.2 | 47.2 | 41.3 | 41.6 | 18.2 | 3.6 | 33.2 | 14.3 | 40.8 |
| Y | 92 | 77 | 39 | 48 | 23 | 12 | 2 | 20 | 10 | 26 |
| Sc | 17.7 | 16.8 | 9.1 | 18.9 | 18.1 | 10.8 | 8.5 | 19.9 | 9.9 | 21.9 |
| Pr | 22.5 | 19.2 | 12.0 | 14.7 | 13.3 | 6.6 | 1.5 | 9.8 | 4.4 | 12.9 |
| Sm | 20.9 | 17.4 | 9.2 | 14.1 | 11.2 | 5.5 | 1.4 | 8.3 | 4.0 | 11.0 |
| Gd | 23.6 | 20.6 | 9.6 | 14.2 | 9.8 | 4.8 | 0.9 | 6.6 | 3.3 | 8.7 |
| Dy | 20.6 | 18.8 | 8.5 | 12.2 | 7.8 | 3.7 | 0.6 | 5.5 | 2.4 | 6.5 |
| Er | 10.10 | 9.65 | 4.33 | 5.84 | 3.61 | 1.82 | 0.29 | 2.88 | 1.15 | 3.10 |
| Yb | 7.97 | 7.78 | 3.60 | 4.80 | 3.17 | 1.71 | 0.33 | 2.75 | 0.99 | 2.81 |
| Eu | 4.80 | 4.00 | 2.10 | 3.12 | 2.42 | 1.23 | 0.28 | 1.74 | 0.89 | 2.51 |
| Ho | 3.87 | 3.60 | 1.60 | 2.20 | 1.35 | 0.66 | 0.10 | 1.01 | 0.43 | 1.15 |
| Tb | 3.80 | 3.30 | 1.54 | 2.26 | 1.46 | 0.72 | 0.12 | 1.00 | 0.45 | 1.24 |
| Tm | 1.35 | 1.28 | 0.60 | 0.79 | 0.49 | 0.26 | 0.05 | 0.41 | 0.16 | 0.44 |
| Lu | 1.20 | 1.15 | 0.53 | 0.71 | 0.46 | 0.26 | 0.05 | 0.41 | 0.15 | 0.41 |
| Total REE | 555 | 493 | 295 | 350 | 295 | 143 | 36 | 228 | 102 | 284 |
| $C_{outl}$ | 1.24 | 1.15 | 0.93 | 1.13 | 0.82 | 0.86 | 0.91 | 0.86 | 1.00 | 0.91 |

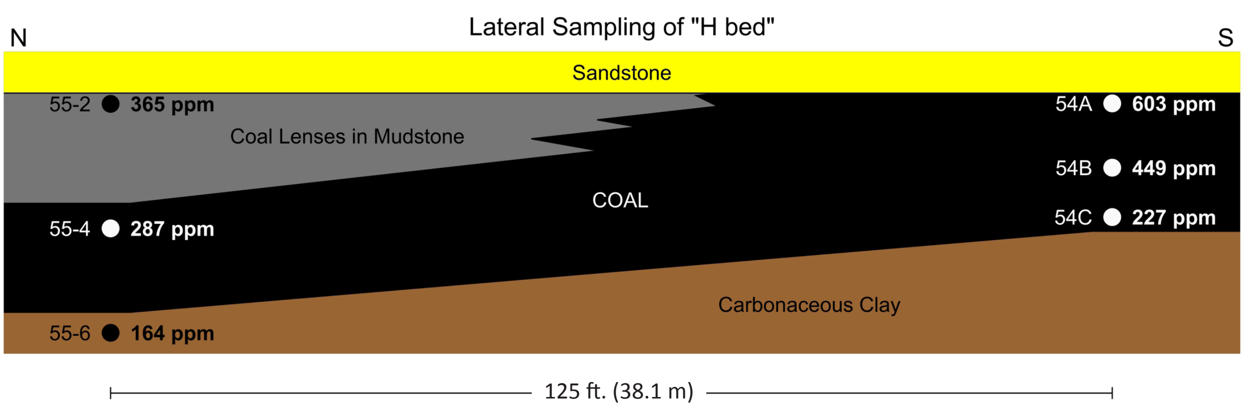



**Figure 21.** Lateral variations in rare earth concentrations at measured section 54 and 55.

While total rare earth concentrations were found to vary substantially between laterally equivalent samples, rare earth compositions (individual element concentrations in relation to the total sample concentration) were markedly more consistent. The major component elements (Ce, Nd, La, and Y) varied by less than 6% Total REE between laterally equivalent sections, the only exception being the Cerium composition decreased nearly 8% across the top of the lower Harmon bed. This exception is a statistical result of relative scandium enrichment in sample 58E, which represents the highest compositional variation of

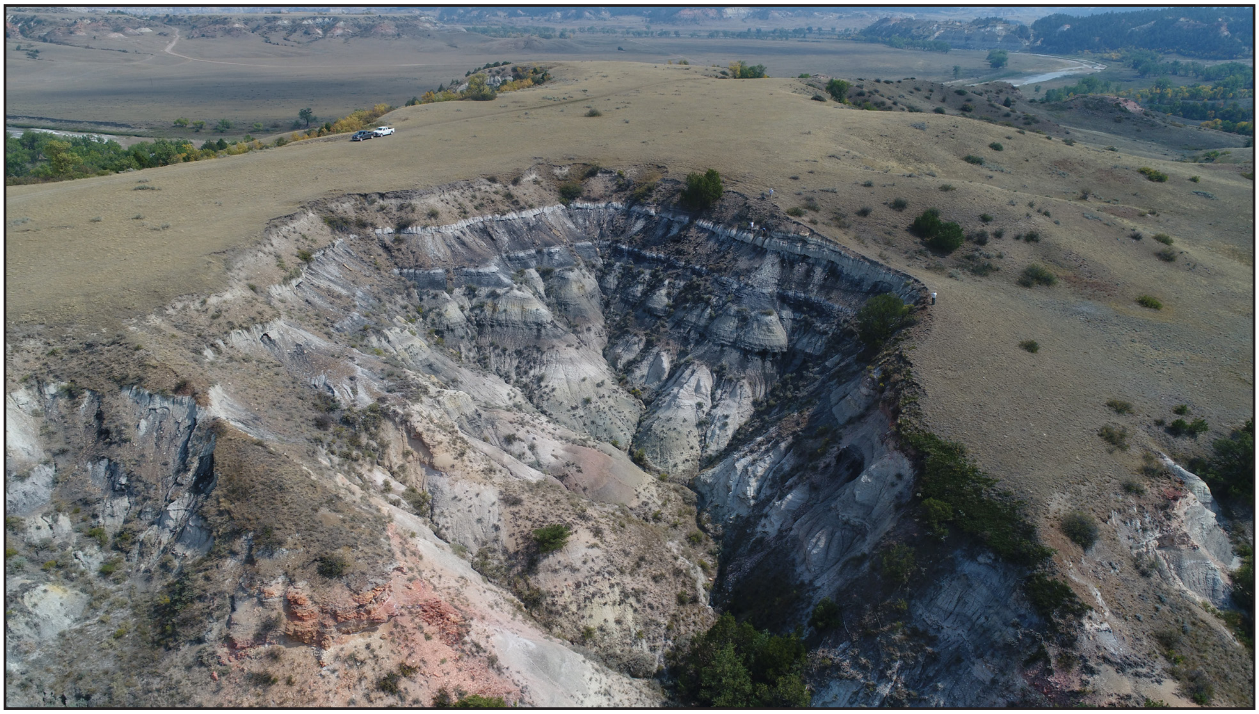


**Figure 22.** A drone photo of a ravine exposing the Harmon and Hanson beds along the Little Missouri River Valley at measured sections 56-58.

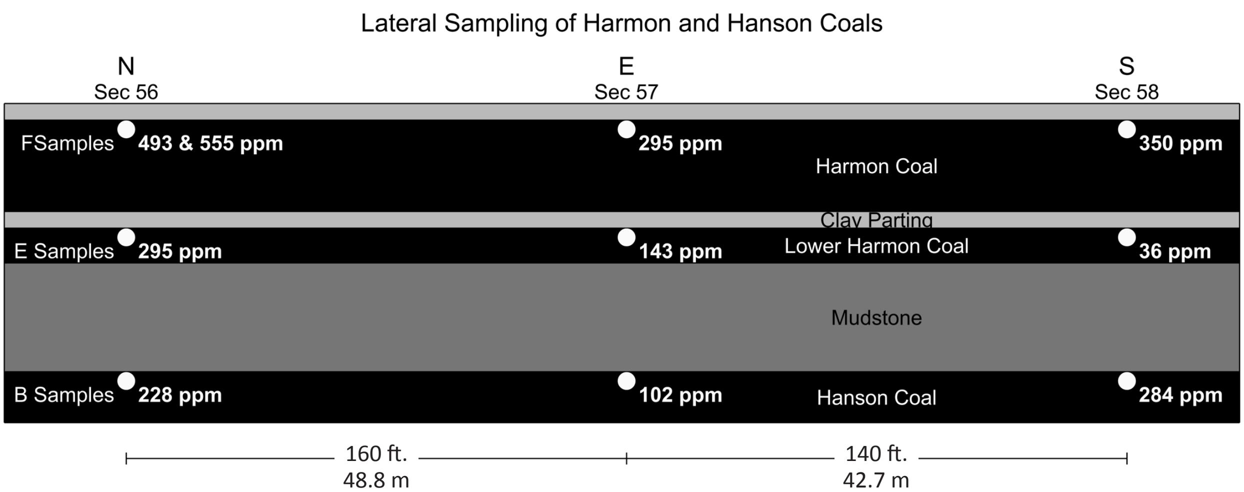



**Figure 23.** Lateral variations in rare earth concentrations at measure sections 56-58.

any element in laterally equivalent samples at 17.6% Total REE. This relative enrichment was not observed above or below in section, as the upper Harmon bed and Hanson bed exhibited lateral variation in scandium compositions of 2.3% and 2.0% Total REE, respectively. The other lanthanides varied laterally by 2.2% Total REE or less.

**Rare Earth Elements Reported on a Coal Ash Basis**

A major attribute of coal that enhances its potential as a rare earth resource is the ease of which elements can be concentrated several fold through simple combustion. A preliminary set of 46 samples were analyzed for ash content in this study, representing several lithologies. Thirty-nine samples characterized as standard coal contained averaged ash contents of 29.52%. Three hard coals (16.39% ash), two

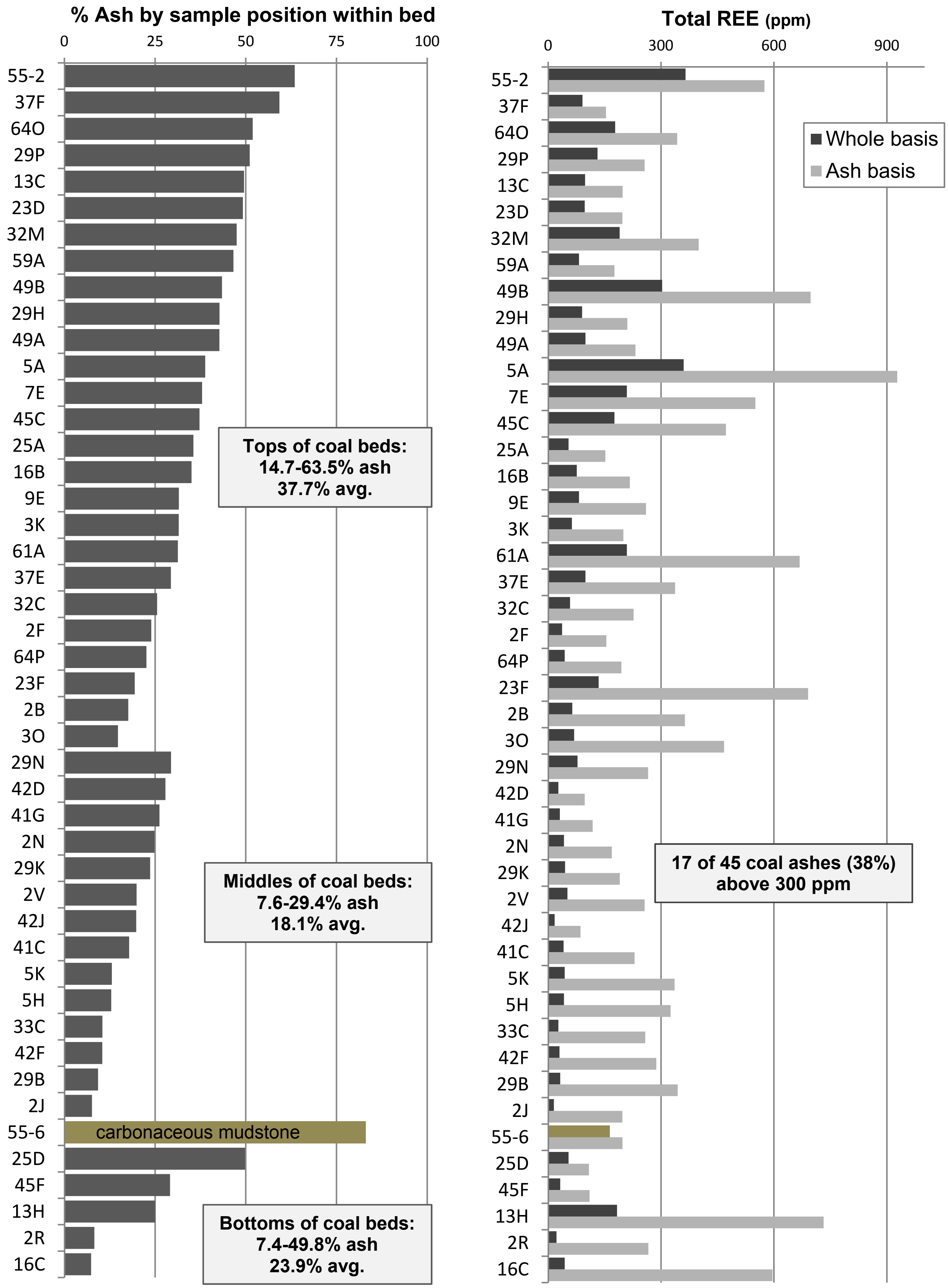



**Figure 24.** Preliminary ash contents and rare earth concentrations on an ash basis of 46 analyzed samples.

powder coals (44.33% ash), one sample of coal lenses in mudstone (63.51% ash), and one carbonaceous mudstone (83.07% ash) were also analyzed. Samples collected from the tops of beds returned the highest ash contents when compared to samples from the middle and bottom portions of beds (figure 24). This may partially reflect an influx of clastics during final depositional stages of the coal, but also likely some incorporation of overlying clastic material during sample collection.

Coal samples were as low as 7.38% ash, reflecting potential for individual samples to concentrate rare earths up to 1355%. The individual ash with the highest rare earth concentration (sample 5A, 928 ppm) was derived from a 360 ppm standard coal collected from the top of a bed. On average, rare earth concentrations in the 47 coals analyzed for ash content increased from 96 ppm to 318 ppm upon combustion. At 30.06% ash, the average rare earth concentrations for the 277 coals analyzed in this study would increase from 128 ppm to 426 ppm on an ash basis. This limited, preliminary dataset on ash content is weighted toward lithologies of standard coal and samples from the uppermost portions of coal beds, which are reflective of the sampling strategy in this study overall and thus not an average of all North Dakota lignite.

## Conclusions

The average rare earth concentrations for all 277 of the North Dakota lignites analyzed in this study is 128 ppm. This is almost twice the average concentrations of 68.5 parts per million for world coal reported by Ketris and Yudovich (2009) and 62.1 parts per million for US coal reported by Finkelman (1993). In the softer lignites, what we described as powder coal, the average of 21 samples was even higher, 207 ppm.

Fourteen of the 277 lignite samples that were analyzed in this study contain rare earth concentrations above 300 ppm (two of these samples are thin coal lenses). Seven additional coal samples had concentrations between 275 – 300 ppm. Stratigraphically, these higher rare earth lignites are found throughout the

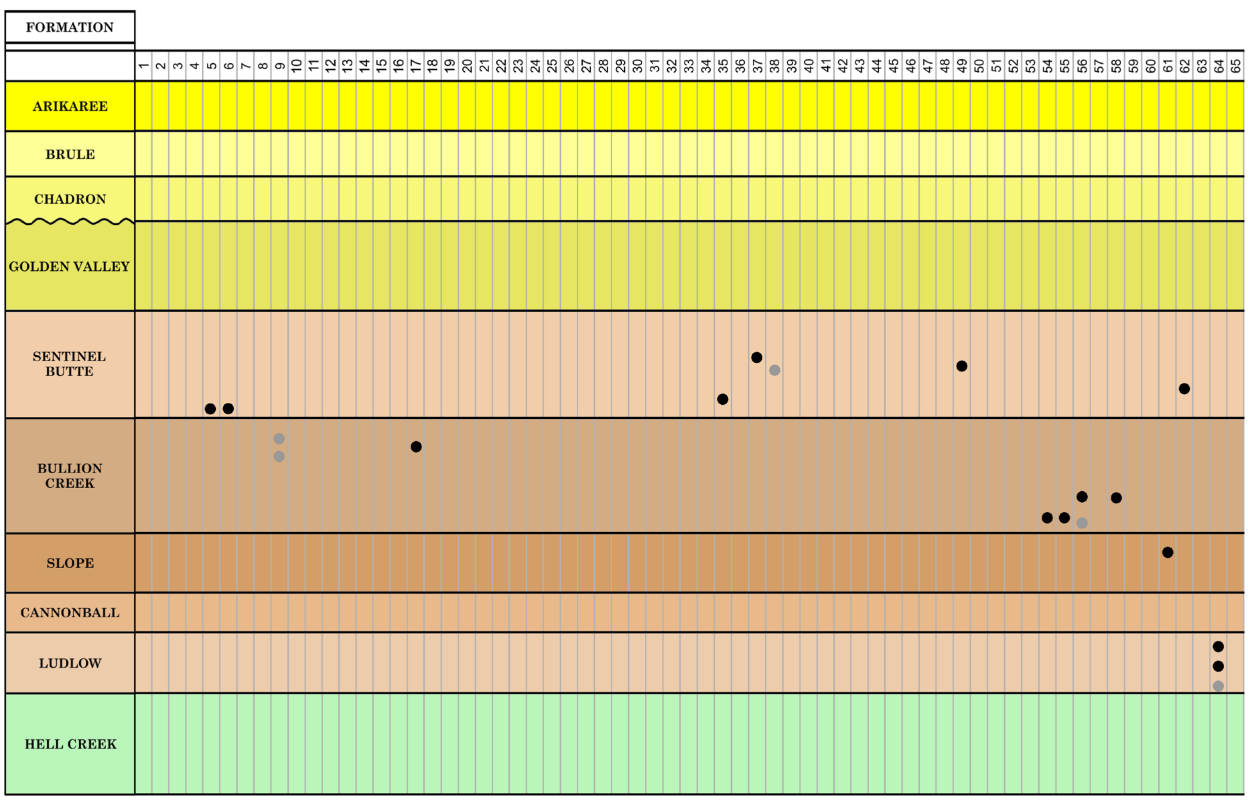
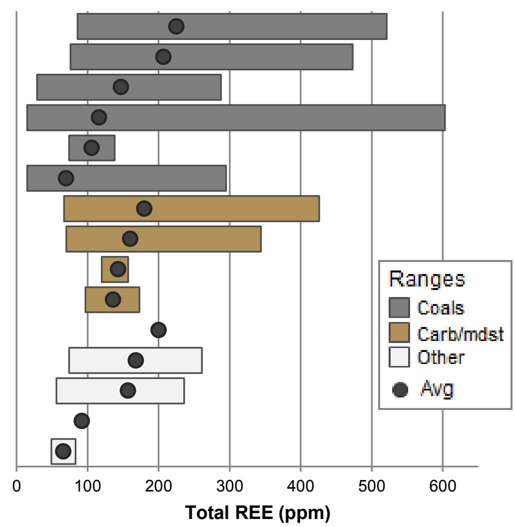



**Figure 25.** Stratigraphic location of samples in this project that exceeded 300 ppm on a whole coal basis. Black dots are coal and gray dots are carbonaceous claystones or mudstones. Fort Union shown in shades of brown.

Fort Union Group, from the lower portion of the Ludlow Formation up to the middle/upper portion of the Sentinel Butte (figure 25). There is an apparent cluster or grouping in the lower Bullion Creek Formation, but that is at least partly due to the addition of four measured sections into the Logging Camp Ranch area after the initial H bed sample (54A) came back with a rare earth concentration of 603 ppm without scandium (figure 3).

The highest average rare earth concentrations came from thin coal lenses in mudstones and claystones (figure 26). The outlook coefficient for this lithology plots between coal and clayey coal suggesting that some of the surrounding mudstone likely was incorporated into the sample (figure 26). The powder coal and weathered coal had rare earth average concentrations of 207 ppm and 147 ppm, respectively. It was noted after the first round of sampling that powder lignite had higher rare earth concentrations than standard lignite (coal) which in turn was higher than hard lignite (hard coal). This may result from an added ability to adsorb rare earths in powder lignite due to the increased surface area. The average concentrations of carbonaceous claystones and mudstones were typically higher than every class of lignite

| Lithology | Samples | Total REE (ppm) High | Low | Avg |
|---|---|---|---|---|
| Coal lenses in mudstone | 18 | 521 | 86 | 225 |
| Powder coal | 21 | 473 | 76 | 207 |
| Weathered coal | 5 | 288 | 29 | 147 |
| Coal | 214 | 603 | 15 | 116 |
| Clayey coal | 2 | 138 | 74 | 106 |
| Hard coal | 17 | 295 | 15 | 70 |
| Carbonaceous claystone | 20 | 426 | 67 | 180 |
| Carbonaceous mudstone | 33 | 344 | 70 | 160 |
| Carb lenses in sandstone | 5 | 157 | 120 | 143 |
| Claystone | 4 | 173 | 97 | 136 |
| Bentonite | 1 | 200 | 200 | 200 |
| Tonstein | 2 | 261 | 74 | 168 |
| Ash | 7 | 236 | 56 | 157 |
| Sandstone | 1 | 92 | 92 | 92 |
| Ejecta | 2 | 83 | 49 | 66 |




| Lithology | Samples | $C_{outl}$ High | Low | Avg |
|---|---|---|---|---|
| Weathered coal | 5 | 2.27 | 1.25 | 1.75 |
| Powder coal | 21 | 2.74 | 0.69 | 1.47 |
| Hard coal | 17 | 2.47 | 0.55 | 1.42 |
| Coal | 214 | 2.7 | 0.57 | 1.42 |
| Coal lenses in mudstone | 18 | 1.82 | 0.77 | 1.31 |
| Clayey coal | 2 | 1.45 | 1.08 | 1.26 |
| Carbonaceous mudstone | 33 | 1.82 | 0.77 | 0.96 |
| Carbonaceous claystone | 20 | 1.41 | 0.58 | 0.94 |
| Claystone | 4 | 1.31 | 0.62 | 0.85 |
| Carb lenses in sandstone | 5 | 0.87 | 0.78 | 0.82 |
| Tonstein | 2 | 2.1 | 0.52 | 1.31 |
| Ejecta | 2 | 1.35 | 1.05 | 1.20 |
| Ash | 7 | 1.63 | 0.77 | 1.00 |
| Bentonite | 1 | 0.92 | 0.92 | 0.92 |
| Sandstone | 1 | 0.71 | 0.71 | 0.71 |

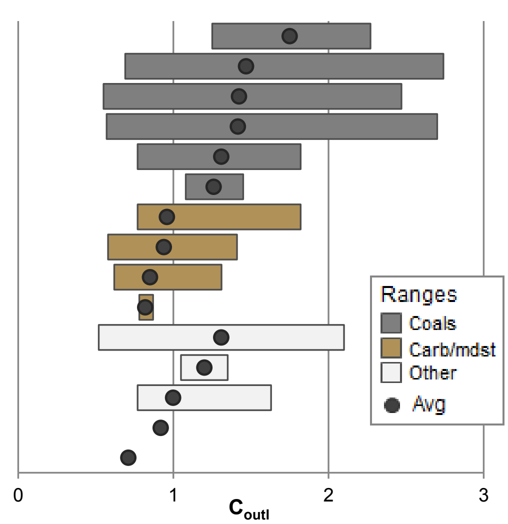
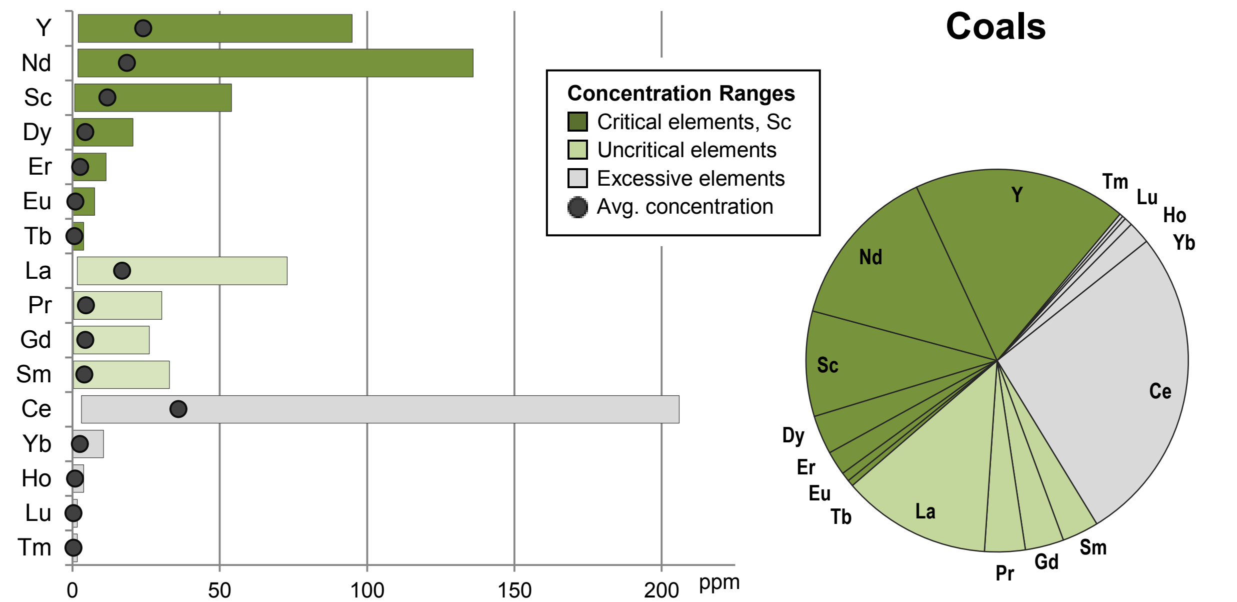
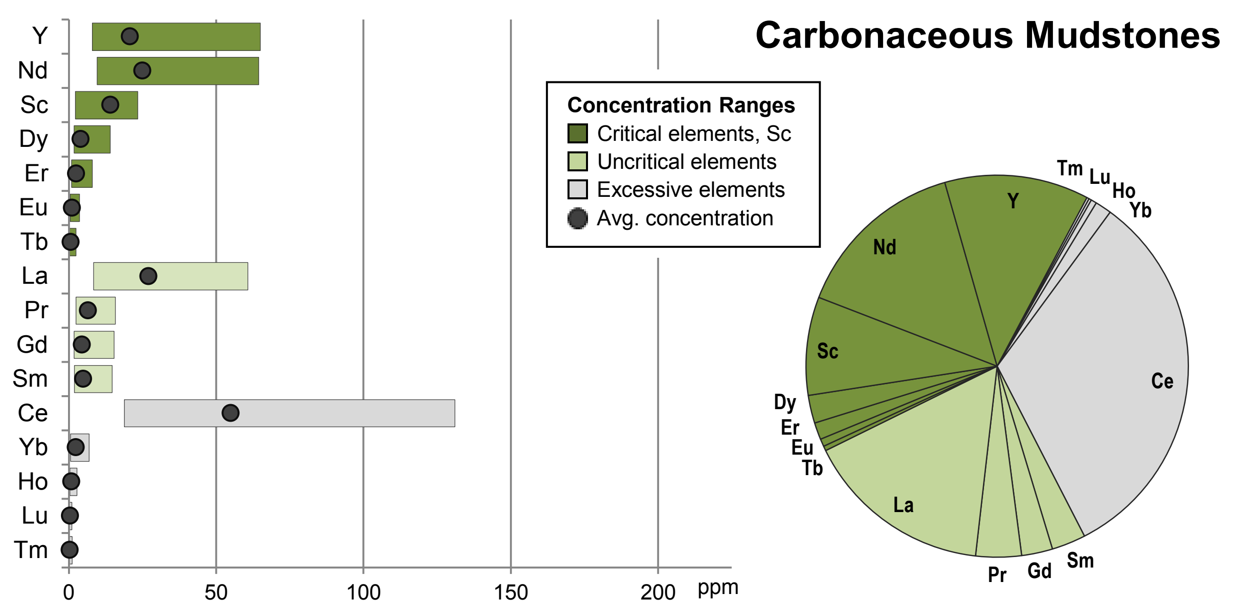



**Figure 26.** Rare earth concentrations (whole coal basis) and outlook coefficient by lithology.




| COAL | Y | Nd | Sc | Dy | Er | Eu | Tb | La | Pr | Gd | Sm | Ce | Yb | Ho | Lu | Tm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG | 24 | 18.6 | 11.9 | 4.4 | 2.72 | 1.02 | 0.71 | 16.9 | 4.6 | 4.4 | 4.1 | 36.1 | 2.54 | 0.92 | 0.40 | 0.39 |
| MIN | 2 | 1.9 | 0.8 | 0.4 | 0.18 | 0.07 | 0.06 | 1.6 | 0.4 | 0.3 | 0.3 | 3.1 | 0.14 | 0.07 | 0.02 | 0.02 |
| MAX | 95 | 136.0 | 54.0 | 20.6 | 11.40 | 7.55 | 3.80 | 72.9 | 30.3 | 26.1 | 32.9 | 206.0 | 10.50 | 3.87 | 1.67 | 1.64 |




| CARB | Y | Nd | Sc | Dy | Er | Eu | Tb | La | Pr | Gd | Sm | Ce | Yb | Ho | Lu | Tm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVG | 21 | 25.0 | 14.1 | 4.0 | 2.44 | 1.09 | 0.68 | 27.0 | 6.6 | 4.5 | 4.9 | 55.0 | 2.36 | 0.81 | 0.37 | 0.36 |
| MIN | 8 | 9.6 | 2.2 | 1.8 | 0.90 | 0.46 | 0.29 | 8.4 | 2.4 | 1.8 | 1.9 | 18.8 | 0.63 | 0.35 | 0.09 | 0.11 |
| MAX | 65 | 64.4 | 23.4 | 14.0 | 7.94 | 3.63 | 2.41 | 60.7 | 15.8 | 15.4 | 14.7 | 131.0 | 6.87 | 2.80 | 1.04 | 1.08 |

**Figure 27.** Elemental compositions of rare earths in 277 analyzed coals (top) and 62 analyzed carbonaceous mudstones (bottom). Economic class based on Seredin and Dai (2012).

except for the coal lenses in mudstone and powder coal, but the outlook coefficients averages were higher in the coals.

The distribution of rare earth elements in coals and carbonaceous mudstones are shown in figure 27. A wider range in concentration of each element occurred in the coal samples. This is likely due to the differences of coal qualities encountered. In a comparison of elemental averages, the coal samples showed greater concentrations of yttrium, erbium, and dysprosium while the carbonaceous mudstones showed greater concentrations of lanthanum, cerium, praseodymium, neodymium, samarium, and scandium.

The percentage of total rare earths (not including scandium) which each element represented in the first 100 samples analyzed for this investigation was presented by Kruger (2017) (Table 1). When these percentages are calculated using the average concentrations of the 277 samples categorized as coals in this investigation, the results are consistent with the previously published table. Five of the critical rare earth elements (erbium, europium, dysprosium, terbium, and yttrium) showed enrichment compared to the percentages estimated to occur in the upper continental crust. Another critical rare earth, neodymium, was found at approximately the same percentage as it occurs in upper continental crust.

It was anticipated the results of this study would enable an exploration model to be generated for rare-earths in Fort Union coals in western North Dakota. Unfortunately, whenever the sampling results suggested a geologic setting where high concentrations could be anticipated (e.g., coals overlain or underlain by channel sandstone or the stratigraphically highest coal in the section) the results of the next sampling round would not reliably support that model. Although coals in contact with channel sandstones accounted for the largest number of samples with concentrations above 300 ppm, it was only a reliable predictor of high concentrations 7 out of 29 times (24%). Based on the 352 samples analyzed during this project, coals in contact with sandstone or siltstone or overlain by gravel have the best chance of containing high rare-earth concentrations. However, the relatively low percentage of time this held true suggests that there are additional factors such as deposition coincident with an ash fall that is not visible in the field

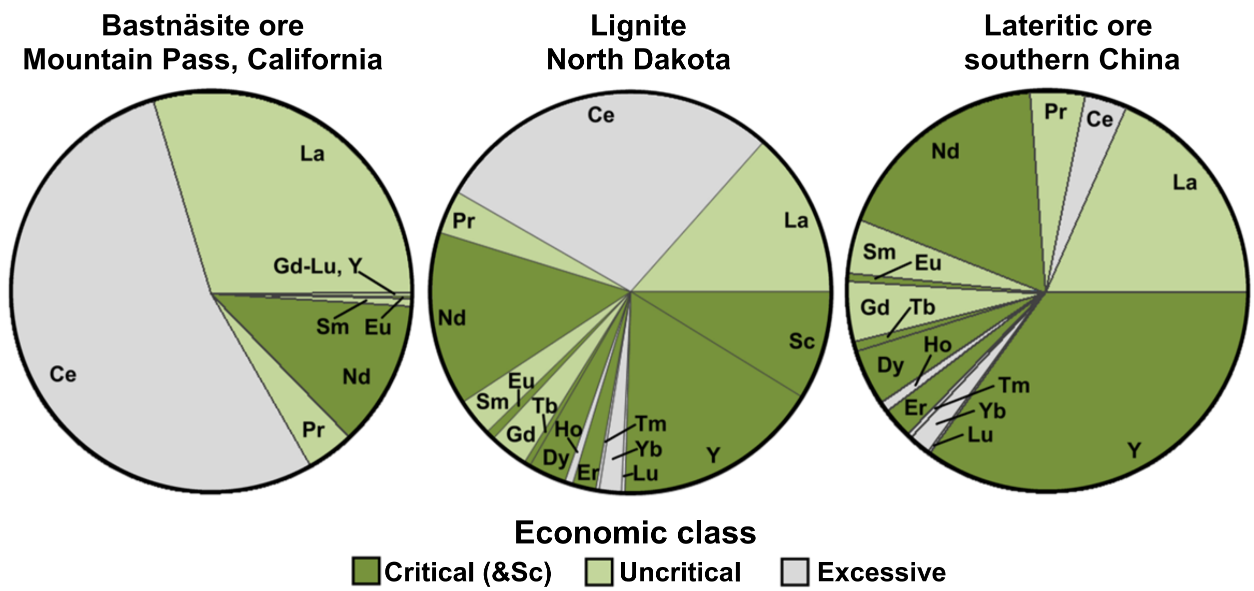



**Figure 28.** Elemental composition of rare earths in North Dakota coals (averaged) compared to conventional deposits. Modified from USGS Fact Sheet 087-02 based on economic class after Seredin and Dai (2012). Note: Charts of conventional deposits do not include scandium.

either as a tonstein, layer of tuff, or a swelling claystone or a result of post depositional phenomena such as leaching on a more localized scale.

The ratios of critical to uncritical to excessive rare earth concentrations in North Dakota lignites compare favorably to those from the carbonatite that was being mined at Mountain Pass in California. On this basis, North Dakota lignites do not compare as favorably to lateritic ore in Souther China (figure 28).

The U.S. Geological Survey maintains the CoalQUAL database, a subset of the more comprehensive coal quality database named USCHEM. As of December 7, 2017 there were a total of 7,647 entries returned in a query for rare earth element concentration data. Of this total, more than 5,500 of the entries contained analyses for the full suite of 16 elements included in this investigation. When the southwestern North Dakota samples from this investigation are compared to the database, seven samples would be included in the top twenty for total rare earth concentrations, with sample 54A (603 ppm) being the fifth highest sample in the database. Sample 62H would contain the number one ranking concentration of the element scandium in the entire database, with a concentration of 54.0 ppm and ten other samples (55-7, 49B, 64U, 28A, 64E, 38B, 12J, 62F, 58B, 65A) would also rank in the top twenty. For the element Yttrium, samples 9B (95ppm), 56F2 (92ppm), 5A (91ppm), 64U(91ppm), and 50D2 (90ppm) would rank 2nd through 6th highest in the database, while nine other samples (65A, 62H, 64T, 56F, 2AA, 49B, 55-7, 62F, 9A) would also rank in the top twenty.

**References**


Bergstrom, J.R., 1956, The general geology of uranium in southwestern North Dakota: North Dakota Geological Survey, Report of Investigations No. 23, 1 plate.

DOE, 2017a, DOE Invests $17.4 Million in Projects To Advance Recovery of Rare-earth Elements From Coal and Coal Byproducts, https://energy.gov/articles/doe-invests-174-million-projects-advance-recovery-rare-earth-elements-coal-and-coal (retrieved December 1, 2017).

DOE, 2017b, High Concentrations of Rare-earth Elements Found in American Coal Basins, https://energy.gov/articles/high-concentrations-rare-earth-elements-found-american-coal-basins (retrieved December 1, 2017).

Ekmann, J.M., 2012, Rare-earth elements in coal deposits – a prospectivity analysis: Search and Discovery Article #80270.

Finkelman, R.B., 1993. Trace and minor elements in coal. In: Engel, M.H., Macko, S.A. (eds.), Organic Geochemistry. Plenum, New York, pp. 593-607.

Franus, W., Wiatros-Motyka, M.M., and Wdowin, W., 2015, Coal fly ash as a resource for rare-earth elements: Environmental Science and Pollution Research, v. 22, p. 9464-9474.

Gambori, J., 2014, Yttrium mineral commodity summaries, February 2014: United States Geological Survey, p. 182-183.

Gambori, J., 2017, Rare-earths mineral commodity summaries, January 2017: United States Geological Survey, p. 134-135.

Hares, C.J., 1928, Geology and lignite resources of the Marmarth Field, southwestern North Dakota: United States Geological Survey Bulletin 775, 110 p.

Haxel, G.B, Hedrick, J.B., and Orris, G.J., 2002, Rare Earth Elements-Critical Resources for High Technology: United States Geological Survey Fact Sheet 087-02, 4 p.

IUPAC, 2005, NOMENCLATURE OF INORGANIC CHEMISTRY, International Union of Pure and Applied Chemistry Recommendations, 2005

Jefferson Lab, 2017, It's Elemental – The Periodic Table of Elements. https://education.jlab.org/itselemental/ (retrieved Dec. 3, 2017).

Ketris, M.P., Yudovich, Y.E., 2009, Estimation of Clarkes for carbonaceous biolithes: world average for trace element contents in black shales and coals: International Journal of Coal Geology, v. 78, p. 135-148.

Kruger, N.W., 2015, A “Rare” Opportunity: GeoNews, v. 42, no. 1, p.7-9.

Kruger, N.W., 2017, Rare-earths in Coal: GeoNews, v. 44, no. 1, p.10-12.

Long, K.R., Van Gosen, B.S., Foley, N.K., and Cordier, Danial, 2010, The principal rare-earth elements deposits of the United States – A summary of domestic deposits and a global perspective: U.S. Geological Survey Scientific Investigations Report 2010-5220, 96 p.

Murphy, E.C., 2005, Uranium, Bowman 100K Sheet: North Dakota Geological Survey

Murphy, E.C., 2006, The lignite reserves of North Dakota: North Dakota Geological Survey, Geologic Investigations No. 104.

Murphy, E.C., 2012, Depth to the Harmon Bed: North Dakota Geological Survey Geologic Investigations no. 159, poster.

Murphy, E.C., Hoganson, J.W., and Forsman, N.F., 1993, The Chadron,Brule, and Arikaree Formations in North Dakota: the buttes of western North Dakota: North Dakota Geological Survey Report of Investigation No. 96, 144 p., 7 plates.

Murphy, E.C., Kruger, N.W., Goven, G.E., Vandal, Q.L., Jacobs, K.C., and Gutenkunst, M.L., 2006, The lignite resources of North Dakota: North Dakota Geological Survey Report of Investigation No. 105, 31 p.

Murphy, E.C., Nordeng, S.H., Juenker, B.J., and Hoganson, J.W., 2009, North Dakota stratigraphic column: North Dakota Geological Survey, Miscellaneous Series No. 91.

Murphy, E.C., 2015, Uranium in North Dakota: North Dakota Geological Survey, Geologic Investigations No. 184, 48 p.

RETA, 2016, http://rareearthtechnicalalliance/Applications/Health-Care.html (retrieved Nov. 2, 2016)

Royce, C.F., 1970, A sedimentologic analysis of the Tongue River-Sentinel Butte interval (Paleocene) of the Williston Basin, western North Dakota: Sedimentary Geology, v. 4, p. 19-80.

Rozelle, P.L., Khadilker, A.B., Pulati, N.S., Klima, M.S., Mosser, M.M., Miller, C.E., and Pisupati, S.V., 2016, A study on removal of rare-earth elements from US coal byproducts by ion exchange: Metallurgical and Materials Transactions E, published online Jan. 4, 2016.Seredin, V.V., and Dai, S., 2012, Coal deposits as potential alternative sources for lanthanides and yttrium: International Journal of Coal Geology, v. 94, p. 67-93.

Seredin, V.V., and Dai, S., 2012, Coal deposits as potential alternative sources for lanthanides and yttrium: International Journal of Coal Geology, v. 94, p. 67-93.

Seredin, V.V., Dai, S., Sun, Y., and Chekryzhov, I.Y., 2013, Coal deposits as promising sources of rare metals for alternative power and energy-efficient technologies: Applied Geochemistry, v. 31, p. 1-11.

Taggart, R.K., Hower, J.C., Dwyer, G.S., Hsu-Kim, H., 2016, Trends in the rare earth element content of U.S.-based coal combustion fly ashes: Environmental Science & Technology. V. 50, p. 5919-5926

Taylor, S.R., and McLennan, S.M., 1985, The Continental Crust – Its Composition and Evolution: Blackwell, Oxford, 312p.

Tse, Pui-Kwan, 2011, China’s rare-earth industry: U.S. Geological Survey Open-File Report 2011-1042, 11 p. United States Geological Survey, Fact Sheet 2014-3078, 4 p.

## APPENDICIES
## APPENDIX A
## Legend and Abbreviations for Measured Sections

Gravel

Sandstone

Siltstone

Claystone

Mudstone

Carbonaceous Claystone

Carbonaceous Mudstone

Lignite

Clinker

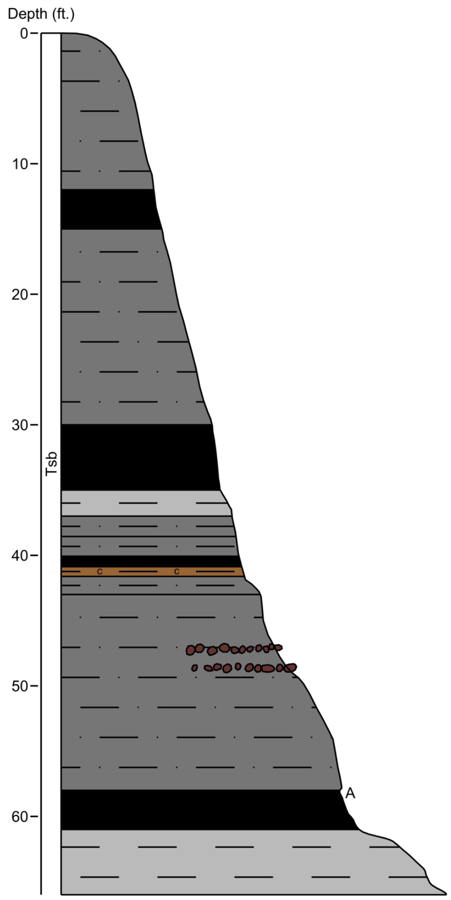
Nodules and Concreations

Covered

| <u>Lithologies</u> | <u>Abbreviations</u> |
|---|---|
| Coal | coal |
| Powder coal | pcoal |
| Hard coal | hcoal |
| Weathered coal | wcoal |
| Clayey coal | ccoal |
| Sandstone | ss |
| Carb lenses in sandstone | clss |
| Siltstone | slst |
| Mudstone | mdst |
| Carbonaceous mudstone | cmdst |
| Coal lenses in mudstone | clmdst |
| Claystone | clst |
| Carbonaceous claystone | cclst |
| Bentonite | bent |
| Clinker | clink |
| Ash | ash |
| Tonstein | ton |

## REE Section 1

**T.146N., R.100W., Sec. 30, NW1/4**
**Elevation at top 2,370 ft.**

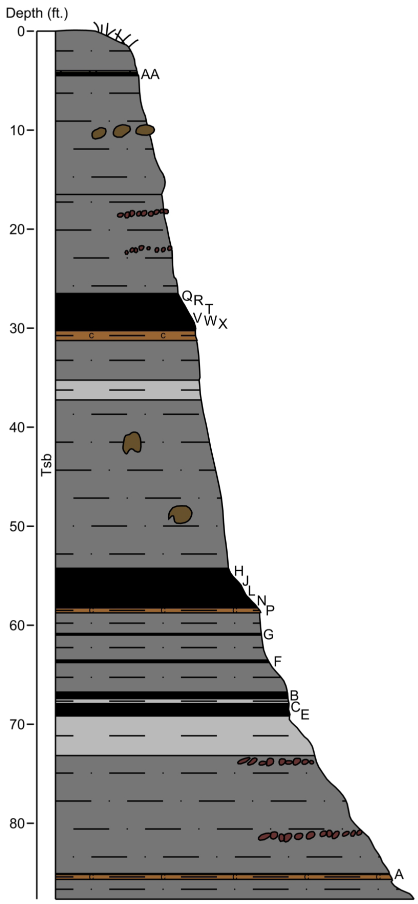



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| 1A | 10.7 | 2.7 | 2.25 | 0.51 | 1.9 | 0.67 | 5.8 | 0.39 | 5.6 | 1.4 | 1.4 | | 0.36 | 0.34 | 2.35 | 21 | 57 | 2.24 | coal |

Looking northeast. Only the lower 3 feet-thick coal was sampled at this location. Some of the coals sampled at Section 2 (approximately 1 mile to the southwest) were observed higher up this section.

# REE Section 2

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

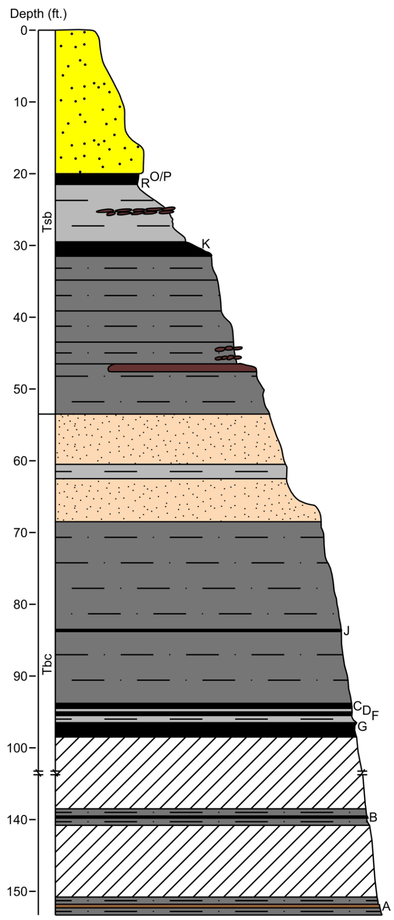



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| 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 | 2.74 | pcoal |
| 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 | 2.01 | coal |
| 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 | 2.10 | hcoal |
| 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 | 1.59 | coal |
| 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 | 1.59 | coal |
| 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 | 0.58 | cclyst |
| 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 | 1.04 | hcoal |
| 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 | 1.65 | coal |
| 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 | 2.19 | hcoal |
| 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 | 1.44 | coal |
| 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 | 1.10 | coal |
| 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 | 0.69 | coal |
| 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 | 1.66 | coal |
| 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 | 1.74 | hcoal |
| 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 | 2.47 | hcoal |
| 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 | 1.31 | clyst |
| 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 | 1.22 | coal |
| 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 | 1.35 | cmdst |

Looking northeast at the lower half of the section. Rocks from higher elevations continues to outcrop southwest of this photo.

## REE Section 3

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

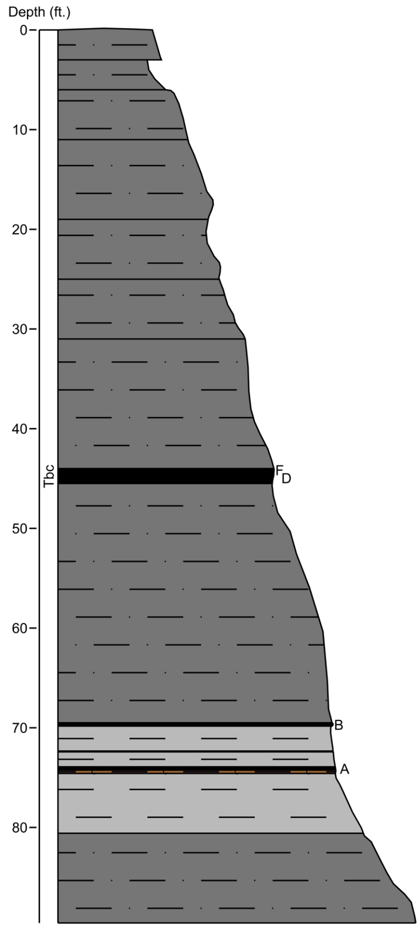



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **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 | 2.14 | coal |
| **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 | 1.92 | coal |
| **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 | 2.17 | coal |
| **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 | 1.98 | coal |
| **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 | 1.89 | pcoal |
| **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 | 0.96 | coal |
| **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 | 0.62 | clyst |
| **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 | 1.38 | coal |
| **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 | 1.37 | coal |
| **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 | 1.06 | coal |
| **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 | 0.83 | cmdst |

Looking east at the top half of the section. Exposures from lower elevations were observed to the southwest.

## REE Section 4

**T.144N., R.103W., Sec. 16, SE1/4**
**Elevation at top 2,349 ft.**

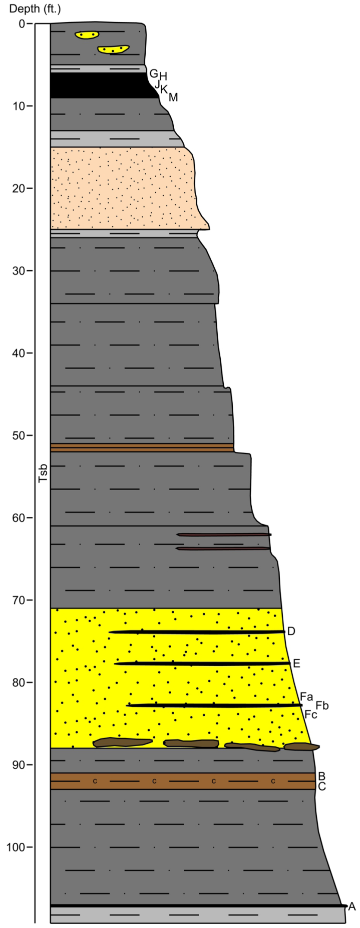



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| 4F | 45.1 | 4.7 | 2.78 | 1.12 | 4.8 | 0.99 | 22.0 | 0.37 | 20.1 | 5.2 | 4.2 | | 0.81 | 0.38 | 2.41 | 26 | 141 | 1.13 | coal |
| 4D | 5.5 | 1.5 | 1.05 | 0.27 | 1.2 | 0.35 | 2.5 | 0.16 | 3.3 | 0.7 | 0.9 | | 0.22 | 0.16 | 1.01 | 9 | 28 | 2.14 | coal |
| 4B | 6.1 | 1.4 | 1.08 | 0.22 | 1.0 | 0.33 | 2.8 | 0.20 | 3.5 | 0.8 | 0.9 | | 0.20 | 0.17 | 1.17 | 8 | 28 | 1.81 | coal |
| 4A | 5.3 | 1.9 | 1.41 | 0.28 | 1.4 | 0.46 | 2.5 | 0.22 | 3.2 | 0.7 | 0.9 | | 0.28 | 0.21 | 1.37 | 11 | 31 | 2.39 | coal |


Looking northwest on a GoogleEarth photo.

## REE Section 5

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

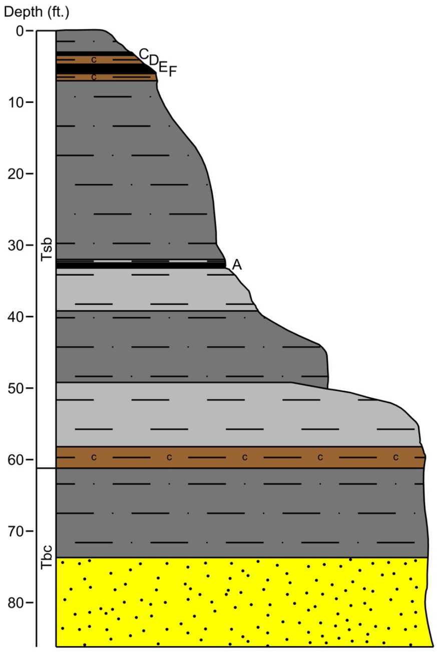



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **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 | 2.06 | coal |
| **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 | 2.21 | coal |
| **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 | 1.85 | coal |
| **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 | 2.00 | coal |
| **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 | 2.13 | coal |
| **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 | 0.83 | clss |
| **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 | 0.83 | clss |
| **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 | 0.81 | clss |
| **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 | 0.78 | clss |
| **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 | 0.87 | clss |
| **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 | 0.87 | cmdst |
| **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 | 1.52 | cmdst |
| **5A** | 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 | 360 | 1.58 | coal |

Looking northeast. Rocks from higher elevations continues to outcrop to the east of this photo.

## REE Section 6

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

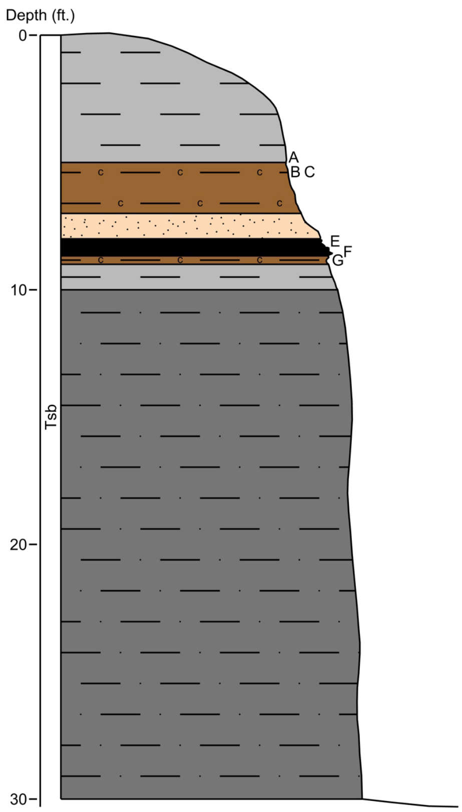



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **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 | 0.95 | coal |
| **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 | 0.88 | cmdst |
| **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 | 1.08 | coal |
| **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 | 1.17 | coal |
| **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 | 1.34 | coal |

Looking northwest. The dark carbonaceous rock below the bentonite on this photo was unable to be sampled due to the sheer cliff exposures.

## REE Section 7

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

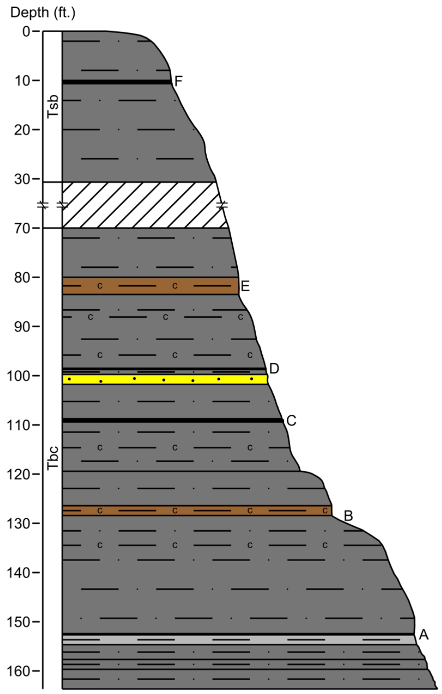



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **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 | 0.92 | bent |
| **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 | 0.91 | cmdst |
| **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 | 0.91 | cmdst |
| **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 | 1.26 | coal |
| **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 | 1.70 | coal |
| **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 | 0.98 | cmdst |

Looking northwest. The westward thickening dark carbonaceous mudstone and coal below the bentonite were accessible at this location, located approximately 0.3 mile southeast of Section 6.

## REE Section 8

**T.143N., R.103W., Sec. 1, SE/SW and SW/SE**
**Elevation at top 2,600 ft.**

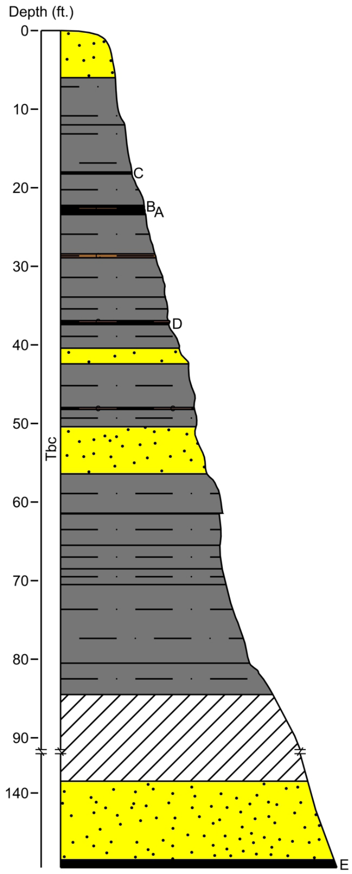



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **8F** | 67.1 | 7.7 | 4.41 | 2.03 | 8.1 | 1.55 | 29.2 | 0.62 | 35.6 | 8.7 | 8.2 | 19.3 | 1.29 | 0.63 | 4.07 | 36 | 235 | 1.18 | coal |
| **8E** | 42.9 | 3.3 | 2.17 | 0.70 | 3.2 | 0.70 | 21.5 | 0.35 | 18.5 | 5.0 | 3.5 | 10.4 | 0.51 | 0.32 | 2.25 | 18 | 133 | 0.93 | cmdst |
| **8D** | 32.6 | 2.8 | 1.72 | 0.69 | 2.9 | 0.57 | 15.4 | 0.27 | 15.8 | 4.0 | 3.2 | 10.5 | 0.46 | 0.25 | 1.72 | 15 | 108 | 1.03 | coal |
| **8C** | 17.6 | 3.6 | 2.66 | 0.55 | 2.8 | 0.83 | 8.4 | 0.45 | 9.2 | 2.2 | 2.2 | 10.7 | 0.51 | 0.40 | 2.76 | 21 | 86 | 1.70 | coal |
| **8B** | 63.9 | 3.7 | 2.21 | 1.05 | 4.3 | 0.73 | 31.1 | 0.34 | 28.3 | 7.5 | 5.2 | 13.0 | 0.62 | 0.33 | 2.28 | 18 | 183 | 0.80 | cmdst |
| **8A** | 38.2 | 4.7 | 3.10 | 0.96 | 4.3 | 1.02 | 19.8 | 0.47 | 16.8 | 4.4 | 3.6 | 11.1 | 0.71 | 0.45 | 3.00 | 25 | 138 | 1.19 | coal |

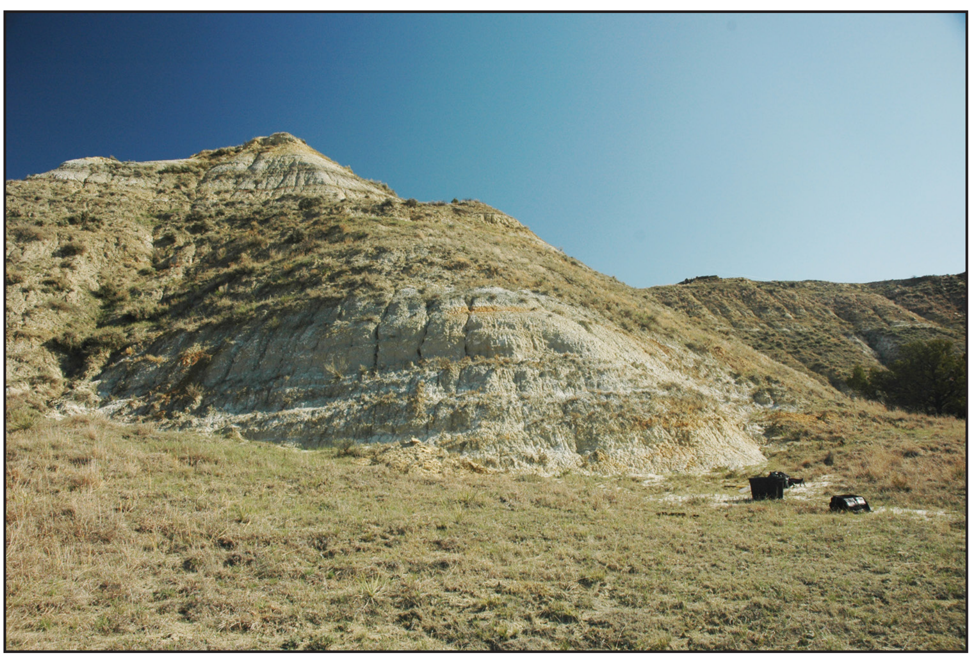
Looking northeast. Higher elevation rocks were exposed along the ridgeline approximately 0.2 miles to the west.

# REE Section 9

**T.143N., R.102W., Sec. 14, NW1/4**
**Elevation at top 2,439 ft.**



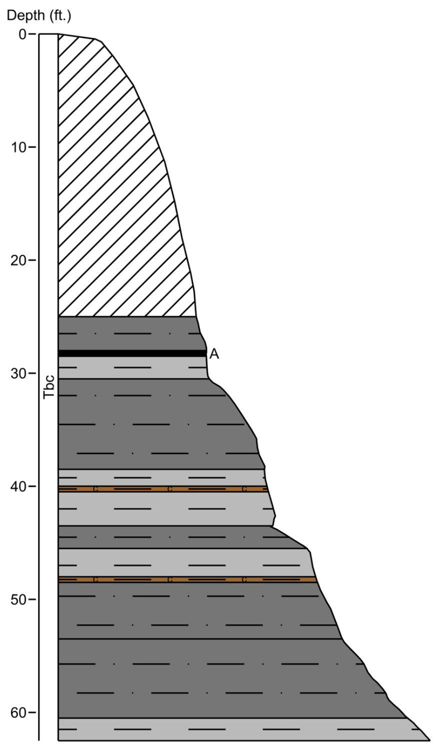

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **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 | 1.60 | coal |
| **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 | 1.72 | clmdst |
| **9A** | 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 | 521 | 1.03 | clmdst |
| **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 | 1.44 | coal |
| **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 | 1.58 | coal |



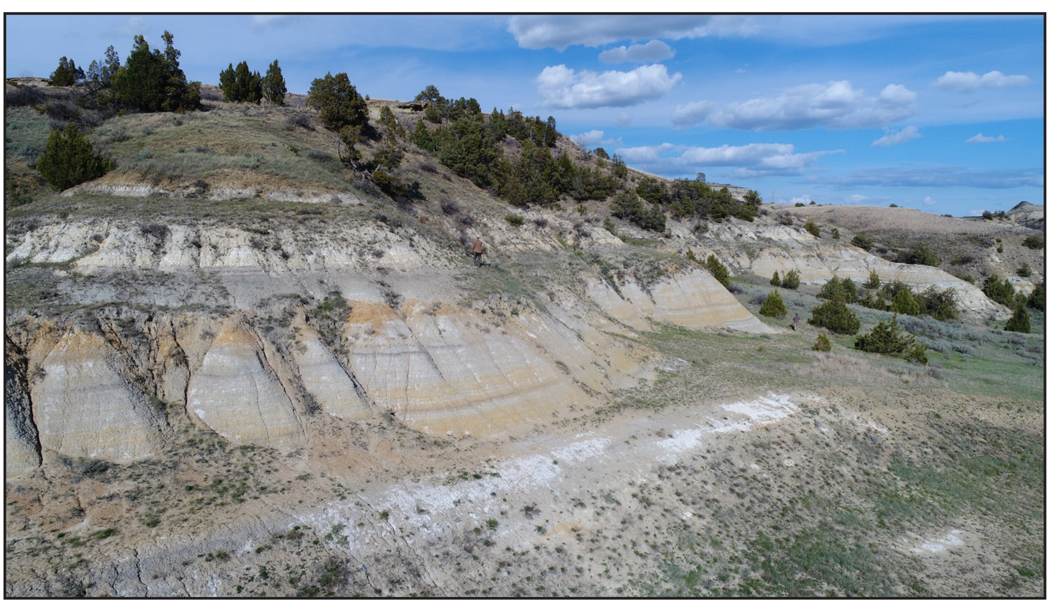
Looking northeast. Section was measured from the base of exposures to the top of the butte. Sample 9e was collected in the road ditch approximately 0.1 mile to the south.

# REE Section 10

**T.143N., R.101W., Sec. 5, SW1/4**
**Elevation at top 2,391 ft.**



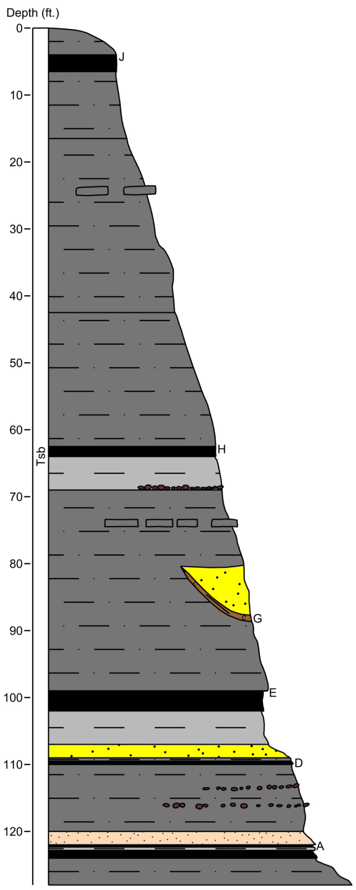

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **10A** | 31.6 | 5.0 | 3.50 | 0.94 | 4.2 | 1.12 | 15.7 | 0.55 | 16.5 | 4.0 | 3.7 | 12.0 | 0.76 | 0.52 | 3.50 | 30 | 134 | 1.52 | coal |



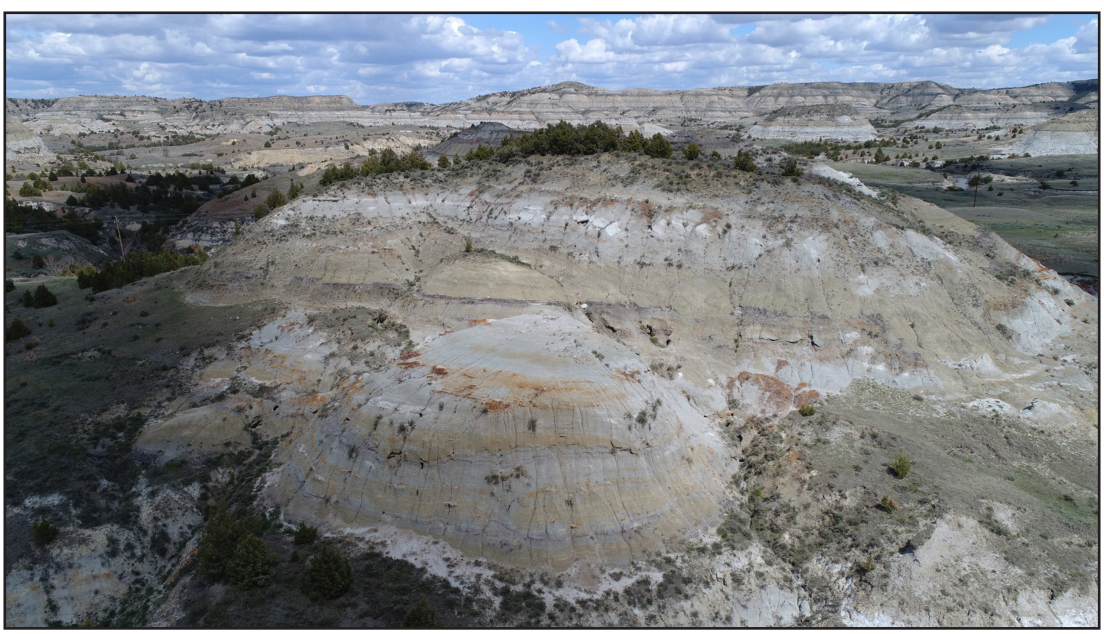
Looking northeast. Section was measured from the base of the exposures to the top of the butte.

## REE Section 11

**T.143N., R.101W., Sec. 15, NE1/4**
**Elevation at top 2,508 ft.**



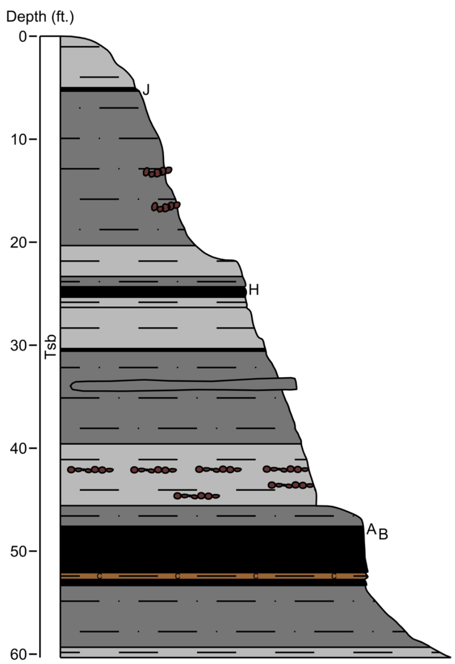

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| 11J | 61.0 | 8.1 | 4.47 | 1.95 | 8.1 | 1.56 | 24.6 | 0.60 | 33.0 | 7.9 | 7.6 | 15.6 | 1.33 | 0.61 | 3.94 | 36 | 216 | 1.25 | coal |
| 11H | 15.1 | 2.5 | 1.50 | 0.63 | 2.6 | 0.52 | 6.9 | 0.19 | 8.7 | 2.0 | 2.2 | 4.5 | 0.42 | 0.20 | 1.26 | 15 | 64 | 1.66 | coal |
| 11G | 20.1 | 1.8 | 1.22 | 0.49 | 1.8 | 0.39 | 10.2 | 0.21 | 9.6 | 2.5 | 1.9 | 9.0 | 0.29 | 0.19 | 1.35 | 9 | 70 | 1.01 | cmdst |
| 11E | 17.0 | 2.0 | 1.23 | 0.53 | 2.2 | 0.41 | 6.4 | 0.19 | 10.2 | 2.4 | 2.3 | 6.7 | 0.34 | 0.18 | 1.18 | 9 | 62 | 1.23 | coal |
| 11D | 52.2 | 4.7 | 3.09 | 1.04 | 4.6 | 0.99 | 25.7 | 0.49 | 24.4 | 6.3 | 4.9 | 11.4 | 0.76 | 0.46 | 3.09 | 24 | 168 | 1.01 | coal |
| 11A | 49.9 | 3.9 | 2.57 | 0.89 | 4.0 | 0.81 | 24.7 | 0.41 | 23.0 | 6.0 | 4.4 | 11.9 | 0.62 | 0.39 | 2.65 | 20 | 156 | 0.94 | cmdst |



Looking northeast. Section was measure from a ravine along the right side of the butte in the foreground to the top of the butte behind it.

## REE Section 12

**T.143N., R.101W., Sec. 23, NE1/4**
**Elevation at top 2,590 ft.**

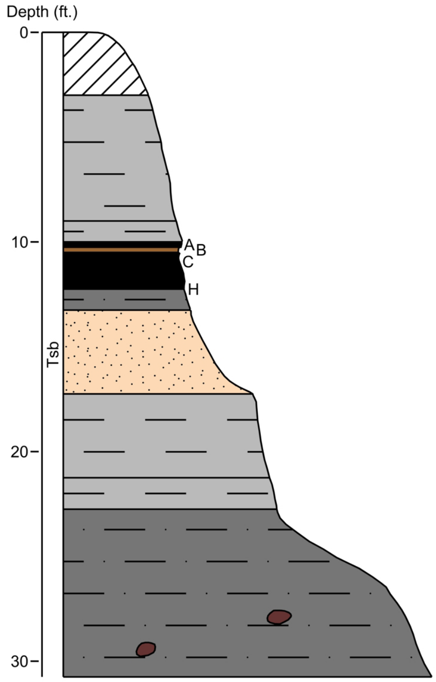



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| **12J** | 79.1 | 7.8 | 4.26 | 2.48 | 8.8 | 1.46 | 37.5 | 0.61 | 41.4 | 10.1 | 9.1 | 22.3 | 1.36 | 0.60 | 4.04 | 32 | 263 | 1.04 | pcoal |
| **12H** | 58.8 | 3.6 | 2.06 | 1.13 | 4.3 | 0.68 | 29.0 | 0.30 | 26.4 | 6.9 | 5.0 | 14.7 | 0.61 | 0.29 | 1.95 | 20 | 176 | 0.87 | coal |
| **12A** | 15.4 | 2.2 | 1.50 | 0.46 | 1.9 | 0.48 | 8.3 | 0.24 | 7.4 | 1.9 | 1.6 | 11.3 | 0.32 | 0.22 | 1.52 | 15 | 70 | 1.51 | coal |
| **12B** | 9.3 | 1.4 | 0.94 | 0.25 | 1.2 | 0.30 | 5.4 | 0.14 | 4.7 | 1.1 | 1.1 | 3.8 | 0.20 | 0.13 | 0.89 | 11 | 42 | 1.72 | hcoal |

Looking northeast. Section was measured from the base of the exposure to the top of the butte.

## REE Section 13

**T.143N., R.100W., Sec. 12, NE1/4**
**Elevation at top 2,721 ft.**

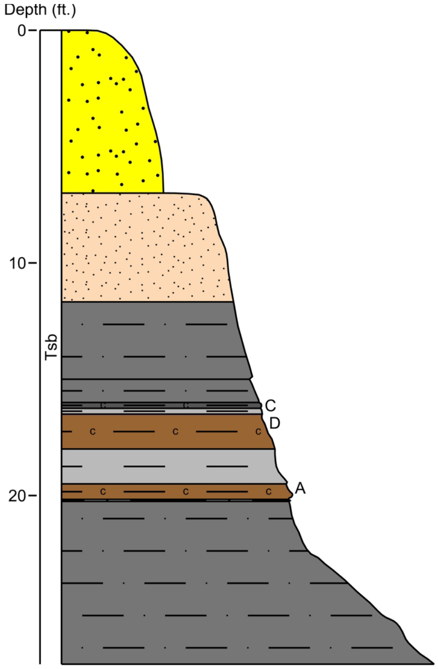



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| **13A** | 37.8 | 4.6 | 2.48 | 1.56 | 5.6 | 0.89 | 14.1 | 0.35 | 26.5 | 5.9 | 6.4 | | 0.82 | 0.34 | 2.31 | 18 | 128 | 1.29 | coal |
| **13B** | 51.6 | 3.4 | 2.41 | 0.80 | 3.4 | 0.77 | 27.5 | 0.40 | 21.9 | 6.1 | 3.7 | | 0.54 | 0.37 | 2.54 | 19 | 144 | 0.86 | clyst |
| **13C** | 30.1 | 3.4 | 1.98 | 0.96 | 3.8 | 0.67 | 12.4 | 0.28 | 18.1 | 4.3 | 3.9 | | 0.58 | 0.27 | 1.83 | 15 | 98 | 1.21 | coal |
| **13H** | 40.4 | 8.4 | 6.15 | 1.52 | 6.9 | 1.95 | 21.5 | 0.99 | 22.5 | 5.4 | 5.4 | | 1.23 | 0.90 | 6.04 | 54 | 183 | 1.87 | coal |

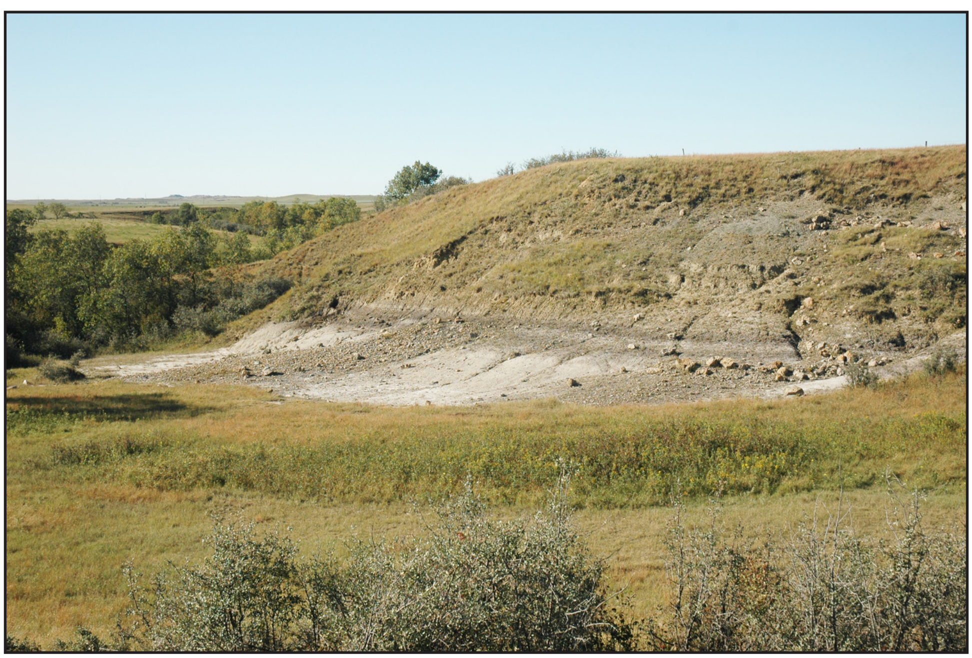
Looking east. The section was measured from the base to the top of this butte.

## REE Section 14

**T.143N., R.99W., Sec. 29, NW1/4**
**Elevation at top 2,670 ft.**

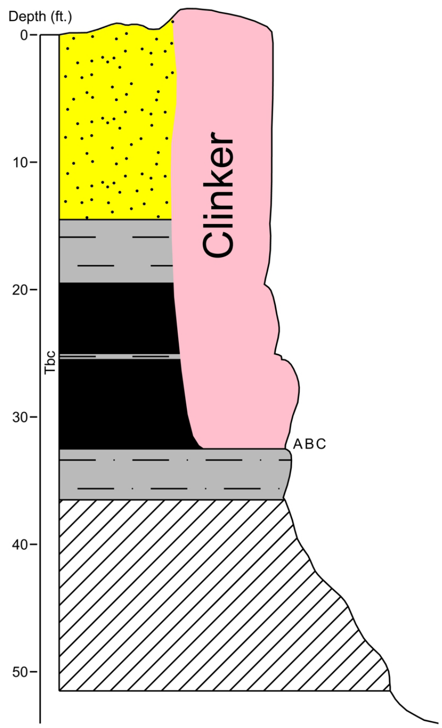



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **14C** | 52.8 | 2.7 | 1.72 | 0.83 | 3.3 | 0.54 | 26.2 | 0.27 | 23.0 | 6.2 | 4.2 | | 0.48 | 0.26 | 1.81 | 14 | 138 | 0.77 | cmdst |
| **14D** | 52.2 | 3.4 | 2.17 | 0.85 | 3.6 | 0.70 | 26.4 | 0.34 | 22.2 | 6.0 | 4.1 | | 0.58 | 0.32 | 2.29 | 18 | 143 | 0.85 | cmdst |
| **14A** | 50.9 | 2.9 | 1.75 | 0.79 | 3.4 | 0.57 | 26.8 | 0.27 | 22.2 | 5.9 | 4.0 | | 0.49 | 0.26 | 1.84 | 14 | 136 | 0.78 | cmdst |



Looking northwest. The section was measured from the base to the top of the hill.

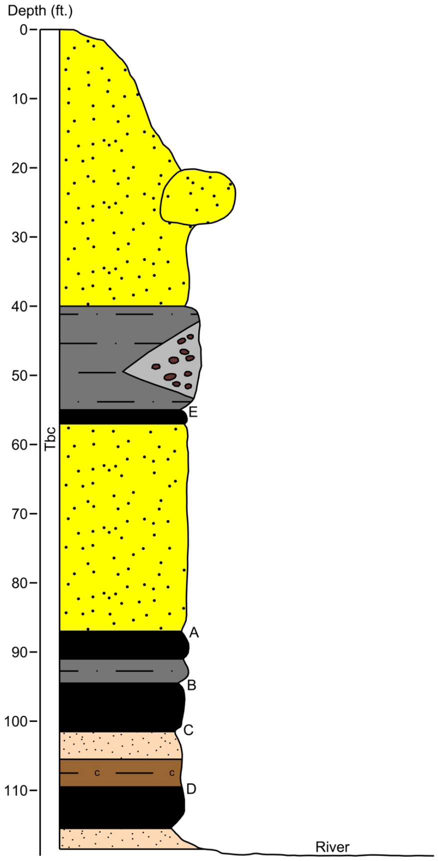
## REE Section 15
**Billings County**




| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **15A** | 58.2 | 5.0 | 2.88 | 1.17 | 5.4 | 1.01 | 34.1 | 0.38 | 25.7 | 6.6 | 5.2 | | 0.81 | 0.41 | 2.53 | 29 | 178 | 1.03 | ash |
| **15B** | 73.4 | 6.6 | 3.58 | 1.51 | 7.3 | 1.28 | 42.7 | 0.46 | 33.6 | 8.5 | 7.0 | | 1.08 | 0.51 | 3.07 | 30 | 221 | 0.97 | ash |
| **15C** | 38.2 | 6.2 | 4.05 | 1.26 | 5.6 | 1.38 | 20.5 | 0.57 | 20.9 | 5.0 | 4.8 | | 0.92 | 0.59 | 3.59 | 39 | 153 | 1.63 | ash |

Looking northwest along the Little Missouri River. The 13-foot-coal has burned to the north generating up to 30 feet of clinker.

## REE Section 16
**Billings County**

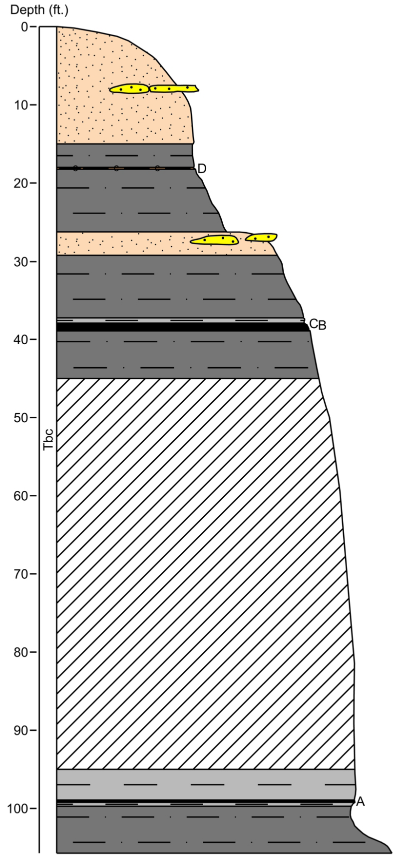



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **16E** | 10.5 | 3.6 | 2.74 | 0.64 | 2.5 | 0.87 | 5.7 | 0.43 | 6.2 | 1.4 | 1.7 | | 0.46 | 0.43 | 2.69 | 25 | 65 | 2.59 | coal |
| **16A** | 7.1 | 1.4 | 0.97 | 0.27 | 1.1 | 0.31 | 3.4 | 0.16 | 4.0 | 1.0 | 0.9 | | 0.20 | 0.15 | 0.96 | 8 | 30 | 1.71 | coal |
| **16B** | 19.5 | 3.8 | 2.43 | 0.60 | 3.1 | 0.81 | 8.7 | 0.37 | 10.4 | 2.5 | 2.6 | | 0.56 | 0.38 | 2.42 | 18 | 76 | 1.52 | coal |
| **16C** | 6.5 | 2.8 | 2.10 | 0.39 | 1.8 | 0.66 | 3.2 | 0.33 | 4.1 | 0.9 | 1.2 | | 0.36 | 0.33 | 2.07 | 17 | 44 | 2.70 | coal |
| **16D** | 37.0 | 2.8 | 1.74 | 0.73 | 3.0 | 0.59 | 19.6 | 0.25 | 18.4 | 4.7 | 3.3 | | 0.45 | 0.26 | 1.65 | 16 | 110 | 1.01 | coal |

Looking north. We had hoped to sample the low point of the fourth coal from the bottom, however it was inaccessible because the outcrop face was too steep.

## REE Section 17

**T.142N., R.102W., Sec. 16, NE1/4**
**Elevation at top 2,505 ft.**

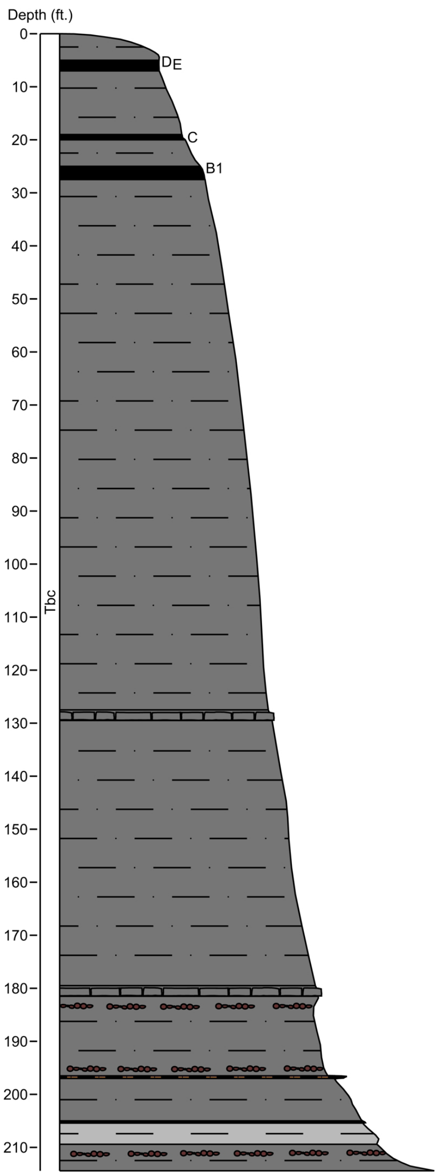



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **17D** | 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 | 1.21 | cmdst |
| **17C** | 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 | 1.25 | coal |
| **17B** | 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 | 386 | 1.24 | coal |
| **17A** | 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 | 1.05 | coal |

Looking northeast. The bottom portion of this section was measured south of the road and the upper portion north of the road.

# REE Section 18

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

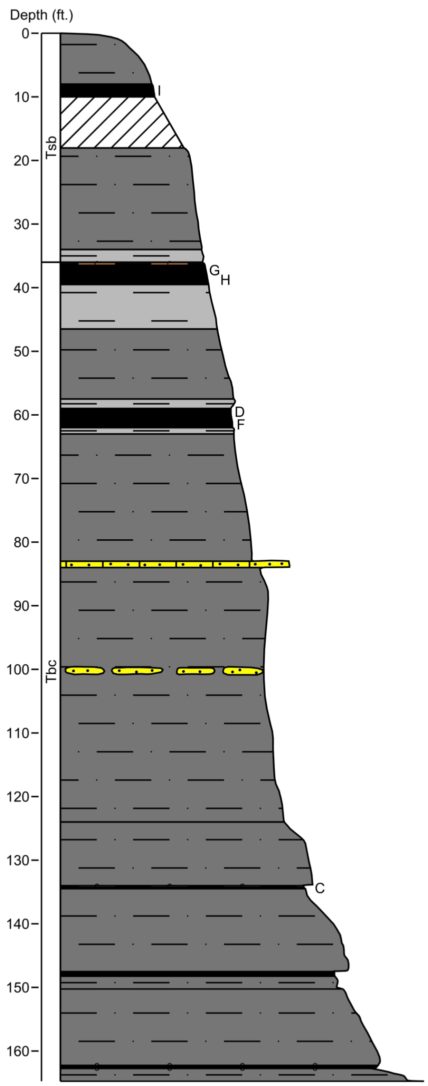



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **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 | 1.84 | coal |
| **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 | 1.91 | coal |
| **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 | 1.86 | pcoal |
| **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 | 1.76 | coal |

Looking northeast. The section was measure from the base to the top of the butt along the ridgeline.

## REE Section 19

**T.142N., R.102W., Sec. 34, NW1/4**
**Elevation at top 2,589 ft.**

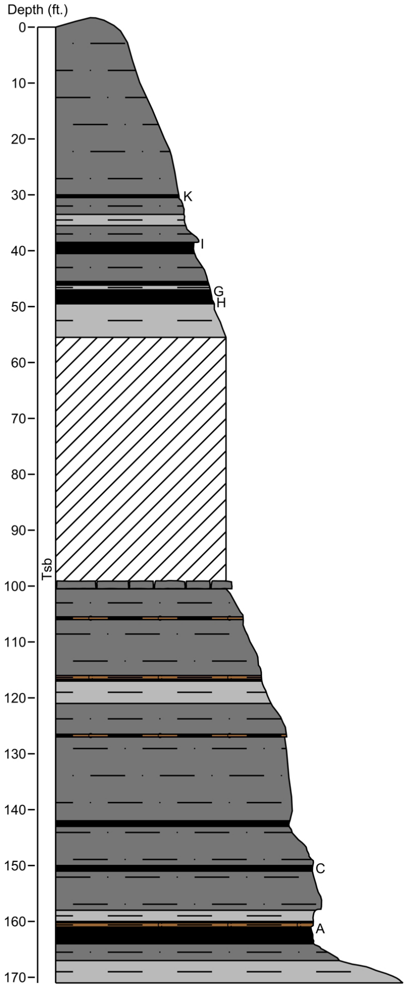



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 19I | 7.3 | 1.3 | 0.86 | 0.30 | 1.2 | 0.29 | 3.7 | 0.11 | 4.3 | 1.0 | 1.0 | 1.5 | 0.20 | 0.12 | 0.71 | 10 | 34 | 1.99 | wcoal |
| 19G | 27.9 | 2.9 | 1.55 | 0.84 | 3.3 | 0.55 | 17.5 | 0.21 | 14.9 | 3.6 | 3.3 | 10.5 | 0.50 | 0.22 | 1.41 | 12 | 101 | 1.08 | coal |
| 19H | 10.3 | 2.4 | 1.61 | 0.38 | 1.9 | 0.53 | 5.7 | 0.23 | 5.4 | 1.3 | 1.3 | 2.9 | 0.35 | 0.23 | 1.47 | 16 | 52 | 2.05 | coal |
| 19D | 18.6 | 3.1 | 1.99 | 0.60 | 2.9 | 0.67 | 11.5 | 0.27 | 9.4 | 2.2 | 2.3 | 4.9 | 0.49 | 0.28 | 1.77 | 19 | 80 | 1.60 | coal |
| 19F | 58.0 | 4.2 | 2.53 | 1.08 | 4.6 | 0.83 | 28.8 | 0.37 | 27.1 | 7.0 | 5.2 | 12.3 | 0.70 | 0.36 | 2.46 | 20 | 176 | 0.90 | coal |
| 19C | 66.2 | 7.6 | 5.53 | 1.22 | 6.2 | 1.77 | 35.2 | 0.79 | 24.7 | 6.6 | 4.8 | 17.2 | 1.11 | 0.79 | 5.03 | 47 | 232 | 1.17 | coal |

Looking north. A 3-foot-coal at the top of the Bullion Creek formation was identified as the contact with the Sentinel Butte formation, visible on this photo as the darker colored butte top.

## REE Section 20

**T.142N., R.100W., Sec. 28, SW1/4**
**T.142N., R.100W., Sec. 29, SE1/4**
**Elevation at top 2,698 ft.**

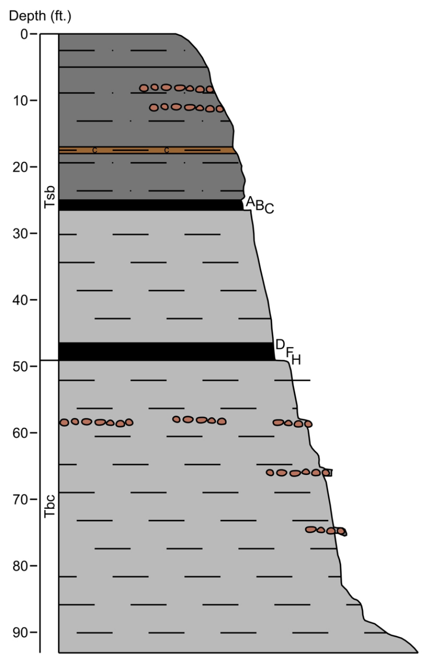



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **20K** | 53.2 | 4.6 | 2.80 | 1.19 | 4.8 | 0.94 | 24.5 | 0.43 | 24.4 | 6.4 | 5.1 | 15.3 | 0.76 | 0.40 | 2.74 | 21 | 169 | 0.95 | coal |
| **20I** | 60.2 | 2.9 | 1.77 | 0.93 | 3.6 | 0.58 | 29.9 | 0.28 | 25.9 | 7.0 | 4.7 | 11.2 | 0.51 | 0.26 | 1.84 | 14 | 166 | 0.73 | cmdst |
| **20G** | 22.5 | 2.8 | 1.80 | 0.61 | 2.7 | 0.60 | 10.8 | 0.27 | 10.8 | 2.7 | 2.5 | 6.8 | 0.45 | 0.26 | 1.74 | 17 | 84 | 1.32 | coal |
| **20H** | 10.8 | 1.1 | 0.71 | 0.25 | 1.2 | 0.24 | 5.5 | 0.11 | 5.1 | 1.3 | 1.2 | 2.9 | 0.19 | 0.10 | 0.68 | 6 | 37 | 1.12 | coal |
| **20C** | 24.8 | 6.1 | 4.69 | 0.96 | 4.6 | 1.48 | 14.8 | 0.75 | 11.9 | 2.9 | 2.9 | 12.2 | 0.86 | 0.68 | 4.51 | 46 | 140 | 2.19 | coal |
| **20A** | 24.7 | 2.8 | 1.58 | 0.74 | 3.0 | 0.54 | 10.3 | 0.22 | 13.4 | 3.3 | 3.0 | 7.6 | 0.47 | 0.22 | 1.44 | 13 | 86 | 1.18 | coal |

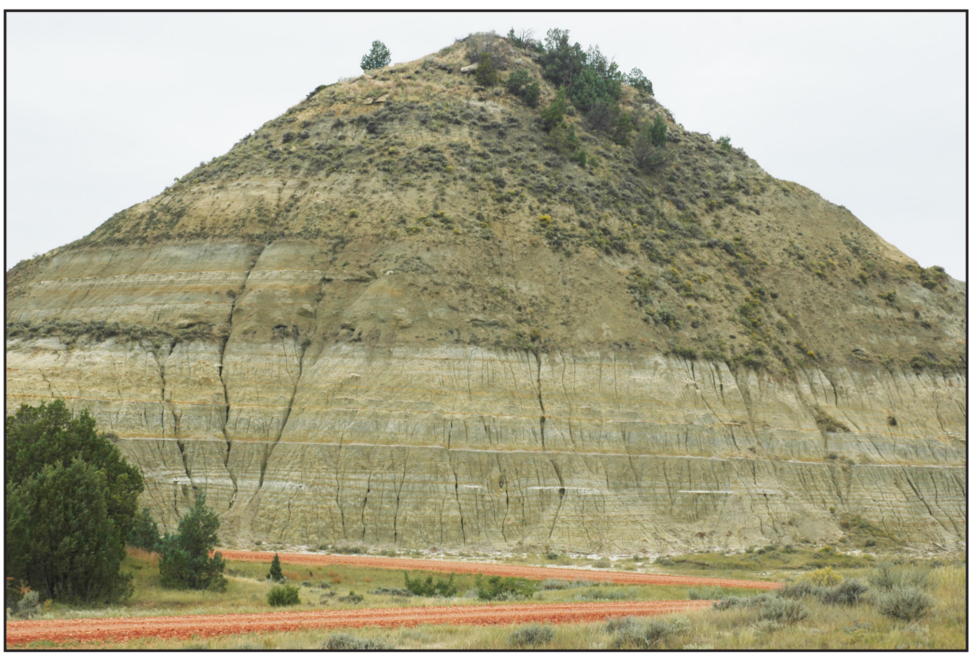
Looking northeast. This photo represents the lower portion of the section. Exposures of higher elevation rocks were measured in a canyon leading up to a plateau approximately 0.2 mile to the northeast.

# REE Section 21

**T.142N., R.101W., Sec. 36, NW1/4**
**Elevation at top 2,580**



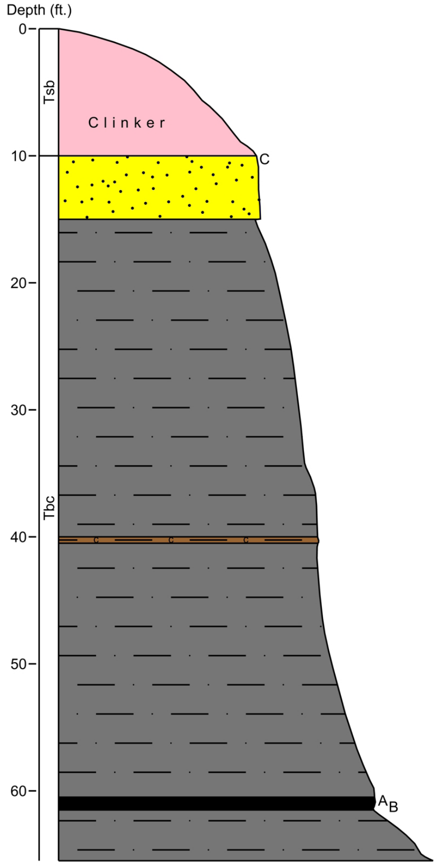

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **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 | 1.36 | coal |
| **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 | 2.22 | coal |
| **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 | 0.88 | coal |
| **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 | 1.38 | coal |
| **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 | 2.66 | coal |
| **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 | 1.91 | coal |



Looking northwest. A two-foot thick coal separates the lighter colored Bullion Creek formation at the bottom third of this outcrop from the darker Sentinel Butte formation above. The section was measured east of this photo.

## REE Section 22

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

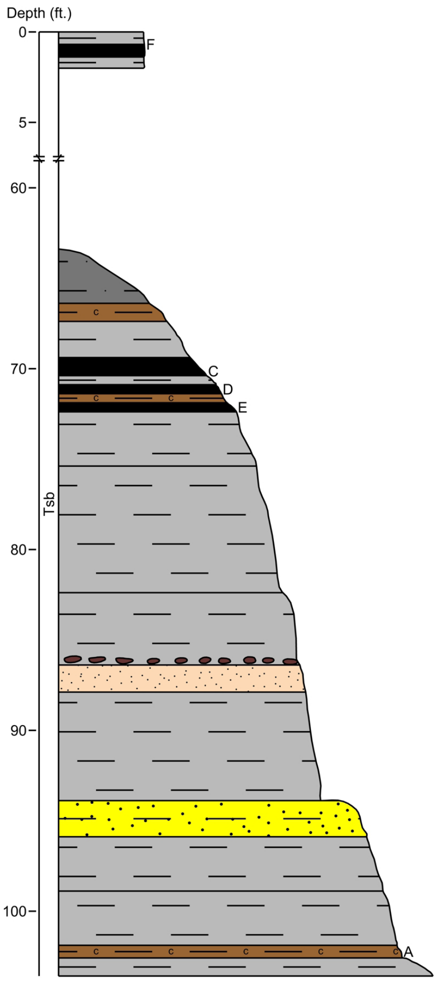



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **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 | 0.90 | ash |
| **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 | 2.16 | coal |
| **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 | 2.34 | coal |

Looking northwest. Levi Moxness and Chris Maike stand near the contact of clinker at the top of the butte and the coal-ash below.

# REE Section 23

**T.142N., R.100W., Sec. 35, SW1/4**
**Elevation at top 2,690 ft.**

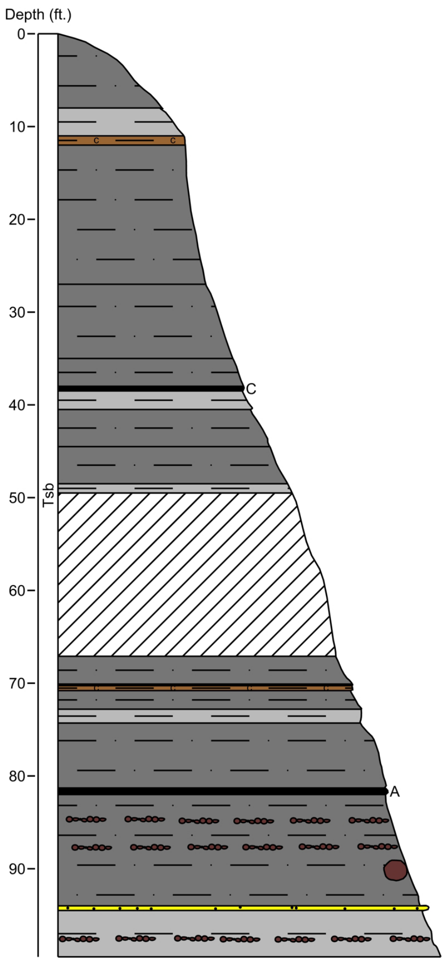



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | **Cerium** | **Dysprosium** | **Erbium** | **Europium** | **Gadolinium** | **Holmium** | **Lanthanum** | **Lutetium** | **Neodymium** | **Praseodymium** | **Samarium** | **Scandium** | **Terbium** | **Thulium** | **Ytterbium** | **Yttrium** | **Total REE** | **Outlook coefficient** | **Lithology** |
| **23F** | 43.9 | 4.2 | 2.84 | 0.79 | 3.8 | 0.92 | 22.8 | 0.43 | 19.2 | 5.1 | 3.6 | | 0.61 | 0.43 | 2.66 | 23 | 134 | 1.05 | coal |
| **23C** | 52.4 | 2.8 | 1.76 | 0.76 | 3.2 | 0.58 | 26.1 | 0.28 | 22.2 | 6.0 | 3.9 | 12.8 | 0.47 | 0.27 | 1.85 | 16 | 151 | 0.79 | coal |
| **23D** | 26.1 | 3.8 | 2.51 | 0.71 | 3.3 | 0.84 | 12.9 | 0.37 | 12.8 | 3.2 | 2.9 | | 0.56 | 0.38 | 2.38 | 24 | 97 | 1.48 | coal |
| **23E** | 25.9 | 4.6 | 2.83 | 0.86 | 3.9 | 0.97 | 10.8 | 0.39 | 13.2 | 3.2 | 3.3 | | 0.67 | 0.40 | 2.50 | 24 | 98 | 1.53 | coal |

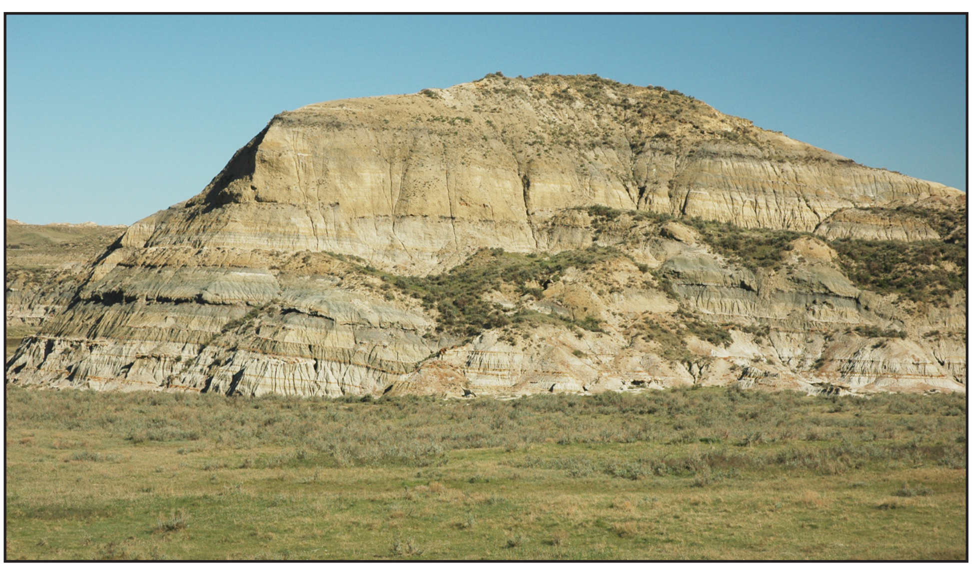
Looking east. This photo shows exposures of the coals from which samples 23C, 23D, and 23E where taken. Sample F was taken from an exposure approximately 0.1 mile to the east.

## REE Section 24

**T.141N., R.100W., Sec. 16, NE1/4**
**Elevation at top 2,599 ft.**



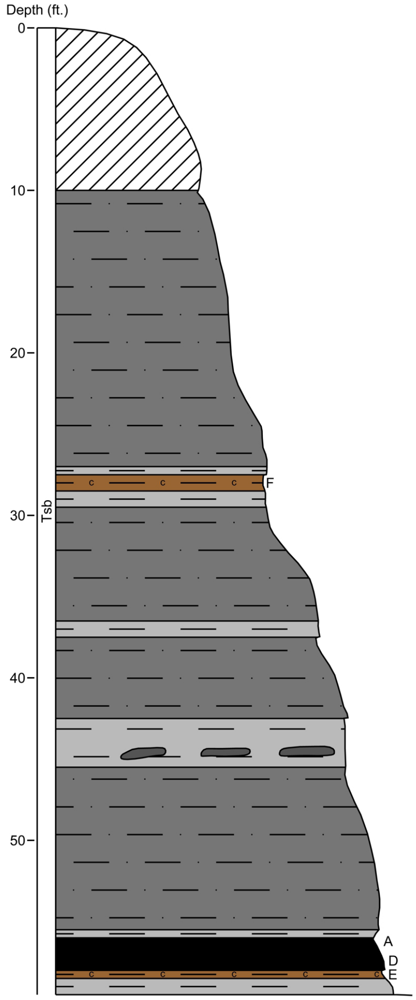

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **24C** | 17.6 | 2.7 | 1.62 | 0.74 | 2.9 | 0.54 | 6.7 | 0.24 | 11.2 | 2.5 | 2.8 | 10.6 | 0.45 | 0.23 | 1.54 | 14 | 76 | 1.52 | coal |
| **24A** | 21.3 | 4.3 | 3.26 | 0.80 | 3.5 | 1.00 | 10.5 | 0.53 | 10.9 | 2.6 | 2.6 | 14.5 | 0.62 | 0.47 | 3.16 | 34 | 114 | 2.04 | coal |



Looking northwest. This photo represents the upper portion of this section. The lower section was measured at exposures approximately 0.1 miles to the southeast of this butte.

## REE Section 25

**T.141N., R.100W., Sec. 22, SE1/4**
**Elevation at top 2,620 ft.**

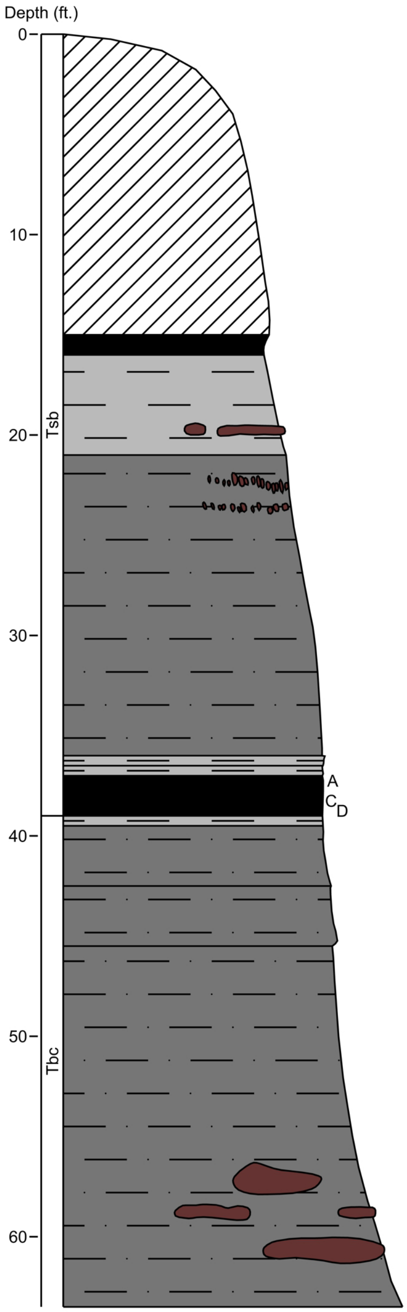



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 25F | 29.7 | 4.4 | 3.29 | 0.94 | 3.4 | 1.04 | 14.1 | 0.54 | 13.6 | 3.5 | 3.0 | | 0.62 | 0.52 | 3.36 | 28 | 110 | 1.45 | cmdst |
| 25A | 15.6 | 2.1 | 1.33 | 0.52 | 2.0 | 0.44 | 7.2 | 0.21 | 8.4 | 2.0 | 1.9 | | 0.31 | 0.20 | 1.35 | 10 | 54 | 1.27 | coal |
| 25D | 16.9 | 1.6 | 1.18 | 0.41 | 1.6 | 0.37 | 8.5 | 0.21 | 8.1 | 2.1 | 1.7 | | 0.25 | 0.19 | 1.28 | 10 | 54 | 1.14 | coal |
| 25E | 79.1 | 7.0 | 3.98 | 2.04 | 7.9 | 1.39 | 39.2 | 0.52 | 38.8 | 9.6 | 8.1 | | 1.14 | 0.57 | 3.39 | 37 | 240 | 1.06 | cmdst |

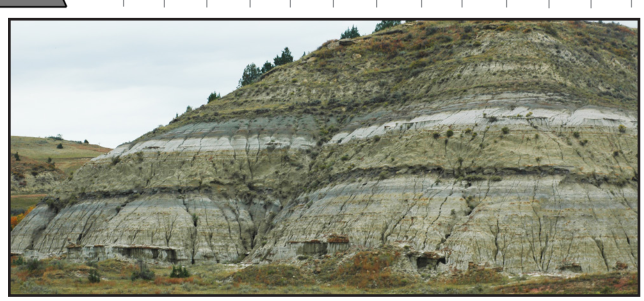
Looking north. Coal was sampled at the base of this butte.

## REE Section 26

**T.141N., R.101W., Sec. 13, SW1/4**
**Elevation at top 2,574 ft.**



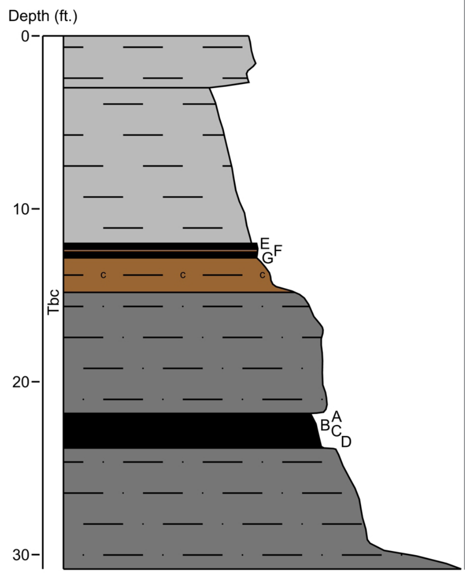

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **26A** | 14.5 | 2.7 | 2.09 | 0.53 | 2.1 | 0.64 | 7.6 | 0.36 | 7.4 | 1.8 | 1.7 | | 0.39 | 0.32 | 2.21 | 18 | 62 | 1.73 | coal |
| **26C** | 4.5 | 1.3 | 1.09 | 0.26 | 1.0 | 0.33 | 2.2 | 0.18 | 2.7 | 0.6 | 0.7 | | 0.19 | 0.16 | 1.11 | 11 | 27 | 2.63 | coal |
| **26D** | 31.6 | 2.6 | 1.92 | 0.58 | 2.3 | 0.61 | 18.1 | 0.32 | 12.7 | 3.5 | 2.2 | | 0.39 | 0.29 | 1.99 | 18 | 97 | 1.04 | cmdst |



Looking northeast. The lowest coal in the section marks the contact of the Bullion Creek formation and the Sentinel Butte formation.

## REE Section 27

**T.141N., R.101W., Sec. 21, NW1/4**
**Elevation at top 2,472 ft.**

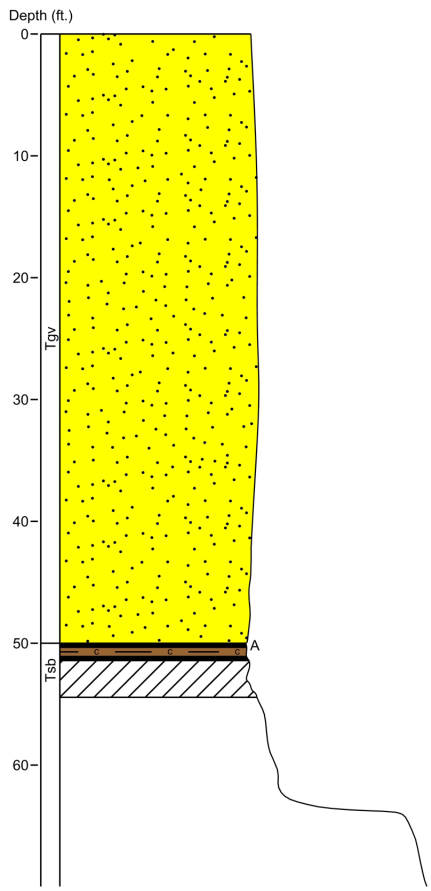



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **27E** | 26.3 | 4.4 | 3.06 | 0.85 | 3.8 | 0.99 | 12.1 | 0.46 | 13.9 | 3.4 | 3.3 | | 0.69 | 0.45 | 2.88 | 25 | 102 | 1.54 | coal |
| **27F** | 51.4 | 2.6 | 1.76 | 0.69 | 2.9 | 0.55 | 26.2 | 0.31 | 21.8 | 5.9 | 3.8 | | 0.42 | 0.28 | 2.00 | 14 | 135 | 0.76 | cclyst |
| **27G** | 27.0 | 4.8 | 3.25 | 0.99 | 4.3 | 1.06 | 11.6 | 0.49 | 15.0 | 3.6 | 3.8 | | 0.76 | 0.48 | 3.10 | 25 | 105 | 1.55 | coal |
| **27A** | 8.9 | 2.6 | 1.96 | 0.44 | 2.0 | 0.63 | 3.6 | 0.30 | 5.8 | 1.3 | 1.5 | | 0.38 | 0.29 | 1.85 | 19 | 51 | 2.52 | coal |
| **27B** | 44.9 | 1.8 | 1.09 | 0.45 | 2.1 | 0.38 | 38.8 | 0.14 | 10.6 | 3.7 | 1.8 | | 0.31 | 0.15 | 0.87 | 12 | 119 | 0.57 | coal |
| **27C** | 8.0 | 1.2 | 0.80 | 0.27 | 1.2 | 0.27 | 4.7 | 0.11 | 4.1 | 1.0 | 1.0 | | 0.20 | 0.11 | 0.68 | 9 | 33 | 1.70 | coal |
| **27D** | 8.8 | 2.7 | 1.83 | 0.51 | 2.2 | 0.61 | 3.3 | 0.26 | 6.0 | 1.3 | 1.7 | | 0.42 | 0.26 | 1.60 | 17 | 48 | 2.47 | coal |

Looking east.  This section was measure from the base of the outcrop to a ledge-forming, indurated clay.

## REE Section 28

**T.139N., R.104W., Sec. 6, SE/SE**
**Elevation at top 3,350 ft.**

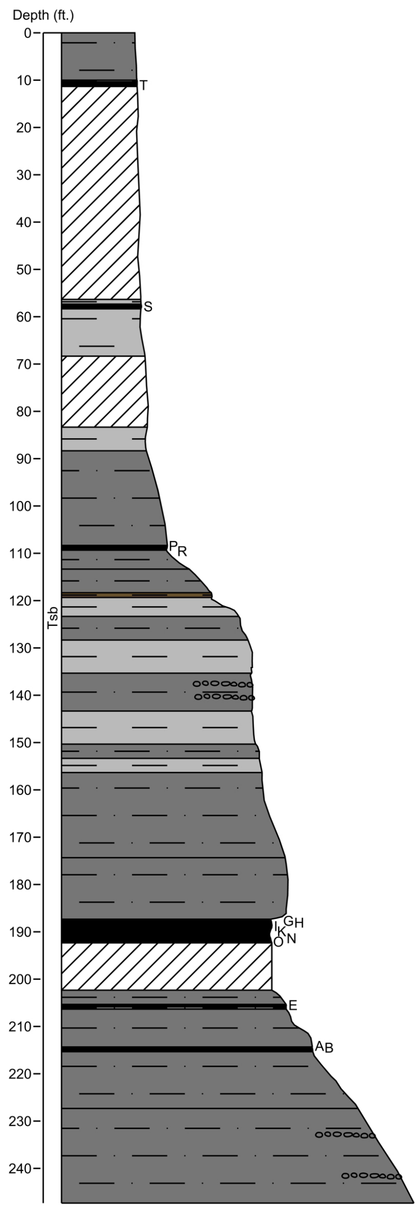



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **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 | 1.38 | coal |

Looking southeast. The section was measured just south of the clinker capped outlier.

# REE Section 29

**T.139N., R.103W., Sec. 16**
**Elevation at top 3,064 ft.**

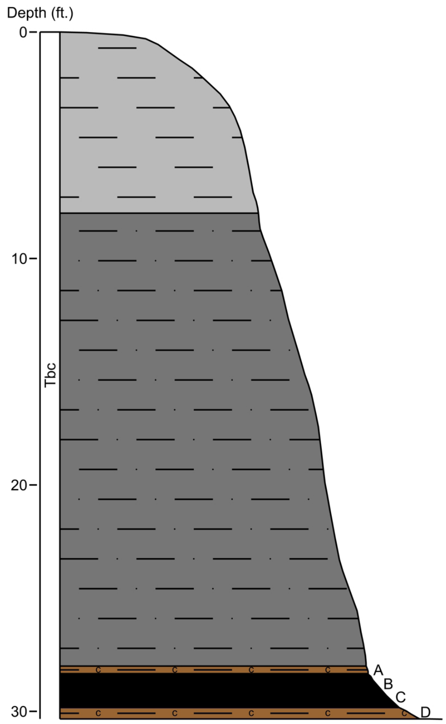



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| 29T | 90.1 | 7.7 | 4.10 | 2.15 | 9.0 | 1.46 | 40.3 | 0.57 | 44.7 | 11.3 | 9.4 | | 1.37 | 0.58 | 3.70 | 34 | 260 | 0.98 | pcoal |
| 29S | 52.5 | 3.5 | 2.66 | 0.82 | 3.4 | 0.80 | 26.5 | 0.44 | 21.9 | 6.0 | 3.9 | | 0.54 | 0.41 | 2.80 | 22 | 148 | 0.90 | pcoal |
| 29P | 34.9 | 5.1 | 3.57 | 1.05 | 4.5 | 1.13 | 17.5 | 0.56 | 17.5 | 4.3 | 3.9 | | 0.78 | 0.53 | 3.49 | 32 | 131 | 1.48 | coal |
| 29R | 55.9 | 4.7 | 3.12 | 1.14 | 4.8 | 1.00 | 27.7 | 0.48 | 24.6 | 6.6 | 4.8 | | 0.78 | 0.46 | 3.01 | 27 | 166 | 1.01 | coal |
| 29G | 38.6 | 2.9 | 1.79 | 1.11 | 3.3 | 0.58 | 19.9 | 0.28 | 19.4 | 5.0 | 3.9 | | 0.50 | 0.27 | 1.81 | 14 | 113 | 0.96 | coal |
| 29H | 26.8 | 3.3 | 1.83 | 0.85 | 3.6 | 0.63 | 12.0 | 0.26 | 15.7 | 3.8 | 3.7 | | 0.57 | 0.26 | 1.74 | 15 | 90 | 1.25 | coal |
| 29I | 13.2 | 1.4 | 0.85 | 0.43 | 1.6 | 0.29 | 6.4 | 0.13 | 6.5 | 1.7 | 1.4 | | 0.25 | 0.12 | 0.81 | 7 | 42 | 1.13 | coal |
| 29K | 14.5 | 1.2 | 0.78 | 0.28 | 1.3 | 0.25 | 7.8 | 0.11 | 6.3 | 1.7 | 1.2 | | 0.20 | 0.11 | 0.70 | 9 | 45 | 1.13 | coal |
| 29N | 23.0 | 2.3 | 1.53 | 0.41 | 2.2 | 0.50 | 13.3 | 0.20 | 8.8 | 2.4 | 1.6 | | 0.36 | 0.21 | 1.26 | 20 | 78 | 1.33 | coal |
| 29O | 43.2 | 5.2 | 3.38 | 0.86 | 4.8 | 1.15 | 22.3 | 0.43 | 17.4 | 4.7 | 3.4 | | 0.79 | 0.46 | 2.76 | 36 | 147 | 1.33 | coal |
| 29E | 26.7 | 5.5 | 4.28 | 1.01 | 4.3 | 1.31 | 12.2 | 0.69 | 13.6 | 3.3 | 3.2 | | 0.81 | 0.63 | 4.17 | 39 | 121 | 1.92 | coal |
| 29A | 9.9 | 1.6 | 1.18 | 0.26 | 1.4 | 0.37 | 6.7 | 0.18 | 5.1 | 1.2 | 1.2 | | 0.24 | 0.17 | 1.12 | 12 | 43 | 1.74 | hcoal |
| 29B | 8.8 | 1.1 | 0.79 | 0.17 | 1.0 | 0.25 | 5.0 | 0.12 | 4.1 | 1.0 | 0.9 | | 0.18 | 0.11 | 0.73 | 8 | 32 | 1.43 | hcoal |

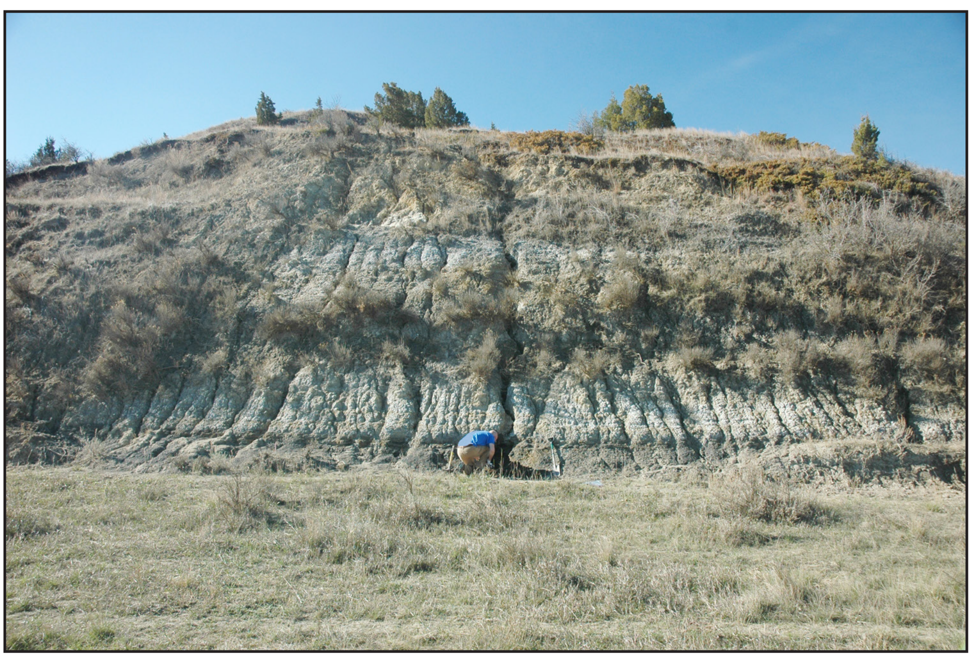
Looking north toward exposures of the rocks represented by the middle of the section.

## REE Section 30

**T.139N., R.101W., Sec. 7, NE1/4**
**Elevation at top 2,445 ft.**



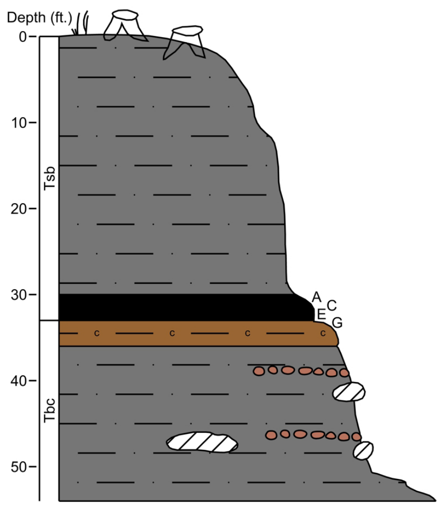

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **30A** | 49.2 | 3.0 | 1.90 | 0.88 | 3.6 | 0.62 | 25.1 | 0.30 | 22.1 | 5.9 | 4.2 | 12.1 | 0.53 | 0.28 | 1.92 | 17 | 149 | 0.87 | cmdst |
| **30B** | 7.7 | 1.2 | 0.77 | 0.29 | 1.1 | 0.25 | 3.9 | 0.12 | 3.9 | 1.0 | 0.9 | 4.3 | 0.18 | 0.11 | 0.73 | 7 | 33 | 1.50 | coal |
| **30C** | 22.5 | 2.9 | 1.97 | 0.59 | 2.5 | 0.63 | 11.4 | 0.30 | 10.7 | 2.8 | 2.3 | 8.7 | 0.42 | 0.29 | 1.92 | 18 | 88 | 1.35 | coal |
| **30D** | 51.0 | 2.7 | 1.55 | 0.82 | 3.5 | 0.52 | 25.6 | 0.23 | 23.2 | 6.1 | 4.3 | 6.6 | 0.48 | 0.23 | 1.53 | 14 | 142 | 0.80 | cclyst |



Looking south. The section was measured from the base to the top of this exposure, located along the south side of Sully Creek road.

## REE Section 31

**T.139N., R.101W., Sec. 16, SE1/4**
**Elevation at top 2,580 ft.**

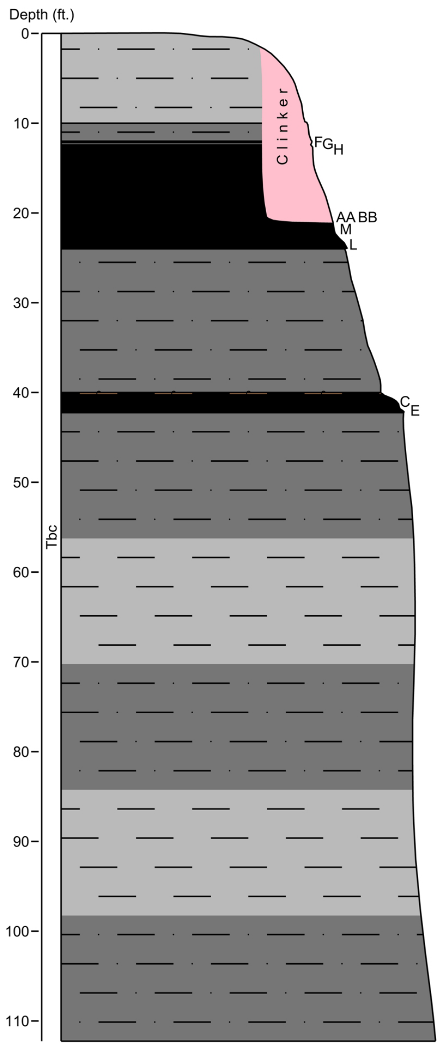



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| **31A** | 17.4 | 2.8 | 1.91 | 0.62 | 2.3 | 0.63 | 11.0 | 0.29 | 8.0 | 2.0 | 2.0 | | 0.43 | 0.28 | 1.84 | 16 | 68 | 1.46 | coal |
| **31C** | 26.2 | 2.8 | 1.82 | 0.78 | 2.9 | 0.60 | 12.4 | 0.27 | 12.9 | 3.2 | 2.9 | | 0.46 | 0.27 | 1.73 | 17 | 86 | 1.23 | clmdst |
| **31E** | 31.0 | 2.8 | 1.89 | 0.79 | 2.9 | 0.62 | 14.4 | 0.29 | 14.6 | 3.7 | 3.0 | | 0.47 | 0.29 | 1.88 | 17 | 96 | 1.10 | coal |
| **31G** | 47.8 | 2.6 | 1.62 | 0.87 | 3.1 | 0.54 | 23.5 | 0.26 | 20.6 | 5.5 | 3.8 | | 0.46 | 0.25 | 1.67 | 12 | 125 | 0.76 | cclyst |

Looking north/northeast. The pit that was dug to sample the three-foot-coal at this site is still visible. The pit was later backfilled and the fill compacted.

## REE Section 32

**T.139N., R.102W., Sec. 23, SE1/4**
**Elevation at top 2,624 ft.**

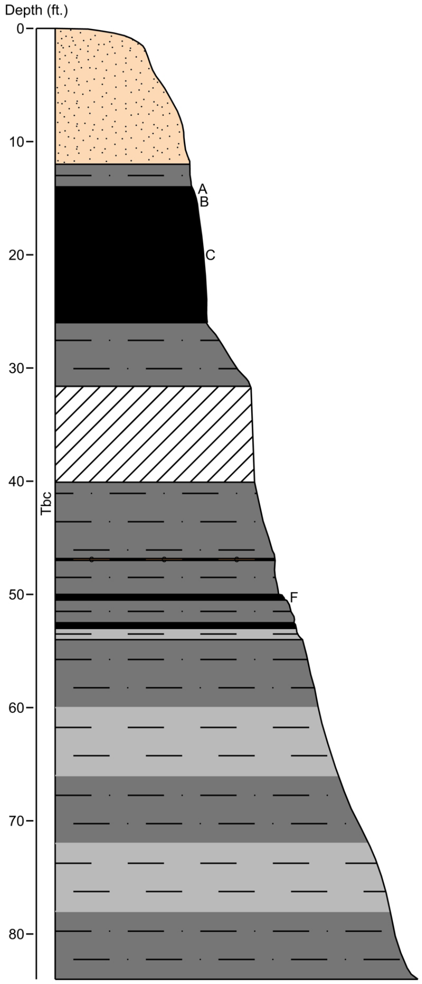



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **32F** | 55.2 | 5.6 | 2.84 | 1.89 | 6.8 | 1.01 | 23.2 | 0.40 | 34.0 | 8.0 | 8.3 | 20.8 | 1.01 | 0.40 | 2.72 | 19 | 191 | 1.08 | coal |
| **32G** | 59.1 | 3.1 | 1.99 | 0.91 | 3.4 | 0.62 | 31.3 | 0.33 | 25.1 | 7.0 | 4.4 | 11.7 | 0.50 | 0.30 | 2.14 | 15 | 167 | 0.75 | cclyst |
| **32H** | 47.4 | 5.6 | 2.99 | 1.56 | 6.4 | 1.07 | 21.4 | 0.42 | 26.9 | 6.4 | 6.2 | 8 | 0.98 | 0.42 | 2.74 | 24 | 162 | 1.19 | coal |
| **32AA** | 40.6 | 2.6 | 1.47 | 1.23 | 3.3 | 0.51 | 19.7 | 0.21 | 18.6 | 4.9 | 3.6 | 7.1 | 0.46 | 0.21 | 1.34 | 12 | 118 | 0.85 | ash |
| **32BB** | 19.5 | 1.2 | 0.71 | 0.34 | 1.4 | 0.24 | 10.3 | 0.10 | 8.5 | 2.3 | 1.5 | 2.7 | 0.21 | 0.10 | 0.66 | 6 | 56 | 0.82 | ash |
| **32M** | 65.5 | 4.1 | 2.47 | 1.94 | 5.1 | 0.82 | 35.8 | 0.34 | 27.3 | 7.4 | 5.2 | 9.2 | 0.70 | 0.35 | 2.22 | 22 | 190 | 0.85 | coal |
| **32L** | 18.1 | 2.0 | 1.15 | 0.68 | 2.2 | 0.40 | 14.3 | 0.15 | 10.6 | 2.7 | 2.3 | 4.2 | 0.33 | 0.16 | 1.01 | 14 | 74 | 1.45 | ccoal |
| **32C** | 15.7 | 1.9 | 1.16 | 0.47 | 2.0 | 0.39 | 8.4 | 0.18 | 7.9 | 1.9 | 1.9 | 4.7 | 0.32 | 0.17 | 1.15 | 10 | 58 | 1.24 | coal |
| **32E** | 43.1 | 4.1 | 2.23 | 0.96 | 4.4 | 0.79 | 18.8 | 0.29 | 22.0 | 5.7 | 4.8 | 8.3 | 0.69 | 0.30 | 1.97 | 20 | 138 | 1.08 | ccoal |

Looking north. The 12-foot-coal measured in this section can be seen at the base of the highest peak. This coal was found reduce to 20-inches of coal overlain by 11-inches of ash (samples 32M & 32 Ash) 150 feet to the northwest. More ash (sample 32 Ash 2) underlying a thin lag of clinker which can be seen on the left-most peak on the photo, was found 130 feet to the south of the thick coal.

## REE Section 33

**T.139N., R.102W., Sec. 26, NW1/4**
**Elevation at top 2,664 ft.**

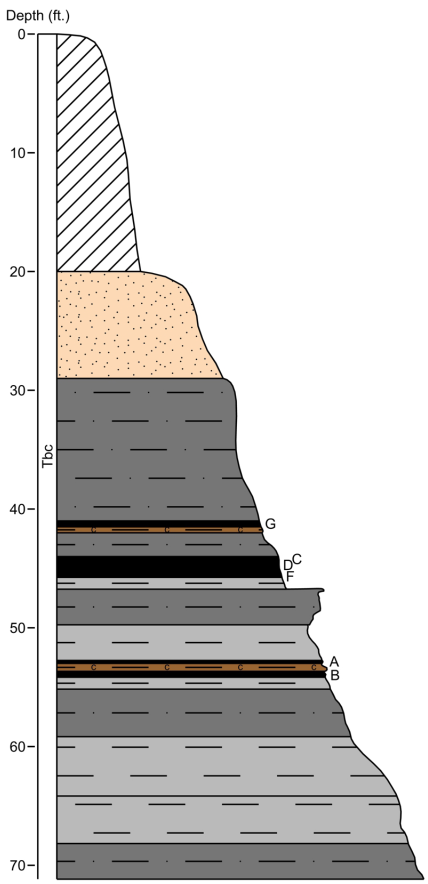



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **33A** | 33.4 | 5.1 | 2.60 | 1.61 | 6.0 | 0.93 | 11.3 | 0.35 | 26.9 | 5.9 | 6.9 | 10.7 | 0.91 | 0.36 | 2.36 | 17 | 132 | 1.45 | coal |
| **33B** | 6.9 | 1.1 | 0.68 | 0.27 | 1.2 | 0.23 | 3.1 | 0.10 | 4.3 | 1.0 | 1.0 | 1.4 | 0.19 | 0.10 | 0.61 | 5 | 27 | 1.45 | coal |
| **33C** | 10.7 | 0.4 | 0.20 | 0.14 | 0.6 | 0.07 | 5.3 | 0.02 | 4.5 | 1.3 | 0.6 | 0.8 | 0.08 | 0.03 | 0.16 | 2 | 27 | 0.67 | coal |
| **33F** | 14.2 | 1.9 | 1.14 | 0.55 | 2.0 | 0.38 | 6.0 | 0.18 | 8.5 | 2.0 | 2.1 | 3.7 | 0.31 | 0.16 | 1.13 | 8 | 52 | 1.27 | coal |

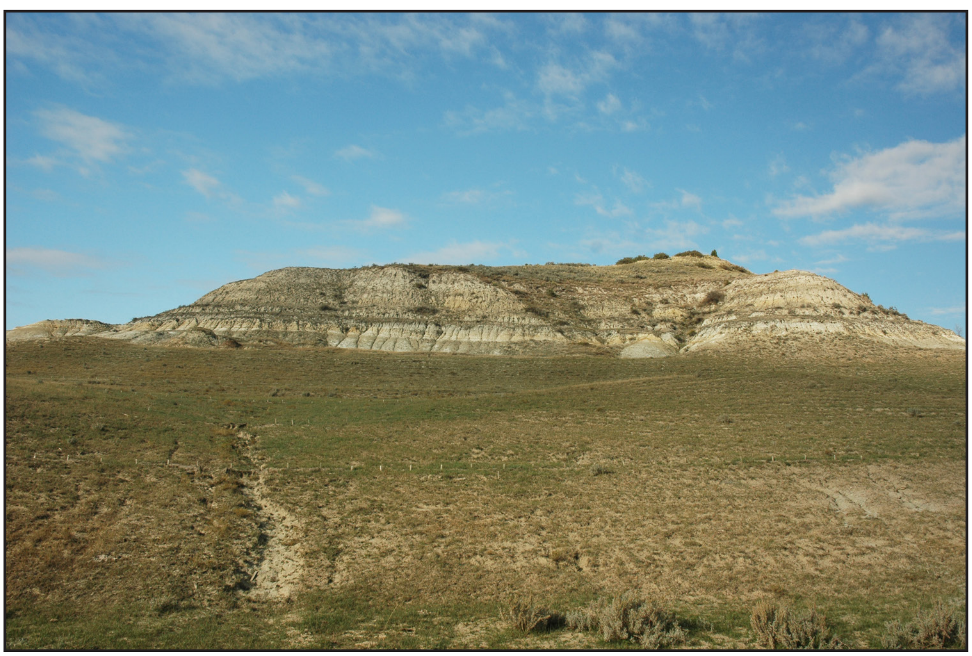
Looking northeast. The thick coal observed in Section 32 outcrops again at the base of the bluff in the background of this photo.

## REE Section 34

**T.139N., R.102W., Sec. 26, SE1/4**
**Elevation at top 2,630 ft.**



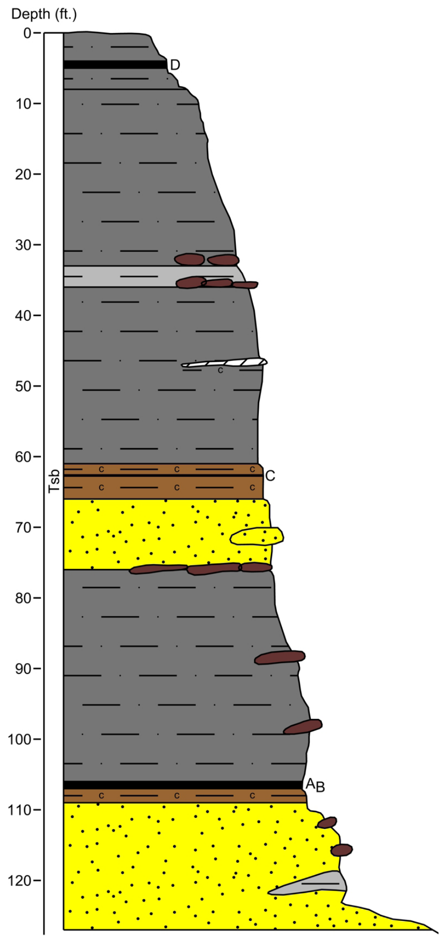

| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **34G** | 12.9 | 4.4 | 3.42 | 0.61 | 3.0 | 1.06 | 5.6 | 0.57 | 7.7 | 1.7 | 2.1 | | 0.61 | 0.55 | 3.53 | 27 | 75 | 2.35 | coal |
| **34C** | 16.7 | 3.4 | 2.16 | 0.69 | 3.1 | 0.71 | 6.6 | 0.35 | 11.2 | 2.5 | 3.1 | | 0.52 | 0.33 | 2.23 | 15 | 69 | 1.62 | coal |
| **34D** | 7.1 | 2.1 | 1.52 | 0.35 | 1.7 | 0.49 | 3.4 | 0.23 | 4.3 | 1.0 | 1.2 | | 0.32 | 0.23 | 1.49 | 13 | 38 | 2.26 | coal |
| **34F** | 55.0 | 8.9 | 5.35 | 1.63 | 8.5 | 1.87 | 22.9 | 0.68 | 31.2 | 7.6 | 7.1 | | 1.49 | 0.77 | 4.49 | 47 | 204 | 1.52 | coal |
| **34A** | 19.2 | 5.6 | 3.98 | 0.83 | 4.1 | 1.29 | 9.5 | 0.60 | 10.5 | 2.5 | 2.9 | | 0.82 | 0.62 | 3.91 | 33 | 99 | 2.14 | coal |
| **34B** | 23.5 | 6.9 | 4.37 | 1.03 | 5.3 | 1.49 | 11.7 | 0.61 | 13.1 | 3.0 | 3.7 | | 1.01 | 0.62 | 3.93 | 36 | 116 | 2.07 | coal |



Looking north. The lower part of this section was measure along the west flank. The middle to top was measured from the south-facing side of the butte.

## REE Section 35

**T.139N., R.101W., Sec. 36, NE1/4**
**Elevation at top 2,675 ft.**

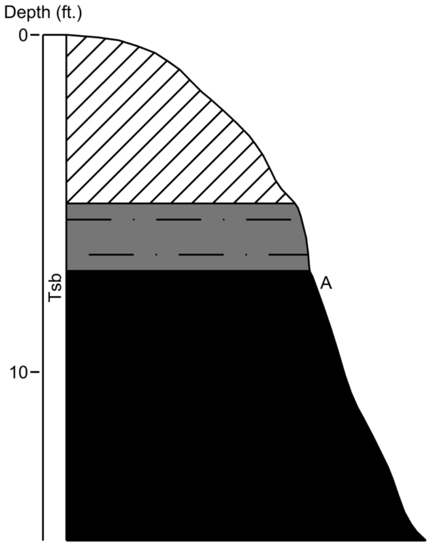



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **35D** | 15.5 | 5.0 | 3.75 | 0.83 | 3.5 | 1.21 | 8.2 | 0.56 | 8.4 | 1.9 | 2.3 | | 0.70 | 0.55 | 3.52 | 34 | 90 | 2.47 | pcoal |
| **35C** | 101 | 11.7 | 7.22 | 2.60 | 11.5 | 2.45 | 43.8 | 1.09 | 51.0 | 12.6 | 11.2 | | 1.95 | 1.08 | 6.92 | 52 | 318 | 1.12 | clmdst |
| **35A** | 16.2 | 5.1 | 3.68 | 0.89 | 3.8 | 1.18 | 7.5 | 0.54 | 9.5 | 2.2 | 2.7 | | 0.75 | 0.54 | 3.42 | 34 | 92 | 2.46 | coal |
| **35B** | 12.4 | 3.0 | 2.17 | 0.68 | 2.3 | 0.69 | 5.5 | 0.35 | 7.3 | 1.7 | 2.0 | | 0.45 | 0.33 | 2.21 | 17 | 58 | 1.91 | coal |

Looking northeast. The section was measured from the base to the top of this small butte. Ned Kruger standing just below the coal where samples 35A and 35B were obtained.

## REE Section 36

**T.138N., R.100W., Sec. 8, NE1/4**
**Elevation at top 2,750 ft.**

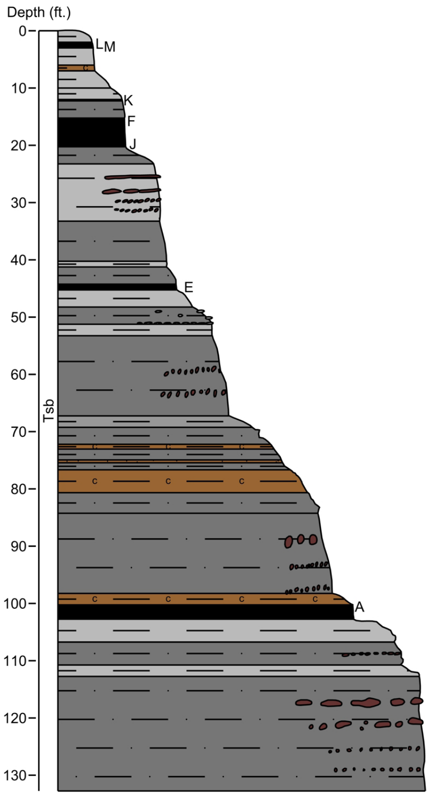



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **36A** | 9.7 | 1.6 | 0.98 | 0.30 | 1.4 | 0.34 | 4.8 | 0.13 | 4.7 | 1.2 | 1.1 | | 0.23 | 0.14 | 0.86 | 9 | 36 | 1.50 | coal |

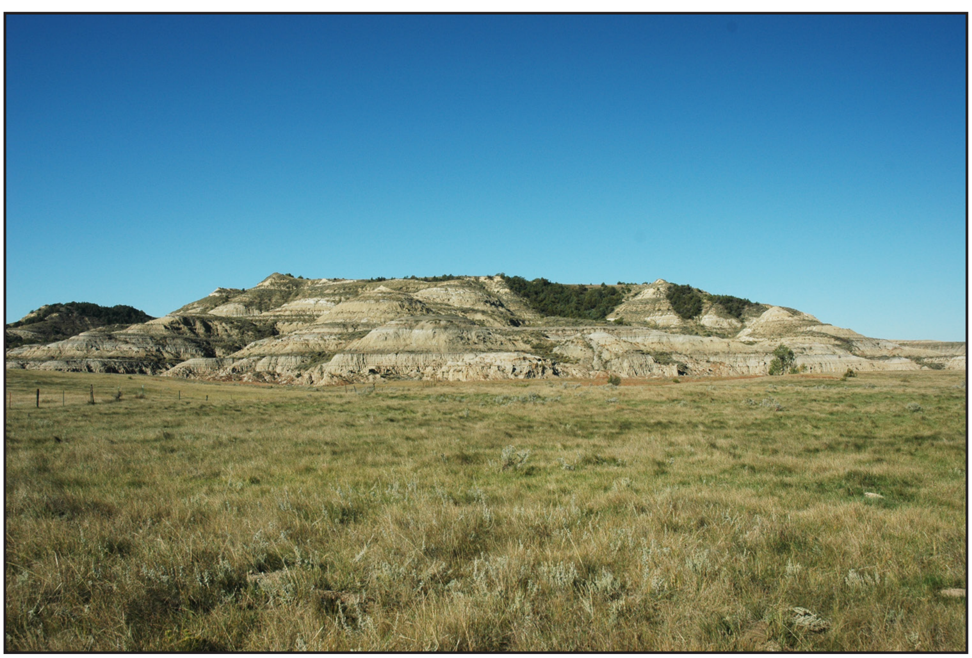
Looking north. Only the top portion of this coal was sampled.

# REE Section 37

**T. 138N., R. 101W., Sec. 10, NE1/4**
**Elevation at top 2,834 ft.**



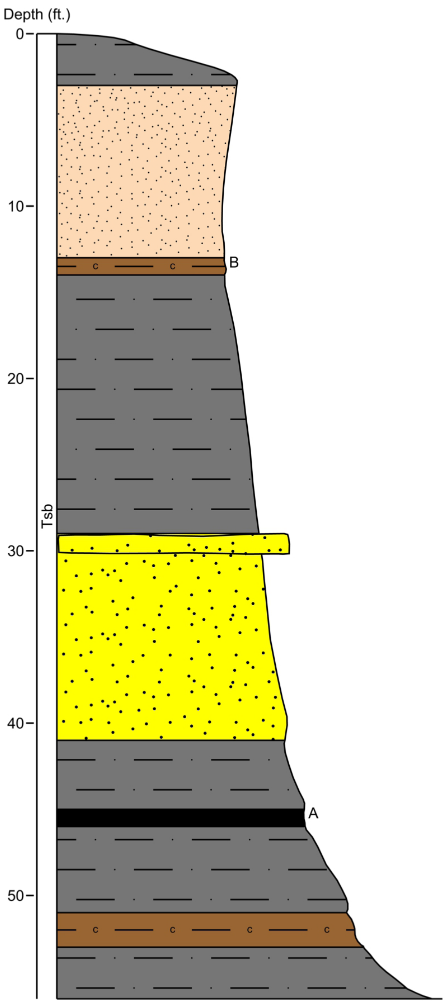

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 37L | 114 | 17.3 | 8.73 | 4.67 | 20.0 | 3.20 | 36.2 | 1.13 | 80.1 | 17.7 | 20.1 | | 2.93 | 1.22 | 7.43 | 64 | 399 | 1.40 | pcoal |
| 37M | 72.2 | 10.3 | 5.89 | 2.24 | 10.0 | 2.09 | 28.6 | 0.81 | 39.3 | 9.6 | 9.3 | 18.9 | 1.71 | 0.85 | 5.29 | 55 | 272 | 1.41 | coal |
| 37K | 45.8 | 3.3 | 2.20 | 0.84 | 3.5 | 0.70 | 23.5 | 0.37 | 21.3 | 5.3 | 3.8 | | 0.51 | 0.35 | 2.35 | 17 | 131 | 0.91 | coal |
| 37F | 26.7 | 3.4 | 1.92 | 0.86 | 3.6 | 0.66 | 12.7 | 0.28 | 15.9 | 3.9 | 3.8 | | 0.54 | 0.29 | 1.85 | 15 | 91 | 1.26 | pcoal |
| 37J | 35.3 | 4.0 | 2.26 | 1.14 | 4.3 | 0.80 | 15.3 | 0.31 | 18.8 | 4.5 | 4.4 | | 0.65 | 0.33 | 2.02 | 17 | 111 | 1.13 | pcoal |
| 37E | 19.3 | 5.2 | 3.95 | 0.88 | 3.7 | 1.23 | 9.6 | 0.64 | 10.4 | 2.4 | 2.7 | | 0.68 | 0.61 | 3.93 | 34 | 99 | 2.14 | pcoal |
| 37A | 28.5 | 3.0 | 1.47 | 1.13 | 3.8 | 0.55 | 11.4 | 0.18 | 18.2 | 4.1 | 4.4 | | 0.53 | 0.20 | 1.25 | 12 | 91 | 1.18 | coal |



Looking west. The section was measured from the base to the top of this complex of buttes on the eastern side of Tracy Mountain.

## REE Section 38

**T.138N., R.101W., Sec. 10, NW1/4**
**Elevation at top 2,886 ft.**

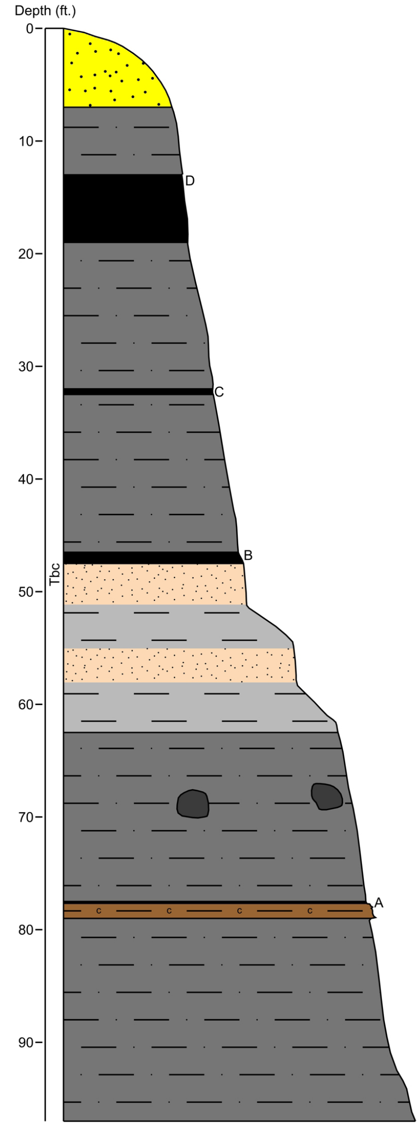



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | **Cerium** | **Dysprosium** | **Erbium** | **Europium** | **Gadolinium** | **Holmium** | **Lanthanum** | **Lutetium** | **Neodymium** | **Praseodymium** | **Samarium** | **Scandium** | **Terbium** | **Thulium** | **Ytterbium** | **Yttrium** | **Total REE** | **Outlook coefficient** | **Lithology** |
| **38B** | 127 | 14.0 | 7.94 | 3.63 | 15.4 | 2.80 | 60.2 | 1.04 | 64.4 | 15.8 | 14.7 | 23.4 | 2.41 | 1.08 | 6.87 | 65 | 426 | 1.13 | cclyst |
| **38A** | 44.7 | 7.8 | 4.65 | 1.64 | 7.6 | 1.60 | 17.2 | 0.67 | 26.4 | 6.2 | 6.6 | 13.4 | 1.28 | 0.66 | 4.27 | 33 | 178 | 1.44 | coal |

Looking north. Rocks just above those found in Section 37 are exposed on the south side of Tracy Mountain. The coal from which sample 38A was taken appears to be a lateral extension of the coal where samples 37L & 37M where collected.

## REE Section 39

**T.138N., R.102W., Sec. 11, NW1/4**
**Elevation at top 2,682 ft.**

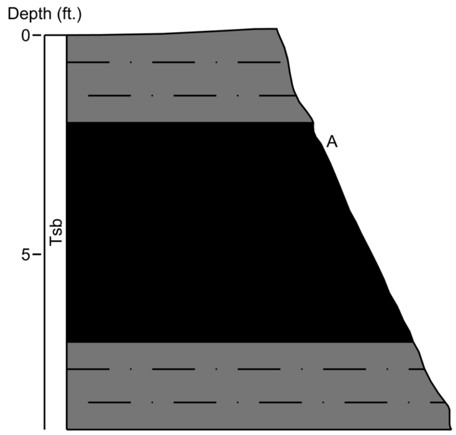



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | |
| **39D** | 8.4 | 0.8 | 0.50 | 0.18 | 0.8 | 0.17 | 5.0 | 0.06 | 3.8 | 1.0 | 0.7 | 1.2 | 0.12 | 0.07 | 0.40 | 6 | 29 | 1.25 | wcoal |
| **39C** | 42.8 | 3.2 | 2.13 | 0.77 | 3.3 | 0.69 | 22.9 | 0.34 | 19.3 | 5.2 | 3.6 | 10.5 | 0.52 | 0.32 | 2.16 | 18 | 136 | 0.95 | clmdst |
| **39B** | 16.2 | 3.2 | 2.21 | 0.54 | 2.5 | 0.72 | 8.3 | 0.34 | 8.5 | 2.1 | 2.1 | 8.5 | 0.47 | 0.32 | 2.14 | 18 | 76 | 1.67 | pcoal |
| **39A** | 22.4 | 4.7 | 3.57 | 0.70 | 3.4 | 1.12 | 11.9 | 0.57 | 10.5 | 2.6 | 2.5 | 12.6 | 0.65 | 0.52 | 3.49 | 31 | 112 | 1.82 | coal |

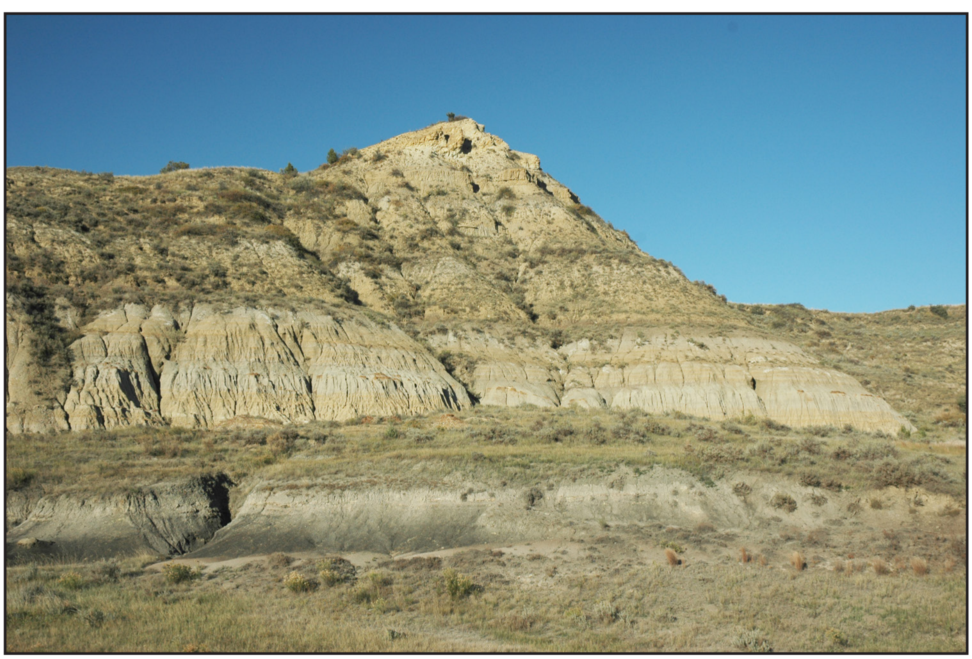
Looking northwest. A 6-foot-coal was observed near the top of the butte in this photo. Further to the west, this coal had burned and formed a clinker layer that caps the butte.

## REE Section 40

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



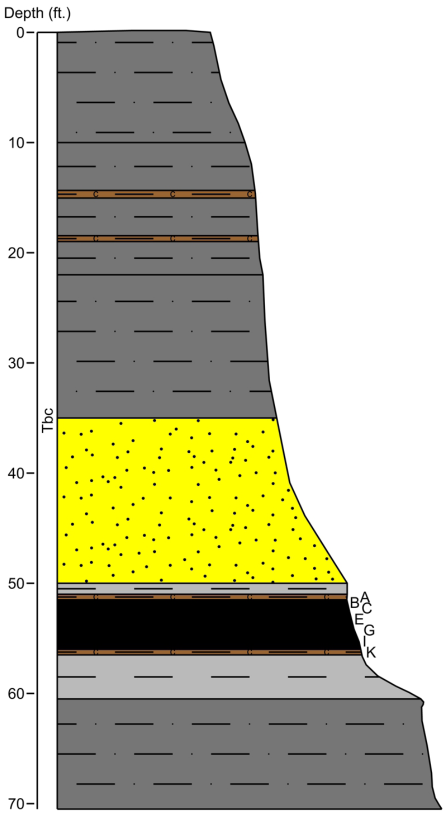

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **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 | 1.08 | coal |



Looking northeast. The coal exposed below the base of the butte behind it was sampled at this location.

## REE Section 41

**T.138N., R.102W., Sec. 16, SW1/4**
**Elevation at top 2,625 ft.**

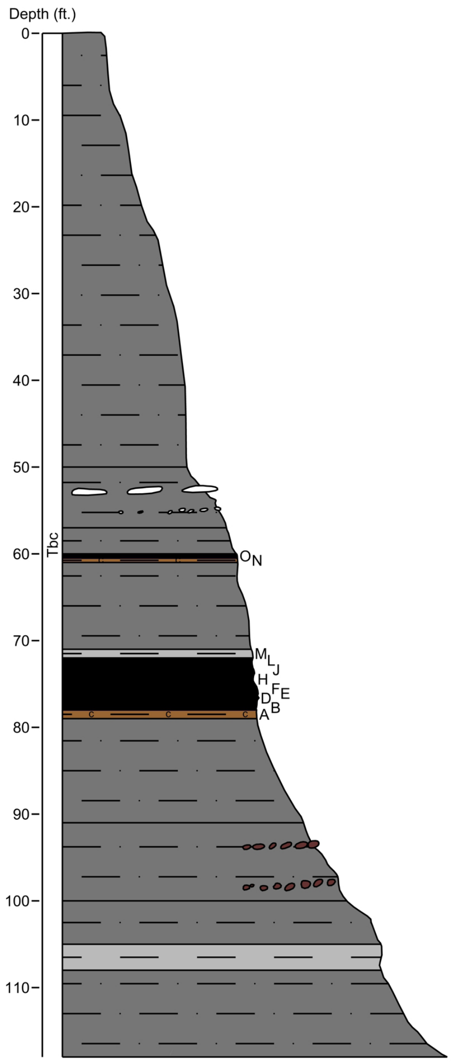



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **41A** | 18.8 | 2.8 | 1.71 | 0.55 | 2.6 | 0.57 | 8.4 | 0.25 | 9.7 | 2.4 | 2.3 | | 0.44 | 0.25 | 1.60 | 15 | 67 | 1.41 | cclyst |
| **41B** | 17.0 | 2.7 | 1.70 | 0.54 | 2.7 | 0.59 | 7.4 | 0.25 | 9.6 | 2.2 | 2.3 | | 0.46 | 0.24 | 1.57 | 15 | 64 | 1.53 | coal |
| **41C** | 12.7 | 1.3 | 0.70 | 0.33 | 1.5 | 0.25 | 5.9 | 0.09 | 6.8 | 1.6 | 1.5 | | 0.23 | 0.10 | 0.60 | 7 | 41 | 1.19 | coal |
| **41E** | 6.1 | 0.5 | 0.29 | 0.15 | 0.6 | 0.10 | 3.0 | 0.04 | 3.3 | 0.8 | 0.7 | | 0.09 | 0.04 | 0.25 | 3 | 19 | 1.12 | coal |
| **41G** | 11.1 | 0.8 | 0.47 | 0.19 | 0.8 | 0.16 | 5.8 | 0.07 | 5.0 | 1.3 | 1.0 | | 0.13 | 0.07 | 0.47 | 4 | 31 | 0.89 | coal |
| **41I** | 6.1 | 0.5 | 0.30 | 0.13 | 0.6 | 0.11 | 3.0 | 0.04 | 3.2 | 0.8 | 0.7 | | 0.09 | 0.04 | 0.27 | 3 | 19 | 1.10 | coal |
| **41K** | 20.9 | 3.3 | 2.07 | 0.63 | 3.1 | 0.69 | 9.1 | 0.32 | 11.0 | 2.7 | 2.5 | | 0.52 | 0.30 | 1.99 | 16 | 75 | 1.39 | cclyst |

Looking northwest. A five-foot-coal outcrops near the middle of the Bullion Creek formation exposures shown in this photo.

## REE Section 42

**T.138N., R.103W., Sec. 36, NESE**
**Elevation at top 2,560 ft.**

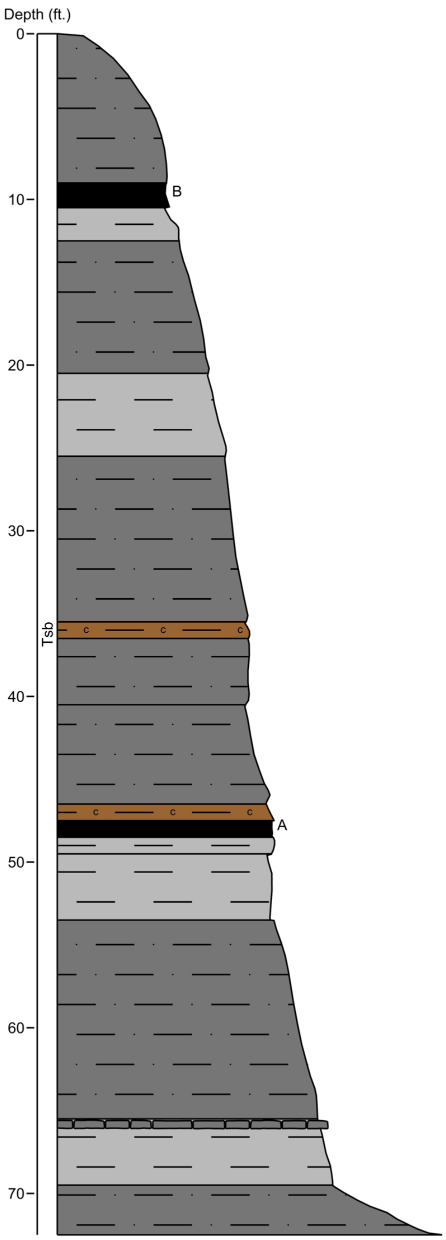



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 42O | 58.8 | 3.6 | 2.20 | 0.90 | 4.1 | 0.71 | 29.1 | 0.35 | 25.6 | 6.8 | 4.8 | | 0.59 | 0.33 | 2.24 | 19 | 159 | 0.83 | coal |
| 42N | 72.9 | 4.5 | 2.58 | 1.16 | 5.3 | 0.85 | 35.1 | 0.38 | 32.4 | 8.6 | 6.3 | | 0.76 | 0.38 | 2.48 | 21 | 195 | 0.81 | cclyst |
| 42M | 40.7 | 2.4 | 1.55 | 0.62 | 2.7 | 0.49 | 21.2 | 0.25 | 17.9 | 4.8 | 3.3 | | 0.41 | 0.24 | 1.60 | 13 | 111 | 0.83 | cclyst |
| 42L | 13.7 | 1.7 | 1.06 | 0.43 | 1.7 | 0.36 | 6.6 | 0.15 | 7.0 | 1.7 | 1.6 | | 0.29 | 0.15 | 0.98 | 11 | 48 | 1.40 | coal |
| 42J | 5.8 | 0.5 | 0.29 | 0.08 | 0.5 | 0.10 | 3.0 | 0.04 | 2.5 | 0.7 | 0.5 | | 0.08 | 0.04 | 0.25 | 3 | 17 | 1.04 | coal |
| 42H | 8.4 | 0.7 | 0.42 | 0.10 | 0.7 | 0.14 | 4.0 | 0.06 | 3.8 | 1.0 | 0.8 | | 0.12 | 0.06 | 0.39 | 3 | 24 | 0.90 | coal |
| 42F | 10.0 | 0.8 | 0.48 | 0.11 | 0.8 | 0.16 | 5.6 | 0.07 | 4.2 | 1.1 | 0.8 | | 0.13 | 0.07 | 0.44 | 5 | 30 | 1.00 | coal |
| 42E | 11.0 | 1.2 | 0.78 | 0.19 | 1.2 | 0.26 | 5.0 | 0.12 | 5.5 | 1.4 | 1.2 | | 0.20 | 0.11 | 0.74 | 9 | 38 | 1.38 | coal |
| 42D | 7.1 | 1.0 | 0.60 | 0.19 | 1.1 | 0.22 | 3.2 | 0.07 | 3.9 | 0.9 | 0.9 | | 0.17 | 0.08 | 0.49 | 7 | 27 | 1.62 | coal |
| 42B | 32.2 | 5.4 | 3.21 | 0.97 | 5.0 | 1.11 | 14.5 | 0.42 | 17.0 | 4.2 | 4.1 | | 0.86 | 0.45 | 2.84 | 24 | 116 | 1.39 | coal |
| 42A | 66.5 | 3.0 | 2.08 | 0.77 | 3.5 | 0.64 | 35.7 | 0.36 | 27.3 | 7.6 | 4.5 | | 0.48 | 0.33 | 2.31 | 17 | 172 | 0.72 | cclyst |

Looking northwest. Due to the steep exposures here, the portion of the section above samples 42O & 42N was based on photos.

# REE Section 43

**T.138N., R.101W., Sec. 35, NW1/4**
**Elevation at top 2,792 ft.**

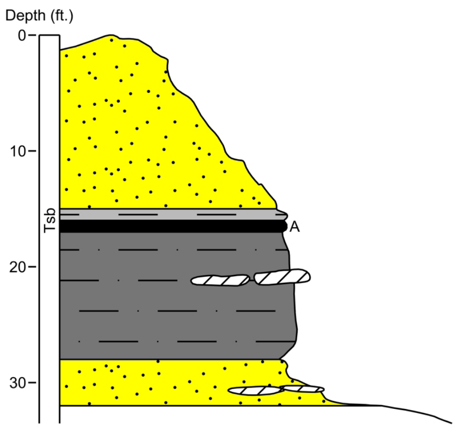



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **43B** | 33.2 | 4.2 | 2.65 | 0.83 | 4.1 | 0.92 | 14.8 | 0.37 | 15.9 | 4.1 | 3.4 | 3.1 | 0.68 | 0.37 | 2.32 | 27 | 118 | 1.38 | pcoal |
| **43A** | 34.4 | 4.8 | 2.88 | 1.17 | 5.0 | 1.00 | 13.5 | 0.40 | 19.7 | 4.7 | 4.6 | 9.5 | 0.80 | 0.40 | 2.57 | 25 | 130 | 1.40 | coal |

Looking northeast. The section was measured from the base to the top of this butte, along the eastern flank.

## REE Section 44

**T.137N., R.101W., Sec. 1, NW/SE/SE**
**Elevation at top 2,940 ft.**

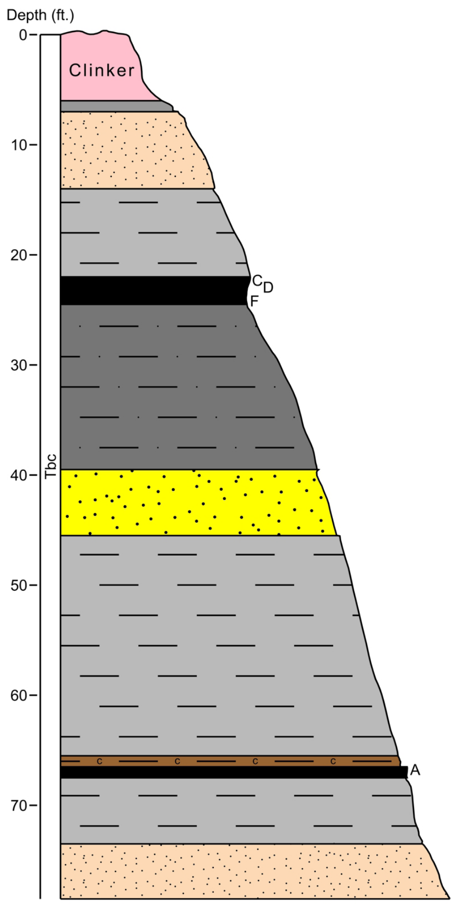



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **44A** | 50.3 | 5.1 | 3.23 | 1.27 | 5.3 | 1.09 | 26.0 | 0.49 | 24.2 | 6.1 | 5.0 | 9.5 | 0.84 | 0.47 | 3.04 | 32 | 174 | 1.20 | pcoal |

Looking west. The section was measured from the base to the top of the small, flat hill. The top of this hill is either a blowout in the soft coal or a small pit where uraniferous coal was removed in the 1950s.

## REE Section 45

**T.137N., R.101W., Sec. 27 SE/SE/SE**
**Elevation at top 2,746 ft.**

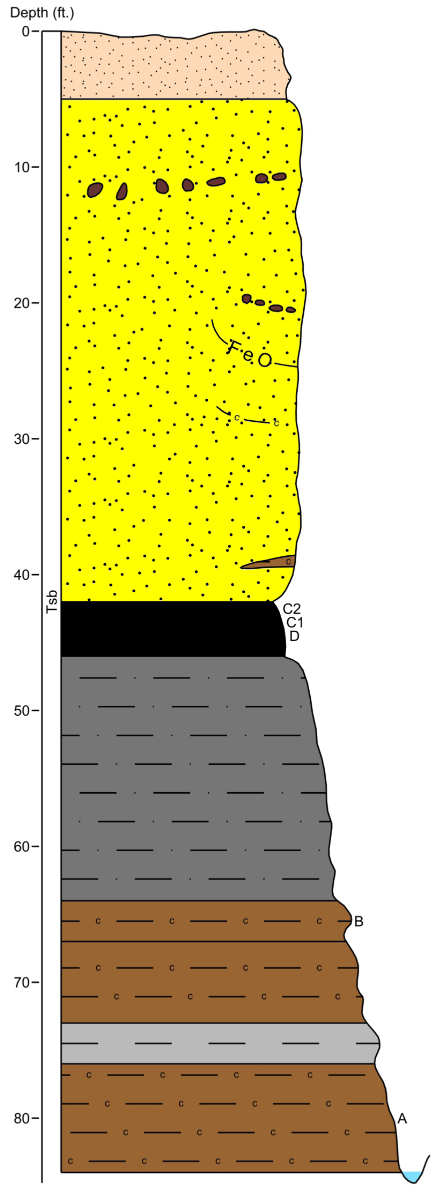



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **45C** | 55.7 | 6.7 | 3.80 | 1.18 | 6.3 | 1.33 | 21.9 | 0.52 | 29.1 | 7.3 | 6.6 | | 1.05 | 0.56 | 3.52 | 30 | 176 | 1.17 | coal |
| **45D** | 13.5 | 1.0 | 0.64 | 0.24 | 1.1 | 0.22 | 9.6 | 0.10 | 5.1 | 1.4 | 1.0 | 2.6 | 0.17 | 0.09 | 0.61 | 7 | 44 | 0.97 | coal |
| **45F** | 9.8 | 1.0 | 0.64 | 0.22 | 1.0 | 0.21 | 5.9 | 0.09 | 4.5 | 1.1 | 1.0 | | 0.15 | 0.09 | 0.58 | 6 | 32 | 1.16 | coal |
| **45A** | 36.6 | 5.8 | 3.04 | 1.41 | 6.3 | 1.10 | 11.0 | 0.40 | 25.4 | 5.7 | 6.3 | | 0.97 | 0.43 | 2.65 | 23 | 130 | 1.45 | coal |

Looking east. The section was measured from the base of exposures to the top of this clinker capped butte.

# REE Section 46

**T.137N., R.100W., Sec. 8, SW/SE/NW**
**Elevation at top 2,948 ft.**

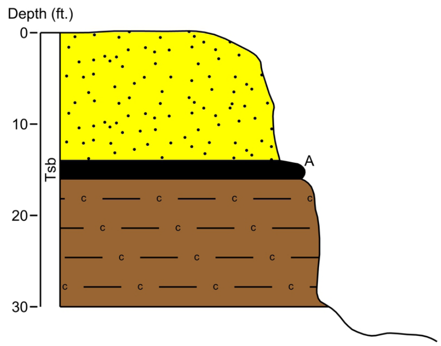



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| **46C2** | 70.5 | 11.6 | 7.75 | 2.05 | 10.2 | 2.53 | 33.4 | 1.21 | 36.1 | 8.7 | 8.1 | 18.1 | 1.76 | 1.14 | 7.56 | 67 | 288 | 1.52 | coal |
| **46C1** | 18.1 | 2.0 | 1.29 | 0.53 | 2.1 | 0.42 | 10.4 | 0.18 | 8.9 | 2.2 | 1.8 | 4.7 | 0.31 | 0.18 | 1.14 | 17 | 71 | 1.50 | wcoal |
| **46D** | 10.6 | 1.0 | 0.57 | 0.24 | 1.1 | 0.20 | 5.8 | 0.08 | 5.4 | 1.3 | 1.1 | 2.2 | 0.17 | 0.08 | 0.49 | 6 | 36 | 1.17 | hcoal |
| **46B** | 47.4 | 5.9 | 3.67 | 1.43 | 5.9 | 1.19 | 20.9 | 0.57 | 25.5 | 6.2 | 5.7 | 17.2 | 0.94 | 0.52 | 3.59 | 33 | 180 | 1.32 | clmdst |
| **46A** | 43.8 | 3.2 | 2.02 | 0.94 | 3.6 | 0.64 | 21.6 | 0.33 | 20.8 | 5.3 | 4.1 | 15.9 | 0.53 | 0.30 | 2.05 | 19 | 144 | 0.99 | cclyst |

Looking south. The section was measured from the base of an intermittent stream south of the butte in the center-background of the photo to the top of the escarpment due east of the butte in the center-background.

## REE Section 47

**T.137N., R.100W., Sec. 21, SW/SW/NW**
**Elevation at top 2,835 ft.**

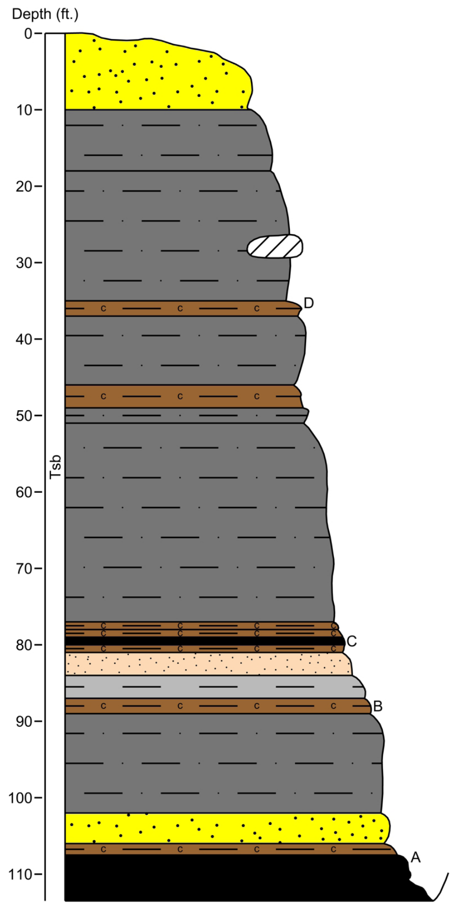



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **47A** | 31.9 | 4.1 | 2.85 | 0.85 | 3.4 | 0.90 | 17.7 | 0.46 | 14.8 | 3.9 | 3.2 | 17.3 | 0.60 | 0.43 | 2.89 | 26 | 131 | 1.34 | coal |

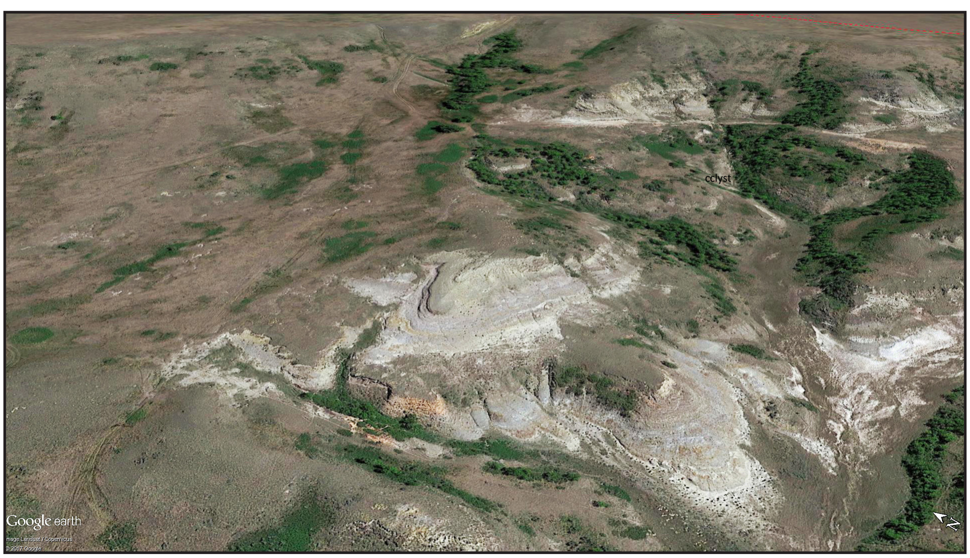
Looking south. The section was measured from the base to the top of this small outcrop.

## REE Section 48

**T.137N., R.100W., Sec. 28, C/NW**
**Elevation at top 2,891 ft.**



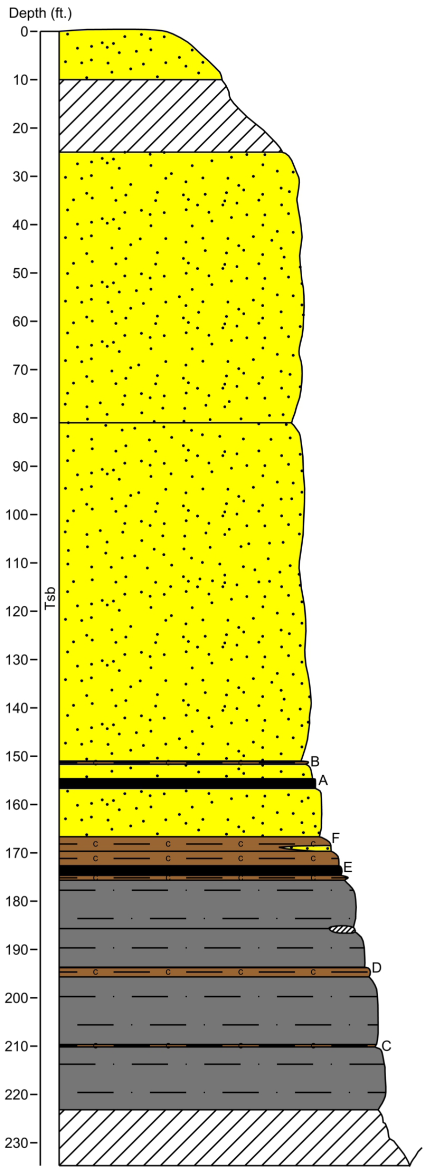

| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| 48D | 55.0 | 8.9 | 5.96 | 1.84 | 8.0 | 1.97 | 24.8 | 0.90 | 28.5 | 7.0 | 6.6 | 17.7 | 1.38 | 0.85 | 5.57 | 59 | 234 | 1.64 | clmdst |
| 48C | 26.3 | 3.7 | 2.46 | 0.7 | 3.2 | 0.82 | 13.9 | 0.35 | 12.2 | 3.2 | 2.7 | 12.0 | 0.57 | 0.34 | 2.25 | 25 | 110 | 1.48 | coal |
| 48B | 46.8 | 3.1 | 1.81 | 0.97 | 3.7 | 0.61 | 23.4 | 0.28 | 22 | 5.7 | 4.3 | 15.1 | 0.55 | 0.26 | 1.83 | 16 | 146 | 0.89 | cclyst |
| 48A | 32.3 | 2.7 | 1.64 | 0.74 | 2.9 | 0.55 | 14.7 | 0.23 | 15.7 | 4.1 | 3.2 | 10.5 | 0.46 | 0.23 | 1.55 | 16 | 108 | 1.07 | coal |



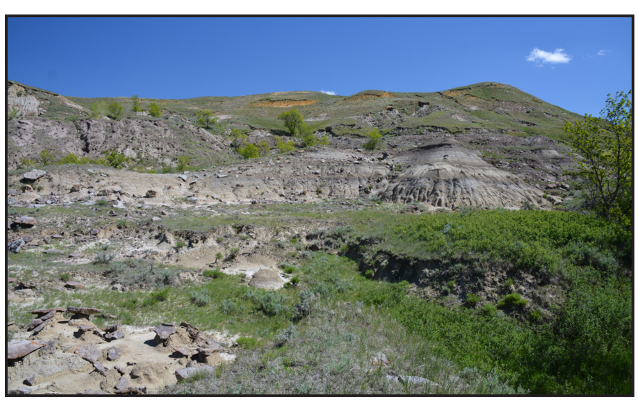

Looking northeast on a GoogleEarth photo. The section was measured from the base of the small, well-vegetated ravine in the foreground to the top of the center-right outcrop in the background.

# REE Section 49

Billings County



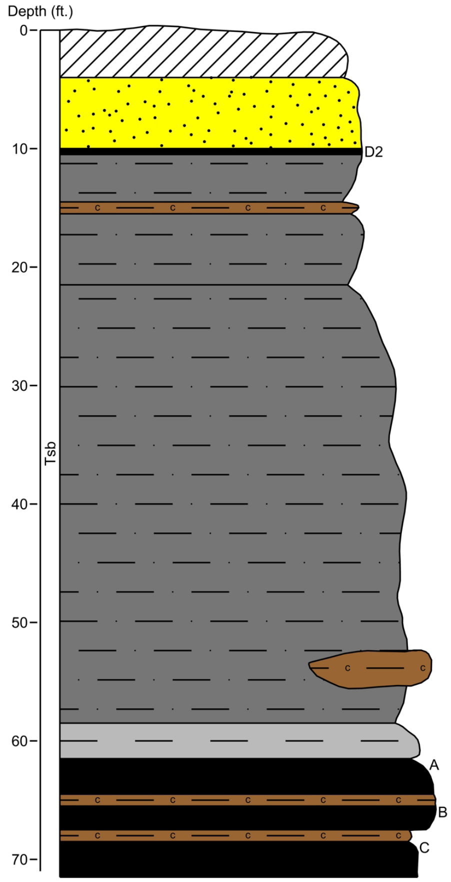

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **49B** | 70.2 | 10.6 | 7.51 | 2.22 | 9.6 | 2.42 | 34.3 | 1.22 | 37.6 | 9.0 | 8.4 | 28.3 | 1.64 | 1.11 | 7.47 | 71 | 303 | 1.58 | coal |
| **49A** | 35.4 | 1.7 | 1.00 | 0.67 | 2.2 | 0.33 | 15.2 | 0.16 | 16.7 | 4.4 | 3.0 | 8.1 | 0.30 | 0.15 | 1.03 | 9 | 99 | 0.79 | coal |
| **49F** | 24.5 | 2.5 | 1.51 | 0.73 | 2.7 | 0.52 | 10.6 | 0.20 | 12.0 | 3.0 | 2.6 | 8.3 | 0.43 | 0.20 | 1.31 | 16 | 87 | 1.24 | coal |
| **49E** | 65.5 | 5.9 | 3.30 | 1.76 | 6.8 | 1.15 | 32.5 | 0.47 | 35.0 | 8.8 | 7.3 | 18.2 | 1.03 | 0.46 | 3.04 | 30 | 221 | 1.09 | coal |
| **49D** | 27.4 | 3.7 | 2.62 | 0.78 | 3.2 | 0.84 | 14.1 | 0.39 | 13.2 | 3.4 | 2.8 | 13.2 | 0.55 | 0.37 | 2.46 | 28 | 117 | 1.55 | clmdst |
| **49C** | 46.3 | 2.8 | 1.64 | 0.96 | 3.4 | 0.55 | 23.7 | 0.26 | 21.2 | 5.6 | 4.1 | 16.6 | 0.49 | 0.24 | 1.63 | 14 | 143 | 0.84 | cmdst |



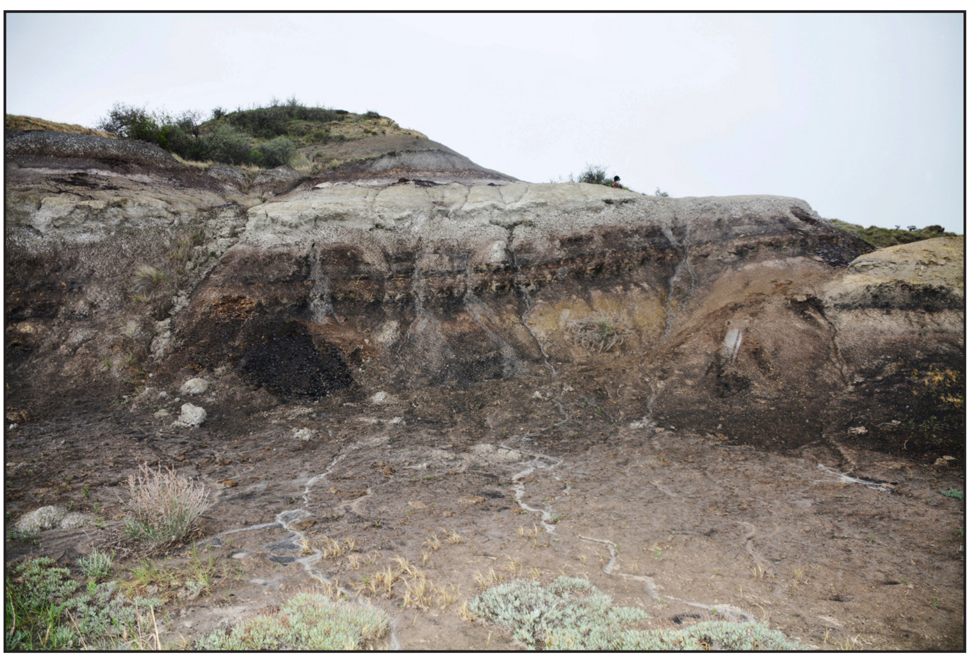
Looking northeast. The section was measured from the base of the knoll in the right-center portion of the photograph and carried through to the top of the hillside on the left.

# REE Section 50

**T.136N., R.101W., Sec. 13, NW/SE/NE**
**Elevation at top 2,929 ft.**




| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| 50D2 | 57.4 | 11.9 | 8.44 | 1.93 | 9.7 | 2.69 | 29.0 | 1.29 | 29.3 | 7.2 | 7.1 | 12.4 | 1.74 | 1.19 | 7.95 | 90 | 279 | 2.03 | pcoal |
| 50A | 78.1 | 7.1 | 3.85 | 2.01 | 8.7 | 1.35 | 34.4 | 0.54 | 43.0 | 10.3 | 9.6 | 12.9 | 1.26 | 0.53 | 3.59 | 33 | 250 | 1.07 | coal |
| 50B | 33.6 | 4.2 | 2.64 | 1.11 | 4.6 | 0.86 | 13.7 | 0.42 | 20.3 | 4.8 | 4.8 | 12.6 | 0.70 | 0.38 | 2.69 | 21 | 128 | 1.32 | coal |
| 50C | 54.4 | 4.2 | 2.41 | 1.28 | 4.9 | 0.79 | 24.2 | 0.37 | 27.5 | 7.0 | 5.8 | 12.6 | 0.72 | 0.34 | 2.40 | 20 | 169 | 0.96 | coal |

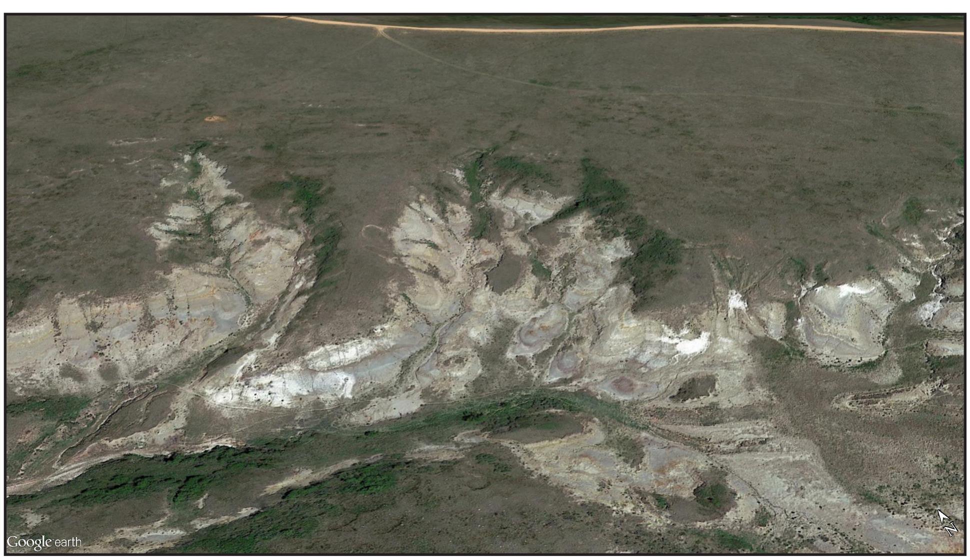


Looking southeast. The measured section started at the base of the three coals (the disturbed area) and ended at the top of this small butte.

# REE Section 51

**T.136N., R.101W., Sec. 23, Center NW**
**Elevation at top 2,841 ft.**

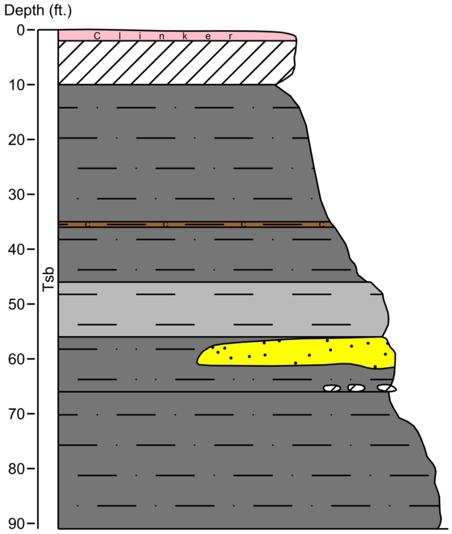

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| 51C | 29.4 | 4.4 | 2.84 | 0.84 | 4.2 | 0.95 | 13.6 | 0.38 | 14.9 | 3.7 | 3.1 | 3.4 | 0.69 | 0.39 | 2.43 | 34 | 119 | 1.72 | wcoal |
| 51B | 42.2 | 5.8 | 3.80 | 1.39 | 5.9 | 1.22 | 17.8 | 0.65 | 23.9 | 5.7 | 5.6 | 15.2 | 0.94 | 0.56 | 4.04 | 29 | 164 | 1.33 | clmdst |
| 51A | 11.8 | 1.6 | 0.98 | 0.44 | 1.6 | 0.32 | 5.1 | 0.15 | 7.2 | 1.7 | 1.7 | 5.5 | 0.25 | 0.14 | 0.96 | 9 | 48 | 1.46 | coal |




Looking northeast on a GoogleEarth photo. The section was measured from the base to the top of the ravine.

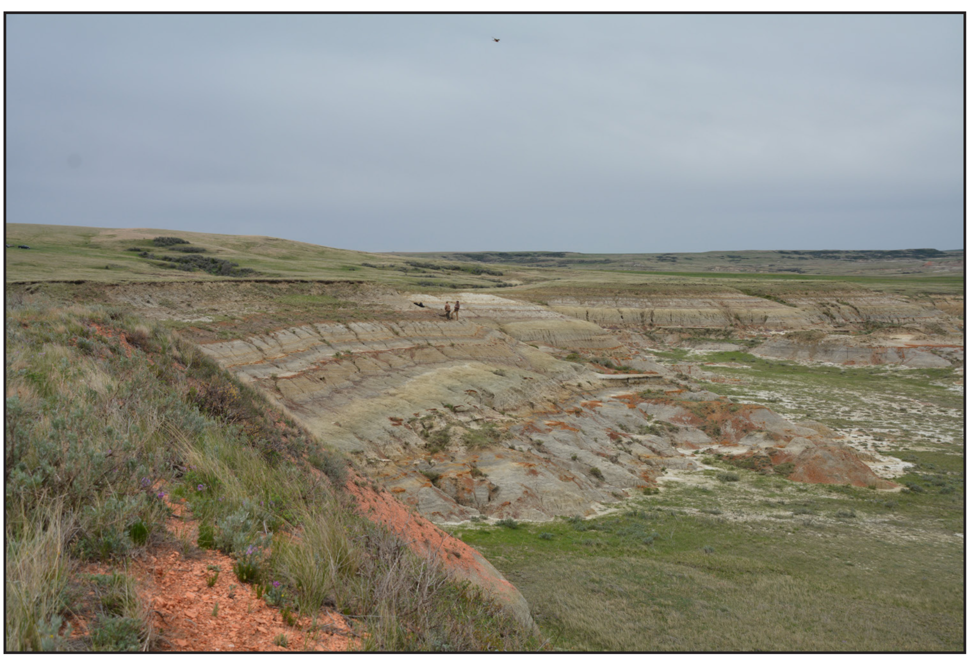
## REE Section 52

**T.136N., R.101W., Sec. 36, NW/SW-SW/NW**
**Elevation at top 2,836 ft.**




| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |

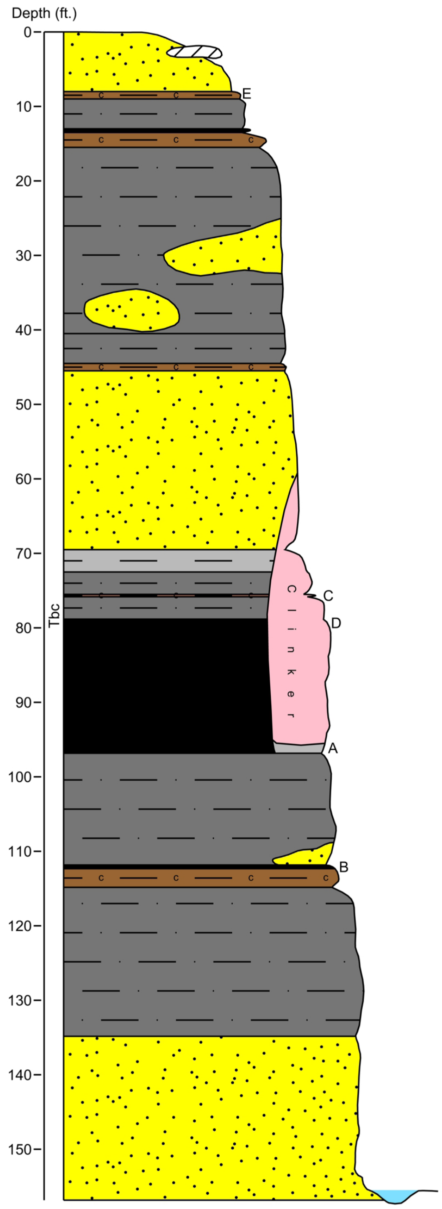
No laboratory analysis for section 52



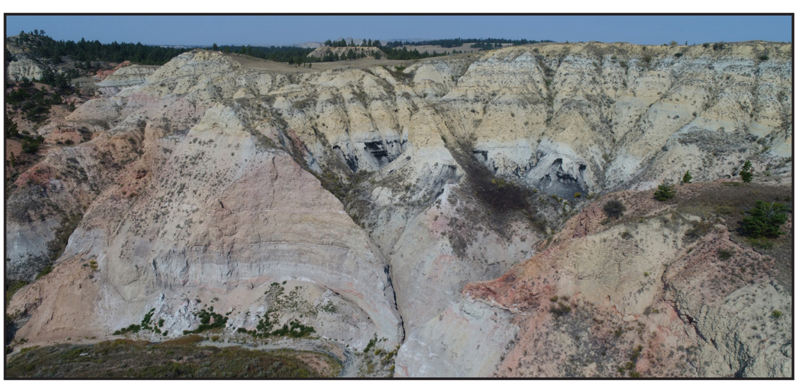
Looking southeast. The coal that generated the clinker in the foreground was covered at this site.

## REE Section 53

**T.136N., R.102W., Sec. 15, SE/SE**
**Elevation at top 2,661 ft.**



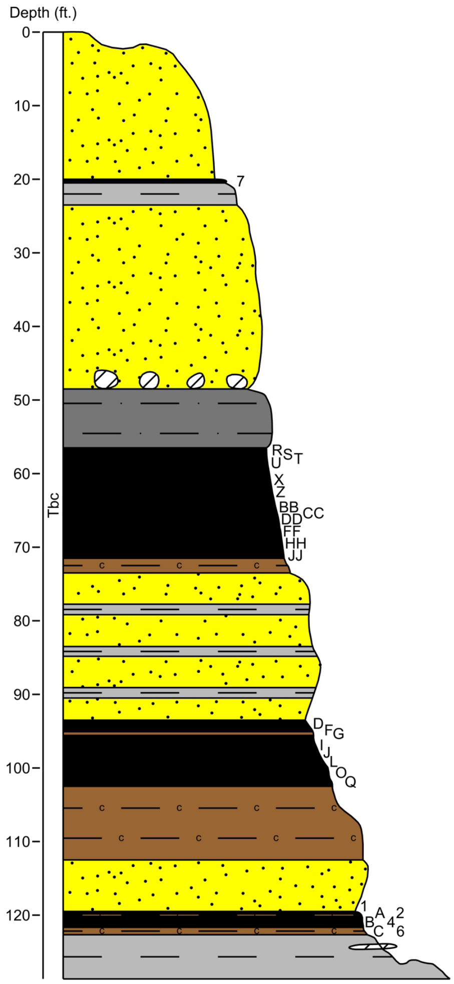

| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| 53E | 55.4 | 4.7 | 2.93 | 1.14 | 5.0 | 0.99 | 28.4 | 0.44 | 26.3 | 6.7 | 5.1 | 11.4 | 0.76 | 0.42 | 2.75 | 27 | 179 | 1.05 | cmdst |
| 53C | 64.1 | 4.6 | 2.83 | 1.13 | 5.0 | 0.94 | 31.4 | 0.44 | 28.7 | 7.7 | 5.6 | 13.1 | 0.79 | 0.42 | 2.89 | 23 | 193 | 0.89 | cmdst |
| 53D | 18.2 | 4.2 | 3.66 | 0.62 | 2.7 | 1.08 | 9.4 | 0.65 | 8.9 | 2.2 | 2.1 | 13.9 | 0.54 | 0.57 | 4.01 | 30 | 103 | 1.96 | coal |
| 53A | 81.1 | 5.0 | 2.85 | 1.38 | 5.4 | 1.00 | 54.7 | 0.39 | 29.0 | 8.3 | 5.2 | 11.2 | 0.82 | 0.40 | 2.62 | 27 | 236 | 0.77 | ash |
| 53B | 98.4 | 4.7 | 2.40 | 1.48 | 6.2 | 0.88 | 53.4 | 0.34 | 39.9 | 10.9 | 7.3 | 13.5 | 0.87 | 0.35 | 2.28 | 21 | 264 | 0.69 | pcoal |



Looking northeast. The section was measured from the base of the outcrop above First Creek to the top of the slope. The Harmon Bed has burned through much of this area.

# REE Sections 54 & 55

**T.136N., R.102W., Sec. 16, NE1/4**
**Elevation at top 2,616 ft.**

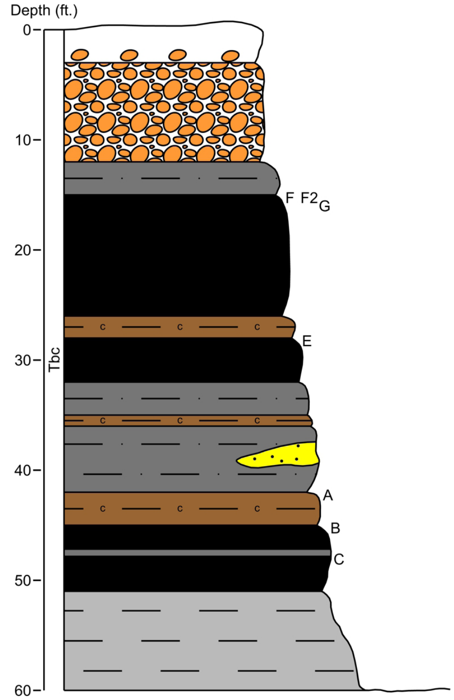



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 55-7 | 47.8 | 11.7 | 8.34 | 1.71 | 8.3 | 2.71 | 25.4 | 1.22 | 24.7 | 6.1 | 6 | 28.4 | 1.63 | 1.2 | 7.75 | 69 | 252 | 1.93 | pcoal |
| 54R | 16.6 | 4.5 | 2.79 | 0.76 | 3.8 | 0.95 | 7.3 | 0.37 | 9.9 | 2.2 | 2.7 | | 0.69 | 0.38 | 2.39 | 28 | 83 | 2.25 | coal |
| 54S | 11.4 | 1.4 | 0.82 | 0.29 | 1.4 | 0.29 | 7.7 | 0.10 | 5.0 | 1.2 | 1.1 | | 0.22 | 0.11 | 0.66 | 11 | 43 | 1.49 | coal |
| 54T | 7.7 | 0.7 | 0.43 | 0.16 | 0.8 | 0.15 | 3.8 | 0.05 | 3.6 | 0.9 | 0.7 | | 0.12 | 0.06 | 0.33 | 6 | 26 | 1.33 | coal |
| 54U | 8.8 | 0.7 | 0.39 | 0.18 | 0.7 | 0.14 | 5.0 | 0.05 | 3.8 | 1.0 | 0.7 | | 0.11 | 0.06 | 0.34 | 5 | 27 | 1.08 | coal |
| 54X | 16.1 | 0.8 | 0.43 | 0.18 | 0.8 | 0.15 | 11.5 | 0.06 | 4.8 | 1.5 | 0.8 | | 0.13 | 0.06 | 0.38 | 4 | 42 | 0.62 | hcoal |
| 54Z | 17.9 | 0.8 | 0.44 | 0.19 | 0.8 | 0.15 | 14.1 | 0.06 | 4.6 | 1.5 | 0.8 | | 0.13 | 0.07 | 0.40 | 4 | 46 | 0.55 | hcoal |
| 54BB | 9.0 | 0.8 | 0.42 | 0.21 | 0.8 | 0.15 | 3.6 | 0.05 | 3.8 | 1.0 | 0.8 | | 0.13 | 0.06 | 0.36 | 4 | 25 | 0.97 | coal |
| 54CC | 11.6 | 0.7 | 0.38 | 0.19 | 0.7 | 0.14 | 7.9 | 0.04 | 3.7 | 1.1 | 0.7 | | 0.12 | 0.05 | 0.31 | 4 | 32 | 0.75 | coal |
| 54DD | 11.8 | 0.6 | 0.33 | 0.17 | 0.7 | 0.12 | 7.2 | 0.04 | 3.8 | 1.2 | 0.7 | | 0.11 | 0.05 | 0.27 | 3 | 30 | 0.65 | coal |
| 54FF | 26.6 | 1.2 | 0.67 | 0.27 | 1.4 | 0.23 | 14.8 | 0.08 | 10.0 | 2.9 | 1.5 | | 0.22 | 0.10 | 0.56 | 5 | 66 | 0.63 | coal |
| 54HH | 11.8 | 1.0 | 0.56 | 0.23 | 1.1 | 0.19 | 5.0 | 0.08 | 5.7 | 1.5 | 1.2 | | 0.17 | 0.09 | 0.53 | 5 | 34 | 1.00 | coal |
| 54JJ | 13.5 | 0.7 | 0.45 | 0.23 | 0.9 | 0.14 | 7.0 | 0.07 | 5.7 | 1.5 | 1.0 | | 0.12 | 0.07 | 0.46 | 4 | 36 | 0.79 | coal |
| 54D | 78.1 | 4.7 | 2.61 | 1.28 | 5.4 | 0.88 | 37.9 | 0.37 | 33.5 | 9.0 | 6.4 | | 0.81 | 0.37 | 2.47 | 22 | 206 | 0.79 | coal |
| 54F | 10.8 | 2.5 | 1.68 | 0.34 | 2.0 | 0.54 | 5.3 | 0.26 | 5.9 | 1.4 | 1.7 | | 0.36 | 0.25 | 1.68 | 14 | 49 | 1.83 | coal |
| 54G | 37.0 | 3.9 | 2.46 | 0.47 | 3.5 | 0.80 | 16.6 | 0.34 | 16.9 | 4.6 | 3.7 | | 0.62 | 0.35 | 2.27 | 21 | 115 | 1.11 | coal |
| 54I | 23.6 | 1.7 | 1.01 | 0.29 | 1.7 | 0.34 | 13.6 | 0.14 | 8.7 | 2.5 | 1.6 | | 0.28 | 0.14 | 0.89 | 9 | 65 | 0.84 | coal |
| 54J | 13.3 | 0.8 | 0.41 | 0.16 | 0.8 | 0.15 | 8.0 | 0.04 | 4.3 | 1.3 | 0.8 | | 0.13 | 0.05 | 0.31 | 4 | 35 | 0.71 | coal |
| 54L | 5.7 | 0.4 | 0.18 | 0.07 | 0.3 | 0.07 | 3.3 | 0.02 | 1.9 | 0.6 | 0.3 | | 0.06 | 0.02 | 0.14 | 2 | 15 | 0.77 | coal |
| 54O | 10.8 | 0.7 | 0.38 | 0.16 | 0.8 | 0.14 | 6.4 | 0.04 | 3.9 | 1.1 | 0.7 | | 0.12 | 0.05 | 0.31 | 4 | 30 | 0.82 | coal |
| 54Q | 10.6 | 1.0 | 0.46 | 0.22 | 1.1 | 0.18 | 6.1 | 0.05 | 4.4 | 1.2 | 0.9 | | 0.17 | 0.06 | 0.33 | 7 | 34 | 1.18 | coal |
| 54A | 206 | 17.9 | 7.69 | 7.55 | 26.1 | 3.04 | 72.9 | 0.88 | 136 | 30.3 | 32.9 | | 3.66 | 1.04 | 6.35 | 51 | 603 | 1.03 | coal |
| 54B | 158 | 16.0 | 6.61 | 6.81 | 24.7 | 2.70 | 60.9 | 0.73 | 114 | 23.9 | 28.9 | | 3.32 | 0.86 | 5.31 | 46 | 499 | 1.15 | coal |
| 54C | 65.2 | 9.2 | 5.45 | 2.96 | 10.9 | 1.86 | 22.7 | 0.87 | 48.4 | 10.1 | 12.4 | | 1.63 | 0.84 | 5.79 | 29 | 227 | 1.30 | coal |
| 55-1 | 36.2 | 1.5 | 0.99 | 0.52 | 2 | 0.32 | 18 | 0.18 | 15.6 | 4.2 | 2.7 | | 0.27 | 0.16 | 1.16 | 8 | 92 | 0.71 | ss |
| 55-2 | 139 | 8.3 | 3.35 | 3.03 | 12 | 1.34 | 69.1 | 0.37 | 64.7 | 16.7 | 13.5 | | 1.67 | 0.41 | 2.67 | 29 | 365 | 0.77 | clmdst |
| 55-4 | 94.7 | 8.2 | 4.6 | 2.04 | 8.9 | 1.66 | 42.7 | 0.58 | 45.0 | 11.9 | 9.0 | 13.9 | 1.41 | 0.63 | 3.95 | 38 | 287 | 0.98 | coal |
| 55-6 | 62.6 | 3.3 | 2.04 | 0.91 | 3.9 | 0.64 | 31.5 | 0.32 | 27.2 | 7.3 | 4.9 | | 0.56 | 0.3 | 2.11 | 16 | 164 | 0.76 | cmdst |

Looking northwest. The section was measured from the base of the outcrop, up the cliff face, and to the top of the adjacent hill.

## REE Section 56

**T.136N., R.102W., Sec. 7, SE/SE**
**Elevation at top 2,600 ft.**

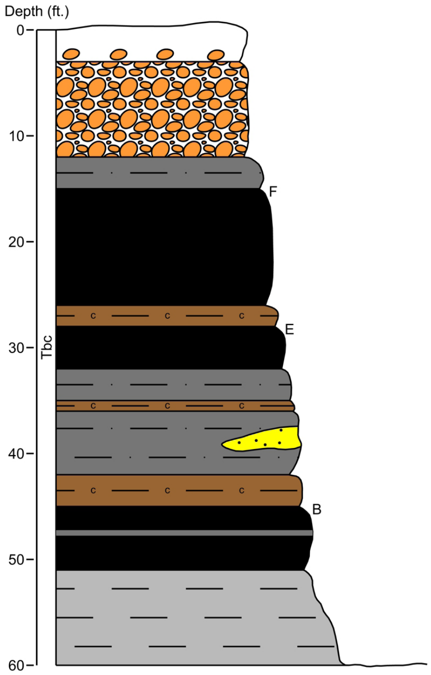



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **56F** | 151 | 18.8 | 9.65 | 4.00 | 20.6 | 3.60 | 64.2 | 1.15 | 77.6 | 19.2 | 17.4 | 16.8 | 3.30 | 1.28 | 7.78 | 77 | 493 | 1.15 | coal |
| **56F$_2$** | 165 | 20.6 | 10.1 | 4.80 | 23.6 | 3.87 | 68.4 | 1.20 | 91.2 | 22.5 | 20.9 | 17.7 | 3.80 | 1.35 | 7.97 | 92 | 555 | 1.24 | coal |
| **56G** | 32.8 | 2.6 | 1.59 | 0.51 | 2.7 | 0.57 | 20.7 | 0.19 | 12.1 | 3.7 | 2.1 | 2.1 | 0.43 | 0.22 | 1.24 | 20 | 104 | 1.06 | coal |
| **56E** | 105 | 7.8 | 3.61 | 2.42 | 9.8 | 1.35 | 41.6 | 0.46 | 52.3 | 13.3 | 11.2 | 18.1 | 1.46 | 0.49 | 3.17 | 23 | 295 | 0.82 | hcoal |
| **56A** | 121 | 8.2 | 4.23 | 2.58 | 9.9 | 1.53 | 58.7 | 0.58 | 55.4 | 14.6 | 11.3 | 16.5 | 1.49 | 0.60 | 4.00 | 33 | 344 | 0.82 | cmdst |
| **56B** | 76.5 | 5.5 | 2.88 | 1.74 | 6.6 | 1.01 | 33.2 | 0.41 | 38.4 | 9.8 | 8.3 | 19.9 | 1.00 | 0.41 | 2.75 | 20 | 228 | 0.86 | coal |
| **56C** | 32.1 | 0.9 | 0.40 | 0.22 | 1.3 | 0.14 | 16.3 | 0.05 | 11.2 | 3.4 | 1.9 | 1.6 | 0.17 | 0.05 | 0.34 | 4 | 74 | 0.52 | ton |

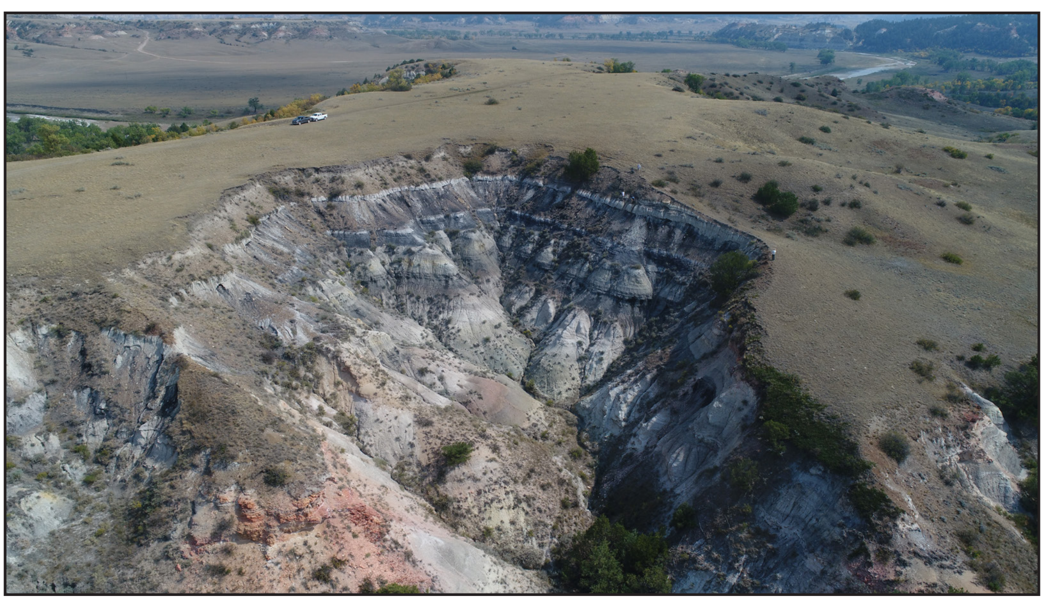
Looking east from a drone. The section was started approximately 50 feet above the base of the outcrop and carried through to the top of the ravine at this locality.

## REE Section 57

**T.136N., R.102W., Sec. 7, SE/SE**
**Elevation at top 2,600 ft.**



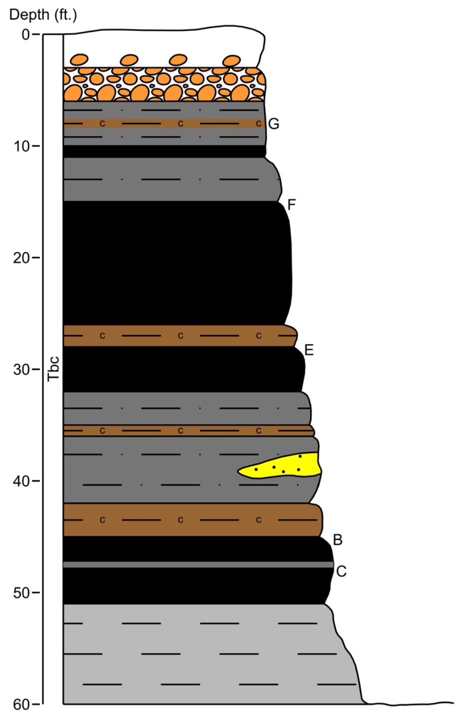

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **57F** | 101 | 8.5 | 4.33 | 2.10 | 9.6 | 1.60 | 47.2 | 0.53 | 44.6 | 12.0 | 9.2 | 9.1 | 1.54 | 0.60 | 3.60 | 39 | 295 | 0.93 | coal |
| **57E** | 49.4 | 3.7 | 1.82 | 1.23 | 4.8 | 0.66 | 18.2 | 0.26 | 25.7 | 6.6 | 5.5 | 10.8 | 0.72 | 0.26 | 1.71 | 12 | 143 | 0.86 | hcoal |
| **57B** | 31.6 | 2.4 | 1.15 | 0.89 | 3.3 | 0.43 | 14.3 | 0.15 | 18.3 | 4.4 | 4.0 | 9.9 | 0.45 | 0.16 | 0.99 | 10 | 102 | 1.00 | coal |



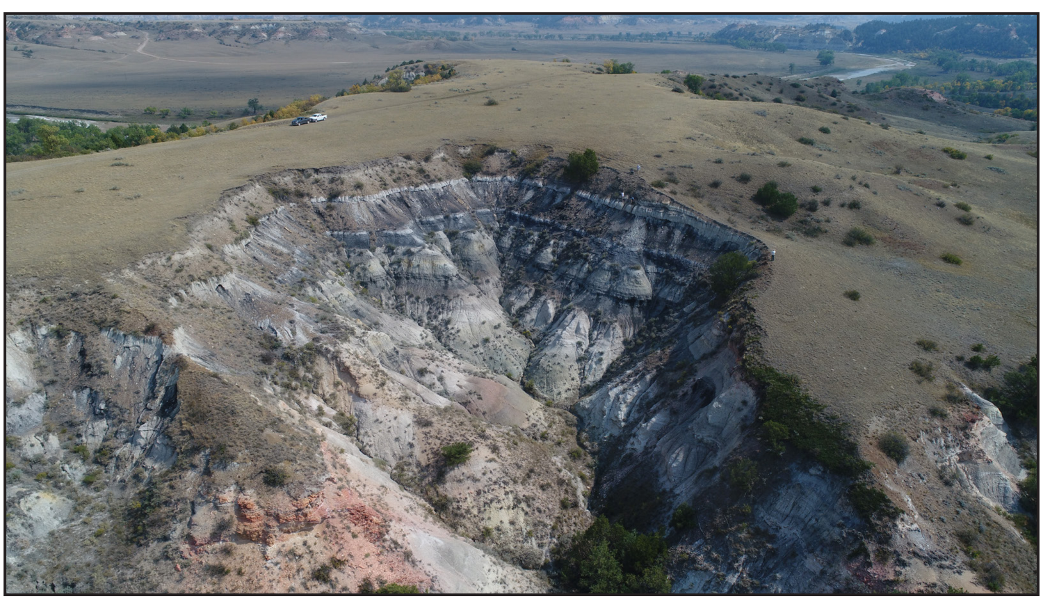
Looking east from a drone. The section was started approximately 50 feet above the base of the outcrop and carried through to the top of the ravine at this locality.

## REE Section 58

**T.136N., R.102W., Sec. 7, SE/SE**
**Elevation at top 2,600 ft.**



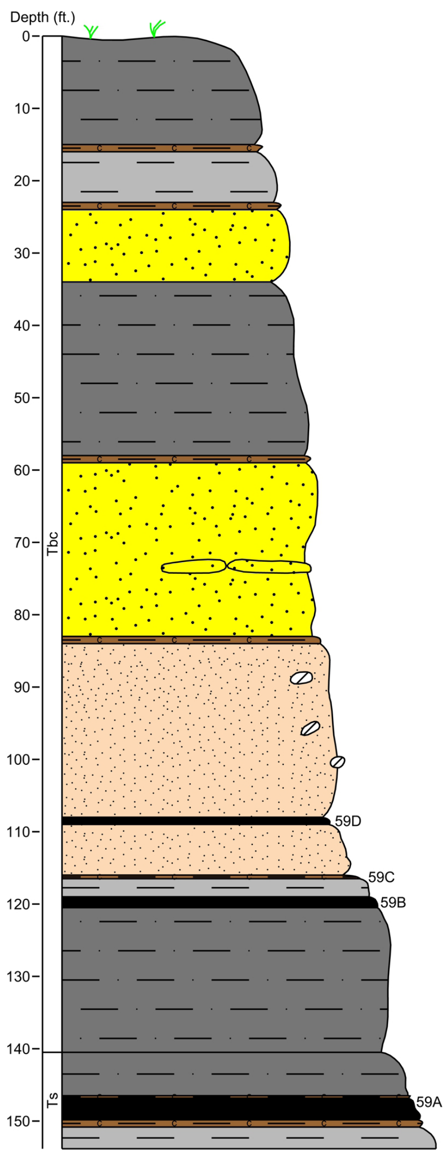

| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
| 58G | 31.1 | 5.5 | 3.62 | 1.27 | 4.9 | 1.23 | 14.4 | 0.52 | 16.3 | 4.0 | 4.0 | 9.1 | 0.86 | 0.52 | 3.28 | 39 | 140 | 1.82 | clmdst |
| 58F | 107 | 12.2 | 5.84 | 3.12 | 14.2 | 2.20 | 41.3 | 0.71 | 59.5 | 14.7 | 14.1 | 18.9 | 2.26 | 0.79 | 4.80 | 48 | 350 | 1.13 | coal |
| 58E | 9.9 | 0.6 | 0.29 | 0.28 | 0.9 | 0.10 | 3.6 | 0.05 | 6.2 | 1.5 | 1.4 | 8.5 | 0.12 | 0.05 | 0.33 | 2 | 36 | 0.91 | hcoal |
| 58B | 94.3 | 6.5 | 3.10 | 2.51 | 8.7 | 1.15 | 40.8 | 0.41 | 50.7 | 12.9 | 11.0 | 21.9 | 1.24 | 0.44 | 2.81 | 26 | 284 | 0.91 | coal |
| 58C | 73.5 | 2.7 | 1.30 | 0.46 | 3.6 | 0.48 | 32.0 | 0.16 | 27.7 | 8.3 | 4.8 | 2.2 | 0.51 | 0.18 | 1.12 | 14 | 173 | 0.62 | clyst |



Looking east from a drone. The section was started approximately 50 feet above the base of the outcrop and carried through to the top of the ravine at this locality.

## REE Section 59

**T.136N., R.103W., Sec. 22, SE/NW/SW**
**Elevation at top 2,794 ft.**

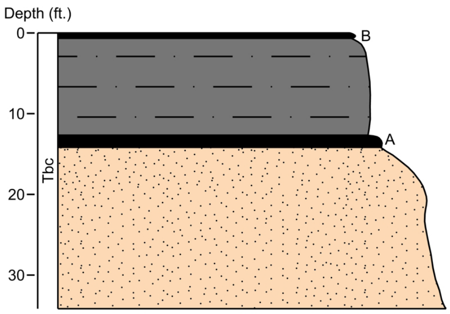



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| **59D** | 38.3 | 7.6 | 5.24 | 1.51 | 6.4 | 1.75 | 19.3 | 0.76 | 20.0 | 4.9 | 4.9 | 15.7 | 1.16 | 0.75 | 4.83 | 56 | 189 | 1.97 | coal |
| **59C** | 30.7 | 6.9 | 4.93 | 1.08 | 5.1 | 1.60 | 15.5 | 0.75 | 15.7 | 3.9 | 3.9 | 15.1 | 1.00 | 0.72 | 4.83 | 44 | 156 | 1.91 | coal |
| **59B** | 22.0 | 3.7 | 2.18 | 0.87 | 3.7 | 0.75 | 7.5 | 0.33 | 13.8 | 3.2 | 3.5 | 9.6 | 0.62 | 0.32 | 2.16 | 18 | 92 | 1.53 | coal |
| **59A** | 21.9 | 2.8 | 1.56 | 0.75 | 2.9 | 0.54 | 8.7 | 0.23 | 12.9 | 3.0 | 3.2 | 6.9 | 0.47 | 0.23 | 1.54 | 14 | 82 | 1.33 | coal |

Looking southeast. The Rhame Bed is exposed at the base of the outcrops in this area. The section was measured from these basal outcrops north to the top of the ridge.

## REE Section 60

**T.136N., R.103W., Sec. 22, NW/NW/SW**
**Elevation at top 2,676 ft.**

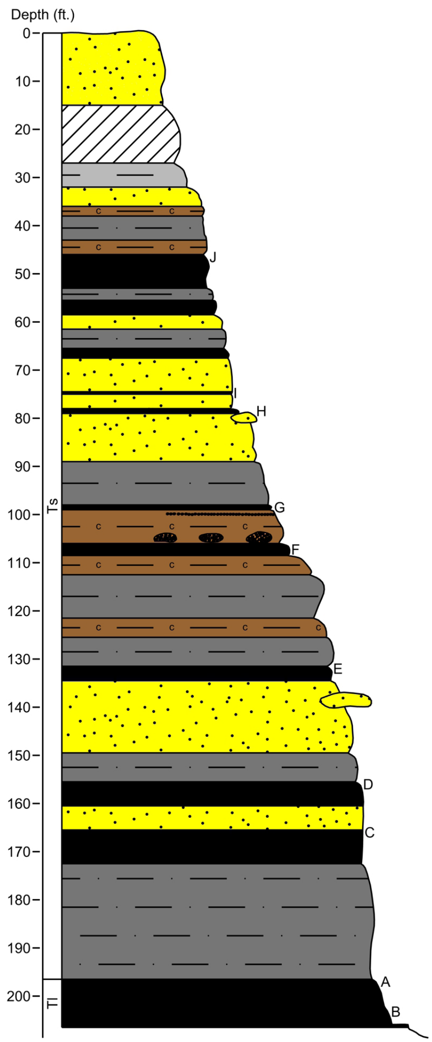



| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | **Cerium** | **Dysprosium** | **Erbium** | **Europium** | **Gadolinium** | **Holmium** | **Lanthanum** | **Lutetium** | **Neodymium** | **Praseodymium** | **Samarium** | **Scandium** | **Terbium** | **Thulium** | **Ytterbium** | **Yttrium** | **Total REE** | **Outlook coefficient** | **Lithology** |
| **60B** | 31.0 | 5.2 | 3.19 | 1.02 | 4.7 | 1.09 | 13.5 | 0.44 | 17.4 | 4.2 | 4.2 | 11.0 | 0.82 | 0.44 | 2.87 | 31 | 132 | 1.64 | coal |
| **60A** | 9.6 | 2.1 | 1.31 | 0.49 | 1.9 | 0.44 | 4.0 | 0.20 | 6.1 | 1.4 | 1.6 | 6.6 | 0.32 | 0.19 | 1.30 | 12 | 50 | 1.90 | coal |

Looking southeast. The Rhame Bed is exposed at the base of the outcrops in this area. The section was measured from these basal outcrops north to the top of the ridge.

# REE Section 61

**T.135N., R.105W., Sec. 10, SW/SW to SE/SW**
**Elevation at top 2,860 ft.**

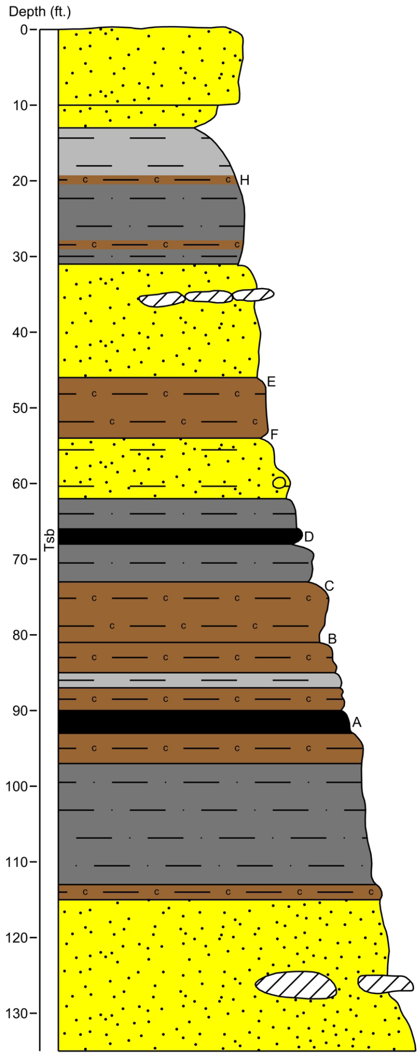



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | | |
| 61J | 22.5 | 3.3 | 2.35 | 0.61 | 2.8 | 0.77 | 12.9 | 0.38 | 10.2 | 2.6 | 2.3 | 10.3 | 0.50 | 0.35 | 2.35 | 25 | 99 | 1.59 | coal |
| 61I | 79.9 | 5.8 | 2.91 | 2.32 | 7.4 | 1.06 | 27.0 | 0.40 | 43.5 | 10.3 | 9.0 | 14.6 | 1.07 | 0.41 | 2.71 | 24 | 232 | 0.94 | pcoal |
| 61H | 118 | 10.4 | 5.26 | 3.68 | 12.2 | 1.93 | 34.7 | 0.64 | 65.6 | 15.8 | 14.0 | 19.4 | 1.88 | 0.71 | 4.49 | 47 | 356 | 1.06 | pcoal |
| 61G | 62.6 | 4.5 | 2.51 | 1.30 | 5.2 | 0.88 | 25.4 | 0.34 | 29.7 | 7.5 | 5.8 | 8.8 | 0.79 | 0.35 | 2.28 | 23 | 181 | 0.93 | coal |
| 61F | 45.3 | 3.0 | 1.53 | 0.93 | 3.7 | 0.57 | 29.6 | 0.20 | 19.5 | 5.1 | 3.7 | 7.3 | 0.53 | 0.20 | 1.31 | 16 | 138 | 0.87 | coal |
| 61E | 44.0 | 2.7 | 1.53 | 0.93 | 3.4 | 0.53 | 18.4 | 0.23 | 20.5 | 5.2 | 3.9 | 9.7 | 0.49 | 0.23 | 1.51 | 14 | 127 | 0.86 | coal |
| 61D | 15.7 | 2.7 | 2.00 | 0.52 | 2.3 | 0.65 | 9.8 | 0.31 | 7.4 | 1.8 | 1.7 | 12.2 | 0.41 | 0.29 | 1.96 | 23 | 83 | 1.91 | coal |
| 61C | 39.4 | 1.9 | 1.15 | 0.64 | 2.4 | 0.39 | 19.1 | 0.19 | 17.2 | 4.7 | 3.1 | 7.3 | 0.34 | 0.18 | 1.21 | 10 | 109 | 0.75 | coal |
| 61A | 49.1 | 7.7 | 3.81 | 2.65 | 9.9 | 1.42 | 10.1 | 0.48 | 50.7 | 10.2 | 11.9 | 12.9 | 1.45 | 0.52 | 3.36 | 33 | 209 | 1.81 | coal |
| 61B | 8.5 | 1.0 | 0.56 | 0.27 | 1.0 | 0.20 | 5.0 | 0.07 | 4.0 | 1.0 | 1.1 | 2.7 | 0.17 | 0.08 | 0.50 | 6 | 32 | 1.28 | hcoal |

Looking southwest. The section was measured from the ravine off to the right and up to the top of this outcrop. Ned Kruger and Levi Moxness collecting sample 61J at the top of the Yule bed.

# REE Section 62

Slope County

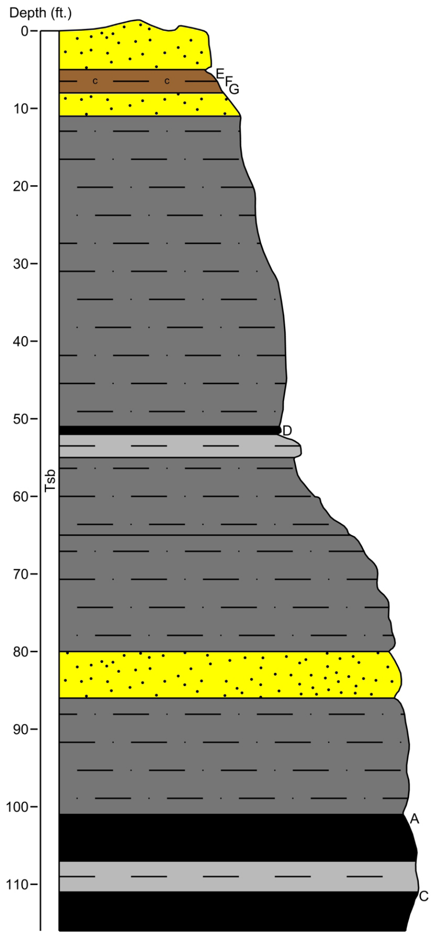



| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | | |
| 62H | 38.6 | 9.7 | 8.31 | 1.50 | 6.6 | 2.41 | 20.2 | 1.52 | 19.4 | 4.8 | 4.6 | 54.0 | 1.25 | 1.25 | 9.04 | 80 | 263 | 2.27 | wcoal |
| 62E | 65.2 | 5.2 | 2.84 | 1.58 | 6.1 | 0.97 | 32.3 | 0.41 | 31.9 | 8.0 | 6.7 | 16.7 | 0.88 | 0.40 | 2.70 | 24 | 206 | 0.95 | cmdst |
| 62F | 116 | 14.9 | 7.66 | 4.20 | 16.9 | 2.73 | 37.0 | 0.97 | 72.2 | 16.6 | 17.4 | 22.1 | 2.57 | 1.02 | 6.60 | 69 | 408 | 1.34 | clmdst |
| 62D | 49.3 | 3.5 | 2.08 | 1.00 | 4.0 | 0.71 | 22.9 | 0.30 | 21.9 | 5.6 | 4.3 | 15.9 | 0.59 | 0.29 | 2.01 | 19 | 153 | 0.91 | pcoal |
| 62C | 37.0 | 5.0 | 2.98 | 1.09 | 4.8 | 1.01 | 17.9 | 0.42 | 18.3 | 4.5 | 4.4 | 11.4 | 0.81 | 0.42 | 2.82 | 26 | 139 | 1.30 | clmdst |
| 62B | 64.3 | 6.0 | 3.19 | 1.69 | 7.2 | 1.11 | 25.8 | 0.45 | 34.7 | 8.4 | 7.7 | 13.3 | 1.07 | 0.45 | 2.98 | 26 | 204 | 1.05 | cclyst |
| 62A | 31.4 | 4.6 | 2.64 | 1.13 | 5.0 | 0.91 | 12.0 | 0.37 | 19.4 | 4.4 | 5.0 | 9.1 | 0.78 | 0.36 | 2.44 | 22 | 122 | 1.42 | coal |

Looking north. The section runs from the base to the top of this butte.

# REE Section 63

Slope County

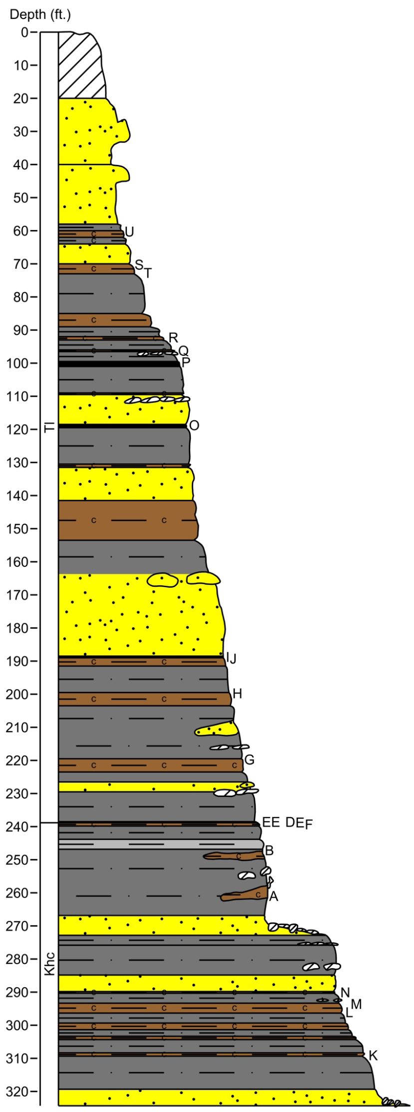



| Sample ID | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | | | | |
| **63E** | 51.6 | 4.1 | 2.76 | 1.05 | 4.4 | 0.88 | 25.3 | 0.43 | 24.1 | 6.2 | 4.7 | 17.7 | 0.67 | 0.40 | 2.72 | 25 | 172 | 1.03 | clmdst |
| **63F** | 41.1 | 3.7 | 2.55 | 0.86 | 3.6 | 0.81 | 20.7 | 0.4 | 18.8 | 4.8 | 3.7 | 14.5 | 0.57 | 0.36 | 2.46 | 25 | 144 | 1.14 | clmdst |
| **63G** | 46.4 | 7.4 | 4.58 | 1.64 | 7.3 | 1.55 | 21.4 | 0.66 | 26.4 | 6.1 | 6.3 | 19.7 | 1.19 | 0.62 | 4.12 | 46 | 201 | 1.63 | clmdst |
| **63D** | 47.7 | 7.3 | 5.58 | 1.26 | 5.7 | 1.72 | 24.6 | 0.95 | 22.7 | 5.8 | 5.0 | 18.4 | 1.02 | 0.83 | 5.79 | 48 | 202 | 1.51 | clmdst |
| **63A** | 17.5 | 3.9 | 2.97 | 0.67 | 3.2 | 0.91 | 8.2 | 0.53 | 10.6 | 2.5 | 2.5 | 10.0 | 0.56 | 0.45 | 3.20 | 26 | 94 | 1.98 | coal |
| **63C** | 22.0 | 4.1 | 2.53 | 0.86 | 4.0 | 0.85 | 9.4 | 0.40 | 12.6 | 3.0 | 3.1 | 11.8 | 0.65 | 0.36 | 2.55 | 19 | 97 | 1.52 | hcoal |

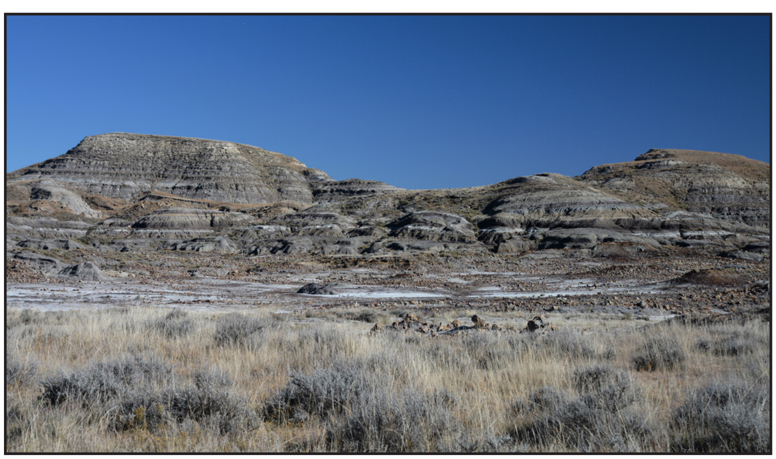
Looking northwest. The measured section started at the base of the HT Butte bed in a deep ravine east of this small butte. The top of the section is at the top of the butte.

# REE Section 64

**T.129N., R.105W., Sec. 2, SE/SE**
**& Sec. 1, SW/SW**
**Elevation at top 3,300 ft.**



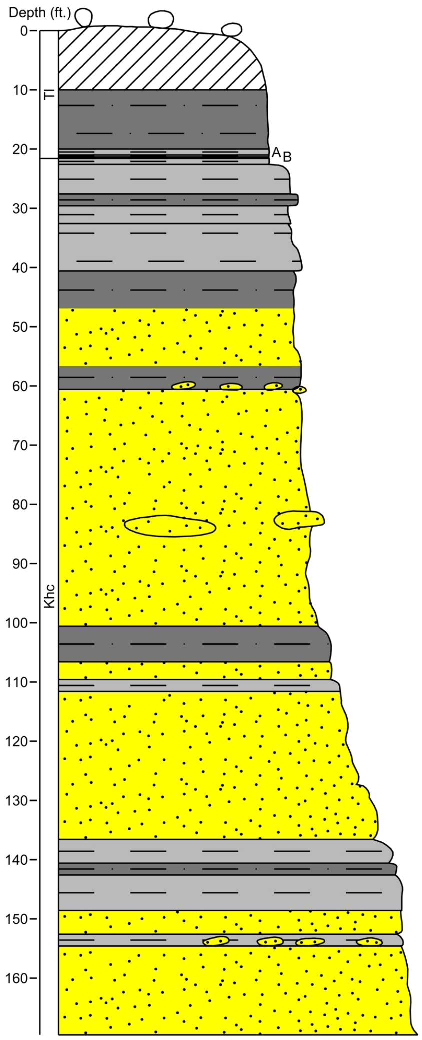

| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **64U** | 139 | 15.4 | 9.19 | 3.50 | 15.6 | 3.22 | 62.7 | 1.19 | 63.6 | 15.7 | 13.6 | 27.0 | 2.57 | 1.26 | 7.98 | 91 | 473 | 1.21 | pcoal |
| **64S** | 94.6 | 6.7 | 4.02 | 1.67 | 7.4 | 1.39 | 47.5 | 0.56 | 41.5 | 11.2 | 8.0 | 11.1 | 1.14 | 0.58 | 3.74 | 40 | 281 | 0.94 | coal |
| **64T** | 129 | 13.5 | 7.86 | 3.08 | 13.6 | 2.79 | 65.1 | 1.02 | 58.4 | 15.2 | 12.0 | 20.8 | 2.22 | 1.08 | 6.82 | 79 | 431 | 1.17 | coal |
| **64R** | 56.1 | 4.8 | 3.29 | 1.13 | 4.8 | 1.08 | 28.9 | 0.50 | 25.1 | 6.7 | 4.9 | 13.9 | 0.77 | 0.48 | 3.23 | 31 | 187 | 1.08 | clmdst |
| **64Q** | 83.1 | 9.5 | 6.20 | 2.52 | 9.8 | 2.07 | 38.7 | 0.95 | 43.6 | 10.5 | 9.4 | 19.6 | 1.53 | 0.91 | 5.99 | 52 | 296 | 1.24 | cclyst |
| **64P** | 5.7 | 1.9 | 1.62 | 0.32 | 1.3 | 0.49 | 2.8 | 0.28 | 3.3 | 0.8 | 0.9 | 9.3 | 0.26 | 0.25 | 1.72 | 13 | 44 | 2.42 | coal |
| **64O** | 41.6 | 7.0 | 4.71 | 1.40 | 5.9 | 1.56 | 18.1 | 0.70 | 21.8 | 5.4 | 5.2 | 15.8 | 1.05 | 0.68 | 4.54 | 43 | 178 | 1.61 | coal |
| **64I** | 131 | 9.5 | 4.96 | 3.20 | 11.6 | 1.82 | 60.7 | 0.60 | 59.3 | 15.4 | 11.6 | 16.6 | 1.72 | 0.67 | 4.08 | 46 | 379 | 0.90 | cclyst |
| **64J** | 63.6 | 6.9 | 4.21 | 1.85 | 7.0 | 1.40 | 27.1 | 0.64 | 32.3 | 8.1 | 7.2 | 13.1 | 1.14 | 0.62 | 4.14 | 35 | 214 | 1.16 | coal |
| **64H** | 43.9 | 3.9 | 2.31 | 1.26 | 4.5 | 0.78 | 21.9 | 0.36 | 22.8 | 5.6 | 4.9 | 15.3 | 0.67 | 0.34 | 2.30 | 18 | 149 | 1.03 | cclyst |
| **64G** | 54.6 | 4.3 | 2.67 | 1.17 | 4.5 | 0.88 | 27.8 | 0.41 | 24.1 | 6.4 | 4.8 | 15.0 | 0.72 | 0.39 | 2.59 | 23 | 173 | 0.95 | cclyst |
| **64D** | 15.3 | 3.6 | 2.22 | 0.72 | 3.1 | 0.74 | 5.8 | 0.36 | 10.0 | 2.2 | 2.8 | 9.8 | 0.56 | 0.33 | 2.31 | 15 | 75 | 1.69 | coal |
| **64E** | 6.6 | 1.1 | 0.87 | 0.19 | 0.7 | 0.26 | 4.1 | 0.16 | 2.7 | 0.7 | 0.6 | 23.7 | 0.15 | 0.14 | 0.99 | 6 | 49 | 1.35 | ej |
| **64EE** | 20.8 | 1.9 | 1.32 | 0.47 | 1.7 | 0.42 | 10.3 | 0.23 | 9.3 | 2.5 | 1.9 | 19.0 | 0.30 | 0.21 | 1.41 | 11 | 83 | 1.05 | ej |
| **64F** | 37.3 | 2.8 | 1.83 | 0.80 | 2.9 | 0.59 | 18.8 | 0.29 | 16.7 | 4.4 | 3.2 | 16.7 | 0.46 | 0.27 | 1.89 | 15 | 124 | 0.93 | cmdst |
| **64B** | 52.5 | 4.0 | 2.48 | 1.15 | 4.4 | 0.82 | 26.9 | 0.38 | 24.5 | 6.3 | 4.8 | 19.0 | 0.67 | 0.36 | 2.45 | 21 | 172 | 0.95 | cmdst |
| **64A** | 52.5 | 4.0 | 2.48 | 1.14 | 4.3 | 0.82 | 26.5 | 0.38 | 24.1 | 6.3 | 4.7 | 18.5 | 0.67 | 0.37 | 2.44 | 20 | 169 | 0.93 | cmdst |
| **64N** | 51.0 | 3.7 | 2.11 | 1.20 | 4.3 | 0.71 | 25.0 | 0.32 | 25.0 | 6.4 | 5.0 | 18.7 | 0.64 | 0.31 | 2.06 | 17 | 163 | 0.91 | cclyst |
| **64M** | 53.4 | 4.0 | 2.42 | 1.15 | 4.4 | 0.81 | 26.8 | 0.37 | 24.4 | 6.4 | 4.8 | 17.8 | 0.66 | 0.36 | 2.39 | 21 | 171 | 0.94 | cmdst |
| **64L** | 34.8 | 3.0 | 1.92 | 0.86 | 3.2 | 0.64 | 15.5 | 0.31 | 16.7 | 4.2 | 3.4 | 17.2 | 0.50 | 0.29 | 1.97 | 14 | 118 | 0.97 | cmdst |
| **64K** | 52.0 | 4.9 | 3.21 | 1.21 | 4.9 | 1.06 | 25.3 | 0.47 | 24.1 | 6.3 | 5.0 | 20.0 | 0.79 | 0.45 | 2.99 | 30 | 183 | 1.13 | cmdst |



Looking east. The section was measured from the base of the exposures to the top of the knoll to the south (right) and then over and up to the top of the butte to the north (left).

## REE Section 65

### Morton County




| Sample ID | Lab Analysis (in µg/g) | | | | | | | | | | | | | | | Total REE | Outlook coefficient | Lithology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cerium | Dysprosium | Erbium | Europium | Gadolinium | Holmium | Lanthanum | Lutetium | Neodymium | Praseodymium | Samarium | Scandium | Terbium | Thulium | Ytterbium | Yttrium | | |
| **65A** | 52.8 | 9.4 | 6.60 | 1.56 | 7.6 | 2.21 | 25.6 | 0.90 | 25.5 | 6.5 | 5.8 | 21.6 | 1.38 | 0.93 | 5.7 | 87 | 261 | 2.10 | ton |
| **65B** | 48.3 | 3.2 | 1.98 | 0.89 | 3.4 | 0.67 | 24.2 | 0.28 | 20.4 | 5.5 | 3.8 | 14.3 | 0.53 | 0.29 | 1.87 | 20 | 150 | 0.91 | cclyst |

Looking north/northwest to measured section 65. The section was measured from the base to the top of the butte. The Ludlow/Hell Creek contact comes in at the break in slope between the gray Hell Creek strata and the overlying brown and yellow colored strata of the Ludlow Formation.

## Appendix B. Rare Earth Concentrations and Outlook Coefficients

Concentrations are reported as µg/g or parts per million.

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1A** | 10.7 | 2.7 | 2.25 | 0.51 | 1.9 | 0.67 | 5.8 | 0.39 | 5.6 | 1.4 | 1.4 | | 0.36 | 0.34 | 2.35 | 21 | **57** | **2.24** |
| **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** | **1.35** |
| **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** | **2.74** |
| **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** | **2.47** |
| **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** | **1.31** |
| **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** | **1.22** |
| **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** | **1.74** |
| **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** | **1.66** |
| **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** | **1.65** |
| **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** | **2.19** |
| **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** | **1.44** |
| **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** | **1.10** |
| **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** | **0.69** |
| **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** | **2.01** |
| **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** | **2.10** |
| **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** | **1.59** |
| **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** | **1.59** |
| **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** | **0.58** |
| **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** | **1.04** |
| **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** | **0.83** |
| **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** | **1.06** |
| **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** | **0.96** |
| **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** | **0.62** |
| **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** | **1.38** |
| **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** | **1.37** |
| **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** | **1.89** |
| **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** | **1.98** |
| **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** | **2.14** |
| **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** | **1.92** |
| **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** | **2.17** |
| **4A** | 5.3 | 1.9 | 1.41 | 0.28 | 1.4 | 0.46 | 2.5 | 0.22 | 3.2 | 0.7 | 0.9 | | 0.28 | 0.21 | 1.37 | 11 | **31** | **2.39** |
| **4B** | 6.1 | 1.4 | 1.08 | 0.22 | 1.0 | 0.33 | 2.8 | 0.20 | 3.5 | 0.8 | 0.9 | | 0.20 | 0.17 | 1.17 | 8 | **28** | **1.81** |
| **4D** | 5.5 | 1.5 | 1.05 | 0.27 | 1.2 | 0.35 | 2.5 | 0.16 | 3.3 | 0.7 | 0.9 | | 0.22 | 0.16 | 1.01 | 9 | **28** | **2.14** |
| **4F** | 45.1 | 4.7 | 2.78 | 1.12 | 4.8 | 0.99 | 22.0 | 0.37 | 20.1 | 5.2 | 4.2 | | 0.81 | 0.38 | 2.41 | 26 | **141** | **1.13** |
| **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** | **1.58** |
| **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** | **0.87** |
| **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** | **1.52** |
| **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** | **0.83** |
| **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** | **0.83** |
| **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** | **0.81** |
| **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** | **0.78** |
| **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** | **0.87** |
| **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** | **2.06** |
| **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** | **2.21** |
| **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** | **1.85** |
| **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** | **2.00** |
| **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** | **2.13** |
| **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** | **1.34** |
| **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** | **0.95** |
| **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** | **0.88** |
| **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** | **1.08** |
| **6F** | 105.0 | 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** | **1.17** |
| **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** | **0.92** |
| **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** | **0.91** |
| **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** | **0.91** |
| **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** | **1.26** |
| **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** | **1.70** |
| **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** | **0.98** |
| **8A** | 38.2 | 4.7 | 3.10 | 0.96 | 4.3 | 1.02 | 19.8 | 0.47 | 16.8 | 4.4 | 3.6 | 11.1 | 0.71 | 0.45 | 3.00 | 25 | **138** | **1.19** |

## Appendix B. Rare Earth Concentrations and Outlook Coefficients (continued)

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **8B** | 63.9 | 3.7 | 2.21 | 1.05 | 4.3 | 0.73 | 31.1 | 0.34 | 28.3 | 7.5 | 5.2 | 13.0 | 0.62 | 0.33 | 2.28 | 18 | **183** | **0.80** |
| **8C** | 17.6 | 3.6 | 2.66 | 0.55 | 2.8 | 0.83 | 8.4 | 0.45 | 9.2 | 2.2 | 2.2 | 10.7 | 0.51 | 0.40 | 2.76 | 21 | **86** | **1.70** |
| **8D** | 32.6 | 2.8 | 1.72 | 0.69 | 2.9 | 0.57 | 15.4 | 0.27 | 15.8 | 4.0 | 3.2 | 10.5 | 0.46 | 0.25 | 1.72 | 15 | **108** | **1.03** |
| **8E** | 42.9 | 3.3 | 2.17 | 0.70 | 3.2 | 0.70 | 21.5 | 0.35 | 18.5 | 5.0 | 3.5 | 10.4 | 0.51 | 0.32 | 2.25 | 18 | **133** | **0.93** |
| **8F** | 67.1 | 7.7 | 4.41 | 2.03 | 8.1 | 1.55 | 29.2 | 0.62 | 35.6 | 8.7 | 8.2 | 19.3 | 1.29 | 0.63 | 4.07 | 36 | **235** | **1.18** |
| **9A** | 170.0 | 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 | **521** | **1.03** |
| **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** | **1.72** |
| **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** | **1.60** |
| **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** | **1.44** |
| **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** | **1.58** |
| **10A** | 31.6 | 5.0 | 3.50 | 0.94 | 4.2 | 1.12 | 15.7 | 0.55 | 16.5 | 4.0 | 3.7 | 12.0 | 0.76 | 0.52 | 3.50 | 30 | **134** | **1.52** |
| **11A** | 49.9 | 3.9 | 2.57 | 0.89 | 4.0 | 0.81 | 24.7 | 0.41 | 23.0 | 6.0 | 4.4 | 11.9 | 0.62 | 0.39 | 2.65 | 20 | **156** | **0.94** |
| **11D** | 52.2 | 4.7 | 3.09 | 1.04 | 4.6 | 0.99 | 25.7 | 0.49 | 24.4 | 6.3 | 4.9 | 11.4 | 0.76 | 0.46 | 3.09 | 24 | **168** | **1.01** |
| **11E** | 17.0 | 2.0 | 1.23 | 0.53 | 2.2 | 0.41 | 6.4 | 0.19 | 10.2 | 2.4 | 2.3 | 6.7 | 0.34 | 0.18 | 1.18 | 9 | **62** | **1.23** |
| **11G** | 20.1 | 1.8 | 1.22 | 0.49 | 1.8 | 0.39 | 10.2 | 0.21 | 9.6 | 2.5 | 1.9 | 9.0 | 0.29 | 0.19 | 1.35 | 9 | **70** | **1.01** |
| **11H** | 15.1 | 2.5 | 1.50 | 0.63 | 2.6 | 0.52 | 6.9 | 0.19 | 8.7 | 2.0 | 2.2 | 4.5 | 0.42 | 0.20 | 1.26 | 15 | **64** | **1.66** |
| **11J** | 61.0 | 8.1 | 4.47 | 1.95 | 8.1 | 1.56 | 24.6 | 0.60 | 33.0 | 7.9 | 7.6 | 15.6 | 1.33 | 0.61 | 3.94 | 36 | **216** | **1.25** |
| **12A** | 15.4 | 2.2 | 1.50 | 0.46 | 1.9 | 0.48 | 8.3 | 0.24 | 7.4 | 1.9 | 1.6 | 11.3 | 0.32 | 0.22 | 1.52 | 15 | **70** | **1.51** |
| **12B** | 9.3 | 1.4 | 0.94 | 0.25 | 1.2 | 0.30 | 5.4 | 0.14 | 4.7 | 1.1 | 1.1 | 3.8 | 0.20 | 0.13 | 0.89 | 11 | **42** | **1.72** |
| **12H** | 58.8 | 3.6 | 2.06 | 1.13 | 4.3 | 0.68 | 29.0 | 0.30 | 26.4 | 6.9 | 5.0 | 14.7 | 0.61 | 0.29 | 1.95 | 20 | **176** | **0.87** |
| **12J** | 79.1 | 7.8 | 4.26 | 2.48 | 8.8 | 1.46 | 37.5 | 0.61 | 41.4 | 10.1 | 9.1 | 22.3 | 1.36 | 0.60 | 4.04 | 32 | **263** | **1.04** |
| **13A** | 37.8 | 4.6 | 2.48 | 1.56 | 5.6 | 0.89 | 14.1 | 0.35 | 26.5 | 5.9 | 6.4 | | 0.82 | 0.34 | 2.31 | 18 | **128** | **1.29** |
| **13B** | 51.6 | 3.4 | 2.41 | 0.80 | 3.4 | 0.77 | 27.5 | 0.40 | 21.9 | 6.1 | 3.7 | | 0.54 | 0.37 | 2.54 | 19 | **144** | **0.86** |
| **13C** | 30.1 | 3.4 | 1.98 | 0.96 | 3.8 | 0.67 | 12.4 | 0.28 | 18.1 | 4.3 | 3.9 | | 0.58 | 0.27 | 1.83 | 15 | **98** | **1.21** |
| **13H** | 40.4 | 8.4 | 6.15 | 1.52 | 6.9 | 1.95 | 21.5 | 0.99 | 22.5 | 5.4 | 5.4 | | 1.23 | 0.90 | 6.04 | 54 | **183** | **1.87** |
| **14A** | 50.9 | 2.9 | 1.75 | 0.79 | 3.4 | 0.57 | 26.8 | 0.27 | 22.2 | 5.9 | 4.0 | | 0.49 | 0.26 | 1.84 | 14 | **136** | **0.78** |
| **14C** | 52.8 | 2.7 | 1.72 | 0.83 | 3.3 | 0.54 | 26.2 | 0.27 | 23.0 | 6.2 | 4.2 | | 0.48 | 0.26 | 1.81 | 14 | **138** | **0.77** |
| **14D** | 52.2 | 3.4 | 2.17 | 0.85 | 3.6 | 0.70 | 26.4 | 0.34 | 22.2 | 6.0 | 4.1 | | 0.58 | 0.32 | 2.29 | 18 | **143** | **0.85** |
| **15A** | 58.2 | 5.0 | 2.88 | 1.17 | 5.4 | 1.01 | 34.1 | 0.38 | 25.7 | 6.6 | 5.2 | | 0.81 | 0.41 | 2.53 | 29 | **178** | **1.03** |
| **15B** | 73.4 | 6.6 | 3.58 | 1.51 | 7.3 | 1.28 | 42.7 | 0.46 | 33.6 | 8.5 | 7.0 | | 1.08 | 0.51 | 3.07 | 30 | **221** | **0.97** |
| **15C** | 38.2 | 6.2 | 4.05 | 1.26 | 5.6 | 1.38 | 20.5 | 0.57 | 20.9 | 5.0 | 4.8 | | 0.92 | 0.59 | 3.59 | 39 | **153** | **1.63** |
| **16A** | 7.1 | 1.4 | 0.97 | 0.27 | 1.1 | 0.31 | 3.4 | 0.16 | 4.0 | 1.0 | 0.9 | | 0.20 | 0.15 | 0.96 | 8 | **30** | **1.71** |
| **16B** | 19.5 | 3.8 | 2.43 | 0.60 | 3.1 | 0.81 | 8.7 | 0.37 | 10.4 | 2.5 | 2.6 | | 0.56 | 0.38 | 2.42 | 18 | **76** | **1.52** |
| **16C** | 6.5 | 2.8 | 2.10 | 0.39 | 1.8 | 0.66 | 3.2 | 0.33 | 4.1 | 0.9 | 1.2 | | 0.36 | 0.33 | 2.07 | 17 | **44** | **2.70** |
| **16D** | 37.0 | 2.8 | 1.74 | 0.73 | 3.0 | 0.59 | 19.6 | 0.25 | 18.4 | 4.7 | 3.3 | | 0.45 | 0.26 | 1.65 | 16 | **110** | **1.01** |
| **16E** | 10.5 | 3.6 | 2.74 | 0.64 | 2.5 | 0.87 | 5.7 | 0.43 | 6.2 | 1.4 | 1.7 | | 0.46 | 0.43 | 2.69 | 25 | **65** | **2.59** |
| **17A** | 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** | **1.05** |
| **17B** | 113.0 | 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 | **386** | **1.24** |
| **17C** | 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** | **1.25** |
| **17D** | 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** | **1.21** |
| **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** | **1.76** |
| **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** | **1.86** |
| **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** | **1.84** |
| **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** | **1.91** |
| **19C** | 66.2 | 7.6 | 5.53 | 1.22 | 6.2 | 1.77 | 35.2 | 0.79 | 24.7 | 6.6 | 4.8 | 17.2 | 1.11 | 0.79 | 5.03 | 47 | **232** | **1.17** |
| **19D** | 18.6 | 3.1 | 1.99 | 0.60 | 2.9 | 0.67 | 11.5 | 0.27 | 9.4 | 2.2 | 2.3 | 4.9 | 0.49 | 0.28 | 1.77 | 19 | **80** | **1.60** |
| **19F** | 58.0 | 4.2 | 2.53 | 1.08 | 4.6 | 0.83 | 28.8 | 0.37 | 27.1 | 7.0 | 5.2 | 12.3 | 0.70 | 0.36 | 2.46 | 20 | **176** | **0.90** |
| **19G** | 27.9 | 2.9 | 1.55 | 0.84 | 3.3 | 0.55 | 17.5 | 0.21 | 14.9 | 3.6 | 3.3 | 10.5 | 0.50 | 0.22 | 1.41 | 12 | **101** | **1.08** |
| **19H** | 10.3 | 2.4 | 1.61 | 0.38 | 1.9 | 0.53 | 5.7 | 0.23 | 5.4 | 1.3 | 1.3 | 2.9 | 0.35 | 0.23 | 1.47 | 16 | **52** | **2.05** |
| **19I** | 7.3 | 1.3 | 0.86 | 0.30 | 1.2 | 0.29 | 3.7 | 0.11 | 4.3 | 1.0 | 1.0 | 1.5 | 0.20 | 0.12 | 0.71 | 10 | **34** | **1.99** |
| **20A** | 24.7 | 2.8 | 1.58 | 0.74 | 3.0 | 0.54 | 10.3 | 0.22 | 13.4 | 3.3 | 3.0 | 7.6 | 0.47 | 0.22 | 1.44 | 13 | **86** | **1.18** |
| **20C** | 24.8 | 6.1 | 4.69 | 0.96 | 4.6 | 1.48 | 14.8 | 0.75 | 11.9 | 2.9 | 2.9 | 12.2 | 0.86 | 0.68 | 4.51 | 46 | **140** | **2.19** |
| **20G** | 22.5 | 2.8 | 1.80 | 0.61 | 2.7 | 0.60 | 10.8 | 0.27 | 10.8 | 2.7 | 2.5 | 6.8 | 0.45 | 0.26 | 1.74 | 17 | **84** | **1.32** |
| **20H** | 10.8 | 1.1 | 0.71 | 0.25 | 1.2 | 0.24 | 5.5 | 0.11 | 5.1 | 1.3 | 1.2 | 2.9 | 0.19 | 0.10 | 0.68 | 6 | **37** | **1.12** |
| **20I** | 60.2 | 2.9 | 1.77 | 0.93 | 3.6 | 0.58 | 29.9 | 0.28 | 25.9 | 7.0 | 4.7 | 11.2 | 0.51 | 0.26 | 1.84 | 14 | **166** | **0.73** |
| **20K** | 53.2 | 4.6 | 2.80 | 1.19 | 4.8 | 0.94 | 24.5 | 0.43 | 24.4 | 6.4 | 5.1 | 15.3 | 0.76 | 0.40 | 2.74 | 21 | **169** | **0.95** |
| **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** | **1.36** |
| **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** | **2.22** |
| **21C** | 109.0 | 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** | **0.88** |
| **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** | **1.38** |
| **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** | **2.66** |
| **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** | **1.91** |

## Appendix B. Rare Earth Concentrations and Outlook Coefficients (continued)

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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** | **2.16** |
| **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** | **2.34** |
| **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** | **0.90** |
| **23C** | 52.4 | 2.8 | 1.76 | 0.76 | 3.2 | 0.58 | 26.1 | 0.28 | 22.2 | 6.0 | 3.9 | 12.8 | 0.47 | 0.27 | 1.85 | 16 | **151** | **0.79** |
| **23D** | 26.1 | 3.8 | 2.51 | 0.71 | 3.3 | 0.84 | 12.9 | 0.37 | 12.8 | 3.2 | 2.9 | | 0.56 | 0.38 | 2.38 | 24 | **97** | **1.48** |
| **23E** | 25.9 | 4.6 | 2.83 | 0.86 | 3.9 | 0.97 | 10.8 | 0.39 | 13.2 | 3.2 | 3.3 | | 0.67 | 0.40 | 2.50 | 24 | **98** | **1.53** |
| **23F** | 43.9 | 4.2 | 2.84 | 0.79 | 3.8 | 0.92 | 22.8 | 0.43 | 19.2 | 5.1 | 3.6 | | 0.61 | 0.43 | 2.66 | 23 | **134** | **1.05** |
| **24A** | 21.3 | 4.3 | 3.26 | 0.80 | 3.5 | 1.00 | 10.5 | 0.53 | 10.9 | 2.6 | 2.6 | 14.5 | 0.62 | 0.47 | 3.16 | 34 | **114** | **2.04** |
| **24C** | 17.6 | 2.7 | 1.62 | 0.74 | 2.9 | 0.54 | 6.7 | 0.24 | 11.2 | 2.5 | 2.8 | 10.6 | 0.45 | 0.23 | 1.54 | 14 | **76** | **1.52** |
| **25A** | 15.6 | 2.1 | 1.33 | 0.52 | 2.0 | 0.44 | 7.2 | 0.21 | 8.4 | 2.0 | 1.9 | | 0.31 | 0.20 | 1.35 | 10 | **54** | **1.27** |
| **25D** | 16.9 | 1.6 | 1.18 | 0.41 | 1.6 | 0.37 | 8.5 | 0.21 | 8.1 | 2.1 | 1.7 | | 0.25 | 0.19 | 1.28 | 10 | **54** | **1.14** |
| **25E** | 79.1 | 7.0 | 3.98 | 2.04 | 7.9 | 1.39 | 39.2 | 0.52 | 38.8 | 9.6 | 8.1 | | 1.14 | 0.57 | 3.39 | 37 | **240** | **1.06** |
| **25F** | 29.7 | 4.4 | 3.29 | 0.94 | 3.4 | 1.04 | 14.1 | 0.54 | 13.6 | 3.5 | 3.0 | | 0.62 | 0.52 | 3.36 | 28 | **110** | **1.45** |
| **26A** | 14.5 | 2.7 | 2.09 | 0.53 | 2.1 | 0.64 | 7.6 | 0.36 | 7.4 | 1.8 | 1.7 | | 0.39 | 0.32 | 2.21 | 18 | **62** | **1.73** |
| **26C** | 4.5 | 1.3 | 1.09 | 0.26 | 1.0 | 0.33 | 2.2 | 0.18 | 2.7 | 0.6 | 0.7 | | 0.19 | 0.16 | 1.11 | 11 | **27** | **2.63** |
| **26D** | 31.6 | 2.6 | 1.92 | 0.58 | 2.3 | 0.61 | 18.1 | 0.32 | 12.7 | 3.5 | 2.2 | | 0.39 | 0.29 | 1.99 | 18 | **97** | **1.04** |
| **27A** | 8.9 | 2.6 | 1.96 | 0.44 | 2.0 | 0.63 | 3.6 | 0.30 | 5.8 | 1.3 | 1.5 | | 0.38 | 0.29 | 1.85 | 19 | **51** | **2.52** |
| **27B** | 44.9 | 1.8 | 1.09 | 0.45 | 2.1 | 0.38 | 38.8 | 0.14 | 10.6 | 3.7 | 1.8 | | 0.31 | 0.15 | 0.87 | 12 | **119** | **0.57** |
| **27C** | 8.0 | 1.2 | 0.80 | 0.27 | 1.2 | 0.27 | 4.7 | 0.11 | 4.1 | 1.0 | 1.0 | | 0.20 | 0.11 | 0.68 | 9 | **33** | **1.70** |
| **27D** | 8.8 | 2.7 | 1.83 | 0.51 | 2.2 | 0.61 | 3.3 | 0.26 | 6.0 | 1.3 | 1.7 | | 0.42 | 0.26 | 1.60 | 17 | **48** | **2.47** |
| **27E** | 26.3 | 4.4 | 3.06 | 0.85 | 3.8 | 0.99 | 12.1 | 0.46 | 13.9 | 3.4 | 3.3 | | 0.69 | 0.45 | 2.88 | 25 | **102** | **1.54** |
| **27F** | 51.4 | 2.6 | 1.76 | 0.69 | 2.9 | 0.55 | 26.2 | 0.31 | 21.8 | 5.9 | 3.8 | | 0.42 | 0.28 | 2.00 | 14 | **135** | **0.76** |
| **27G** | 27.0 | 4.8 | 3.25 | 0.99 | 4.3 | 1.06 | 11.6 | 0.49 | 15.0 | 3.6 | 3.8 | | 0.76 | 0.48 | 3.10 | 25 | **105** | **1.55** |
| **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** | **1.38** |
| **29A** | 9.9 | 1.6 | 1.18 | 0.26 | 1.4 | 0.37 | 6.7 | 0.18 | 5.1 | 1.2 | 1.2 | | 0.24 | 0.17 | 1.12 | 12 | **43** | **1.74** |
| **29B** | 8.8 | 1.1 | 0.79 | 0.17 | 1.0 | 0.25 | 5.0 | 0.12 | 4.1 | 1.0 | 0.9 | | 0.18 | 0.11 | 0.73 | 8 | **32** | **1.43** |
| **29E** | 26.7 | 5.5 | 4.28 | 1.01 | 4.3 | 1.31 | 12.2 | 0.69 | 13.6 | 3.3 | 3.2 | | 0.81 | 0.63 | 4.17 | 39 | **121** | **1.92** |
| **29G** | 38.6 | 2.9 | 1.79 | 1.11 | 3.3 | 0.58 | 19.9 | 0.28 | 19.4 | 5.0 | 3.9 | | 0.50 | 0.27 | 1.81 | 14 | **113** | **0.96** |
| **29H** | 26.8 | 3.3 | 1.83 | 0.85 | 3.6 | 0.63 | 12.0 | 0.26 | 15.7 | 3.8 | 3.7 | | 0.57 | 0.26 | 1.74 | 15 | **90** | **1.25** |
| **29I** | 13.2 | 1.4 | 0.85 | 0.43 | 1.6 | 0.29 | 6.4 | 0.13 | 6.5 | 1.7 | 1.4 | | 0.25 | 0.12 | 0.81 | 7 | **42** | **1.13** |
| **29K** | 14.5 | 1.2 | 0.78 | 0.28 | 1.3 | 0.25 | 7.8 | 0.11 | 6.3 | 1.7 | 1.2 | | 0.20 | 0.11 | 0.70 | 9 | **45** | **1.13** |
| **29N** | 23.0 | 2.3 | 1.53 | 0.41 | 2.2 | 0.50 | 13.3 | 0.20 | 8.8 | 2.4 | 1.6 | | 0.36 | 0.21 | 1.26 | 20 | **78** | **1.33** |
| **29O** | 43.2 | 5.2 | 3.38 | 0.86 | 4.8 | 1.15 | 22.3 | 0.43 | 17.4 | 4.7 | 3.4 | | 0.79 | 0.46 | 2.76 | 36 | **147** | **1.33** |
| **29P** | 34.9 | 5.1 | 3.57 | 1.05 | 4.5 | 1.13 | 17.5 | 0.56 | 17.5 | 4.3 | 3.9 | | 0.78 | 0.53 | 3.49 | 32 | **131** | **1.48** |
| **29R** | 55.9 | 4.7 | 3.12 | 1.14 | 4.8 | 1.00 | 27.7 | 0.48 | 24.6 | 6.6 | 4.8 | | 0.78 | 0.46 | 3.01 | 27 | **166** | **1.01** |
| **29S** | 52.5 | 3.5 | 2.66 | 0.82 | 3.4 | 0.80 | 26.5 | 0.44 | 21.9 | 6.0 | 3.9 | | 0.54 | 0.41 | 2.80 | 22 | **148** | **0.90** |
| **29T** | 90.1 | 7.7 | 4.10 | 2.15 | 9.0 | 1.46 | 40.3 | 0.57 | 44.7 | 11.3 | 9.4 | | 1.37 | 0.58 | 3.70 | 34 | **260** | **0.98** |
| **30A** | 49.2 | 3.0 | 1.90 | 0.88 | 3.6 | 0.62 | 25.1 | 0.30 | 22.1 | 5.9 | 4.2 | 12.1 | 0.53 | 0.28 | 1.92 | 17 | **149** | **0.87** |
| **30B** | 7.7 | 1.2 | 0.77 | 0.29 | 1.1 | 0.25 | 3.9 | 0.12 | 3.9 | 1.0 | 0.9 | 4.3 | 0.18 | 0.11 | 0.73 | 7 | **33** | **1.50** |
| **30C** | 22.5 | 2.9 | 1.97 | 0.59 | 2.5 | 0.63 | 11.4 | 0.30 | 10.7 | 2.8 | 2.3 | 8.7 | 0.42 | 0.29 | 1.92 | 18 | **88** | **1.35** |
| **30D** | 51.0 | 2.7 | 1.55 | 0.82 | 3.5 | 0.52 | 25.6 | 0.23 | 23.2 | 6.1 | 4.3 | 6.6 | 0.48 | 0.23 | 1.53 | 14 | **142** | **0.80** |
| **31A** | 17.4 | 2.8 | 1.91 | 0.62 | 2.3 | 0.63 | 11.0 | 0.29 | 8.0 | 2.0 | 2.0 | | 0.43 | 0.28 | 1.84 | 16 | **68** | **1.46** |
| **31C** | 26.2 | 2.8 | 1.82 | 0.78 | 2.9 | 0.60 | 12.4 | 0.27 | 12.9 | 3.2 | 2.9 | | 0.46 | 0.27 | 1.73 | 17 | **86** | **1.23** |
| **31E** | 31.0 | 2.8 | 1.89 | 0.79 | 2.9 | 0.62 | 14.4 | 0.29 | 14.6 | 3.7 | 3.0 | | 0.47 | 0.29 | 1.88 | 17 | **96** | **1.10** |
| **31G** | 47.8 | 2.6 | 1.62 | 0.87 | 3.1 | 0.54 | 23.5 | 0.26 | 20.6 | 5.5 | 3.8 | | 0.46 | 0.25 | 1.67 | 12 | **125** | **0.76** |
| **32 ASH** | 40.6 | 2.6 | 1.47 | 1.23 | 3.3 | 0.51 | 19.7 | 0.21 | 18.6 | 4.9 | 3.6 | 7.1 | 0.46 | 0.21 | 1.34 | 12 | **118** | **0.85** |
| **32 ASH2** | 19.5 | 1.2 | 0.71 | 0.34 | 1.4 | 0.24 | 10.3 | 0.10 | 8.5 | 2.3 | 1.5 | 2.7 | 0.21 | 0.10 | 0.66 | 6 | **56** | **0.82** |
| **32C** | 15.7 | 1.9 | 1.16 | 0.47 | 2.0 | 0.39 | 8.4 | 0.18 | 7.9 | 1.9 | 1.9 | 4.7 | 0.32 | 0.17 | 1.15 | 10 | **58** | **1.24** |
| **32E** | 43.1 | 4.1 | 2.23 | 0.96 | 4.4 | 0.79 | 18.8 | 0.29 | 22.0 | 5.7 | 4.8 | 8.3 | 0.69 | 0.30 | 1.97 | 20 | **138** | **1.08** |
| **32F** | 55.2 | 5.6 | 2.84 | 1.89 | 6.8 | 1.01 | 23.2 | 0.40 | 34.0 | 8.0 | 8.3 | 20.8 | 1.01 | 0.40 | 2.72 | 19 | **191** | **1.08** |
| **32G** | 59.1 | 3.1 | 1.99 | 0.91 | 3.4 | 0.62 | 31.3 | 0.33 | 25.1 | 7.0 | 4.4 | 11.7 | 0.50 | 0.30 | 2.14 | 15 | **167** | **0.75** |
| **32H** | 47.4 | 5.6 | 2.99 | 1.56 | 6.4 | 1.07 | 21.4 | 0.42 | 26.9 | 6.4 | 6.2 | 8.0 | 0.98 | 0.42 | 2.74 | 24 | **162** | **1.19** |
| **32L** | 18.1 | 2.0 | 1.15 | 0.68 | 2.2 | 0.40 | 14.3 | 0.15 | 10.6 | 2.7 | 2.3 | 4.2 | 0.33 | 0.16 | 1.01 | 14 | **74** | **1.45** |
| **32M** | 65.5 | 4.1 | 2.47 | 1.94 | 5.1 | 0.82 | 35.8 | 0.34 | 27.3 | 7.4 | 5.2 | 9.2 | 0.70 | 0.35 | 2.22 | 22 | **190** | **0.85** |
| **33A** | 33.4 | 5.1 | 2.60 | 1.61 | 6.0 | 0.93 | 11.3 | 0.35 | 26.9 | 5.9 | 6.9 | 10.7 | 0.91 | 0.36 | 2.36 | 17 | **132** | **1.45** |
| **33B** | 6.9 | 1.1 | 0.68 | 0.27 | 1.2 | 0.23 | 3.1 | 0.10 | 4.3 | 1.0 | 1.0 | 1.4 | 0.19 | 0.10 | 0.61 | 5 | **27** | **1.45** |
| **33C** | 10.7 | 0.4 | 0.20 | 0.14 | 0.6 | 0.07 | 5.3 | 0.02 | 4.5 | 1.3 | 0.6 | 0.8 | 0.08 | 0.03 | 0.16 | 2 | **27** | **0.67** |
| **33F** | 14.2 | 1.9 | 1.14 | 0.55 | 2.0 | 0.38 | 6.0 | 0.18 | 8.5 | 2.0 | 2.1 | 3.7 | 0.31 | 0.16 | 1.13 | 8 | **52** | **1.27** |
| **34A** | 19.2 | 5.6 | 3.98 | 0.83 | 4.1 | 1.29 | 9.5 | 0.60 | 10.5 | 2.5 | 2.9 | | 0.82 | 0.62 | 3.91 | 33 | **99** | **2.14** |
| **34B** | 23.5 | 6.9 | 4.37 | 1.03 | 5.3 | 1.49 | 11.7 | 0.61 | 13.1 | 3.0 | 3.7 | | 1.01 | 0.62 | 3.93 | 36 | **116** | **2.07** |
| **34C** | 16.7 | 3.4 | 2.16 | 0.69 | 3.1 | 0.71 | 6.6 | 0.35 | 11.2 | 2.5 | 3.1 | | 0.52 | 0.33 | 2.23 | 15 | **69** | **1.62** |
| **34D** | 7.1 | 2.1 | 1.52 | 0.35 | 1.7 | 0.49 | 3.4 | 0.23 | 4.3 | 1.0 | 1.2 | | 0.32 | 0.23 | 1.49 | 13 | **38** | **2.26** |

## Appendix B. Rare Earth Concentrations and Outlook Coefficients (continued)

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **34F** | 55.0 | 8.9 | 5.35 | 1.63 | 8.5 | 1.87 | 22.9 | 0.68 | 31.2 | 7.6 | 7.1 | | 1.49 | 0.77 | 4.49 | 47 | **204** | **1.52** |
| **34G** | 12.9 | 4.4 | 3.42 | 0.61 | 3.0 | 1.06 | 5.6 | 0.57 | 7.7 | 1.7 | 2.1 | | 0.61 | 0.55 | 3.53 | 27 | **75** | **2.35** |
| **35A** | 16.2 | 5.1 | 3.68 | 0.89 | 3.8 | 1.18 | 7.5 | 0.54 | 9.5 | 2.2 | 2.7 | | 0.75 | 0.54 | 3.42 | 34 | **92** | **2.46** |
| **35B** | 12.4 | 3.0 | 2.17 | 0.68 | 2.3 | 0.69 | 5.5 | 0.35 | 7.3 | 1.7 | 2.0 | | 0.45 | 0.33 | 2.21 | 17 | **58** | **1.91** |
| **35C** | 101.0 | 11.7 | 7.22 | 2.60 | 11.5 | 2.45 | 43.8 | 1.09 | 51.0 | 12.6 | 11.2 | | 1.95 | 1.08 | 6.92 | 52 | **318** | **1.12** |
| **35D** | 15.5 | 5.0 | 3.75 | 0.83 | 3.5 | 1.21 | 8.2 | 0.56 | 8.4 | 1.9 | 2.3 | | 0.70 | 0.55 | 3.52 | 34 | **90** | **2.47** |
| **36A** | 9.7 | 1.6 | 0.98 | 0.30 | 1.4 | 0.34 | 4.8 | 0.13 | 4.7 | 1.2 | 1.1 | | 0.23 | 0.14 | 0.86 | 9 | **36** | **1.50** |
| **37A** | 28.5 | 3.0 | 1.47 | 1.13 | 3.8 | 0.55 | 11.4 | 0.18 | 18.2 | 4.1 | 4.4 | | 0.53 | 0.20 | 1.25 | 12 | **91** | **1.18** |
| **37E** | 19.3 | 5.2 | 3.95 | 0.88 | 3.7 | 1.23 | 9.6 | 0.64 | 10.4 | 2.4 | 2.7 | | 0.68 | 0.61 | 3.93 | 34 | **99** | **2.14** |
| **37F** | 26.7 | 3.4 | 1.92 | 0.86 | 3.6 | 0.66 | 12.7 | 0.28 | 15.9 | 3.9 | 3.8 | | 0.54 | 0.29 | 1.85 | 15 | **91** | **1.26** |
| **37J** | 35.3 | 4.0 | 2.26 | 1.14 | 4.3 | 0.80 | 15.3 | 0.31 | 18.8 | 4.5 | 4.4 | | 0.65 | 0.33 | 2.02 | 17 | **111** | **1.13** |
| **37K** | 45.8 | 3.3 | 2.20 | 0.84 | 3.5 | 0.70 | 23.5 | 0.37 | 21.3 | 5.3 | 3.8 | | 0.51 | 0.35 | 2.35 | 17 | **131** | **0.91** |
| **37L** | 114.0 | 17.3 | 8.73 | 4.67 | 20.0 | 3.20 | 36.2 | 1.13 | 80.1 | 17.7 | 20.1 | | 2.93 | 1.22 | 7.43 | 64 | **399** | **1.40** |
| **37M** | 72.2 | 10.3 | 5.89 | 2.24 | 10.0 | 2.09 | 28.6 | 0.81 | 39.3 | 9.6 | 9.3 | 18.9 | 1.71 | 0.85 | 5.29 | 55 | **272** | **1.41** |
| **38A** | 44.7 | 7.8 | 4.65 | 1.64 | 7.6 | 1.60 | 17.2 | 0.67 | 26.4 | 6.2 | 6.6 | 13.4 | 1.28 | 0.66 | 4.27 | 33 | **178** | **1.44** |
| **38B** | 127.0 | 14.0 | 7.94 | 3.63 | 15.4 | 2.80 | 60.2 | 1.04 | 64.4 | 15.8 | 14.7 | 23.4 | 2.41 | 1.08 | 6.87 | 65 | **426** | **1.13** |
| **39A** | 22.4 | 4.7 | 3.57 | 0.70 | 3.4 | 1.12 | 11.9 | 0.57 | 10.5 | 2.6 | 2.5 | 12.6 | 0.65 | 0.52 | 3.49 | 31 | **112** | **1.82** |
| **39B** | 16.2 | 3.2 | 2.21 | 0.54 | 2.5 | 0.72 | 8.3 | 0.34 | 8.5 | 2.1 | 2.1 | 8.5 | 0.47 | 0.32 | 2.14 | 18 | **76** | **1.67** |
| **39C** | 42.8 | 3.2 | 2.13 | 0.77 | 3.3 | 0.69 | 22.9 | 0.34 | 19.3 | 5.2 | 3.6 | 10.5 | 0.52 | 0.32 | 2.16 | 18 | **136** | **0.95** |
| **39D** | 8.4 | 0.8 | 0.50 | 0.18 | 0.8 | 0.17 | 5.0 | 0.06 | 3.8 | 1.0 | 0.7 | 1.2 | 0.12 | 0.07 | 0.40 | 6 | **29** | **1.25** |
| **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** | **1.08** |
| **41A** | 18.8 | 2.8 | 1.71 | 0.55 | 2.6 | 0.57 | 8.4 | 0.25 | 9.7 | 2.4 | 2.3 | | 0.44 | 0.25 | 1.60 | 15 | **67** | **1.41** |
| **41B** | 17.0 | 2.7 | 1.70 | 0.54 | 2.7 | 0.59 | 7.4 | 0.25 | 9.6 | 2.2 | 2.3 | | 0.46 | 0.24 | 1.57 | 15 | **64** | **1.53** |
| **41C** | 12.7 | 1.3 | 0.70 | 0.33 | 1.5 | 0.25 | 5.9 | 0.09 | 6.8 | 1.6 | 1.5 | | 0.23 | 0.10 | 0.60 | 7 | **41** | **1.19** |
| **41E** | 6.1 | 0.5 | 0.29 | 0.15 | 0.6 | 0.10 | 3.0 | 0.04 | 3.3 | 0.8 | 0.7 | | 0.09 | 0.04 | 0.25 | 3 | **19** | **1.12** |
| **41G** | 11.1 | 0.8 | 0.47 | 0.19 | 0.8 | 0.16 | 5.8 | 0.07 | 5.0 | 1.3 | 1.0 | | 0.13 | 0.07 | 0.47 | 4 | **31** | **0.89** |
| **41I** | 6.1 | 0.5 | 0.30 | 0.13 | 0.6 | 0.11 | 3.0 | 0.04 | 3.2 | 0.8 | 0.7 | | 0.09 | 0.04 | 0.27 | 3 | **19** | **1.10** |
| **41K** | 20.9 | 3.3 | 2.07 | 0.63 | 3.1 | 0.69 | 9.1 | 0.32 | 11.0 | 2.7 | 2.5 | | 0.52 | 0.30 | 1.99 | 16 | **75** | **1.39** |
| **42A** | 66.5 | 3.0 | 2.08 | 0.77 | 3.5 | 0.64 | 35.7 | 0.36 | 27.3 | 7.6 | 4.5 | | 0.48 | 0.33 | 2.31 | 17 | **172** | **0.72** |
| **42B** | 32.2 | 5.4 | 3.21 | 0.97 | 5.0 | 1.11 | 14.5 | 0.42 | 17.0 | 4.2 | 4.1 | | 0.86 | 0.45 | 2.84 | 24 | **116** | **1.39** |
| **42D** | 7.1 | 1.0 | 0.60 | 0.19 | 1.1 | 0.22 | 3.2 | 0.07 | 3.9 | 0.9 | 0.9 | | 0.17 | 0.08 | 0.49 | 7 | **27** | **1.62** |
| **42E** | 11.0 | 1.2 | 0.78 | 0.19 | 1.2 | 0.26 | 5.0 | 0.12 | 5.5 | 1.4 | 1.2 | | 0.20 | 0.11 | 0.74 | 9 | **38** | **1.38** |
| **42F** | 10.0 | 0.8 | 0.48 | 0.11 | 0.8 | 0.16 | 5.6 | 0.07 | 4.2 | 1.1 | 0.8 | | 0.13 | 0.07 | 0.44 | 5 | **30** | **1.00** |
| **42H** | 8.4 | 0.7 | 0.42 | 0.10 | 0.7 | 0.14 | 4.0 | 0.06 | 3.8 | 1.0 | 0.8 | | 0.12 | 0.06 | 0.39 | 3 | **24** | **0.90** |
| **42J** | 5.8 | 0.5 | 0.29 | 0.08 | 0.5 | 0.10 | 3.0 | 0.04 | 2.5 | 0.7 | 0.5 | | 0.08 | 0.04 | 0.25 | 3 | **17** | **1.04** |
| **42L** | 13.7 | 1.7 | 1.06 | 0.43 | 1.7 | 0.36 | 6.6 | 0.15 | 7.0 | 1.7 | 1.6 | | 0.29 | 0.15 | 0.98 | 11 | **48** | **1.40** |
| **42M** | 40.7 | 2.4 | 1.55 | 0.62 | 2.7 | 0.49 | 21.2 | 0.25 | 17.9 | 4.8 | 3.3 | | 0.41 | 0.24 | 1.60 | 13 | **111** | **0.83** |
| **42N** | 72.9 | 4.5 | 2.58 | 1.16 | 5.3 | 0.85 | 35.1 | 0.38 | 32.4 | 8.6 | 6.3 | | 0.76 | 0.38 | 2.48 | 21 | **195** | **0.81** |
| **42O** | 58.8 | 3.6 | 2.20 | 0.90 | 4.1 | 0.71 | 29.1 | 0.35 | 25.6 | 6.8 | 4.8 | | 0.59 | 0.33 | 2.24 | 19 | **159** | **0.83** |
| **43A** | 34.4 | 4.8 | 2.88 | 1.17 | 5.0 | 1.00 | 13.5 | 0.40 | 19.7 | 4.7 | 4.6 | 9.5 | 0.80 | 0.40 | 2.57 | 25 | **130** | **1.40** |
| **43B** | 33.2 | 4.2 | 2.65 | 0.83 | 4.1 | 0.92 | 14.8 | 0.37 | 15.9 | 4.1 | 3.4 | 3.1 | 0.68 | 0.37 | 2.32 | 27 | **118** | **1.38** |
| **44A** | 50.3 | 5.1 | 3.23 | 1.27 | 5.3 | 1.09 | 26.0 | 0.49 | 24.2 | 6.1 | 5.0 | 9.5 | 0.84 | 0.47 | 3.04 | 32 | **174** | **1.20** |
| **45A** | 36.6 | 5.8 | 3.04 | 1.41 | 6.3 | 1.10 | 11.0 | 0.40 | 25.4 | 5.7 | 6.3 | | 0.97 | 0.43 | 2.65 | 23 | **130** | **1.45** |
| **45C** | 55.7 | 6.7 | 3.80 | 1.18 | 6.3 | 1.33 | 21.9 | 0.52 | 29.1 | 7.3 | 6.6 | | 1.05 | 0.56 | 3.52 | 30 | **176** | **1.17** |
| **45D** | 13.5 | 1.0 | 0.64 | 0.24 | 1.1 | 0.22 | 9.6 | 0.10 | 5.1 | 1.4 | 1.0 | 2.6 | 0.17 | 0.09 | 0.61 | 7 | **44** | **0.97** |
| **45F** | 9.8 | 1.0 | 0.64 | 0.22 | 1.0 | 0.21 | 5.9 | 0.09 | 4.5 | 1.1 | 1.0 | | 0.15 | 0.09 | 0.58 | 6 | **32** | **1.16** |
| **46A** | 43.8 | 3.2 | 2.02 | 0.94 | 3.6 | 0.64 | 21.6 | 0.33 | 20.8 | 5.3 | 4.1 | 15.9 | 0.53 | 0.30 | 2.05 | 19 | **144** | **0.99** |
| **46B** | 47.4 | 5.9 | 3.67 | 1.43 | 5.9 | 1.19 | 20.9 | 0.57 | 25.5 | 6.2 | 5.7 | 17.2 | 0.94 | 0.52 | 3.59 | 33 | **180** | **1.32** |
| **46C1** | 18.1 | 2.0 | 1.29 | 0.53 | 2.1 | 0.42 | 10.4 | 0.18 | 8.9 | 2.2 | 1.8 | 4.7 | 0.31 | 0.18 | 1.14 | 17 | **71** | **1.50** |
| **46C2** | 70.5 | 11.6 | 7.75 | 2.05 | 10.2 | 2.53 | 33.4 | 1.21 | 36.1 | 8.7 | 8.1 | 18.1 | 1.76 | 1.14 | 7.56 | 67 | **288** | **1.52** |
| **46D** | 10.6 | 1.0 | 0.57 | 0.24 | 1.1 | 0.20 | 5.8 | 0.08 | 5.4 | 1.3 | 1.1 | 2.2 | 0.17 | 0.08 | 0.49 | 6 | **36** | **1.17** |
| **47A** | 31.9 | 4.1 | 2.85 | 0.85 | 3.4 | 0.90 | 17.7 | 0.46 | 14.8 | 3.9 | 3.2 | 17.3 | 0.60 | 0.43 | 2.89 | 26 | **131** | **1.34** |
| **48A** | 32.3 | 2.7 | 1.64 | 0.74 | 2.9 | 0.55 | 14.7 | 0.23 | 15.7 | 4.1 | 3.2 | 10.5 | 0.46 | 0.23 | 1.55 | 16 | **108** | **1.07** |
| **48B** | 46.8 | 3.1 | 1.81 | 0.97 | 3.7 | 0.61 | 23.4 | 0.28 | 22.0 | 5.7 | 4.3 | 15.1 | 0.55 | 0.26 | 1.83 | 16 | **146** | **0.89** |
| **48C** | 26.3 | 3.7 | 2.46 | 0.70 | 3.2 | 0.82 | 13.9 | 0.35 | 12.2 | 3.2 | 2.7 | 12.0 | 0.57 | 0.34 | 2.25 | 25 | **110** | **1.48** |
| **48D** | 55.0 | 8.9 | 5.96 | 1.84 | 8.0 | 1.97 | 24.8 | 0.90 | 28.5 | 7.0 | 6.6 | 17.7 | 1.38 | 0.85 | 5.57 | 59 | **234** | **1.64** |
| **49A** | 35.4 | 1.7 | 1.00 | 0.67 | 2.2 | 0.33 | 15.2 | 0.16 | 16.7 | 4.4 | 3.0 | 8.1 | 0.30 | 0.15 | 1.03 | 9 | **99** | **0.79** |
| **49B** | 70.2 | 10.6 | 7.51 | 2.22 | 9.6 | 2.42 | 34.3 | 1.22 | 37.6 | 9.0 | 8.4 | 28.3 | 1.64 | 1.11 | 7.47 | 71 | **303** | **1.58** |
| **49C** | 46.3 | 2.8 | 1.64 | 0.96 | 3.4 | 0.55 | 23.7 | 0.26 | 21.2 | 5.6 | 4.1 | 16.6 | 0.49 | 0.24 | 1.63 | 14 | **143** | **0.84** |
| **49D** | 27.4 | 3.7 | 2.62 | 0.78 | 3.2 | 0.84 | 14.1 | 0.39 | 13.2 | 3.4 | 2.8 | 13.2 | 0.55 | 0.37 | 2.46 | 28 | **117** | **1.55** |
| **49E** | 65.5 | 5.9 | 3.30 | 1.76 | 6.8 | 1.15 | 32.5 | 0.47 | 35.0 | 8.8 | 7.3 | 18.2 | 1.03 | 0.46 | 3.04 | 30 | **221** | **1.09** |
| **49F** | 24.5 | 2.5 | 1.51 | 0.73 | 2.7 | 0.52 | 10.6 | 0.20 | 12.0 | 3.0 | 2.6 | 8.3 | 0.43 | 0.20 | 1.31 | 16 | **87** | **1.24** |

## Appendix B. Rare Earth Concentrations and Outlook Coefficients (continued)

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50A** | 78.1 | 7.1 | 3.85 | 2.01 | 8.7 | 1.35 | 34.4 | 0.54 | 43.0 | 10.3 | 9.6 | 12.9 | 1.26 | 0.53 | 3.59 | 33 | **250** | **1.07** |
| **50B** | 33.6 | 4.2 | 2.64 | 1.11 | 4.6 | 0.86 | 13.7 | 0.42 | 20.3 | 4.8 | 4.8 | 12.6 | 0.70 | 0.38 | 2.69 | 21 | **128** | **1.32** |
| **50C** | 54.4 | 4.2 | 2.41 | 1.28 | 4.9 | 0.79 | 24.2 | 0.37 | 27.5 | 7.0 | 5.8 | 12.6 | 0.72 | 0.34 | 2.40 | 20 | **169** | **0.96** |
| **50D2** | 57.4 | 11.9 | 8.44 | 1.93 | 9.7 | 2.69 | 29.0 | 1.29 | 29.3 | 7.2 | 7.1 | 12.4 | 1.74 | 1.19 | 7.95 | 90 | **279** | **2.03** |
| **51A** | 11.8 | 1.6 | 0.98 | 0.44 | 1.6 | 0.32 | 5.1 | 0.15 | 7.2 | 1.7 | 1.7 | 5.5 | 0.25 | 0.14 | 0.96 | 9 | **48** | **1.46** |
| **51B** | 42.2 | 5.8 | 3.80 | 1.39 | 5.9 | 1.22 | 17.8 | 0.65 | 23.9 | 5.7 | 5.6 | 15.2 | 0.94 | 0.56 | 4.04 | 29 | **164** | **1.33** |
| **51C** | 29.4 | 4.4 | 2.84 | 0.84 | 4.2 | 0.95 | 13.6 | 0.38 | 14.9 | 3.7 | 3.1 | 3.4 | 0.69 | 0.39 | 2.43 | 34 | **119** | **1.72** |
| **53A** | 81.1 | 5.0 | 2.85 | 1.38 | 5.4 | 1.00 | 54.7 | 0.39 | 29.0 | 8.3 | 5.2 | 11.2 | 0.82 | 0.40 | 2.62 | 27 | **236** | **0.77** |
| **53B** | 98.4 | 4.7 | 2.40 | 1.48 | 6.2 | 0.88 | 53.4 | 0.34 | 39.9 | 10.9 | 7.3 | 13.5 | 0.87 | 0.35 | 2.28 | 21 | **264** | **0.69** |
| **53C** | 64.1 | 4.6 | 2.83 | 1.13 | 5.0 | 0.94 | 31.4 | 0.44 | 28.7 | 7.7 | 5.6 | 13.1 | 0.79 | 0.42 | 2.89 | 23 | **193** | **0.89** |
| **53D** | 18.2 | 4.2 | 3.66 | 0.62 | 2.7 | 1.08 | 9.4 | 0.65 | 8.9 | 2.2 | 2.1 | 13.9 | 0.54 | 0.57 | 4.01 | 30 | **103** | **1.96** |
| **53E** | 55.4 | 4.7 | 2.93 | 1.14 | 5.0 | 0.99 | 28.4 | 0.44 | 26.3 | 6.7 | 5.1 | 11.4 | 0.76 | 0.42 | 2.75 | 27 | **179** | **1.05** |
| **54A** | 206.0 | 17.9 | 7.69 | 7.55 | 26.1 | 3.04 | 72.9 | 0.88 | 136.0 | 30.3 | 32.9 | | 3.66 | 1.04 | 6.35 | 51 | **603** | **1.03** |
| **54B** | 158.0 | 16.0 | 6.61 | 6.81 | 24.7 | 2.70 | 60.9 | 0.73 | 114.0 | 23.9 | 28.9 | | 3.32 | 0.86 | 5.31 | 46 | **499** | **1.15** |
| **54BB** | 9.0 | 0.8 | 0.42 | 0.21 | 0.8 | 0.15 | 3.6 | 0.05 | 3.8 | 1.0 | 0.8 | | 0.13 | 0.06 | 0.36 | 4 | **25** | **0.97** |
| **54C** | 65.2 | 9.2 | 5.45 | 2.96 | 10.9 | 1.86 | 22.7 | 0.87 | 48.4 | 10.1 | 12.4 | | 1.63 | 0.84 | 5.79 | 29 | **227** | **1.30** |
| **54CC** | 11.6 | 0.7 | 0.38 | 0.19 | 0.7 | 0.14 | 7.9 | 0.04 | 3.7 | 1.1 | 0.7 | | 0.12 | 0.05 | 0.31 | 4 | **32** | **0.75** |
| **54D** | 78.1 | 4.7 | 2.61 | 1.28 | 5.4 | 0.88 | 37.9 | 0.37 | 33.5 | 9.0 | 6.4 | | 0.81 | 0.37 | 2.47 | 22 | **206** | **0.79** |
| **54DD** | 11.8 | 0.6 | 0.33 | 0.17 | 0.7 | 0.12 | 7.2 | 0.04 | 3.8 | 1.2 | 0.7 | | 0.11 | 0.05 | 0.27 | 3 | **30** | **0.65** |
| **54F** | 10.8 | 2.5 | 1.68 | 0.34 | 2.0 | 0.54 | 5.3 | 0.26 | 5.9 | 1.4 | 1.7 | | 0.36 | 0.25 | 1.68 | 14 | **49** | **1.83** |
| **54FF** | 26.6 | 1.2 | 0.67 | 0.27 | 1.4 | 0.23 | 14.8 | 0.08 | 10.0 | 2.9 | 1.5 | | 0.22 | 0.10 | 0.56 | 5 | **66** | **0.63** |
| **54G** | 37.0 | 3.9 | 2.46 | 0.47 | 3.5 | 0.80 | 16.6 | 0.34 | 16.9 | 4.6 | 3.7 | | 0.62 | 0.35 | 2.27 | 21 | **115** | **1.11** |
| **54HH** | 11.8 | 1.0 | 0.56 | 0.23 | 1.1 | 0.19 | 5.0 | 0.08 | 5.7 | 1.5 | 1.2 | | 0.17 | 0.09 | 0.53 | 5 | **34** | **1.00** |
| **54I** | 23.6 | 1.7 | 1.01 | 0.29 | 1.7 | 0.34 | 13.6 | 0.14 | 8.7 | 2.5 | 1.6 | | 0.28 | 0.14 | 0.89 | 9 | **65** | **0.84** |
| **54J** | 13.3 | 0.8 | 0.41 | 0.16 | 0.8 | 0.15 | 8.0 | 0.04 | 4.3 | 1.3 | 0.8 | | 0.13 | 0.05 | 0.31 | 4 | **35** | **0.71** |
| **54JJ** | 13.5 | 0.7 | 0.45 | 0.23 | 0.9 | 0.14 | 7.0 | 0.07 | 5.7 | 1.5 | 1.0 | | 0.12 | 0.07 | 0.46 | 4 | **36** | **0.79** |
| **54L** | 5.7 | 0.4 | 0.18 | 0.07 | 0.3 | 0.07 | 3.3 | 0.02 | 1.9 | 0.6 | 0.3 | | 0.06 | 0.02 | 0.14 | 2 | **15** | **0.77** |
| **54O** | 10.8 | 0.7 | 0.38 | 0.16 | 0.8 | 0.14 | 6.4 | 0.04 | 3.9 | 1.1 | 0.7 | | 0.12 | 0.05 | 0.31 | 4 | **30** | **0.82** |
| **54Q** | 10.6 | 1.0 | 0.46 | 0.22 | 1.1 | 0.18 | 6.1 | 0.05 | 4.4 | 1.2 | 0.9 | | 0.17 | 0.06 | 0.33 | 7 | **34** | **1.18** |
| **54R** | 16.6 | 4.5 | 2.79 | 0.76 | 3.8 | 0.95 | 7.3 | 0.37 | 9.9 | 2.2 | 2.7 | | 0.69 | 0.38 | 2.39 | 28 | **83** | **2.25** |
| **54S** | 11.4 | 1.4 | 0.82 | 0.29 | 1.4 | 0.29 | 7.7 | 0.10 | 5.0 | 1.2 | 1.1 | | 0.22 | 0.11 | 0.66 | 11 | **43** | **1.49** |
| **54T** | 7.7 | 0.7 | 0.43 | 0.16 | 0.8 | 0.15 | 3.8 | 0.05 | 3.6 | 0.9 | 0.7 | | 0.12 | 0.06 | 0.33 | 6 | **26** | **1.33** |
| **54U** | 8.8 | 0.7 | 0.39 | 0.18 | 0.7 | 0.14 | 5.0 | 0.05 | 3.8 | 1.0 | 0.7 | | 0.11 | 0.06 | 0.34 | 5 | **27** | **1.08** |
| **54X** | 16.1 | 0.8 | 0.43 | 0.18 | 0.8 | 0.15 | 11.5 | 0.06 | 4.8 | 1.5 | 0.8 | | 0.13 | 0.06 | 0.38 | 4 | **42** | **0.62** |
| **54Z** | 17.9 | 0.8 | 0.44 | 0.19 | 0.8 | 0.15 | 14.1 | 0.06 | 4.6 | 1.5 | 0.8 | | 0.13 | 0.07 | 0.40 | 4 | **46** | **0.55** |
| **55-1** | 36.2 | 1.5 | 0.99 | 0.52 | 2.0 | 0.32 | 18.0 | 0.18 | 15.6 | 4.2 | 2.7 | | 0.27 | 0.16 | 1.16 | 8 | **92** | **0.71** |
| **55-2** | 139.0 | 8.3 | 3.35 | 3.03 | 12.0 | 1.34 | 69.1 | 0.37 | 64.7 | 16.7 | 13.5 | | 1.67 | 0.41 | 2.67 | 29 | **365** | **0.77** |
| **55-4** | 94.7 | 8.2 | 4.60 | 2.04 | 8.9 | 1.66 | 42.7 | 0.58 | 45.0 | 11.9 | 9.0 | 13.9 | 1.41 | 0.63 | 3.95 | 38 | **287** | **0.98** |
| **55-6** | 62.6 | 3.3 | 2.04 | 0.91 | 3.9 | 0.64 | 31.5 | 0.32 | 27.2 | 7.3 | 4.9 | | 0.56 | 0.30 | 2.11 | 16 | **164** | **0.76** |
| **55-7** | 47.8 | 11.7 | 8.34 | 1.71 | 8.3 | 2.71 | 25.4 | 1.22 | 24.7 | 6.1 | 6.0 | 28.4 | 1.63 | 1.20 | 7.75 | 69 | **252** | **1.93** |
| **56A** | 121.0 | 8.2 | 4.23 | 2.58 | 9.9 | 1.53 | 58.7 | 0.58 | 55.4 | 14.6 | 11.3 | 16.5 | 1.49 | 0.60 | 4.00 | 33 | **344** | **0.82** |
| **56B** | 76.5 | 5.5 | 2.88 | 1.74 | 6.6 | 1.01 | 33.2 | 0.41 | 38.4 | 9.8 | 8.3 | 19.9 | 1.00 | 0.41 | 2.75 | 20 | **228** | **0.86** |
| **56C** | 32.1 | 0.9 | 0.40 | 0.22 | 1.3 | 0.14 | 16.3 | 0.05 | 11.2 | 3.4 | 1.9 | 1.6 | 0.17 | 0.05 | 0.34 | 4 | **74** | **0.52** |
| **56E** | 105.0 | 7.8 | 3.61 | 2.42 | 9.8 | 1.35 | 41.6 | 0.46 | 52.3 | 13.3 | 11.2 | 18.1 | 1.46 | 0.49 | 3.17 | 23 | **295** | **0.82** |
| **56F** | 151.0 | 18.8 | 9.65 | 4.00 | 20.6 | 3.60 | 64.2 | 1.15 | 77.6 | 19.2 | 17.4 | 16.8 | 3.30 | 1.28 | 7.78 | 77 | **493** | **1.15** |
| **56FII** | 165.0 | 20.6 | 10.10 | 4.80 | 23.6 | 3.87 | 68.4 | 1.20 | 91.2 | 22.5 | 20.9 | 17.7 | 3.80 | 1.35 | 7.97 | 92 | **555** | **1.24** |
| **56G** | 32.8 | 2.6 | 1.59 | 0.51 | 2.7 | 0.57 | 20.7 | 0.19 | 12.1 | 3.7 | 2.1 | 2.1 | 0.43 | 0.22 | 1.24 | 20 | **104** | **1.06** |
| **57B** | 31.6 | 2.4 | 1.15 | 0.89 | 3.3 | 0.43 | 14.3 | 0.15 | 18.3 | 4.4 | 4.0 | 9.9 | 0.45 | 0.16 | 0.99 | 10 | **102** | **1.00** |
| **57E** | 49.4 | 3.7 | 1.82 | 1.23 | 4.8 | 0.66 | 18.2 | 0.26 | 25.7 | 6.6 | 5.5 | 10.8 | 0.72 | 0.26 | 1.71 | 12 | **143** | **0.86** |
| **57F** | 101.0 | 8.5 | 4.33 | 2.10 | 9.6 | 1.60 | 47.2 | 0.53 | 44.6 | 12.0 | 9.2 | 9.1 | 1.54 | 0.60 | 3.60 | 39 | **295** | **0.93** |
| **58B** | 94.3 | 6.5 | 3.10 | 2.51 | 8.7 | 1.15 | 40.8 | 0.41 | 50.7 | 12.9 | 11.0 | 21.9 | 1.24 | 0.44 | 2.81 | 26 | **284** | **0.91** |
| **58C** | 73.5 | 2.7 | 1.30 | 0.46 | 3.6 | 0.48 | 32.0 | 0.16 | 27.7 | 8.3 | 4.8 | 2.2 | 0.51 | 0.18 | 1.12 | 14 | **173** | **0.62** |
| **58E** | 9.9 | 0.6 | 0.29 | 0.28 | 0.9 | 0.10 | 3.6 | 0.05 | 6.2 | 1.5 | 1.4 | 8.5 | 0.12 | 0.05 | 0.33 | 2 | **36** | **0.91** |
| **58F** | 107.0 | 12.2 | 5.84 | 3.12 | 14.2 | 2.20 | 41.3 | 0.71 | 59.5 | 14.7 | 14.1 | 18.9 | 2.26 | 0.79 | 4.80 | 48 | **350** | **1.13** |
| **58G** | 31.1 | 5.5 | 3.62 | 1.27 | 4.9 | 1.23 | 14.4 | 0.52 | 16.3 | 4.0 | 4.0 | 9.1 | 0.86 | 0.52 | 3.28 | 39 | **140** | **1.82** |
| **59A** | 21.9 | 2.8 | 1.56 | 0.75 | 2.9 | 0.54 | 8.7 | 0.23 | 12.9 | 3.0 | 3.2 | 6.9 | 0.47 | 0.23 | 1.54 | 14 | **82** | **1.33** |
| **59B** | 22.0 | 3.7 | 2.18 | 0.87 | 3.7 | 0.75 | 7.5 | 0.33 | 13.8 | 3.2 | 3.5 | 9.6 | 0.62 | 0.32 | 2.16 | 18 | **92** | **1.53** |
| **59C** | 30.7 | 6.9 | 4.93 | 1.08 | 5.1 | 1.60 | 15.5 | 0.75 | 15.7 | 3.9 | 3.9 | 15.1 | 1.00 | 0.72 | 4.83 | 44 | **156** | **1.91** |
| **59D** | 38.3 | 7.6 | 5.24 | 1.51 | 6.4 | 1.75 | 19.3 | 0.76 | 20.0 | 4.9 | 4.9 | 15.7 | 1.16 | 0.75 | 4.83 | 56 | **189** | **1.97** |
| **60A** | 9.6 | 2.1 | 1.31 | 0.49 | 1.9 | 0.44 | 4.0 | 0.20 | 6.1 | 1.4 | 1.6 | 6.6 | 0.32 | 0.19 | 1.30 | 12 | **50** | **1.90** |
| **60B** | 31.0 | 5.2 | 3.19 | 1.02 | 4.7 | 1.09 | 13.5 | 0.44 | 17.4 | 4.2 | 4.2 | 11.0 | 0.82 | 0.44 | 2.87 | 31 | **132** | **1.64** |
| **61A** | 49.1 | 7.7 | 3.81 | 2.65 | 9.9 | 1.42 | 10.1 | 0.48 | 50.7 | 10.2 | 11.9 | 12.9 | 1.45 | 0.52 | 3.36 | 33 | **209** | **1.81** |

## Appendix B. Rare Earth Concentrations and Outlook Coefficients (continued)

| NDGS ID | Ce | Dy | Er | Eu | Gd | Ho | La | Lu | Nd | Pr | Sm | Sc | Tb | Tm | Yb | Y | Total REE | $C_{outl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **61B** | 8.5 | 1.0 | 0.56 | 0.27 | 1.0 | 0.20 | 5.0 | 0.07 | 4.0 | 1.0 | 1.1 | 2.7 | 0.17 | 0.08 | 0.50 | 6 | **32** | **1.28** |
| **61C** | 39.4 | 1.9 | 1.15 | 0.64 | 2.4 | 0.39 | 19.1 | 0.19 | 17.2 | 4.7 | 3.1 | 7.3 | 0.34 | 0.18 | 1.21 | 10 | **109** | **0.75** |
| **61D** | 15.7 | 2.7 | 2.00 | 0.52 | 2.3 | 0.65 | 9.8 | 0.31 | 7.4 | 1.8 | 1.7 | 12.2 | 0.41 | 0.29 | 1.96 | 23 | **83** | **1.91** |
| **61E** | 44.0 | 2.7 | 1.53 | 0.93 | 3.4 | 0.53 | 18.4 | 0.23 | 20.5 | 5.2 | 3.9 | 9.7 | 0.49 | 0.23 | 1.51 | 14 | **127** | **0.86** |
| **61F** | 45.3 | 3.0 | 1.53 | 0.93 | 3.7 | 0.57 | 29.6 | 0.20 | 19.5 | 5.1 | 3.7 | 7.3 | 0.53 | 0.20 | 1.31 | 16 | **138** | **0.87** |
| **61G** | 62.6 | 4.5 | 2.51 | 1.30 | 5.2 | 0.88 | 25.4 | 0.34 | 29.7 | 7.5 | 5.8 | 8.8 | 0.79 | 0.35 | 2.28 | 23 | **181** | **0.93** |
| **61H** | 118.0 | 10.4 | 5.26 | 3.68 | 12.2 | 1.93 | 34.7 | 0.64 | 65.6 | 15.8 | 14.0 | 19.4 | 1.88 | 0.71 | 4.49 | 47 | **356** | **1.06** |
| **61I** | 79.9 | 5.8 | 2.91 | 2.32 | 7.4 | 1.06 | 27.0 | 0.40 | 43.5 | 10.3 | 9.0 | 14.6 | 1.07 | 0.41 | 2.71 | 24 | **232** | **0.94** |
| **61J** | 22.5 | 3.3 | 2.35 | 0.61 | 2.8 | 0.77 | 12.9 | 0.38 | 10.2 | 2.6 | 2.3 | 10.3 | 0.50 | 0.35 | 2.35 | 25 | **99** | **1.59** |
| **62A** | 31.4 | 4.6 | 2.64 | 1.13 | 5.0 | 0.91 | 12.0 | 0.37 | 19.4 | 4.4 | 5.0 | 9.1 | 0.78 | 0.36 | 2.44 | 22 | **122** | **1.42** |
| **62B** | 64.3 | 6.0 | 3.19 | 1.69 | 7.2 | 1.11 | 25.8 | 0.45 | 34.7 | 8.4 | 7.7 | 13.3 | 1.07 | 0.45 | 2.98 | 26 | **204** | **1.05** |
| **62C** | 37.0 | 5.0 | 2.98 | 1.09 | 4.8 | 1.01 | 17.9 | 0.42 | 18.3 | 4.5 | 4.4 | 11.4 | 0.81 | 0.42 | 2.82 | 26 | **139** | **1.30** |
| **62D** | 49.3 | 3.5 | 2.08 | 1.00 | 4.0 | 0.71 | 22.9 | 0.30 | 21.9 | 5.6 | 4.3 | 15.9 | 0.59 | 0.29 | 2.01 | 19 | **153** | **0.91** |
| **62E** | 65.2 | 5.2 | 2.84 | 1.58 | 6.1 | 0.97 | 32.3 | 0.41 | 31.9 | 8.0 | 6.7 | 16.7 | 0.88 | 0.40 | 2.70 | 24 | **206** | **0.95** |
| **62F** | 116.0 | 14.9 | 7.66 | 4.20 | 16.9 | 2.73 | 37.0 | 0.97 | 72.2 | 16.6 | 17.4 | 22.1 | 2.57 | 1.02 | 6.60 | 69 | **408** | **1.34** |
| **62H** | 38.6 | 9.7 | 8.31 | 1.50 | 6.6 | 2.41 | 20.2 | 1.52 | 19.4 | 4.8 | 4.6 | 54.0 | 1.25 | 1.25 | 9.04 | 80 | **263** | **2.27** |
| **63A** | 17.5 | 3.9 | 2.97 | 0.67 | 3.2 | 0.91 | 8.2 | 0.53 | 10.6 | 2.5 | 2.5 | 10.0 | 0.56 | 0.45 | 3.20 | 26 | **94** | **1.98** |
| **63C** | 22.0 | 4.1 | 2.53 | 0.86 | 4.0 | 0.85 | 9.4 | 0.40 | 12.6 | 3.0 | 3.1 | 11.8 | 0.65 | 0.36 | 2.55 | 19 | **97** | **1.52** |
| **63D** | 47.7 | 7.3 | 5.58 | 1.26 | 5.7 | 1.72 | 24.6 | 0.95 | 22.7 | 5.8 | 5.0 | 18.4 | 1.02 | 0.83 | 5.79 | 48 | **202** | **1.51** |
| **63E** | 51.6 | 4.1 | 2.76 | 1.05 | 4.4 | 0.88 | 25.3 | 0.43 | 24.1 | 6.2 | 4.7 | 17.7 | 0.67 | 0.40 | 2.72 | 25 | **172** | **1.03** |
| **63F** | 41.1 | 3.7 | 2.55 | 0.86 | 3.6 | 0.81 | 20.7 | 0.40 | 18.8 | 4.8 | 3.7 | 14.5 | 0.57 | 0.36 | 2.46 | 25 | **144** | **1.14** |
| **63G** | 46.4 | 7.4 | 4.58 | 1.64 | 7.3 | 1.55 | 21.4 | 0.66 | 26.4 | 6.1 | 6.3 | 19.7 | 1.19 | 0.62 | 4.12 | 46 | **201** | **1.63** |
| **64A** | 52.5 | 4.0 | 2.48 | 1.14 | 4.3 | 0.82 | 26.5 | 0.38 | 24.1 | 6.3 | 4.7 | 18.5 | 0.67 | 0.37 | 2.44 | 20 | **169** | **0.93** |
| **64B** | 52.5 | 4.0 | 2.48 | 1.15 | 4.4 | 0.82 | 26.9 | 0.38 | 24.5 | 6.3 | 4.8 | 19.0 | 0.67 | 0.36 | 2.45 | 21 | **172** | **0.95** |
| **64D** | 15.3 | 3.6 | 2.22 | 0.72 | 3.1 | 0.74 | 5.8 | 0.36 | 10.0 | 2.2 | 2.8 | 9.8 | 0.56 | 0.33 | 2.31 | 15 | **75** | **1.69** |
| **64E** | 6.6 | 1.1 | 0.87 | 0.19 | 0.7 | 0.26 | 4.1 | 0.16 | 2.7 | 0.7 | 0.6 | 23.7 | 0.15 | 0.14 | 0.99 | 6 | **49** | **1.35** |
| **64EE** | 20.8 | 1.9 | 1.32 | 0.47 | 1.7 | 0.42 | 10.3 | 0.23 | 9.3 | 2.5 | 1.9 | 19.0 | 0.30 | 0.21 | 1.41 | 11 | **83** | **1.05** |
| **64F** | 37.3 | 2.8 | 1.83 | 0.80 | 2.9 | 0.59 | 18.8 | 0.29 | 16.7 | 4.4 | 3.2 | 16.7 | 0.46 | 0.27 | 1.89 | 15 | **124** | **0.93** |
| **64G** | 54.6 | 4.3 | 2.67 | 1.17 | 4.5 | 0.88 | 27.8 | 0.41 | 24.1 | 6.4 | 4.8 | 15.0 | 0.72 | 0.39 | 2.59 | 23 | **173** | **0.95** |
| **64H** | 43.9 | 3.9 | 2.31 | 1.26 | 4.5 | 0.78 | 21.9 | 0.36 | 22.8 | 5.6 | 4.9 | 15.3 | 0.67 | 0.34 | 2.30 | 18 | **149** | **1.03** |
| **64I** | 131.0 | 9.5 | 4.96 | 3.20 | 11.6 | 1.82 | 60.7 | 0.60 | 59.3 | 15.4 | 11.6 | 16.6 | 1.72 | 0.67 | 4.08 | 46 | **379** | **0.90** |
| **64J** | 63.6 | 6.9 | 4.21 | 1.85 | 7.0 | 1.40 | 27.1 | 0.64 | 32.3 | 8.1 | 7.2 | 13.1 | 1.14 | 0.62 | 4.14 | 35 | **214** | **1.16** |
| **64K** | 52.0 | 4.9 | 3.21 | 1.21 | 4.9 | 1.06 | 25.3 | 0.47 | 24.1 | 6.3 | 5.0 | 20.0 | 0.79 | 0.45 | 2.99 | 30 | **183** | **1.13** |
| **64L** | 34.8 | 3.0 | 1.92 | 0.86 | 3.2 | 0.64 | 15.5 | 0.31 | 16.7 | 4.2 | 3.4 | 17.2 | 0.50 | 0.29 | 1.97 | 14 | **118** | **0.97** |
| **64M** | 53.4 | 4.0 | 2.42 | 1.15 | 4.4 | 0.81 | 26.8 | 0.37 | 24.4 | 6.4 | 4.8 | 17.8 | 0.66 | 0.36 | 2.39 | 21 | **171** | **0.94** |
| **64N** | 51.0 | 3.7 | 2.11 | 1.20 | 4.3 | 0.71 | 25.0 | 0.32 | 25.0 | 6.4 | 5.0 | 18.7 | 0.64 | 0.31 | 2.06 | 17 | **163** | **0.91** |
| **64O** | 41.6 | 7.0 | 4.71 | 1.40 | 5.9 | 1.56 | 18.1 | 0.70 | 21.8 | 5.4 | 5.2 | 15.8 | 1.05 | 0.68 | 4.54 | 43 | **178** | **1.61** |
| **64P** | 5.7 | 1.9 | 1.62 | 0.32 | 1.3 | 0.49 | 2.8 | 0.28 | 3.3 | 0.8 | 0.9 | 9.3 | 0.26 | 0.25 | 1.72 | 13 | **44** | **2.42** |
| **64Q** | 83.1 | 9.5 | 6.20 | 2.52 | 9.8 | 2.07 | 38.7 | 0.95 | 43.6 | 10.5 | 9.4 | 19.6 | 1.53 | 0.91 | 5.99 | 52 | **296** | **1.24** |
| **64R** | 56.1 | 4.8 | 3.29 | 1.13 | 4.8 | 1.08 | 28.9 | 0.50 | 25.1 | 6.7 | 4.9 | 13.9 | 0.77 | 0.48 | 3.23 | 31 | **187** | **1.08** |
| **64S** | 94.6 | 6.7 | 4.02 | 1.67 | 7.4 | 1.39 | 47.5 | 0.56 | 41.5 | 11.2 | 8.0 | 11.1 | 1.14 | 0.58 | 3.74 | 40 | **281** | **0.94** |
| **64T** | 129.0 | 13.5 | 7.86 | 3.08 | 13.6 | 2.79 | 65.1 | 1.02 | 58.4 | 15.2 | 12.0 | 20.8 | 2.22 | 1.08 | 6.82 | 79 | **431** | **1.17** |
| **64U** | 139.0 | 15.4 | 9.19 | 3.50 | 15.6 | 3.22 | 62.7 | 1.19 | 63.6 | 15.7 | 13.6 | 27.0 | 2.57 | 1.26 | 7.98 | 91 | **473** | **1.21** |
| **65A** | 52.8 | 9.4 | 6.60 | 1.56 | 7.6 | 2.21 | 25.6 | 0.90 | 25.5 | 6.5 | 5.8 | 21.6 | 1.38 | 0.93 | 5.70 | 87 | **261** | **2.10** |
| **65B** | 48.3 | 3.2 | 1.98 | 0.89 | 3.4 | 0.67 | 24.2 | 0.28 | 20.4 | 5.5 | 3.8 | 14.3 | 0.53 | 0.29 | 1.87 | 20 | **150** | **0.91** |