Extraction of REE from Coal

S203-UTA-PPM4002 Mod 01
University of Utah – REE recovery from Western Coals

PROJECT REPORT

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Supported by Leonardo Technologies under
U.S. Department of Energy Prime Award DE-F0004002

January 2015

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LIST OF ACRONYMS

REE – Rare Earth Elements (La, Ce, Pr, Nd, Sm, Eu, Sm, Tb, Dy, Ho, Er, Tm, Yb, Lu)

LREE – Light Rare Earth Elements (La, Ce, Pr, Nd, Sm)

HREE – Heavy Rare Earth Elements (Eu, Sm, Tb, Dy, Ho, Er, Tm, Yb, Lu)

REE+Y+Sc – Rare earth elements with yttrium (Y) and scandium (Sc)

ICP-MS – Inductively Coupled Plasma - Mass Spectrometry

WHIMS – Wet High Intensity Magnetic Separator

ASTM – American Society for Testing and Materials

ROM – Run-of-mine

QEMSCAN – Quantitative Evaluation of Minerals by SCANning Electron Microscopy

EXECUTIVE SUMMARY

This work has been undertaken by the University of Utah to investigate the potential for extracting rare earth elements (REE), including lanthanum, La, cerium, Ce, praseodymium, Pr, neodymium, Nd, samarium, Sm, europium, Eu, gadolinium, Gd, terbium, Tb, dysprosium, Dy, holmium, Ho, erbium, Er, ytterbium, Yb, lutetium, Lu, as well as yttrium, Y, and scandium, Sc (REE+Y+Sc) from different Western U.S. coal samples (Note: thulium, Tm, is a REE which is not included in this study).

The work had two major objectives:

1) to select, collect, prepare, and analyze samples from a number of Western U.S. coal deposits (i.e. basins, mines, seams); and
2) to employ conventional physical separation technologies on selected coal samples to investigate REE+Y+Sc concentration potential.

Based on preliminary geologic assessment, 36 different samples from 7 different states were selected for analysis. All acquired samples were sampled, prepared, and analyzed according to ASTM (American Society for Testing and Materials) standards. As reported in the literature, more potent REE+Y+Sc deposits in the World are found within geologically older, lower quality coal deposits formed by both erosional and tectonic processes – typically within the coal matrix of high ash and low S coals. Therefore, in addition to raw coal samples, a number of partings/reject/refuse samples were collected and analyzed.

All collected samples were crushed, grinded, homogenized, screened, and split in order to provide representative subsamples for further physical separation and elemental analysis.

Particle classification, density separation (float-sink/washability analysis), flotation, and wet magnetic separation were employed in order to provide REE+Y+Sc enriched fractions. Through this task, effectiveness of existing/conventional technologies to concentrate REE+Y+Sc from different coal and coal waste materials is evaluated.

All raw samples and split fractions obtained through physical separation tests were analyzed for their REE, yttrium, and scandium contents using ICP-MS. Furthermore, the proximate analysis was performed to obtain information about the ash, moisture, fixed C, volatile matter, S, and Btu contents of all raw samples and selected split fractions.

Summary of the key findings are the following:

1) Coal samples considered in this study demonstrated a particularly wide range of properties – samples collected from 7 Western U.S. coal basins, 7 states, and 15 mine sites. The proximate analysis of all coal raw samples show a wide range of ash, volatiles, fixed carbon, and sulfur concentrations, and calorific values. Limit results of proximate analysis for all investigated samples are given in table below.

Assay (%)	min	max
Ash	5.17	86.65
Volatiles	13.63	48.55
Fixed Carbon	1.72	56.36
Sulfur	0.02	2.46
Calorific Value (Btu/lb)	300	13410

2) The results of elemental analysis of all received samples revealed a particularly wide range of REE+Sc+Y concentrations within 34 samples analyzed. The ranges of light rare earth elements (LREE), heavy rare earth elements (HREE), scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium, dysprosium, and holmium concentrations are given below.

expressed per ash basis		
Assay (ppm)	min	max
LREE	63.42	346.44
HREE	8.07	87.45
Sc	3.21	58.55
Y	9.72	173.36
La	16.72	85.41
Ce	20.13	170.02
Pr	0.65	24.73
Nd	12.79	74.59
Gd	2.68	20.14
Dy	1.72	24.03
Er	0.99	18.49

expressed per whole sample basis		
Assay (ppm)	min	max
LREE	3.86	254.50
HREE	0.55	52.16
Sc	0.25	34.92
Y	0.72	103.41
La	1.04	62.74
Ce	1.67	124.90
Pr	0.06	12.74
Nd	0.76	54.80
Gd	0.16	12.01
Dy	0.11	14.34
Er	0.07	8.24

3) The elemental analysis of raw samples revealed a wide range of LREE/HREE ratio. The ratio was found to be in the range from 2.67 for NDBMFUB1 sample to 13.43 for NMSJMSJB1 sample.

4) Of all the received coal samples, only a small number demonstrated elevated REE+Y+Sc concentrations – 9 samples (ash samples excluded) had REE+Y+Sc concentrations over 150 ppm when expressed per whole sample basis, while 30 samples had REE+Y+Sc concentrations over 150 ppm if reported per ash basis.

5) The samples from the Fort Union Basin, Powder River Basin, and North Central Basin demonstrated highest REE+Y+Sc concentrations. The North Central Basin samples, including Sand Coulee outcrop and Belt outcrop samples, contain over 200 ppm of REE+Y+Sc expressed per whole sample basis.

6) Comparison of the coal proximate analysis data with corresponding elemental analysis results revealed that samples with lower sulfur content generally have higher REE+Y+Sc concentrations. In addition, there is a slight trend toward higher REE+Y+Sc concentrations for coals with lower fixed carbon contents.

7) The wet high intensity magnetic separation method cannot be used to efficiently concentrate REE elements – it is effective only for the removal of the pyritic content of the coal. Using this mineral concentration method, extremely low mass yields were obtained (less than 2.5%) for most of the tests performed.

8) The froth flotation method cannot be used to effectively concentrate REE elements from fine coal of -100 mesh (<149 µm). The reason for this trend lies in the fact that most of the REE are found to be finely disseminated within the coal matrix with mineral grain size less than 5 microns, and, therefore, cannot be separated from the coal due to their poor liberation at feed particle size of -100 mesh. With the further liberation of the feed material, these results might change providing that economically feasible, efficient, and selective solution(s) for ultrafine coal particle recovery using flotation process is available. Further comprehensive mineralogical and experimental investigation is necessary to determine the potential for REE concentration from coal material using the froth flotation method.

9) The REE+Y+Sc concentrations in six gravity fractions (i.e. 1.2, 1.4, 1.6, 1.8, 2.0, and 2.2 SG) of ten selected coal samples were determined using standard float-sink/washability analysis. Three different particle size fractions of selected coals were prepared and tested, namely -3348-516 µm, -516-149 µm, and -149 µm. Maximum REE+Y+Sc concentrations were found within the coal ashes of light fractions. Furthermore, the most REE+Y+Sc concentrated density fractions of coal were found to be within the intermediate densities tested, or from 1.4 to 1.8 SG – the REE concentration in density fractions curve shows a quadratic trend. This general trend was found to be true for most of the samples analyzed but varies in magnitude for coals of different type. The REE recovery in intermediate density fractions was found to be larger for finer particle sizes. The REE could be concentrated using density-based mineral concentration methods, and the recoveries could be increased using finer particle sizes. The improvement of current and development of new fine particle density-based concentration technologies will be necessary to overcome the limitations of currently available technologies.

10) The mineral liberation analysis, QEMSCAN, was used to investigate the mineralogical properties of the sample which demonstrated the highest REE+Y+Sc concentrations, i.e. MOSONCB3. Both a detailed areal scan of one prepared sample using 5 µm resolution, as well as linear scans of three additional samples using 4 µm resolution and 100 µm line spacing were performed. For the MOSONCB3 sample, ICP-MS analysis found REE+Y+Sc concentrations of 382 ppm. On the other hand, there were no REE bearing minerals detected within over six million pixels analyzed using QEMSCAN method. We could give two potential, and completely different, reasons for this finding. First, the REE bearing minerals are finely disseminated within the sample with the largest grain size smaller than 4 µm. Second, the REE mineral grains are very large, and only few are present within the bearing sample so none of the existing grains was exposed during the sample preparation (polishing) and detected. While we believe that the first answer represents the more reasonable reason for this finding, a further comprehensive mineralogical analysis using microprobe, SEM-EDX, and/or nano-CT should be performed in the future. The findings of this analysis will be critical for development and optimization of new REE concentration technologies.

INTRODUCTION

This research work has been undertaken to investigate the potential for extracting rare earth elements, yttrium and scandium from different Western U.S. coal samples. The work had two major objectives:

1) to select, collect, prepare, and analyze samples from a number of Western U.S. coal deposits (i.e. basins, mines, seams); and
2) to employ conventional physical separation technologies on selected coal samples to investigate REE+Y+Sc concentration potential.

The main subtasks of this research effort included the following four main tasks:

1) TASK 1: Sample Acquisition
2) TASK 2: Sample Homogenization and Preparation
3) TASK 3: Physical Separation
4) TASK 4: Elemental and Proximate Analyses

In the following report, the details of the experimental methods used and overview of obtained results will be given.

Sample Acquisition

Run-of-mine (ROM) coal, refuse, partings, and outcrop samples from 7 U.S. States and 15 sampling sites, representing 7 different western coal deposits were sampled according to ASTM D2234 standard. A total of 17 raw coal samples and 5 coal refuse samples were collected from 13 active coal mine sites. Additional 14 samples were also received during the project period and they include 8 outcrop samples from the Great Falls Field (Montana), 2 ash samples from New Mexico, and 4 pulverized coal samples obtained from four distinct mine sites. A full list of samples considered in this study, including their unique designation which will be used throughout the report, is given in Table 1.

Distribution of analyzed samples within 7 main Western U.S. coal basins/deposits and their classification over three main coal types is given in Figure 1. The size and color of bubbles in the figure correspond to the total volatiles content in each considered sample. As can be seen in the figure, typically, more than two samples are received from each sampled location. A wide range of coal samples with widely different characteristics was considered through this work.

A map showing geographic distribution of sampling locations of all received coal samples, which are shown as stars in the figure, is given in Figure 2. For each sampling location, corresponding coal basin, coal type, and sample name are also given.

Due to the proprietary nature of most of the samples, names and pictures of the mines that generously provided the samples will not be included in the report. In Figure 3 and Figure 4,

pictures of the Sand Coulee outcrop and Belt outcrop sampling sites are given. Both sampling sites belong to the North Central Basin, Great Falls Field and represent the region which has demonstrated elevated concentrations of REE in the past.

In Figure 3, the image at the top shows the abandoned coal mine portal. Most of the sample was collected from the coal and shale on the each side of the portal (images in the middle, left and right). One sample was collected from shale material near the bottom of the coal seam (bottom image).

In Figure 4, the image of the whole Belt outcrop is given at the top, while the more detailed images of the site are offered in the middle. The images of the exact sampling sites are given at the bottom of the figure.

A minimum of 70 lb of sample was collected for each sampled site with an average particle size of about 2” for most of the samples considered in this study.

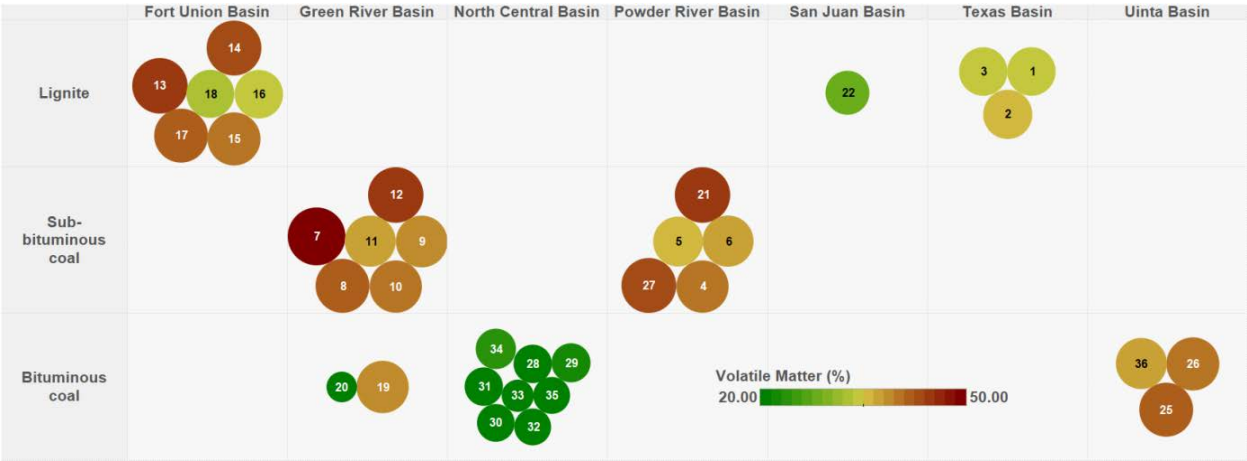

Figure 1: Distribution of considered samples within seven main coal basins and three different coal types

Table 1: A list of samples considered through the project with the information about sampling location, coal type, coal basin names, sample type

#	Sample Name	State	Coal Type	Coal Basin	Sample Type
1	TXJMTEB1	Texas	Lignite	Texas Basin	Refuse
2	TXJMTEB2	Texas	Lignite	Texas Basin	ROM
3	TXJMTEB3	Texas	Lignite	Texas Basin	Refuse
4	MOAMPRB1	Montana	Sub-bituminous coal	Powder River Basin	ROM
5	MORMPRB1	Montana	Sub-bituminous coal	Powder River Basin	ROM
6	MORMPRB2	Montana	Sub-bituminous coal	Powder River Basin	ROM
7	WYKMGRB1	Wyoming	Sub-bituminous coal	Green River Basin	ROM
8	WYKMGRB2	Wyoming	Sub-bituminous coal	Green River Basin	ROM
9	WYKMGRB3	Wyoming	Sub-bituminous coal	Green River Basin	ROM
10	WYKMGRB4	Wyoming	Sub-bituminous coal	Green River Basin	ROM
11	WYKMGRB5	Wyoming	Sub-bituminous coal	Green River Basin	ROM
12	WYKMGRB6	Wyoming	Sub-bituminous coal	Green River Basin	ROM
13	NDBMFUB1	North Dakota	Lignite	Fort Union Basin	ROM
14	NDBMFUB2	North Dakota	Lignite	Fort Union Basin	ROM
15	NDFMFUB1	North Dakota	Lignite	Fort Union Basin	ROM
16	NDFMFUB2	North Dakota	Lignite	Fort Union Basin	Refuse
17	NDFMFUB3	North Dakota	Lignite	Fort Union Basin	Refuse
18	NDFMFUB4	North Dakota	Lignite	Fort Union Basin	ROM
19	COTMGRB1	Colorado	Bituminous coal	Green River Basin	ROM
20	COTMGRB2	Colorado	Bituminous coal	Green River Basin	Refuse
21	WYNMPRB1	Wyoming	Sub-bituminous coal	Powder River Basin	PP Feed
22	NMSJMSJB1	New Mexico	Lignite	San Juan Basin	ROM
23	NMSJMSJB2	New Mexico	Lignite	San Juan Basin	Ash
24	NMSJMSJB3	New Mexico	Lignite	San Juan Basin	Ash
25	UTSYMUIB1	Utah	Bituminous coal	Uinta Basin	PP Feed
26	UTSUMUIB1	Utah	Bituminous coal	Uinta Basin	PP Feed
27	WYBTMPRB1	Wyoming	Sub-bituminous coal	Powder River Basin	PP Feed
28	MOBONCB1	Montana	Bituminous coal	North Central Basin	Outcrop
29	MOBONCB2	Montana	Bituminous coal	North Central Basin	Outcrop
30	MOBONCB3	Montana	Bituminous coal	North Central Basin	Outcrop
31	MOBONCB4	Montana	Bituminous coal	North Central Basin	Outcrop
32	MOSONCB1	Montana	Bituminous coal	North Central Basin	Outcrop
33	MOSONCB2	Montana	Bituminous coal	North Central Basin	Outcrop
34	MOSONCB3	Montana	Bituminous coal	North Central Basin	Outcrop
35	MOSONCB4	Montana	Bituminous coal	North Central Basin	Outcrop
36	UTWMUIB1	Utah	Bituminous coal	Uinta Basin	ROM

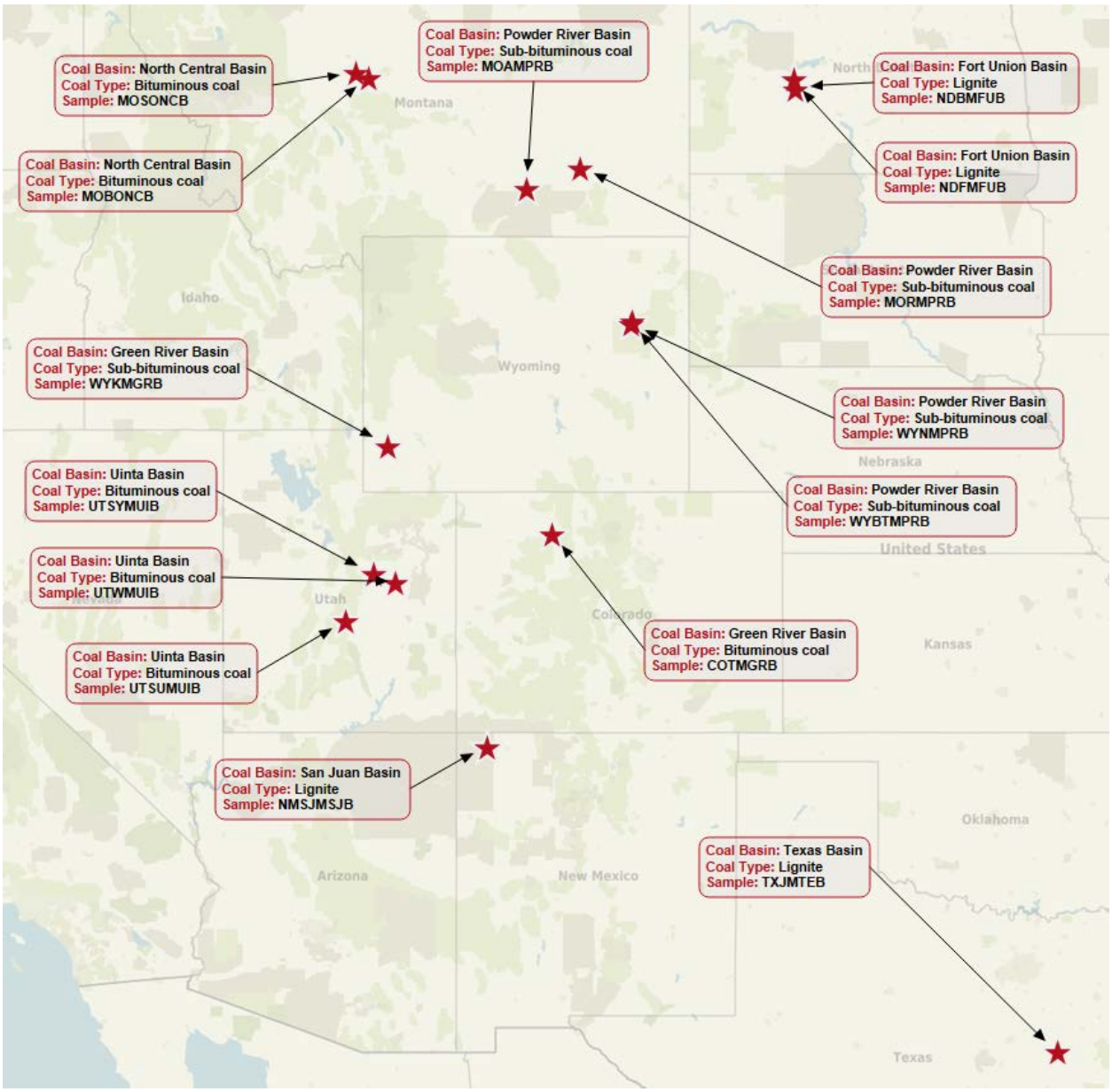

Figure 2: Geographic distribution of all sampling locations with corresponding coal basin, coal type, and sample names

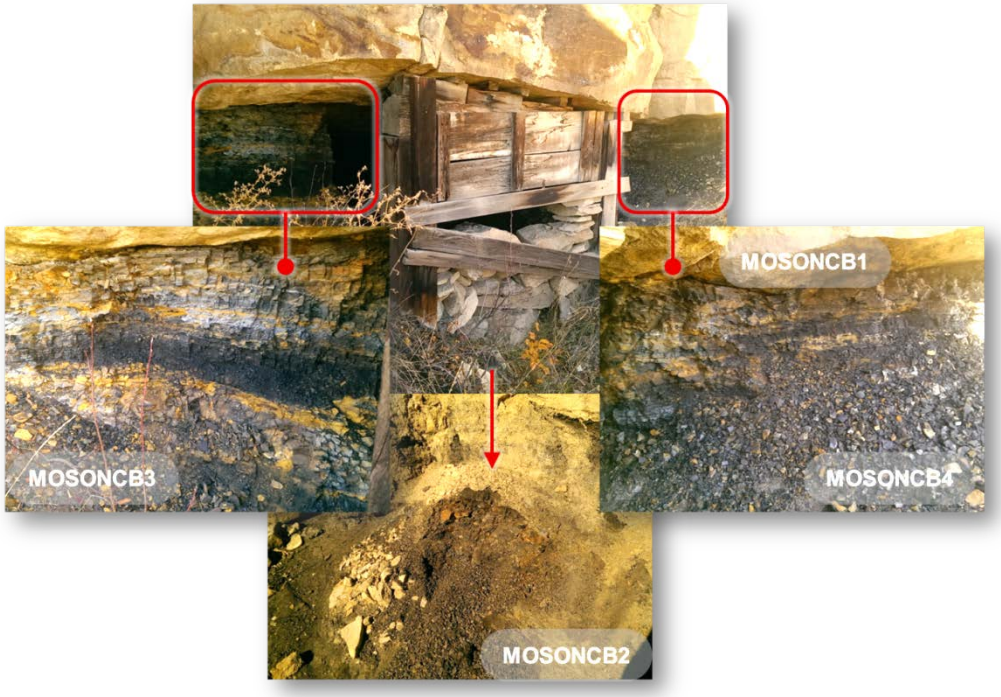

Figure 3: Pictures of the Sand Coulee outcrop sampling site

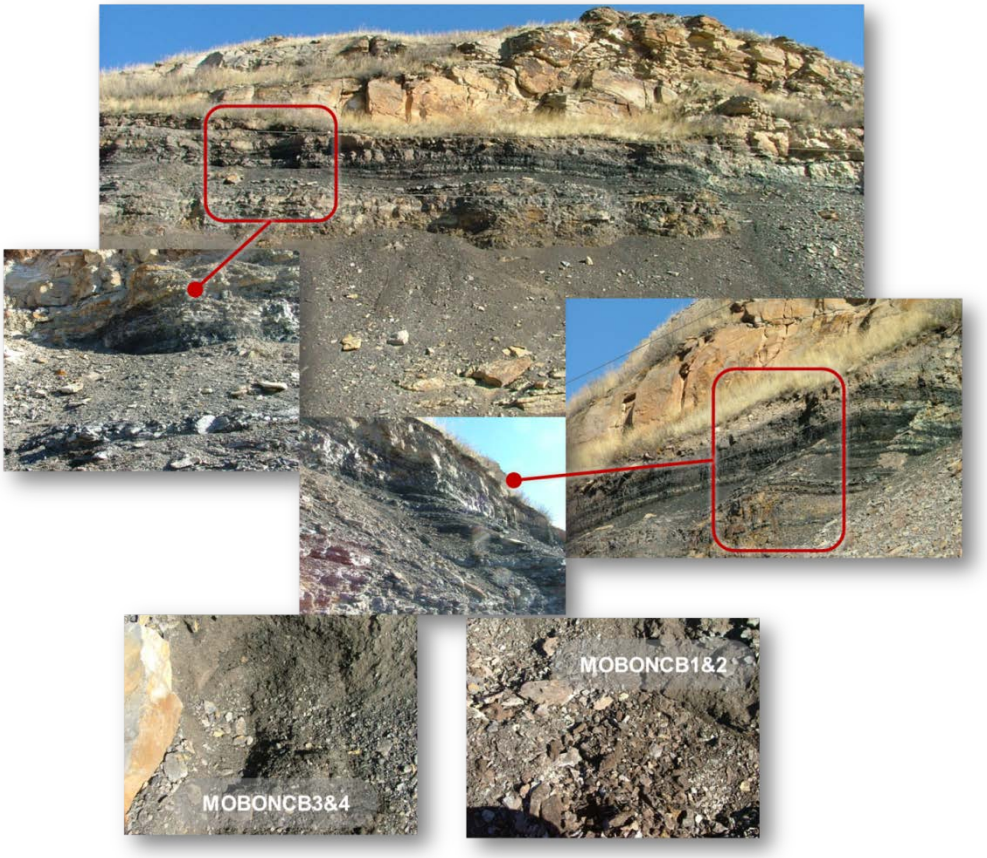

Figure 4: Pictures of the Belt outcrop sampling site

METHODS

In the following sections, details of the experimental methods used through this study are given.

Sample Homogenization and Preparation

The received samples were crushed, grinded, dry screened, wet screened, homogenized, sampled, and prepared for subsequent chemical analysis and physical separations. A detailed sample preparation procedure is given in Appendix 1.

All coarse samples (Figure 5, left) were crushed using a pilot scale jaw crusher with a CSS of about 1”. The jaw crusher product was subsequently crushed using a pilot scale roll crusher (6 mm gap) shown in Figure 5, right. In Figure 6, pictures of the received WYKMGRB2 sample, as well as the product after the roll crusher are given. If necessary, sample was additionally grinded using Fritsch grinder unit shown in Figure 7, left. The products of the roll crusher were screened using Sweco screening unit (Figure 7, right). The screening was performed to create three distinct size fractions: 6 by 30 mesh, 30 by 100 mesh, and 100 mesh x 0 (Sweco industrial grade sieve series), or -3348-516 µm, -516-149 µm, and -149 µm.

Figure 5: Pictures of jaw crusher, Sepor rotary sample splitter (left), and roll crusher (right)

Figure 6: As received WYKMGRB2 coal sample (left) and product obtained after the roll crusher (right)

Figure 7: Pictures of rotary micro splitter, Fritsch grinder (left), and Sweco screening unit (right)

In Appendix 2, pictures of all coal samples prepared through this project are given. Pictures of all three size fractions are offered. In addition, pictures of corresponding ash samples obtained according to the ASTM D6357–11 and ASTM D3174–12 standards are presented in Appendix 2. To facilitate better comparison across the samples, the concentrations of total ash, volatiles, and fixed carbon are also included in the figures.

Physical Separation

A series of physical separation methods were used in the lab to provide information about the feasibility of REE+Y+Sc concentration from the various coal samples. In addition, effectiveness of conventional technologies to concentrate REE+Y+Sc from selected coal samples was evaluated.

Based on the results of elemental ICP-MS analysis (details given in the following sections), physical separation tests were initiated only on samples which exhibited elevated REE+Y+Sc concentrations (>200 ppm per ash basis).

The following physical separation techniques were used to concentrate REE+Y+Sc from selected samples:

5) density separation (float-sink or washability analysis),
6) froth flotation separation, and
7) wet high intensity magnetic separation.

The pictures of used experimental units/setups are given in Figure 8 to Figure 11.

Float and Sink (Washability) Analysis

Gravity separation of coal from its associated gangue is the most commonly used process in coal washing plants. Due to their low density, pure coal particles (density range of liberated coal particles goes between 1.2 to 1.5 SG) can fairly easily be separated from heavier gangue particles (density range of liberated minerals goes from 1.8 to 5 SG or sometimes even larger). Coal washability analysis is performed to provide separation data (partition information) under ideal conditions. The basic principle of the washability analysis, or also known as a float-sink analysis, is as follows: a weighted amount of coal sample of particular size class is introduced into the series of heavy media (liquids) starting from the lowest to the highest density. The floating and sink fractions are collected separately and analyzed for their weight and ash contents.

Six different density media created using aqueous caesium formate solutions were selected in this study – 1.2, 1.4, 1.6, 1.8, 2.0, and 2.2 SG density fractions. Low toxicity aqueous solutions of caesium formate were used as a replacement for white spirit, perchloroethylene, bromoform and tetrabromoethane dense media. The aqueous caesium formate solutions spanned the required density range for coal float sink testing (1.1 to 2.2 SG) and had sufficiently low viscosity (2 to 5cP) to allow effective separations within typical operating times. Caesium formate solutions were close to neutral (pH 8 to 9) and chemically stable under the used experimental conditions, and did not appear to react significantly with coal.

Batch washing, to minimize caesium entrainment in the samples and maximize the removal of caesium formate from coal, was used. This procedure required using 7 litres of water for every kilogram of coal sample washed. The caesium formate dosages used to create six discrete gravity fractions are given in Table 2.

The washability analysis was performed according to ASTM D4371-06 standard using -3348+516 µm, -516+149 µm, and -149 µm size fractions. A brief summary of the washability testing procedure is given in Appendix 1. Pictures of the experimental setups used for the washability analysis of samples are given in Figures 8 and 9.

Table 2: Caesium formate dosages used to create six different dense media

Density (g/cm^3)	CsFo (wt %)	CsFo (kg)	Water (l)	CsF/Water (kg/l)
1.2	23.4	281.0	919.9	0.3
1.4	41.0	575.3	825.5	0.7
1.6	54.4	872.8	727.9	1.2
1.8	64.7	1167.2	633.4	1.8
2.0	72.8	1460.8	539.8	2.7
2.2	80.0	1764.2	436.2	4.0
2.4	87.0	2100.0	350.0	6.0

Figure 8: Float and sink analysis setup for -149 µm (left) and -516+149 µm particle size fraction (right)

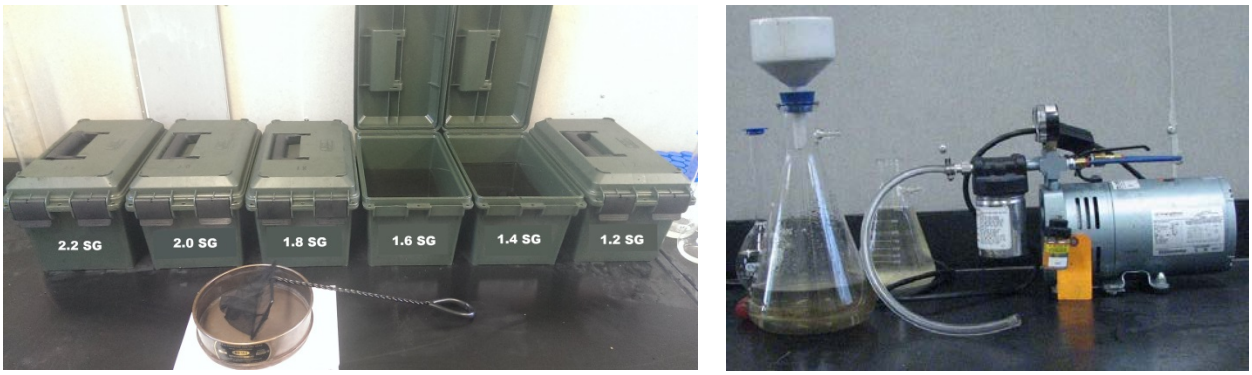

Figure 9: Float and sink analysis setup for - -3348+516 µm particle size fraction (left) and sample dewatering station (right)

Potential sources of experimental error could be due to minor material loss during the sample manipulation, rinsing, filtration, and drying. In addition, the particle floatability depends on both particle size and density, according to the Stokes law, but also it depends on the particle surface properties. Micro- or nano-bubbles might form on the hydrophobic surfaces of tested particles which could reduce the effective density of heavier particles. In such cases, the bias could be expected toward the lighter density fractions. The overall expected relative error of mass yield

data is estimated to be about 4%. This error is reported as error bars in the washability graphs given in the following section.

In addition, further errors are introduced due to slight caesium formate adsorption on coal particles. Coal immersed in caesium format solutions retain from 1 ml/kg for coarse coal, to 15 ml/kg for fine coal. The average error of 5% is therefore expected for all the ash data obtained from float and sink recovered fractions. This error is reported as error bars in the washability graphs given in the following section.

A statistical method called propagation of error is used to estimate the errors of all REE+Y+Sc assays reported per density fractions and per ash. If we assume that ICP-MS experimental procedure come with 2% error, the cumulative errors of unbalanced assays in ash, mass balanced assays in ash, and mass balanced assays in density fractions are calculated to be 5.38%, 6.67%, and 7.81% respectively. These errors are reported as error bars in the washability graphs given in the following section.

Magnetic Separation

In minerals processing, magnetic separation is used to concentrate magnetic particles from non-magnetic particles. The Carpco wet high-intensity magnetic separator (WHIMS) is used to explore the possibility of concentrating REE+Y+Sc using the high intensity magnetic field strength. Square pieces of steel mesh (opening size 8 mm) are stacked inside the collector box (10 mm spacing) to facilitate creation of a more homogeneous magnetic field Figure 10 (right). A continuous slurry feeding system is built to allow at least three volume recirculation times and in that way improve the recovery of paramagnetic material (Figure 10). Selected fine (-149 µm) coal samples with elevated REE concentrations were suspended using a mixer and slurry was fed in the separation box continuously using slurry pump. The experiment was run using high intensity filed strength for all of the tests. A detailed experimental procedure is given in Appendix 1.

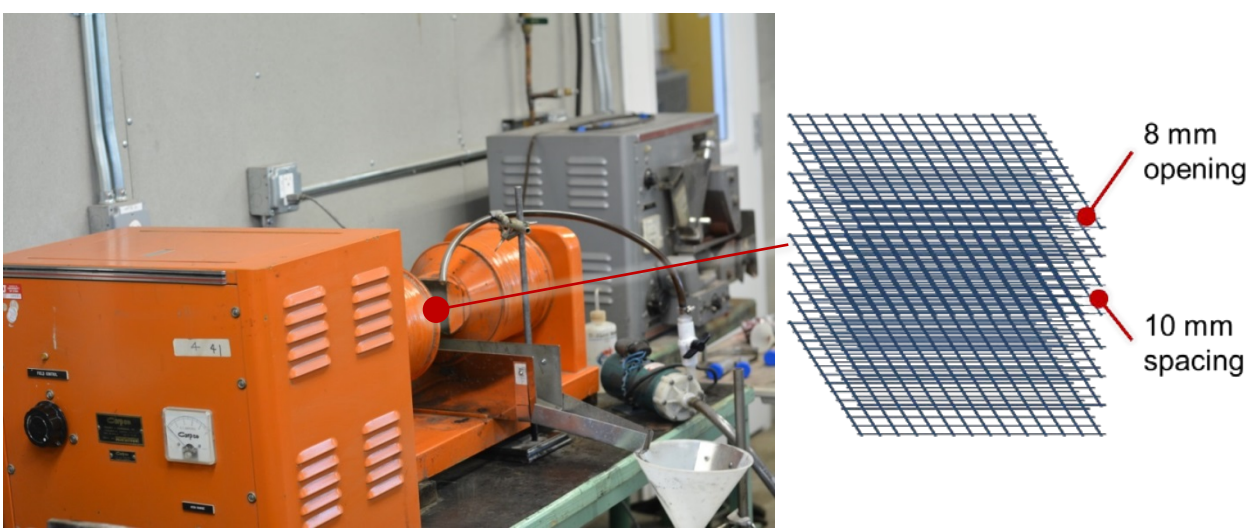

Figure 10: Carpco wet high intensity magnetic separation (WHIMS) unit

The potential sources of error of the experimental data obtained through this experimental effort are the following: sample loss during slurry mixing, pumping, and distribution; sample loss during particle recovery from the collector box and mesh filling; and sample loss during the filtration, drying, and weighting. The average relative errors of the unbalanced results are estimated to be around 4%, and mass balanced results around 6%.

Flotation Separation

Flotation is a mineral separation method which utilizes the difference in particle surface properties to separate hydrophobic minerals from the hydrophilic gangue. The flotation of coal sample is strongly influenced by the type of coal – lignite has hydrophilic surface property and non-ionic collector is needed to facilitate the flotation process, while bituminous coals show strong hydrophobic surface properties and concentrate mass yield can go over 90%.

Selected coal samples (a total of 10 samples) were selected and separated using froth flotation technique in order to investigate the possibility of REE+Y+Sc concentration using this conventional method. The fine coal particles (-149 µm) are used as the flotation feed material and the flotation is performed using 3 l bench Denver flotation cell (Figure 11).

Figure 11: Picture of the bench Denver units used through flotation testing

To allow for more efficient particle separation, kerosene was added as a collector agent for coal in dosages adjusted according to the coal/sample type. Flotation testing of all selected samples with <40% of ash was successfully performed using 20-40 kg/tone of kerosene. For higher quality coals, much smaller kerosene dosages were utilized. Only the finest (-149 µm) particle size class was used as a feed material. A wide range of concentrate mass yields from 25% to 95% were achieved. Detailed experimental procedure is given in Appendix 1. The picture of the

flotation units used during flotation testing is given in Figure 11. All collected split fractions were sent to proximate and elemental (ICP-MS) analysis.

The following is a list of potential sources of error of the experimental data obtained through flotation testing: sample loss during slurry mixing; sample loss during froth recovery; and sample loss during the filtration, drying, and weighting. The average relative errors of the unbalanced results are estimated to be around 3%, and mass balanced results around 5%.

Elemental and Proximate Analyses

All received samples as well as all split fractions generated during the physical separation testing were subjected to elemental analysis using an ICP-MS instrument. A set of 13 REEs plus Y and Sc were analyzed according to the ASTM D6357 procedure. Elemental analyses of received raw coal samples and obtained split fractions were performed in the ICP MS Metals Lab, College of Earth and Mines Science, University of Utah.

The accuracy of the implemented sample digestion and ICP-MS analytical methods was evaluated by running a standard reference material, NIST SRM 1633c. This reference offers values for Dy, Eu, La, Lu and Sc (with an estimate for the uncertainty) and information values for Ce, Nd, Sm, Tb, and Yb (not enough information to estimate an error but still a number is reported). For each batch of samples analyzed, from 3 to 4 SRM samples were prepared and analyzed to evaluate the ICP-MS analysis error. Table 3 below shows typical errors for the set of 10 elements calculated by comparing the reported SRM concentration with the obtained average concentration for the set of four tested SRM samples.

Table 3: Concentration deviation from the NIST SRM 1633c standard

Element	*Sc*	*La*	*Ce*	*Nd*	*Sm*	*Eu*	*Tb*	*Dy*	*Yb*	*Lu*
Deviation	7.96%	2.19%	2.02%	10.10%	8.93%	2.44%	0.35%	0.72%	2.24%	2.46%

Coal proximate analysis of all received coal and coal refuse samples as well as splits obtained through the physical separation testing were performed. The SGS North America, Inc. Minerals Services, was the lab that performed the full proximate analysis of all selected samples. Information about the ash, moisture, fixed C, volatiles, S, and Btu contents in raw coals is reported in Appendix 3. The confidence intervals for the reported concentrations were not offered by SGS.

RESULTS

Work Summary

Table 4 summarizes the overall work performed in this study through the illustrative work map. The dark green column represents the elemental and proximate analysis of all received samples. The results of ICP-MS elemental analysis and proximate analysis are summarized in Tables 28, 29, and 30, which are given in Appendix 3 and Appendix 4. A total of 12 samples were selected for detailed physical separation testing, of which 10 samples were subjected to Flotation separation testing (light green column in Table 4), 11 to magnetic separation testing (yellow column in Table 4), and 10 samples to float and sink analysis (orange to red columns in Table 4).

Table 4: Work map with an overview of all experimental work performed in this study

#	Sample Name	Raw sample	Flotation	Magnetic Separation	Float&Sink -100	Float&Sink -30+100	Float&Sink -6+30
1	TXJMTEB1						
2	TXJMTEB2						
3	TXJMTEB3						
4	MOAMPRB1						
5	MORMPRB1						
6	MORMPRB2						
7	WYKMGRB1						
8	WYKMGRB2						
9	WYKMGRB3						
10	WYKMGRB4						
11	WYKMGRB5						
12	WYKMGRB6						
13	NDBMFUB1						
14	NDBMFUB2						
15	NDFMFUB1						
16	NDFMFUB2						
17	NDFMFUB3						
18	NDFMFUB4						
19	COTMGRB1						
20	COTMGRB2						
21	WYNMPRB1						
22	NMSJMSJB1						
23	NMSJMSJB2						
24	NMSJMSJB3						
25	UTSYMUIB1						
26	UTSUMUIB1						
27	WYBTMPRB1						
28	MOBONCB1						
29	MOBONCB2						
30	MOBONCB3						
31	MOBONCB4						
32	MOSONCB1						
33	MOSONCB2						
34	MOSONCB3						
35	MOSONCB4						
36	UTWMUIB1						

All fractions obtained through the physical separation testing were subjected to both elemental and proximate analysis. The obtained raw results for mass yields, ash and REE contents were mass balanced and reported in the following section.

Elemental and Proximate Analysis Results

The results of the elemental analysis of all received samples revealed particularly wide range of REE+Sc+Y concentrations within 36 samples analyzed. In Figure 12 a full list of samples with their corresponding REE+Y+Sc concentrations per whole sample basis is given. The color and size of the circles in the figure is used to demonstrate the distribution and magnitude of REE+Y+Sc concentrations for all presented samples. As can be seen in the figure, only a fraction of samples contains more than 150 ppm of REE+Y+Sc, and most of these samples were obtained from the North Central basin, including Sand Coulee and Belt outcrop samples. A substantial difference between REE+Y+Sc concentrations of North Central basin and the rest of the analyzed samples is enhanced by much higher ash content within the North Central basin samples. This trend can be better observed in Figure 13, which is a bar graph showing REE concentrations in both whole sample and ash. For example, there are several coal samples, namely UTWMUIB1, WYBTMPRM1, WYNMPRB1, COTMGRB1, and NDBMFUB1, which have high REE concentrations in the ash (>250 ppm) but this amount becomes small when expressed per whole sample basis. Most of the mentioned samples are coals of very high quality (low ash, high fixed carbon, and high volatiles) and would be used in the power plants in their raw form.

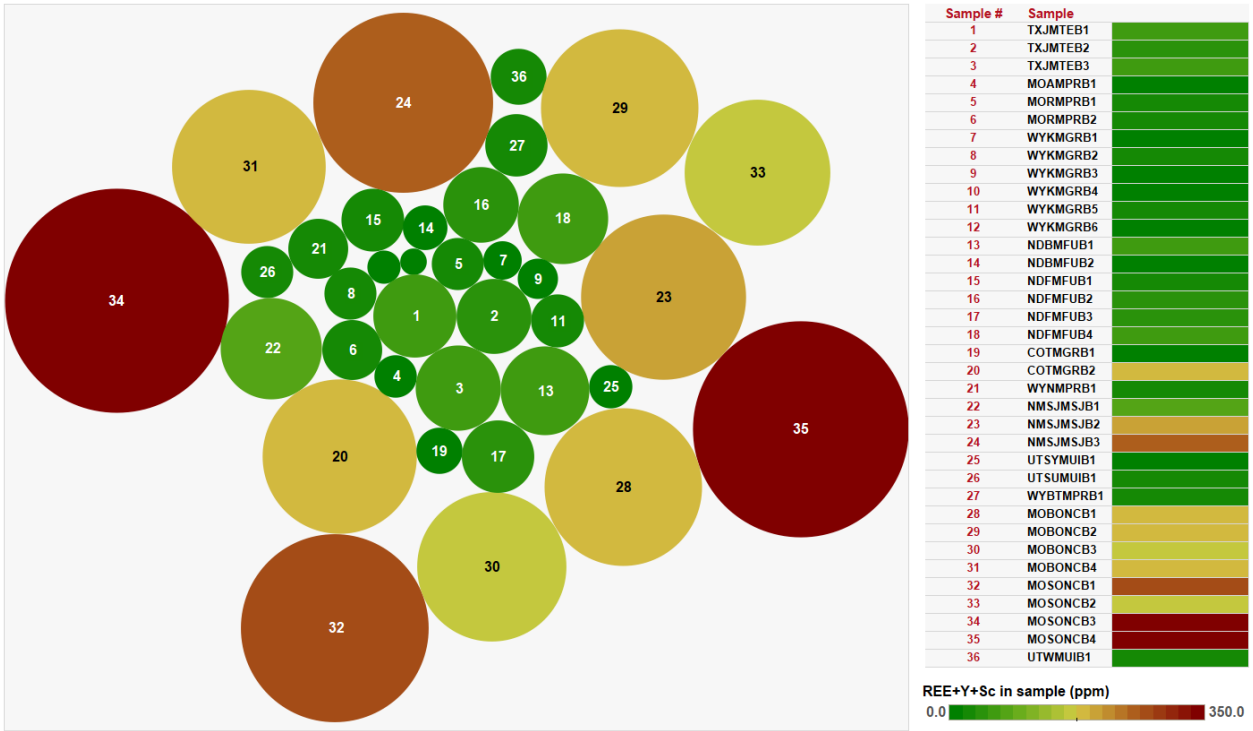

Figure 12: A full list of received samples with their assigned numbers, sample name, and total REE+Y+Sc concentration in the sample

Only a small number of samples analyzed were found to contain high REE concentrations and the concentrations are mostly below the previously reported levels for the sampled coal deposits. The reason for this finding may lie in the fact that only several samples have been collected from each sampling site. To enable more accurate determination of the REE potential of selected coal

deposit, detailed prospecting study and mineralogical analysis of full core samples would have to be performed.

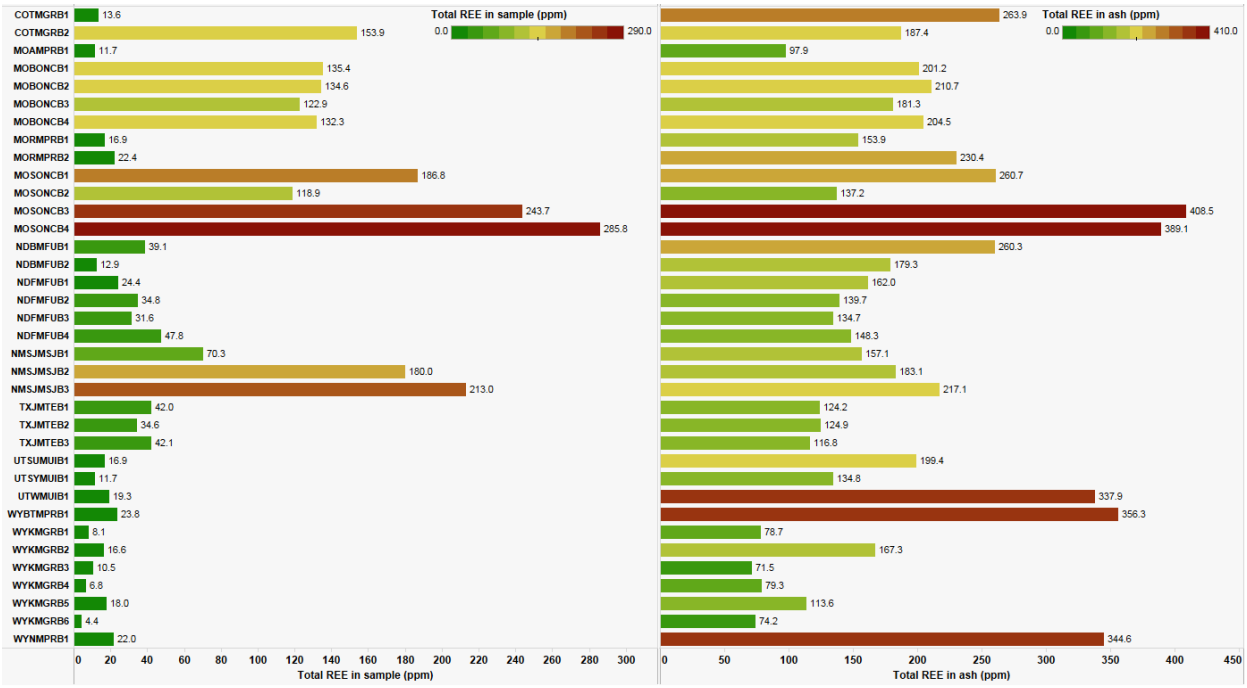

Figure 13: Concentration of REE in all investigated samples in the whole sample (left) and ash (right)

Figures 14 and 15 show sorted stacked bar graph of REE, Y, and Sc concentrations for all analyzed samples. The concentrations are reported per ash and whole sample basis, respectively. It should be noted here that while the results of elemental analysis of two ash samples received from New Mexico (NMSJMSJB2 and NMSJMSJB3) are included in both figures, it would be reasonable to compare the assay values for these samples with assays reported per ash basis for other samples.

As presented in Figures 14 and 15, of 36 total samples only the first 9 samples demonstrated total REE+Y+Sc concentrations of over 150 ppm in the whole sample (ash samples excluded), while 30 of them have over 150 ppm of REE+Y+Sc in their inorganic/ash fraction. The samples subjected to further physical separation testing were selected from this sample group.

The concentration ranges of light rare earth elements (LREE), heavy rare earth elements (HREE), scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, gadolinium, dysprosium, and holmium are given in Table 5.

The elemental analysis of raw samples revealed a wide range of LREE/HREE ratio as presented in Figure 16. The points in the figure are colored based on the sample origin (coal basin name). The LREE/HREE ratio was found to be in the range from 2.67 for NDBMFUB1 to 13.43 for NMSJMSJB1 sample.

Table 5: REE+Y+Sc concentration ranges over all analyzed samples

Assay (ppm)	expressed per whole sample basis		expressed per ash basis	
	min	max	min	max
Sc	0.25	34.92	3.21	58.55
Y	0.72	103.41	9.72	173.36
La	1.04	62.74	16.72	85.41
Ce	1.67	124.90	20.13	170.02
Pr	0.06	12.74	0.65	24.73
Nd	0.76	54.80	12.79	74.59
Sm	0.17	10.62	2.83	16.28
Eu	0.08	2.41	0.73	4.18
Gd	0.16	12.01	2.68	20.14
Tb	0.02	2.21	0.35	3.70
Dy	0.11	14.34	1.72	24.03
Ho	0.02	3.08	0.33	5.17
Er	0.07	8.24	0.99	18.49
Yb	0.07	8.63	0.91	16.97
Lu	0.01	1.24	0.12	2.07
LREE	3.87	254.50	63.42	346.44
HREE	0.55	52.16	8.07	87.45
REE	4.42	285.85	71.49	408.47
REE+Y+Sc	5.39	381.99	84.41	640.38

All ICP-MS results are summarized in Appendix 4. Furthermore, a series of detailed bar graphs showing distribution of individual REE, Y, and Sc concentrations over a whole range of considered samples is given in Appendix 5.

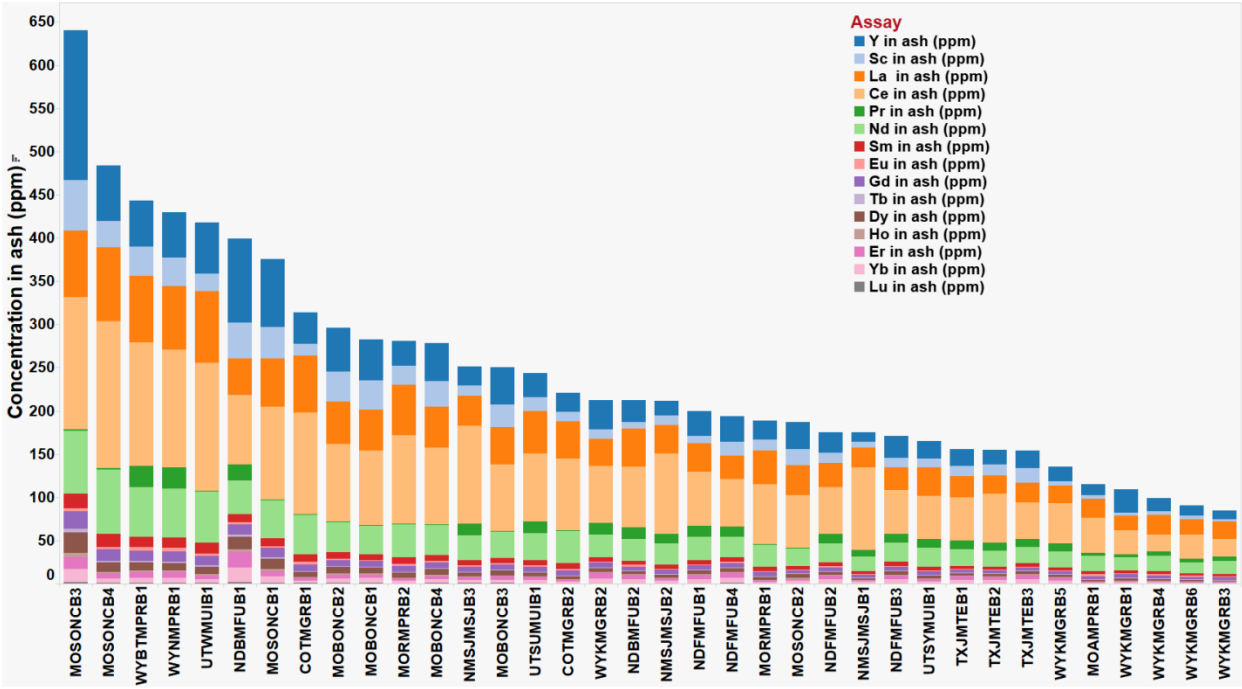

Figure 14: A stacked bar graph of REE, Sc, and Y concentrations for all samples in ash

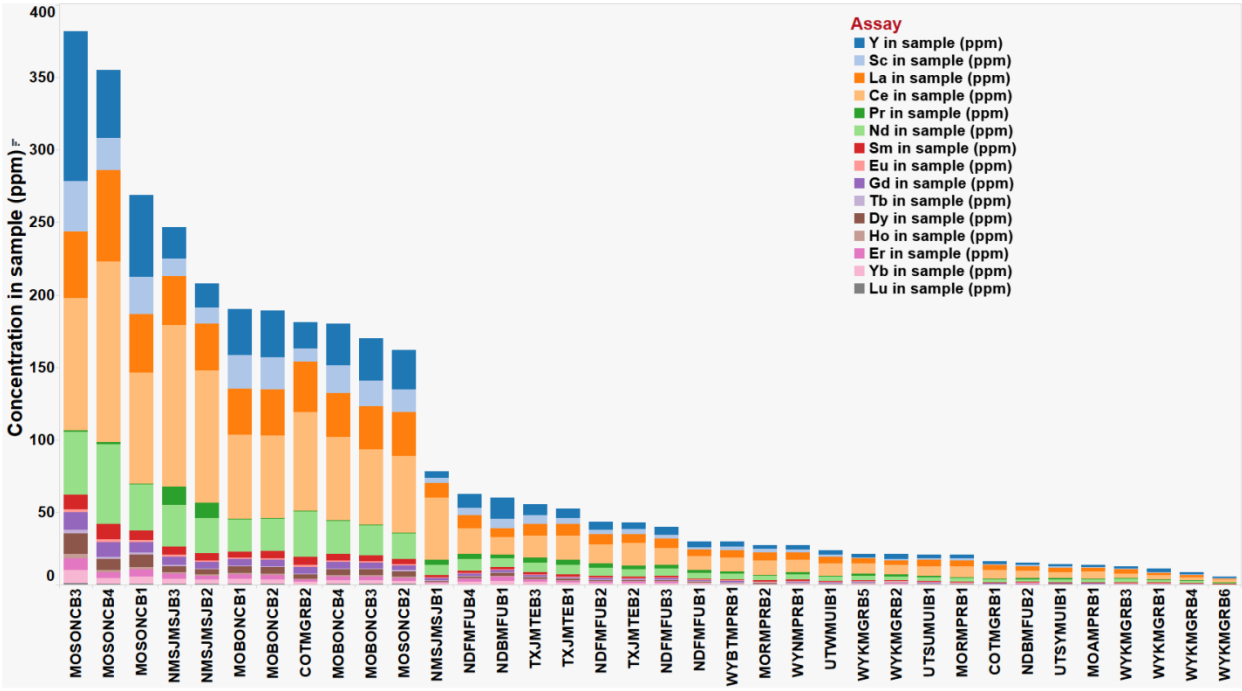

Figure 15: A stacked bar graph of REE, Sc, and Y concentrations for all samples reported on a whole sample basis

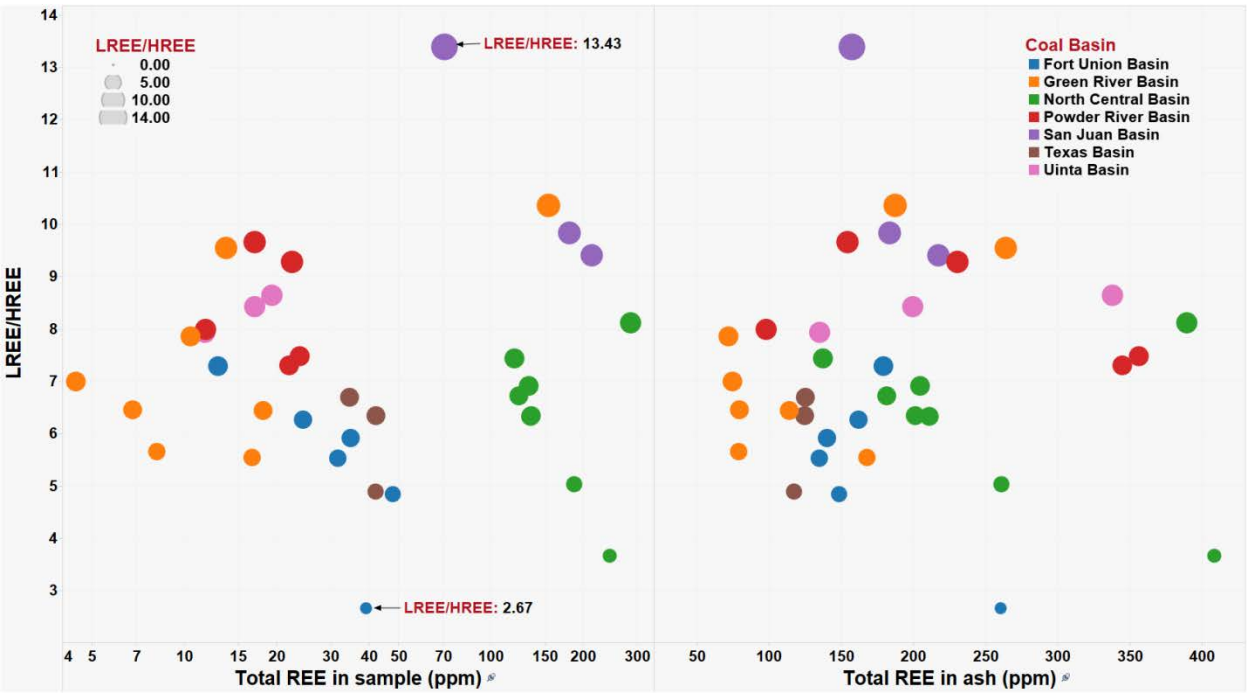

Figure 16: The LREE/HREE ratio for all samples in relation to the total REE concentration expressed per whole sample basis (left) and per ash basis (right)

The results of proximate analysis for all received samples are given in Figure 17. For convenience, a stacked bar graph with REE+Y+Sc concentrations is also given in Figure 17

(top). As evident from Figure 17, a particularly diverse group of samples were received and analyzed. The ranges of ash, volatiles, fixed carbon, and sulfur concentrations for all analyzed samples as well as the total coal caloric value are given in Table 5.

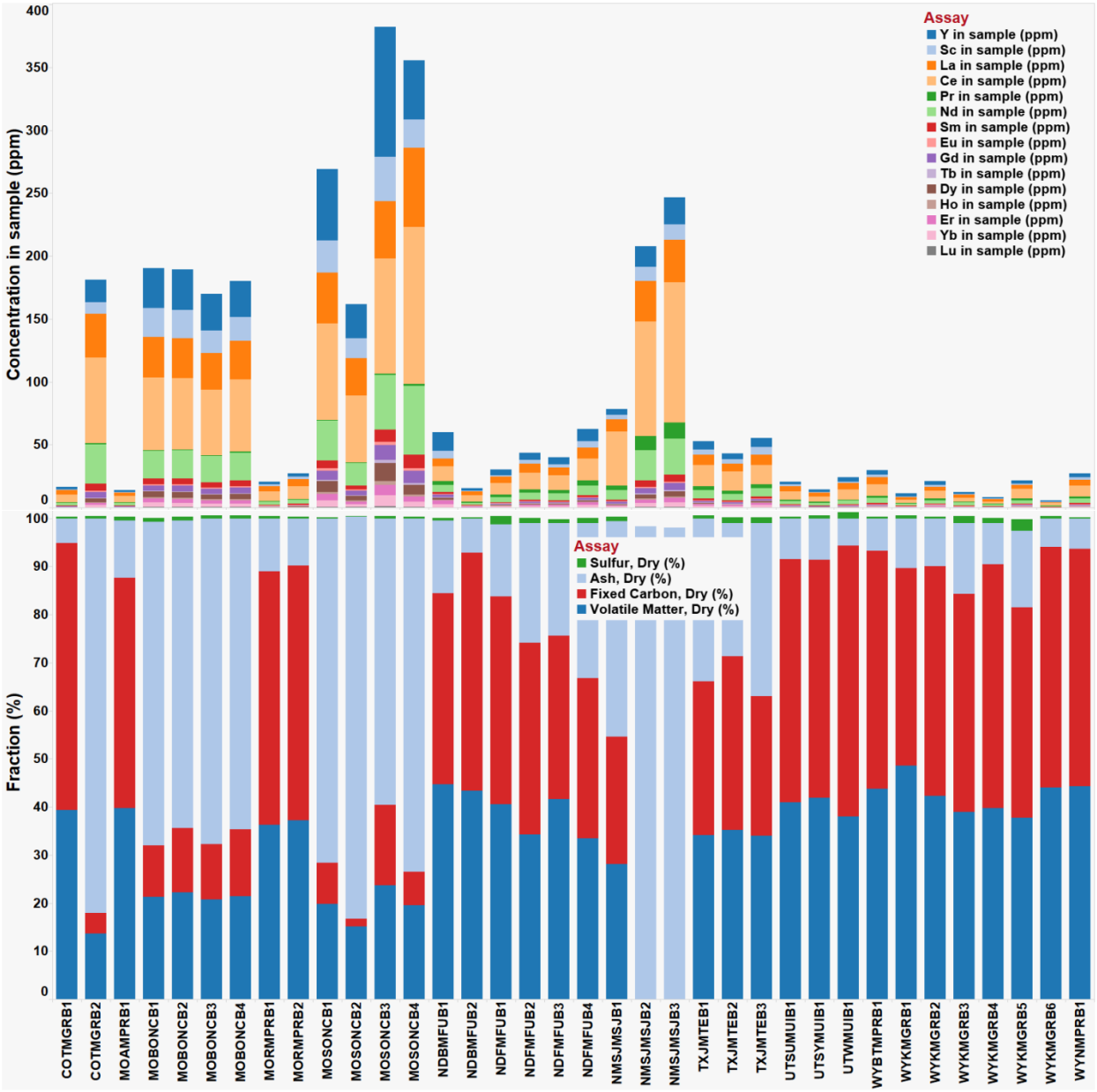

Figure 17: The overview of the elemental and proximate analysis results for all samples, including REE+Y+Sc (top) and ash, volatiles, fixed carbon, and sulfur concentrations (bottom)

Table 6: Ash, volatiles, fixed carbon, and sulfur concentrations, and caloric value ranges for all analyzed samples

Assay (%)	min	max
Ash	5.17	86.65
Volatiles	13.63	48.55
Fixed Carbon	1.72	56.36
Sulfur	0.02	2.46
Calorific Value (Btu/lb)	300	13410

Total REE+Y+Sc concentration as a function of total sulfur, volatile matter, and fixed carbon contents for all raw coal samples considered in this study is given in Figure 18. Both concentrations per ash (top row) and whole sample basis (bottom row) are given. The points in the figure are colored based on the sample origin (coal basin name). As can be seen from the figure (Figure 18, top and bottom left), samples with higher REE+Y+Sc concentrations generally have lower sulfur contents (<1%). In addition, there is a slight trend toward higher REE+Y+Sc concentrations for coals with lower fixed carbon contents.

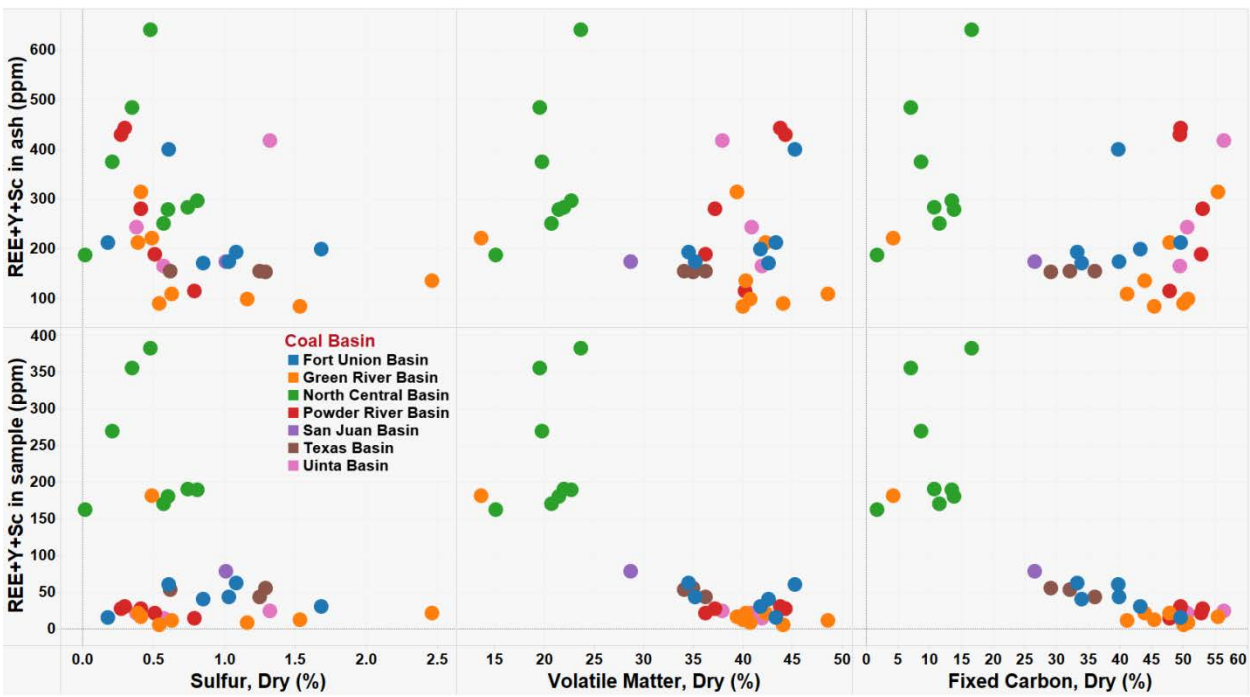

Figure 18: Total REE+Y+Sc concentration as a function of total sulfur, volatile matter, and fixed carbon contents for all raw coal samples considered

Float and Sink (Washability) Analysis Results

The REE+Y+Sc concentrations in six gravity fractions (i.e. 1.2, 1.4, 1.6, 1.8, 2.0, and 2.2 SG) of ten selected coal samples were determined using standard float-sink/washability analysis and elemental analysis of obtained density fractions. At least seven split fractions were sampled,

ashed, and sent for elemental and proximate analysis. The raw ICP-MS results for all washability tests are given in Appendix 6 (Tables 31-34). Obtained mass yield and assay data were used to mass balance the experimental results for each performed test. All balanced results are summarized in Appendix 7 (Tables 35-38).

Three distinct particle size classes are used through this study including -3348+516 µm, -516+149 µm, and -149 µm. The obtained REE+Y+Sc concentrations are reported over seven distinct density classes, namely -1.2, +1.2-1.4, +1.4-1.6, +1.6-1.8, +1.8-2.0, +2.0-2.2, and +2.2 SG. The balanced results of coal washability analysis are given in Tables 6-21 and Figures 19-34.

Maximum REE+Y+Sc concentrations are found within the coal ashes of light fractions. The most concentrated density fractions are found to be those within the intermediate range of densities, or from 1.4 to 1.8 SG. From Figures 19-34 it is apparent that the curve of REE distributions in density fractions shows a quadratic trend with the maximum about +1.4-1.6 and +1.6-1.8 densities.

There is significant similarity in the REE distribution trend among the tested samples. This general trend, however, varies in magnitude for coals of different type. This might indicate that coal samples of different type may still have similar mode of REE occurrence (or mineralogical distribution) in the coal matrix. More detailed mineralogical analysis would have to be performed in order to support this finding further.

It is important to be noted here that tested samples from the North Central basin, namely Sand Coulee and Belt samples, demonstrated completely different REE distribution trends. This could be explained by the fact that these samples are not coal but coaly-clay material with more than 70% of ash of which a major part (>60%) is clay. For these samples, the mass yield is very low for low density fractions and majority of material is recovered within the heaviest density fractions.

The washability analysis was performed for three size classes of the UTWMUIB1 sample. The results of the washability analysis for these samples are given in Figures 31-33 and Tables 18-20. The features of REE distribution curves for the three different size classes are very similar – the most similarity can be seen between -3348+516 µm and 516+149 µm samples. With a further reduction in particle size, the REE distribution curve becomes more symmetrical. In addition, a much larger fraction of REE material is concentrated within -1.8 SG fractions.

From the washability analysis of selected samples it can be concluded that the REE could be concentrated using density-based mineral concentration methods, and the REE recoveries could be increased using finer particle sizes. On the other hand, the improvement of current and development of new density-based concentration technologies of fine particles will be necessary to overcome the limitations of currently available technologies.

Table 7: REE concentrations in gravity fractions for NDBMFUB1 and -516+149 µm size fraction

Sample Name:	NDBMFUB1
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	2.70	49.44	39.58	7.40	0.28	0.24	0.35
Ash (%)		14.09	1.70	5.88	18.13	45.65	58.97	66.17	72.54
Concentration in Fraction (ppm)	Sc	6.26	1.28	5.34	7.64	6.95	5.93	3.01	4.26
	Y	14.55	3.28	10.56	19.35	19.96	13.60	10.08	10.28
	La	6.29	1.32	4.21	8.20	12.05	6.29	4.26	3.44
	Ce	12.14	2.47	8.91	15.12	21.74	11.51	8.04	6.57
	Pr	2.28	0.03	0.37	5.25	0.18	0.13	0.12	0.03
	Nd	5.83	1.25	4.02	7.83	9.14	5.73	4.31	3.54
	Sm	1.45	0.27	0.41	2.74	1.96	1.39	0.95	1.22
	Eu	0.42	0.04	0.18	0.71	0.65	0.38	0.27	0.30
	Gd	1.80	0.34	0.75	3.22	1.82	1.65	1.20	1.22
	Tb	0.31	0.04	0.12	0.58	0.25	0.27	0.21	0.30
	Dy	2.15	0.41	1.03	3.69	2.09	1.94	1.44	1.52
	Ho	0.47	0.06	0.19	0.87	0.35	0.41	0.30	0.30
	Er	2.77	0.19	1.69	4.73	0.68	0.99	0.74	0.63
	Yb	2.53	0.19	1.42	4.46	0.69	1.00	0.69	0.63
	Lu	0.20	0.01	0.08	0.36	0.19	0.17	0.14	0.02
	LREE	48.80	9.90	33.82	66.13	71.98	44.58	30.77	29.34
	HREE	10.65	1.28	5.46	18.62	6.72	6.81	4.99	4.92
	REE	59.45	11.18	39.28	84.75	78.70	51.39	35.76	35.76
	REE+Y+Sc	80.26	15.74	55.18	111.74	105.61	70.92	48.85	48.80

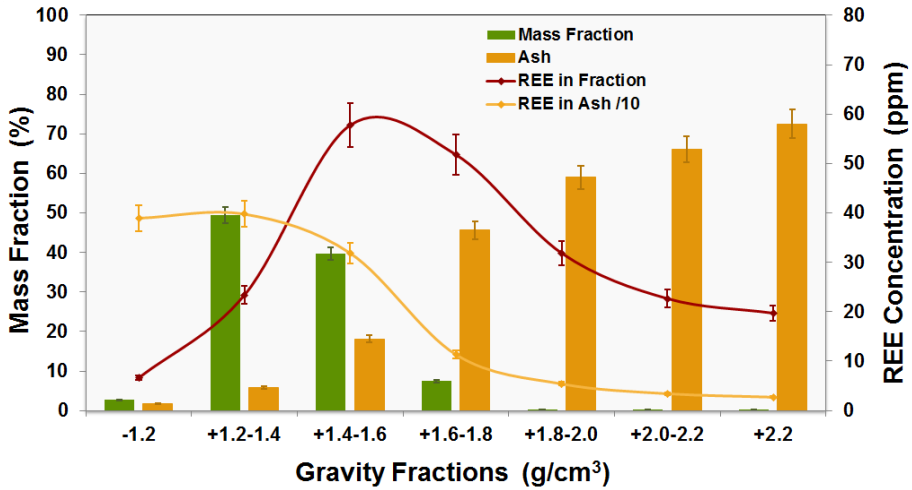

Figure 19: REE concentrations in gravity fractions for NDBMFUB1 and -516+149 µm size fraction

Table 8: REE concentrations in gravity fractions for NDBMFUB1 and -149 µm size fraction

Sample Name:	NDBMFUB1
Sample Size:	-149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	2.02	27.53	37.60	31.44	0.54	0.52	0.35
Ash (%)		14.23	1.14	3.86	14.96	20.97	59.86	66.83	72.38
Concentration in Fraction (ppm)	Sc	6.26	1.04	3.86	6.90	8.04	6.82	2.13	1.99
	Y	14.39	3.79	8.98	16.17	17.82	21.27	6.35	3.36
	La	6.32	1.47	4.16	6.83	7.98	8.32	3.43	1.70
	Ce	12.13	2.92	7.46	13.81	15.03	11.23	6.21	2.78
	Pr	2.12	0.01	0.07	2.16	4.10	0.16	0.14	0.01
	Nd	5.82	1.32	3.82	6.18	7.50	6.80	3.44	1.56
	Sm	1.46	0.28	0.50	1.29	2.59	1.92	0.69	0.54
	Eu	0.42	0.07	0.17	0.32	0.77	0.61	0.17	0.30
	Gd	1.79	0.33	0.54	1.98	2.78	1.92	0.59	0.66
	Tb	0.31	0.05	0.10	0.30	0.53	0.38	0.12	0.13
	Dy	2.17	0.40	0.56	2.69	3.11	2.48	0.88	0.75
	Ho	0.47	0.08	0.12	0.46	0.82	0.68	0.17	0.19
	Er	2.76	0.10	0.81	3.15	4.27	0.90	0.69	0.18
	Yb	2.55	0.06	0.87	2.89	3.86	0.89	0.73	0.17
	Lu	0.20	0.02	0.09	0.19	0.33	0.30	0.11	0.08
	LREE	48.50	10.83	28.85	53.34	63.06	56.52	22.39	11.94
	HREE	10.67	1.11	3.26	11.98	16.47	8.16	3.46	2.46
	REE	59.17	11.94	32.11	65.32	79.53	64.68	25.85	35.76
	REE+Y+Sc	79.82	16.77	44.95	88.39	105.39	92.77	34.33	19.75

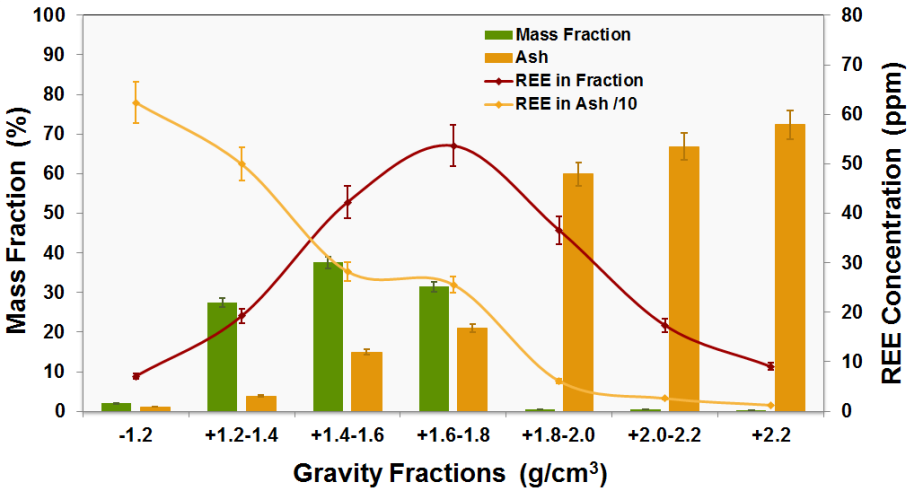

Figure 20: REE concentrations in gravity fractions for NDBMFUB1 and -149 µm size fraction

Table 9: REE concentrations in gravity fractions for NDBMFUB2 and -516+149 µm size fraction

Sample Name:	NDBMFUB2
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	4.74	47.43	45.13	2.13	0.32	0.04	0.20
Ash (%)		7.17	1.18	3.63	8.56	53.94	61.49	66.41	76.53
Concentration in Fraction (ppm)	Sc	0.53	0.11	0.23	0.86	1.01	1.13	0.75	0.30
	Y	1.81	0.30	1.26	2.43	4.10	3.04	2.23	1.80
	La	3.15	0.67	2.31	4.14	6.03	5.20	3.59	3.25
	Ce	4.86	1.57	3.69	6.22	9.22	7.95	5.40	4.73
	Pr	0.21	0.30	0.18	0.22	0.58	0.74	0.55	0.05
	Nd	1.82	0.69	1.44	2.25	3.82	2.28	1.97	1.70
	Sm	0.33	0.16	0.25	0.42	0.67	0.54	0.37	0.30
	Eu	0.13	0.10	0.10	0.14	0.39	0.37	0.21	0.10
	Gd	0.32	0.10	0.24	0.41	0.67	0.58	0.36	0.30
	Tb	0.04	0.01	0.03	0.05	0.16	0.45	0.15	0.05
	Dy	0.28	0.07	0.24	0.31	0.77	0.83	0.65	0.25
	Ho	0.06	0.02	0.04	0.07	0.17	0.46	0.12	0.05
	Er	0.35	0.11	0.25	0.45	0.78	0.67	0.25	0.12
	Yb	0.35	0.11	0.21	0.49	0.79	0.64	0.28	0.15
	Lu	0.03	0.01	0.02	0.03	0.16	0.05	0.01	0.02
	LREE	12.71	3.80	9.36	16.54	25.43	20.88	14.86	12.13
	HREE	1.56	0.53	1.13	1.95	3.89	4.05	2.03	1.04
	REE	14.27	4.33	10.49	18.49	29.32	24.93	16.89	35.76
	REE+Y+Sc	16.61	4.74	11.98	21.78	34.43	29.10	19.87	15.27

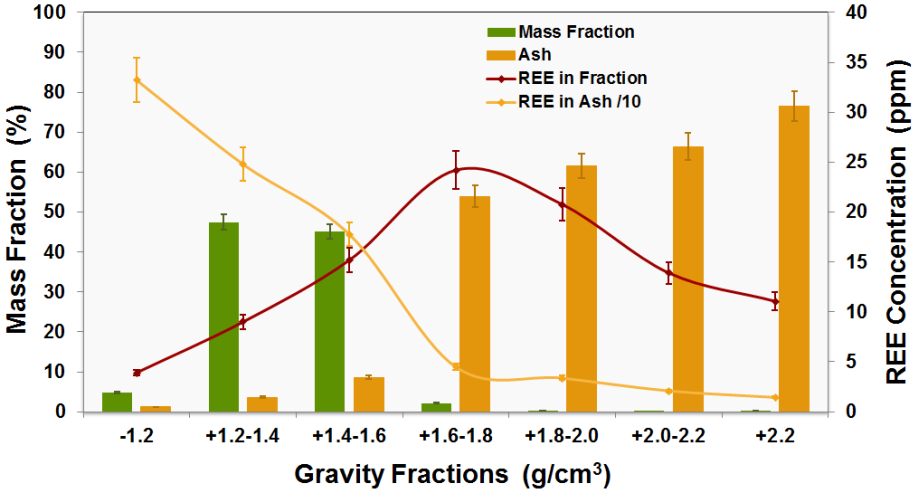

Figure 21: REE concentrations in gravity fractions for NDBMFUB2 and -516+149 µm size fraction

Table 10: REE concentrations in gravity fractions for WYKMGRB2 and -516+149 µm size fraction

Sample Name:	WYKMGRB2
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	2.44	88.82	6.38	1.27	0.40	0.16	0.53
Ash (%)		9.56	1.55	6.22	39.42	56.49	62.49	69.39	75.97
Concentration in Fraction (ppm)	Sc	1.07	0.32	1.04	1.47	2.16	1.12	0.96	0.79
	Y	3.15	1.02	3.21	3.13	4.24	2.83	1.93	1.58
	La	2.88	1.22	2.78	4.28	5.81	4.04	1.93	1.60
	Ce	6.23	3.31	6.27	6.32	10.02	7.77	3.88	3.16
	Pr	0.68	0.13	0.08	7.97	5.67	3.82	1.56	1.50
	Nd	2.40	0.96	2.31	4.03	3.22	3.14	1.85	1.57
	Sm	0.49	0.19	0.48	0.53	1.50	1.21	0.45	0.37
	Eu	0.11	0.04	0.09	0.23	0.41	0.37	0.21	0.20
	Gd	0.49	0.17	0.47	0.80	1.06	0.78	0.43	0.40
	Tb	0.07	0.02	0.06	0.13	0.27	0.16	0.09	0.08
	Dy	0.46	0.14	0.47	0.40	0.58	0.49	0.29	0.27
	Ho	0.10	0.02	0.10	0.05	0.11	0.12	0.09	0.09
	Er	0.57	0.08	0.54	1.03	0.97	1.02	0.43	0.39
	Yb	0.51	0.07	0.45	1.41	1.00	0.75	0.34	0.37
	Lu	0.04	0.01	0.04	0.03	0.08	0.04	0.04	0.03
	LREE	16.90	7.15	16.17	27.73	32.62	23.93	12.56	10.57
	HREE	2.35	0.55	2.22	4.08	4.48	3.73	1.92	1.83
	REE	19.25	7.70	18.39	31.81	37.10	27.66	14.48	35.76
	REE+Y+Sc	23.47	9.04	22.64	36.41	43.50	31.61	17.37	14.77

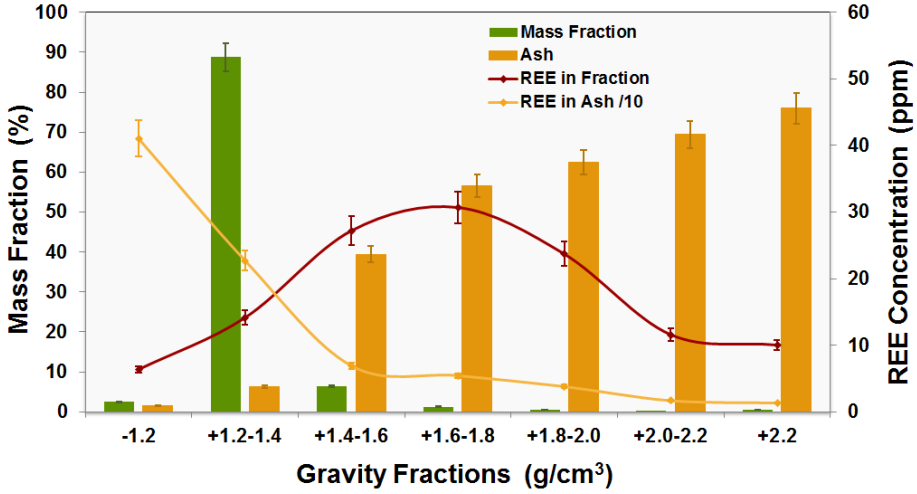

Figure 22: REE concentrations in gravity fractions for WYKMGRB2 and -516+149 µm size fraction

Table 11: REE concentrations in gravity fractions for MORMPRB2 and -516+149 µm size fraction

Sample Name:	MORMPRB2
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.58	8.92	83.42	3.97	1.04	0.58	1.48
Ash (%)		9.97	1.20	2.19	6.91	45.87	63.08	67.68	76.55
Concentration in Fraction (ppm)	Sc	2.10	0.52	0.98	1.99	6.62	5.91	2.11	0.78
	Y	2.80	0.59	1.84	2.24	14.64	13.87	4.20	1.27
	La	5.76	1.25	1.93	5.70	15.23	13.15	7.53	2.90
	Ce	10.02	2.20	2.73	10.14	23.88	21.41	11.73	4.82
	Pr	0.10	0.02	0.06	0.07	0.64	0.21	0.20	0.21
	Nd	3.69	0.82	1.67	3.53	10.82	9.33	5.08	2.74
	Sm	0.76	0.22	0.45	0.63	3.91	2.79	0.82	0.38
	Eu	0.22	0.04	0.09	0.14	1.82	1.54	0.46	0.28
	Gd	0.67	0.16	0.42	0.51	3.62	4.18	0.88	0.58
	Tb	0.09	0.02	0.06	0.06	0.58	0.79	0.15	0.10
	Dy	0.52	0.12	0.37	0.36	3.59	3.93	0.63	0.17
	Ho	0.10	0.02	0.07	0.07	0.63	0.80	0.17	0.10
	Er	0.26	0.05	0.10	0.16	2.41	1.80	0.34	0.24
	Yb	0.27	0.07	0.16	0.18	2.36	1.10	0.26	0.12
	Lu	0.04	0.01	0.03	0.03	0.08	0.43	0.11	0.04
	LREE	25.23	5.62	9.66	24.30	75.74	66.67	31.67	13.10
	HREE	2.17	0.49	1.30	1.51	15.09	14.57	3.00	1.63
	REE	27.40	6.11	10.96	25.81	90.83	81.24	34.67	35.76
	REE+Y+Sc	32.30	7.22	13.78	30.04	112.09	101.02	40.98	16.78

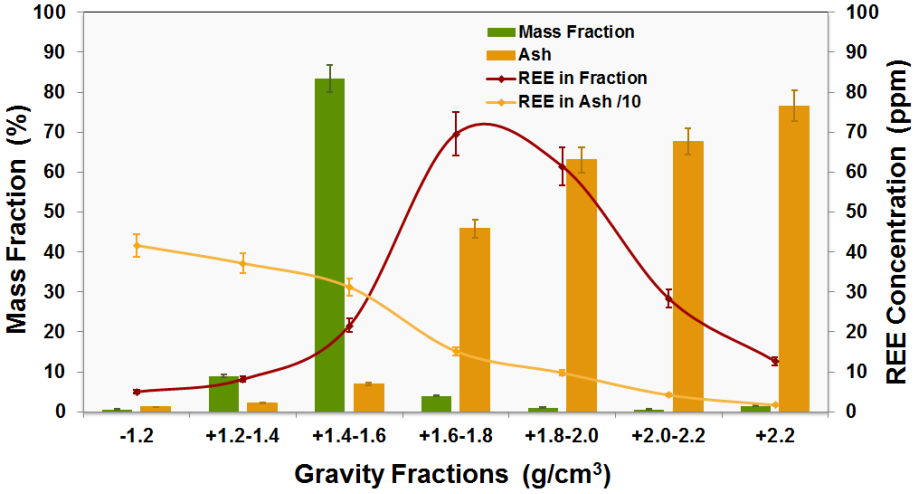

Figure 23: REE concentrations in gravity fractions for MORMPRB2 and -516+149 µm size fraction

Table 12: REE concentrations in gravity fractions for MORMPRB2 and -149 µm size fraction

Sample Name:	MORMPRB2
Sample Size:	-149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.00	8.92	83.42	3.97	1.04	0.58	1.48
Ash (%)		10.00	0.00	2.09	4.18	29.79	52.75	69.32	73.18
Concentration in Fraction (ppm)	Sc	2.12	0.00	1.48	1.54	4.91	3.49	0.79	0.87
	Y	2.80	0.00	2.02	1.96	6.60	5.33	1.99	1.93
	La	5.84	0.00	3.76	4.77	11.39	8.93	3.29	3.04
	Ce	9.93	0.00	6.66	7.87	20.14	16.02	4.79	5.46
	Pr	0.10	0.00	0.05	0.10	0.13	0.12	0.03	0.02
	Nd	3.72	0.00	2.76	2.69	8.47	5.63	2.41	2.30
	Sm	0.76	0.00	0.49	0.66	1.34	0.97	0.36	0.51
	Eu	0.22	0.00	0.27	0.07	0.77	0.66	0.13	0.24
	Gd	0.67	0.00	0.44	0.56	1.28	0.62	0.51	0.49
	Tb	0.09	0.00	0.04	0.08	0.17	0.15	0.04	0.06
	Dy	0.52	0.00	0.35	0.39	1.13	0.88	0.17	0.37
	Ho	0.10	0.00	0.08	0.07	0.24	0.17	0.04	0.06
	Er	0.26	0.00	0.09	0.20	0.62	0.19	0.12	0.04
	Yb	0.27	0.00	0.09	0.23	0.56	0.22	0.05	0.06
	Lu	0.04	0.00	0.04	0.02	0.11	0.10	0.02	0.03
	LREE	25.27	0.00	17.22	19.59	52.98	40.49	13.66	14.13
	HREE	2.17	0.00	1.40	1.62	4.88	2.99	1.08	1.35
	REE	27.44	0.00	18.62	21.21	57.86	43.48	14.74	35.76
	REE+Y+Sc	32.36	0.00	22.12	24.71	69.37	52.30	17.52	18.28

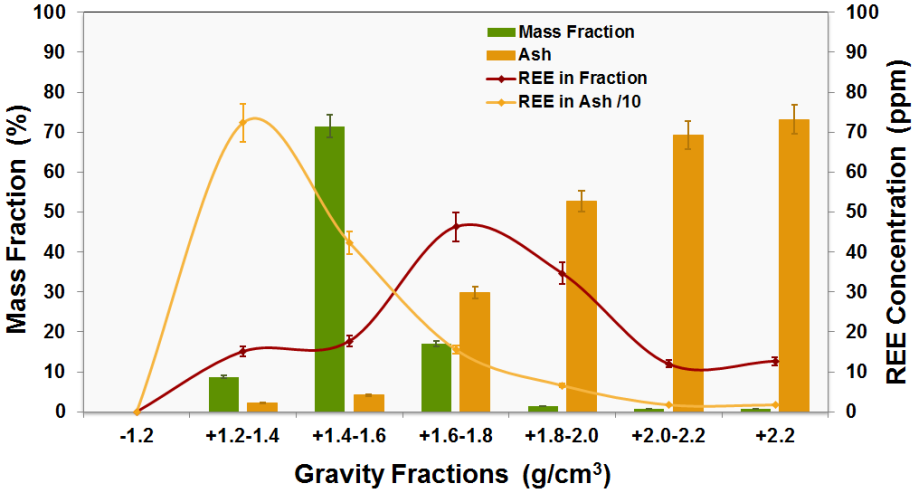

Figure 24: REE concentrations in gravity fractions for MORMPRB2 and -149 µm size fraction

Table 13: REE concentrations in gravity fractions for COTMGRB1 and -516+149 µm size fraction

Sample Name:	COTMGRB1
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	2.09	90.17	5.47	1.31	0.57	0.24	0.15
Ash (%)		5.20	1.12	3.45	15.12	43.59	63.63	71.41	83.88
Concentration in Fraction (ppm)	Sc	0.71	0.29	0.63	1.14	3.71	3.15	1.87	1.82
	Y	1.90	0.80	1.67	3.85	8.11	8.30	4.82	2.59
	La	3.40	1.45	2.95	8.10	12.09	12.04	11.25	10.35
	Ce	6.05	2.62	5.19	14.98	21.90	22.76	22.06	17.85
	Pr	0.06	0.01	0.05	0.22	0.25	0.16	0.12	0.15
	Nd	2.36	0.99	2.00	6.19	9.48	9.16	6.51	3.98
	Sm	0.47	0.19	0.39	1.07	2.65	1.45	1.48	1.54
	Eu	0.14	0.06	0.12	0.28	0.83	0.63	0.81	0.64
	Gd	0.42	0.17	0.34	1.04	2.62	2.05	1.97	1.28
	Tb	0.05	0.02	0.05	0.05	0.30	0.15	0.04	0.06
	Dy	0.29	0.11	0.25	0.62	1.68	0.80	0.66	0.25
	Ho	0.06	0.02	0.04	0.23	0.31	0.16	0.06	0.07
	Er	0.15	0.07	0.14	0.14	1.03	0.61	0.98	0.82
	Yb	0.17	0.07	0.14	0.31	1.04	0.41	0.80	0.48
	Lu	0.02	0.01	0.01	0.17	0.21	0.05	0.04	0.02
	LREE	14.95	6.35	12.88	35.56	58.19	57.01	48.11	38.29
	HREE	1.30	0.53	1.09	2.84	8.03	4.86	5.36	3.62
	REE	16.25	6.88	13.97	38.40	66.22	61.87	53.47	35.76
	REE+Y+Sc	18.86	7.97	16.26	43.39	78.04	73.32	60.16	46.32

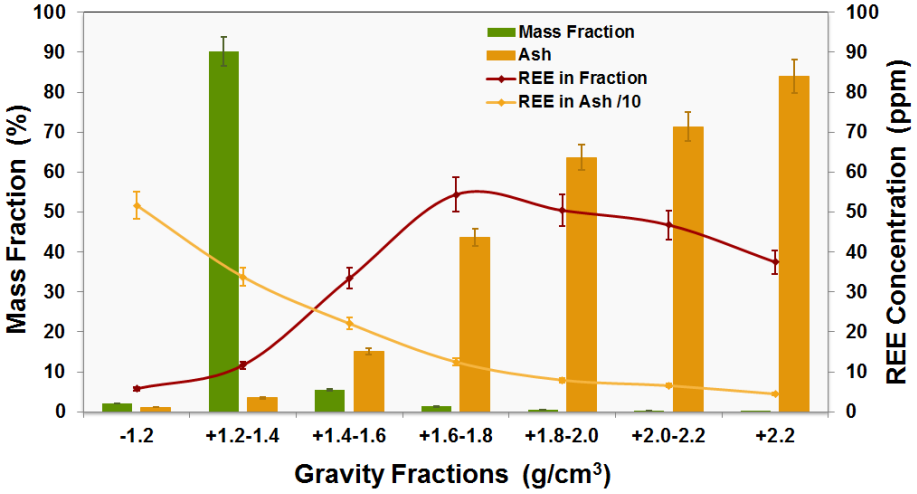

Figure 25: REE concentrations in gravity fractions for COTMGRB1 and -516+149 µm size fraction

Table 14: REE concentrations in gravity fractions for COTMGRB1 and -3348+516 µm size fraction

Sample Name:	COTMGRB1
Sample Size:	-3348+516 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.14	90.94	6.66	1.30	0.40	0.34	0.21
Ash (%)		5.46	2.01	3.86	10.03	51.01	60.49	64.44	70.24
Concentration in Fraction (ppm)	Sc	0.71	0.33	0.57	1.46	4.42	3.41	4.69	4.25
	Y	1.90	0.89	1.67	2.98	8.42	8.42	8.23	7.62
	La	3.41	1.59	3.02	5.80	12.28	12.12	13.52	12.25
	Ce	6.12	2.86	5.45	10.19	22.03	22.82	18.31	22.74
	Pr	0.06	0.01	0.03	0.40	0.51	0.18	0.06	0.10
	Nd	2.36	1.09	2.03	4.62	9.75	9.27	6.31	5.45
	Sm	0.47	0.21	0.34	1.51	3.70	1.72	0.92	1.02
	Eu	0.14	0.06	0.08	0.57	1.79	0.82	0.85	0.80
	Gd	0.42	0.19	0.28	1.50	3.74	2.43	1.43	0.84
	Tb	0.05	0.02	0.04	0.14	0.62	0.16	0.04	0.04
	Dy	0.29	0.12	0.19	1.05	2.94	0.96	0.62	1.20
	Ho	0.06	0.02	0.03	0.38	0.76	0.18	0.05	0.04
	Er	0.15	0.08	0.10	0.39	2.09	0.74	1.03	0.55
	Yb	0.17	0.08	0.10	0.63	2.19	0.47	1.28	0.66
	Lu	0.02	0.01	0.01	0.19	0.12	0.05	0.03	0.01
	LREE	15.03	6.98	13.11	26.96	61.11	57.94	52.04	53.43
	HREE	1.30	0.58	0.83	4.85	14.25	5.81	5.33	4.14
	REE	16.33	7.56	13.94	31.81	75.36	63.75	57.37	35.76
	REE+Y+Sc	18.94	8.78	16.18	36.25	88.20	75.58	70.29	69.44

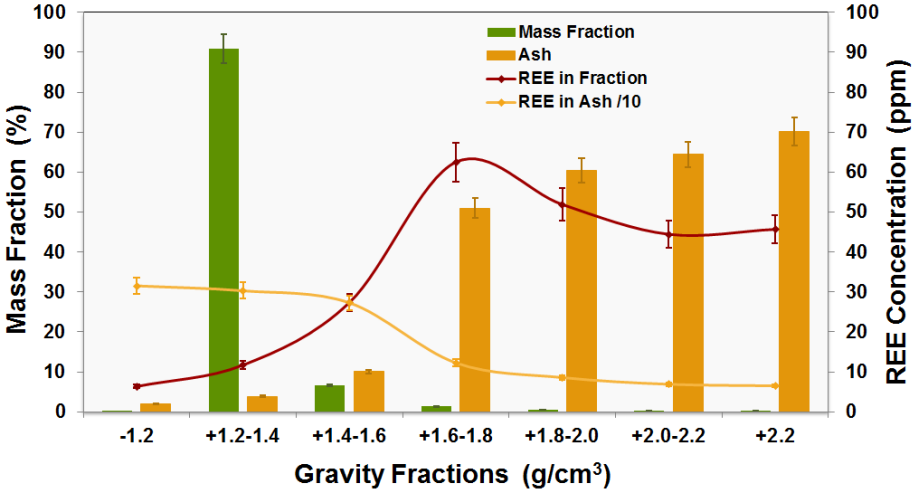

Figure 26: REE concentrations in gravity fractions for COTMGRB1 and -3348+516 µm size fraction

Table 15: REE concentrations in gravity fractions for MOSONCB3 and -516+149 µm size fraction

Sample Name:	MOSONCB3
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.03	0.01	0.03	0.05	4.19	5.79	89.90
Ash (%)		59.68	1.25	2.12	6.70	8.85	10.38	26.59	64.19
Concentration in Fraction (ppm)	Sc	35.00	1.30	1.85	4.53	5.02	6.32	9.28	38.04
	Y	104.33	3.34	5.17	13.00	14.70	19.65	38.51	112.64
	La	45.77	1.70	2.43	6.01	6.82	7.19	12.61	49.76
	Ce	85.24	3.14	4.42	11.09	12.64	13.86	33.77	91.99
	Pr	1.10	0.04	0.04	0.14	0.17	0.16	0.44	1.19
	Nd	42.55	1.58	2.26	5.61	6.36	7.56	20.73	45.64
	Sm	9.72	0.36	0.49	1.26	1.41	1.67	3.96	10.47
	Eu	2.41	0.09	0.13	0.31	0.34	0.40	0.94	2.60
	Gd	11.94	0.45	0.63	1.57	1.73	2.40	4.58	12.88
	Tb	2.21	0.09	0.13	0.31	0.34	0.43	0.73	2.39
	Dy	14.19	0.54	0.75	1.90	2.09	2.97	4.92	15.33
	Ho	3.08	0.13	0.16	0.42	0.45	0.61	1.01	3.34
	Er	8.31	0.32	0.44	1.09	1.20	1.40	2.25	9.03
	Yb	8.64	0.32	0.45	1.12	1.25	1.31	2.37	9.40
	Lu	1.23	0.04	0.04	0.15	0.16	0.25	0.35	1.33
	LREE	323.71	11.46	16.66	41.64	47.12	56.41	119.30	349.73
	HREE	52.01	1.98	2.73	6.87	7.56	9.77	17.15	56.30
	REE	375.72	13.44	19.39	48.51	54.68	66.18	136.45	35.76
	REE+Y+Sc	515.05	18.08	26.41	66.04	74.40	92.15	184.24	556.71

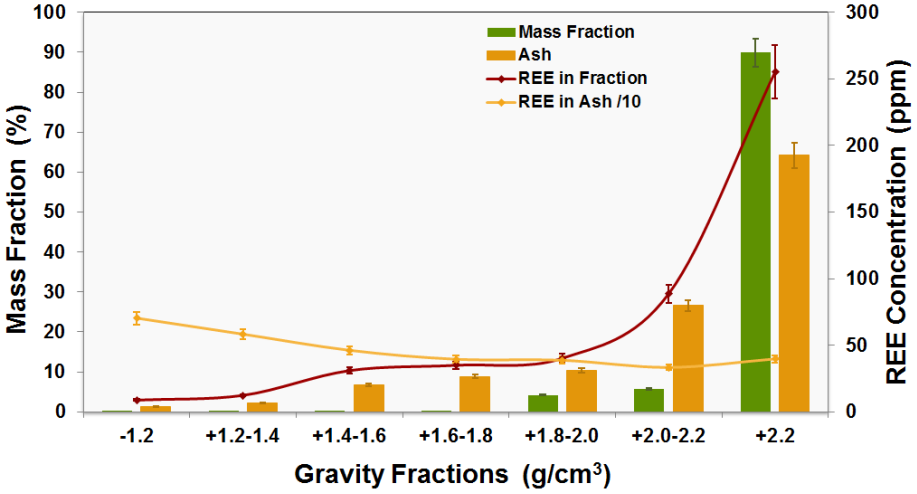

Figure 27: REE concentrations in gravity fractions for MOSONCB3 and -516+149 µm size fraction

Table 16: REE concentrations in gravity fractions for MOSONCB3 and -3348+516 µm size fraction

Sample Name:	MOSONCB3
Sample Size:	-3348+516 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.00	0.05	0.05	0.30	1.48	8.08	90.04
Ash (%)		59.64	0.00	2.81	5.57	9.55	16.57	27.98	63.42
Concentration in Fraction (ppm)	Sc	34.87	0.00	0.45	1.21	1.50	1.43	7.46	38.02
	Y	104.25	0.00	1.09	3.36	4.07	4.30	23.46	113.59
	La	45.62	0.00	1.24	1.57	1.22	1.17	5.55	50.14
	Ce	89.88	0.00	2.10	3.04	2.33	2.28	12.28	98.67
	Pr	1.10	0.00	0.22	0.33	0.31	0.29	1.28	1.10
	Nd	43.57	0.00	0.93	1.53	1.26	1.22	6.21	47.80
	Sm	9.71	0.00	0.16	0.32	0.30	0.30	1.46	10.65
	Eu	2.41	0.00	0.03	0.08	0.08	0.08	0.37	2.64
	Gd	12.01	0.00	0.16	0.41	0.44	0.45	2.31	13.12
	Tb	2.21	0.00	0.03	0.07	0.09	0.09	0.46	2.41
	Dy	14.36	0.00	0.14	0.48	0.59	0.63	3.26	15.64
	Ho	3.08	0.00	0.03	0.10	0.13	0.14	0.79	3.35
	Er	8.23	0.00	0.09	0.29	0.36	0.32	2.12	8.95
	Yb	8.62	0.00	0.08	0.26	0.32	0.36	1.90	9.40
	Lu	1.23	0.00	0.02	0.04	0.06	0.06	0.30	1.34
	LREE	329.00	0.00	6.19	11.36	10.99	10.99	57.70	359.97
	HREE	52.15	0.00	0.58	1.73	2.07	2.13	11.51	56.85
	REE	381.15	0.00	6.77	13.09	13.06	13.12	69.21	35.76
	REE+Y+Sc	520.27	0.00	8.31	17.66	18.63	18.85	100.13	568.43

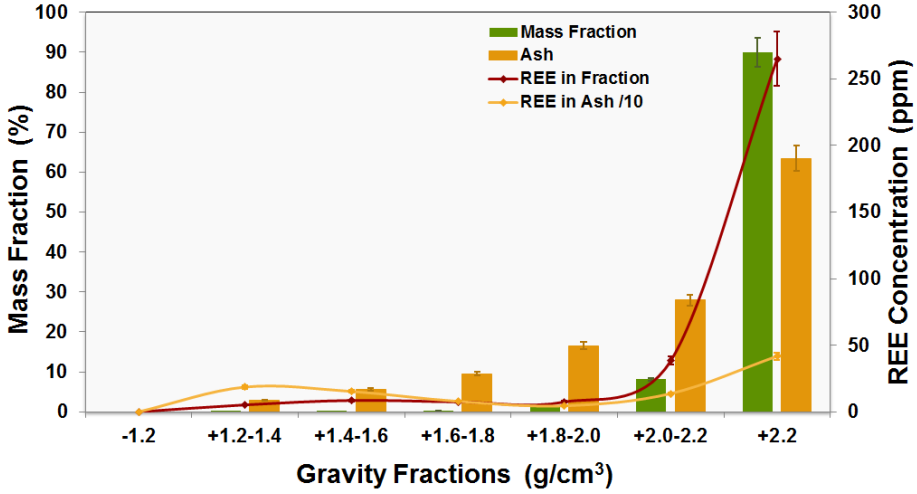

Figure 28: REE concentrations in gravity fractions for MOSONCB3 and -3348+516 µm size fraction

Table 17: REE concentrations in gravity fractions for MOBONCB3 and -516+149 µm size fraction

Sample Name:	MOBONCB3
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.15	0.37	0.14	1.49	6.14	5.52	86.20
Ash (%)		67.76	1.38	3.70	8.76	15.56	26.86	54.42	72.91
Concentration in Fraction (ppm)	Sc	16.79	1.95	1.75	3.97	7.46	12.64	12.14	17.66
	Y	28.26	1.96	1.70	5.90	9.12	14.01	25.14	30.00
	La	27.30	3.26	2.75	5.55	8.37	13.77	20.17	29.23
	Ce	51.30	0.04	6.07	9.48	14.11	24.01	34.74	55.29
	Pr	0.59	1.41	0.09	0.10	0.21	0.16	0.60	0.63
	Nd	20.83	0.29	4.28	3.97	6.42	10.82	18.05	22.10
	Sm	4.25	0.06	0.08	1.17	2.01	2.07	3.62	4.52
	Eu	0.93	0.27	0.24	0.25	0.34	0.40	0.73	0.99
	Gd	4.04	0.04	0.47	1.18	1.66	1.80	3.15	4.32
	Tb	0.62	0.27	0.29	0.09	0.19	0.23	0.56	0.66
	Dy	3.86	0.05	0.49	1.76	2.06	2.11	3.48	4.07
	Ho	0.87	0.18	0.17	0.34	0.38	0.47	0.64	0.92
	Er	2.50	0.18	0.16	1.06	1.38	1.25	2.27	2.64
	Yb	2.73	0.02	0.03	0.95	1.38	1.28	2.49	2.90
	Lu	0.39	0.01	0.01	0.15	0.18	0.21	0.33	0.41
	LREE	149.32	8.97	16.72	30.14	47.70	77.48	114.46	159.43
	HREE	15.94	1.02	1.86	5.78	7.57	7.75	13.65	16.91
	REE	165.26	9.99	18.58	35.92	55.27	85.23	128.11	35.76
	REE+Y+Sc	210.31	13.90	22.03	45.79	71.85	111.88	165.39	224.00

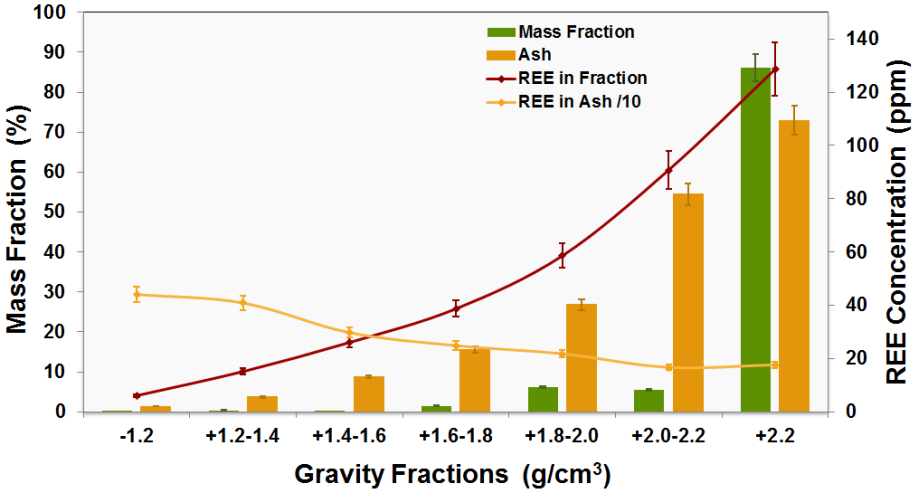

Figure 29: REE concentrations in gravity fractions for MOBONCB3 and -516+149 µm size fraction

Table 18: REE REE concentrations in gravity fractions for WYBTMPRB1 and -149 µm size fraction

Sample Name:	WYBTMPRB1
Sample Size:	-149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	18.05	20.67	53.08	7.62	0.29	0.08	0.22
Ash (%)		6.45	1.52	3.27	5.07	32.24	51.25	60.71	70.01
Concentration in Fraction (ppm)	Sc	2.18	1.60	2.53	2.28	1.96	0.91	0.61	0.66
	Y	3.42	2.38	3.84	3.67	3.18	1.72	1.54	0.90
	La	4.97	3.60	5.00	5.50	4.57	3.63	2.91	1.54
	Ce	9.20	6.46	8.87	10.48	7.93	6.30	4.97	2.80
	Pr	1.59	0.04	2.30	1.92	1.13	0.20	0.07	0.01
	Nd	3.70	2.53	3.81	4.09	3.59	2.21	1.23	1.23
	Sm	0.78	0.44	0.97	0.89	0.33	0.73	0.25	0.22
	Eu	0.26	0.16	0.39	0.23	0.39	0.24	0.18	0.09
	Gd	0.76	0.53	1.26	0.66	0.65	0.64	0.25	0.20
	Tb	0.10	0.03	0.23	0.06	0.14	0.11	0.12	0.03
	Dy	0.58	0.33	1.11	0.44	0.73	0.39	0.26	0.17
	Ho	0.11	0.06	0.19	0.08	0.24	0.26	0.17	0.03
	Er	0.44	0.06	0.27	0.57	0.94	0.84	0.12	0.04
	Yb	0.41	0.05	0.30	0.49	0.97	0.37	0.06	0.04
	Lu	0.05	0.07	0.06	0.04	0.06	0.06	0.12	0.01
	LREE	25.84	17.05	27.32	28.83	22.69	15.70	11.58	7.36
	HREE	2.71	1.29	3.81	2.57	4.12	2.91	1.28	0.61
	REE	28.55	18.34	31.13	31.40	26.81	18.61	12.86	35.76
	REE+Y+Sc	34.15	22.32	37.50	37.35	31.95	21.24	15.01	9.53

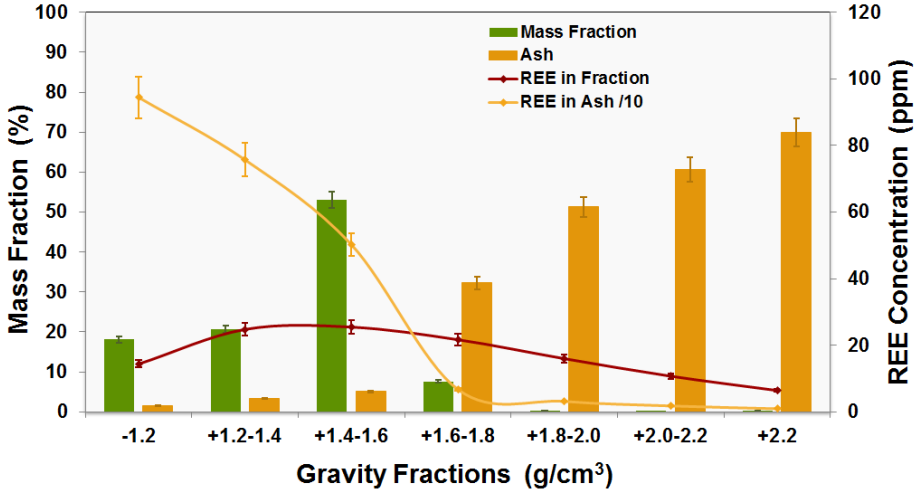

Figure 30: REE concentrations in gravity fractions for WYBTMPRB1 and -149 µm size fraction

Table 19: REE concentrations in gravity fractions for UTWMUIB1 and -516+149 µm size fraction

Sample Name:	UTWMUIB1
Sample Size:	-516+149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	5.68	88.29	3.84	0.85	0.51	0.03	0.79
Ash (%)		5.70	1.43	3.03	39.30	52.80	68.19	75.42	78.38
Concentration in Fraction (ppm)	Sc	1.17	0.67	0.86	6.11	7.77	6.69	0.98	4.39
	Y	3.12	1.90	1.89	24.15	20.10	23.78	39.45	13.90
	La	3.85	1.86	2.63	25.57	30.78	18.22	12.42	11.31
	Ce	7.17	3.75	4.76	46.70	56.12	45.01	27.70	31.04
	Pr	0.77	0.33	0.78	0.99	1.58	1.52	1.21	0.81
	Nd	3.18	1.31	2.15	22.08	25.04	14.94	11.71	8.68
	Sm	0.57	0.36	0.35	3.98	4.34	5.04	3.24	2.51
	Eu	0.13	0.08	0.08	0.85	0.65	0.34	1.98	0.76
	Gd	0.56	0.37	0.35	3.85	4.07	4.09	3.43	2.68
	Tb	0.08	0.06	0.05	0.52	0.61	0.47	0.52	0.33
	Dy	0.45	0.29	0.27	3.58	2.80	3.83	3.33	1.86
	Ho	0.10	0.07	0.06	0.62	0.63	0.41	2.16	0.67
	Er	0.28	0.17	0.20	1.53	1.57	1.89	1.76	1.19
	Yb	0.25	0.17	0.16	1.72	1.27	2.01	1.68	1.15
	Lu	0.04	0.03	0.03	0.26	0.30	0.23	0.26	0.17
	LREE	19.83	10.18	13.42	129.57	145.73	115.20	96.72	72.63
	HREE	1.87	1.25	1.20	12.93	11.90	13.27	15.11	8.79
	REE	21.70	11.42	14.62	142.50	157.64	128.47	111.84	35.76
	REE+Y+Sc	25.99	14.00	17.36	172.75	185.51	158.94	152.27	99.71

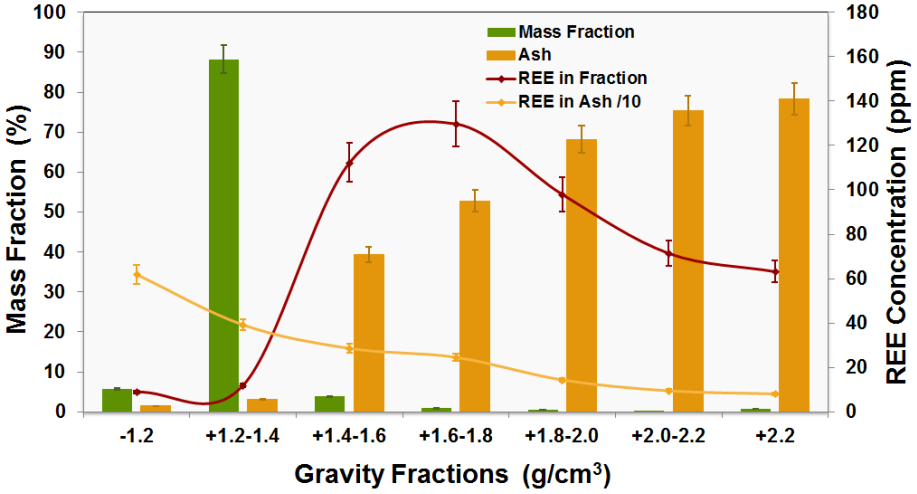

Figure 31: REE concentrations in gravity fractions for UTWMUIB1 and -516+149 µm size fraction

Table 20: REE concentrations in gravity fractions for UTWMUIB1 and -3348+516 µm size fraction

Sample Name:	UTWMUIB1
Sample Size:	-3348+516 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	0.33	92.65	5.92	0.35	0.16	0.11	0.48
Ash (%)		5.70	1.58	2.95	37.98	55.36	63.94	69.11	71.85
Concentration in Fraction (ppm)	Sc	1.15	0.60	0.78	6.31	5.58	5.51	5.01	3.68
	Y	3.17	1.74	2.53	11.66	13.72	15.84	14.15	9.34
	La	3.80	1.64	2.67	18.05	27.27	28.93	19.98	18.63
	Ce	7.07	3.00	4.42	42.83	46.61	46.67	35.05	31.43
	Pr	0.78	0.34	0.38	6.51	4.47	4.80	3.78	3.13
	Nd	3.19	1.42	2.09	18.03	17.85	18.53	16.63	13.64
	Sm	0.57	0.26	0.38	3.20	2.96	3.04	3.11	2.16
	Eu	0.13	0.08	0.08	0.78	0.66	0.66	0.74	0.62
	Gd	0.57	0.28	0.36	3.50	3.01	3.16	3.45	2.21
	Tb	0.08	0.04	0.05	0.39	0.40	0.42	0.47	0.26
	Dy	0.44	0.24	0.31	2.25	2.36	2.47	2.87	1.42
	Ho	0.10	0.06	0.07	0.45	0.51	0.53	0.64	0.38
	Er	0.28	0.14	0.21	1.23	1.36	1.48	1.76	0.83
	Yb	0.25	0.14	0.18	1.16	1.29	1.41	1.64	0.74
	Lu	0.04	0.02	0.03	0.18	0.22	0.23	0.26	0.12
	LREE	19.73	9.00	13.25	106.58	118.46	123.32	97.71	82.01
	HREE	1.88	1.00	1.29	9.92	9.81	10.35	11.83	6.57
	REE	21.60	10.00	14.54	116.50	128.27	133.67	109.54	35.76
	REE+Y+Sc	25.93	12.34	17.85	134.47	147.57	155.02	128.71	101.60

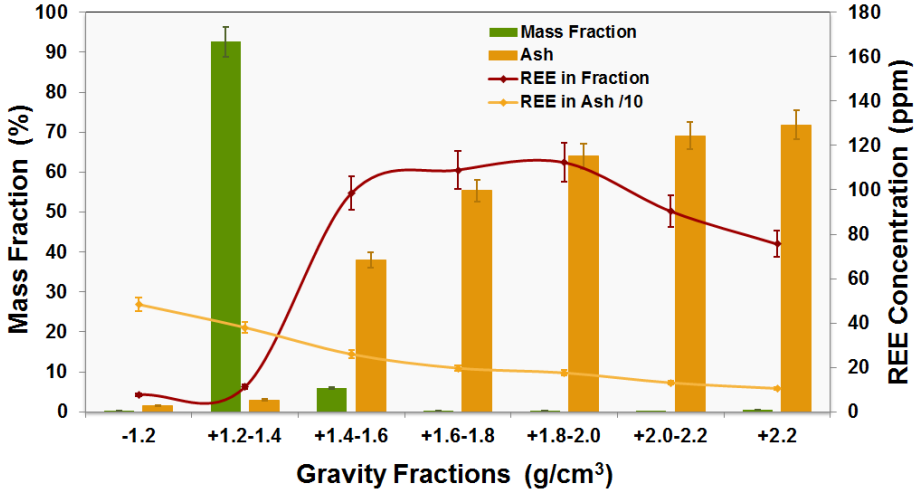

Figure 32: REE concentrations in gravity fractions for UTWMUIB1 and -3348+516 µm size fraction

Table 21: REE concentrations in gravity fractions for UTWMUIB1 and -149 µm size fraction

Sample Name:	UTWMUIB1
Sample Size:	-149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	6.14	84.89	7.47	1.06	0.33	0.02	0.10
Ash (%)		5.69	0.87	3.59	23.93	47.44	63.63	71.26	81.32
Concentration in Fraction (ppm)	Sc	1.20	0.48	0.71	6.25	8.69	3.68	0.62	0.43
	Y	3.66	1.17	2.56	15.68	20.58	7.65	1.69	1.06
	La	5.00	1.46	3.71	19.59	24.68	8.43	1.96	1.62
	Ce	11.52	2.72	8.96	42.33	50.28	16.29	3.46	2.93
	Pr	0.77	0.32	0.37	5.08	5.01	1.34	0.59	0.36
	Nd	3.82	1.20	2.35	19.59	24.55	8.93	2.05	1.33
	Sm	0.62	0.23	0.38	3.25	3.19	0.74	0.21	0.22
	Eu	0.13	0.05	0.11	0.39	0.76	0.22	0.50	0.08
	Gd	0.62	0.23	0.38	3.25	3.12	0.79	1.18	0.22
	Tb	0.08	0.05	0.07	0.20	0.35	0.07	0.18	0.03
	Dy	0.47	0.22	0.33	2.04	2.05	0.38	0.79	0.15
	Ho	0.11	0.05	0.10	0.27	0.42	0.09	0.22	0.03
	Er	0.31	0.14	0.23	1.21	1.44	0.34	0.39	0.11
	Yb	0.26	0.09	0.22	0.81	1.09	0.22	0.38	0.08
	Lu	0.04	0.05	0.04	0.10	0.21	0.07	0.10	0.02
	LREE	26.59	7.58	19.04	111.78	136.99	47.06	10.58	7.93
	HREE	2.02	0.87	1.46	8.28	9.44	2.19	3.74	0.71
	REE	28.61	8.45	20.50	120.05	146.43	49.25	14.33	35.76
	REE+Y+Sc	33.47	10.11	23.77	141.99	175.71	60.59	16.64	10.13

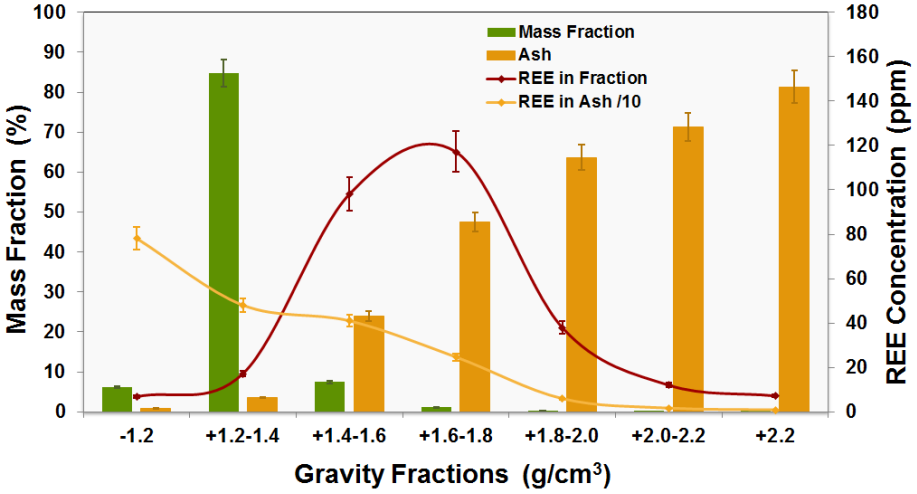

Figure 33: REE concentrations in gravity fractions for UTWMUIB1 and -149 µm size fraction

Table 22: REE concentrations in gravity fractions for WYNMPRB1 and -149 µm size fraction

Sample Name:	WYNMPRB1
Sample Size:	-149 µm

Density Fractions		Feed	-1.2	+1.2-1.4	+1.4-1.6	+1.6-1.8	+1.8-2.0	+2.0-2.2	+2.2
Mass Fraction (%)		100	12.93	28.44	53.41	2.17	1.36	0.95	0.74
Ash (%)		6.37	1.25	3.04	5.54	31.72	47.50	57.35	68.33
Concentration in Fraction (ppm)	Sc	2.21	0.71	2.24	2.58	2.97	1.58	1.10	0.77
	Y	3.43	1.23	3.58	3.92	4.47	2.60	2.15	1.27
	La	4.77	1.57	4.31	5.81	6.62	3.83	2.90	2.14
	Ce	8.70	5.37	7.44	10.15	12.92	7.40	5.90	4.50
	Pr	0.54	0.25	0.51	0.65	0.46	0.20	0.14	0.01
	Nd	3.74	1.33	3.64	4.34	5.78	3.36	2.81	2.06
	Sm	0.75	0.27	0.77	0.85	1.06	0.52	0.42	0.38
	Eu	0.27	0.09	0.24	0.32	0.34	0.23	0.21	0.10
	Gd	0.74	0.26	0.82	0.82	1.06	0.52	0.46	0.37
	Tb	0.10	0.03	0.09	0.12	0.11	0.08	0.07	0.04
	Dy	0.55	0.18	0.51	0.67	0.79	0.39	0.27	0.21
	Ho	0.11	0.05	0.14	0.11	0.17	0.13	0.11	0.05
	Er	0.43	0.05	0.41	0.57	0.17	0.13	0.11	0.05
	Yb	0.40	0.05	0.43	0.51	0.17	0.13	0.11	0.05
	Lu	0.04	0.01	0.04	0.06	0.01	0.01	0.01	0.01
	LREE	24.14	10.73	22.49	28.30	34.29	19.51	15.41	11.13
	HREE	2.65	0.72	2.68	3.18	2.82	1.61	1.36	0.86
	REE	26.79	11.45	25.17	31.47	37.10	21.12	16.77	35.76
	REE+Y+Sc	32.43	13.39	30.98	37.97	44.54	25.31	20.02	14.04

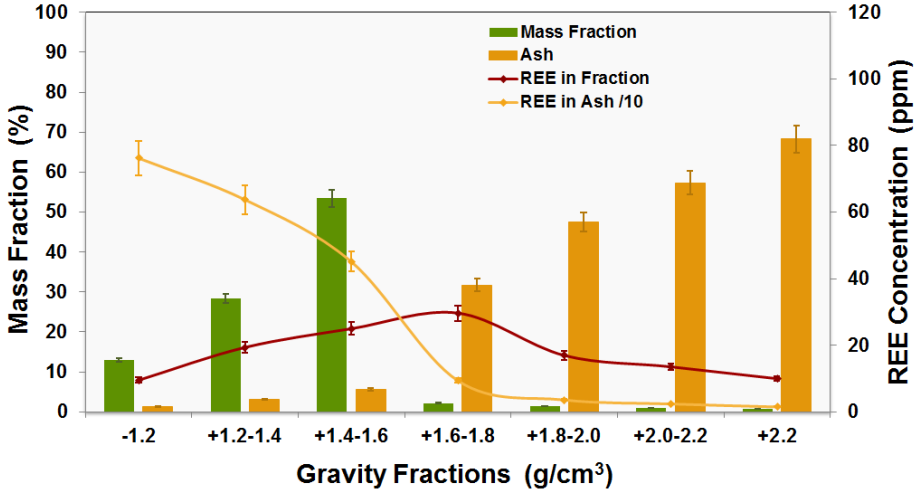

Figure 34: REE concentrations in gravity fractions for WYNMPRB1 and -149 µm size fraction

Magnetic Separation Results

The magnetic separation testing was performed to investigate the potential for REE+Y+Sc concentration using this physical separation method. The tests were performed on 11 selected samples and information about the mass yield, REE+Y+Sc concentrations, ash, fixed carbon, sulfur, and volatiles contents were obtained through elemental and proximate analysis of collected split fractions. All obtained results were mass balanced prior data analysis. Recoveries of all investigated assays as well as total REE recovery and mass yields were calculated for all cases using the balanced data. Tables containing all mass balanced data and REE+Y+Sc assays expressed per ash (Table 39) and whole sample (Table 40) basis are given in Appendix 8. The recovery data calculated for both obtained fractions are given in Table 41.

In Figure 35 coal combustibles recovery in non-magnetic fraction is presented as a function of ash and sulfur rejection in magnetic fraction. In addition, the plot showing a relationship between the combustible and REE recoveries in the non-magnetic fraction is given in this figure. For each plot, a linear model with 95% confidence band was used to facilitate easier observation of the trends.

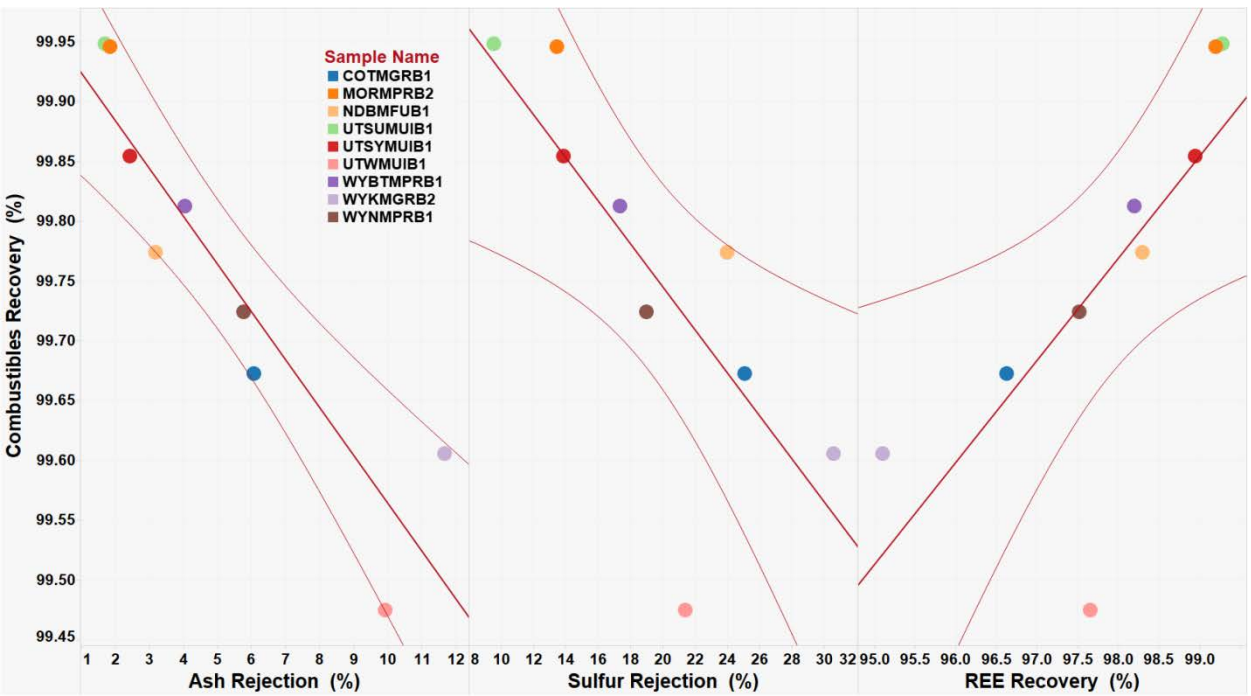

Figure 35: Combustibles recovery in non-magnetic fraction in relation with the ash rejection (left), sulfur rejection (middle), and REE recovery (right)

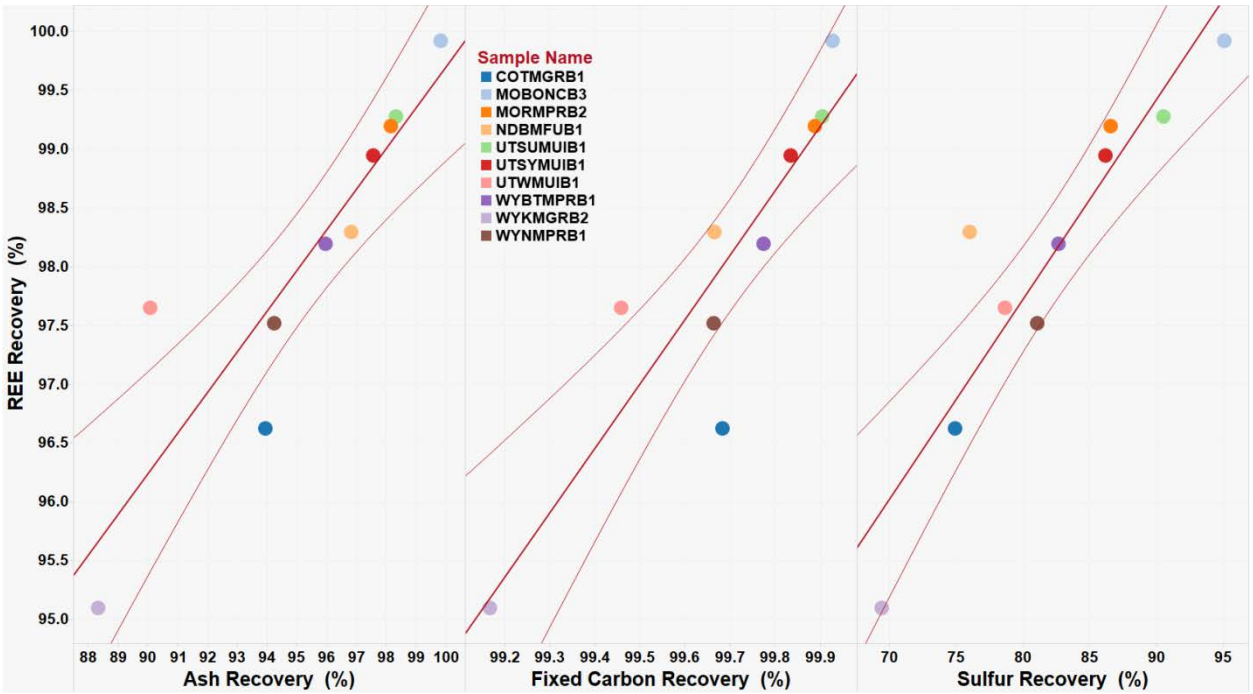

Figure 36: REE recovery in non-magnetic fraction in relation with the ash recovery (left), fixed carbon recovery (middle), and sulfur recovery (right)

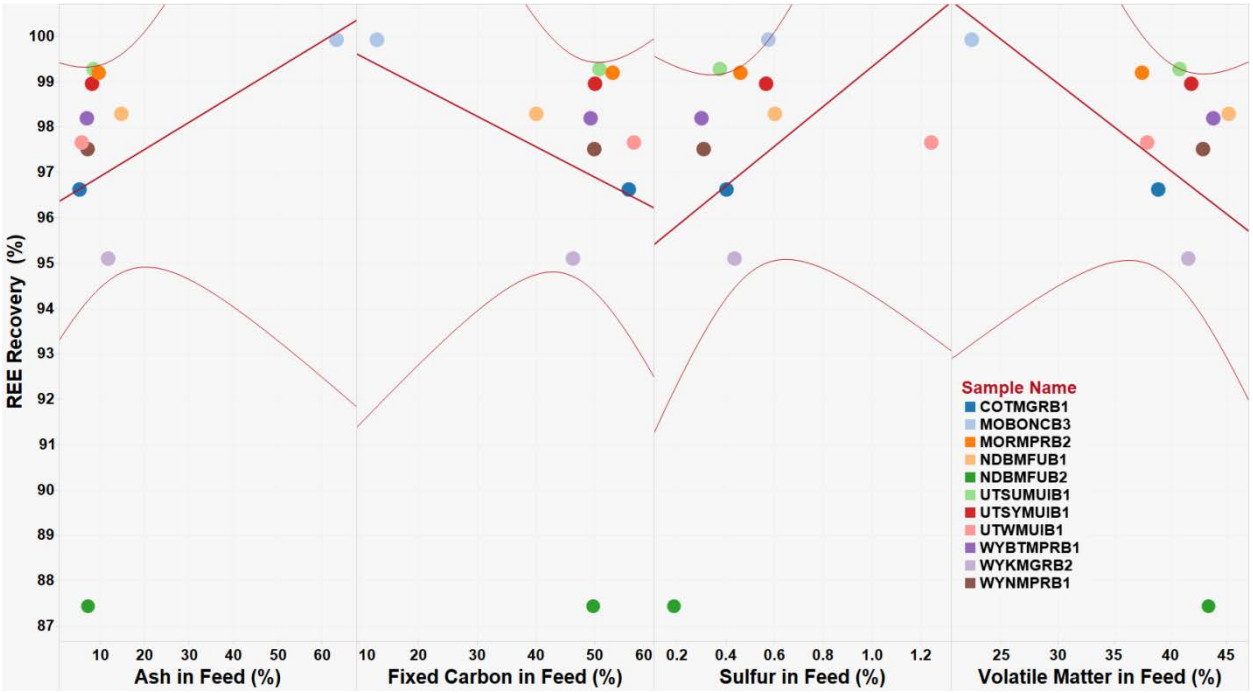

Figure 37: REE recovery in relation with the ash (far left), fixed carbon (middle left), sulfur (middle right), and volatiles (far right) concentrations

As can be observed in Figure 35, only a small part of the total feed ash fraction (<11%) can be recovered using the magnetic separation method. The recovered material represents the paramagnetic fraction of the inorganic part of the coal, which is composed of the pyritic minerals, as demonstrated by elevated sulfur rejection values (between 8 and 30%). In addition, for the non-magnetic fraction, a direct relationship between the combustible recovery and REE recovery is observed, again suggesting that the main REE association is with the organic part of the coal matrix.

Total REE recovery in the non-magnetic fraction was plotted against the ash, fixed carbon, and sulfur recoveries for all tested cases in Figure 36. Again, the linear model with 95% confidence band is offered with each plot. It can be observed in the figure that for samples with high ash, fixed carbon, and sulfur recoveries, which suggest that the total mass yield is also high, the REE recovery is high. Therefore, the same conclusion about the REE+Y+Sc mineralogical distribution within the coal matrix can be made.

Figure 37 shows the REE recovery in the non-magnetic fraction as a function of the ash, fixed carbon, sulfur, and volatiles concentration in the feed obtained via proximate analysis. Considering very wide confidence bands in presented plots, it can be concluded that there is no obvious relationship between the coal sample property and obtained REE recovery.

Particularly low mass yield of the magnetic fraction was achieved (<2%) for most of the tested samples, which indicates that only a small fraction of coal material possesses paramagnetic properties; most of which originates from the pyritic fraction of the coal. Within the magnetic fraction recovered, only a minute concentration of REE, Y, and Sc can be found, indicating that REE cannot be effectively concentrated using this WHIMS method. Further REE+Y+Sc mineral liberation through comminution process might facilitate increase in process efficiency, which should be investigated in the future and preferably in conjunction with detailed mineralogical analysis of treated samples.

Flotation Separation Results

The froth flotation method was used during the physical separation testing on 10 selected samples to investigate its potential to concentrate REE+Y+Sc elements from the raw coal materials. Summary of the balanced mass yield, REE+Y+Sc concentrations, ash, fixed carbon, sulfur, and volatiles contents are given in Appendix 9, Table 42 and Table 43. Also, given in Appendix 9 are recoveries of each individual REE element, Y, Sc, LREE, HREE, and total REE for all ten performed tests (Table 44).

In Figure 38 coal combustibles recovery in collected concentrate (floatable) fraction is presented as a function of ash and sulfur rejection in tails (non-floatable) fraction. In addition, the plot showing a relationship between the combustible and REE recoveries in the concentrate fraction is given in this figure. As in the previous figures, a linear model with 95% confidence band was used to facilitate easier observation of the trends. A wide range of samples, with particularly different physical and chemical properties were considered for this analysis, causing a great variation between the obtained results. This has also presented a challenge during the actual

experiments, since no common experimental procedure could be established and used with all samples. General conclusions should, therefore, be made with a caution in this case.

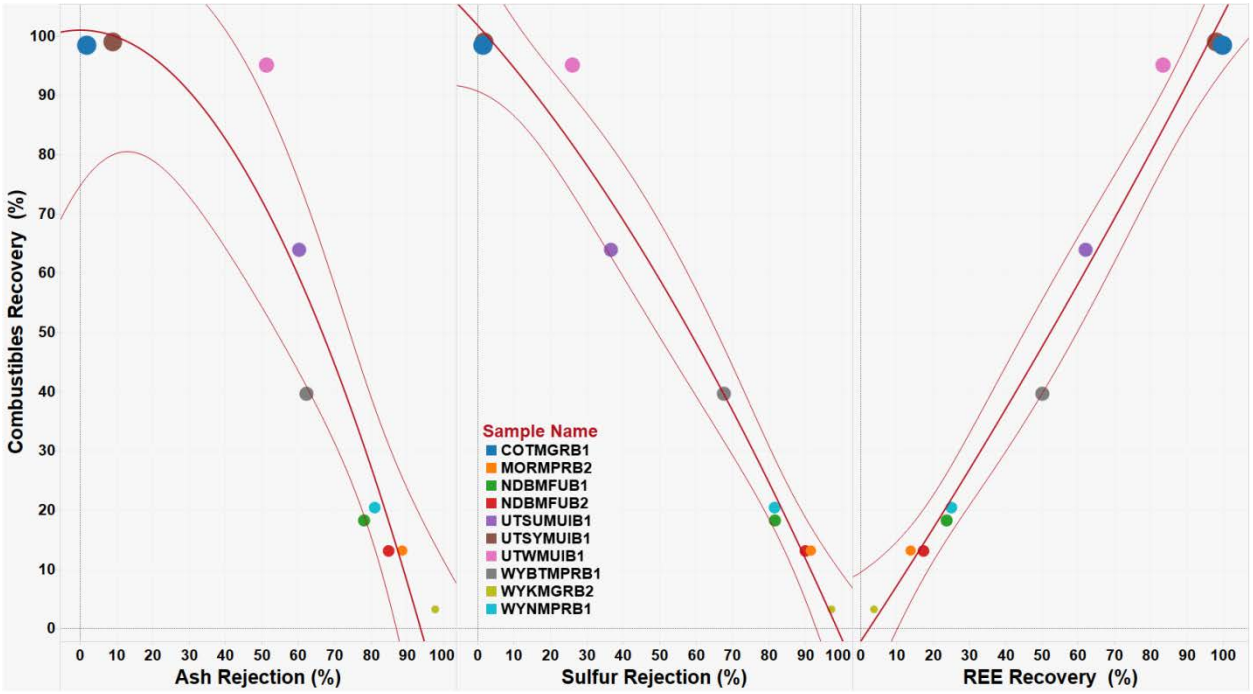

Figure 38: Combustibles recovery in concentrate in relation with the ash rejection (left), sulfur rejection (middle), and REE recovery (right)

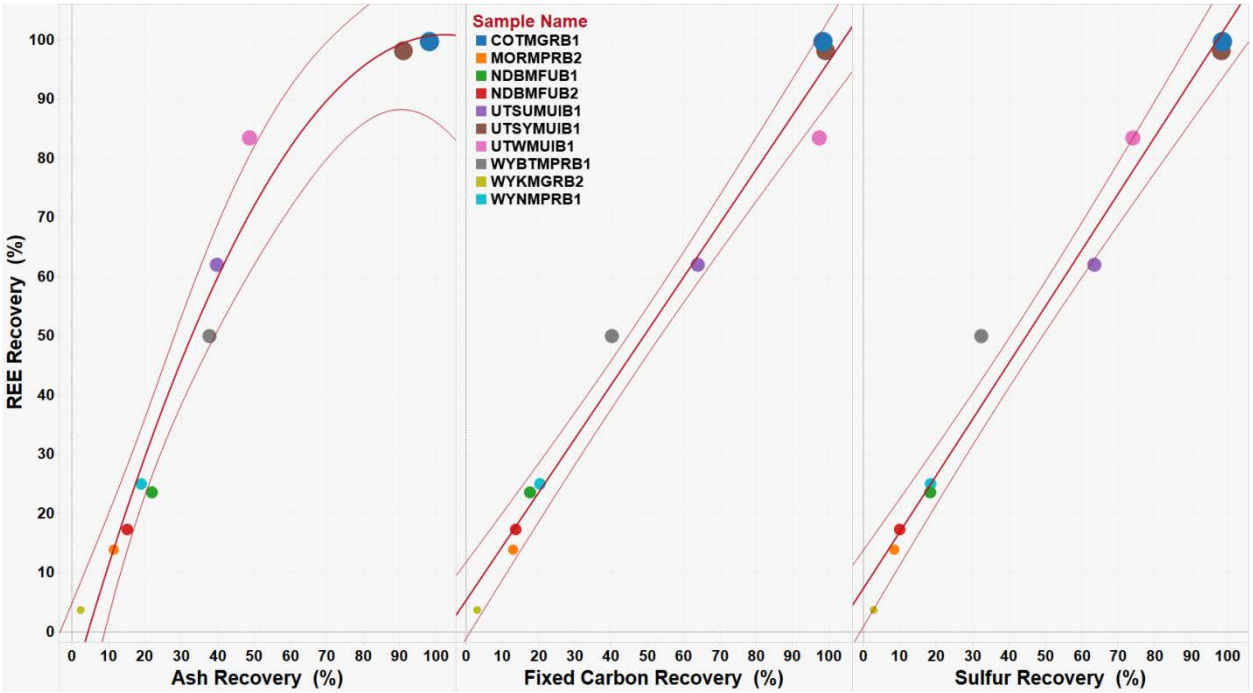

Figure 39: REE recovery in concentrate in relation with the ash recovery (left), fixed carbon recovery (middle), and sulfur recovery (right)

From Figure 38 it can be seen that for high quality coals particularly high combustible recoveries are obtained, which is resulting in high REE recoveries in the concentrate. Particularly promising results are obtained for the UTWMUIB1 sample, as evident from good ash rejection and high REE recovery obtained. For majority of other samples, separation efficiency was not satisfactory and potential reasons for this finding will be discussed at the end of this section.

Total REE recovery in the concentrate fraction plotted against the ash, fixed carbon, and sulfur recoveries is given in Figure 39. As observed in the previous section, for samples with high ash, fixed carbon, and sulfur recoveries, REE recovery is high due to high total mass yield for these cases.

Figure 40 shows total REE recovery in the concentrate fraction as a function of the ash, fixed carbon, sulfur, and volatiles concentrations of the feed. Similar to the observation made for Figure 37, wide confidence bands can be noticed in presented plots. In general, high REE recoveries are obtained when using samples with low ash and high fixed carbon contents, which are characteristic for high quality coals.

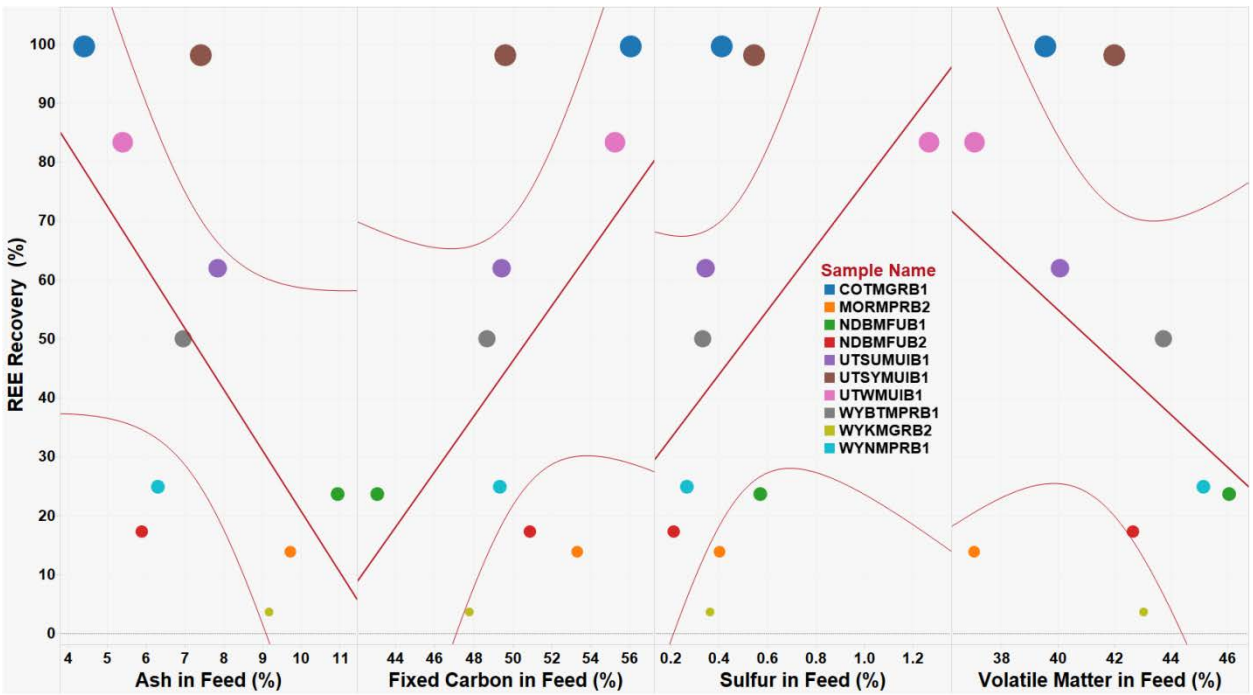

Figure 40: REE recovery in concentrate in relation with the ash (far left), fixed carbon (middle left), sulfur (middle right), and volatiles (far right) concentrations

In conclusion, the froth flotation method cannot be used to effectively concentrate REE elements from fine (<149 µm) coal material. The reason for this trend lies in the fact that most of the REE are found to be finely disseminated within the coal matrix, with mineral grain size less than 5 microns, and, therefore, cannot be separated from the coal due to their poor liberation at feed particle size of -100 mesh. With further liberation of the feed material, these results might change providing that economically feasible, efficient, and selective solution(s) for ultrafine

particle recovery using flotation process is available. Further comprehensive mineralogical and experimental investigation is necessary to determine the potential for REE concentration from coal material using froth flotation method. In addition, development of improved chemical solutions for the selective recovery of REE+Y+Sc bearing minerals will be required to facilitate improved REE+Y+Sc recovery.

Mineralogical Analysis using QEMSCAN

The mineral liberation analysis, QEMSCAN, was used to investigate the mineralogical properties of the sample which demonstrated the highest REE+Y+Sc concentrations, i.e. MOSONCB3. Both a detailed areal scan of one prepared sample using 5 µm resolution, as well as linear scans of six additional samples using 4 µm resolution and 100 µm line spacing were performed.

For the MOSONCB3 sample, ICP-MS analysis found that the total REE+Y+Sc concentration in the sample is 382 ppm. However, within over six million pixels analyzed using QEMSCAN method, there were no REE bearing minerals detected. We could give two potential, and completely opposing, reasons for this finding:

1) the REE bearing minerals are finely disseminated within the sample with the largest grain size smaller than 4 µm.
2) the REE mineral grains are very large, and only a few are present within the bearing sample, so none of the existing grains was exposed during the sample preparation (polishing) procedure and therefore detected.

While we believe that the first answer represents the more probable reason for this finding, a further comprehensive mineralogical analysis using microprobe, SEM-EDX, and/or nano-CT should be performed in the future. The findings of this analysis will be critical for improvement of existing and development and optimization of new REE concentration technologies.

The overview of the QEMSCAN results is given in Figure 35 for one raw MOSONCB3 sample and 3348+516 µm size fraction (top) and for all sink fractions obtained through the washability analysis of the 516+149 µm size fraction. As noted before, the Sand Coulee sample is a coaly-clay material not coal, which is characteristic material within the partings or thin layers of contact zone between the coal and partings. As can be seen in the figure, the clay carries most of the mass of this sample (area in orange). The remaining detected components are quartz, pyrite, other sulphates, and feldspar. Since the coal and resin are both composed of carbon, they are both within the white fraction of the area in the figures.

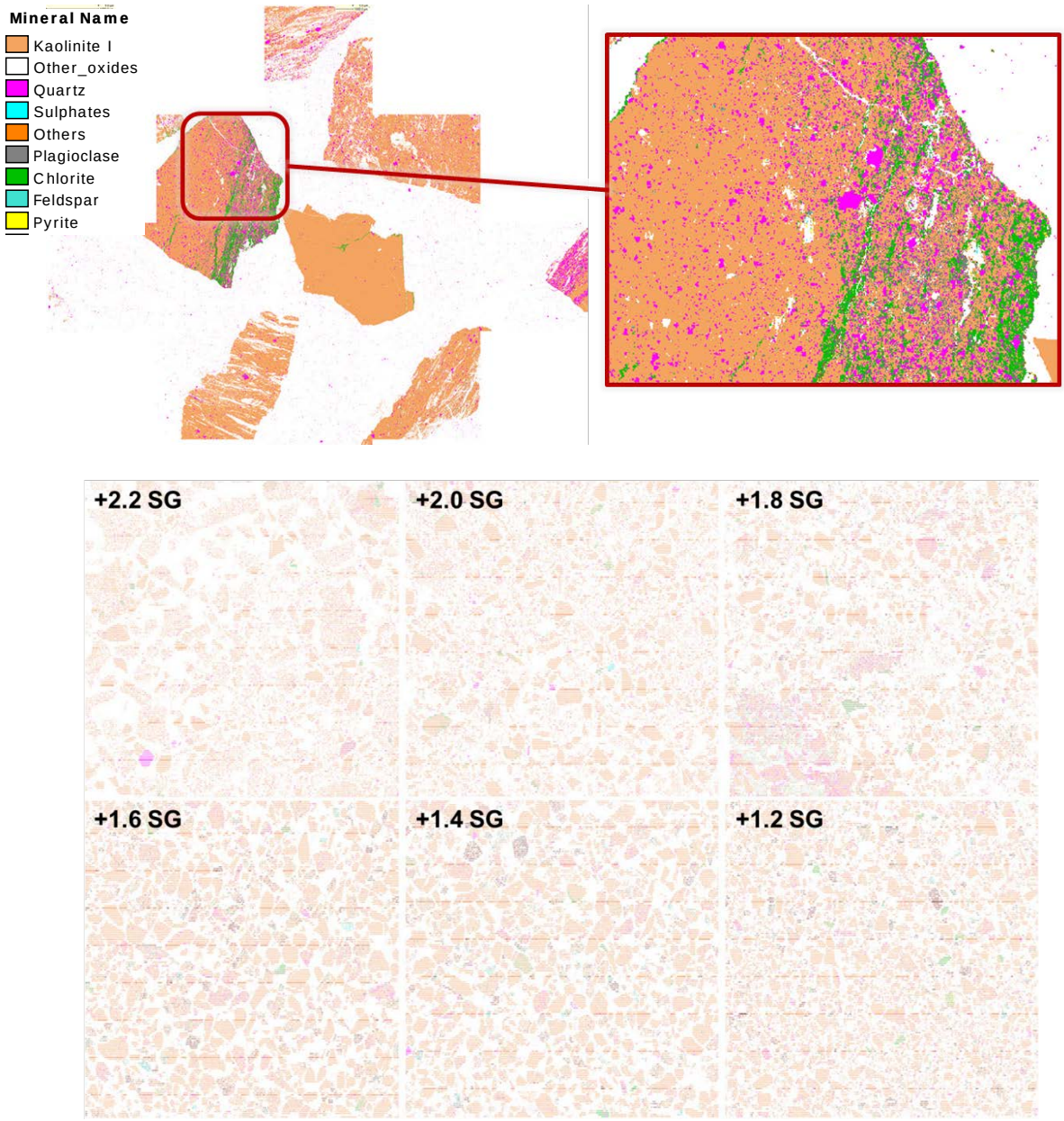

Figure 41: Results of the QEMSCAN mineralogical analysis of MOSONCB3 sample. Areal scan of raw sample (top); linear scan of several cumulative density fractions (bottom)

RECOMMENDATIONS (FUTURE ANALYSIS)

This report summarizes findings obtained through extensive experimental study of 36 samples from the Western U.S. coal deposits. Despite the limited scope of the study, a valuable set of information was obtained and can be used as a baseline for future research studies in this area. Based on the obtained findings, the recommendations for future investigations are given below:

Mineralogical Analysis

Information about detailed mineralogical composition of different REE-rich coal deposits is necessary to facilitate sound development and optimization of future REE concentration technologies. Potential analytical methods/approaches that can provide a more detailed insight into mineralogical composition of coal and coal refuse samples include microprobe, SEM-EDX, and/or nano X-ray CT.

Physical Separation Technologies

The efficient concentration of REE minerals from REE rich coal and coal refuse materials will require manipulation and treatment of ultrafine particles (<15 µm) with increased degree of liberation. To address the shortcomings of currently used technologies for coal preparation and/or mineral separation, a range of new separation technologies for the treatment, classification, concentration, and dewatering of REE bearing coal and coal refuse materials/mixtures will have to be developed.

Froth Flotation

Through this study it was found that froth flotation cannot effectively concentrate investigated REE elements from fine coal material with particles of less than 100 mesh (<149 µm). Low separation efficiency can be attributed to low degree of REE mineral liberation due to very small REE minerals grain size (<5 µm). For that reason, further liberation of the feed material will be necessary to improve the process performance.

Recovery of ultrafine particles (<15 µm) has been a major challenge for majority of conventional minerals and coal processing technologies, including flotation. To overcome this issue, a new set of efficient, selective, and economically feasible solution(s) for ultrafine particle recovery and treatment will have to be developed.

Furthermore, separation performance of the froth flotation process strongly depends on chemical properties of minerals and overall flotation system. Hence, in order to increase our understanding of the complex surface phenomena occurring at the mineral/water/air interfaces in microscale, new comprehensive and integrated molecular and multiphysics models will have to be developed in the future. This work has to be followed by extensive experimental study of complex interfaces, which will serve to validate developed models and provide system information necessary for accurate model

development. Only in this way, new effective flotation reagents and other supporting reagents for selective REE recovery can be developed.

Density-Based Mineral Separation

This study demonstrated that REE can be concentrated using density-based mineral concentration methods. It was observed that there is a direct correlation between REE recovery and particle size – higher recovery was observed for finer feed particles. On the other hand, most of the conventional density-based technologies are not effective in this particle size range. The improvement of current and development of new (ultra)fine particle density-based concentration technologies will be necessary to overcome the limitations of currently available technologies.

Dewatering of Complex Colloidal Slurries

To ensure more efficient REE separation from coal and coal refuse materials, raw material will have to be grinded further to facilitate generation of particle with large degree of liberation. This will in turn result in generation of very large volumes of ultrafine (colloidal) slurries that will have to be handled carefully after the REE concentration stage. In addition, water presents an invaluable resource that will have to be preserved during the operation through efficient and sustainable treatment, recovery, and recycling. In order to achieve this goal, new technologies for dewatering and purification of complex colloidal slurries will have to be developed in the future.

Chemical Separation Technologies

From the presented results it is clear that in order to achieve better REE separation efficacy from coal materials considered in the study and by using physical beneficiation methods, further minerals liberation (by at least an order of magnitude) will be required. This operation comes with a great cost and slurries that are created are very hard to manage and treat due to their complex colloidal nature. Therefore, future studies should be focused on inventing new processing strategies and novel chemical pathways for REE recovery and extraction from rich coal refuse resources, such as fly and bottom ash generated in the power plants. More efficient and selective chemical extraction processes, such as leaching and solvent extraction, will have to developed and tested in the future.

APPENDICES

APPENDIX 1: Experimental Procedures

Sample Preparation

Table 23: Experimental procedure for sample preparation

Step 1	All coarse raw coal samples were crushed using a pilot scale jaw crusher with a CSS of about 1”.
Step 2	The jaw crusher product was crushed using a pilot scale roll crusher of 6 mm gap.
Step 3	The products of the roll crusher were screened using Sweco screening unit and No. 6, 30, and 100 US series screens.
Step 4	Coarse (3360 – 595 µm) and medium (595 – 149 µm) fractions were wet screened to remove ultrafines and fractions were filtered, dried, and split.

Washability Analysis

Table 24: Experimental procedure for washability analysis

Step 1	From the bulk, minimum of 800 to 1000g of -30+100 mesh sample, which was previously wet screened to remove any ultrafine material, is prepared.
Step 2	Six equal subsamples of minimum 50 to 100 g are prepared using Rotary Micro Riffler, weighted, and feed into the 1000 ml separation flask.
Step 3	500ml caesium formate solution with pre-selected density is poured in the flask. The sample is carefully suspended within the dense media using centrifugal type PTFE impeller fitted on an overhead stirrer. Inner walls of the flask are rinsed using the same dense solution. Flasks are filled to their 1000 ml mark.
Step 4	Wait for at least 30 minutes to allow full separation of all particles into float and sink fractions.
Step 5	Stopcock of the separation flask is opened until all sink particles are released from the flask.
Step 6	Sink particles are collected on a filter paper of a Buchner funnel. The Buchner funnel is connected with a filtration flask and vacuum pump to promote the filtration process. The caesium formate solution is collected in the filtration flask and can be reused in the next test.
Step 7	After the sink material is collected, a new Buchner funnel is installed. The stopcock is opened again to collect the float fraction of the sample.
Step 8	The collected float and sink material is moved into the 1000 ml flask, which is then filled with water. Sample is suspended in the water using centrifugal type PTFE impeller fitted on an overhead stirrer. The sample is stirred for at least 5 minutes to maximize caesium formate dissolution from the sample surface to the liquid.
Step 9	Sample is moved into the large laboratory vacuum filtration unit and rinsed several times with water during the filtration process.
Step 10	Collected sample is dried in the oven, then weighted and two fractions are prepared for proximate and ICP – MS analysis.

Magnetic Separation

Table 25: Experimental procedure for magnetic separation

Step 1	300g fine or medium sized particle is mixed with water to make the slurry with 10% w/w of solids.
Step 2	Keep mixing the slurry using a lab scale mixer.
Step 3	Choose the high intensity magnetic field, set the current as 4A.
Step 4	Release the air in the slurry pump, turn on the pump, start the experiment.
Step 5	Keep running the pump for 30 minutes so that the slurry is circulated for 6 times.
Step 6	Rinse the tubes and collector box by clean water.
Step 7	Turn off the magnetic field, filter the concentrate and tail in the experiment.

Flotation Separation

Table 26: Experimental procedure for froth flotation separation

Step 1	400 g of fine (-149 µm) coal sample is placed in a 3 L flotation cell to make a 20% w/w slurry. The agitator is activated while the air valve is closed.
Step 2	0.2 ml to 1.6 ml of collector is added in the slurry and agitated for 5 minutes. Kerosene dosage is adjusted depending on the coal/sample type.
Step 3	0.1ml of frother (MIBC) is added in the slurry and air valve is opened.
Step 4	The time is recorded from the point when concentrate starts leaving the cell. The froth is collected for at least 5 minutes (longer for low quality coals). Water is added in the floatation cell to assist in concentrate collection and pulp level control.
Step 5	Collected concentrate is weighted.
Step 6	Both concentrate and tail splits are filtrated , dried, and measured.

ICP-MS Analysis

Table 27: Experimental procedure for ICP-MS sample analysis

Step 1	Clean the PTFE 50 ml tubes using milli-Q water. Add 15 ml of aqua regia in the tubes, close the tubes using PTFE caps, and place the tubes on 150˚C hotplate for one hour.
Step 2	Clean up the PTFE tubes using milli-Q water. Dry the tubes in the oven at 90˚C.
Step 3	Reduce the surface charge from the PTFE tubes using ionizing blower and measure the clean tube empty weight.
Step 4	Add around 100 mg of sample (ash) in each PTFE tube, reduce the surface charge from the PTFE tubes using ionizing blower, and measure the weight of tubes with the sample.
Step 5	Add 5 ml concentrated AR grade HF and 5 ml concentrated AR grade HNO_3 in each tube, and gently stir the acid with the ash sample.

Step 6	Put the tube on the 120˚C digestion hotplate, gently close the tube caps to reflux the acid for 15 minutes.
Step 7	Remove the caps and wait until all of the acid is boiled/dried out.
Step 8	Add 3 ml concentrate AR grade HNO_3, reflux for 15 minutes.
Step 9-1	Check the status of the solution. If sediment still appears at the tube bottom, add 3 ml concentrated AR grade HF. Wait until all of the acid dried out.
Step 9-2	If the solution is clear, wait until all of the acid is boiled/dried out.
Step 10	Repeat steps 7 to 9 at least two times.
Step 11	Add around 15 ml 5% HNO_3. Reflux for 15 minutes until all samples are dissolved in the solution.
Step 12	Measure the weight of the tubes when the tubes cool down.
Step 13	Add 1 ml of created solution and 0.1 ml of standard tracing solution in the test tube. Dilute the solution to 10 ml using 2.4% HNO_3.
Step 14	Send the diluted solution to ICP-MS analysis.

APPENDIX 2: Prepared Coal Samples and Corresponding Ash

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
1	TXJMTEB1	33.85	32.09	34.06
2	TXJMTEB2	27.69	36.08	35.23
3	TXJMTEB3	36.00	29.04	33.96
4	MOAMPRB1	11.97	47.84	39.79
5	MORMPRB1	10.97	52.83	36.20
6	MORMPRB2	9.74	53.07	37.19

Figure 42: Pictures of three size fractions and ash samples for the following analyzed coal samples TXJMTEB1, TXJMTEB2, TXJMTEB3, MOAMPRB1, MORMPRB1, and MORMPRB2

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
7	WYKMGRB1	10.30	41.15	48.55
8	WYKMGRB2	9.91	47.84	42.25
9	WYKMGRB3	14.66	45.37	38.97
10	WYKMGRB4	8.52	50.72	39.76
11	WYKMGRB5	15.85	43.85	37.70
12	WYKMGRB6	5.96	49.97	44.07

Figure 43: Pictures of three size fractions and ash samples for the following analyzed coal samples WYKMGRB1, WYKMGRB2, WYKMGRB3, WYKMGRB4, WYKMGRB5, and WYKMGRB6

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
13	NDBMFUB1	15.00	39.75	44.75
14	NDBMFUB2	7.17	49.52	43.31
15	NDFMFUB1	15.06	43.15	40.59
16	NDFMFUB2	24.90	39.90	34.20
17	NDFMFUB3	23.45	33.99	41.56
18	NDFMFUB4	32.26	33.25	33.49

Figure 44: Pictures of three size fractions and ash samples for the following analyzed coal samples NDBMFUB1, NDBMFUB2, NDFMFUB1, NDFMFUB2, NDFMFUB3, and NDFMFUB4

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
19	COTMGRB1	5.17	55.45	39.38
20	COTMGRB2	82.11	4.26	13.63
21	WYNMPRB1	6.37	49.39	44.24
22	NMSJMSJB1	44.75	26.56	28.09

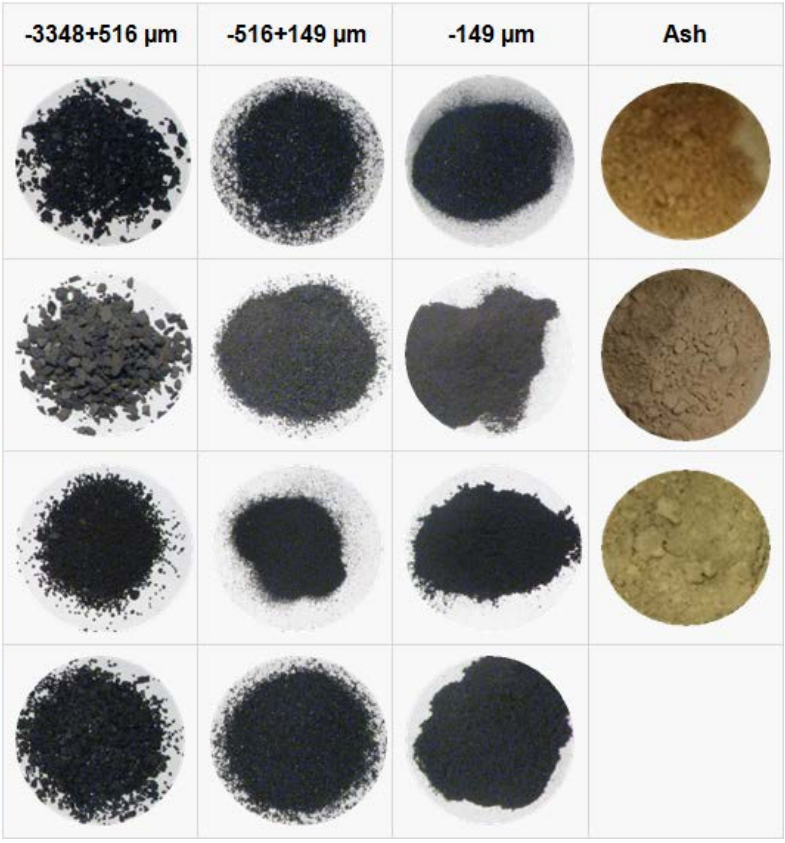

Figure 45: Pictures of three size fractions and ash samples for the following analyzed coal samples COTMGRB1, COTMGRB2, WYNMPRB1, and NMSJMSJB1

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
25	UTSYMUIB1	8.65	49.46	41.89
26	UTSUMUIB1	8.48	50.63	40.89
27	WYBTMPRB1	6.68	49.54	43.78
28	MOBONCB1	67.29	10.76	21.25
29	MOBONCB2	63.88	13.44	22.18
30	MOBONCB3	67.76	11.52	20.72

Figure 46: Pictures of three size fractions and ash samples for the following analyzed coal samples UTSYMUIB1, UTSUMUIB1, WYBTMPRB1, MOBONCB1, MOBONCB2, and MOBONCB3

#	Sample	Assay Ash	Assay Fixed C	Assay Volatiles
31	MOBONCB4	64.70	13.86	21.44
32	MOSONCB1	71.64	8.62	19.74
33	MOSONCB2	83.65	1.72	15.07
34	MOSONCB3	59.65	16.65	23.70
35	MOSONCB4	73.46	6.99	19.55
36	UTWMUIB1	5.70	56.36	37.94

Figure 47: Pictures of three size fractions and ash samples for the following analyzed coal samples MOBONCB4, MOSONCB1, MOSONCB2, MOSONCB3, MOSONCB4, and UTWMUIB1

APPENDIX 3: Summary of Proximate Analysis of as Received Samples

Table 28: Results of proximate analysis of all received coal samples

Sample Name	Moisture (%)	Ash (%)	Fixed Carbon (%)	Sulfur (%)	Volatile Matter (%)	Calorific Value (Btu/lb)
TXJMTEB1	27.17	33.85	32.09	0.62	34.06	8158
TXJMTEB2	26.39	27.69	36.08	1.25	36.23	8482
TXJMTEB3	24.94	36.00	29.04	1.29	34.96	7867
MOAMPRB1	25.24	11.97	47.84	0.79	40.19	11237
MORMPRB1	14.24	10.97	52.83	0.51	36.20	11515
MORMPRB2	17.53	9.74	53.07	0.41	37.19	11701
WYKMGRB1	32.62	10.30	41.15	0.63	48.55	8959
WYKMGRB2	15.57	9.91	47.84	0.39	42.25	11612
WYKMGRB3	19.16	14.66	45.37	1.53	39.97	11257
WYKMGRB4	16.39	8.52	50.72	1.16	40.76	12208
WYKMGRB5	17.66	15.85	43.85	2.46	40.30	11091
WYKMGRB6	22.95	5.96	49.97	0.54	44.07	12080
NDBMFUB1	6.67	15.00	39.75	0.61	45.25	10128
NDBMFUB2	5.20	7.17	49.52	0.18	43.31	10755
NDFMFUB1	33.79	15.06	43.15	1.68	41.79	10225
NDFMFUB2	26.56	24.90	39.90	1.03	35.20	8761
NDFMFUB3	29.46	23.45	33.99	0.85	42.56	7702
NDFMFUB4	25.08	32.26	33.25	1.08	34.49	7924
COTMGRB1	5.25	5.17	55.45	0.41	39.38	13224
COTMGRB2	1.74	82.11	4.26	0.49	13.63	1735
WYNMPRB1	24.11	6.37	49.39	0.27	44.24	11529
NMSJMSJB1	7.86	44.75	26.56	1.01	28.69	7293
NMSJMSJB2	NA	NA	NA	NA	NA	NA
NMSJMSJB3	NA	NA	NA	NA	NA	NA
UTSYMUIB1	3.22	8.65	49.46	0.57	41.89	12851
UTSUMUIB1	4.82	8.48	50.63	0.38	40.89	12473
WYBTMPRB1	21.07	6.68	49.54	0.30	43.78	11554
MOBONCB1	16.06	67.29	10.76	0.74	21.95	2487
MOBONCB2	15.77	63.88	13.44	0.81	22.68	2822
MOBONCB3	12.00	67.76	11.52	0.57	20.72	2571
MOBONCB4	11.69	64.70	13.86	0.60	21.44	2842
MOSONCB1	4.10	71.64	8.62	0.21	19.74	300
MOSONCB2	4.73	86.65	1.72	0.02	15.07	300
MOSONCB3	6.74	59.65	16.65	0.48	23.70	3358
MOSONCB4	4.90	73.46	6.99	0.35	19.55	1598
UTWMUIB1	7.60	5.70	56.36	1.32	37.94	13410

APPENDIX 4: Summary of ICP-MS Results of as Received Samples

Table 29: Results of elemental ICP-MS analysis of all received samples – concentrations are expressed per whole sample basis

Sample Name	Ash (%)	Sc (ppm)	Y (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Yb (ppm)	Lu (ppm)	LREE in sample (ppm)	HREE in sample (ppm)	REE in sample (ppm)	REE+Y+Sc in sample (ppm)
TXJMTEB1	33.85	4.05	6.53	8.20	16.83	3.45	6.60	1.24	0.27	1.15	0.16	1.04	0.22	1.42	1.36	0.09	36.33	5.72	42.05	52.63
TXJMTEB2	27.69	3.61	4.54	5.80	15.66	2.58	5.07	1.00	0.24	0.94	0.13	0.82	0.17	1.09	1.03	0.07	30.10	4.49	34.59	42.74
TXJMTEB3	36.00	6.09	7.14	8.12	15.29	3.46	6.71	1.35	0.32	1.31	0.20	1.33	0.28	1.83	1.75	0.13	34.92	7.14	42.06	55.30
MOAMPRB1	11.97	0.54	1.47	2.58	4.87	0.48	2.04	0.45	0.29	0.42	0.05	0.24	0.05	0.12	0.11	0.02	10.42	1.30	11.72	13.73
MORMPRB1	10.97	1.44	2.33	4.30	7.56	0.07	2.80	0.57	0.14	0.50	0.07	0.38	0.07	0.19	0.20	0.03	15.30	1.58	16.89	20.66
MORMPRB2	9.74	2.11	2.80	5.71	9.97	0.10	3.72	0.76	0.22	0.67	0.09	0.52	0.10	0.26	0.27	0.04	20.26	2.18	22.44	27.35
WYKMGRB1	10.30	0.34	2.82	1.72	2.90	0.35	1.56	0.35	0.12	0.38	0.05	0.28	0.06	0.17	0.13	0.02	6.89	1.22	8.11	11.27
WYKMGRB2	9.91	1.14	3.30	3.08	6.56	1.32	2.58	0.52	0.12	0.53	0.08	0.47	0.10	0.62	0.57	0.04	14.05	2.53	16.58	21.02
WYKMGRB3	14.66	0.47	1.43	2.90	3.05	0.68	2.21	0.47	0.11	0.39	0.05	0.25	0.05	0.16	0.15	0.02	9.30	1.18	10.48	12.38
WYKMGRB4	8.52	0.35	1.30	1.90	1.72	0.41	1.49	0.33	0.08	0.30	0.04	0.20	0.04	0.12	0.11	0.02	5.85	0.91	6.76	8.41
WYKMGRB5	15.85	0.73	2.68	3.25	7.44	1.46	2.89	0.56	0.12	0.55	0.08	0.46	0.09	0.58	0.51	0.04	15.59	2.42	18.01	21.42
WYKMGRB6	5.96	0.25	0.72	1.04	1.67	0.23	0.76	0.17	0.10	0.16	0.02	0.11	0.02	0.07	0.07	0.01	3.87	0.55	4.42	5.39
NDBMFUB1	15.00	6.19	14.68	6.27	12.05	2.79	5.83	1.45	0.42	1.80	0.31	2.15	0.47	2.77	2.55	0.20	28.40	10.65	39.05	59.93
NDBMFUB2	7.17	0.53	1.81	3.17	5.02	0.94	1.84	0.33	0.13	0.32	0.04	0.28	0.06	0.35	0.35	0.03	11.30	1.55	12.85	15.20
NDFMFUB1	15.06	1.32	4.28	4.94	9.44	1.92	3.97	0.77	0.21	0.74	0.10	0.63	0.13	0.77	0.72	0.05	21.04	3.36	24.40	30.00
NDFMFUB2	24.90	2.85	5.88	6.96	13.45	2.75	5.52	1.09	0.37	1.03	0.15	0.94	0.19	1.16	1.11	0.08	29.76	5.03	34.80	43.52
NDFMFUB3	23.45	2.55	5.85	6.21	11.81	2.47	5.21	1.04	0.34	1.00	0.14	0.89	0.18	1.12	1.08	0.08	26.75	4.84	31.58	39.99
NDFMFUB4	32.26	4.98	9.68	8.91	17.59	3.74	7.82	1.59	0.47	1.59	0.23	1.51	0.32	1.97	1.95	0.15	39.65	8.17	47.83	62.49
COTMGRB1	5.17	0.70	1.89	3.39	6.09	0.06	2.34	0.46	0.14	0.41	0.05	0.29	0.06	0.15	0.16	0.02	12.35	1.29	13.64	16.24
COTMGRB2	82.11	9.17	18.26	34.85	68.01	0.80	31.06	5.61	1.23	4.72	0.60	3.06	0.60	1.49	1.60	0.23	140.32	13.55	153.87	181.30
WYNMPRB1	6.37	2.08	3.32	4.69	8.70	1.54	3.62	0.76	0.27	0.75	0.10	0.56	0.11	0.42	0.39	0.04	19.31	2.64	21.95	27.35
NMSJMSJB1	44.75	3.29	4.60	10.04	42.90	3.48	7.54	1.44	0.34	1.37	0.17	0.95	0.19	0.82	0.94	0.10	65.40	4.88	70.28	78.17
NMSJMSJB2	98.30	11.12	16.48	32.34	90.96	10.96	24.31	4.85	1.08	4.51	0.61	3.45	0.69	2.84	3.09	0.35	163.42	16.62	180.04	207.64
NMSJMSJB3	98.10	11.93	21.62	33.81	111.44	12.74	28.69	5.84	1.26	5.58	0.76	4.30	0.86	3.51	3.75	0.42	192.53	20.45	212.98	246.52
UTSYMUIB1	8.65	0.85	1.75	2.85	4.35	0.85	1.93	0.37	0.09	0.36	0.05	0.27	0.06	0.23	0.22	0.02	10.35	1.30	11.66	14.26
UTSUMUIB1	8.48	1.35	2.40	4.11	6.69	1.17	2.63	0.51	0.13	0.50	0.07	0.38	0.08	0.31	0.30	0.03	15.11	1.79	16.91	20.66
WYBTMPRB1	6.68	2.26	3.55	5.18	9.54	1.65	3.82	0.81	0.27	0.79	0.11	0.60	0.12	0.45	0.43	0.05	21.00	2.80	23.80	29.61
MOBONCB1	67.29	23.08	31.69	31.99	57.92	0.67	21.91	4.49	0.97	4.22	0.68	4.48	1.00	2.82	3.83	0.44	116.98	18.44	135.42	190.19
MOBONCB2	63.88	22.30	32.21	31.64	56.90	0.62	22.40	4.69	0.99	4.50	0.70	4.56	1.01	2.95	3.19	0.45	116.26	18.36	134.62	189.13
MOBONCB3	67.76	17.70	29.30	29.33	52.23	0.59	20.57	4.24	0.92	4.01	0.62	3.85	0.87	2.52	2.72	0.39	106.96	15.90	122.86	169.86
MOBONCB4	64.70	19.02	28.83	30.63	57.28	0.69	22.29	4.71	1.02	4.34	0.66	4.10	0.89	2.55	2.76	0.38	115.60	16.70	132.30	180.14
MOSONCB1	71.64	25.73	56.53	40.29	76.67	0.88	31.36	6.60	1.54	7.33	1.31	8.43	1.79	4.80	5.05	0.71	155.80	30.95	186.75	269.01
MOSONCB2	86.65	15.89	27.08	29.98	53.17	0.56	17.58	3.52	0.76	3.42	0.58	3.76	0.82	2.16	2.27	0.32	104.82	14.08	118.89	161.86
MOSONCB3	59.65	34.92	103.41	45.73	91.50	1.11	43.45	9.71	2.41	12.01	2.21	14.34	3.08	8.24	8.63	1.24	191.49	52.16	243.65	381.99
MOSONCB4	73.46	22.50	46.96	62.74	124.90	1.44	54.80	10.62	2.28	9.79	1.39	7.80	1.55	3.95	4.02	0.57	254.50	31.35	285.85	355.32
UTWMUIB1	5.70	1.19	3.35	4.71	8.42	0.08	3.37	0.68	0.15	0.65	0.09	0.48	0.10	0.24	0.25	0.04	17.27	2.00	19.26	23.81

Table 30: Results of elemental ICP-MS analysis of all received samples – concentrations are expressed per ash basis

Sample Name	Ash (%)	Sc (ppm)	Y (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Yb (ppm)	Lu (ppm)	LREE in ash (ppm)	HREE in ash (ppm)	REE in ash (ppm)	REE+Y+Sc in ash (ppm)
TXJMTEB1	33.85	11.97	19.30	24.24	49.72	10.18	19.51	3.67	0.81	3.41	0.48	3.06	0.65	4.18	4.03	0.28	107.32	16.89	124.21	155.49
TXJMTEB2	27.69	13.05	16.38	20.96	56.54	9.31	18.30	3.60	0.86	3.41	0.47	2.95	0.62	3.93	3.71	0.26	108.71	16.22	124.93	154.36
TXJMTEB3	36.00	16.93	19.84	22.56	42.48	9.61	18.63	3.74	0.89	3.63	0.56	3.69	0.79	5.07	4.85	0.35	97.01	19.83	116.84	153.61
MOAMPRB1	11.97	4.47	12.30	21.53	40.70	4.00	17.07	3.77	2.44	3.54	0.43	2.03	0.39	0.99	0.91	0.16	87.07	10.88	97.95	114.72
MORMPRB1	10.97	13.08	21.28	39.19	68.92	0.68	25.55	5.16	1.32	4.55	0.64	3.47	0.67	1.70	1.81	0.27	139.50	14.44	153.93	188.30
MORMPRB2	9.74	21.69	28.71	58.67	102.36	1.00	38.22	7.77	2.30	6.89	0.96	5.34	1.04	2.67	2.81	0.41	208.02	22.42	230.44	280.83
WYKMGRB1	10.30	3.31	27.37	16.72	28.14	3.44	15.15	3.44	1.21	3.68	0.52	2.71	0.58	1.63	1.28	0.20	66.89	11.82	78.71	109.39
WYKMGRB2	9.91	11.48	33.30	31.07	66.15	13.33	25.99	5.27	1.20	5.36	0.77	4.79	0.99	6.26	5.77	0.40	141.81	25.54	167.35	212.13
WYKMGRB3	14.66	3.21	9.72	19.76	20.81	4.61	15.06	3.18	0.78	2.68	0.35	1.72	0.33	1.10	1.00	0.12	63.42	8.07	71.49	84.41
WYKMGRB4	8.52	4.16	15.23	22.36	20.13	4.80	17.52	3.86	0.91	3.48	0.48	2.39	0.48	1.46	1.25	0.18	68.66	10.63	79.29	98.69
WYKMGRB5	15.85	4.62	16.92	20.49	46.93	9.20	18.21	3.51	0.73	3.46	0.47	2.88	0.59	3.69	3.21	0.22	98.34	15.25	113.60	135.14
WYKMGRB6	5.96	4.15	12.06	17.40	28.02	3.88	12.79	2.83	1.61	2.71	0.36	1.78	0.35	1.22	1.12	0.14	64.92	9.28	74.20	90.41
NDBMFUB1	15.00	41.30	97.90	41.79	80.35	18.59	38.89	9.70	2.81	11.98	2.04	14.31	3.11	18.49	16.97	1.33	189.31	71.03	260.35	399.55
NDBMFUB2	7.17	7.35	25.31	44.26	70.02	13.05	25.66	4.66	1.77	4.46	0.62	3.88	0.80	4.82	4.85	0.40	157.66	21.61	179.27	211.93
NDFMFUB1	15.06	8.75	28.44	32.77	62.67	12.74	26.38	5.13	1.43	4.92	0.68	4.17	0.85	5.09	4.80	0.36	139.70	22.29	162.00	199.18
NDFMFUB2	24.90	11.44	23.60	27.94	54.00	11.04	22.18	4.36	1.47	4.15	0.60	3.77	0.77	4.66	4.44	0.33	119.53	20.21	139.74	174.78
NDFMFUB3	23.45	10.89	24.97	26.49	50.37	10.55	22.23	4.43	1.44	4.26	0.61	3.79	0.79	4.78	4.60	0.35	114.06	20.62	134.68	170.53
NDFMFUB4	32.26	15.45	30.01	27.61	54.52	11.61	24.23	4.94	1.46	4.92	0.72	4.67	0.99	6.09	6.04	0.46	122.91	25.34	148.25	193.70
COTMGRB1	5.17	13.61	36.57	65.57	117.77	1.20	45.35	8.97	2.67	7.99	1.05	5.60	1.10	2.96	3.18	0.48	238.87	25.02	263.89	314.08
COTMGRB2	82.11	11.16	22.24	42.44	82.82	0.98	37.82	6.83	1.50	5.75	0.73	3.73	0.73	1.82	1.95	0.29	170.90	16.50	187.40	220.80
WYNMPRB1	6.37	32.65	52.05	73.65	136.54	24.20	56.77	11.97	4.18	11.78	1.57	8.77	1.72	6.67	6.14	0.68	303.12	41.51	344.63	429.33
NMSJMSJB1	44.75	7.34	10.28	22.43	95.88	7.77	16.85	3.21	0.77	3.06	0.39	2.12	0.43	1.83	2.09	0.23	146.14	10.91	157.05	174.67
NMSJMSJB2	98.30	11.32	16.77	32.90	92.53	11.15	24.73	4.94	1.09	4.59	0.62	3.51	0.70	2.89	3.15	0.35	166.24	16.90	183.15	211.23
NMSJMSJB3	98.10	12.16	22.04	34.47	113.59	12.99	29.25	5.96	1.28	5.69	0.78	4.39	0.87	3.58	3.83	0.43	196.26	20.85	217.10	251.30
UTSYMUIB1	8.65	9.88	20.27	32.95	50.23	9.81	22.37	4.32	1.02	4.21	0.57	3.16	0.66	2.67	2.54	0.27	119.68	15.08	134.76	164.91
UTSUMUIB1	8.48	15.91	28.32	48.48	78.94	13.74	31.05	6.02	1.49	5.89	0.80	4.49	0.91	3.63	3.55	0.38	178.24	21.13	199.37	243.60
WYBTMPRB1	6.68	33.81	53.09	77.49	142.76	24.73	57.25	12.08	3.98	11.86	1.60	8.95	1.75	6.76	6.37	0.70	314.32	41.97	356.29	443.19
MOBONCB1	67.29	34.30	47.09	47.55	86.07	1.00	32.56	6.67	1.44	6.28	1.01	6.66	1.48	4.19	5.69	0.65	173.85	27.40	201.25	282.64
MOBONCB2	63.88	34.90	50.43	49.53	89.08	0.97	35.06	7.35	1.56	7.05	1.10	7.15	1.59	4.62	4.99	0.70	181.99	28.75	210.74	296.07
MOBONCB3	67.76	26.12	43.24	43.28	77.07	0.87	30.36	6.26	1.36	5.92	0.92	5.68	1.28	3.71	4.02	0.57	157.85	23.47	181.32	250.68
MOBONCB4	64.70	29.39	44.55	47.34	88.53	1.06	34.45	7.28	1.57	6.71	1.02	6.33	1.38	3.93	4.27	0.59	178.67	25.81	204.48	278.43
MOSONCB1	71.64	35.92	78.91	56.24	107.02	1.23	43.78	9.22	2.15	10.23	1.83	11.77	2.49	6.69	7.05	0.99	217.48	43.20	260.68	375.50
MOSONCB2	86.65	18.34	31.25	34.60	61.36	0.65	20.29	4.07	0.87	3.94	0.66	4.34	0.94	2.49	2.62	0.37	120.97	16.24	137.21	186.80
MOSONCB3	59.65	58.55	173.36	76.66	153.39	1.85	72.85	16.28	4.04	20.14	3.70	24.03	5.17	13.81	14.47	2.07	321.03	87.45	408.47	640.38
MOSONCB4	73.46	30.63	63.93	85.41	170.02	1.96	74.59	14.46	3.10	13.33	1.89	10.62	2.11	5.37	5.48	0.77	346.44	42.68	389.12	483.69
UTWMUIB1	5.70	20.90	58.84	82.55	147.72	1.47	59.19	11.97	2.71	11.45	1.54	8.41	1.68	4.19	4.36	0.70	302.90	35.04	337.93	417.68

APPENDIX 5: Rare Earth, Yttrium, and Scandium Concentrations in Received Samples

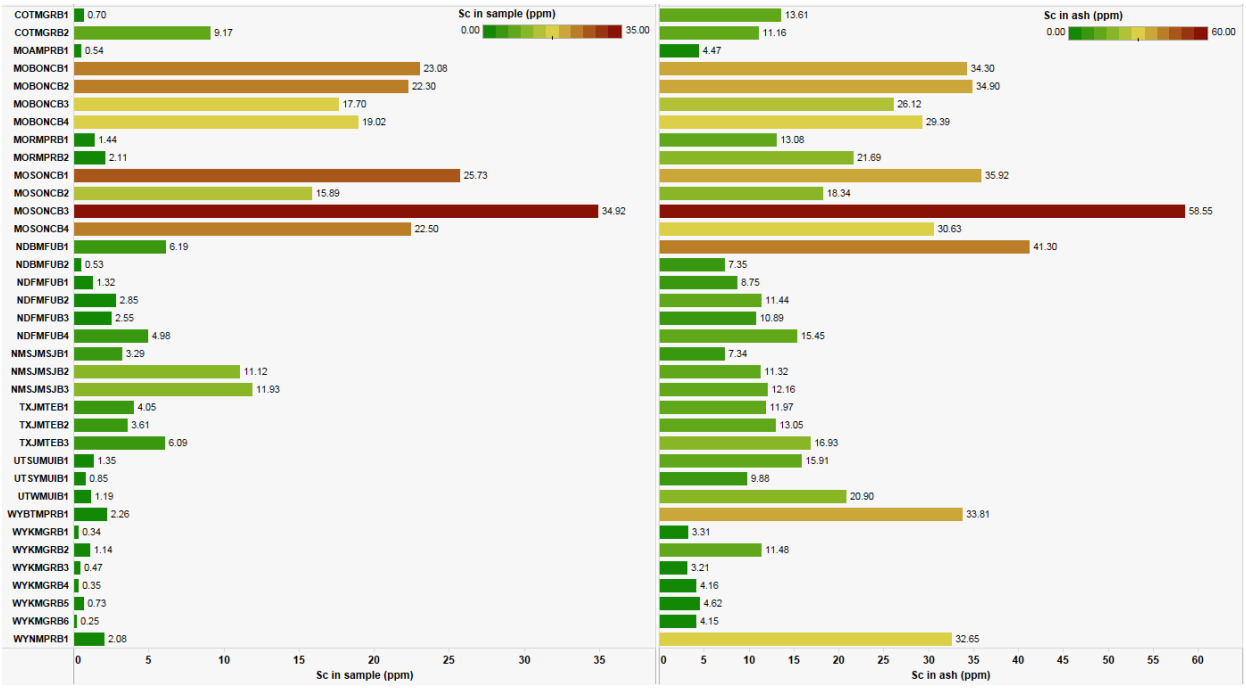

Figure 48: Concentration of Scandium in all investigated samples in the whole sample (left) and ash (right)

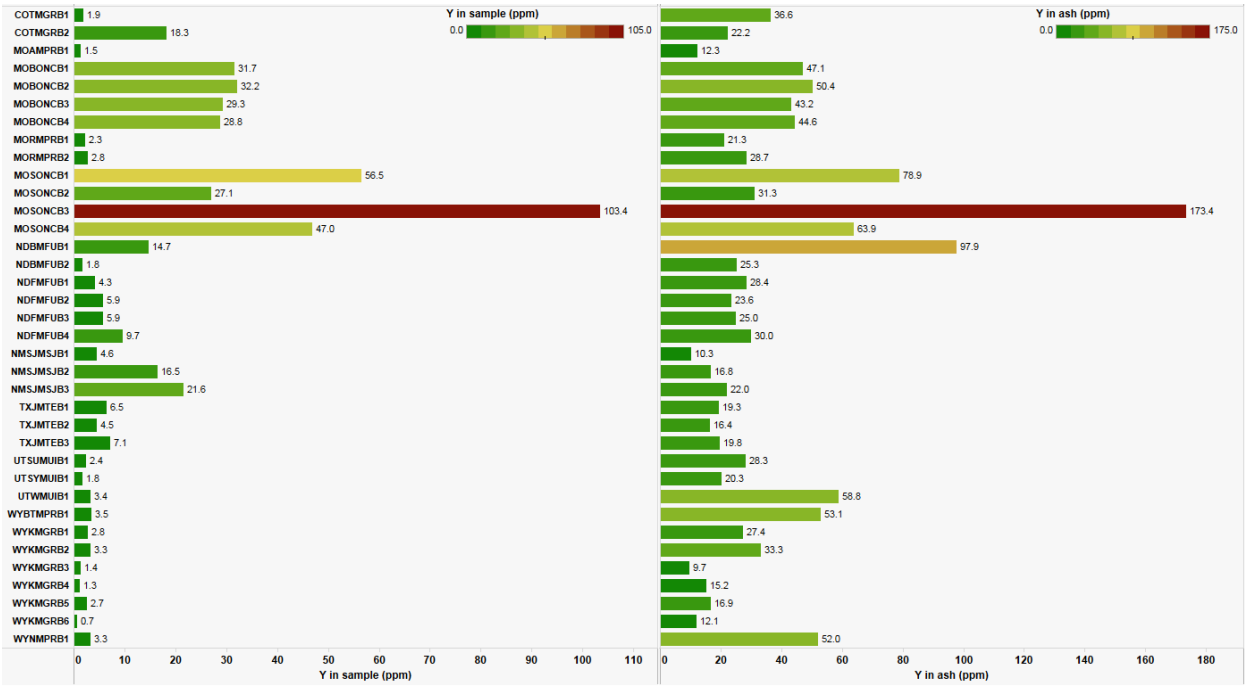

Figure 49: Concentration of Yttrium in all investigated samples in the whole sample (left) and ash (right)

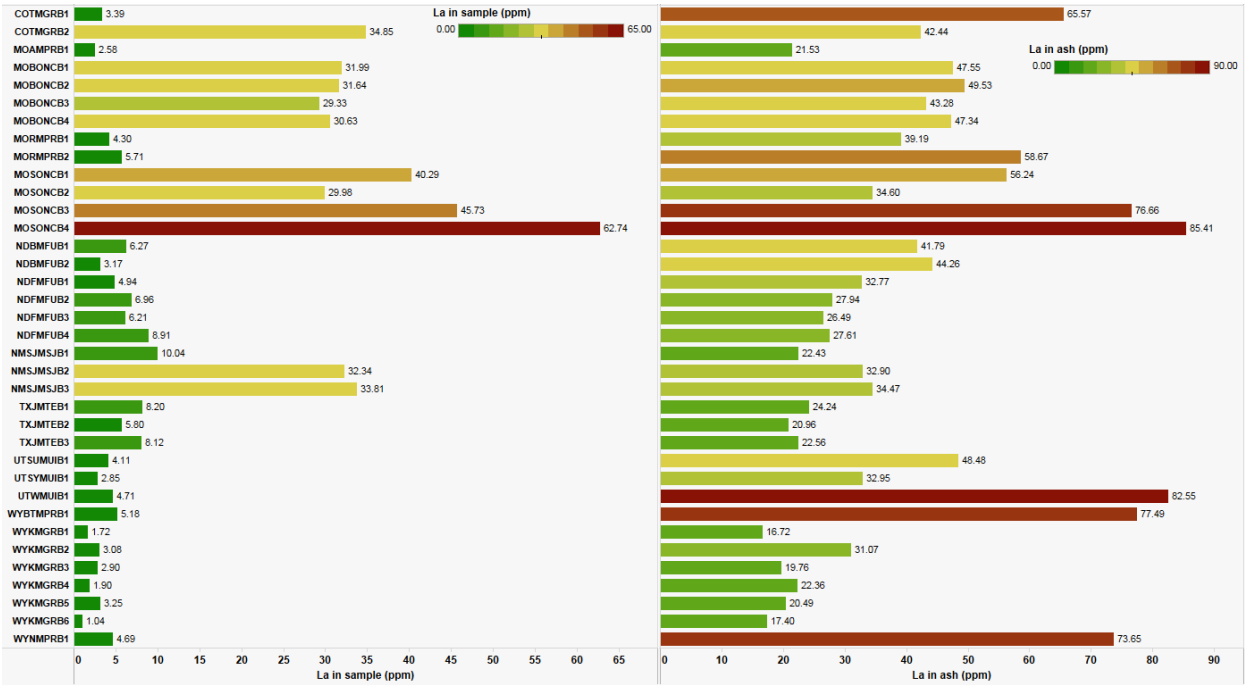

Figure 50: Concentration of Lanthanum in all investigated samples in the whole sample (left) and ash (right)

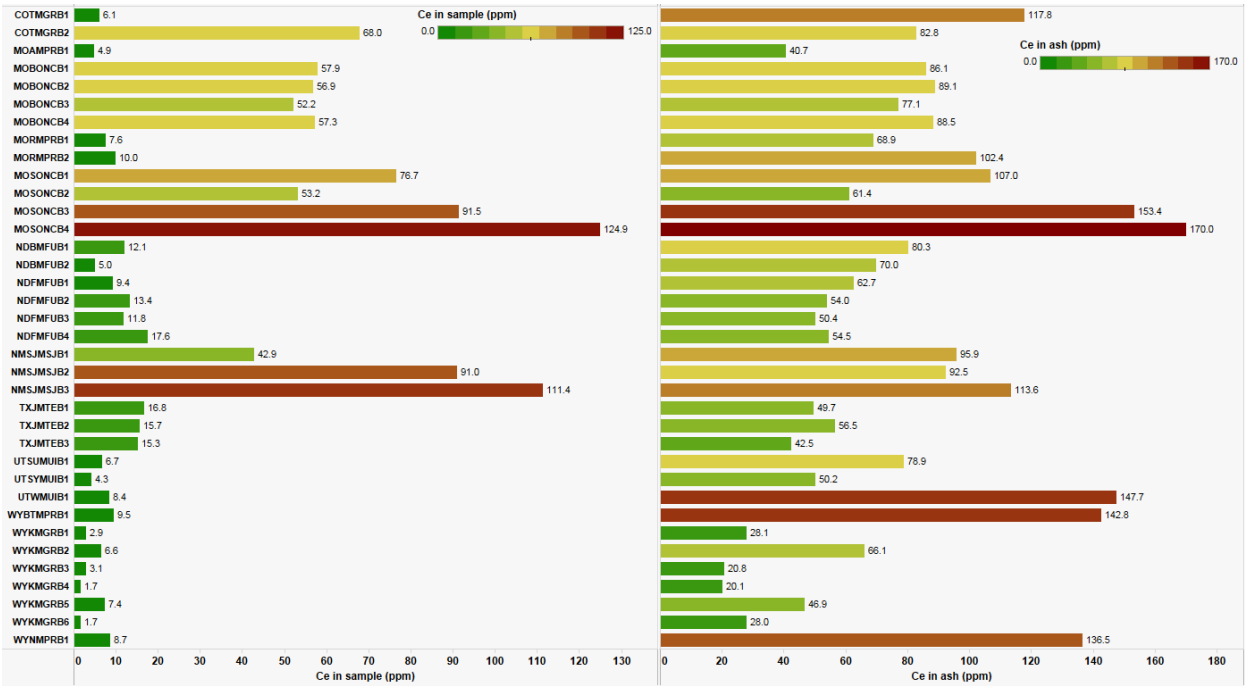

Figure 51: Concentration of Cerium in all investigated samples in the whole sample (left) and ash (right)

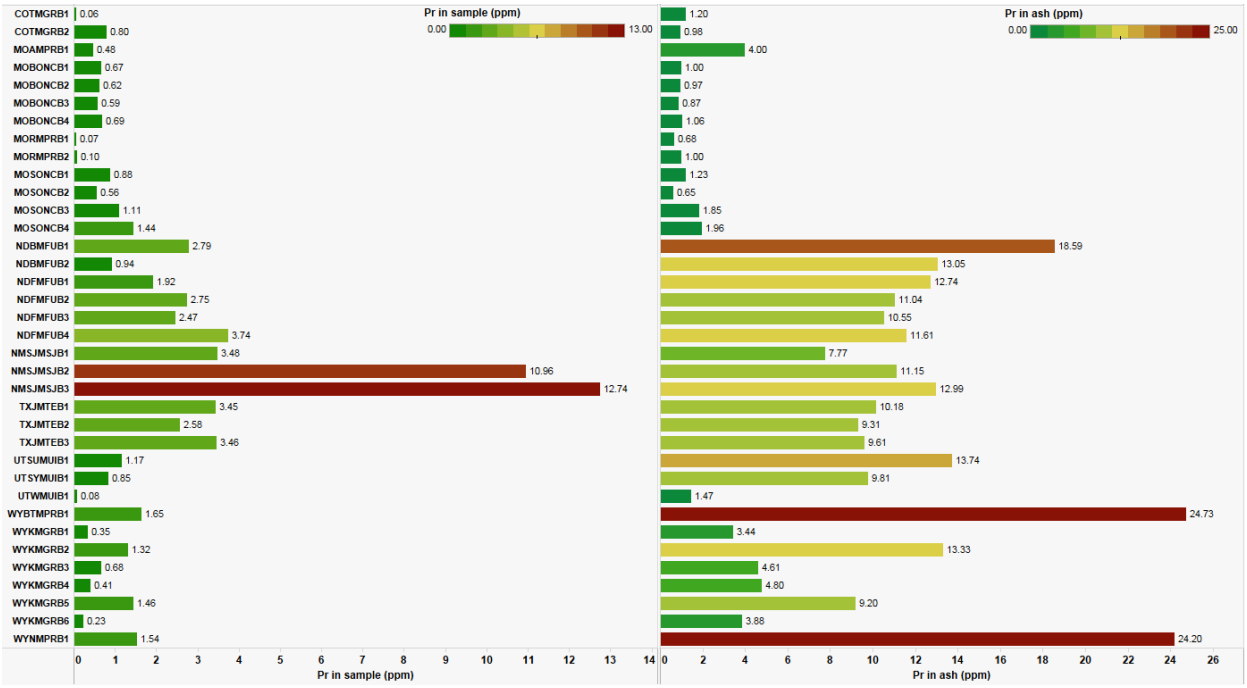

Figure 52: Concentration of Praseodymium in all investigated samples in the whole sample (left) and ash (right)

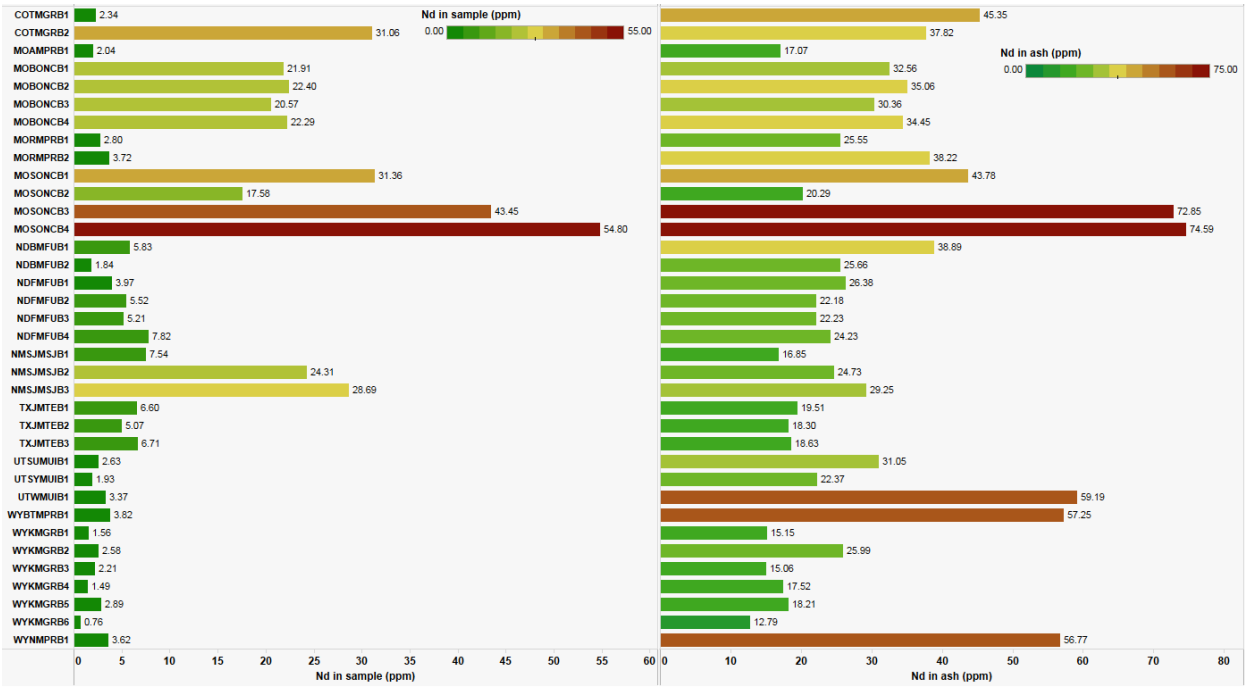

Figure 53: Concentration of Neodymium in all investigated samples in the whole sample (left) and ash (right)

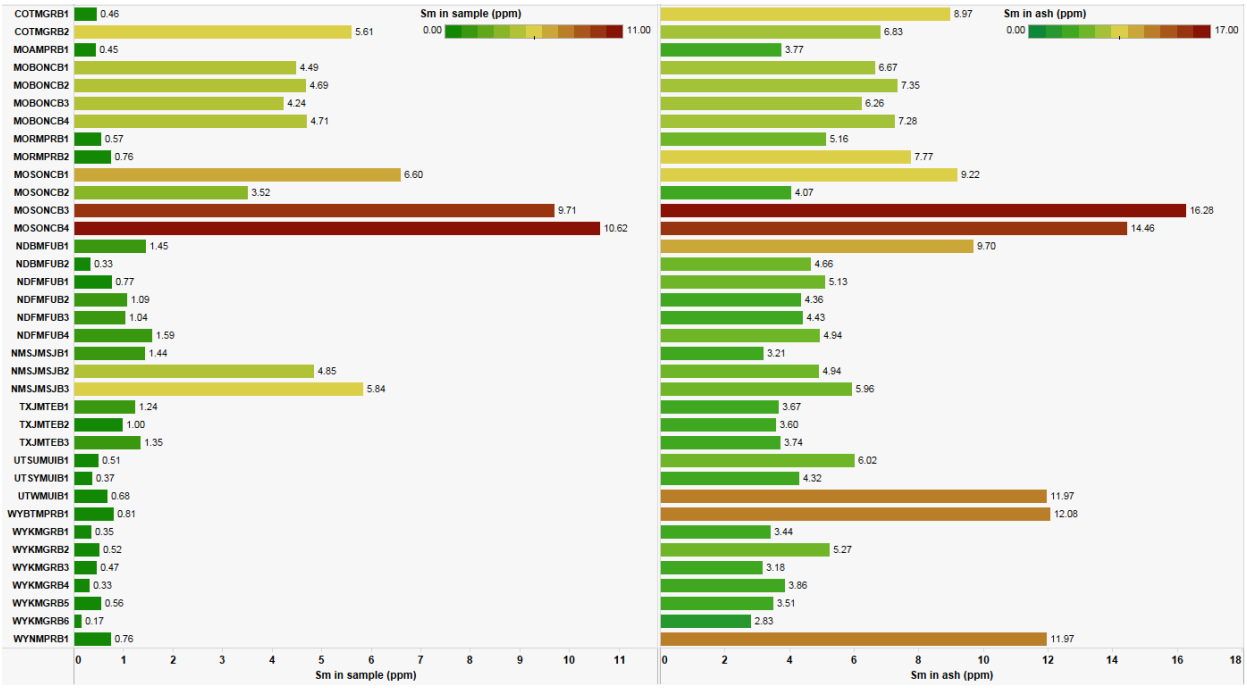

Figure 54: Concentration of Samarium in all investigated samples in the whole sample (left) and ash (right)

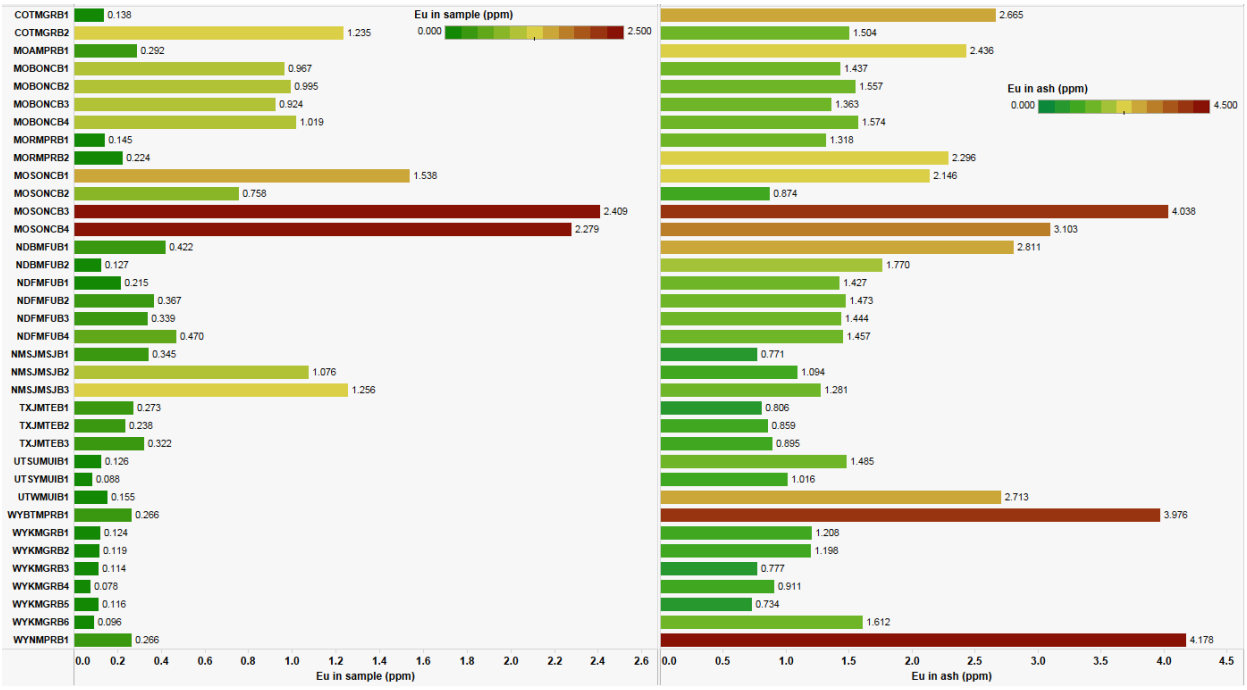

Figure 55: Concentration of Europium in all investigated samples in the whole sample (left) and ash (right)

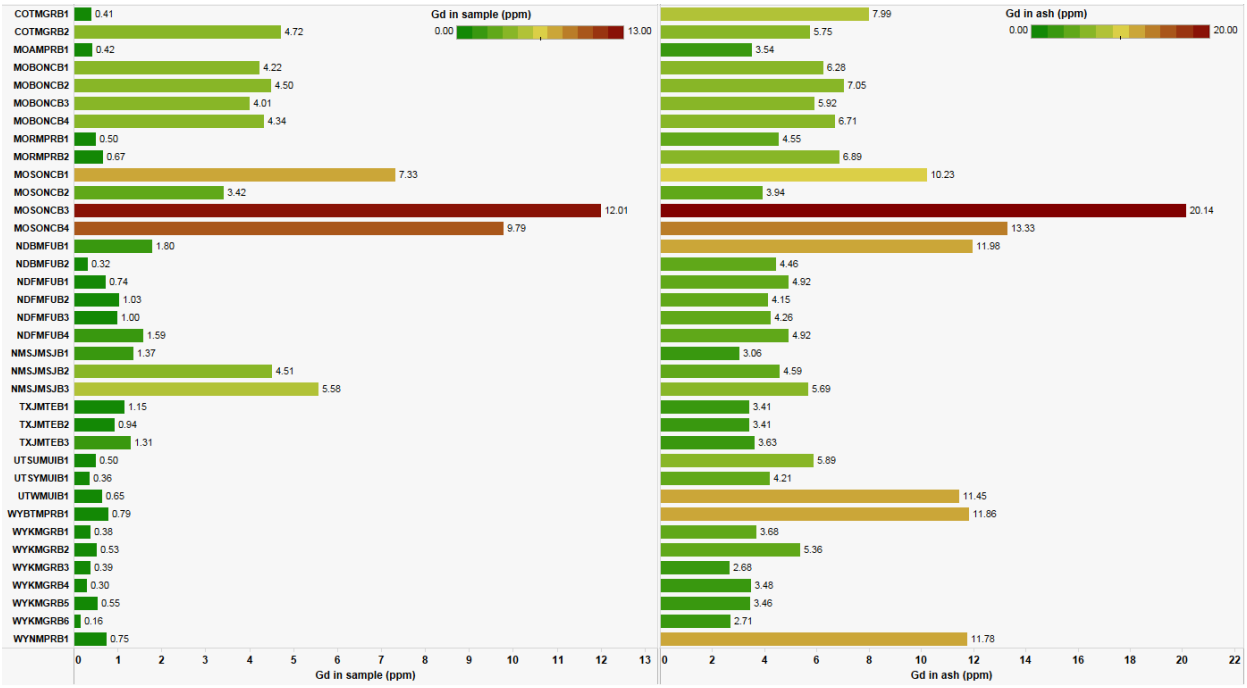

Figure 56: Concentration of Gadolinium in all investigated samples in the whole sample (left) and ash (right)

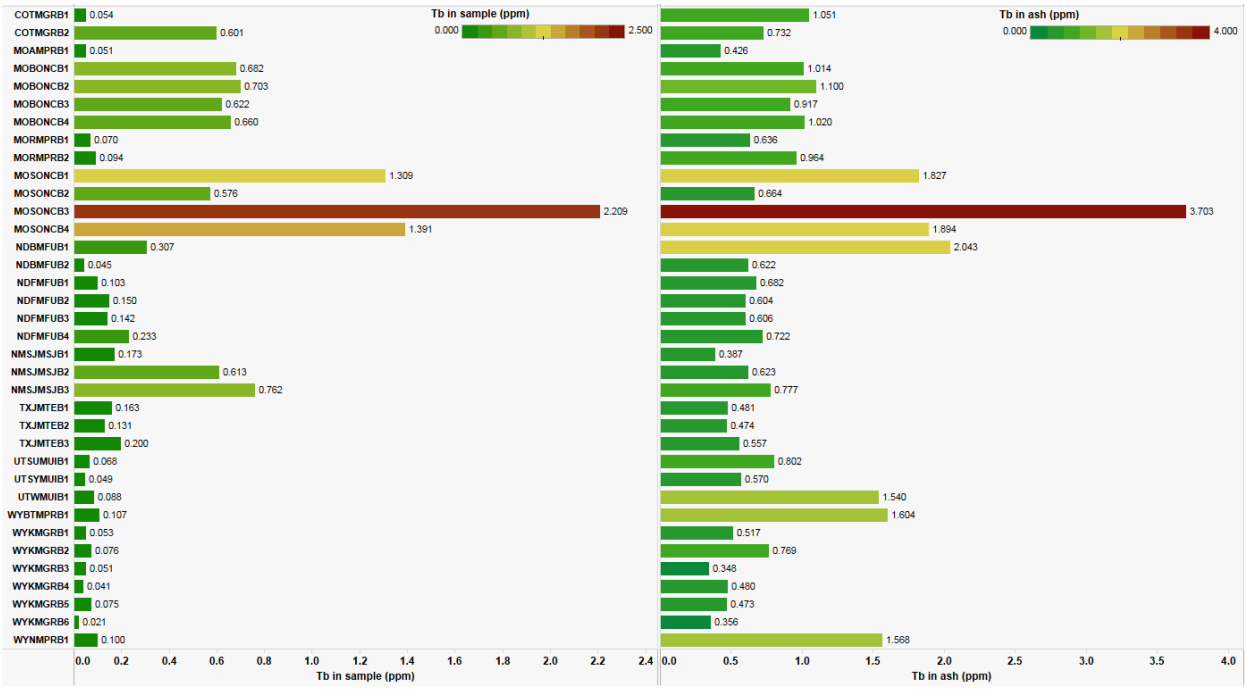

Figure 57: Concentration of Terbium in all investigated samples in the whole sample (left) and ash (right)

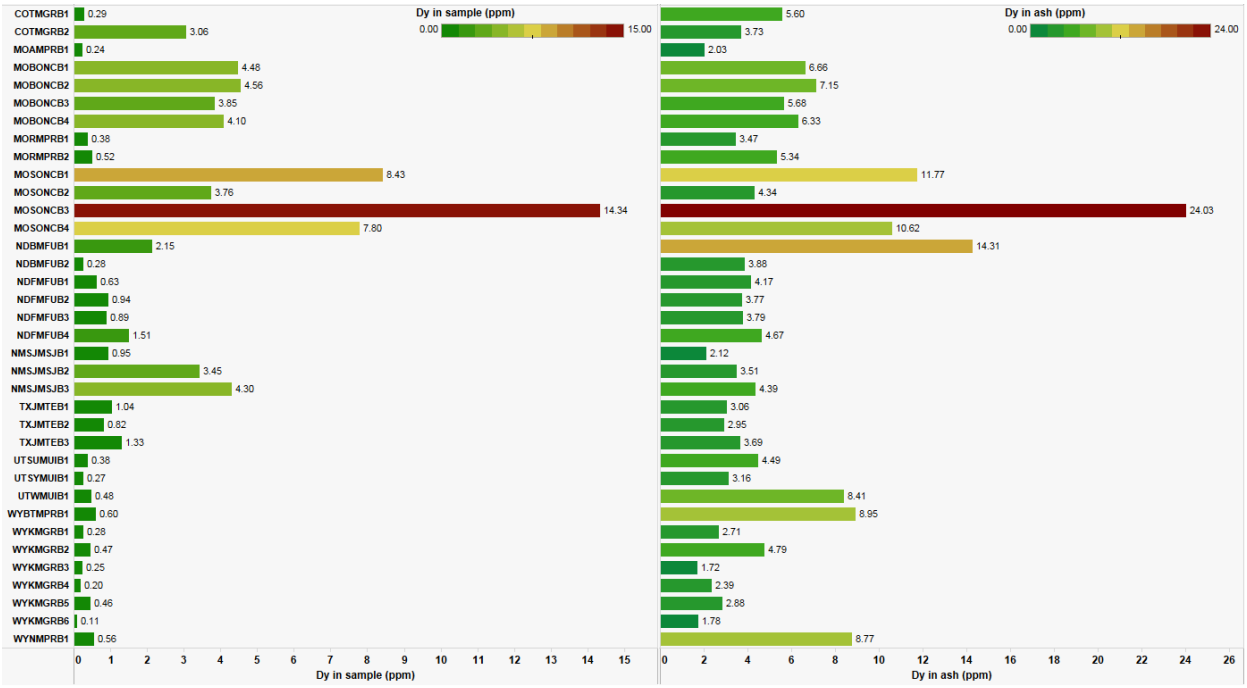

Figure 58: Concentration of Dysprosium in all investigated samples in the whole sample (left) and ash (right)

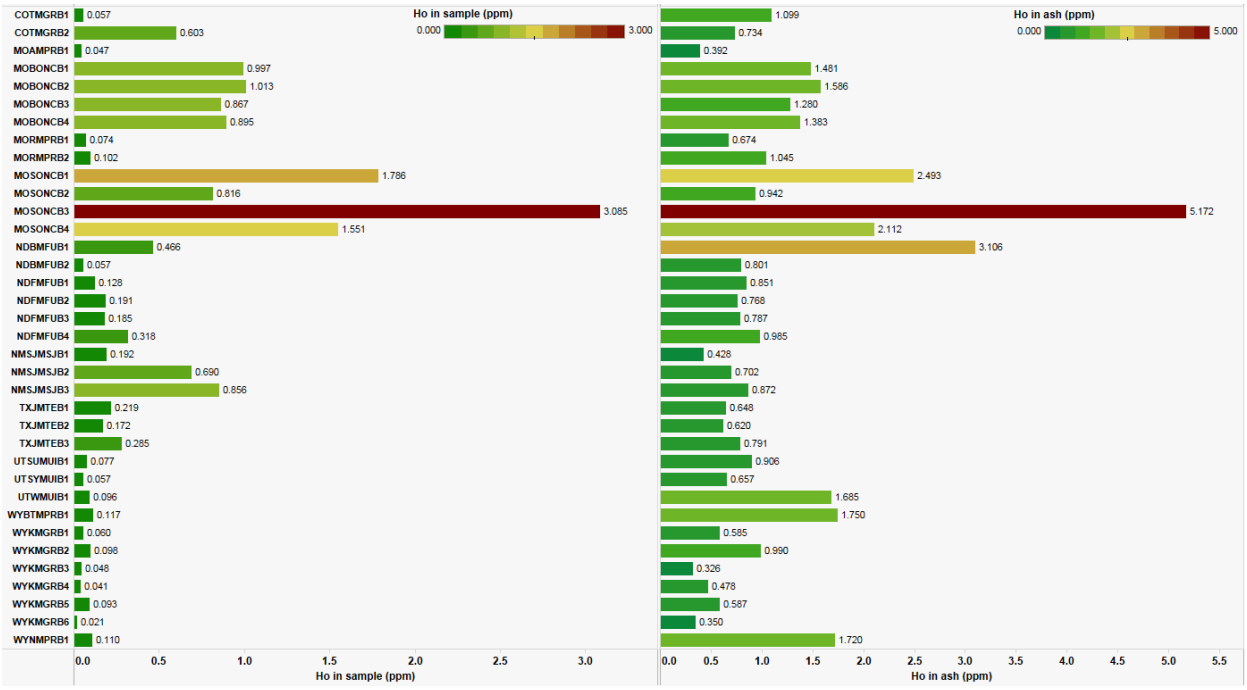

Figure 59: Concentration of Holmium in all investigated samples in the whole sample (left) and ash (right)

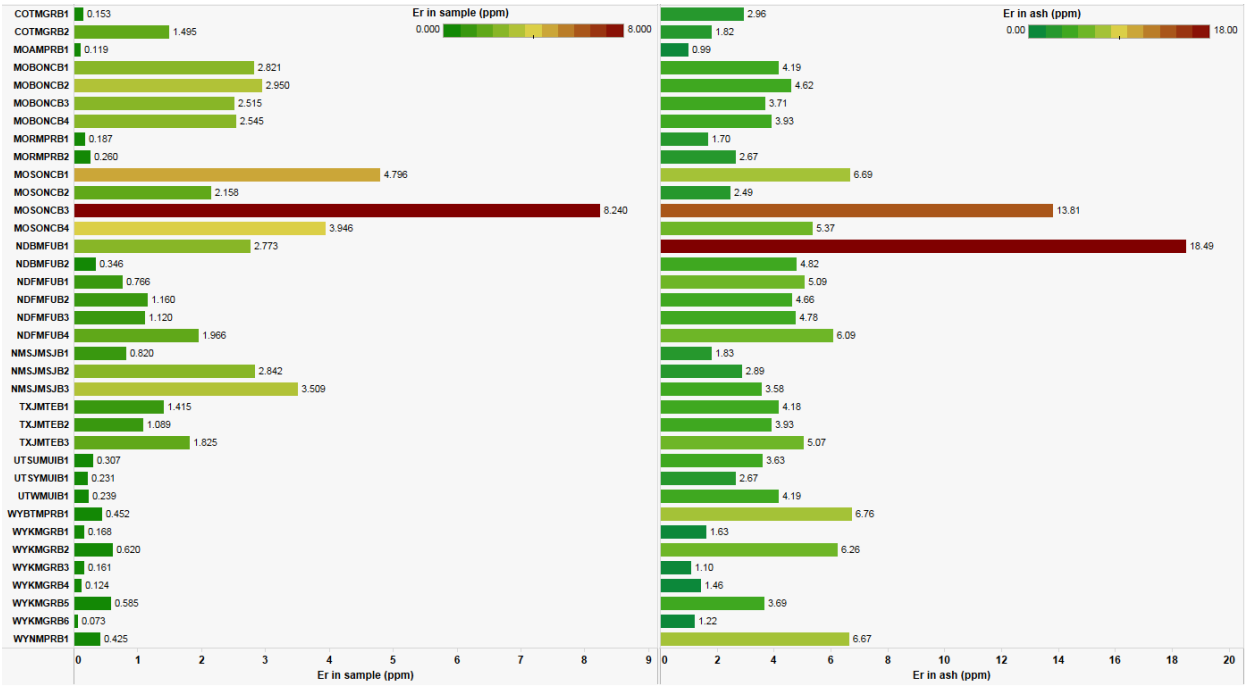

Figure 60: Concentration of Erbium in all investigated samples in the whole sample (left) and ash (right)

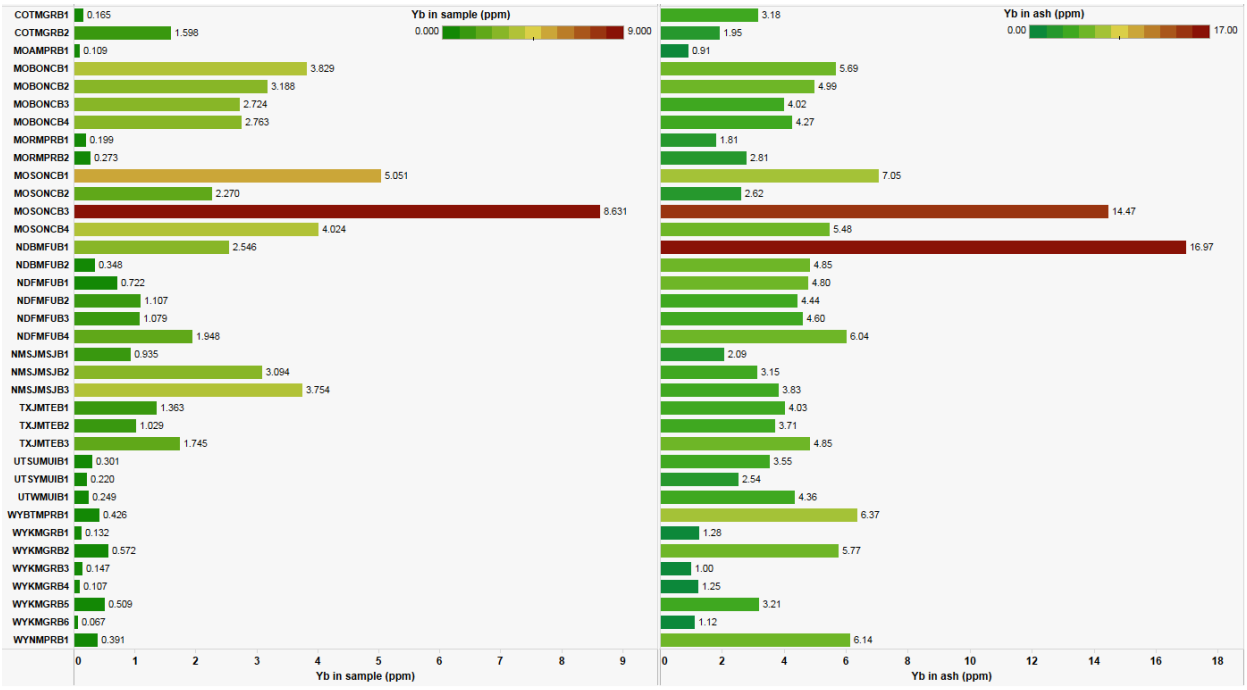

Figure 61: Concentration of Ytterbium in all investigated samples in the whole sample (left) and ash (right)

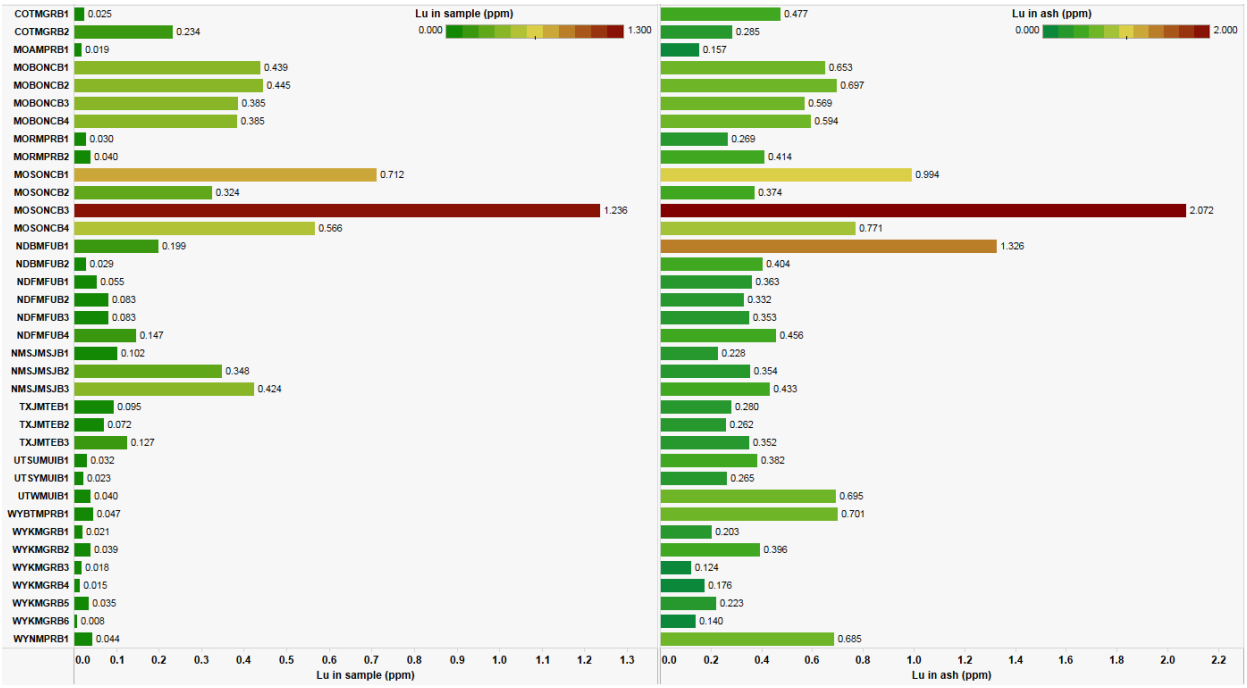

Figure 62: Concentration of Lutetium in all investigated samples in the whole sample (left) and ash (right)

APPENDIX 6: Washability Analysis – Unbalanced ICP-MS results

Table 31: Raw ICP-MS results of density fractions for NDBMFUB1, NDBMFUB2, MORMPRB2, and WYKMGRB2 samples (-30+100 size class)

Sample Name	Particle Size	Density Class	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	-30+100	+1.2	16.19	56.73	23.04	42.14	0.47	21.63	5.28	1.53	6.63	1.14	7.90	1.73	4.19	4.26	0.74	92.56	28.11	120.67	193.59
NDBMFUB1	-30+100	+1.4	13.17	44.15	20.07	36.48	0.38	18.01	4.25	1.23	5.18	0.89	6.18	1.34	3.15	3.22	0.58	79.20	21.77	100.97	158.29
NDBMFUB1	-30+100	-1.4	32.17	89.46	35.52	64.94	0.71	33.49	8.23	2.23	10.44	1.77	12.21	2.67	6.37	6.36	1.12	142.89	43.16	186.05	307.69
NDBMFUB1	-30+100	-1.6	24.43	80.68	31.88	58.22	0.66	29.96	7.35	2.00	9.33	1.60	11.07	2.42	6.00	6.06	1.03	128.07	39.50	167.57	272.68
NDBMFUB1	-30+100	-1.8	24.83	80.29	31.09	57.63	0.63	29.50	7.32	1.99	9.25	1.58	11.08	2.42	5.74	5.80	1.04	126.17	38.91	165.07	270.19
NDBMFUB1	-30+100	-2.0	28.50	89.38	34.99	64.73	0.72	33.42	8.22	2.23	10.46	1.78	12.33	2.68	6.54	6.57	1.13	142.08	43.71	185.79	303.67
NDBMFUB1	-30+100	-2.2	24.63	79.67	31.56	58.63	0.65	30.52	7.48	2.03	9.45	1.61	11.14	2.41	5.78	5.77	1.01	128.85	39.19	168.04	272.34
NDBMFUB2	-30+100	+1.2	4.50	26.25	47.19	68.60	0.61	24.46	4.26	1.50	4.35	0.61	3.81	0.80	1.92	2.05	0.36	145.13	15.39	160.53	191.28
NDBMFUB2	-30+100	+1.4	4.15	21.55	42.23	61.11	0.52	21.69	3.75	1.18	3.74	0.51	3.14	0.65	1.48	1.58	0.29	129.29	12.58	141.87	167.57
NDBMFUB2	-30+100	-1.6	6.00	28.68	61.77	90.03	0.81	31.82	5.47	1.84	5.46	0.74	4.55	0.94	2.31	2.48	0.42	189.90	18.73	208.64	243.32
NDBMFUB2	-30+100	-1.8	6.34	25.86	52.60	77.21	0.69	26.88	4.54	1.57	4.53	0.61	3.73	0.79	2.00	2.20	0.38	161.93	15.80	177.73	209.94
NDBMFUB2	-30+100	-2.0	7.86	35.33	54.03	83.19	0.73	29.15	5.19	1.76	5.45	0.79	5.08	1.06	2.60	2.70	0.45	172.31	19.90	192.21	235.41
NDBMFUB2	-30+100	-2.2	8.87	37.71	52.32	79.37	0.74	30.09	5.56	1.87	5.94	0.87	5.48	1.13	2.68	2.75	0.46	168.07	21.19	189.26	235.85
MORMPRB2	-30+100	+1.2	8.57	22.23	30.91	54.13	0.52	23.54	4.43	1.18	4.20	0.59	3.52	0.70	1.58	1.61	0.29	113.54	13.68	127.21	158.02
MORMPRB2	-30+100	+1.4	8.31	21.94	28.19	49.59	0.49	21.50	4.09	1.24	3.94	0.56	3.38	0.68	1.49	1.54	0.28	103.86	13.11	116.97	147.21
MORMPRB2	-30+100	-1.6	11.61	28.41	39.66	66.75	0.64	28.23	5.32	1.10	5.16	0.74	4.42	0.88	1.97	1.98	0.35	140.60	16.61	157.21	197.23
MORMPRB2	-30+100	-1.8	10.74	26.56	32.99	58.36	0.55	24.46	4.67	1.00	4.59	0.67	4.12	0.83	1.87	1.89	0.33	121.03	15.30	136.33	173.64
MORMPRB2	-30+100	-2.0	11.42	28.48	32.14	57.46	0.55	24.84	4.83	1.14	4.83	0.72	4.42	0.89	1.98	2.01	0.35	119.82	16.33	136.16	176.06
MORMPRB2	-30+100	-2.2	13.60	31.70	35.73	62.65	0.62	27.34	5.36	1.13	5.40	0.80	4.94	0.99	2.24	2.26	0.39	131.69	18.13	149.82	195.12
WYKMGRB2	-30+100	+1.2	8.95	27.80	20.02	34.76	0.37	17.37	3.57	0.85	3.79	0.56	3.50	0.73	1.65	1.63	0.29	76.09	12.99	89.08	125.83
WYKMGRB2	-30+100	-1.4	22.29	68.47	36.29	62.77	0.65	30.70	6.59	1.64	7.93	1.24	8.04	1.71	3.83	3.70	0.68	137.00	28.77	165.77	256.53
WYKMGRB2	-30+100	-1.6	6.45	17.98	10.69	18.72	0.21	9.21	1.90	0.47	2.21	0.34	2.19	0.46	1.09	1.07	0.18	40.73	8.00	48.73	73.16
WYKMGRB2	-30+100	-1.8	10.60	27.94	17.47	30.35	0.32	15.16	3.17	0.76	3.53	0.54	3.43	0.72	1.66	1.64	0.30	66.48	12.57	79.05	117.59
WYKMGRB2	-30+100	-2.0	9.56	26.92	16.85	29.35	0.30	14.63	3.06	0.74	3.41	0.52	3.32	0.70	1.57	1.55	0.29	64.18	12.09	76.28	112.76
WYKMGRB2	-30+100	-2.2	11.23	28.20	17.90	31.12	0.33	15.32	3.17	0.78	3.59	0.54	3.47	0.73	1.69	1.67	0.30	67.84	12.77	80.61	120.04

Table 32: Raw ICP-MS results of density fractions for COTMGRB1, MOSONCB3, UTWMUIB1, and MOBONCB3 samples (-30+100 size class)

Sample Name	Particle Size	Density Class	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
COTMGRB1	-30+100	+1.2	14.36	43.05	73.02	129.05	1.29	54.30	9.69	2.75	8.69	1.14	6.71	1.34	3.23	3.42	0.58	267.36	27.87	295.22	352.64
COTMGRB1	-30+100	-1.4	18.02	52.13	85.09	148.67	1.55	62.91	11.26	3.40	10.25	1.37	8.04	1.62	4.06	4.33	0.71	309.49	33.78	343.27	413.42
COTMGRB1	-30+100	-1.6	15.90	46.48	78.88	139.05	1.40	58.57	10.44	3.10	9.44	1.25	7.31	1.46	3.53	3.78	0.64	288.33	30.50	318.83	381.22
COTMGRB1	-30+100	-1.8	15.54	47.26	78.87	139.22	1.40	58.95	10.49	3.11	9.58	1.28	7.45	1.48	3.53	3.74	0.63	288.93	30.80	319.73	382.53
COTMGRB1	-30+100	-2.0	14.26	43.24	77.62	136.96	1.36	57.08	10.05	2.88	9.04	1.18	6.79	1.36	3.18	3.43	0.58	283.07	28.43	311.50	368.99
COTMGRB1	-30+100	-2.2	11.60	37.16	65.99	120.56	1.23	49.45	8.79	2.41	7.96	1.04	6.04	1.20	2.83	2.95	0.49	246.01	24.93	270.95	319.70
MOSONCB3	-30+100	+1.2	39.54	150.27	62.46	118.87	1.21	56.14	12.46	2.97	16.17	2.98	21.50	4.70	10.88	11.18	1.96	251.15	72.34	323.49	513.29
MOSONCB3	-30+100	+1.4	45.88	166.19	65.23	122.42	1.28	56.94	13.14	3.15	17.36	3.22	23.23	5.10	11.91	12.18	2.13	259.01	78.28	337.29	549.37
MOSONCB3	-30+100	+1.6	43.85	161.45	63.26	118.87	1.24	55.43	12.85	3.06	16.72	3.12	22.53	4.94	11.49	11.83	2.07	251.64	75.76	327.40	532.70
MOSONCB3	-30+100	+1.8	49.13	171.15	64.92	121.06	1.25	57.18	13.21	3.19	17.63	3.29	23.88	5.22	12.26	12.49	2.14	257.63	80.10	337.73	558.01
MOSONCB3	-30+100	+2.0	31.52	125.75	60.37	107.71	1.09	47.71	10.11	2.40	12.82	2.38	17.38	3.87	9.23	9.77	1.68	226.99	59.52	286.51	443.78
MOSONCB3	-30+100	+2.2	32.93	127.00	57.69	102.46	1.00	44.50	9.86	2.31	12.66	2.37	17.53	3.91	9.36	9.87	1.73	215.51	59.74	275.25	435.18
UTWMUIB1	-30+100	+1.2	19.62	63.57	82.01	142.90	1.48	66.61	12.32	2.66	11.61	1.56	9.28	1.88	4.33	4.36	0.76	305.33	36.45	341.78	424.98
UTWMUIB1	-30+100	+1.4	23.21	87.25	84.09	151.29	1.60	73.72	14.46	3.19	14.31	2.05	12.29	2.55	5.91	6.15	1.08	325.15	47.54	372.69	483.14
UTWMUIB1	-30+100	-1.4	39.29	133.34	150.72	261.24	2.71	122.10	23.00	5.03	22.56	3.09	18.60	3.81	8.91	8.94	1.55	559.78	72.50	632.27	804.90
UTWMUIB1	-30+100	-1.6	33.15	109.81	135.33	234.02	2.42	107.66	20.06	4.37	19.19	2.62	15.74	3.21	7.41	7.54	1.29	499.49	61.37	560.86	703.82
UTWMUIB1	-30+100	-1.8	34.06	108.64	139.10	241.41	2.49	111.00	20.38	4.39	19.39	2.62	15.71	3.20	7.37	7.50	1.30	514.38	61.48	575.85	718.56
UTWMUIB1	-30+100	-2.0	17.56	65.84	73.42	116.48	1.35	60.59	11.51	2.52	11.01	1.54	9.28	1.92	4.55	4.77	0.83	263.35	36.42	299.77	383.17
UTWMUIB1	-30+100	-2.2	29.29	108.00	122.58	214.23	2.26	99.91	18.60	4.03	17.76	2.44	14.73	2.97	6.94	6.95	1.19	457.58	57.01	514.59	651.87
MOBONCB3	-30+100	+1.2	14.95	34.81	32.03	52.85	0.51	23.17	4.35	0.93	4.17	0.62	4.35	0.99	2.37	2.52	0.45	112.92	16.39	129.32	179.07
MOBONCB3	-30+100	+1.4	13.47	28.47	29.57	51.10	0.48	21.21	3.94	0.82	3.83	0.57	4.10	0.92	2.23	2.41	0.42	106.30	15.30	121.60	163.54
MOBONCB3	-30+100	+1.6	13.43	29.73	31.53	51.90	0.50	22.54	4.19	0.88	3.86	0.58	3.95	0.89	2.16	2.34	0.41	110.65	15.07	125.73	168.89
MOBONCB3	-30+100	+1.8	12.39	28.53	30.43	50.19	0.47	21.45	3.96	0.85	3.74	0.55	3.78	0.87	2.02	2.14	0.39	106.50	14.34	120.83	161.76
MOBONCB3	-30+100	+2.0	10.72	26.87	29.22	47.48	0.48	19.99	3.64	0.76	3.36	0.50	3.43	0.80	2.04	2.19	0.37	100.82	13.45	114.26	151.85
MOBONCB3	-30+100	+2.2	10.28	24.17	29.16	47.03	0.44	19.38	3.50	0.74	3.28	0.47	3.28	0.77	1.87	2.00	0.35	99.52	12.75	112.27	146.72

Table 33: Raw ICP-MS results of density fractions for NDBMFUB1, WYBTMPRB1, WYNMPRB1, MORMPRB2, and UTWMUIB1 samples (-100 size class)

Sample Name	Particle Size	Density Class	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	-100.00	+1.2	41.10	87.10	43.20	80.50	0.43	39.40	8.60	3.26	10.52	1.74	13.01	2.79	3.02	3.04	1.18	172.13	38.56	210.69	338.89
NDBMFUB1	-100.00	+1.4	40.10	82.30	39.60	73.70	0.38	36.30	7.95	2.91	9.83	1.65	12.33	2.65	2.83	2.78	1.12	157.93	36.10	194.03	316.43
NDBMFUB1	-100.00	-1.6	28.20	64.90	31.20	57.70	0.30	28.10	6.18	1.94	7.76	1.28	9.74	2.07	2.21	2.22	0.90	123.48	28.12	151.60	244.70
NDBMFUB1	-100.00	-1.8	28.00	58.80	26.10	51.20	0.27	25.00	5.52	1.78	6.88	1.15	8.72	1.89	2.04	2.06	0.83	108.09	25.35	133.44	220.24
NDBMFUB1	-100.00	-2.0	25.60	54.30	23.90	47.50	0.25	23.30	5.08	1.60	6.31	1.07	8.15	1.76	1.93	1.94	0.78	100.03	23.54	123.57	203.47
NDBMFUB1	-100.00	-2.2	17.30	36.80	20.60	38.10	0.23	20.20	4.20	1.37	4.71	0.77	5.60	1.18	1.33	1.36	0.52	83.33	16.84	100.17	154.27
WYBTMPRB1	-100.00	+1.2	26.20	41.40	57.70	105.70	0.59	46.40	8.29	2.98	8.14	1.12	7.51	1.44	1.70	1.67	0.56	218.68	25.12	243.80	311.40
WYBTMPRB1	-100.00	+1.4	22.70	34.00	50.60	92.90	0.50	41.30	7.27	2.41	7.00	0.95	6.12	1.21	1.36	1.32	0.48	192.57	20.85	213.42	270.12
WYBTMPRB1	-100.00	-1.6	23.40	39.20	47.00	86.60	0.45	39.00	7.28	2.38	7.47	1.04	6.97	1.41	1.52	1.52	0.57	180.33	22.88	203.21	265.81
WYBTMPRB1	-100.00	-1.8	21.10	35.60	46.30	85.20	0.43	38.20	6.88	2.27	6.98	0.95	6.38	1.27	1.34	1.34	0.51	177.01	21.04	198.05	254.75
WYBTMPRB1	-100.00	-2.0	22.10	36.60	48.80	89.60	0.45	40.00	7.20	2.40	7.19	0.99	6.65	1.33	1.36	1.40	0.54	186.05	21.86	207.91	266.61
WYBTMPRB1	-100.00	-2.2	21.20	33.90	42.40	77.30	0.38	34.60	6.27	2.11	6.32	0.90	6.17	1.23	1.27	1.28	0.50	160.95	19.78	180.73	235.83
WYNMPRB1	-100.00	+1.2	24.40	42.40	52.80	98.90	0.50	45.20	8.33	2.91	8.26	1.16	7.53	1.53	1.57	1.54	0.58	205.73	25.08	230.81	297.61
WYNMPRB1	-100.00	+1.4	21.30	32.90	49.10	92.40	0.45	41.40	7.37	2.50	7.09	0.96	6.17	1.21	1.27	1.26	0.48	190.72	20.94	211.66	265.86
WYNMPRB1	-100.00	-1.6	25.00	38.90	48.60	90.80	0.44	41.30	7.70	2.71	7.70	1.09	7.06	1.42	1.43	1.42	0.59	188.84	23.42	212.26	276.16
WYNMPRB1	-100.00	-1.8	21.90	31.00	40.50	75.80	0.37	34.10	6.19	2.17	6.25	0.86	5.65	1.12	1.15	1.16	0.46	156.96	18.82	175.78	228.68
WYNMPRB1	-100.00	-2.0	24.40	37.30	48.20	90.60	0.45	41.30	7.39	2.61	7.46	1.04	6.83	1.37	1.40	1.40	0.54	187.94	22.65	210.59	272.29
WYNMPRB1	-100.00	-2.2	17.20	28.30	35.70	67.00	0.32	30.70	5.54	1.95	5.69	0.79	5.10	1.04	1.02	1.03	0.42	139.26	17.04	156.30	201.80
MORMPRB2	-100.00	+1.2	17.90	24.80	44.40	79.20	0.36	33.70	5.72	3.60	5.38	0.69	4.45	0.87	0.85	0.89	0.37	163.38	17.10	180.48	223.18
MORMPRB2	-100.00	+1.4	15.10	20.70	36.40	65.30	0.30	27.80	4.73	3.57	4.43	0.58	3.72	0.74	0.75	0.77	0.32	134.53	14.88	149.41	185.21
MORMPRB2	-100.00	-1.6	20.00	30.90	50.40	87.50	0.40	36.00	6.23	1.59	6.04	0.85	5.46	1.08	1.10	1.09	0.45	180.53	17.66	198.19	249.09
MORMPRB2	-100.00	-1.8	16.80	25.10	38.20	67.10	0.31	27.70	4.79	1.24	4.74	0.67	4.44	0.87	0.89	0.93	0.37	138.10	14.15	152.25	194.15
MORMPRB2	-100.00	-2.0	15.40	22.40	36.10	64.80	0.30	27.00	4.62	1.16	4.37	0.60	3.96	0.80	0.82	0.85	0.36	132.82	12.92	145.74	183.54
MORMPRB2	-100.00	-2.2	17.00	20.70	39.50	73.30	0.35	30.90	5.01	1.27	4.45	0.58	3.78	0.76	0.83	0.92	0.38	149.06	12.97	162.03	199.73
UTWMUIB1	-100.00	+1.2	21.03	54.90	70.90	127.30	13.85	58.65	10.28	2.50	10.22	1.37	8.08	1.77	4.74	4.28	0.69	280.99	33.66	314.64	390.58
UTWMUIB1	-100.00	-1.4	31.17	83.60	101.30	181.30	19.06	83.23	14.79	3.37	14.78	2.03	12.55	2.70	6.86	6.40	1.09	399.68	49.78	449.45	564.23
UTWMUIB1	-100.00	-1.6	30.73	77.40	91.30	161.90	17.94	79.02	13.87	3.15	14.06	1.89	11.22	2.50	6.47	5.79	1.02	364.02	46.10	410.12	518.25
UTWMUIB1	-100.00	-1.8	28.00	72.60	92.20	154.00	17.28	75.18	13.16	2.98	13.22	1.77	10.58	2.34	6.10	5.42	0.94	351.83	43.35	395.18	495.78
UTWMUIB1	-100.00	-2.0	25.12	63.90	82.70	147.10	15.72	67.01	11.74	2.69	11.89	1.58	9.24	2.06	5.38	4.87	0.85	324.27	38.55	362.82	451.83
UTWMUIB1	-100.00	-2.2	20.33	54.80	68.20	122.00	13.52	55.84	9.91	2.21	9.76	1.33	7.84	1.73	4.86	4.33	0.71	269.47	32.78	302.25	377.38

Table 34: Raw ICP-MS results of density fractions for UTWMUIB1, MOSONCB3, and COTMGRB1 samples (-6+30 size class)

Sample Name	Particle Size	Density Class	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
UTWMUIB1	-6+30	-1.2	25.63	73.05	68.87	125.96	14.45	60.10	11.32	3.04	11.70	1.61	9.91	2.23	6.24	5.67	0.94	280.70	41.35	322.05	420.73
UTWMUIB1	-6+30	+1.2-1.4	36.60	104.63	121.56	205.90	23.22	99.77	17.81	3.90	17.81	2.39	14.74	3.19	8.57	7.76	1.29	468.27	59.66	527.92	669.15
UTWMUIB1	-6+30	+1.4-1.6	21.59	39.88	133.38	218.06	22.33	90.33	13.85	2.78	12.00	1.43	7.74	1.59	4.21	3.98	0.65	477.94	34.39	512.34	573.80
UTWMUIB1	-6+30	+1.6-1.8	10.29	25.31	50.31	85.96	8.24	32.94	5.46	1.22	5.56	0.74	4.34	0.94	2.52	2.38	0.41	182.91	18.10	201.01	236.61
UTWMUIB1	-6+30	+1.8-2.0	5.17	18.56	33.88	54.66	5.62	21.70	3.56	0.78	3.70	0.50	2.90	0.62	1.73	1.65	0.26	119.43	12.14	131.57	155.29
UTWMUIB1	-6+30	+2.0-2.2	2.91	11.44	11.64	20.40	2.20	9.68	1.82	0.43	2.01	0.28	1.68	0.38	1.02	0.96	0.16	45.74	6.91	52.65	66.99
UTWMUIB1	-6+30	+2.2	1.74	4.43	8.84	14.91	1.49	6.47	1.03	0.30	1.05	0.12	0.68	0.18	0.40	0.35	0.06	32.73	3.13	35.86	42.03
MOSONCB3	-6+30	-1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOSONCB3	-6+30	+1.2-1.4	32.40	82.00	92.70	159.30	16.53	70.14	12.00	2.81	13.20	1.85	11.22	2.51	6.88	6.16	1.07	350.67	45.70	396.38	510.77
MOSONCB3	-6+30	+1.4-1.6	59.38	167.60	77.60	152.20	16.57	75.92	15.96	3.79	20.36	3.45	23.73	5.39	14.22	12.34	2.08	338.25	85.35	423.60	650.58
MOSONCB3	-6+30	+1.6-1.8	92.86	256.30	75.60	145.00	17.06	78.18	18.33	4.64	26.90	5.11	36.50	8.44	22.36	19.41	3.25	334.17	126.60	460.77	809.93
MOSONCB3	-6+30	+1.8-2.0	85.87	241.50	63.40	123.80	15.63	67.67	16.37	4.17	24.81	4.67	33.78	7.94	22.06	18.98	2.96	286.87	119.38	406.25	733.63
MOSONCB3	-6+30	+2.0-2.2	79.28	246.50	55.40	113.80	13.54	59.73	15.02	3.91	23.70	4.67	34.07	8.04	22.75	19.88	3.15	257.49	120.18	377.67	703.45
MOSONCB3	-6+30	+2.2	53.19	173.10	67.80	120.10	14.04	58.63	12.48	3.04	17.25	3.19	23.47	5.62	16.22	14.89	2.39	273.04	86.07	359.11	585.40
COTMGRB1	-6+30	-1.2	18.37	51.70	64.30	111.20	12.52	51.97	9.19	3.25	9.23	1.29	7.76	1.71	4.72	4.32	0.71	249.18	32.99	282.16	352.23
COTMGRB1	-6+30	+1.2-1.4	25.72	68.90	133.00	232.00	25.54	99.55	15.59	5.46	14.85	1.87	10.77	2.31	6.57	6.19	1.02	505.68	49.05	554.72	649.34
COTMGRB1	-6+30	+1.4-1.6	8.71	23.70	50.90	95.80	10.18	38.93	6.23	1.59	5.51	0.66	3.67	0.77	2.17	1.97	0.32	202.04	16.66	218.70	251.11
COTMGRB1	-6+30	+1.6-1.8	7.45	22.00	72.10	136.80	13.97	52.45	7.90	1.76	6.46	0.72	3.47	0.70	1.97	1.66	0.26	283.22	16.99	300.22	329.67
COTMGRB1	-6+30	+1.8-2.0	7.53	23.98	79.83	143.26	15.19	59.42	8.91	2.04	7.42	0.82	4.08	0.79	2.04	1.61	0.26	306.62	19.04	325.65	357.16
COTMGRB1	-6+30	+2.0-2.2	17.42	54.42	73.94	133.29	14.49	56.75	9.41	2.20	9.53	1.32	8.03	1.75	4.64	3.93	0.63	287.88	32.03	319.91	391.75
COTMGRB1	-6+30	+2.2	27.77	91.37	86.62	141.07	14.49	57.65	9.70	2.22	11.55	1.84	12.62	2.94	8.14	7.51	1.26	309.53	48.08	357.61	476.76

APPENDIX 7: Washability Analysis – Balanced results

Table 35: Washability analysis results for NDBMFUB1, NDBMFUB2, MORMPRB2, and WYKMGRB2 samples – assays in sample and -30+100 size class

Sample Name	Particle Size	Density Class	Mass Fraction	Ash (%)	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	-30+100	Feed	100.00	14.09	6.26	14.55	6.29	12.14	2.28	5.83	1.45	0.42	1.80	0.31	2.15	0.47	2.77	2.53	0.20	27.99	10.65	38.64	153.19
NDBMFUB1	-30+100	-1.2	2.70	1.70	1.28	3.28	1.32	2.47	0.03	1.25	0.27	0.04	0.34	0.04	0.41	0.06	0.19	0.19	0.01	5.34	1.28	6.62	12.60
NDBMFUB1	-30+100	+1.2-1.4	49.44	5.88	5.34	10.56	4.21	8.91	0.37	4.02	0.41	0.18	0.75	0.12	1.03	0.19	1.69	1.42	0.08	17.92	5.46	23.38	83.38
NDBMFUB1	-30+100	+1.4-1.6	39.58	18.13	7.64	19.35	8.20	15.12	5.25	7.83	2.74	0.71	3.22	0.58	3.69	0.87	4.73	4.46	0.36	39.14	18.62	57.76	116.69
NDBMFUB1	-30+100	+1.6-1.8	7.40	45.65	6.95	19.96	12.05	21.74	0.18	9.14	1.96	0.65	1.82	0.25	2.09	0.35	0.68	0.69	0.19	45.07	6.72	51.79	79.15
NDBMFUB1	-30+100	+1.8-2.0	0.28	58.97	5.93	13.60	6.29	11.51	0.13	5.73	1.39	0.38	1.65	0.27	1.94	0.41	0.99	1.00	0.17	25.06	6.82	31.87	45.75
NDBMFUB1	-30+100	+2.0-2.2	0.24	66.17	3.01	10.08	4.26	8.04	0.12	4.31	0.95	0.27	1.20	0.21	1.44	0.30	0.74	0.69	0.14	17.68	4.99	22.67	32.99
NDBMFUB1	-30+100	+2.2	0.35	72.54	4.26	10.28	3.44	6.57	0.03	3.54	1.22	0.30	1.22	0.30	1.52	0.30	0.63	0.63	0.02	14.80	4.92	19.72	30.35
NDBMFUB2	-30+100	Feed	100.00	7.17	0.53	1.81	3.15	4.86	0.21	1.82	0.33	0.13	0.32	0.04	0.28	0.06	0.35	0.35	0.03	10.37	1.56	11.93	113.74
NDBMFUB2	-30+100	-1.2	4.74	1.18	0.11	0.30	0.67	1.57	0.30	0.69	0.16	0.10	0.10	0.01	0.07	0.02	0.11	0.11	0.01	3.39	0.53	3.92	8.96
NDBMFUB2	-30+100	+1.2-1.4	47.43	3.63	0.23	1.26	2.31	3.69	0.18	1.44	0.25	0.10	0.24	0.03	0.24	0.04	0.25	0.21	0.02	7.87	1.13	9.00	57.69
NDBMFUB2	-30+100	+1.4-1.6	45.13	8.56	0.86	2.43	4.14	6.22	0.22	2.25	0.42	0.14	0.41	0.05	0.31	0.07	0.45	0.49	0.03	13.25	1.95	15.20	62.76
NDBMFUB2	-30+100	+1.6-1.8	2.13	53.94	1.01	4.10	6.03	9.22	0.58	3.82	0.67	0.39	0.67	0.16	0.77	0.17	0.78	0.79	0.16	20.32	3.89	24.21	30.44
NDBMFUB2	-30+100	+1.8-2.0	0.32	61.49	1.13	3.04	5.20	7.95	0.74	2.28	0.54	0.37	0.58	0.45	0.83	0.46	0.67	0.64	0.05	16.71	4.05	20.76	24.12
NDBMFUB2	-30+100	+2.0-2.2	0.04	66.41	0.75	2.23	3.59	5.40	0.55	1.97	0.37	0.21	0.36	0.15	0.65	0.12	0.25	0.28	0.01	11.89	2.04	13.93	16.20
NDBMFUB2	-30+100	+2.2	0.20	76.53	0.30	1.80	3.25	4.73	0.05	1.70	0.30	0.10	0.30	0.05	0.25	0.05	0.12	0.15	0.02	10.03	1.06	11.09	13.09
MORMPRB2	-30+100	Feed	100.00	9.97	2.10	2.80	5.76	10.02	0.10	3.69	0.76	0.22	0.67	0.09	0.52	0.10	0.26	0.27	0.04	20.33	2.17	22.50	125.30
MORMPRB2	-30+100	-1.2	0.58	1.20	0.52	0.59	1.25	2.20	0.02	0.82	0.22	0.04	0.16	0.02	0.12	0.02	0.05	0.07	0.01	4.51	0.49	5.00	6.17
MORMPRB2	-30+100	+1.2-1.4	8.92	2.19	0.98	1.84	1.93	2.73	0.06	1.67	0.45	0.09	0.42	0.06	0.37	0.07	0.10	0.16	0.03	6.84	1.30	8.14	18.90
MORMPRB2	-30+100	+1.4-1.6	83.42	6.91	1.99	2.24	5.70	10.14	0.07	3.53	0.63	0.14	0.51	0.06	0.36	0.07	0.16	0.18	0.03	20.07	1.51	21.58	107.24
MORMPRB2	-30+100	+1.6-1.8	3.97	45.87	6.62	14.64	15.23	23.88	0.64	10.82	3.91	1.82	3.62	0.58	3.59	0.63	2.41	2.36	0.08	54.48	15.08	69.56	88.17
MORMPRB2	-30+100	+1.8-2.0	1.04	63.08	5.91	13.87	13.15	21.41	0.21	9.33	2.79	1.54	4.18	0.79	3.93	0.80	1.80	1.10	0.43	46.89	14.57	61.45	76.36
MORMPRB2	-30+100	+2.0-2.2	0.58	67.68	2.11	4.20	7.53	11.73	0.20	5.08	0.82	0.46	0.88	0.15	0.63	0.17	0.34	0.26	0.11	25.37	2.99	28.36	33.14
MORMPRB2	-30+100	+2.2	1.48	76.55	0.78	1.27	2.90	4.82	0.21	2.74	0.38	0.28	0.58	0.10	0.17	0.10	0.24	0.12	0.04	11.05	1.63	12.68	15.44
WYKMGRB2	-30+100	Feed	100.00	9.56	1.07	3.15	2.88	6.23	0.68	2.40	0.49	0.11	0.49	0.07	0.46	0.10	0.57	0.51	0.04	12.68	2.35	15.03	118.18
WYKMGRB2	-30+100	-1.2	2.44	1.55	0.32	1.02	1.22	3.31	0.13	0.96	0.19	0.04	0.17	0.02	0.14	0.02	0.08	0.07	0.01	5.81	0.55	6.36	9.82
WYKMGRB2	-30+100	+1.2-1.4	88.82	6.22	1.04	3.21	2.78	6.27	0.08	2.31	0.48	0.09	0.47	0.06	0.47	0.10	0.54	0.45	0.04	11.92	2.22	14.14	106.17
WYKMGRB2	-30+100	+1.4-1.6	6.38	39.42	1.47	3.13	4.28	6.32	7.97	4.03	0.53	0.23	0.80	0.13	0.40	0.05	1.03	1.41	0.03	23.13	4.08	27.21	36.72
WYKMGRB2	-30+100	+1.6-1.8	1.27	56.49	2.16	4.24	5.81	10.02	5.67	3.22	1.50	0.41	1.06	0.27	0.58	0.11	0.97	1.00	0.08	26.23	4.49	30.71	36.23
WYKMGRB2	-30+100	+1.8-2.0	0.40	62.49	1.12	2.83	4.04	7.77	3.82	3.14	1.21	0.37	0.78	0.16	0.49	0.12	1.02	0.75	0.04	19.98	3.72	23.70	26.93
WYKMGRB2	-30+100	+2.0-2.2	0.16	69.39	0.96	1.93	1.93	3.88	1.56	1.85	0.45	0.21	0.43	0.09	0.29	0.09	0.43	0.34	0.04	9.67	1.92	11.60	13.68
WYKMGRB2	-30+100	+2.2	0.53	75.97	0.79	1.58	1.60	3.16	1.50	1.57	0.37	0.20	0.40	0.08	0.27	0.09	0.39	0.37	0.03	8.20	1.84	10.04	12.15

Table 36: Washability analysis results for COTMGRB1, MOSONCB3, UTWMUIB1, and MOBONCB3 samples – assays in sample and -30+100 size class

Sample Name	Particle Size	Density Class	Mass Fraction	Ash (%)	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
COTMGRB1	-30+100	Feed	100.00	5.20	0.71	1.90	3.40	6.05	0.06	2.36	0.47	0.14	0.42	0.05	0.29	0.06	0.15	0.17	0.02	12.34	1.30	13.64	115.54
COTMGRB1	-30+100	-1.2	2.09	1.12	0.29	0.80	1.45	2.62	0.01	0.99	0.19	0.06	0.17	0.02	0.11	0.02	0.07	0.07	0.01	5.26	0.53	5.79	8.68
COTMGRB1	-30+100	+1.2-1.4	90.17	3.45	0.63	1.67	2.95	5.18	0.05	1.99	0.39	0.12	0.33	0.05	0.25	0.04	0.14	0.14	0.01	10.57	1.09	11.66	103.49
COTMGRB1	-30+100	+1.4-1.6	5.47	15.12	1.14	3.85	8.10	14.98	0.22	6.19	1.07	0.28	1.04	0.05	0.62	0.23	0.14	0.31	0.17	30.56	2.84	33.40	42.72
COTMGRB1	-30+100	+1.6-1.8	1.31	43.59	3.71	8.11	12.09	21.90	0.25	9.48	2.65	0.83	2.62	0.30	1.68	0.31	1.02	1.05	0.21	46.37	8.03	54.40	63.82
COTMGRB1	-30+100	+1.8-2.0	0.57	63.63	3.15	8.30	12.04	22.75	0.16	9.16	1.44	0.63	2.05	0.15	0.80	0.16	0.61	0.41	0.05	45.56	4.86	50.42	59.29
COTMGRB1	-30+100	+2.0-2.2	0.24	71.41	1.87	4.82	11.25	22.06	0.12	6.51	1.48	0.81	1.97	0.04	0.66	0.06	0.98	0.80	0.04	41.42	5.36	46.77	51.83
COTMGRB1	-30+100	+2.2	0.15	83.88	1.82	2.59	10.34	17.85	0.15	3.98	1.54	0.65	1.28	0.06	0.25	0.07	0.82	0.48	0.02	33.87	3.62	37.49	40.24
MOSONCB3	-30+100	Feed	100.00	59.68	35.00	104.33	45.77	85.24	1.10	42.55	9.72	2.41	11.94	2.21	14.19	3.08	8.31	8.64	1.23	184.38	52.01	236.39	440.73
MOSONCB3	-30+100	-1.2	0.03	1.25	1.30	3.34	1.70	3.14	0.04	1.58	0.36	0.09	0.45	0.09	0.54	0.13	0.32	0.32	0.04	6.82	1.98	8.80	12.17
MOSONCB3	-30+100	+1.2-1.4	0.01	2.12	1.85	5.17	2.43	4.42	0.04	2.26	0.49	0.13	0.63	0.13	0.75	0.16	0.44	0.45	0.04	9.64	2.73	12.37	17.55
MOSONCB3	-30+100	+1.4-1.6	0.03	6.70	4.53	13.00	6.01	11.09	0.14	5.61	1.26	0.31	1.57	0.31	1.90	0.42	1.09	1.12	0.15	24.11	6.87	30.98	44.01
MOSONCB3	-30+100	+1.6-1.8	0.05	8.85	5.02	14.70	6.82	12.64	0.17	6.36	1.41	0.34	1.73	0.34	2.09	0.45	1.20	1.25	0.16	27.40	7.56	34.96	49.71
MOSONCB3	-30+100	+1.8-2.0	4.19	10.38	6.32	19.65	7.19	13.86	0.16	7.56	1.67	0.40	2.40	0.43	2.97	0.61	1.40	1.31	0.25	30.44	9.77	40.21	64.05
MOSONCB3	-30+100	+2.0-2.2	5.79	26.59	9.28	38.51	12.61	33.77	0.44	20.73	3.96	0.94	4.58	0.73	4.92	1.01	2.25	2.37	0.35	71.51	17.15	88.66	132.96
MOSONCB3	-30+100	+2.2	89.90	64.19	38.04	112.64	49.76	91.99	1.19	45.64	10.47	2.60	12.88	2.39	15.33	3.34	9.03	9.40	1.33	199.05	56.29	255.34	457.88
UTWMUIB1	-30+100	Feed	100.00	5.70	1.17	3.11	3.85	7.17	0.77	3.18	0.57	0.13	0.56	0.08	0.45	0.10	0.28	0.25	0.04	15.54	1.87	17.41	120.53
UTWMUIB1	-30+100	-1.2	5.68	1.43	0.67	1.91	1.86	3.75	0.33	1.31	0.36	0.08	0.37	0.06	0.29	0.07	0.17	0.17	0.03	7.60	1.25	8.85	16.44
UTWMUIB1	-30+100	+1.2-1.4	88.29	3.03	0.86	1.89	2.63	4.77	0.78	2.15	0.35	0.08	0.35	0.05	0.27	0.07	0.20	0.16	0.03	10.68	1.20	11.88	102.06
UTWMUIB1	-30+100	+1.4-1.6	3.84	39.30	6.11	24.15	25.56	46.70	0.99	22.08	3.98	0.85	3.85	0.52	3.58	0.62	1.53	1.72	0.26	99.31	12.94	112.25	140.24
UTWMUIB1	-30+100	+1.6-1.8	0.85	52.80	7.77	20.10	30.78	56.12	1.58	25.04	4.35	0.64	4.07	0.61	2.80	0.63	1.57	1.27	0.30	117.86	11.90	129.76	150.71
UTWMUIB1	-30+100	+1.8-2.0	0.51	68.19	6.69	23.78	18.21	45.01	1.51	14.95	5.04	0.34	4.09	0.46	3.83	0.41	1.90	2.01	0.23	84.73	13.26	97.99	122.28
UTWMUIB1	-30+100	+2.0-2.2	0.03	75.42	0.98	39.45	12.41	27.70	1.21	11.71	3.24	1.98	3.42	0.52	3.33	2.16	1.76	1.67	0.26	56.29	15.11	71.39	110.87
UTWMUIB1	-30+100	+2.2	0.79	78.38	4.39	13.90	11.30	31.04	0.81	8.68	2.51	0.76	2.67	0.32	1.86	0.67	1.19	1.15	0.16	54.33	8.79	63.12	77.81
MOBONCB3	-30+100	Feed	100.00	67.76	16.79	28.26	27.30	51.30	0.59	20.83	4.25	0.93	4.04	0.62	3.86	0.87	2.50	2.73	0.39	104.27	15.94	120.21	248.47
MOBONCB3	-30+100	-1.2	0.15	1.38	1.95	1.96	3.26	0.04	1.41	0.29	0.06	0.27	0.04	0.27	0.05	0.18	0.18	0.02	0.01	5.06	1.02	6.08	8.19
MOBONCB3	-30+100	+1.2-1.4	0.37	3.70	1.75	1.70	2.75	6.07	0.09	4.28	0.08	0.24	0.47	0.29	0.49	0.17	0.16	0.03	0.01	13.27	1.86	15.13	17.20
MOBONCB3	-30+100	+1.4-1.6	0.14	8.76	3.97	5.90	5.55	9.48	0.10	3.97	1.17	0.25	1.18	0.09	1.76	0.34	1.06	0.95	0.15	20.27	5.78	26.05	32.09
MOBONCB3	-30+100	+1.6-1.8	1.49	15.56	7.46	9.12	8.37	14.11	0.21	6.42	2.01	0.34	1.66	0.19	2.06	0.38	1.38	1.38	0.18	31.12	7.57	38.69	49.30
MOBONCB3	-30+100	+1.8-2.0	6.14	26.86	12.64	14.01	13.77	24.01	0.16	10.82	2.07	0.40	1.80	0.23	2.11	0.47	1.25	1.28	0.21	50.83	7.75	58.58	78.73
MOBONCB3	-30+100	+2.0-2.2	5.52	54.42	12.14	25.14	20.17	34.74	0.60	18.05	3.62	0.73	3.15	0.56	3.48	0.64	2.27	2.49	0.33	77.18	13.65	90.83	121.49
MOBONCB3	-30+100	+2.2	86.20	72.91	17.66	30.00	29.23	55.29	0.63	22.10	4.52	0.99	4.32	0.66	4.07	0.92	2.64	2.90	0.41	111.76	16.92	128.68	244.88

Table 37: Washability analysis results for NDBMFUB1, WYBTMPRB1, WYNMPRB1, MORMPRB2, and UTWMUIB1 samples – assays in sample and -100 size class

Sample Name	Particle Size	Density Class	Mass Fraction	Ash (%)	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	-100.00	Feed	100.00	14.23	6.26	14.39	6.32	12.13	2.12	5.82	1.46	0.42	1.79	0.31	2.17	0.47	2.76	2.55	0.20	27.85	10.67	38.52	152.91
NDBMFUB1	-100.00	-1.2	2.02	1.14	1.04	3.79	1.47	2.92	0.01	1.32	0.28	0.07	0.33	0.05	0.40	0.08	0.10	0.06	0.02	6.00	1.11	7.11	12.92
NDBMFUB1	-100.00	+1.2-1.4	27.53	3.86	3.86	8.98	4.16	7.46	0.07	3.82	0.50	0.17	0.54	0.10	0.56	0.12	0.81	0.87	0.09	16.01	3.26	19.27	55.78
NDBMFUB1	-100.00	+1.4-1.6	37.60	14.96	6.90	16.17	6.83	13.81	2.16	6.18	1.29	0.32	1.98	0.30	2.69	0.46	3.15	2.89	0.19	30.27	11.98	42.25	96.02
NDBMFUB1	-100.00	+1.6-1.8	31.44	20.97	8.04	17.82	7.98	15.03	4.10	7.50	2.59	0.77	2.78	0.53	3.11	0.82	4.27	3.86	0.33	37.20	16.47	53.67	102.93
NDBMFUB1	-100.00	+1.8-2.0	0.54	59.86	6.82	21.27	8.32	11.23	0.16	6.80	1.92	0.61	1.92	0.38	2.48	0.68	0.90	0.89	0.30	28.43	8.16	36.59	58.40
NDBMFUB1	-100.00	+2.0-2.2	0.52	66.83	2.13	6.35	3.43	6.21	0.14	3.44	0.69	0.17	0.59	0.12	0.88	0.17	0.69	0.73	0.11	13.91	3.45	17.36	24.22
NDBMFUB1	-100.00	+2.2	0.35	72.38	1.99	3.36	1.70	2.78	0.01	1.56	0.54	0.30	0.66	0.13	0.75	0.19	0.18	0.17	0.08	6.59	2.45	9.05	12.76
WYBTMPRB1	-100.00	Feed	100.00	6.45	2.18	3.42	4.97	9.20	1.59	3.70	0.78	0.26	0.76	0.10	0.58	0.11	0.44	0.41	0.05	20.24	2.71	22.95	126.37
WYBTMPRB1	-100.00	-1.2	18.05	1.52	1.60	2.38	3.60	6.46	0.04	2.53	0.44	0.16	0.53	0.03	0.33	0.06	0.06	0.05	0.07	13.07	1.29	14.36	34.79
WYBTMPRB1	-100.00	+1.2-1.4	20.67	3.27	2.53	3.84	5.00	8.87	2.30	3.81	0.97	0.39	1.26	0.23	1.11	0.19	0.27	0.30	0.06	20.95	3.81	24.76	49.27
WYBTMPRB1	-100.00	+1.4-1.6	53.08	5.07	2.28	3.67	5.50	10.48	1.92	4.09	0.89	0.23	0.66	0.06	0.44	0.08	0.57	0.49	0.04	22.88	2.57	25.45	82.20
WYBTMPRB1	-100.00	+1.6-1.8	7.62	32.24	1.96	3.18	4.57	7.93	1.13	3.59	0.33	0.39	0.65	0.14	0.73	0.24	0.94	0.97	0.06	17.55	4.12	21.67	32.47
WYBTMPRB1	-100.00	+1.8-2.0	0.29	51.25	0.91	1.72	3.63	6.30	0.20	2.21	0.73	0.24	0.64	0.11	0.39	0.26	0.84	0.37	0.06	13.06	2.91	15.97	17.99
WYBTMPRB1	-100.00	+2.0-2.2	0.08	60.71	0.61	1.54	2.91	4.97	0.07	1.23	0.25	0.18	0.25	0.12	0.26	0.17	0.12	0.06	0.12	9.43	1.29	10.72	12.34
WYBTMPRB1	-100.00	+2.2	0.22	70.01	0.66	0.90	1.54	2.80	0.01	1.23	0.22	0.09	0.20	0.03	0.17	0.03	0.04	0.04	0.01	5.80	0.61	6.41	7.53
WYNMPRB1	-100.00	Feed	100.00	6.37	2.21	3.43	4.77	8.70	0.54	3.74	0.75	0.27	0.74	0.10	0.55	0.11	0.43	0.40	0.04	18.50	2.65	21.15	124.58
WYNMPRB1	-100.00	-1.2	12.93	1.25	0.71	1.23	1.58	5.38	0.25	1.33	0.27	0.09	0.26	0.03	0.18	0.05	0.05	0.05	0.01	8.80	0.73	9.53	23.69
WYNMPRB1	-100.00	+1.2-1.4	28.44	3.04	2.24	3.58	4.32	7.45	0.51	3.64	0.77	0.24	0.82	0.09	0.51	0.14	0.41	0.43	0.04	16.69	2.68	19.37	51.39
WYNMPRB1	-100.00	+1.4-1.6	53.41	5.54	2.57	3.92	5.80	10.14	0.65	4.34	0.85	0.32	0.82	0.12	0.67	0.11	0.57	0.50	0.06	21.79	3.18	24.96	82.29
WYNMPRB1	-100.00	+1.6-1.8	2.17	31.72	2.97	4.47	6.62	12.92	0.46	5.79	1.06	0.34	1.06	0.11	0.79	0.16	0.17	0.17	0.01	26.85	2.82	29.66	36.31
WYNMPRB1	-100.00	+1.8-2.0	1.36	47.50	1.58	2.60	3.83	7.41	0.20	3.36	0.52	0.23	0.52	0.08	0.38	0.13	0.13	0.13	0.00	15.32	1.61	16.92	20.89
WYNMPRB1	-100.00	+2.0-2.2	0.95	57.35	1.10	2.15	2.90	5.90	0.14	2.81	0.42	0.21	0.46	0.07	0.27	0.11	0.11	0.11	0.01	12.16	1.36	13.52	16.62
WYNMPRB1	-100.00	+2.2	0.74	68.33	0.77	1.27	2.14	4.50	0.01	2.06	0.38	0.10	0.37	0.03	0.21	0.05	0.05	0.05	0.01	9.09	0.87	9.96	11.97
MORMPRB2	-100.00	Feed	17.90	10.00	2.12	2.80	5.84	9.93	0.10	3.72	0.76	0.22	0.67	0.09	0.52	0.10	0.26	0.27	0.04	20.35	2.17	22.52	43.22
MORMPRB2	-100.00	-1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MORMPRB2	-100.00	+1.2-1.4	8.67	2.09	1.48	2.02	3.76	6.66	0.05	2.76	0.49	0.27	0.44	0.04	0.35	0.08	0.09	0.09	0.04	13.72	1.40	15.12	25.81
MORMPRB2	-100.00	+1.4-1.6	71.48	4.18	1.54	1.96	4.77	7.87	0.10	2.69	0.66	0.07	0.56	0.08	0.39	0.07	0.20	0.23	0.02	16.09	1.62	17.71	91.15
MORMPRB2	-100.00	+1.6-1.8	17.05	29.79	4.91	6.60	11.39	20.14	0.13	8.47	1.34	0.77	1.28	0.17	1.13	0.24	0.62	0.56	0.11	41.47	4.88	46.35	70.00
MORMPRB2	-100.00	+1.8-2.0	1.34	52.75	3.49	5.33	8.93	16.02	0.12	5.63	0.97	0.66	0.62	0.15	0.88	0.17	0.19	0.22	0.10	31.67	2.99	34.66	41.33
MORMPRB2	-100.00	+2.0-2.2	0.76	69.32	0.79	1.99	3.29	4.79	0.03	2.41	0.36	0.13	0.51	0.04	0.17	0.04	0.12	0.05	0.02	10.88	1.09	11.97	14.72
MORMPRB2	-100.00	+2.2	0.71	73.18	0.87	1.93	3.04	5.46	0.02	2.30	0.51	0.24	0.49	0.06	0.37	0.06	0.04	0.06	0.03	11.33	1.35	12.67	15.32
UTWMUIB1	-100.00	Feed	100.00	5.69	1.20	3.66	5.00	11.52	0.77	3.82	0.62	0.13	0.62	0.08	0.47	0.11	0.31	0.26	0.04	21.73	2.02	23.75	127.41
UTWMUIB1	-100.00	-1.2	6.14	0.87	0.48	1.18	1.46	2.72	0.32	1.20	0.23	0.05	0.23	0.05	0.22	0.05	0.14	0.09	0.05	5.93	0.87	6.80	14.12
UTWMUIB1	-100.00	+1.2-1.4	84.89	3.59	0.71	2.56	3.72	8.96	0.37	2.35	0.38	0.11	0.38	0.07	0.33	0.10	0.23	0.22	0.04	15.79	1.46	17.25	104.70
UTWMUIB1	-100.00	+1.4-1.6	7.47	23.93	6.25	15.68	19.59	42.33	5.08	19.59	3.25	0.39	3.24	0.20	2.04	0.28	1.21	0.81	0.10	89.84	8.27	98.12	121.27
UTWMUIB1	-100.00	+1.6-1.8	1.06	47.44	8.69	20.58	24.69	50.28	5.01	24.55	3.19	0.76	3.12	0.35	2.05	0.42	1.44	1.10	0.21	107.73	9.45	117.17	138.82
UTWMUIB1	-100.00	+1.8-2.0	0.33	63.63	3.68	7.65	8.42	16.29	1.34	8.93	0.74	0.22	0.79	0.08	0.38	0.10	0.34	0.22	0.08	35.73	2.20	37.92	45.91
UTWMUIB1	-100.00	+2.0-2.2	0.02	71.26	0.62	1.69	1.97	3.46	0.59	2.05	0.21	0.51	1.18	0.18	0.79	0.22	0.38	0.38	0.11	8.27	3.75	12.02	13.73
UTWMUIB1	-100.00	+2.2	0.10	81.32	0.43	1.06	1.62	2.93	0.36	1.33	0.23	0.08	0.23	0.02	0.15	0.03	0.11	0.07	0.02	6.46	0.72	7.17	8.33

Table 38: Washability analysis results for UTWMUIB1, MOSONCB3, and COTMGRB1 samples – assays in sample and -6+30 size class

Sample Name	Particle Size	Density Class	Mass Fraction	Ash (%)	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
UTWMUIB1	-6+30	Feed	100.00	5.70	1.15	3.17	3.79	7.07	0.78	3.18	0.57	0.13	0.57	0.08	0.44	0.10	0.28	0.25	0.04	15.39	1.88	17.27	120.43
UTWMUIB1	-6+30	-1.2	0.33	1.58	0.60	1.74	1.64	2.99	0.34	1.42	0.26	0.08	0.28	0.04	0.24	0.06	0.14	0.14	0.02	6.65	1.00	7.64	9.71
UTWMUIB1	-6+30	+1.2-1.4	92.65	2.95	0.78	2.53	2.66	4.42	0.38	2.09	0.38	0.08	0.35	0.05	0.31	0.07	0.21	0.18	0.03	9.93	1.28	11.22	106.39
UTWMUIB1	-6+30	+1.4-1.6	5.92	37.98	6.30	11.66	18.05	42.83	6.51	18.03	3.20	0.77	3.50	0.39	2.25	0.45	1.23	1.16	0.17	88.62	9.92	98.54	116.12
UTWMUIB1	-6+30	+1.6-1.8	0.35	55.36	5.57	13.72	27.27	46.61	4.47	17.85	2.96	0.66	3.01	0.40	2.36	0.51	1.37	1.29	0.22	99.16	9.82	108.97	123.04
UTWMUIB1	-6+30	+1.8-2.0	0.16	63.94	5.51	15.84	28.93	46.67	4.80	18.54	3.04	0.66	3.16	0.42	2.47	0.53	1.48	1.41	0.23	101.97	10.36	112.33	128.33
UTWMUIB1	-6+30	+2.0-2.2	0.11	69.11	5.01	14.15	19.98	35.05	3.78	16.63	3.11	0.74	3.44	0.48	2.87	0.64	1.76	1.64	0.26	78.55	11.83	90.38	104.64
UTWMUIB1	-6+30	+2.2	0.48	71.85	3.68	9.33	18.63	31.43	3.13	13.64	2.16	0.62	2.21	0.26	1.42	0.38	0.83	0.73	0.11	69.00	6.57	75.56	85.38
MOSONCB3	-6+30	Feed	100.00	59.64	34.87	104.25	45.62	89.88	1.10	43.57	9.71	2.41	12.01	2.21	14.36	3.08	8.23	8.62	1.23	189.87	52.15	242.02	446.27
MOSONCB3	-6+30	-1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOSONCB3	-6+30	+1.2-1.4	0.05	2.81	0.45	1.09	1.24	2.10	0.22	0.93	0.16	0.03	0.16	0.03	0.14	0.03	0.09	0.08	0.02	4.65	0.58	5.23	6.37
MOSONCB3	-6+30	+1.4-1.6	0.05	5.57	1.21	3.36	1.57	3.04	0.33	1.53	0.32	0.08	0.41	0.07	0.48	0.10	0.29	0.26	0.04	6.79	1.73	8.52	11.93
MOSONCB3	-6+30	+1.6-1.8	0.30	9.55	1.50	4.07	1.22	2.33	0.31	1.26	0.30	0.08	0.44	0.09	0.59	0.13	0.36	0.32	0.06	5.42	2.07	7.49	11.86
MOSONCB3	-6+30	+1.8-2.0	1.48	16.57	1.43	4.30	1.17	2.28	0.29	1.22	0.30	0.08	0.45	0.09	0.63	0.14	0.32	0.36	0.06	5.26	2.13	7.39	13.17
MOSONCB3	-6+30	+2.0-2.2	8.08	27.98	7.46	23.46	5.55	12.28	1.28	6.21	1.46	0.37	2.31	0.46	3.26	0.79	2.12	1.90	0.30	26.78	11.51	38.29	69.83
MOSONCB3	-6+30	+2.2	90.04	63.42	38.02	113.59	50.14	98.67	1.10	47.80	10.65	2.64	13.12	2.41	15.64	3.35	8.95	9.40	1.34	208.35	56.84	265.20	468.83
COTMGRB1	-6+30	Feed	100.00	5.46	0.71	1.90	3.41	6.12	0.06	2.36	0.47	0.14	0.42	0.05	0.29	0.06	0.15	0.17	0.02	12.42	1.30	13.72	115.62
COTMGRB1	-6+30	-1.2	0.14	2.01	0.33	0.89	1.59	2.86	0.01	1.09	0.21	0.06	0.19	0.02	0.12	0.02	0.08	0.08	0.01	5.76	0.58	6.34	7.37
COTMGRB1	-6+30	+1.2-1.4	90.94	3.86	0.57	1.67	3.02	5.45	0.03	2.03	0.34	0.08	0.28	0.04	0.19	0.03	0.10	0.10	0.01	10.87	0.83	11.70	104.31
COTMGRB1	-6+30	+1.4-1.6	6.66	10.03	1.46	2.98	5.80	10.19	0.40	4.62	1.51	0.57	1.50	0.14	1.05	0.38	0.39	0.63	0.19	22.52	4.85	27.37	37.01
COTMGRB1	-6+30	+1.6-1.8	1.30	51.01	4.42	8.42	12.28	22.03	0.51	9.75	3.70	1.79	3.74	0.62	2.94	0.76	2.09	2.19	0.12	48.27	14.25	62.52	72.24
COTMGRB1	-6+30	+1.8-2.0	0.40	60.49	3.41	8.42	12.12	22.82	0.18	9.27	1.72	0.82	2.43	0.16	0.96	0.18	0.74	0.47	0.05	46.11	5.81	51.92	60.74
COTMGRB1	-6+30	+2.0-2.2	0.34	64.44	4.69	8.23	13.52	18.31	0.06	6.31	0.92	0.85	1.43	0.04	0.62	0.05	1.03	1.28	0.03	39.12	5.34	44.45	53.02
COTMGRB1	-6+30	+2.2	0.21	70.24	4.25	7.62	12.25	22.74	0.10	5.45	1.02	0.80	0.84	0.04	1.20	0.04	0.55	0.66	0.01	41.55	4.14	45.70	53.53

APPENDIX 8: Magnetic Separation –Results

Table 39: REE+Y+Sc concentrations in ash in magnetic separation partitions

Sample Name	Stream Name	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+ Y+Sc (ppm)
NDBMFUB1	Feed	47.42	110.06	47.73	90.65	19.16	42.96	10.96	3.26	13.52	2.30	15.59	3.36	15.63	14.43	1.43	211.46	69.50	280.96	438.44
NDBMFUB1	Mag	21.98	45.95	29.43	54.15	9.65	23.20	5.51	1.63	6.31	1.02	6.41	1.33	6.58	4.98	0.58	121.94	28.83	150.77	218.69
NDBMFUB1	NonMag	48.26	112.16	48.32	91.85	19.47	43.60	11.14	3.31	13.75	2.34	15.89	3.42	15.93	14.74	1.45	214.39	70.84	285.23	445.65
NDBMFUB2	Feed	8.55	28.65	51.21	80.57	14.28	29.39	5.47	2.16	5.28	0.73	4.44	0.91	4.51	4.52	0.44	180.92	23.00	203.92	241.11
NDBMFUB2	Mag	8.65	26.58	50.39	80.21	12.97	28.85	5.59	2.47	5.43	0.74	4.24	0.84	3.50	3.44	0.39	178.01	21.06	199.06	234.29
NDBMFUB2	NonMag	8.53	28.95	51.34	80.62	14.47	29.47	5.45	2.12	5.26	0.73	4.47	0.92	4.66	4.68	0.45	181.35	23.28	204.63	242.11
UTSYMUIB1	Feed	11.99	25.49	41.01	63.67	1.17	27.86	5.39	1.27	5.20	0.70	3.88	0.80	2.68	2.66	0.32	139.10	17.51	156.62	194.10
UTSYMUIB1	Mag	5.29	9.79	16.52	28.40	0.35	12.84	2.47	0.57	2.35	0.31	1.66	0.33	0.93	0.99	0.13	60.59	7.27	67.86	82.94
UTSYMUIB1	NonMag	12.16	25.88	41.61	64.55	1.19	28.23	5.46	1.29	5.27	0.71	3.94	0.81	2.72	2.70	0.32	141.06	17.77	158.83	196.87
WYBTMPRB1	Feed	25.38	43.11	64.61	117.66	1.18	48.06	10.12	3.30	9.72	1.31	7.17	1.40	3.91	3.98	0.55	241.63	31.35	272.98	341.47
WYBTMPRB1	Mag	10.99	19.13	28.97	52.48	0.56	21.62	4.55	1.48	4.33	0.59	3.17	0.62	1.63	1.67	0.24	108.18	13.73	121.92	152.04
WYBTMPRB1	NonMag	25.99	44.12	66.11	120.40	1.20	49.17	10.36	3.38	9.95	1.35	7.34	1.44	4.01	4.08	0.56	247.24	32.09	279.34	349.44
UTSUMUIB1	Feed	9.69	19.06	33.34	54.20	0.42	21.18	4.24	1.06	4.14	0.56	3.08	0.62	1.46	1.53	0.26	113.37	12.71	126.08	154.83
UTSUMUIB1	Mag	4.10	8.14	14.28	23.20	0.21	9.06	1.82	0.46	1.78	0.24	1.32	0.27	0.62	0.65	0.11	48.57	5.43	54.00	66.24
UTSUMUIB1	NonMag	9.79	19.25	33.66	54.73	0.42	21.38	4.28	1.07	4.18	0.57	3.11	0.63	1.47	1.55	0.26	114.48	12.83	127.31	156.34
WYNMPRB1	Feed	27.19	45.80	62.79	116.46	1.22	48.45	10.46	3.49	10.21	1.38	7.59	1.50	4.41	4.38	0.59	239.38	33.56	272.94	345.93
WYNMPRB1	Mag	11.54	20.21	27.17	50.03	0.53	20.93	4.59	1.48	4.45	0.61	3.31	0.66	1.72	1.74	0.26	103.25	14.24	117.49	149.24
WYNMPRB1	NonMag	28.14	47.37	64.97	120.53	1.27	50.13	10.82	3.61	10.56	1.43	7.86	1.55	4.58	4.54	0.61	247.71	34.74	282.45	357.97
MORMPRB2	Feed	11.86	19.66	41.14	73.04	0.65	27.83	5.20	1.38	4.73	0.66	3.81	0.72	1.65	1.67	0.29	147.86	14.91	162.77	194.29
MORMPRB2	Mag	5.08	8.55	17.94	31.94	0.28	12.22	2.26	0.59	2.06	0.29	1.66	0.32	0.71	0.72	0.13	64.63	6.47	71.10	84.73
MORMPRB2	NonMag	11.98	19.87	41.58	73.81	0.66	28.12	5.25	1.39	4.78	0.66	3.85	0.73	1.67	1.69	0.29	149.42	15.06	164.49	196.34
COTMGRB1	Feed	13.65	37.81	69.87	124.50	1.24	49.19	9.27	2.79	8.36	1.09	6.04	1.19	3.03	3.26	0.52	254.07	26.27	280.35	331.81
COTMGRB1	Mag	7.05	20.26	39.11	68.87	0.66	28.40	4.96	1.51	4.54	0.59	3.44	0.68	1.61	1.72	0.30	141.99	14.39	156.39	183.70
COTMGRB1	NonMag	14.08	38.95	71.85	128.09	1.28	50.53	9.55	2.87	8.60	1.12	6.21	1.22	3.12	3.36	0.53	261.30	27.04	288.34	341.36
UTWMUIB1	Feed	18.91	52.47	69.04	107.37	1.27	53.27	10.64	2.48	10.12	1.37	7.68	1.55	3.89	3.92	0.63	241.59	31.66	273.24	344.62
UTWMUIB1	Mag	5.18	14.10	16.38	21.80	0.32	14.56	2.79	0.70	2.64	0.37	2.18	0.44	1.16	1.06	0.18	55.85	8.73	64.58	83.86
UTWMUIB1	NonMag	20.42	56.70	74.84	116.80	1.38	57.54	11.50	2.67	10.95	1.49	8.29	1.67	4.19	4.24	0.69	262.06	34.18	296.24	373.37
WYKMGRB2	Feed	10.26	30.21	28.93	56.07	0.61	24.10	4.87	1.15	4.89	0.69	4.26	0.88	3.03	2.52	0.35	114.58	17.77	132.35	172.82
WYKMGRB2	Mag	4.32	13.01	12.99	22.32	0.23	10.75	2.16	0.55	2.12	0.29	1.78	0.37	1.02	0.84	0.15	48.45	7.12	55.57	72.91
WYKMGRB2	NonMag	11.04	32.48	31.04	60.53	0.66	25.87	5.23	1.23	5.25	0.74	4.58	0.95	3.29	2.74	0.38	123.33	19.18	142.51	186.03
MOBONCB3	Feed	29.30	53.91	53.08	91.74	0.80	41.25	8.13	1.72	8.06	1.24	8.08	1.74	4.63	4.81	0.73	195.01	31.02	226.03	309.24
MOBONCB3	Mag	13.67	27.28	23.61	40.64	0.41	18.45	3.61	0.76	3.58	0.56	3.83	0.87	2.06	2.17	0.38	86.72	14.21	100.93	141.89
MOBONCB3	NonMag	29.33	53.96	53.13	91.83	0.81	41.29	8.13	1.72	8.07	1.24	8.09	1.74	4.64	4.82	0.73	195.19	31.05	226.24	309.53

Table 40: REE+Y+Sc, ash, fixed C, sulfur, and volatiles in whole sample within magnetic separation partitions

Sample Name	Stream Name	Mass fraction	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	Ash (%)	Fixed Carbon (%)	Sulfur (%)	Volatile Matter (%)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	Feed	100.00	7.00	16.24	7.04	13.38	2.83	6.34	1.62	0.48	2.00	0.34	2.30	0.50	2.31	2.13	0.21	14.76	40.06	0.60	45.21	31.21	10.26	41.47	64.71
NDBMFUB1	Mag	0.66	15.57	32.56	20.86	38.37	6.84	16.44	3.90	1.15	4.47	0.72	4.54	0.94	4.66	3.53	0.41	70.86	20.26	21.80	22.65	86.41	20.43	106.84	154.97
NDBMFUB1	NonMag	99.34	6.94	16.14	6.95	13.21	2.80	6.27	1.60	0.48	1.98	0.34	2.29	0.49	2.29	2.12	0.21	14.39	40.19	0.46	45.36	30.84	10.19	41.03	64.11
NDBMFUB2	Feed	100.00	0.61	2.05	3.67	5.78	1.02	2.11	0.39	0.16	0.38	0.05	0.32	0.07	0.32	0.32	0.03	7.17	49.69	0.19	43.40	12.97	1.65	14.62	17.29
NDBMFUB2	Mag	1.82	4.38	13.46	25.51	40.61	6.57	14.61	2.83	1.25	2.75	0.37	2.15	0.43	1.77	1.74	0.20	50.63	25.01	0.90	21.83	90.13	10.66	100.79	118.63
NDBMFUB2	NonMag	98.18	0.54	1.84	3.27	5.13	0.92	1.88	0.35	0.13	0.33	0.05	0.28	0.06	0.30	0.30	0.03	6.36	50.15	0.17	43.80	11.54	1.48	13.02	15.41
UTSYMUIB1	Feed	100.00	0.96	2.05	3.30	5.12	0.09	2.24	0.43	0.10	0.42	0.06	0.31	0.06	0.22	0.21	0.03	8.04	50.01	0.57	41.91	11.19	1.41	12.60	15.61
UTSYMUIB1	Mag	0.33	3.14	5.81	9.81	16.86	0.21	7.62	1.47	0.34	1.40	0.18	0.98	0.20	0.55	0.59	0.08	59.36	25.29	23.75	20.99	35.97	4.31	40.28	49.24
UTSYMUIB1	NonMag	99.67	0.96	2.04	3.28	5.08	0.09	2.22	0.43	0.10	0.42	0.06	0.31	0.06	0.21	0.21	0.03	7.87	50.09	0.49	41.98	11.10	1.40	12.50	15.50
WYBTMPRB1	Feed	100.00	1.74	2.96	4.44	8.08	0.08	3.30	0.70	0.23	0.67	0.09	0.49	0.10	0.27	0.27	0.04	6.87	49.32	0.30	43.81	16.60	2.15	18.75	23.45
WYBTMPRB1	Mag	0.45	6.75	11.74	17.78	32.21	0.34	13.27	2.80	0.91	2.66	0.36	1.94	0.38	1.00	1.03	0.15	61.38	24.62	11.45	21.97	66.40	8.43	74.83	93.32
WYBTMPRB1	NonMag	99.55	1.72	2.92	4.38	7.97	0.08	3.26	0.69	0.22	0.66	0.09	0.49	0.10	0.27	0.27	0.04	6.62	49.44	0.25	43.91	16.37	2.12	18.49	23.14
UTSUMUIB1	Feed	100.00	0.82	1.61	2.82	4.59	0.04	1.79	0.36	0.09	0.35	0.05	0.26	0.05	0.12	0.13	0.02	8.47	50.75	0.38	40.80	9.61	1.08	10.68	13.12
UTSUMUIB1	Mag	0.19	3.07	6.11	10.71	17.41	0.15	6.80	1.37	0.34	1.34	0.18	0.99	0.20	0.46	0.48	0.08	75.06	25.45	18.85	20.38	36.45	4.08	40.53	49.72
UTSUMUIB1	NonMag	99.81	0.82	1.61	2.81	4.57	0.04	1.78	0.36	0.09	0.35	0.05	0.26	0.05	0.12	0.13	0.02	8.35	50.80	0.34	40.84	9.55	1.07	10.63	13.05
WYNMPRB1	Feed	100.00	1.92	3.23	4.43	8.22	0.09	3.42	0.74	0.25	0.72	0.10	0.54	0.11	0.31	0.31	0.04	7.06	49.86	0.31	42.90	16.89	2.37	19.26	24.41
WYNMPRB1	Mag	0.66	7.08	12.40	16.67	30.69	0.32	12.84	2.82	0.91	2.73	0.38	2.03	0.40	1.06	1.07	0.16	61.35	25.26	8.84	20.91	63.35	8.74	72.08	91.56
WYNMPRB1	NonMag	99.34	1.88	3.17	4.35	8.07	0.08	3.36	0.72	0.24	0.71	0.10	0.53	0.10	0.31	0.30	0.04	6.69	50.03	0.25	43.05	16.58	2.33	18.91	23.96
MORMPRB2	Feed	100.00	1.13	1.87	3.92	6.96	0.06	2.65	0.50	0.13	0.45	0.06	0.36	0.07	0.16	0.16	0.03	9.52	52.98	0.46	37.53	14.08	1.42	15.50	18.51
MORMPRB2	Mag	0.22	3.97	6.69	14.03	24.97	0.22	9.55	1.76	0.46	1.61	0.22	1.30	0.25	0.56	0.56	0.10	78.20	26.47	27.55	18.93	50.54	5.06	55.60	66.26
MORMPRB2	NonMag	99.78	1.12	1.86	3.90	6.92	0.06	2.64	0.49	0.13	0.45	0.06	0.36	0.07	0.16	0.16	0.03	9.37	53.04	0.40	37.57	14.00	1.41	15.41	18.40
COTMGRB1	Feed	100.00	0.72	1.99	3.68	6.55	0.07	2.59	0.49	0.15	0.44	0.06	0.32	0.06	0.16	0.17	0.03	5.26	55.71	0.40	38.97	13.37	1.38	14.76	17.47
COTMGRB1	Mag	0.63	3.58	10.27	19.83	34.91	0.34	14.40	2.51	0.77	2.30	0.30	1.74	0.35	0.82	0.87	0.15	50.70	28.10	16.07	19.37	71.99	7.30	79.29	93.13
COTMGRB1	NonMag	99.37	0.70	1.94	3.58	6.37	0.06	2.51	0.48	0.14	0.43	0.06	0.31	0.06	0.16	0.17	0.03	4.98	55.89	0.30	39.10	13.00	1.35	14.35	16.99
UTWMUIB1	Feed	100.00	1.08	3.00	3.94	6.13	0.07	3.04	0.61	0.14	0.58	0.08	0.44	0.09	0.22	0.22	0.04	5.71	56.63	1.24	37.96	13.80	1.81	15.61	19.69
UTWMUIB1	Mag	1.06	2.77	7.53	8.75	11.64	0.17	7.78	1.49	0.37	1.41	0.20	1.16	0.24	0.62	0.57	0.10	53.39	28.90	25.04	18.44	29.82	4.66	34.48	44.78
UTWMUIB1	NonMag	98.94	1.06	2.95	3.89	6.07	0.07	2.99	0.60	0.14	0.57	0.08	0.43	0.09	0.22	0.22	0.04	5.20	56.93	0.99	38.16	13.63	1.78	15.41	19.42
WYKMGRB2	Feed	100.00	1.21	3.57	3.41	6.62	0.07	2.85	0.57	0.14	0.58	0.08	0.50	0.10	0.36	0.30	0.04	11.80	46.31	0.44	41.64	13.52	2.10	15.62	20.40
WYKMGRB2	Mag	1.73	3.45	10.39	10.37	17.83	0.18	8.59	1.72	0.44	1.69	0.23	1.42	0.29	0.81	0.67	0.12	79.87	22.36	7.75	20.40	38.70	5.69	44.39	58.23
WYKMGRB2	NonMag	98.27	1.17	3.45	3.29	6.42	0.07	2.74	0.55	0.13	0.56	0.08	0.49	0.10	0.35	0.29	0.04	10.61	46.73	0.31	42.01	13.08	2.03	15.12	19.73
MOBONCB3	Feed	100.00	18.50	34.04	33.52	57.93	0.51	26.05	5.13	1.09	5.09	0.78	5.10	1.10	2.93	3.04	0.46	63.15	13.00	0.58	22.36	123.14	19.59	142.72	195.27
MOBONCB3	Mag	0.12	12.21	24.36	21.08	36.29	0.37	16.48	3.22	0.68	3.20	0.50	3.42	0.77	1.84	1.94	0.34	89.30	7.89	23.52	12.33	77.44	12.69	90.13	126.70
MOBONCB3	NonMag	99.88	18.51	34.06	33.53	57.96	0.51	26.06	5.13	1.09	5.09	0.78	5.10	1.10	2.93	3.04	0.46	63.11	13.01	0.55	22.37	123.19	19.60	142.79	195.35

Table 41: Calculated recoveries for REE+Y+Sc, ash, fixed C, sulfur, and volatiles relative to both partitions obtained using magnetic separation

Sample Name	Stream Name	R_{Sc} (%)	R_{Y} (%)	R_{La} (%)	R_{Ce} (%)	R_{Pr} (%)	R_{Nd} (%)	R_{Sm} (%)	R_{Eu} (%)	R_{Gd} (%)	R_{Tb} (%)	R_{Dy} (%)	R_{Ho} (%)	R_{Er} (%)	R_{Yb} (%)	R_{Lu} (%)	R_{Ash} (%)	J_{Ash} (%)	R_{FixC} (%)	R_{S} (%)	J_{S} (%)	R_{vol} (%)	R_{REE} (%)	R_{Comb} (%)	Mass Yield (%)
NDBMFUB1	Mag	1.47	1.32	1.96	1.90	1.60	1.71	1.59	1.58	1.48	1.41	1.31	1.26	1.34	1.09	1.29	3.17	96.83	0.33	23.98	76.02	0.33	1.70	0.23	0.66
NDBMFUB1	NonMag	98.53	98.68	98.04	98.10	98.40	98.29	98.41	98.42	98.52	98.59	98.69	98.74	98.66	98.91	98.71	96.83	3.17	99.67	76.02	23.98	99.67	98.30	99.77	99.34
NDBMFUB2	Mag	13.03	11.94	12.66	12.81	11.70	12.63	13.16	14.73	13.25	13.00	12.30	11.92	9.98	9.79	11.26	12.87	87.13	0.92	8.76	91.24	0.92	12.57	0.97	1.82
NDBMFUB2	NonMag	86.97	88.06	87.34	87.19	88.30	87.37	86.84	85.27	86.75	87.00	87.70	88.08	90.02	90.21	88.74	87.13	12.87	99.08	91.24	8.76	99.08	87.43	99.03	98.18
UTSYMUIB1	Mag	1.07	0.93	0.98	1.08	0.73	1.12	1.11	1.08	1.10	1.07	1.04	1.00	0.84	0.90	0.99	2.43	97.57	0.17	13.82	86.18	0.16	1.05	0.15	0.33
UTSYMUIB1	NonMag	98.93	99.07	99.02	98.92	99.27	98.88	98.89	98.92	98.90	98.93	98.96	99.00	99.16	99.10	99.01	97.57	2.43	99.83	86.18	13.82	99.84	98.95	99.85	99.67
WYBTMPRB1	Mag	1.75	1.79	1.81	1.80	1.92	1.82	1.82	1.81	1.80	1.80	1.78	1.79	1.68	1.69	1.77	4.04	95.96	0.23	17.32	82.68	0.23	1.80	0.19	0.45
WYBTMPRB1	NonMag	98.25	98.21	98.19	98.20	98.08	98.18	98.18	98.19	98.20	98.20	98.22	98.21	98.32	98.31	98.23	95.96	4.04	99.77	82.68	17.32	99.77	98.20	99.81	99.55
UTSUMUIB1	Mag	0.71	0.72	0.72	0.72	0.83	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.71	0.71	0.72	1.68	98.32	0.10	9.50	90.50	0.09	0.72	0.05	0.19
UTSUMUIB1	NonMag	99.29	99.28	99.28	99.28	99.17	99.28	99.28	99.28	99.28	99.28	99.28	99.28	99.29	99.29	99.28	98.32	1.68	99.90	90.50	9.50	99.91	99.28	99.95	99.81
WYNMPRB1	Mag	2.45	2.54	2.49	2.48	2.49	2.49	2.53	2.45	2.52	2.55	2.51	2.52	2.25	2.30	2.51	5.77	94.23	0.34	18.96	81.04	0.32	2.48	0.28	0.66
WYNMPRB1	NonMag	97.55	97.46	97.51	97.52	97.51	97.51	97.47	97.55	97.48	97.45	97.49	97.48	97.75	97.70	97.49	94.23	5.77	99.66	81.04	18.96	99.68	97.52	99.72	99.34
MORMPRB2	Mag	0.79	0.80	0.80	0.80	0.80	0.81	0.80	0.79	0.80	0.80	0.80	0.80	0.79	0.79	0.80	1.84	98.16	0.11	13.41	86.59	0.11	0.80	0.05	0.22
MORMPRB2	NonMag	99.21	99.20	99.20	99.20	99.20	99.19	99.20	99.21	99.20	99.20	99.20	99.20	99.21	99.21	99.20	98.16	1.84	99.89	86.59	13.41	99.89	99.20	99.95	99.78
COTMGRB1	Mag	3.13	3.24	3.39	3.35	3.24	3.50	3.24	3.29	3.29	3.26	3.45	3.47	3.21	3.20	3.50	6.06	93.94	0.32	25.08	74.92	0.31	3.38	0.33	0.63
COTMGRB1	NonMag	96.87	96.76	96.61	96.65	96.76	96.50	96.76	96.71	96.71	96.74	96.55	96.53	96.79	96.80	96.50	93.94	6.06	99.68	74.92	25.08	99.69	96.62	99.67	99.37
UTWMUIB1	Mag	2.72	2.67	2.36	2.02	2.49	2.71	2.60	2.80	2.59	2.64	2.82	2.83	2.96	2.69	2.80	9.93	90.07	0.54	21.37	78.63	0.52	2.35	0.53	1.06
UTWMUIB1	NonMag	97.28	97.33	97.64	97.98	97.51	97.29	97.40	97.20	97.41	97.36	97.18	97.17	97.04	97.31	97.20	90.07	9.93	99.46	78.63	21.37	99.48	97.65	99.47	98.94
WYKMGRB2	Mag	4.92	5.03	5.24	4.65	4.41	5.21	5.18	5.62	5.06	4.97	4.89	4.90	3.92	3.91	4.93	11.68	88.32	0.83	30.60	69.40	0.85	4.90	0.39	1.73
WYKMGRB2	NonMag	95.08	94.97	94.76	95.35	95.59	94.79	94.82	94.38	94.94	95.03	95.11	95.10	96.08	96.09	95.07	88.32	11.68	99.17	69.40	30.60	99.15	95.10	99.61	98.27
MOBONCB3	Mag	0.08	0.09	0.08	0.08	0.09	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.17	99.83	0.07	4.91	95.09	0.07	0.08	0.03	0.12
MOBONCB3	NonMag	99.92	99.91	99.92	99.92	99.91	99.92	99.92	99.93	99.92	99.92	99.92	99.92	99.92	99.92	99.91	99.83	0.17	99.93	95.09	4.91	99.93	99.92	99.97	99.88

APPENDIX 9: Flotation Separation – Results

Table 42: REE+Y+Sc concentrations in ash in flotation process partitions

Sample Name	Stream Name	Sc in ash (ppm)	Y in ash (ppm)	La in ash (ppm)	Ce in ash (ppm)	Pr in ash (ppm)	Nd in ash (ppm)	Sm in ash (ppm)	Eu in ash (ppm)	Gd in ash (ppm)	Tb in ash (ppm)	Dy in ash (ppm)	Ho in ash (ppm)	Er in ash (ppm)	Yb in ash (ppm)	Lu in ash (ppm)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	Feed	35.98	77.62	40.33	75.44	0.72	33.27	8.73	2.84	10.37	1.70	10.48	2.22	5.22	5.41	0.93	158.50	39.18	197.67	311.27
NDBMFUB1	Conc	35.60	76.73	45.66	83.28	0.80	35.66	9.01	2.83	10.38	1.68	10.25	2.16	5.11	5.37	0.90	174.41	38.67	213.08	325.41
NDBMFUB1	Tails	36.08	77.87	38.84	73.23	0.70	32.60	8.66	2.85	10.37	1.71	10.55	2.24	5.25	5.42	0.93	154.02	39.32	193.34	307.29
NDBMFUB2	Feed	7.80	26.28	45.75	71.72	0.60	25.45	5.14	2.34	4.93	0.67	3.68	0.74	1.71	1.87	0.33	148.66	16.26	164.92	199.01
NDBMFUB2	Conc	7.91	27.64	52.70	83.69	0.69	29.07	5.70	2.44	5.40	0.71	3.87	0.77	1.74	1.93	0.33	171.86	17.19	189.05	224.60
NDBMFUB2	Tails	7.78	26.04	44.51	69.58	0.58	24.80	5.04	2.33	4.84	0.66	3.64	0.74	1.70	1.86	0.33	144.52	16.10	160.62	194.44
UTSYMUIB1	Feed	15.90	36.75	58.80	88.82	1.28	38.82	7.52	1.81	7.09	0.96	5.30	1.08	3.06	3.12	0.42	195.24	22.85	218.09	270.75
UTSYMUIB1	Conc	17.14	39.86	63.44	95.54	1.38	41.82	8.10	1.94	7.65	1.04	5.73	1.17	3.32	3.38	0.46	210.27	24.69	234.96	291.97
UTSYMUIB1	Tails	3.23	4.95	11.35	20.12	0.21	8.15	1.59	0.41	1.36	0.17	0.89	0.17	0.46	0.48	0.07	41.43	4.03	45.45	53.63
WYBTMPRB1	Feed	22.98	39.09	60.61	110.74	1.18	44.96	9.36	3.05	8.80	1.20	6.41	1.26	3.33	3.42	0.49	226.85	27.96	254.81	316.88
WYBTMPRB1	Conc	27.35	46.07	80.88	149.64	1.56	59.25	11.87	4.10	10.93	1.45	7.58	1.47	3.85	3.92	0.56	303.21	33.86	337.06	410.48
WYBTMPRB1	Tails	20.33	34.85	48.28	87.07	0.94	36.27	7.83	2.41	7.50	1.05	5.70	1.13	3.02	3.12	0.44	180.40	24.37	204.77	259.94
UTSUMUIB1	Feed	11.19	22.19	36.59	61.54	0.62	24.35	4.71	1.17	4.49	0.61	3.37	0.68	1.81	1.90	0.28	127.82	14.31	142.13	175.50
UTSUMUIB1	Conc	17.75	36.76	57.02	95.83	0.97	37.96	7.37	1.81	7.02	0.96	5.30	1.07	2.82	2.96	0.44	199.15	22.37	221.52	276.03
UTSUMUIB1	Tails	6.85	12.56	23.10	38.90	0.40	15.36	2.96	0.75	2.82	0.39	2.10	0.42	1.14	1.21	0.17	80.72	8.99	89.71	109.12
WYNMPRB1	Feed	24.09	41.87	59.54	110.24	1.15	46.15	9.85	3.30	9.45	1.28	6.92	1.36	3.58	3.61	0.53	226.94	30.05	256.99	322.95
WYNMPRB1	Conc	26.95	46.62	79.26	148.24	1.55	61.36	12.28	4.57	11.32	1.49	7.83	1.52	3.91	3.92	0.57	302.69	35.13	337.82	411.39
WYNMPRB1	Tails	23.42	40.76	54.92	101.33	1.06	42.58	9.29	3.00	9.01	1.24	6.70	1.33	3.50	3.54	0.52	209.17	28.85	238.03	302.21
MORMPRB2	Feed	12.04	16.82	34.24	60.02	0.54	22.18	4.59	1.50	4.14	0.57	3.05	0.60	1.41	1.48	0.24	121.58	12.98	134.56	163.42
MORMPRB2	Conc	11.56	17.95	43.12	74.90	0.62	26.90	5.41	1.19	4.93	0.65	3.39	0.63	1.35	1.37	0.23	150.94	13.74	164.68	194.19
MORMPRB2	Tails	12.10	16.67	33.10	58.12	0.53	21.58	4.49	1.54	4.03	0.56	3.01	0.59	1.42	1.50	0.24	117.82	12.89	130.71	159.48
COTMGRB1	Feed	15.36	36.68	75.12	136.33	1.30	51.93	10.31	3.24	9.33	1.19	6.27	1.23	3.05	3.32	0.53	274.99	28.17	303.16	355.21
COTMGRB1	Conc	15.59	37.23	76.32	138.44	1.32	52.73	10.46	3.29	9.48	1.21	6.37	1.25	3.10	3.37	0.53	279.28	28.60	307.88	360.70
COTMGRB1	Tails	3.50	7.24	11.12	23.95	0.22	9.50	2.00	0.94	1.75	0.22	1.20	0.24	0.55	0.62	0.10	46.79	5.62	52.41	63.15
UTWMUIB1	Feed	12.64	37.95	50.06	84.73	0.87	37.58	7.08	1.74	6.88	0.93	5.58	1.14	2.70	2.77	0.47	180.32	22.22	202.54	253.13
UTWMUIB1	Conc	22.77	67.23	87.16	144.75	1.48	63.34	11.89	2.79	11.69	1.59	9.60	1.98	4.71	4.84	0.82	308.61	38.01	346.63	436.62
UTWMUIB1	Tails	3.01	10.12	14.79	27.68	0.29	13.08	2.51	0.75	2.31	0.30	1.75	0.34	0.80	0.81	0.13	58.37	7.20	65.57	78.70
WYKMGRB2	Feed	13.68	45.00	36.87	64.72	0.70	31.81	6.50	1.59	6.68	0.95	5.83	1.21	2.88	2.86	0.48	140.59	22.47	163.06	221.74
WYKMGRB2	Conc	17.56	58.62	61.02	102.57	1.09	49.72	9.68	2.26	9.54	1.32	8.05	1.61	3.73	3.71	0.64	224.09	30.88	254.96	331.14
WYKMGRB2	Tails	13.58	44.67	36.27	63.78	0.69	31.37	6.42	1.57	6.60	0.94	5.78	1.20	2.86	2.83	0.48	138.53	22.26	160.80	219.04

Table 43: REE+Y+Sc, ash, fixed C, sulfur, and volatiles in whole sample within flotation separation partitions

Sample Name	Stream Name	Mass fraction	Sc in sample (ppm)	Y in sample (ppm)	La in sample (ppm)	Ce in sample (ppm)	Pr in sample (ppm)	Nd in sample (ppm)	Sm in sample (ppm)	Eu in sample (ppm)	Gd in sample (ppm)	Tb in sample (ppm)	Dy in sample (ppm)	Ho in sample (ppm)	Er in sample (ppm)	Yb in sample (ppm)	Lu in sample (ppm)	Ash (%)	Fixed Carbon (%)	Sulfur (%)	Volatile Matter (%)	LREE (ppm)	HREE (ppm)	REE (ppm)	REE+Y+Sc (ppm)
NDBMFUB1	Feed	300.00	3.94	8.49	4.41	8.26	0.08	3.64	0.96	0.31	1.13	0.19	1.15	0.24	0.57	0.59	0.10	10.94	43.04	0.57	46.06	17.35	4.29	21.63	34.06
NDBMFUB1	Conc	56.05	4.58	9.86	5.87	10.70	0.10	4.58	1.16	0.36	1.33	0.22	1.32	0.28	0.66	0.69	0.12	12.85	40.77	0.56	46.47	22.41	4.97	27.38	41.82
NDBMFUB1	Tails	243.95	3.79	8.18	4.08	7.69	0.07	3.42	0.91	0.30	1.09	0.18	1.11	0.24	0.55	0.57	0.10	10.51	43.56	0.57	45.96	16.18	4.13	20.31	32.28
NDBMFUB2	Feed	300.00	0.46	1.55	2.70	4.23	0.04	1.50	0.30	0.14	0.29	0.04	0.22	0.04	0.10	0.11	0.02	5.89	50.86	0.21	42.64	8.76	0.96	9.72	11.73
NDBMFUB2	Conc	39.75	0.53	1.86	3.55	5.64	0.05	1.96	0.38	0.16	0.36	0.05	0.26	0.05	0.12	0.13	0.02	6.74	52.38	0.16	40.80	11.58	1.16	12.73	15.13
NDBMFUB2	Tails	260.25	0.45	1.50	2.56	4.01	0.03	1.43	0.29	0.13	0.28	0.04	0.21	0.04	0.10	0.11	0.02	5.76	50.63	0.22	42.92	8.33	0.93	9.26	11.20
UTSYMUIB1	Feed	400.00	1.18	2.72	4.36	6.58	0.09	2.88	0.56	0.13	0.53	0.07	0.39	0.08	0.23	0.23	0.03	7.41	49.61	0.54	41.99	14.46	1.69	16.15	20.05
UTSYMUIB1	Conc	393.93	1.17	2.73	4.35	6.55	0.09	2.86	0.55	0.13	0.52	0.07	0.39	0.08	0.23	0.23	0.03	6.85	49.99	0.54	42.15	14.41	1.69	16.10	20.00
UTSYMUIB1	Tails	6.07	1.40	2.15	4.93	8.74	0.09	3.54	0.69	0.18	0.59	0.08	0.39	0.08	0.20	0.21	0.03	43.43	24.90	0.60	31.66	17.99	1.75	19.74	23.29
WYBTMPRB1	Feed	400.00	1.60	2.72	4.21	7.70	0.08	3.12	0.65	0.21	0.61	0.08	0.45	0.09	0.23	0.24	0.03	6.95	48.67	0.33	43.73	15.76	1.94	17.71	22.02
WYBTMPRB1	Conc	158.26	1.82	3.06	5.37	9.94	0.10	3.94	0.79	0.27	0.73	0.10	0.50	0.10	0.26	0.26	0.04	6.64	49.51	0.27	43.35	20.14	2.25	22.39	27.27
WYBTMPRB1	Tails	241.74	1.45	2.49	3.45	6.22	0.07	2.59	0.56	0.17	0.54	0.07	0.41	0.08	0.22	0.22	0.03	7.15	48.12	0.37	43.97	12.90	1.74	14.64	18.58
UTSUMUIB1	Feed	400.00	0.88	1.74	2.87	4.83	0.05	1.91	0.37	0.09	0.35	0.05	0.26	0.05	0.14	0.15	0.02	7.85	49.44	0.34	40.07	10.03	1.12	11.15	13.77
UTSUMUIB1	Conc	247.98	0.89	1.85	2.87	4.82	0.05	1.91	0.37	0.09	0.35	0.05	0.27	0.05	0.14	0.15	0.02	5.03	51.00	0.35	40.90	10.02	1.13	11.15	13.89
UTSUMUIB1	Tails	152.02	0.85	1.56	2.87	4.84	0.05	1.91	0.37	0.09	0.35	0.05	0.26	0.05	0.14	0.15	0.02	12.43	46.91	0.33	38.70	10.04	1.12	11.15	13.57
WYNMPRB1	Feed	400.00	1.52	2.64	3.75	6.95	0.07	2.91	0.62	0.21	0.60	0.08	0.44	0.09	0.23	0.23	0.03	6.31	49.32	0.26	45.14	14.31	1.89	16.20	20.36
WYNMPRB1	Conc	81.51	1.58	2.74	4.66	8.72	0.09	3.61	0.72	0.27	0.67	0.09	0.46	0.09	0.23	0.23	0.03	5.88	49.21	0.24	45.13	17.80	2.07	19.86	24.19
WYNMPRB1	Tails	318.49	1.50	2.61	3.52	6.50	0.07	2.73	0.60	0.19	0.58	0.08	0.43	0.09	0.22	0.23	0.03	6.41	49.35	0.27	45.14	13.42	1.85	15.27	19.39
MORMPRB2	Feed	400.00	1.17	1.63	3.33	5.83	0.05	2.15	0.45	0.15	0.40	0.06	0.30	0.06	0.14	0.14	0.02	9.71	53.31	0.40	37.01	11.81	1.26	13.07	15.87
MORMPRB2	Conc	51.92	0.98	1.52	3.66	6.36	0.05	2.28	0.46	0.10	0.42	0.06	0.29	0.05	0.11	0.12	0.02	8.49	53.54	0.26	37.98	12.82	1.17	13.98	16.49
MORMPRB2	Tails	348.08	1.20	1.65	3.28	5.75	0.05	2.14	0.44	0.15	0.40	0.06	0.30	0.06	0.14	0.15	0.02	9.89	53.28	0.42	36.87	11.66	1.28	12.93	15.78
COTMGRB1	Feed	400.00	0.67	1.61	3.30	5.99	0.06	2.28	0.45	0.14	0.41	0.05	0.28	0.05	0.13	0.15	0.02	4.39	56.06	0.41	39.55	12.07	1.24	13.31	15.60
COTMGRB1	Conc	393.61	0.68	1.63	3.34	6.06	0.06	2.31	0.46	0.14	0.42	0.05	0.28	0.05	0.14	0.15	0.02	4.38	56.06	0.41	39.57	12.23	1.25	13.48	15.80
COTMGRB1	Tails	6.39	0.18	0.37	0.56	1.21	0.01	0.48	0.10	0.05	0.09	0.01	0.06	0.01	0.03	0.03	0.01	5.07	56.20	0.40	38.73	2.37	0.29	2.66	3.20
UTWMUIB1	Feed	400.00	1.07	3.18	4.13	6.93	0.07	3.00	0.56	0.14	0.55	0.08	0.46	0.10	0.22	0.22	0.04	5.39	55.23	1.27	37.04	16.49	2.03	18.52	22.77
UTWMUIB1	Conc	379.39	1.11	3.30	4.28	7.17	0.07	3.10	0.58	0.14	0.57	0.08	0.47	0.10	0.23	0.23	0.04	5.18	57.22	1.27	37.84	14.94	1.84	16.78	21.19
UTWMUIB1	Tails	20.61	0.28	0.94	1.37	2.55	0.03	1.21	0.23	0.07	0.21	0.03	0.16	0.03	0.07	0.07	0.01	9.27	18.44	1.16	22.29	34.46	4.25	38.71	39.93
WYKMGRB2	Feed	400.00	1.25	4.13	3.38	5.94	0.06	2.92	0.60	0.15	0.61	0.09	0.54	0.11	0.26	0.26	0.04	9.17	47.79	0.36	43.03	12.90	2.06	14.96	20.34
WYKMGRB2	Conc	12.81	1.21	4.04	4.21	7.07	0.08	3.43	0.67	0.16	0.66	0.09	0.55	0.11	0.26	0.26	0.04	6.89	46.18	0.33	46.94	15.44	2.13	17.57	22.82
WYKMGRB2	Tails	387.19	1.26	4.13	3.35	5.90	0.06	2.90	0.59	0.15	0.61	0.09	0.53	0.11	0.26	0.26	0.04	9.25	47.84	0.36	42.90	12.81	2.06	14.87	20.26

Table 44: Calculated recoveries for REE+Y+Sc, ash, fixed C, sulfur, and volatiles relative to both partitions obtained using flotation separation

Sample Name	Stream Name	R_{Sc} (%)	R_{Y} (%)	R_{La} (%)	R_{Ce} (%)	R_{Pr} (%)	R_{Nd} (%)	R_{Sm} (%)	R_{Eu} (%)	R_{Gd} (%)	R_{Tb} (%)	R_{Dy} (%)	R_{Ho} (%)	R_{Er} (%)	R_{Yb} (%)	R_{Lu} (%)	R_{Ash} (%)	J_{Ash} (%)	R_{FixC} (%)	R_{S} (%)	J_{S} (%)	R_{vol} (%)	R_{REE} (%)	R_{Comb} (%)	Mass Yield (%)
NDBMFUB1	Conc	21.71	21.69	24.84	24.22	24.44	23.52	22.63	21.80	21.96	21.64	21.46	21.28	21.49	21.79	21.34	21.94	78.06	17.70	18.40	81.60	18.85	23.65	18.28	18.68
NDBMFUB1	Tails	78.29	78.31	75.16	75.78	75.56	76.48	77.37	78.20	78.04	78.36	78.54	78.72	78.51	78.21	78.66	78.06	21.94	82.30	81.60	18.40	81.15	76.35	81.72	81.32
NDBMFUB2	Conc	15.37	15.93	17.45	17.68	17.52	17.30	16.80	15.79	16.60	16.23	15.94	15.65	15.48	15.60	15.27	15.15	84.85	13.64	10.04	89.96	12.68	17.37	13.13	13.25
NDBMFUB2	Tails	84.63	84.07	82.55	82.32	82.48	82.70	83.20	84.21	83.40	83.77	84.06	84.35	84.52	84.40	84.73	84.85	15.15	86.36	89.96	10.04	87.32	82.63	86.87	86.75
UTSYMUIB1	Conc	98.19	98.80	98.28	97.98	98.52	98.13	98.11	97.99	98.29	98.39	98.50	98.57	98.65	98.62	98.50	91.10	8.90	99.24	98.32	1.68	98.86	98.14	99.07	98.48
UTSYMUIB1	Tails	1.81	1.20	1.72	2.02	1.48	1.87	1.89	2.01	1.71	1.61	1.50	1.43	1.35	1.38	1.50	8.90	91.10	0.76	1.68	98.32	1.14	1.86	0.93	1.52
WYBTMPRB1	Conc	45.02	44.57	50.47	51.11	50.19	49.85	47.96	50.82	47.01	45.71	44.73	44.28	43.65	43.30	43.38	37.83	62.17	40.25	32.35	67.65	39.23	50.04	39.70	39.57
WYBTMPRB1	Tails	54.98	55.43	49.53	48.89	49.81	50.15	52.04	49.18	52.99	54.29	55.27	55.72	56.35	56.70	56.62	62.17	37.83	59.75	67.65	32.35	60.77	49.96	60.30	60.43
UTSUMUIB1	Conc	63.11	65.89	61.98	61.93	61.73	62.00	62.18	61.53	62.19	62.25	62.47	62.68	62.09	61.78	62.19	39.77	60.23	63.94	63.39	36.61	63.29	61.99	63.89	61.99
UTSUMUIB1	Tails	36.89	34.11	38.02	38.07	38.27	38.00	37.82	38.47	37.81	37.75	37.53	37.32	37.91	38.22	37.81	60.23	39.77	36.06	36.61	63.39	36.71	38.01	36.11	38.01
WYNMPRB1	Conc	21.25	21.15	25.29	25.55	25.57	25.26	23.67	26.31	22.76	21.97	21.49	21.15	20.76	20.59	20.43	19.00	81.00	20.33	18.53	81.47	20.37	24.97	20.47	20.38
WYNMPRB1	Tails	78.75	78.85	74.71	74.45	74.43	74.74	76.33	73.69	77.24	78.03	78.51	78.85	79.24	79.41	79.57	81.00	19.00	79.67	81.47	18.53	79.63	75.03	79.53	79.62
MORMPRB2	Conc	10.89	12.12	14.29	14.16	12.90	13.76	13.37	9.04	13.53	12.90	12.61	11.98	10.84	10.46	11.12	11.35	88.65	13.04	8.45	91.55	13.32	13.89	13.16	12.98
MORMPRB2	Tails	89.11	87.88	85.71	85.84	87.10	86.24	86.63	90.96	86.47	87.10	87.39	88.02	89.16	89.54	88.88	88.65	11.35	86.96	91.55	8.45	86.68	86.11	86.84	87.02
COTMGRB1	Conc	99.58	99.64	99.73	99.68	99.69	99.66	99.64	99.46	99.65	99.65	99.65	99.64	99.67	99.66	99.65	98.15	1.85	98.40	98.44	1.56	98.44	99.68	98.41	98.40
COTMGRB1	Tails	0.42	0.36	0.27	0.32	0.31	0.34	0.36	0.54	0.35	0.35	0.35	0.36	0.33	0.34	0.35	1.85	98.15	1.60	1.56	98.44	1.56	0.32	1.59	1.60
UTWMUIB1	Conc	87.79	86.32	84.85	83.25	82.80	82.15	81.80	77.89	82.78	83.30	83.89	84.62	84.84	85.08	85.40	48.73	51.27	97.36	73.93	26.07	95.28	83.40	95.06	94.85
UTWMUIB1	Tails	12.21	13.68	15.15	16.75	17.20	17.85	18.20	22.11	17.22	16.70	16.11	15.38	15.16	14.92	14.60	51.27	48.73	2.64	26.07	73.93	4.72	16.60	4.94	5.15
WYKMGRB2	Conc	3.09	3.13	3.98	3.81	3.76	3.76	3.58	3.43	3.44	3.35	3.32	3.21	3.12	3.13	3.24	2.41	97.59	3.09	2.94	97.06	3.49	3.76	3.28	3.20
WYKMGRB2	Tails	96.91	96.87	96.02	96.19	96.24	96.24	96.42	96.57	96.56	96.65	96.68	96.79	96.88	96.87	96.76	97.59	2.41	96.91	97.06	2.94	96.51	96.24	96.72	96.80