Technical Report

In support of data uploaded for DE EE0007603
"Assessing rare earth element concentrations in geothermal and oil and gas produced waters: A potential domestic source of strategic mineral commodities"

Description: This report contains rare earth element concentrations of reservoir rock associated with Wyoming oil and gas reservoirs. These data accompany water samples collected from the same reservoir as part of this study.

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Introduction

This work (Task 3 within)was developed to complement the geochemical assessments of produced water and geothermal water samples. Specifically, this task was designed to test the influence of reservoir rock-type and corresponding mineralogy/geochemistry on the concentrations of REE found in oil and gas produced waters. There has been no direct investigation of REE reactions relative to rock-type in deep oil and gas brine prior to this investigation. At most we have inferences of these potential reactions. For instance, brines from mature sandstone reservoirs may have lower Eu concentrations than brines associated with unaltered basalt due to the higher abundance of plagioclase feldspar in basalt.

Task 3 consists of three subtasks: (1) subtask 3.1, Analyze whole rock geochemistry and REE; (2) subtask 3.2, Analyze minerals and crystallography; and (3) subtask 3.3, Measure cation exchange capacities of selected rock samples. This task also includes two Milestones for Budget Period 1, described below. Milestone 3-1 has been completed and is documented in this report. Milestone 3-2 has also been completed and is documented in Attachments A, B, and C.

Milestones for Budget Period 1

3-1 Complete analysis of major, minor elements, and REEs, in rock samples related to OGTW

3-2 Format rock data into templates and upload to the National Geothermal Repository

All rock samples have varying REE concentrations that exceed those of the analyzed brines, suggesting the potential for influencing the compositions of the fluids.

Sample Selection Methodology

A total of 101 rock samples were collected for analysis. Eighty-eight reservoir rock samples were selected from the catalog available at the USGS Core Research Center, Lakewood, Colorado (Figures 1 and 2). Specific samples were down-selected by proximity, formation, and reservoir interval relative to the wells sampled in Task 2, as well as evaluated for facies variation and reservoir character using geophysical data available at the Wyoming Oil and Gas Commission website (Figure 3).

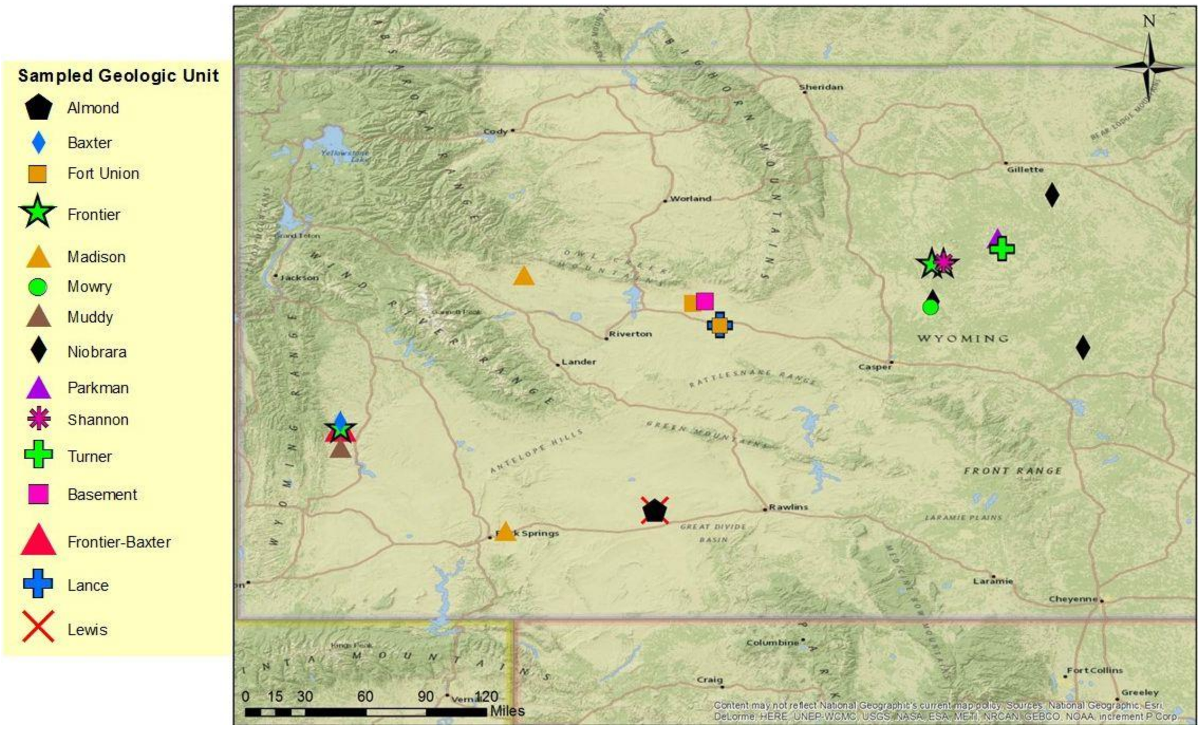


Figure 1: The location and formation of oil and gas core collected at the USGS Core Research Center. Core is representative of the three major basins where produced water samples were collected, and correlates to sampled intervals.

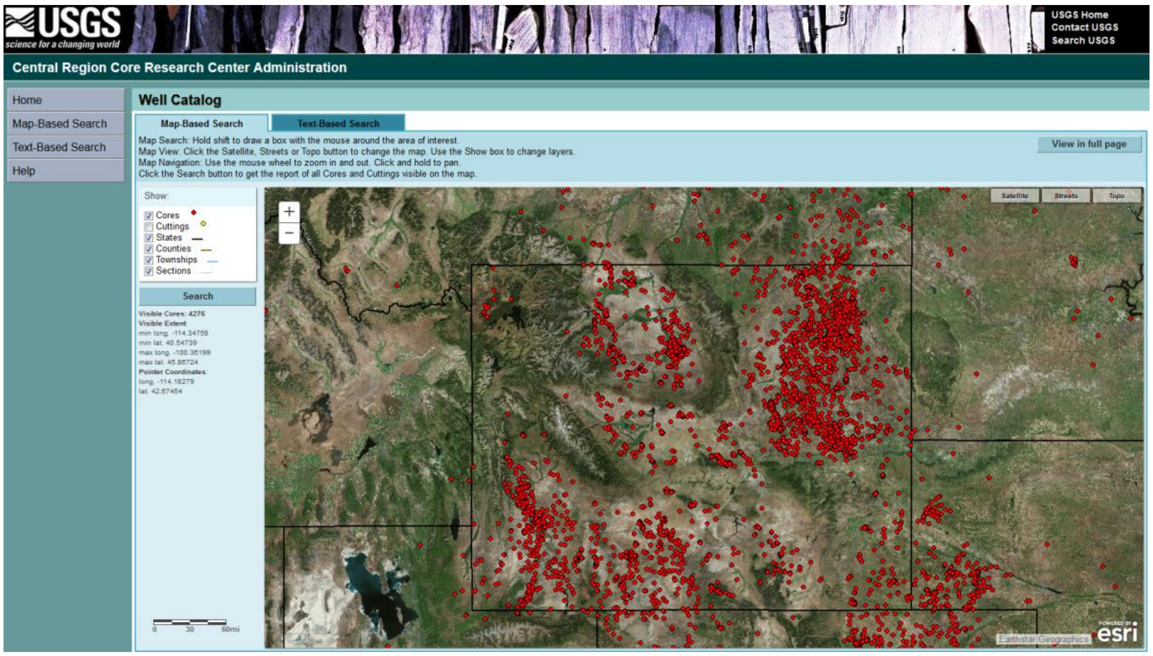
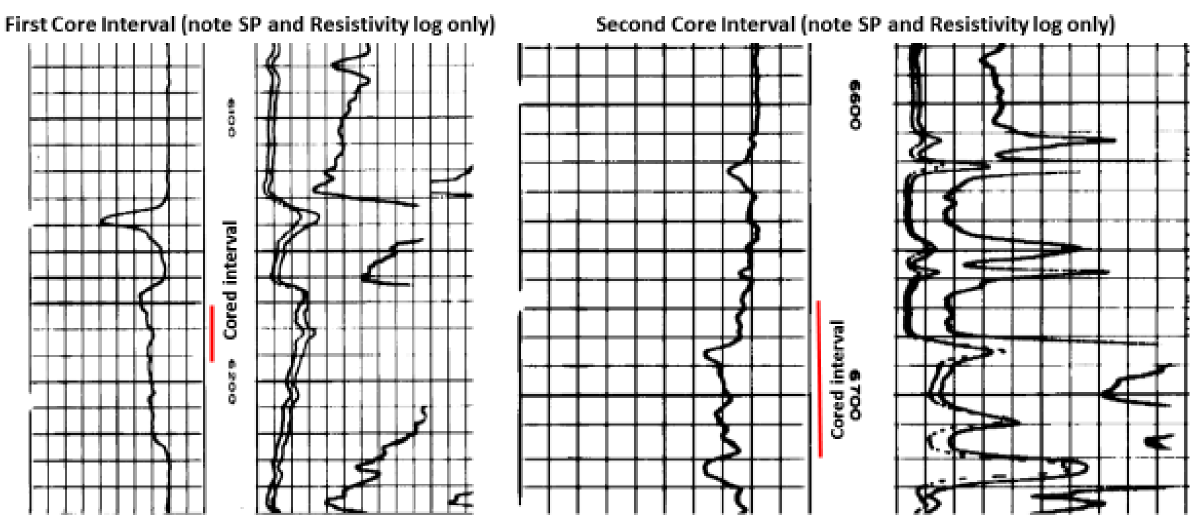


Figure 2: Screen capture of all core (red dots) in Wyoming available from the USGS Core Research Center Database and surrounding states (as of 6/10/2017). These data represent all available core; sample selection was refined relative to available core, proximity to sampled wells, reservoir interval, and reservoir character.



Api #: 4900922783 B209 Frontier Formation

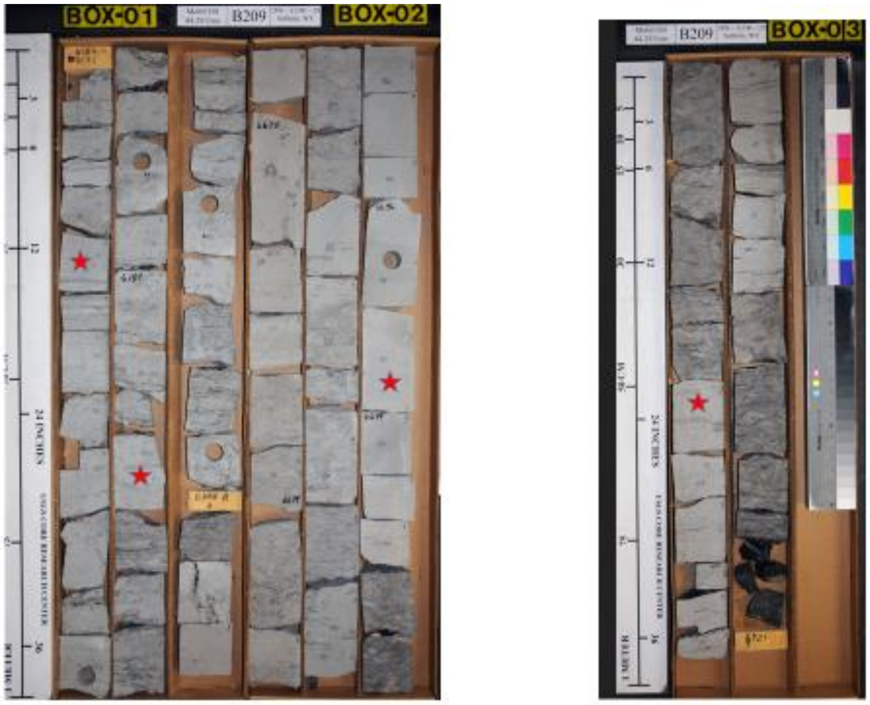


Figure 3: Petrophysical data (top) from the Wyoming Oil and Gas Commission website, and corresponding core box photos (bottom) from the USGS CRC website. Most samples were selected after analysis of petrophysical log data to verify the best reservoir intervals. The paired geophysical logs at the top of the figure show the interval of the Frontier Formation with available core (highlighted by red line adjacent to SP log). The core boxes at the bottom of the figure have red stars indicating samples selected for analysis.

Thirteen rock samples were collected in the field to correspond with naturally occurring geothermal samples that were analyzed by Idaho National Laboratories (Idaho Falls, ID) (Figure 4). Representative samples were selected of specific rock types in which geothermal waters occur. Broader geologic regions associated with these rock types include the Snake River Plain (SRP), Basin and Range structures east of the SRP, and large scale/deep seated orogenic uplifts of the Sawtooth Mountains, ID.

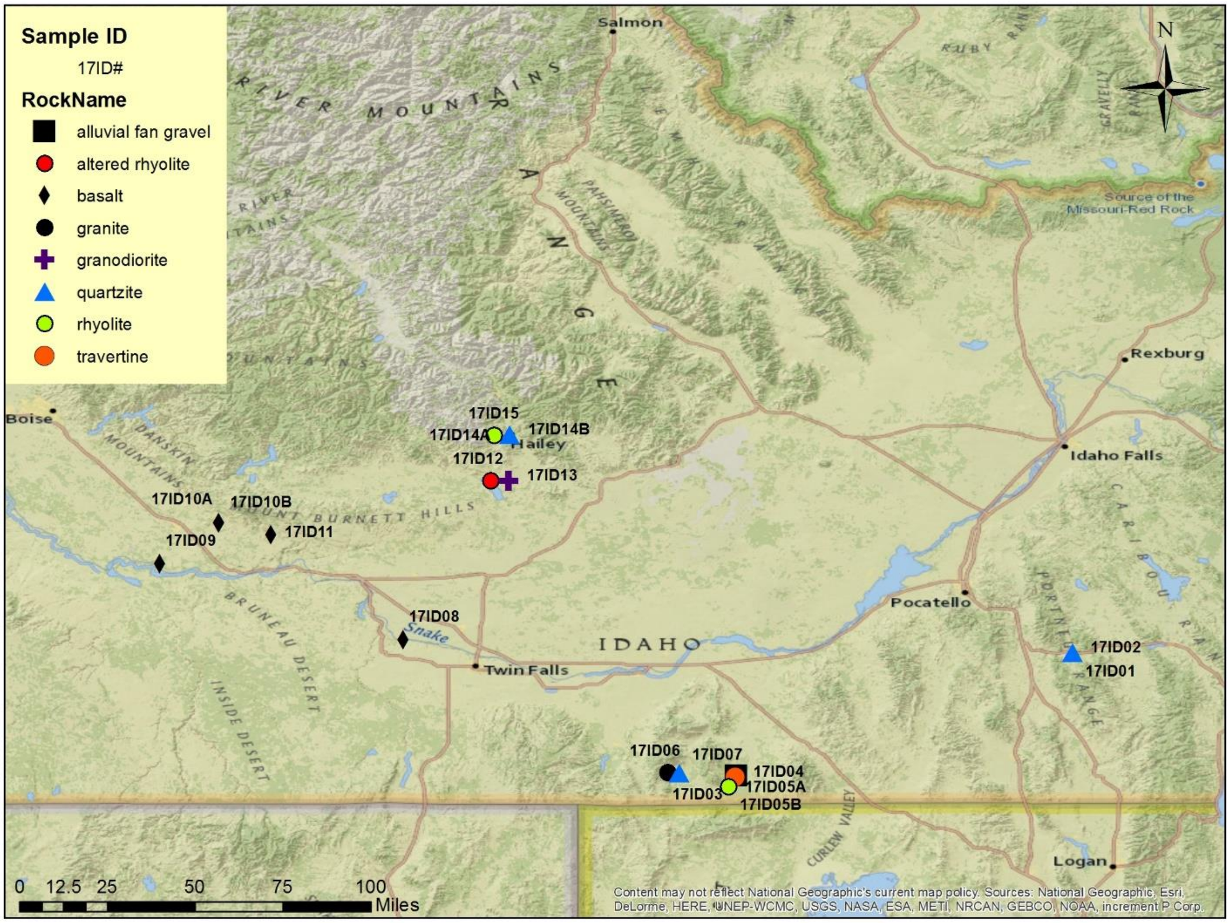


Figure 4: Sample locations, identification number and lithology of samples collected to complement geothermal water samples in Idaho.

Analysis

After selection, samples were split for thin section preparation, geochemical analysis and advanced petrologic analysis methods including SEM or microprobe. Samples selected for petrographic analysis were shipped to Wagner Petrographic for thin section preparation. Most slides were impregnated with blue epoxy for porosity evaluation and stained for carbonate evaluation. Samples selected for geochemical analysis were shipped to ALS Geochemistry. Major oxide compositions were determined using ALS Geochemistry analytical protocol ME-ICP06 and ME-MS81; ICP-AES was performed and coupled with results from ICP-MS analysis. Processing the samples for major and trace element compositions included the complete solubilization of highly refractory REE-bearing minerals, such as zircon and monazite, to obtain realistic REE compositions. Data from the geochemical analysis of oil and gas reservoir rock are presented in Attachments A and B. Data from the geochemical analysis of geothermal rock samples from Idaho are presented in Attachment C.

Results

Oil and Gas Reservoirs

Samples from oil and gas reservoirs are divided into subgroups of rock type. Subgroups include shale, sandstone and carbonate, along with basement rocks from cuttings in deeper wells. All samples have been normalized to the North American Shale Composite (NASC) (Condie, 1993).

Overall, shale samples trend to a NASC normalized value of 1 (Figure 5). Interpreting REE concentrations per formation shows that: (1) Baxter Shale samples are depleted relative to NASC; (2) Lewis Shale samples are enriched in LREEs and depleted in HREEs relative to NASC; (3) Mowry Shale samples are both enriched and depleted in total REEs relative to NASC; and (4) the majority of Niobrara Shale samples are depleted in total REEs relative to NASC, with some enrichment in LREEs; a single sample has REE enrichment; another sample has a significant depletion in LREEs.

Niobrara Shale samples with relative enrichment in HREEs compared to LREEs are interpreted to be potentially influenced by organic content, illitic clay content, or the presence of zircon (Wani and Mondal, 2011; Uysal and Golding, 2003; Condie, 1991). Those samples with REE patterns with negative slopes (LREEs>HREEs), such as the Lewis Shale, are likely reflecting the REE composition of clastic detrital materials.

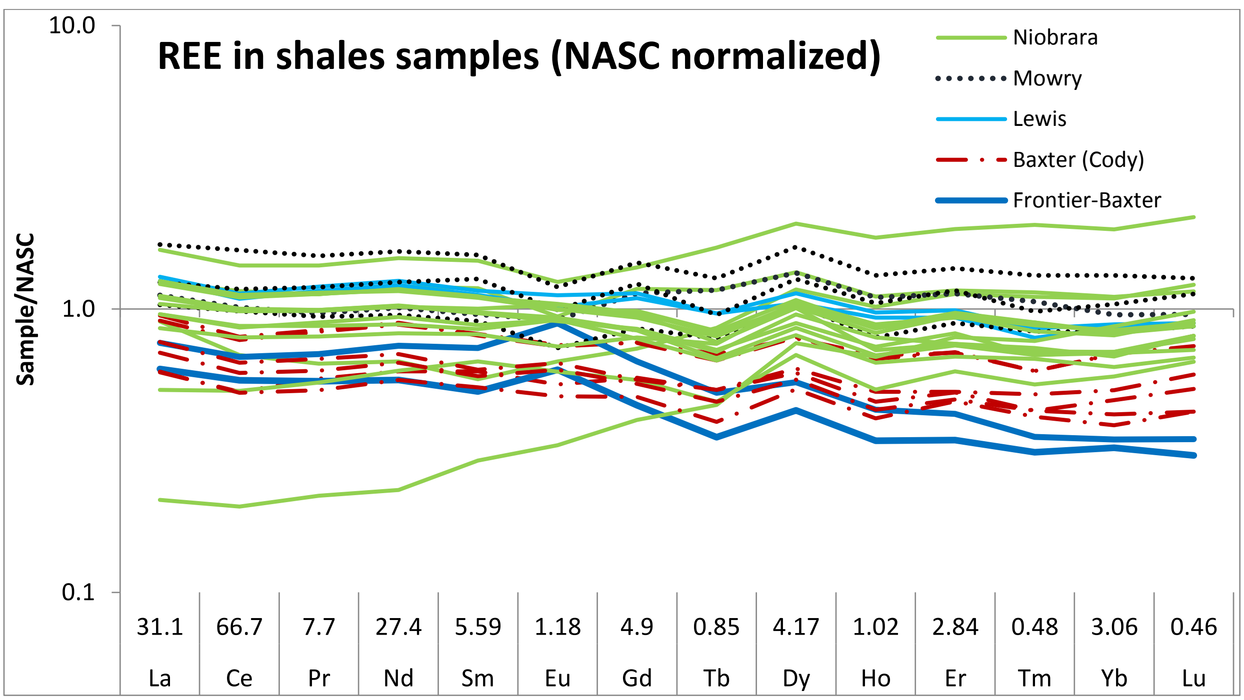


Figure 5: REE concentrations of shale samples collected at the Core Research Center normalized to the North American Shale Composite (NASC) (Gromet et al., 1984). Normalizing values are provided in the X-axis; Y-axis is logarithmic and unitless due to normalization. While

most samples follow the NASC trend, some are enriched in HREE and nearly all Wyoming shales have a Dy and Gd enrichment.

Samples from sandstone reservoir basins have typical clastic sediment REE patterns (Kritsananuwat, et al. 2014; Condie 1991), with LREE enrichment relative to HREE (Figure 6). Most sandstone samples -- including those from the Almond, Fort Union, Lance, Shannon, Frontier, and Parkman formations -- have total REE values lower than NASC. This is expected of a detrital sediment with a high percentage of non-REE bearing minerals such as quartz. One Frontier Formation sample has total REE enrichment relative to NASC, and a few Muddy and Turner formation samples have slightly elevated concentrations of LREEs relative to NASC.

One Frontier Formation sample has increased MREE concentrations compared to NASC. This increase may indicate hydrothermal deposition of REEs in a redox boundary of the sediment, or a mineral control that is different than other sandstone samples. Additionally, a single Muddy Formation sample exhibits a steeper decreasing slope from LREEs to HREEs compared with other Muddy Formation samples. This is likely indicative of a mineral component, such as monazite, increasing the LREE concentration.

Madison Limestone is the only carbonate lithology assessed in this study (Figure 6). All carbonate samples are depleted in total REEs and have flatter overall NASC normalized REE patterns. There are two groupings of REE concentrations in the Madison samples. Three of the ten samples have relatively flat REE NASC normalized profiles, and the remaining samples have variable saw-tooth patterns and lower REE concentrations. This may represent groups of carbonates that have different rock/water interaction variables, although analytical variability cannot be currently removed from consideration.

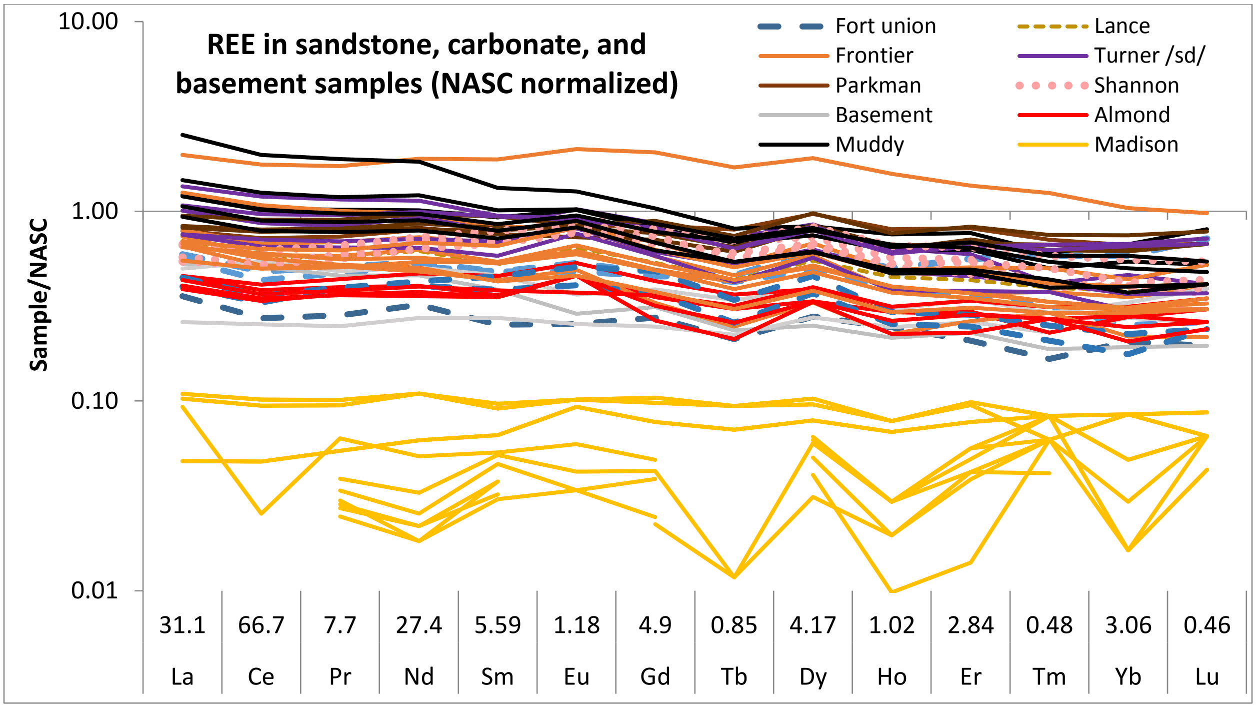


Figure 6: REE concentrations of sandstone, carbonate, and basement samples collected at the Core Research Center normalized to the North American Shale Composite (Gromet et al., 1984). Normalizing values are provided in the X-axis; Y-axis is logarithmic and unit-less due to normalization. Note that most sandstones have a light to heavy REE depletion profile (relative to NASC), and that carbonates have distinctly low REE profiles.

Rock Samples Associated with Geothermal Waters in Idaho

Several lithologies were identified as host reservoirs to the geothermal water samples collected from Idaho hot springs. Like oil and gas samples, all samples have been normalized to NASC (Gromet et al., 1984) for comparative analysis (Figure 7). Diversity of rock types in this evaluation has resulted in a wide variety of REE behaviors.

In general, basalt samples behave predictably (Condie, 1993). They cluster as a group and have positive Eu anomalies and slightly enriched HREEs. They are relatively enriched in total REEs compared to NASC. Despite variable hydrothermal alteration of these samples from relatively fresh to highly altered, they generally behave as single group. This initially suggests that most REEs have not been mobilized from these samples.

Rhyolite samples are less constrained, forming three REE profile types. Some samples have a typical rhyolite REE behavior (Condie, 1993), with enriched total REE concentrations and minor negative Eu anomalies. LREEs are slightly enriched, resulting in a negatively sloped REE trend. With respect to this study, it is important to note the REE trend exhibited by the altered rhyolite sample. This sample is similar in composition to the typical rhyolites described above, but has undergone significant alteration from geothermal fluids. This has resulted in a negative Eu anomaly. The remaining REE concentrations are enriched with respect to other rhyolite samples. This is expected when other whole-rock constituents or mineral species have been removed via hydrothermal alteration. The relative enrichment in LREE and HREE is evidence of these species remaining in the host rhyolite after alteration.

Idaho sandstone/quartzite host rocks have atypical REE trends. All quartzite samples are relatively depleted in total REEs when compared to NASC. Two hydrothermally altered samples have the lowest concentration of total REE of the Idaho suite. This is direct evidence of metasomatic alteration of REE minerals/compositions. Unaltered samples corresponding to these REE depleted samples were not found, so inferences of REE removal via hydrothermal alteration can only be suggested at this time. The significant negative Eu anomalies of the two depleted samples hint at hydrothermal alteration, but again, unaltered host rock will need to be evaluated before determination of this behavior. The remaining sandstone/quartzite samples appear to be similar to typical sandstones evaluated elsewhere and exhibit relatively greater LREE concentrations compared to HREEs, resulting in a negatively sloped REE profile.

Both a granite and granodiorite were evaluated for REE concentrations. They do not show evidence of hydrothermal loss of specific REE, and have typical REE behaviors (Condie, 1993). It is likely that hydrothermal waters sourced from these rocks have limited water/rock interaction. This is typical of jointing in basement rocks where hydrothermal fluid is restricted along conduits.

Alluvial fan deposits and travertine sourced from hydrothermal waters flowing through those deposits were sampled for REE concentrations. Results are inconclusive due to trace concentrations, but initial observation suggests travertine samples have a relative depletion in total REEs when compared to alluvial fan deposits and underlying rhyolites. REEs are likely not being dissolved from rock into fluid in significant concentrations in this particular system.

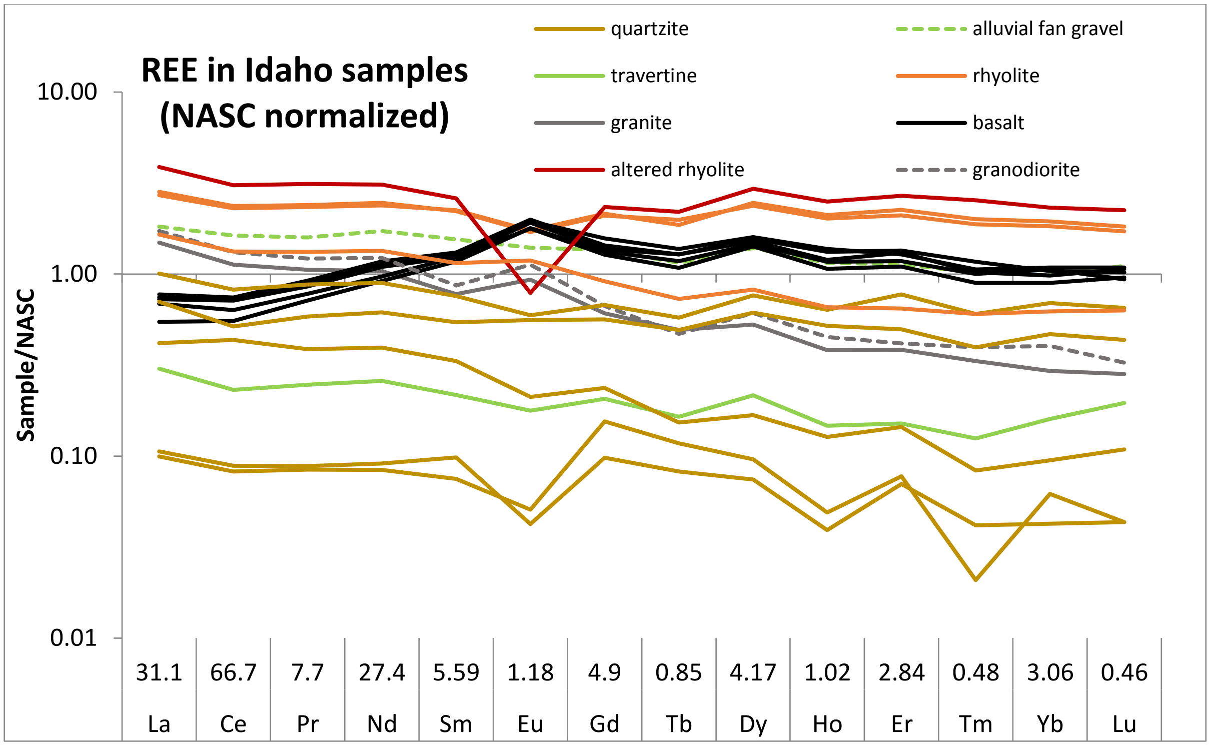


Figure 7: REE concentrations of Idaho rock samples collected in the field and normalized to the North American Shale Composite (Gromet et al., 1984). Normalizing values are provided in the X-axis; Y-axis is logarithmic and unitless due to normalization. REE concentrations of this sample set vary; notable conclusions include the low concentration of REE in quartzite samples (potentially indicative of REE solubilization) and Eu-enriched and Eu-depleted rhyolites.

Preliminary Results

Preliminary assessment of the relation of REE concentration to specific chemical elements indicates some correlations. Yttrium (Y), commonly used as a proxy for REE behavior, has an expected positive correlation to total REE concentrations in both CRC and Idaho samples (Figure 8). A "better fit correlation" is recorded between Thorium (Th) and total REE concentrations of all samples (Figure 9). This correlation may relate to a REE-bearing mineral(s) with a Th component that also contributes a majority percentage of total REE. In both oil and gas reservoir rocks and Idaho samples, monazite is a likely source because it is a common accessory mineral in sediments and a trace mineral in igneous rocks. Thorium is measured using the gamma log curves, and log response could be further analyzed for the development of a predictive tool for REE concentrations in oil and gas reservoirs. It is important to note that monazite is enriched with respect to LREEs instead of HREEs, suggesting additional influence from HREE minerals. Another common accessory mineral, zircon, also harbors REE in its structure. Figure 10 shows a weak correlation between Zirconium (Zr) and total REE concentrations (more so in Idaho samples), suggesting some influence of this mineral in total REE concentrations. Unlike monazite, zircon prefers HREEs to LREEs in its crystal structure.

The impact of weathering on REE concentrations is assessed using the Chemical Index of Alteration developed by Nesbitt and Young, 1982 (Figure 11). Additional analysis will be necessary relative to individual lithologies, as no trend is apparent with singular groupings (Figure 11).

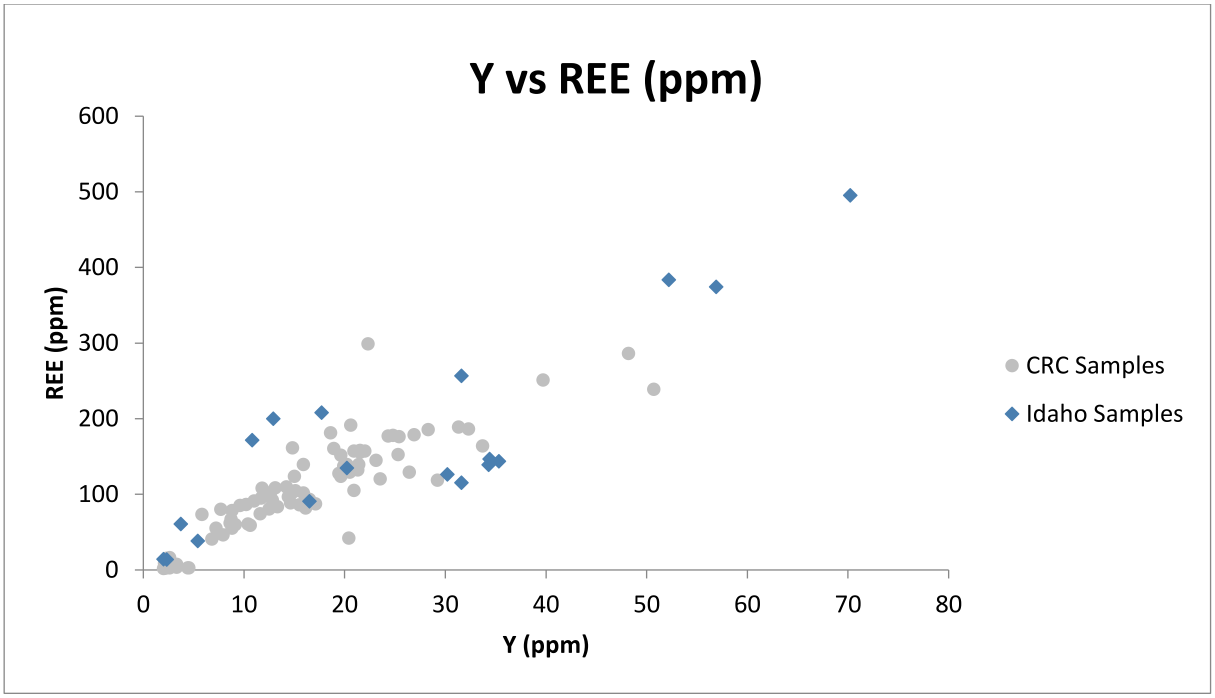


Figure 8: Bivariate plot of Y versus REE concentrations, in ppm, of oil and gas reservoir samples from the Core Research Center (CRC) and igneous and metasomatic rocks associated with geothermal springs in Idaho.

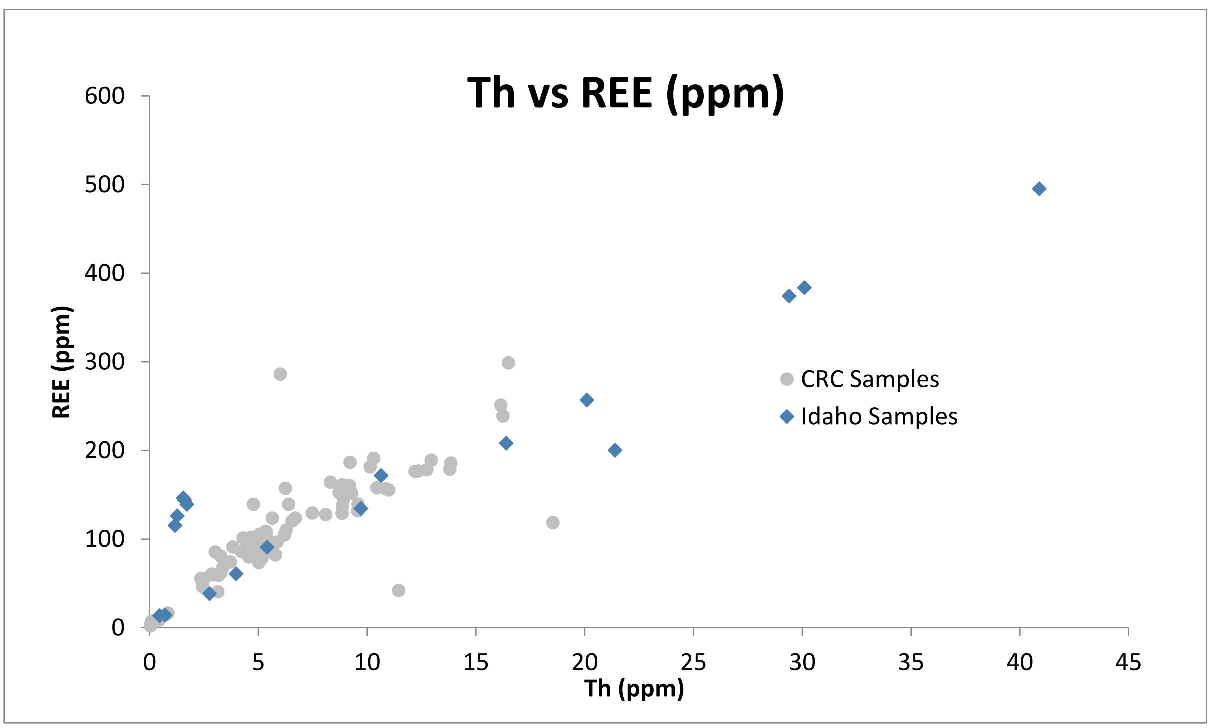


Figure 9: Bivariate plot of Th versus REE concentrations, in ppm, of oil and gas reservoir samples from the Core Research Center (CRC) and igneous and metasomatic rocks associated with geothermal springs in Idaho.

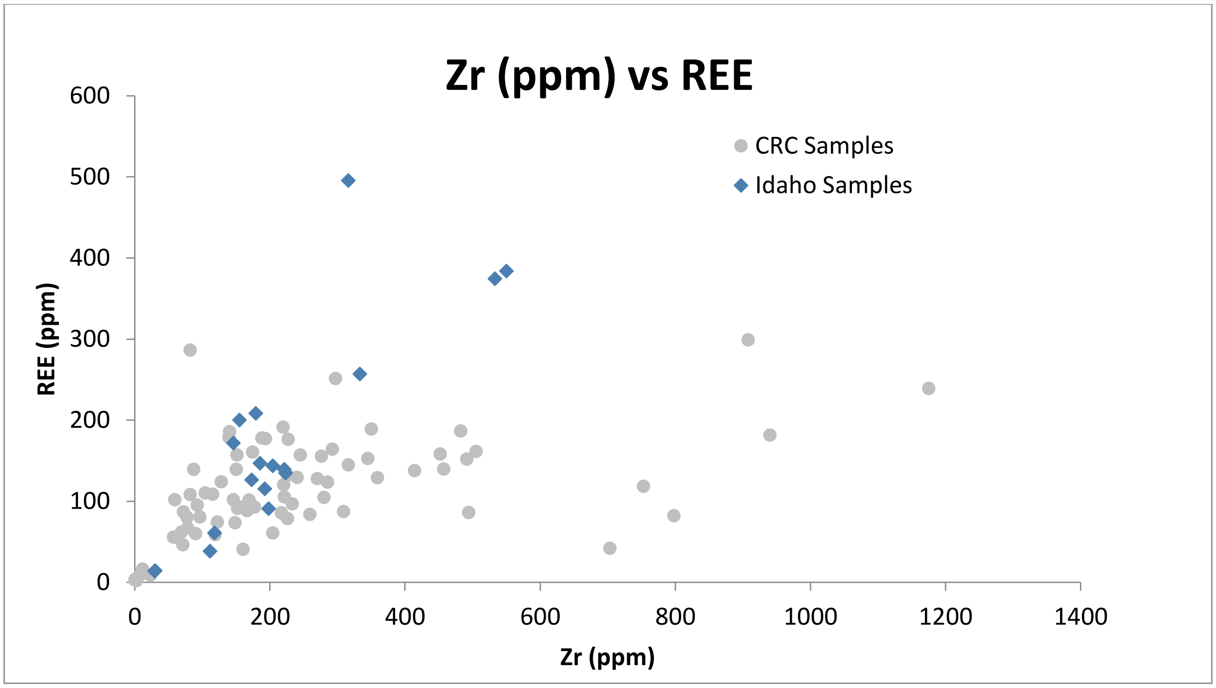


Figure 10: Bivariate plot of Zr versus REE concentrations, in ppm, of oil and gas reservoir samples from the Core Research Center (CRC) and igneous and metasomatic rocks associated with geothermal springs in Idaho.

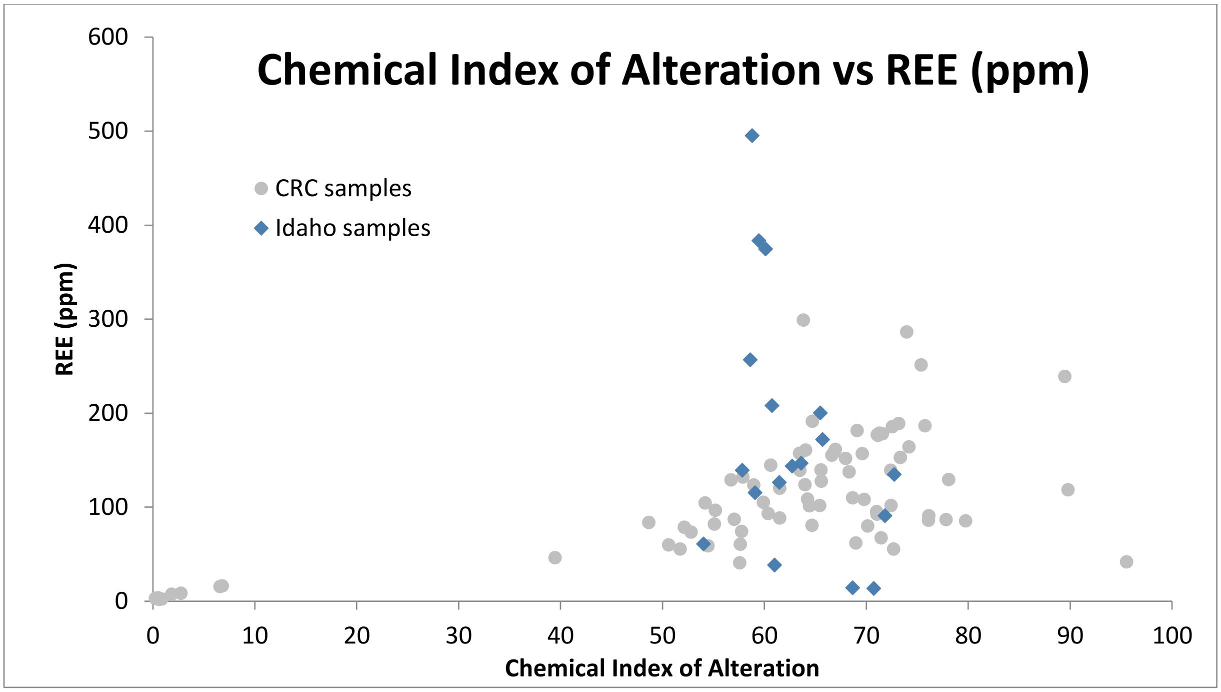


Figure 11: Bivariate plot of the Chemical Index of Alteration (after Nesbitt and Young, 1982) versus REE concentrations, in ppm, of oil and gas reservoir samples from the Core Research Center (CRC) and igneous and metasomatic rocks associated with geothermal springs in Idaho.

Some of the differences in reservoir rock mineral compositions and distributions are shown in Figures 12 (a and b) and 13 (a and b). The mineralogical differences due to hydrothermal alteration are displayed by Figures 12a and b. Both rock samples are porphyritic rhyolites from Idaho, though hydrothermal fluids have altered the sample in Figure 12b. This has resulted in degradation of reactive minerals, such as plagioclase and the formation of clay minerals. Figures 13a and b portray different lithologies from oil and gas reservoirs. The Muddy Formation is a typical immature Cretaceous sandstone (Figure 13a), with multiple generations of cements and numerous reactive minerals. This sample has a "sandstone typical" REE pattern of LREE>HREE (Figure 6), likely due to monazite as a primary accessory mineral. The sample of the Mowry Shale has a larger silt component than other shales (Figure 13b), but also contains organics in its matrix (typical of shale versus sandstone). The organics and/or illite clays likely contribute to the enrichment of MREE and HREE in the CRC samples (Figure 5).

Figures 12a and b: Figure 12a (top) shows a thin section of sample 17ID05A, a porphyritic rhyolite collected in Idaho. Figure 12b (bottom) shows a thin section of sample 17ID15, an altered porphyritic rhyolite sampled in Idaho. Note the relatively unaltered plagioclase, the significant mineral source of Eu, in Figure 12a relative to 12b.

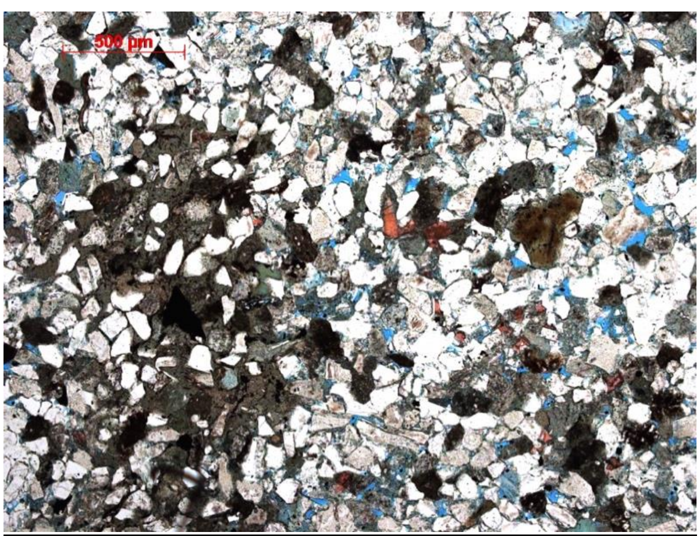
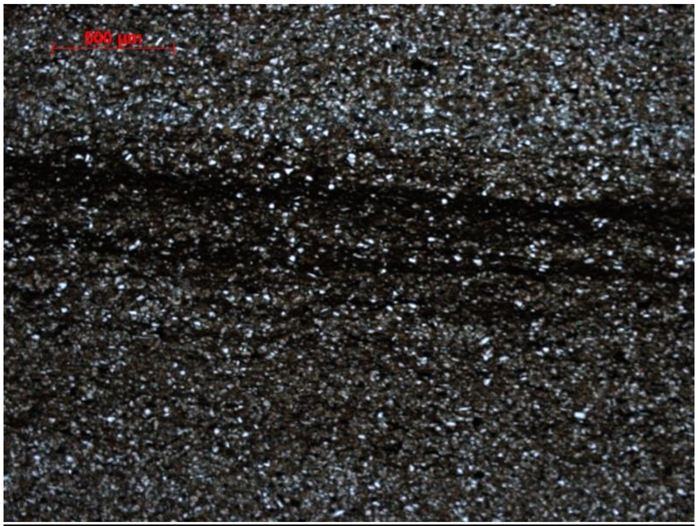


Figure 13a and b: Figure 13a (top) shows a thin section of sample D839, Muddy Formation, 8,204', which was collected at the USGS Core Research center. Figure 13b (bottom) shows a thin section of sample W075, Mowry Shale, 10,646.5' that was collected at the USGS Core Research center. Note the heterogeneity of detrital clasts and cements in the immature sediments of the Muddy. Relative to the sandstone, the Mowry Shale has a high organic component and finer grains.



Attachments

Appendix A and B contain the geochemical data analyzed from these samples.

References

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Appendix A

Major oxides

Major Oxide Whole Rock Geochemistry (1/4)															
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	Total
Sample ID	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
C233-8615.5	70.2	2.71	2.89	8.62	3.36	0.25	0.55	<0.01	0.08	0.04	0.13	0.01	0.03	11	99.87
C233-8790.5	85.6	2.82	2.59	2.84	1.67	0.22	0.41	<0.01	0.21	0.04	0.19	<0.01	0.12	4.32	101.03
S462-7431	81.4	4.02	1.94	3.53	2.04	0.07	0.83	<0.01	0.11	0.02	0.2	<0.01	0.01	6.11	100.28
C233-11919.5	86.9	4.71	1.96	2.13	0.79	0.28	0.85	<0.01	0.2	0.06	0.12	0.01	0.03	3.46	101.5
A648-6140	78.1	13.55	1.41	0.07	0.26	0.21	1.07	0.01	1.11	0.01	0.02	0.01	0.03	4.71	100.57
A648-6143	75.2	14.7	2.09	0.06	0.31	0.18	1.24	0.01	1.11	0.01	0.02	0.01	0.02	5.03	99.99
W074-11986	82	9.34	2.63	0.17	0.65	1.27	1.07	0.01	0.62	0.01	0.02	0.01	0.03	3.36	101.19
E173-12218	80.3	5.2	6.98	3.26	1.04	0.64	0.15	<0.01	0.13	0.03	1.1	0.02	0.03	3.09	101.97
E173-12227.5	86.8	6.05	3.62	0.35	0.56	1.31	0.6	<0.01	0.14	0.02	0.08	0.01	0.03	1.55	101.12
W075-10650	73	8.53	2.77	5.16	0.78	1.19	1	0.01	0.46	0.16	0.02	0.01	0.03	7.28	100.4
E124-10108.5	85.2	3.7	4.2	2.08	0.45	0.7	0.26	<0.01	0.11	0.02	0.3	0.01	0.11	2.42	99.56
A029-7321.5	62	7.91	3.31	9.75	1.92	1.55	1.48	<0.01	0.29	0.12	0.12	0.03	0.04	10.35	98.87
E183-10643.5	77.7	6.41	4.65	3.09	1.98	1.41	0.82	0.01	0.22	0.05	0.15	0.01	0.04	4.6	101.14
GA18-24785-24800	87.3	2.46	4.11	2.63	0.43	0.05	1.72	0.01	0.2	0.04	0.03	0.01	0.21	1.82	101.02
GA18-24700-24715	88.9	2.45	2.02	1.93	0.63	0.05	1.57	<0.01	0.24	0.02	0.04	0.01	0.1	2.33	100.29
GA18-23505-23525	85.6	3.54	3.11	1.95	0.86	0.12	1.63	0.01	0.2	0.02	0.04	0.01	0.33	2.65	100.07
T932-10344	83.2	6.96	1.25	1.99	0.91	1.37	0.85	<0.01	0.15	0.03	0.09	0.01	0.02	3.64	100.47
T932-10340	87	6.38	1.34	0.89	0.49	1.33	0.73	<0.01	0.13	0.02	0.1	0.01	0.02	2.25	100.69
T932-10323	59.7	16.45	5.54	1.68	2.21	0.96	3.05	0.01	0.6	0.03	0.16	0.02	0.07	10.2	100.68
T932-10294	60.7	16.5	5.15	1.59	2.2	1.16	3.28	0.01	0.6	0.03	0.18	0.02	0.07	8.89	100.38
D839-8195	80	8.38	3.62	1.26	0.29	3.13	1.33	0.01	0.66	0.04	0.33	0.01	0.11	1.23	100.4
D839-8217	78.1	10.1	3.13	1.11	0.55	3.14	1.98	<0.01	0.23	0.03	0.21	0.01	0.08	2.13	100.8
D904-4582	60.9	4.65	1.48	14.8	1.37	0.77	1.36	<0.01	0.29	0.09	0.25	0.04	0.04	13.25	99.29
D904-4568	60.1	9.4	2.95	7.79	3.39	1.04	2.41	0.01	0.45	0.04	0.27	0.02	0.05	10.95	98.87
D904-4558	62.3	8.66	2.42	7.72	3.38	1.08	2.15	0.01	0.44	0.03	0.27	0.02	0.05	10.55	99.08
B209-6185	76.4	10.6	3.2	1.2	1.41	3.1	1.39	<0.01	0.31	0.02	0.14	0.02	0.08	2.99	100.86
B209-6676	88.2	6.64	2.09	0.26	0.37	0.61	0.91	<0.01	0.16	0.02	0.05	0.01	0.02	2.2	101.54
D037-7499	1.69	0.13	0.7	30.7	21	0.03	0.03	<0.01	0.01	0.03	0.01	<0.01	<0.01	45.9	100.23
D037-7496	1.31	0.1	0.76	30.1	20.6	0.04	0.02	<0.01	0.01	0.03	0.03	<0.01	0.01	45.9	98.91

Major Oxide Whole Rock Geochemistry (2/4)															
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	Total
Sample ID	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
D037-7504	1.47	0.08	0.59	30.6	21.1	0.05	0.02	<0.01	<0.01	0.02	0.01	<0.01	0.01	45.9	99.85
D037-7536	2	0.18	3.92	29.3	20.2	0.06	0.06	0.01	0.01	0.04	0.01	0.01	0.03	42.6	98.43
D037-7538	4.2	0.38	0.66	29.6	20.1	0.05	0.12	<0.01	0.02	0.01	0.04	0.01	<0.01	44.5	99.69
D037-7593	1.02	0.09	0.23	30.3	21.2	0.06	0.02	<0.01	<0.01	0.01	0.01	<0.01	0.21	46.1	99.25
D037-7581	0.69	0.05	0.71	30.9	21.2	0.05	0.02	<0.01	<0.01	0.01	0.02	0.01	0.02	45.7	99.38
E173-12224	81.1	7.01	3.6	1.1	0.57	2.08	0.81	<0.01	0.46	0.03	0.17	0.01	0.02	1.81	98.77
E173-12230	84	6.01	5.56	0.57	0.94	1.27	0.35	<0.01	0.11	0.02	0.07	0.01	0.02	2.09	101.02
E173-12232	84.5	6.24	4.78	0.51	0.87	1.34	0.49	<0.01	0.13	0.02	0.11	0.01	0.02	1.92	100.94
S462-7416	80.8	2.95	2.77	3.93	2.28	0.05	0.55	<0.01	0.1	0.03	0.22	<0.01	0.04	6.99	100.71
S462-7428	83.8	3.29	1.8	3.78	2.1	0.05	0.6	<0.01	0.07	0.02	0.2	<0.01	0.01	6.06	101.78
W075-10646.5	73.2	10.95	5.28	0.38	1.21	1.21	1.59	0.01	0.48	0.03	0.1	0.01	0.04	4.98	99.47
W075-10657.5	79.5	8.34	3.25	1.45	0.85	1.2	0.98	0.01	0.5	0.04	0.05	0.01	0.04	4.21	100.43
W075-10663	74.3	12.25	2.82	0.2	0.94	1.34	1.72	0.01	0.64	0.01	0.08	0.01	0.04	5.76	100.12
E815-9182	64.5	12.7	3.92	3.19	1.97	0.85	2.73	0.01	0.58	0.02	0.23	0.02	0.07	7.69	98.48
E815-933	65.7	15.2	3.68	1.52	2.15	0.8	3.24	0.02	0.7	0.01	0.18	0.02	0.09	8.41	101.72
E815-9140	67.3	14.05	3.99	1.28	1.9	0.83	2.97	0.02	0.66	0.02	0.15	0.02	0.08	7.6	100.87
E815-9164	64.9	15.65	4.15	1.24	2.02	0.83	3.36	0.02	0.7	0.02	0.17	0.02	0.09	8.32	101.49
E815-9190	74.9	9.66	3.88	2.77	1.47	1.39	1.62	0.01	0.42	0.02	0.2	0.02	0.06	5.38	101.8
E815-9199	71.1	10.65	3.61	3.25	1.93	1.39	1.97	0.01	0.5	0.02	0.23	0.02	0.05	6.66	101.39
E815-9202	65.6	11.75	4.64	2.92	2.27	1.35	2.27	0.01	0.5	0.03	0.23	0.02	0.05	7.52	99.16
E815-9218	72.5	10.1	3.33	3.24	2.08	1.45	1.78	0.01	0.51	0.02	0.25	0.02	0.05	6.47	101.81
A029-7299.85	72.1	10.5	3.82	2.43	2.03	1.83	1.65	0.01	0.38	0.04	0.13	0.01	0.04	5.64	100.61
A029-7310.5	52.3	5.79	2.94	17.4	1.56	1.16	1.31	0.01	0.31	0.16	0.12	0.04	0.03	15.4	98.53
A029-7317	72.2	8.6	3.83	3.86	2.21	1.65	1.73	0.01	0.41	0.05	0.13	0.02	0.04	6.15	100.89
E124-10113	87.8	3.65	4.26	1.54	0.43	0.69	0.27	<0.01	0.1	0.02	0.16	0.01	0.08	2.37	101.38
E124-10116	83	7.6	2.28	1.17	0.63	1.62	1.15	0.01	0.47	0.02	0.21	0.01	0.03	3.54	101.74
E124-1025	79	8.89	2.67	1.7	1.12	1.63	1.44	0.01	0.43	0.02	0.18	0.02	0.04	4.25	101.4
E124-10135.5	67.4	5.89	3.37	11.25	0.58	1.46	0.65	<0.01	0.15	0.06	0.18	0.05	0.03	10.2	101.27
A648-6136.5	92.6	4.51	1.4	0.04	0.07	0.08	0.06	<0.01	0.88	0.01	0.02	<0.01	0.02	1.82	101.51

Major Oxide Whole Rock Geochemistry (3/4)															
Sample ID	SiO2 (%)	Al2O3 (%)	Fe2O3 (%)	CaO (%)	MgO (%)	Na2O (%)	K2O (%)	Cr2O3 (%)	TiO2 (%)	MnO (%)	P2O5 (%)	SrO (%)	BaO (%)	LOI (%)	Total (%)
A648-6143	96.7	1.4	2.11	0.04	0.14	0.05	0.25	<0.01	0.35	0.03	0.03	<0.01	0.01	0.45	101.56
A648-6146	79.4	8.08	4.62	0.11	0.76	0.17	1.34	0.01	0.62	0.11	0.02	0.01	0.02	4.57	99.84
T932-10342	64.6	5.22	2.98	8.98	3.44	0.9	0.53	<0.01	0.13	0.08	0.06	0.02	0.01	12.9	99.85
T932-10350	86.5	5.77	1.42	0.54	0.25	1.27	0.65	<0.01	0.1	0.02	0.05	0.01	0.03	1.92	98.53
T932-10359	84.1	3.28	2.13	3.83	1.44	0.32	0.65	<0.01	0.17	0.08	0.17	0.01	0.03	5.65	101.86
E183-10616	79.3	6.71	3.41	2.59	1.75	1.59	0.86	0.01	0.24	0.03	0.14	0.02	0.04	4.64	101.33
E183-10624.5	76.8	8.23	3.04	2.08	1.34	1.83	1.18	0.01	0.29	0.02	0.12	0.02	0.05	4.07	99.08
E183-10647	70.4	6.56	3.26	5.5	2.2	1.28	0.91	0.01	0.31	0.07	0.14	0.03	0.04	7.64	98.35
B209-6175	53.7	7.58	1.72	16.4	0.68	2.26	1.2	<0.01	0.21	0.2	0.11	0.03	0.05	14.3	98.44
B209-6189	74.3	9.42	3.28	2.34	1	3.04	1.16	<0.01	0.3	0.03	0.14	0.02	0.08	3.69	98.8
B209-6697	80.4	5.42	1.76	4.2	0.34	0.6	0.76	<0.01	0.17	0.05	0.1	0.02	0.02	5	98.84
B209-6708	80.5	3.66	1.83	6.88	0.23	0.2	0.5	<0.01	0.15	0.05	0.11	0.02	0.02	6.61	100.76
D839-8192.5	66.2	8.26	1.73	9.17	0.27	3.01	1.48	<0.01	0.2	0.16	0.2	0.03	0.08	7.8	98.59
D839-8200	79.2	8.99	3.23	0.98	0.42	3.03	1.61	<0.01	0.18	0.03	0.19	0.01	0.09	1.86	99.82
D839-8204	79.5	9	2.09	1.23	0.35	3.13	1.7	<0.01	0.21	0.03	0.2	0.02	0.09	1.86	99.41
D839-8210	76.3	10.95	4.51	0.83	0.83	3.05	2.09	<0.01	0.29	0.04	0.24	0.02	0.11	2.51	101.77
D904-4541.5	70.3	7.52	2.62	5.75	3.09	1.39	1.63	<0.01	0.29	0.03	0.21	0.02	0.09	8.73	101.67
D904-4547	67.4	7.5	2.5	6.16	3.37	1.38	1.59	0.01	0.3	0.03	0.25	0.02	0.08	9.56	100.15
D904-4553.5	42.4	5.25	1.81	22.6	3.37	0.99	1.18	<0.01	0.27	0.05	0.19	0.04	0.04	21.2	99.39
D380-2058	9.98	0.51	0.65	29.9	17.75	0.03	0.17	<0.01	0.04	0.04	0.02	0.01	<0.01	42.1	101.2
D380-2060	7.93	1.36	0.56	29.6	18.85	0.04	0.43	<0.01	0.06	0.03	0.03	0.01	<0.01	42.5	101.4
D380-2061	6.47	1.38	0.8	30.4	18.45	0.04	0.44	<0.01	0.06	0.03	0.01	0.01	<0.01	42.5	100.59

Trace Elements

Trace Element Whole Rock Geochemistry (1/4)																
	Ba	Cr	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Y	Zr
Sample ID	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
C233-8615.5	303	20	0.44	3.2	1.9	2.3	16.6	<1	71.3	0.2	2.43	0.93	19	1	7.9	71
C233-8790.5	1110	30	0.47	3.2	18.5	5.7	14.3	1	45.5	0.4	5.79	2.52	14	1	16.1	798
S462-7431	125	20	0.61	4.4	3	2.8	22.1	1	41.8	0.2	3.72	1.3	19	1	11.6	122
C233-11919.5	240	30	1.23	5.6	4.3	5.8	31.5	1	54.3	0.4	4.51	1.64	30	1	12.8	177
A648-6140	243	60	6.77	18.9	18.6	21.7	51	3	60.5	1.5	18.55	3.74	87	2	29.2	753
A648-6143	177	70	2.84	12.1	29.4	20.3	51.8	2	69.3	1.5	16.25	5.26	56	2	50.7	1175
W074-11986	294	50	2.69	10.5	12.3	15.5	43.9	2	91.2	1	9.22	4.82	50	2	32.3	482
E173-12218	316	30	0.48	7.5	2.3	4.9	5.6	1	222	0.4	6.01	3.5	86	<1	48.2	82
E173-12227.5	244	30	0.87	6.7	2.4	4.8	20.6	1	78	0.4	5.05	1.54	75	1	11.7	92
W075-10650	256	40	2.86	10.9	7.8	12.9	42.9	2	121	0.9	8.32	3.99	45	2	33.7	292
E124-10108.5	962	30	0.6	4.5	2.2	4.2	9.9	1	97.2	0.4	4.78	1.47	62	<1	20.2	87
A029-7321.5	363	30	1.8	8.4	5.8	6.9	50.2	1	266	0.6	6.55	1.98	36	1	23.5	220
E183-10643.5	358	40	1.43	8.1	4.2	5.5	32.9	1	141	0.4	4.66	1.53	62	2	16.5	161
GA18-24785-24800	1915	40	0.64	3.3	4	4.4	29.9	1	108	0.1	5.02	1.21	14	19	5.8	148
GA18-24700-24715	880	20	0.67	3.5	6.1	4.2	27.8	1	86.4	0.2	5.17	2.38	24	20	8.8	226
GA18-23505-23525	3060	60	1.32	4.8	4.2	3.7	37.7	1	103.5	0.2	3.14	1.19	35	28	6.8	160
T932-10344	164	30	2.69	8.1	1.9	4	31.3	1	98.7	0.1	3.28	1.09	29	1	8.6	69
T932-10340	149	20	2.71	7.2	2.2	3.3	27.7	1	80.3	0.1	3.37	1.09	30	1	8.7	78
T932-10323	626	90	11.65	21.9	4.1	13.6	143.5	2	192	0.8	13.85	4.6	179	2	28.3	140
T932-10294	632	80	12.1	21.7	4.1	14.1	150	2	188.5	0.9	13.8	3.84	169	2	26.9	139
D839-8195	1005	50	3.34	9.4	21.6	20.3	48.9	1	139	0.8	16.5	3.33	32	2	22.3	908
D839-8217	700	30	5.35	12.8	4.8	10.6	81.4	2	131.5	0.6	9.19	2.73	38	1	18.9	174
D904-4582	330	30	5.39	5.6	8	7.1	48.7	1	345	0.4	5.27	2.25	28	1	17.1	309
D904-4568	463	50	9.38	12.6	6.3	11.8	100.5	2	170	0.7	9.57	3.49	81	1	21.3	226
D904-4558	436	50	7.72	11.1	9.3	11.2	83.4	1	156	0.7	8.85	3.53	64	1	20.5	359
B209-6185	688	30	2.34	13.2	3.1	6.9	50.2	1	161.5	0.4	5.37	1.45	54	1	13.1	115
B209-6676	216	20	1.33	8	2.1	4.5	32.9	1	84.3	0.2	4.66	1.3	27	1	10.2	72
D037-7499	5.8	20	0.05	0.2	<0.2	<0.2	1.1	1	30	<0.1	0.05	0.19	<5	<1	2	2
D037-7496	60.2	20	0.03	0.2	<0.2	<0.2	0.7	1	46	<0.1	0.05	0.63	7	1	3.3	0.1

Trace Element Whole Rock Geochemistry (2/4)																
	Ba	Cr	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	U	V	W	Y	Zr
Sample ID	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
D037-7504	129.5	20	0.02	0.1	<0.2	<0.2	0.7	<1	41.5	<0.1	0.05	1.48	5	1	2.6	0.1
D037-7536	263	50	0.1	0.5	<0.2	<0.2	1.9	2	53.6	<0.1	0.05	0.67	9	1	2.2	2
D037-7538	37.3	20	0.23	0.8	<0.2	<0.2	4.1	<1	58.2	0.1	0.1	1.35	11	1	3.3	6
D037-7593	1970	30	0.09	0.1	<0.2	<0.2	0.9	<1	40.9	<0.1	0.05	<0.05	<5	1	4.4	0.1
D037-7581	151.5	10	0.04	0.1	<0.2	<0.2	0.6	<1	53.7	<0.1	0.05	1	5	<1	4.5	0.1
E173-12224	231	30	1.14	8	11.5	12.4	29.1	1	121.5	0.8	8.87	2.41	45	21	14.8	505
E173-12230	208	30	0.59	7.8	1.8	3.8	12.6	1	78	0.4	4.55	1.2	72	1	7.7	77
E173-12232	207	30	0.67	7.8	2.2	4.8	16.3	1	81.9	0.4	5.29	1.49	74	<1	11.8	82
S462-7416	364	20	0.22	2.8	2.2	1.7	14.6	1	35.4	0.2	2.93	0.98	13	1	9.1	90
S462-7428	103	20	0.29	3.2	2.9	1.9	15.7	1	32.8	0.2	3.17	1.07	16	<1	10.6	119
W075-10646.5	365	50	4.38	13.1	9.3	14.8	67.8	2	116	1.1	12.95	6.12	59	2	31.3	350
W075-10657.5	319	50	2.69	10.5	9	14.1	41.7	2	101	1	8.71	3.6	52	2	25.3	345
W075-10663	364	50	4.91	15.5	8.1	21.4	72	3	118.5	1.5	16.15	7.28	69	3	39.7	297
E815-9182	578	70	6.77	15.8	6.5	13.8	107	2	171.5	1	10.85	3.53	140	1	22	245
E815-933	757	100	8.51	18.5	5.2	16	131.5	2	148	1.1	12.35	5.21	181	2	24.3	193
E815-9140	739	110	7.96	17.8	6	16.1	123	2	147	1.1	12.2	4.59	180	2	25.4	227
E815-9164	771	100	9.16	19.4	5.4	16.7	135	2	149.5	1.2	12.75	4.74	195	2	24.8	188
E815-9190	488	50	3.2	11.3	10.1	10.4	58.3	1	157	0.8	8.86	2.81	86	1	19.9	414
E815-9199	426	50	4.22	13	11	12.3	72.9	2	160	0.9	10.45	3.47	91	1	21.5	452
E815-9202	440	60	4.84	14	7.1	12.7	81.1	2	143	1.1	11	3.36	95	2	21.5	276
E815-9218	424	50	3.56	12	11	12.1	63.7	1	144.5	0.9	9.59	3.11	94	1	21.4	457
A029-7299.85	355	50	2.41	10.5	7.1	8.1	57.7	2	113.5	0.7	8.1	2.22	59	2	19.4	270
A029-7310.5	303	40	1.63	6.9	7.2	7.8	45.9	1	305	0.7	6.7	1.93	30	2	19.6	285
A029-7317	343	50	2.45	10	8.4	9.4	63.1	2	141.5	0.8	8.93	2.61	48	2	23.1	316
E124-10113	664	30	0.48	4.5	1.5	3.4	9	1	86.2	0.3	4.67	1	62	1	12.6	59
E124-10116	294	30	1.27	7.8	22	10.8	34.6	1	114.5	0.8	10.15	3.02	55	1	18.6	940
E124-1025	322	40	2.21	10.7	11.8	10.5	48.7	1	125.5	0.8	9.29	2.88	67	1	19.6	491
E124-10135.5	225	30	0.84	6.6	2.7	5.3	21.2	1	375	0.5	6.28	1.48	94	1	14.2	104
A648-6136.5	133.5	30	0.29	5.6	17	16.1	2.3	2	20.7	1.2	11.45	2.81	25	2	20.4	703

Trace Element Whole Rock Geochemistry (3/4)																
Sample ID	Ba (ppm)	Cr (ppm)	Cs (ppm)	Ga (ppm)	Hf (ppm)	Nb (ppm)	Rb (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Th (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Zr (ppm)
A648-6143	56.7	20	0.41	2.2	12	5.8	8.8	1	25.1	0.5	4.21	1.91	16	1	15.5	494
A648-6146	186.5	40	3.42	10.7	6.2	11.6	57.1	2	57	0.9	7.48	3.19	63	1	26.4	240
T932-10342	125	10	0.61	5.5	1.6	3.1	18.2	<1	163	0.3	2.36	0.73	24	<1	8.8	62
T932-10350	240	20	0.6	6.3	1.4	2.7	22.4	1	70.5	0.2	2.53	0.76	22	1	7.2	57
T932-10359	217	20	0.79	3.5	5.2	4.2	21.3	1	87.3	0.2	2.87	1.28	30	1	10.4	204
E183-10616	346	40	1.45	7.4	4.5	5.8	33.2	1	131	0.3	4.39	1.45	74	1	14.6	166
E183-10624.5	450	40	2.22	10.7	3.9	7	48.6	1	178	0.4	5.39	1.75	101	1	15.9	146
E183-10647	376	40	1.82	7.9	5.8	7	36.3	1	236	0.4	5.06	1.88	81	1	20.9	221
B209-6175	406	20	1.43	8.4	2.4	5.1	37.3	1	281	0.3	3.27	1.15	41	1	12.5	96
B209-6189	638	30	1.61	9.8	4.5	6.7	40.1	1	205	0.4	4.31	1.39	51	1	14.7	169
B209-6697	174	20	1.01	5.6	3.8	4.9	26.5	1	136.5	0.3	3.84	1.19	30	1	11	152
B209-6708	140.5	20	0.65	3.9	5.3	3.8	16.2	1	169.5	0.2	3.03	0.94	22	1	9.6	217
D839-8192.5	698	30	1.25	9.3	3.9	8.3	52.9	1	238	0.4	6.25	1.81	35	1	20.9	151
D839-8200	718	30	1.24	9.6	3.4	8.3	55.2	1	115.5	0.4	5.64	1.78	37	2	15	128
D839-8204	725	20	1.41	9.2	3.8	8.8	59.3	1	128.5	0.4	6.4	2	37	1	15.9	150
D839-8210	857	30	1.94	13.4	5.8	12.9	78.8	2	112.5	0.8	10.3	3.12	47	2	20.6	219
D904-4541.5	687	30	2.51	8.5	6.1	8.1	51.8	1	134	0.5	5.86	2.88	57	1	14.4	233
D904-4547	622	30	2.57	8.5	7.3	8.5	52.3	1	132	0.5	6.2	3.07	60	1	15.1	280
D904-4553.5	289	20	2.14	5.7	6.6	7.1	37.4	1	320	0.4	5.02	2.36	46	1	13.3	259
D380-2058	13.2	20	0.27	0.8	0.6	0.7	4.7	2	87.2	<0.1	0.43	0.78	21	<1	2.1	23
D380-2060	21.4	20	0.83	1.7	0.3	1	13.2	1	69.2	<0.1	0.81	0.49	21	<1	2.3	11
D380-2061	23	20	0.84	1.8	0.3	1.1	13.8	1	77.7	<0.1	0.85	0.53	24	<1	2.6	11

Rare earth Elements

Rare Earth Element Information (1/4)

Sample ID	Formation	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
C233-8615.5	Fort union	11.1	18.2	2.18	8.8	1.41	0.3	1.35	0.18	1.16	0.25	0.59	0.08	0.63	0.09
C233-8790.5	Fort union	18.4	32.2	3.92	14.7	2.68	0.57	2.23	0.39	2.55	0.51	1.6	0.28	1.79	0.33
S462-7431	Fort union	17.2	28.9	3.63	14	2.69	0.63	2.32	0.36	2.06	0.4	1.01	0.15	0.77	0.12
C233-11919.5	Lance	21.5	37.7	4.44	16.9	2.94	0.76	2.62	0.37	2.29	0.46	1.23	0.19	1.16	0.18
A648-6140	Niobrara	28.1	45.9	4.94	17.9	3.16	0.77	3.55	0.73	4.88	1.04	3.21	0.53	3.33	0.56
A648-6143	Niobrara	50.3	95	10.95	41.4	8.27	1.47	6.87	1.4	8.34	1.82	5.44	0.95	5.84	0.97
W074-11986	Niobrara	38.8	77.2	8.68	32.9	6.62	1.11	5.77	0.99	5.62	1.13	3.3	0.55	3.38	0.53
E173-12218	Frontier	61.6	117.5	13.3	51.9	10.5	2.51	10	1.45	7.94	1.61	3.87	0.6	3.18	0.45
E173-12227.5	Frontier	22.9	39.1	4.49	17.2	3.02	0.73	2.42	0.36	2.16	0.41	1.05	0.18	1.08	0.18
W075-10650	Mowry	34.8	67.5	7.45	27.7	5.35	1.08	5.56	0.99	5.59	1.12	3.22	0.51	2.92	0.44
E124-10108.5	Turner	31.3	57.8	6.45	25.4	4.71	1.21	4.25	0.62	3.55	0.65	1.69	0.2	1.41	0.19
A029-7321.5	Parkman	24.5	48.2	5.66	21.9	4.43	0.99	4.12	0.68	4.04	0.82	2.31	0.34	2.03	0.31
E183-10643.5	Shannon	17.8	35.7	4.54	18.6	4.15	1.08	3.97	0.59	3.05	0.58	1.58	0.19	1.24	0.17
GA18-24785-24800	Granite	16.4	34	3.52	12.6	2.16	0.34	1.53	0.2	1.04	0.22	0.65	0.09	0.59	0.09
GA18-24700-24715	Granite	15.5	36.2	3.72	13.8	2.57	0.43	1.9	0.29	1.61	0.31	0.97	0.14	1.01	0.18
GA18-23505-23525	Granite	8.1	16.9	1.91	7.5	1.53	0.3	1.21	0.19	1.15	0.25	0.74	0.11	0.84	0.12
T932-10344	Almond	14	25.6	3.06	11.1	2.02	0.54	1.73	0.26	1.4	0.3	0.84	0.11	0.85	0.14
T932-10340	Almond	14.2	27.4	3.38	12.9	2.55	0.63	2.1	0.31	1.62	0.3	0.82	0.13	0.86	0.12
T932-10323	Lewis	40.4	75.5	9.24	34.4	6.49	1.32	5.57	0.82	4.73	0.99	2.81	0.41	2.7	0.41
T932-10294	Lewis	39.1	72.5	8.92	33.3	6.27	1.2	5.35	0.82	4.37	0.95	2.65	0.38	2.62	0.4
D839-8195	Muddy	78.6	132	14.5	50.1	7.43	1.5	5.08	0.69	3.47	0.77	2.18	0.29	2.05	0.37
D839-8217	Muddy	37.8	68.7	7.84	27.7	5.19	1.2	3.98	0.58	3.12	0.63	1.78	0.24	1.66	0.24
D904-4582	Cody	18.6	34	4.37	16.5	3.37	0.64	2.8	0.44	2.57	0.52	1.45	0.24	1.58	0.27
D904-4568	Cody	29.5	53.2	6.49	24.5	4.51	0.87	3.73	0.59	3.28	0.7	1.99	0.29	2.12	0.34
D904-4558	Cody	28.3	51.9	6.4	24.1	4.56	0.88	3.72	0.56	3.32	0.68	2	0.29	2.12	0.37
B209-6185	Baxter	23.6	45.2	5.34	20.3	4.07	1.05	3.2	0.43	2.3	0.45	1.21	0.17	1.06	0.16
B209-6676	Baxter	19.1	37.4	4.28	15.4	2.86	0.72	2.24	0.3	1.83	0.35	0.98	0.15	0.99	0.14
D037-7499	Madison	0.7	<0.5	0.21	0.6	0.21	<0.03	0.11	0.01	0.13	0.02	0.12	0.02	<0.03	0.02
D037-7496	Madison	1.4	<0.5	0.3	0.9	0.29	0.05	0.21	0.01	0.25	0.03	0.14	0.04	0.05	0.02

Rare Earth Element Information (2/4)

Sample ID	Formation	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
D037-7504	Madison	1.2	<0.5	0.26	0.7	0.26	0.04	0.12	<0.01	0.21	0.02	0.11	0.03	<0.03	0.02
D037-7536	Madison	1.2	<0.5	0.23	0.5	0.21	<0.03	0.13	<0.01	0.17	0.01	0.04	0.03	<0.03	0.02
D037-7538	Madison	2.9	1.7	0.49	1.4	0.3	0.07	0.24	<0.01	0.25	0.03	0.12	0.03	0.09	0.03
D037-7593	Madison	1	<0.5	0.22	0.6	0.18	<0.03	0.17	<0.01	0.26	0.03	0.16	0.03	0.05	0.03
D037-7581	Madison	1.3	<0.5	0.19	0.5	0.17	0.04	0.19	<0.01	0.27	0.03	0.16	0.04	0.05	0.02
E173-12224	Frontier	39	71.8	7.72	26.8	4.61	0.98	3.36	0.44	2.83	0.5	1.44	0.24	1.34	0.24
E173-12230	Frontier	20.3	34.6	3.94	13.2	2.42	0.58	1.61	0.21	1.38	0.23	0.75	0.14	0.67	0.1
E173-12232	Frontier	24.7	45.1	5.31	20	3.79	1.01	2.83	0.39	2.44	0.39	1.07	0.16	0.95	0.15
S462-7416	Fort Union	13.9	23.9	3.06	11.1	2.16	0.48	1.81	0.22	1.54	0.26	0.7	0.1	0.54	0.11
S462-7428	Fort Union	12.5	22	3.04	11.7	2.54	0.6	2.38	0.29	1.9	0.3	0.81	0.12	0.69	0.11
W075-10646.5	Mowry	38.6	78.3	9.18	34.1	7.13	1.17	6.01	0.81	5.32	1.07	3.3	0.47	3.18	0.52
W075-10657.5	Mowry	32.2	65.5	7.23	26.1	5.06	0.86	4.18	0.67	4.33	0.81	2.53	0.4	2.54	0.4
W075-10663	Mowry	52.5	107.5	11.85	43.7	8.68	1.41	7.14	1.09	6.9	1.34	3.95	0.63	4.02	0.59
E815-9182	Niobrara	34	66.2	7.64	28.2	5.44	1.1	4.14	0.6	3.99	0.81	2.14	0.34	2.16	0.36
E815-933	Niobrara	38.3	74.1	8.71	32	6.14	1.23	4.75	0.7	4.24	0.84	2.69	0.4	2.47	0.42
E815-9140	Niobrara	38.1	73.2	8.71	32.1	6.2	1.17	4.83	0.71	4.48	0.88	2.75	0.43	2.51	0.4
E815-9164	Niobrara	39	74.8	8.78	31.7	6.12	1.18	4.57	0.68	4.35	0.87	2.69	0.42	2.58	0.41
E815-9190	Niobrara	29.8	58.1	6.71	24.2	4.75	1.08	3.85	0.56	3.37	0.66	1.93	0.32	1.91	0.31
E815-9199	Niobrara	34.6	66.8	7.65	28.1	5.4	1.07	4.17	0.61	3.72	0.75	2.33	0.33	2.16	0.37
E815-9202	Niobrara	32.4	65.5	7.59	27.9	5.6	1.22	4.69	0.65	4.2	0.73	2.14	0.35	2.08	0.37
E815-9218	Niobrara	29.8	57.3	6.9	25.7	4.91	1.08	4.12	0.57	3.58	0.7	2.11	0.33	2.14	0.33
A029-7299.85	Parkman	26	53.4	6.24	23.6	4.57	0.96	3.76	0.55	3.52	0.67	1.92	0.32	1.91	0.31
A029-7310.5	Parkman	25.5	52	6.1	22.4	4.25	0.86	3.47	0.52	3.41	0.64	2.02	0.3	1.88	0.31
A029-7317	Parkman	29.5	60.4	6.95	26.5	5.26	0.99	4.36	0.63	4.07	0.78	2.36	0.36	2.29	0.36
E124-10113	Turner	23.4	43.5	4.96	17.6	3.26	0.9	2.86	0.36	2.37	0.39	1.08	0.18	0.92	0.14
E124-10116	Turner	42.1	79.9	8.88	31.2	5.29	1.08	3.95	0.54	3.32	0.61	1.85	0.32	2.06	0.33
E124-1025	Turner	33.4	64.5	7.36	27.2	5.26	1.06	4.01	0.54	3.47	0.64	1.85	0.3	2	0.31
E124-10135.5	Turner	23.5	47.4	5.34	19.6	3.86	0.96	2.99	0.44	2.63	0.49	1.29	0.2	1.12	0.17
A648-6136.5	Niobrara	6.6	13.4	1.69	6.3	1.63	0.39	1.99	0.39	3.16	0.69	2.26	0.37	2.66	0.45

Rare Earth Element Information (3/4)																
Sample ID	Formation	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
A648-6143	Niobrara	16.1	34.3	4.24	16.6	3.65	0.71	2.75	0.4	2.87	0.53	1.71	0.26	1.77	0.3
A648-6146	Niobrara	26.6	52.9	6.16	22.5	4.55	0.87	3.89	0.64	4.41	0.9	2.65	0.43	2.54	0.4
T932-10342	Almond	12.1	22.5	2.81	10.3	1.97	0.54	1.56	0.22	1.4	0.27	0.81	0.13	0.75	0.12
T932-10350	Almond	12.6	23.2	2.78	9.8	1.97	0.54	1.3	0.18	1.39	0.23	0.65	0.13	0.63	0.11
T932-10359	Almond	13.5	24.4	2.94	11	2.14	0.44	1.77	0.27	1.66	0.32	0.96	0.15	0.96	0.16
E183-10616	Shannon	16.9	34.9	4.34	17.4	3.79	0.91	3.62	0.48	2.73	0.52	1.33	0.2	1.22	0.18
E183-10624.5	Shannon	20.8	41.6	5	19.3	3.87	0.93	3.27	0.51	2.82	0.54	1.53	0.24	1.29	0.2
E183-10647	Shannon	20.6	41.5	5.08	20	4.43	0.98	3.94	0.6	3.45	0.67	1.84	0.28	1.7	0.25
B209-6175	Frontier	17.1	33.3	3.9	14.8	3.02	0.78	2.59	0.37	2.11	0.41	1.05	0.16	0.95	0.16
B209-6189	Frontier	21.7	42.2	4.8	18.7	3.68	0.97	3.07	0.43	2.55	0.48	1.34	0.2	1.23	0.19
B209-6697	Frontier	20.1	40.1	4.3	15.6	2.97	0.7	2.4	0.33	1.99	0.38	0.99	0.15	0.93	0.14
B209-6708	Frontier	21	37.7	4.02	13.8	2.39	0.54	1.84	0.26	1.59	0.3	0.88	0.14	0.89	0.14
D839-8192.5	Muddy	37.3	67.7	7.5	26.6	4.79	1.12	3.82	0.59	3.3	0.68	1.82	0.26	1.53	0.22
D839-8200	Muddy	29.1	52.6	5.98	21.7	4.02	0.97	3.05	0.46	2.57	0.48	1.34	0.19	1.23	0.19
D839-8204	Muddy	33	59.7	6.75	24.6	4.41	1.05	3.35	0.46	2.54	0.5	1.4	0.21	1.14	0.19
D839-8210	Muddy	45.4	83.5	9.15	33.3	5.65	1.21	4.21	0.61	3.41	0.66	1.95	0.28	1.78	0.25
D904-4541.5	Baxter	21.8	39.7	4.66	17.7	3.24	0.72	2.67	0.4	2.35	0.45	1.36	0.21	1.3	0.2
D904-4547	Baxter	23.8	43.1	5.13	19	3.41	0.76	2.76	0.44	2.48	0.48	1.44	0.21	1.46	0.24
D904-4553.5	Baxter	18.7	33.8	3.98	15.4	2.96	0.58	2.4	0.34	2.17	0.42	1.34	0.2	1.19	0.2
D380-2058	Madison	1.5	3.2	0.42	1.7	0.37	0.11	0.38	0.06	0.33	0.07	0.22	0.04	0.15	0.03
D380-2060	Madison	3.2	6.3	0.73	3	0.51	0.12	0.51	0.08	0.4	0.08	0.27	0.03	0.26	0.03
D380-2061	Madison	3.4	6.8	0.78	3	0.54	0.12	0.48	0.08	0.43	0.08	0.28	0.04	0.26	0.04

Appendix B

Major Oxides

Major Oxide Whole Rock Geochemistry (4/4)															
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	Total
Sample ID	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
17ID01	98.9	0.29	0.43	0.04	0.04	0.01	0.07	0.01	0.02	0.37	0.01	<0.01	0.09	0.29	100.56
17ID02	98.7	0.46	0.67	0.02	0.06	0.01	0.14	<0.01	0.02	0.01	0.01	<0.01	<0.01	0.21	100.29
17ID03	68.9	10.1	3.65	3.73	0.8	3.13	3.2	0.02	0.51	0.08	0.21	0.02	0.12	6.04	100.51
17ID04	9.81	1.33	1.43	48.6	0.15	0.21	0.49	<0.01	0.07	0.21	0.02	0.08	0.01	37.9	100.31
17ID05A	70	12.2	4.13	1.75	0.45	2.93	4.71	<0.01	0.5	0.06	0.09	0.01	0.13	2.2	99.16
17ID05B	72.5	12.4	3.45	1.43	0.31	3.15	5	<0.01	0.49	0.04	0.1	0.01	0.12	1.53	100.53
17ID06	72.8	14.4	2.4	2.29	0.49	3.61	3.42	<0.01	0.24	0.04	0.08	0.03	0.16	0.58	100.54
17ID07	99	0.47	0.64	0.04	0.1	0.02	0.28	<0.01	0.12	0.01	0.01	<0.01	0.01	0.21	100.91
17ID08	45.3	14.15	14.6	9.84	7.24	2.24	0.32	0.05	2.62	0.19	0.45	0.03	0.23	1.44	98.7
17ID09	46.7	14.65	14.65	9.75	7.47	2.53	0.69	0.04	2.57	0.2	0.48	0.03	0.04	-0.22	99.58
17ID10A	44.8	14.9	12.55	9.72	5.61	2.49	0.75	0.04	2.67	0.21	0.52	0.03	0.04	3.87	98.2
17ID10B	43.8	14.8	14.4	9.76	5.39	2.48	0.6	0.04	2.58	0.17	0.43	0.03	0.05	4.11	98.64
17ID11	46.6	14.95	13.35	10.25	6.48	2.29	0.6	0.04	2.16	0.2	0.47	0.04	0.11	1.04	98.58
17ID12	73.9	12.15	2.96	1.29	0.22	3.01	5.28	<0.01	0.26	0.05	0.07	0.03	0.09	1.67	100.98
17ID13	65.4	15.3	4.36	4.16	2.09	3.3	2.67	0.01	0.65	0.07	0.19	0.06	0.1	1.55	99.91
17ID14A	82.3	6.71	2.45	2.79	0.48	0.06	2.09	0.01	0.41	0.02	0.27	<0.01	0.21	3.54	101.34
17ID4B	74.5	13.2	3.94	0.8	0.8	0.07	4.08	0.02	0.65	0.01	0.06	<0.01	0.41	3.34	101.88
17ID15	64.5	14.95	5.17	2.94	2.31	2.69	4.66	0.01	0.57	0.05	0.17	0.05	0.17	2.88	101.12

Trace Elements

Rare Earth Element Information (4/4)															
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Sample ID	Formation	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
17ID01	quartzite	3.1	5.5	0.65	2.3	0.42	0.06	0.76	0.1	0.4	0.05	0.22	0.01	0.19	0.02
17ID02	quartzite	3.3	5.9	0.68	2.5	0.55	0.05	0.48	0.07	0.31	0.04	0.2	0.02	0.13	0.02
17ID03	alluvial fan gravel	56.7	108.5	12.25	47.2	8.67	1.65	6.66	0.98	5.81	1.18	3.21	0.49	3.02	0.51
17ID04	travertine	9.4	15.4	1.9	7.1	1.21	0.21	1.01	0.14	0.9	0.15	0.43	0.06	0.49	0.09
17ID05A	rhyolite	84.4	153.5	18	65.4	12.55	2.05	10.5	1.58	10.25	2.15	6.4	0.96	5.95	0.84
17ID05B	rhyolite	88	158	18.45	67.6	12.4	2.01	10.25	1.69	9.92	2.06	5.98	0.9	5.61	0.79
17ID06	granite	46.3	75.2	8.12	28.5	4.34	1.1	2.98	0.42	2.2	0.39	1.09	0.16	0.9	0.13
17ID07	quartzite	13	29	2.98	10.8	1.86	0.25	1.16	0.13	0.7	0.13	0.41	0.04	0.29	0.05
17ID08	basalt	17	36.8	5.52	25.1	6.57	2.11	6.53	1	6.08	1.19	3.35	0.48	3.24	0.43
17ID09	basalt	22.6	47.7	6.59	30	6.98	2.26	6.7	1.09	6.31	1.22	3.72	0.49	3.01	0.49
17ID10A	basalt	23.2	48.7	6.88	30.7	7.15	2.3	7.69	1.17	6.67	1.4	3.64	0.51	3.33	0.5
17ID10B	basalt	24	49.6	7.1	32.2	7.36	2.35	7.04	1.09	6.53	1.35	3.82	0.56	3.18	0.47
17ID11	basalt	21.4	42.3	5.99	26.6	6.9	2.1	6.26	0.92	5.93	1.09	3.12	0.43	2.74	0.44
17ID12	altered rhyolite	120.5	205	24.1	85.1	14.55	0.93	11.45	1.87	12.25	2.55	7.66	1.22	7.1	1.03
17ID13	granodiorite	53.6	88	9.37	33.6	4.84	1.33	3.27	0.4	2.55	0.46	1.18	0.19	1.23	0.15
17ID14A	quartzite	21.9	34.4	4.5	16.9	3.04	0.66	2.76	0.42	2.56	0.53	1.41	0.19	1.43	0.2
17ID4B	quartzite	31.3	54.7	6.76	24.5	4.23	0.7	3.32	0.49	3.18	0.65	2.2	0.29	2.12	0.3
17ID15	rhyolite	51.3	88.6	10.2	36.8	6.42	1.4	4.48	0.62	3.42	0.67	1.84	0.29	1.91	0.29

Rare Earth Elements

Rare Earth Element Information (4/4)																
Sample ID	Formation	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)	Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)	Lu (ppm)
17ID01	quartzite	3.1	5.5	0.65	2.3	0.42	0.06	0.76	0.1	0.4	0.05	0.22	0.01	0.19	0.02
17ID02	quartzite	3.3	5.9	0.68	2.5	0.55	0.05	0.48	0.07	0.31	0.04	0.2	0.02	0.13	0.02
17ID03	alluvial fan gravel	56.7	108.5	12.25	47.2	8.67	1.65	6.66	0.98	5.81	1.18	3.21	0.49	3.02	0.51
17ID04	travertine	9.4	15.4	1.9	7.1	1.21	0.21	1.01	0.14	0.9	0.15	0.43	0.06	0.49	0.09
17ID05A	rhyolite	84.4	153.5	18	65.4	12.55	2.05	10.5	1.58	10.25	2.15	6.4	0.96	5.95	0.84
17ID05B	rhyolite	88	158	18.45	67.6	12.4	2.01	10.25	1.69	9.92	2.06	5.98	0.9	5.61	0.79
17ID06	granite	46.3	75.2	8.12	28.5	4.34	1.1	2.98	0.42	2.2	0.39	1.09	0.16	0.9	0.13
17ID07	quartzite	13	29	2.98	10.8	1.86	0.25	1.16	0.13	0.7	0.13	0.41	0.04	0.29	0.05
17ID08	basalt	17	36.8	5.52	25.1	6.57	2.11	6.53	1	6.08	1.19	3.35	0.48	3.24	0.43
17ID09	basalt	22.6	47.7	6.59	30	6.98	2.26	6.7	1.09	6.31	1.22	3.72	0.49	3.01	0.49
17ID10A	basalt	23.2	48.7	6.88	30.7	7.15	2.3	7.69	1.17	6.67	1.4	3.64	0.51	3.33	0.5
17ID10B	basalt	24	49.6	7.1	32.2	7.36	2.35	7.04	1.09	6.53	1.35	3.82	0.56	3.18	0.47
17ID11	basalt	21.4	42.3	5.99	26.6	6.9	2.1	6.26	0.92	5.93	1.09	3.12	0.43	2.74	0.44
17ID12	altered rhyolite	120.5	205	24.1	85.1	14.55	0.93	11.45	1.87	12.25	2.55	7.66	1.22	7.1	1.03
17ID13	granodiorite	53.6	88	9.37	33.6	4.84	1.33	3.27	0.4	2.55	0.46	1.18	0.19	1.23	0.15
17ID14A	quartzite	21.9	34.4	4.5	16.9	3.04	0.66	2.76	0.42	2.56	0.53	1.41	0.19	1.43	0.2
17ID4B	quartzite	31.3	54.7	6.76	24.5	4.23	0.7	3.32	0.49	3.18	0.65	2.2	0.29	2.12	0.3
17ID15	rhyolite	51.3	88.6	10.2	36.8	6.42	1.4	4.48	0.62	3.42	0.67	1.84	0.29	1.91	0.29