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Characterization of Rare Earth Elements in BC Coal

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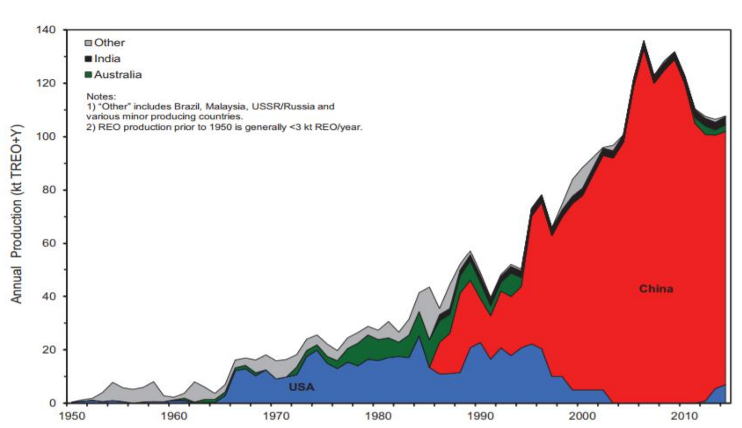
Introduction

- Rare Earth Elements (REEs) are a group of 17 elements in the periodic table, including 15 lanthanides and 2 chemically similar transition metals: Sc and Y.
- REEs are used in magnets, metallurgy, battery alloys, ceramics, polishing, glass, phosphors, catalyst and others (Chegwidden & Kingsnorth, 2010; Lynas, 2010; Zepf, 2013).
- Coal with enriched concentrations of REEs (Table 1) on coal ash basis have been found in different countries such as in Sydney basin, Nova Scotia, Canada (72 – 483 ppm; Birk et al., 1991), Far Eastern Russian deposits (300 – 1000 ppm; Seredin, 1996) and Fire clay coal bed in the US (500 - 4000 ppm; Hower et al., 1999).
- Some of the enriched coal (0.68% to 2.03% of rare earth oxide) have comparable rare earth concentrations of traditional deposit and these coal ashes can be viewed as potential source for these metals (Seredin et al., 2012).
- Furthermore, the United States Department of Energy has provided US$10 million in funding to research projects that demonstrate the techno-economic feasibility of domestic REE separation technologies from coal and/or its byproducts (National Energy Technology Limited, 2016).
- The purpose of this ongoing research is to characterize and quantify the REE and their mode of occurrence in BC coal deposits and coal processing products, and to study the possible extraction of these elements. This paper shows the preliminary results from studies conducted on coal samples originating from coal deposits in southeastern BC.

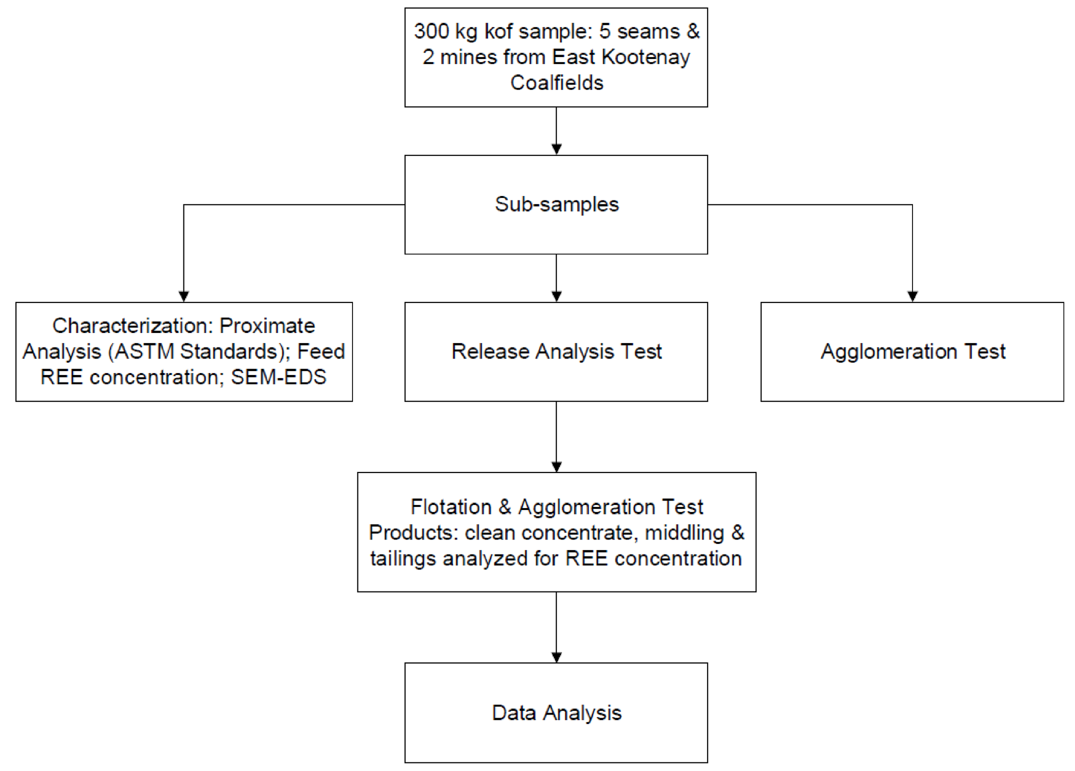
Table 1. Genetic Types of Rare-Earth Element Enrichment in Coal (Seredin & Finkelman, 2008; Seredin & Dai, 2012)

Genetic type	Mode of REEs input	Coalification stage
Terrigenous	Surface waters	Peat-bog stage
Tuffaceous	Leaching of acid & falling alkaline volcanic ash	Peat-bog stage
Infiltrational	Meteoric ground water	Epigenetic (Lignite, Sub-Bituminous, Bituminous-Anthracite)
Hydrothermal	Thermal mineral water & deep fluids	Any stage

Figure 1. Global REO Production Trend (Pui-Kwan, 2011; Humphries 2013; Weng et al., 2015)



Methods and Materials



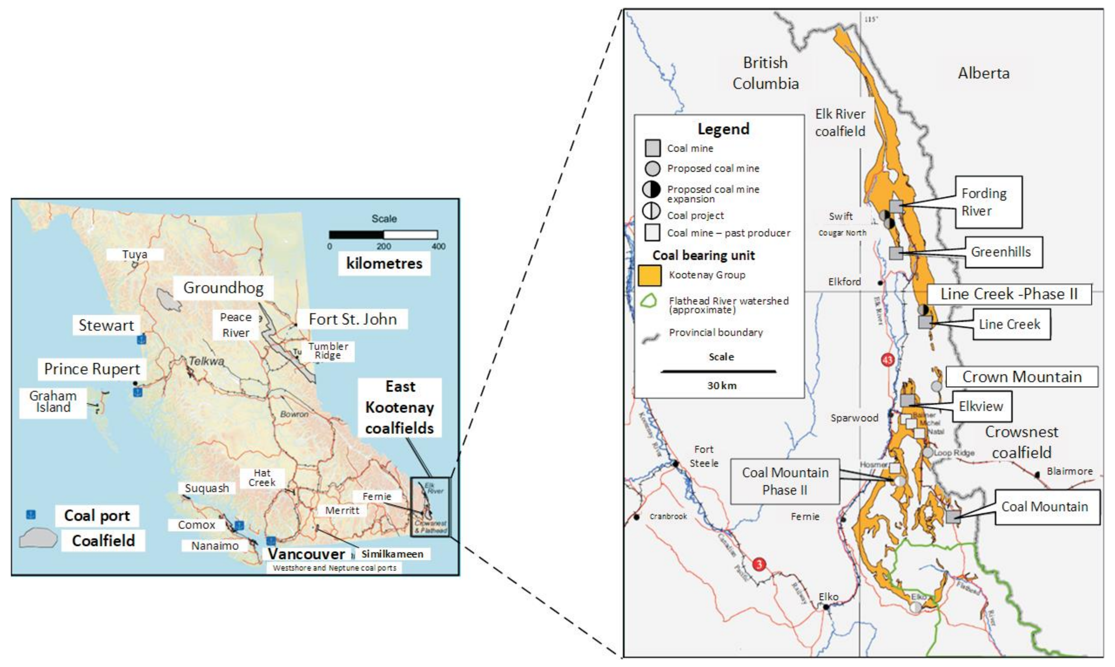


Figure 2. Location of East Kootenay coalfields and coal mines in the southeastern British Columbia (adapted from the BC Ministry of Energy, Mines and Petroleum Resources, 2015, 2016).

Results

- Feed coal samples (samples S1–S5) are classified as medium volatile bituminous coal.
- Among the treated samples, the REE content (Table 2) in flotation concentrate (~569 ppm) is more than the tailings (~340 ppm) and the similar trend was observed for the agglomeration product (~315 ppm) compared to its tailings (~258 ppm). Ce, La, Nd and Y accounted for 80% of the total REE.
- The highest concentration was reported in the flotation product with low ash content, indicating that some of the REE are associated with the organic matter of the coal. Furthermore, mass balance showed that 60 to 80% of total REE by weight in the coal is present in the tailings and middling streams.
- Additionally, correlation analysis showed a significant amount of organic matter associated with REE, which might be due to the organic affinity of REE with humic acid.
- Rare-earth element content normalized to the upper continental crust indicated a similar source for all the samples and one of the possible REE sources identified as volcanic ash.
- Based on the elements found using SEM-EDX (Figure 3), it can be inferred that some of the REE are associated with alumino-silicate minerals, which may be clay, although further analysis is required.
- In addition, REE strongly correlate with U (r > +0.86 on ash basis; r > +0.96 on whole coal basis) and Th (r > +0.89 on ash basis; r > +0.98 on whole coal basis). This suggests that one of the REE mineral phases could be monazite.

Table 2. Rare-earth element (REE) content of the five British Columbia feed coal samples and flotation and agglomeration products (ash basis, in ppm)

Sample ID	Sample Name	Ce	Dy	Er	Eu	Gd	Ho	La	Lu	Nd	Pr	Sm	Tb	Tm	Y	Yb	REE* (Ash Basis)
S1	Feed Sample	114	9.8	5.9	2.7	10.5	2.0	58	0.9	55	14.2	13.0	1.6	0.9	56	5.7	350
S2	Feed Sample	101	8.4	5.1	2.6	8.7	1.8	53	0.8	45	12.3	9.8	1.7	0.8	59	4.8	315
S3	Feed Sample	91	6.6	4.2	1.7	7.0	1.5	49	0.7	42	11.2	8.6	1.1	0.6	42	3.9	270
S4	Feed Sample	97	7.1	4.7	2.3	7.7	1.6	55	0.7	45	11.9	8.9	1.5	0.7	54	4.4	302
S5	Feed Sample	101	9.0	5.5	2.5	8.8	1.9	54	0.9	47	12.3	10.4	1.7	0.8	60	5.2	320
S6	Flotation Concentrate	185	16.0	9.9	4.1	16.1	3.4	97	1.7	86	22.7	18.0	2.7	1.5	96	9.8	569
S7	Flotation Tailings	111	9.7	5.9	2.5	9.5	2.0	58	0.9	52	13.4	11.2	1.6	0.9	57	5.4	340
S8	Flotation Concentrate	141	13.0	7.8	3.2	12.7	2.6	74	1.6	66	17.4	14.6	2.1	1.2	77	7.7	441
S9	Flotation Tailings	83	5.8	3.7	1.6	6.3	1.2	44	0.6	38	10.1	8.1	1.0	0.5	35	3.3	241
S10	Agglomeration Concentrate	101	8.8	5.3	2.5	9.0	1.8	53	0.8	46	12.2	10.6	1.6	0.8	57	5.2	315
S11	Agglomeration Middling	96	8.2	5	2.3	8.4	1.7	51	0.8	44	11.8	9.4	1.5	0.8	53	4.9	298
S12	Agglomeration Tailings	84	6.3	3.9	2.1	6.9	1.3	46	0.6	38	10.2	7.9	1.4	0.6	45	3.6	258

*REE = Ce + Dy + Er + Eu + Gd + Ho + La + Lu + Nd + Pr + Sm + Tb + Tm + Y + Yb + Sc** + Pm***
**ICP-MS analysis was not done for Sc.
***Pm – It is extremely rare and generally considered not to exist in nature (Resende et., 2010).

Table 3. Outlook coefficient (C_{outl}) for British Columbia coal samples and flotation and agglomeration products. Abbreviation: REE, rare-earth elements. (ash basis, in ppm)

$$C_{outl} = \frac{\frac{\sum Nd, Eu, Tb, Dy, Er, Y}{Total\ REE}}{\frac{\sum Ce, Ho, Tm, Yb, Lu}{Total\ REE}}$$

Sample ID	Sample Name	C_{outl}	Critical REEs (ppm)
S1	Feed Sample	1.06	131
S2	Feed Sample	1.12	122
S3	Feed Sample	0.99	97
S4	Feed Sample	1.09	114
S5	Feed Sample	1.14	125
S6	Flotation Concentrate	1.07	214
S7	Flotation Tailings	1.08	129
S8	Flotation Concentrate	1.10	169
S9	Flotation Tailings	0.97	85
S10	Agglomeration Concentrate	1.11	121
S11	Agglomeration Middling	1.10	114
S12	Agglomeration Tailings	1.07	97

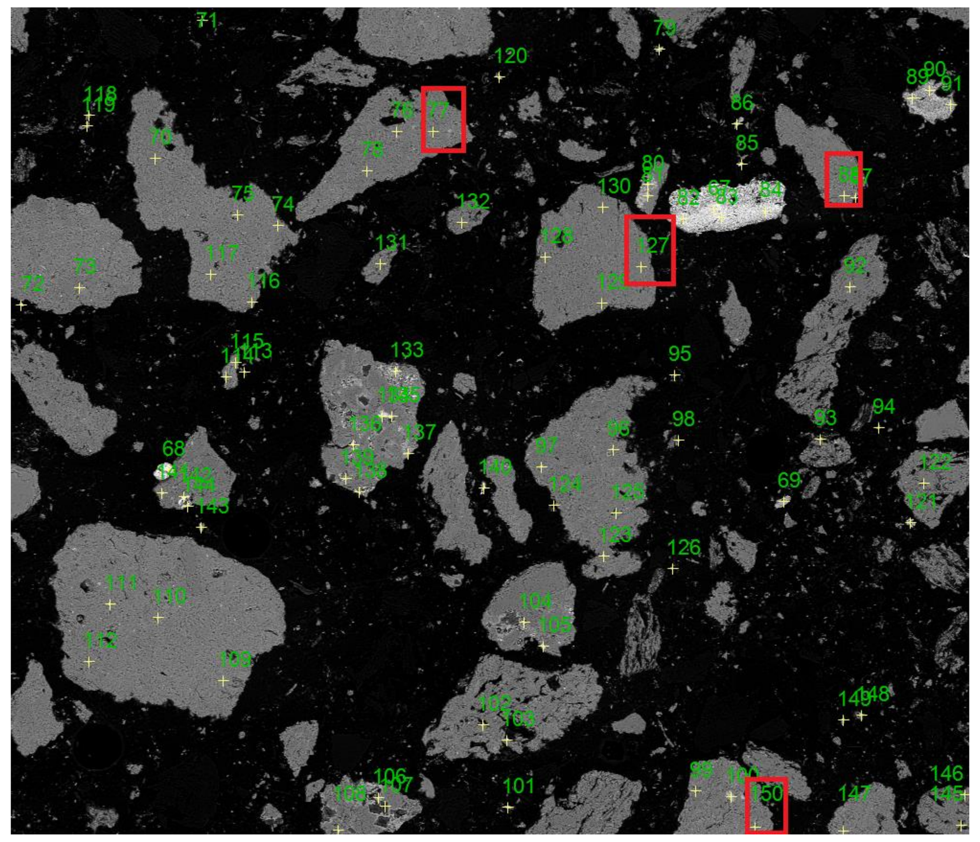


Figure 3. REEs sites in the sample S3 (Magnification: 200x).
(Elements found in EDX at the highlighted area as follows: **77:** Y, Gd, Dy, P, O, Si, K; **88:** Dy, P, K, Si, O, Fe, Ti; **127:** Ce, Ba, Al, Si, P, K, Ca, Ti, Fe, O; **150:** Ce, P, Si, Al, K, O)

Conclusions

- Five coal samples from BC coal deposits were tested for the presence of REE and it was found that total REE concentration on an ash basis varied from 240 to 570 ppm.
- It was inferred from the data that REE in the coal samples are associated with both the organic and inorganic portions of the coal constituents.
- Further studies will include sequential extraction, X-ray diffraction analysis and detailed SEM-EDX, required to estimate the quantity of REE associated with organic matter and inorganic matter of the coal samples.
- With the development of extraction techniques for REE in coal, these elements will be extracted as byproducts of coal mining, which strengthens the brownfield operations by increasing profitability and possible green credits as these REE are used in the clean energy technologies.
- In case of the greenfield operations, the possibility of extracting REE from coal will increase the competitiveness of the deposits and its feasibility for actual mining and extraction.

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Reference to the Full Article

Kumar,V., Kumar,A. and Holuszko, M.E. (2018): Occurrence of rare-earth elements in selected British Columbian coal deposits and their derivative products; *in* Geoscience BC Summary of Activities 2017: Minerals and Mining, Geoscience BC, Report 2018-1, p. 87–100.
URL Access:
http://cdn.geosciencebc.com/pdf/SummaryofActivities2017/MM/SoA2017_MM_Kumar.pdf

References

1. BC Ministry of Energy, Mines and Petroleum Resources (2016): British Columbia coal industry overview 2015; BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey, Information Circular 2016-2, 14 p., URL http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/InformationCirculars/Documents/IC2016-2%20coal.pdf [September 2017].
2. BC Ministry of Energy, Mines and Petroleum Resources (2015): The East Kootenay coalfields; BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey, Information Circular 2015-10, 1 p., URL http://www.empr.gov.bc.ca/Mining/Geoscience/Publications Catalogue/InformationCirculars/Documents/IC2015-10.pdf [September 2017]
3. Birk, D. and White, J.C. (1991): Rare earth elements in bituminous coals and underclays of the Sydney basin, Nova Scotia: element sites, distribution, mineralogy; International Journal of Coal Geology, v. 19, p. 219–251, doi:10.1016/0166- 5162(91)90022-B
4. Chegwidden, J., and Kingsnorth, D.J. (2010): Rare earths facing the uncertainty's of supply; 6th International Rare Earth Conference, Hong Kong., URL https://www.slideshare.net/Tehama/rare-earths-facing-the-uncertaintys-of-supply [September 2017]
5. Hower, J. C., Ruppert, L. F., & Eble, C. F. (1999). Lanthanide, yttrium, and zirconium anomalies in the fire clay coal bed, eastern kentucky. *International Journal of Coal Geology, 39*(1), 141-153. doi:10.1016/S0166-5162(98)00043-3
6. Humphries, M. (2010). Rare earth elements: The global supply chain. Retrieved from: https://fas.org/sgp/crs/natsec/R41347.pdf
7. Lynas. (2010): ASX Mid Caps Conference Presentation., URL http://www.asx.com.au/smalltomidcaps/newyork/2010/presentation_lynas.pdf [September 2017]
8. NETL. (2016). Rare earth elements program. Retrieved from: https://www.netl.doe.gov/File%20Library/Research/Coal/Rare%20Earth%20Elements/REE-Project-Portfolio-2016.pdf
9. Seredin, V. V. (1996). Rare earth element-bearing coals from the russian far east deposits. International Journal of Coal Geology, 30(1), 101-129. doi:10.1016/0166-5162(95)00039-9
10. Seredin, V.V., & Dai, S. (2012). Coal deposits as potential alternative sources for lanthanides and yttrium. International Journal of Coal Geology, 94, 67-93. doi:10.1016/j.coal.2011.11.001
11. Seredin, V. V., & Finkelman, R. B. (2008). Metalliferous coals: A review of the main genetic and geochemical types. International Journal of Coal Geology, 76(4), 253-289. doi:10.1016/j.coal.2008.07.016
12. Tse, Pui-Kwan, 2011, China's rare-earth industry: U.S. Geological Survey Open-File Report 2011–1042, 11 p., Retrieved from: https://pubs.usgs.gov/of/2011/1042
13. Weng, Z., Jowitt, S.M., Mudd, G.M., & Hague, N. (2015): A detailed assessment of global rare earth element resources: opportunities and challenges; Economic Geology, v.110, p. 1925-1952, URL http://econgeol.geoscienceworld.org/content/econgeo/110/8/1925.full.pdf [November 2017]
14. Zepf, V. (2013): Rare earth elements a new approach to the nexus of supply, Demand and USE: Exemplified along the use of neodymium in permanent magnets; Springer Berlin Heidelberg, URL https://doi.org/https://doi.org/10.1007/978-3-642-35458-8 [September 2017]