Microanalysis of Rare Earth Elements in Coal Prep Fines

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Rare earth elements (REE) are necessary for the advancement of technological and energy applications. The Rare Earth Metals Market is expected to surpass $20 Billion by 2024; the demand for products containing REE include those related to renewable energy, magnets for wind turbine generators, computer hard drives, catalysts, and superconductors [1]. Efforts to secure a domestic source of REE require the development of efficient and cost-effective methods for REE extraction from naturally occurring materials (e.g., mined from geologic formations), recycled products, and/or waste streams. The United States consumes more than 900 million tons of coal per year [2]; there is an estimated 2 billion cubic yards of coal refuse in Pennsylvania [3], 10 million tons annually in Virginia and 120 million tons of coal refuse from over 600 coal preparation plants in 21 coal-producing states [4].

The characterization of REE mineral phases in coal source rock and coal waste is a key component to the development of innovative and economically feasible techniques to extract REE.

For this study, we focused on samples from the Pittsburgh coal seam #8 which included dried ponded fines from the Isabella preparation plant operated by the National Mine Corporation. Multiple microanalytical techniques and image processing techniques were used to investigate the morphology, grain size, presence of mineral phases, and elemental composition of grains/coatings using SEM-EDS, EPMA-WDS, FIB-SEM, XRD (bulk unoriented and oriented mounts), and synchrotron based µ-XRF. Quantitative x-ray microanalysis by EDS and WDS was performed using standard blocks REEP25-15+FC and Geller #489.

The coal parting of the Pittsburgh formation contains clay (illite and smectite) with abundant quartz, pyrite, (Fe, Ti) oxide, plagioclase, calcite, and zircon. Pyrite and iron oxide coexist in the underclay and contain Dy, Er, and Tb (Figure 2). The Isabella fines are organic-rich (~70% organic carbon by weight). The inorganic fraction is composed of intermediate amounts of quartz and clay (kaolinite and illite) with minor and trace amounts -K-feldspar and anhydrite respectively. Pittsburgh formation and Isabella fines contain ~300 ppm REE+ytrrium (REY). The Isabella fines have a mean grain size of 27 µm and 0.2 µm specific surface area.

Backscattered electron (BSE) images and elemental x-ray maps were collected on single fields of view and/or were montaged. At least 400 high resolution (0.10-0.12 micrometer/pixel) BSE images were acquired to montage larger areas. PerGeos® was used for image processing and segmentation of different material phases obtained from the BSE images to determine the distribution and occurrence. The Pittsburgh formation is a low porosity material (2-6% by volume) with a distribution of REY.
mineral phases equal to 1.5-2.4 % volume. REY-bearing phases are associated with clay minerals and a proportion of the REY is assumed to exist as the ion-exchangeable form.

This characterization workflow allowed for the quantification of REE mineral phases in the source rock samples and respective coal fines. This quantitative data and our interpretations will inform future REE extraction techniques and technologies practical for commercial utilization of coal and byproducts generated by mining operations and power plants.

References:

Figure 1. 2D montage and 3D segmentation of the Pittsburgh underclay (UC-07). Light blue = pores, dark blue = matrix (quartz and clay), and red = siderite and REY-bearing phases.

Figure 2. EPMA-WDS quantitative elemental mapping of Pittsburgh underclay (UC-07). Scale bar is 10 microns. Analysis conditions 20 keV, 45 nA, map dwell time=250ms.