Rare Earth Study

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In the fall of 2014, the Geological Survey's proposed budget included a funding request to initiate a study of the rare earth element concentrations in western North Dakota lignites. The study was funded and the Survey began collecting coal samples in the fall of 2015. The study area is centered on the Little Missouri River badlands and extends from McKenzie County to Bowman County (fig. 1). This area was chosen for two primary reasons; 1) it has extensive outcrops of coal-bearing rocks and 2) some of the coals in that area are heavily mineralized by metals and metalloids, such as uranium, molybdenum, germanium, etc., and it was thought that the rare earth elements may be concentrated in those coals by the same geochemical processes.

Survey geologists have collected 1,197 rock samples from McKenzie, Billings, Golden Valley, Slope, and Bowman Counties for the rare earth study (fig. 1). The vast majority of these samples (94%) come from lignite beds that range in thickness from a few inches up to 20 feet thick. The coal samples include eight coal ash samples collected from outcrops where the lignite had burned, likely after contact with a prairie fire. Survey scientists also collected 32 tonstein (clay layers in coal that are altered volcanic ash) and volcanic ash/bentonite samples to investigate a potential connection between volcanic ash and increased rare earth element concentrations in the underlying rocks. Additionally, two samples of the ejecta from the asteroid impact on the Yucatan Peninsula, believed to have caused the extinction of the dinosaurs, were collected in Bowman County as potential sources of rare earth elements. Thirty-two sandstone samples were also collected in areas where lignite was directly overlain or underlain by sandstone. Rock samples were systematically collected from all of the coal-bearing formations in western North Dakota. However, the majority of samples came from the Bullion Creek and Sentinel Butte Formations since they are the dominant rock units in that part of the state.

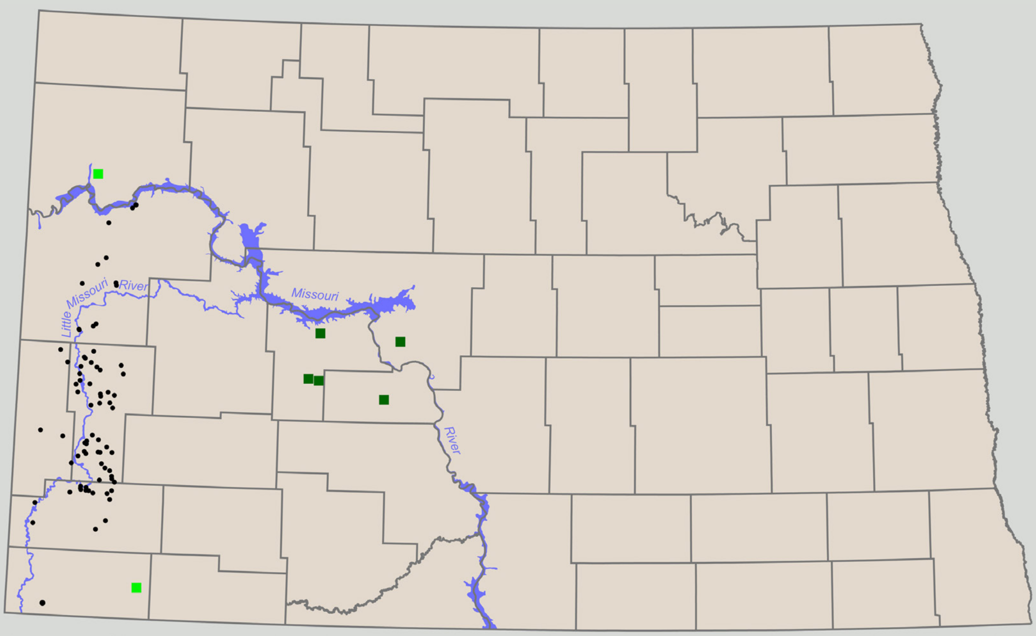

Figure 1. The locations of the Geological Survey rare earth samples sites (black dots). The dark green squares are lignite mines and the light green squares are leonardite mines.

In 2010, the U.S. Geological Survey published a report documenting 28 rare earth element districts or deposits in the United States. Most of these districts/deposits occur in carbonatites (uncommon types of igneous rocks), pegmatites (dikes, sills, veins), iron ore deposits associated with magmatic-hydrothermal processes, or in alluvial deposits (Long et al., 2010). None of the identified deposits were in coals. In 2015, as a means of securing the nation's economic growth and national security, the U.S. Department of Energy (DOE) created the Rare Earth Elements from Coal and Coal By-Products RD&D (Research, Development, and Demonstration) Program that is focused on developing rare earth element separation and recovery technologies that are both economic and environmentally friendly. The program is

The rare earth elements typically include the 15 elements in the lanthanide series (atomic numbers 57-71) plus the elements scandium (atomic number 21) and yttrium (atomic number 39). A number of high-tech products rely on rare earth elements including cell phones, flat-screen TVs, wind turbines, high-performance magnets, satellites, electric cars, and military aircraft (Erickson, 2018). A more thorough discussion of rare earth elements and their applications can be found in two previous DMR Newsletter articles by Kruger (2015 and 2017).

focused on developing these technologies for coals that contain a minimum concentration of 300 parts per million (ppm) of total rare earth elements (DOE NETL, 2018a). Initially, the National Energy Technology Laboratory and others estimated that six million metric tons of rare earth elements could be derived from western coal reserves (not including North Dakota) and five million metric tons from eastern coals, with several additional millions of tons coming from coal ash, coal mine refuse, and coal mine rejected rock (DOE NETL, 2018b). In comparison to this estimated 11+ million metric tons, the U.S. consumes about 16,000 metric tons of rare earth elements per year (Erickson, 2018). Based upon these estimates, U.S. coals and coal by-products appear to be a significant potential source of rare earth elements if they can both safely and cheaply be removed. It should be noted, that any future reports on the rare earth element potential of U.S. coals will now include North Dakota lignites as a result of the initial work done by the ND Geological Survey.

Survey geologists continue to explore for new areas of high rare earth element concentrations and to expand the sampling radius in the high concentration areas we had previously discovered. Both approaches are being used to gather additional data that might ultimately lead to identification of the geochemical processes concentrating the rare earths in these coals (fig. 2). Sixty-four measured sections representing 60 different localities were generated during the initial phase of the project (Kruger et al., 2017). Last fall, the number of measured sections was expanded to 97 covering 17 additional localities (Murphy et al., 2018). Currently 184 measured sections have been compiled from 124 localities. A total of 755 of the 1,196 rock samples Geological Survey scientists have collected have been analyzed. Of these, 106 samples (14%) meet or exceed the 300 ppm threshold (fig. 3). The percentage of coal samples exceeding the 300 ppm threshold was 5% during the initial phase (Kruger et al., 2017) and rose to 9% during the second phase as we began resampling at some of the initial high rare earth localities (Murphy et al., 2018). Of the 106 samples with high rare earth element concentrations, 79 are from three localities that have undergone an expanded sampling program and the remaining 27 samples come from 15 different sites. Lin and others (2018) evaluated 5,400 samples in the U.S.G.S. coal quality database (COALQUAL) and determined that a total rare earth concentration of 653 ppm (a lignite from Mississippi) was the highest quantitatively measured whole rock analysis in that database. Twelve of our North Dakota lignite samples, coming from four different localities in western North Dakota, exceed 653 ppm. A whole-rock analysis of 1,145 ppm is the highest rare earth concentration that we have discovered so far. It should be noted that the rare earth element concentrations in North Dakota lignites that are currently being mined could be lower than those lignites in western North Dakota and still be economic to develop because the existing infrastructure would likely result in lower processing costs.

As the Geological Survey was discovering high concentrations of rare earths in southwestern North Dakota lignites, the University of North Dakota Institute for Energy Studies and the Energy and Environmental Research Center were seeking funding from the U.S. Department of Energy to devise cost-effective methods of removing rare earths from ND lignites and coal ash and to study the methods used to measure rare earth concentrations in coal-based resources. In 2017, the DOE awarded these UND entities grants totaling $4.25 million (Hoeven, 2017). The high rare earth element concentration discoveries made by the Geological Survey contributed to the success of these grant requests.

In 2009, the Chinese produced 95% of the world's rare earth elements (Long et al., 2010). By 2017, the percent of rare earths coming from China had dropped to 80% (U.S.G.S., 2018). Although the Chinese still produce the majority of rare earth elements in the world, not everyone is in agreement that they can control the world market. Heffernan (2015) and Vincent (2018) point to the Chinese attempt to do so in 2009 and 2010, which resulted in rare earth price increases of up to 2,000%. This short-lived price spike was countered by the reopening of the Mountain Pass mine in California and the opening of new rare earth mines in Australia, Japan, and Vietnam. In 2015, Heffernan noted that 60 rare earth deposits in 16 countries were in advanced development. In the

Figure 2. This Slope County outcrop contains North Dakota's highest concentrations of rare earth elements. Due to its significance, Survey geologists have collected 172 coal samples across this 400-foot-long outcrop.

fourth quarter of 2015, production at the Mountain Pass mine was suspended as the owner (Molycorp) filed for bankruptcy. In 2017, MP Mine Operations LLC, a buyout group that included a Chinese company as a minority investor (Shenghe Resources Holding Co.), purchased the mine (Brickley, 2017). The Mountain Pass mine reopened in 2018 and currently is exporting rare earth element concentrate to China (Joseph Gambogi, personal communication, October 29, 2018).

Though there is some debate as to the ability of a single country to control the rare earth elements in the current world market, it is advantageous for the U.S. to identify potential sources of rare earth elements and the methods to safely remove them from the host material. The more knowledgeable we are about the geochemistry of North Dakota's vast lignite resources (1.3 trillion tons – Murphy et al., 2006) the better positioned we will be to react to future needs of the country.

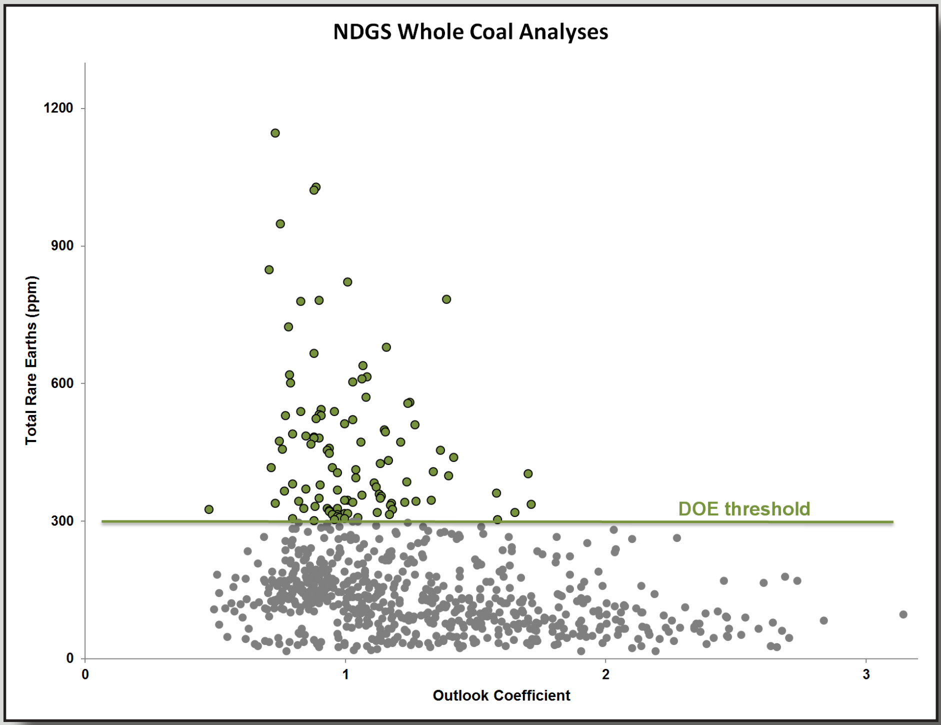

Figure 3. Rare earth element concentrations (whole rock basis) for 755 of the Geological Survey samples collected in western North Dakota.

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