Critical Minerals in North Dakota

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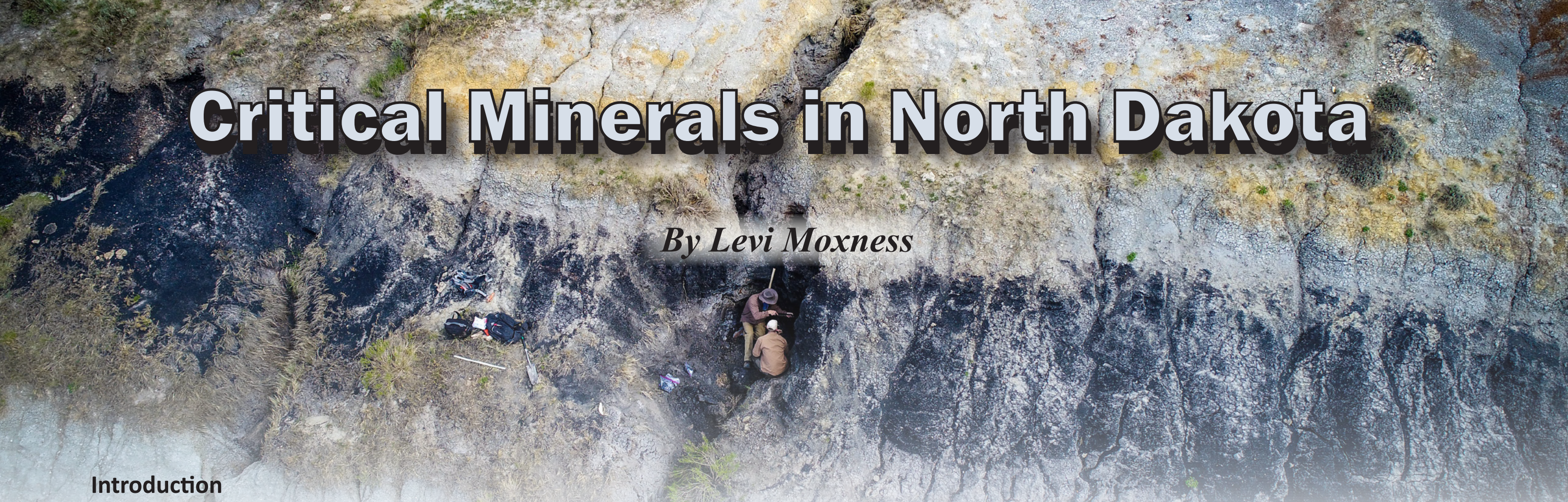

Introduction

Previous Geo News articles (Kruger, 2015; Murphy, 2019) introduced a troubling imbalance in international trade: the United States relies on China for nearly all of its rare earth elements; vital components of the smaller, stronger magnets used in most modern technology. China has used its monopoly as leverage in trade negotiations to great effect, considering it has the potential to disrupt the ability of U.S. industry to manufacture nearly anything with a modern electronic component. China has announced plans to target U.S. military suppliers in December 2020 with sanctions on Lockheed Martin, which produces Patriot missiles and F-35 fighter jets, and other U.S. defense firms. The U.S. has scrambled to reduce its import reliance on China and now sources about 20% of its rare earth needs indirectly from Australia (USGS, 2020), which opened its own rare earth mine with financial backing from Japan, the target of a rare earth embargo from China in 2010. The U.S. has stated its ultimate strategic goal is to meet most of the country's rare earth needs with domestic production. The only U.S. rare earths mine reopened in Mountain Pass, CA, in 2018, but it still exports all its ore to China to be refined, now with a 25% Chinese tariff. New rare earth deposits, such as the Bear Lodge Mountains in Wyoming and the Bokan Mountain in Alaska, are being developed, but recreating a full domestic supply chain will take many years.

The U.S. rare earth element import reliance is just one of the many strategic liabilities in the mineral commodities sector. In 2018, at the height of international trade tensions, the U.S. Department of the Interior released a list of 35 critical commodities (table 1) that (1) were identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) are from a supply chain that is vulnerable to disruption, and (3) serve an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security (USGS, 2018). Signs of support from the U.S. Department of Defense and U.S. Department of Energy have spurred a new wave of exploration for domestic sources of these critical minerals.

Known Critical Minerals in North Dakota

The traditional ore sources for many of the minerals on the list are igneous (crystalline bedrock). North Dakota has glacial or sedimentary bedrock cover over the entirety of the state, and thus the traditional igneous ore sources are likely too deep to be economically mined, if present at all. Some minerals can be found in the glacial cover, such as the small manganese springs in the Turtle Mountains (Hendricks and Laird, 1943). Recent investigations by the North Dakota Geological Survey (NDGS) indicate those deposits are sourced from the underlying Cretaceous marine bedrock. Potash is present over a mile below ground in the Devonian Prairie Formation of the Williston Basin in North Dakota. It can be solution-mined and has been examined recently in North Dakota for production like that which is seen in the Canadian portion of the basin (Murphy, 2011; Kruger, 2020). Uraniferous coal was mined in Billings and Slope counties in the 1960s (Murphy, 2015). The likely original source of this uranium is the mostly eroded volcanic ash in the White River Group (Denson and Gill, 1965). As the volcanic sediments weathered, the released minerals were carried downward and accumulated in Fort Union Group sandstones and particularly lignites, which were mined, burned down, and shipped out of state for processing. Mineralized coal is an attractive ore because it can be burned, and the minerals are concentrated up to 20-fold in the remaining ash. Atomic Age investigators focused primarily on uranium, but which other elements followed this same enrichment model and may be economically concentrated in North Dakotas lignites?

The rare earth elements (including yttrium and scandium) are one group of critical elements that has attracted particular interest for its potential to be produced from coal (Kruger, 2017). Since 2015, the NDGS has collected over 1,400 samples of lignite and associated sediments from across six western North Dakota counties. Several beds have been identified with rare earth concentrations above 300 parts per million (ppm) (Kruger et al., 2017; Murphy et al., 2018), which is the threshold put forth by the U.S. Department of Energy as a target for concentrations that may be promising. The full economic equation for commercial production includes many other variables, some still unknown. Several research groups are actively working on the most cost-effective and environmentally friendly methods for extracting rare earths from U.S. coal, and their resulting leaching technologies will determine what concentrations are required for economic feasibility – after also considering the market prices of rare earths, the thickness of the lignite bed to be mined, the thickness of the overburden to be removed, and whether the coal is processed strictly as mineral ore or also utilized as part of an existing power generation operation.

Table 1. Critical mineral commodities as recognized by the U.S. Department of the Interior (USGS, 2018). The U.S. import reliance is a percent estimate of 2019 consumption from foreign sources, where supply is often controlled by a few dominant producers (USGS, 2020). Prospects for production from coal adapted from Dai and Finkelman (2018). *Molybdenum is not deemed critical by the U.S. but is a potential value-added product from coal.

Critical Mineral Commodity	U.S. Import Reliance	Top National Producer	Primary or Noteworthy Industry Applications	Key Industries: Aerospace	Defense	Energy	Electronics	Other	Coal as a source?
Aluminum	22%	China	Aircraft, lightweight alloys	✓	✓	✓	✓	✓	Yes
Antimony	84%	China	Lead-acid batteries		✓	✓	✓	✓	Promising
Arsenic	100%	China	Microwave communications		✓	✓	✓	✓	Not Promising
Barite	87%	China	Oil & gas drilling fluid			✓	✓	✓	Not Promising
Beryllium	>21%	U.S	Satellite communications	✓	✓	✓	✓	✓	Promising
Bismuth	96%	China	Pharmaceuticals, solders		✓	✓	✓	✓	Not Promising
Cesium	100%	Canada	Medical appl., satellites	✓	✓	✓	✓	✓	Promising
Chromium	72%	South Africa	Jet engines, stainless steels	✓	✓	✓	✓	✓	Promising
Cobalt	78%	Congo	Jet engines, rechar. batteries	✓	✓	✓	✓	✓	Not Promising
Fluorspar	100%	China	Metal and uranium production			✓	✓	✓	Not Promising
Gallium	100%	China	Radar, LEDs, cell phones	✓	✓	✓	✓	✓	Yes
Germanium	>50%	China	Infrared devices, fiber optics	✓	✓	✓	✓	✓	Yes
Graphite	100%	China	Rechar. batteries, body armor	✓	✓	✓	✓	✓	Not Promising
Hafnium	N/A	Australia	Jet engines, nuclear appl.	✓	✓	✓	✓	✓	Promising
Helium	EXP	U.S	MRI machines				✓	✓	Not Promising
Indium	100%	China	Flat panel displays, alloys	✓	✓	✓	✓	✓	Not Promising
Lithium	>25%	Australia	Rechar. batteries, alloys	✓	✓	✓	✓	✓	Promising
Magnesium	52%	China	Incendiary countermeasures	✓	✓	✓	✓	✓	Yes
Manganese	100%	China	Metal production, alloys	✓	✓	✓	✓	✓	Not Promising
Molybdenum*	EXP	U.S	Steel alloys	✓	✓	✓	✓	✓	Very Promising
Niobium	100%	Brazil	High-strength steel	✓	✓	✓	✓	✓	Very Promising
Platinum Metals	32-64%	South Africa	Catalysts, superalloys	✓		✓	✓	✓	Very Promising
Potash	91%	Canada	Agricultural fertilizer			✓	✓	✓	Not Promising
Rare Earths	100%	China	Batteries, lasers, fiber optics	✓	✓	✓	✓	✓	Very Promising
Rhenium	82%	Chile	Jet engines, catalysts	✓		✓	✓	✓	Very Promising
Rubidium	100%	Canada	Medical appl., satellites	✓	✓	✓	✓	✓	Not Promising
Strontium	100%	Spain	Alloys, magnets, flares	✓	✓	✓	✓	✓	Not Promising
Tantalum	100%	Rwanda	Capacitors, superalloys	✓	✓	✓	✓	✓	Promising
Tellurium	>95%	China	Infrared devices, solar cells		✓	✓	✓	✓	Not Promising
Tin	77%	China	Solder, flat panel displays		✓		✓	✓	Not Promising
Titanium	86%	China	Superalloys, airframes, armor	✓	✓	✓	✓	✓	Promising
Tungsten	>50%	China	Cutting/drilling tools, alloys	✓	✓	✓	✓	✓	Promising
Uranium	N/A	Kazakhstan	Nuclear and medical appl.	✓	✓	✓		✓	Historically Yes
Vanadium	93%	China	Superalloys, airframes, steel	✓	✓	✓	✓	✓	Yes
Zirconium	EXP	Australia	Jet engines, nuclear appl.	✓	✓	✓	✓	✓	Very Promising

New Exploration

Regardless of the final economic outlook for producing rare earths alone from coal, its prospects could increase substantially if additional valuable minerals were present that could be co-produced from the same coal. Several mineral commodities are already commercially produced from coal or coal ash, including aluminum, gallium, germanium, magnesium, silicon, selenium, and vanadium (Dai and Finkelman, 2018). Extraction methods are being developed for additional highly promising elements like gold, silver, platinum, palladium, molybdenum, niobium, rhenium, and zirconium. Highly elevated concentrations of antimony, beryllium, chromium, cesium, iridium, iron, hafnium, lithium, osmium, rhodium, ruthenium, tantalum, titanium, and tungsten have been found in coal or coal ash that are on par with conventional ores, and are one supply/demand disruption away from receiving heavy interest.

Some concentrations of these elements in North Dakota lignites have been reported, as summarized in the USGS's COALQUAL database (Lin et al., 2018). Many critical elements are strongly represented with as many as 7,600 analyses reported, but less than 200 represent North Dakota coals. With so few samples, it is not surprising none of the critical element concentrations in North Dakota's lignites are among the top in the database, which is primarily bituminous Appalachian coals. These 200 entries also likely do not reflect the state's most enriched seams, instead being full-bed samples of the thick coals preferred for supplying coal power plants. Representing the full thickness of a major lignite with one mixed concentration is likely to dilute any signal from enriched zones at the top or bottom of the bed, if present.

With nearly 1,000 analyses of rare earths in North Dakota lignite since 2015, the NDGS has compiled a substantial dataset of where coals may be mineralized and is now leveraging this new information to investigate the occurrence of other critical minerals alongside the rare earths. As many as 349 samples have been analyzed for the most potentially economic element, germanium (fig. 1), and the NDGS hopes to add hundreds more analyses of the most promising 6-10 elements in the next year (fig. 2). This strategy of targeting thinner mineralized zones has already yielded point concentrations for nine elements higher than any of the thousands of U.S. coal seams in the USGS COALQUAL database. The NDGS is also investigating the strength of each element's correlation with rare earth enrichment. If we can establish which mineral commodities are present, and which can be expected to be enriched with rare earths, this could further focus exploration and remove some uncertainties from the economic development equation.

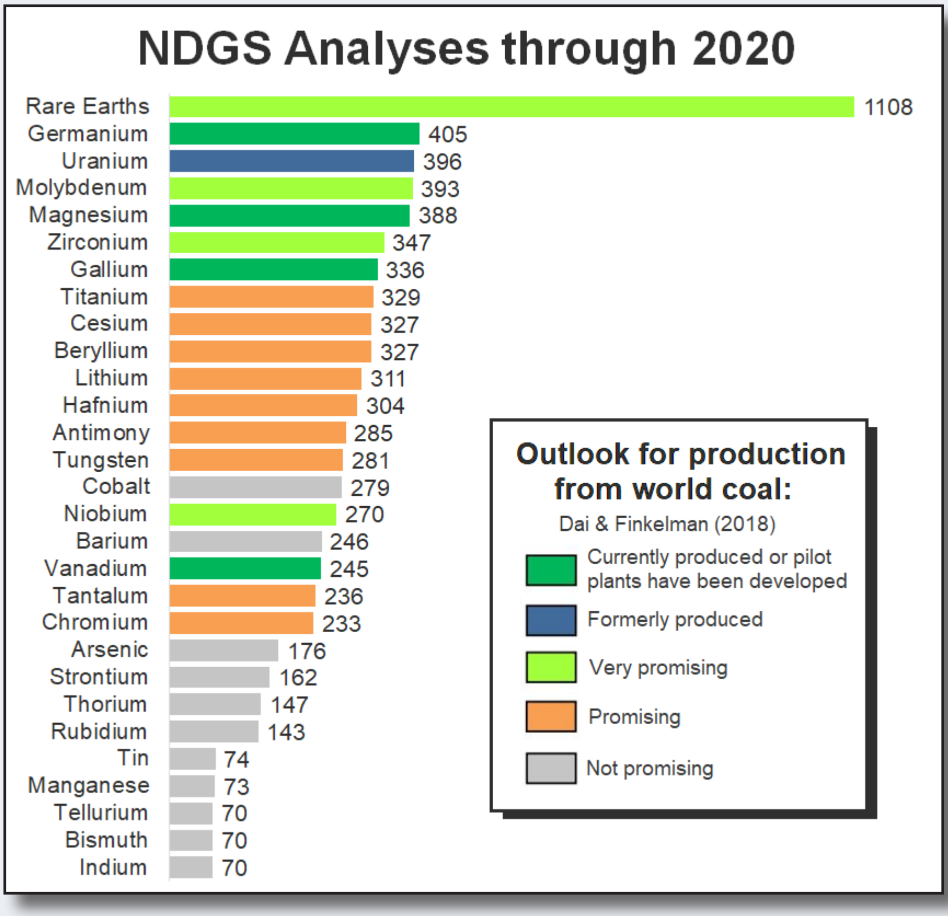

Figure 1. The number of analyses for each critical element examined by the NDGS in North Dakota lignites as of November 2020. Note: thorium is a problematic contaminant in many ore sources, so determining its presence is an important part of an economic assessment.

Figure 2. State geologist Ed Murphy measures a stratigraphic section in Slope County in October 2020. Approximately 1,500 samples have been collected from across 200 of these sections, totaling tens of thousands of feet logged during the rare earths and critical minerals study. Photograph taken looking south with the Little Missouri River in the background.

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