24-078

Rare Earth Elements (REE) and Other Critical Minerals in Late Cretaceous Coal and Related Strata in the San Juan and Raton Basins, New Mexico: Preliminary Observations

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ABSTRACT

Critical minerals are becoming more important in our technological society because they are used in many of our electronic devices, batteries, and magnets. In New Mexico, low to moderate concentrations of critical minerals are found in Late Cretaceous coal and related strata in the San Juan and Raton Basins. These rocks are being characterized as part of the DOE's CORE-CM (Carbon Ore, REE, and Critical Minerals) program. The New Mexico coal, humate, and clinker deposits are relatively low in REE (<325 ppm TREE), Li (<90 ppm), V (<168 ppm), Co (<51 ppm), Ni (<108 ppm), Zr (<557 ppm), and many other critical minerals compared to normal economic deposits. Some of these rocks are enriched in Al_2O_3 (<40%) and Sr (<3740 ppm), both critical minerals. Common minerals hosting the critical minerals in these rocks include clay minerals, zircon, and rutile/anatase. As the demand for some of these elements increases because of increased need and short supplies, the dollar value per ton of ore rises, enhancing deposit economics. Ultimately, economic potential will most likely depend upon production of more than one commodity, maybe even from coal, humate, and clinker deposits.

INTRODUCTION

The demands of our technological society will require additional mineral resources production, especially critical minerals. *Critical minerals* are mineral commodities that are essential to the economic and national security of the U.S., and is from a supply chain that is vulnerable to global and national disruption. In the mining industry, *minerals* refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities. Thus, the term mineral includes all inorganic substances, as well as hydrocarbons, such as oil and natural gas, and carboniferous deposits, including coal and humate.

Coal is mined and primarily used in generating electricity in power plants, but coal also is essential in the manufacture of steel, production of cement, carbon fibers and foams, medicines, tars, synthetic petroleum-based fuels, and home and commercial heating. Coal also can be a potential source of carbon fiber, coking coal, and graphite.

New Mexico has a wealth of mineral resources, including coal (McLemore et al., 2017), and some of these critical minerals are associated with various mineral deposits in the San Juan Basin in New Mexico (McLemore, 2017a, b; 2018; John and Taylor, 2016). But there has not been a systematic evaluation of their location and resource assessment. This project is one of 13 CORE-CM (Carbon Ore, Rare Earth Elements and Critical Minerals) projects funded by the U.S. Department of Energy (DOE) to identify and quantify the distribution of rare earth elements (REE) and critical minerals in coal beds and related stratigraphic units in coal basins throughout the U.S.

Coal deposits from throughout the world are known to contain high concentrations of critical minerals and REE (Dai and Finkelman, 2018), but a basin-wide geochemical and mineralogical characterization study of New Mexico coals is needed to determine the potential for critical minerals and REE. The purposes of the CORE-CM project are to 1) identify, quantify, and characterize the distribution of critical minerals, including REE, in coal beds and related stratigraphic units in the San Juan and Raton basins in New Mexico, 2) identify possible sources of critical minerals and REE in the basins, 3) identify the coal mine and nonfuel carbon-based waste products that could contain critical minerals and REE, and 4) test and develop new technologies in identifying and quantifying critical minerals and REE in high-fidelity geologic models. In this paper we are presenting data on three types of deposits in the San Juan Basin. Future reports will discuss the potential for REE and critical minerals in adjacent strata in the San Juan and Raton basins.

GEOLOGY

The San Juan Basin is a predominant Laramide (Upper Cretaceous–Early Tertiary age structural basin in northern New Mexico and southern Colorado that host and produced important energy and mineral resources, including coal, uranium, petroleum, and gas (Figure 1, 2).

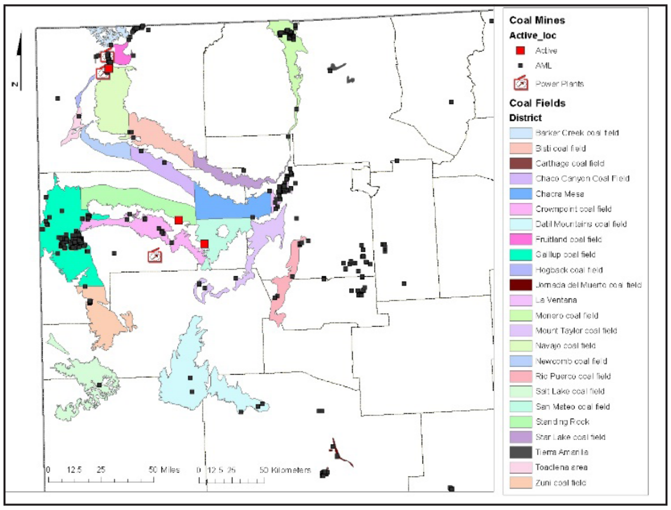

Figure 1. Location map of coal fields in the San Juan basin, New Mexico (modified from Hoffman, 2017). Active coal mines are surface operations. Lee Ranch mine suspended operations in 2016, but plans to reopen. Coal fields are summarized in Table 1 (end of report). Only the Four Corners power plant remains open

Stratigraphic units in the San Juan Basin dips inward from the highlands towards the center of the basin, creating a trough-like feature. San Juan Basin has three major coal-bearing units: Crevasse Canyon, Menefee, and Fruitland formations in 26 coal fields.

Coal is mined in New Mexico and fuels electrical generating plants in New Mexico and Arizona. Coal mining on a significant scale began in New Mexico in 1862, when U.S. Army troops from Fort Craig opened the Government mine in the Carthage field (Socorro County) to supply coal for smithing at Forts Seldon, Bayard, and Stanton. Coal mining continued to expand in the 1880s throughout New Mexico supplying the railroads with fuel. Three surface mines remain in operation today; El Segundo, Lee Ranch and Navajo. New Mexico is 12th in coal production in U.S. in 2020, with production at approximately 10,249,000 short tons. However, production is decreasing because of mine closures. New Mexico is 15th in estimated recoverable coal reserves in U.S. (65 million short tons of recoverable reserves at mines and 6,719 million short tons estimated recoverable reserves in the basin).

Coal is a sedimentary rock that is composed of more than 50% by weight of organic material and is formed by the compaction of decaying plant material deposited in ancient peat swamps or mires. Coal is readily combustible and is burned for fuel. Several factors beside the thickness and quality of the coal determine whether a coal deposit is economic: 1) the technology available for extraction, 2) distance to a market, and 3) available transportation network. Throughout the history of mining coal in New Mexico, these factors have changed. Coal also contains minerals that are noncombustible and do not burn. These minerals could contain REE and other critical minerals that could be recovered from coal mining or from the coal ash remaining after the coal is burned. In the future, the concentration of critical minerals, including REE could be a factor in producing coal deposits.

Humates are weathered coal or highly organic mudstone that are found in the coal-bearing sequences (Newcomer et al., 2021). They can transition to coal at depth (Figure 3). They are locally also termed leonardite or weathered lignite; other terms are explained in Newcomer et al. (2021). The difference between coal and humate is brownish color and more humic acid content in humates and black coal burns, whereas high quality humate dissolves in water.

New Mexico has significant deposits of humates, predominantly in the Fruitland and Menefee formations in the eastern San Juan Basin. Humate is produced from ~10 mines and mills in New Mexico. The Horizon Ag Products mine and mill are south of Cuba. Menefee Mining operates

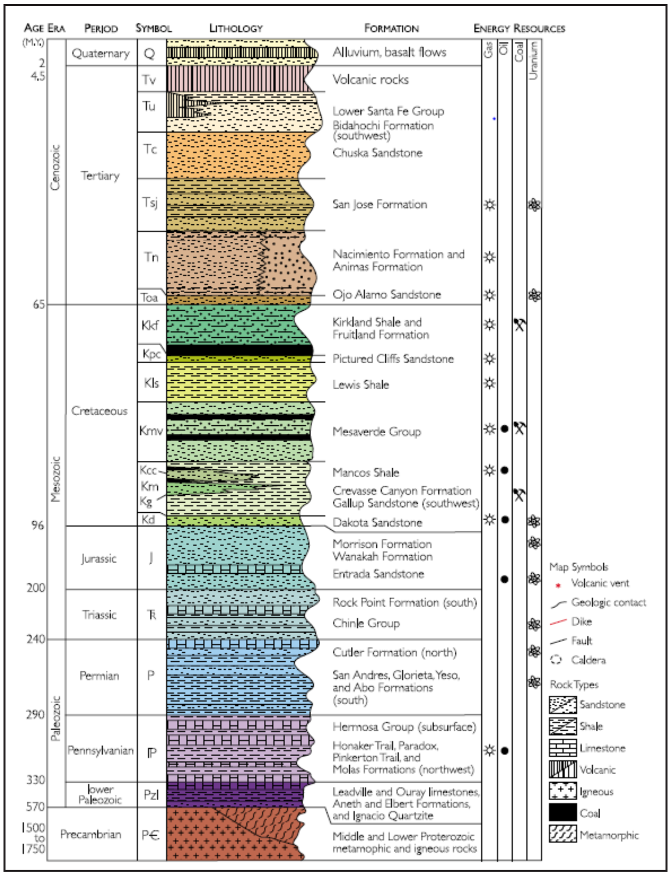

Figure 2. Stratigraphy of the San Juan Basin, New Mexico. Note the stratigraphic units that have gas, petroleum, coal, and uranium potential. Many of these same stratigraphic units have the potential for critical minerals and REE (from Brister and Hoffman, 2002)

one pit and a mill near Cuba. The mining operations, processing site, and transportation facility of U-Mate International, Inc. are located in the Gallup area. The Eagle Mesa mine is near Cuba and the Morningstar mine is in San Juan County. The Jaramillo humate mine in McKinley County is under development by Anasazi Stone LLC. Both El Segundo and Navajo mine produce some humate. Humate mining began in New Mexico in the 1970s, and production amounts to more than 900,000 metric tons of humate. Humate is used as a soil conditioner, medicinal uses, dispersant and viscosity control in oil-well drilling muds, stabilizer for ion-exchange resins in water treatment, and a source of water-soluble brown stain for wood finishing. Approximately 12.1 billion short tons of humate resources are within the San Juan Basin.

Bright red clinker deposits (also known as natural scoria and red dog deposits) are associated with some coal beds in the San Juan Basin coal fields. These clinker deposits are believed to originally be coal beds and adjacent strata that caught fire and/or burned in place. The fire was caused by forest or grass fires, lightning strikes, or even natural combustion. In some areas in the western U.S., evidence suggests that prehistoric humans may have ignited some of the coal beds in place. Coal seam fires can spread extensively underground. Temperatures can reach 1000°F, baking surrounding rocks. The sketch by Hoffman (1996) illustrates the process of forming these deposits. Natural clinker deposits are quarried and used to make roads, bricks, and other industrial uses.

In New Mexico, natural clinker deposits along with the adjacent coal beds are being sampled as part of the project to determine if these deposits could have elevated concentrations of REE or other critical minerals. The bright red color of the clinker deposits (Figure 4) is in sharp contrast to the normal gray, tan, and black colors in the Cretaceous beds in the San Juan Basin and are excellent exploration indicators of nearby coal seams because they are resistant to erosion.

METHODS

Sample Collection

Different sampling strategies will be employed based upon the purpose of each sampling task. Several types of samples were collected: composite, select, profile samples, composite mine waste, and drill core samples as described below. Samples are archived at NMBGMR for future examination. Two separate splits of each samples are generally collected: one split for chemical analyses that is submitted to the chemical laboratory and a second split that is archived at NMBGMR. Selected sample sites are marked on topographic maps and a digital photograph is taken at all localities. Photographs provide visual record of the sample site; the photograph form identifies site specifics, provides basic location and other data about the photograph. Location information by GPS, type of sample, and field and laboratory petrographic descriptions are collected. Geologic observations are recorded on the field description form or field book. A global positioning system (GPS) reading is recorded as well. Hand specimen description provides a record of what was collected, aids in petrographic description, and provides information on sample for the labs (high S may be treated differently than low S). The hand specimen description is the preliminary data required to determine what samples need specific detailed analyses. Location, type of sample, and other descriptive data were entered into the project database.

Composite samples include sampling along the width and thickness of the sedimentary layer or bed in order to obtain a representative sample of the unit. Multiple subsamples are collected and homogenized for a composite sample.

Select samples include hand specimens of mineralized rocks (including ore samples), grab samples of the mine wastes, samples from individual cells, etc. from anywhere in the mine or outcrop being sampled and are collected for specific purposes (to identify minerals, separate chemical analyses, etc.). These samples are collected separate from the composite sample. The volume or number of samples collected is highly dependent on the type of laboratory test to be conducted and the availability of the sample. Remove weathering surfaces from rock samples. If the purpose of sampling is for geochemical analysis, break samples into smaller chips. Store the sample in a well-labeled bag.

Figure 3. Humate mine in the Star Lake field, northern New Mexico. The humate is the upper brownish layers overlying the black coal

Figure 4. Brick-red clinker deposits in the San Juan Basin coal fields

Profile samples are generally composite samples collected from individual stratigraphic layers or beds along a vertical exposed section of an outcrop, road cut, or open pit wall, if safe. Use a pick to clean the surface of the profile gently to prevent the edges from caving in. Identify the changes in different lithologies (i.e., color, thickness, depth texture, grain size, etc.) and record them in the field notebook. Collect samples carefully by scraping directly into a well-labeled sample bag, (include sampling depth on the sample bag) or decontaminated container using a small pick, trowel or scoop to avoid cross-contamination from different lithologies. In addition, sample from the midpoint of the profile as much as possible, sampling the edge can result in mixing lithologies. Assign one GPS location and waypoint to the pit and different sample IDs to each lithology sampled.

A *composite sample* of *the mine waste* is collected after sample units have been identified in a particular mine feature. Composite samples of waste rock piles were collected, using procedures developed by Munroe (1999) and the U.S. Geological Survey (USGS) (Smith et al., 2000; Smith, 2007; McLemore et al., 2014; USGS 2023 memo). This type of sampling is developed by the USGS and poses no stability or erosion risks of the waste rock piles or tailings. Each sampling unit should be subdivided into at least 30 cells of roughly equal area. To do this, flags/markers are placed equidistant from each other forming a rough grid, where the flag/maker represents the center of each cell. GPS locations should also be recorded simultaneously, while placing flags/markers or while removing flags/markers after sampling. The overburden or overlying surface material (i.e., leaves, grass, roots, cover material of tailings, etc.) is first removed. Collect the desired volume into the required sieve size (e.g., 4 mm for waste rock piles), and sieve into a single decontaminated bucket or bag, making sure to homogenize as you sample. Finally, all the composite samples should be thoroughly homogenized again and then transferred into appropriately labeled sample containers.

Drill core samples are collected from existing drill core. Core is generally described (logged) and photographed before sampling. Only ½ of the core is split or sawed, with the remaining core left in the box undisturbed. If the core has already been sampled, then only ¼ is removed. A note with your name, project, date, and purpose of sampling is stored in the box where the sample was taken from.

Some general precautions in sampling include the following. All equipment should be cleaned to prevent cross-contamination of the sample. Sampling tools (buckets, sampling bags, shovels, trowels, and sieves) should be constructed of materials suitable for environmental sampling (typically stainless steel, plastic, or aluminum). Devices plated with chrome or other materials should not be used as they can introduce contaminants to the samples. All equipment used for sampling should be rinsed with deionized water and air-dried prior to use. Wear disposable gloves while sieving to avoid contamination.

The samples are transported from the field to NMBGMR, where each sample is prepared for analyses. Selected samples are cut and chips sent for preparation of polished thin sections. The prepared samples are then sent to a laboratory for chemical analyses. NMBGMR standards are submitted blind to the commercial laboratory with each sample batch to assure analytical quality.

Geochemical Analyses

Geochemical data are a critical part of geologic mapping and for evaluation for critical mineral resources central to the mission of Earth MRI. Geochemical analyses of samples collected for this study were determined by the USGS laboratory and by ALS Laboratory (description of methods can be found at ALS Geochemistry Fee Schedule USD (2).pdf and in future reports). Samples were submitted to the laboratories where sample preparation occurred. Duplicate samples and standards were analyzed and uncertainty of analyses is generally <5%. Specific analytical methods for each element and additional quality assurance and quality control (QA/QC) are available on request. Chemical plots were created using ioGAS-64 (ioGAS™ - REFLEX (reflexnow.com). Chemical analyses will be presented in future reports.

Petrography and Mineralogy

Hand sample descriptions of both sawed samples and thin sections were entered into the project's SQLS database. Polished thin sections of selected samples of the igneous, altered, and mineralized rocks were made by Quality Thin Sections. Thin sections were scanned in both plane and plane polarized light, and selected photomicrographs were taken. Mineralogy of selected samples was determined by visual and petrographic, X-ray diffraction (XRD), and electron microprobe methods.

X-ray diffraction (XRD) analysis was performed on either whole rock or mineral separates performed on a PANalytical X- Pert PRO® diffractometer at the NMBGMR X-ray Diffraction Laboratory. Analyses were conducted using 45 kV X-ray beam tension and 40 mA X-ray beam current. XRD scans were identified using X'Pert HighScore Plus® software, which identifies intensity peaks and matches patterns to a Powder Diffraction File database. XRD data will be available in the final report. Petrographic descriptions, including mineralogy and texture, of thin sections using plane, plane polarized, and reflective light were entered into the SQLS database.

PRELIMINARY RESULTS

Mineralogy

Common minerals hosting the critical minerals in these rocks include clay minerals, zircon, and rutile/anatase, as determined from petrographic and XRD analyses.

Chemistry

Results of chemical analyses are shown in Figures 5–11.

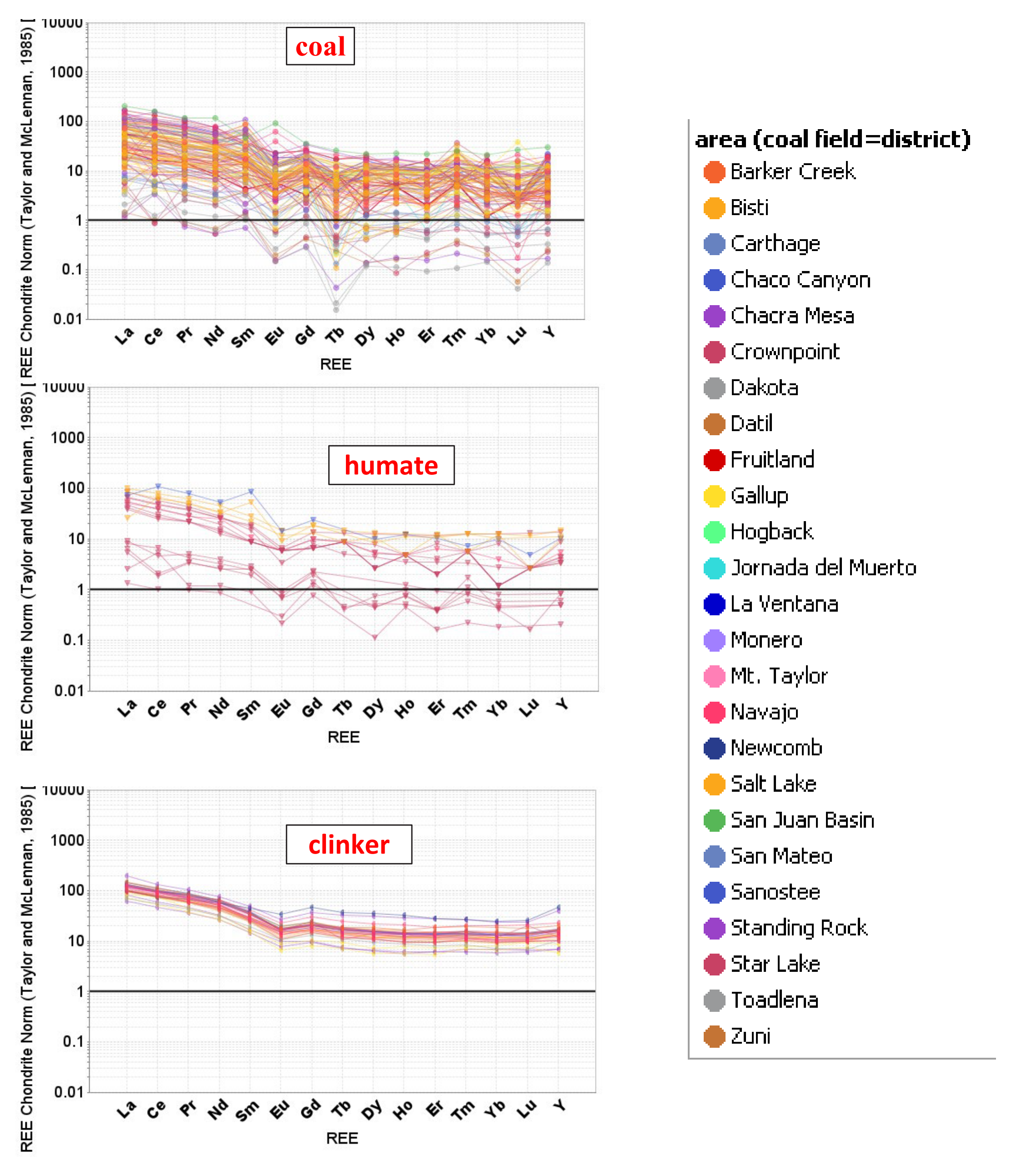

Figure 5. Chondrite-normalized REE plots (Taylor and McLennan, 1985) for coal, humate, and clinker deposits in the San Juan Basin. See Table 1 for summary of coal fields (districts) sampled and Figure 3 for locations of coal fields

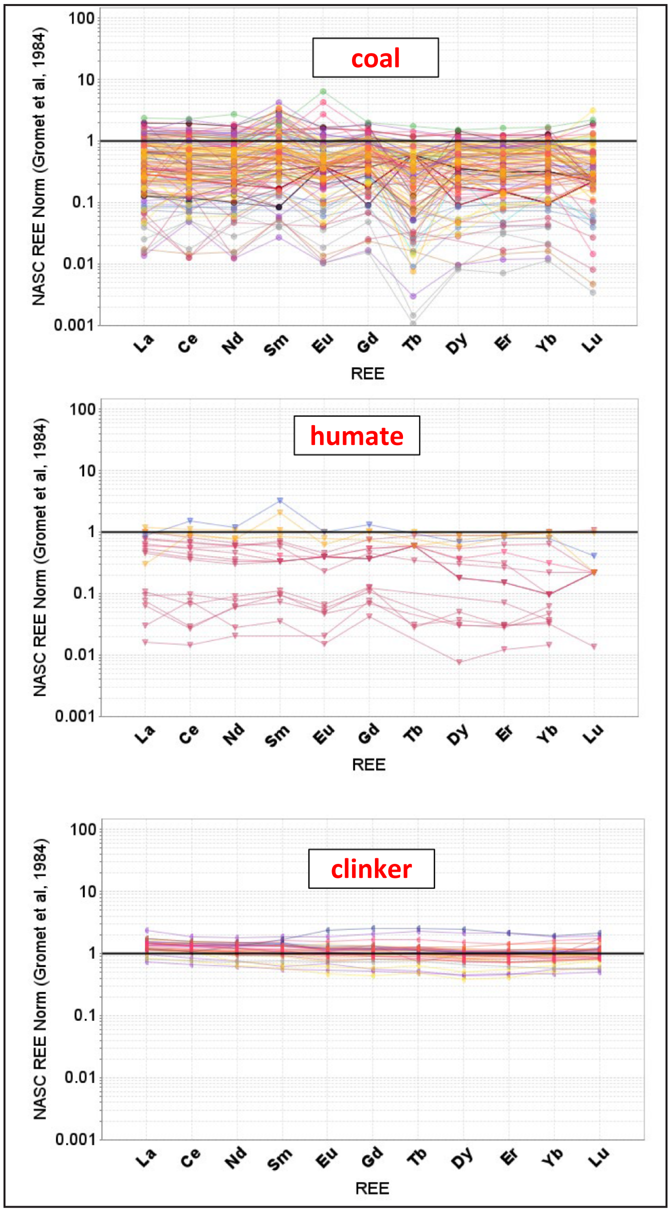

Figure 6. Samples normalized to North American Shale Composite (Gromet et al., 1984). See Table 1 for summary of coal fields and Figure 5 for key

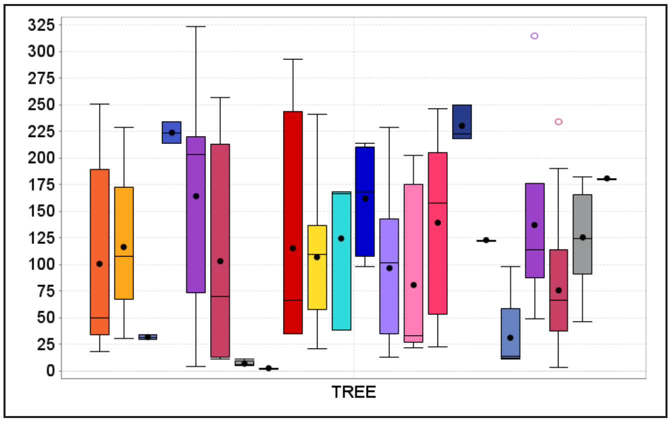

Figure 7. Box and whisker plots of TREE (ppm) in coal, humate, and clinker samples. See Table 1 for summary of coal fields and Figure 5 for key

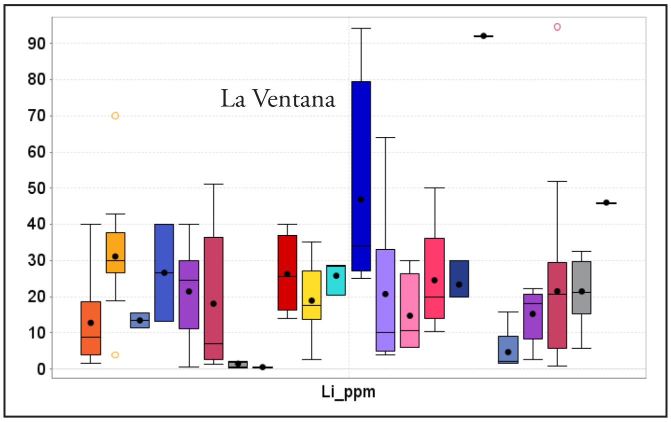

Figure 8. Box and whisker plots of Li (ppm) in coal, humate, and clinker samples. See Table 1 for summary of coal fields and Figure 5 for key

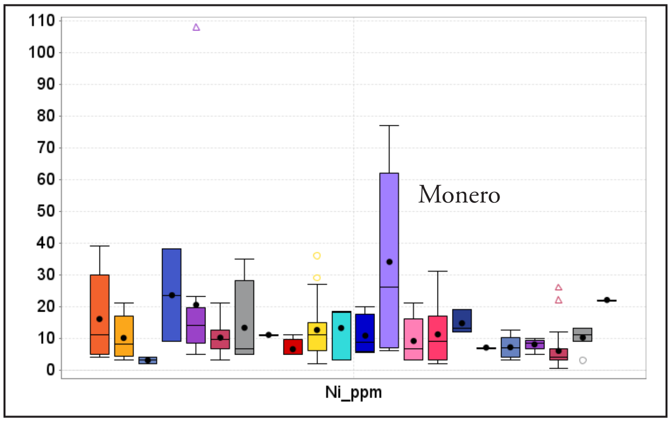

Figure 9. Box and whisker plots of Ni (ppm) in coal, humate, and clinker samples. See Table 1 for summary of coal fields and Figure 5 for key

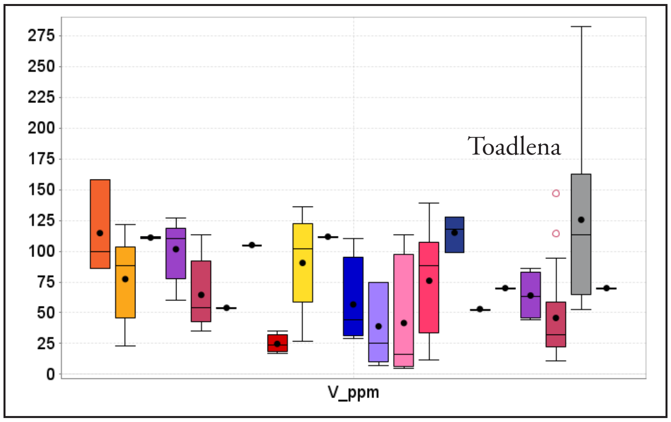

Figure 10. Box and whisker plots of V (ppm) in coal, humate, and clinker samples. See Table 1 for summary of coal fields and Figure 5 for key

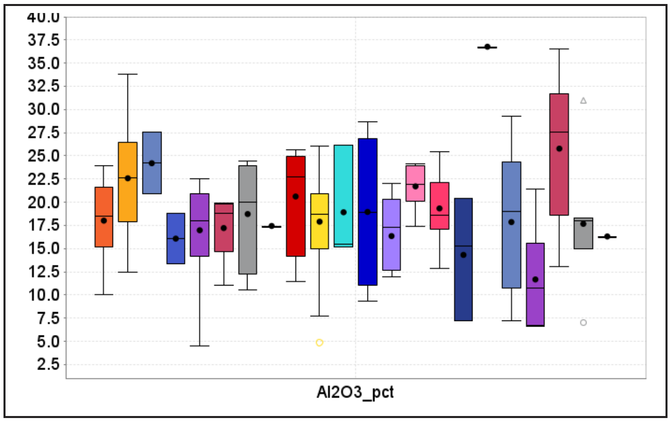

Figure 11. Box and whisker plots of Al_2O_3 (%) in coal, humate, and clinker samples. See Table 1 for summary of coal fields and Figure 5 for key

PRELIMINARY CONCLUSIONS

The New Mexico coal, humate, and clinker deposits are relatively low in REE (<325 ppm TREE), Li (<90 ppm), V (<168 ppm), Co (<51 ppm), Ni (<108 ppm), Zr (<557 ppm), Hf (<14 ppm), and many other critical minerals compared to normal economic deposits. However, some of these rocks are enriched in Al_2O_3 (as much as 40%) and Sr (as much as 3740 ppm), both critical minerals. Common minerals hosting the critical minerals in these rocks include clay minerals, zircon, and rutile/anatase. Potential geologic sources of REE and other critical minerals in New Mexico coal, humate, and clinker deposits include Proterozoic granitic and metamorphic rocks (such as those found in the Zuni and Nacimiento Mountains), the Jurassic-Cretaceous arc volcanism and magmatism forming the Mogollon Highlands to the south and west, and recycling of older sediments, although hydrothermal or weathering fluids could concentrate some of the critical minerals. More chemical and mineralogical analyses are required to fully understand the distribution and origin of REE and critical minerals in these deposits. As the demand for some of these elements increases because of increased need and short supplies, the dollar value per ton of ore rises, enhancing deposit economics. Ultimately, economic potential will most likely depend upon production of more than one commodity, maybe even from coal, humate, and clinker deposits.

ACKNOWLEDGMENTS

This report is part of on-going studies of mineral resources in New Mexico, supported by the New Mexico Bureau of Geology and Mineral Resources (NMBGMR), Nelia Dunbar, Director and State Geologist. Current research is funded through a DOE grant Carbon Ore, Rare Earth Elements, and Critical Minerals (CORE-CM) assessment of San Juan River-Raton Coal Basin, New Mexico, DE-FE0032051. Thanks to Mark Leo-Russell for database support, students of the NMBGMR Economic Group for sample collecting and prepration (especially Abena Serwah Acheampong-Mensah, Zohreh Motlagh Kazemi, Harriett Tetteh, Anita Appah, and Brielle Hunt).

Any persons wishing to conduct geologic investigations on the Navajo Nation must first apply for and receive a permit from the Minerals Department, P.O. Box 1910, Window Rock, Arizona 6515 and telephone no. 928-871-6588.

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Table 1. Samples from coal fields in the San Juan and Raton basins. Coal fields and reserves are delineated by Hoffman (1996, 2017). District Id is from the New Mexico Mines Database (McLemore, 2010a, 2017). Representative samples have been and will be collected from each coal field. At least 3 samples will be collected from each coal field. Red=no analyses at this time

District ID	District (coal field)	Year of Initial Production	Year of Last Production	Estimated Cumulative Production	Formation	Number of Samples Analyzed	Number of Coal Analyzed	Demonstrated Resources, million tons (Hoffman, 2017)
DIS257	Barker Creek		1905		Menefee	9	6	w
DIS150	Bisti	1980	1988	40,075,148	Fruitland	50	16	872
DIS208	Carthage	1861	1963		Crevasse Canyon, Tres Hermanos	2	2	30
DIS259	Chaco Canyon	1905			Menefee	2	1	46
DIS260	Chacra Mesa		1945		Menefee	25	8	140
DIS118	Crownpoint	1914	1951	20,758	Crevasse Canyon	12	8	663
na	Dakota	na	na	na	na	4	4	
DIS262	Datil	1917	1940	66,980	Dakota	1	1	47
DIS155	Fruitland	1889	2001	3,137,957,050	Crevasse Canyon, Tres Hermanos	5	4	550
DIS119	Gallup	1882	2001	121,522,629,885	Fruitland	48	26	610
DIS156	**Hogback**	1907	1971	301,237	Crevasse Canyon			66
DIS264	Jornada del Muerto		1927		Menefee	6	3	0
DIS174	La Ventana	1904	1983		Crevasse Canyon	4	4	263
DIS146	Monero	1882	1970	5,277,552	Menefee	9	7	40
DIS016	Mount Taylor	1952	1953	69,948	Menefee	7	5	19
DIS157	Navajo	1963	9999	4,714,689,147	Crevasse Canyon	19	9	1340
DIS258	Newcomb				Fruitland		3	126
DIS021	Raton	1898	2002	954,470,032	Menefee	27	12	
DIS003	**Rio Puerco**	1937	1944	139,555	Vermejo, Raton			25
DIS009	Salt Lake	1987	1987	100,000	Crevasse Canyon	2	1	323
DIS121	San Mateo	1983	2001	954,470,032	Moreno Hill	9	5	385
DIS261	Standing Rock	1952	1958		Menefee	11	4	392
DIS158	Star Lake				Menefee	47	30	946
DIS263	**Tierra Amarilla**	1955	1955		Fruitland			4.5
DIS159	Toadlena				Menefee	16	6	0
DIS124	**Zuni**	1908	1926	16,010	Menefee	1	1	83
	coal ash					5		
	beach placer sandstone					40		
	uranium sandstone							
	Other samples					18		
	total samples					379	166	7153.5

24-079

Real-Time Dust Monitoring in Occupational Environments: A Case Study on Using Low-Cost Dust Monitors for Enhanced Data Collection and Analysis

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Abstract

A worker's personal exposure to respirable dust in occupational environments has traditionally been monitored using established methodologies which entail the collection of an 8-hour representative sample that is sent away for laboratory analysis. While these methods are very accurate, they only provide information on the average exposure during a specific time period, generally a worker's shift. The availability of relatively inexpensive aerosol sensors can allow researchers and practitioners to generate real-time data with unprecedented spatial and temporal granularity. Low-cost dust monitors (LCDM) were developed and marketed for air pollution monitoring and are mostly being used to help communities understand their local and even hyper-local air quality. Most of these integrated sensing packages cost less than $300 per unit, in contrast to wearable or area dust monitors specifically built for mining applications which have been around for decades but still average around $5,000 each. At the National Institute for Occupational Safety and Health (NIOSH), we are leveraging the power of high-volume data collection from networks of LCDM to establish baseline respirable hazard levels and to monitor for changes on a seasonal basis as well as following any application of control technologies. We have seen the effective use and advantages of monitoring live data before, during, and after events like shift changes, operational changes, ventilation upgrades, adverse weather events, and machine maintenance. However, many factors have prevented a systematic adoption of LCDMs for exposure monitoring: concern for their analytical performance, the complexity of use, and lack of understanding of their value are some factors. This contribution outlines a one-year case study at a mine in Wisconsin USA, covering the installation, maintenance, data visualizations, and collaboration between NIOSH researchers and the industrial hygiene professionals at the mine.

INTRODUCTION

Exposure to respirable crystalline silica (RCS) poses a silent but potent threat to the health and well-being of workers across a wide range of industries. Silica, in its fine particulate form, can become airborne during various industrial processes, construction activities, and mining operations. The hazards of crystalline silica exposure are not to be underestimated, as they can lead to severe and often irreversible health consequences, including the development of debilitating lung diseases such as silicosis and an increased risk of lung cancer [1]. Silicosis is a fibrotic lung disease characterized by the chronic impairment of normal lung function due to the phagocytosis of crystalline silica within the lung, resulting in lysosomal damage [2]. Dust containing crystalline silica is invariably created through the mining