

Deploying a New AI Software Tool for Rapid Characterization & Quantification of Unconventional Sources of Critical Minerals

Creason, C.G.,¹ Rose, K.,¹ Montross, S.,¹ Maymi, N.,² Jackson, Z.,² O'Barr, S.,² Bishop, E.,² Wingo, P.,¹ Hazle, G.,³ Skipwith, S.,³ Moyes, A.,³ Lindemann, G.,³ Atkins, C.,³ Hird, J.,⁴ Taglia, F.⁴

1 National Energy Technology Laboratory
2 NETL Site Support Contractor
3 Ramaco Carbon
4 Weir International



Research & Innovation Center

Project Summary

The effort will accelerate application and commercial utilization of an NETL-developed technology to rapidly characterize critical mineral occurrences within secondary and/or unconventional feedstocks, such as coal refuse or waste impoundments.

The project involves deploying a machine-learning enhanced x-ray fluorescence (XRF) characterization system that enables near real-time detection of unconventional critical mineral resources both at the surface and subsurface. This field-deployable system will characterize the mineralogical (chemical) form and distribution of the material's critical mineral content, providing strategic information for extraction approaches and technologies.

Conventional vs. Unconventional

Conventional critical mineral resources refer to known deposits that are presently part of the global resource base, with known geologic controls and enrichment processes that produced these occurrences.

Unconventional critical mineral resources refer to any resource from a geologic or secondary byproduct host that is distinctive from the mechanisms resulting in conventional, established deposits. These require revised or new methods and models to characterize and assess that focus on the unique source and temporal controls resulting in these deposits. (Source: Yesenchak et al., 2022)

Project Outline

This project will field-demonstrate the commercial potential of a prototype software technology involving advanced x-ray-based elemental and mineralogical characterization and science-based, data-driven modeling methods pioneered by NETL to rapidly detect and quantify critical mineral resources from secondary and/or unconventional feedstocks.

Key project tasks are outlined below:

- Software Development**
 - Modify existing URC resource assessment tool, GUI
 - Incorporate additional machine learning capabilities
- Searchable Database**
 - Elemental-mineral assemblages (e.g., XRF, ICP-MS, XRD)
 - Lithologic characterization, geophysical measurements
- Sample Recoverability Index**
 - Index dataset for software tool module
 - Recoverability benchtop extractions
- Software Demonstration**
 - Software field demonstration (pXRF sampling)
 - Predictive ML training of mineral (chemical) form
- Software Validation**
 - Validated software ML predictions using ICP-MS, LIBS, XRD, and or SEM
- Deployment of Downhole Capabilities**
 - Downhole XRF and ML software field deployment and testing
- Resource Reserves Modeling**
 - Estimate resource reserves using field-based software output
- Market Readiness & Alignment**
 - Solicit external user feedback on software user-friendliness
 - Perform TEA to inform strategy for technology distribution
- DEIA Engagements**
 - Workforce development for underrepresented and minority STEM students (local rural and tribal communities)

Industry Partners



Ramaco Carbon: Ramaco Carbon, LLC is a subsidiary of Ramaco Resources, Inc. (NASDAQ: METC). Ramaco Carbon focuses on higher value uses for carbon ore and the development of critical minerals at the Brook Mine located just north of Sheridan, WY.

Weir International: Since 1936, WEIR has been providing professional, independent and objective consulting services to the United States and international engineering, geology, mining operations, and energy industries.

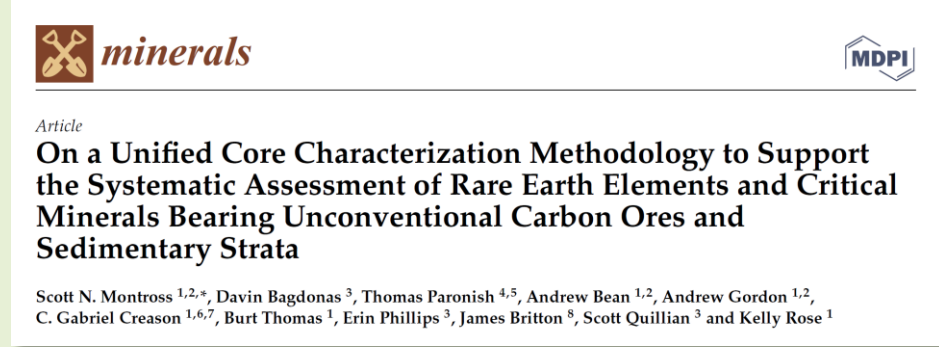


Background & Motivation

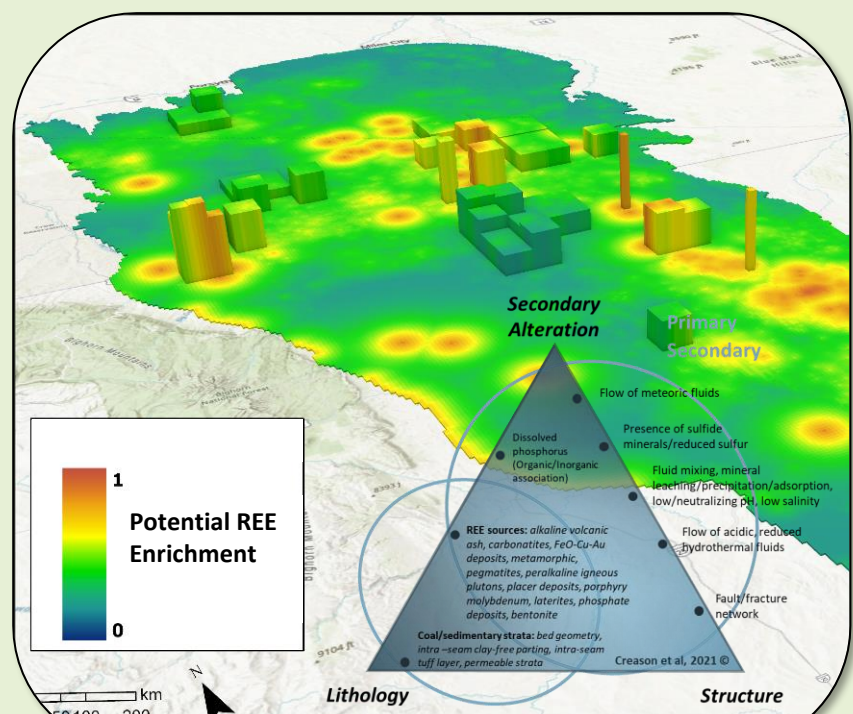
Current approaches for detecting the quantity and/or form of critical minerals (e.g., ICP-MS, LIBS, XRD) are costly and time-intensive. Handheld x-ray fluorescence is a quick, non-destructive method to characterize elemental composition, but challenges with interference and sensitivity limit its applicability for resource characterization.

This project will leverage 7+ years of FECM/NETL-RIC applied R&D (blue text figures below) to enable rapid and cost-effective detection of critical minerals from unconventional sources. These combined tools and approaches will enable commercial stakeholders to make timely, inexpensive assessments of potential resources, reducing the need to collect, pay, and wait for ICP-MS sample analyses.

Systematic Methods & Data to Find & Quantify *in situ* Critical Minerals

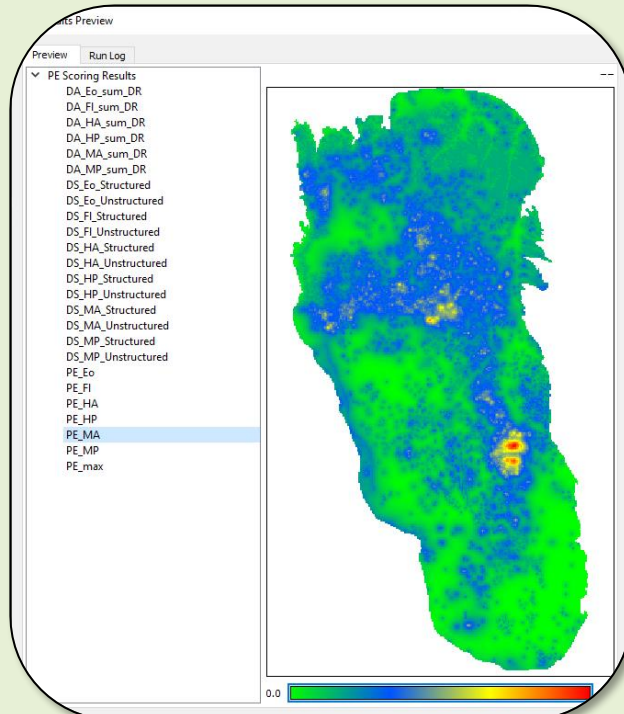


AI-Informed Unconventional CM Resource Assessment



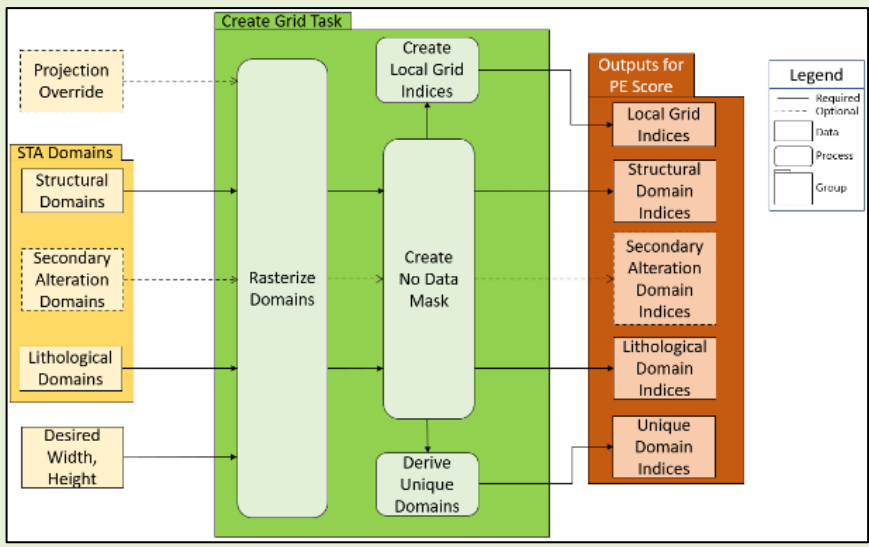
A Geo-Data Science Method for Assessing Unconventional Rare-Earth Element Resources in Sedimentary Systems

Streamlined User-Friendly Software Tool



A Python Tool for Predicting and Assessing Unconventional Rare-Earth and Critical Mineral Resources

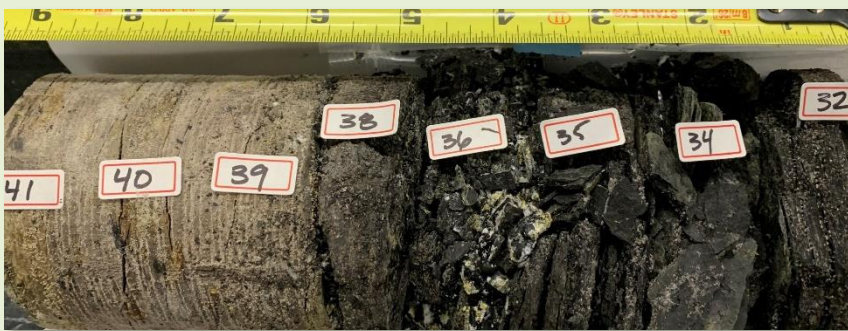
Software Development



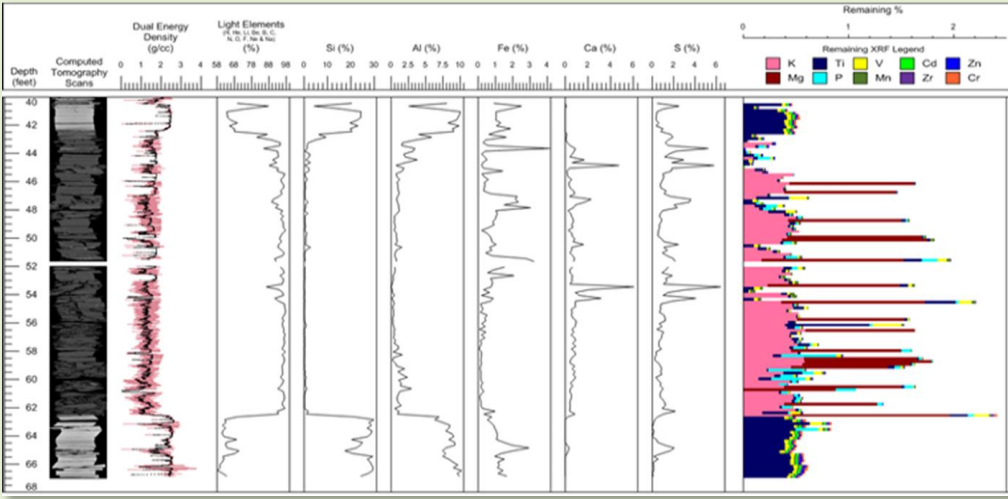
Handheld XRF



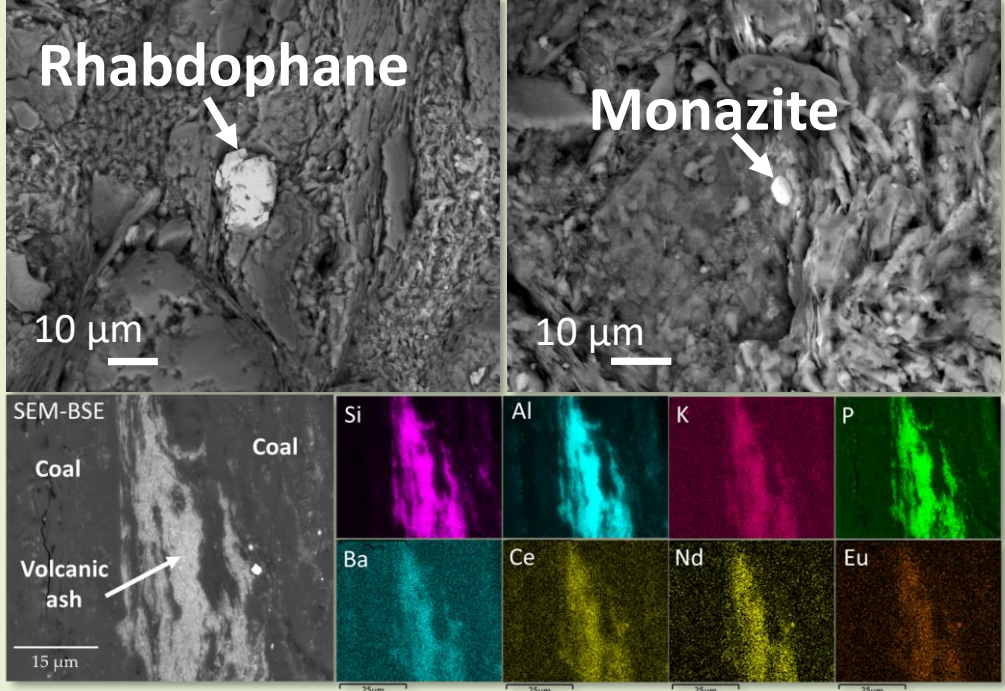
Core Characterization



Multi-Sensor Core Logging



Mineralogy



Downhole Deployment



References

Creason, C.G., Justman, D., Rose, K., Montross, S., Bean, A., Mark-Moser, M., Wingo, P., Sabbatino, M., Thomas, R.B., **2023**. A Geo-Data Science Method for Assessing Unconventional Rare-Earth Element Resources in Sedimentary Systems. Nat Resour Res. <https://doi.org/10.1007/s11053-023-10163-x>

Creason, C.G., Montross, S., Justman, D., Mark-Moser, M., Thomas, R.B., Bean, A., Rose, K. **2021**. Towards A Geo-Data Science Method for Assessing Rare Earth Elements and Critical Mineral Occurrences in Coal and Other Sedimentary Systems; DOE/NETL-2021/2653; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR, 2021; p 32. DOI: 10.2172/1809028

Justman, D., Creason, C.G., Gordon, A., Yesenchak, R., Mark-Moser, M., Rose, K., Montross, S., Wingo, P., Sabbatino, M. (*in revision*). A Regional Geospatial Characterization of Rare-Earth Occurrence Potential within Unconventional Sedimentary Systems of the Central Appalachian Basin. Natural Resources Research. In preparation

Justman, D., Creason, C.G., Montross, S., Mark-Moser, M., Thomas, R.B., Bean, A., Rose, K. **2021**. Supplementary data for Technical Report: Towards A Geo-Data Science Method for Assessing Rare-Earth Element Occurrences in Coal and Other Sedimentary Systems, 5/24/2021, <https://edx.netl.doe.gov/dataset/supplementary-data-ree-sed-trs>, DOI: 10.18141/1784272

Justman, D., Creason, C.G., Sabbatino, M., Rocco, N., DiGuilio, J., Rose, K., Thomas, R.B., REE and Coal Open Geodatabase, **2018**, <https://edx.netl.doe.gov/dataset/ree-and-coal-open-geodatabase>, DOI: 10.18141/1475030STA

Montross, S., Bagdonas, D., Paronish, T., Bean, A., Gordon, A., Creason, C.G., Thomas, B., Phillips, E., Britton, J., Quillian, S., Rose, K., **2022**. On a Unified Core Characterization Methodology to Support the Systematic Assessment of Rare Earth Elements and Critical Minerals Bearing Unconventional Carbon Ores and Sedimentary Strata. Minerals. 2022; 12(9):1159. <https://doi.org/10.3390/min12091159>

Wingo, P., Justman, D., Creason, C.G., Mark-Moser, M., Montross, S., Rose, K., **2023**. URC Assessment Method. <https://edx.netl.doe.gov/dataset/urc-assessment-method>, DOI: 10.18141/1963714

Yesenchak, R., Justman, D., Bauer, S., Sabbatino, S., Creason, C.G., Gordon, A., Montross, S., Rose, K., **2023**. National Critical Minerals Data Dashboard, 3/21/2023, <https://edx.netl.doe.gov/dataset/national-critical-minerals-data-dashboard>

Yesenchak, Y., Justman, D., Bauer, S., Creason, C.G., Gordon, A., Montross, S., Sabbatino, M., Rose, K., **2022**. Unlocking the Potential of Unconventional Critical Mineral Resources Story Map, 10/21/2022, <https://edx.netl.doe.gov/dataset/unlocking-the-potential-of-unconventional-critical-mineral-resources-story-map>, DOI: 10.18141/1891489

Outcome

This field-deployable system will characterize the mineralogical (chemical) form and distribution of the material's critical mineral content, providing strategic information for extraction approaches and technologies. Demonstrating this technology in field applications with industry partners at an active site with high resource potential will increase the visibility and realization of critical mineral production potential from domestic unconventional sources.

The key outcome will be an inexpensive, portable, user-friendly software package for characterizing critical mineral in unconventional feedstocks. The ML-informed software system will support rapid, quantitative evaluation and assessment of critical mineral potential in coal refuse materials at the surface, and, where boreholes are available, from downhole scans as well. Within the software package will be a database that calibrates elemental XRF measurements to minerals and mineral assemblages, specifically tailored to secondary and unconventional critical mineral feedstocks.

Disclaimer: This report/presentation was prepared as an account of work sponsored by an agency of the United States Government, under the United States Department of Energy, Office of Technology Transitions, DOE Award Number TC-23NT020203. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed therein do not necessarily state or reflect those of the United States Government or any agency thereof.

