NETL URC Assessment Method

A Geo-Data Science Driven Method to Assess REE Occurrences from Unconventional Geologic Sources

Critical Minerals FWP DOE FECM-1022420 Task 9

Kelly Rose, National Energy Technology Laboratory
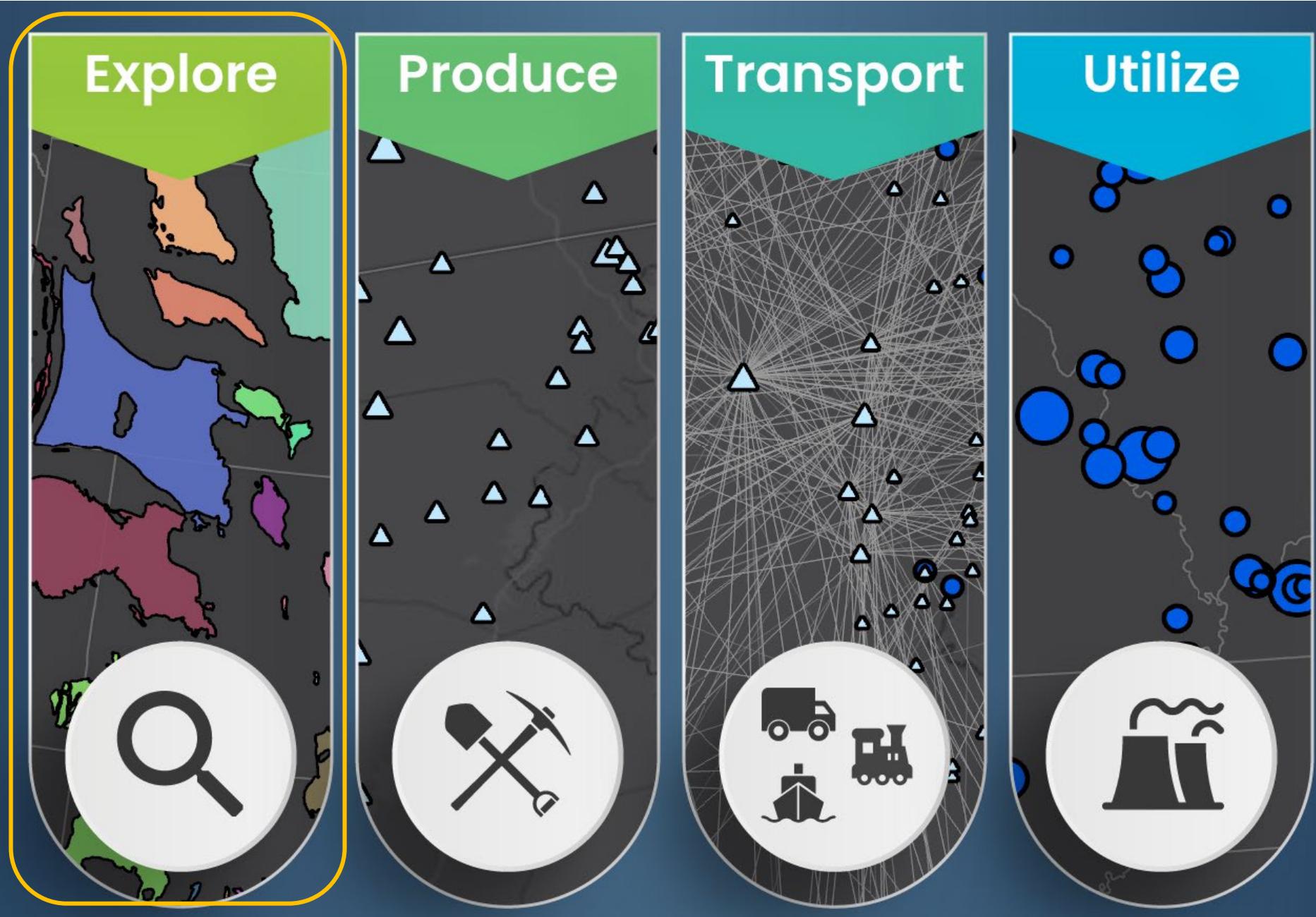
Email: *kelly.rose@netl.doe.gov*

NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL Geo-Data Science Team:

Kelly Rose[1], Gabe Creason[1,2], Devin Justman[1,3], Scott Montross[1,3], Andrew Gordon[1,3], Rachel Yesenchak[1,3], Michael Sabbatino[1,3], Patrick Wingo[1,3], and R. Burt Thomas[1]

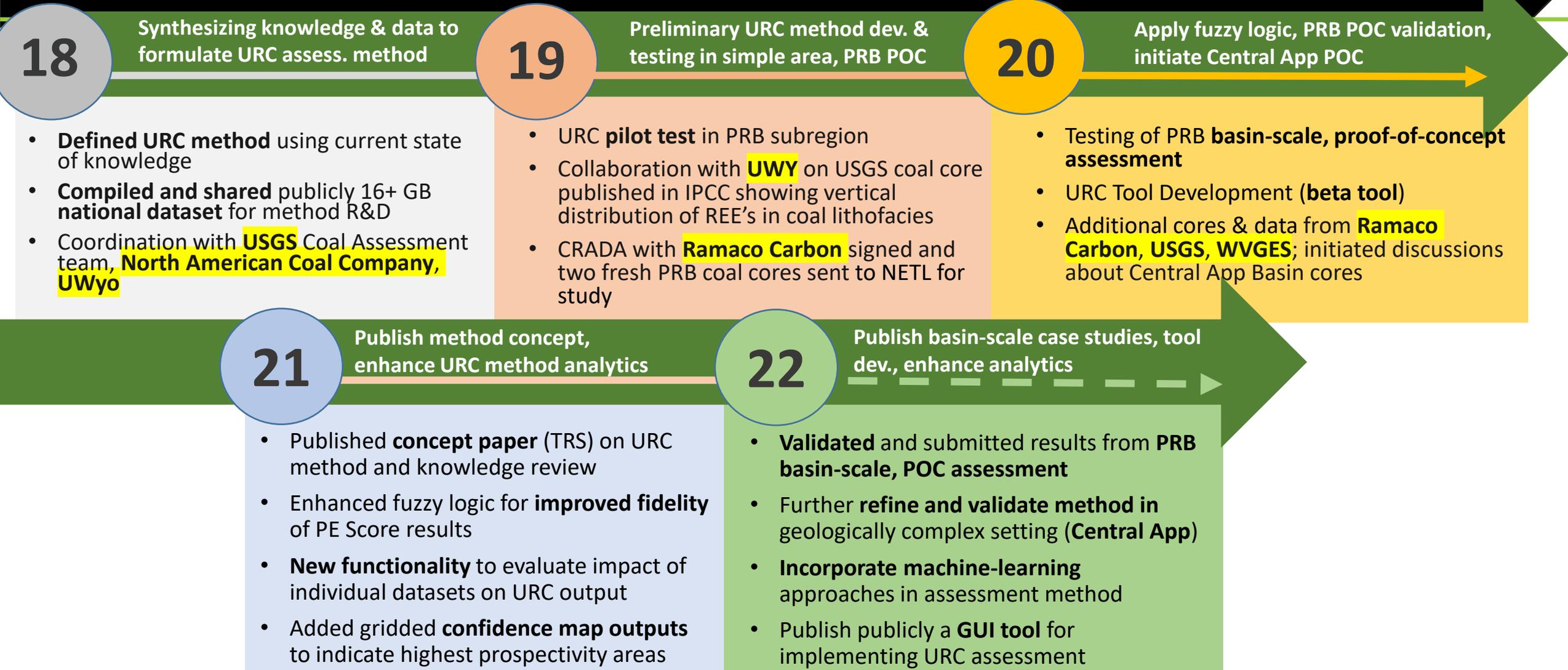1 NETL; 2 ORISE, Oregon State University;
3 LRST Contractor; 4 ITSS Contractor

U.S. DEPARTMENT OF ENERGY

Developing data, models & tools to predict occurrence of unconventional REE/CM resources

Explore

Produce

Transport

Utilize

Highlights – NETL's URC Method Work & Partnerships to Date

NETL — NATIONAL ENERGY TECHNOLOGY LABORATORY

18 — Synthesizing knowledge & data to formulate URC assess. method

- **Defined URC method** using current state of knowledge
- **Compiled and shared** publicly 16+ GB **national dataset** for method R&D
- Coordination with **USGS** Coal Assessment team, **North American Coal Company, UWyo**

19 — Preliminary URC method dev. & testing in simple area, PRB POC

- URC **pilot test** in PRB subregion
- Collaboration with **UWY** on USGS coal core published in IPCC showing vertical distribution of REE's in coal lithofacies
- CRADA with **Ramaco Carbon** signed and two fresh PRB coal cores sent to NETL for study

20 — Apply fuzzy logic, PRB POC validation, initiate Central App POC

- Testing of PRB **basin-scale, proof-of-concept assessment**
- URC Tool Development (**beta tool**)
- Additional cores & data from **Ramaco Carbon, USGS, WVGES**; initiated discussions about Central App Basin cores

21 — Publish method concept, enhance URC method analytics

- Published **concept paper** (TRS) on URC method and knowledge review
- Enhanced fuzzy logic for **improved fidelity** of PE Score results
- **New functionality** to evaluate impact of individual datasets on URC output
- Added gridded **confidence map outputs** to indicate highest prospectivity areas

22 — Publish basin-scale case studies, tool dev., enhance analytics

- **Validated** and submitted results from **PRB basin-scale, POC assessment**
- Further **refine and validate method in** geologically complex setting (**Central App**)
- **Incorporate machine-learning** approaches in assessment method
- Publish publicly a **GUI tool** for implementing URC assessment

Where things started…

Research Objective

Develop an assessment methodology for systematically predicting **Unconventional Rare-earth and Critical mineral (URC) occurrences** in sedimentary strata …

https://www.explorenature.org/center-event/x-marks-spot-irvine-scavenger-hunt/

- Is based off known **mechanisms** that result in accumulation of REE/CMs in sedimentary strata
- Can be used to identify **areas** with *higher REE/CM prospectivity*
- Can be used to constrain whether REE/CM concentrations and volumes suggest **viability** of *commercial extraction*

Accelerating access to domestic REE & CM resources from unconventional sources

Mineral resources come from geologic media...
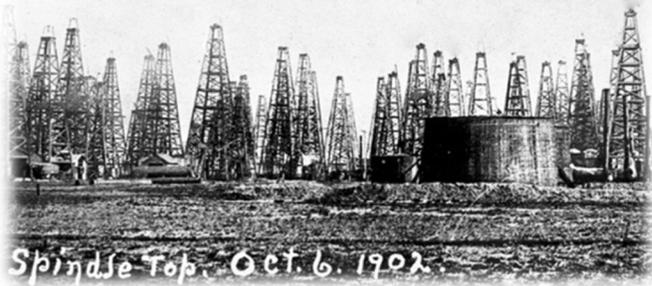
Economic deposits are not random...

Spindle Top - Oct. 6, 1902.

Systematic*, geologic-driven methods improve predictability...

To unlock domestic REE & CM potential, requires data & knowledge informed predictions

*The "dry hole" metric for oil/gas wells went from 40% in the 1960s to about 10% in 2010 – EIA

NETL

Finding the "*needles*" in the proverbial geological "*haystack*"

NETL is developing the URC method to identify domestic deposits and unlock the economic REE/CM supply from unconventional systems

For prediction and ID of high concentration deposits

1st approach for assessing REE/CMs in unconventional sediments

Using a big-data, ML enabled geoscience approach

Common Mechanisms Concentrating Rare Earth Elements

volcanic ash fall

i. deposition of heavy mineral sands (placers)

iv. leaching of volcanic ash by groundwater

ii. alteration of volcanic ash deposited in swamps (tonsteins)

vi. accumulation within marine phosphates

raised bog peatland

marginal marine peatland

iii. chemical erosion of igneous basement (laterites)

alkaline magma chamber

v. hydrothermal alteration

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Linking Together Geologic Processes & Data

Secondary Alteration

Primary
Secondary

100's of published studies

- Flow of meteoric fluids
- Presence of sulfide minerals/reduced sulfur
- Dissolved phosphorus (Organic/Inorganic association)
- Fluid mixing, mineral leaching/precipitation/adsorption, low/neutralizing pH, low salinity
- REE sources: alkaline volcanic ash, carbonatites, FeO-Cu-Au deposits, metamorphic, pegmatites, peralkaline igneous plutons, placer deposits, porphyry molybdenum, laterites, phosphate deposits, bentonite
- Flow of acidic, reduced hydrothermal fluids
- Fault/fracture network
- Coal/sedimentary strata: bed geometry, intra –seam clay-free parting, intra-seam tuff layer, permeable strata

Creason et al, 2021 ©

Lithology   Structure

Geologic Processes

REE/CM Assessment

Data

EDX
Energy Data eXchange

100's spatial datasets
6.5+ million records

# of overlapping datasets

URC Assessment Method: Key Concepts
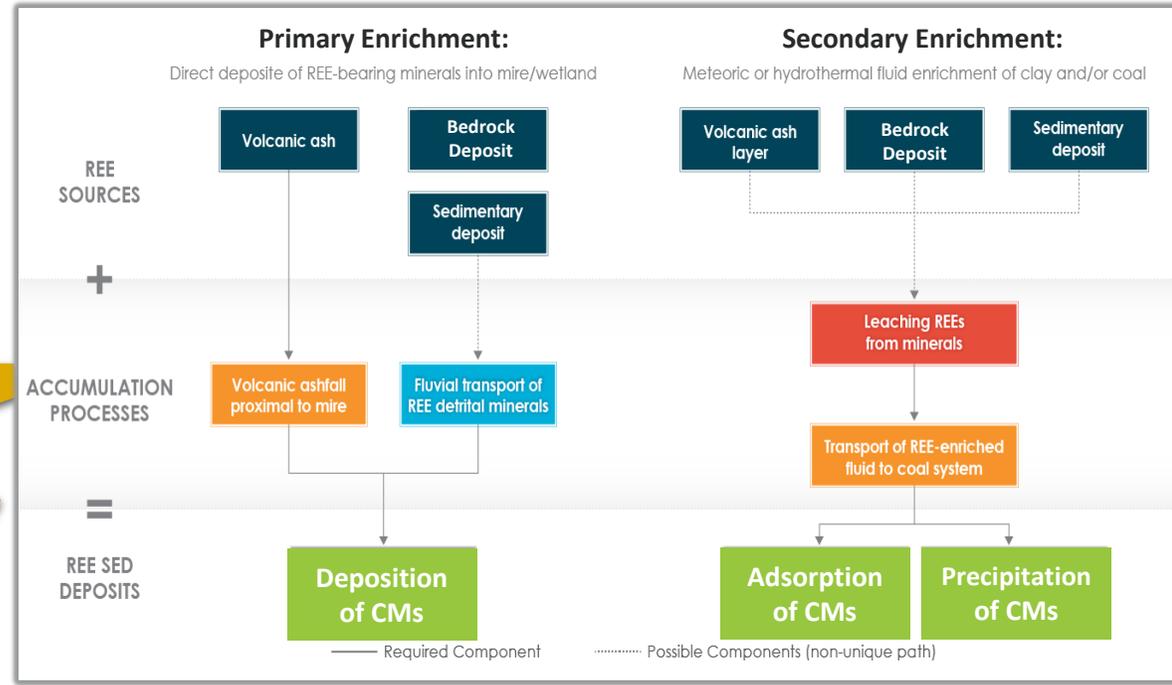
Primary Enrichment:
Direct deposite of REE-bearing minerals into mire/wetland

Secondary Enrichment:
Meteoric or hydrothermal fluid enrichment of clay and/or coal

REE SOURCES

| Volcanic ash | Bedrock Deposit |
| Sedimentary deposit | |

| Volcanic ash layer | Bedrock Deposit | Sedimentary deposit |

+

ACCUMULATION PROCESSES

| Volcanic ashfall proximal to mire | Fluvial transport of REE detrital minerals |

Leaching REEs from minerals

Transport of REE-enriched fluid to coal system

=

REE SED DEPOSITS

Deposition of CMs

Adsorption of CMs   Precipitation of CMs

— Required Component   ...... Possible Components (non-unique path)

Creason, C. G., Montross, S. N., Justman, D., Mark-Moser, M., Thomas, R., 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
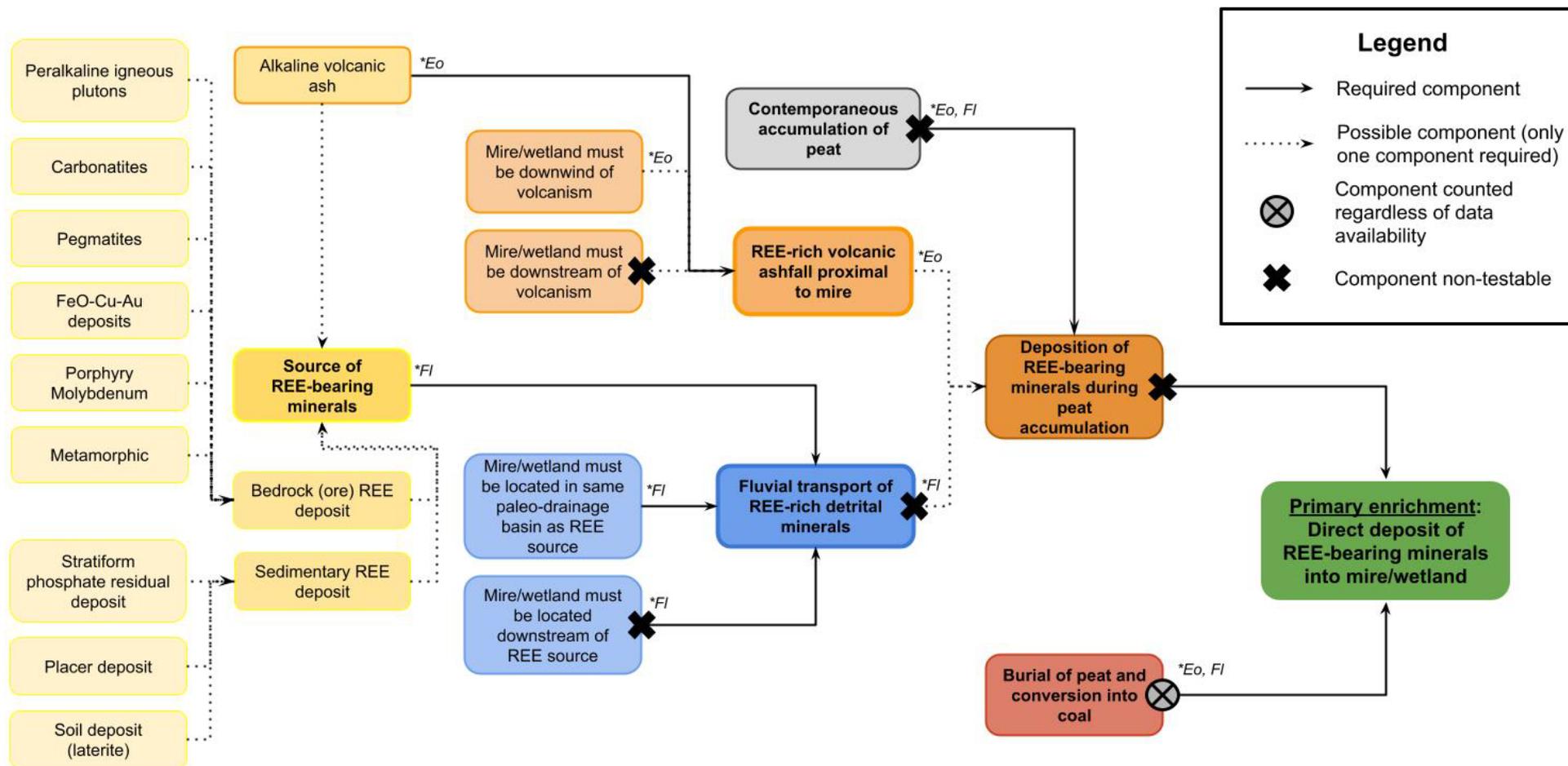
Case Study: Powder River Basin

Basin Selection Criteria:

- ✓ Relatively simple geologic history
- ✓ Abundant data publicly available
  - ✓ Partnerships may offer additional data access

70+ spatial datasets
6.5+ million records

# of overlapping datasets

Datasets per
1x1 km cell

0
1
2 - 3
4 - 5
6 - 10

0 10 20 40 60 80 Miles
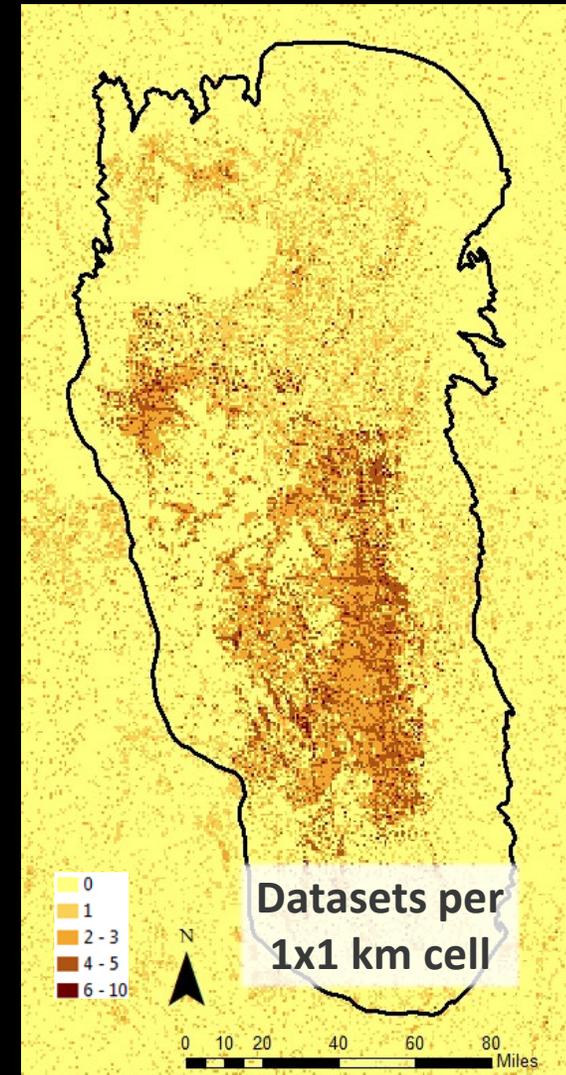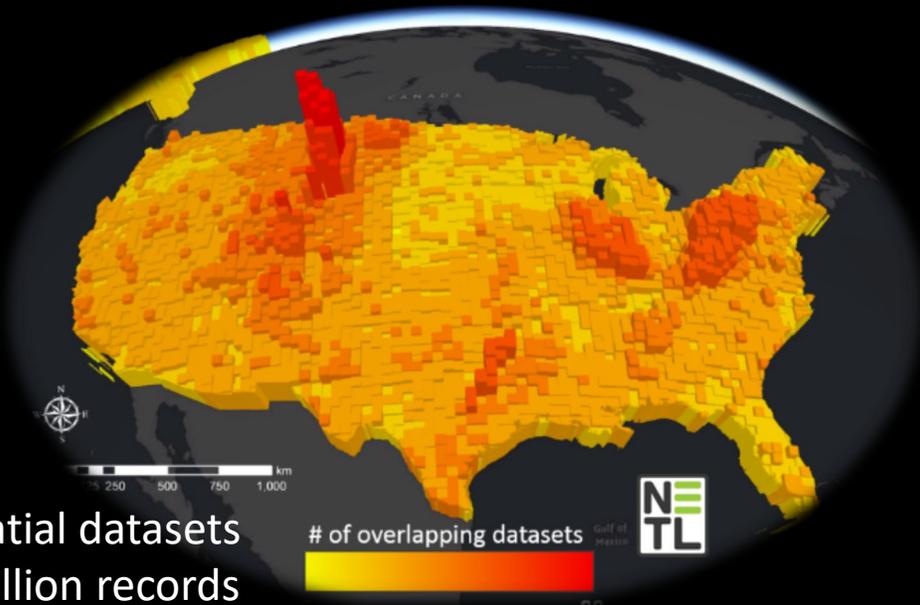
Step 1: Postulate spatiotemporal domains

Identify distinct domains based on shared geologic attributes
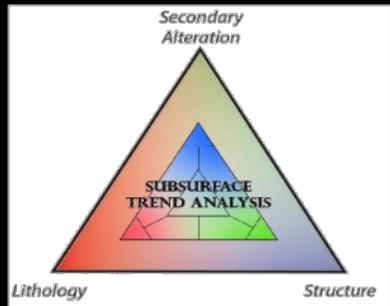
Rose et al., 2020
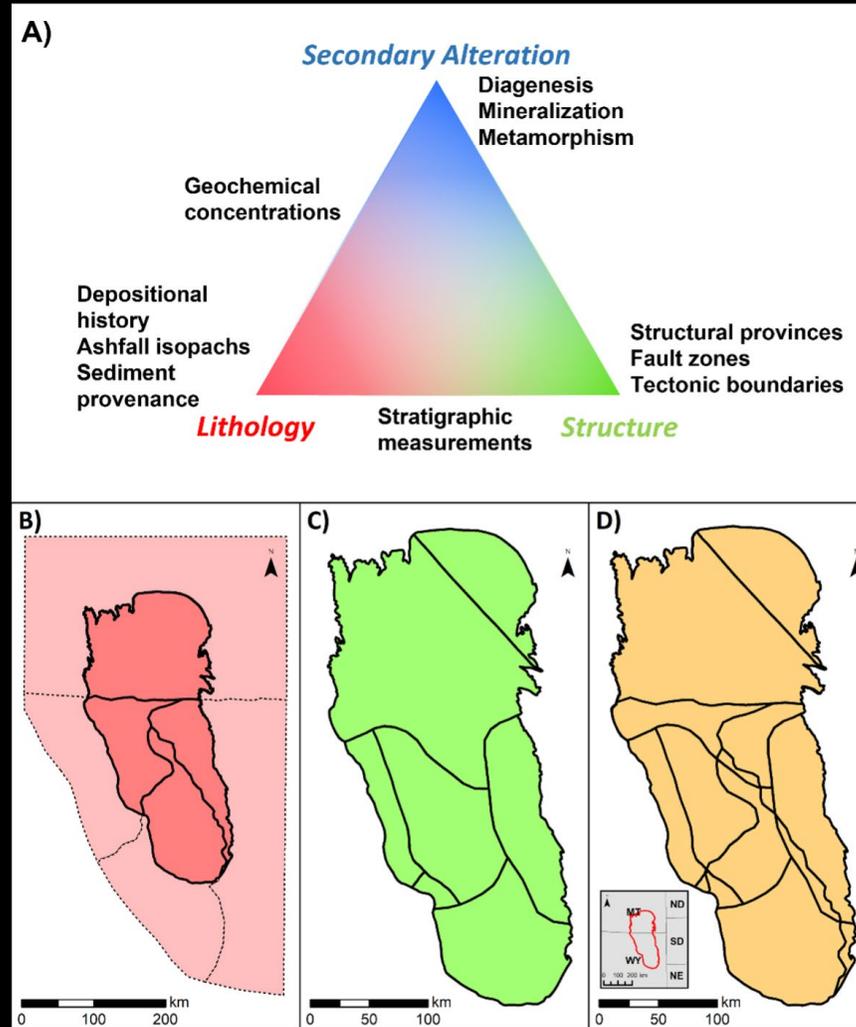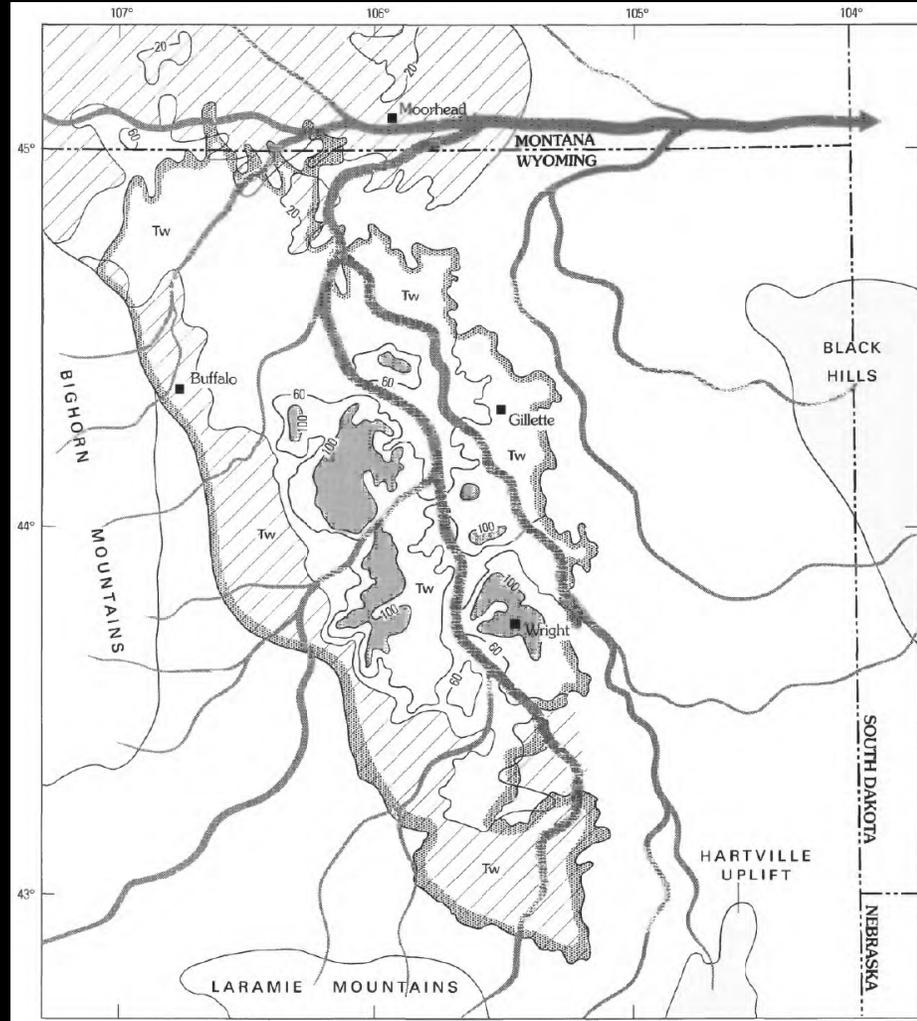
Seeland 1993 (USGS Bulletin 1917-Q)

Step 2: Inventory knowledge-data

Assess limitations of data availability for a particular enrichment mechanism

- **Data Required (Dr_m): minimum number of components** (datasets) for mechanism m

- **Data Availability (Da_m): proportion of geologic components** **with data available** for mechanism m

$$Da_m = \frac{\sum Da_{m,c}}{Dr_m} \quad (1)$$

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY
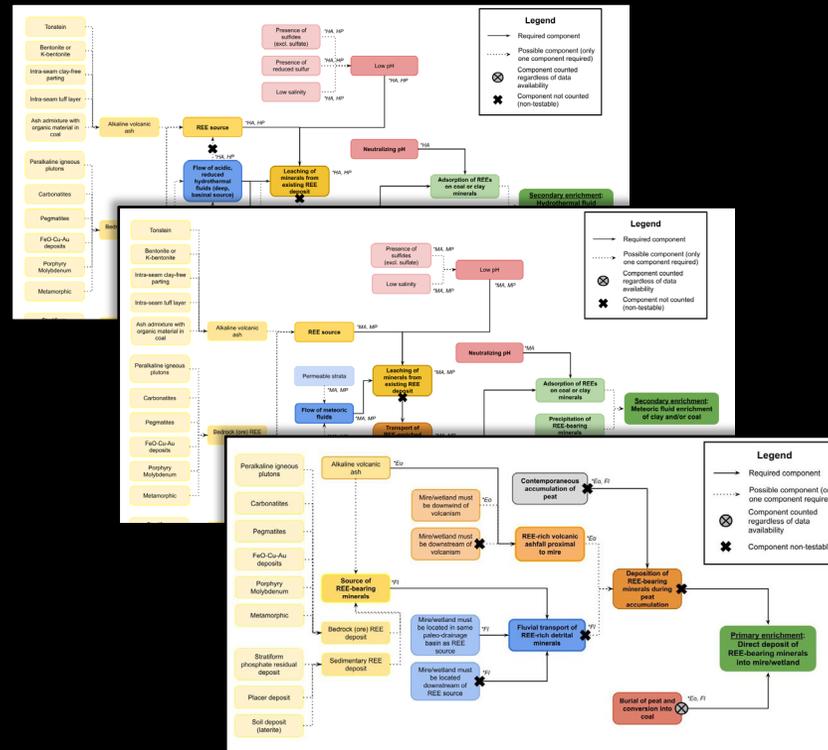
Data Availability for Powder River Basin

Primary
A) Eolian   B) Fluvial

Secondary - Meteoric
C) Adsorption   D) Precipitation

Secondary - Hydrothermal
E) Adsorption   F) Precipitation

Data Availability

Data Availability
<10%
<20%
<30%
<40%
<50%
<60%
<70%
<80%
<90%
<=100%

N

km
0   100   200
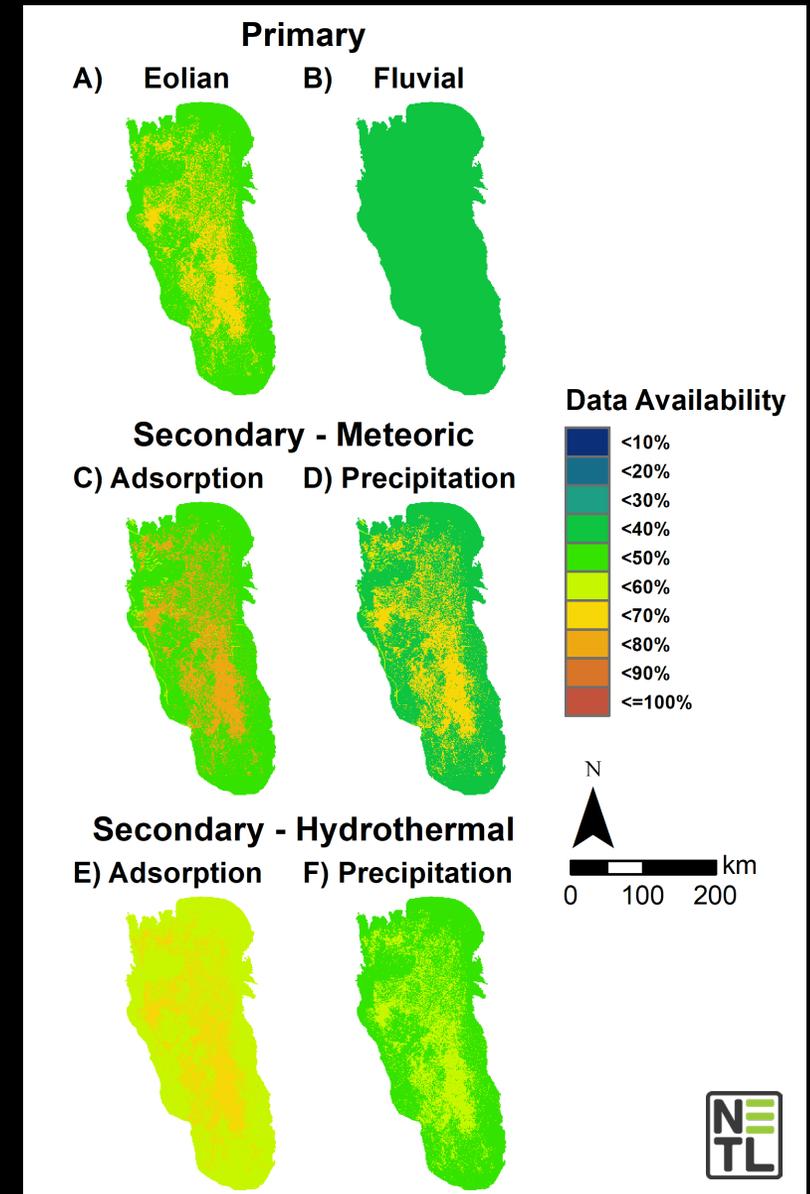
Step 3:
Calculate PE Score using fuzzy logic
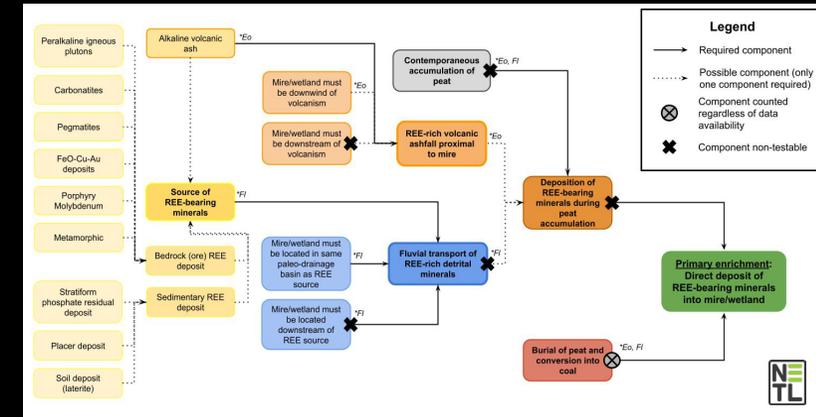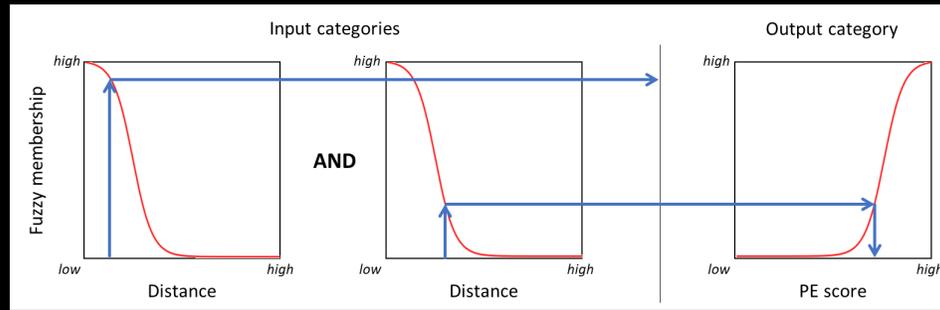
Translate data into component representations
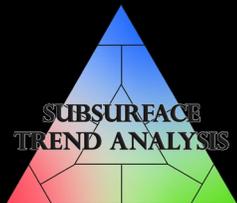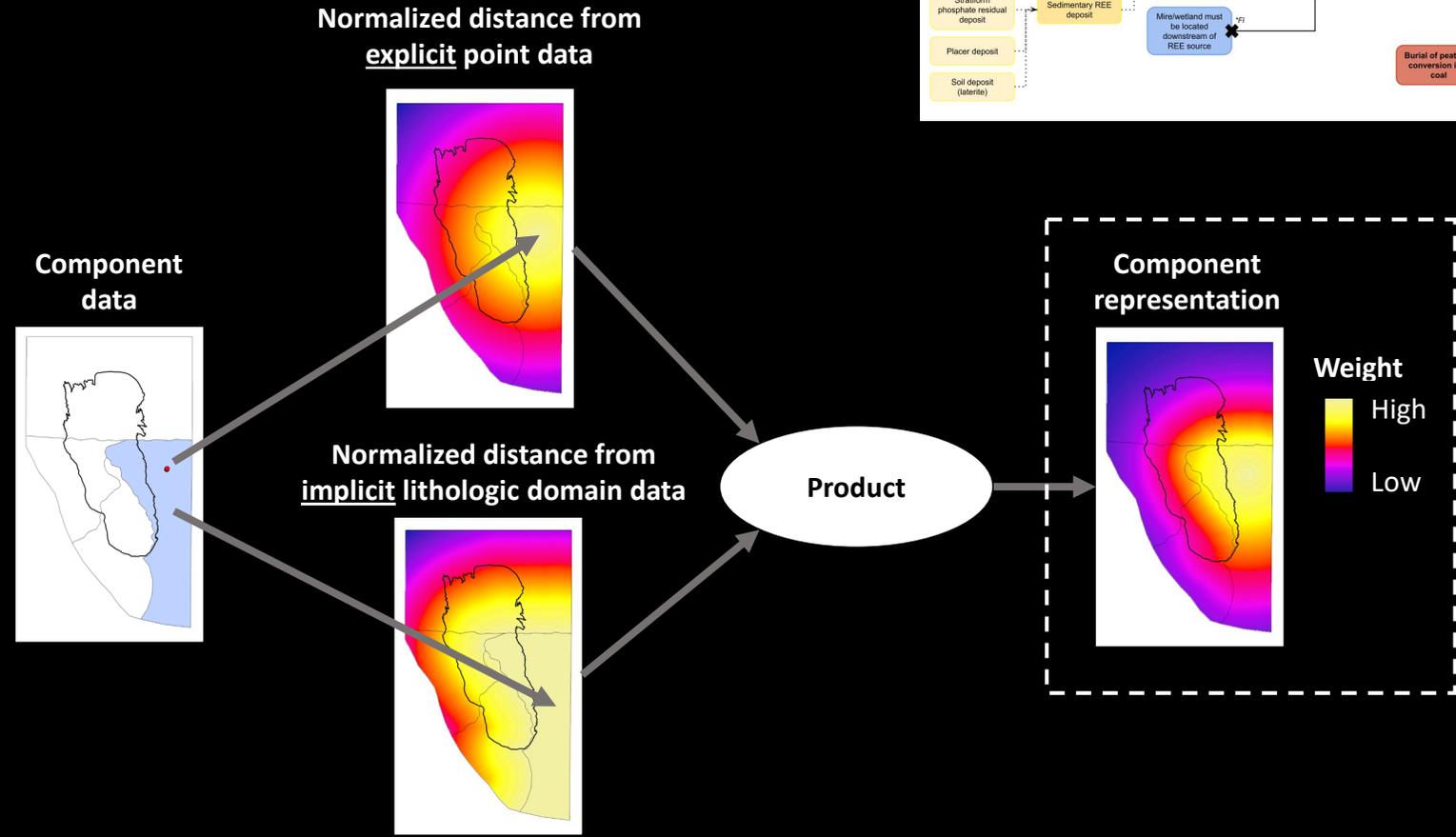
Justman et al., 2020   Rose et al., 2020

Step 3:
Calculate PE Score using fuzzy logic
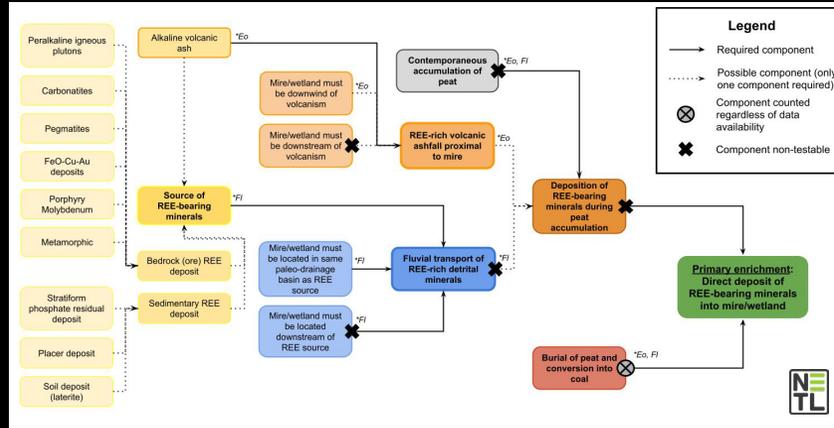
Combine representations into PE score maps

Component representation
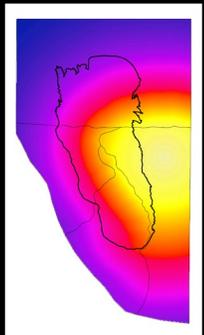
Weight
High
Low

Data Supporting, unstructured (Ds_m):
arithmetic combination of geologic components with evidence for mechanism m

$$Ds_m = \frac{\sum Ds_{m,c}}{Dr_m} \quad (2)$$

Data Supporting, structured ($\widetilde{Ds_m}$):
fuzzy combination of geologic components with evidence of mechanism m

$$\widetilde{Ds_m} = \widetilde{Ds_{m,c}} \cdot Dr_m^* \quad (3)$$
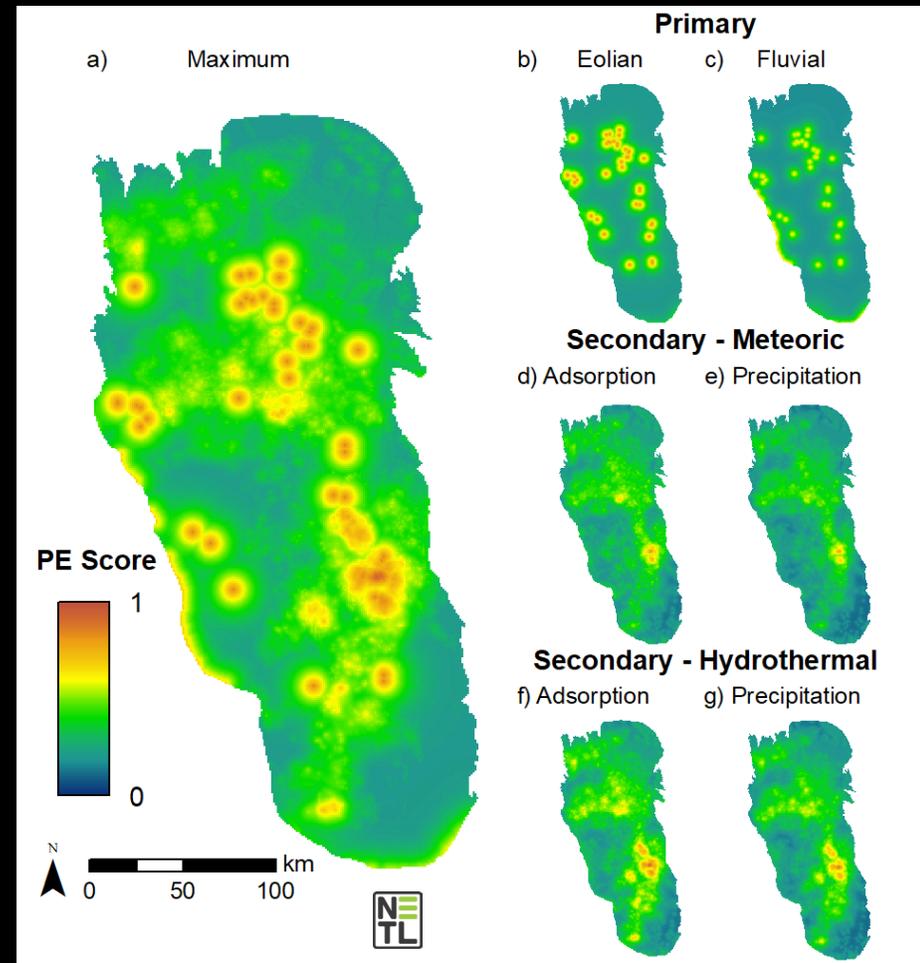
Potential Enrichment Score (PE_m):
map of URC resource prospectivity that can be compared across enrichment mechanisms

$$PE_m = fuzzySUM(Ds_m, \widetilde{Ds_m}) \quad (4)$$

Step 4: Spatial integration of predictions and observations

Confidence Score (C_m):

- Combination of PE score and normalized log of summed REE concentrations

- Variable Grid Method™ to qualify PE Scores with measured concentration data

- Grid area/height scales inversely with confidence score

$$C_m = PE_m \cdot \left(\frac{\log(LaCeY_{xi}) - \min(\log(LaCeY_x))}{\max(LaCeY_x) - \min(\log(LaCeY_x))} \right)$$
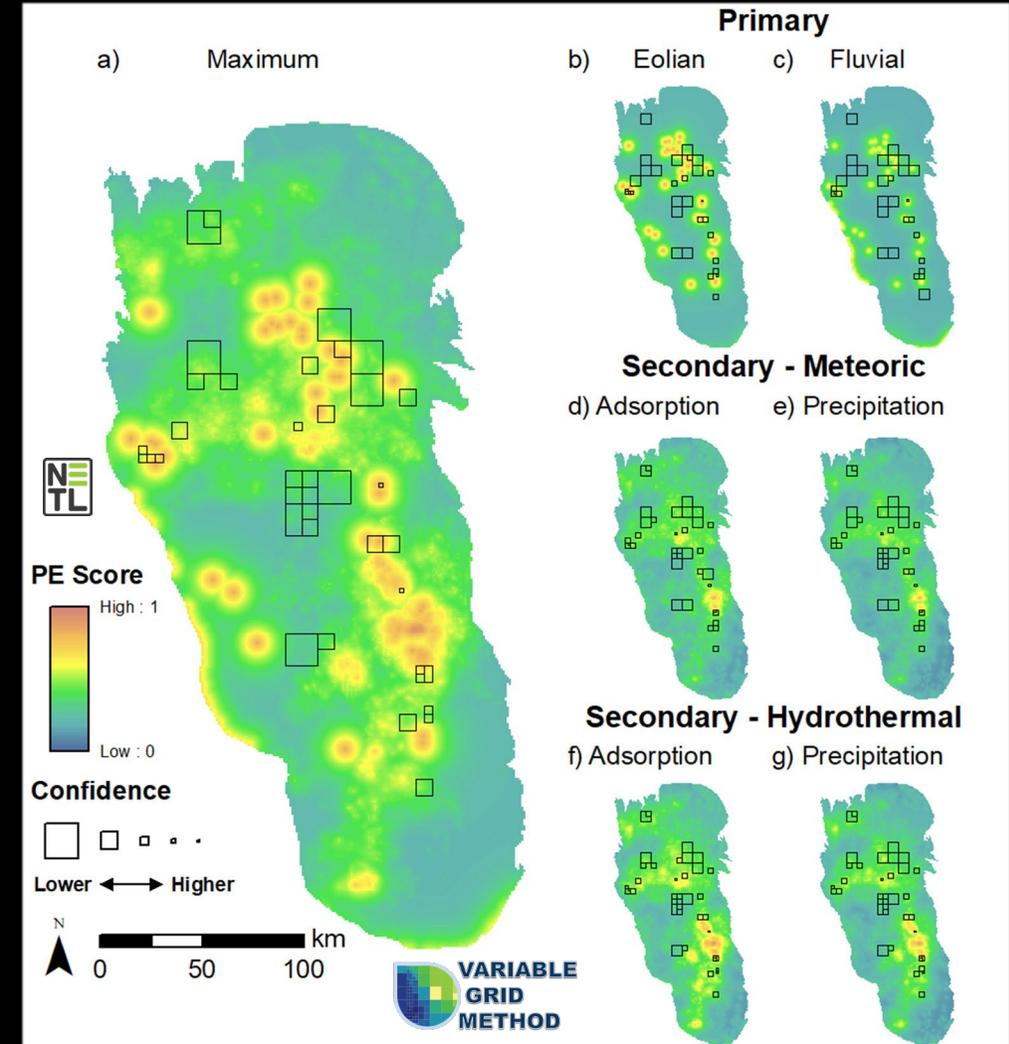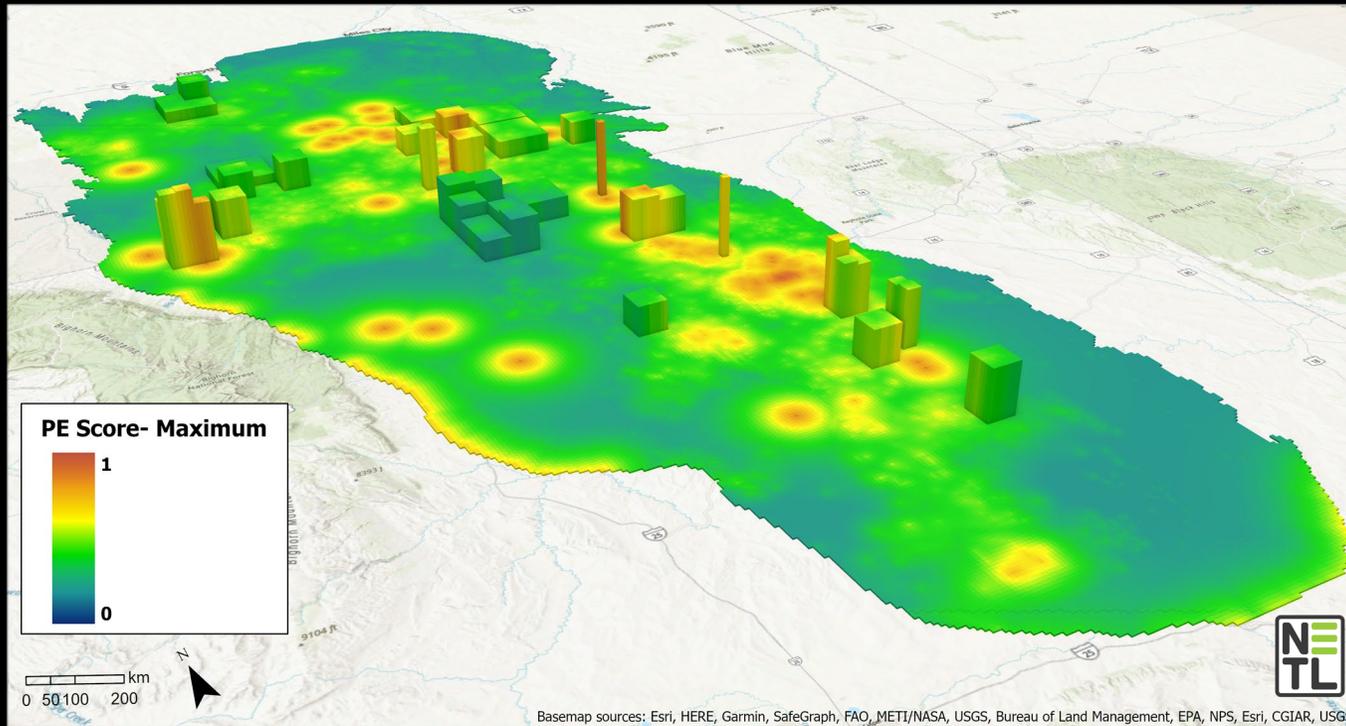
Current Status & Next Steps

Second Case Study, URC Tool, and External Partnerships

Case Study II:
Central Appalachia

Structural Domains
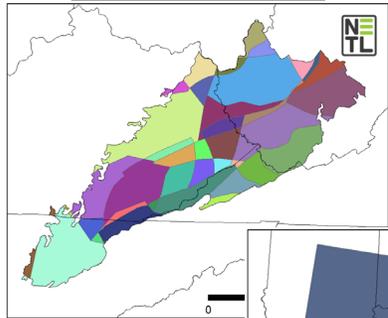
Lithologic Domains

Secondary Alteration Domains

Cumulative Spatial Impact Layers

SUBSURFACE TREND ANALYSIS

VARIABLE GRID METHOD

GUI Assessment Tool
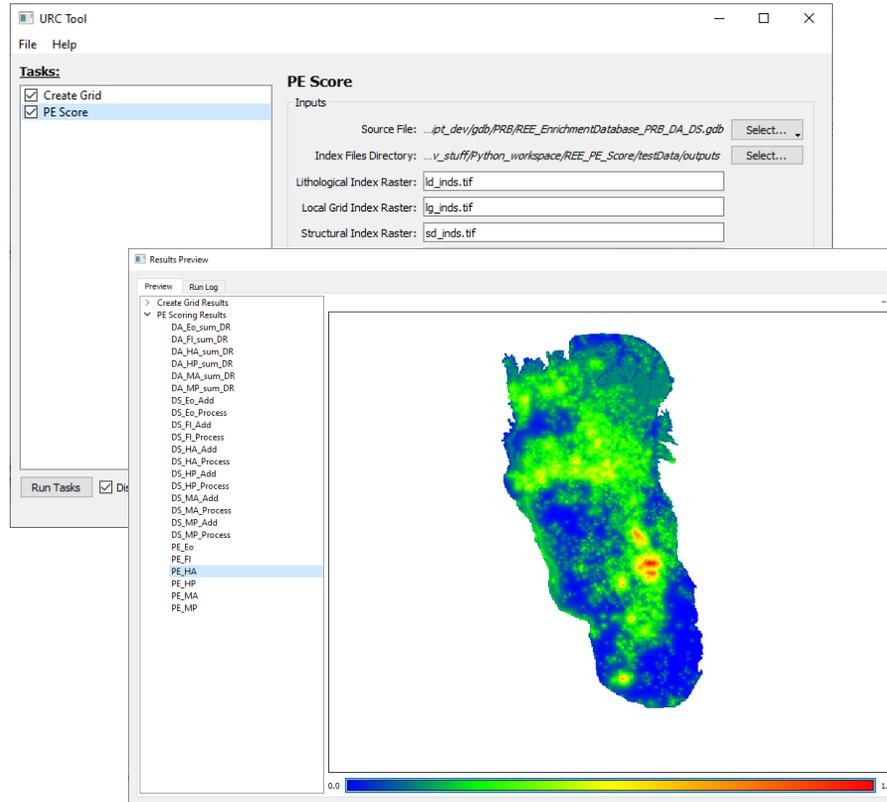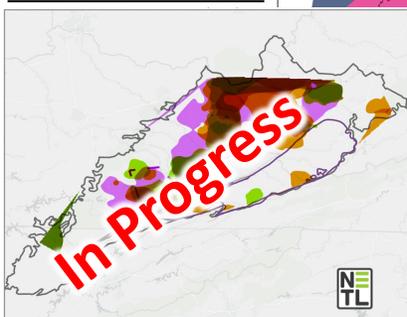
- **Testing in geologically complex Central Appalachian Basin**
  - Formulating new approach for identifying geospatial domains of secondary alteration

- **Validating method based on CoalQual data, REE coal core data (Uwyo, WVGES)**

- **Coordinating with external partners**
  - Access to additional samples and data for Central App (WVGES, Kentucky Geological Survey, USGS, Ramaco Carbon)
  - Knowledge of local geology in Central App

- **Developing GUI assessment tool**
  - Guide end-user implementation of data collation, grid construction, and calculation of PE Score
  - Accessible documentation and source code
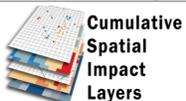
Quantifying REE occurrence and zones of enrichment from core to seam/mine scale

Upscaling of core analysis results to evaluate spatial occurrence

- Developed & completed a systematic analysis (following methods outlined in Montross et al., 2022) of multiple rock cores

- Demonstrated advanced use of XRF for more rapid REE quant.

- Identified distinct zones of REE enrichment in coal and non-coal bearing sedimentary strata

- Upscaling using lithogeochemical logs and stratigraphic correlation to constrain spatial (x,y,z) distribution of REE in coal seams and demonstrate continuity of resource at the mine scale
- Used in PRB URC assessment validation
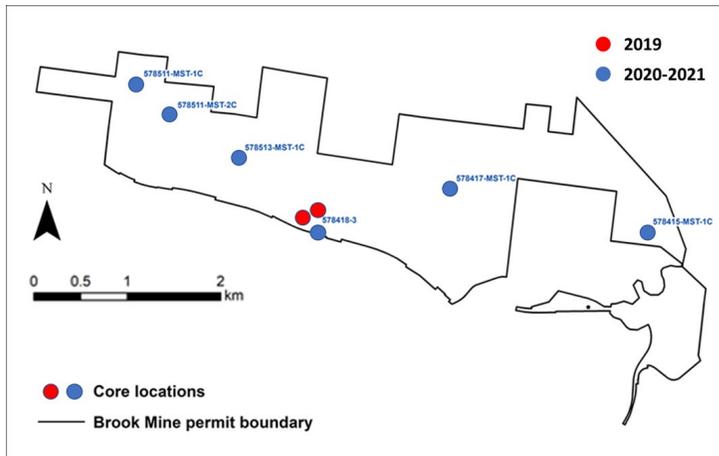
New characterization methods to improve REE/CM resource quantification

1. Core collection and field descriptions

2. Core logging and data collection

3. Discrete subsampling and microanalysis

4. Data analysis and interpretation

Montross et al 2022
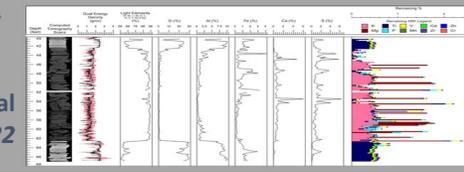
Documented geologic variability, *including a **thick ore** horizon with REE/CM 500 to over 2700 ppm*

Summary

URC Assessment Method:
- Evaluates REE enrichment potential and predominant REE phase
- Identifies key data gaps that hinder REE exploration and quantification

Lessons:
- Data availability is critically important to successful assessment
- Need for geologically constrained validation data
- Need additional data and information for key enrichment processes
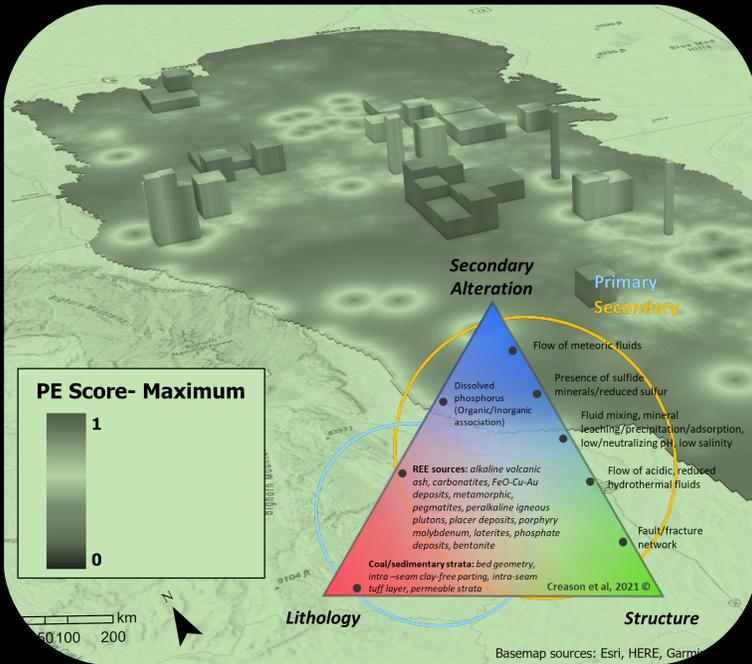
Key Takeaways:
- URC Method is multi-scale, data dependent, and adaptable to other geologic systems
- With more knowledge & data, the accuracy of the approach will improve
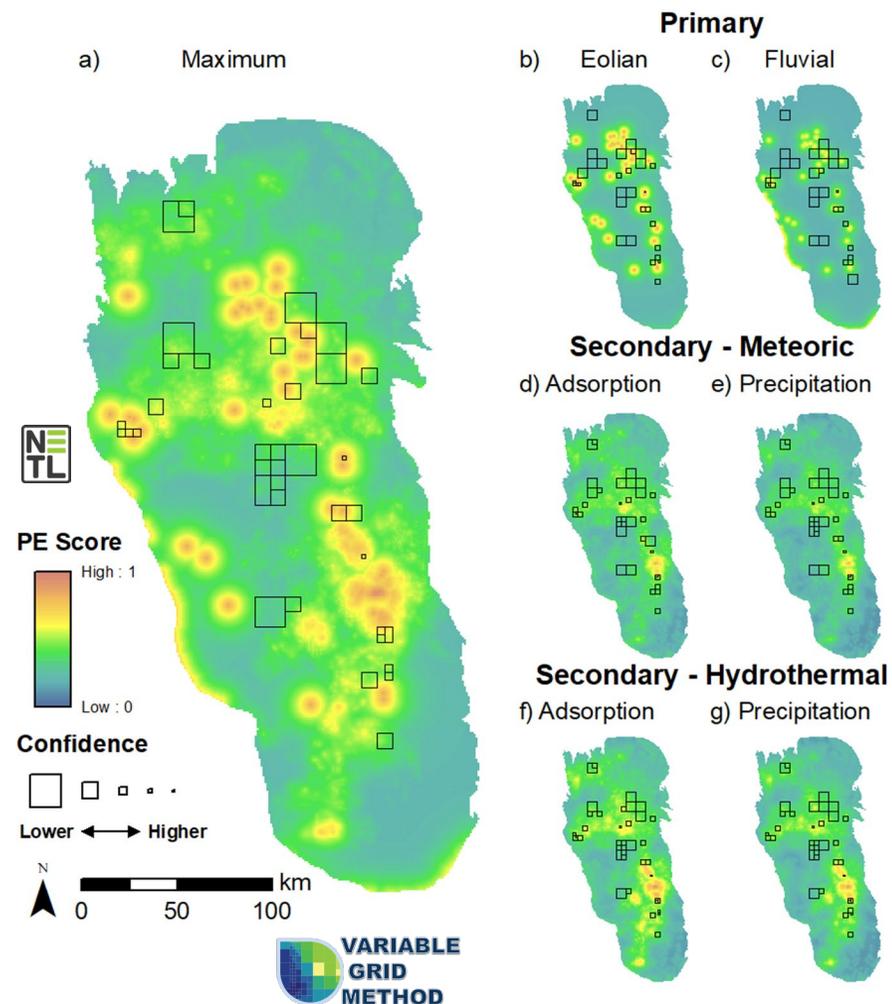
Geo-data Science to Unlock Unconventional Rare Earth Elements and Critical Minerals Domestic Potential

Unconventional REE/CM Resource Assessment

Creason, et al., (in review). *A Geo-Data Science Method for Assessing Unconventional Rare-Earth Occurrences in Sedimentary Systems.* **Submitted to** *Natural Resources Research.*

Systematic Methods & Data to Constrain REE/CM

Montross, et al., On a unified core characterization methodology to support the **systematic assessment of rare earth element and critical mineral bearing** unconventional carbon ores and sedimentary strata. Minerals 2022, 12

Big data & digitalization to support REE-CM supply chain & waste beneficiation
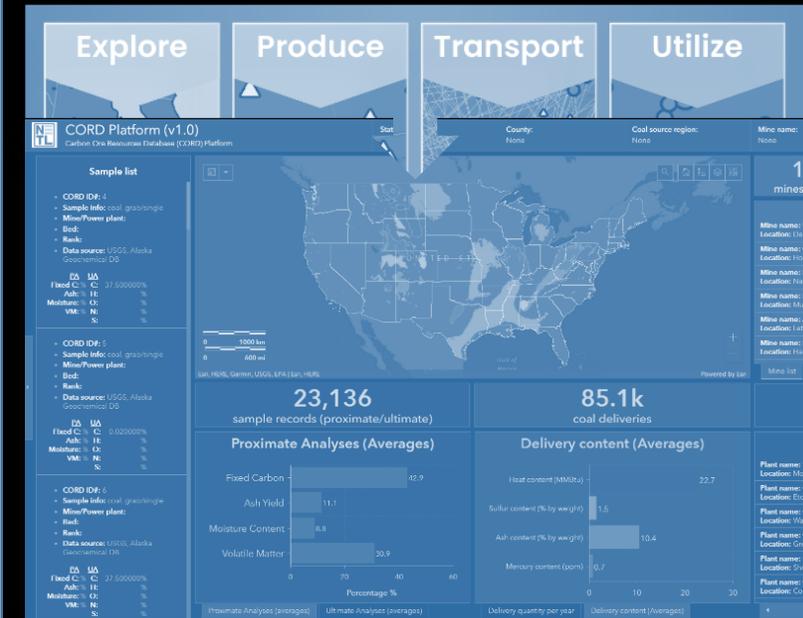
Justman, et al. (2022). **A database and framework for carbon ore resources and associated supply chain data.** *Data in Brief.*
https://doi.org/10.1016/j.dib.2021.107761

Citations

Select Pubs, Data, Tools

Bagdonas, D., Nye, C., Thomas, R., and Rose, K., **2019**. *Rare Earth Element Occurrence and Distribution in Powder River Basin Coal Core, Wyoming*, Proceedings of the Thirty Sixth Annual 2019 International Pittsburgh Coal Conference, September 3 - 6, 2019, 13 pgs.

Bauer, J.R. and Rose, K., **2015.** *Variable Grid Method: An Intuitive Approach for Simultaneously Quantifying and Visualizing Spatial Data and Uncertainty*. Transactions in GIS, 19: 377-397. https://doi.org/10.1111/tgis.12158

Creason, C.G., Justman, D., Rose, K., Montross, S., Bean, A., Mark-Moser, M., Wingo, P., Sabbatino, M., Thomas, R.B. (**in review**). *A Geo-Data Science Method for Assessing Unconventional Rare-Earth Occurrences in Sedimentary Systems.* **In review,** Natural Resources Research.

Creason, C. G., Montross, S. N., Justman, D., Mark-Moser, M., Thomas, R., 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., 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., Rose, K., Bauer, J., **2020**. *A knowledge-data framework and geospatial fuzzy logic-based approach to model and predict structural complexity*, Journal of Structural Geology, Volume 141, 2020, 104153, ISSN 0191-8141, https://doi.org/10.1016/j.jsg.2020.104153.

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.N.; Bagdonas, D.; Paronish, T.; Bean, A.; Gordon, A.; Creason, C.G.; Thomas, B.; Phillips, E.; Britton, J.; Quillian, S.; Rose, K. 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, 1159. https://doi.org/10.3390/min12091159

Romeo, L., Nelson, J., Wingo, P., Bauer, J., Justman, D. and Rose, K., **2019**. *Cumulative spatial impact layers: A novel multivariate spatio-temporal analytical summarization tool*. Transactions in GIS, 23(5), pp.908-936.

Rose, K., Bauer, J.R., and Mark-Moser, M., 2020, A systematic, science-driven approach for predicting subsurface properties, Interpretation, 8:1, 167-181 https://doi.org/10.1190/INT-2019-0019.1

Thank You

National Energy Technology Laboratory

Email: *kelly.rose@netl.doe.gov*

Geo-Data Science Team:

- *Geology* - Kelly Rose[1], Gabe Creason[3], Andrew Gordon[2], Rachel Yesenchak[2]
- *Geochemistry* - Scott Montross[2] & Burt Thomas[1]
- *Geostatistics, GIS/Geology* - Devin Justman[2], Kelly Rose[1], Rachel Yesenchak[2]
- *Database & Computing Scientists* – Mike Sabbatino[2], Patrick Wingo[2], ITSS comp scientists[4]

*[1] NETL; [2] LRST Contractor; [3] ORISE, Oregon State University; [4] ITSS Contractor