Developing a geo-data science driven method to assess REE’s in coal related strata

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April, 2018
Project Goals

To develop an assessment methodology for systematically predicting REE concentrations in coal and coal-related strata that...

- Is based off known mechanisms that result in concentration of REEs in coal & coal related strata
- Can be used to identify areas with higher REE prospectivity
- Can be used to constrain whether REE concentrations and volumes suggest viability of commercial extraction in priority US coal bearing basins

There is the risk that existing data on REE occurrences in different regions/coal types & ages is insufficient and that prior data collection efforts were biased. Inadequate and/or inappropriate data, could result in missed opportunities.
Where are REE enriched coals likely to be a viable commodity?

How may these resources vary?

MILLIONS OF SHORT TONS OF COAL PRODUCED BY STATE (2014)

Wyoming 395.70
West Virginia 112.2
Kentucky 77.3
Pennsylvania 60.9
Illinois 58
Montana 44.6
Indiana 39.3
New Mexico 22
North Dakota 29.2
Colorado 24
Ohio 22.3
Texas 43.7
Virginia 15.1
Utah 17.9
Ala... 16.4
Ariz... 8.1
M... Lo...

SHORT TONS OF COAL PRODUCED BY FIELDS AND BASINS (2014)

Data sources: Energy Information Administration (EIA) state level data (2015)

REE subtask 9.1.1

Data Source: EIA

REE subtask 9.1.1
What are the **mechanisms** of REE enrichment in coal & coal-related strata?

*Not all coals are created equal...*

**Common Mechanisms Concentrating Rare Earth Elements**

1. deposition of heavy mineral sands (placers)
2. alteration of volcanic ash by groundwater
3. chemical erosion of igneous basement (laterites)
4. leaching of volcanic ash by groundwater
5. hydrothermal alteration
6. accumulation within marine phosphates

*It’s about more than just rock type...it’s about the history the rock has experienced*
Where and when are REEs enriched in coal and coal-related strata?

Region, basin, outcrop, depth/time?

Formation, member, bed, parting, seam?

Thickness, composition?

...All of these scales are relevant!
Devil’s in the Details...

- Not all coal basins are created equal
- Subsurface complexity results in 3D heterogeneity
Challenge: Assessment method must address different REE Coal Enrichment Mechanisms

Step 1 - Knowledge Review

- Comprehensive review of >100 publications
- Focused on better understanding the occurrence of REE’s in sedimentary systems and the geological factors that influence the distribution of REE’s in coal deposits

Key takeaways

1. **REE concentrations more likely** to increase if host strata is spatially and temporally **proximal to REE-rich volcanic sources or REE-rich bedrock**
2. Post-depositional **geologic history** of the coal basins influences concentration mechanisms
3. Coal **depositional environment is important**
   - Freshwater vs. marine setting can impact concentration mechanisms
4. **Type and abundance of coal forming plants vary through geological time and space**
   - Coal depositional environments changed with geological evolution of plants and tectonic environment
REE Distributions in coal-bearing strata depend on Time and Space

- Evolution of coal-forming plants
- Coal basin history
- Mechanisms of REE enrichment
- Proximity of basins to REE volcanic sources
- KEY: spatial-temporal gaps in REE sample data

Configuration of continents through time (323 MYA to present)

Dates from GSA 2009 Geologic Time Scale; Plant diversity adapted from 'The Earth Through Time' 8th Ed., by Harold Levin
US Coal Fields and Paleogene-aged Volcanic Rocks

Note relative proximity of Western US Coal basins to volcanism during times of deposition (i.e., basins located near volcanic rocks of similar age)

Data Source: USGS
Depositional environment of Paleogene coal fields

<table>
<thead>
<tr>
<th>Era</th>
<th>Period</th>
<th>Millions of years ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td>Neogene</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Quaternary</td>
<td>2.6</td>
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<tr>
<td>Paleogene</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>Cretaceous</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Jurassic</td>
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<tr>
<td></td>
<td>Permian</td>
<td>251</td>
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<tr>
<td></td>
<td>Carboniferous</td>
<td>299</td>
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<tr>
<td></td>
<td>Mississippian</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>Devonian</td>
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<td></td>
<td>Silurian</td>
<td>416</td>
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<tr>
<td></td>
<td>Ordovician</td>
<td>444</td>
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<tr>
<td></td>
<td>Cambrian</td>
<td>488</td>
</tr>
</tbody>
</table>

Present West coast of US

Terrestrial Coal

Major Paleogene Coal Fields

Marine Coal

Copyright: Scottry
PALEOMAP Project © 2013
<table>
<thead>
<tr>
<th>Period</th>
<th>Epoch</th>
<th>Formation</th>
<th># of coal beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paleogene</td>
<td>Eocene</td>
<td>Wasatch</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Paleocene</td>
<td>Fort Union</td>
<td>40</td>
</tr>
</tbody>
</table>

3D Visualization by depth (10X vertical exaggeration)

![3D visualization of coal beds by formation and period with depth scale from 0 to 7000 feet above sea level and a color gradient from Shallow to Deep.](image)
Challenge: Integrate and Evaluate “Big” Datasets

Key Points

- Mixed/multiple data sources
- Inconsistent scale of data
- Homogenized samples lose vertical resolution of resource enrichment
- Managing large database
- Incomplete records within datasets (e.g., different analyses for related samples)

The inherent complexity of these systems & data resources, coupled with heterogeneous and ambiguous data, provide unique challenges when trying to assess and predict REE distributions and occurrences in sedimentary, coal related strata.
Systematic Assessments Work

Random grab samples & “probing” are costly

Oil & Gas Exploration, 1900’s

Systematic, geoscience founded, methods & models are key to efficient & effective natural resource exploration

Oil & Gas Exploration, ~2015
Approach: Developing a REE Coal Assessment Method

Two main components

1. **Geological Characterization**
   Criteria to inform where conditions most favorable for REE-enrichment of coals
   - **Geological data** (cores, well logs, coalbed depth/thickness; USGS US-STRAT, USGS CRAs, surficial geology)
   - **Geochemical data** (coal and other samples; USGS CoalQual, NUREsed, NGS, and NGD)
   - Existing information/data for **known REE occurrences** (USGS bedrock deposits)
   - **Coal basin geohistory** to identify potential enrichment mechanisms (e.g., syndepositional volcanism)

2. **Spatial/Volumetric Assessment**
   Tools used to assess REE coal spatial extent and assess REE coal resource potential
   - **Geostatistical analysis** of geological/geochemical data to identify spatial patterns/anomalies in both regional and local scale (cluster and or hot spot analyses)
   - Seam-based **geometry calculations** using core data, other geological data (generate circular cross sections? 3D model?)
   - Local/regional **coal production history**
1. Geological Characterization

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To assess REE coal spatial extent and assess REE coal resource potential

- **Geostatistical analysis** of geological/geochemical data to identify spatial patterns/anomalies in both regional and local scale (cluster and or hot spot analyses)
- Seam-based **geometry calculations** using core data, other geological data (generate circular cross sections? 3D model?)
- Local/regional **coal production history**
- Advanced computing approaches
Challenge: Compile and Evaluate Field Datasets

From NETL, USGS, EIA, State Geological Surveys, etc

- Compiled database of over 200 publicly available, basin- and national-scale spatial datasets
- Determined relationships between REE concentrations and distributions
- Identified critical information gaps and future data needs for testing of resource assessment method

<table>
<thead>
<tr>
<th>Data Categories/Source</th>
<th>Number of Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal mines</td>
<td>48,529</td>
</tr>
<tr>
<td>Coal resource and geology</td>
<td>681,965</td>
</tr>
<tr>
<td>Deposits</td>
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<tr>
<td>Geochemical</td>
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<tr>
<td>Geophysical</td>
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</tr>
<tr>
<td>DOI-Skytruth</td>
<td>48,529</td>
</tr>
<tr>
<td>Wyoming Geological Survey</td>
<td>6,882</td>
</tr>
<tr>
<td>EIA</td>
<td>985</td>
</tr>
<tr>
<td>USGS</td>
<td>681,965</td>
</tr>
<tr>
<td>NETL</td>
<td>772</td>
</tr>
<tr>
<td>Grand Total</td>
<td>3,417,126</td>
</tr>
</tbody>
</table>

Data Volume

Number of overlapping datasets:

- 5
- 88
Challenge: Data Gaps & Scale of Data

Key Points

- Sample collection biases (over or underrepresented coal fields)
- Precision of spatial location data
- REE resource may be independent of coal quality
  - High REE potential may occur in marginally economic coal fields
- Selective mining of high concentration resources may require vertical (depth) constraints
- REE resource may be concentrated in mine reject piles
  - (not in CoalQual data)
Challenge: Regional Data Gaps
Paleozoic vs. Cenozoic Coals

NETL REE Coal Samples – Sources LTI and HQ

- 514 samples from LTI
- 768 samples from NETL-HQ (258 available on EDX)
- Total = 772 samples
Challenge: Regional Data Gaps

USGS CoalQual Data – Total REE + Y (>150 ppm)

KEY POINTS

- High REE measured in coal basins nationwide
- Highest values observed in data sparse regions
**Need better sample data to support predictions**

*USGS CoalQual Data example*

**KEY POINTS**

- **Samples vertically homogenized** (averaged) across coal seams
- Own their own, these measurements are not enough
  - Need to integrate measured information with other measurements and contextual information to inform prediction
REE Sample Data

What is needed?

- Sample ID
  - Unique ID, Project ID, Lab ID, Stratigraphic ID (CoalQual), API #

- Sample Description
  - Material, Sample Type (hand sample, drill core, fly ash, etc.)
  - Seam Name, Seam Thickness, Stratigraphic Association
  - Sample Status

- Geolocation Information
  - Lat./Long., UTM, Depth

- Site Characteristics
  - Site Name, Lithology of Adjacent Rock

- Collection Information
  - Name of Collector, Date Collected, Date Analyzed, Date and Reference for Analyses Published

- Chemical Analysis Information (if available)
  - Lab Name, Analysis Technique, Sample Prep Method, Alteration, Other Significant Mineralogy, Trace Element Conc., Oxide Conc., REY Conc., Vitrine Reflectance

- Other Metadata
  - Contact Info, Links to Data (if published)

Need for a more systematic, consistent REE coal/sed sample acquisition, analytical & database curation approach
What’s the value of data?

• Use data/information to build a more complete picture
• In this era of big data... each small piece helps complete the “puzzle”
• More data/information = more accurate R&D, analysis and predictions

DATA IS THE NEW OIL

but do you have the resource to refine it?
Underpinned by A Virtual Library & Laboratory for Energy Science

- Virtualizing team analytics
- Continued innovations to connect DOE FE affiliated researchers to online resources (tools, data, etc)
- Increasing # of tools and apps for use in team workspaces
- In development since 2011

https://edx.netl.doe.gov
Building a Virtual DOE R&D Data Framework

- Role based security to manage access
- Contributors indicate “license” restrictions on data use
- Potential for data to mature and matriculate up the pyramid over time
- Collaborative community for energy R&D

Shared Access

Trusted Community
DOE, NSF, USGS, State Regulators

Private Trusted Partners
DOE R&D + Outside R&D Community

Private Trusted Project Partners
NETL/FE R&D Community

Team/Project Private Workspaces
NETL Carbon Storage Community (Oil/Gas, Coal, others)
Advanced Data Computing & Tools to develop a Virtual FE R&D Data Framework

Combination of advanced, big data driven, tools & capabilities, hosted via private side of EDX to build a virtual data system for DOE FE researchers:

- Federating with billions of open-source, online data sets
- Offering data through EDX Geocube, a spatial data tool, or via direct search on EDX
- Gradually identifying key data gaps, and filling in the U.S. subsurface data puzzle.

*These attributes & data sources are evolving quickly with implementation of new tools and engagement of key stakeholders

Database with different data types, formats, and resolutions

Ongoing collaboration/coordination

- Connected with several REE science teams at Idaho National Laboratory, and University of Wyoming
  - pursued studies related to REE and geothermal systems, including in relation to oil and gas field’s produced waters
  - potential to explore other prospecting techniques to help drive out year assessments and technology development...

- Univ. of Wyoming Carbon Management Institute – Subcontract to collect vertically constrained core material through Powder River Basin Wyodak Core. Including high gamma ray section
  - To Date, 50 samples have been ashed and await analysis
  - Continued discussions and potential samples to be collected with industry partners of the Carbon Management Institute

- USGS
  - Preliminary discussions with Dr. Ruppert at the USGS (Appalachian Basin-Coal) regarding the coordination and collaboration of our efforts with their CRA methodologies
  - We decided it was appropriate to discuss a MOU for this effort to facilitate exchange of samples and USGS coalbed assessment maps
  - Peter Warwick (POC Gulf lignite), Brian Schaffer (POC for Powder River Basin)
Ongoing Efforts

Project is here, Formulating approach, gathering data, preliminary analytics

Next step, FY18, testing of REE assessment approach in 1 basin

FY19, refine approach based on basin 1 findings, apply & testing in basin 2

FY20, if approach is validated, then develop into fuzzy logic tool to streamline use

• Test and demonstrate method in select basins
• Help determine if REE concentrations and volumes support commercial extraction in priority U.S. coal bearing sedimentary basins

Next steps
• Gather and evaluate relevant data for initial assessment of priority basin(s)
• Continue collaboration with geochemistry experts at NETL and the U. of Wyoming to provide validation/calibration field data for PRB
• Incorporate Subsurface Trend Analyses in the assessment approach
• Prepare and publish catalog of data aligned in REE coal assessment needs
  • Integration into Geocube tool hosted on EDX for public access
Building a Geo-Data Science Method to Predict Coal REE Prospectivity

Geo-Data Science Team:
- **Geochemistry** - Scott Montross & Burt Thomas
- **Geology** - Emily Cameron, Gabe Creason, Jenny DiGuilio
- **Geostatistics, GIS, Geology** - Devin Justman, Roy Miller & Kelly Rose
- **Data/Database Scientist** – Mike Sabbatino

Thank you
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