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Sustainable Sourcing of Rare Earth Elements

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What Is Sustainable Sourcing?

Selection of raw materials that:

1) **Provide good economic value at competitive cost**
2) **Meet high environmental standard**
3) **Conform to purchasers' social values and standards**

Tate et al (2014)

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Why Is The USGS Involved?

- Approached by researchers from a European company for LCA data on REE mines
- Invited by European Commission to contribute LCA data for mining
- Ongoing efforts to integrate environmental factors into mineral resource assessments
- Mineral supply issues – environmental and regulatory risks

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How Is Sustainability Assessed?

- European cooperators use LCA methods
- Initial effort for REE began with commercial LCA software
- There is no standard industrial process for REE production – an LCA required for each REE mining project
- Are there efficiencies to scale with respect to sustainability?

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Reconnaissance Study REEs

- System boundary: mine face to final mineral product (LOM)
- Excludes exploration and mine construction
- Final mineral product varies from project to project – mixed REE flotation concentrate, various mixed REE leach products, separated REEs or mixtures as oxides, oxalates, carbonates, etc.
- No work yet on LCA for custom cracking and separation facilities

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Reconnaissance Study REEs

- **Select Sustainability Indicators**
- **Started with a standard list (Azapagic, 2004)**
- **Selected a subset based on data availability:**
  geometallurgical
  economic
  process inputs
  process outputs (including wastes)
- **Social measures largely outside USGS capability**

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Reconnaissance Study REEs

- Tried to learn as much as possible about sustainability of Chinese REE production
- Studies 2 new REE mines and about 35 proposed REE mines outside of China
- Data from NI 43-101 reports (feasibility studies), CPRs, EIAs and other permitting documents
- Lots of data gaps and inconsistencies – will have to develop estimation capability

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Lessons Learned

Three major determinants of REE sustainability:

- **Mineral deposit type (carbonatite, alkaline-igneous rock related, etc)**
- **Geometallurgical variations within deposit type (grain size, optimal grind, acid consumption)**
- **Location (climate, distance from existing infrastructure, depth/orientation of orebody**

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Carbonatite

Mountain Pass Discovery Outcrop Sample

Araxá Laterite

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Alkaline Igneous Rock-Related

Bokan Mountain REE Deposit, Alaska

Dotson Vein

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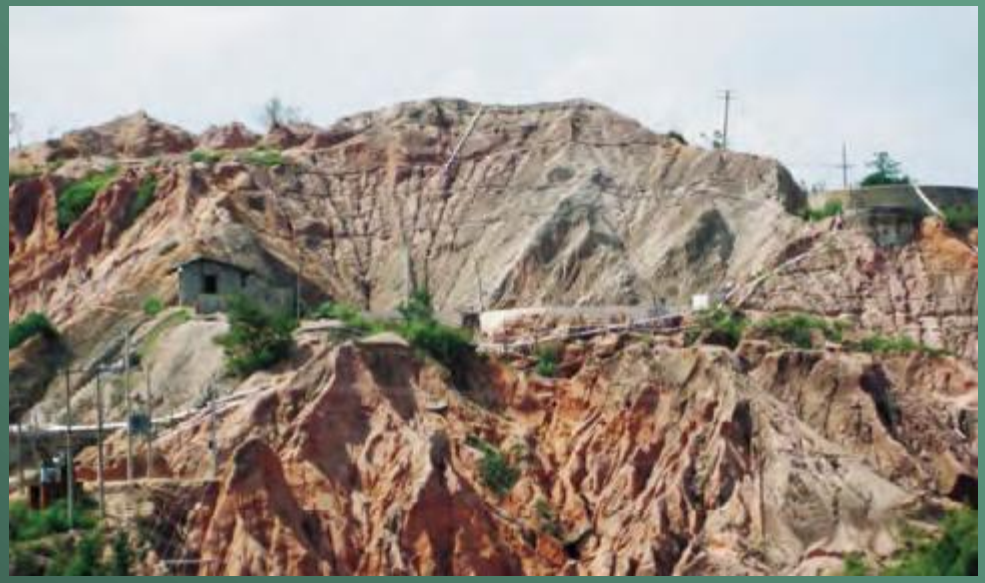
‘Weathered Crust’

Stewartsville, Virginia, USA

Ganzhou, South China



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Heavy Mineral Sands

Mineral Sands Dredge, Sierra Leone

OSCOM Plant, India

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Other Deposit Types

Paleoplacer U-REE (Elliot Lake, Ontario)

IOCG/IOA

Monazite pegmatite/dike (Steenkampskraal, South Africa)

Aluminous clay (Grand Vallée, Québec)

Metalliferous black shale (Buckton, Alberta)

Bauxite residues (“red mud”)

Sedimentary phosphate

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Results - Geometallurgy

- Significant variation in ore mineral grain size within and across deposit types
- Carbonatites generally finer grained than alkaline igneous rock-related deposits
- Carbonatites generally higher in grade
- Acid consumption lower for alkaline igneous rock-related deposits, highest for weathered carbonatites

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Results - Economics

- Carbonatites (except Lofdal, Namibia) LREE rich – Ce in excess supply
- Some alkaline igneous rock-related deposits enriched in REEs in short supply (Y Nb Tb Dy Eu Er)
- Capital intensity highest for alkaline igneous rock-related deposits
- Significant variations in metallurgical recovery within deposit types

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Results – Process Inputs

- Footprint of REE projects range from 3 to 115 m^2 per t TREO recovered – UG mines have a much smaller footprint than OP mines
- Water requirements range from 10 to 3,275 m^3 per t TREO recovered – lowest for projects that recycle process water
- Diesel fuel requirements depend on mining method, strip ratio, and whether power is generated on site

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Results – Process Outputs

- Projects examined would produce between 980 to 55,000 tpy TREO
- Projects would produce up to 6,700 t waste rock and 13,300 t tailings per t TREO recovered
- Alkaline igneous rock-related deposits generally more radioactive than carbonatites
- Highest radioactivity per t TREO recovered is in heavy mineral placers

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Final Thoughts

- Need a unifying metric that combines various Sustainability Indicators
- Not clear how to develop and objective metric – much subjectivity in choices of indicators and weighting of indicators
- Given common environmental standards, would cost of production be a good proxy for sustainability?

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