DRIVING THE START OF THE GREEN REVOLUTION

CREATING VITAL REFERENCE MATERIALS FOR REE PROSPECTING

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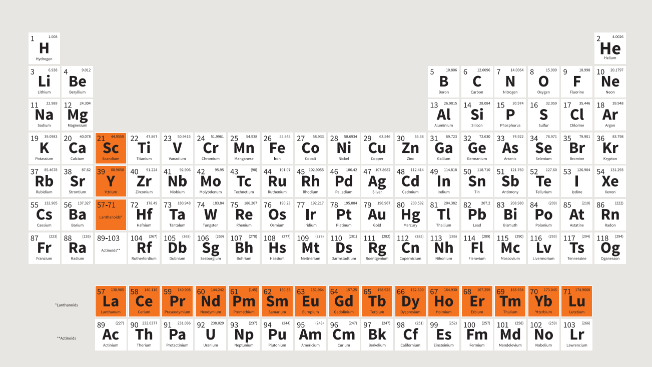
Paragon Scientific

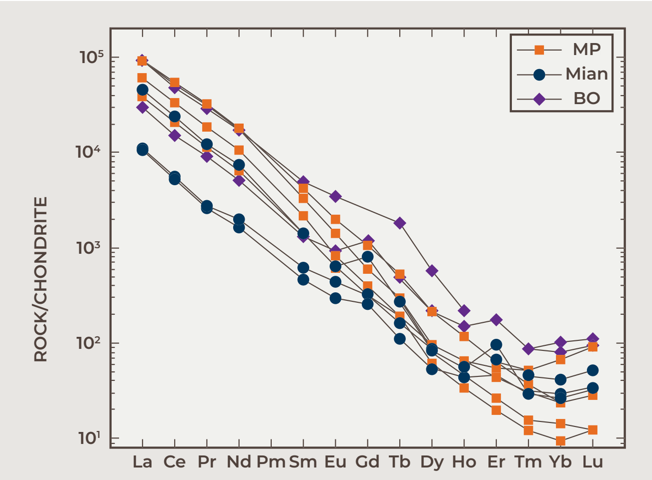
When it comes to creating a greener future, the power and potential of Rare Earth Elements (REEs) is undeniable. But there's a lot to be done to ensure we can effectively harness these crucial elements, today and tomorrow.

So what are REEs – and why are they such a challenge?

Although not as rare as gold (they're found in basically all rocks), the difficulty is finding them in high enough concentrations to make mining them financially viable, ore-grade material. Due to the high concentrations of uncommon elements, instrumental analysis of High Concentration REE materials is complicated by unexpected spectral overlaps and complex matrix effects. And as global production is currently dominated by China and a few other countries, supply is hugely affected by political and similar factors.



- Not as rare as Au or many other elements, often 10s-100s ppm
- Rarely found in ore-grade concentrations
- Concentration of REEs in different carbonatites normalized to the solar system concentration of each REE (see below)



Verplank et al. (2016)

The power & potential of REEs

A myriad of uses for huge environmental gains

Cerium Oxide is used for UV absorption in solar panels

NdFeB- Permanent Magnets for wind turbines

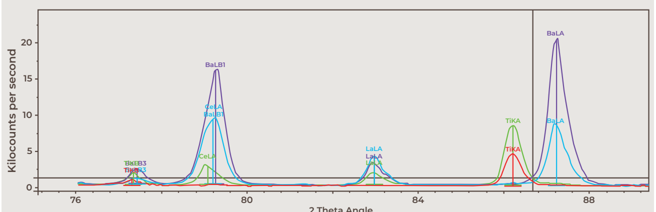
La – Key component in NiMh hybrid car batteries

Pr – Used in Mg-alloys for jet engines

- Major component for permanent magnets
- Photovoltaics
- Alloying elements in 'exotic' alloys
- Batteries
- Catalysts
- Polishing compounds
- Glass additives

The limitations of current REE analysis

- Field exploration for REEs typically done using handheld XRF (or LIBs)
- Limited calibration materials for REEs
- Matrix dependent
- Overlaid WD XRF spectra from our Rare Earth ore (blue) with 2 other REE Ores (green and cyan), and Basalt (red) as a baseline - illustrates the complex spectral overlaps when high concentrations of REEs are present in a sample



Above: WD-XRF scan from 76 to 89 degrees. The blue spectrum is MBH-REE-ORE1-22-P while the green and cyan spectra are other REE ores, the red spectra is a basalt, meant to represent a more typical geologic material. Compare the simplicity of the red spectrum with only the TiKa and TiKb peaks with the REE ore spectras that have large Ba, Ce, and La peaks, introducing complicated overlaps, absorptions, and other matrix effects.

China's domination of global production

(tons)	2020 Production	2021 Production	Reserves	% of 2021 Global Production
China*	140,000	168,000	44,000,000	60%
USA	39,000	43,000	1,800,000	15%
Burma	31,000	26,000		9%
Australia	21,000	22,000	4,000,000	8%
Thailand	3,600	8,000		3%
Others	10,100	10,100	71,180,000	3.6%
World Total	240,000	280,000	120,000,000	

*Almost all of the HREE's are produced by China

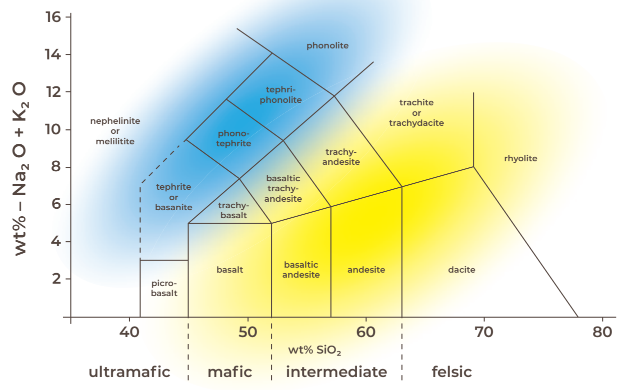
Data from U.S. Geological Survey, Mineral Commodity Summaries, January 2022

Country	Reserves (Tons)	Country	Reserves (Tons)
China	44,000,000	United States	1,800,000
Vietnam	22,000,000	Greenland	1,500,000
Russia	21,000,000	Tanzania	890,000
Brazil	21,000,000	Canada	830,000
India	6,900,000	South Africa	790,000
Australia	4,000,000	Other countries	280,000
World Total			120,000,000

Data from U.S. Geological Survey, Mineral Commodity Summaries, January 2022

Carbonatites

- Geologic origins of carbonatites is still unclear
- Associated with alkaline magmatism (syenite nephelines / shonkinite nearby) (blue shaded area on image below)
- Fractional crystallization of an alkaline magma ("weird" magma) leads to a melt enriched in incompatible elements, like REEs
- Either separation of an immiscible carbonatite melt or release of a volatile-enriched fluid
- Primary REE-bearing mineral is Bastnasite – (Ce,La, Y)CO3F, also of interest is Barite and Ancylite (Sr, Ce, La-carbonate)



MBH-REE-ORE1-22-P

The challenges of limited quality control materials and analytical methods

- Acquired 200kg of medium grade REE ore via USGS
- Crushed, milled, blended, and bottled a portion of the material - bottled portion will become a CRM
- In-house homogeneity testing and round robin-testing for certification
- Majors by WD-XRF – Significant method development challenges because of the unique elements and matrix
- Minors and traces by ICP-OES / MS – REE minerals tend to be refractory, very challenging dissolutions, additionally, Ba and S in sinter digestions readily precipitated as $BaSO_4$ and precipitated $PbSO_4$
- Many labs are not prepared for wt% level REEs, as there are not many CRMS available for REEs in this concentration range. Our product provides these calibration points, allowing them to extend their analytical methods
- Results cannot be easily quality controlled by totaling (high CO_2+ F + strange oxide configurations)

Achieving excellent calibration points using QA and QC materials

Ore grade MBH-REE-ORE1-22-P uses:

- Handheld XRF / LIBS calibration or check sample
- QA / QC, Grade control
- High-end calibration point for many elements, not just REEs

Element	Concentration (g/100g)	Element	Concentration (mg/kg)
CeO_2	4.5	Cs	0.40
La_2O_3	3.1	Dy	49
Nd_2O_3	1.06	Er	13
Pr_6O_{11}	0.41	Eu	100
Sm_2O_3	0.074	Ho	5.6
BaO	19.9	Lu	1.04
SrO	3.7	Nb	43
		Rb	6.0
		Sc	10
		Tb	14.8
		Th	246
		Tm	1.28
		U	34
		Y	165
		Yb	7.2

- Carbonate from Marble Hill Georgia was used as a diluent for additional ground ore material to create 3 additional products.
  - Dominantly $CaCO_3$ (calcite / aragonite) + ~5% dolomite and quartz
  - REE "blank"
  - Low in most trace elements (except Sr @.1-.2 wt%
  - Major element composition and mineralogy similar to carbonatite to avoid introducing new matrix effects
  - Diluted carbonatites to be homogenized and bottled to create a suite of materials with varying levels of REEs in a natural matrix, which can be used for in-situ analysis for REE exploration

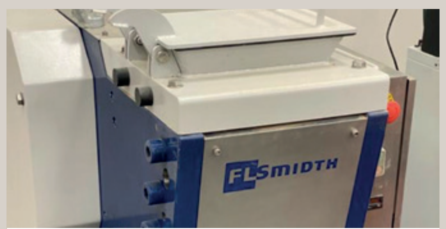
Developing quality materials for field portable instrumentation

- Handheld XRF / LIBS calibration or check samples at closer concentrations
- QA/QC, Grade control
- High-end calibration and mid-points for many elements, not just REEs, some of which are important pathfinders
- Covers key range for Ce, La, Nd, and Pr

(g/100g)	MBH-REE-LO-RM-22-P	MBH-REE-MID-RM-22-P	MBH-REE-LO-RM-22-P
BaO	0.75	1.9	9.9
CeO_2	0.18	0.45	2.3
La_2O_3	0.12	0.30	1.5
Nd_2O_3	0.040	0.10	0.52
Pr_6O_{11}	0.015	0.038	0.20
SrO	0.22	0.44	1.9
(mg/kg)	**MBH-REE-LO-RM-22-P**	**MBH-REE-MID-RM-22-P**	**MBH-REE-LO-RM-22-P**
Sm	24	61	303
Th	9.8	25	127
U	1.8	3.9	17
Y	10	21	89

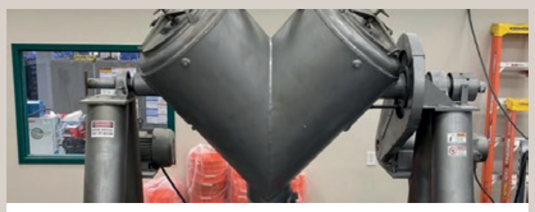
Brand-new facility modeled after USGS GRM production facility

Designed in conjunction with Steve Wilson, formerly of the USGS, our new production facility is purpose-built to the exacting standards required of a ISO17034 certified reference material production.

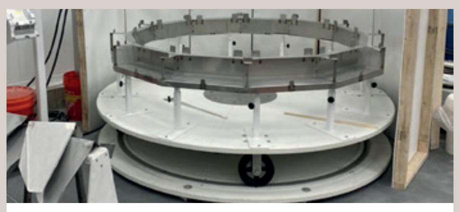


1. Jaw Crusher – Designed to take rock up to 5" in diameter and reduce them down to 2 mm in diameter

2. Ceramic Lined Ball Mill – Contains grinding media (alumina balls) and ground material. The mill is used to grind the crushed material from step 1 into powder



3. V-Blender – Designed to mix starting powders producing a homogeneous mixture



4. Spinning Riffler – Used to bottle powdered material

Conclusions

A huge step forward in the green revolution

- Acquired a single ore grade REE material
- Processed and bottled in new facility
- Produced an ore grade REE CRM
- Mixed the high grade material with a suitable dilutant to create additional RMs
- Suite of dilutions targeting handheld XRF (and LIBS) for exploration geologist looking for new REE deposits

Future Work

Taking even bigger strides towards a greener tomorrow

- REEs in other matrices (Heavy Mineral Sands, bauxite / red mud)
- REEs from other carbonatites, different element ratios
- Similar work for Li-spodumene and Li-lepidolite in felsic matrices
- Other form factors besides loose powder cups, pressed pellets, glasses

LGC