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THE FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS

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REE Distribution of Selected Deposits in New Mexico

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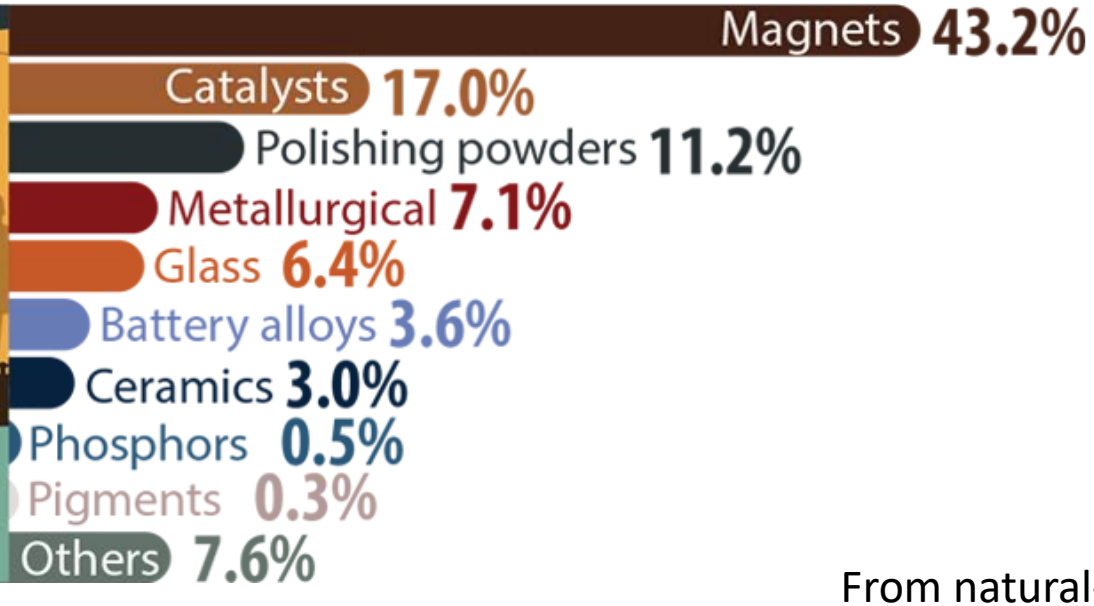
Rare earth elements

- Similar, but slightly different properties
- Creates unique demand for each element
  - Magnets (Nd, Pr, Sm, Dy), catalysts (La), polishing (Ce), phosphors (Eu, Y), lightweight alloys (Sc), etc.



From natural-resources.canada.ca

Rare earth elements

- No dedicated REE exchange
  - Prices are not as straightforward as precious metals
- Wide range in REE prices
  - LREE-enriched deposits more common than HREE
  - Bastnäsite, monazite > xenotime
- Important to characterize REE distribution in deposits

TABLE 3
RARE-EARTH-OXIDE PRICES[1]

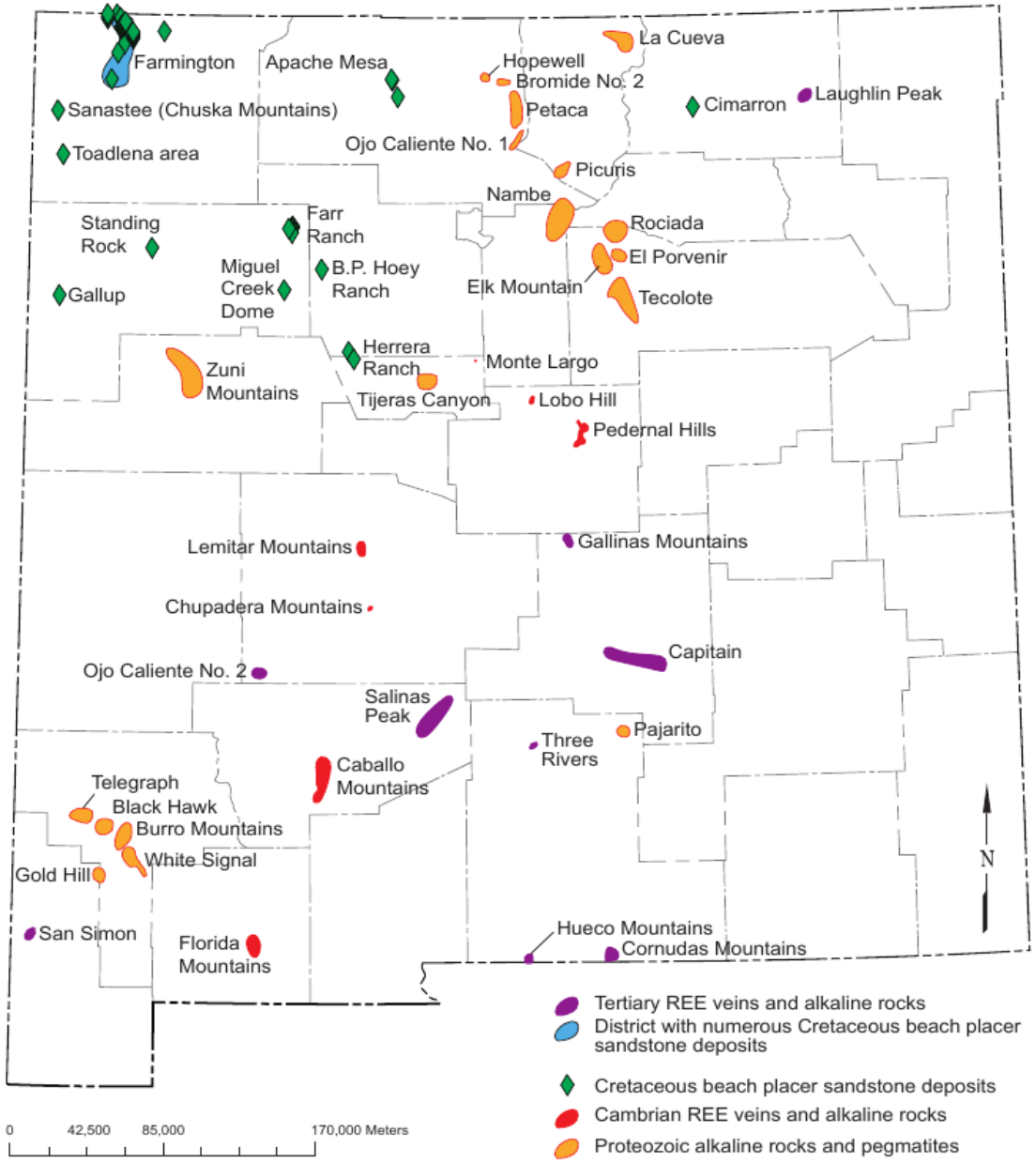
Product (oxide)	Purity (percent)	Price (dollars per kilogram) 2017	2018
Scandium[2]	99.990	4,600	4,600
Yttrium[3]	99.999	3	3
Lanthanum[3]	99.500	2	2
Cerium[3]	99.500	2	2
Praseodymium[3]	99.500	65	63
Neodymium[3]	99.500	50	50
Samarium[3]	99.500	2	2
Europium[3]	99.990	77	53
Gadolinium[3]	99.999	37	44
Terbium[3]	99.990	501	455
Dysprosium[3]	99.500	187 [r]	179

[r]Revised.
[1]Products are listed in order of atomic number.
[2]Source: Stanford Metals Corp.
[3]Source: Argus Media group – Argus Metals International.

From 2018 USGS Mineral Yearbook

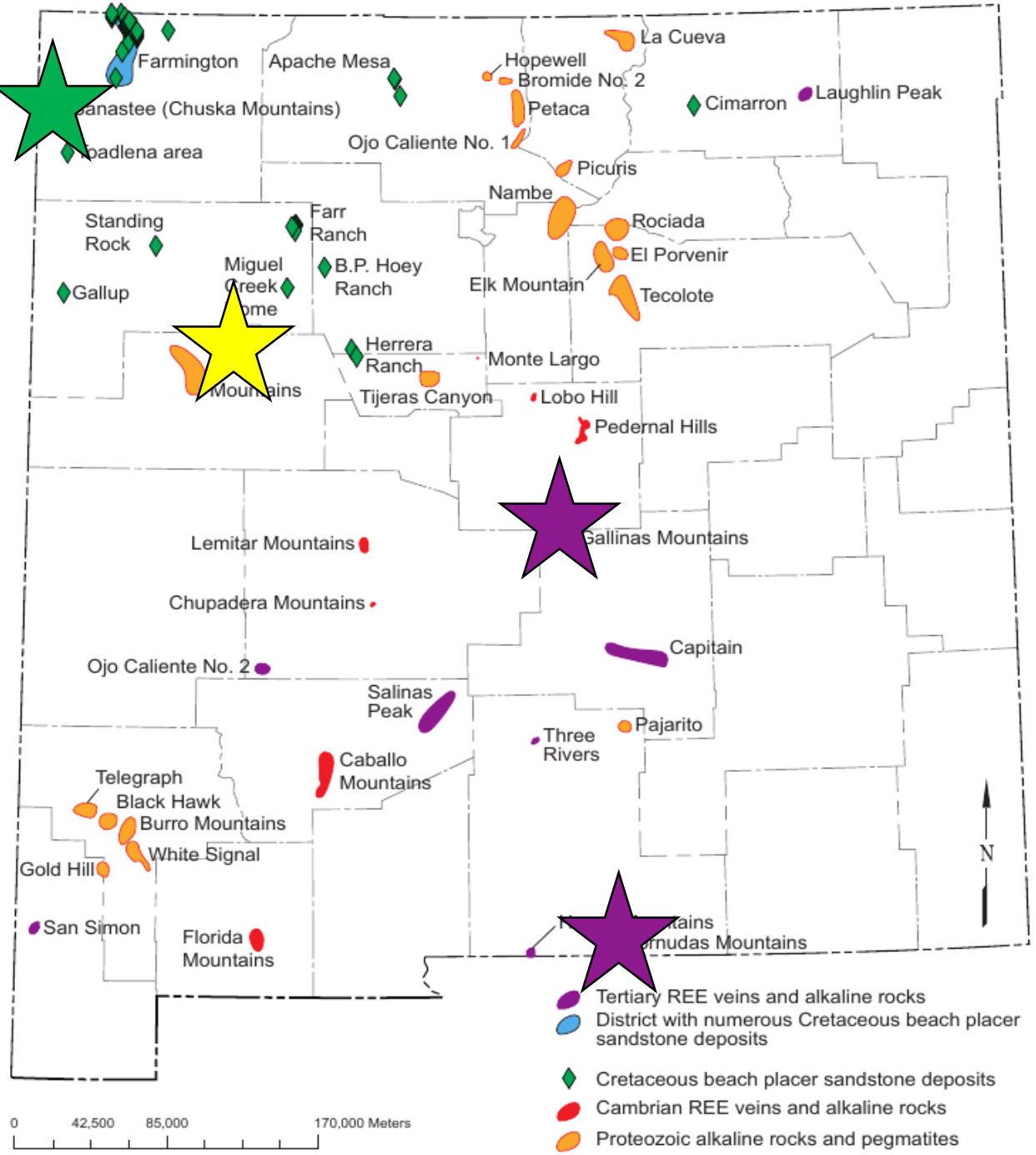
REE in New Mexico

- Several types of REE deposits in New Mexico
  - Proterozoic alkaline rocks and pegmatites
  - Cambrian alkaline rocks and carbonatites
  - Cretaceous beach placer (heavy mineral) sandstones
  - Tertiary alkaline rocks and REE veins



Sanostee beach placer sandstone

Grants uranium district



Gallinas Mountains

Cornudas Mountains

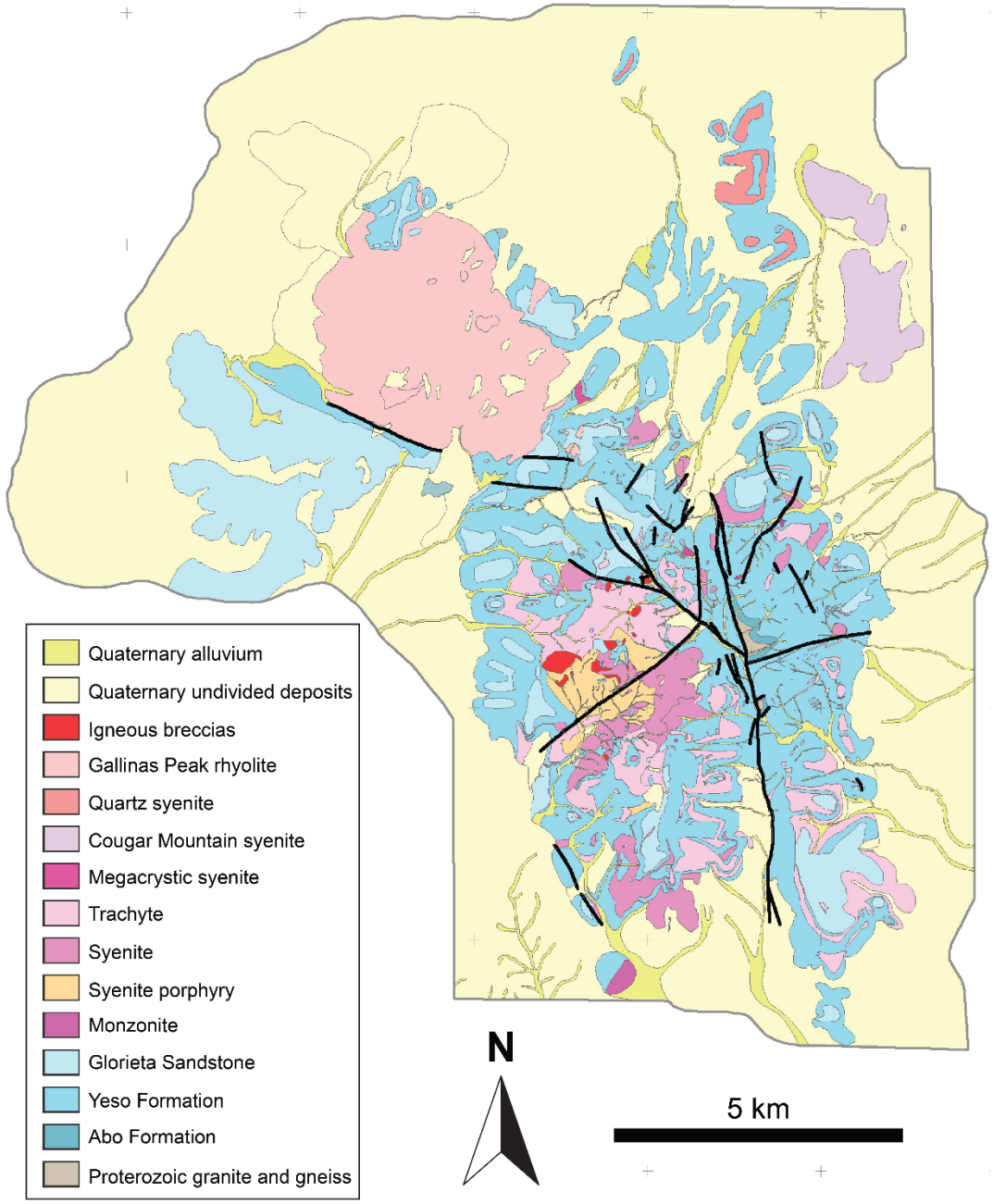
Methodology

- Whole rock and trace element geochemical dataset at the NMBGMR
  - ALS Geochem, USGS labs
- IMDEX ioGAS used for analysis
- 90th percentile values of total REE
- **What's the distribution of REE in the most enriched samples from each district?**

	SampleId	Project EJO	Date collected	Date analyzed	Chem Lab File No. (wQA/QC
610	Gal1017	Gallinas Mountains	5/26/2020	11/10/2020	MRP-18942
611	Gal1018avg	Gallinas Mountains	5/26/2020	11/10/2020	MRP-18942
612	Gal102	Gallinas Mountains	9/10/2019	4/27/2020	MRP-18649
613	Gal103	Gallinas Mountains	1/23/2020	4/27/2020	MRP-18649
614	Gal1032	Gallinas Mountains	5/27/2020	11/10/2020	MRP-18942
615	Gal1052	Gallinas Mountains	5/28/2020	11/10/2020	MRP-18942
616	Gal106	Gallinas Mountains	1/29/2020	4/27/2020	MRP-18649
617	Gal1066	Gallinas Mountains	5/29/2020	11/10/2020	MRP-18942
618	Gal107	Gallinas Mountains	1/29/2020	4/27/2020	MRP-18649
619	Gal1085	Gallinas Mountains	10/22/2020	6/1/2021	MRP-19076
620	Gal1089	Gallinas Mountains	10/22/2020	6/1/2021	MRP-19076
621	Gal11	Gallinas Mountains	9/10/2020	4/27/2020	MRP-18649
622	Gal111	Gallinas Mountains	11/7/2019	4/27/2020	MRP-18649
623	Gal1148Avg	Gallinas Mountains	11/6/2020	6/1/2021	MRP-19076
624	Gal1150	Gallinas Mountains	11/6/2020	6/1/2021	MRP-19076
625	Gal1154	Gallinas Mountains	11/18/2020	6/1/2021	MRP-19076
626	Gal1180	Gallinas Mountains	11/20/2020	6/1/2021	MRP-19076
627	Gal1181	Gallinas Mountains	11/20/2020	6/1/2021	MRP-19076
628	Gal125	Gallinas Mountains	3/4/2020	9/16/2020	NM20-002_MRP
629	Gal126	Gallinas Mountains	3/4/2020	9/16/2020	NM20-002_MRP
630	Gal128	Gallinas Mountains	3/5/2020	9/16/2020	NM20-002_MRP
631	Gal129	Gallinas Mountains	3/5/2020	9/16/2020	NM20-002_MRP
632	Gal130	Gallinas Mountains	3/5/2020	9/16/2020	NM20-002_MRP
633	Gal131	Gallinas Mountains	3/5/2020	9/16/2020	NM20-002_MRP
634	Gal132avg	Gallinas Mountains	3/5/2020	9/16/2020	NM20-002_MRP
635	Gal136avg	Gallinas Mountains	3/11/2020	9/16/2020	NM20-002_MRP
636	Gal137	Gallinas Mountains	3/11/2020	9/16/2020	NM20-002_MRP
637	Gal138	Gallinas Mountains	3/11/2020	9/16/2020	NM20-002_MRP

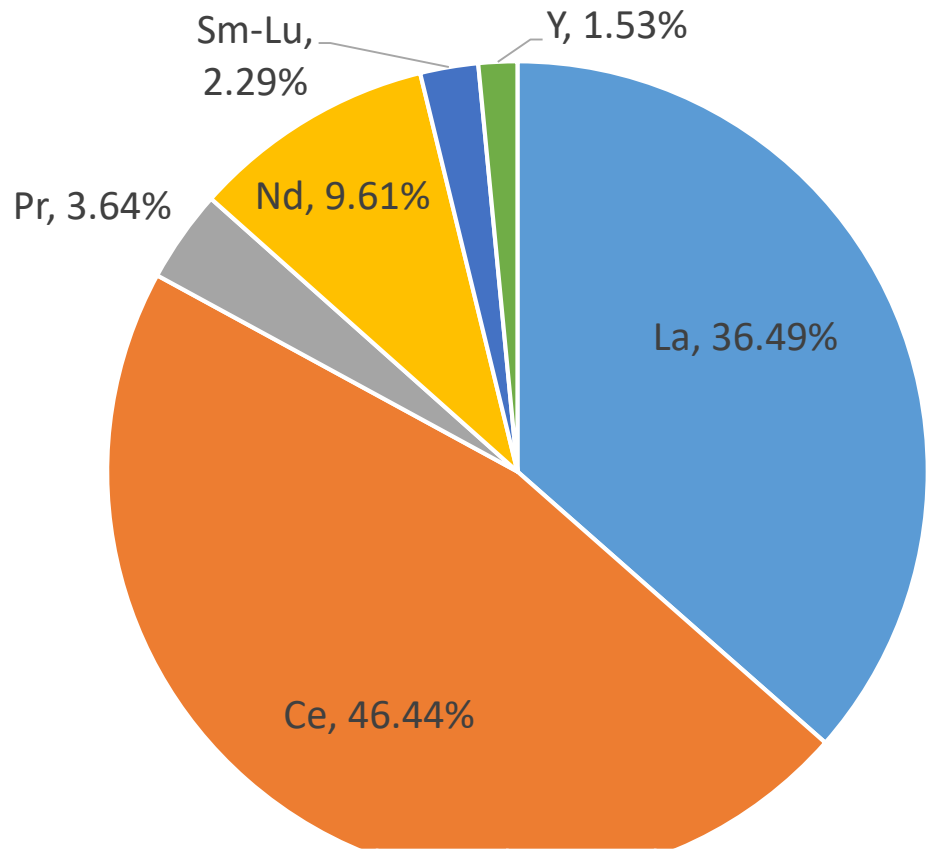
Gallinas Mountains

- Eocene-Oligocene trachyte/syenite intrude Permian sediments
  - Bastnäsite-bearing fluorite veins and breccias
  - Fe skarns
- Historic mining of Pb, Cu, Fe, Ag, fluorite, REE
- USGS Earth MRI project
- REE possibly related to carbonatite at depth?
  - Could fluorite and barite be recovered with REE?



REE distribution in the Gallinas Mountains

- Bastnäsite-(Ce) primary REE mineral
  - Little to no phosphorus (no monazite or xenotime)
- Locally up to ~9% TREO
- Sample n=28 for TREO > 1.3% (90th percentile)
- Average 2.75% TREO
- Contained value: $371/tonne



	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Y	Total
REO (ppm)	10039	12760	1000	2628	257	53	167	19	66	11	25	16	2	455	**27499**
Oxide price (USD/kg)	$3.41	$3.55	$64.67	$65.38	$2.13	$27.72	$38.37	$1,172.61	$292.80	$89.55	$36.81	$13.50	$803.06	$3.00	
Contained value	$34.23	$45.30	$64.69	$171.84	$0.55	$1.48	$6.42	$22.32	$19.27	$0.95	$0.92	$0.22	$1.53	$1.36	**$371.07**

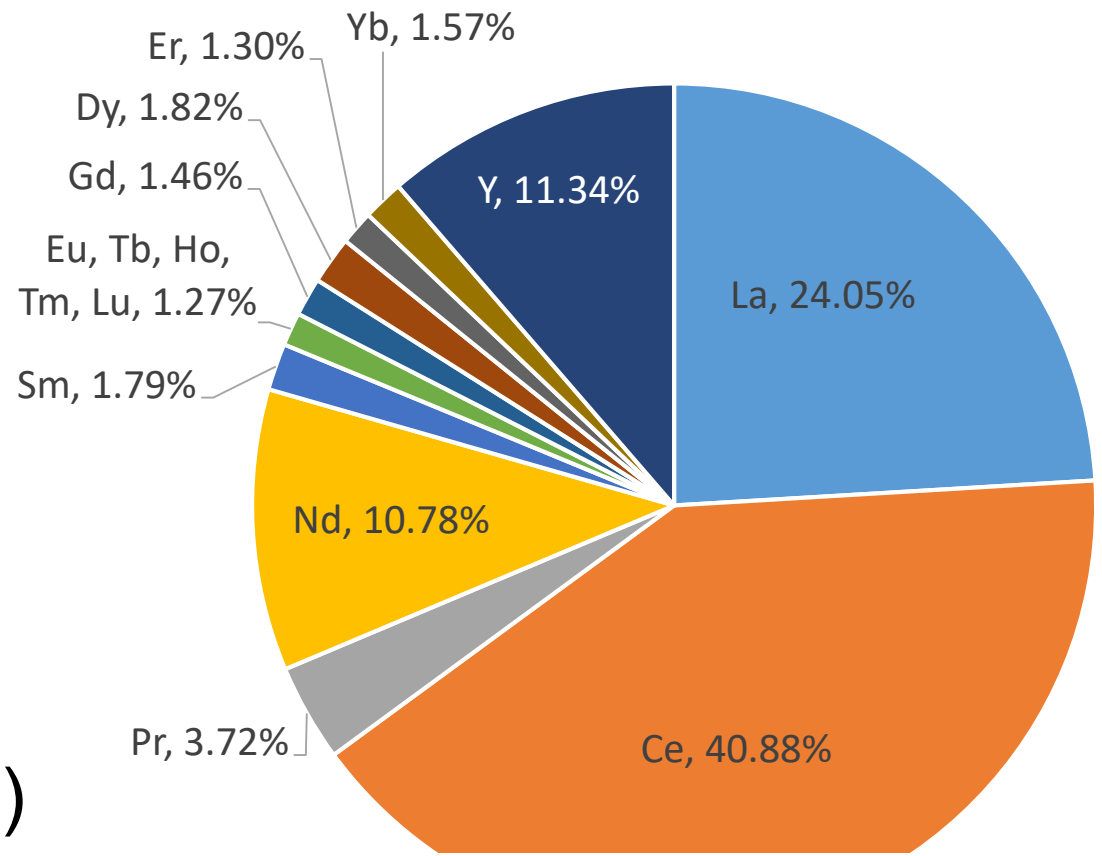
Cornudas Mountains

- Eocene-Oligocene nepheline syenite and phonolite intrude Permian Hueco limestone
  - Eudialyte-group minerals (zirconosilicates)
  - Disseminated and contact metasomatic zones
- Explored for REE and nepheline syenite for bottle glass
- Recently remapped under USGS Earth MRI


E. Owen photograph

REE distribution in the Cornudas Mountains

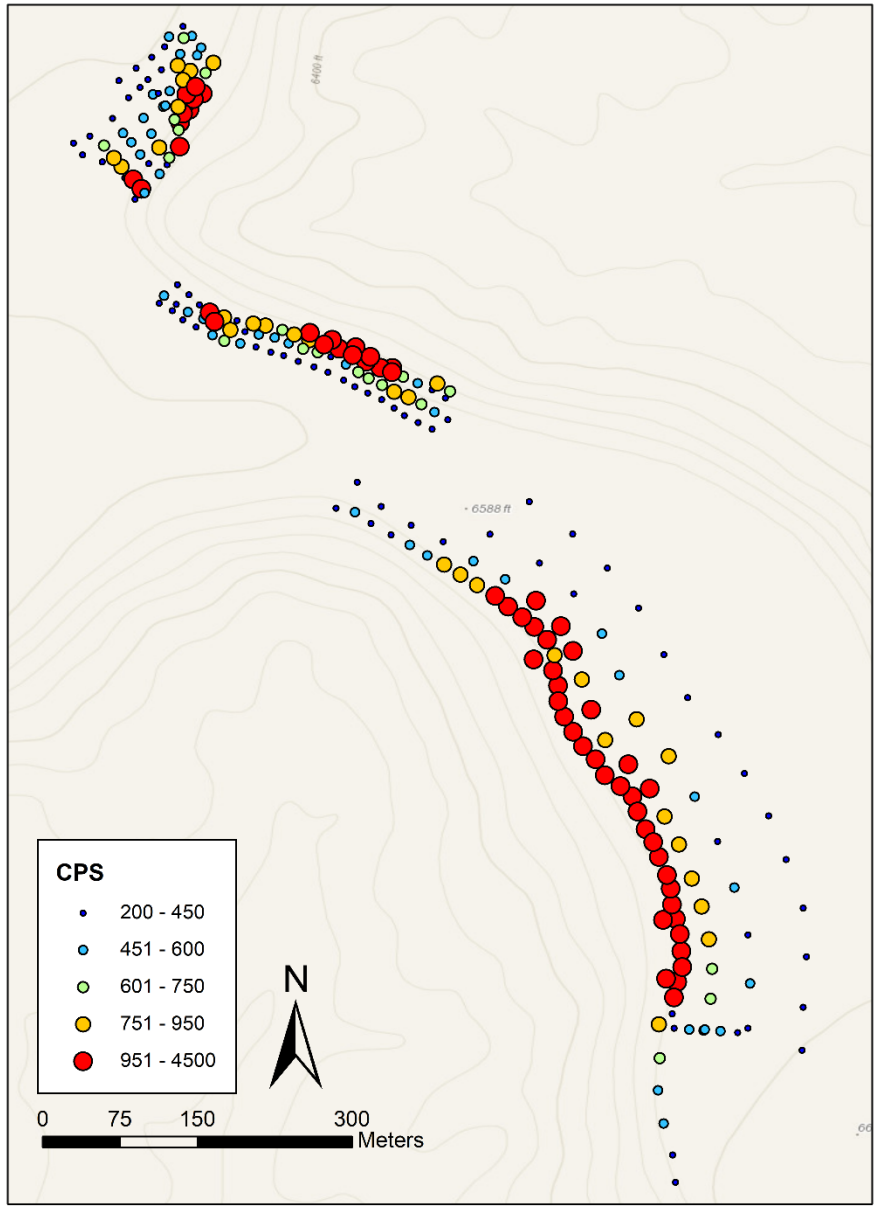
- Eudialyte main REE-bearing mineral
  - Variable REE substitution
- Locally up to ~0.4% TREO (contact metasomatic zones)
- Sample n=40 for TREO > 0.2% (90th percentile)
- Average 0.28% TREO
- Contained value: $67/tonne (plus Zr!)



	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Y	Total
REO (ppm)	675	1145	104	301	50	4	40	8	50	11	36	43	7	344	**2816**
Oxide price (USD/kg)	$3.41	$3.55	$64.67	$65.38	$2.13	$27.72	$38.37	$1,172.61	$292.80	$89.55	$36.81	$13.50	$803.06	$3.00	
Contained value	$2.30	$4.06	$6.74	$19.66	$0.11	$0.10	$1.55	$8.99	$14.62	$0.97	$1.31	$0.58	$5.40	$1.03	**$67.41**

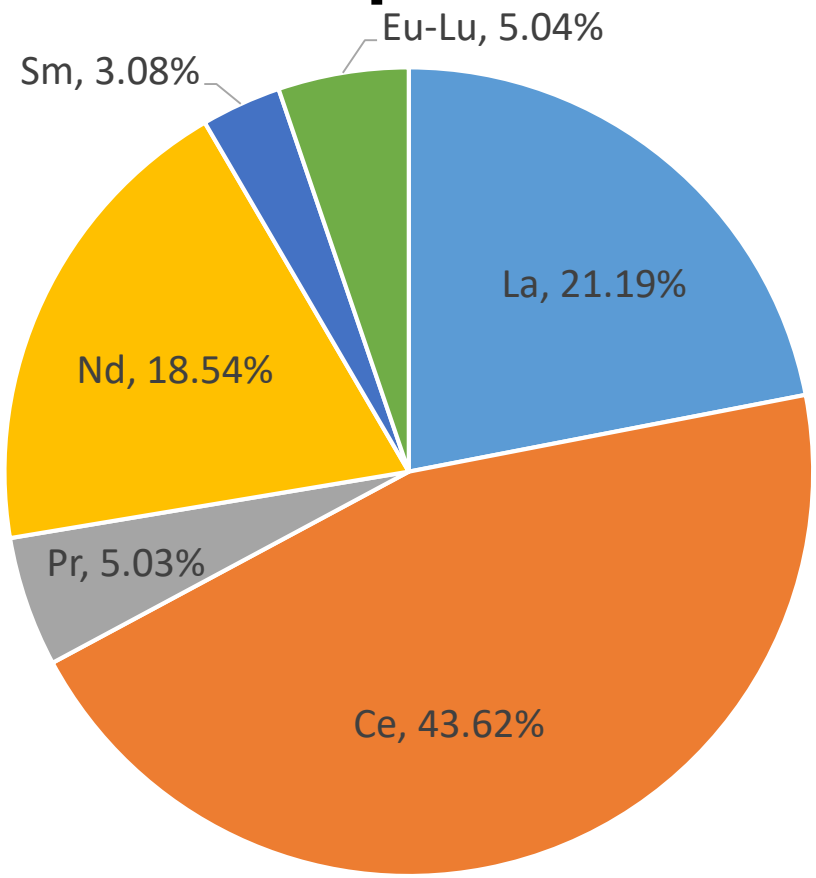
Sanostee BPS deposit

- Cretaceous accumulation of heavy minerals
  - Zircon, ilmenite, rutile, monazite(?)
  - Sorting by wave action in coastal environments
- Discovered with aeroradiometric survey during U boom
  - Th, U substitution in zircon
- Being revisited as part of DoE CORE-CM project
  - On Navajo tribal lands, permit acquired



REE distribution in the Sanostee deposit

- Zircon main REE-bearing mineral
  - Variable REE substitution
- Locally up to ~1% TREO
- Sample n=5 for TREO > 0.34% (90th percentile)
- Average 0.64% TREO
- Contained value: $165/tonne
  - Plus Zr and Ti!



	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Y	Total
REO (ppm)	1355	2787	321	1179	195	4	127	15	64	10	31	49	9	288	**6435**
Oxide price (USD/kg)	$3.41	$3.55	$64.67	$65.38	$2.13	$27.72	$38.37	$1,172.61	$292.80	$89.55	$36.81	$13.50	$803.06	$3.00	
Contained value	$4.62	$9.89	$20.75	$77.11	$0.42	$0.12	$4.87	$17.66	$18.85	$0.90	$1.14	$0.66	$7.24	$0.86	**$165.09**

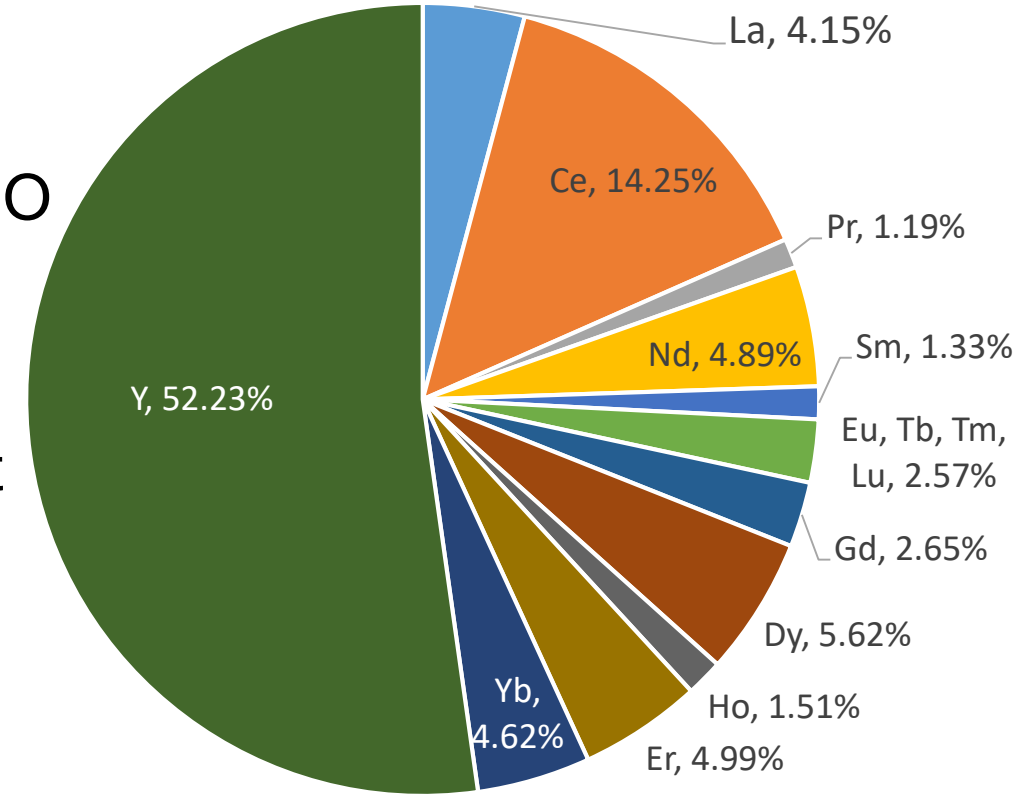
Grants U district

- Jurassic sedimentary hosted uranium deposits
  - Primary uraninite
  - Average grade ~0.2% U_3O_8 average grade
- World-class uranium district
  - More than 169,500 short tons U_3O_8 produced from 1950 to 2002
- Recovery of REE from uraninite?
  - HREE selective extractions

From NMBGMR photo archive

REE distribution in the Grants district

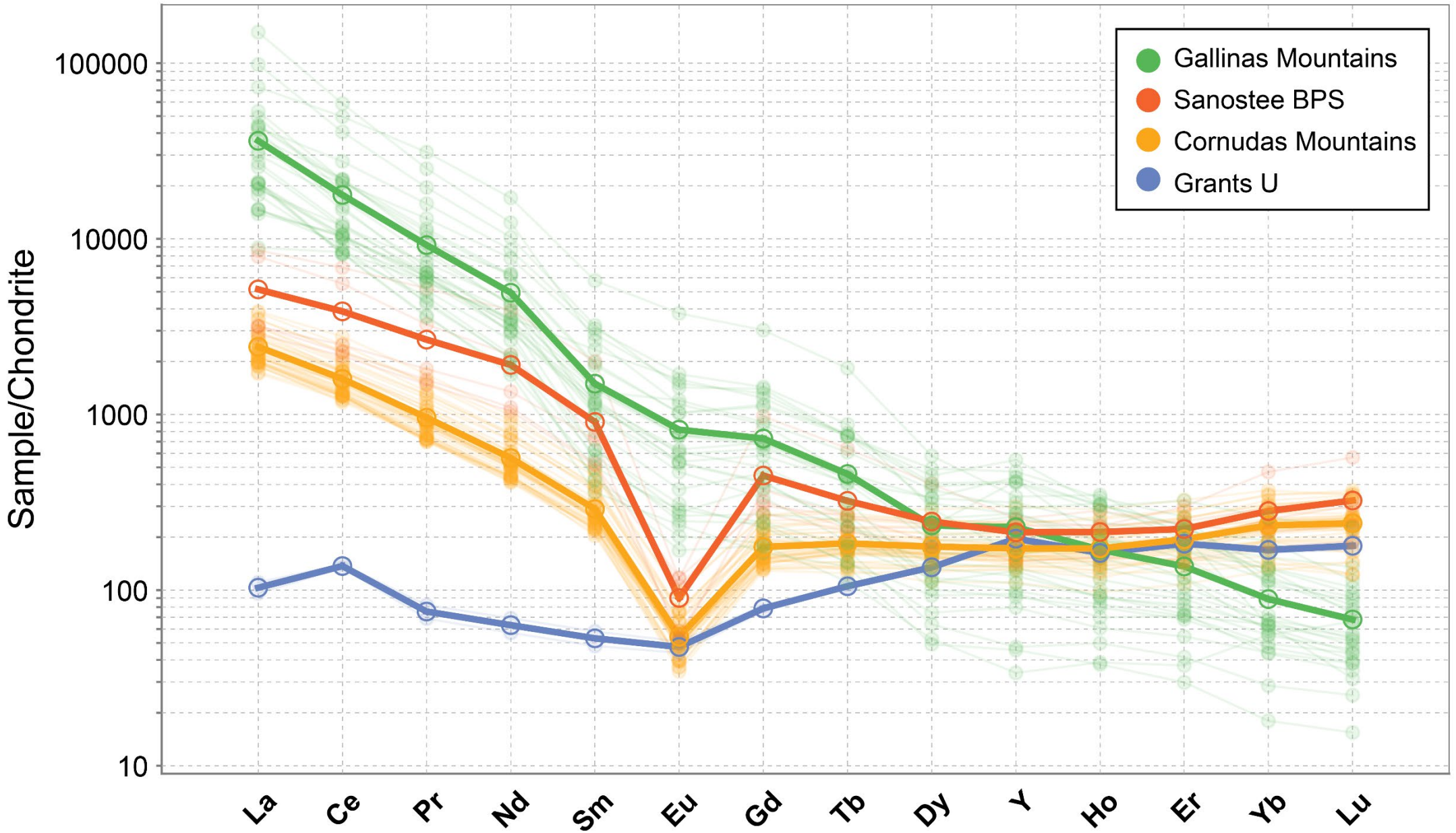
- REE possibly substituting in uraninite
  - Worldwide uraninite can contain ~3% TREO
- Sample n=2 for TREO > 600 ppm (90th percentile)
  - Need more data, sample collection difficult
- Average ~710 ppm TREO
- Contained value: $28/tonne (plus U!)



	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu	Y	Total
REO (ppm)	29	98	8	34	9	3	18	4	38	10	34	31	5	391	**713**
Oxide price (USD/kg)	$3.41	$3.55	$64.67	$65.38	$2.13	$27.72	$38.37	$1,172.61	$292.80	$89.55	$36.81	$13.50	$803.06	$3.00	
Contained value	$0.10	$0.35	$0.53	$2.20	$0.02	$0.09	$0.69	$5.12	$11.14	$0.91	$1.24	$0.42	$4.01	$1.17	**$27.99**

REE	Oxide price (USD/kg)	REO concentration (ppm)				Contained value (USD/tonne)			
		Gallinas	Cornudas	Sanostee	Grants	Gallinas	Cornudas	Sanostee	Grants
La	$3.41	10039	675	1355	29	$34.23	$2.30	$4.62	$0.10
Ce	$3.55	12760	1145	2787	98	$45.30	$4.06	$9.89	$0.35
Pr	$64.67	1000	104	321	8	$64.69	$6.74	$20.75	$0.53
Nd	$65.38	2628	301	1179	34	$171.84	$19.66	$77.11	$2.20
Sm	$2.13	257	50	195	9	$0.55	$0.11	$0.42	$0.02
Eu	$27.72	53	4	4	3	$1.48	$0.10	$0.12	$0.09
Gd	$38.37	167	40	127	18	$6.42	$1.55	$4.87	$0.69
Tb	$1,172.61	19	8	15	4	$22.32	$8.99	$17.66	$5.12
Dy	$292.80	66	50	64	38	$19.27	$14.62	$18.85	$11.14
Ho	$89.55	11	11	10	10	$0.95	$0.97	$0.90	$0.91
Er	$36.81	25	36	31	34	$0.92	$1.31	$1.14	$1.24
Yb	$13.50	16	43	49	31	$0.22	$0.58	$0.66	$0.42
Lu	$803.06	2	7	9	5	$1.53	$5.40	$7.24	$4.01
Y	$3.00	455	344	288	391	$1.36	$1.03	$0.86	$1.17
	Total:	**27499**	**2816**	**6435**	**713**	**$371.07**	**$67.41**	**$165.09**	**$27.99**

USD/TREO (%)			
Gallinas	Cornudas	Sanostee	Grants
$135	$239	$257	$393


Gallinas Mountains
Sanostee BPS
Cornudas Mountains
Grants U
Sample/Chondrite
100000
10000
1000
100
10
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Y
Ho
Er
Yb
Lu

Conclusions

- REE distribution important for economics of a deposit
  - Overall grade is still important, but not the only factor
  - REE could be a coproduct or byproduct
  - Mineralogy and metallurgy important
- Importance of good trace element geochem as we explore non-traditional critical mineral deposits
  - Overlooked byproducts?

Acknowledgements

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Questions?