REE extraction and traceability studies based on European advanced REE resources

PROMETIA Scientific Seminar

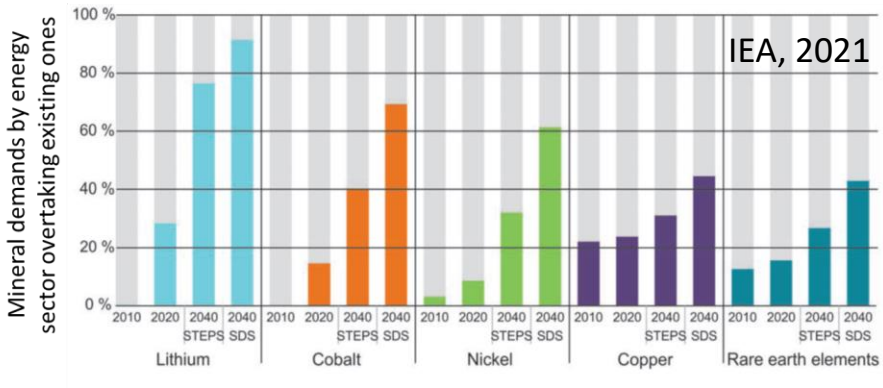
Xuan Liu, Jason Yang (GTK)

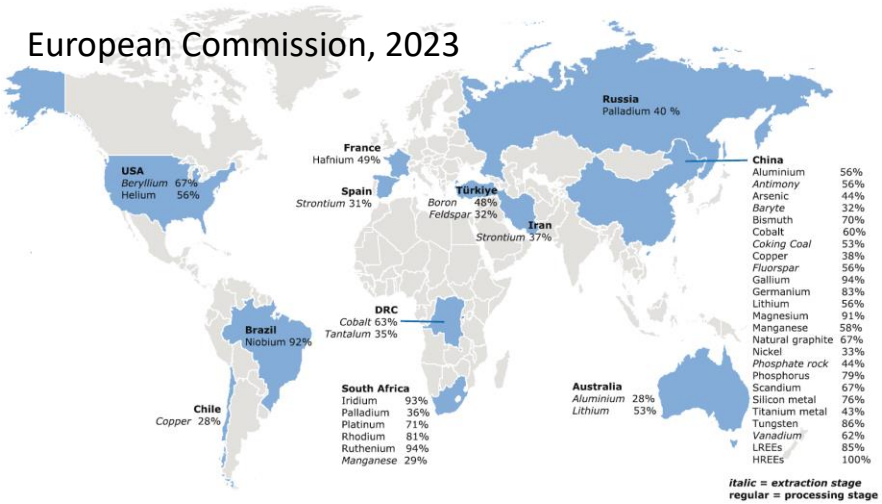
28-30.11.2023

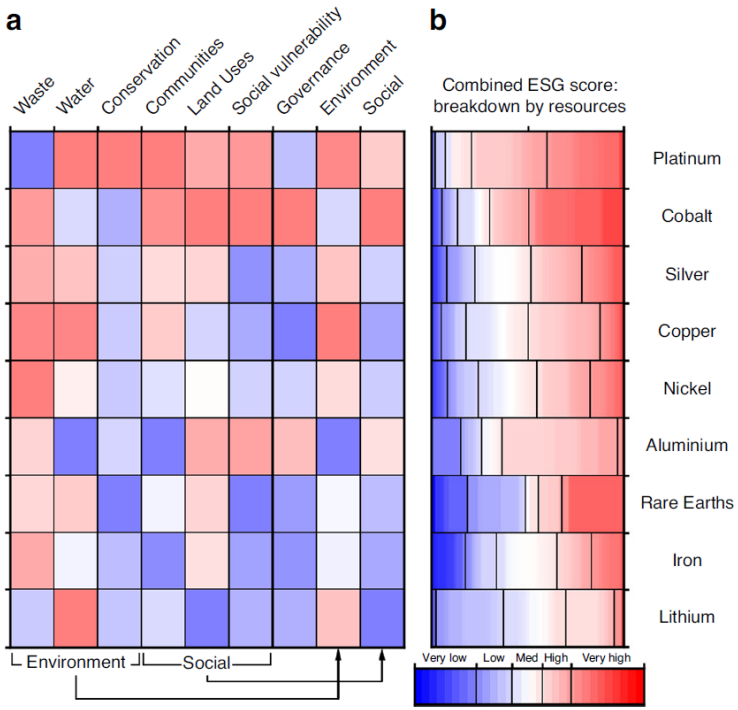
Background

"…the clean energy transition will be significantly mineral intensive…" *World Bank, 2018*

Over half of critical metals face medium to very high ESG risk. *Lèbre et al., 2020, Nat. Comm.*







Also check: Simon Michaux (2021, GTK open report): https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf
Mark P. Mills (2022, Manhattan Institute report): The "Energy Transition" Delusion: A Reality Reset

Background

Four pathways to a low-carbon future:

- **Allow artisanal and small-scale mining (ASM)**
- **Incorporate minerals into climate and energy planning**
- **Explore new resources streams**
- **Develop mineral-metal traceability**

Sovacool et al., 2020, Science

In this talk:

1. **REE extraction (Jason Yang)**
2. **REE traceability (Xuan Liu)**

REE extraction

Jason Yang

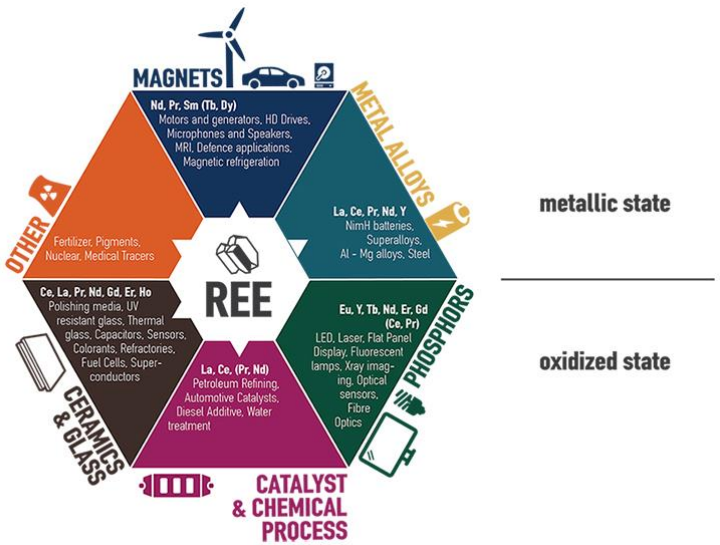
Rare earth elements (REE) and applications

REE, the group of 17 metalic elements including scandium (Sc 21), yttrium (Y 37), and the lanthanides (lanthanum (La) 57 - lutetium (Lu) 71).

light REE (LREE): First eight REE, Sc and La to gadolinium (Gd)
heavy REE (HREE): Remaining eight REE terbium (Tb) to lutetium (Lu), together with Y

Depending elements REE have various of industrial applications. REO mainly used in catalysts, glassmaking, metallurgy and alloys, ceramics, and permanent magnets.

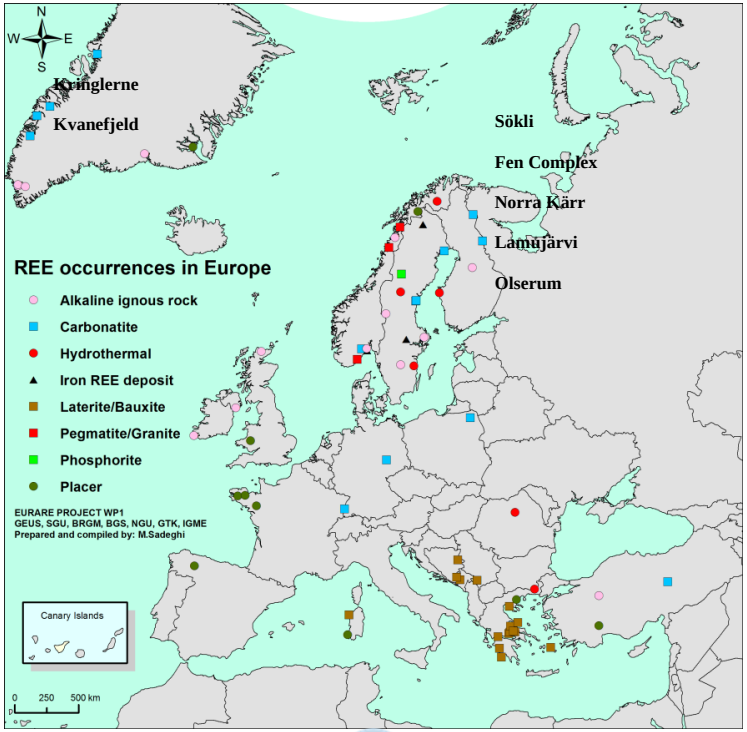
Both LREE and HREE listed by EC the CRMs, because of highly economic importance and high supply risks with import reliance (imports minus exports) 100%.



https://www.eurare.org/RareEarthElements.html

REE advanced resources in Europe

Sample	Total REE (TREE) and ratio of heavy REE to light REE (HR/LR)	Mineralogical analysis
Kvanefjeld (Greenland)	TREE 0.81%, HR/LR 17%/83%	25 minerals are identified. The major rock minerals are arfvedsonite (31.68 Wt %), naujakasite (11.46 Wt %), albite (11.27 Wt %) and orthoclase (9.51 Wt %). The main REE mineral is steenstrupine (5.58 Wt %). The other minor REE minerals are monazite and vitusite.
Norra Karr (Sweden)	TREE 0.44% HR/LR 48%/52%	23 minerals are identified. The major rock minerals are aegirine, K-feldspar, albite, analcime and nepheline. The main REE mineral is eudialyte (7.2%).
Kringlerne (Greenland)	TREE 0.57%	30 minerals are identified. Th major rock minerals are eudialyte (33.36 Wt %), nepheline (14.16 Wt %), arfvedsonite (13.54 Wt %), albite (12.57 Wt %) and sodalite (11.71 Wt %). Eudialyte is the main REE-carrier mineral.
Fen RØDBERG Complex (Norway)	TREE 1.5%, HR/LR 4%/96%	31 minerals are identified. The major rock minerals are magnetite, hematite and goethite which are grouped as Fe-oxides (78.22 Wt %) and calcite (10.77 Wt %). The main REE minerals are synchysite (0.98 Wt %) and parisite (0.77 Wt %). The other minor REE minerals are monazite, allanite, bastnasite, ferrocolumbite and pyrochlore.
Olserum (Sweden)	TREE 0.5%, HR/LR 36%/64%	28 minerals are identified. The major rock minerals are quartz (47.89 Wt %), biotite (19.66 Wt %) and albite (11.90 Wt %). The main REE minerals are monazite (0.61 Wt %) and xenotime (0.31 Wt %). The other minor REE minerals are allanite and pyrochlore
Nea Peramos (Greece)	TREE 0.6 % HR/LR 4% /96%	The minerals consist of mainly of granite and granodiorite The mainly identified minerals by optical microscopy and SEM-EDS are : quartz, mica, epidote, alanite,magnetite, titanite, ilmenite, monazite, xenotime,zircon, apatite



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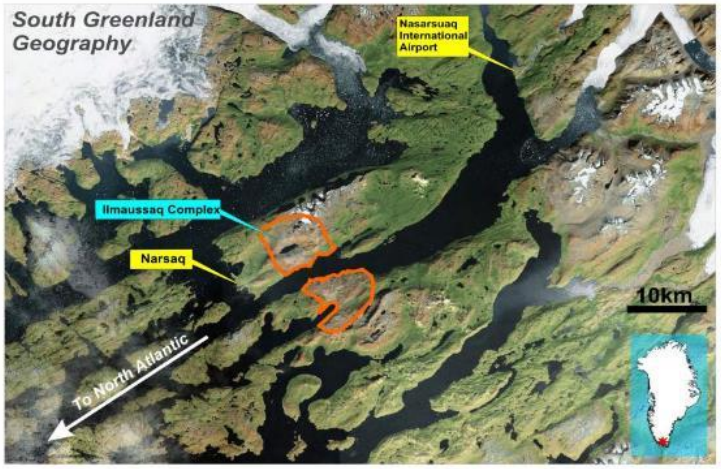
REE advanced resources in Europe

Kvanefjeld REE deposit and Steenstrupine*

One of the world's largest known REE deposit located in Greenland, GME has invested over $60M over past 5 years in exploration and research, 619Mt ore @ 1.06% TREO (17% in Heavy REE), 0.03% U_3O_8 and 0.3% Zn,

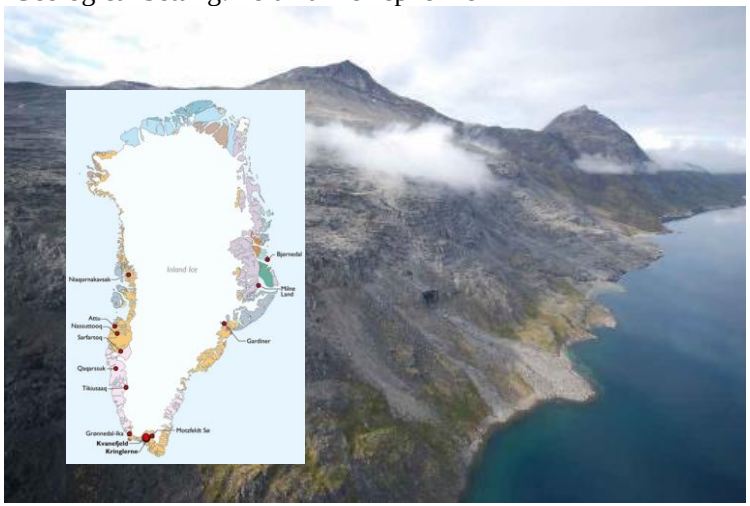


Geological Setting: Peralkaline nepheline
principal REE mineral:
Steenstrupine
$(Na_{14}Ce_6Mn_2Fe_2(Zr,Th,U)(PO_4)_7Si_{12}O_{36}(OH)_2.3H_2O)$

REE advanced resources in Europe

Kringlerne Eudialyte Deposit

In Greenland owned by Tanbreez Mining Greenland, a large deposit @ 0.68% TREO, estimated TREO reserves close to Kvanefjeld. Similar to Norra Karr ore in mineralogy and HREE content (HREE/LREE % ratio: 31/69), no radiation issues.
Major REE mineral:
Eudialyte (33 wt%) in coarse grain size (500 µm). TREE 0.57%
Geological Setting: Peralkaline nepheline



Eudialyte:
$Na_4(Ca,Ce)_2(Fe,Mn,Y)ZrSi_8O_{22}(OH,Cl)_2$

Norra Kärr Eudialyte Deposit

In Sweden, 331Kt of TREO at 0.44% (48% in heavy REE) No radioactivity
Major REE mineral: Eudialyte typically has a significant content of U, Pb, Nb,Ta (Tantalum), Zr, Hf (Hafnium), and REE.
Tasman Metals Limited owned the deposit, granted test mine permit 2013, plans to be in production by 2016
TREE 0.44%
HR/LR 48%/52%

Beneficiation studies on Advanced European REE resources

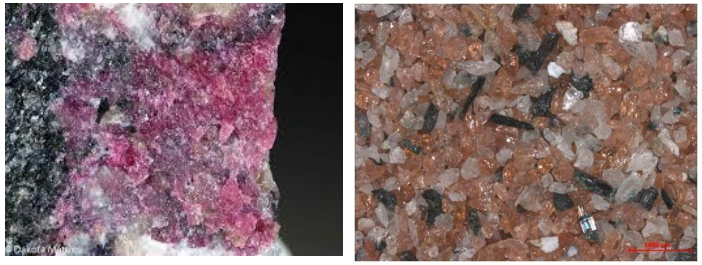
Lab scale bench testwork

Kvanefjeld ore, Olserum ore - Flotation

Norra Närr ore, Kringlerne ore - WHIMS & DHIMS

Rordberg ore (Complex REE minerals) - Acid leaching

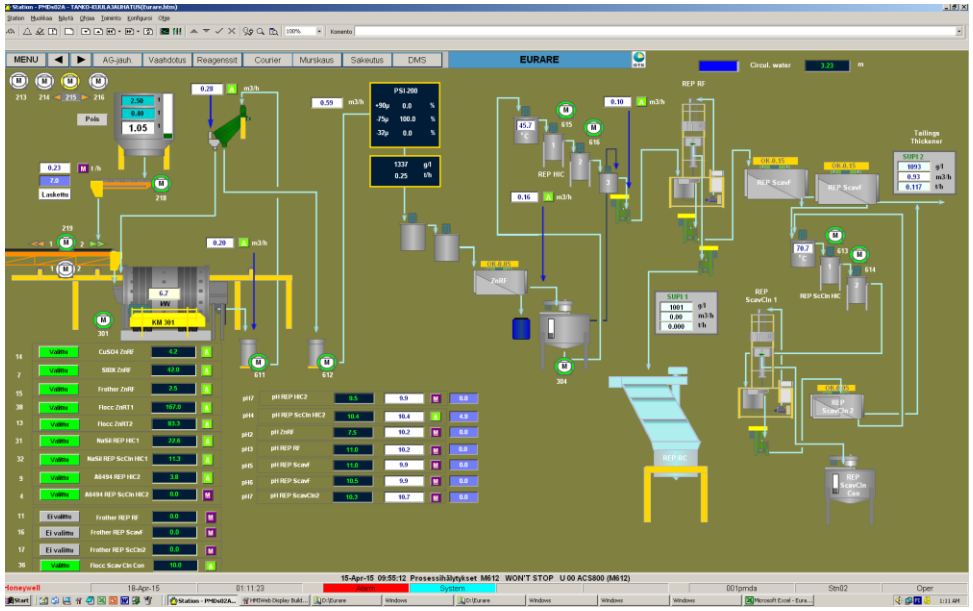
Steenstrupine $Na_{14}Ce_6Mn_2Fe_2(Zr,Th,U)(PO_4)_7Si_{12}O_{36}(OH)_2.3H_2O$

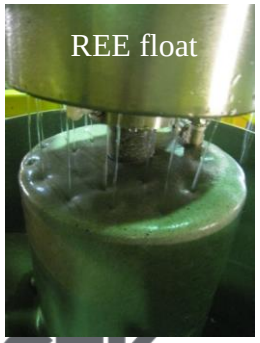


Eudialyte: $Na_4(Ca,Ce)_2(Fe,Mn,Y)ZrSi_8O_{22}(OH,Cl)_2$

Beneficiation studies on Advanced European REE resources

Pilot plant demonstration of Steenstrupine beneficiation* (2015)

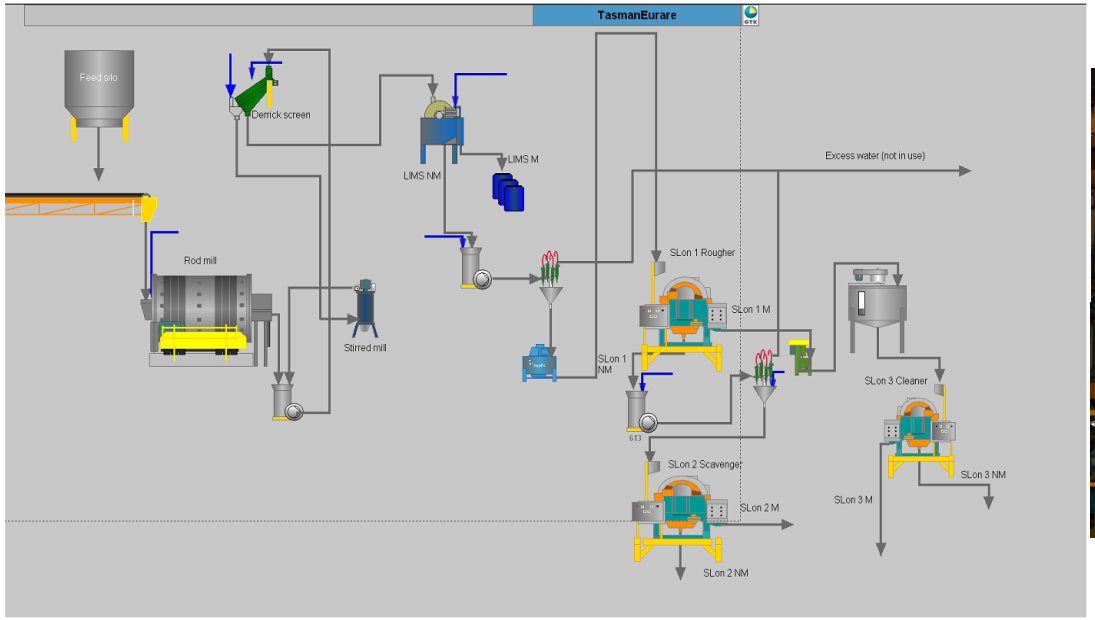




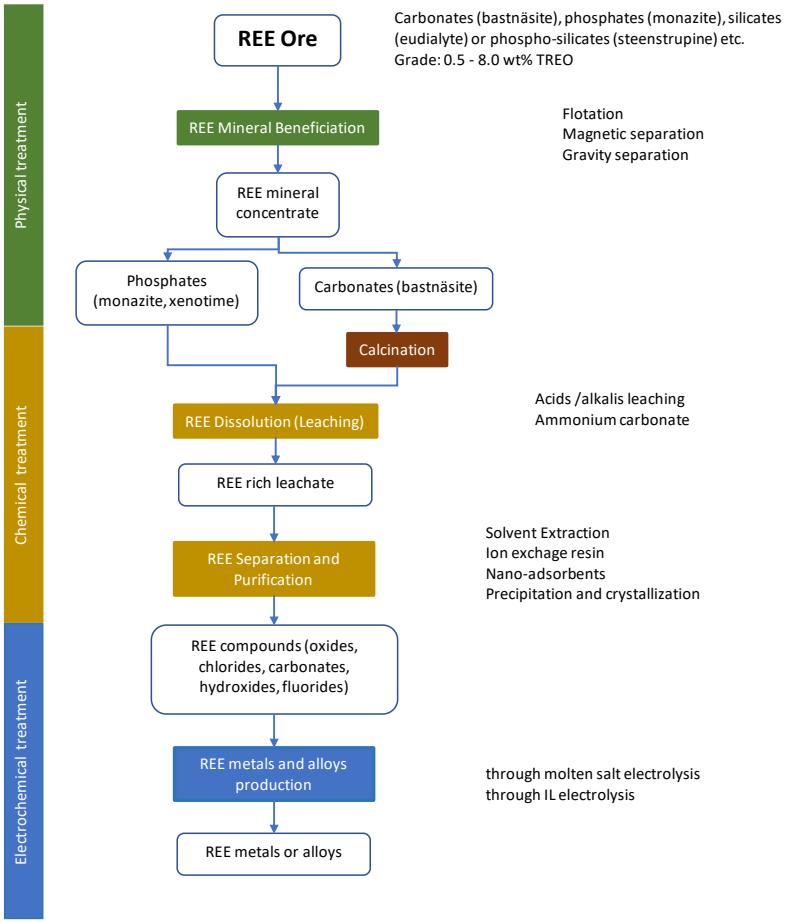
GTK

Beneficiation studies on Advanced European REE resources

Magnetic separation pilot plant testwork on Norra Kärr ore (2016)



REE value chain



REE value chain in Europe was established through the project EURARE based on several European advanced REE resources in 2012-2016
https://www.eurare.org/home.html

REE traceability studies

Xuan Liu

State of the art

Traceability: the ability to trace information along supply chain of mineral and metal (exploration → mining → trading → smelting/refining → manufacturing → fabrication)

Material (ESG relevant)

Mine of origin

Refining methods; Mineral Type; Quantity; Quality

Movement

Transaction (Time, Place, Name); Ownership; Conformity claims; Certificates

Document -based

- Due Diligence
- Sustainability schemes
- Responsible sourcing
- Certification
- Chain of Custody
- Auditing
- Blockchain

Geo -based

- Tracing/Provenancing
  - Certification of metal source
  - Forensic of metal

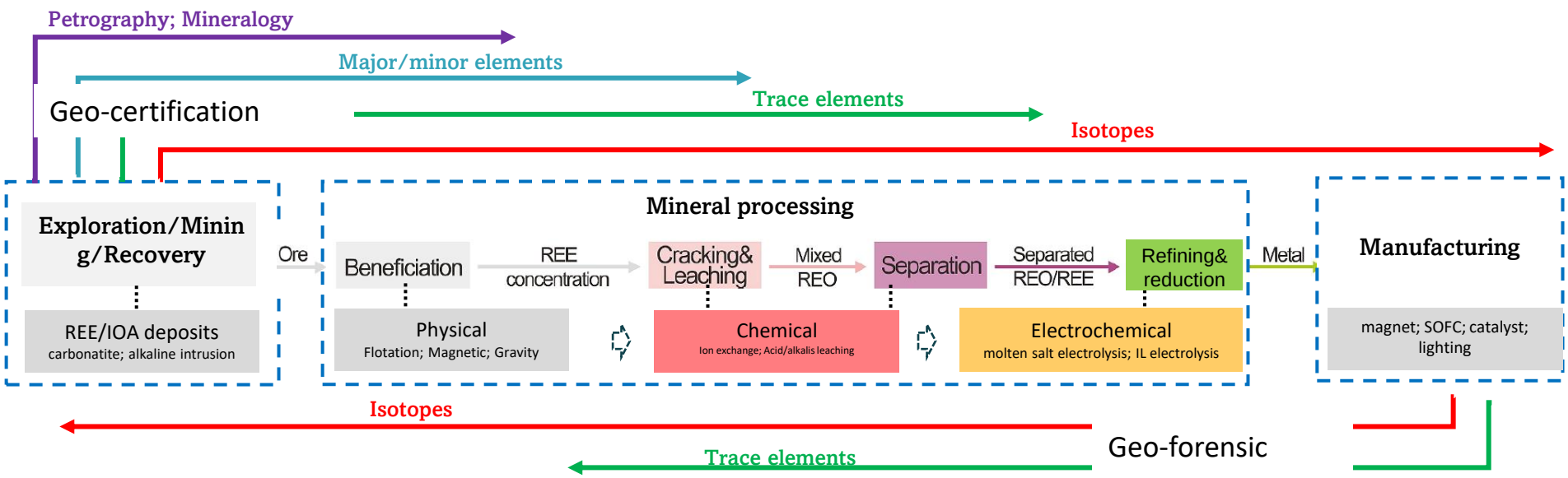
State of the art

Nordic Sustainable Minerals (NSM)

- Funding org.: Nordic Innovation
- Total budget: 1.5M euros
- Project duration: 2022.7-2024.6 (2 yrs)
- 8 partners

Nordic Innovation

NSM methodology



Nd magnet pilot

Sampling

Demagnetization

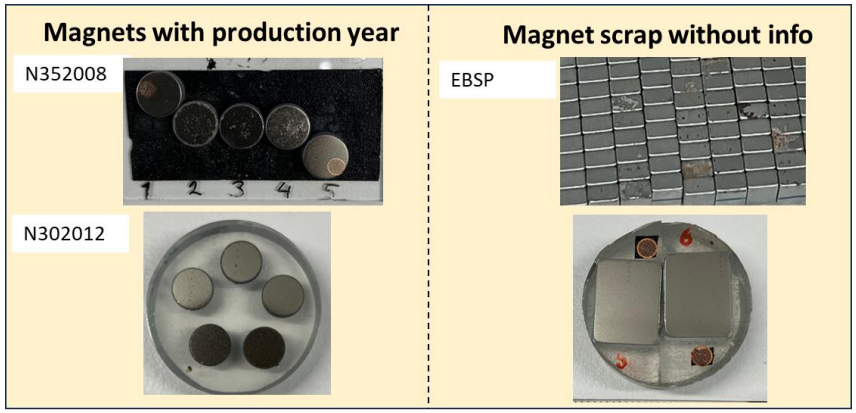
Sample prep.

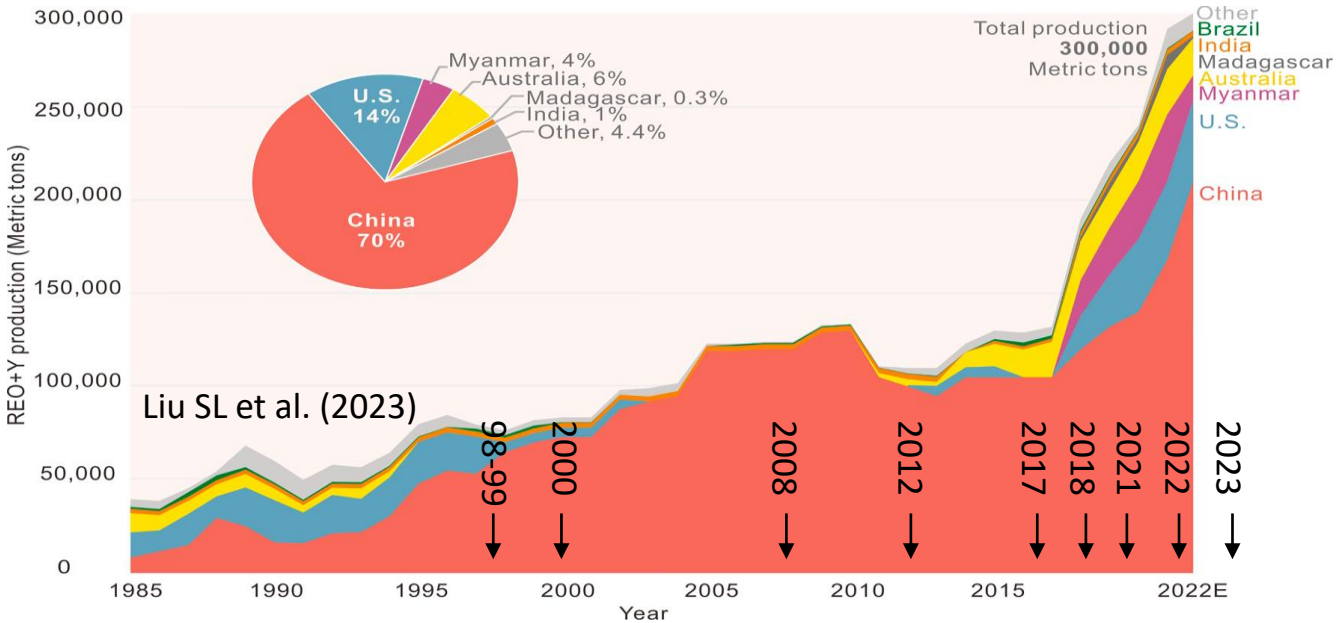
Phase characterization

Trace element analyses

Nd isotope analyses

- Are they different in chemistry?
- How likely is it to trace them?





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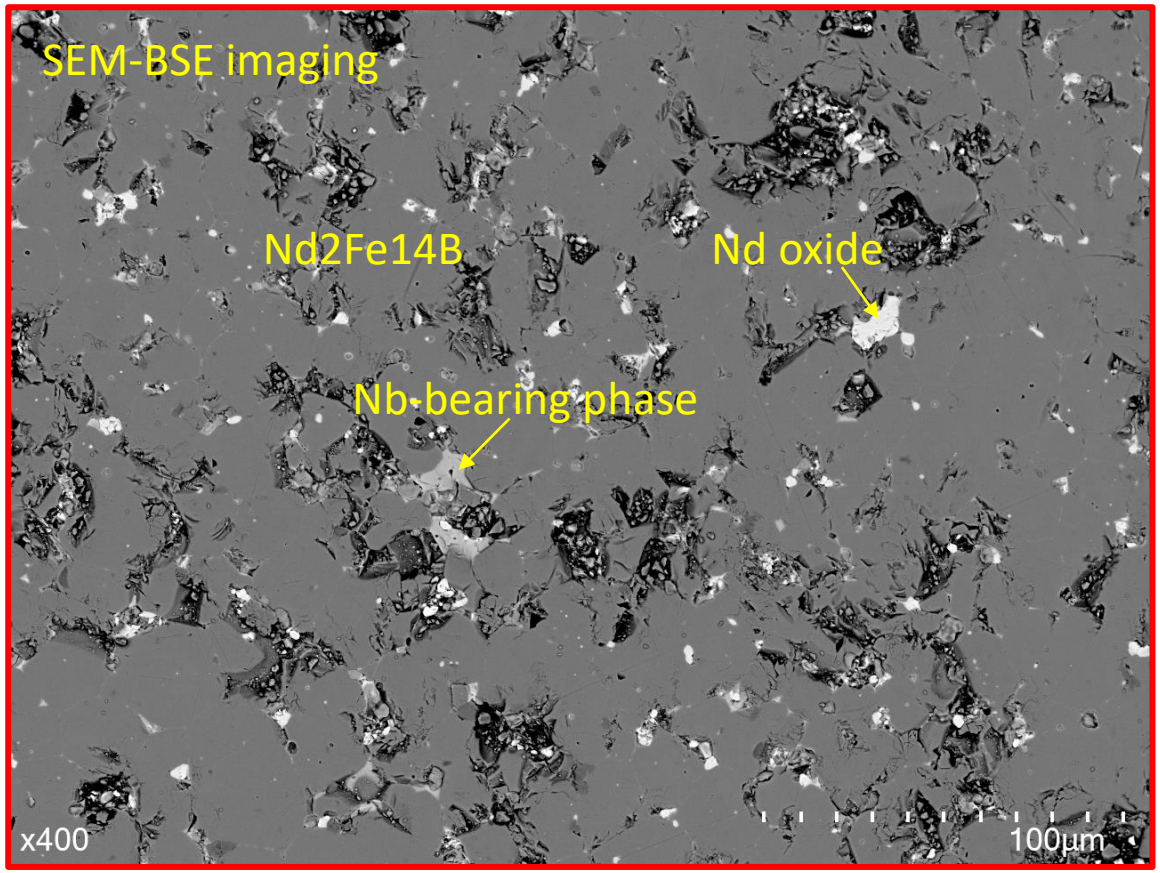

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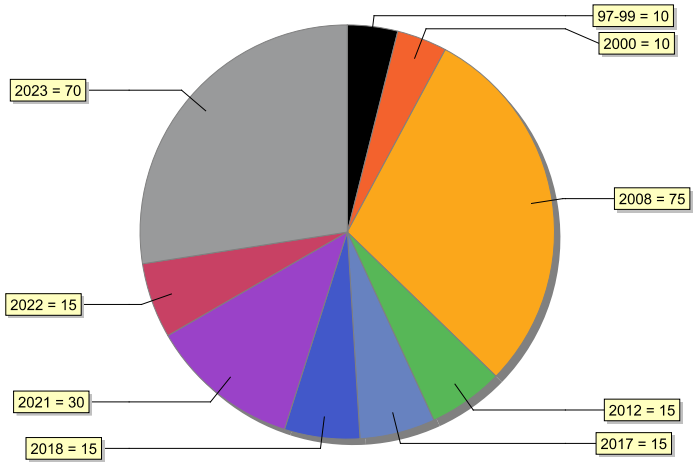
Nd isotope analyses

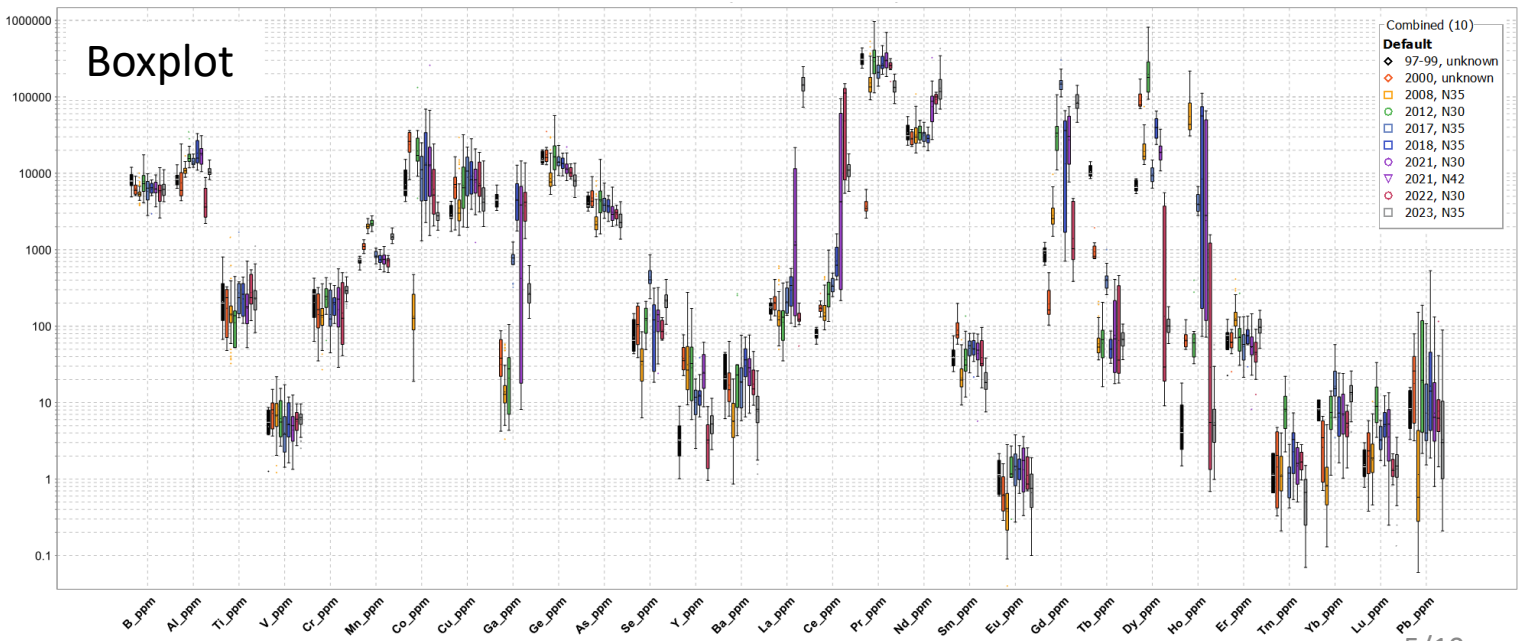
Trace elements by LA-ICP-MS

9 samples

255 analytical points

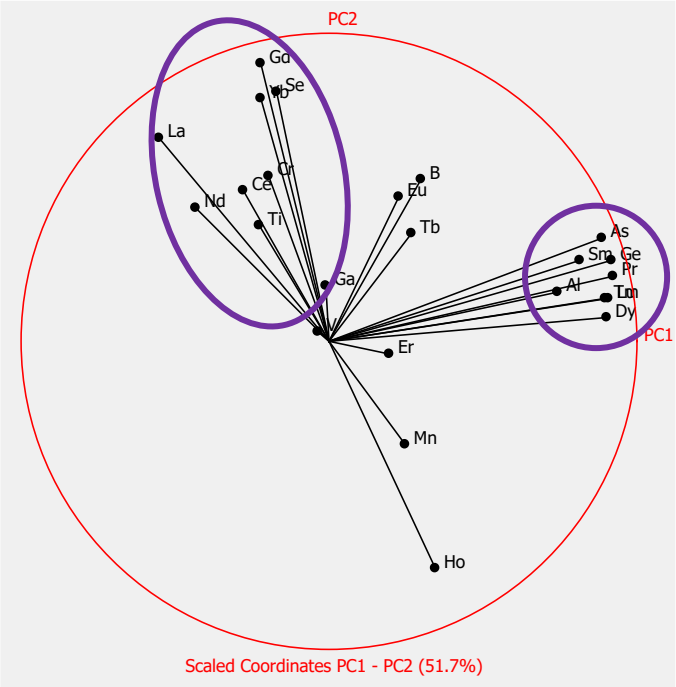
30 elements



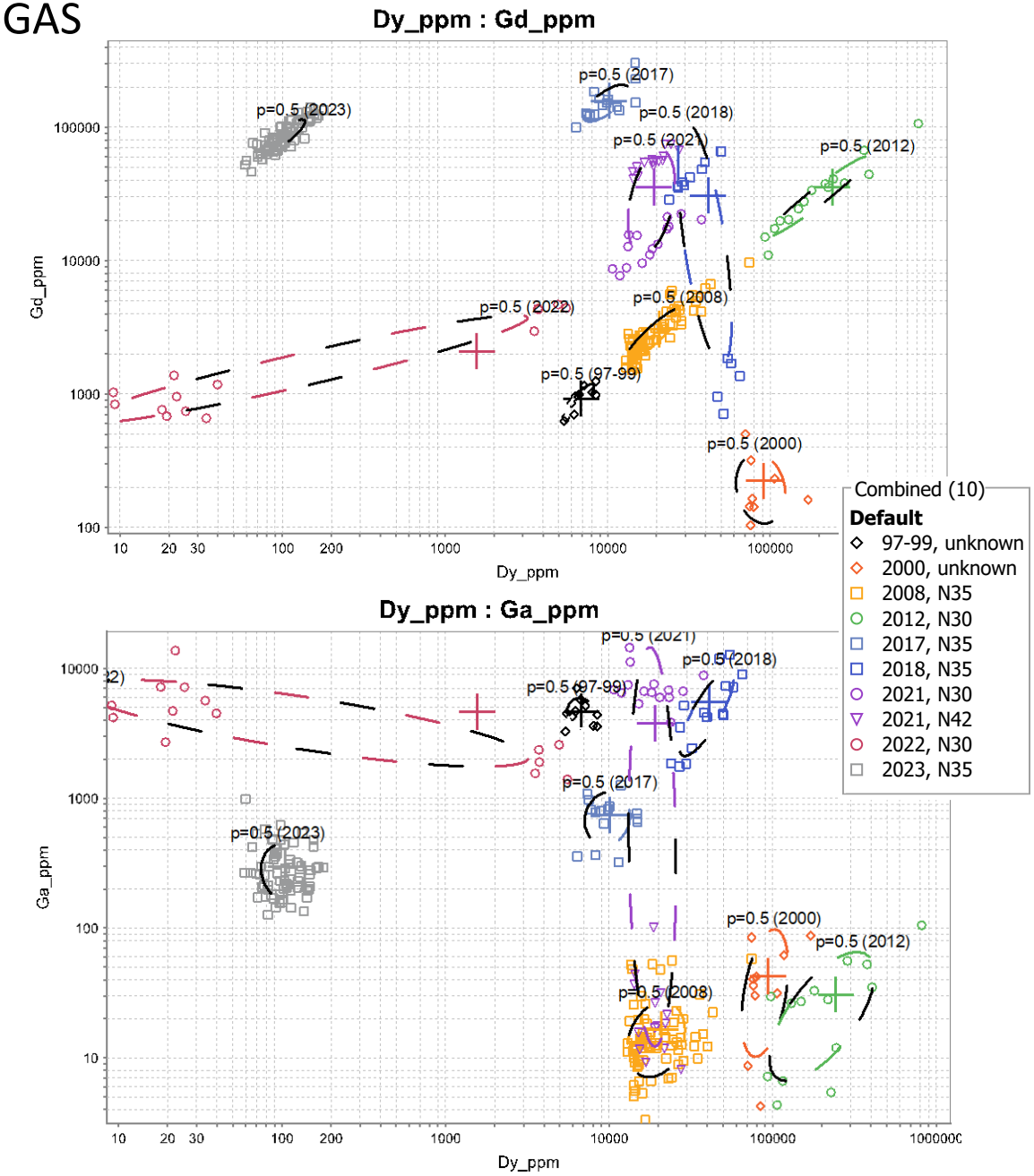


Trace element data analysis by IoGAS

Magnets with production year



Principal Component Analysis (PCA)
Variables correlation and variability analysis



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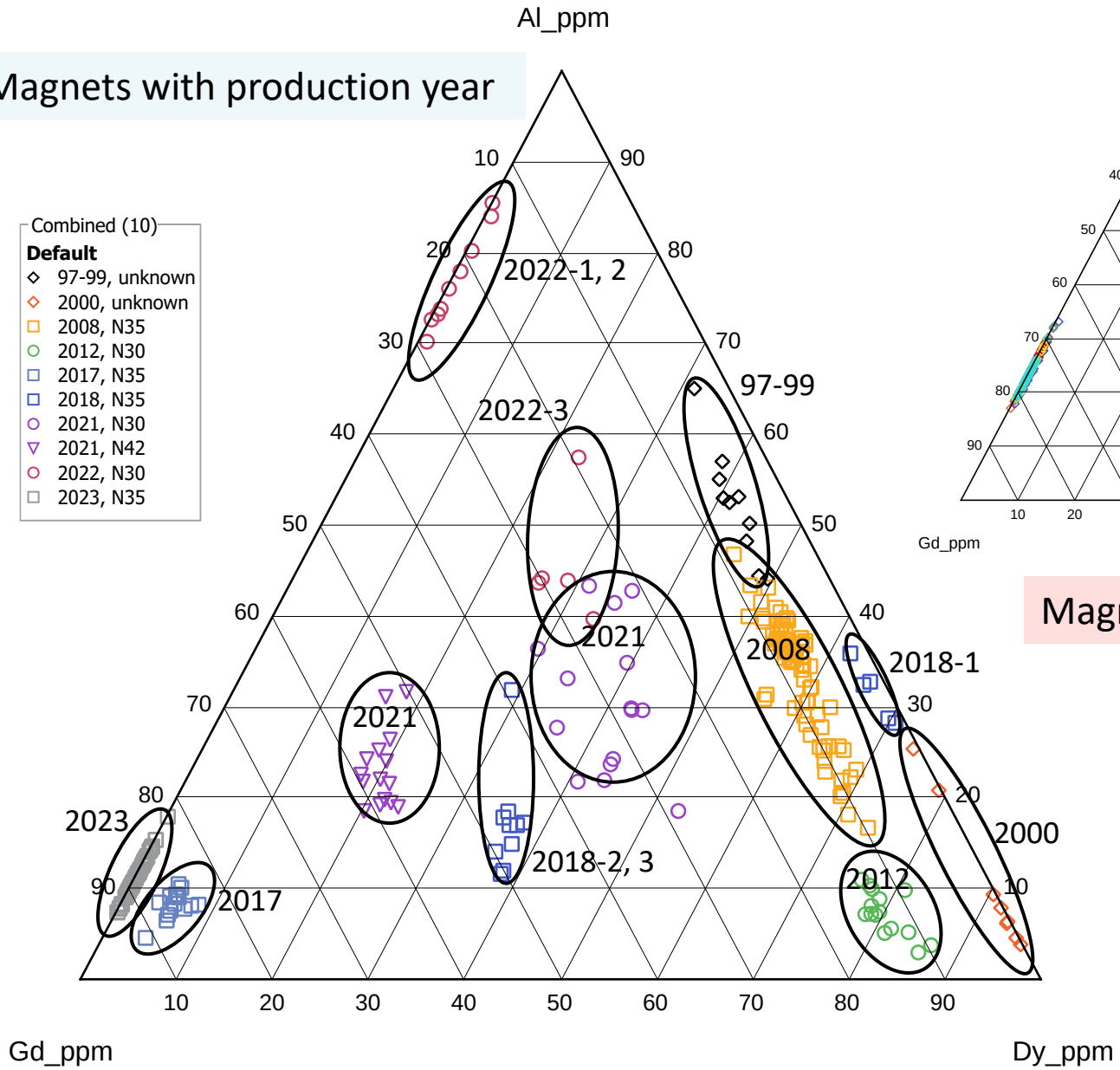

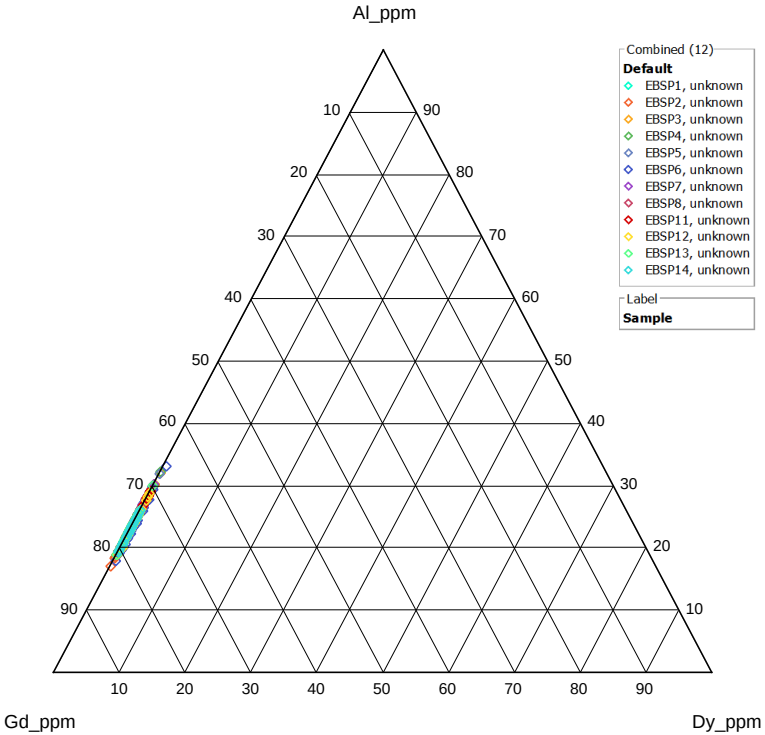

Magnets without information

Sampling

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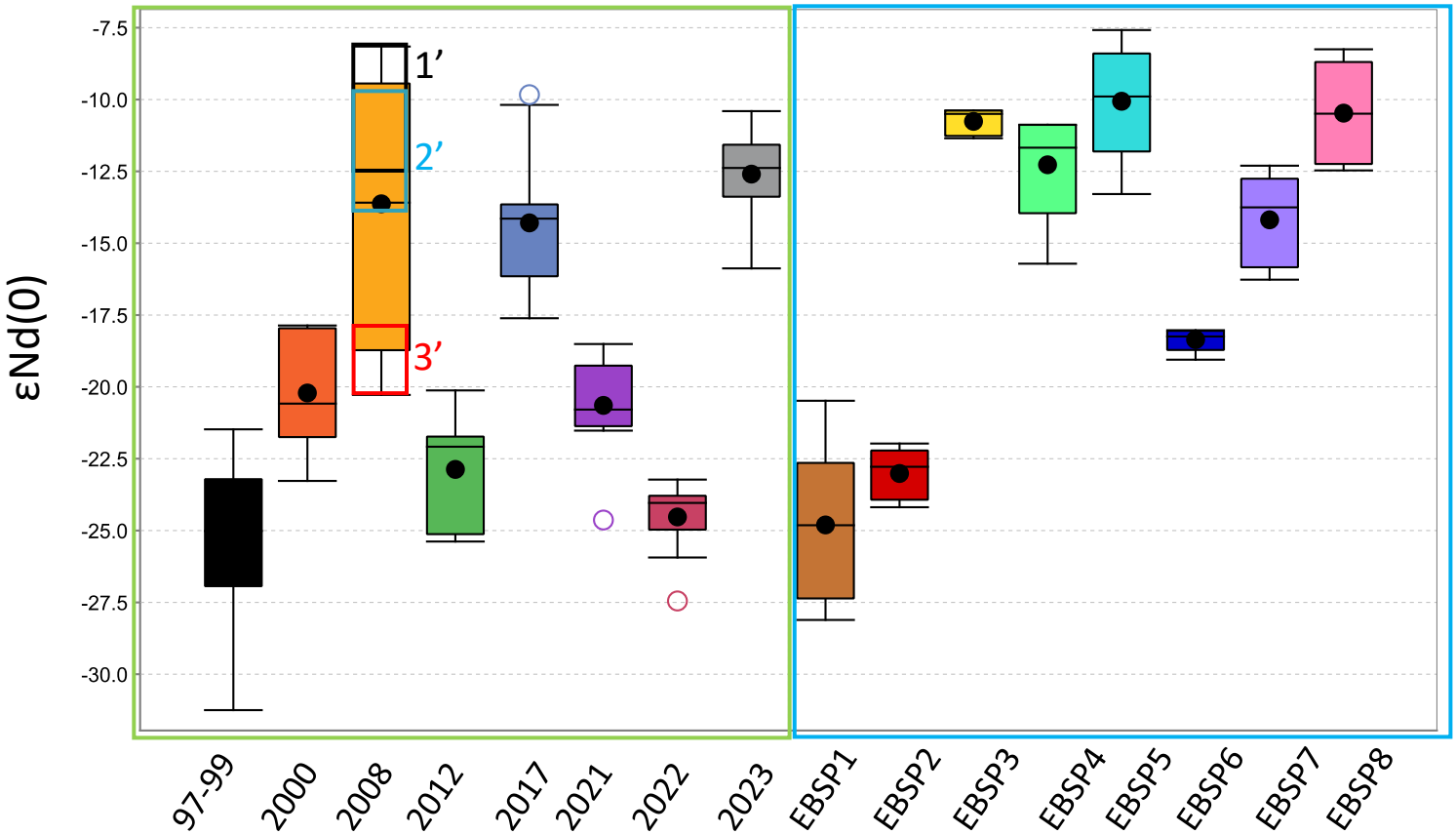
Nd isotope analyses

Nd isotopes by LA-MC-ICP-MS

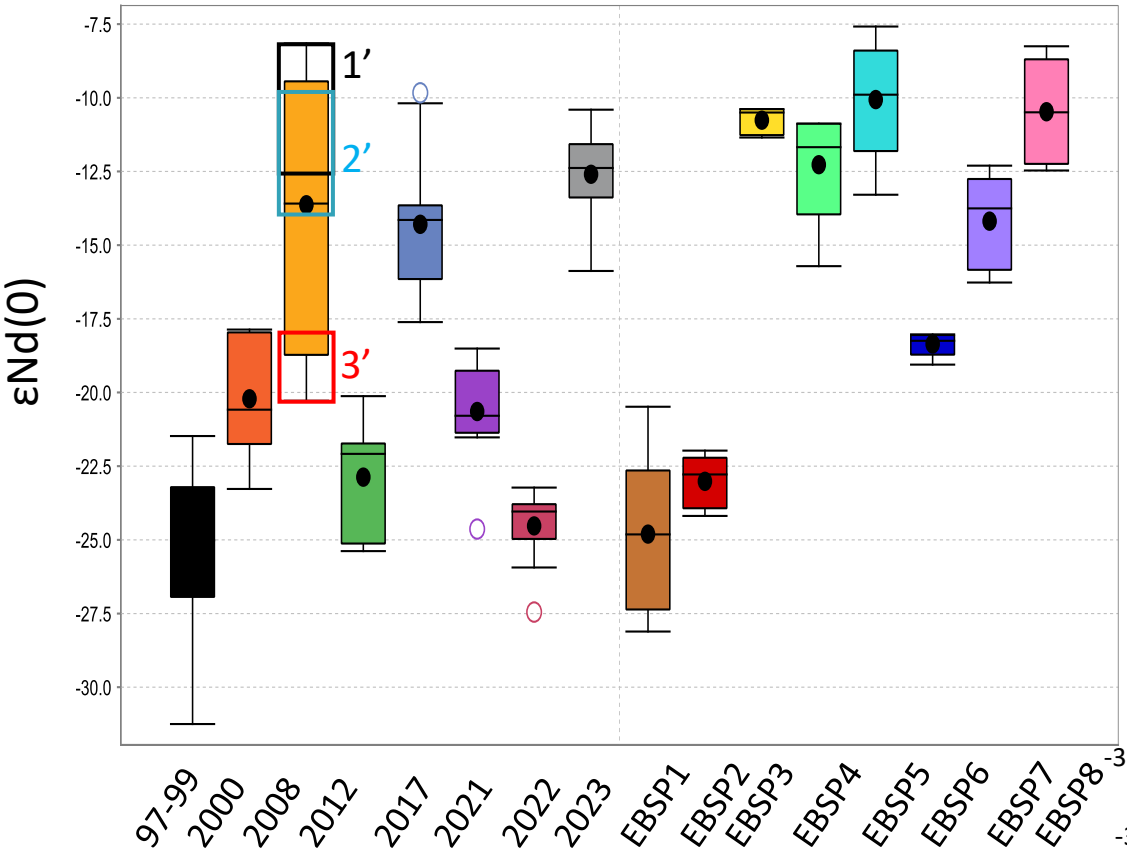
(10-15 points per p. year on 1-3 blocks)



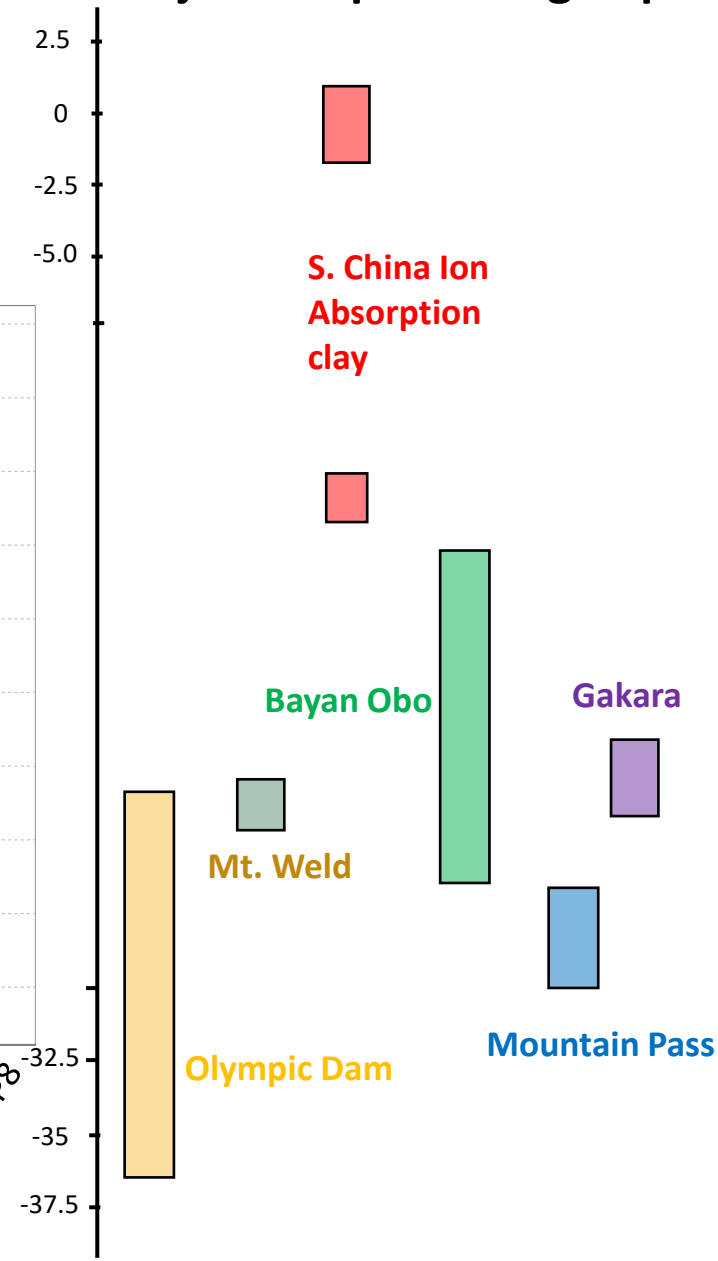
Magnets with production year

Magnets without info

Nd magnets



Major REE-producing deposits



Nd magnet pilot

- ❑ **Are they different in chemistry?**

  YES, they are different!

- ❑ **How likely is it to trace them?**

  VERY likely to be traceable!

A better estimate of probability requires:

- Combine more signatures (TE + Isotopes)
- Establish a better database
- Understand more about element-isotope conservativity along value chain
- Acquire more precise and accurate TE-isotope measurements
- Have probability statistics models

FOR EARTH AND FOR US

The Geological Survey of Finland (GTK) produces impartial and objective research data and services in support of decision-making in industry, academia, and wider society to accelerate the transition to a sustainable, carbon-neutral world. GTK employs more than 400 experts specializing in the mineral economy, circular economy, solutions related to energy, water and the environment, as well as digital solutions. GTK is a research institution governed by the Finnish Ministry of Employment and the Economy, operating in Finland and globally.
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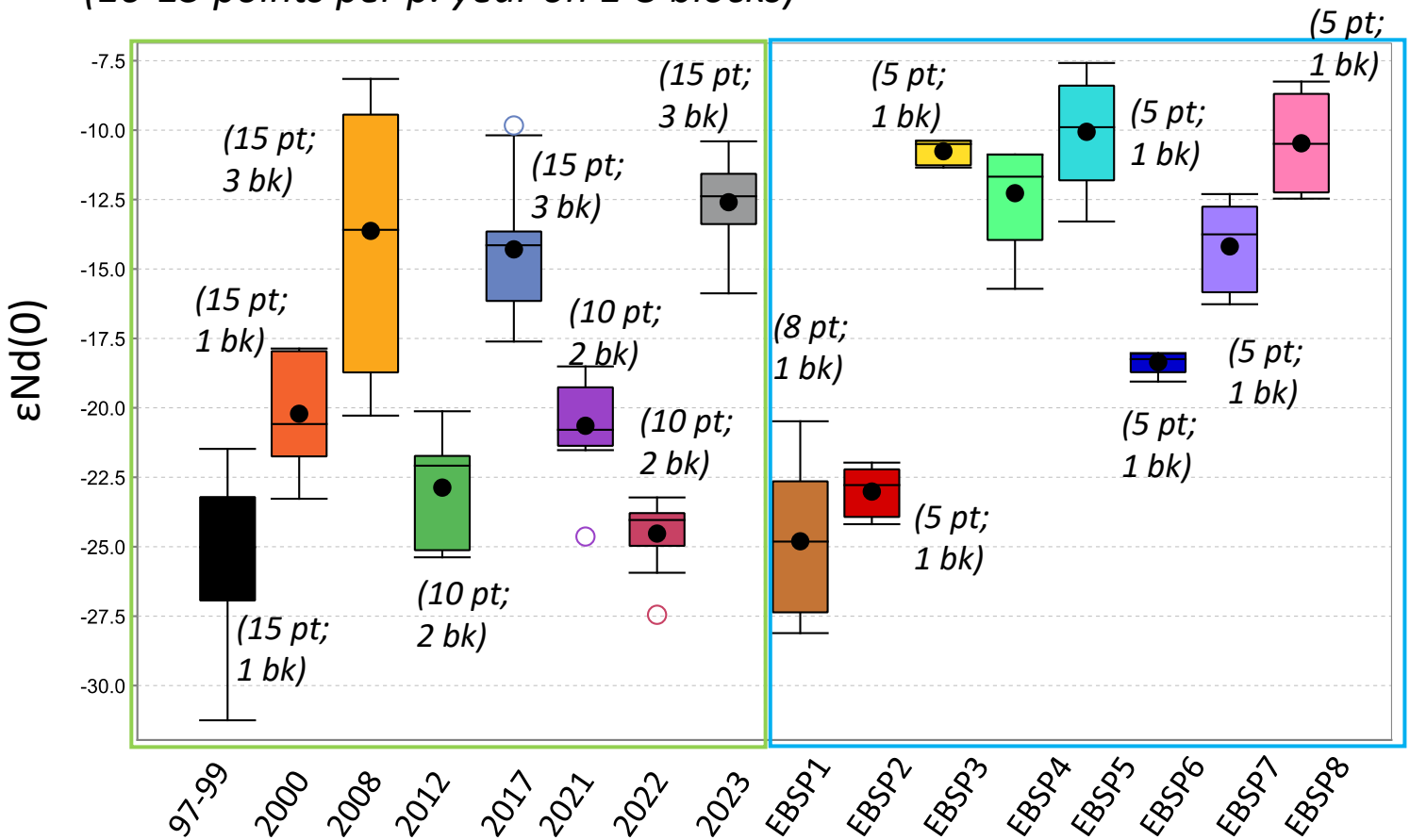

Magnets with production year

Magnets without info