PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

ASTER Analyse Systémique des Terres Rares Flux et Stocks

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Where to find rare earth primary resources in continental Europe & Greenland ?

J. Tuduri*[1], N. Charles[1], O. Pourret[2], D. Guyonnet[1], A. Rollat[3], J. Melleton[1], K. Goodenough[4]

1: BRGM; 2: Institut Polytechnique LaSalle Beauvais; 3: SOLVAY; 4 BGS-EURARE

**** j.tuduri@brgm.fr***

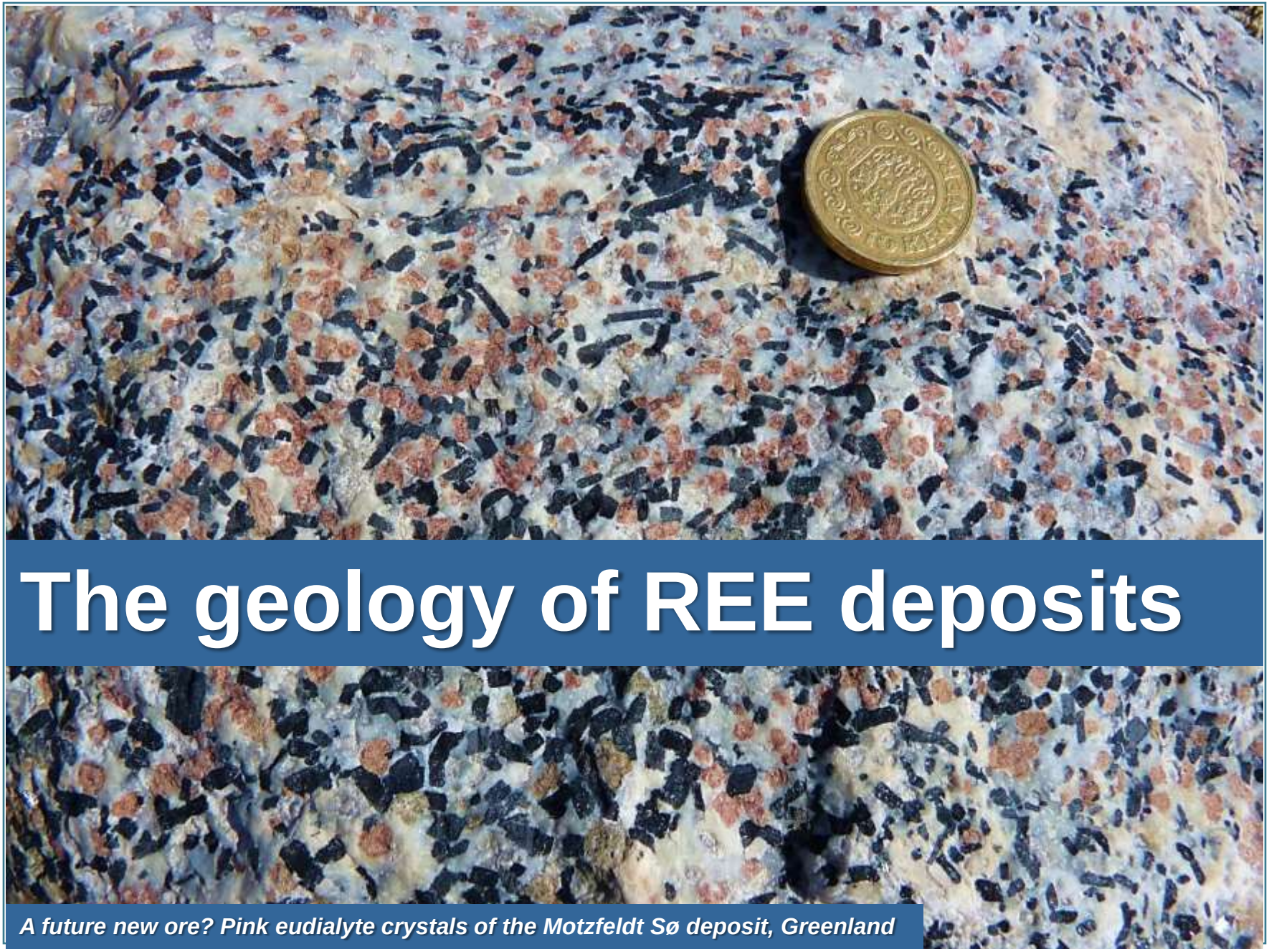
Why?

- ✓ **Obtain first estimates of primary REE resources potentials in continental Europe and Greenland**
- ✓ **Establish an European typology of REE deposits and occurrences**
- ✓ **Bring out guides for future exploration**
- ✓ **Provide input to the EURARE database structure**
- ✓ **Improve MFA model of specific REE for EU-28 taking into account lithospheric stocks**

Overview of the presentation

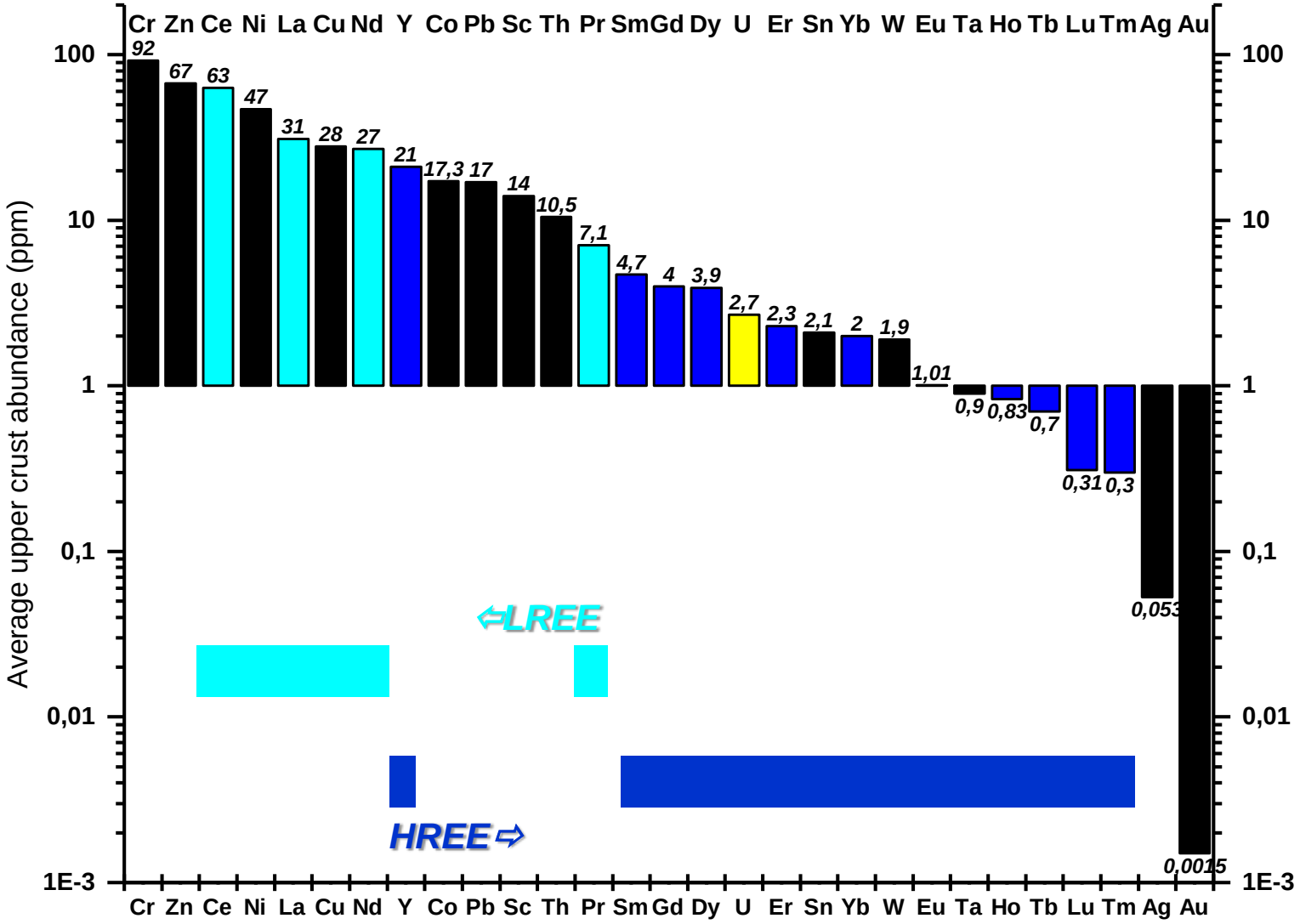
- ✓ **The geology of REE deposits**
- ✓ **REE occurrences in Europe and Greenland**
- ✓ **Where are economic potentials?**
- ✓ **Conclusions**

The geology of REE deposits



A future new ore? Pink eudialyte crystals of the Motzfeldt Sø deposit, Greenland

Are the REE so rare?



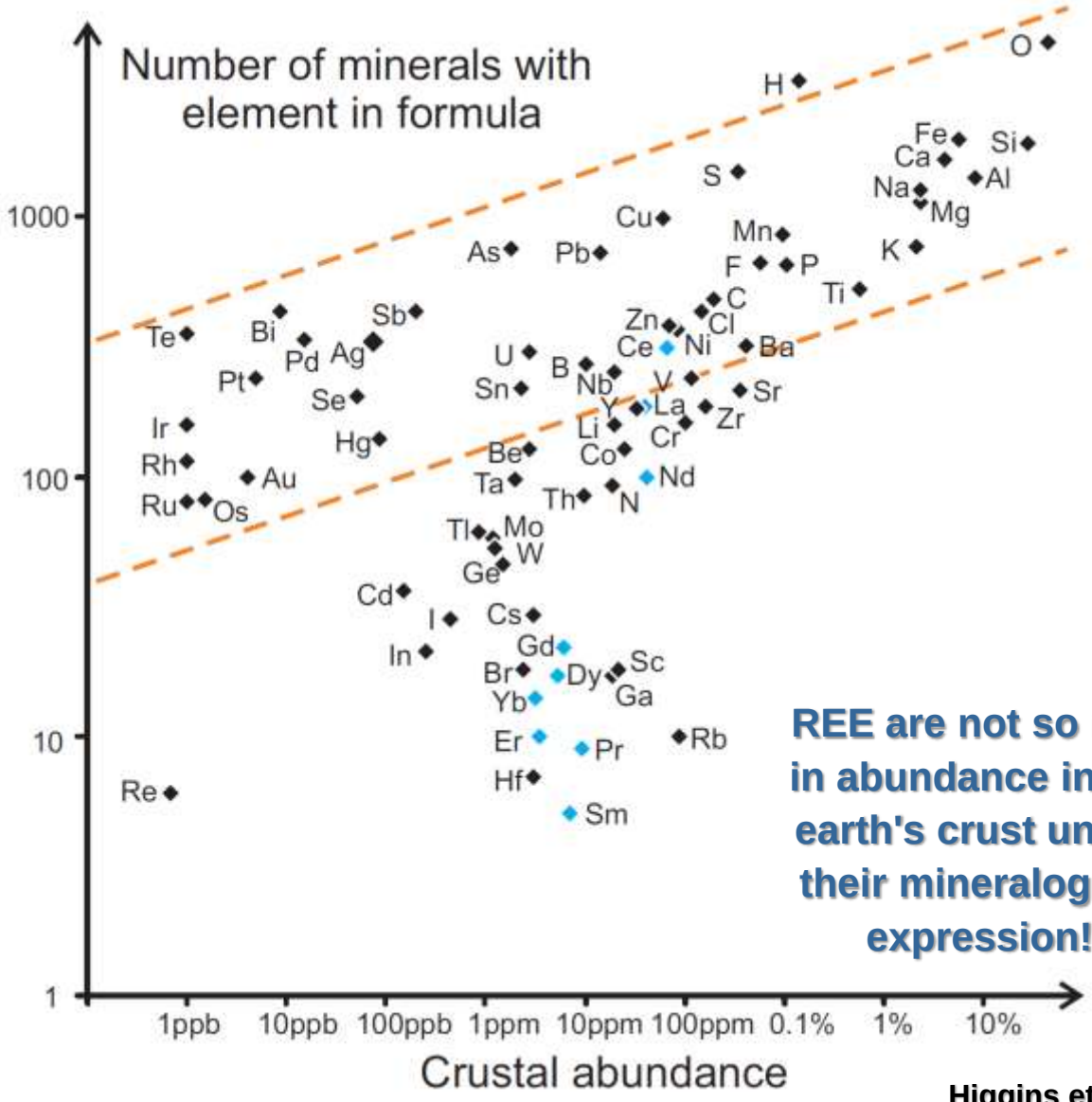
Relative abundance of rare earth elements in the Earth's crust (Rudnick & Gao, 2003)

About REE mineralogy

Bastnaesite (Luzenac-F)

Loparite (Khibiny-R)

Xenotime (Novo Horizonte-B)



REE are not so rare in abundance in the earth's crust unlike their mineralogical expression!

Higgins et al., 2010

About REE mineralogy

Bastnaesite (Luzenac-F)

Loparite (Khibiny-R)

Xenotime (Novo Horizonte-B)

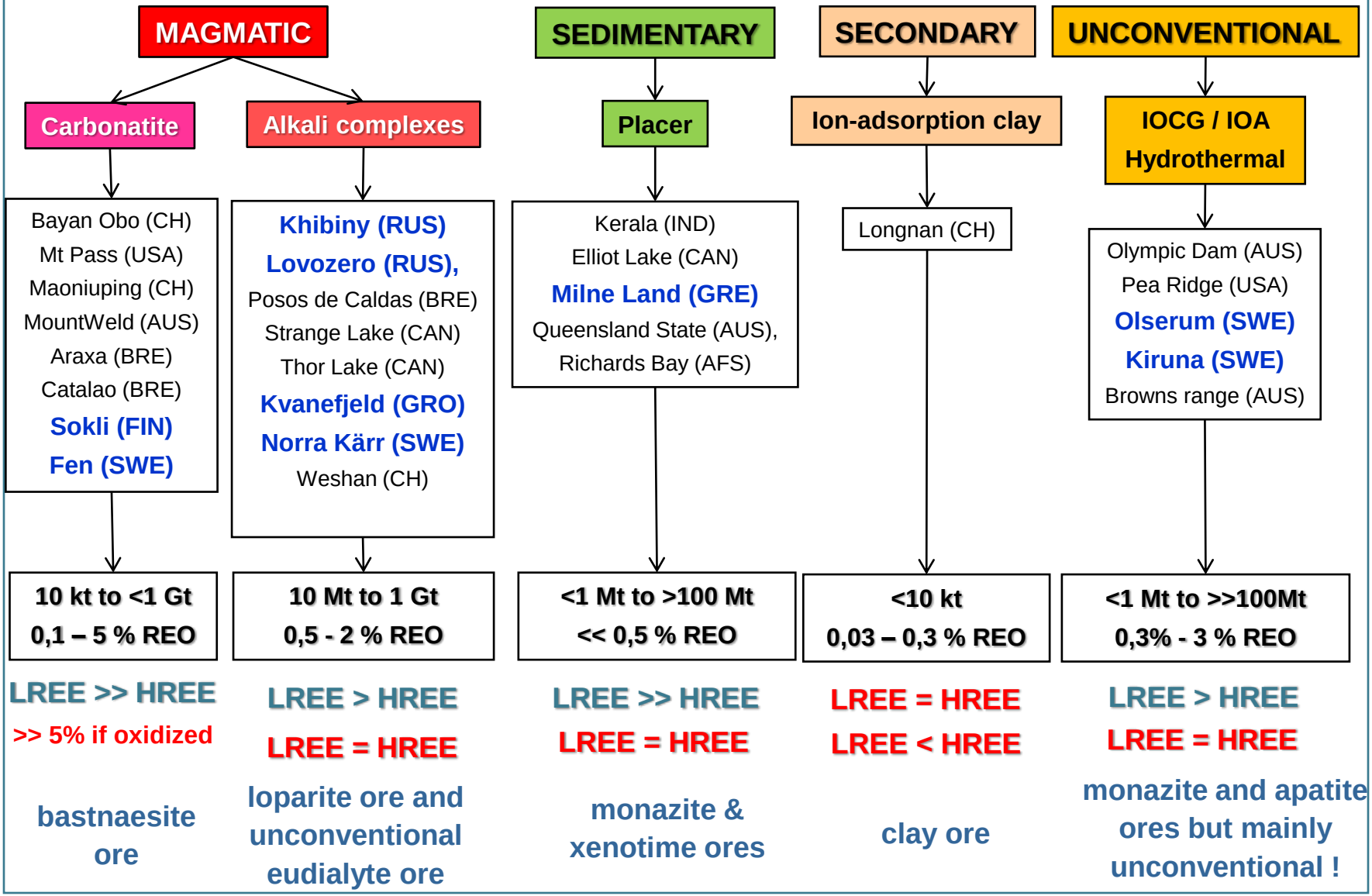
Mineral name	Chemical formula	Weight percent		
		RE_2O_3	ThO_2	UO_2
Euxenite	$([REE],U,Th)(Nb,Ta,Ti)_2O_6$	16-30	<4.3	3-9
Fergusonite	$[REE]NbO_4$	43-52	<8	<13.6
Loparite	**$(Na,[LREE],Ca,Sr,Th)(Ti,Nb,Ta)O_3$**	**28-37**	**1.6**	**0.03**
Pyrochlore	$(Ca,Na,U,[REE])_2(Nb,Ta)_2O_6(OH,F)$	< 22	<4	<27
Uraninite	UO_2	<1.5	<12.2	50-98
Ancylite	$Sr[LREE](CO_3)_2(OH).H_2O$	46-53	<0.4	<0.1
Bastnäsite	**$[LREE]CO_3(F,OH)$**	**58-75**	**<2.8**	**<0.1**
Parisite	$Ca[LREE]_2(CO_3)_3F_2$	50-59	<4	<0.3
Synchysite	$Ca[LREE](CO_3)_2(F,OH)$	48-53	<5	-
Allanite	$([REE],Ca)_2(Al,Fe)_3Si_3O_{12}(OH)$	2.5-17	<3	
Clay minerals	**e.g. adsorbed REE on kaolinite / halloysite $Al_2Si_2O_5(OH)_4$**	**<<4**	**<0.01**	**<0.001**
Eudialyte	$(Na,[REE])_{15}(Ca,[REE])_6(Fe,Mn)_3(Si,Nb)_2(Zr,Ti)_3Si_{24}O_{72}(OH,F,Cl,H_2O)_6$	1-10		<0.1
Gadolinite	$[REE]_2FeBe_2Si_2O_{10}$	45-54	<0.4	
Steenstrupine	$Na_{14}[LREE]_6Mn_2Fe_2(Zr,Th)(PO_4)_7Si_{12}O_{36}.3(H_2O)$	< 31	<6	<1
Thorite	$(Th,U,[REE])SiO_4$	<3	65-81	10-16
Zircon	$(Zr,[HREE],Th,U)SiO_4$	< 19	0.01-0.8	0.01-4
Apatite	**$Ca_5(PO_4)_3(F,Cl,OH)$**	**<<2***		**<0.05**
Monazite	**$([LREE],Th,Ca)(P,Si)O_4$**	**35-71**	**<20**	**<16**
Xenotime	**$([HREE],Zr,U)(P,Si)O_4$**	**54-74**	**<8.4**	**<5.8**

Tuduri et al. (in prep)

Chemistry of most common REE-bearing minerals.

In bold currently used rare earth raw materials.

Different deposit models and different expressions of REE enrichment



REE occurrences in continental Europe and Greenland

The Kvanefjeld REE, U, Zn project, Ilímaussaq complex, Greenland

Methods

Data mining

- ✓ Scientific publications in international journals
- ✓ European mining geodatabase (*e.g.* promine.gtk.fi)
- ✓ Press releases, websites, annual reports of exploration companies
- ✓ Statistical data (EUROSTAT, USGS, BGS, GTK, Roskill, WTA, etc.)

Owing to the unreliability of some data

- ✓ Systematic verification with published data in literature
- ✓ Harmonization of informations in a database
- ✓ Coherence verification, thanks to experts of concerned domains

Products

Tous les objets Access

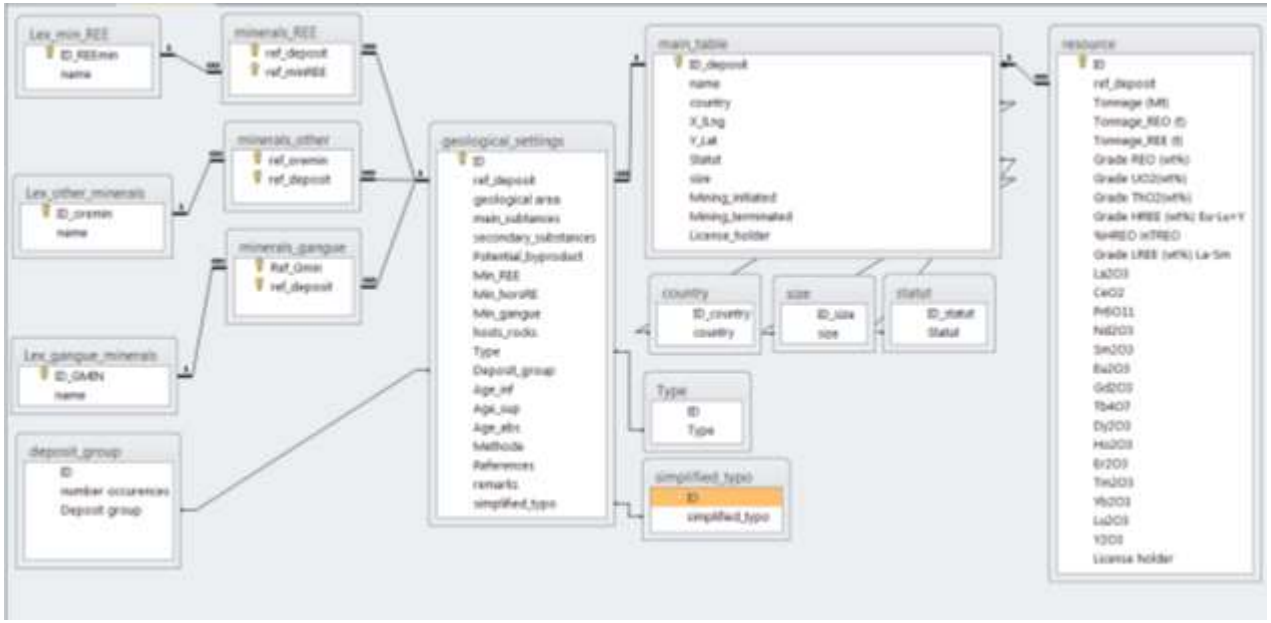
Rechercher...

Tables

- geological_settings
- Lex_gangue_minerals
- Lex_min_REE
- Lex_other_minerals
- lex_ref
- main_table
- minerals_gangue
- minerals_other
- minerals_REE
- promine data
- resource

main_table | Relations

ID_deposit	name	country	X_ILng	Y_Lat	Statut	size	Mining_initiat	Mining_termina	License_holder	Clig
1	Acqueville	France	-1,75300	49,62200	Closed mine					
2	Aeretveit Eretveit mine	Norway	7,88600	58,47000	showing					
3	Afrikanda	Russia	32,75563	67,43118	Not exploited				ng Company (CJSC)	
4	Agios Ioannis Nissi	Greece	23,26252	38,50714	Active mine				ralurgical Larco SA	
5	Aksu Diamas	Turkey	30,56393	37,56183	Project				t Mineral Metal Inc	
6	Alluaiv / Lovozero	Russia	34,50363	67,86571	Not exploited				ng Company (CJSC)	
7	Almunge	Sweden	18,12541	59,87726	project				Tasman metals	
8	Alnö	Sweden	17,44791	62,44875	showing				Tasman metals	
9	Alpe di Fieud Fontana	Switzerland	8,56000	46,51800	showing					
10	Amorgos	Greece	25,88682	36,83760	Not exploited					
11	Arize	France	1,13784	42,94942	Not exploited					
13	Gras	France	-1,73685	47,75890	Not exploited					
14	Arran	Great Britain	-5,31949	55,60986	showing					
15	Arvogno Toceno	Italy	8,45400	46,17000	showing					
16	Askagens Kvartsbrott	Sweden	14,35200	59,71100	Active mine					
17	Atalandi	Greece	22,81889	38,54791	Not exploited	Very small				
18	Attu	Greenland	-53,54069	67,88517	Not exploited					
19	Azov Sea Costs dykes	Ukraine	36,34000	47,11000	showing					



> 400 occurrences of REE in Continental Europe & Greenland

Results : great diversity of deposit models

ENDOGENE DEPOSITS

Magmatic

- *Carbonatite*
  - *Fen-Søve (NO)*
- *Alkaline igneous rocks*
  - *Norra Kärr (SE)*
- *Pegmatite*
  - *Langesundsfjord-Larvik (NO)*
- *Granite-related*
  - *Kovela (FI)*

Magmatic-Hydrothermal

- *Porphyry-High sulphidation*
  - *Bor (RS)*
- *Skarn*
  - *Bastnäs (SE)*
- *Iron oxide-Apatite*
  - *Kirunavaara (SE)*

Hydrothermal

- *Metasomatism*
  - *Luzenac (FR)*
- *Veins*
  - *Olserum (SE)*
  - *Northern Pennines (UK)*
  - *Alpine veins (F, AU)*

EXOGENE DEPOSITS

Basinal

- *Placer*
  - *Nea Peramos (GR)*
- *Palaeoplacer*
  - *Milne Land (GL)*
- *Phosphorite*
  - *Tåsjö (SE)*
- *Authigenic*
  - *Grand Fougeray (FR)*

Regolith

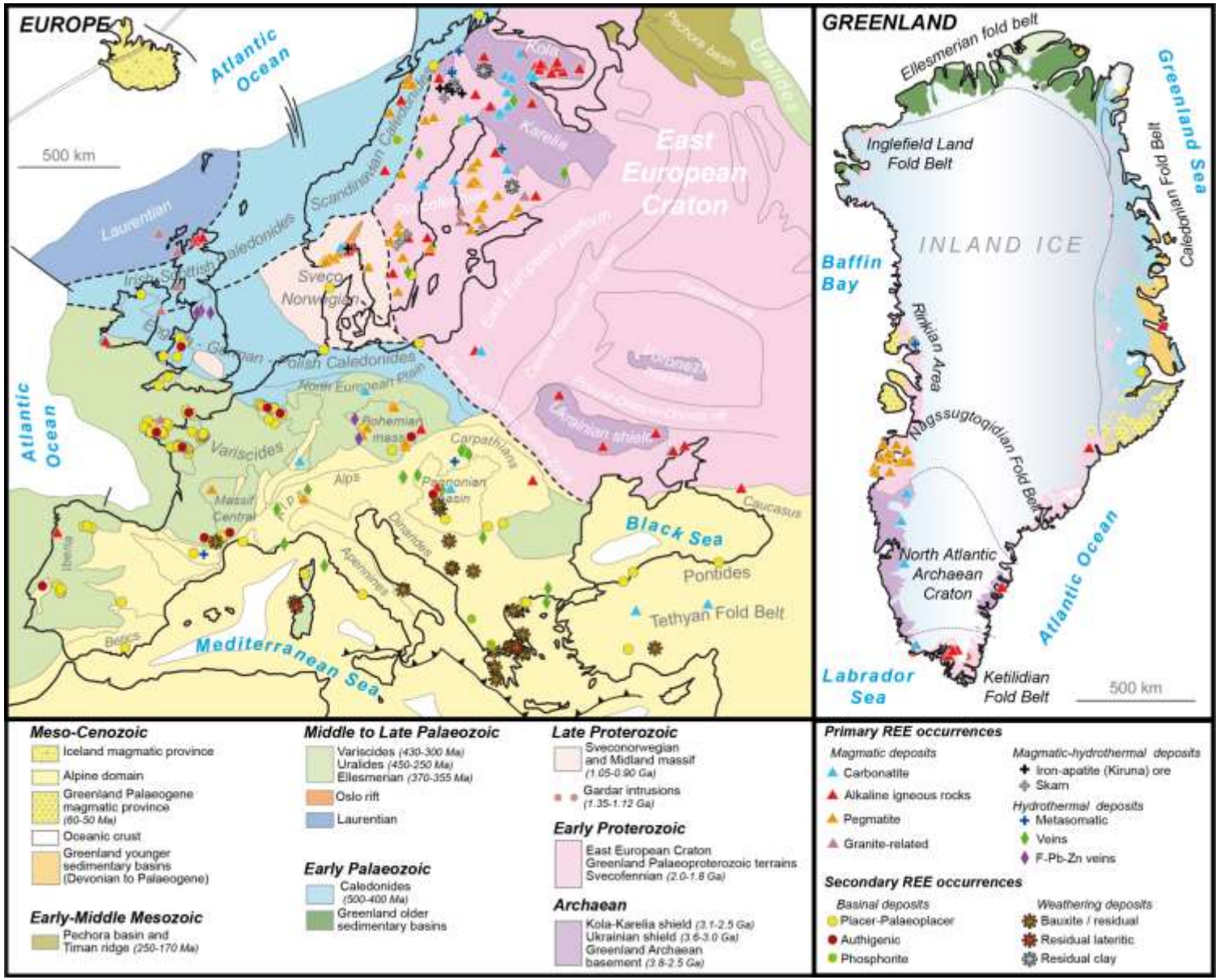
- *Ion-adsorption clays*
  - *Mäkärä (FI)*
- *Bauxite - Laterite*
  - *Grebnik (XK)*
  - *Aghios Ioannis (GR)*

Ilímaussaq complex in Kringlerne (Greenland)

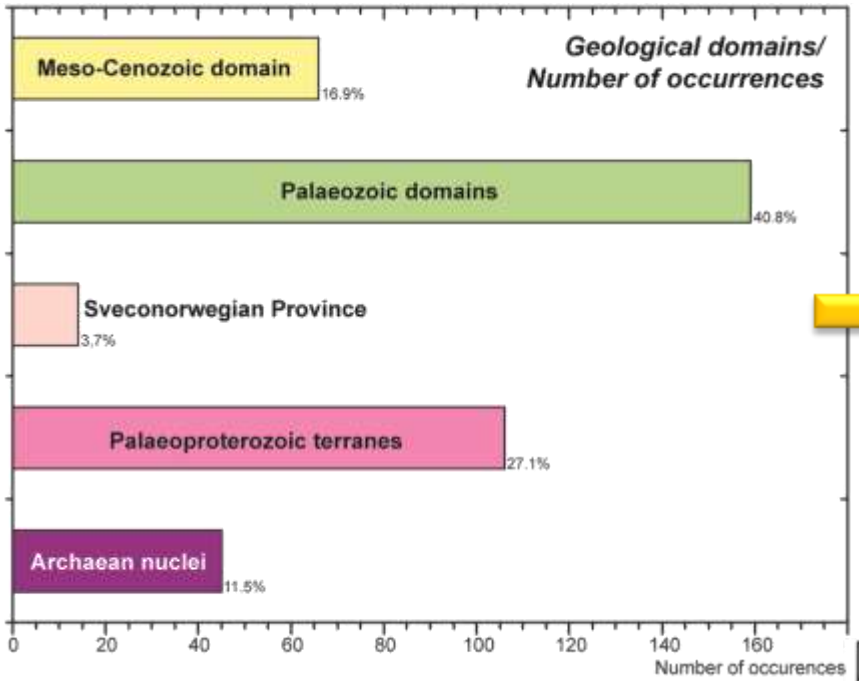
Luzenac talc deposit, Pyrenees (France)

Bauxite deposit, Bédarieux (France)

Geological inheritance *vs* geological potentialities



Charles et al. (2014), Tuduri et al. (in prep)



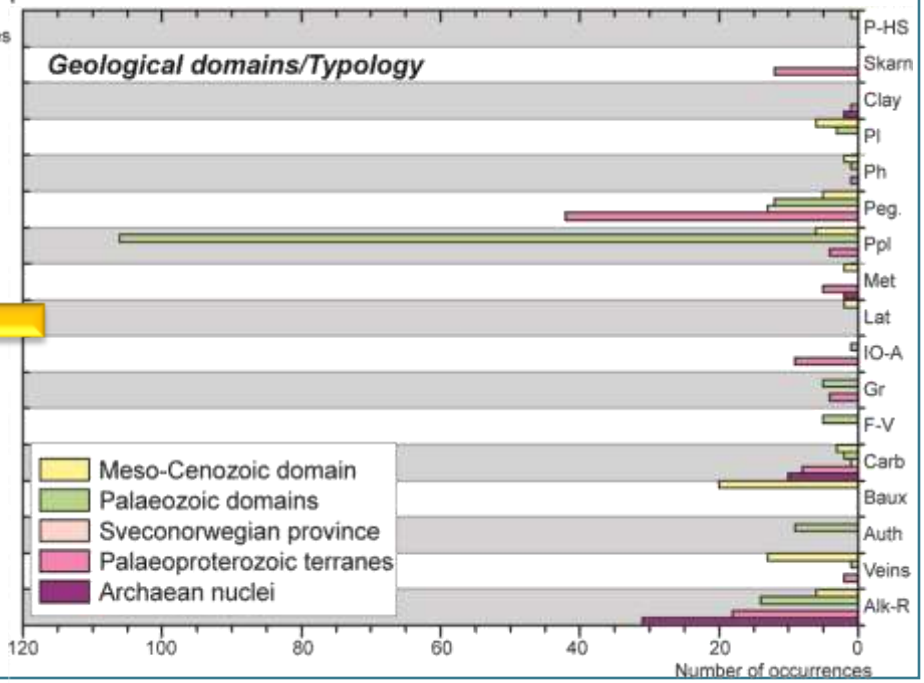
REE occurrences are mostly located in the Palaeozoic domain

But Palaeozoic are mainly characterized by monazite palaeoplacers which are (very) small and of little economic interest.

e.g. Bailleul (France)

3.5Mt @ 0.5% REO

↳15kt REE



Where are economic potentials?

Kringlerne project part of the Ilímaussaq complex in Greenland (© Tanbreez)

REE production in Europe

~3 100t REO

(loparite-Russia-2012)

$(Na,Ce,Ca)(Ti,Nb)O_3$

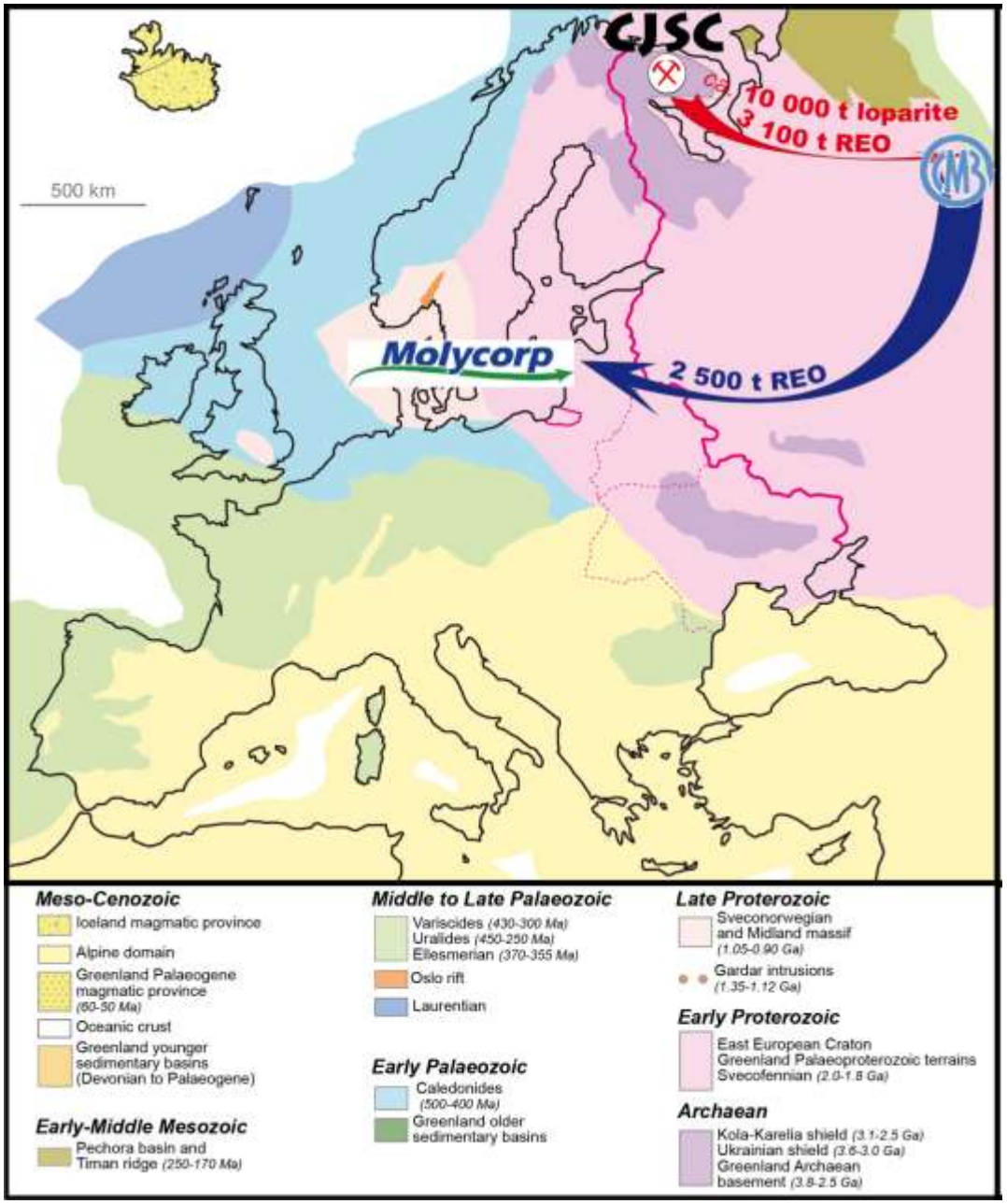
TREO - 29-33%

TiO_2 - 37-40%

Nb_2O_5 - 7-9%

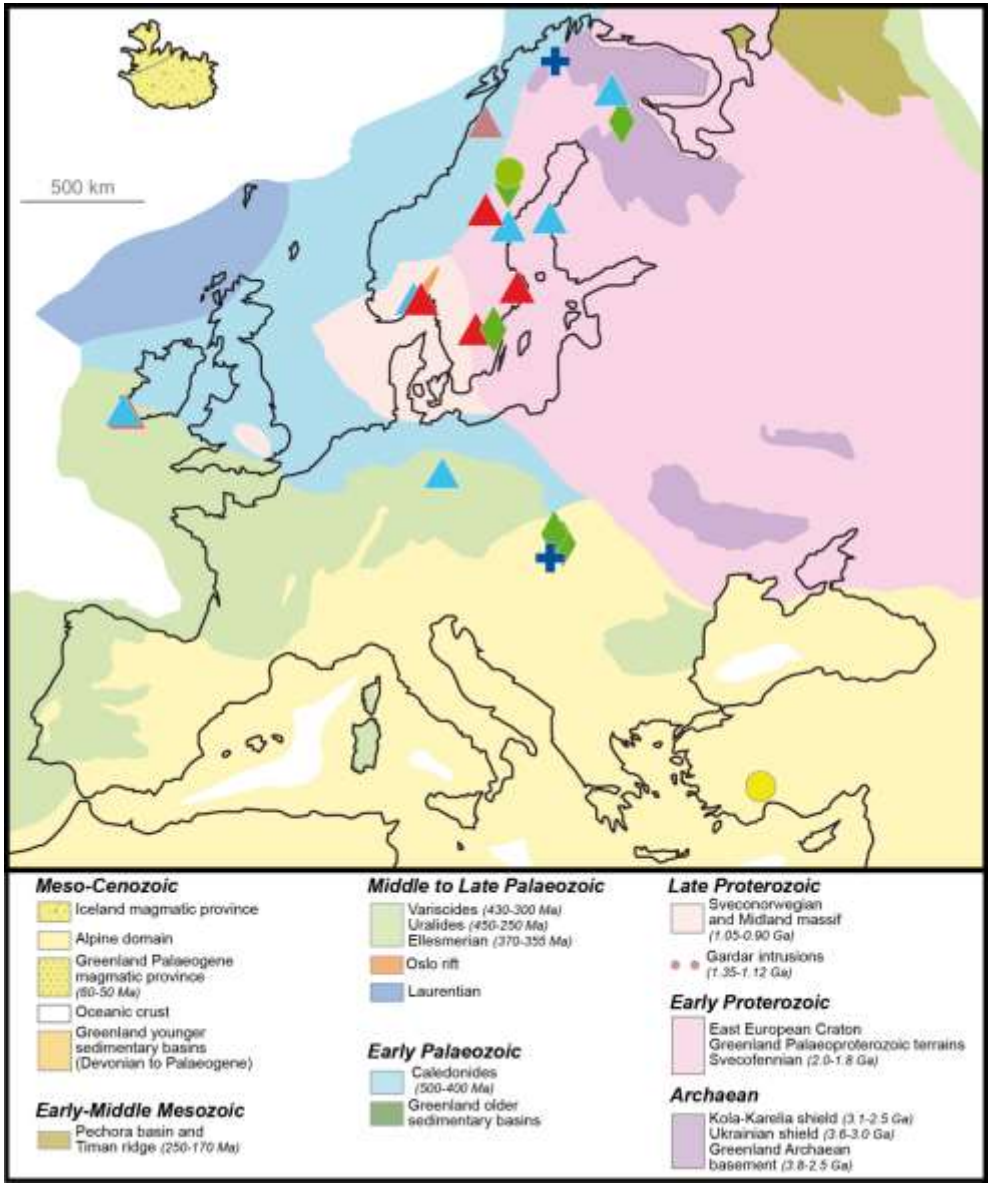
Ta_2O_5 - 0.5-0.8%

ThO_2 - 0.5%



REE exploration in Europe

(~ 2 Mt REO recognized)



TASMAN METALS LTD

SELTENERDEN STORKWITZ AG

AMR

Dragon Mining

REE MINERALS

AUROPEAN VENTURES INC.

YARA

NORGE Mineral Resources AG

21st NORTH

ULTRA RESOURCES CORP

MAWSON

COASTAL PACIFIC MINING CORPORATION

REE exploration in Greenland (~ 40 Mt REO recognized)

GREENLAND MINERALS AND ENERGY LTD

NUNA MINERALS

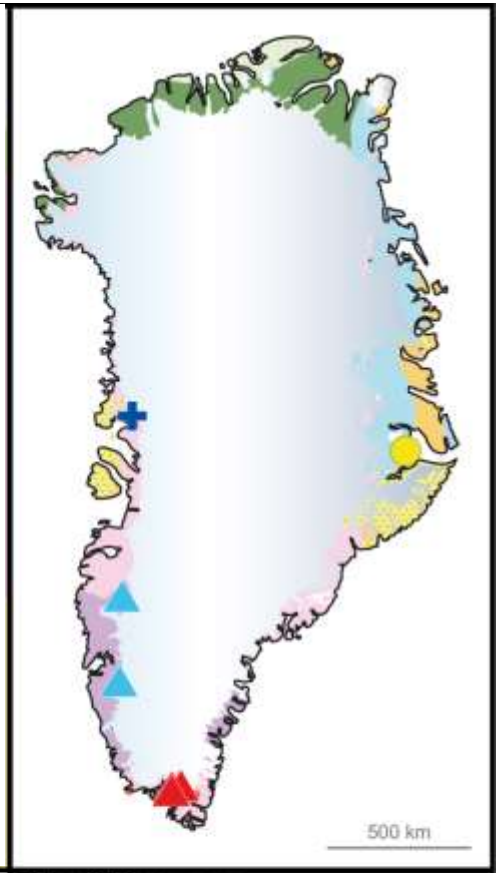
TANBREEZ
mining for greener technologies

ROAM RESOURCES

HUDSON RESOURCES INC

Avannaa Resources

CGRG
czech geological research group



Meso-Cenozoic
- Iceland magmatic province
- Alpine domain
- Greenland Palaeogene magmatic province (60-50 Ma)
- Oceanic crust
- Greenland younger sedimentary basins (Devonian to Palaeogene)

Early-Middle Mesozoic
- Pechora basin and Timan ridge (250-170 Ma)

Middle to Late Palaeozoic
- Variscides (430-300 Ma)
- Uralides (450-250 Ma)
- Ellesmerian (370-355 Ma)
- Oslo rift
- Laurentian

Early Palaeozoic
- Caledonides (500-400 Ma)
- Greenland older sedimentary basins

Late Proterozoic
- Sveconorwegian and Midland massif (1.05-0.90 Ga)
- Gardar intrusions (1.35-1.12 Ga)

Early Proterozoic
- East European Craton
- Greenland Palaeoproterozoic terrains
- Svecofennian (2.0-1.8 Ga)

Archaean
- Kola-Karelia shield (3.1-2.5 Ga)
- Ukrainian shield (3.6-3.0 Ga)
- Greenland Archaean basement (3.8-2.5 Ga)

Primary REE occurrences

Magmatic deposits
- Carbonatite
- Alkaline igneous rocks
- Pegmatite
- Granite-related

Magmatic-hydrothermal deposits
- Iron-apatite (Kiruna) ore
- Skarn

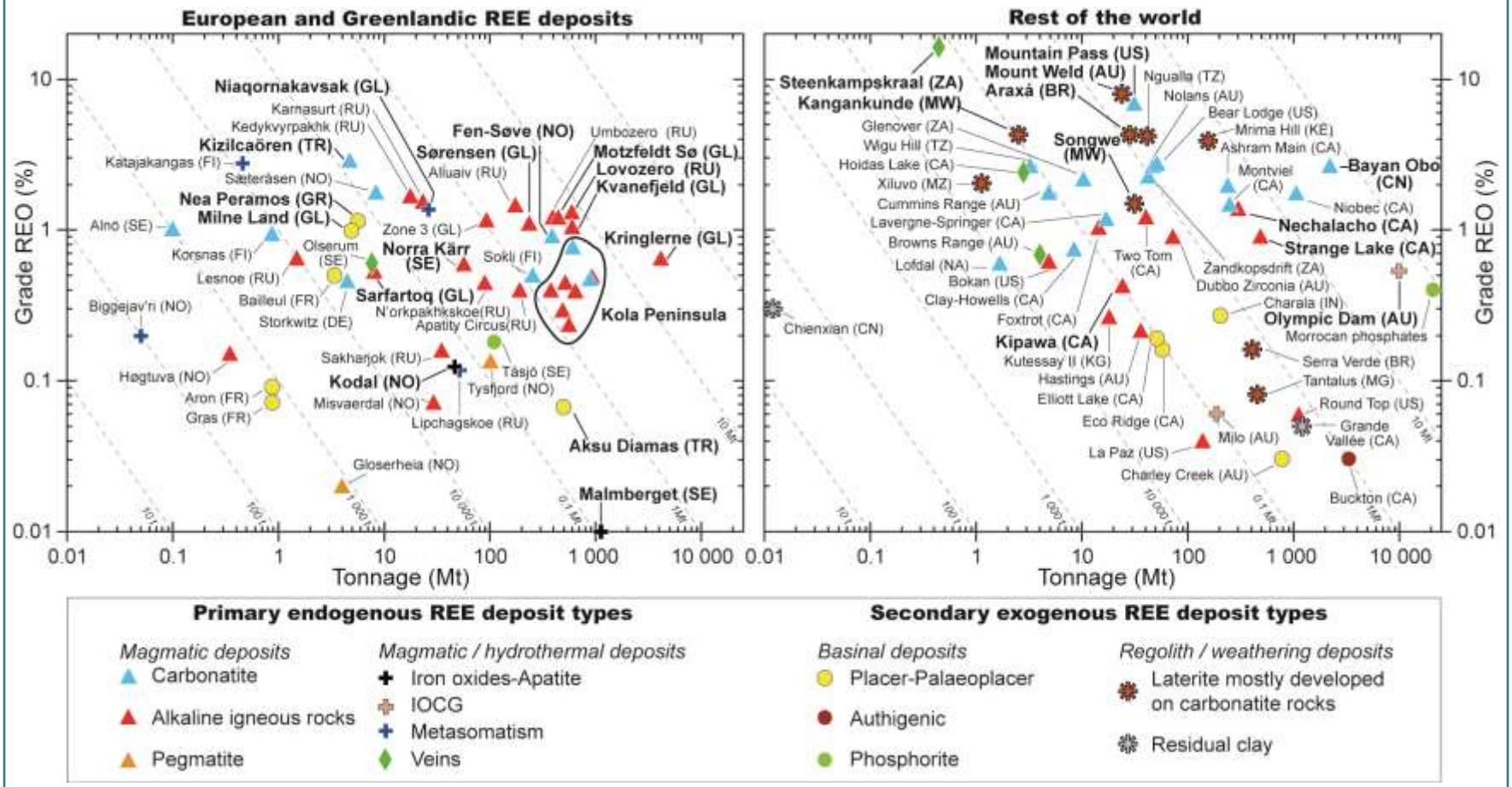
Hydrothermal deposits
- Metasomatic
- Veins
- F-Pb-Zn veins

Secondary REE occurrences

Basinal deposits
- Placer-Palaeoplacer
- Authigenic
- Phosphorite

Weathering deposits
- Bauxite / residual
- Residual lateritic
- Residual clay

Grade, tonnage and typology



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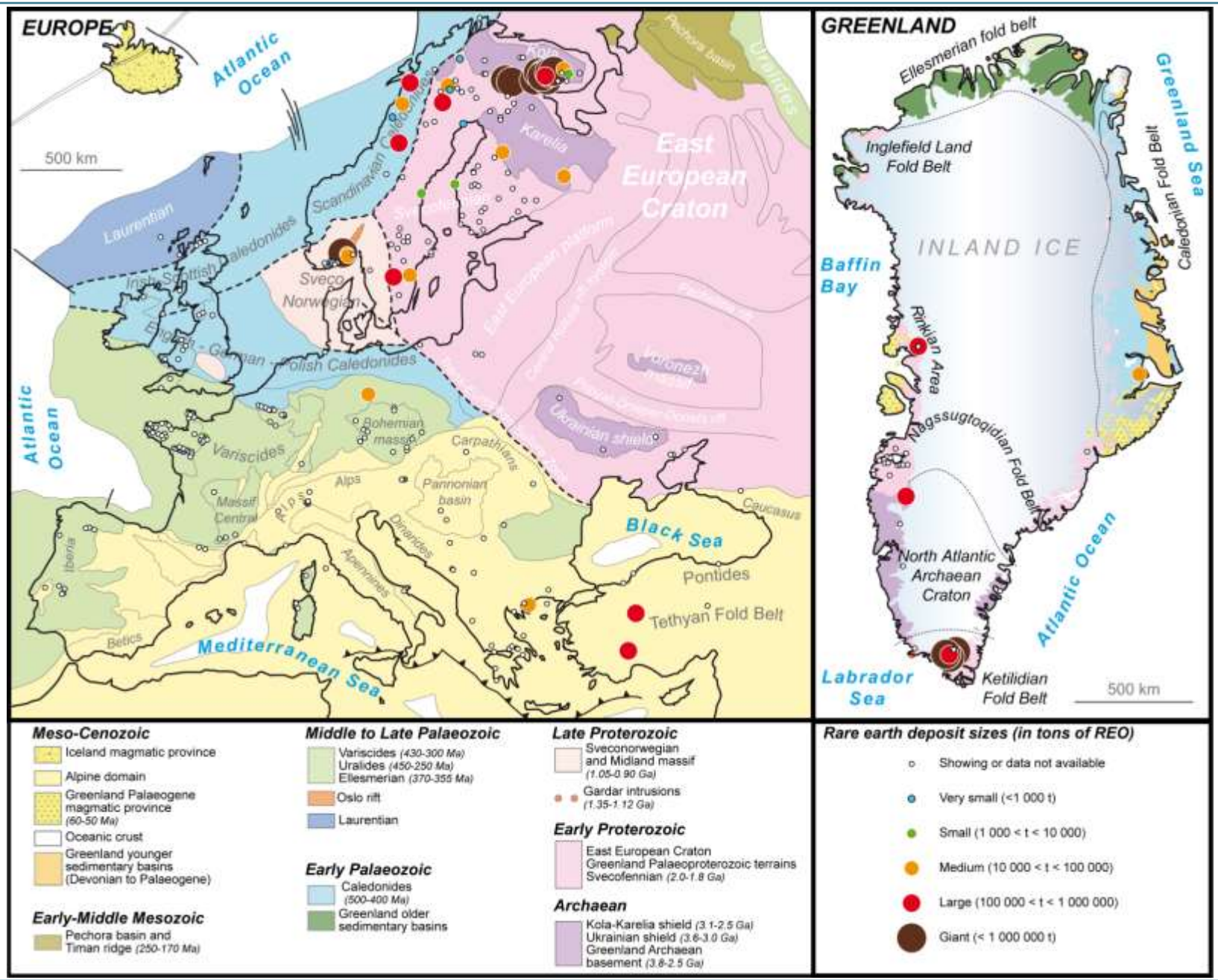

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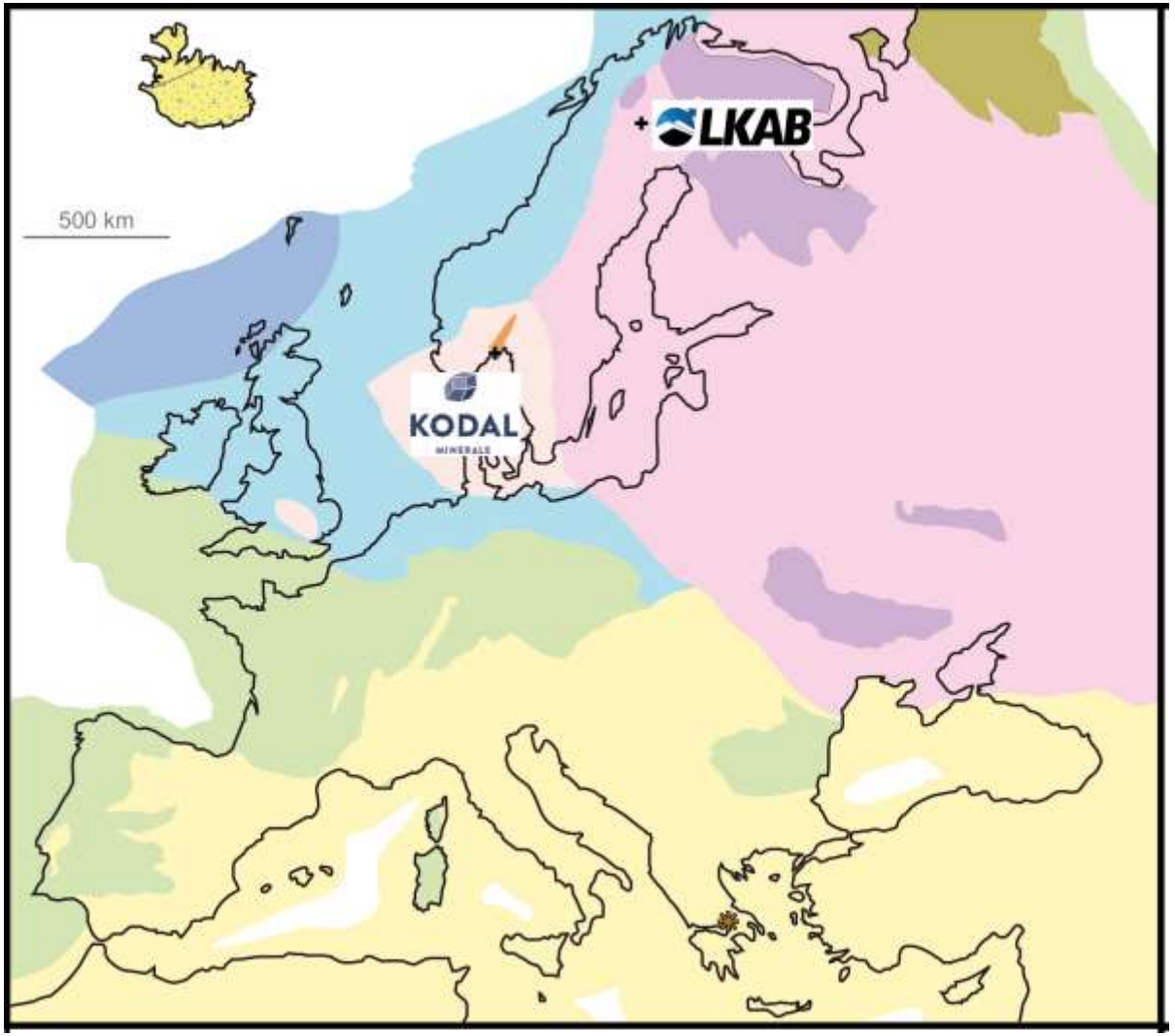
Others opportunities

There are some unconventional deposits

(apatite – FeOx, bauxite)

where REE could be considered as by-products.



Conclusions

Detrital monazites from Brittany placers (Colin, BRGM)

Updated, well-documented and “reliable” **database** for REE occurrences in continental **Europe and Greenland**

Up to now **400** distinct **occurrences** (mine, project, showings), classified by **typology** in continental Europe and Greenland

Heterogeneity of degree of **knowledge** by country

Real potential for **primary deposits** (magmatic, hydrothermal) in **North Europe** and **South Greenland**

Underexplored potential for **secondary deposits** (sedimentary, weathering) in **South** and **West Europe**

Perspectives

Improve **synergy** with the **EURARE** Project

Promote **scientific studies** for REE in **underexplored areas**

Encourage the development of **new mineral processing**

Better assess the **criticality** and **influence** of **future REE projects** on the economy (MFA, Sankey diagrams)

Influence of exploration projects on REEs market

Norra Kärr: 58.1 Mt @ 0.59% TREO (0.3% HREE)

Kvanefjeld: 619 Mt @ 1.056% TREO (0.124% HREE)

Kringlerne: 4,300 Mt @ 0.65% TREO (0.21% HREE)

Tb (2010)

Terbium example (HREE)

Norra Kärr: 1,900 t

Kvanefjeld: 10,500 t

Kringlerne: 110,000 t

Guyonnet et al. (2014)

Should one of the studied mining prospects enters production, criticality of heavy REEs should be significantly influenced

Thank you for your attention

Sunset in the Kangerdluarssuk camp, Kringlerne REE deposit (Greenland)