Conference on
Exploration and Exploitation
of Critical Raw Materials

Sedimentary Phosphorites

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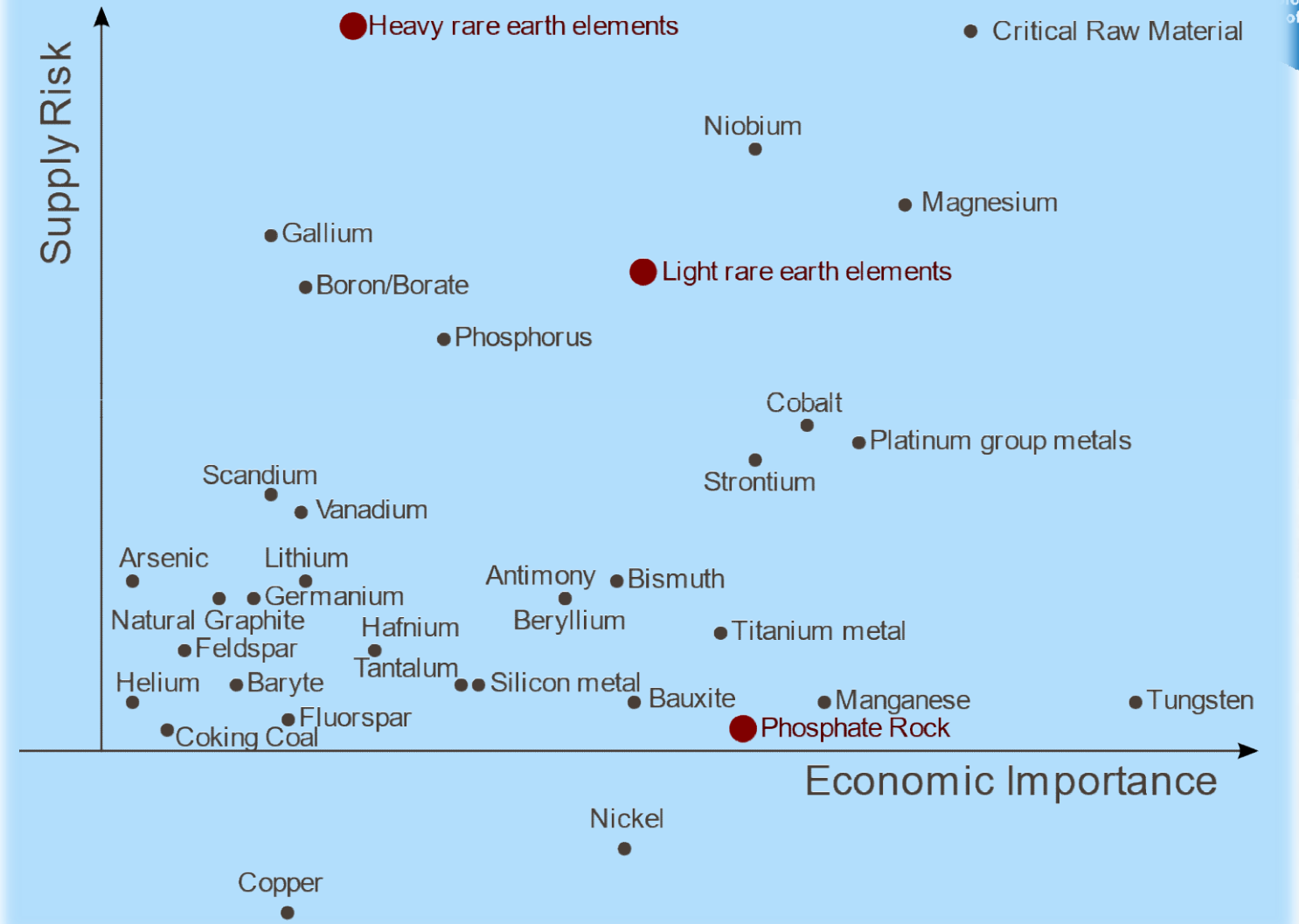
EGT-TWINN

Funded by
the European Union

Outline

1) Phosphorite resources and reserves
2) Sedimentary phosphorite deposits – formation and importance
3) Estonian phosphorite deposits

EU CRM list 2023



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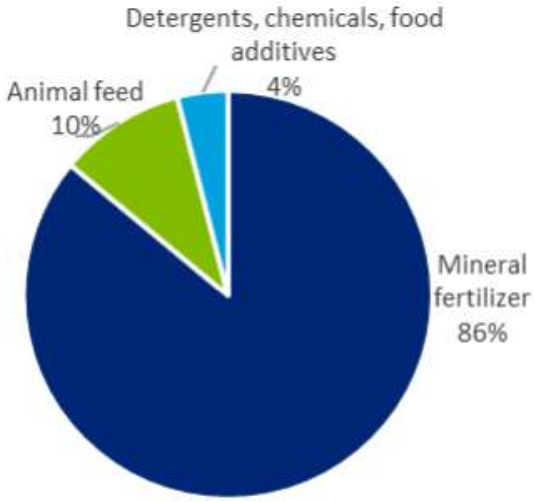
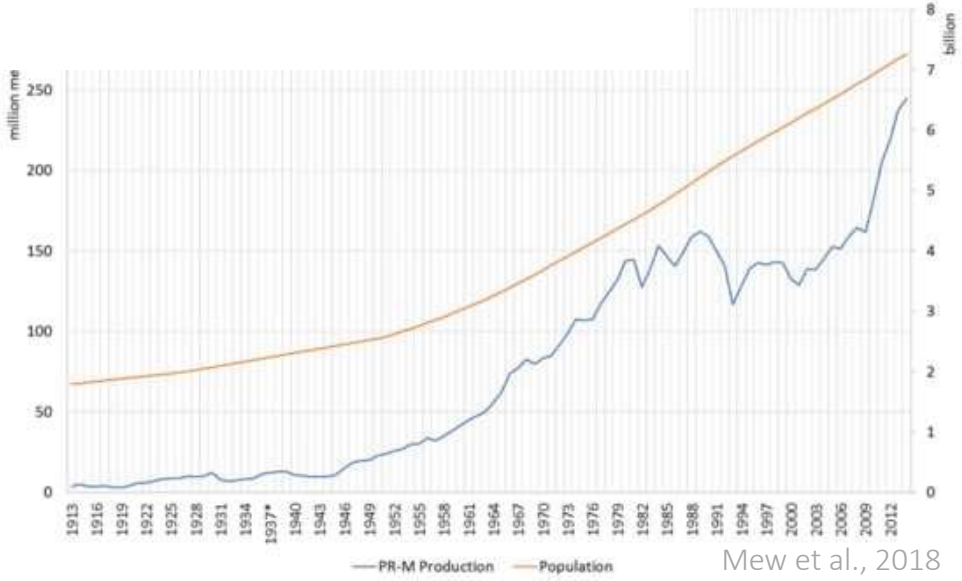
Phosphorus consumption in the EU



EU consumption: 2 011 kt as P_2O_5

Scrreen phosphate rock update 2023

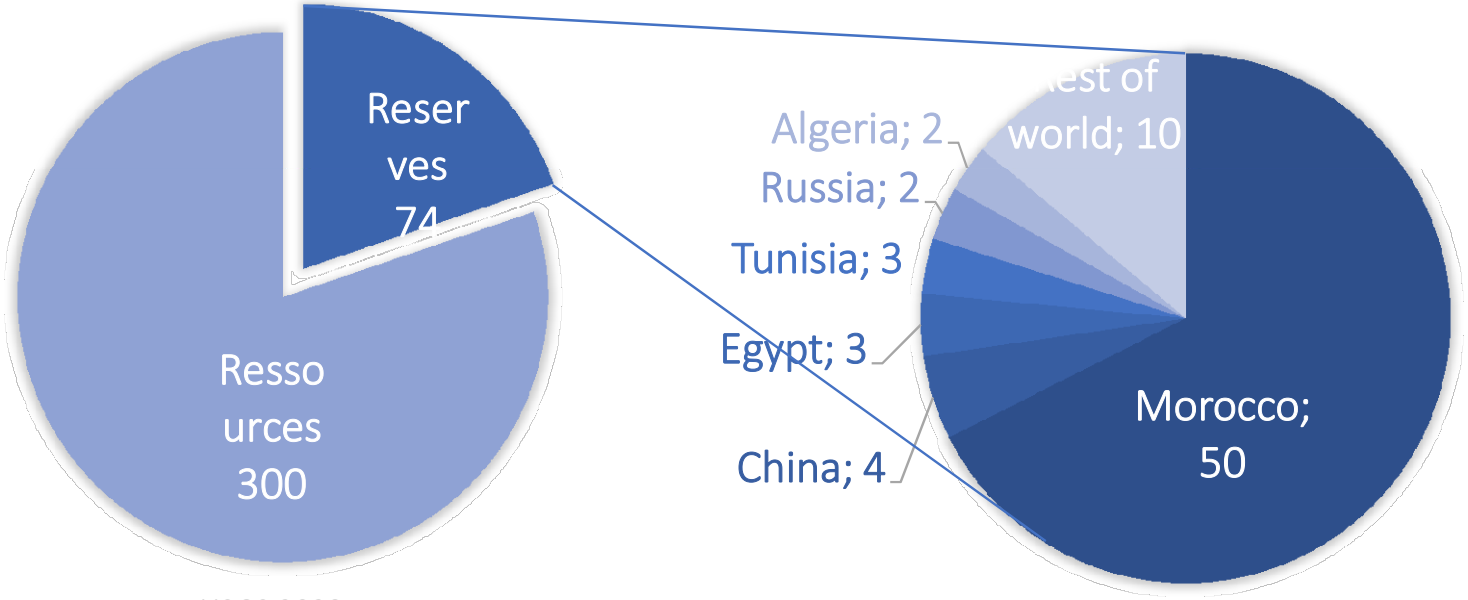
- Phosphate rock is primarily used for the production of fertilizer.
- There are no substitutes for phosphate rock.
- Other uses like Lithium-Phosphorus-Iron batteries are minor in volume but may have significant economic importance
- Phosphate rock mining volumes have increased, matching the growth of the human population.



Mew et al., 2018

Global resources and reserves of phosphate rock (billion tons)

Billion tons of phosphate rock (P_2O_5 about 30%)



USGS 2023

Reserves for about 300 years

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Phosphate rock mining in the world and in EU (2023)

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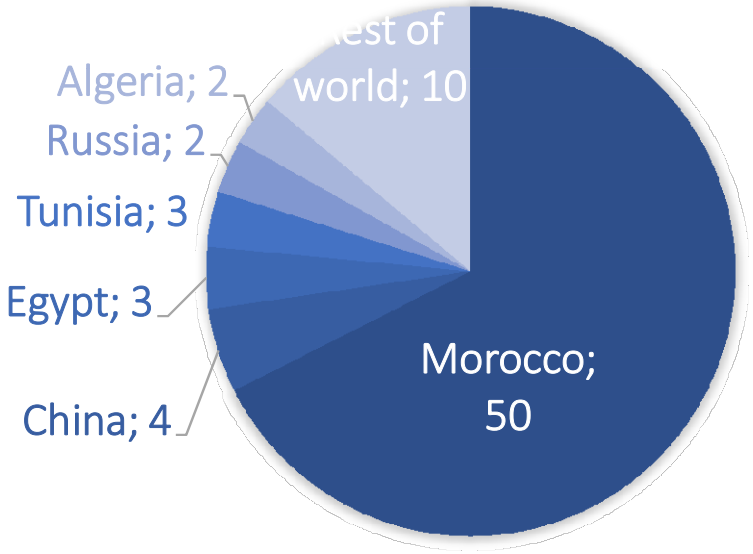
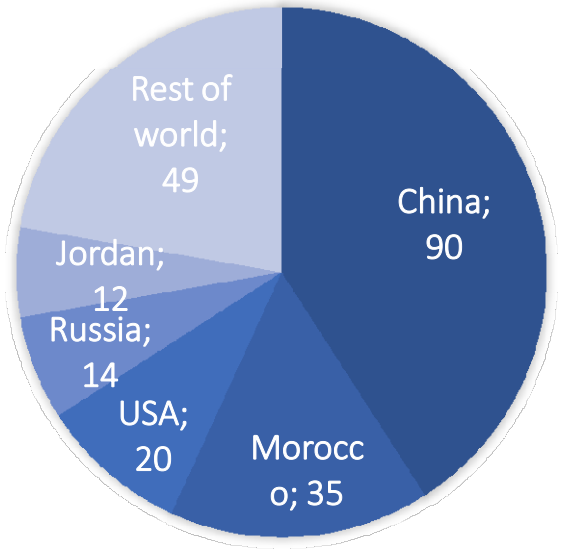
Million tons of phosphate rock (P_2O_5 about 30%), total 220Mt

World

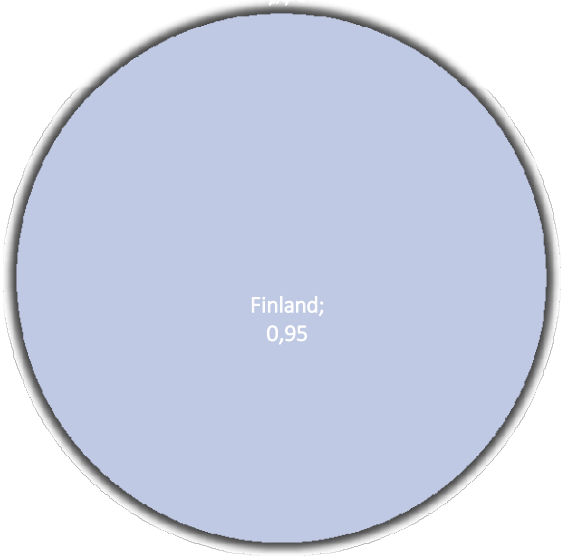


Billion ton



Million ton

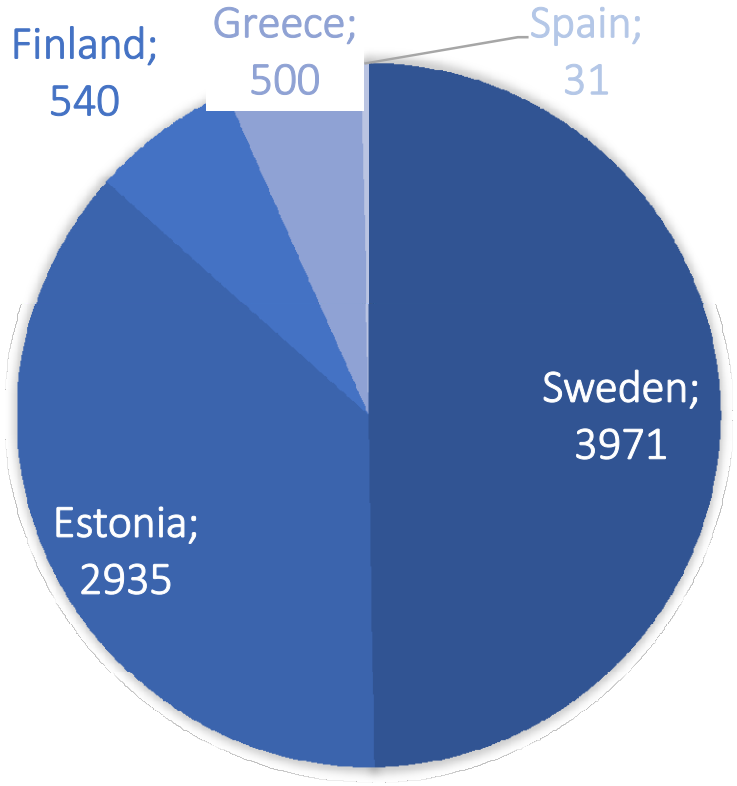
EU



Million ton

USGS 2023

Resources of phosphate ore in EU (million tons)



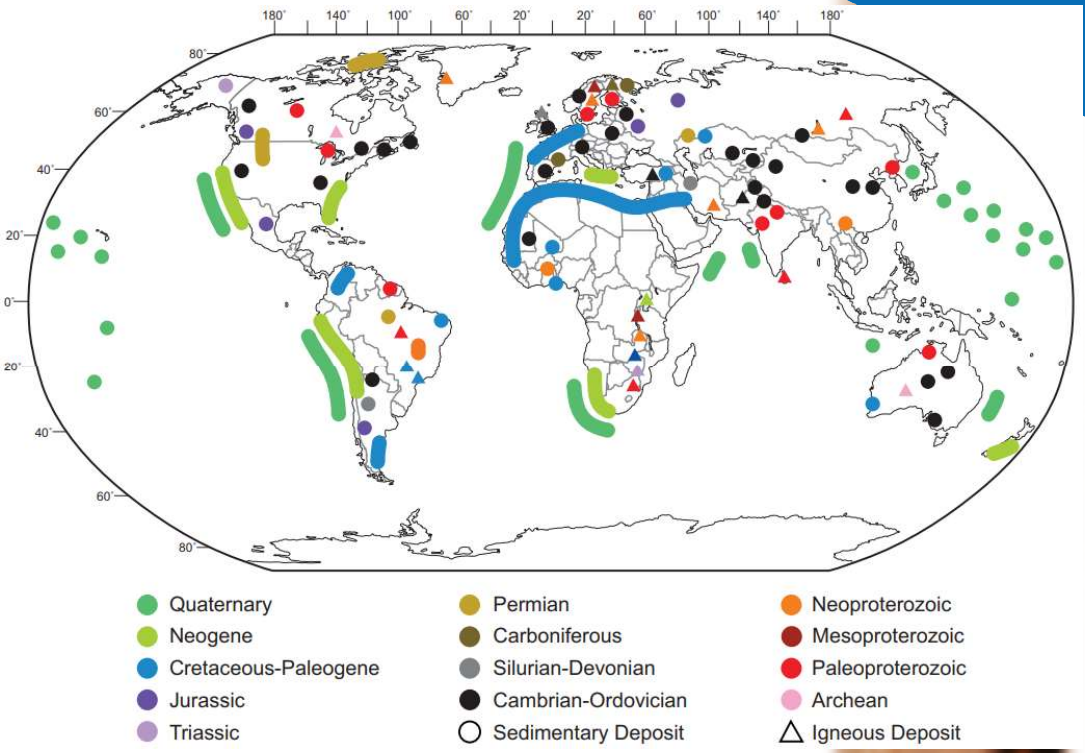
Scrreen phosphate rock update 2023

Remarks:

- P_2O_5 concentrations vary between deposits.
- Sweden has low-grade ore (up to 2,4% P_2O_5) as a by-product of iron mining
- Sweeden, Greece and Finland resources according to internationally recognized standard

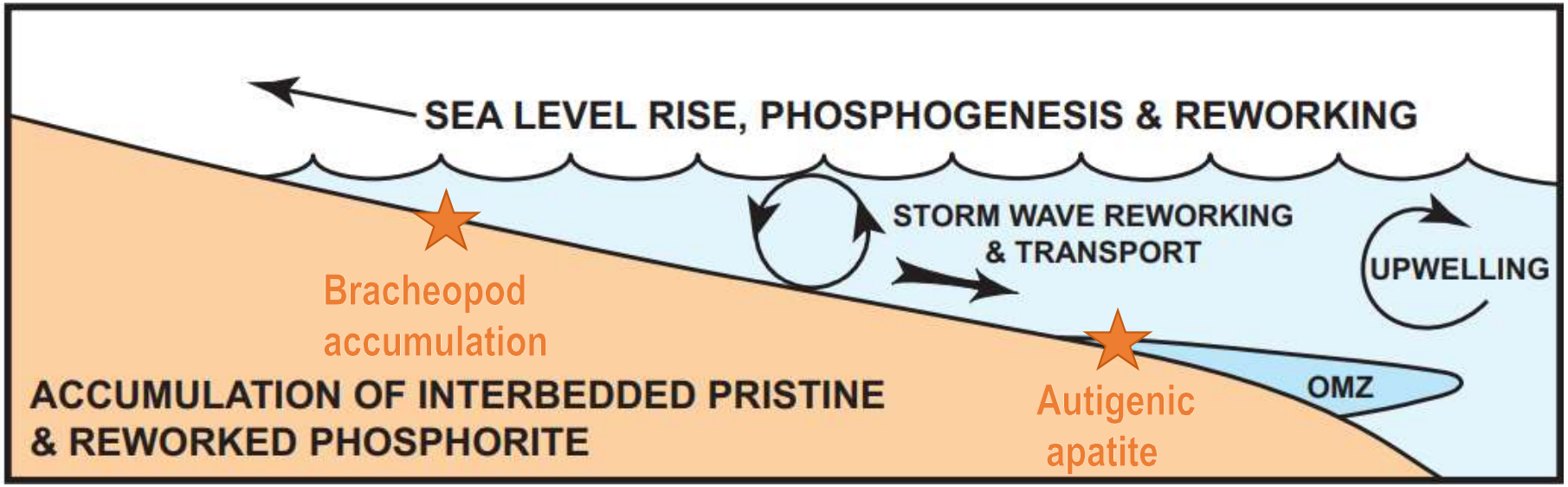
Origin of phosphorite deposits

- There are two types of phosphate deposits: igneous and sedimentary.
  - ✓ 95% of phosphorite deposits are sedimentary origin, forming through upwelling.
    - ✓ Autigenic apatite – formed in upwelling systems
    - ✓ Biogenic apatite – (bracheopod) shells, bonnes, guano
  - ✓ 5% of phosphorite deposits are igneous - typically carbonatite, which is an igneous rock with over 50 vol % of carbonate minerals.



(Pufahl & Groat, 2017)

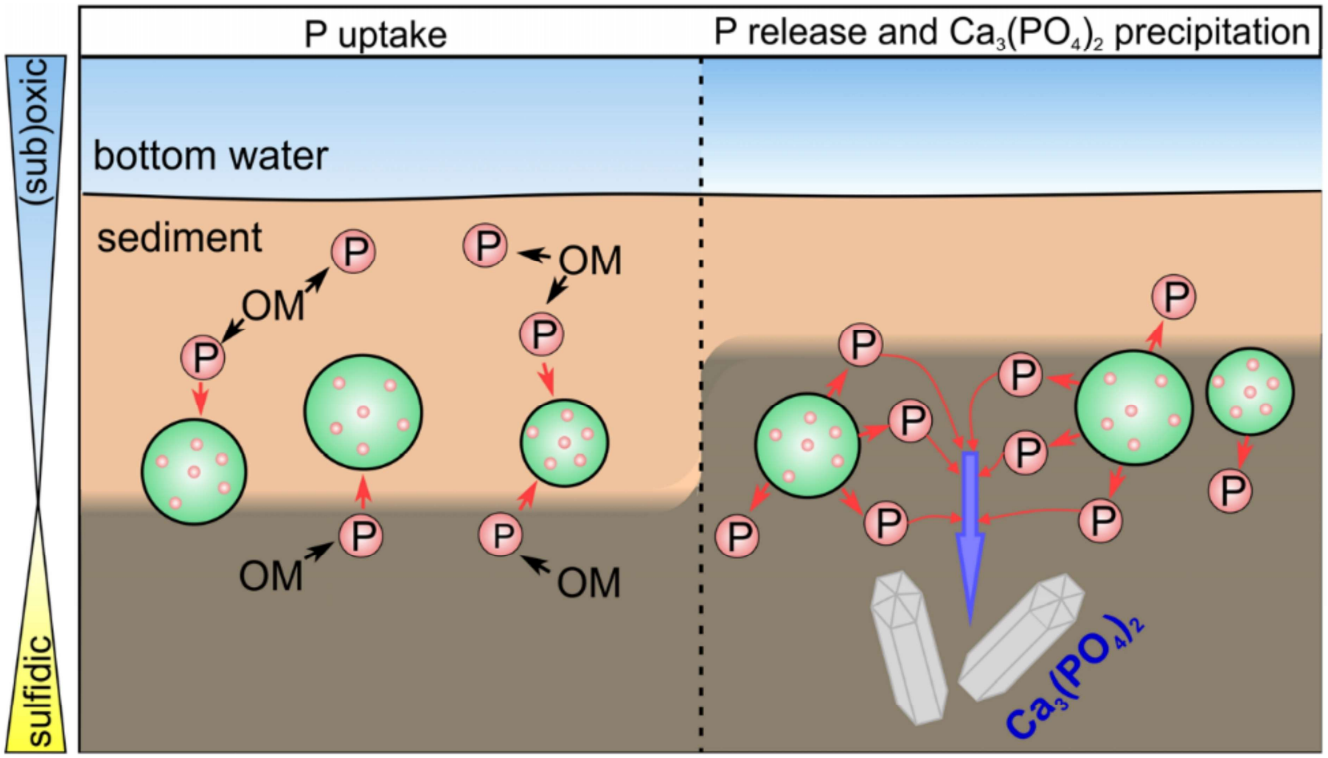
Formation of sedimentary phosphorite

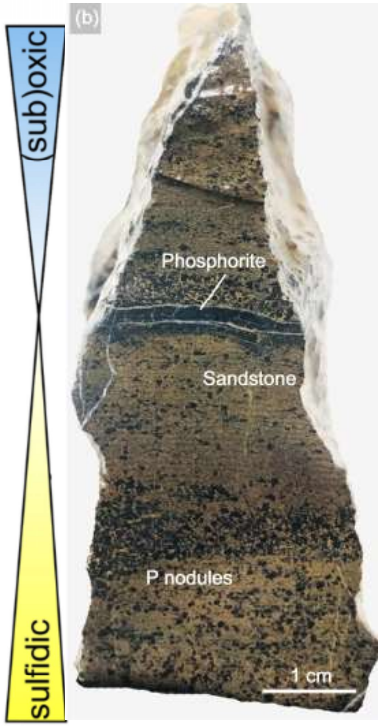


(Pufahl & Groat, 2017)

- ✓ Although high productivity upwelling zones area makes up a small fraction of the world ocean (by most estimates less than 1%), they account for 5% of global marine primary production and 17% of global fish catch (Pauly and Christensen, 1995).

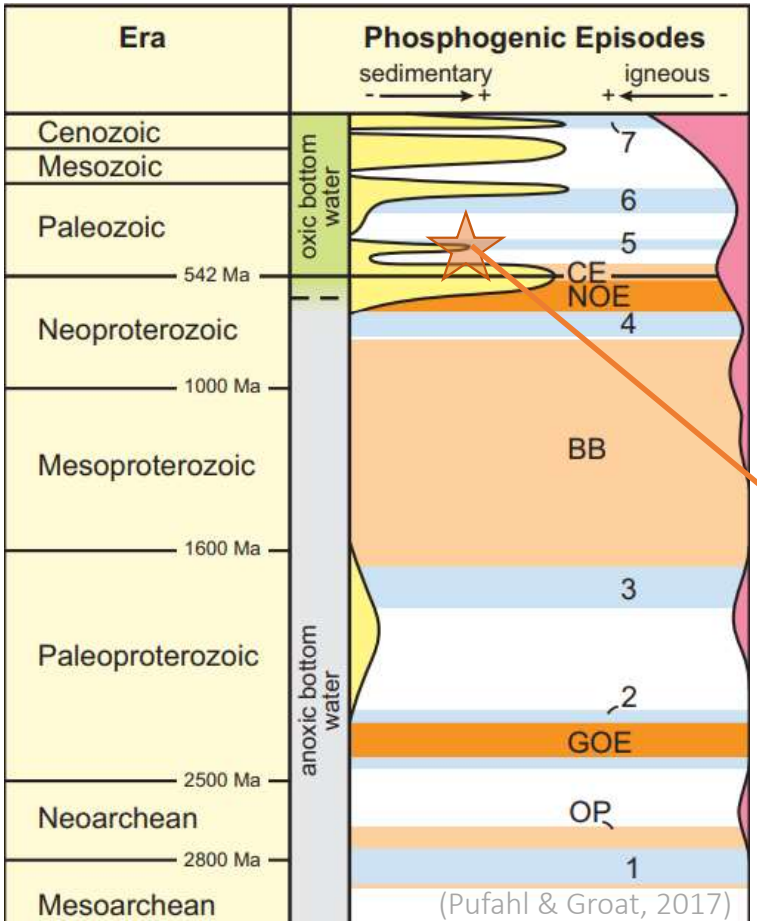
Formation of sedimentary phosphorite





Brock & Schulz-Vogt (2011) Hashempour et al., 2024

Temporal distribution of phosphorite



(Pufahl & Groat, 2017)

- ✓ BB = Boring Billion
- ✓ CE = Cambrian Explosion
- ✓ GOE = Great Oxidation Event
- ✓ NOE = Neoproterozoic Oxygenation Event
- ✓ OP = appearance of oxygenic photosynthesis;

Estonian phosphorite

Trace elements in phosporite

- Phosphorus is mainly found in apatite
- Apatite is prone to chemical substitutions
- Substitutions can be beneficial (e.g., REEs) or harmful (e.g., U, Cd, As).
  - ✓ Total REE concentrations range from 500 to 2,000 ppm total REEs
  - ✓ The U concentration in sedimentary phosphorite is generally between 50 and 200 ppm.

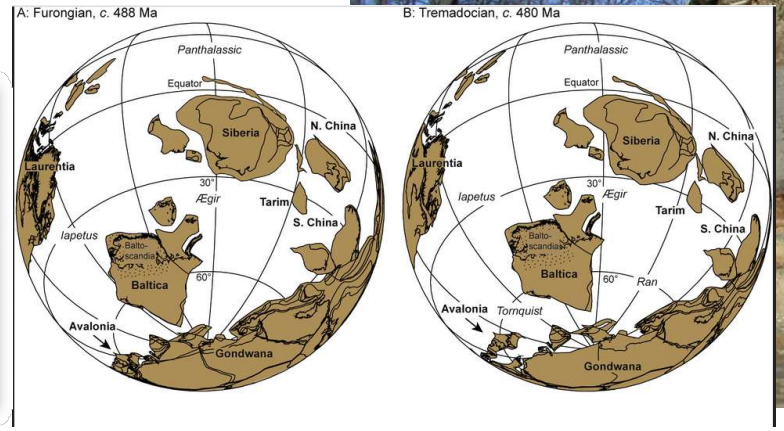
$Ca_5(PO_4)_3(OH,F,Cl)$.

Mg, U, Sr, Th, Cd, REE

CO_3, SO_4, VO_4, AsO_4

Phosphorite in Estonia

- Deposited during the Cambrian and Ordovician
- Phosphatic sandstone containing brachiopod shells overlayed by black shale



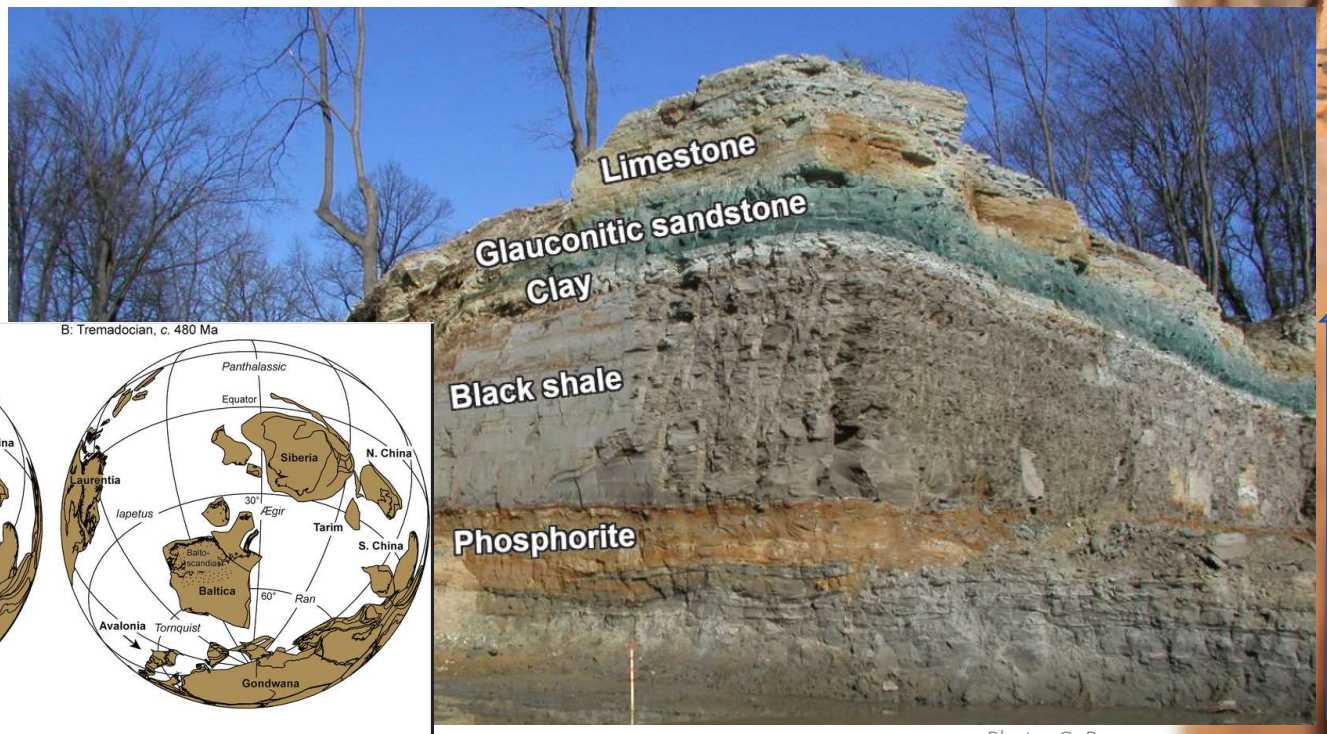
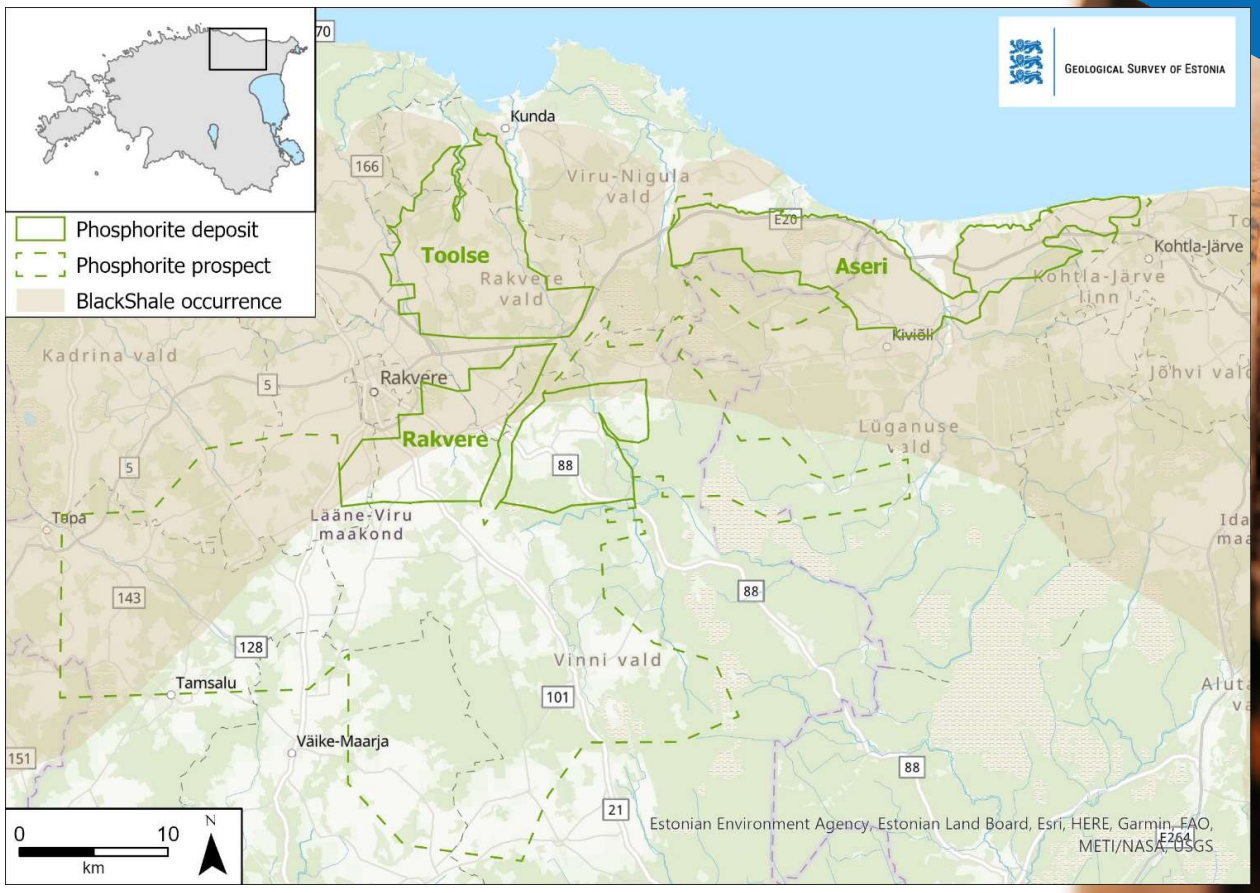


Photo: G. Baranov

The maps are based on the BugPlates2014 software (Torsvik, 2009) with modifications
Stouge et. al. (2020) https://doi.org/10.1016/j.palaeo.2019.04.007

Phosphorite deposits in Estonia

- There are significant phosphorite deposits in North-East Estonia.
- 2.9 billion tons of P_2O_5 ore (10% P2O5 in average) in deposits and 8.4 billion tons as prospects.



Historical exploration in Estonia

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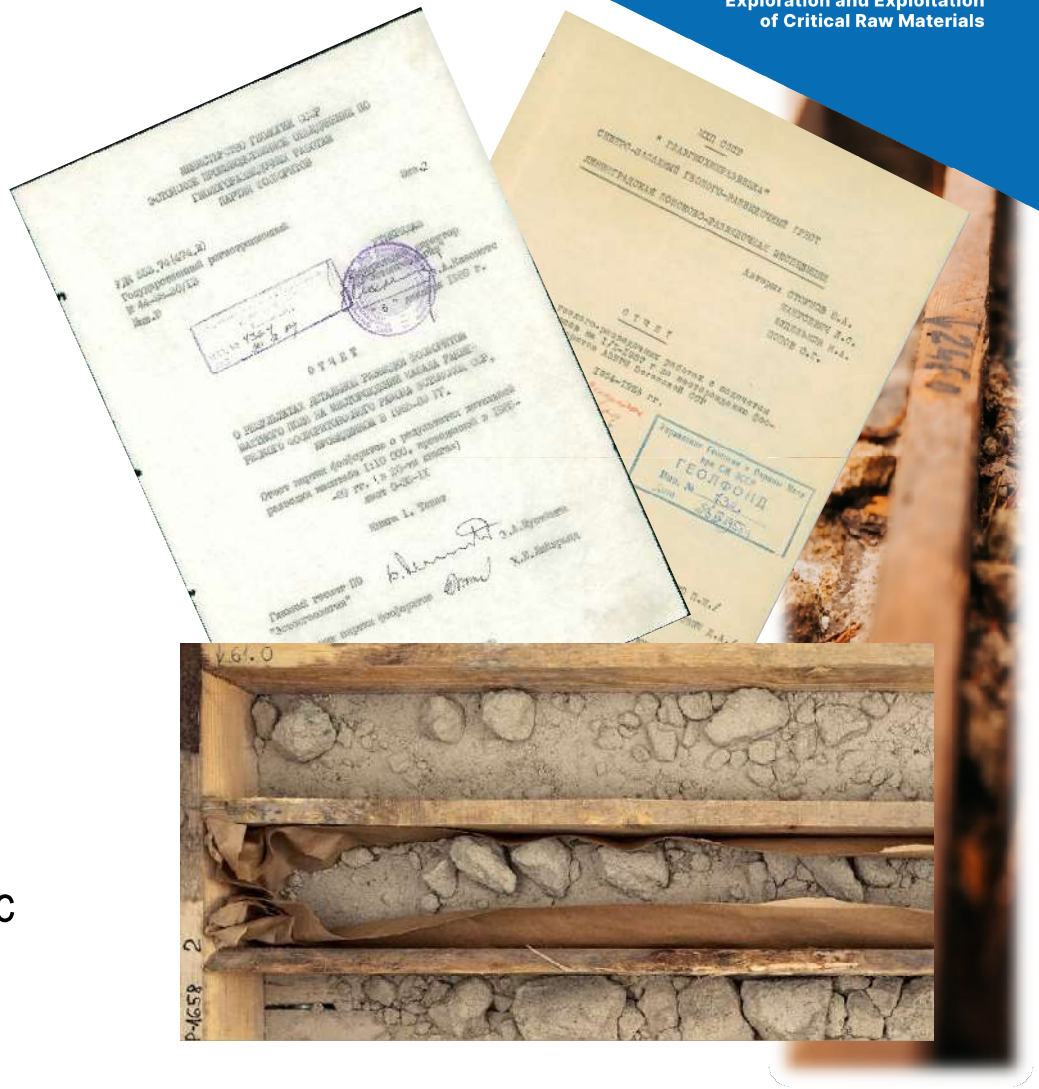
- Extensive exploration during 1950-1980.
- Thousands of drill cores were drilled and >10 000 samples have been analysed.
- Small number of poor-quality cores have been preserved.
- Reports are preserved in the Geological Archive and digitized (.pdf's) versions can be publicly accessed at https://fond.egt.ee/fond/
- Exploration was ended due to strong opposition from the public, the so-called „*Phosphorite war* "
- Until the establishment of GSE in 2018, no systematic phosphorite exploration in Estonia for 30 years



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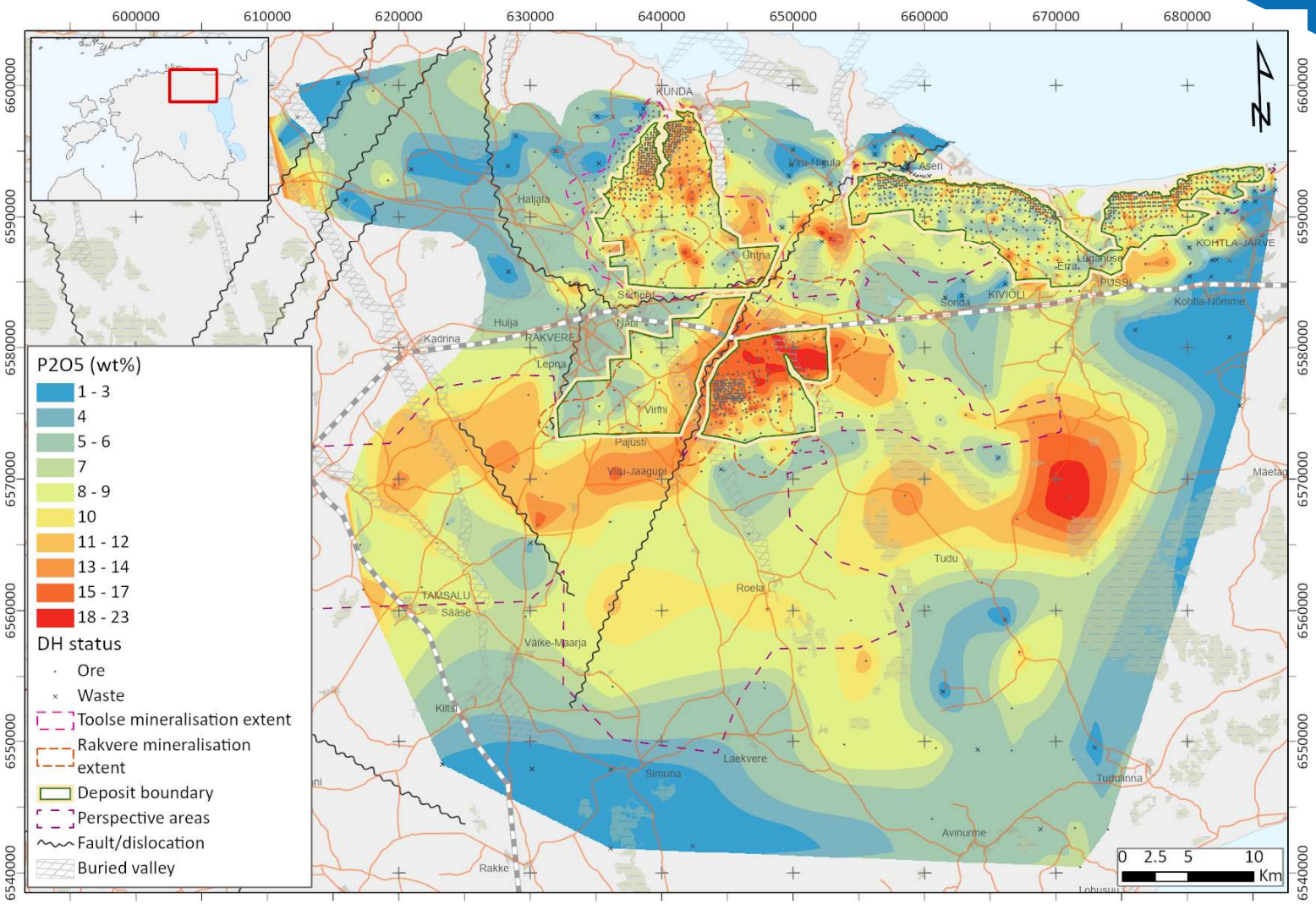
P_2O_5 grade map



Date created: 02.05.2022 Author: johannes.vind

Coordinate system: L-EST97 (EPSG:3301)

L. Joosu, et al., 2023

Rakvere deposit:
- 1900 Mt@13%
- 140km^2

Toolse deposit:
- 612 Mt@9%
- 110km^2

Aseri deposit:
- 312 Mt@8%
- 122 km^2

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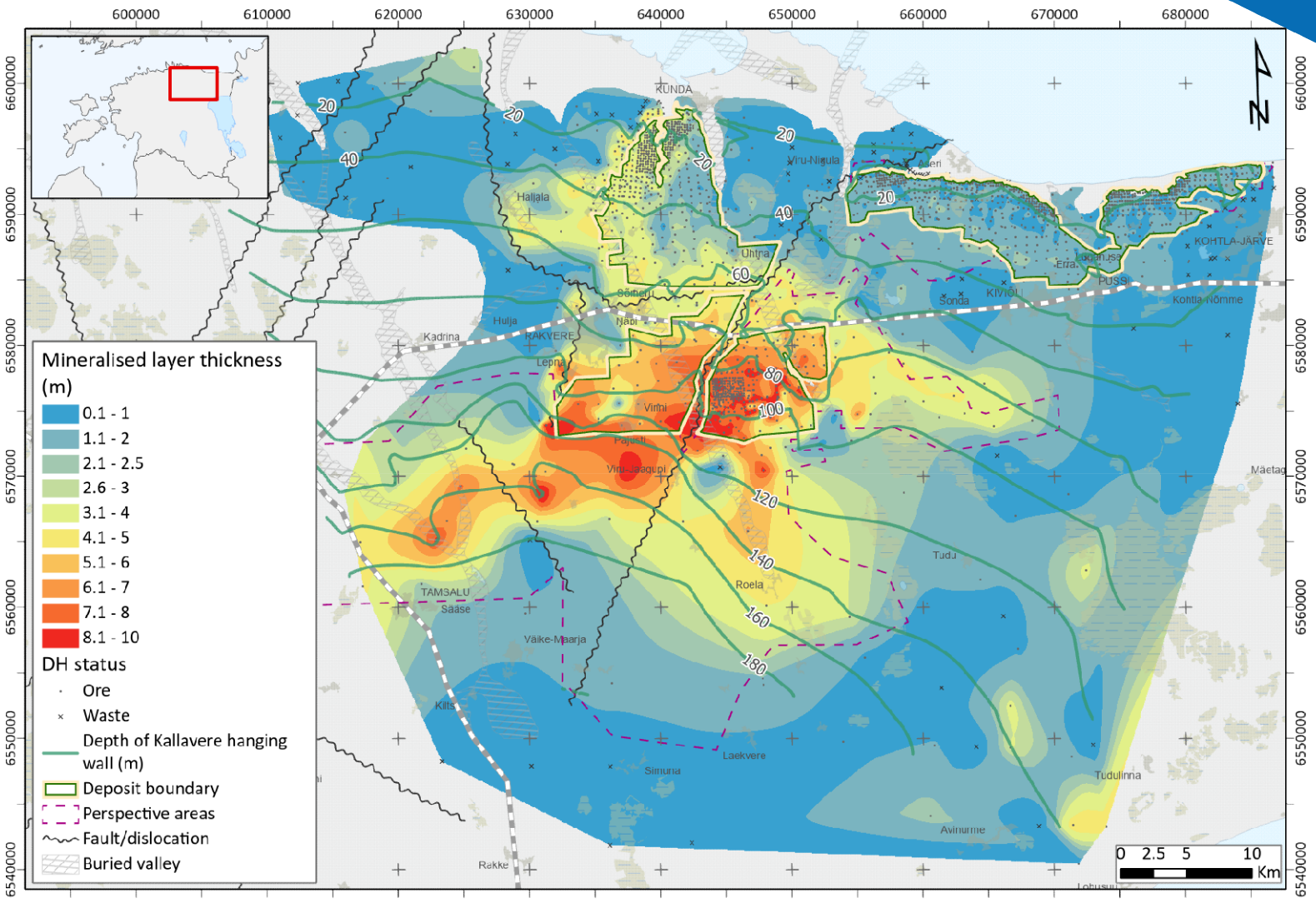
Depth and thickness



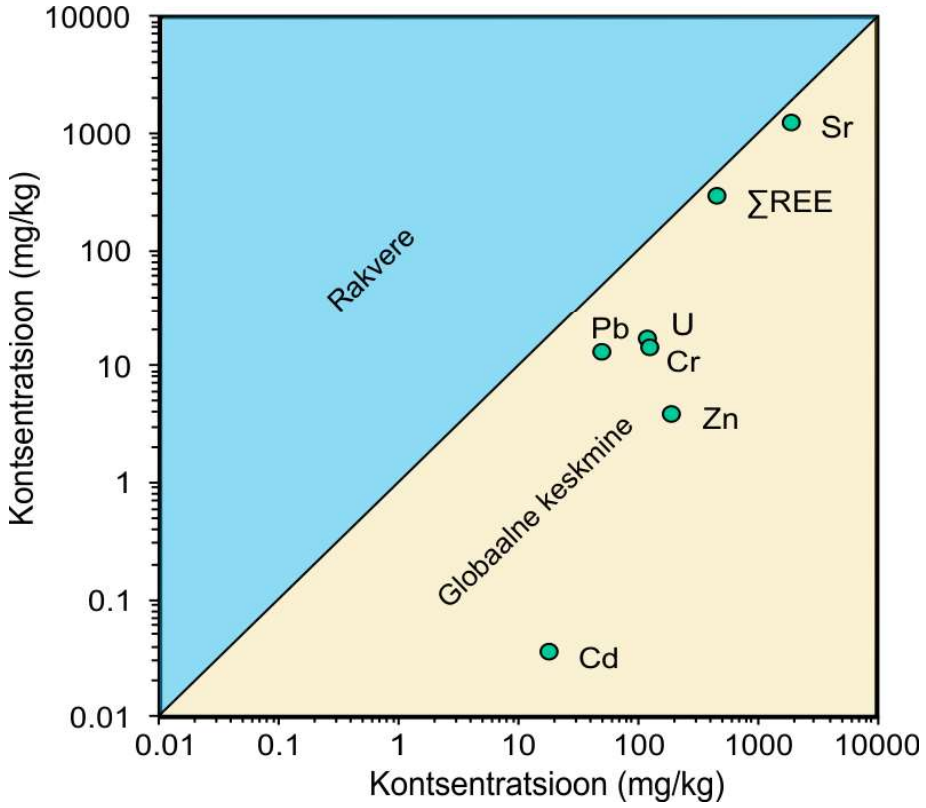
Date created: 20.06.2022 Author: johannes.vind

Coordinate system: L-EST97 (EPSG:3301)

L. Joosu, et al., 2023

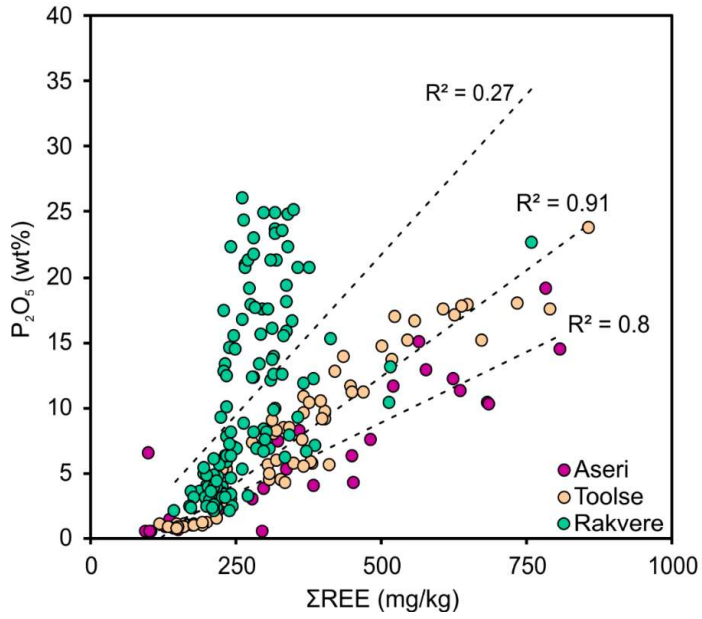
Trace elements in phosporite

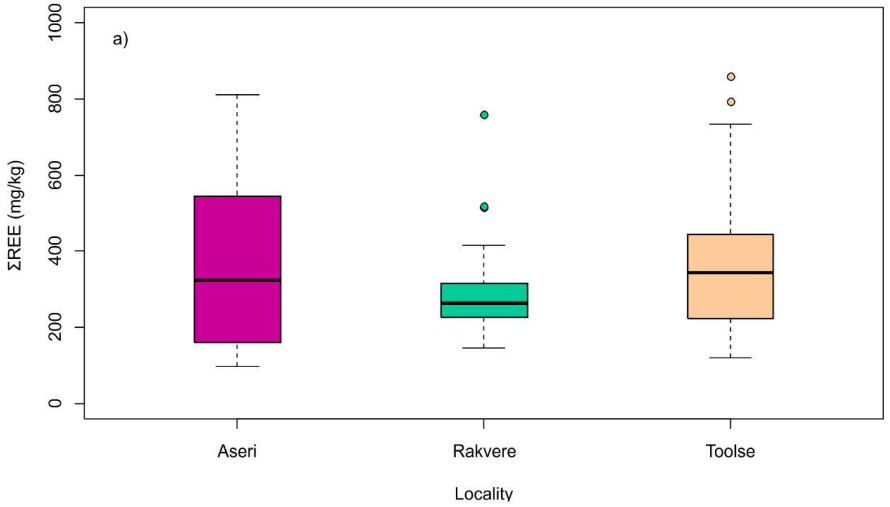
- Low values compared to global averages
- U values are 4 times lower than the world average
- Order of magnitude lower Cd concentrations (world average 18 mg/kg, in Estonia ca 0.05 mg/kg).



Rare Earth Elements

- In the Toolse deposit, 300-400 mg/kg, in the apatite shells ~1200 mg/kg.
- In the Aseri deposit, similar concentrations in ore, in apatite shells ~2000 mg/kg.
- In the Rakvere deposit, there is no significant enrichment of REEs, ~270 mg/kg.





Current exploration

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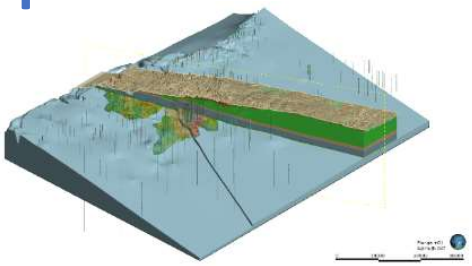

ANALYSES & MODELLING

FORMATION OF GEOLOGICAL SURVEY OF ESTONIA

2023 Q2 RESULTS OF DRILLING & MODELLING

SCOPING

PRE-FEASIBILITY

FEASIBILITY

2018 — 2019 — 2020 — 2021 — 2022 — 2023–2025

DECISION

DECISION

DECISION

PLANNING AND PERMITS

EXPLORATION DRILLING

Q4 REPORT ON FOCUS AREAS, MINING COST & HYDROGEOLOGY

Ongoing phosphorite exploration

- **Identify the economic potential of phosphorite valorization in the target area while minimizing the environmental impact.**
- **Find economic ways to utilize associated resources (including REEs, K, etc.).**

Take away

- Phosphorus and rare earth elements (REE) are listed as critical raw materials by the EU
- EU imports 85% of its phosphorus demand and 100% REE demand
- In sedimentary phosphorites, REEs substitute diagenetically in the apatite structure, meaning they can be a potential resource for REEs
- Estonia has significant phosphate resources, containing elevated concentrations of REEs
- The Geological Survey of Estonia is conducting a research and exploration project to gain a better understanding of its economic potential and environmental impact.

Thank You

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