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REPower-CEST project results

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Geological Survey of Finland

Suomen ympäristökeskus
Finlands miljöcentral
Finnish Environment Institute

GTK

VTT

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Clean Energy System Transition
(REPower-CEST)

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REPower-CEST project – Clean Energy System Transition

Consortium: SYKE, **GTK**, VTT
Funding: EU recovery and resilience plan (RRP) for Finland (NextGenerationEU)
Main product: Energy transition roadmap 2035 for Finland

WP3 "**Critical Raw Materials**" coordinated by GTK

Topic for today:

Task 3.2. National Exploration Programme

- Peräpohja regional geology
- Vähäjoki fingerprinting work

THE FOCUS

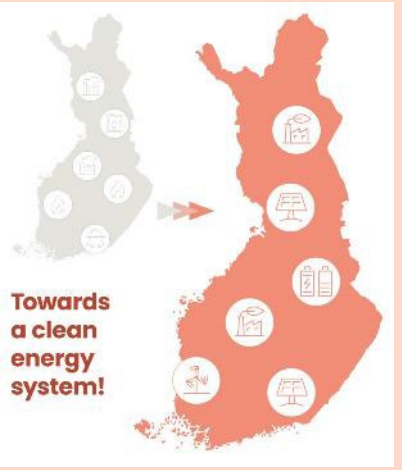
Energy transition and the efficient use of natural resources to increase the resilience, security, and sustainability of Finland's energy system.

THE PURPOSE

To create a comprehensive view of the means, effects, challenges and opportunities related to the green transition.

THE GOAL

To create information management solutions, services, and tools for promoting the transition.



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Task 3.2 Aims

- Generate EU's CRMA required National Exploration Program (NEP) concept
  - Instead of concept we wrote Finland's NEP for 2025-2030, submitted to TEM in May 2025, and commission in September 2025
- Test the NEP concept in practice
  - Instead of testing the concept we carried out tasks outlined in EU's requirement for NEPs in Peräpohja Belt

Main aims for Peräpohja Belt NEP work:

1. Gain better understanding on structural framework and model it in 3D
2. Map and model spatial extent and location of evaporate hosting Petäjäskoski fm in 3D
3. Carry out fingerprinting work on Vähäjoki Fe-Cu-Co-Au deposit – what of a creature it is?

Focus on epigenetic Au-Co and Fe-Cu-Co-Au mineral systems, 1 & 2 relevant also to magmatic Ni-Cu mineral systems

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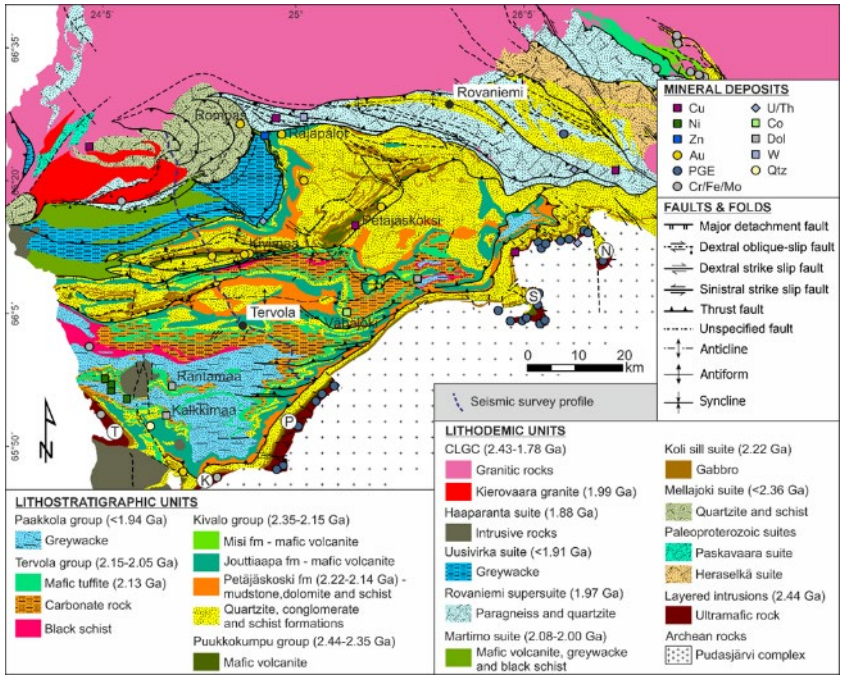
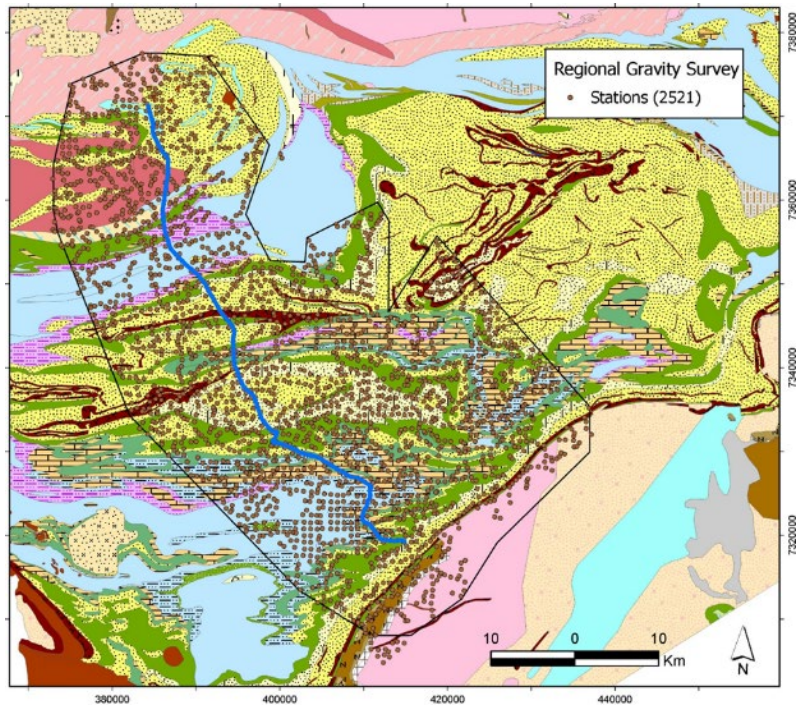
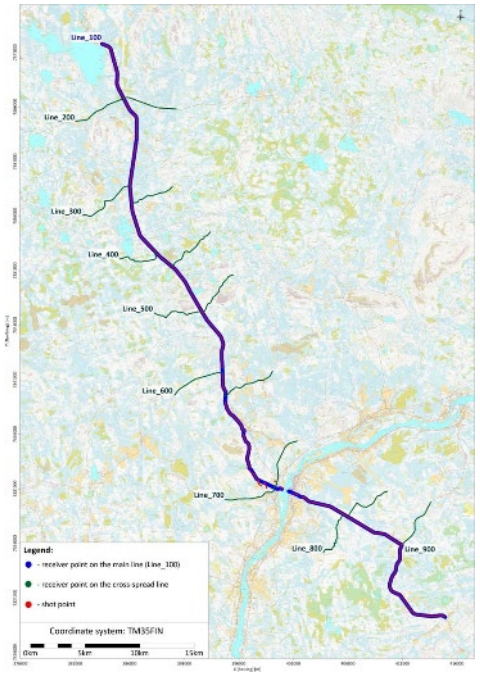
Regional scale work

- 70 km reflection seismic profile across the belt
- Ground gravity survey at the core part of the PB
- Bedrock mapping (scouting) & petrophysical sampling
- Joint geophysical & geological 3D modeling

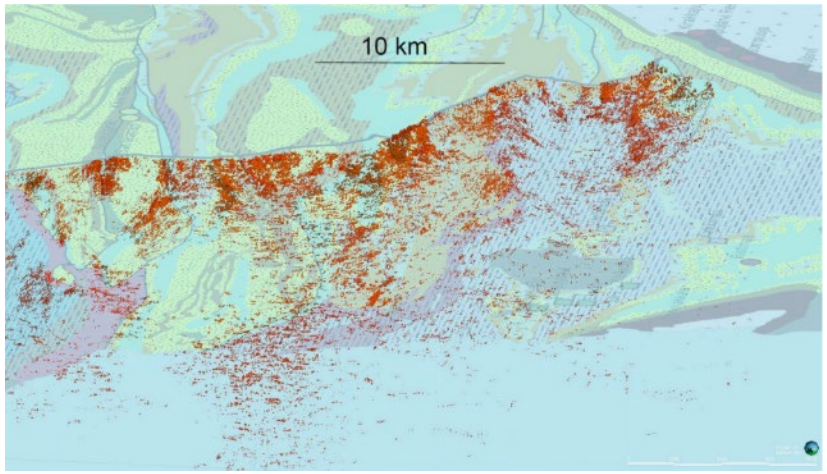


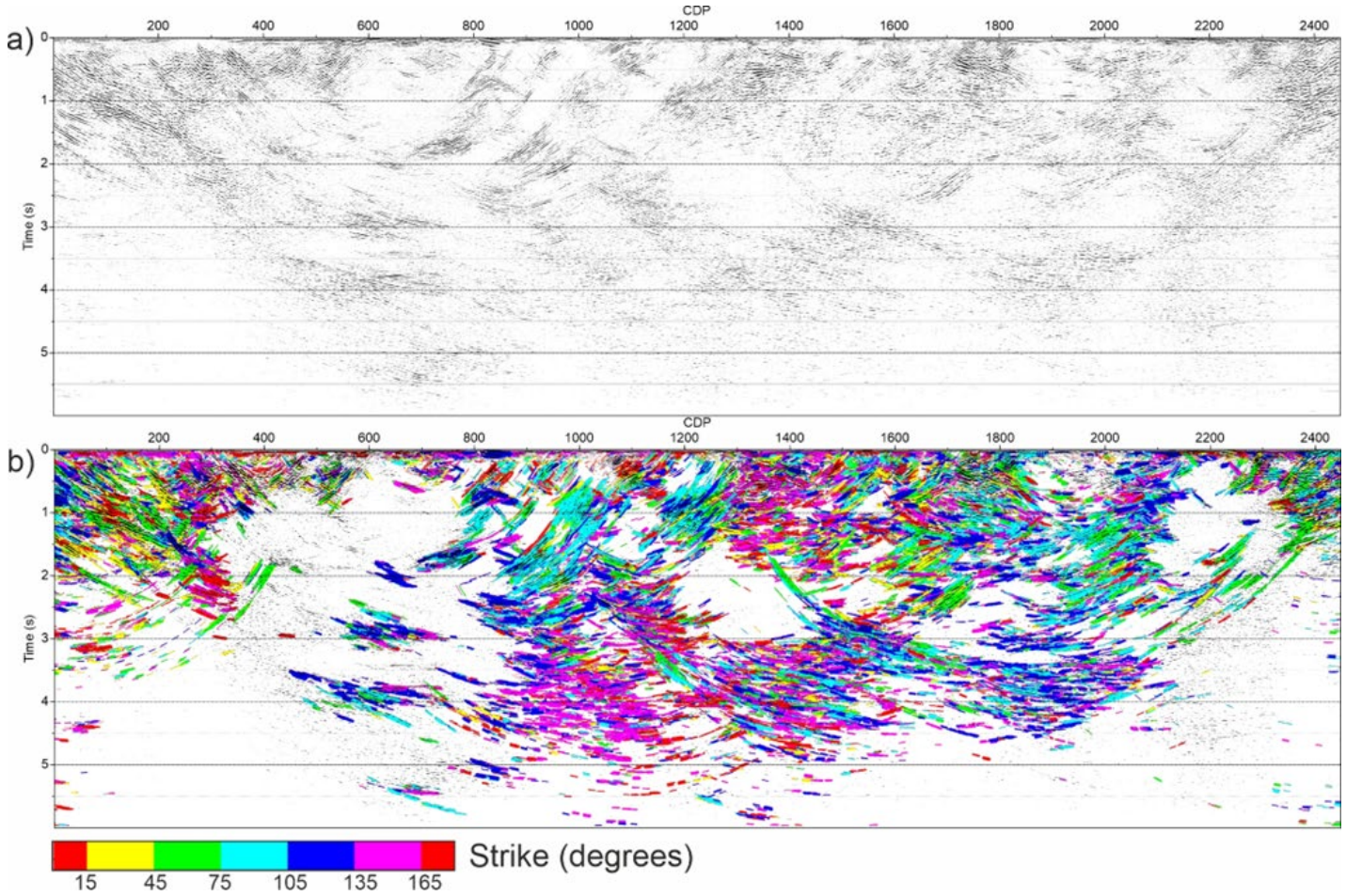




Seismic survey & processing

- Survey conducted by Geopartner Geofizyka ltd & GTK in September 2024
- 8 additional cros-spread lines were laid for improved azimuthal coverage required by 3D orientation analysis
- Data processed in two steps: 1) conventional DMO stack and post-stack time migration, 2) processing with reflection orientation analysis workflow





Migrated stack section (a) and the same section overlayed with the migrated strike attribute (b). Thresholding by error < 31° and semblance > 0.002. Plot at no VE assuming V=6000 m/s.

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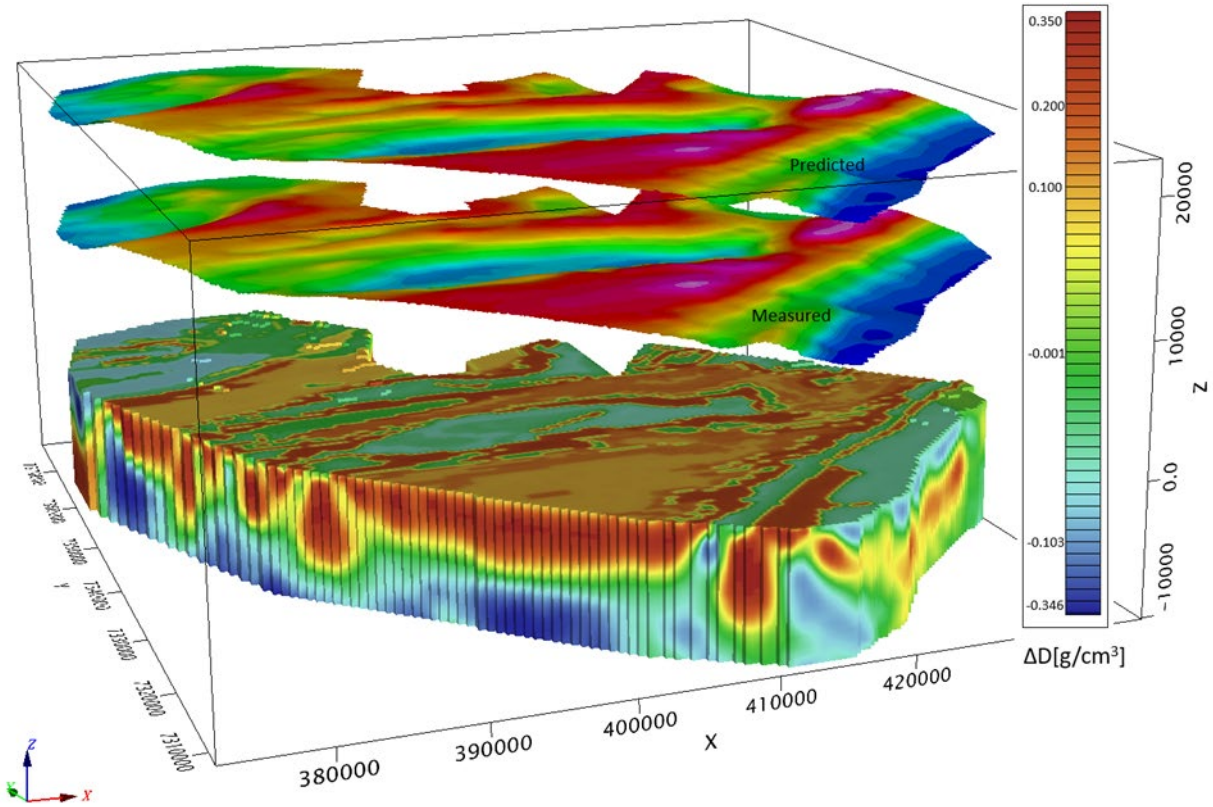
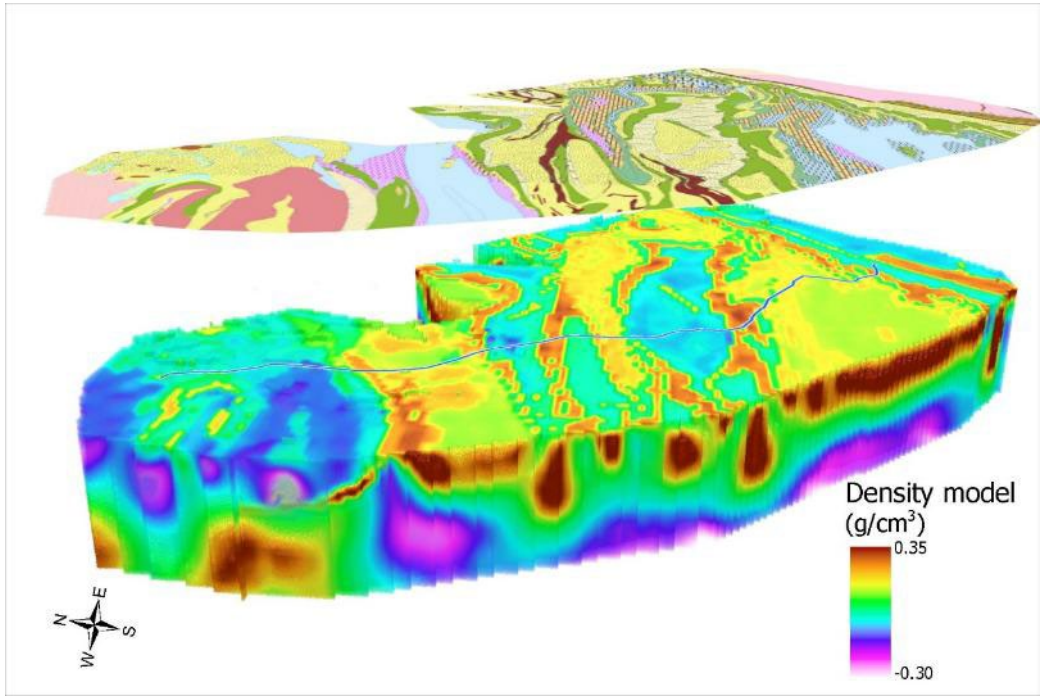
Gravity model



3D density model of Peräpohja survey area obtained by constraining the inversion by density model constructed for the geology. Measured and predicted gravity anomalies are presented on the same color scale over the model



3D-density model obtained by constraining both parameter constraints and gradient constraints. The density color scale is presented as relative values.

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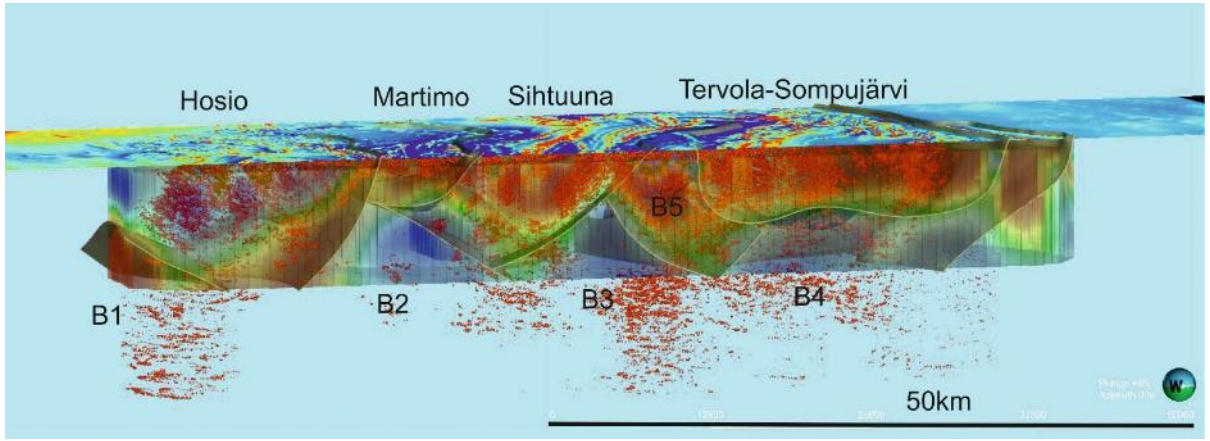
Geological 3D model

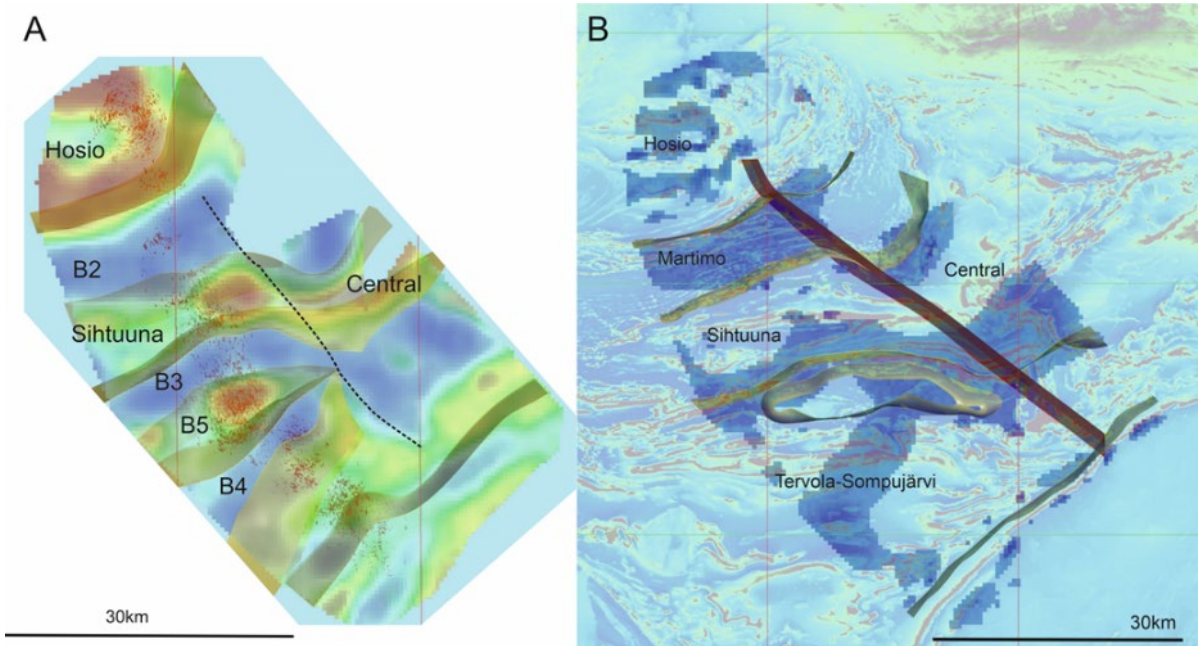
- Geological 3D model was constructed using acquired seismic and gravity data & model together with surface geological data and pre-existing geophysical data
- Model volume was divided into 10 main domains based on their geophysical and structural characteristics

Table 1. Structural-geophysical domains and their structural and geophysical characteristics.

Structural-geophysical domains	Seismic data	Gravity inversions	Surface patterns
Hosio	N dipping seismic reflectors and overprinting S dipping reflectors. Reflectivity stronger than B2.	North dipping, low-angle density contrasts near the surface. Steeper at domain boundary.	Similar pattern as in Martimo
Martimo	Strong reflectivity, bowl shaped reflectors aligning with density anomalies. Dip changes from N to S dipping moving towards N.	High density, low angle bottom contact, relatively shallow depth compared to Sihtuuna	Rounded shapes in airborne magnetics and foliation measurements, Recumbent folding observed
Sihtuuna	Consistently N- dipping, steep reflectors	High and low. Inconsistent patterns. Strike of density contrasts E-W.	Consistent E-W striking pattern in airborne magnetics and foliation measurements lithological contacts not folded and parallel to main schistosity.
Tervola-Sompujärvi	Scattered reflection patterns, strong reflectivity	High density	Complex folding patterns with E-W axial traces

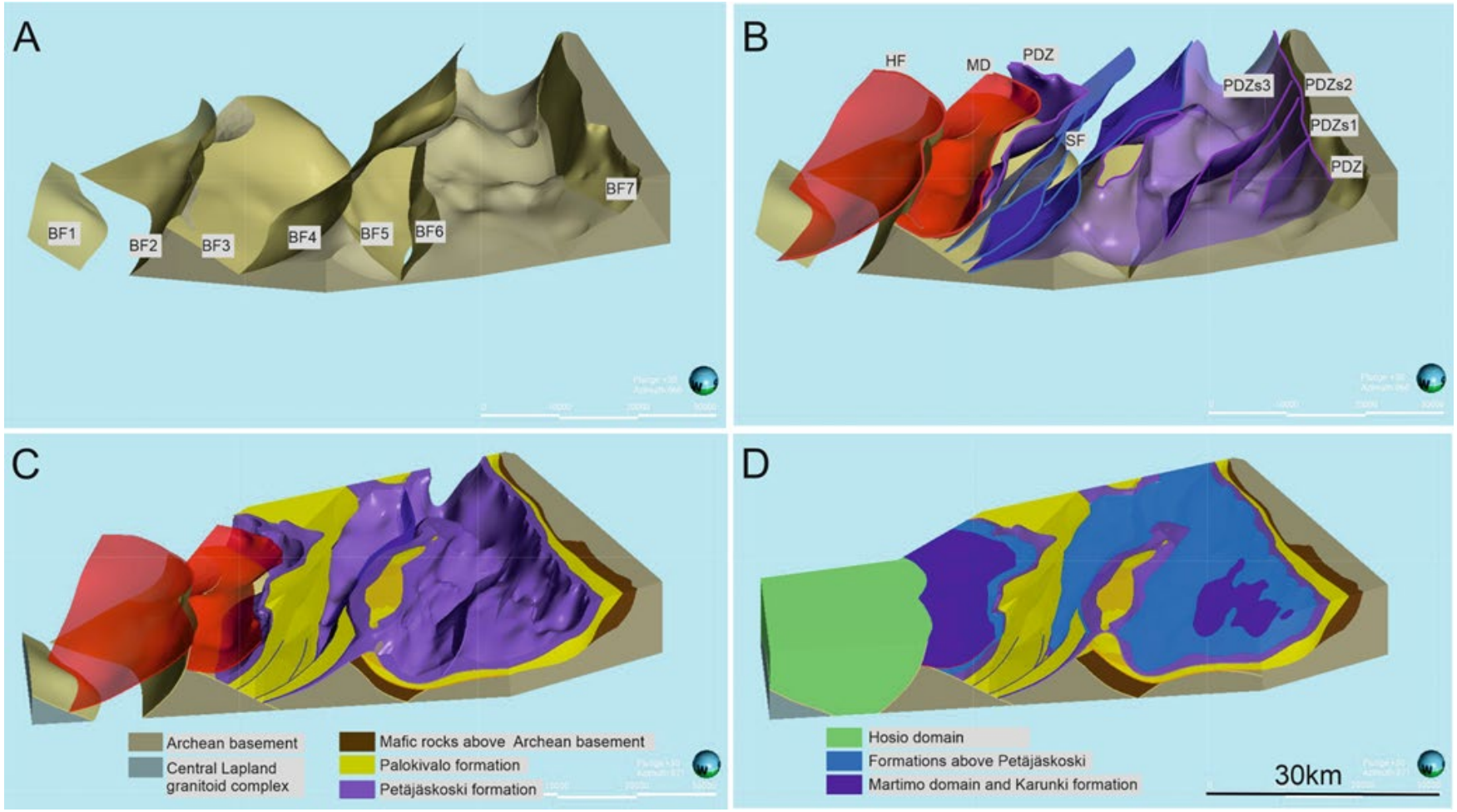


Structural-geophysical domains, section along seismic line. View towards east.



Structural-geophysical domains at section from -6000m to -10 000m B) Domains at the surface, low density values are filtered and overlain by transparent airborne magnetic anomaly map.

Geological 3D model



A) Archean basement and basements faults
B) Martimo (red), Sihtuuna (blue) and fault systems related to the Petäjäskoski formation (purple)
C) lithologies under the Petäjäskoski formation and
D) all modelled lithologies. View towards the east.

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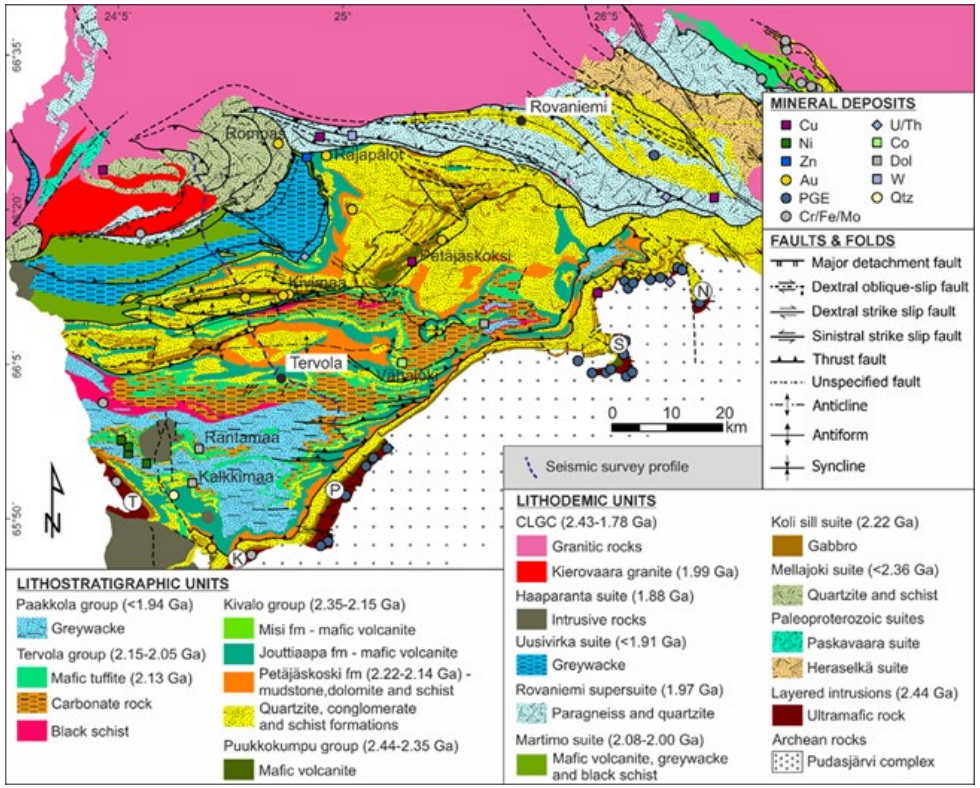
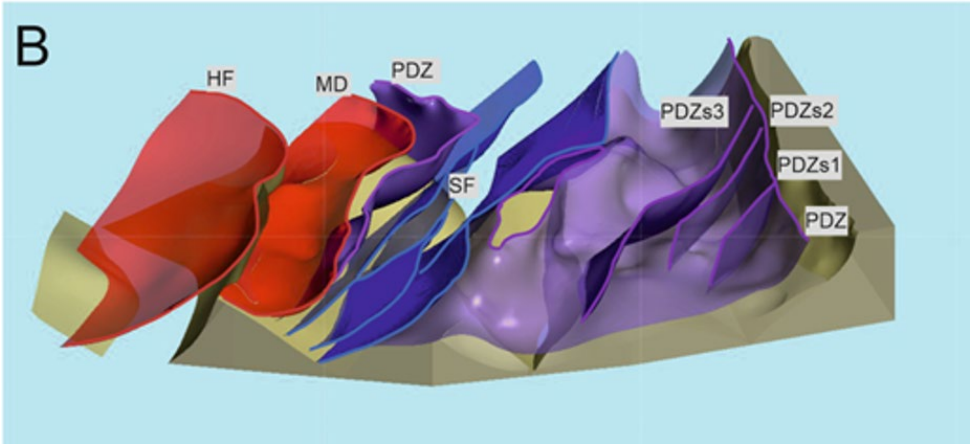
Implications to the structural PB framework

- Martimo and Hosio domains are thin-skinned, low-angle Nappe systems generated in D1 thrust stage as suggested by Lahtinen et al. (2019)
- At central and southern parts D2 N-S compressional thrust and fold features dominate and deformation is influenced by reactivation of Archean basement faults as suggested by Piippo et al. (2019) – however no indications of NW-SE oriented central graben exists, rather a similarly oriented (blind) faulting
- South of Sihtuuna Petäjäskoski fm acted as detachement surface resulting thin-skinned thrust folding on ovelying sequences (also suggested by Piippo et al. (2019))
- Petäjäskoski significant not only as potential ligand (Cl, S) source but as a significant strutural feature





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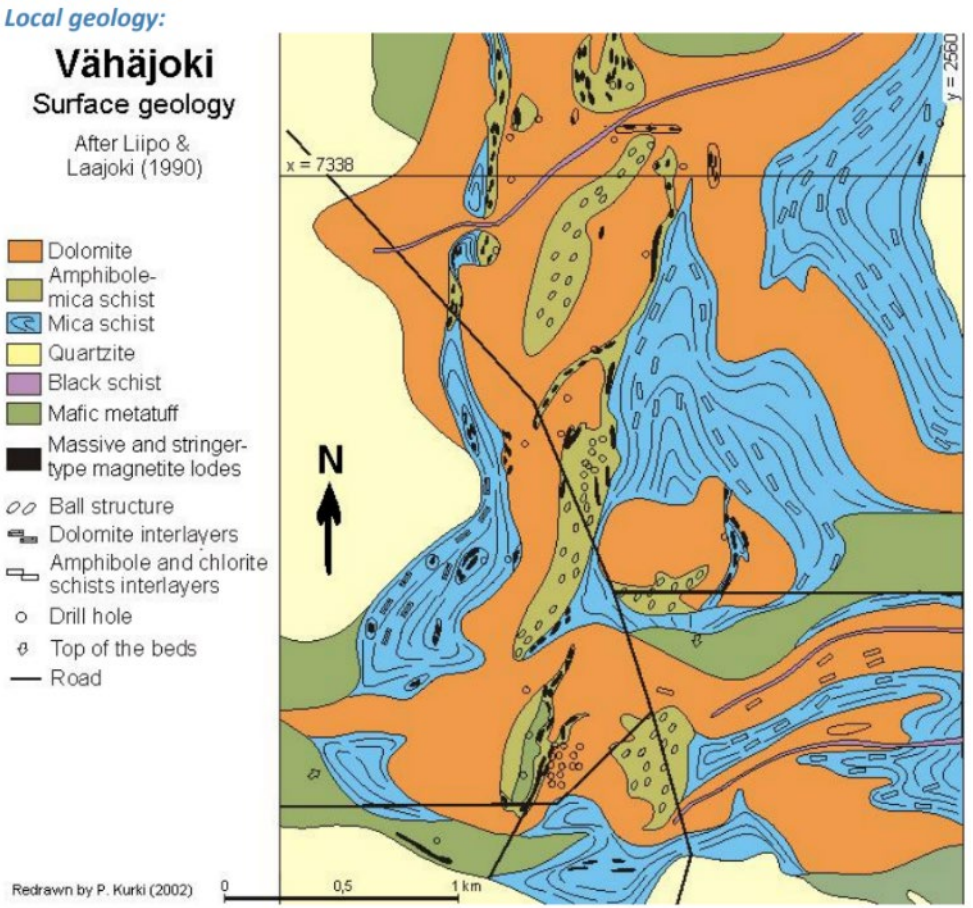
Vähäjoki Fe-Co-Cu-Au deposit fingerprinting

- Deposit consist of 30+ magnetite-rich bodies in an c. 2.5 x 3.5 km area
  - magnetite bodies are variably enriched in Cu, Co, and Au
- *Non-compliant* res. est.: 10.2 Mt @ 39.4% Fe, 0.16% Cu, 290 ppm Co, 0.2 ppm Au
  - Co-Cu-Au richest ore bodies 0.1-1.0 Mt @ 0.05-1.0% Cu, 0.03-0.5% Co, and 0.5-1.0 ppm Au
- Host rocks: dolomitic marble with subordinate mica schist & minor mafic volcanic rocks
- Deposit is hosted by an extensive breccia system, Co-Cu-Au parts always hosted by mgt-rich rocks
- Fe ore: mgt-chl-bt (+dolomite & carbonates as clasts)
- Fe-Co-Cu-Au ore: mgt-bt-afb*-chl-py-po-cpy ± cob, apy, bor, moly, tellurides, native gold

*Actinolite, cummingtonite & hornblende



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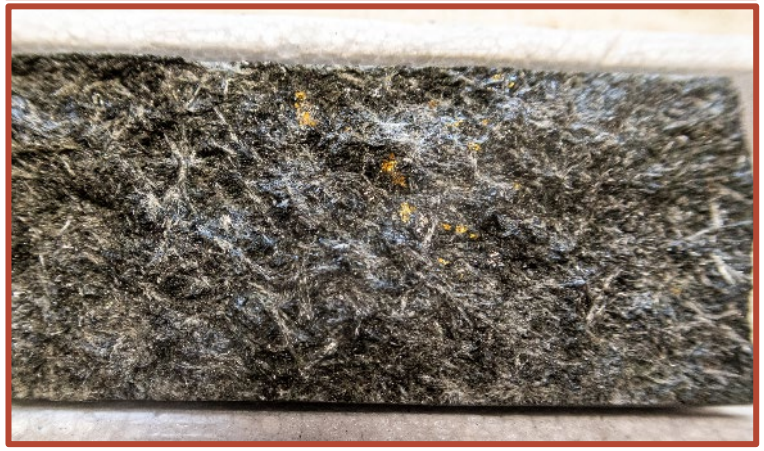
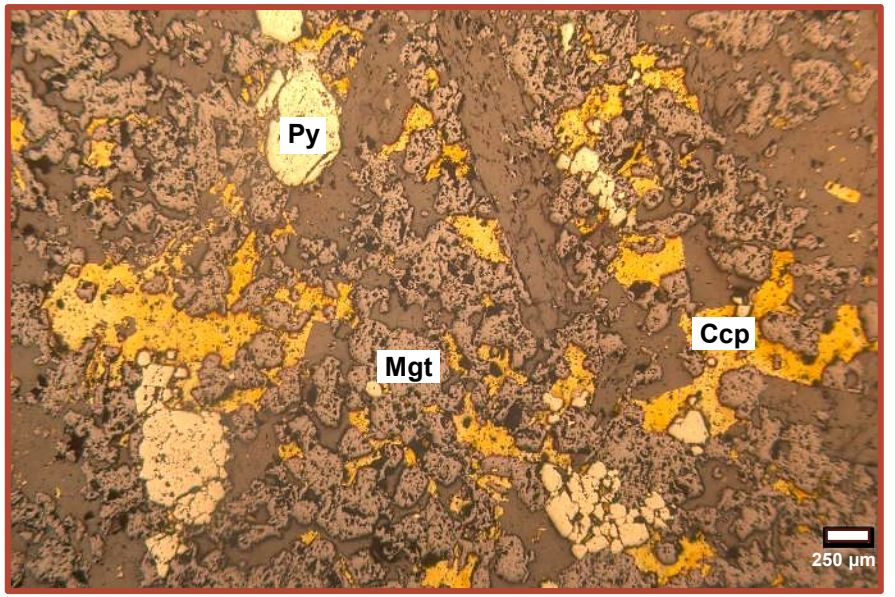
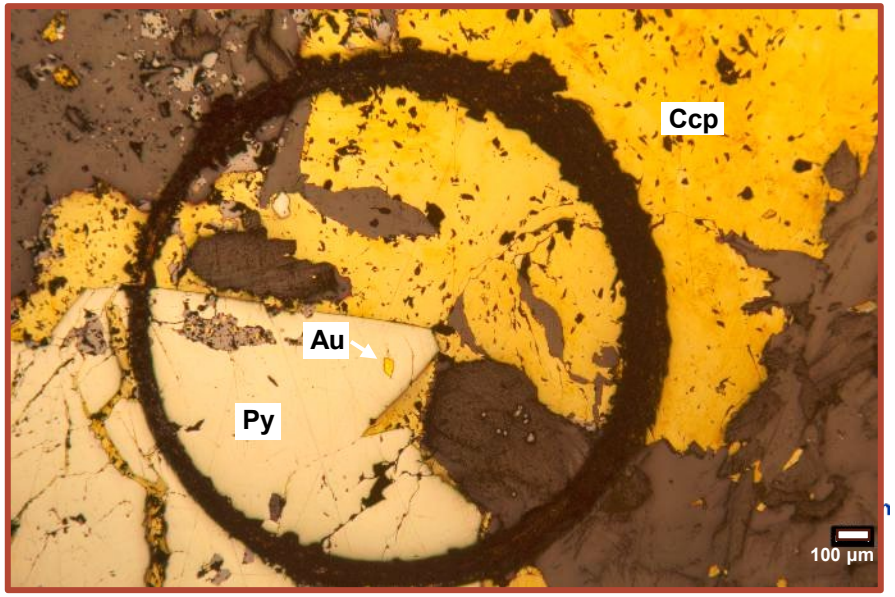
Vähäjoki ore







Breccia system in the field

Vähäjoki area: dolomite clasts, chlorite, biotite, and/or amphiboles and magnetite in matrix

Meanwhile at Ahvenlampi, c. 20 km NNW from Vähäjoki at the same stratigraphical level….

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Whole rock chemistry

- Dolomitic marble
- Fe ore

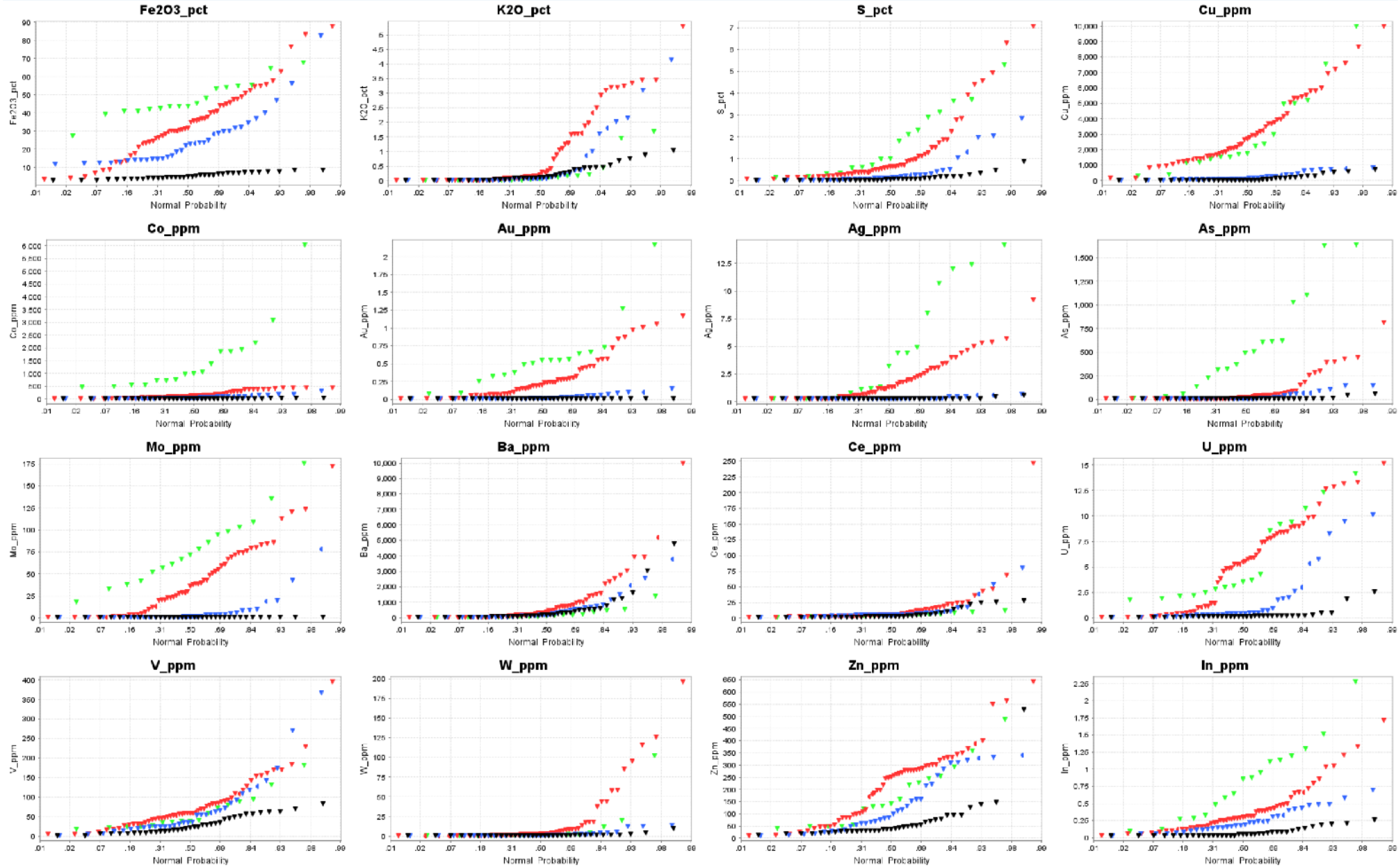
Fe + K, V

- Fe-Co-Cu-Au ore
- Fe-Cu-Au ore

Fe-Cu-Co-Au + Ag, As, Bi, In, Mo, S, Sb, Te, U, W, Zn + more K

High Ba content throughout the system

Co-As association – Separate Co-stage?



Magnetite geochemistry

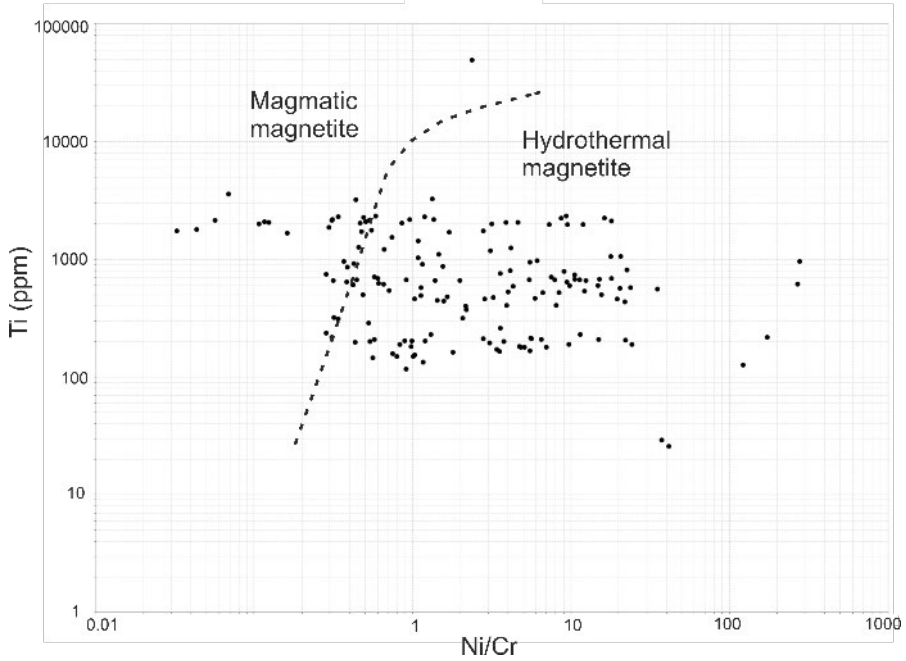
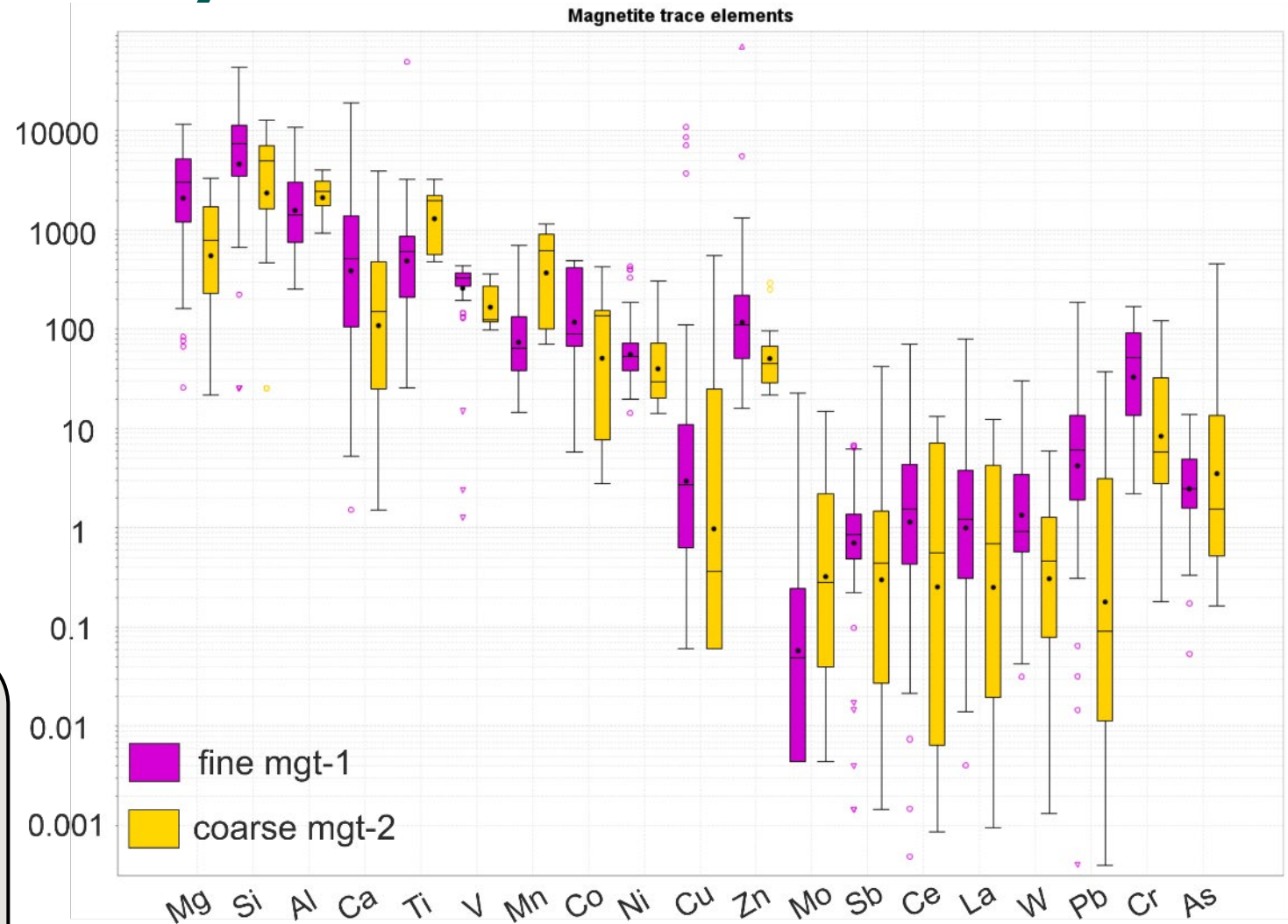


Diagram by Dare et al. (2014)



High median **Mg**, **Si**, **Al** (thousands of ppm), **Ca**, **Ti**, **V** (hundreds of ppm), **Co**, **Mn** (c. 100 ppm)

Different generations of mgt based on textural and trace element characteristics: Fine **mgt-1** followed by coarse **mgt-2** associated with coarse sulfides

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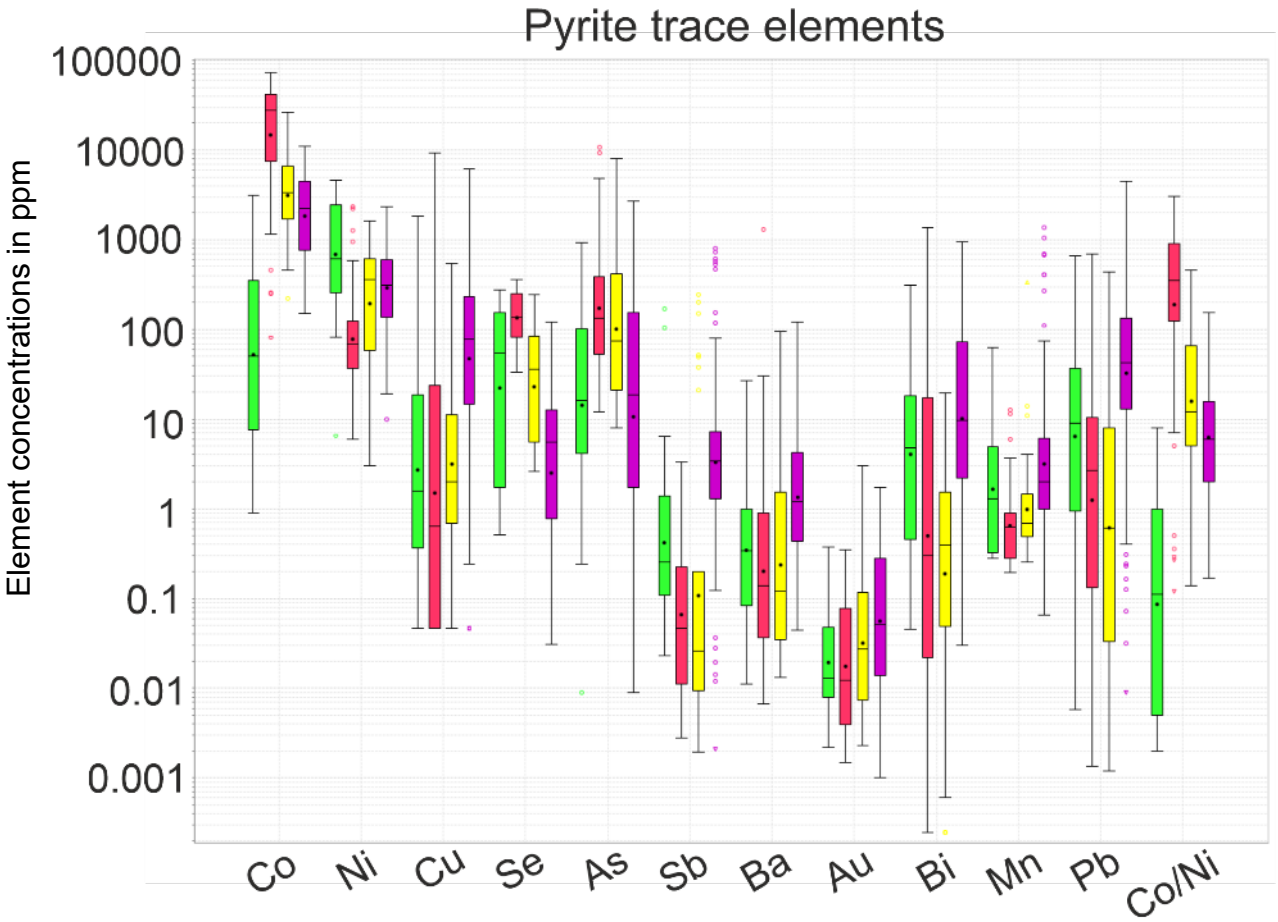
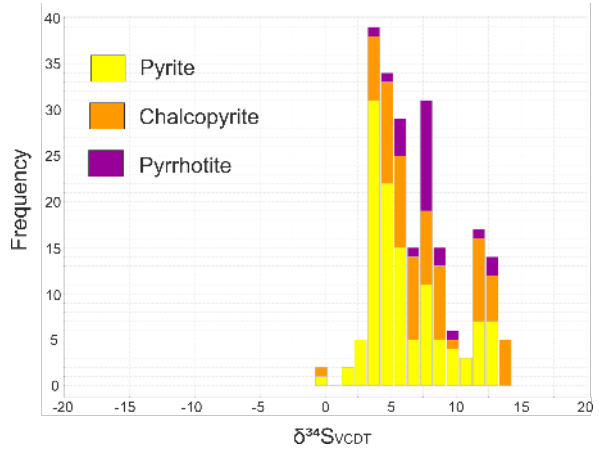
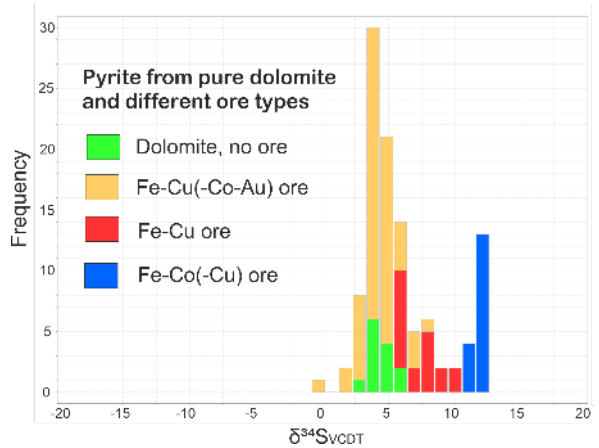
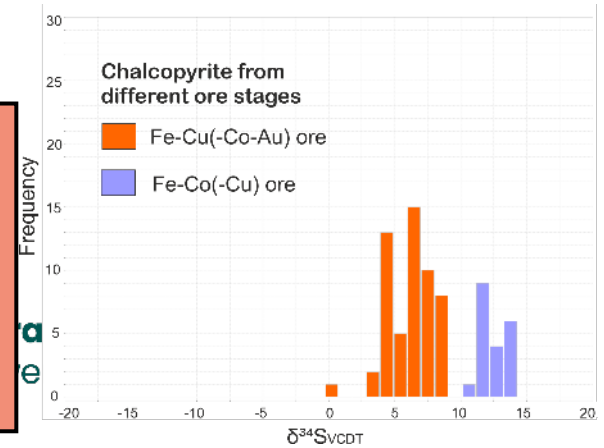
Pyrite trace elements and S-isotopes



- Anhedral Py, no ore
- Subhedral Py, Fe-Co(-Cu)
- Sub- to euhedral Py, Fe-Cu(-Co-Au)
- Anhedral Py, Cu-(Fe-Co-Au)

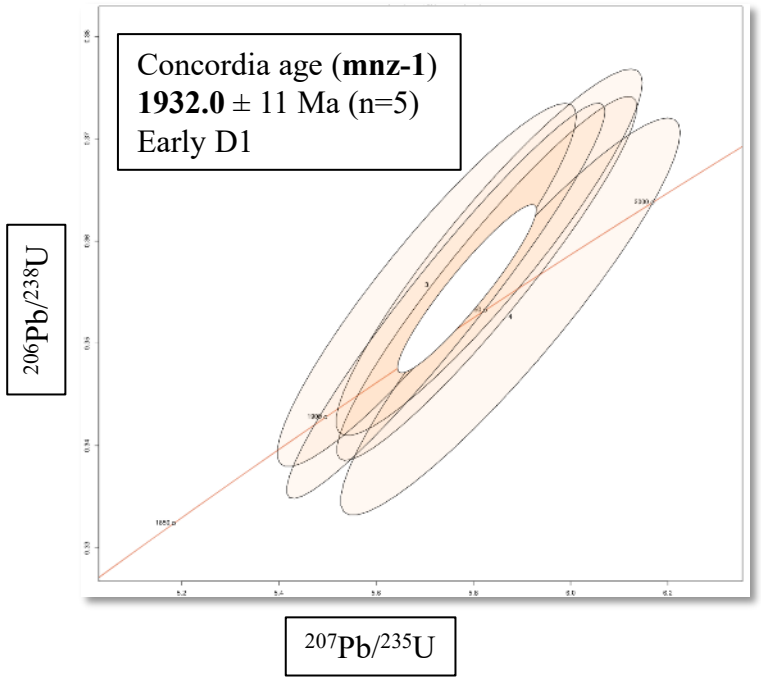


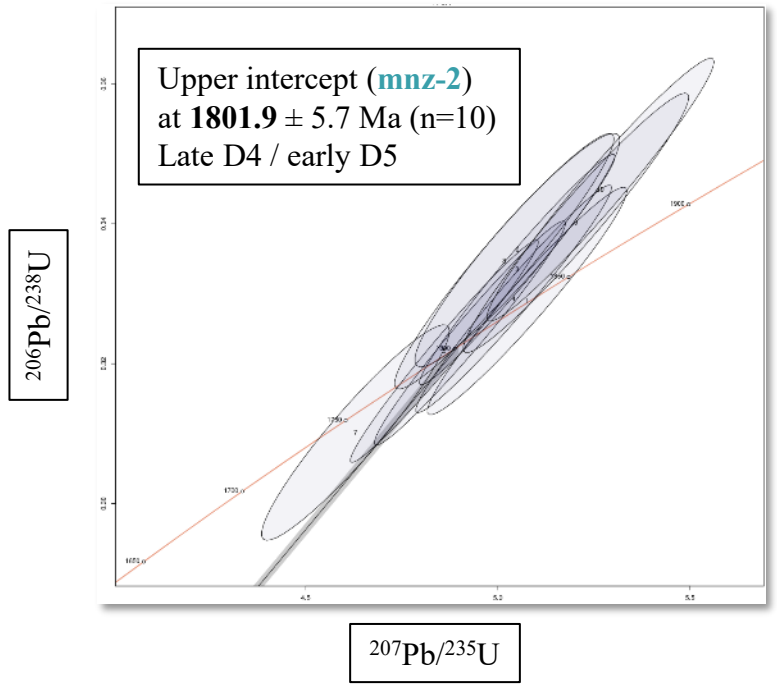


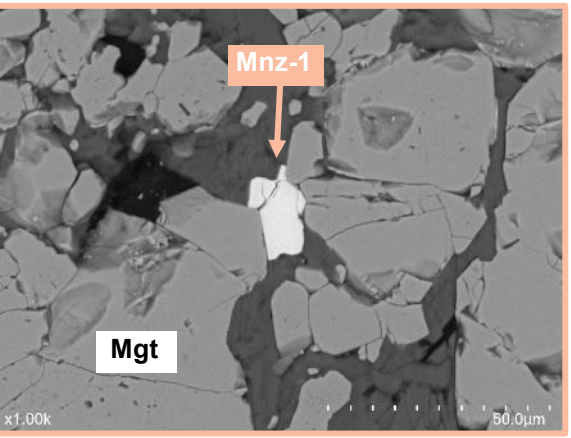


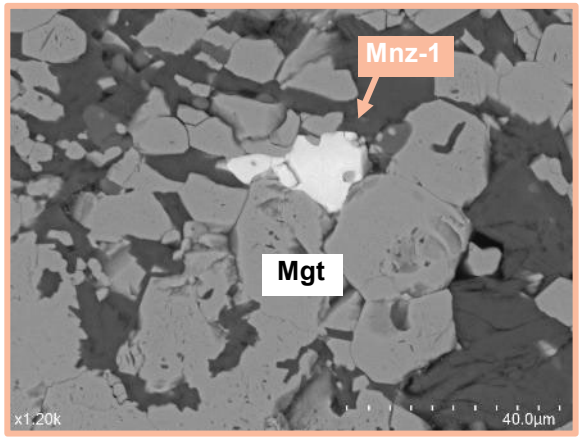
- High to very high Co-concentrations in pyrite (up to 7 wt%) in Cu-Co-Au ores
- δ34S values of py & cpy vary between 0 to +14 per mil
  - Distinct S-isotope compostition of chalcopyrite in Co-rich and Co-poor ores
  - > +10 per mil δ34S values suggesting involvement of evaporate sourced sulfur

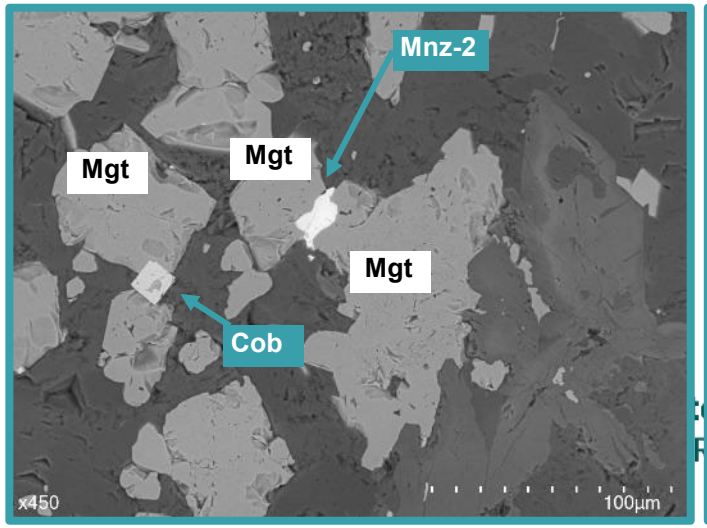
U-Pb geochronology - monazite

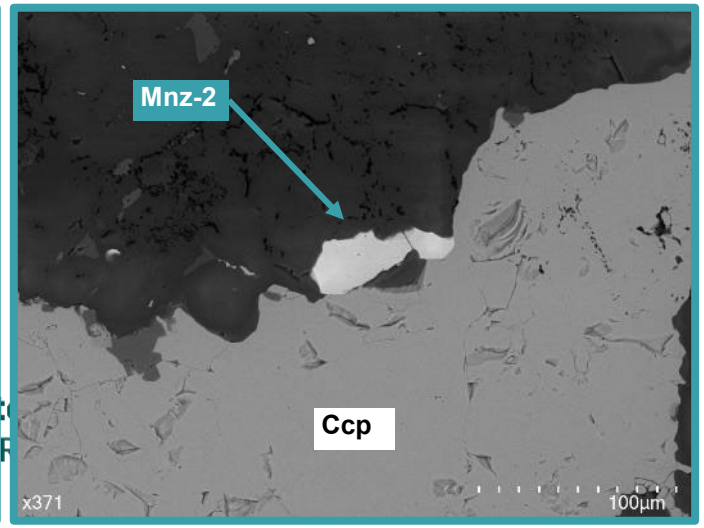




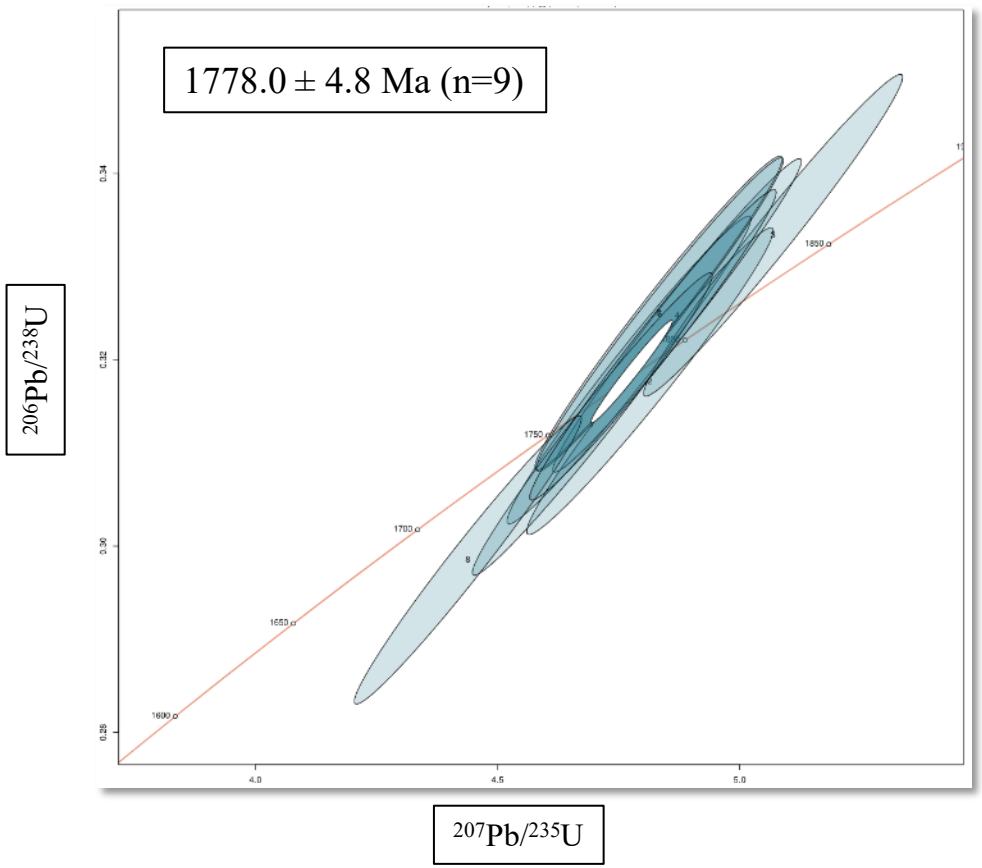


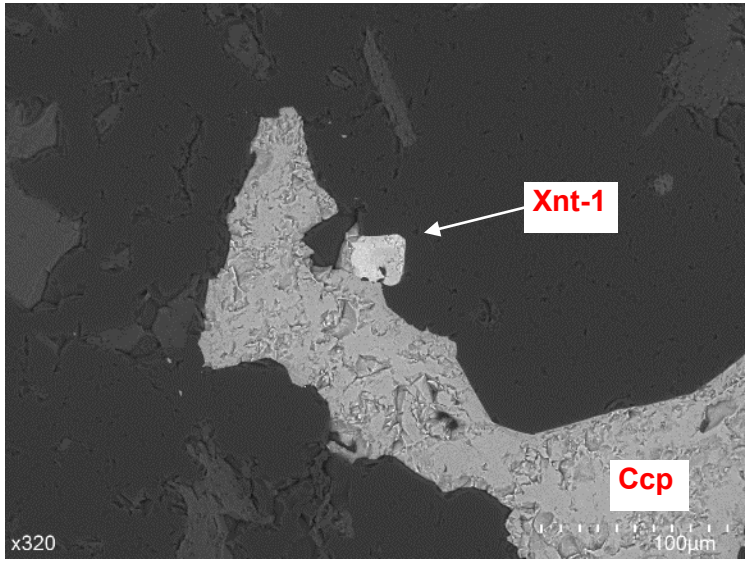


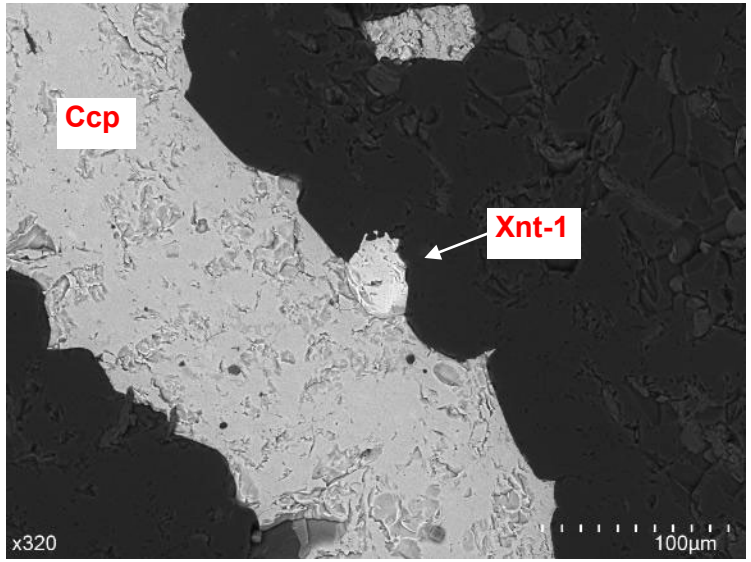


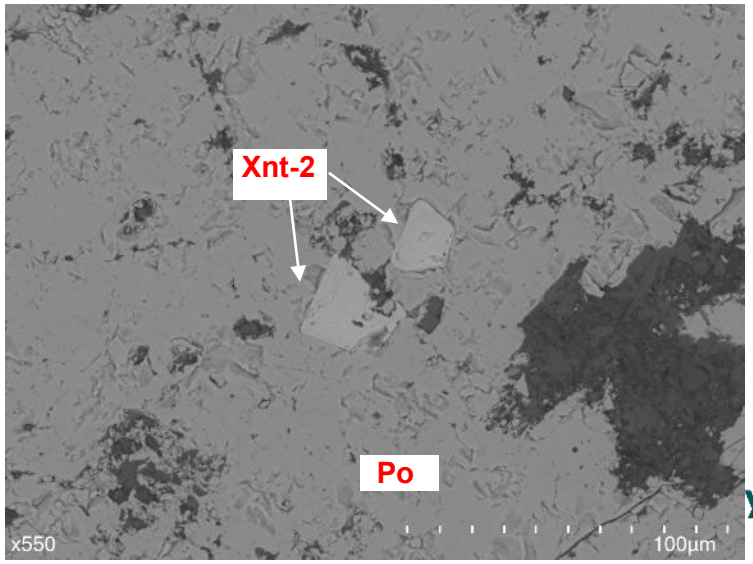


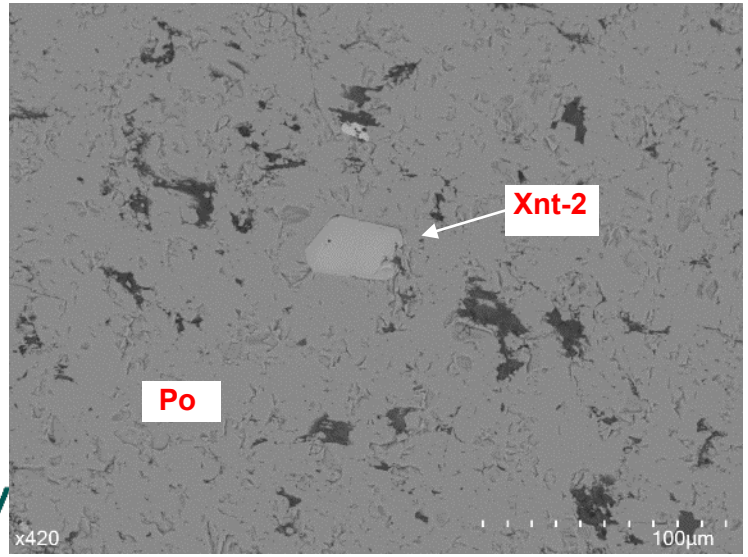
U-Pb geochronology - xenotime











Concordia ages:

Xtm-1 associated with Ccp (n=3): **1792.2** ± 8.4 Ma

Xtm-2 in recrystallized Po (n=6): **1771.5** ± 5.8 Ma

Combined age (n=9): **1778.0** ± 4.8 Ma → D5

Petäjäskoski fm evaporites

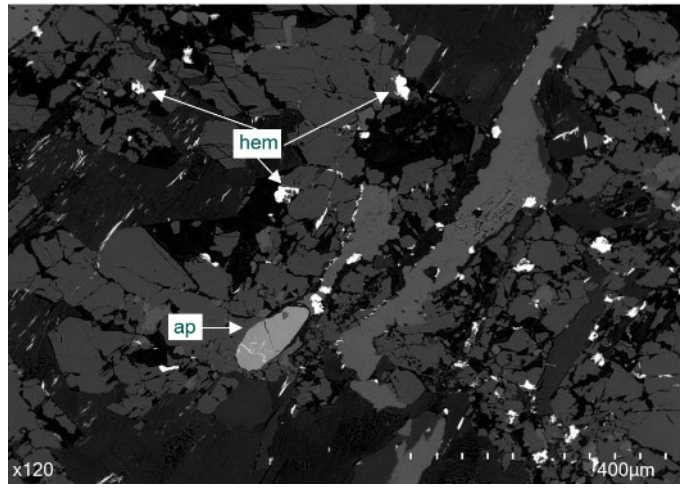
Kyläkoski et al. (2012) described Petäjäskoski Fm (Pfm)→ metasediments with **evaporitic** origin in Peräpohja

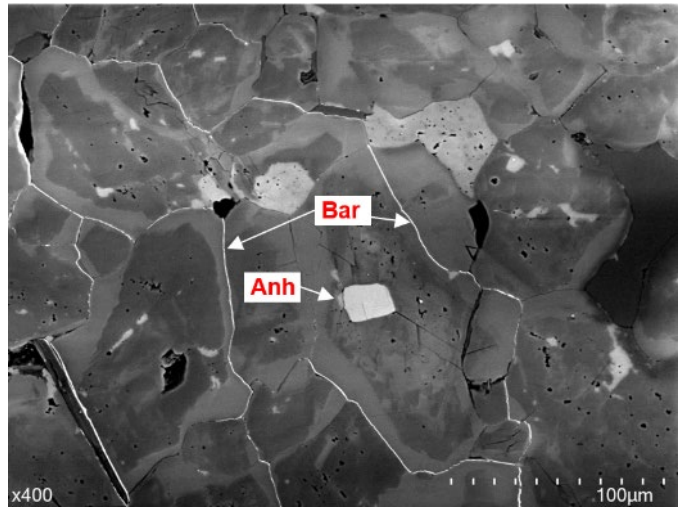
Mudstone-quartzite-carbonate sequence with Pfm affinition was recognized at the footwall of Vähäjoki

- Geochemistry & mineralogy of mudstones in Vähäjoki fits perfectly with **phlogopitic** end-member from Pfm
- Anhydrite + late barite veinlets
- Phosphorite layers

Source for chlorine needed to mobilize Fe and base metals, potential source for S and Fe?

Implications to the formation of breccia system hosting the deposit – initially collapse breccias related to dissolution of evaporate sequences?





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Summary

- Vähäjoki Fe-Co-Cu-Au deposit is a completely epigenetic, multi-stage deposit hosted by an extensive breccia system
- Geochemical signal: Fe-Co-Cu-Au ± Ag, As, Ba, Bi, In, K, Mo, S, Te, U, V, W, Zn
- Two texturally, mineralogically and chemically distinct stages:
  - Early magnetite stage: mgt-chl-bt
  - Sulfide stage(s): sulfides-afb-bt ± gold, scheelite, tellurides, possibly early Co-dominated and late Cu-dominated substages
- Age constraints:
  - Magnetite stage 1932 ± 11 Ma: early orogenic (early D_1)
  - Sulphide stage(s): 1802 ± 6 Ma - 1778.0 ± 4.8 Ma: late orogenic (D_4 - D_5), contemporaneous with known Au-Co deposits in PSB and KSB as well as base metal enriched Au-deposits in CLGB
- Sulphur isotope data: high δ34S values in sulfides suggest involvement of evaporate sourced sulfur

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Discussion

Genetic classification: Geochemistry, mineralogy, mineral composition, stage-wise formation consistent with IOCG definition presented in the literature, however:

- Magnetite and Cu-Co-Au were deposited in completely different tectonic regimes (130+ Ma time gap in between)
- Magnetite stage does not temporally correlate any known magmatism, coeval felsic intrusives for sulfide stage(s) occur at northern margin of the belt. => If magmatic component present, not a single evolving system as a whole

Alternative genetic classification: sulfide stage represents contemporaneous Au-Co, and Au-Cu mineralization event in PSB (and KSB) overprinting earlier magnetite bodies

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