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Abstracts of
the 2nd **GeoDays**
12th–14th March 2024, Turku, Finland

TURUN YLIOPISTO

Åbo Akademi

Edited by Jussi S. Heinonen

The 2nd GeoDays
12th–14th March 2024, Turku, Finland

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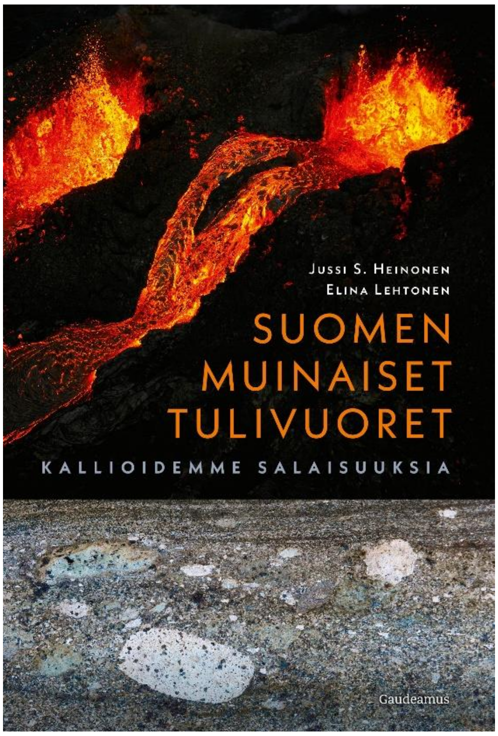

Gaudeamus

Gaudeamus on Helsingin yliopiston omistama tiede- ja tietokirjakustantamo.

Jussi S. Heinonen & Elina Lehtonen

Suomen muinaiset tulivuoret — Kallioidemme salaisuuksia

"Suomen muinaiset tulivuoret" vie lukijan ennennäkemättömälle retkelle eri puolille maata ihmettelemään tulivuorenpurkauksia, jääkausia ja muita geologisia tapahtumia sekä kiviaineksessa nykyään piileskelevää elämää.

Saatavilla kirjakaupoissa ja tilattavissa myös Gaudeamuksen verkkosivuilta: https://kauppa.gaudeamus.fi/

Vieraile Elina Lehtosen posterilla saadaksesi alennuskampanjakoodin!

Contents

Foreword/Esipuhe/Förord 4
Map 5
Schedule 6
Program 8
Abstracts 15

Foreword

Geosciences play an essential role in the study of planetary processes, global change, and the sustainable use of natural resources – also in the future. This role is not always understood or appreciated in the public discourse or among decision-makers. The GeoDays meeting aims to bring together a wide range of experts from universities, institutions, and private sector – also from the brinks of geosciences. It is intended to connect people from early-career researchers to highly experienced specialists. The meeting consists of talks, a poster session, workshops, short courses, and research and working group meetings. We trust that GeoDays will strengthen our field and continue to be a suitable channel for networking and discussion also in the future.

Esipuhe

Geotieteet ovat keskeisessä roolissa planetaaristen prosessien, globaalin muutoksen ja luonnonvarojen kestävän käytön tutkimuksessa – myös tulevaisuudessa. Tätä roolia ei aina ymmärretä tai arvosteta julkisessa keskustelussa tai päättäjien keskuudessa. GeoDays-kokouksen tavoitteena on tuoda yhteen laaja joukko asiantuntijoita yliopistoista, instituutioista ja yksityiseltä sektorilta – myös geotieteiden reunavyöhykkeiltä. Kokouksen tarkoituksena on yhdistää ihmisiä uransa alkuvaiheessa olevista tutkijoista erittäin kokeneisiin asiantuntijoihin. Kokous koostuu esitelmistä, posterisessiosta, työpajoista, lyhytkursseista sekä tutkimus- ja työryhmäkokouksista. Luotamme siihen, että GeoDays vahvistaa alaamme ja on jatkossakin sopiva kanava verkostoitumiselle ja keskustelulle.

Förord

Geovetenskaper spelar en viktig roll i studierna av planetära processer, globala förändringar och hållbar användning av naturresurser – också i framtiden. Denna roll förstås eller uppskattas inte alltid i det offentliga samtalet eller bland beslutsfattare. GeoDays-mötet strävar efter att samla ett brett spektrum av experter från universitet, institutioner och privata sektorn – även från gränsen av geovetenskaper. Det är avsett att koppla samman personer från forskare i början av sina karriärer till mycket erfarna specialister. Mötet består av presentationer, en postersession, workshops, korta kurser samt forsknings- och arbetsgruppsmöten. Vi litar på att GeoDays kommer att stärka vårt område och fortsätta vara en lämplig kanal för nätverkande och diskussion, även i framtiden.

Map of the 2nd GeoDays, 12.–14.3.2024, Turku *© Google Maps*

Important locations:

-GeoHouse (Akatemiankatu 1): Workshops & Ice breaker (Tue), GSF meeting (Thu)

-Educarium (Assistentinkatu 5):

- Lobby: Registration (Wed & Thu)
- EDU 1: Opening, awards, sessions 1, 2, 3, 5, 6, and 7 (Wed & Thu)
- EDU 2: Sessions 4 and 8 (Wed & Thu)
- Floors 2 and 3: Poster session (Wed)

-Restaurant Koulu (Eerikinkatu 18): Wednesday evening

Schedule of the 2nd GeoDays, 12.–14.3.2024, Turku (Tue)

Tuesday 12.3.2023

9:00			FIRST Meeting (9:00-15:30) Geohouse 205	
9:15				
9:30				
9:45				
10:00				**PhD course**
10:15				Results (Esa)
10:30				
10:45				
11:00				
11:15				Imposter syndrome (Esa)
11:30				
11:45				
12:00				Lunch (12:00-13:15)
12:15				
12:30				
12:45				
13:00				
13:15				Ville V.
13:30				Discussion (Jussi)
13:45				
14:00				
14:15				
14:30				
14:45				
15:00	ILP Meeting (15:00-17:00) Geohouse 303			Break
15:15				Presentation (Jussi)
15:30		SSK Meeting (15:30-17:00) Geohouse 203		
15:45				
16:00			Geologia.fi Meeting (16:00-17:00) Geohouse 205	
16:15				
16:30				
16:45				
17:00				
17:15				
17:30	Registration (17:30-18:00) GeoHouse, Akatemiankatu 1			
17:45				
18:00	Icebreaker (18:00-20:00) GeoHouse, Akatemiankatu 1, 4th floor			
18:15				
18:30				
18:45				
19:00				
19:15				
19:30				

Schedule of the 2nd GeoDays, 12.–14.3.2024, Turku (Wed & Thu)

	Wednesday 13.3.2023		Thursday 14.3.2023	
8:00				
8:15				
8:30	Registration (8:30-9:00)			
8:45			Registration (8:45-9:00)	
9:00	Opening (9:00-9:15) - EDU1		Opening (9:00-9:15) - EDU1	
	Session 1 (9:15-10:15) - EDU1		*Session 5 (9:15-10:15) - EDU1*	
9:15	**Keynote: Heinonen, A. (GTK)**		**Keynote: Troll (Uppsala Univ.)**	
9:30				
9:45	**Invited: Lax (SGU)**		Beier (HY)	
10:00	**Invited: Korhonen (Sorsa Foundation)**		Ranta (HY)	
10:15	Coffee (10:15-10:45) - Educarium		Coffee (10:15-10:45) - Educarium	
10:30				
	Session 2 (10:45-11:45) - EDU1		*Session 6 (10:45-11:45) - EDU1*	
10:45	**Invited: Heinonen, S. (HY)**		Dauner (HY)	
11:00	Rintamäki (HY)		Itkonen (Hyttinen et al.; Sitowise)	
11:15	Courbis (HY)		Saarni (TY)	
11:30	Moisio (Afonin et al.; OY)		**Invited: Virtasalo (GTK)**	
11:45	Lunch (11:45-13:00) **Options**: *Macchiavelli* (near, but crowded), *Pikku Maccia* (near, but crowded), *Calonian kahvila*, *Fabbes Cafe*, *Kårkafé Arken* + plenty of restaurants on Hämeenkatu!		Lunch (11:45-13:00) **Options**: *Macchiavelli* (near, but crowded), *Pikku Maccia* (near, but crowded), *Calonian kahvila*, *Fabbes Cafe*, *Kårkafé Arken* + plenty of restaurants on Hämeenkatu!	
12:00				
12:15				
12:30				
12:45				
	S3A (13:00-14:30) - EDU1	*S4A (13:00-14:30) - EDU2*	*S7A+7B (13:00-14:30) - EDU1*	*S8A (13:00-14:30) - EDU2*
13:00	Cutts (GTK)	**Invited: Saarinen (HY)**	**Invited: Lunkka (OY)**	Soukka (OY)
13:15	Islam (TY)	Trasune (HY)	Hovikoski (Palmu et al.; GTK)	Aranha (OY)
13:30	Karvinen (HY)	Granqvist (HY)	Åberg (GTK)	Virtanen (CNRS-UO-BRGM)
13:45	Mikkola (GTK)	Bohm (HY)	Korkka-Niemi (GTK)	Kara (TY)
14:00	Teräs (ÅA)	Liu (HY)	Junna (GTK)	Sarala (OY)
14:15	Saukko (ÅA)	-	Billah (TY)	**Inv.: Kronqvist (Agnico Eagle)**
14:30	Coffee (14:30-15:00) - Educarium		Coffee (14:30-15:00) - Educarium	
14:45				
	S3B (15:00-16:30) - EDU1	*S4B (15:00-16:30) - EDU2*	*S7B (15:00-16:30) - EDU1*	*S8B (15:00-16:30) - EDU2*
15:00	Lehtonen (HY)	Salonen (HY)	Nenonen (EAWAG)	**Invited: Kietäväinen (HY)**
15:15	Engström (GTK)	Chung (Nat. Taiwan Univ.)	Nystrand (ÅA)	Eilu (Eilu Geoconsult)
15:30	Eklund (ÅA)	Bakhia (HY)	Kotilainen (GTK)	Karlsson (GTK)
15:45	Johnson (ÅA)	Foister (HY)	Silvennoinen (HY)	Lindberg (ÅA)
16:00	Strand (OY)	Salminen (OY)	Paul (HY)	Hartikainen (OY)
16:15	Pesonen (HY)	Toivanen (OY)	Seitsamo-Ryynänen (HY)	-
16:30	Poster session (16:30-18:30) Educarium floors 2 and 3 (+ SKGK meeting 17:00-19:00, Geohouse 203)		Awards, words from K.H. Renlund foundation, and ending (16:30-17:30) - EDU1	
16:45				
17:00				
17:15				
17:30				
17:45				
18:00			**18:00 -> Monthly meeting of GSF (open to all!)** **GeoHouse (Akatemiankatu 1, room 404)** **presentation: Perttu Mikkola** ***"Missä Outokumpu loppuu ja Kotalahti alkaa? Perustiedon päivitystä malmipotentiaalisten alueiden rajamailla Savossa"***	
18:15				
18:30	18:30 -> Restaurant Koulu (Eerikinkatu 18)			
18:45				
19:00				

Program of the 2nd GeoDays, Educarium, Turku

Tuesday 12th March

Workgroup/project meetings:

09:00-15:30 Meeting of the Academy of Finland project FIRST (GeoHouse 203, Akatemiankatu 1, 2nd floor)

15:00-17:00 Meeting of the International Lithosphere Program (GeoHouse 303, Akatemiankatu 1, 3rd floor)

15:30-17:00 Meeting of "Suomen Stratigrafinen Komitea" (GeoHouse 203, Akatemiankatu 1, 2nd floor)

16:00-17:00 Meeting of "Geoportaali (geologia.fi)" (GeoHouse 205, Akatemiankatu 1, 2nd floor)

Workshops:

10:15-16:00 A workshop for PhD students: Writing results, Imposter syndrome – Peer support, Writing discussion, Giving a presentation (GeoHouse 404, Akatemiankatu 1, 4th floor)

17:30-18:00 Registration (GeoHouse, Akatemiankatu 1, 4th floor)

18:00-20:00 Ice breaker (GeoHouse, Akatemiankatu 1, 4th floor)

Wednesday 13th March

8:30-9:00 Registration (Educarium lobby, Assistentinkatu 5)

9:00- 9:15 Opening of the meeting (Educarium EDU1, Assistentinkatu 5)

The organizing committee

Wednesday Plenary, Session 1 (EDU1): Natural resources and their exploitation - different perspectives

Chair: Jussi Heinonen & Antti Ojala

9:15-9:45 **Keynote: From exploitation of natural resources to utilization of raw materials**

Aku Heinonen (Geological Survey of Finland) page 15

9:45-10:00 **Invited**: Geopolitics and green transition – how do they affect the need for geoscientists?

Kaj Lax (Geological Survey of Sweden) page 16

10:00-10:15 **Invited**: Everything We Mine, We Use: Some implications of markets and innovation for critical metals

Janne M. Korhonen (Sorsa Foundation) page 17

10:15-10:45 Coffee break (Educarium)

Wednesday Plenary, Session 2 (EDU1): Seismological research in Finland - the past and the present

Chair: Johanna Salminen

10:45-11:00 **Invited**: Seismo100: One hundred years of instrumental seismology in Finland

Suvi Heinonen (Institute of Seismology, University of Helsinki) page 18

11:00-11:15 Source characteristics of induced seismicity are controlled by pore pressure variations and geological constraints at the experimental Otaniemi EGS, Espoo, Finland

Annukka E. Rintamäki (Institute of Seismology, University of Helsinki) page 19

11:15-11:30 A 3D shear wave velocity model from ambient noise surface wave tomography in the Helsinki area

Roméo Courbis (Institute of Seismology, University of Helsinki) page 20

11:30-11:45 Frost quakes in northern Finland during winter weather conditions
Kari Moisio (University of Oulu) – Abstract: Afonin et al. page 21

11:45-13:00 Lunch break

Session 3a: Crustal evolution in the Fennoscandia 1 (EDU1)

Chair: Kaisa Nikkilä

13.00-13:15 In situ Lu-Hf dating of garnet and apatite to understand fluid processes
Kathryn A. Cutts (Geological Survey of Finland) page 22

13:15-13:30 Determining the age and metamorphic evolution of the Pyhäsalmi region, Central
S. Rakibul Islam (University of Turku) page 23

13:30-13:45 In situ geochronology of apatite, calcite, monazite in the Siilinjärvi glimmerite-carbonatite complex, Finland
Seppo Karvinen (University of Helsinki) page 24

13:45-14:00 Pasalanmäki hornblende gneisses revisited, an attempt to solve the age and origin of highly heterogeneous rock group in Central Finland
Perttu Mikkola (Geological Survey of Finland) page 25

14:00-14:15 General fractional crystallization model for shoshonitic magmatic rocks in southern Finland
Oliver Teräs (Åbo Akademi University) page 26

14:15-14:30 Megacrysts in metaplutonic and metasupracrustal rocks in southernmost Finland
Anna Saukko (Åbo Akademi University) page 27

Session 4a: From mud, peat, rock and old teeth – Detecting environmental variability and geodiversity across temporal scales, part 1 (EDU2)

Chair: Miikka Tallavaara

13.00-13:15 **Invited**: New developments in vertebrate paleoecology and ecometrics research
Juha Saarinen (University of Helsinki) page 34

13:15-13:30 Reconstructing palaeoclimate with plant macrofossils: methodological overview
Liva Trasune (University of Helsinki) page 35

13:30-13:45 Spatiotemporal Arctic peat fire patterns and climate implications
Sonja K.J. Granqvist (University of Helsinki) page 36

13:45-14:00 Modern-type aeolian regime and global cooling-modulated dust provenance in the Late Paleogene of Central-East Asia
Katja Bohm (University of Helsinki) page 37

14:00-14:15 The establishment of Asian modern zoogeographic regions and its underlying climatic and tectonic mechanisms
Liping Liu (University of Helsinki) page 38

14:15-14:30 (no presentation)

14:30-15:00 Coffee break (Educarium)

Session 3b: Crustal evolution in the Fennoscandia 2 (EDU1)

Chair: Esa Heilimo

15.00-15:15 Anna Hietanen – edelläkävijä geologiassa
Elina Lehtonen (University of Helsinki) page 28

15:15-15:30 The Kopparnäs study site in Southern Finland – characterization of a fault zone
Jon Engström (Geological Survey of Finland) page 29

15:30-15:45 Formation of the granite-migmatite belt in Southern Finland by lateral spreading of hot lithosphere
Olav Eklund (Åbo Akademi University) page 30

15:45-16:00 1865 Ma Svecofennian mantle-derived magmatism in Nagu, SW Finland
Anna E. Johnson (Åbo Akademi University) page 31

16:00-16:15 Stratigraphy in practice: naming Precambrian geological units in Finland
Kari Strand (University of Oulu) page 32

16:15-16:30 Some new aspects of supercontinents in deep time: huge rotations, enhanced velocities and lock in latitudes
Lauri J. Pesonen (University of Helsinki) page 33

Session 4b: From mud, peat, rock and old teeth – Detecting environmental variability and geodiversity across temporal scales, part 2 (EDU2)

Chair: Saija Saarni

15.00-15:15 Uncovering Holocene climate fluctuations and ancient conifer populations: insights from a high-resolution multi-proxy record from Northern Finland
J. Sakari Salonen (University of Helsinki) page 39

15:15-15:30 Speleothem-inferred hydroclimate in northern Africa during the past 300 ka
Yun-Chuan Chung (National Taiwan Univesrity) page 40

15:30-15:45 Reassessing out-of-Africa I: Paleodietary and body mass insights from Dmanisi herbivores challenge prevailing grassland hypotheses
Alexander Bakhia (University of Helsinki) page 41

15:45-16:00 Quantifying heterogeneity of hominin environments in and out of Africa
Tegan I.F. Foister (University of Helsinki) page 42

16:00-16:15 Plot-scale geodiversity in northern environments
Henriikka M.S. Salminen (University of Oulu) page 43

16:15-16:30 Defining and assessing geodiversity: Perspective for biodiversity investigations with new European geodiversity data
Maija Toivanen (University of Oulu) page 44

Poster session (Educarium floors 2 and 3)

16:30-18:30

Session order (general, 3, 7, 8; no posters for sessions 1, 2, 4, 5, 6) and then alphabetical order by first author

General:

1. *Christian Ahläng (ÅA) – represented by Anna Saukko (ÅA)*: Teaching geology to geography and science teachers (page 43)
2. *Roméo Courbis (HY)*: FLEX-EPOS mobile Finnish Seismic Instrument Pool: FINSIP (page 46)
3. *Teemu Karlsson (GTK)*: Geologia.fi (no abstract)
4. *Elina Lehtonen (HY)*: Geology field in The Helsinki Term Bank for The Arts and Sciences (Tieteen termipankki) (page 47)
5. *Sonja Silvennoinen (HY)*: Kansainvälinen geodeettis-geofysikaalinen unioni (IUGG) (page 48)
6. *Ilmari Smedberg (GTK)*: New approach to national doctoral education in Finland: UEF and GTK collaborating on 3D modelling of aquifer characteristics with geophysical data (page 49)

Sessions 3A and 3B:

7. *Heider Al Humadi (Univ. of Babylon) – represented by Jaakko Kara (TY)*: U-Hf-Pb isotope zircon data of a basalt from the Pushtashan ophiolite, NE Iraq: indication of an extensional period above a suprasubduction zone (page 50)
8. *Helena Hansson (ÅA)*: Age determination and classification of the charnockite series rocks at Houtskär, SW Finland (page 51)

9. *Matias Hirsimäki (TY)*: Rytkynkylä volcanite sequence, a preliminary lithological assessment of a potentially mineralized locality on the Raahe-Ladoga shear complex (page 52)
10. *Nikolaos Karampelas (HY)*: Considerable mineral chemical heterogeneity in the episyenites of the Proterozoic Suomenniemi rapakivi granite complex, southeastern Finland: New insights into high-temperature metasomatic processes (page 53)
11. *Jaro Kuikka (GTK)*: Geochronology and source(s) of pegmatites from the Kitee-Tohmajärvi region (page 54)
12. *Lauri A.M. Malinen (HY)*: Geochemistry and petrography of igneous intrusions at Grønsteinfjellet-Botneheia, central Spitsbergen, Svalbard (page 55)
13. *Perttu Mikkola (GTK)*: 1.88 Ga A-type Svecofennian magmatism revealed east of the CFGC; petrography, geochemistry and age of the Sorsakoski granitoids, Central Finland (page 56)
14. *Anna M.R. Sartell (HY)*: Geochemistry and geochronology of the High Arctic Large Igneous Province on Svalbard (page 57)
15. *Artur V. Tvauri (HY)*: Chemical composition of tourmaline in the Kaustinen lithium pegmatites (page 58)
16. *Teemu Vehkamäki (TY)*: Sequential crystallization of zircon, monazite and xenotime in the cordierite-orthoamphibole rocks in Orijärvi, southern Finland (page 59)

Sessions 7A and 7B:

17. *Dmitry N. Andreev (State Establishment of Institute of Hydrogeology and Engineering Geology, Uzbekistan) – represented by Samrit Luoma (GTK)*: Hydrogeological characterization of the Akhangaran River alluvial aquifer, north-eastern Uzbekistan (page 60)
18. *Suvi Erhovaara (GTK)*: Geochemical characteristics and long-term carbon accumulation rate in the Puukkosuo, a northern boreal sloping fen (page 61)
19. *Mandi Hannula (TY)*: Traces of Glacier-Induced Meltwater Processes in the Satakunta Hummocky Moraine Area: Mapping of Potential Blisters (page 62)
20. *Juuso Ikonen (GTK)*: Combining pre-sampling UAS-TIR and GEM-2 to focus water sampling with hydrogeochemical analysis including isotopes of H, O, Sr, and S from two mine sites in northern Finland (page 63)
21. *Max A.O. Kankainen (HY)*: Emission and burial potential of blue carbon habitats in Finnish lakes (page 64)
22. *Juulia J. Kautto (TY)*: Murtoos and related landforms cross-cutting ribbed moraine in Western Finland: Implications for rapidly increasing subglacial drainage (page 65)
23. *Karoliina Kehusmaa (TY)*: Mine water induced meromixis – investigating a mixing regime shift from the recent sediment record of Lake Valkeinen (page 66)
24. *Jasmin Maunula (HY)*: Characterising magnetic minerals in urban aerosol dust in Helsinki (page 67)
25. *Nishant Nishant (HY)*: Investigating the applicability of CuO extraction for detecting biomarkers of marine organic matter in Baltic Sea sediments (page 68)
26. *Viktoriia Pastukhova (TY)*: Geochemical evidence for land use change and human influence on Lake Patalahti (page 69)
27. *Sohvi Railo (TY)*: Diatoms as a micropaleontological proxy and their seasonal succession in the ice-covered Baltic Sea (page 70)
28. *Rahat Riaz (HY)*: Investigating the potential of lignin phenols to study sources and fate of terrestrial organic matter in coastal Baltic Sea sediments (page 71)
29. *Antti Sainio (GTK)*: Marine geological inventories around the Åland, the Baltic Sea, as part of Biodiversea LIFE IP project (page 72)
30. *Sarianna M. Salminen (TY)*: Climatic factors controlling long-term variation in the abundance of different chemical fractions of phosphorus in Finnish archipelago sea sediments (page 73)
31. *Maarit Saresma (GTK)*: Free fall cone penetration tests (FFCPT) for seabed strength characterization for offshore construction planning (page 74)
32. *Sampo Soini (TY)*: The internal structure and deposition of a triangle-type murtoo in the northeastern Baltic Sea Ice Lobe of the Fennoscandian Ice Sheet (page 75)
33. *Heta Ulmanen (HY)*: Weekly monitoring of the occurrence of per- and polyfluoroalkyl substances (PFAS) in Vantaa River, southern Finland (page 76)
34. *Virpi A. Vepsä (HY)*: The Pärvie postglacial fault system: Interaction between surface and groundwater systems (page 77)
35. *Annika A. Åberg (HY)*: 3D hydrogeochemistry and particle tracking to detect groundwater flow patterns within an aapa mire–outwash plain system in a boreal environment at a mining development site (page 78)

Sessions 8A and 8B:

36. *Héctor R. Campos Rodríguez (CNRS-Université d'Orléans-BRGM)*: On the carbonaceous materials and sulfides in the black shales and schists of the Matarakoski Formation: characteristics of the possible sulfur source of the Kevitsa Cu-Ni-(PGE) sulfide deposits (page 79)
37. *Hanna Kaasalainen (GTK)*: SMARTTEST – Smart circular economy field testing facility for extractive waste and side streams (page 80)
38. *Charmee Kalubowila (OY) – represented by Pertti Sarala (OY)*: CoDa based approach to till and surficial geochemistry in mineral exploration (page 81)
39. *Fereshteh Khammar (HY)*: Modelling iron oxide Cu-Au (IOCG) mineral prospectivity in Finland, application of hybrid mineral systems-based approach (page 82)
40. *Petri Pulli (OY)*: Prospectivity modeling of lithium-rich pegmatite deposits surrounding the Central Finland Granitoid Complex (page 83)
41. *Markus Raatikainen (OY)*: SOM and clustering techniques for surface geochemical data in Au exploration – example from northern Finland (page 84)
42. *Miradjie Rama (GTK)*: Mine tailing productization and utilization enhancement with automated mineralogy (MinerAll) (page 85)

Thursday 14th March

8:45-9:00 Registration (Educarium lobby, Assistentinkatu 5)

9:00- 9:15 Opening of the day (Educarium EDU1, Assistentinkatu 5)

Olav "Joffi" Eklund

Thursday Plenary, Session 5 (EDU1): Active igneous systems

Chair: Jussi Heinonen & Antti Ojala

9:15-9:45 **Keynote: Magma as a chemical probe into the Earth's interior: High resolution sampling of recent basaltic eruptions**

Valentin R. Troll (Uppsala University) page 86

9:45-10:00 Structural control on plume-ridge interaction in northern Iceland

Christoph Beier (University of Helsinki) page 87

10:00-10:15 Magmatic sulfur systematics at the Iceland hotspot viewed through the lens of melt inclusions

Eemu Ranta (University of Helsinki) page 88

10:15-10:45 Coffee break (Educarium)

Thursday Plenary, Session 6 (EDU1): Snapshots of environmental geology and geoengineering

Chair: Kirsti Korkka-Niemi

10:45-11:00 Sediment carbon sequestration in vegetated areas of Finnish lakes: the Blue Lakes project

Ana Lúcia L. Dauner (University of Helsinki) page 89

11:00-11:15 Steps towards remediation of the Hiedanranta zero fibre area, Tampere, Finland

Arto Itkonen (Sitowise Oy) – Abstract: Hyttinen et al. page 90

11:15-11:30 Microplastic deposition controlled by the winter conditions at Baltic Sea estuary

Saija Saarni (University of Turku) page 91

11:30-11:45 **Invited**: Geophysical, geological and geotechnical seabed characterization for offshore construction

Joonas J. Virtasalo (Geological Survey of Finland) page 92

11:45-13:00 Lunch break

Session 7a: Approaches to classify Quaternary deposits: applications in hydrogeology and hydroclimate (EDU1)

Chair: Antti Ojala

13.00-13:15 **Invited**: Stratigraphic approach to classify Quaternary deposits in Finland
Juha Pekka Lunkka (University of Oulu) page 93

13:15-13:30 Updated classification of the glaciofluvial deposits in GTK's map database
Jussi Hovikoski (Geological Survey of Finland) – Abstract: Palmu et al. page 94

13:30-13:45 Development of 3D hydrogeological modelling workflows
Annika A. Åberg (Geological Survey of Finland) page 95

13:45-14:00 HYGLO Water Oriented Living Lab
Kirsti I. Korkka-Niemi (Geological Survey of Finland) page 96

Session 7b: Aquatic sedimentation and geochemistry (EDU1)

14:00-14:15 Recent increase in carbon accumulation in Finnish lake sediments and the role of catchment land use
Tuomas Junna (Geological Survey of Finland) page 97

14:15-14:30 Geochemical signals from biogenic varves reflect hydroclimate and lake mixing conditions in central Finland
Mohib Billah (University of Turku) page 98

Session 8a: Eploration, modelling and processing of mineral resources 1 (EDU2)

Chair: Pertti Sarala

13.00-13:15 New results of the platinum group mineral nuggets in the Finnish Lapland
Tapio Soukka (University of Oulu) page 105

13:15-13:30 Regional-scale prospectivity analysis of northern Finland for CRMs hosted in ultramafic-mafic orthomagmatic deposits
Malcolm Aranha (University of Oulu) page 106

13:30-13:45 From the mantle source to crustal sink: petrogenesis and sulphide saturation of the Central Lapland Greenstone Belt komatiites, Finland
Ville J. Virtanen (CNRS-Université d'Orléans-BRGM) page 107

13:45-14:00 Age determination of Au-precipitating fluid activity in SW Finland
Jaakko Kara (University of Turku) page 108

14:00-14:15 Snow geochemistry as a mineral exploration tool – Example from Saramäki Cu-Co-Zn deposit, eastern Finland
Pertti Sarala (University of Oulu) page 109

14:15-14:30 **Invited**: Kittilä Mine, within the Palaeoproterozoic Central Lapland Greenstone Belt (CLGB)
Mathias Kronqvist (Agnico Eagle Finland) page 110

14:30-15:00 Coffee break (Educarium)

Session 7b (continued): Aquatic sedimentation and geochemistry (EDU1)

Chair: Peter Österholm

15.00-15:15 Effects of organic ligands on the structure, colloidal properties and PO_4 uptake of Fe oxidation products
Ville V. Nenonen (Swiss Federal Institute of Aquatic Science and Technology) page 99

15:15-15:30 An accelerated incubation method for the identification of acid sulfate soils
Miriam I. Nystrand (Åbo Akademi University) page 100

15:30-15:45 Giant saline water inflow in AD 1951 triggered the Baltic Sea hypoxia
Aarno T. Kotilainen (Geological Survey of Finland) page 101
15:45-16:00 Holocene deoxygenation history in the coastal Bothnian Sea with magnetic greigite as a proxy for hypoxia
Sonja Silvennoinen (University of Helsinki) page 102
16:00-16:15 Deciphering trace metal covariation patterns in coastal marine sediments using correlation matrices
K. Mareike Paul (University of Helsinki) page 103
16:15-16:30 Investigating late-stage fracture minerals beneath the Baltic Sea near Olkiluoto, Finland
Minja Seitsamo-Ryynänen (University of Helsinki) page 104

Session 8b: Eploration, modelling and processing of mineral resources 2 (EDU2)
Chair: Tapio Halkoaho
15.00-15:15 **Invited**: Geological hydrogen in Finland – aspects and prospects
Riikka Kietäväinen (University of Helsinki) page 111
15:15-15:30 Cobalt deposits in Finland
Pasi Eilu (Eilu Geoconsult) page 112
15:30-15:45 Critical raw materials in closed extractive waste sites: a case study from Finland
Teemu Karlsson (Geological Survey of Finland) page 113
15:45-16:00 Magnesium extraction from mine tailings in Siilinjärvi
Sofia Lindberg (Åbo Akademi University) page 114
16:00-16:15 Continuously compressing crushers and non-toxic flotation chemicals – Elimination of critical bottlenecks in the global clean energy
Samuel Hartikainen (University of Oulu) page 115
16:15-16:30 (no presentation)

From exploitation of natural resources to utilization of raw materials

Aku Heinonen

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Criticality of geological raw materials (e.g., metals, industrial minerals, aggregates etc.) for the modern society and living standards has traditionally been self-evident for the geoscientific expert audiences but the recent recognition of their importance for the twin (green and digital) transition has rapidly re-introduced them to the public debate as well. Furthermore, the Critical Raw Materials Act (CRMA) initiative by the European Commission in 2023 entered critical and strategic geological raw materials in an unprecedented way onto the European policy and governance agenda. Recent geopolitical developments have further emphasized the vulnerable, interconnected, and global nature of the raw materials markets. Especially the dominant role adopted by China in the production and processing of many geological raw materials has made evident the exposure of critical value chains and the immaterial basis of western economies to the raw material-based world order.

Regardless of the heightened awareness to the relevance of raw materials and their availability, from the geoscientific perspective the discourse surrounding the multitude of these different types of geological resources has taken on a rather clinical slant. The "raw material speak" has penetrated the terminology, which is seen most keenly in the disappearance of the term natural resources from the discussion. Geological raw materials are, first and foremost, resources derived from the abiotic nature and, therefore, should be depicted as non-renewable natural resources. However, most current policy documents, technical presentations, and practical applications tend to prefer the term raw material, which encompasses a much broader variety of materials, not just the primary mineral commodities belonging to the realm of natural resources. For example, from the circular economy perspective, raw materials comprise also secondary material flows such as extraction side streams, recycled scrap, and reprocessed end-of-life materials, which cannot strictly be classified as natural resources.

This is the practical reason for the preferred usage of raw material terminology over natural resources, but from a systemic point of view, talking about natural resources also brings about the negative associations of extraction and exploitation and their undesired external effects. These associations in turn make evident the negative opportunity costs of natural resource use and tend to counteract the positive psychological effects of their applications such as green energy solutions and electrification. Furthermore, exploitation of geological natural resources is often equated with the extraction of fossil fuels adding another negative association to the usage of the terminology. Roughly speaking, from a marketing point of view it is not beneficial to talk about the dirty business of natural resource extraction but rather of the clinical and clean utilization of raw materials that can be purchased off-the-shelf, preferably from circular or recycled sources. In doing so, the western "downstream economies", especially the European ones, have managed to distance themselves from the upstream raw material basis of their very existence.

The main thesis of this contribution is that the preference of raw material terminology instead of natural resources has been necessary for the new circular economy models and disconnection of the energy system from the usage of fossil fuels but at the same time it has, in part, externalized and sterilized the discourse on geological resources and had a profound impact in the way that primary raw material extraction is perceived today in the West. On the other hand, it is evident that the natural resource -focused approach has enabled actors like China to develop a bottle neck scenario, in which it exerts a strong upstream control on most of the global raw material flows vital for the technology-based economies. The recent realization of this imbalance in Europe has most likely come too late and our reaction time is further hindered by adherence to the clinical "raw material speak". Talking about natural resources instead of raw materials has the added benefit of making the external social and environmental effects of resource extraction more visible and the industry operations more transparent.

Geopolitics and green transition – how do they affect the need for geoscientists?

Kaj Lax

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Recent geopolitical developments and policies related to those clearly point to a marked increase in geoscientific training in the near future. Climate change and the related increase in the need for metals and minerals for a green transition will not be possible without substantial efforts in the entire value chain, from mapping to exploration, mining and processing, and environmental management. This will affect not only the need for an increased workforce within private and public sectors, but also for research. Other examples of geoscientifically significant growth areas, that also are related to climate change and raw materials, are CCS, geoenergy (including energy storage), and groundwater.

One recent example is the critical raw materials act, CRMA, that was negotiated in EU last year and is expected to be implemented in the member states near the end of this year or early 2025. This act, which was adopted by a large majority of Members of Parliament (549 votes to 43, with 24 abstentions) will, for instance, introduce mandatory national exploration programmes (i e mapping programmes) in member states with high mineral resource potential.

Everything We Mine, We Use: Some implications of markets and innovation for critical metals

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The demand for and mining of critical metals are expected to surge as the green transition progresses. Opposing new mines is often seen as hypocrisy that shifts the burden of mining and its impacts to poor countries, or even as a betrayal of the green transition.

As the famous saying goes, predictions are hard, especially of the future. Nevertheless, in my presentation, I will highlight some findings from economics and innovation research and empirical observations that, in my view, justify opposition to mines in the absence of better information, even though new mines will undoubtedly be needed.

My argument is primarily based on market economy mechanisms and the nature of radical innovations. In short, assumptions about the need for raw materials and thus mines are often based on a misconception similar to the famous "lump of labor" fallacy in economics. The lump of labor fallacy refers to the belief that the amount of work in society is constant, and that an increase in the workforce, for example through immigration, leads to higher unemployment. Similarly, the need for raw materials is often assumed to be constant, and failure to meet this need is seen as a threat.

In reality, the need for both labor and raw materials is a variable primarily dependent on their price. The cheaper they are to use, the more carelessly they are consumed. Conversely, a rise in price reduces usage and encourages both more efficient use and the search for substitutes.

For example, silver was recently predicted to become a critical bottleneck for the production of solar panels. In reality, the need for silver per solar panel halved between 2018 and 2023, and even completely silver-free panels are now available. Panel production volumes are about seven years ahead of even the most optimistic forecasts, and the lack of silver did not prevent, for example, the Chinese from installing so many solar panels in 2023 that their annual electricity production now accounts for about a quarter of the world's total nuclear power production.

Improving the efficiency of critical metal usage and finding substitutes would be in society's overall interest, especially in the long term. To encourage the search for substitutes, the price of critical metals should remain fairly high. Opening new mines would inevitably lead to a drop in price. It is worth asking whether it is appropriate to promote the opening of mines and, effectively, the rapid depletion of metal deposits. Especially if replacing some metals with new technologies proves to be genuinely difficult, rapid consumption of the deposits is likely not in society's overall interest.

However, the possibilities of technology are likely underestimated. One reason for this, based on innovation research, may be that radical innovations often combine knowledge from entirely different fields. For this and other reasons, expert assessments of technology's possibilities are often too cautious. If consumption forecasts are based on cautious estimates of technological development, they should be considered to be upper-bound estimates.

The market economy is an adaptive system that adjusts to the given constraints. If opening mines is easy and cheap, more critical metals will be used. If it becomes more difficult, they will be used less. It does not follow, however, that the green transition or other societal goals must necessarily suffer as a result. This could happen, but the history of technology gives reasons for cautious optimism regarding the market’s ability to circumvent such problems.

In any case, opposing new mines is a rational "first order approximation" strategy for individual countries and communities. This is especially true if there are reasons to believe that the value of minerals will increase, and/or future technology will permit extraction with smaller environmental impacts. The greater the opposition to new mines, the more those opening them must invest in overcoming the opposition. This means that a slightly larger portion of the mine's benefits remains with the local community and Finland.

Because all the costs and difficulties of opening new mines should increase the price of metals and therefore help stimulate innovation, and because markets and technology have repeatedly proven their ability to adapt to resource constraints, local opposition to new mines does not, *a priori*, conflict with the ethical obligation to accelerate the green transition.

Finally, since profitable mines will be operate as long as they are profitable, the argument “we should mine, or otherwise the children in Congo will have to do so” is spurious. While new production should, *ceteris paribus*, depress the price of a metal, it is far from clear whether this could cause other profitable mines to close – especially if the demand for metals keeps rising.

Seismo100: One hundred years of instrumental seismology in Finland

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Introduction

The year 2024 marks 100 years since the first instrumental seismological measurements in Finland. Seismic monitoring began in Finland when the Finnish Academy of Sciences and Letters donated two horizontally registering seismographs to the University of Helsinki. Nowadays the Institute of Seismology at the University of Helsinki (ISUH) uses seismological measurements to, for example, assess the seismic hazard at nuclear power plant sites, study the occurrence of earthquakes, identify seismically active areas and participate in global nuclear test monitoring. Besides hosting the national seismic network, researchers at ISUH perform active and passive seismic imaging at various scales as well as contribute to an increased understanding of planet Earth through geodynamic modelling, for example.

From earthquakes to imaging the lithosphere

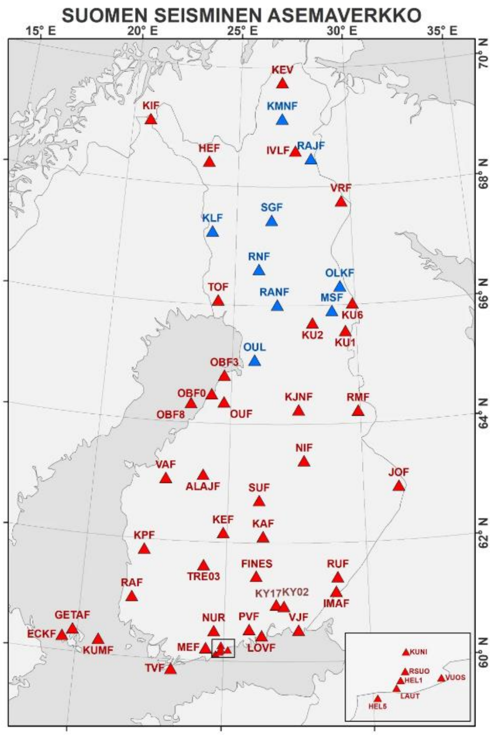

Figure 1. Permanent stations of the Finnish national seismic network. Stations marked with red are operated by Institute of Seismology, University of Helsinki and blue are by the Sodankylä Geophysical Observatory, University of Oulu.

The basis for many activities at ISUH is the national permanent seismic network, which consists of over 40 seismometers operated by ISUH and 9 seismometers operated by Sodankylä Geophysical Observatory of University of Oulu (Figure 1). These seismic stations are used to record seismic waves from earthquakes, explosions and other seismic events. Recordings of relevant stations are used to identify the source of the events, locate the focal coordinates and determine the magnitudes. Data generated by the Finnish seismic network is linked to the Global Seismographic Network and shared to several international seismic data centers (ORFEUS, ISC, EMSC, IRIS, GEOFON). Besides seismological monitoring, observational activities are needed for monitoring related to the nuclear test-ban treaty that was signed in 1996. Since 1976, scientific experts from ISUH have taken part in the expert board of the nuclear weapon non-proliferation organization.

In addition, ISUH aims to better understand the evolution of the lithosphere and its connection to natural seismicity studies focussed on imaging the crust and lithosphere. These studies can range in scale from detailed studies at the scale of mining sites to transects traversing much of a country. To aid in such projects, ISUH owns portable broadband seismometers and geophones utilized in temporary installations, such as seismic soundings. At the largest spatial scale, ISUH was a key partner in the FIRE project (Finnish Reflection Experiment 2001-2003) that was imaging crustal structures down to Moho depths along over 2000 km of profiles across Finland. Later, ISUH also participated in the HIRE project (High Resolution Reflection Seismic Experiment 2007-2010), where high resolution seismic reflection data (>5 km depth penetration) was acquired in 16 sites of economic interest by Geological Survey of Finland. Since acquisition of over 300 km long SVEKA profile running through the Ladoga-Bothnian Bay zone to the Archean Karelian province in 1981, ISUH has conducted numerous crustal scale refraction seismic surveys both in Finland (e.g. KOKKY, SOFIC) and abroad.

ISUH is also involved in seismological projects related to sensitive infrastructure, sustainability and the green transition. In the SEISMIC RISK project (2020-2023), ISUH was leading the consortium studying how to mitigate induced seismic risk associated with deep geothermal power stations. In addition, seismic hazard studies associated with nuclear power plants and nuclear waste disposal have also been conducted by researchers at ISUH. ISUH has active collaborations especially with neighbouring countries and international seismic networks, and will continue to contribute to a broader understanding of the seismicity and deep earth structure with 100 years of experience.

Source characteristics of induced seismicity are controlled by pore pressure variations and geological constraints at the experimental Otaniemi EGS, Espoo, Finland

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Introduction

In 2018 and 2020, two ~6 km deep geothermal wells were stimulated by high-pressure water injection to develop an experimental enhanced geothermal system (EGS) in Otaniemi, Espoo, Finland. The stimulations activated pre-existing fracture networks and induced thousands of small earthquakes. We study the source processes of the induced earthquakes by centroid full moment tensor (MT) analysis. The MT solutions shed light on the style of faulting, fault geometry, and stress interactions.

Methods

To retrieve the MT solutions we preform waveform fitting in the time domain with the probabilistic seismic source analysis framework Grond. The analysis workflow minimises the misfit between synthetic and observed P- and S-wave phases from ~30 stations within 9-km radius of the EGS site. We use a homogeneous velocity model and account for small scale crustal variations by using empirically determined time and amplitude corrections. The low attenuation of the Precambrian bedrock combined with carefully defined corrections yields high resolution MT solutions.

Results and discussion

We select 301 induced events in the moment magnitude (M_W) range 0.3-2.0 with the lowest uncertainties in the MT solutions for further analysis. On average, the solution distribution has 80 % of double-couple (DC) component and 20 % of non-DC component. The DC component represents shear failure on a planar fault. Fracture opening and closing are expressed as a combination of the two non-DC components, isotropic (ISO) and compensated linear vector dipole (CLVD). However, non-DC component may also arise from modelling artefacts, complex faulting processes, or anisotropy and heterogeneity in the source medium.

The DC component reveals dominantly reverse faulting (Figure 1) with relatively uniform roughly northward striking and eastward dipping estimated fault planes. The observed reverse faulting at the depth of ~6 km, is in apparent contrast to a previously reported stress field estimate based on wellbore measurements down to 1.8 km that indicates dominant strike-slip faulting. We will discuss the potential causes of the apparent discrepancy between stress field and MT solutions including the stress field being modified by the pore pressure, a geologically controlled local stress variations, or a stress change occurring with depth.

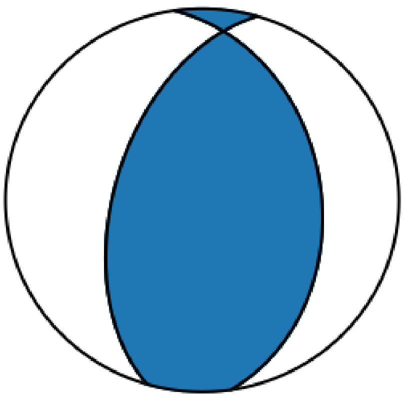

Figure 1. A lower-hemisphere equal-area projection double-couple focal mechanism of a representative M_W1.1 induced earthquake that occurred at the depth of 6.2 km on 9 June 2018.

We observe a difference in the non-DC components between the 2018 and 2020 MT solution distributions. The 2018 solutions have an average closing component and the 2020 solutions have an average opening component, which implies that the pre-existing pore pressure was higher during the 2020 stimulation. Within the 283 events of the 2018 induced seismicity the CLVD component trends towards negative values with increasing distance from injection well. We interpret the CLVD spatial distribution to be related to pore pressure variations. The ISO component over the full set of 301 events shows clear spatial variation that has no clear association with distance to the injection wells. We interpret the spatial variation of the ISO component to be geologically controlled. We will discuss the potential causes of the difference in non-DC components between the two injections.

A 3D shear wave velocity model from ambient noise surface wave tomography in the Helsinki area

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Introduction
In our passive ambient noise surface wave tomography in the Helsinki area we invert Rayleigh and Love wave dispersion data. The tomography constrains a 3D shear wave velocity vS model of the top 8 km of the crust. The model resolves a thin low-velocity layer over a comparatively homogeneous, high-velocity substrate with weak yet consistent vertical and lateral velocity variations. The vS model can serve as starting model for updated monitoring, and it can inform the network and array design for improved imaging studies to support geo-energy projects and hazard assessment.

Methods
We use data from 260 surface stations operated by the Institute of Seismology, University of Helsinki, between 2016 and 2020 in three acquisition campaigns. The deployments allow us to image the subsurface vS structure in a 40 km by 30 km area that is centered around the Aalto University campus. The instruments were installed on 98 individual sites that were uniquely, permanently, or recurrently occupied. The networks combined different sensor types and recorders, and a variable number of stations per site. The good signal-to-noise ratio of fundamental mode Rayleigh and Love waves reconstructed in ZZ and TT noise cross-correlation functions supports passive surface wave imaging in the 0.25 to 10 Hz range. We invert the frequency dependent station pair-wise group velocity data on a 1 km by 1 km 2D grid following a standard FTAN analysis. The lateral resolution is in the 3 km range. Local group dispersion constrains together with the area-averaged *f-k* phase velocity dispersion the local 1D vS models. We apply a widely used Neighborhood Algorithm and use a 5-layer parameterization to aggregate the 3D vS model.

Results
The area-average group velocity move-out pattern and the *f-k* phase velocity plot are spectacularly featureless—this reflects the weak average dispersion in the southern Fennoscandian Shield environment. To the first order the medium appears well approximated by a homogeneous half-space with vS = 3.4 km/s. The good data quality supports the resolution of vertical and lateral variations. For example, high frequency dispersion suggests comparatively soft, shallow material across the Laajalahti bay. The model resolves an average few tens of meters thin top layer with vS = 0.7 km/s. A denser, more homogeneous network is required to reconcile its distribution with geological observations. In the south and south-eastern part the vS model shows a layer between 1.5 km and 3.5 km depth with a 5 to 10% velocity increase. This feature is corroborated by a vertical seismic profiling result below the Aalto University campus. To the north the velocity profile does not exhibit this high-velocity layer. Isosurface visualizations for vS = 3.45 km/s or similar suggest that this layer is discontinuous across the Porkkala-Mäntsälä fault. The vS model exhibits a 5 km large region in the center of the domain that exhibits greater structural complexity, which can potentially be linked to the deformation pattern observed at the surface. Updated results and interpretations are presented during the meeting.

Frost quakes in northern Finland during winter weather conditions

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We present results of experiment in northern Finland during winter, 2022-2023, that studied seismic events, specifically frost quakes caused by seasonal freezing in the so-called Critical Zone (CZ) of the Earth.

The recent climate change studies (IPCC, 2021) predict in the Arctic and sub-Arctic (Boreal) areas generally higher weather variability, increase in precipitation, more humid winter seasons, thinner and even absent snow cover during winter. Unusual weather conditions, such as rapid temperature decrease in combination with thin snow cover can initiate massive fracturing of water-saturated soil and rock due to sudden freezing and expansion (Okkonen et al., 2020). Urban environments, infrastructures and industrial facilities are more and more vulnerable to these unusual weather conditions. Several reports have been made of significant fracturing (frost quakes) from different geographic areas e.g., Finland, Canada, USA during recent years, resulting in mechanical damage to the pavements and roads.

To record such events instrumentally we installed two high-resolution seismic arrays with co-located soil temperature stations at two sites in Finland, one in the sub-Arctic area in Oulu and the other one, above the Polar Circle in Sodankylä (Afonin et al., 2023). Objective was to reveal relationship between frost quake occurrence and winter weather conditions and to evaluate the possible hazard caused by them. The equipment recorded continuous seismic and soil temperature data from November 2022 to April 2023. From the data two types of seismic events, frost quakes and frost tremors were identified with different characteristic frequency content. The sources of frost quakes in Talvikangas were mainly located on irrigated wetland while in Sodankylä about 50% of registered frost quakes were caused by ice fracturing on the Kitinen river. However, several relatively strong events with origin in wetlands were also recorded. A significant number of sources of frost tremors are confined to wetland areas cut by irrigation channels and to roads without snow during winter, both in Talvikangas and in Sodankylä.

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In situ Lu-Hf dating of garnet and apatite to understand fluid processes

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Introduction

Understanding fluid processes is crucial for understanding the magmatic/metamorphic evolution of rocks, and mineral transport and deposition. Targeted in situ geochronology of minerals that have interacted with fluids allow us to investigate the temporal evolution of these fluid systems. Combined with trace element and/or stable isotope analysis it is possible to gain insight into the source/evolution of mineralising fluids. These results contribute to modelling and understanding of mineral systems that can be used for targeting mineral deposits in Finland.

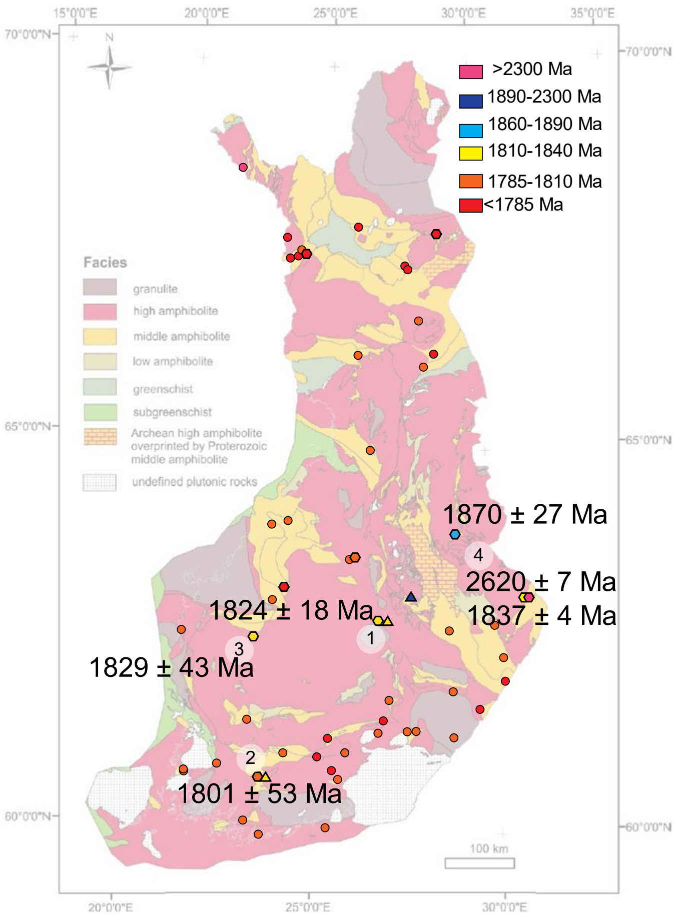

Figure 1. Metamorphic map of Finland (Hölttä & Heilimo, 2017). Spots are monazite ages <1810 Ma (Hölttä et al., 2020). Hexagons are Lu-Hf garnet ages and triangles are apatite. Numbered locations are: 1, Kiviniemi; 2, Somera-Tammela; 3, Hapaaluoma; 4, Tipasjärvi/Ilomantsi Greenstone Belts; 4, H. Garnet ages for these locations are on the figure.

Some preliminary results

The Kiviniemi Sc deposit is hosted in a garnet bearing ferrodiorite (1857 ± 2 Ma, U-Pb zircon; Halkoaho et al., 2020). In situ Lu-Hf analysis of garnet produces an age of 1824 ± 18 Ma and for apatite an age of 1835 ± 19 Ma. Garnet and apatite geochronology has also been applied to Li-bearing pegmatites in the Somera-Tammela region (Fig. 1). Garnet has an age of 1801 ± 53 Ma and apatite 1835 ± 26 Ma. A second sample produced a nearly identical apatite age of 1835 ± 15 Ma. The Hapaaluoma pegmatite, further to the north (Fig. 1) was dated only with apatite and gave an age of 1829 ± 43 Ma.

Two garnets were sampled from inferred Archean deposits, the Sotkamo silver mine hosted in the Tipasjärvi Greenstone Belt and the Hosko gold deposit hosted in the Ilomantsi Greenstone Belt. In Sotkamo, garnet from a quartz vein hosting mineralisation produced a Lu-Hf age of 1870 ± 27 Ma. Two garnet samples were dated from Hosko. In mineralised sediments, garnet associated with vein quartz produced an age of 1837 ± 4 Ma. Garnet in a granitic vein cross-cutting sediments gave an age of 2620 ± 7 Ma. This sample clearly recorded a resetting event with younger ages obtained from the rim.

Despite only having age results so far, it is clear the Svecofennian orogeny had a strong impact on mineral systems, reworking of deposits thought to be Archean. This impact is also seen in broad resetting of monazite ages throughout Finland during the late Svecofennian (Fig. 1). Further work is required to understand the effect of fluids and orogenesis on mineral systems.

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Determining the age and metamorphic evolution of the Pyhäsalmi region, Central Finland: relationship between metamorphism, ore genesis and evolution

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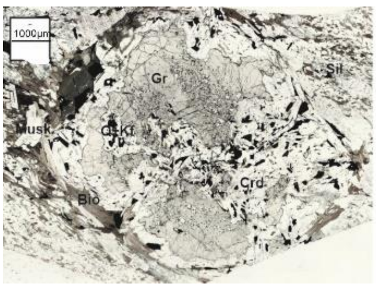
Introduction

Volcanic massive sulfide (VMS) deposits, especially from Precambrian sequences have experienced various degree of metamorphism and deformation resulting in redistribution, modification and remobilization of primary ore-bodies (Mookherjee, 1976; Marshall & Gilligan, 1987). Since Pentti Eskola's metamorphic facies concept, metamorphic petrology has radically advanced with new in situ techniques allowing us to tie regional structures, ages and metamorphic/ore mineral assemblages together to make interpretations about the tectonic settings of metamorphism, ore genesis and evolution. This study aims to constrain the metamorphic conditions (i.e., modeling the P-T-t path utilizing the metamorphic index minerals and equilibrium mineral assemblages) for Paleoproterozoic ore potential in the Pyhäsalmi region. Moreover, this study also focuses on the consequences of the metamorphism on the VMS ore deposit which led to the remobilization of the ore minerals. Additionally, we will study the microstructures relating porphyroblasts and ore mineral growth. Understanding the retrograde metamorphism of the Pyhäsalmi region will provide new information for the remobilized ore deposits in Pyhäsalmi and also other ore potential regions.

Preliminary results

Petrographic study of drill core samples from the Pyhäsalmi region reveals a conspicuous reaction rim of biotite, cordierite, sillimanite as well as a symplectitic intergrowth of quartz and K-feldspar around a σ-type garnet porphyroblast indicating retrograde metamorphism where a low-pressure mineral, cordierite produces a rim around a high-pressure mineral, garnet (Fig.1). The presence of chloritization of biotite, as well as saussuritization and epidotization of plagioclase are very common features likely related to retrograde hydrothermal alteration.3D analysis of the micro-CT data shows two morphologically distinct sulphides (folded and cubic form) as well as inclusions patterns in the garnet implying syn-kinematic growth (Fig 2). Integrating this 3D analysis with 2D scanning electron microscope (SEM) analysis and energy dispersive X-ray spectroscopy (EDS) elemental maps exhibit homogeneous compositional and textural distribution of iron and sulphur within and outside the garnet, suggesting liquid-state remobilization history of the sulphides. In situ Lu-Hf inverse isochron ages from garnets represent a new insight, producing two different age groups of rocks (i.e., 1895 ± 53 Ma and 1824 ± 16 Ma), both slightly younger than previously studied ages from the Pyhäsalmi region (i.e., 1.92 Ga).



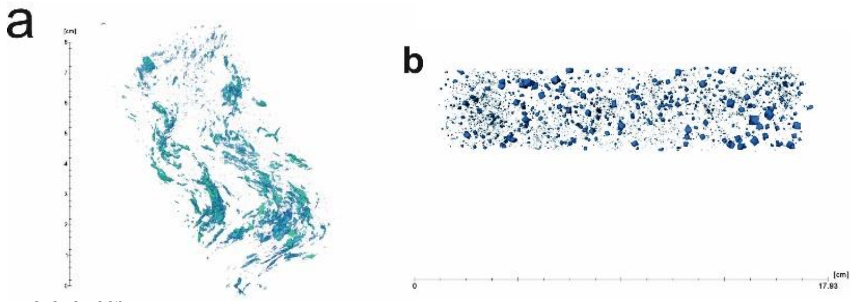


Figure 1. low-pressure mineral, cordierite (Crd) produces a rim around a high-pressure mineral, garnet (Gr).

Figure 2. Micro-CT images of two different form of sulphides from **a)** PYS-144 1397 showing folded sulphide **b)** PYS-129 421 showing cubic sulphide.

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In situ geochronology of apatite, calcite, monazite in the Siilinjärvi glimmerite-carbonatite complex, Finland

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Introduction

The Siilinjärvi glimmerite-carbonatite complex (O'Brien et al., 2015), located in eastern Finland, is Neoarchean (~2,600 Ma), based on zircon U-Pb dating (Rukhlov and Bell, 2010). The complex was affected by Svecofennian regional metamorphism that overprinted Rb-Sr and Pb-Pb systems in micas and apatite, respectively (Tichomirowa et al., 2006). The closure temperature of Lu-Hf isotope system in apatite (660–730°C; Glorie et al., 2023) is significantly higher than that of U-Pb (350–570 ◦C °C; Chew and Spikings, 2021) making Lu-Hf a more robust system against resetting. Recent technical advancements have also enabled *in situ* determination of Lu-Hf isotope ratios in several new mineral phases (e.g., calcite, apatite, Simpson et al., 2022; Glorie et al., 2023).

Samples and analytical method

A preliminary study of Siilinjärvi apatite using the Lu-Hf isotopes yielded ages around 2,000 Ma, much younger than the previously determined zircon U-Pb age. A more detailed follow-up study on Lu-Hf in apatite (6 samples) and calcite (4 samples) from the Siilinjärvi complex was conducted at the University of Adelaide, Australia, using *in situ* laser ablation tandem inductively coupled plasma mass spectrometry (LA-ICP-MS/MS), followed by monazite U-Pb dating of sample SAA4 by LA-single collector (SC)-ICP MS at the Geological Survey of Finland.

Preliminary results and discussion

The Lu-Hf data were plotted and calculated in IsoplotR (Vermeesch, 2018) as inverse isochrons and weighted mean ages. The results indicate Paleoproterozoic ages for calcite, between 1,800–1,900 Ma. This is likely due to resetting of the Lu-Hf system during the Svecofennian orogeny. There is more variability in the Lu-Hf ages in apatite, with weighted mean ages between 2,040±35 and 2,240±40 Ma, predating the Svecofennian orogeny and clearly non-contemporaneous with the Archean zircon U-Pb age. Sample SAA4 originates from a shear zone which is evident from the occurrence of similarly oriented alkali amphibole and phlogopite. Monazite in the sample is primarily located in contact with or near apatite, indicating a metasomatic origin. Monazite U-Pb results show low concentrations of U and a poorly defined U-Pb intercept age of 1,800 Ma. The results show that the apatite Lu-Hf system has been disturbed after the Neoarchean crystallization but closed prior to the Svecofennian orogeny. Based on the monazite U-Pb age, the monazite was formed in a metasomatic reaction between apatite and a fluid in the late stages of the Svecofennian orogeny.

Acknowledgements

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Pasalanmäki hornblende gneisses revisited, an attempt to solve the age and origin of highly heterogeneous rock group in Central Finland

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Introduction

Geologist occasionally tend to lump together rocks that are either too difficult to understand or irrelevant for their research question under a "waste bin" rock name. One example of such lumping are the hornblende gneisses occurring within the Raahe-Ladoga suture zone in Pasalanmäki, Leppävirta, Central Finland. These rocks vary from fine grained variably migmatized gneisses into nearly unoriented tonalites, common nominator in addition to location being that most of them contain hornblende, feature which separates them from the paragneisses enveloping them.

In order to better evaluate the regional ore potential Geological Survey of Finland launched in 2021 a project aiming at better understanding of these rocks. So far two master thesis have been finalised, other focusing on the geochemistry and petrography of these rocks (Savakko, 2023) and other on their age determinations (Tuppurainen, 2023).

Results

Based on the field observations and petrography the hornblende gneisses have two main end members: fine grained biotite-hornblende gneisses which often have banded migmatitic appearance and medium grained biotite-hornblende tonalites, with weak to moderate orientation. Locally observed cm-scale compositional layering of the fine-grained gneisses suggest that they originated as supracrustal rocks. Their leucosomes are mineralogically similar to the tonalites and there is some field evidence that the tonalites could represent melting products of the gneisses. The relatively abundant felsic dykes display variable degree of deformation, some have been deformed but some show no signs of significant deformation.

Gneisses and tonalites are geochemically similar calc-alkaline intermediate to felsic rocks with SiO_2 typically between 55 and 70 wt.%. REE patterns are highly variable, with Eu/Eu*=0.67–5.82 and $(La/Yb)_N$=2.5–72.9, indicating that feldspar accumulation played a role in their genesis. Their geochemical characteristics indicate formation in arc environment.

All single grain age zircon U–Pb age determinations (n=7) provide similar results, instead of clear magmatic or metamorphic populations they are characterised by mainly concordant $^{207}Pb/^{206}Pb$ ages forming a continuous span from 1.93 to 1.87 Ga without indications of significant inheritance from older sources. In case of tonalites and gneisses this span could be attributed to lead-loss in conditions combining high metamorphic degree, partial melting and active deformation. It has been shown that under such conditions the crystal dislocations can act as pathways increasing the diffusive speed by orders of magnitude (Piazolo et al. 2012). In case of sampled dykes the spread is attributed to inheritance.

Conclusions

Our current interpretation is that the Pasalanmäki gneisses and tonalites (i.e. the hornblende gneisses) are part of the older Svecofennian magmatism (1.93–1.91 Ga) which took place in the island arc that collided with the Karelia Province at ~1.91 Ga. Location within the Raahe–Ladoga suture zone has subjected them to prolonged high degree metamorphism and deformation resulting in significant lead loss in zircons.

Alternatively, the tonalites could have been formed through extensive partial melting and mobilisation of the gneisses. Which would explain their less deformed character. Major challenge with this interpretation being: why the adjacent, similarly metamorphosed and deformed paragneisses, were not completely mobilized?

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General fractional crystallization model for shoshonitic magmatic rocks in southern Finland

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We have characterized the geochemistry, age and whole-rock Sr-Nd isotope composition of the Tistronskär LREE-rich monzodiorite, and the geochemistry and age of the Loukee high Ba-Sr granite dykes in western and southern Finland. In this study, we aim to: (i) investigate the petrogenesis of the post-orogenic magmatism (1.81-1.76 Ga) in the southern Finland; (ii) show the distribution of post-orogenic magmatism in the Svecofennian province and (iii) evaluate, which processes control the geochemical variations in the shoshonitic magma series.

The zircon U-Pb geochronology defines an age of 1806 ± 3 Ma for the Tistronskär monzodiorite and an age of 1794 ± 12 Ma for the Loukee granite, which are similar to other post-orogenic shoshonitic intrusions in western and southern Finland (Rutanen et al., 2011). The obtained near-chondritic initial εNd value of -0.3 ± 0.4 at 1806 Ma suggest a subcontinental lithospheric mantle source for the Tistronskär monzodiorite. Overall geochemistry and age indicate that the parental magma for the Tistronskär monzodiorite as well as other shoshonitic intrusions was formed in a post-orogenic setting in a mature continental arc environment, predated by voluminous anatectic leucogranite magmatism at 1.86-1.79 Ga. Slab retreat due to roll-back, lower crust delamination, or the decay of radioactive isotopes, is suggested to be the cause of magmatism in a mature continental arc environment. Moreover, the composition, timing and isotope data of the shoshonitic magmatism are broadly compatible with melts generated in an enriched mantle source, where earlier subduction enriched the mantle wedge in Ba, Sr and LREE from subducting sediments.

Shoshonitic rocks in southern Finland range from monzogabbro through monzonites to granites and geochemical characteristics imply that fractional crystallization processes controlled the geochemistry of the whole magmatic series. To examine this assumption, we have modelled the fractional crystallization of basaltic trachy-andesitic magma (stemmed from an enriched mantle wedge sources) intruding the upper crustal level using the Magma Chamber Simulator (Bohrson et al., 2020). Modelling results are consistent with fractional crystallization along the liquid lines of descent of spinel, apatite, hematite/ilmenite and clinopyroxene, followed by orthopyroxene, plagioclase, biotite, and K-feldspar at lower temperatures (< 900 °C). Melt composition changes from basaltic trachy-andesite to rhyolite following the shoshonitic series. Suggested major element modelling acts as a framework for the more precise trace element modelling. As the transition from major- to trace element modelling is at some point mandatory because, for example, classifying granites according to major elements is difficult due to granite forming melts following the eutectic minimum trends, and thus clustering the major element composition (Moyen et al., 2021). Our fractional crystallization model is a generalization meaning that geochemical patterns seen in the shoshonitic rock series stemmed from individual intrusion. This kind of generalization is mandatory in order to adapt magmatic models to the entire orogeny and not just locally. This kind of over-generalizing approach also creates concerns, for example in the case of possible false correlations in non-homogeneous data (Rollinson & Pease, 2021).

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Megacrysts in metaplutonic and metasupracrustal rocks in southernmost Finland

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Potassium feldspar megacrysts – grains significantly larger than the surrounding matrix – are ubiquitous in granitoid rocks. Scientific debate on potassium feldspar megacryst formation in granitoids has been ongoing since the late 19th century, and while some research attributes them to metasomatic alteration (Stone & Austin, 1961), the predominant view is that they form during magma crystallization, either as phenocrysts (Vernon, 1986) or because of thermal fluctuations caused by incremental magma pulses (e.g., Johnson and Glazner, 2010).

In the Hanko-Ekenäs archipelago area of Southern Finland (Figure 1), an early Svecofennian (c. 1.88 Ga) granitoid that contains potassium feldspar megacrysts occurs as interlayers among the older (c. 1.89 Ga) supracrustal units. On outcrops in proximity of regional-scale shear zones to the south and east, where both rock types are present, the supracrustal rocks contain potassium feldspar megacrysts that are indistinguishable from those in the granitoid. Further away from the shear zones the supracrustal rocks contain smaller and fewer megacrysts. On outcrops not associated with shear zones or the early Svecofennian granitoid, the supracrustal rocks do not contain megacrysts. The supracrustal rocks themselves are heterogeneous, their protoliths comprising lavas, volcanogenic sediments, and other sediments (Hopgood et al., 1976), and on some outcrops the heterogeneity is reflected in the megacrysts so that mafic units contain smaller megacrysts than felsic units. All the early Svecofennian rocks were subjected to the regional metamorphic event during the late Svecofennian (1.84-1.82 Ga) and thus deformed and partially melted, further obfuscating the pre-existing features of the rocks.

Although the potassium feldspar megacrysts in the early Svecofennian granitoid may be magmatic, the megacrysts in the supracrustal rocks cannot be phenocrysts. The thermal cycling model that results in euhedral crystals is also inconsistent with the asymmetric megacrysts of the study area. Thus, the megacrysts present in the supracrustal rocks may have formed through influx of K-rich fluids while coarsening took place in the plutonic rocks. The fluids likely migrated along the shear zones prevalent in the region in multiple pulses between the granitoid emplacement at 1.88 Ga and the partial melting event at 1.83 Ga.

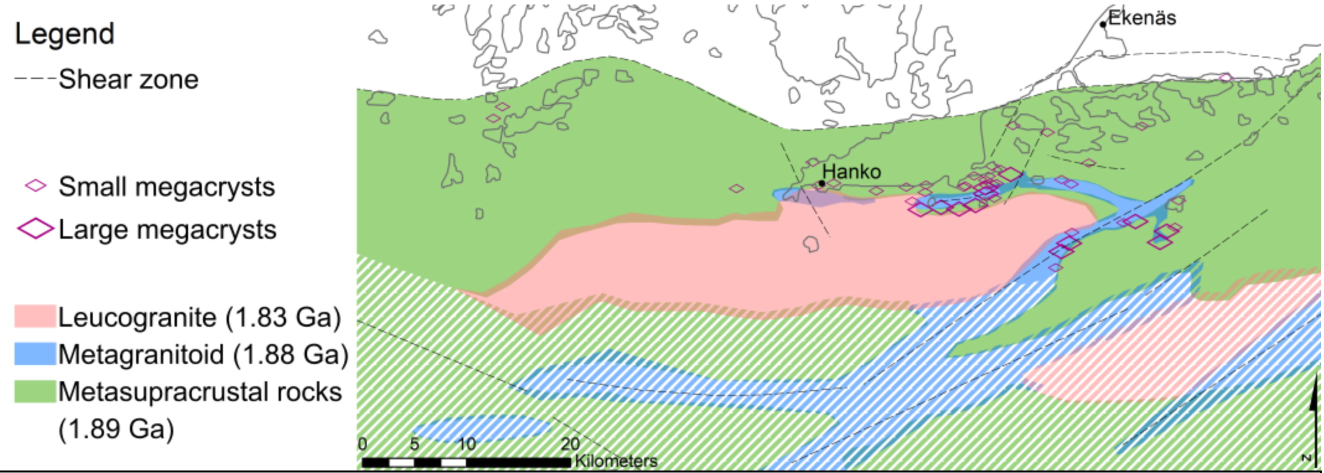

Figure 1. Lithological map of the study area displaying the relative sizes of potassium feldspar megacrysts in originally supracrustal rocks.

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Anna Hietanen – edelläkävijä geologiassa

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Anna Hietanen (1909–1994) oli suomalaissyntyinen geologi, joka väitteli vuonna 1938 aiheesta ”*On the petrology of Finnish quartzites*”. Hän oli ensimmäinen geologian alalta väitellyt nainen Suomessa ja mahdollisesti myös Pohjoismaissa. Kesti 24 vuotta, että toinen nainen väitteli geologiasta Helsingin yliopistossa.

Väitöksensä jälkeen Hietanen lähti kahdeksi vuodeksi, 1938–1940, Yhdysvaltoihin tutkijavaihtoon. Ensimmäisen vuoden hän vietti Brywn Mawr Collegessa. Toisen vuoden Hietanen työskenteli Johns Hopkinsin yliopistossa, jossa hän työskenteli Ernst Cloosin (1898–1974) kanssa. Tutkijavaihtonsa jälkeen Hietanen palasi Suomeen, ja paluun jälkeisessä ajassa yksi merkittävä asia häneen liittyen on hänen jatkosodan aikana tekemänsä laajat kenttätyöt. Hietanen haki Helsingin yliopistossa 1940-luvulla avoinna ollutta geologian ja mineralogian apulaisen virkaa. Virantäyttö kesti yli vuoden, ja lopulta virkaan valittiin Martti Saksela. Vuonna 1946 Hietanen muutti Yhdysvaltoihin, jossa hän jatkoi geologian uraansa. Monet hänen tutkimusartikkelinsa käsittelevät metamorfisia kiviä, ja Yhdysvalloissa hänen tutkimusalueitaan olivat esimerkiksi Idaho ja Kalifornia. Vuonna 1975 julkaistussa artikkelissaan ”*Generation of potassium-poor magmas in the northern Sierra Nevada and the Svecofennian of Finland*” Hietanen vertaili Sierra Nevadan ja Etelä-Suomen geologiaa ja esitti ensimmäisen laattatektonisen mallin Suomen kallioperän kehitykselle. Hietasen ura on saanut tunnustusta sekä Yhdysvalloissa että Suomessa, mutta hänestä ei tiettävästi ole aiemmin tehty laajempaa tutkimusta tai elämäkertaa.

Tutkiessani Anna Hietasta olen keskittynyt erityisesti 1900-luvun alkupuoliskoon, jolloin hän vaikutti pääosin Suomessa. Tutkimukseni pohjalta työstän aiheesta tietokirjaa. Hietasen ulkonaisten vaiheiden lisäksi olen kartoittanut etenkin hänen akateemiseen lähipiiriin kuuluneita henkilöitä, pohtinut hänen sukupuolensa merkitystä geologian alalla ja selvittänyt esimerkiksi sitä, kuinka sota-aika mahdollisesti vaikutti häneen geologina. Erilaisten aineistojen tutkimisen ja haastatteluiden lisäksi olen tehnyt kenttätöitä Hietaseen liittyvissä paikoissa.

In English:

Anna Hietanen (1909–1994) was a Finnish-born geologist who defended her doctoral thesis in 1938. Her thesis topic was "*On the Petrology of Finnish quartzites*". Hietanen was the first woman to have a doctorate in the field of geology in Finland and possibly also in the Nordic countries. At the University of Helsinki, it took 24 years to another woman to defend her doctorate thesis in the field of geology.

After her dissertation, Hietanen moved to the United States for two years, 1938–1940, on a researcher exchange. She spent her first year at Brywn Mawr College, and the second year at Johns Hopkins University, where she worked with Ernst Cloos (1898–1974). After this Hietanen returned to Finland and made, for example, extensive fieldwork during the Continuation War. Hietanen applied for an assistant position in geology and mineralogy that was open in the 1940s at the University of Helsinki. It took over one year to fill the position, and finally Martti Saksela was elected to the position. In 1946, Hietanen moved to the United States, where she continued her career as a geologist. Many of Hietanen's research articles are concentrated on metamorphic rocks, and in the USA her research areas were, for example, Idaho and California. In her article "*Generation of potassium-poor magmas in the northern Sierra Nevada and the Svecofennian of Finland*" published in 1975, Hietanen compared the geology of the Sierra Nevada and southern Finland and presented the first plate tectonic model for the development of the Finnish bedrock. Hietanen's career has been recognized both in the United States and in Finland, but, to my knowledge, no extensive research or biography has been done on her before.

In my research on Anna Hietanen, I have focused especially on the first half of the 20th century, when she mainly lived in Finland. Based on my research, I am working on a non-fiction book on the subject. In addition to Hietanen's external stages, I have been interested to study who formed the academic circle around Hietanen, considered the importance of her gender in the field of geology and studied, for example, how the wartime possibly affected her as a geologist. In addition to researching various materials and conducting interviews, I have done fieldwork in places related to Hietanen.

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The Kopparnäs study site in Southern Finland – characterization of a fault zone

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Topographic lineaments are easily interpreted from digital elevation models but verifying them as ductile or brittle deformation zones, and subsequently characterizing their geological and hydrological properties demands comprehensive studies. Outcrop mapping may reveal spots where deformation zones can be found and studied, but commonly the structure is buried by overburden, vegetation and water bodies.

Ground geophysical methods can be applied to study the location, dimensions and orientation of the deformation zone and give some indication of their nature. Ground Penetrating Radar (GPR) is one geophysical study that can be utilized to reveal the subsurface bedrock structures, especially subhorizontal fractures and faults, but might be masked if the quaternary deposits are thick. Another geophysical method is Electrical Resistivity Tomography (ERT) where subsurface structures can be imaged with electrical resistivity measurements on the ground surface or in boreholes with multi-electrode cables. However, to study deformation zones and bedrock structures in detail drillholes are required to intersect these deformation zones within the bedrock.

The Kopparnäs study site in southern Finland, is located in the crystalline basement that was formed and modified during the 1.9–1.8 Ga Svecofennian orogeny (Nordbäck et al., 2023). The bedrock was subjected to multiple tectonic events of distributed deformation, first during a compressional stage, then followed by an extensional stage and finally a transpressional stage. Hence, the geological history of the site with several stages of ductile and brittle deformation provides good prospects for exploring fault zones in the area.

The site has been studied by the Geological Survey of Finland (GTK) for several years, and during recent years (summer 2022 and 2023) two measurement campaigns of GPR and ERT studies were performed. Earlier a drillhole was drilled and intersected the deformation zone at 100 m depth and it was classified as an approximately 25 m wide subvertical E–W orientated multi-core fault zone. The drillcore has been studied in detail and comprehensive sampling has been performed for various petrophysical properties, while the drillhole has been logged with various geophysical devices and imaged with acoustic and optical methods.

The result from the two geophysical GPR and ERT campaigns indicate that these surface studies is a viable method to study fractures, faults, and brittle deformation zones, especially when these methods are coupled together. The initial results from drillcore studies suggest that faulting strongly impacts the petrophysical characteristics of the rock, typically increasing porosity and reducing bulk density. This change is most likely related to the fracturing at the site being often associated with mineral alteration and dissolution. These features have altered and deformed the multiple fault cores in distinctively manner, that can be observed as different sheared induced features, such as mylonitic, breccia and cataclastic structures.

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Formation of the granite-migmatite belt in Southern Finland by lateral spreading of hot lithosphere

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The term "Late Svecofennian granite-migmatite (LSGM) zone" of southern Finland was coined by Ehlers et al. (1993) who defined it as a 500 km long and 100 km wide belt transecting the southern Svecofennides from WSW to ENE. The zone comprise rocks of different origin in high temperature and low-pressure metamorphosis forming various types of migmatites. These migmatites were intruded by by so called late-orogenic granites at 1.85 – 1.82 Ga.

Based on structural field evidences and analogue modelling, Cagnard et al. (2006) suggest that the LGMZ was formed as a consequence of lateral flow during compression of hot and weak lithospheres. A situation in favour of HTLP metamorphism, migmatization and granite formation.

Even though several attempts to classify the late orogenic granites geochemically, there are no consensus. Probably because the migmatization and granite formation took place in all previously formed rocks like metavolcanites, various types of metasediments and granitoids.

Liegeois et al. (1998) presented a geochemical method how to distinguish granitoids formed by melting of a hot and weak lithosphere and granitoids formed in more cratonic environments. The rocks formed from a hot weak lithosphere are called High-K- Calk-alkaline (HCKA) rocks typically occuring in post-collisional setting during large relative movements of terranes along major shear zones.

We treated a geochemical data set with about 200 so called late orogenic (1.85 – 1.82 Ga) with the method presented by Liegeois (1998) and found out that these rocks plotted in the field of HKCA and Shoshonites. According to Liegeois (1998) these type of rocks series were generated from K-rich andesites in the lower crust or from a phlogopite K-richterite bearing lithospheric mantle.

To produce HKCA magmas, a hot and weak lithosphere is needed in combination with displacement of terranes that magmabodies can rise.

It seems that there is no need to look at the late-orogenic event as a period of crustal thickening, but as a long lived lateral flow during the post-collisional period.

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1865 Ma Svecofennian mantle-derived magmatism in Nagu, SW Finland

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Introduction

The Svecofennian orogeny in southern Finland is traditionally divided into two compressional stages, the 1.89-1.87 Ga (synorogenic) stage and the ca 1.84-1.82 Ga (lateorogenic) stage. The term "intraorogenic" that was introduced by Simonen (1980) is used to describe the poorly defined phase that occurred between these two, with some overlapping. Intraorogenic magmatism is typically bimodal, and the mafic components show MORB affinities that imply extensional tectonics.

During the last 20 years, an increasing number of mafic intrusions (i.e. Kara et al. 2020 and references therein) of intraorogenic ages have been identified in the Late Svecofennian Granite and Migmatite zone (LSGM, Ehlers et al. 1993) in the Southern Finland Subprovince (SFS), continuing into both Sweden and Russia. Mature quartzites (Bergman et al. 2008, Lahtinen & Nironen 2010) are found in the same areas. The LSGM zone has been interpreted as an area of high-T low-P metamorphism concentrating in an extensional sedimentary basin with volcaniclastic deposits and situated in a zone of inherited crustal weakness.

The Kaiplot gabbro in Nagu

The Kaiplot gabbro is situated on a number of islands and islets in Nagu in the southwestern archipelago of Finland. U-Pb dating (TIMS, zircon) gave an age of 1865±2 Ma, i.e. an intraorogenic age. The outcrops occur as dykes as well as plutonic bodies and have been emplaced in at least two separate pulses. Outcrops containing fragments of earlier pulses, as well as dark magmatic enclaves are found. Net-veining structures and incomplete mixing between the mafic rock and a felsic rock type is seen in places, a feature also described by Väisänen et al. (2012a) regarding slightly younger intraorogenic rocks from Korpo, some 20 km to the west.

The mafic rocks consist of mainly plagioclase and varying proportions of ortho- and clinopyroxene, amphibole and minor biotite. Geochemical whole-rock analysis was done on 18 samples, of which 15 can be defined as gabbros and the remaining 3 as dioritic gabbros in a TAS diagram. The tholeiitic Kaiplot gabbro has Mg# of 62.75 to 37.05, with the most primitive samples being close to chemical equilibrium with the mantle. During transport and emplacement, assumably both differentiation and assimilation of crustal material have taken place. The incompatible trace element signatures imply depleted to slightly enriched MORB and BABB affinities. Compared to other intraorogenic mafic rocks in the SFS, the Kaiplot gabbro is the most depleted and least contaminated/altered mantle derived intrusion. The Kaiplot gabbro confirms an extensional tectonic episode at around 1865 Ma.

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Stratigraphy in practice: naming Precambrian geological units in Finland

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Introduction

Stratigraphy allows us to establish and communicate the timings of Earth history and provides also the means to determine the duration and rates of Earth processes (Coe 2022; Miall 2022). Formal stratigraphic practices, including the definition of formations and stages, had their origins in nineteenth-century field geology (Miall 2022), and have evolved into a set of carefully defined procedures for naming and correlating the various kinds of stratigraphic unit. Lithostratigraphic classification of the sedimentary record remains the basic descriptive process for stratigraphic documentation, because of the large body of documentation is based on lithostratigraphy; but the ultimate future goal is now to develop stratigraphic frameworks based on sequence stratigraphy (Catuneanu et al. 2011). Several commissions and subcommissions and numerous working groups of the International Union of Geological Sciences (IUGS), mostly under the auspices of the International Commission on Stratigraphy (ICS), have been carrying this work for many years, like many national groups incl. Stratigraphic Commission of Finland (SCF, see Fig. 1).

Guidelines for naming Precambrian geological units in Finland

The SCF was established in 2006 and the first edition of Guidelines and Procedures for Naming Precambrian Geological Units in Finland was published in 2010 (Strand, Köykkä & Kohonen 2010). The Precambrian Subcommission of the SCF and the Geological Survey of Finland (GTK) have jointly developed the Precambrian geological nomenclature in Finland, and there will be coming now a new revised edition of the Guidelines which provides a summary of the current practices and recommendations. These guides present the principles of the classification of geological units, the procedure for the naming of formal and informal units and advice for the application of the different classifications. Special emphasis has been placed on: (1) the parallel use of lithostratigraphic and lithodemic units and (2) the classification of tectonic/structural geological units in the Precambrian of Finland. A specific chapter for sequence stratigraphy will quide to utilize it as a modern approach to integrated stratigraphic analysis. The GTK is maintaining the stratigraphic database under its map services (Kohonen & Tarvainen 2021). To avoid misunderstanding and confusion and to help in transferring knowledge of geoscience information and systems, geological units need to be named and classified according to accepted guidelines and stratigraphic codes.

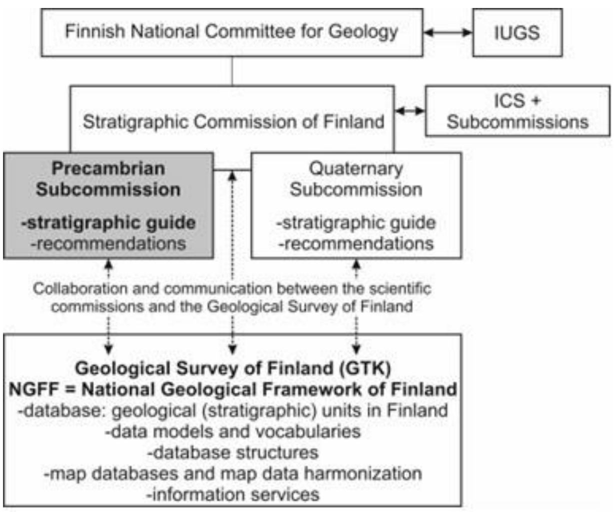

Figure 1. The roles of the Stratigraphic Commission of Finland and the Geological Survey of Finland in the development of stratigraphic procedures and databases.

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Some new aspects of supercontinents in deep time: huge rotations, enhanced velocities and lock in latitudes

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This presentation updates the paleogeography of the Earth in deep time (Pesonen et al., 2021). Based on the new reconstructions of continents and cratons we analyse the kinematic and dynamic aspects of the Earth with a particular focus on plate velocity, paleolatitudes and block rotations using high quality paleomagnetic data. We test the observed paleolatitude distributions by data of paleoclimatically sensitive sediments and compare the palaeolatitude lock in-curves with those obtained by mantle dynamic models.

Our new models of continental reconstructions suggest that the Nuna supercontinent (1.8-1.3 Ga) consisted of three clans of continents. The Laurentian clan (Laurentia, Siberia, Baltica) remained nearly intact and, after broken-up from Nuna, drifted with high velocities to polar latitudes. The Australian clan (Australian cratons including Mawson, N and S Chinas, Tarim, India) followed the Laurentia with some reorganizations. The Amazonian clan (Amazonia, Congo-Sao Francisco, W Africa, Rio Plata) experienced huge clockwise rotations just before amalgamating with Laurentian continents to form the Rodinia supercontinen (1.0-0.7 Ga). The latitudinal lock in-curves are similar with those obtaided by mantle dynamic models. The plate velocity curves reveal considerable variations in velocity with some three or four "lulls" and "peaks". The shapes of the velocity curves match with curves of zircon age, metamorphic probability, subduction activity, and oxygen isotope ($\delta^{18}O$). A noticeable feature in the velocity curve is the distinct minimum at 1.6-1.4 Ga during Nuna tenure when the A-type granite activity was at maximum.

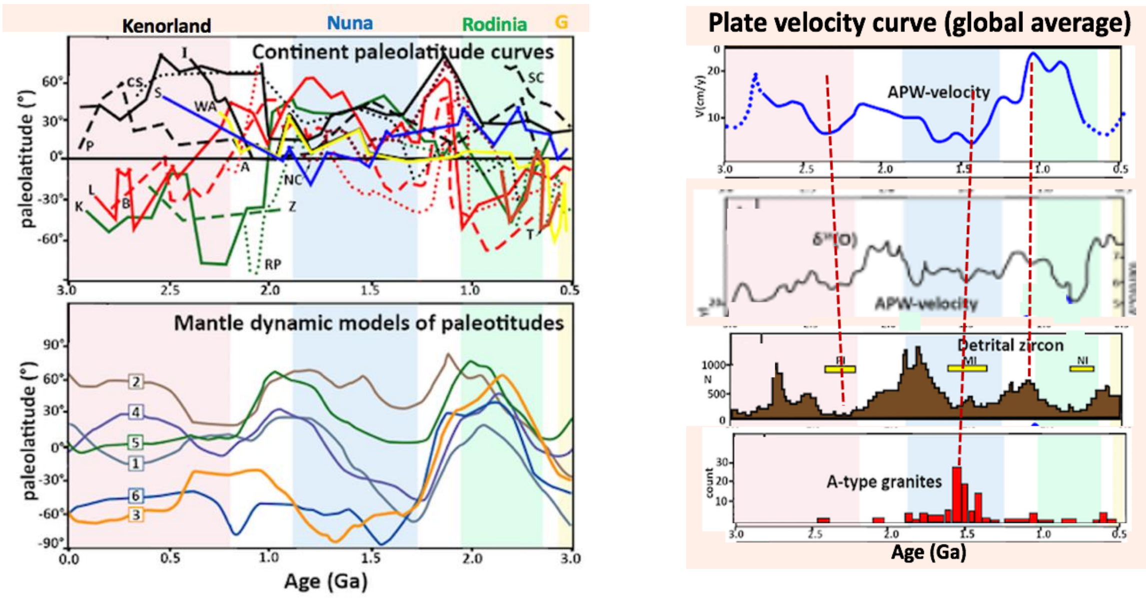

Figure 1. Left: Continental lock in- and mantle dynamics curves of paleolatitude. Note: the age in the upper (lower) figure is geochronologic ("model age"), respectively. Right:Plate velocity (APW-) curves compared with curves of zircon $\delta^{18}O$, detrital zircon age and A-type granite distribution. Major lows and peaks are indicated by vertical red lines (Pesonen et al., 2021).

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New developments in vertebrate paleoecology and ecometrics research

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Introduction

Research on fossil mammal record continues to provide new understanding on the evolution of mammals, but also importantly about ecological adaptations of mammals and their interactions with environments in the past. Such understanding serves a a basis for reconstructing past climatic and environmental (for example plant community) conditions in terrestrial ecosystems based on the distribution of functional traits and dietary patterns in fossil communities of mammals. Furthermore, with some limitations, such methods could be extended beyond fossil mammal communities to extend their coverage further back in time. However, functional traits have evolved through time following different patterns on separate continents, and thus it is important to look into non-analogue trait-environment associations beyond the establishment of modern functional trait conditions in mammals and other organisms. This can be achieved by multi-proxy comparisons from the fossil record, for example by analysing associations between fossil plant and mammal assemblages.

Recent results and new research directions in vertebrate ecometrics research

Several new approaches to analysing relationships between mammalian functional trait distribution and properties of their paleoenvironments (=ecometrics) have been developed lately and are being developed (e.g., Fortelius et al., 2002; Liu et al., 2012; Zliobaite et al., 2018; Oksanen et al., 2019; Saarinen et al., 2021, Wilson and Parker, 2023). In my own research I have explored the use of dietary patterns and body size of large herbivorous mammals as indicators of past environmental conditions, particularly vegetation structure (Saarinen et al., 2016; Saarinen and Lister, 2016, 2023), and this line of research actively continues in my research group, including extending of these methods to analyse associations between environments with functional trait distribution of previously unstudied groups of large vertebrates such as endemic South American mammals and dinosaurs. We also develop mesowear angle analysis method (Saarinen et al., 2015) for various herbivorous vertebrate groups, exploring its use as a universal dietary analysis method applicable to morphologically vastly separate dentitions. Using such new evidence, we explore associations of vertebrate ecometrics and properties of climate and plant communities in the past using direct proxy comparisons from the fossil record. The ultimate goal is to develop increasingly universal ecometric models for analysing associations of trait distribution in vertebrate communities with their environment, that would account for differences between continents and evolution of vertebrate functional traits through time.

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Reconstructing palaeoclimate with plant macrofossils: methodological overview

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Introduction

Plant macrofossils can effectively represent past local environment. They offer higher plant taxonomic resolution with reduced noise from long-distance transport compared to commonly used pollen, and therefore are recognised as instrumental tool in climate research (Birks, 2003). The potential of plant macrofossils is further increased by the recent development of new quantitative climate reconstruction tools compatible with these proxies.

Plant macrofossils commonly use climate reconstructions with so-called indicator-species approach, i.e., methodologies are built upon known observations of modern plant distributions and climate (modern analogues). Hence this proxy allows complementary palaeoclimate reconstructions using an approach which is not limited by the spatial availability of calibration samples obtained from surface sediments (e.g., pollen or chironomids). However, since new plant macrofossil-based climate reconstruction algorithms have been introduced, we raise the question of the practical differences that available methods have on the reconstructed climate.

Tasks and aims

Our objective is to evaluate and compare the impact that various methodological choices have on the reconstructed climate. We reconstruct January and July temperature patterns of the Lateglacial (14–11 ka BP) period, which consists of abrupt and intense climate shifts, the most noticeably Younger Dryas cooling event. We use unfiltered plant macrofossil assemblages from 13 sites of Baltic States to evaluate each method's ability to handle the presence of plants that possibly have a weak sensitivity to temperature and to reconstruct coherent palaeoclimatic shifts. The algorithms we test include the traditional Mutual Climate Range (MCR; Mosbrugger & Utescher, 1997) method, recently developed Common Northern Distribution Limit (CNDL; Väliranta et al., 2015), and coexistence likelihood estimation based CRACLE (Harbert & Baryiames, 2020) and CREST (Chevalier, 2022) algorithms. Additionally, we test the influence of another methodological choice – the choice of modern analogue region (MAR; e.g., using region of specific Eurasian continentality regime) – on the reconstructed palaeoclimate.

Results

On aggregate, CREST and CRACLE can reconstruct abrupt climate events without prior filtering of summer and winter-sensitive plants, however, the intensity of seasonal changes and absolute temperatures varies between algorithms. In contrast, the MCR is highly sensitive to the presence of taxa with poor climate indicator value, and shows no distinct climatic shifts. While disparities are present between the algorithms, we note that the choice of MAR has a greater influence on the results. This means that an evaluation of the most appropriate MAR needs to be conducted prior to the reconstructions. Moreover, we emphasize that 1) the choice of the MAR should be based on the characteristics of the past environment rather than, e.g., using the same spatial extent as the study site/s, and 2) for the long-term reconstructions, the "dynamic calibration set" concept (Birks, 1998) should be considered by using a range of MARs and mirroring the continuously changing broadscale environmental regime of the past.

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Spatiotemporal Arctic peat fire patterns and climate implications

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Introduction

In recent years unexpected wildfires have raged through Arctic peatlands. Peatlands are the largest natural terrestrial carbon stocks and thawing and drying of arctic permafrost can make them susceptible to fire, which can turn them into a net source of carbon (Turetsky et al., 2015).

Arctic peat fires are usually ignited by increasing temperatures and lightning (Descals et al., 2022). They propagate horizontally and vertically, leading to the largest fires on Earth in terms of mass of fuel consumed per unit surface (Huang & Rein, 2017). Peat fires are frequently reported in tropical, temperate and boreal regions but their fast spread in the Arctic is alarming and has led to calls for immediate action (Irannezhad et al., 2020).

Knowledge on arctic peatland fires is virtually missing (McCarty et al., 2020). No information exists on the depth of these fires and how old carbon they release. Arctic peats are comparably shallow and thus thousands of years old peat may be burned (Witze et al., 2020). This work produces pioneering and critically called for data on arctic peat fires, which can be implemented in global climate modelling (Figure 1).

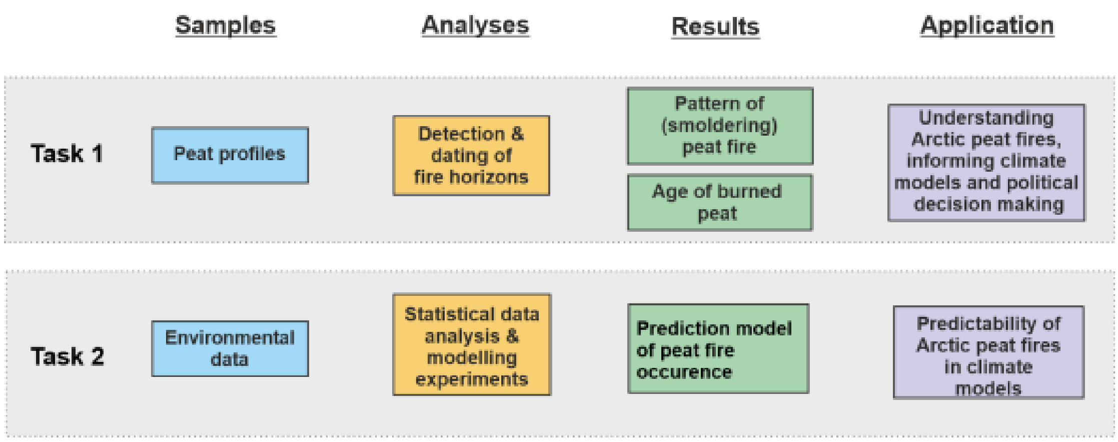

Figure 1. An overview of project tasks, analyses, results, and applications.

Other important things to consider

Samples are collected from at least five peatlands in Alaska, Canada and Greenland during summer 2024. Peat profiles from burnt locations are collected in transects down to the mineral soil and dated by radiocarbon dating. The prediction model is built by using GAM and GLM.

Objectives:
O1. To determine the age of carbon released in Arctic peat fires
O2. To investigate the vertical spread of recently documented Arctic peat fires
O3. To develop a predictor model to elucidate which environmental traits promote Arctic wildfires

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Modern-type aeolian regime and global cooling-modulated dust provenance in the Late Paleogene of Central-East Asia

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Atmospheric mineral dust is an important component of the climate system yet its long-term effect and response to climate changes are poorly understood. Central-East Asia is one of the major global dust sources, and holds a globally exceptional geological archive of past wind-blown mineral dust, the Chinese Loess Plateau (CLP). Provenance research on aeolian dust deposits, such as those on the CLP and adjacent areas, sheds light on the whole dust cycle from emission to transport to deposition and is one of the few ways to reveal past atmospheric circulation patterns. While most of the dust on the CLP is late Neogene or Quaternary, older deposits are also found especially in the regions west or northwest of the central CLP.

Here we investigate the provenance of a rare Paleogene (35–27 Ma) aeolian dust sequence from Ulantatal, Inner Mongolia, China, ~400 km northwest of the CLP. We combine detrital zircon U-Pb geochronology and detrital rutile trace element geochemistry to define the dust sources, anisotropy of magnetic susceptibility to reveal past surface wind directions, and dust source contribution modelling for modern dust transport comparison.

The results indicate that despite changes in paleogeography and a significantly warmer global climate, the late Paleogene aeolian regime was comparable to the modern circulation with dominating westerly and northwesterly dust transporting winds. The Ulantatal dust provenance is also similar to that of the late Neogene-Quaternary CLP dust deposits that formed under bipolar icehouse climate states.

The results thus reinforce the use of modern analogues to explain the past dust cycle. We propose that, as today, late Paleogene westerly wind circulation patterns would have been modulated by an Arctic Oscillation (AO)-like situation. The warm Eocene favoured a long-term negative phase of AO-like conditions, leading to meridional westerly circulation and the dominance of a northwesterly dust transport pathway to Ulantatal. After the Eocene-Oligocene transition, during which the global climate cooled significantly, long-term positive phase of AO-like conditions initiated, which led to stronger and more zonal westerlies. The Siberian High also formed, strengthened or moved southward at the Eocene-Oligocene transition and started to control dust transport along the northwesterly pathway. We argue that in addition to global cooling, increased Paleogene Northern Hemisphere ice volume may have been the ultimate driver of this modern-type dust transport regime in the Ulantatal region, possibly also controlling initial Ulantatal dust sequence formation via development of the Siberian High and modern-type aeolian regime. The similarity between the Ulantatal and late Neogene northern CLP dust provenance signals suggests that the increased Northern Hemisphere ice volume, via its control on the northwesterly dust transport, could have promoted increased loess formation also in the late Miocene. Alternatively, older dust deposits to the northwest/west of the current CLP depocenter, such as those preserved in Ulantatal, may have eroded in the Miocene and acted as sources for the late Miocene northern CLP dust.

The establishment of Asian modern zoogeographic regions and its underlying climatic and tectonic mechanisms

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The complex and contrasted distribution of terrestrial biota in Asia has been linked to active tectonics and dramatic climatic changes during the Neogene. However, the timings of the emergence of these distributional patterns and the underlying climatic and tectonic mechanisms remain disputed.

In our recent work, we applied a computational data analysis technique, called redescription mining, to track these spatiotemporal phenomena by studying the associations between the prevailing herbivore dental traits of mammalian communities and climatic conditions during the Neogene. Our data consisted of the values of seven dental traits of herbivore mammals and nineteen standard climatic variables across the study area in East Asia. In this context, redescription mining automatically identifies regions with common characteristics in both their dental traits distribution and their climatic conditions.

First, we considered data from the present day, about extant species and modern climate. Redescriptions we extracted capture the most prominent modern biogeographic regions. Specifically, two of the most accurate redescriptions capture the north–south temperature division in East Asia, corresponding to the Palearctic and Indomalaya realms. A third redescription captures the east–west precipitation division in East Asia, corresponding to the monsoon pattern.

Second, we considered data representing the Neogene, through fossil mammalian communities and climatic estimates from paleoclimate models. We split the Neogene into five intervals and evaluated the redescriptions on each subset.

Our results indicate that a north–south temperature division in East Asia already existed in the beginning of the Miocene but matched the modern Palearctic–Indomalaya pattern only after the Middle Miocene Climate Cooling; The east–west monsoon precipitation division emerged in the late Late Miocene and implies a high Tibetan Plateau having arisen by then; The emergence of Alpine fauna in the Tibetan Plateau in the Pliocene suggests the full establishment of the modern zoogeographical distribution in East Asia and near-*modern* elevation of the Tibetan Plateau.

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Uncovering Holocene climate fluctuations and ancient conifer populations: insights from a high-resolution multi-proxy record from Northern Finland

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Introduction

Holocene proxy data indicate repeated abrupt, sub-millennial disruptions in northern hemisphere climate in the early part of the current interglacial (12–8 ka), commonly linked to climatic and oceanic impacts of freshwater routing and outburst floods related to the residual ice sheets in North America and Europe (Clark et al., 2001). However, the precise climate signals of these abrupt events remain poorly resolved, including the amplitude and seasonality of associated temperature and moisture changes, as well as spatial expression and possible inter-regional correlations. This is due to the paucity of high-resolution proxy datasets, as well as seasonal biases in the available proxies, hampering a consistent hemispheric detection and characterization of the events.

Figure 1. Kuutsjärvi.

Site and methods

In this study, we describe a core sequence from the Kuutsjärvi lake, northern Finland (67.75°N 29.61°E), analysed for climate and vegetation proxies including pollen, plant macrofossils, sedimentary ancient DNA (*sed*aDNA), as well as conifer stomata and non-pollen palynomorphs (NPP's) analysed from pollen slides. A quantitative mean July air temperature reconstruction was prepared from the pollen data using a calibration model ensemble including both classical and machine-learning approaches. With robust chronology (23 radiocarbon dates) and high resolution (mean pollen sample interval 47 years and mean *sed*aDNA interval of 157 years over 10.7–4 ka), the Kuutsjärvi proxy data reveal a sequence of abrupt climate and vegetation shifts over the early Holocene. Finally, we incorporate high-resolution climate simulations (CESM1.0.5) for the early Holocene, to evaluate hypotheses about the limiting climate parameters that may explain ecological responses to abrupt events revealed by the Kuutsjärvi proxy data.

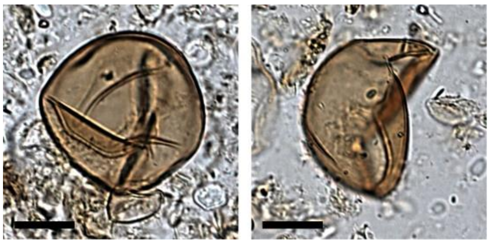

Figure 2. Larch pollen grains from the Kuutsjärvi sequence. Scale bars = 20 µm.

Results

Our data indicate an early arrival of spruce by 9.2 ka (pollen, *sed*aDNA, and stoma finds), as well as the first evidence for Holocene presence of larch in Finland, with pollen finds dating to 9.6–5.9 ka. Two abrupt decreases of tree cover occur at 10.4 and 10.1 ka, coinciding with spikes in charcoal and coprophile fungal spores. We interpret these to represent a two-pronged signal of the 10.3k climate event (Clark et al. 2001), with cooling and drought resulting in forest loss, wildfires, and increased reindeer populations. The Kuutsjärvi sequence also shows a clear signal of the 8.2k climate event (Alley & Ágústsdóttir, 2005), previously poorly documented in northern Fennoscandia, with a collapse of the pine-birch forest and replacement by juniper developing in tight synchrony with Greenland isotopic proxies over 8.4–8.0 ka. We interpret this vegetation impact to result from some combination of drought and likely winter-dominant cooling.

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Speleothem-inferred hydroclimate in northern Africa during the past 300 ka

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Northern Africa, a critical territory for human evolution and migration, has experienced variations in precipitation, related to the westerlies and the West African Monsoon (WAM), over glacial and interglacial cycles. Model simulations suggest that a southern shift in the westerlies and the Mediterranean storm track could result in enhanced winter precipitation in northern Africa during the periods of reduced Northern Hemisphere (NH) winter insolation. However, the specifics regarding changes in precipitation and moisture source during the Late Quaternary remain unclear. Here we present a speleothem-based precipitation reconstruction since 300 thousand years ago (ka) from Tunisia, northern Africa, to address the humid/arid periods in the region. A total of 125 ^{230}Th ages of 20 speleothems were analyzed by MC-ICP-MS in the High-Precision Mass Spectrometry and Environment Change Laboratory (HISPEC), National Taiwan University. The age distribution reveals a peak in late Marine Isotope Stage 7 (MIS7) (243-191 ka), two peaks in MIS5 (130-71 ka), and one peak in MIS1 (14.6-0 ka), indicating more humid conditions during interglacial periods and lower values during glacial periods, specifically MIS8 (300-243 ka), MIS6 (191-130 ka), and MIS4-2 (71-14.6 ka). The observed humid periods in the southern fringe of the Mediterranean may be attributed to the southward shift and strengthening of the westerlies and the Mediterranean storm track, possibly coupled with a more local moisture source related to convective precipitation from the Mediterranean. Our speleothem dating data supports the hypothesis that the drier climatic conditions from MIS 5 to MIS 4 acted as a driving force for *Homo sapiens* to migrate into Eurasia (Tierney, et al., 2017).

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Reassessing out-of-Africa I: Paleodietary and body mass insights from Dmanisi herbivores challenge prevailing grassland hypotheses

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One of the key discussions surrounding the dispersal of hominin species out of Africa during the Early Pleistocene has been centred on the environmental conditions which the species dispersed into. Some researchers synchronize this dispersal with the expansion of grasslands, placing hominins within the narrow savanna-grassland niche. Conversely, others emphasise the adaptability of hominins to varied, diverse environments as the main reason behind Out-of-Africa I -event. In order to test these conflicting hypotheses, reconstructing the paleoenvironments at early Eurasia hominin sites such as Dmanisi is required**.**

Here we explore the paleodiets and average body mass of the Early Pleistocene (c. 1.8 Ma) herbivore community in Dmanisi. These are crucial for understanding the prevalent biome coinciding with hominin presence at the site. We used dental mesowear analysis to identify the dietary categories among the fossil taxa, which reflect the vegetation herbivores interacted with in Dmanisi. Additionally, regression equations were applied to post-cranial skeletal measurements to estimate body mass of fossil specimen. A mean body mass value of all ungulates in Dmanisi was then compared with mean body mass values from other Pleistocene localities and correlated with locality-specific net primary productivity values, to see how the mean body mass value in Dmanisi compares to the prediction based on primary productivity.

Our results show that the herbivore community was primarily composed of mixed feeders and browsers, with limited evidence for grazing in the mesowear analysis. Smaller-sized ungulates at Dmanisi suggest limited resource availability, likely due to low net primary productivity and heightened interspecific competition. Together the results imply that hominins occupied a relatively diverse, ecotone habitat in Dmanisi, consisting of shrublands and woodlands. This suggests that the Dmanisi was not as grassy as previously assumed, and the spread of grassland environments probably was not the catalyst for the hominin dispersal.

Quantifying heterogeneity of hominin environments in and out of Africa

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To understand Homo sapiens expansion we need to investigate the plasticity which has enabled our species' rapid dispersal. By investigating the environments which hominins adapted to throughout time we can better understand the origins of plasticity. By conducting a systematic review of published environmental reconstruction of hominin sites in the early Pleistocene, we have found that during this period Homo was occupying heterogeneous environments ranging from fully open to fully forested habitats across Africa and Eurasia (Foister et al., 2023). The results of the review also suggest that humans started to use a wider range of different habitat types when they expanded out of Africa for the first time. To better understand the width of the niche Homo occupied in this period, we need to further investigate this habitat variability and validate these findings.

To validate our finding of between locality heterogeneity out of Africa we have utilised mean ordinated hypsodonty of large plant eating mammals to investigate the environmental variability of the regions occupied by Homo during the early Pleistocene. We use the mean ordinated hypsodonty of large mammal communities as this is a proxy for environmental aridity (Fortelius et al., 2002). Hypsodonty is a measure of tooth height and is an evolutionary response to increased dental wear. The increased wear associated with hypsodonty arises from several interrelated factors such as the proportion of grass in the food ingested, the occlusal pressure required to break the plant tissues and the dust load on the vegetation. The higher the mean hypsodonty of a herbivore community, the more open, grass dominated, and seasonal the environment tends to be (Fortelius et al., 2002; Liu et al., 2012, Žliobaitė et al. 2016). Our preliminary results show that the variance of mean hypsodonty across sites occupied by early Homo increased out of Africa, with the highest variance displayed in Asia. This supports the burgeoning hypothesis that Homo in this period was not constrained to the environmental limits of its African niche, but was increasingly able to exploit a wider range of environments.

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Plot-scale geodiversity in northern environments

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Introduction

Geodiversity refers to the natural range of geological, geomorphological, soil and hydrological features including their assemblages, structures, systems, and contributions to landscapes (Gray, 2013). It is often assessed at landscape or regional scale either quantitatively or qualitatively. Previously there has been a lack of empirical data to dive into the concept of geodiversity in smaller scales but recently developed field method by Hjort et al. (2022) is now being used to gather quantitative information about abiotic nature at more local scales. Plot-scale geodiversity provides unique knowledge of the abiotic environments and their interplay with soil characteristics, and it can be assessed from both natural and disturbed locations. The method produces a measure of georichness i.e. the total number of different geofeatures (geological, geomorphological, and hydrological features).

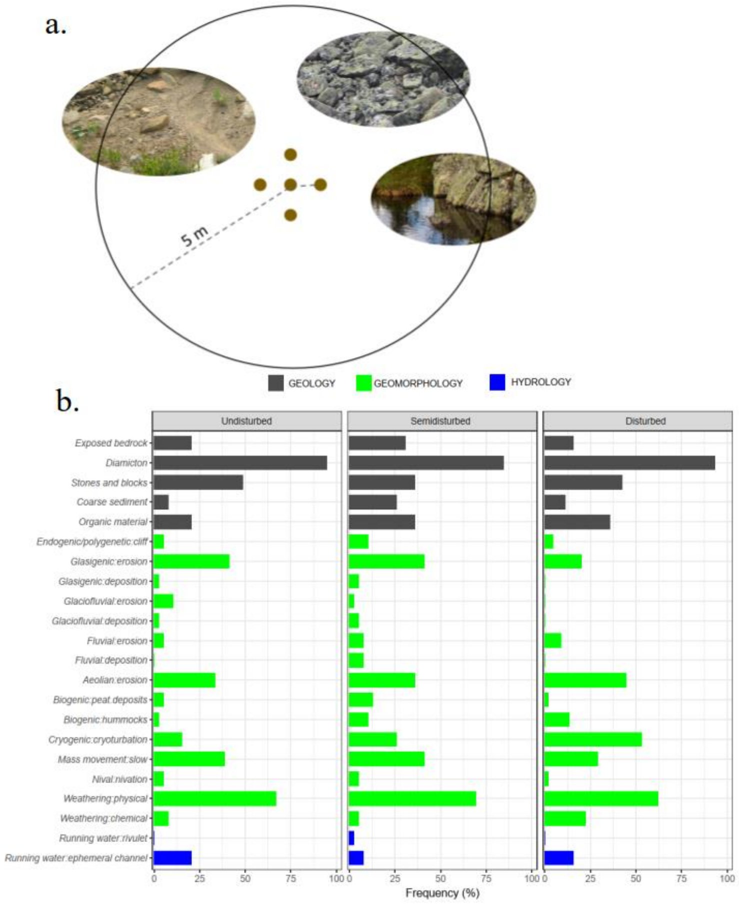

Figure 1. a. Study set up for a plot-scale geodiversity method and soil sampling (brown). **b.** Relative frequencies of observed geofeatures on undisturbed(left), semi-disturbed(middle) and disturbed(right) study plots.

Assessment and use of plot-scale geodiversity

We used the plot-scale field method to assess geodiversity of 123 study plots located in several fells and highlands in Northern Finland at or nearby areas of ski resorts. Geodiversity was assessed from a plot with 5 meters radius (Fig 1a).

As human activities have altered the land surface of the earth profoundly and are the main cause of the most contemporary environmental change (Lewis & Maslin, 2015) these plots were classified into three classes based on the volume of human land use disturbance (undisturbed, semi-disturbed, disturbed, Fig 1b). In addition, soil samples, to define pH and nutrient levels, were taken (five circles in Fig 1a) to study the relation between commonly used soil variables and geodiversity. Moreover, we observed how tourism activities affect these soil variables.

The information about plot-scale geodiversity can be used f.e. to understand biodiversity patterns (Salminen et al. 2023) or to explore the impact of tourism on geodiversity. Studying plot-scale geodiversity also contributes to the deeper understanding of geodiversity and its patterns which, in the end, affect all living things on earth.

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Defining and assessing geodiversity: Perspective for biodiversity investigations with new European geodiversity data

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Introduction: getting on the same page

The term "geodiversity" has gained attention within scientific discourse during the past 10 years, though its comprehensive understanding and recognition are not universally shared. Research interests vary from conceptual development to geoconservation and biodiversity research, to name a few. It has been suggested, for example, that nature conservation targeted towards the abiotic environment (i.e. geodiversity) could simultaneously safeguard biodiversity. This is also referred to as the 'Conserving Nature's Stage' conservation strategy. While geodiversity has great applied potential, there's still not enough research to agree on how geodiversity should be assessed. Even if we wanted to target conservation actions to geodiverse areas, we lack information on their location. Thus, globally consistent assessment methods could really advance unlocking geodiversity's potential in both theory and practice.

Grid-based geodiversity assessment in biodiversity investigations

One specific niche within geodiversity research is to investigate geodiversity's connection to biodiversity. Are biotic and abiotic diversities linked and how does it matter to conservation? At a broader scale, a usual way of describing biodiversity is to measure it as species richness, using a grid-based methodology. Adopting these mundane ecological assessment methods, we measured geodiversity as 'georichness' to describe European geodiversity (Fig. 1, Toivanen *et al*. 2024a). Here, 'georichness' refers to the abundance of distinct 'geofeatures' within a grid cell, including a variety of geological, pedological, geomorphological, and hydrological elements. As a result, we produced geodiversity data at two resolutions (1-km and 10-km) using open access geospatial data and GIS methods (full data available at Toivanen *et al*. 2024b) and demonstrated its use in geodiversity–biodiversity context to guide further use.

While the empirical evidence of the geodiversity–biodiversity link is still geographically and taxonomically limited, many previous investigations suggest that they are positively linked. Our demonstration with the new European geodiversity data, where we correlated georichness and plant species richness in Finland and Switzerland, suggested the same positive link between the two (see results in Toivanen *et al.* 2024a). These findings highlight the complementary applied potential of geodiversity and biodiversity in conservation efforts, such as the global '30% by 2030' target. Yet, more empirical evidence is needed to put these observations in practice.

Our accessible grid-based assessment method and openly available geodiversity data not only facilitate further exploration of the geodiversity–biodiversity relationship but also serve as a valuable resource for variety of geodiversity research. While initially designed for biodiversity investigations, these data hopefully inspire diverse geodiversity research and help to communicate geodiversity's significance as an integral part of natural diversity. After all, geodiversity plays a key role in sustaining many vital ecosystem and geosystem functions.

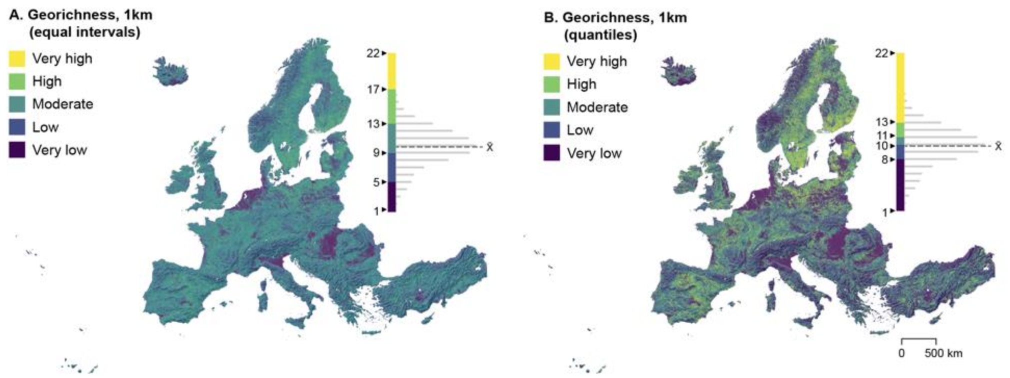

Figure 1. Georichness in Europe at 1-km resolution. The spatial distribution of geodiversity is represented with equal intervals (a) and quantiles (b) to highlight the low, moderate, and high diversity areas. (Toivanen *et al.* 2024a).

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Teaching geology to geography and science teachers

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Background

Although geology is not included in the Finnish national school curricula as a separate subject, geological themes are present in geography, biology, chemistry, and physics curricula in both comprehensive schools and upper secondary schools. Because most of the teachers of these subjects have not studied geology, many find geological themes difficult to teach and, therefore, leave their students with poor understanding of geology. Many geological organisations in Finland have developed material suitable for teachers, but due to a lack of connection between the organisations and teachers, those materials have not always been successfully distributed. Another problem faced by teachers is the limited time they have to prepare for lessons, as the workload of creating new exercises or class activities from new information is large.

We chose to tackle both problems by organizing teacher training events where the participating teachers are provided with both information on subjects they are unfamiliar with, and “classroom ready” activities they can directly incorporate in their own teaching.

Project

In 2023, we organized teacher training events as two separate, six hour long theme days: *Geology Close to the School*, and *The Geology of Climate Change*. Each theme day was organized once in Helsinki, once in Turku and once in Vaasa. The project was carried out via Skolresurs, a centre for STEM education, with extensive experience in arranging teacher trainings and an active network of active teachers and educators.

We started Geology Close to the School with a geologic time scale exercise and a brief lecture on the geological history of Finland to provide the participants with a basic understanding of what kind of geological processes the bedrock has been through. We followed these up with an exercise in rock classification, exercises to simulate how different rock types form, and a field trip to a nearby outcrop to encourage the teachers to “read” the rocks and outcrops. At the end of the theme day, we discussed the most recent glaciation and simulated some glacial deposits with a simple stream table.

The Geology of Climate Change theme day consisted of lectures in paleoclimate, the current climate change, energy, and the need for critical raw materials. As exercises to pause the lectures, we had the participants discuss and correct climate change misconceptions in teaching, and research where critical raw materials used in wind turbines and electrical vehicles are currently produced and where they could be mined. We had also guest geoscientists give us guided tours at local laboratories to give the participants examples of current research within the field.

Results

We created lecture material and classroom activities in collaboration with active teachers and teacher trainers. This way, we ensured that all material was closely tied to both the curriculum and well suited and straightforward to use in class. The feedback from the participants was very positive.

Acknowledgements

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FLEX-EPOS mobile Finnish Seismic Instrument Pool: FINSIP

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The advent of efficient seismic data storage and transmission and powerful computing systems, progress in the understanding of the seismic wavefield coupled with the development of new types of analysis techniques and algorithms, and the manufacturing of sensitive, affordable sensor systems has led to an evolution in the data acquisition styles of public sector research institutions. Despite these game-changing and promising developments, the access to many seismic sensors for large-N deployments is not pervasive. Even in developed countries, it is challenging for a single institution to acquire and maintain a sufficiently large mobile pool of instruments and ensure sustainable data production and distribution.

Here we report on establishing the Finnish mobile seismic instrument pool that is owned and operated by seven Finnish academic and research institutions. The pool is funded by the Research Council of Finland, and its call for research infrastructure, through the FLEX-EPOS project (funding decisions no. 328984, 328776, 328778-328782, 328784 and 328786), under the FIN-EPOS umbrella. The project finances the build-up stage that started in 2021 and ends in 2024. After what the pool will continue to operate. By 2024, the seismic instrumentation is anticipated to include 46 Güralp broadband seismometers, 5 Güralp accelerometers, and 1197 and 70 Geospace and SmartSolo self-contained geophone units, respectively. It is making this one of the largest coherent mobile seismic instrument pools in Europe in the public sector.

The pool supports domestic and international collaborative projects of temporary deployments to enhance data-driven subsurface and environmental applications. The instrumentation supports active and passive experiments that can last a few days up to a few years. Continuous experiments of extended duration can be realized using external batteries in addition to the GSB or Smartsolo internal battery.

From our experience between 2018 and 2023 involving the preparation of the successful funding application to the first two years of operation we summarize a checklist of suggestions and recommendations related to data management, administration, communication, and organization. This experience of building such an extensive public seismic acquisition infrastructure from the ground up can inform the general discussion about best practices for establishing and maintaining a mobile pool infrastructure, and our lessons learned are useful for communities considering similar research infrastructure projects. Our report on the equipment, facilities, ownership, and governance structure, project management, and data systems is essential background information for the access to and utilization of the pool instruments by potential users and collaborators, and the interaction with the support community.

Geology field in The Helsinki Term Bank for The Arts and Sciences (Tieteen termipankki)

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The Helsinki Term Bank for the Arts and Sciences (HTB, Tieteen termipankki in Finnish) is a multidisciplinary project, which aims to gather a permanent terminological database for all fields of research in Finland. The THB was launched in 2011 and the project has created wiki-based website (http://tieteentermipankki.fi), which offers a collaborative and open environment for terminological work. Anyone can participate in the discussion about terms.

The data available for all users includes for example the term and its synonyms in Finnish, definition(s), pictures and term equivalents in other languages. The working method is a type of limited crowdsourcing, called niche-sourcing, in which the research community takes responsibility for the terminology work. The working method therefore supports open discussion of the terminology and democratic way to do term work. The goals of the project serve language policy and sociology of science as well.

An extensive Finnish research terminology database will help those researchers, translators, journalists and others who write about research and its results in the arts and sciences and in Finnish. By gathering the scientific terminology in one place, the bank also improves the possibilities for multidisciplinary discussion and research. With periodical status and ISSN number, work in the HTB can be included in a list of publications and research data systems.

Geology field in the HTB started in August 2018 with the grant from the Kordelin Foundation as a part of Major cultural projects. After that, the work has continued with the grants from the K. H. Renlund Foundation; I am currently doing term work related to hydrogeology and environmental geology with a grant awarded by the K. H. Renlund Foundation. I have been the coordinator of the geology field since the field was initiated. However, the term work has been done in co-operation with several experts and researchers.

Geological term work in the HTB has many potential uses. Updating and creating established terms in Finnish serves for example scientist, teachers from university levels to elementary schools, and journalists. In addition, the HTB offers interface and a possibility for discussion between different branches of sciences. If you are interested in term work related to geology or geosciences, come and discuss the possibilities. It would be great to make geological terms and term work more visible in Swedish as well.

In Finnish:

Tieteen termipankki (http://tieteentermipankki.fi) on kaikkien Suomessa harjoitettavien tieteenalojen yhteinen, avoin ja jatkuvasti päivitettävä termitietokanta tiedeyhteisön ja kansalaisten käyttöön. Hanketta toteutetaan talkooperiaatteella yhteistyössä koko maan tutkijoiden kanssa. Tieteen termipankin verkkopalvelu avattiin vuonna 2012. Termipankki on edelleen rakentumassa sisällöiltään. Termipankissa kunkin alan tutkijat tuottavat sisältöjä alansa aihealueelle.

Geologian aihealue aloitti Tieteen termipankissa elokuussa 2018 osana Kordelinin säätiön Suurten kulttuurihankkeiden rahoitusta. Tämän jälkeen työ on jatkunut K. H. Renlundin säätiön rahoituksella; tällä hetkellä teen termityötä hydrogeologian ja ympäristögeologian termien parissa Renlundin säätiön apurahalla. Olen ollut aihealueen koordinaattori vuodesta 2018 lähtien. Termityötä on kuitenkin tehty yhteistyössä useiden asiantuntijoiden ja tutkijoiden kanssa.

Geologisella termityöllä Tieteen termipankissa on monia käyttömahdollisuuksia. Suomen kielen vakiintuneiden termien päivittäminen ja luominen palvelee esimerkiksi tutkijoita, opettajia yliopistotasosta peruskouluun sekä toimittajia. Tieteen termipankki tarjoaa lisäksi alustan ja mahdollisuuden keskusteliin eri tieteenalojen välillä.

Jos olet kiinnostunut geologiaan tai laajemmin geotieteisiin liittyvästä termityöstä, tule keskustelemaan mahdollisuuksista. Olisi hienoa saada geologian aihealueelle geologisia termejä näkyvämmäksi myös ruotsin kielellä. Tieteen termipankilla on kausijulkaisun status sekä ISSN-tunnus, ja näin ollen termipankin käsitesivun kirjoittaja tai merkittäviä muokkauksia tehnyt voi osoittaa työpanoksensa tutkimustietojärjestelmässä ja julkaisuluettelossaan.

Kansainvälinen geodeettis-geofysikaalinen unioni (IUGG)

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Rakenne ja strategia

Vuonna 1919 perustettu kansainvälinen geodeettis-geofysikaalinen unioni (IUGG) on valtioista riippumaton tieteellinen yhteistyöjärjestö, joka on sitoutunut edistämään, tukemaan ja viestimään tietoa maapallosta, sitä ympäröivästä avaruudesta ja niissä muutoksia aiheuttavista dynaamisista prosesseista. IUGG edistää ja koordinoi Maan ja lähiavaruuden fysikaalista, kemiallista ja matemaattista tutkimusta ja kannustaa kerätyn tiedon soveltamista yhteiskunnallisiin tarpeisiin, kuten mineraalivarojen käyttöön, luonnonuhkien hallintaan ja ympäristön suojeluun. IUGG keskittyy etenkin Maan sisä- ja pintaosien, hydrosfäärin, kryosfäärin ja ilmakehän fysiikkaan ja kemiaan sekä vastaavaan tutkimukseen muista planeetoista.

Tällä hetkellä IUGG:llä on 73 jäsenmaata Afrikassa, Aasiassa, Euroopassa, Pohjois- ja Keski-Amerikassa, Oseaniassa ja Etelä-Amerikassa, ja jäsenmaiden tutkijat osallistuvat IUGG:n toimintaan kansallisten komiteoiden kautta. IUGG koostuu kahdeksasta puoliautonomisesta alajärjestöstä: Kansainvälinen kryosfäärin ja glasiologian assosiaatio (IACS), kansainvälinen geodesian assosiaatio (IAG), kansainvälinen geomagnetismin ja aeronomian assosiaatio (IAGA), kansainvälinen hydrologisten tieteiden assosiaatio (IAHS), kansainvälinen meteorologian ja ilmakehätieteiden assosiaatio (IAMAS), kansainvälinen fysikaalisen meritieteen assosiaatio (IAPSO), kansainvälinen seismologian ja maapallon sisäosien fysiikan assosiaatio (IASPEI) ja kansainvälinen vulkanologian ja maan sisäosien kemian assosiaatio (IAVCEI). IUGG:n alaisuudessa toimii myös komissioita ja työryhmiä, jotka edistävät tutkimusta erityisissä poikkitieteellisissä kysymyksissä: ilmasto- ja ympäristömuutos (CCEC), data ja tieto (UCDI), geofysikaaliset riskit ja kestävyys (GRC), matemaattinen geofysiikka (CMC), planetaariset tieteet (UCPS), Maan syvien sisäosien tutkimus (SEDI) sekä historian työryhmä (WGH). Assosiaatioiden ja toimikuntien kautta IUGG tekee tutkimusta, kokoaa havaintoja, luo näkemyksiä, koordinoi toimintaa, pitää yhteyttä muihin tieteellisiin elimiin, toimii vaikuttajana, osallistuu koulutukseen ja pyrkii laajentamaan valmiuksia ja osallistumista maailmanlaajuisesti.

Pyrkimyksiä

IUGG:n assosiaatiot ja komissiot järjestävät symposiumeja ja työpajoja ajankohtaisista aiheista edustamillaan tieteenaloilla, ja IUGG:n yleiskokous järjestetään joka neljäs vuosi. IUGG on käynnistänyt monia yhteistyöhankkeita, jotka ovat johtaneet menestyneisiin monitieteisiin tutkimusohjelmiin. Näistä esimerkkejä ovat Kansainvälinen litosfääriohjelma (ILP – IUGG:n ja Kansainvälisen geologisten tieteiden unionin yhteishanke), Kansainvälinen geodeettinen havaintojärjestelmä (GGOS), Merenpinnan keskikorkeuspalvelu (PSMSL), Äärimmäiset luonnonvaarat ja yhteiskunnalliset vaikutukset (ENHANS), Kansainvälinen suistojen vuosi (IYD), Planeetta Maan matematiikka (MPE), Maailman datasysteemi (WDS), Maailman ilmastotutkimusohjelma (WCRP) ja Kansainvälinen geosfääri-biosfääriohjelma (IGBP). IUGG harjoittaa myös julkaisutoimintaa: IUGG:n Special Publication Series -julkaisusarja (Cambridge University Press) sekä assosiaatioiden lehdet kuten Journal of Geodesy (IAG), Hydrological Sciences Journal (IAHS) ja Bulletin of Volcanology (IAVCEI).

Vastatakseen muuttuvan maailman ympäristöllisiin ja yhteiskunnallisiin haasteisiin parhaalla mahdollisella tavalla, IUGG kiinnittää erityistä huomiota tutkijanuran alkuvaiheessa olevien kansainväliseen tiedetoimintaan osallistamiseen esimerkiksi assosiaatioiden strategioiden ja matka-apurahojen kautta; osallistuvien maiden ja toimijoiden mahdollisuuksiin tarjota avoin pääsy tietoaineistoihin; alueellisten ja globaalien yhteistyöhankkeiden käynnistämiseen; ja tulevien geotieteilijäsukupolvien koulutukseen osallistumiseen ottaen huomioon haasteet ja eriarvoisuudet (sukupuolten välinen eriarvoisuus, erilaisista taustoista tuleville koulutuksen tarjoaminen, poikkitieteellisen tiedon tarve). Suomen geodeettis-geofysikaalisella kansalliskomitealla on edustajia jokaisessa IUGG:n assosiaatiossa ja Suomi on ollut alusta alkaen aktiivisesti mukana IUGG:n toiminnassa.

New approach to national doctoral education in Finland: UEF and GTK collaborating on 3D modelling of aquifer characteristics with geophysical data

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Introduction

Finnish governmental research institutes and University of Eastern Finland (UEF) are experimenting a new approach to build a national model to doctoral education in Finland. The doctoral researcher signs employment contract with both parties with allocated percentual sharing between parties resulting in full time PhD position. Research institute provides support, equipment and enhances the skills PhD candidate needs to become a successful contributor in the society in the particular theme of research whilst university has main responsibility on supervision and scientific relevance of the research.

In the doctoral thesis project presented here, UEF collaborates with Geological Survey of Finland (GTK). Project belongs to UEF's profile area "Environmental change and sustainable use of natural resources" and is part of the Finnish Centre of Excellence of Inverse Modelling and Imaging and Research Council of Finland's Flagship of Advanced Mathematics for Sensing Imaging and Modelling (FAME). Within GTK, this project contributes especially to two strategic goals related to geophysical solutions and sustainable water resources: (1) to make extensive use of geophysical methods for near-surface applications and applying joint data interpretation methods to problem solving and (2) to be a nationally leading producer and expert in hydrogeological knowledge.

Research plan

Groundwater makes up over 90 percent of the world's liquid freshwater resource (Shiklomanov, 1993). With increased pressure on this basic resource, we need to have a much better understanding of both where and how much water exists and what we can sustainably extract. According to the United Nations World Water Development Report, approximately five billion people, constituting two-thirds of the global population, will face severe water shortages by 2050.

This PhD thesis project focuses on developing numerical methods and analysis tools to integrate multiple geophysical techniques into a unified three-dimensional (3D) model of a groundwater reservoir. The primary geophysical methods in the research plan include active seismic measurements and electric resistivity tomography. These non-invasive geophysical imaging methods offer cost-efficient, comprehensive insights into the aquifer system across its entire area, avoiding the limitations of traditional borehole drilling methods. To enhance 3D groundwater modelling, a hybrid imaging method based on joint inversion is introduced, incorporating simulations and machine learning algorithms for effective integration.

In this work, a man-made aquifer with known dimensions and controllable water behaviour is utilized for modelling. This same test site will be employed in real data acquisition, with simulated and actual data compared to enhance comprehension of resolution, the ability to detect hydrogeological features, and to refine our capacity for planning cost-efficient geophysical measurements. Necessary data is collected through several field campaigns to observe potential changes in geophysical responses. The research conducted in (Khalili et al., 2023), forms the basis for the work undertaken in this PhD thesis. The project seeks to advance our understanding of the impact of climate change effects on aquifer systems, including alternating periods of severe drought and rainy periods.

Equipment for geophysical measurements

Geological Survey of Finland has the equipment for different types of geophysical data acquisitions. For ERT there is ABEM Terrameter LS2 measurement device and the GPS devices. For seismic data acquisition GTK owns weight drop source and 1C geophones and has access to ~1000 3C geophones through FLEX-EPOS instrument pool.

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U-Hf-Pb isotope zircon data of a basalt from the Pushtashan ophiolite, NE Iraq: indication of an extensional period above a suprasubduction zone

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Introduction

Pushtashan is one of the several ophiolites from the Neo-Tethyan oceanic crust, preserved within the Zagros Suture Zone, Kurdistan Region, northeast Iraq. The closest other ophiolites are, e.g., Mawat, Bulfat, Rayat and Penjwen (Fig 1). The ophiolite assemblages are exposed as tectonic slices with tectonic contacts. Two kinds of basalts, old and young, occur within the Pustashan ofiolite. The older basalts and andesites are intruded by the 96 Ma felsic dykes (Ismail et al., 2017). The younger basalts show tectonic contacts with the old ones. The sedimentary rocks overlie the basalts and andesites. The plutonic rock assemblages are composed mainly of gabbros and norites associated with serpentinised peridotite. We present here a U-Pb zircon age and Hf zircon isotopes from the younger basalt.

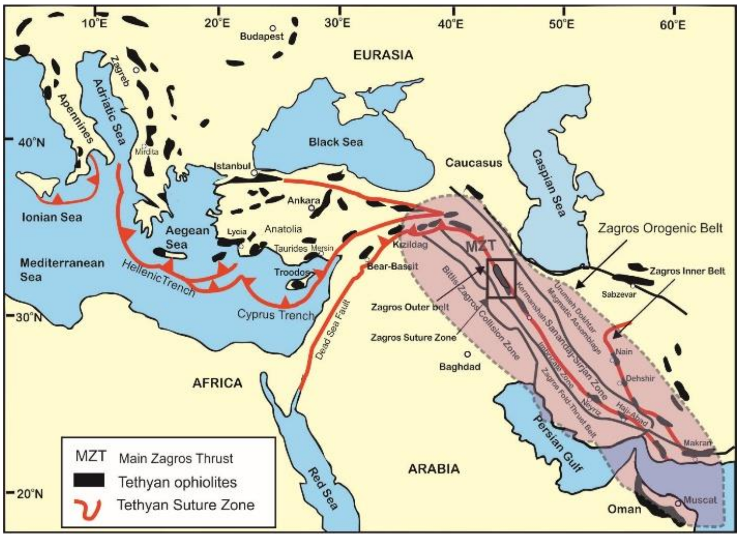

Figure 1. Tethyan ophiolites and tectonic units in the Zagros Orogenic Belt. Location of the ophiolites in the Zagros Suture Zone indicated, including Pushtashan (modified after Dilek et al.,2007).

Results and discussion

The analysis on the younger basalt yields an age of c. 75 Ma, which we interpret to represent the crystallisation age of the basalt. The initial ε_{Hf} values of the zircons show positive values between c.-1 and +10 with an average value of c. +5 indicating that the basaltic magma comes from a juvenile source with contamination by an older crust.

Younger ages on mafic rocks have been found in nearby ophiolites: 81 Ma gabbro in Mawat (Al Humadi et al., 2019), 79 Ma and 36 Ma gabbros in Kermanshah (Ao et al., 2016) and 39 Ma basaltic rocks in Bulfat (Ali, 2017). We suggest that the 75 Ma Pustashan basalt together with other young basalts, gabbros and felsic dykes in other Zagros ophiolites reflect the late-stage magmatic events related to several extensional periods above a suprasubduction zone.

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Age determination and classification of the charnockite series rocks at Houtskär, SW Finland

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Introduction

Charnockite series rocks are characterized by the occurrence of orthopyroxene and garnet in felsic rocks, which indicates that the rocks have been dehydrated. Charnockite series rocks can be either magmatic or metamorphic and it can sometimes be hard to determine their petrogenesis. Charnockites are formed deep in the crust and can usually be found in granulite facies areas (Touret & Huizenga, 2012). In the Turku archipelago, on the island of Houtskär, charnockite series rocks have been mapped as granodiorites in which orthopyroxene and garnet occur. These rocks have also been age determined by Suominen (1991) using the TIMS method, and he found the rocks to be 1862 ± 6 Ma old. This means the rocks would have formed amid the intraorogenic stage during the Svecofennian Orogeny, throughout which there seems to have been a stage of extension related magmatism.

In this study, the Houtskär charnockite series rocks were re-examined, and a new age determination was conducted to verify whether the charnockites indeed formed during the intraorogenic stage and to assess the extent of charnockitization at Houtskär. This investigation aims to provide insights into the timeframe of the intraorogenic stage of the Svecofennian Orogeny and the maturity of the magma produced during that stage.

Material and methods

54 samples were collected and prepared for petrologic studies, 11 samples were analyzed using X-Ray Fluorescence (XRF) at the Geohouse in Turku. One sample was age determined using LA-SC-ICPMS at the Finnish Geosciences Research Laboratory (SGL) at the Geological Survey of Finland (GTK) in Espoo.

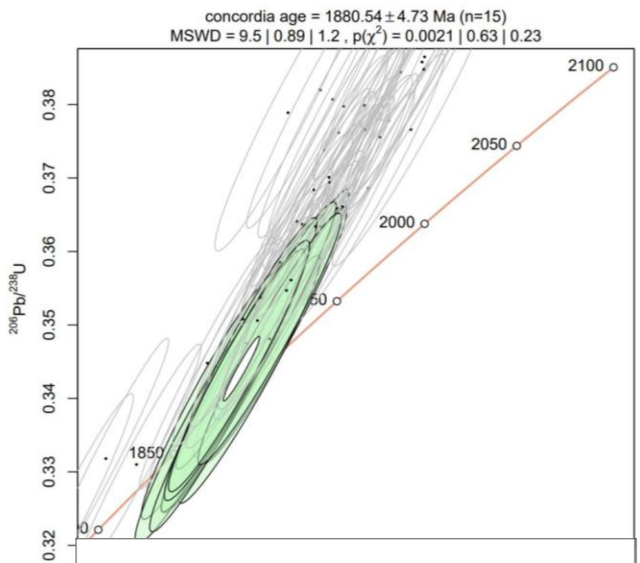

Figure 1. The U-Pb age determination of sample 04-HOU-2021 using LA-SC-ICPMS. Only analyses that were less than 3% disconcordant were used.

Discussion of the results so far

The geochemical analysis, as well as the petrography of the rocks show a varying composition from gabbrodioritic to granodioritic and some of the granodioritic samples contain orthopyroxene, meaning they can be classified as charnockite series rocks.

The age determination yielded an age of 1880.5 ± 4.7 Ma (Fig 1), which is older than the previous one given by Suominen (1991). This means that Suominens (1991) age probably represents a mixed age between older cores and younger rim growth. This new age can indicate that the charnockite series rocks at Houtskär are metamorphic and originally formed during the synorogenic stage of the Svecofennian Orogen, during which plutonic continental arc rock series were formed. The charnockitization of these rocks must have taken place later than the previously reported mixed age.

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Rytkynkylä volcanite sequence, a preliminary lithological assessment of a potentially mineralized locality on the Raahe-Ladoga shear complex

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Introduction

The Raahe-Ladoga shear complex is one of the most important ore potential regions in Finland with multiple historical volcanogenic massive sulphide (VMS) deposits eg. Vihanti, Pyhäsalmi and Rauhala located on it in Northern-Ostrobothnia. The aforementioned deposits have produced in total ca. 90 Mt of ore, of which the most common commodities have been Zn, Cu, Pb, S and Au. In addition to the large deposits, multiple smaller satellite VMS and orogenic gold deposits locate around the Vihanti-Pyhäsalmi region, primarily hosted in volcanite sequences (Geological survey of Finland, 2024).

Aside from Svecofennian plutonic rocks, the lithology in the Vihanti-Pyhäsalmi region is dominated by volcano-sedimentary rocks of three primary suites, the Vihanti-, Pyhäsalmi- and Ylivieska suites. Vihanti- and Pyhäsalmi suites are older, ca. 1.93–1.92 Ga, characterized by felsic to intermediate, commonly rhyolitic plagioclase porphyritic volcanites, while the Ylivieska suite, ca. 1.89–1.88 Ga, is characterized by a variety of felsic to mafic metavolcanites where the mafic endmembers are commonly andesitic uralite plagioclase porphyrites (Mäki et al., 2015; Kousa, 2018). The Rytkynkylä volcanite sequence locates in the middle of the Vihanti-Pyhäsalmi region, but it is not clear whether it belongs to Pyhäsalmi or Ylivieska suite. Thus, the goal of this study is to clarify the suite to which the Rytkynkylä volcanic sequence belongs to and explore its potential for mineralization.

Results

Field observations show that the Rytkynkylä mafic/intermediate volcanite sequence is controlled by the dextral Rauhanperä shear zone on the northeastern side of the volcanite (Mäki et al., 2015). The southwestern side of the volcanite has an intrusive contact with a Svecofennian granitoid. It has been observed that the Rytkynkylä volcanite sequence contains small mineralization localities of arsenopyrite, pyrite, pyrrhotite, chalcopyrite and ilmenite. In addition to the volcanite sequence mineralizations, the southwestern granitoid has minor disseminated pyrite mineralization and the northeastern shear zone has minor galena mineralization.

Petrographic analysis shows that the volcanite sequence is composed of mafic to intermediate uralite plagioclase porphyrite that is andesitic by composition. The volcanite sequence has undergone localized, sometimes extreme, hydrothermal metamorphosis that has, in some samples, eg. altered all plagioclase into epidote. The southern granitoid bordering the volcanite has a tonalitic/granodioritic composition. Like the volcanite, the northern granite has undergone extreme alteration near and on the Rauhanperä shear zone with one locality having unakite, and mylonitization of the granite and the volcanite by the lithology contact.

U–Pb age determination on the volcanite, using a sample deemed as unaltered as possible on the field, was attempted. However, electron microscopy (SEM) studies showed that no zircon grains were found from the sample and the age determination could not be accomplished.

Conclusions

Based on dominant uralite plagioclase porphyrite lithologies of the Rytkynkylä volcanite sequence and the local shear zone dynamics, the preliminary assessment of the Rytkynkylä volcanite sequence thus far favours it being a part of the younger Ylivieska suite ca. 1.89–1.88 Ga. This would imply that it is not a continuation of the older Pyhäsalmi suite VMS rich island arc volcanites. Nevertheless, some potential mineralizations have been found in the Rytkynkylä volcanite and will be analysed further in the future.

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Considerable mineral chemical heterogeneity in the episyenites of the Proterozoic Suomenniemi rapakivi granite complex, southeastern Finland: New insights into high-temperature metasomatic processes

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Alkali-rich fluids percolating through the upper mantle and crust can cause significant geochemical and mineralogical changes to the host lithological units. One of such metasomatic processes is episyenitization, characterized by the leaching of quartz and formation of sodic amphibole and/or pyroxene as well as hydrothermally recrystallized alkali-feldspar. The reactions between the, often metal-rich, fluids and the host rock have been linked to enrichment of varying commodities such as rare earth elements (REE), uranium and phosphorus (Barton and Johnson, 1996). Episyenite systems are rather underexplored owing to the complexity of metasomatic recrystallization, controlled by highly varying fluid composition, temperature, and fugacity of oxygen.

The Suomenniemi rapakivi granite complex in southeastern Finland is host to quartz-poor, Na-augite- and aegirine-rich episyenite dykes, which have been interpreted to be the result of pervasive recrystallization caused by alkali-rich fluids (Suikkanen and Rämö, 2017; Suikkanen et al., 2019). This process has dissolved quartz in the granite protolith and precipitated metasomatic alkali-feldspars, sodic amphibole and carbonate minerals, and transformed original igneous amphiboles into sodic pyroxene. There are notable differences between the Suomenniemi episyenite bodies in terms of mineral mode, petrography and mineral chemistry, implying varying interaction between the host rock and infiltrating hydrothermal fluids.

This project aims to examine geochemical variability between different episyenite bodies using major and trace element geochemistry of rock-forming minerals, feldspar, amphibole and clinopyroxene in particular. Electron microprobe data reveals different geochemical groups/trends in feldspar and mafic minerals, highlighting considerable variability between samples from different episyenite bodies. This variability is caused by different metasomatic intensities, possibly by a range of fluid temperatures, or different fluid generations, with variable compositions. (Figure 1). The EPMA data will be complemented by trace element analyses of clinopyroxene, carbonates and Ti-andradite using the LA-ICP-MS instrument at UH (Hellabs). The comprehensive major and trace element data, augmented by fluid inclusion trace element geochemistry and thermometry, will most probably lead to new insights regarding the processes that controlled episyenitization of the Suomenniemi complex rapakivi granites.

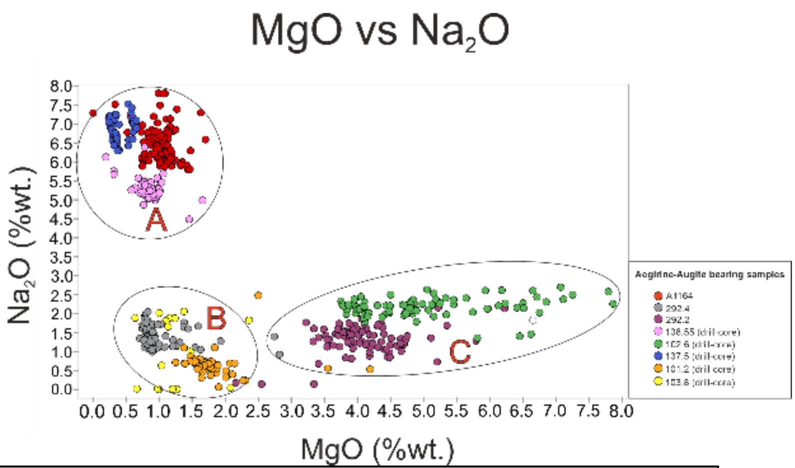

Figure 1. Bi-variate plot of MgO vs. Na2O (wt.%) of clinopyroxene from the Suomenniemi episyenites. A: pyroxene from the most evolved alkali-rich samples. B: pyroxene from samples with relatively little alteration, from near wall rock. C: pyroxene from relatively mafic samples rich in Mg. Note the distinct grouping of certain samples with similar compositions.

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Geochronology and source(s) of pegmatites from the Kitee-Tohmajärvi region

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The Kitee-Tohmajärvi Li province (Rasilainen et al. 2018) is located in the Svecofennian domain in Eastern Finland. The bedrock within the province is dominated by mica schists and gneisses, along with some larger granodiorite and granite intrusions (Nykänen 1968). Regional metamorphism is dominantly in lower to middle amphibolite facies (Hölttä & Heilimo 2017), regarded as permissive for the formation of Lithium-Cesium-Tantalum (LCT)-type pegmatites and Li deposits (Selway et al. 2005). Approximately 500 pegmatite bodies have been discovered within the Kitee-Tohmajärvi Li province, ranging from one meter to more than 50 meters in width and up to one kilometer in length. Most of the pegmatites in Kitee-Tohmajärvi region are simple, but a number of complex-type (LCT) pegmatites, including three spodumene-bearing, were discovered in the 70s and 80s from Potoskavaara in the northern parts of the Li province (Alviola 1974a, b). Recently additional indications of Li mineralization were discovered in central Kitee (Kuikka et al. 2023).

Up to date there is only a limited amount of scientific research done on the pegmatites of the Kitee-Tohmajärvi region. Pegmatites within the Li province are poorly classified and a potential parental granite for pegmatites has not been identified. The possibility of LCT pegmatite formation through anatexis should be studied. This abstract is part of the first author's PhD project aiming to evaluate the regional fertility of pegmatites of the Kitee-Tohmajärvi region as well as propose the source(s) of the pegmatites. 11 bulk rock samples have been collected from pegmatite dykes and intrusions in Kitee in 2023 (Fig. 1). The samples have been analyzed with whole-rock geochemistry for major and relevant trace elements and will be dated by laser ablation-inductively coupled plasma mass spectrometer (LA-ICP-MS) with single-grain U-Pb dating of columbite-tantalite and apatite minerals. In addition, existing age material from relevant host rock units will be reanalyzed. We hypothesize that pegmatites from western parts of the Kitee-Tohmajärvi Li province are directly related to the Puruvesi granite intrusion west of Kitee and are of different origin compared to pegmatites from middle and eastern Kitee.

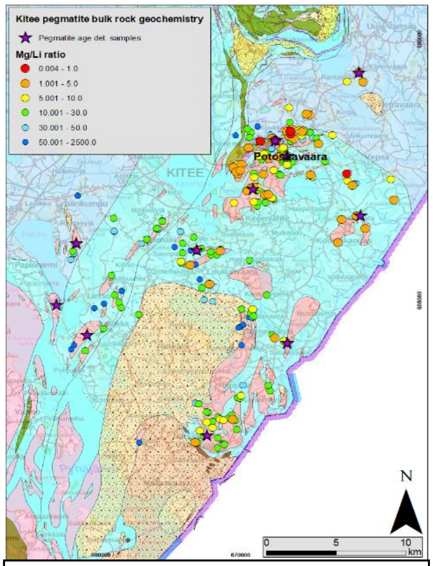

Figure 1. Mg / Li ratios of the pegmatite bulk rock geochemistry indicate differences in degree of fractionation between sample points. Lower values indicate a more evolved pegmatite.

Preliminary analytical results from pegmatite rock samples collected between 2019−2022 show distinct differences in the degree of fractionation between pegmatites of the Kitee-Tohmajärvi region. Bulk rock geochemistry (Fig. 1) indicates that the pegmatites are generally evolved to some degree. Most pegmatites of Potoskavaara, and some in parts of central Kitee show clear geographical trends of extreme fractionation. The pegmatites closest to the Puruvesi granite seem to have a slightly lower degree of fractionation, as well as simpler mineral composition which could imply a different pegmatite source or a structural constraint of pegmatite formation. However, similar pegmatite composition is observed in parts of eastern Kitee as well.

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Geochemistry and petrography of igneous intrusions at Grønsteinfjellet-Botneheia, central Spitsbergen, Svalbard

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The High Arctic Large Igneous Province (HALIP) consist of intrusive and extrusive rocks, along with pyroclastic material on Svalbard, northern Greenland, the offshore Alpha-Mendeleev Ridge, Sverdrup Basin of Arctic Canada, the New Siberian Islands and Franz Josef Land.

HALIP on Svalbard is classified as the Diabasodden Suite, which are relatively accessible compared to other HALIP outcrops in the Arctic. However, a comprehensive examination of the Diabasodden Suite is lacking. The aim of this MSc thesis is to contribute to the understanding of magma evolution and characterization of dykes and sills exposed in central Spitsbergen through geochemical analysis and petrographical studies. In particular, we focus on the Grønsteinfjellet-Botneheia area where doleritic intrusions are emplaced in Triassic-Jurassic siliciclastic successions. The intrusions typically form sills, with individual sills exposed over a length of more than 10 km. One dyke and a few transgressive segments are also exposed in the study area. The entire study area is covered by high-resolution digital outcrop models (DOMs). The DOMs were processed using structure-from-motion photogrammetry with hundreds of drone-based photographs and allow us to put the geochemical samples in a regional context.

To date, whole-rock major element data from 20 samples have been analysed using wavelength dispersive X-ray fluorescence (WD-XRF) analyses at HelLabs, at the University of Helsinki. Additionally, the loss on ignition (LOI) was considered in WD-XRF analyses. The samples SiO_2 contents range from 49.36 to 51.41 wt%, Na_2O from 2.13 to 3.68 wt%, and K_2O from 0.14 to 1.11 wt%. In the total alkali versus silica (TAS) classification, all the dolerite samples classify as tholeiitic basalts. The MgO-FeO- Al_2O_3 major-element plot, with Al_2O_3 ranging from 13.50 to 15.51 wt%, FeO^T from 12.46 to 14.20 wt%, and MgO from 3.23 to 6.44 wt%, suggests the tectonic setting of the sampled dolerites to be continental. Further geochemical analyses, such as for obtaining trace elemental data, are considered based on whole-rock major element data from samples. Thin sections are being prepared in HelLabs for general description of mineral assemblages, textural and structural details.

Geochemical data and petrographic studies of the central Spitsbergen samples will contribute to understanding HALIP magmatic evolution in Svalbard and how their geochemical signature relates to other HALIP rocks in the high Arctic.

1.88 Ga A-type Svecofennian magmatism revealed east of the CFGC; petrography, geochemistry and age of the Sorsakoski granitoids, Central Finland

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Introduction

Rocks can be classified in multiple ways, e.g. based on their mineralogy, chemistry or age relative to crustal development. Nironen (2005) used all of these attributes when dividing the voluminous granitoids of Central and Southern Finland into preorogenic, synorogenic (with subclasses synkinematic and postkinematic), lateorogenic and postorogenic groups. The postkinematic group (1.88–1.86 Ga) with A- and C-type granite affinities is locally voluminous both within and around the Central Finland Granitoid Complex (CFGC). These granitoids, together with the associated diorites and gabbros, form the bimodal Saarijärvi suite (Geological Survey of Finland unit classification). This suite has been interpreted as being emplaced in, or adjacent to, major transtensional shear zones.

This work, largely based on the unpublished M.Sc. thesis of the second author (Pietilä 2020), aims to confirm the tentative correlation of potassium feldspar megacrystic granitoid intrusions in the Sorsakoski area east of the CGFC to the Saarijärvi suite. Our inferences are based on petrographical and geochemical methods as well as U-Pb zircon geochronology.

Results

Four quartz monzonite and granite intrusions at Sorsakoski form a 40 km long and 10 km wide complex within the Raahe-Ladoga suture zone. The intrusions consist mainly of potassium feldspar megacrystic quartz monzonites and granites. Biotite together with hornblende are the typical mafic minerals in the granitoids, clinopyroxene and orthopyroxene are only locally present. Geochemically the granitoids are mainly calc-alkaline, ferroan, per- to metaluminous, and have high Zr and REE contents. Result of a single grain zircon U-Pb age determination from northern part of the complex (1876 ± 4 Ma) overlaps within error with the pre-existing one from southern parts (1882 ± 5 Ma) and confirms the emplacement age of the complex as 1.88 Ga. The granitoids are typically unoriented but are crosscut by plastic shear zones varying in width from centimetres to tens of metres.

The less voluminous mafic members, diorites and gabbros, display compositional effects of fractionation of clinopyroxene observable as significant scatter in e.g. Mg#, CaO and Al_2O_3. Contact between the mafic and felsic members are sharp, clear magma mingling structures were found from only one outcrop.

Conclusions

The studied intrusions display similar mineralogy, petrography, geochemistry, nature of magmatism (bimodal) and age as the previously studied A-type Saarijärvi suite intrusions. The Sorsakoski granitoids extend the area covered by the Saarijärvi suite eastwards beyond the CFGC.. Although the studied intrusions are only weakly deformed, excluding the numerous shear zones, referring to them as “poskinematic” would be somewhat misleading as they were emplaced during regional D3 at 1.88 Ga.

Together with the marginally younger, and also bimodal, I-type Heinävesi suite emplaced just 20 km farther east, the Sorsakoski granitoids are one more indication of the eastern boundary zone of the Svecofennian lower crust that produced A-type magmas when intruded by mafic magmas from the mantle.

It has been hypothesized that the Saarijärvi suite intrusions display ages younging gradually (1885=>1870 Ma) from CFGC NE corner towards SW (Rämö et al. 2001). Based on age determinations published after the initial interpretation and this study the potential pattern could be that there is an older (~1880 Ma) subgroup in the east, slightly younger subgroup in the west (~1870 Ma). In addition to which the Raahe-Ladoga suture was more or less continuously intruded by small number of intrusions with ages down to 1860 Ma (Halkoaho et al. 2020).

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Geochemistry and geochronology of the High Arctic Large Igneous Province on Svalbard

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Large Igneous Provinces are magmatic provinces with large magma volumes (> 100,000 km^3) emplaced and/or erupted in an intraplate tectonic setting over a large area (> 100,000 km^2) within a few Myr (< 5 Myr), thus having the potential for significant impact on the global climate (Bryan & Ernst, 2008). The High Arctic Large Igneous Province (HALIP) was emplaced during the Early Cretaceous and is one of the most prominent tectono-magmatic elements of the Arctic. The sills, dikes, and lava flows of the HALIP can be found across the High Arctic, specifically on Svalbard, northern Greenland, in the Arctic Ocean, Canada, and Russia. Radiometric ages for the HALIP range from ~140 and 80 Ma, suggesting a long-lived and multi-phase magmatic system, with pulses at ca 122 ± 2 Ma, 95 ± 3 Ma, and 81 ± 4 Ma recorded in the Sverdrup Basin of Arctic Canada (Dockman et al., 2018). On Svalbard, the dolerites related to HALIP magmatism are formally classified as the Diabasodden Suite. Here, the dolerites have mainly been emplaced as sills at shallow depths and occur all over the archipelago. Despite the relative accessibility of outcrops, the HALIP on Svalbard has been under-looked. As such, available U-Pb geochronology of the Diabasodden Suite is limited to three samples, indicating a shorter time span of 125 – 122 Ma (Corfu et al., 2013). Yearly field campaigns since 2020 have resulted in over 150 collected samples from Spitsbergen and Nordaustlandet. This has been accomplished by strategically targeting outcrops to build a good spatially representative dataset of the Diabasodden Suite. Additionally, a large number of samples have also been taken for a detailed case-study at Wallenbergfjellet in central Spitsbergen. The dolerite samples are used for whole-rock major and trace element geochemical analysis, U-Pb baddeleyite geochronology and petrological studies. Furthermore, during all field campaigns, drone images have also been acquired. These data form the basis for constructing high-resolution digital outcrop models (DOMs), which are used for thickness measurements of the sills and to put the geochemical data into a 3D perspective. The resulting DOMs are made openly available through the Svalbox geoscientific database (Betlem et al., 2023). Here we present the results from the project to date, including geochronology, DOMs, and the current dataset of whole-rock geochemical data from the HALIP on Svalbard since 2020. This extensive geochemical study will be used to reconstruct how the HALIP magma was emplaced on Svalbard, and in comparison with existing data from the circum-Arctic.

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Chemical composition of tourmaline in the Kaustinen lithium pegmatites

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Introduction

Understanding the geochemical characteristics of pegmatite-hosted lithium deposits and their petrogenesis is crucial in developing exploration practices to meet the rapidly increasing demand for lithium. The albite-spodumene pegmatites of the Kaustinen Li-province host one of the most significant lithium resources in Europe. Economic potential and petrogenesis of the Kaustinen Li pegmatites have been studied previously (Ahtola et al., 2015; Lahaye et al., 2022; Martikainen, 2012), however the magmatic-hydrothermal processes behind the petrogenesis and lithium enrichment are not fully yet understood.

Tourmaline is a frequently used petrogenetic indicator for various magmatic and hydrothermal processes, however its potential to study the evolution of Li-pegmatites and mineralization has gained surprisingly little attention. Wide P-T-X stability range, complex mineral chemical structure with an abundance of varying trace elements, and high resistance to alteration (Van Hinsberg et al., 2011) make tourmaline an ideal proxy for the study of the Kaustinen Li province. In this study, the major and trace element compositions of tourmaline from six albite-spodumene pegmatites and the Kaustinen pegmatite granite are analysed in order to investigate: 1) the regional variations in tourmaline chemistry between the individual pegmatites and the assumed source pluton, and- 2) how this reflects the origin, evolution, and fractionation of the pegmatite forming melts?

Preliminary results

The major element compositions of tourmalines from the Rapasaaret and Läntta pegmatites have been analysed using an electron-probe microanalyser (EPMA). Preliminary results show that all the tourmalines belong to the alkali group, with Ca being significantly higher in the Läntta than in the Rapasaaret pegmatite (Figure 1a). The tourmalines show within-dike variation, with decreasing Mg and increasing Li+Al from contact to core (Figure 1b). The composition of the host rock seems to have had a strong effect on the mineral chemistry of tourmaline across pegmatite and wall rock contact: tourmaline in the contact of the Läntta pegmatite, which has intruded a mafic metavolcanic rock has significantly higher Ca and Mg than the tourmaline in the contact of the Rapasaaret pegmatite with a mica schist wall rock.

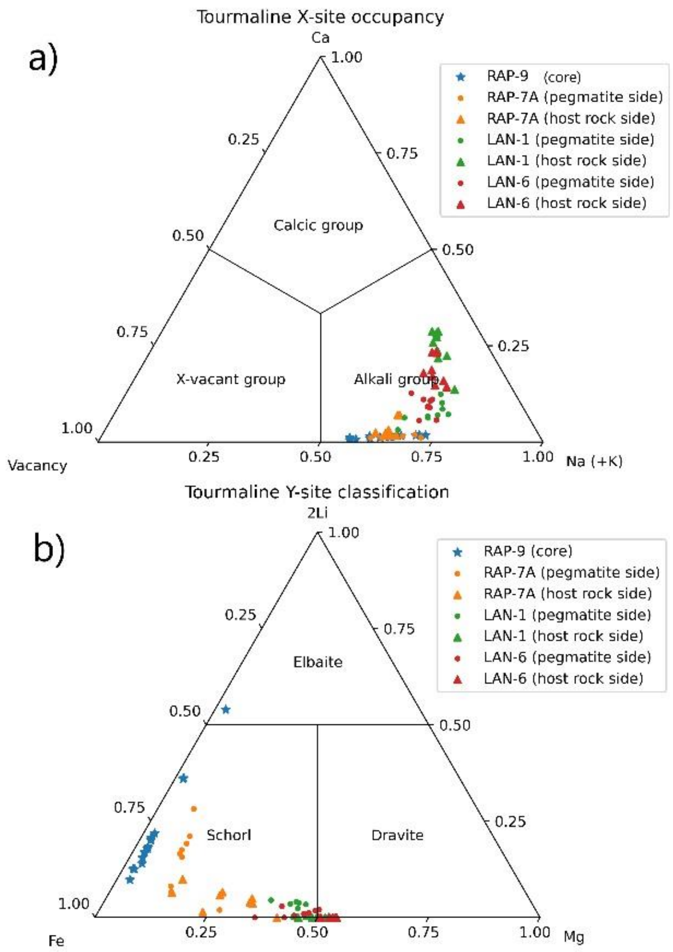

Figure 1. Tourmaline chemical classification plots after Henry et al. (2011). Classification based on X-site occupancy (a) and Y-site occupancy (b). RAP = Rapasaaret, LAN = Läntta.

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Sequential crystallization of zircon, monazite and xenotime in the cordierite-orthoamphibole rocks in Orijärvi, southern Finland

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Introduction

Zircon, monazite and xenotime are widely used in U-Pb geochronology owing to their different closure temperatures. This provides of a powerful tool in unravelling the magmatic-metamorphic history of various rock types. Zircon is regarded as the most robust of these minerals, with closure temperature of c. 900 °C (Cherniak & Watson, 2001). Thus, zircon usually preserves the original magmatic crystallisation age of the rock. Monazite and xenotime are traditionally thought to have lower closure temperatures; c.720 °C for monazite (Parrish 1990) and c. 600 °C for xenotime (Cherniak, 2006). They are therefore more readily affected by subsequent metamorphism.

We have sampled two cordierite-orthoamphibole rocks (COR) from the area of VMS-type Orijärvi mining camp. Samples were collected close to the old Orijärvi mine and the Iilijärvi mineralised zone, respectively. We separated zircons, monazites and xenotimes for laser ablation U-Pb analyses. Additional monazite and xenotime grains were analysed in-situ on the thin section samples. The U-Pb analyses were performed in the Finnish Geosciences Research Laboratory at the Geological Survey of Finland in Espoo.

Results

The COR close to the Orijärvi mine contains zircons of many morphological types. The grains are metamict and rich in inclusions. Most analyses are discordant and their $^{207}Pb/^{206}Pb$ ages show a declining pattern from c. 1.9 Ga to 1.78 Ga. Five oldest analyses form a coherent group with a weighted average age of c. 1.89 Ga. The monazites show both elongated and rounded morphologies. The analyses from the separated grains and the thin sections both yield a concordia age of c. 1.80 Ga. The xenotimes are all rounded in shape and yield a concordia age of c.1.82 Ga.

Not many zircons were found from the Iilijärvi COR and all are highly damaged and discordant. The monazites are mostly rounded with a few prismatic grains. Monazite ages are mostly concordant with a concordia age of c. 1.82 Ga. The thin section analyses show a more homogenous population with a similiar concordia age of c. 1.82 Ga. The Iilijärvi xenotimes are rounded in shape and yield a concordia age of c. 1.79 Ga for both the separated sample and the thin section analyses. Xenotimes are often found close to the cracks in the thin section.

Discussion

The c. 1.89 Ga zircons from the Orijärvi COR are the oldest age group of the data. Based on the zircon's properties, we regard this a magmatic age. However, hydrothermal and metamorphic events have strongly affected the zircons, as evidenced by the totally damaged Iilijärvi zircons and only partly preserved Orijärvi ones. The monazite and xenotime yield younger ages of c. 1.80 Ga and c. 1.82 Ga. These ages are regarded as metamorphic. The youngest age group of c. 1.79 Ga is found from the Iilijärvi COR xenotimes. They have been affected by a more intense hydrothermal alteration based on the thin section textures.

Despite the hydrothermal activity, ages show a familiar pattern with the oldest ages coming from the zircon, followed by the monazite and then the xenotime. The latter two minerals show some overlap in their ages, but the youngest population of the data is present only in the xenotime.

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Hydrogeological characterization of the Akhangaran River alluvial aquifer, north-eastern Uzbekistan

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Shallow permeable aquifer in the Akhangaran River Valley in north-eastern Uzbekistan (Fig. 1) is an important fresh water source for public water supply, agriculture, mining process and industry in the area. The aquifer is hydraulically connected to surface water and responses directly to climate variables (e.g., temperature and precipitation) and human activities. The risks and threats to a shallow aquifer are changes in groundwater recharge due to change in precipitation and temperature caused by climate change, and contamination of groundwater from risk areas. Water demand is expected to increase. On the other hand, water availability will diminish due to decrease in groundwater recharge and groundwater resources, especially during the drought in summer time. Lack of clean water can cause a crisis to water users. Water resource management as well as adaptation and mitigation to water crisis requires comprehensive understanding of groundwater resources and their connection to surface water bodies in changing climate and land use.

The hydrogeological characterization of alluvial aquifer in the Akhangaran River Valley was performed using the integration of the geological drilling data, geophysical data from seismic refraction surveys and vertical electrical sounding (VES) surveys, as well as hydrogeological data. Seismic refraction survey provided information of the underlain pre-Quaternary deposits varying from Tertiary sedimentary bedrock to Paleozoic bedrock and the groundwater level. The results of VES and borehole data revealed the river valley filled with unconsolidated Quaternary sand and gravel deposits along the Akhangaran River and its tributaries, and the alluvial-proluvial deposits of loam, loamy sand and pebbles along the floodplain terrace and both sides of the river. These findings provide the geological framework for the upcoming groundwater flow modeling and useful information for water resources managements in the area.

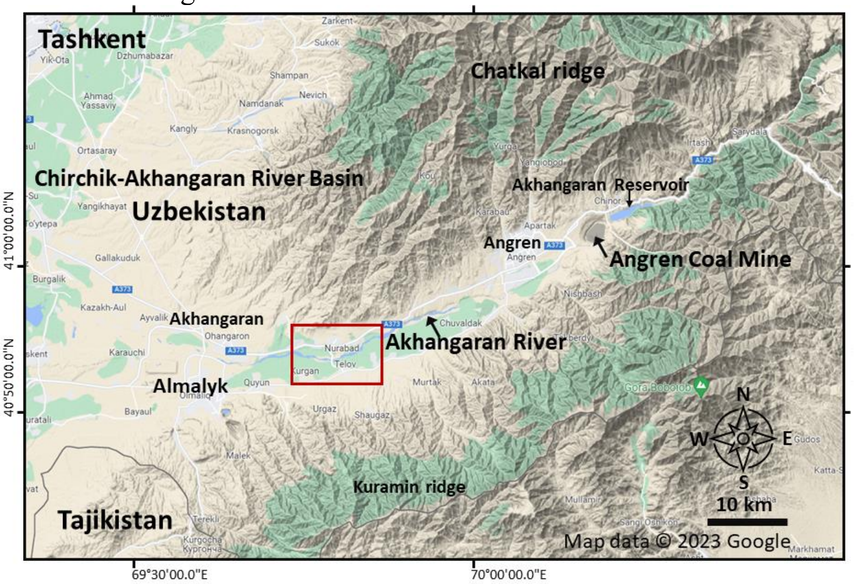

Figure 1. Location of the Akhangaran River Valley alluvial aquifer, north-east Uzbekistan.

Acknowledgements
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Geochemical characteristics and long-term carbon accumulation rate in the Puukkosuo, a northern boreal sloping fen

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Introduction

Northern peatlands contribute to carbon cycle either as a sink or a source. Groundwater dependent nutrient rich sloping fen ecosystems are typical morphological peatland type for northeastern Finland. We aim to assess if the long-term carbon accumulation pattern and the groundwater effect in peat geochemistry in sloping fen in the carbonate bedrock area differs from the typical northern aapa mire. In addition, we modelled the bathymetry of the peat basin and the type of the basal sediment to assess the flow patterns of water and nutrients. The study site Puukkosuo is situated in Oulanka, Kuusamo and is part of the ongoing EcoClimate project of Oulanka Research Station, which focuses on climate and environmental change monitoring.

Methods

The 3D structure of the Puukkosuo basin was modelled with Leapfrog Geo (Seequent) based on dense network of GPR profiles (5.5 km) and reference peat stratigraphy. Three peat profiles across the basin were collected to demonstrate the peat composition, humification, geochemistry and carbon accumulation. Pore water samples were collected to assess the groundwater effect. Trace elements were analysed from both, peat and pore water samples. In addition, pore water samples were analysed for major ion composition, pH, EC, TOC, TC, IC, NO_3+NO_2, NH_4, Tot N, Tot P, stable isotopic composition of water and $\delta^{13}C$ (DIC) to assess the effect from adjacent bedrock and groundwater. The peat accumulation rate, based on radiocarbon dates and bulk density, as well as carbon content were used to calculate the long-term carbon accumulation.

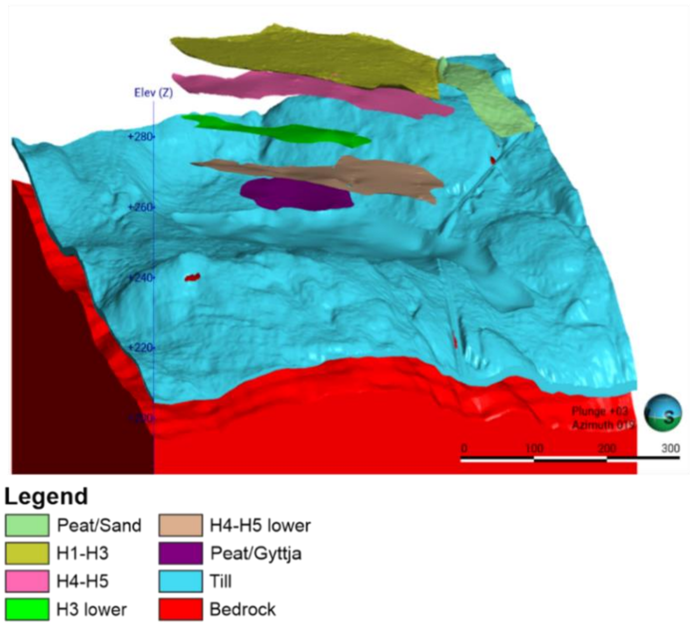

Figure 1. An exploded 3D view of the Puukkosuo model depicting peat layers based on the von Post scale humification.

Preliminary results

The 3D model of the bathymetry of the peat basin demonstrates different flow-through patterns formed after deglaciation (Fig. 1). Interfaces between von Post score of humification H3-H4 and H4-5 were detectable in 100 MHz GPR profiles and 5 layers of variating humification level were interpreted. The humification degrees in the Puukkosuo have only minor variation, the highest humification degree are recorded during the Holocene Thermal Maximum. The peat geochemistry can be classified into five groups according to the specific geochemical characteristics.

The groundwater effect originating from the northeastern slope of the fen is visible in the pore water geochemistry in the middle part of the fen. It is plausible that the nutrients in the western edge of the Puukkosuo originates mainly from the surface runoff.

Our results demonstrate that the basin bathymetry influences to the carbon accumulation patterns. The results indicate that the carbon accumulation rate in the basal part of the basin exceeds the average rate in the northern boreal zone, whereas the surface layer demonstrates typical carbon accumulation values.

Acknowledgements

This work is made in collaboration with Oulanka Research Station.

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Traces of Glacier-Induced Meltwater Processes in the Satakunta Hummocky Moraine Area: Mapping of Potential Blisters

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Climate change and concerns about contemporary glaciers have sparked interest in studying past glaciations and their traces. LiDAR technology (Light Detection and Ranging) has revolutionized geomorphological research and served as the most important source of material in our research.

This study was conducted in Satakunta, western Finland, where Mäkinen et al. (2023) identified the first water blister mark within a subglacial meltwater route. Blisters are formed by supraglacial meltwater storage draining rapidly through ice via moulins or hydrofractures to the bed, where the pressurized water is able to lift up the ice and increase subglacial discharge. Supraglacial lake drainage and associated water blister development has been recorded in the Greenland Ice Sheet (Das et al. 2008; Dow et al. 2015). On palaeo ice-sheet beds potential blister marks can be identified as circular depressions with radiating discharge channels.

Utilizing LiDAR Digital Elevation Models, the research identifies potential blisters. Criteria for blister identification include a circular shape, radially emanating discharge channels, geomorphological changes in the surroundings that follow the glacier's flow direction, eroded boulder fields within the blister edges and discharge channels. Blister marks typically have diameters of a few hundred meters.

Based on our research, all potential blisters were located in the subglacial meltwater route that runs close to the Kynsikangas sinistral strike-slip fault zone. Furthermore, the highest points in the terrain were important features controlling blister mark position. These environments were likely related to crevasse patterns in ice, allowing rapid drainage of supraglacial meltwaters. However, fieldwork including terrain observation, excavations, ground penetrating radar survey and coring, is crucial for a comprehensive understanding. This could potentially offer an advanced criterion for further studies or, at the very least, facilitate the discovery of potential blisters.

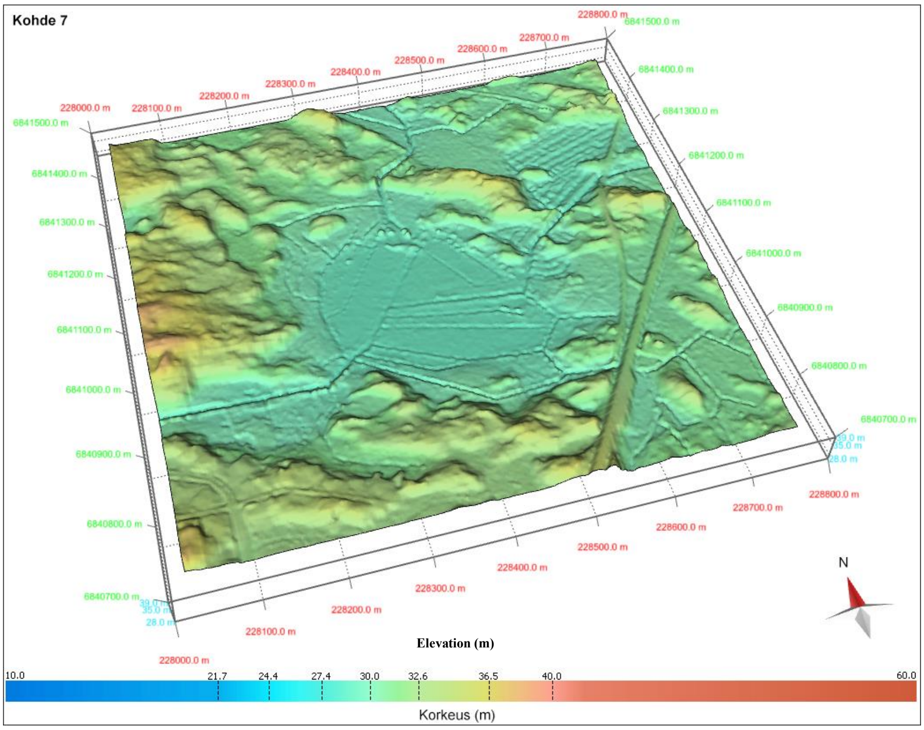

Figure 1. 3D-model of potential blister. The circle shape of the potential blister and the emanating discharge channels can be seen in the model.

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Combining pre-sampling UAS-TIR and GEM-2 to focus water sampling with hydrogeochemical analysis including isotopes of H, O, Sr, and S from two mine sites in northern Finland

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Mining environments require understanding about the geological complexity of the area, often at a regional scale. To better plan a water sampling campaign at the two mine sites here, a combination of thermal infrared images captured by unmanned aircraft systems (UASs) and manual GEM-2 measurements were used as pre-sampling methods in deciding the sampling locations (Ikonen et al. 2024). Similar study methods were used in Alakangas et al. 2019.

The study sites were an abandoned Au-Cu mine in Saattopora and an active Ni-Cu-PGE mine in Kevitsa, northern Finland, in the sub-arctic boreal zone. Anomalies from TIR images and GEM-2 conductivity values were used to focus water sampling from which hydrogeochemistry and isotopic compositions of oxygen, hydrogen, strontium, and sulfur were analyzed to better understand the flow regime of possible effluent waters at these mine sites.

The TIR images were useful in pinpointing potential groundwater surface water interaction sites. This was confirmed with the oxygen and hydrogen isotopic data. Isotopic values for the two groundwater solutes used here (Sr and S), reflected the local geology and the biogeochemical environment at the mine sites. The electrical conductivity values attained with GEM-2 measurements were influenced by the local mineralogy, especially the conductive sulfide bearing paraschist rock. The anomalies from UAS-TIR and GEM-2 data revealed sampling sites well suited for tracking potential effluent waters at the two mine sites studied here (Fig 1).

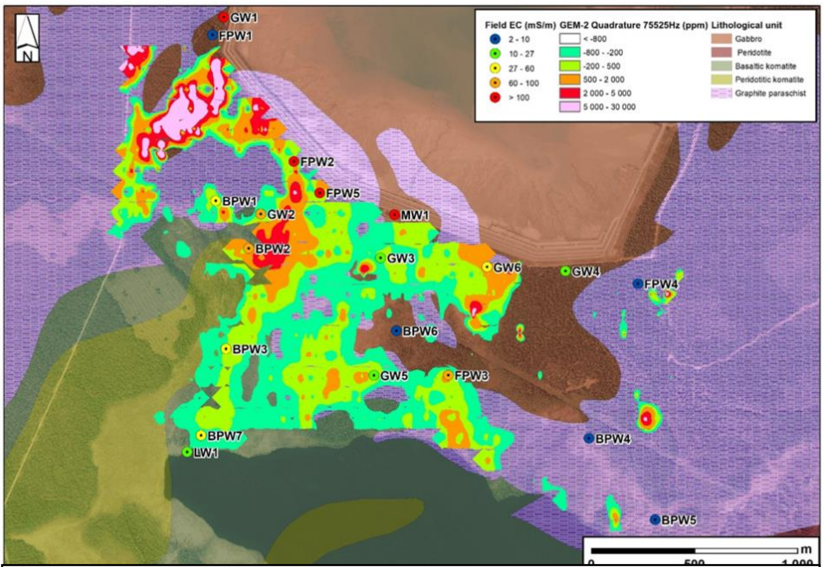

Figure 1. GEM-2 quadrature values on the bedrock map from the Kevitsa mine study site showing anomalies of the topsoil. Field EC values are shown from water sampling stations.

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Emission and burial potential of blue carbon habitats in Finnish lakes

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Introduction

Boreal lakes represent an important long-term carbon sink and pose as major candidates for natural based solutions to mitigate climate change through carbon sequestration (Dean & Gorham, 1998; Kortelainen et la., 2004, 2013). At the same time lakes are recognised as large sources of atmospheric carbon and previous studies have shown a weak linear relationship between lake sediment carbon emission and burial rate (Kortelainen et al., 2013; Lundin et al., 2015). In coastal marine environments it has recently been shown that shallow water vegetated areas, or so called "blue carbon" habitats, may sequester as much as 50% of the total global marine carbon (Macreadie et al., 2019). The carbon fluxes of equivalent blue carbon habitats in lacustrine environments remains largely unexplored. In this study we aim to quantify sediment carbon burial and remineralization rates in Finnish lakes, both in blue carbon habitats and deeper open water areas. Initial results suggest that shallow water vegetated areas host considerable sediment carbon stocks, although the deposits are thinner in vertical extent and of overall smaller magnitude than stocks in deep open water areas. Porewater analysis shows that upwards diffusive fluxes of TCO_2 and CH_4 occur in both shallow and deep water areas. However due to the short water column, blue carbon habitats emit more dissolved carbon directly into the surface water than do deeper open water areas. In all cases more than 99,5 % of the water column inorganic carbon pool is in the form of TCO_2 rather than CH_4, while sediment total organic carbon inventories are generally several orders of magnitude greater than those of porewater TCO_2 and CH_4.

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Murtoos and related landforms cross-cutting ribbed moraine in Western Finland: Implications for rapidly increasing subglacial drainage

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Abstract
Murtoos and their related depositional landforms have recently been associated with subglacial meltwater routes (SMR), representing transition from distributed to channelized drainage systems within the Fennoscandian Ice Sheet (e.g. Ojala et al. 2022). SMRs are often found cross-cutting ribbed moraine fields and can later be occupied by eskers or exhibit downflow transition to eskers. Vérité et al. (2022) propose that repeated subglacial flooding of ribbed moraine features can form murtoos. Here we describe the Lestijärvi-Kinnula ribbed moraine field that has been intensively modified by subglacial meltwater flow, including murtoo formation. The aim of this ongoing study is to interpret the spatio-temporal development and the depositional environment of the SMR, and discuss the subglacial hydrology responsible for its evolution.

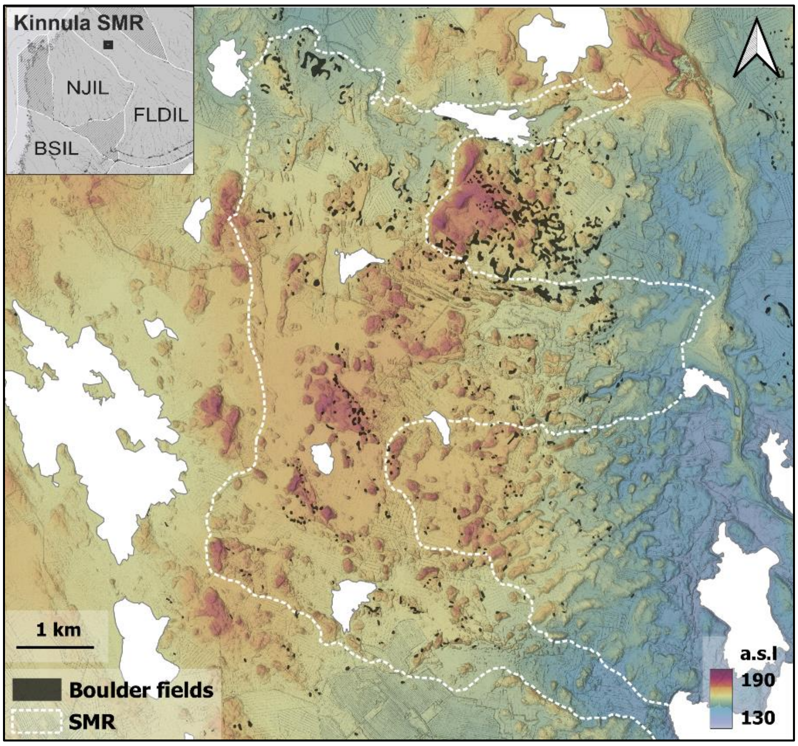

Figure 1. Location of the delineated SMR, located W of the Lestijärvi-Kinnula esker (Hillshade, DEM and boulder fields © National Land Survey of Finland).

The study area is located in Western Finland within the trunk of the Finnish Lake District Ice Lobe (Figure 1, FLDIL). The study is based on geomorphological mapping conducted using high-resolution LiDAR DEM along with sedimentological data from excavated pits, ground-penetrating radar surveys and geomorphological field control.

The murtoo related ridges characteristic for the SMR were interpreted to evolve on erosional remnants of till, forming a base for the deposition of sorted sediments and later murtoos in subglacial conduits. The various escarpments indicate meltwater erosion after murtoo formation. Large channels are present along the margins of the SMR and seem to have spilled over, forming extensive boulder fields. Many of the ridges and ribbed moraine also exhibit reworking by meltwater flows.

Overall, the results indicate rapid increase in subglacial drainage. However, the spatio-temporal characteristics of the formation of the SMR remain to be discussed. The SMR may have been flooded due to an outburst from a potential subglacial lake, and/or due to supraglacial water sources, such as moulins or a water blister (cf. Mäkinen et al. 2023).

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Mine water induced meromixis – investigating a mixing regime shift from the recent sediment record of Lake Valkeinen

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Sulfidic mine waters remain a major and often unresolved ecological threat to nearby waterbodies. This is not only due to the acidity and the high concentrations of metals, but also because of the high salinity of the drainage (Lottermoser, 2007). Increasing salinity is a stressor on organisms adapted to freshwater conditions and can have harmful effects on the ecosystem (Karjalainen et al., 2023; Leppänen et al., 2019, 2017). In addition, salinity can lead to a change in the circulation regime of a lake. Most Finnish lakes are dimictic, i.e. the water column mixes completely twice a year. Saline mine waste waters can disrupt the stratification patterns of a lake, leading to permanent stratification, i.e. meromixis, and bottom water anoxia (Kehusmaa et al., 2023). The volumes of saline wastewaters required and the time scales of changes in mixing regimes are hard to predict. Long-term water monitoring data from small headwater lakes is seldom available. In these cases, lake sediment offers a natural archive of past water quality in the lake. Meromictic lakes especially are a great opportunity for palaeolimnological studies because the anoxic conditions of the lake bottom protect the sediments from the post-depositional reworking by animals and plants.

In this study, the impacts of mining and the development of meromixis were investigated from the recent sediment record of small natural lake Valkeinen. The lake is located near the Kotalahti Ni-Cu mine, which was in operation from 1957 to 1987. Various chemical and physical proxies were used in concert with diatom assemblage analysis to obtain a comprehensive picture of the impacts of mining on the lake and to try to discern the most suitable proxies for observing the development of meromixis from the sediment record. The sediment sequence was dated with the ^{137}Cs method which identified the Chernobyl nuclear fallout of 1986 at the 8-9 cm sediment depth, and the nuclear bomb tests of the late 50s and early 60s at the depth of 27-28 cm. Therefore, the sequence in 8-28 cm sediment depth represents the period of active mining. The major element data obtained from the µXRF analysis, magnetic susceptibility, and sediment bulk density also showed distinct changes around these depths. The diatom assemblages of Lake Valkeinen were dominated by planktonic cyclotelloid species. Small fragilarioid species were also rather abundant throughout the core. Synurophyte algae and chrysophyte cysts were also present in the samples. The main change in the species assemblages occurred at the depth of 9-16 cm, which could represent intensifying pollution from the mine, leading to the onset of meromixis, and consequent change in the ecological conditions of the lake.

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Characterising magnetic minerals in urban aerosol dust in Helsinki

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The complex impact of iron oxide aerosols has been generally underestimated and only recently recognised (Moteki et al. 2017). This particulate matter (PM), although constituting only a small fraction of overall atmospheric dust, plays a crucial role in global processes. For example, iron oxide pollution is contributing to atmospheric heating and modulation of aquatic ecosystems. Furthermore, elevated concentrations of iron oxide aerosol have been associated with detrimental impacts on human health, including cardiovascular, respiratory, and neurogenerative diseases. Particularly harmful are the smallest size fraction as PM infiltrates sensitive regions of the respiratory system (PM_{10}, $PM_{2.5}$) and even bloodstream ($PM_{0.1}$) (Hofman et al. 2017).

In urban areas, the magnetic material from combustion and friction processes from vehicular traffic has been proven to be a major source of magnetic particulate matter (Maher & Gonet 2019). In contrast, natural sources predominately originate from mineral dust from exposed surficial deposits. Magnetic PM from natural and anthropogenic sources are distinctly different, characterised by variations in magnetic properties, grain size, and morphology. Environmental magnetic methods are considered robust methods for characterising magnetic PM, identifying the source, and providing a quantitative approach to measure the amount of magnetic PM (e.g., Hofman et al. 2017).

Despite the global importance of iron oxides, investigation of magnetic minerals and their sources in atmospheric dust in Finland is still in its early stages. This work aims to characterise the magnetic minerals, discern between anthropogenic and natural sources, and quantify the abundance of magnetic aerosol dust in subarctic Finland using environmental magnetic methods. To accomplish this, a 44-year-long time series (1962–2005) of filter-captured aerosol dust from the meteorological station located in Kaisaniemi, Helsinki, is investigated. The filters (Whatman 42 paper filters) were originally collected for monitoring airborne beta radioactivity by the Finnish Meteorological Institute (Paatero et al. 1994). Later, the trace element concentration of seventeen elements in the air filters were measured (Ioannidou et al. 2023).

Magnetic susceptibility for the weekly filters (all years: 1962–2005), and different laboratory remanent magnetisation measurements (selected years: 1969, 1987, 1996) were done at the Solid Earth Geophysics laboratory of the University of Helsinki (UH). Low-temperature remanence magnetisations with room temperature hysteresis loops and backfield curves were conducted at the Institute for Rock Magnetism at the University of Minnesota (Maunula 2024). Scanning Electron Microscope (SEM) studies were done at the HelLabs (UH).

The magnetic susceptibility values fluctuate between years. Values increase from 1960 to 1970, followed by a general decrease from 1970 to 1987, then reaching a high peak in 1984–1986. Subsequent increase is observed again until 1997 with very high peaks in 1993–1997. Following this the values are decreasing into 2005. Remanent magnetisation results show that the magnetic PM in the filters (1969, 1987, 1996) is composed of different amounts of magnetite, maghemite and hematite. Notably, the 1996 sample shows a superparamagnetic component. Moreover, discernible variations in magnetic PM are evident between winter and summer months, with hematite being prominent in the winter. Magnetite and maghemite are interpreted to originate from anthropogenic sources which is supported by the SEM analyses showing typical anthropogenic rounded iron oxide particles whereas hematite is from natural sources ($PM_{0.1}$–$PM_{2.5}$).

This MSc thesis work is part of a larger project, where the ultimate objective is to model the past and future impact of magnetic minerals released by anthropogenic activities to the atmosphere and human health.

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Investigating the applicability of CuO extraction for detecting biomarkers of marine organic matter in Baltic Sea sediments

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Coastal ecosystems play a crucial role in the global carbon cycle. Recent studies have shown that vegetated coastal ecosystems may help in mitigating climate change through burial of carbon into sediments. However, different coastal habitats influence carbon storage and sequestration in distinct ways. The highly indented shoreline and coastal zone of the Baltic Sea provides a variety of habitats for marine life and hosts widespread zones of organic-rich sediment accumulation. Benthic and planktonic communities are expected to be major contributors of marine organic matter (OM) to the sediments, with additional OM supplied from the terrestrial environment. The aim of this project is to identify and quantify the sources of the organic matter in the coastal sediments of the northern Baltic Sea. Overall, this will contribute to the assessment of blue carbon stocks and carbon burial rates in the Baltic Sea coastal zone.

Analysis of molecular biomarkers has proven to be an important tool to investigate the source and deposition of carbon in marine sedimentary environments. The cupric oxide (CuO) oxidation method is prominently used to characterise lignin phenols derived from vascular land plant material. However, CuO oxidation products derived from marine sources like macrophytes, phytoplankton, zooplankton, and bacteria have also been reported (Goni & Hedges, 1995). The characteristic pattern of these CuO products may thus help to differentiate the biological sources in bulk sediment samples, but this approach has never previously been employed in the Baltic Sea. Here, we focus mainly on the macroalgae *Fucus vesiculosus* which is abundant in the coastal regions of Baltic Sea, contains phenolic biomarker compounds (Ilvessalo & Tuomi, 1989) and is known to contribute to sediment carbon cycling in the study area (Kahma et al., 2020). Analysis of CuO-extracted *Fucus* material shows the array of phenolic compounds synthesised by the macroalgae, while initial field data suggests that some of these compounds are identifiable in sediment samples.

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Geochemical evidence for land use change and human influence on Lake Patalahti

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Introduction

This research is dedicated to assessing human influence on Lake Patalahti, located next to the Himos ski resort in Jämsä, central Finland. The development of ski resorts induces the enhanced construction of tourism-related infrastructure, leading to significant changes in landscape structure and functions of ecosystems (Kangas et al., 2012). In our research, we use lake sediments since they provide continuous information on past environmental changes, including those induced by human activities.

The research aims to determine the pathways of the anthropogenic influence and their rate and the lake responses by studying the lake sediments in high resolution. Here, we present the first results of human impact on the lake during the last 40 years of ski resort operation. A high-resolution micro X-ray fluorescence spectrometry was applied to study geochemical changes in the Patalahti sediment profile (Davies et al., 2015).

Geochemical changes in the top part of the Patalahti sediment profile

The current results show distinct changes in the topmost 12 cm sediment (see Fig.1; the Himos Ski Resort operation period is highlighted with pale blue). These changes relate to the human activity in the surrounding catchment area, including the construction and operation of the Himos Ski Resort. Human-enhanced soil erosion from the slope area is reflected by an increasing trend in Ti.

Based on the decreasing Si/Ti ratio results, which reflect changes in the amount of biogenic Si, the catchment erosion processes seem to exceed the primary production within the lake during the last 40 years. Yet, further investigation of organic matter sources and flux calculations is needed to support this claim. Within the same interval, the growing trend of Fe and the appearance of varve structures reflect oxygen depletion, which, together with the growing percentage of organic matter, can reflect developing eutrophication.

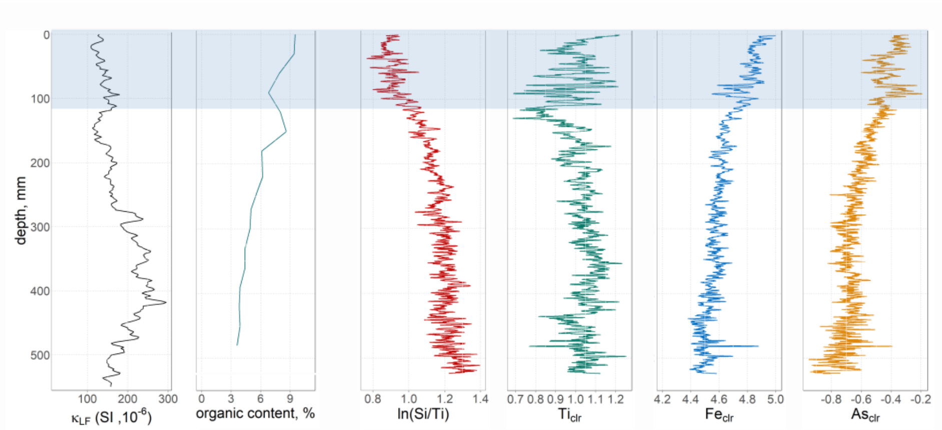

Figure 1. Description of Patalahti sediment profile: magnetic susceptibility, organic content, µXRF geochemical results as center log ratios of Ti, Fe, and As; based on Cs-137 dating, the top 12 cm covers 40 years of the ski resort operation (highlighted with pale blue).

The increased As concentrations are previously suspected to relate to ski resort development (Chapron et al., 2007). It is likely, that the peak in As discovered within the top 10 cm of the Patalahti sediment profile is also caused by the construction of Himos Ski Resort infrastructure.

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Diatoms as a micropaleontological proxy and their seasonal succession in the ice-covered Baltic Sea

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Introduction

Diatoms are globally important marine primary producers, commonly used as micropaleontological proxies in sedimentary records. They preserve well in the sediment and often have narrow environmental tolerances which make them excellent indicators of past environmental change. However, the annual succession of diatom communities through all seasons is deficiently known (Luostarinen et al., 2023), even in the relatively well-studied Baltic Sea, which limits the use of diatoms in reconstructing and understanding changes in marine system seasonality. In this study, the seasonal succession of diatom species was studied at a 1–8 week resolution over a one-year period (October 2012–October 2013) using an automated sediment-trap at Tvärminne Storfjärden (Gulf of Finland). The seasonally resolved, species-specific data contribute to the interpretation of ecosystem effects of past and future seasonal changes from otherwise lower-resolution sediment-core data. The diatom analysis followed standard methods and included quantification of diatom species fluxes. The identified species fluxes and species compositions were compared to environmental data (sea-ice thickness, sea-surface temperature, salinity, nutrient conditions).

Results

The diatom species communities in Tvärminne Storfjärden followed changes in the formation and melt of sea ice, nutrient levels, sea-surface temperature and salinity. There were two large seasonal diatom blooms during the study period (main spring bloom in May 2013, autumn bloom in November 2012 and September 2013) with differing species compositions. The diatom species communities were distinct in winter and early spring, late spring, and autumn, which marked the most important phases in the seasonal succession. The winter community consisted mainly of sea-ice species such as *Pauliella taeniata* and a cold-water species *Thalassiosira levanderi*, but also a less common sea-ice species *Stauroneis radissonii* had a significant contribution and could potentially serve as a proxy of ice cover in the Baltic Sea. The spring bloom had two stages: an initial stage in April, which started with sea-ice thinning, and a massive main spring bloom in May, which started when surface water warmed rapidly. *T. levanderi* dominated the under-ice bloom in April, benefiting from the lack of competition in the cold waters, increasing light availability and optimal nutrient conditions. The diatom production collapsed after the *T. levanderi*'s bloom and sea-ice melt, while dinoflagellate *Biecheleria baltica* peaked at the beginning of May, clearly showing the competition between these important primary producer groups in the Baltic Sea. *Skeletonema marinoi* and *Diatoma moniliformis* dominated the spring bloom in May. Diatom fluxes gradually decreased after the spring bloom and other primary producers dominated the summer waters. In the autumn small centric species (*Cyclotella choctawhatcheeana*, *Cyclotella atomus* and *Minidiscus proschkinae*) formed a bloom as turbidity and nutrient levels increased. These species have previously interpreted as a summer species and the timing of the blooms was an important find.

This study demonstrates that diatom species dominance can change rapidly when environmental conditions change. In addition to environmental conditions, intra- and interspecies competition play an important role in developing of the species community of each season. Recognizing the different seasonal species communities and the environmental factors behind them will help to distinguish the seasonal phases without, for example, overestimating the annual sea surface temperatures. The results will be important for future sediment-core studies from the coastal Baltic Sea.

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Investigating the potential of lignin phenols to study sources and fate of terrestrial organic matter in coastal Baltic Sea sediments

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Lignin is the second most abundant natural material on the earth (after cellulose). It comprises a group of phenolic polymers that are primarily found in the woody tissues of vascular plants and are essentially absent from all other living organisms. Lignin has been widely used as a tracer for terrestrial organic carbon in marine environments since the 1970s. However, its applicability to reconstruct anthropogenic inputs of organic carbon, for example through forest industry activities and land-use change, is under-studied. Here we present preliminary data of sediment lignin phenol parameters in Pohjanpitäjänlahti estuary, offshore from the Mustionjoki river in the Gulf of Finland., as proof of concept for using lignin to trace terrestrial organic carbon in this system. Samples extracted by alkaline CuO oxidation were analyzed for total lignin oxidation products (Λ) as well as elemental and stable carbon isotope (C and $\delta^{13}C$) composition. The results showed that spatial variability in lignin content (Λ mg/100 mg OC) is in accordance with the trend observed for $\delta^{13}C$ and C/N ratios. Stations near to the river mouth show high Λ with values ranging between 2.8-5.7 mg/100 mg OC, and depleted $\delta^{13}C$ values (around -28.22 to -27.25 ‰), associated with high OC content (2.1-5.2%), while lower Λ and enriched $\delta^{13}C$ values were observed at distal stations of the transect. This trend is consistent with the preferential deposition of lignin-rich and isotopically depleted terrigenous material-close to the river. Moreover, the relative predominance of Vanillyl (V) phenols near to river mouth reflects a stronger woody gymnosperm source compared to distal stations of the transect. The molecular ratios of Cinnamyl/ Vanillyl (C/V) and Syringyl/ Vanillyl (S/V) phenols of all sediments ranged between 0.16-0.57 and 0.079-0.74, respectively, which reflects the mixed input from non-woody gymnosperm to woody and nonwoody angiosperm plant tissues in the region. Elevated signals of S/V ratios (indicating more angiosperm material) were observed in the mid-stations of the transect, while the C/V ratios (indicating more non-woody material) increased at distal stations. Grasses are generally characterized by higher C/V ratios than leaves. The general trend towards higher C/V ratios toward distal stations could thus reflect higher grass-based lignin in these stations. Thus, the total lignin yield pattern, and diagenetic ratios along the transect of the river Mustionjoki could be explained by preferential deposition of different pools of organic matter introduced by the river. The first pool comprises fresh plant debris with a strong gymnosperm source, reflected in high lignin yield and is primarily deposited with the coarser mineral particles (silts and sands) near the river mouth. The second pool is comprised of highly altered organic matter associated with low lignin yield, primarily derived from angiosperm sources and showing preferential transport to distal areas of the transect. These results are important for the later interpretation of human impacts on the deposition of terrestrial organic matter in sediments of the northern Baltic Sea.

Marine geological inventories around the Åland, the Baltic Sea, as part of Biodiversea LIFE IP project

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Introduction

Biodiversea LIFE IP (2021-2029) is the largest collaborative project to date to safeguard the biodiversity of the Baltic Sea in Finland. The main objective of the project is to enhance the protection of marine nature and promote the sustainable use of natural resources in the marine and coastal areas of Finland. The project activities include inventories in the Åland offshore areas among others. Here the primary aim is to produce science-based information for selecting and establishing new marine protected areas (MPAs) in locations that have high nature values.

In relation to this, the Geological Survey of Finland (GTK) has focused on the geological mapping of the seabed around the Åland Islands. The marine geological surveys provide essential information on the seabed geodiversity, distribution of the sediments and background information for habitat modelling. The comprehensive mapping data supports and guides the planning and coordination of different uses of marine areas. The research areas have been selected in collaboration with other project partners to identify potential biodiversity hotspots and areas with nature values.

Methods and preliminary results

GTK has carried out marine geological surveys in an offshore area south of Åland in 2023 using different seismo-acoustic methods i.e., sub-bottom profilers such as Chirp sonars and seismic reflection profiler along with side scan sonar and multibeam echo sounder onboard R/V Geomari. Based on the preliminary results the research area is topographically heterogenic with bathymetry varying mainly from 10-70 m. The seafloor is dominated by underwater bedrock outcrops that may reach to depths of 10-20 m. Most of the bedrock depressions are filled with glacial and postglacial clays which are covered with 5-10 m of brackish-water and modern sediments. Thickness of these clay basins varies from approximately 5-40 m depending on the depth of the basin. Thin sand layers cover the clay basins especially in the northern part of the research area which complicates the interpretation of the deepest sediment structures. The mapped data is used to make seabed substrate map of the research area which will be used in further investigations such as the selection of potential sampling sites.

Funding

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Climatic factors controlling long-term variation in the abundance of different chemical fractions of phosphorus in Finnish archipelago sea sediments

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Phosphorus is one of the key nutrients that significantly controls the growth of organisms in marine systems. However, excessive phosphorus input accelerates biological production and actuates eutrophication and hypoxia (Schindler 1977), which have deteriorated the environmental status especially of inner the Finnish Archipelago Sea (Jokinen et al. 2018). Though external phosphorus load has diminished, the problems and challenges caused by eutrophication have not been conquered (HELCOM 2009, HELCOM 2023, McCrackin et al. 2018). Previous studies have shown the significance of internal load of phosphorus that hinders the recovery of the Archipelago Sea (Puttonen et al. 2014, 2016). However, the accumulation, preservation, and long-term variations in the burial of phosphorus within the sediment is not fully known. Conquering the eutrophication-caused problems and challenges requires thorough understanding of the mechanisms behind them. Thus, we trace long-term variations in chemical forms and contents of sediment phosphorus in detail to reveal the importance of different processes on phosphorus deposition, burial, and release.

We investigate variations in the abundance of different chemical fractions of phosphorus, i.e. different binding and solubility forms of phosphorus, during the last 60 years with seasonal resolution from varved sediments of Halikonlahti Bay in inner Finnish Archipelago Sea. We applied the phosphorus fractionation method by Jensen and Thamdrup 1993, as described in Lukkari et al. 2007. We compare abundances of different phosphorus fractions to hydro-climate parameters to study how variations in the conditions, such as occurrence and timing of precipitation or snow and ice cover, control the washout of phosphorus from the catchment. In addition, we investigate if the changes in enhanced leaching of phosphorus are directly mediated to sediment deposits. According to our knowledge, varved marine sediments have not been earlier used to study long-term variations in chemical phosphorus fractions with sub-annual resolution. The importance of this study lies within high temporal resolution allowing to assess the response of phosphorus burial to past hydro-climate conditions. This can further improve our understanding on phosphorus burial and internal loading and hence enables the use of rehabilitation actions and target them better spatially and temporally in inner Finnish Archipelago Sea and its catchment.

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Free fall cone penetration tests (FFCPT) for seabed strength characterization for offshore construction planning

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Increasing interest towards offshore construction requires fast and cost-effective ground investigation methods. Free fall CPT techniques are developed for subsurface strength evaluation for offshore wind farm site assessment and cable route surveys. FFCPTs provide a rapid measurement of the seabed undrained shear strength to support the site characterization together with geophysical surveys and sediment coring.

This study presents FFCPT measurements combined with seismoacoustic sub-bottom profiles and sediment coring from selected offshore sites in the Finnish sea areas. The study shows the variability of the dynamic undrained shear strength in different fine-grained sediment units (Fig. 1). The interpretation of the FFCPT values related to strain-rate effects is discussed.

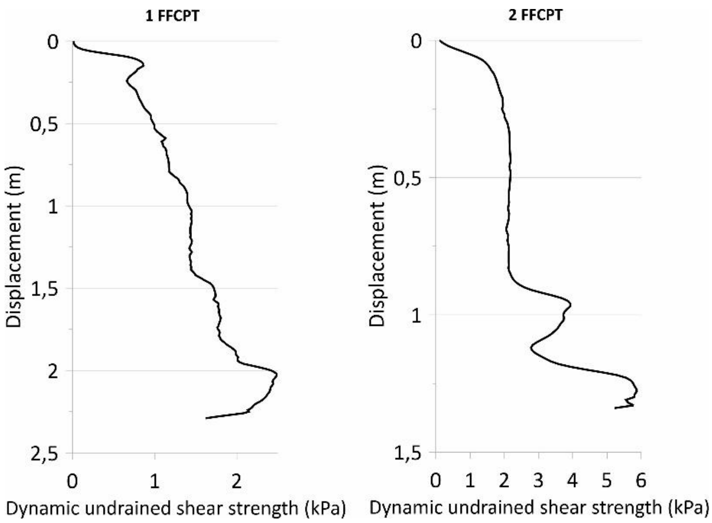

Figure 1. FFCPT profiles from two offshore study sites. 1 FFCPT shows dynamic undrained shear strength in brackish-water mud. 2FFCPT shows the dynamic strength in postglacial lacustrine and glaciolacustrine clay and silt.

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The internal structure and deposition of a triangle-type murtoo in the northeastern Baltic Sea Ice Lobe of the Fennoscandian Ice Sheet

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The internal structure and genesis of subglacial landforms called murtoos have been studied mainly in the triangular distal part of the landforms (Peterson Becher and Johnson, 2021; Mäkinen *et al.*, 2023). This study, conducted within the Loimaa sublobe of northeastern BSIL, was the first one in which the internal structure of murtoo was excavated and studied thoroughly from the proximal part to the distal part using ground penetrating radar (GPR), sedimentology and boulder mapping in and on the murtoo (Fig. 1). Additionally, the morphometry of Myllykoski murtoo (61,4362°, 22,4606°) was scanned with a terrestrial laser scanner using 0.1 m resolution before excavation (Soini, 2023).

It was verified that the sediment grain size of the murtoo increases significantly from the proximal part to the distal part, which indicates rapid increase of the meltwater flow in a short distance and in a short period of time. Due to sorting processes and the lack of periods of slow meltwater flow the proportion of clay and silt in the sediment is very low. In the murtoo body, which makes up most of the murtoo mass, the boulders were orientated in accordance with the main meltwater flow and ice-flow directions. The noticeable orientation occurred in the centre of the murtoo while in the margins of the landform the clasts had no proper orientation and were orientated chaotically. The weak orientation and angularity of boulders and cobbles and altering structures of finer sandy interbeds within the murtoo diamicton indicate short transportation distance and rapid deposition. Rock types of the grain-size samples were also compatible with the bedrock of the study area (Soini, 2023).

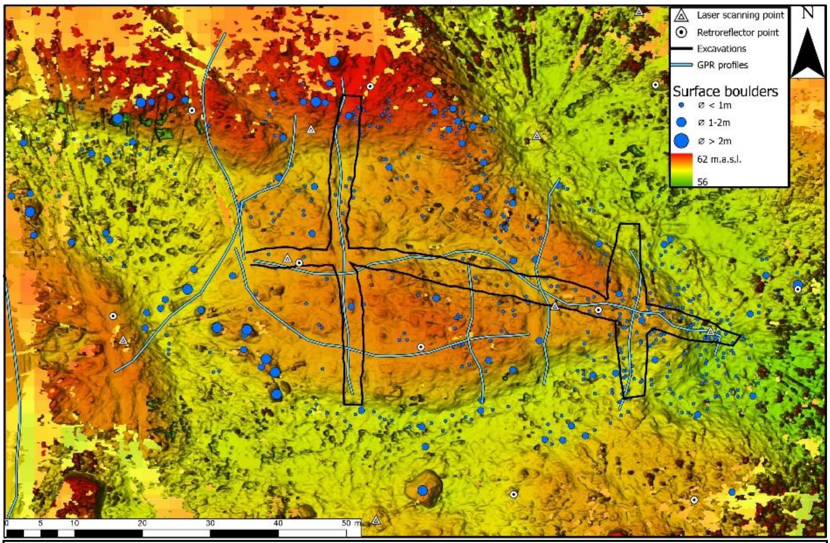

Figure 1. Hill-shaded DEM of the studied murtoo with excavated trenches, GPR profiles, surface boulders and LiDAR scanning points added.

The Myllykoski murtoo can be divided into three depositional units as proposed by Mäkinen *et al.* (2023). The core consists of gravelly boulder-rich sediment on which the sandier diamicton with sorted interbeds of the murtoo body is deposited. Boulders larger than 1 m in diameter have not been yet discovered in the murtoo body (Mäkinen *et al.*, 2023; Soini, 2023). Also, small-scale glacifluvial UFR bedforms appear inside the murtoo body (Hovikoski *et al.*, 2023). The third main unit, the murtoo mantle consists of sandy and stony ablation till with boulders larger than those found inside the murtoo. The sorting effect of the meltwater flow, the periodicity of its strength and the prevailed normal effective pressure close to zero have been key factors during the deposition of the murtoo.

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Weekly monitoring of the occurrence of per- and polyfluoroalkyl substances (PFAS) in Vantaa River, southern Finland

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Per- and polyfluoroalkyl substances (PFAS) are persistent environmental contaminants linked to multiple adverse impacts and they are ubiquitous in the Finnish aquatic environment. The Vantaa River watershed is densely populated and constitutes a reserve water source for water supply in the Helsinki Metropolitan area (1 million people). The aim of this research was to quantify PFAS concentrations and test a load estimator software (LOADEST) to determine loads at the mouth of Vantaa River before it flows into the Baltic Sea. Weekly water sampling was conducted near a continuous gauging station (Oulunkylä station) between March 2023 and October 2023 resulting in 28 samples. Water samples were analyzed for 50 PFAS in a commercial laboratory in Finland. Instantaneous daily load (riverine export) of individual and total PFAS (g/day) were calculated from the measured PFAS concentration in the river and daily river discharge data. The USGS application LOADEST was used to calculate individual and total PFAS loads at a daily interval over the monitoring period.

Σ_{50} PFAS concentration averaged 25 ng/L (range was 7-53 ng/L) and Σ_{50} PFAS load averaged 27 g/day (range was 6-121 g/day). Six PFAS constituted 83,4% of total quantified PFAS, perfluorooctane sulphonic acid (PFOS) and perfluoropentane acid (PFPeA) accounted for 40%. The total Σ_{50}PFAS load at Oulunkylä was 4,7 kg over the entire monitoring period (197 days). In addition, the PFAS yield (kg/km^2 yr) calculated by dividing the annual PFAS load by the drainage area was 5.15 10^{-3} kg/km^2 yr in Vantaa River. Statistical measures of model performance indicated that LOADEST models for Σ_{50}PFAS was within acceptable limits, with a Load Bias of –0.5% and a Nash-Sutcliffe Efficiency Index of 0.9. Further monitoring and modeling are warranted as this study shows that LOADEST can successfully be applied to the Vantaa River watershed, and it could be used to track the PFAS load reaching the Baltic Sea and follow the evolution of the system after restriction or ban of individual PFAS in Europe.

The Pärvie postglacial fault system: Interaction between surface and groundwater systems

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Introduction

Post and endglacial faulting was active in northern Fennoscandia in the Early Holocene producing intraplate seismicity (up to Mag. 8) (Lagerbäck and Sundh, 2008; Kukkonen et al., 2011). The Pärvie postglacial fault system (PPGS) in North Sweden is a seismically active thrust fault which is about 160 km long and has maximum vertical displacement of 13 m (Lagerbäck and Sund, 2008).

In this study, surface and groundwater interaction within the PPGS is investigated as part of the Research Council of Finland funded DAFNE-22 project to address the following hypotheses: 1) PPGS provides more efficient pathways for fluid flow than the average crystalline bedrock, 2) The groundwater composition near the fault zone differs from those further from the fault zone, and 3) The difference is the result of more active rock-water interactions closer to the fault zone compared to more distant sources.

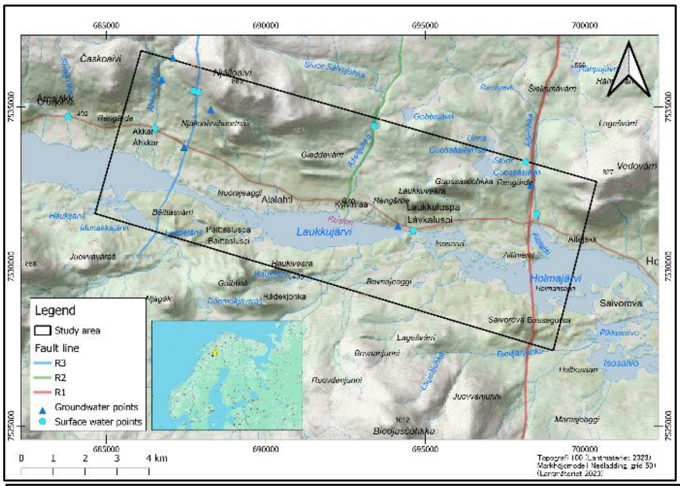

Figure 1. The area of interest, faults, and water sample points are shown on the map. In a small index map, the research area in relation to northern Fennoscandia.

Materials and methods

In August 2023, drone scanning campaign (infrared and orthophotography) and terrain surveys were carried out within the 7.6- hectare research area about 30 km west of Kiruna town in the Pattas, Laukku, and Holma Lake area, which covers the main fault line of the PPGS (R3 in Fig 1.) and two secondary fault lines (R2 and R1) east of the main fault.

In total, 17 water samples were also collected from streams, springs, lakes, and boreholes (Fig. 1). pH, temperature, and electric conductivity were measured in the field with YSI multiparameter probe. Alkalinity was defined both in the field and in the laboratory by titration. Major and trace elements as well as water stable isotopes were analysed in Environmental laboratory of University of Helsinki, Department of Geosciences and Geography.

Results and discussion

Some springs, groundwater seepage sites, as well as groundwater discharge into the streams were identified from the thermal infrared data. Isotopic composition of 14 water samples plots straight or very close to the Global Meteoric Water Line, reflecting rainwater source and dynamic groundwater recharge. In only three samples, collected from streams and ponds near the secondary faults, evaporated waters were observed (d-excess < 10 ± 1 ‰).

Dissolved silicate concentrations (DSi) (Range: 1.5-7.6 mg/l; Md 4.2 mg/l) reflect the reasonable long residence time of groundwater and the discharge of the groundwater into the streams. Two water samples, collected near R1 from an old borehole at 20 m and 90 m depth, had the highest DSi from 7.3 to 7.6 mg/l. The deeper sample had the highest concentrations of dissolved solids (TDS 70.35 mg/l), indicating longer relative residence time. Further analysis of the geochemical and thermal data is ongoing and will be completed by the summer 2024.

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3D hydrogeochemistry and particle tracking to detect groundwater flow patterns within an aapa mire–outwash plain system in a boreal environment at a mining development site

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Introduction

The 3D hydrogeochemical characterization of an aapa mire–outwash plain system in the Sakatti mining development site, in northern Finland was performed with a combination of statistical hydrogeochemical methods, PCA, correlation calculations and SiroSOM clustering, as well as groundwater flow modelling with particle tracking. The study applied two hydrogeochemical databases including major cations (Na, K, Ca, Mg), anions (Cl, NO, SO_4, HCO^3), metals (Al, Cr, Mn, Fe, Co, Ni, Zn), and pH (n = 95), and isotope samples of D and ^{18}O (n = 322).

Results and implications

The 3D groundwater flow model indicated that the flow paths of the site are variable and can be grouped at three scales: large-scale (>1000 m), medium-scale (1000–100 m) and small-scale flow (<100 m). Large-scale flow paths originate from the mire islands flowing via the subpeat sediments and via the weathered and fractured bedrock to the River Kitinen. Medium-scale flow paths travel from the outwash plain areas and adjacent finger-like mire areas via the subsurface to the river. Small-scale flow is present in the banks of the River Kitinen and in the Viiankiaapa mire and is related to variation in the topography, as well as the string and flark pattern of the mire.

According to hydrogeochemical analysis, $Ca\text{-}HCO_3$ is the predominating water type in the site. Seven hydrogeochemical clusters were obtained with SiroSOM analysis: groundwater, groundwater with elevated trace elements linked to the dissolution of mafic minerals or mafic sulphides, mire porewaters, diluted surface waters, surface waters with elevated SO_4 and rather high pH, and two more distinct clusters with slightly elevated SO_4 and low Mn and Fe, as well as waters with elevated EC and metals. In general, the concentrations of elements in groundwater decrease when travelling through peat and increase in bedrock due to the longer residence time and flow path. Changes in redox conditions alter the hydrogeochemical signal of mire (pore) waters compared to oxygen-rich groundwater discharging in springs.

Based on 3D investigation of water stable isotopes groundwater recharges in outwash plain and in the Viiankiaapa mire area. The *d*-excess distribution varies between -20.9–10.6 displaying evaporated (<5) water, mixed water and water of meteoric (>8) origin. The low *d*-excess values in springs of the riverbank and shallow bedrock wells suggest water infiltration from the Viiankiaapa mire into the groundwater.

The simulated backward (BW) particle tracking in outwash plain areas indicated average residences times of 10–100 years. Likely recharge areas were evaluated with BW tracking and calculated *d*-excess values (n = 141). Longer flow paths (>20 m), GW well and porewater samples obtained better correspondence to the expected recharge areas (evaporated water/meteoric water) than SW samples and spring samples.

Understanding of the groundwater flow patterns, as well as the recharge and discharge areas in a mining development site enables successful planning and positioning of the mining activities. Groundwater flow modelling and validation of the model with stable isotopes can be used to plan and optimize groundwater monitoring in future mining sites. SOM and PCA analyses derived from hydrogeochemical datasets and viewed in 3D can be used in delineating areas with specific or anomalous geochemistry to understand the baseline geochemistry.

On the carbonaceous materials and sulfides in the black shales and schists of the Matarakoski Formation: characteristics of the possible sulfur source of the Kevitsa Cu-Ni-(PGE) sulfide deposits

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Kevitsa is a 2.06 Ga mafic-ultramafic intrusion hosting ore-grade disseminated Cu-Ni-(PGE) sulfide deposit. The sulfide deposit formation was intensified due to assimilation of sulfur-bearing crustal rocks. A potential sulfur source for the Kevitsa deposits is the adjacent sulfur-rich black shales and schists of the Matarakoski Formation, belonging to the 2.15–2.05 Ga Savukoski Group. We reviewed eight drill cores with > 900 m of black schist from the vicinity (within ca. 3.5 km surface distance) of the Kevitsa intrusion. The regional Matarakoski black shales and schists include massive and thinly laminated portions with preserved primary bedding and variable carbon contents. Intervals of nearly pure carbon are present locally. Collapse breccias within the black shales and schists likely indicate dissolution of soluble interbeds. Carbonate-sulfide veins are common and crosscut the bedding of the sequence.

We characterized the carbonaceous materials and sulfides from samples representing the massive (n = 3), thinly laminated (n = 3), carbon-dominated (n = 1), and contact-metamorphosed (n = 3) types of the Matarakoski black schists. Raman spectroscopic measurements indicate that the carbonaceous material in the regional black schist is disordered graphitic material. The main features of the spectra are well-developed G-band ("graphite-band") related to stacked graphene sheet structure as well as minor D1 and D2-bands ("defect-bands") arising from structural defects within the individual graphene sheets. Thermometry based on the structural ordering of the graphitic carbon yields peak temperature for the regional metamorphism in the range of 500–550 ± 50 °C. In the ca. 10 m thick recrystallized contact aureole, the amount of carbon decreases towards to the intrusion contact. We were able to identify and measure the structural ordering from one of our three contact-metamorphosed samples. The sample contains disseminated micron-scale carbon, with slightly more organized graphitic structure compared to the regional black schist. Thermometry indicates a peak metamorphic temperature of 560 ± 50 °C. We interpret this as true contact metamorphic peak temperature due to the systematic increase in structural ordering towards the intrusive contact within the contact aureole.

The most common sulfide in the Matarakoski black schist is pyrrhotite. It is ubiquitously present as disseminated grains within the ground mass, and locally as intergrowths with silicate grains. The grain size of the intergrown sulfides and silicates exceed that of the groundmass, which indicates formation during the regional metamorphism. Chalcopyrite is sparse and intergrown with pyrrhotite. Pyrite, which is typically common in black schists, is absent possibly due to the high degree of regional metamorphism. The contact aureole contains mostly disseminated pyrrhotite, but it is less abundant compared to the regional black schists. The distal part of the contact aureole is particularly depleted in sulfides. Based on our observations, contact metamorphism caused depletion of carbon and sulfur in the black schist. Interpreting the reactions and estimating carbon and sulfur fluxes in the contact aureole is complicated due to the later regional metamorphic processes. We intend to conduct whole-rock and mineral chemical study to understand the regional and contact metamorphic reactions in more detail.

SMARTTEST – Smart circular economy field testing facility for extractive waste and side streams

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Introduction to extractive waste management

Management of extractive waste plays a critical role in the environmental safety, social acceptability, and economic viability of mining. Extractive waste management solutions need to be tailored based on the waste characteristics and with mine closure in mind. Resource efficiency can be improved and the need for virgin material resources can be reduced in the mining industry by using circular economy materials. This, however, requires testing of the characteristics and the long-term behaviour of extractive waste and side streams already in the early stages of the mine lifecycle.

SMARTTEST – Innovative field-testing for extractive waste

SMARTTEST develops flexibly customizable and comprehensively instrumented field-testing concept and facility for side streams and mining waste. The project will pilot the field-testing concept and evaluate its performance through different case examples. The case examples will focus on different extractive waste management solutions, including the suitability of dry disposal techniques in Nordic conditions, the use of side streams in the final cover structures of extractive waste facility, and the disposal of waste rock and co-disposal of side streams with waste rock. Case examples will take advantage of both large-scale (9–18 m^3) and smaller-scale (1 m^3) field tests to be run over a period of about two years focus. SMARTTEST aims to develop and use digital solutions to collect, transfer and manage monitoring data, and develop and pilot a numerical modelling concept to support the interpretation and up-scaling of data from the field tests.

The field-testing facility will be situated at GTK Mintec mineral processing pilot plant site in Outokumpu, allowing for long-term field testing of circular economy and extractive waste management solutions already when mineral processing is planned. The field-testing concept and facility developed in the project thus expands GTK Mintec's opportunities for cooperation and development. Moreover, SMARTTEST project promotes circular economy and environmentally sound management of extractive waste.

SMARTTEST project is funded by the European Regional Development Fund (ERDF) from the Regional Council of North-Karelia, Agnico Eagle Finland Oy, EPSE Oy, Fatec Oy, Kanteleen Voima Oy, Kemira Oyj, Mawson Oy, Sokli Oy, and Geological Survey of Finland.

CoDa based approach to till and surficial geochemistry in mineral exploration

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Geochemical data is considered as compositional data (CoDa) which can be summed up to a fixed constant (e.g., percentages, proportions) and these data contains the ratios between measured components that represent relative information between measurements (Filzmoser et al., 2018). In Finland, three main datasets are available for regional scale research: targeting till, regional till and rock geochemical datasets. The use of those datasets in mineral exploration are going to be considered in this abstract. The targeting till geochemical data set contains around 385 000 till samples collected by the Geological Survey of Finland (GTK) where the sampling density lies between 6-12 samples per km^2 (Gustavsson et al., 1979). The regional till data which cover the whole Finland has sampling density of one sample per 4 km^2 including the full data set of 82 062 samples (Salminen & Tarvainen, 1995) and the rock geochemical dataset contains the concentrations of different elements in Finnish bedrock for 6544 samples (Geological Survey of Finland, 2007). A subset of data from the Central Lapland area, Finland has been considered and the targeting till geochemical data set has serious data quality issues, typically connected to values related to detection limits, zeros and even negative analytical results, and values marked with special symbols where extensive data cleaning was required. Q-Q plots were used to evaluate the distribution of concentrations between different map sheets in the regional as well as in the targeting till data sets to analyse the mismatch between map sheets and they vary quite strongly between map sheets in targeting till data for some elements such as Ni, Fe. Moreover, they vary between targeting and regional till data sets despite compositional transformation. Thus, it was decided not to combine the values from the map sheets in the analysis, but to analyse the map sheets (1:100 000 scale) separately, as the small areas contain enough sample points to carry out the analysis. However, the differences between the two data sets might be mainly due to different analytical techniques. PCA maps were generated for a selected area which contains two Ni-Cu-PGE deposits (Sakatti and Kevitsa), by considering all 3 data sets separately. According to PCAs, the loadings for Cu are lower in both targeting and regional till data sets whereas it is higher in the weathered bedrock PCA, which could indicate till transportation. Furthermore, in all three plots Ti, V and Al positively correlate with each other.

Another approach in surficial geochemistry is to test how upper soil weak leach geochemical methods and biogeochemistry is working in tracing the critical metal sources in different soil types and land use areas in Europe. The target areas locate in Czech Republic, Finland, Poland and Portugal. Aims are to test if the deposit is detectable at the surface, influence of the bedrock lithology, and the influence of surface cover on the geochemical signal on thick sediment cover such as a top of esker and typical till cover. Preliminary results of upper soil analysis in Akanvaara test site show a significant response to many elements with known mineralized bedrock targets observed in the drill core data and elemental distribution is also reflecting the lithological variations of the rock units in the bedrock. Based on the results, it is obvious that a) there is good or moderate correlation for several elements between the surface geochemical data and underlying bedrock, and b) soil analysis method using certain soil sampling procedure and selective extraction is an effective, environmentally friendly geochemical exploration technique in the glaciated terrains.

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Modelling iron oxide Cu-Au (IOCG) mineral prospectivity in Finland, application of hybrid mineral systems-based approach

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Iron oxide Cu-Au deposits are defined as one of the major global suppliers of iron, copper, and gold. These deposits also play a crucial role in providing important resources of U, Ag, and 'critical minerals' such as REEs and Co. In northern Finland, deposits in the Kolari IOCGs (i.e., Hannukainen, Kuervitikko, and the Cu-Rautuvaara Fe-Cu-Au deposits) share common characteristics displaying association with IOCG deposits. In this contribution, we drive a combination of both data- and knowledge-driven approaches, fuzzy logic, and weight of evidence in mineral prospectivity mapping (MPM). We consider four components that are supposed to be implemented efficiently in the modeling of the mineral systems-based approach. i.e., (1) available sources of ore metals and sulfur (e.g., copper, gold, uranium, rare-earth elements); (2) energy/fluid flow drivers in the ore-forming system; (3) architecture and pathways; and (4) trap/precipitation of ore metals to form ore bodies. The translation of mineral system components into mappable criteria and the generation of mineral potential maps are demonstrated. They are enhanced by integrating diverse and rich input data sets derived from geological (scale-free geology map), geochemical (till sample), and geophysical data (magnetic, radiometric, electromagnetic measurements, and gravity worms). The ultimate posterior map highlights a correlation with known IOCG deposits while demonstrating high-favorability areas and new promising target areas. The validation is run using Receiver Operating Characteristic (ROC) analysis and the average Area Under the Curve (AUC) methodology. Values of promising targets against known IOCG deposits reached scores > 0.7, reflecting a favorable posterior map. The results and high validation scores support the application of MPM as a tool and also the combination approach as a practical approach in the exploration of such deposits and other mineral systems, applicable to companies and governments on different scales.

Prospectivity modeling of lithium-rich pegmatite deposits surrounding the Central Finland Granitoid Complex

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Theoretical framework for the research comprises of circulation of lithium in nature, natural enrichment processes of lithium, prospectivity modelling based on mineral systems modelling approach, with emphasis on pegmatite genesis processes, and what factors distinguish the formation of lithium-bearing pegmatites from other pegmatites. Research is regionally focused on geological development of the Central Finland Granitoid Complex and the surrounding western Svecofennian bedrock.

Research aims to construct of a preliminary lithium prospectivity mineral systems model for pegmatites and derive dependencies of critical factors for lithium enrichment (mapping criteria and data sets, regional geological and geophysical information and availability public/non-public). Evaluation of the preliminary lithium mineral systems model using a prospective modelling tool, based on fuzzy logic, which is available in the Geological Survey of Finland GTK's public information service (https://gtkdata.gtk.fi/mpm/).

Research aims to further analyse to what extent do the criteria to be mapped and the publicly available data meet? What additional data materials would be needed in order to refine prospectivity? Mapping, is there any added value for prospectivity modeling available from the GTK's and possible other operators' non-public datasets? Would it theoretically be possible to develop new measurements (e.g. drone measurements). The research uses GTK's existing geological and geophysical data. For the execution of the research, an IT project will be established, in which shared folders will be created for the research's source publications and prospective models, to which the research participants and supervisors will have access.

SOM and clustering techniques for surface geochemical data in Au exploration – example from northern Finland

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Introduction

A basis on data analysis and modelling in glaciated terrains are provided by regional till geochemical datasets. These include the geochemical datasets of till and pre-glaciated weathered bedrock. Large legacy surface geochemical datasets are potential for use in mineral exploration, especially when subjected to data mining techniques. In this study, neural network-based, unsupervised clustering method, called Self-organising Maps (SOM) (Kohonen, 2001) together with a k-means clustering are used. SOM was selected due to its ability to process multivariate data and its ability to cluster these results (Kohonen, 2001). K-means clustering was selected because it is part of the used software GisSOM, which was provided by the Geological Survey of Finland. GisSOM can be downloaded from GitHUB.

Legacy data can have several challenges including, for example, substantial differences in average concentration values between neighbouring map sheets, variable detection limits, over all problems with concentrations, and data points where Au concentrations were not analysed. There are multiple ways to overcome these issues. The first method is clr and ilr transformation that gives promising result. However, it seems that rr (response ratio) method and subsequently using a qq-plot method (Daneshfar & Cameron, 1998), results in better levelling than either ilr and/or clr. Missing Au values were solved using pathfinder elements, which were decided by comparing nearby mineralisation compositions. The selected elements are Ti, V, Cr, Co, Ni, and Cu.

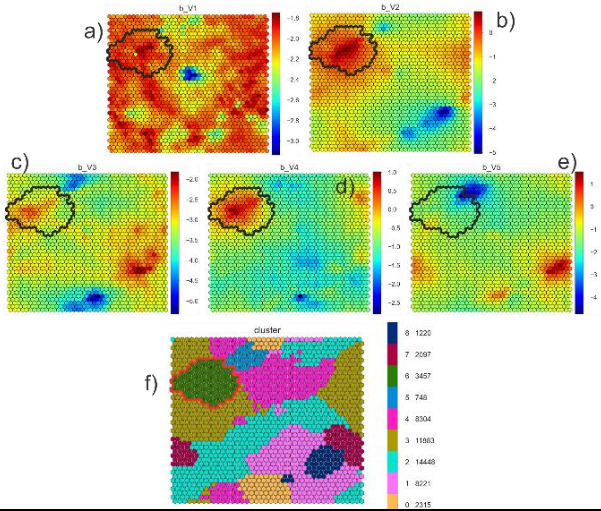

Figure 1. Results of SOM. a) Ti, b) V, c) Cr, d) Co, e) Ni and f) k-means clustering results. Cu is missing due to ilr (isometric log ratio) transformation. Black and red line indicates the cluster 6.

SOM and its utilisation

An architecture and geometry for the SOM are decided. Geometry affects the neighbourhood function and number of neighbouring nodes. Here $\boldsymbol{A} = \sqrt{5 \times \sqrt{\boldsymbol{m}}}$ function for architecture is used (Vesanto & Alhoniemi, 2000; Hautala *et al.*, 2021). Where A is the upwards rounded number for SOM architecture. For example, if A = 10.4 then A is rounded to 11, whereby the architecture is 11x11. The number of data points in the inserted dataset is denoted by m. The calculated 11x11 architecture forms the grid space. The data points are converted into n-dimensional vectors (nD). Each node is assigned one vector called 'codebook vector' or 'seed-vector'. The rest of the data vectors are now compared against the codebook vectors. The node that has the most similar values (e.g., cosine and dot-product) with the compared vector is called the best matching unit (BMU). The BMU gains the compared data vector, and the vector value of the node is modified by the data vector that is gained. Furthermore, depending on the chosen geometry of the nodes the neighbouring nodes are also altered. After going through all data vectors and hundreds of iterations SOMs for each input are ready. With the k-means clustering a unified clustering representation of the inputs can be gained.

The SOMs of same iteration are topographically linked, meaning that node in Ni SOM space 3, 5 (Fig. 1e) is the same node as in Co SOM space 3, 5 (Fig. 1d). This can indicate cluster association between these elements. Thus, preliminary clustering can be carried out before the k-means clustering (Fig. 1a–e).

Using this method, it is possible to construct element associations between clusters and Au. This is done using the spatial location of the clusters (Fig. 1f) that are within known areas of gold mineralisation.

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Mine tailing productization and utilization enhancement with automated mineralogy (MinerAll)

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MinerAll -automated mineralogy for sustainable mining
GTK is currently conducting several research projects on tailings management, with the aim of recovering valuable resources from tailings and promoting their use in new applications.

The project MinerAll is focused on developing automated mineralogy to maximize the utilization potential of tailings. Currently, GTK Mintec obtains information on the mineralogy of tailings samples through process mineralogy research using scanning electron microscope-based automated mineralogy analysis. However, to estimate the utilization potential of the tailings, this information needs to be combined with mineral utilization data. The goal is to develop a database containing mineral properties as well as their application areas and methods for systematic and automated analysis and visualization of the suitability of tailings for different uses (e.g., as a raw material for a certain geopolymer), the related processing characteristics, and possible harmful components. These will allow rapid and cost-effective determination of minerals and harmful components in the tailings, as well as the assessment of the potential for recovery of valuable raw materials and beneficial uses of the tailings. In the future, automated mineralogy combined with the databases and software tool being developed in the project can be used already in the mine planning phase, making a significant contribution to reducing mining waste.

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Magma as a chemical probe into the Earth's interior: High resolution sampling of recent basaltic eruptions

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Magma is one of the most important probes into the Earth's interior. In principle, magma contains information on its source, on the rocks it passed during ascent, and on the processes the magma experienced *en route* from source to surface. This information is locked in the chemical and isotopic compositions of minerals and groundmass of erupted rocks and can be read by petrologists to understand volcanic phenomena and geochemical processes. The recent basaltic eruptions on Iceland and in the Canary Islands have now given us the opportunity to study the evolution of eruptions in extreme detail, with high resolution sampling allowing us to identify rapid changes in magma composition and interpret these in respect to magma sources, magma storage and transport, and our understanding of magma plumbing systems.

The recent eruptions at Fagradalsfjall have shown rapid compositional changes in major and trace elements during the eruption (Bindeman et al., 2022). This has been interpreted as reflecting different mantle components that are sampled during a single eruption. Stable isotopes such as such oxygen remain virtually unchanged, however, through the 2021 to 2022 events. This is an important indication that the Icelandic plume is not providing the low oxygen isotope signature seen in many rocks in central Iceland and crustal processes must be held responsible instead.

Another major basaltic eruption in recent years was the 2021 Tajogaite eruption on La Palma, which lasted for three months and caused enormous damage in the densely populated Western regions of the island. Here too, rapid compositional changes of lava composition were detected during the first weeks of the eruption, which in conjunction with the seismic record indicate that the eruption was initially fed from a lower crustal reservoir, but supply changed to a deeper upper mantle reservoir as the eruption progressed (Day et al., 2022). The initial magmas show more variable oxygen isotope compositions than later erupted samples, which we interpret as reflecting interaction with the sub island ocean crust during pre-eruptive crustal magma storage.

In both these cases, detailed time resolved sampling of erupted lavas and pyroclastic products allows investigation of mineralogical and chemical changes on a daily to weekly timescale and gives us the opportunity to correlate this information with seismic data and changes in eruptive style. High resolution sampling of ongoing eruptions offers an exciting approach to further advance our understanding of the inner workings of volcanic storage and supply systems, magma genesis, and their link to subaerial eruptive phenomena.

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Structural control on plume-ridge interaction in northern Iceland

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Melting along the mid-ocean ridges is the result of decompression melting of the normal depleted mid-ocean ridge mantle, whereas melting in the intraplate environment is the result of thermochemical plumes. The geochemically enriched intraplate sources, situated close to the depleted mantle upwelling underneath mid-ocean ridges, provide tracers with which the melting and melt ascent processes occurring in these two geodynamic environments can be deciphered. The Arctic Kolbeinsey Ridge extends several hundreds of kilometres north of Iceland and is one of the classic regions of plume-ridge interaction. Here, we present major element, trace element, and Sr-Nd-Pb isotope data of basaltic glasses from the 290 km long southernmost Kolbeinsey Ridge segment and its southern boundary to Iceland, the Tjörnes oblique spreading area, along with published and new data from the northernmost Iceland volcanoes. In addition, we compare these with new data from the on-land Sveinar-Randarhólar Fissure extending northward from Askja volcano. Along the southern Kolbeinsey Ridge, trace element (e.g., $(La/Sm)_N$, Nb/Zr, K/Ti) and Sr-Nd isotope signatures decrease from enriched plume signatures at northern Iceland to mid-ocean ridge-like signatures at the northern segment end. We can show that the incompatible element and radiogenic isotope variability of lavas erupted along the southernmost 25 km of the Kolbeinsey Ridge is similar to those from the Tjörnes area. In contrast, glasses sampled further north generally deviate towards trace element and isotope compositions of mid-ocean ridge basalts. Much of the variability of the southernmost Kolbeinsey Ridge segment cannot be explained with simple mixing of melts. Instead, we propose a model in which the geochemical mantle heterogeneity between the Icelandic intraplate melting and Kolbeinsey mid-ocean ridge melting regimes is preserved in melts rising along the Tjörnes oblique spreading centre and the slower spreading sections of the southernmost Kolbeinsey Ridge segment. Lavas from the Sveinar-Randarhólar Fissure contrastingly display a remarkable major, trace element, and petrological homogeneity over a total length of ~75 km, indicating limited fractionation and interaction with the neighbouring country rocks and efficient homogenization prior to eruption. We can show that these magmas were transported from a reservoir underneath Askja volcano at sub-surface levels for ~60 km, likely due to remnant ice coverage in the region before reaching surface levels. Thus, the efficient transport of magma from an on-axis into an off-axis environment is the result of a strong, pre-existing structural domain opening pathways for magma transport over lateral distances of 10-100 kilometres. We conclude that even in plume-ridge environments in which a high-flux mantle plume interacts with a slow spreading centre (<20 mm/a), structural crustal features may provide sufficient pathways to preserve much of the original signature of mantle heterogeneity, whereas melts may be homogenized along the spreading axis in axial magma chambers prior to eruption.

Magmatic sulfur systematics at the Iceland hotspot viewed through the lens of melt inclusions

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Sulfur dissolved in silicate melts drives volcanic SO_2 emissions—one of the principal hazards of eruptions—and partakes in many ore-forming processes. However, magmatic S systematics remain incompletely understood because the record of true melt S contents in both extrusive and intrusive rocks is largely erased by degassing. Here, we use a new compilation of published and new data from mineral-hosted melt inclusions—which preserve pre-eruptive melt S contents—from the Iceland hotspot to investigate the behavior of S during mantle melting, crustal magma evolution and eruptive degassing.

Modelling of partial mantle melting indicates that lower-degree melting, prevalent at off-rift zones, likely occurs under sulfide-saturated conditions and leads to decoupling of S from incompatible volatiles like Cl seen in natural melt inclusion data. This effect is expressed as an anticorrelation between S/Cl and La/Yb, which further requires that the enriched mantle source preferentially tapped at off-rift settings has a low S/Cl ratio (5-10). By contrast, higher S/Cl and low La/Yb of rift zone melt inclusions reflect higher-degree and sulfide-undersaturated melting of a more depleted source with high S/Cl (~200-300).

Pre-eruptive sulfur concentrations are strongly regulated by the sulfide solubility limit. Most melts appear to reach sulfide saturation at MgO contents of ~6 wt.% during crustal magma evolution. A peak in modelled sulfide solubility limit coincides with highest S values (500–2600 ppm, average 1400 ppm) seen in evolved basalts at 4-6 wt.% MgO. The S concentrations are moderate (400–1500 ppm, average 1100 ppm) in Mg-rich basaltic eruptions (>8 wt.% MgO) and low (0–400 ppm, average 100 ppm) in andesitic and rhyolitic melts (SiO_2 > 57 w%).

Finally, we use the 'petrological method' (Devine et al., 1984)—suggested by comparison with direct measurements of recent Icelandic eruptions to accurately gauge total SO_2 emissions (Bali et al., 2018)—to estimate S emission potentials (ΔS_{max}) for 68 eruptions from 22 of Iceland's 33 presently active volcanic systems. Highest ΔS_{max} (2100–2600 ppm) are found in the Hekla 1913 CE, Eldgjá 939 CE and Surtsey 1963-67 CE eruptions, all evolved basaltic eruptions in the propagating rift South Iceland Volcanic Zone.

Our results can be used to assess volcanic gas hazards at Icelandic volcanoes where no direct measurements are available. More generally, the results underline the governing role of sulfide solubility in decoupling S from the other volatile elements during both melting and magma differentiation, and in ultimately controlling the eruptible S contents of hotspot magmas.

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Sediment carbon sequestration in vegetated areas of Finnish lakes: the Blue Lakes project

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Over the last two decades, several studies have shown the importance of aquatic vegetated ecosystems to global carbon sequestration, so-called "Blue Carbon" (Macreadie et al., 2019). This term originally referred to coastal environments (*e.g.*, mangroves and sea grasses), but the importance of vegetated areas to the carbon sink in lacustrine environments is still poorly understood. It has been suggested that lake ecosystems represent the second largest areal carbon stocks in the Finnish landscape (*e.g.*, Kortelainen et al., 2004), but most studies have focused on open water sedimentation areas. Thus, our goal is to understand how the macrophyte vegetation affects the sedimentary carbon sink in shoreline areas of boreal lakes.

We sampled three large lakes (Vesijärvi, Kallavesi and Oulujärvi) across a latitudinal gradient in Finland. The lakes and sites were chosen based on previous satellite information about the presence of macrophyte vegetation. In each lake, we retrieved sediment cores from 3 different sites and, in each site, from 3 different zones (landside, transitional and waterside). All sediment cores were retrieved from vegetated areas. Each core was sliced every 2 cm in the top 20 cm, and then every 10 cm below. In total, we retrieved 9 cores and 362 samples. Organic matter content (OM, in %) is determined as loss-on-ignition at 450° C.

Data generated so far (approx. 85% of all samples) show that the OM contents of the sediment vary between 0 and 90% OM (mean = 21 % ± 27). The median value of 2.7% is within the range observed in previous studies of coastal marine vegetated areas (Buczko et al., 2022; Martins et al., 2022). Analysis of Covariance showed that the sedimentary OM content has a great variability among lakes. Such variability may relate to the dominant vegetation type or to the sedimentation regime. Sampling sites included dominance of common reed (*Phragmites australis*), *Equisetum sp.* and *Carex sp.*, and a range of grain size classes. Previous studies of OM content and C stock in coastal marine vegetated regions observed similar spatial variability between sampling sites, with lower values in waterside samples, as observed in our data.

All samples will be further analysed for total organic carbon content and combined with bulk density measurements to determine spatially normalized carbon stocks. This data will be combined with satellite imagery to estimate carbon stocks in macrophyte environments throughout Finland. Since almost 10% of Finland's surface area is covered by lakes, our carbon stock estimates may be significant in the context of total carbon storage in the Finnish landscape.

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Steps towards remediation of the Hiedanranta zero fibre area, Tampere, Finland

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Hiedanranta bay area is known for the massive zero fibre deposit up to 14 m thick (Fig. 1). Volume of the deposit is estimated to be approximately 1.2-1.3 million cubic meters, and surface area approximately 28 ha. Zero fibre, a byproduct of the pulp and paper industry, has accumulated on the lakebed through the discharge of industrial wastewater in 1914-1981. It can be coarse wood material (large wood chips and wood shavings) or loose pulp cellulose fibres. It has a very high water and organic matter content, and low pH. Zero fibre contains high levels of nutrients and variable amount of contaminants (mostly metals).

It has been recognized that zero fibre has a high potential to produce greenhouse gases, as well as other gases causing unpleasant odours. In addition, weak ice cover is common in the area during winters. Construction of a high class new urban area next to the site demands remediation of the site in order to ensure that risks generated by the site are acceptable in the future, and to improve the recreational potential of the water area.

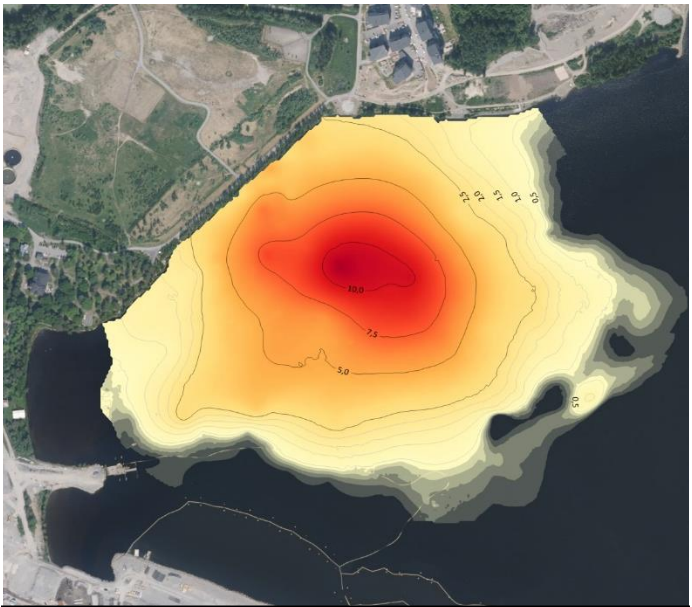

Figure 1. Estimated thickness of the Hiedanranta zero fibre deposit. Aerial photo: National Land Survey of Finland, 2023.

Development of a remediation plan

Surface sediment, long core, sediment trap and gas samplings were performed in the area. In addition, a high-resolution 3D hydrodynamic and a wave modelling study was carried out. Based on the results, a remediation plan was developed. The plan includes partial removal of the zero fibre (approx. 400 000 m^3), dewatering of the material with a complicated treatment train, and utilization of the residue. Once started, the remediation is expected to last some five years.

Results and conclusions

Preliminary findings indicate transport of the zero fibre to surrounding areas, but no mixing with natural lake sediments. Generally, the contaminant levels are low. Gas release rates and gas compositions vary within the area. The central area seems to produce almost pure methane, but the proportion of H_2S increases clearly at the near-shore areas, where gas release rate seems to be higher, as well. Total GHG emissions were calculated to correspond some 0.2–1 % of the total emissions of the City of Tampere. Surprisingly, the weak ice areas seem to form in the same locations in the area each year. This may be due to focusing of gas release, the heat generated by warmer runoff waters or the heat generated by sediment. The exact mechanism remains unclear.

In Finland, problems generated by the zero fibre areas are poorly studied if compared e.g. with Sweden. Releases from Swedish zero fibre areas have been proposed to equal up to 7 % of all national anthropogenic GHG emissions (Lehoux et al. 2021). Actions at the Hiedanranta zero fibre area are more urgent than in most cases. Selection of the most sustainable remediation solution is difficult in a complicated case like this where volumes are large and the usability and treatment properties of the material are poor. Nevertheless, the proposed solution is believed to reach the desired future state of the area with the best balance of environmental, social and economical impacts.

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Microplastic deposition controlled by the winter conditions at Baltic Sea estuary

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Microplastics (plastic materials with particle sizes smaller than 5mm) are acknowledged as emerging pollutants and considered to be ubiquitous, pervasive and irreversible, being found everywhere on the planet (Geyer et al., 2017). Majority of the microplastics in the oceans are derived from land resulting from traffic, industry and insufficient waste management. While rivers are responsible of transporting microplastics to the sea (Mennekes and Nowack, 2023) the oceans are considered as sinks (Rochman, 2018), leaving ecologically active and critical estuaries with their diverse biogeochemical processes in between. The chains of lacustrine, riverine and marine environments are critical in terms of the global microplastic budget, yet, the flux rates of microplastics from catchments to water bodies are poorly investigated. We monitored microplastic and sediment accumulation rates along the transect within Halikonlahti estuary (inner Archipelago Sea) using multiple sediment traps. In addition to sediment and microplastic fluxes, seasonal variation of sediment (detrital supply, organic matter, major element components) and microplastic (particle size, shape, plastic material) characteristics and hydroclimatic conditions were recorded.

Estuaries can efficiently trap nutrients and organic carbon through various processes involving flocculation and aggregation (Jilbert et al., 2018). Previously published laboratory experiments have shown that these processes can influence microplastic accumulation as well (Leiser et al., 2021). Hence, estuaries have potential to act as microplastic filters decreasing their access from coastal areas to oceans. This could further decrease the water quality in the systems suffering multiole environmental problems such as eutrophication, oxygen depletion and other pollutants. However, ice cover prevents riverine fresh water mixing with the brackish estuarine waters (Salmela et al., 2022) and can hence lead to microplastic transport further to the sea. In order to understand and predict the future environmental risk posed by microplastics in these sensitive systems, it is crucial to understand the flux rates and processes controlling microplastic accumulation within estuarine systems. The monitoring campaign through two contrasting winters shows a great variation in microplastic transport and deposition patterns. Outward transport of microplastics is more pronounced during strong winter ice conditions, while open water conditions led to a more rapid accumulation of microplastics within the upper estuary. This can lead to increased microplastic concentrations at the upper estuary following the warming future winter conditions.

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Geophysical, geological and geotechnical seabed characterization for offshore construction

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Offshore wind power production is the fastest growing construction activity in the Finnish sea areas. Currently, the single Finnish offshore wind power producer is located in Tahkoluoto, Pori, three offshore wind power projects are in development and two more will launch in 2024. The developed and launching projects are all located in the Gulf of Bothnia, each covering an area of 120–220 km^2 with a planned electricity production capacity of more than 1 GW.

Seabed site characterization is a critical part of the design process, required to install turbines and cables as well as to understand environmental impacts. Current methods for characterizing near-surface seabed layers rely on extensive sediment coring and stratigraphic correlation to sub-bottom profiles from marine seismic surveys. The site investigations in the Finnish sea areas are complicated by the complex glacial and post-glacial sediment cover, which results in highly variable geometry of seabed layers and their geotechnical properties. The turbines are preferably installed on hard substrates (bedrock, till). However, cables usually need to cross areas of both hard and soft substrates (lacustrine and brackish-water muds) with differing requirements for construction.

This presentation provides an overview of currently developed and future techniques at GTK and onboard *r/v Geomari* for determining the geotechnical properties of seabed layers for construction site characterization. Free-Fall Cone Penetrometer (FF-CPT) is a cost-effective tool to replace part of the sediment coring and to provide *in-situ* quantitative information about the undrained shear strength of soft sediment layers of the seabed (Saresma et al., 2023). Multichannel seismic techniques provide a further means of deriving P-wave velocity and energy loss (Q) of seismic facies, which can be inverted to geotechnical properties such as the undrained shear strength of seabed layers. Finally, ideas for future research activities, connected to offshore wind power production, are presented.

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Stratigraphic approach to classify Quaternary deposits in Finland

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Recent developments in the geomorphological mapping and new concepts of sediment classification as well as advances in geochronological methods have led to the need to review the classification of the Finnish Quaternary glacial (mainly Pleistocene) and non-glacial (mainly Holocene) deposits. The Finnish Stratigraphy Committee's Quaternary Stratigraphy Task Group has made an overview study on the stratigraphical classification of the Quaternary sedimentary sequences and introduces the practices how the superficial Quaternary deposits are classified in Finland.

It is typical that the Quaternary glacial sediment strata in the central areas of the formerly glaciated terrains are often thin (or absent), and sediment units are limited in their lateral extent. This is also the case in Finland and more broadly in the Fennoscandian Shield area, where glacial sediment units constituting glacial landforms can be relatively thick and often glaciotectonically deformed, but their lateral extent is highly limited. In contrast, the Holocene Baltic Sea Basin sediments, overlying the glacial strata, are more widespread and continuous. Since the pre-Holocene sediment units are very limited in their lateral extent, their correlation across different areas have been difficult and therefore, a strictly formal stratigraphical approach has been challenging to carry out. Instead of applying the formal stratigraphical approach, there are many informal practices used to classify the Finnish Quaternary deposits. The use of informal stratigraphical practices has been dependent on the nature of basic or applied research foci and the availability and development of technical devices to categorise different aspects of the Quaternary sediment strata and their three-dimensional entities. The approaches to classify the Quaternary deposits have included traditional litho-, bio-, and chronostratiraphical approaches, morpholitogenetic and hydrostratigraphic, chemo- and pedostratigraphic, magneto- and seismostratigraphic and sequence- and allostratigraphic practices in addition to geochronological tools which have been used to absolute and incremental dating.

Advantages and disadvantages of the above-mentioned stratigraphical approaches will be discussed, and the stratigraphical problems related to the classification of the Finnish Quaternary deposits will be addressed.

Updated classification of the glaciofluvial deposits in GTK's map database

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Effective land use and conservation require a clear classification system of sedimentary units, with well-defined vocabulary and unified mapping practices. To ensure harmonization of GTK's map database (Putkinen et al., 2017), the mapping and classification of the glaciofluvial deposits is currently being updated. This work is based on earlier geological mapping campaigns as well as previous and ongoing LiDAR DEM based mapping of morpho-lithogenetic units (Palmu et al., 2021).

In GTK's map data hierarchy, the general class *glaciofluvial deposits* is broadly defined to include sub-, en-, and supraglacial meltwater flow deposits as well as interlinked subaquatic glaciolacustrine environments directly sourced by glaciofluvial processes (e.g., delta).

The updated classification maintains esker as the dominant glaciofluvial deposit type, which can be further divided into two subclasses: the sinuous main ridges, referred to as *esker core*, and the related lateral and frontal depositional elements, known as esker splay or *esker sand* (Lewington et al., 2020).

The *ice marginal deposits* class covers a broad range of dominantly glaciofluvial deposit types formed at or in the vicinity of the ice-margin. The subclass types include glaciotectonized ridges or zones forming the proximal parts of glaciofluvial complexes, termed as *proximal ice-contact deposits*, as well as sandurs and deltas. The subclass *sandur* is defined to cover both the extensive supra-aquatic outwash plains as well as the delta top sub-environment characterized by braided streams and sheet flood deposits. The subclass *delta* refers to the subaqueous mainly coarse-grained portion of the delta (i.e., delta foreset or delta front), whereas its distal portions (i.e., delta bottomset or pro-delta) and related, often reworked and relatively fine-grained deposits are included in the subclass *ice-marginal distal zone deposits*.

Glaciofluvial deposits that occur further away from the ice-marginal setting and are isolated or detached from the proglacial depositional systems, are classified as *extramarginal deposits*. Finally, the classification recognizes glaciofluvial deposits buried under basinal sediments as a specific deposit type.

In this poster, we provide typical LiDAR DEM examples of the main deposit types and highlight their characteristics.

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Development of 3D hydrogeological modelling workflows

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Introduction

The Geological Survey of Finland (GTK) aims to use more detailed multi-layered 3D geological/hydrostratigraphical models as a base for groundwater flow modelling. Therefore, GTK has developed the processes for converting 3D geological/hydrostratigraphical models to groundwater flow models. The HYGLO (Hydrogeology and the Global Change) project enabled usage of selected HYGLO research sites, Puukkosuo and Haaralamminkangas in Oulanka, Riku in Kangasala and Jänneniemi in Kuopio to construct 3D models and test variable workflows, for the conversion to groundwater flow models.

Two geological 3D modelling software, Groundhog and Leapfrog Geo, as well as two groundwater flow modelling GUIs, FEFLOW and GMS (MODFLOW) were selected to the workflow development and description. In addition, the software Road Doctor intended for interpretation and processing of GPR profiles, was used to describe GPR profile usage in 3D modelling. Three of the described sites, Riku, Haaralamminkangas and Jänneniemi represent aquifers in glaciofluvial sediments and one, Puukkosuo, is a fen.

Workflows and their implications

The workflows include Groundhog – FEFLOW track (Riku), Groundhog – GMS track (Riku), and Leapfrog – GMS track (Oulanka and Jänneniemi). In addition, the Puukkosuo site was used to test the workflow between Road Doctor and Leapfrog.

As a 3D geological modelling software, Groundhog is easy-to use and suitable for scattered and non-continuous units commonly occurring boreal formerly glaciated areas. However, in Groundhog, the visualization is limited and synthetic 2D profiles requires attention with the depths of the units. The modeller should be careful when generating esker flanks since the interpolation can cause undulating contacts.

In boreal formerly glaciated areas, Leapfrog is suggested to use in sites with dense drilling network and geophysics and if the visualization plays pivotal role in the usage. In Leapfrog modelling, the modeler must be careful since the contact surface which defines upper or lower boundary of geological units must be edited as a whole, even parts that does not form the actual unit as Leapfrog uses set operations approach (cf. Lemon and Jones 2003). The velocity-corrected interphases of GPR profiles from Road Doctor, were easy to use in Leapfrog as unit boundaries, but required filtering/selection to get desired geometry.

The constructed 3D geological models (Groundhog and Leapfrog) were converted to groundwater flow grids. As a simplicity full layered grids were used in the groundwater flow models. GIS software was used to construct continuous layers to the groundwater flow models as the Groundhog and Leapfrog derived 3D models consisted of non-continuous units. In FELOW, being a finite-element grid-based model, layers on top and bottom the groundwater well screen must be added, which could be considered already in 3D modelling. The results of the groundwater flow models can be used to evaluate and reconstruct the 3D geological/hydrostratigrahic model.

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HYGLO Water Oriented Living Lab

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Geological Survey of Finland (GTK) has established a network of hydrogeological test sites accepted for new EU Water Oriented Living Lab (WoLL) Atlas 2024 based on the evaluation of Water Europe. WoLLs are defined as real-life, water-oriented demo-type and platform-type environments of a cross-sector nexus approach (Water Europe 2019). HYGLO WoLL consists of 10 test sites (Fig. 1), which have been established into different geological environments in Finland during last 3 years in HYGLO (Hydrogeology and Global Change) project of GTK (Hyvärinen 2023).

HYGLO WoLL supports the studies in management of water resources, groundwater-surface water interaction, groundwater in carbon cycle, sedimentary aquifer – bedrock aquifer interface, managed aquifer recharge, mining environment, pristine environment etc. Long term focus of the HYGLO WoLL is in hydrogeology and global change in subarctic and arctic environments – to establish research platforms to study phenomes connected to global change such as flooding, draughts, extreme events, changes in snow cover and groundwater recharge.

Hydrogeology and hydrogeochemistry of all sites have been studied and conceptual or numerical 3D hydrogeological model has or will be constructed. Numerical flow modelling using climate change scenarios, transport modelling as well as risk and vulnerability assessment will be performed in some of the sites.

All sites are equipped with observation wells, CTD sensors, multiparameter sensors, and some of the sites with weather stations and soil moisture stations, as well. Continuous data will be collected by LoRaWAN-telemetry and shared with partners and stakeholders. In addition, groundwater samples will be taken for chemical analyses at least twice a year. Part of the data will be shared, harmonized and analysed in ongoing European wide GSEU project and used in forthcoming EGDI maps.

GTK has committed to maintain the HYGLO WoLL sites and will have separate agreements with local partners. In four of the sites, partners are water companies representing local governance, in three sites university and /or their research station, in some cases company, municipality, regional governmental agency or governmental institute and in one case local outdoor association representing citizens.

HYGLO WoLL can offer case study sites into the national and international research proposals and projects. We hope, that in future, existing and forthcoming partners and collaborators will develop the HYGLO WoLL sites together with GTK.

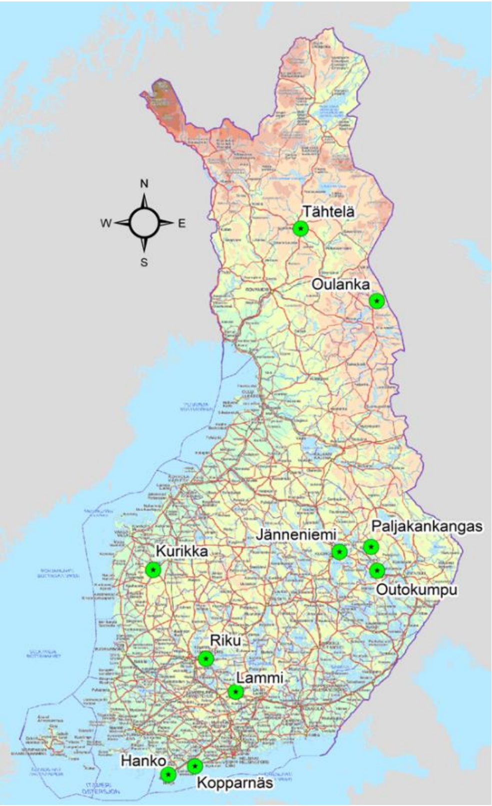

Figure 1. HYGLO WoLL sites of the Geological Survey of Finland. Basemap: Topographic map © the National Land Survey of Finland (7/2023).

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Recent increase in carbon accumulation in Finnish lake sediments and the role of catchment land use

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Lakes are active environments in the global carbon cycle, where terrestrially derived organic carbon (OC) from the surrounding catchment and *in situ* produced OC can either pass through system, escape to the atmosphere as CO_2 or be stored in the sediments. Sediment carbon burial is the only mechanism that locks carbon away from the biogeochemical cycles for geological timescales. Due to high number of lakes in boreal areas such as Finland, lakes host a large pool or carbon, making lake sediments a potentially significant, permanent carbon sink. While estimates of carbon accumulation rates over the past few millennia in Finnish lakes have been made, several studies around the world have reported increases in both carbon availability and burial rates in the recent past. Our goal is to calculate modern (post 1986) rates of carbon accumulation across a variety of Finnish lakes, and to identify potential drivers and controls of modern carbon burial.

Using ^{137}Cs dating and C/N analysis, we calculated the post year 1986 carbon accumulation rates from lake sediment cores collected from 220 individual lakes in southern and central Finland. The linkages between carbon accumulation rates, lake morphometry and catchment land use were investigated.

Our results show that the rate of modern carbon accumulation in lake sediments has increased since mid-Holocene and is linked to the rate of sediment mass accumulation and land use. The highest rates of carbon accumulation were generally measured in lakes where the catchment area comprises of higher amounts of wetlands and agricultural land. However, in relation to the rate of sediment accumulation, the burial rate of carbon was proportionally higher in smaller, shallow lakes with elevated C:N ratios and lesser amounts of agricultural activity in the catchment area. Our results suggest potential preferential remineralization of fresh autochthonous, algal OC and preferential deposition and permanent burial of allochthonous, terrigenously derived OC, making the lakes in forested catchment areas especially important sedimentary carbon sinks.

Geochemical signals from biogenic varves reflect hydroclimate and lake mixing conditions in central Finland

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Annually laminated (varved) lacustrine sediments are sensitive recorders of climatic-induced variability in the catchment. In a Boreal setting, climatic information is usually extracted from clastic-biogenic varves, although the potential of biogenic varves remains almost unexplored. The organic-rich sublayers of Boreal biogenic varves usually include thicker growing season lamina enriched with amorphous organic matter and thinner winter lamina reinforced with fine-grained organic matter settled under ice cover during the winter season. This study explores the properties and controls of varve formation in Lake Kallio-Kourujärvi and their implications in understanding past hydroclimate and lake oxygen conditions using micro-XRF combined with stable carbon and nitrogen isotope analysis. Lake Kallio-Kourujärvi is located in central Finland and has organic-rich varves. The thickness of these varves is controlled by the accumulation of biogenic matter that originates from terrestrial sources and autochthonous production. The varve counting provides an age estimate for the 1,8 m long varved sediment sequence of approximately 3700 years before the present (BP). The results from major elemental data reveal that changes in iron and sulfur are consistent with the varve thickness data previously shown to be sensitive for precipitation, as well as decadal changes in North Atlantic Oscillations (NAO) forced winter precipitation. Positive NAO results in higher winter laminae thickness and increased deposition of Sulphur (figure 1) possibly due to enhanced contribution from groundwater source. Precipitation likely increases the transport of soluble Iron(II) from the catchment, which settles into sediment as particulate Iron(III) after being oxidised in the water column. DurinStrong changes in redox conditions by the elements iron, manganese, and sulphur are indicated between around 1600 BP and 3700 BP. The variation of redox-sensitive elements suggests that changes in hydroclimatic conditions and past water mixing conditions can be reconstructed from the biogenic varve records.

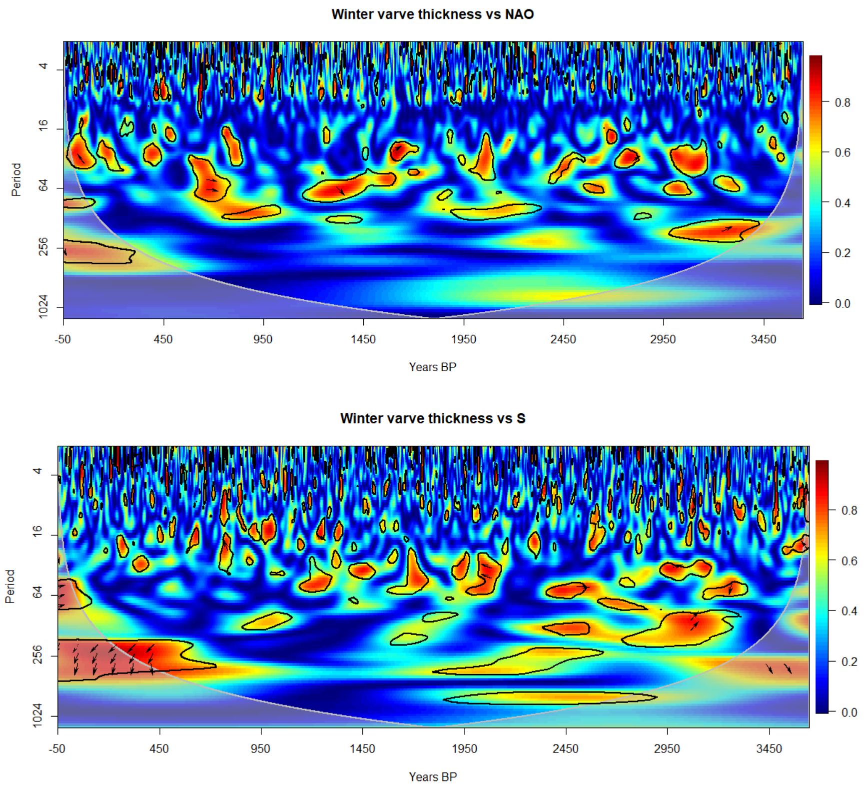

Figure 1: Wavelet analysis of winter varve thickness and NAO (top) and winter varve thickness and sulphur.

Effects of organic ligands on the structure, colloidal properties and PO_4 uptake of Fe oxidation products

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The oxidation of dissolved Fe(II) in natural waters leads to the precipitation of amorphous to poorly-crystalline Fe(III)-solids that can sequester dissolved phosphate (PO_4) and other nutrients or contaminants (Senn et al, 2015). In addition to inorganic solutes, also dissolved organic matter (DOM) can strongly affect the structure, transformation, colloidal properties, and PO_4 binding of Fe(III)-precipitates (Vindedahl et al., 2016).

For an improved understanding of the fate of PO_4 in aquatic environments, there is a need for a mechanistic insights into the effects of DOM on Fe(III)-precipitate formation at natural redox interfaces and consequences for PO_4 and organic carbon (OC) sequestration. In this laboratory study, we examined the effects of model organic ligands (citrate, 3,4-dihydroxybenzoate (3,4-DHB), galacturonate, 2,4-dihydroxybenzoate (2,4-DHB), humate) on the formation and transformation of Fe(III)-precipitates in bicarbonate-buffered aqueous solutions at two PO_4 levels, with either Na or Ca as electrolyte cation. Changes in the structure and colloidal properties of the precipitates were probed with spectroscopic and microscopic techniques and related to changes in PO_4 retention.

The Fe(III)-precipitates formed in OC-free control experiments were mixtures of amorphous Fe(III)-phosphate and poorly-crystalline lepidocrocite. Increasing organic ligand concentrations led to less (and less crystalline) lepidocrocite and increasing ferrihydrite formation, resulting in more effective PO_4 and OC binding. In the Na electrolyte, above a certain concentration, strongly binding ligands effectively stabilized colloidal Fe(III) or complexed Fe(III), and thereby limited PO_4 removal. In the presence of Ca, these effects were strongly attenuated, leading to singificantly higher PO_4 and OC retention by filterable solids. The effects of the organic ligands decreased in the order citrate > 3,4-dihydroxybenzoate > galacturonate > 2,4-dihydroxybenzoate ≥ humate; along with decreasing strenght of Fe(III)-ligand complexation.

In conclusion, organic ligands can enhance the co-precipitation and retention of PO_4 and OC with Fe(III) at redox-interfaces via their effect on the structure of the Fe(III)-precipitates. On the other hand, organic ligands can also lead to more negatively charged and colloidally more stable Fe(III)-precipitates, and thereby enhance the transport of PO_4 and OC in environmental systems in colloidal form.

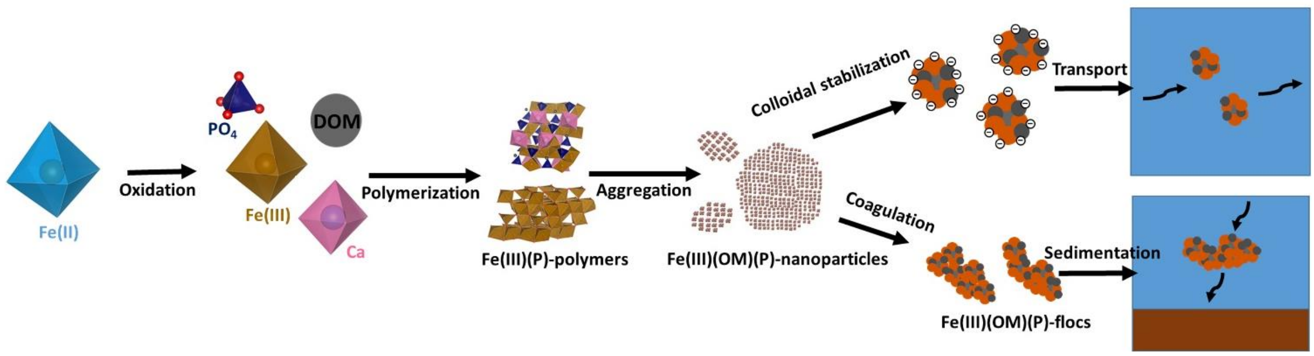

Figure 1. A schematic of Fe(III)-phosphate co-precipitate formation in the presence of Ca and dissolved organic matter.

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An accelerated incubation method for the identification of acid sulfate soils

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Large areas of sulfide bearing sediments are worldwide located along deltas, coastal plains, and inland settings and if exposed to oxidation, these sediments will commonly become very acidic and develop to acid sulfate (AS) soils (pH <4 for mineral soils and <3 for organic soils). These sediments pose a great threat to their surrounding aquatic environment (e.g., reoccurring large fish kills) and construction work (e.g., high corrosion risk) if disturbed. Finland has the largest surface area of sulfide bearing sediments. They were deposited in the former Baltic Sea and are today found in coastal areas up to 100 m above the current sea level due to strong post glacial land uplift. In Finland acid sulfate soils are the largest source of many potentially toxic metals to the water courses including the estuaries. Thus, management techniques to minimize these hazards are important but rely above all on a correct identification of AS soil materials in an early stage when they still are in a reduced and harmless form. The incubation pH method is one of the most preferred, reliable, and easy used AS soil identification method, and simulates the natural oxidation behaviour of possible existing sulfidic materials by letting a wet soil sample oxidise in room temperature for a maximum of 19 weeks. An AS soil is identified if the amount of acidity produced during soil oxidation exceeds its acid-neutralizing capacity and thereby lowers the mineral/organic soil pH to <4/3. An identification duration of 19 weeks is, however, in many cases considered as to time-consuming and the main goal in this study was to further develop and improve the incubation method in such a manner, that the outcome would be a substantially reduced incubation time. To ensure the usability of the method, different type (e.g., grain sizes, sulfur concentrations, sample locations and sample depths) of known well homogenized sulfidic soil materials were chosen along the Finnish coastline. The intention was to increase the oxidation/acidification rate and, thus, decrease the time needed for incubation. Enhanced oxygen availability was trialed by optimising the soil sample thickness (alternatives tried were 2 mm, 5 mm, and 10 mm thick samples) and by stirring the samples during the incubation three times per week. Temperature dependency on the microbiologically mediated oxidation was trialed at different temperatures (in 4 °C, 22 °C, 30 °C, 40 °C and 50 °C). In addition, trials were made to quick start the microbiologically mediated oxidation by "doping" samples with microbes from previously oxidized samples. Another quick start "doping" agent tested was ozonated water. In all trials, pH was measured three times per week. The incubation time was significantly reduced (generally by at least 50%) by optimising the sample thickness to 2 mm and adding heat to 30-40 °C. The incubation time was in mineral soil samples additionally reduced by stirring the sample, i.e., by increasing the air penetration. Potential mineral acid sulfate soils (i.e., hypersulfidic mineral soils) could by that already be identified in an average of 3 weeks and potential peat samples (i.e., hypersulfidic organic soils) in an average of 4 weeks. For most of the mineral soil samples an incubation time of ≤2 weeks was enough to identify AS soils, but in clay-rich material (clay >50%) the incubation time was prolonged to 5 weeks. Conclusionary, results suggest that the accelerated incubation method enables reliable identification of AS soil materials in a maximum incubation time of 5 weeks.

Giant saline water inflow in AD 1951 triggered the Baltic Sea hypoxia

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Introduction

A marked sedimentological change in subsurface sediments from the entire Baltic Proper, the Baltic Sea, has been previously observed.

We have studied this seabed change using acoustic profiling, hydrographic instrumental monitoring (AD 1950-2021) data (near-bottom-water parameters: oxygen, salinity and temperature) and sediment core data like artificial radionuclide (^{137}Cs, ^{241}Am), the total carbon (TC) and total inorganic carbon (TIC) contents, XRF scanning data (e.g., Mn, Ca, K), and benthic foraminifer counting.

Sudden environmental change due to giant saline water inflow AD 1951

The results of our studies of sediment cores from basin-wide transects indicate (Moros et al. 2024) that this sedimentological change was caused by large hydrographic and environmental changes that started at the end of the Little Ice Age (LIA) (~ AD 1850) and were accelerated by a rapid change in water column stratification resulting from the giant saline water inflow from the North Sea into the Baltic Sea basin in AD 1951.

On a longer timescale, winter-time deep-water convection gradually weakened due to the warming of the atmosphere and ocean after the end of the LIA, but still contributed to complete ventilation of bottom water of the entire Baltic Proper, while currents prevented accumulation and even eroded seabed sediments above a water depths of ca. 150-160 m until the early 1950's. The hydrographic conditions changed markedly with the giant saline water inflow AD 1951. The accompanied increase in stratification caused a collapse of the already weakened vertical convection, leading to hypoxia in the bottom waters, which in turn forced a sudden phosphate release from the sediments (i.e., internal loading) and increased primary production in the late 1950s, in addition to the increased anthropogenic nutrient loading.

The sharp sedimentological boundary reflects this sudden environmental change, with the convection collapse the delivery of fine-grained re-worked material to the subbasins stopped, the base (depth) of sediment re-suspension shifted upwards and much calmer conditions prevailed also in shallower water depths until today. This enabled from the late 1950s onwards the accumulation of organic carbon-rich sediments also at water depths between 150 and ca. 60–70 m. The recent limit of sediment resuspension at a water depth of ca. 60–70 m marks the modern winter-time mixing depth.

The speed (<10 years) of the seabed change triggered by external forcing (temperature and stratification) and accelerated by internal processes is remarkable. The combined effect of stratification and temperature changes seems to have played a stronger role than previously thought.

Our study also indicates that the environmental and depositional conditions, and the degree of oxygenation in the deep basins, essentially did not change during the last ~70 years, except momentarily in some basins the oxygen situation improved for a short time, e.g., after the major salt water inflows of 1993, 2003 and 2014. Furthermore, those conditions will probably not change soon as under modern climatic conditions the main contributor of phosphorous to the ecosystem will be the seabed sediments and the anthropogenic nutrient loading. Summing up the effects of climate change, major saline water inflows to the Baltic Sea and anthropogenic nutrient loading; nutrient loads, among others, need to be further reduced in the future.

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Holocene deoxygenation history in the coastal Bothnian Sea with magnetic greigite as a proxy for hypoxia

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Introduction

Bottom water oxygen depletion, hypoxia, causes severe ecosystem disturbance in the water basin and forms sulphide sediments. When these sediments are uplifted above sea level, they become acid sulphate soils known to cause societal, financial, and environmental harm. In 2018, the central Baltic Sea was determined to contain one of the largest hypoxic zones in the world (Fennel & Testa, 2018), and during the past decades, increasing hypoxic conditions have been obtained also in the coastal zone (Conley et al., 2011). While the Holocene development of repeated hypoxia in the Baltic Sea basin is well studied in multiple Central and Southern Baltic deep-sea cores, less is known about the development of the coastal zone during the Holocene thermal maximum (HTM). Understanding the driving forces for coastal hypoxia during HTM is topical, providing an analogy for assessing future development of hypoxia in a warming climate and thus, the future formation of sulphide sediments.

Forming in oxygen deficient environments in sulfidic and methanic redox zones, a magnetic iron sulphide greigite (Fe_3S_4) has the potential to act as an environmental indicator and aid in environmental reconstructions (Li et al. 2019, Ebert et al. 2020, Chen et al. 2021). Understanding the origin, presence, and behaviour of greigite in sedimentary environments can be used in reconstructing past environmental conditions, including periods of hypoxia (Roberts et al. 2015, Roberts et al. 2018).

Oxygen depletion in the Bothnian coast

A high resolution (0.65 cm/a) 40-m long sediment core from coastal Bothnian Sea (Kurikka, S. Ostrobothnia, Finland) was analysed with lithological and environmental magnetic methods. This core covers local deglaciation and basin evolution from a freshwater to brackish phase until isolation from the sea (~10.8–4.5 ka BP). Environmental magnetic methods and occurrence of greigite was used to assess hypoxia variation along the sediment sequence.

Results indicate that hypoxia was common, but frequently interrupted during the HTM in the shallowing coastal Bothnian Sea. Two multicentennial predominantly hypoxic periods and two intensive decadal hypoxic events are observed with more regular oxic conditions in between. However, the greigite concentrations are variable throughout the hypoxic interval, indicating unstable oxygen conditions and perennial trends in hypoxia intensity. The pattern seen in Kurikka record corresponds with the description of a multicentennial nature of hypoxia variability in the Baltic Sea with oscillating intensity (Zillen et al., 2008; Jilbert & Slomp, 2013; Carstensen et al., 2014), suggesting basin-wide regularity and drivers of hypoxia.

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Deciphering trace metal covariation patterns in coastal marine sediments using correlation matrices

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Human activities since the 19th century have led to a drastic increase in excess trace metal deposition in many coastal sediments. Provided that these sedimentary trace metals have remained relatively immobile after deposition, they can provide a record of the local–intercontinental pollution history. Factors controlling this proxy potential are the trace metal's geochemistry (e.g., particle- and host phase affinity), and depositional environmental factors (e.g., bathymetry, organic matter loading, particulate shuttling, bioturbation, redox variability). Yet, the relative importance and interactions between these controls are still poorly understood for many coastal environments, hampering the reliable use of trace metal as proxies for environmental change.

Here we use correlation matrices of sedimentary enrichments of 16 metal(loids) (Pb, Cd, Cu, Zn, Sb, Sn, Ni, As, Tl, V, Mo, U, Re, Fe, Mn, Al) and two non-metals (S and total organic carbon), supplemented by total solid phase ranges and sediment profiles to investigate the role of trace metal- and site-specific factors in controlling metal sequestration across nine contrasting study sites (variable basin restriction, salinity, distance from shore, water depth, redox condition).

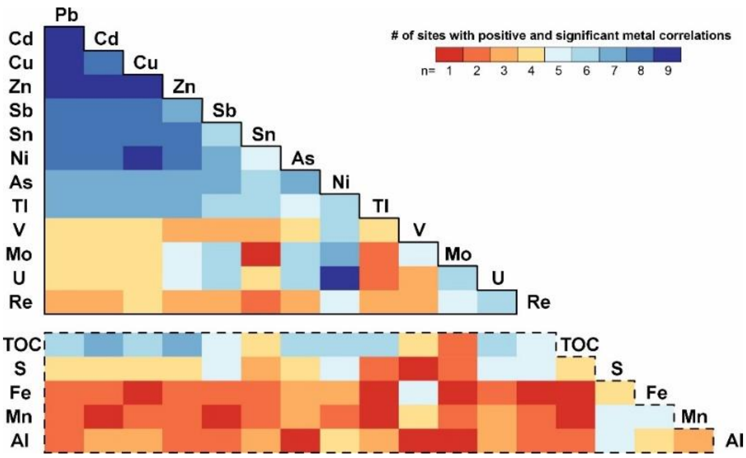

Figure 1. Summed correlation matrix of sedimentary trace metals ranked after Pb. The colours correspond to the number of study sites (1–9) that have a positive and significant correlation for a given element, whereby 9 is the maximum (= nine sites) and 1 the minimum (= one site). The dashed border highlights trace metal-host phases correlations (organic matter compounds = TOC, sulfides = S, Fe-/Mn (oxy)(hydr)oxides = Fe and Mn, and silicates/clay minerals = Al).

Summed trace metal correlations show site-wide positive correlations of Pb, Cd, Zn and Cu (Fig. 1), suggesting generally little overprinting by depositional environmental factors for these elements and hinting at a primary control of anthropogenic drivers (e.g., similar sources and loading history). However, Zn, Cd, Cu (and Sb, Ni, and As) also show covariation with the redox-sensitive trace metals and (paleo)-redox proxies Mo and U (Paul et al., 2023a, b), implying that primary anthropogenic signals stored in these enrichments may be partially obscured by redox variability. Therefore, Pb appears to be the most robust pollution indicator of the metals investigated.

Our findings demonstrate that correlation matrices provide a useful method for quickly investigating co-variability of trace metal enrichments, and thus geochemical behaviour, in different coastal sedimentary environments. However, we caution against generalization of correlation patterns in a broader context, without additional consideration of e.g., total elemental ranges and sediment profiles when investigating trace metal sequestration mechanisms in more dynamic redox environments.

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Investigating late-stage fracture minerals beneath the Baltic Sea near Olkiluoto, Finland

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Introduction

To enhance our understanding of the paleohydrogeological evolution in crystalline bedrock, fracture mineral samples were collected for geochemical, isotope geochemical, and mineralogical investigations from drill cores OL-KR58 and OL-KR58B, which were drilled beneath the Baltic Sea near Olkiluoto Island in southwest Finland. The results of this study were then compared to those obtained from the repository site for spent nuclear fuel at Olkiluoto. Unlike the groundwaters at Olkiluoto Island, the hydrological conditions at the OL-KR58 and OL-KR58B are considered to be stable without the local pressure field from Olkiluoto Island, and therefore, meteoric freshwater did not infiltrate the shallow depths beneath the seafloor during the Holocene Epoch. The lack of influence of modern-day precipitation enables the detection of a previously only indirectly observed signal of the earlier Littorina Sea stage of the Baltic Sea from the fracture minerals. The migration of a redox front between methanic and sulfidic environments has been demonstrated by the records of $\delta^{13}C$ in calcite and $\delta^{34}S$ in coexisting pyrite (Sahlstedt et al. 2013; 2016). The latest occurrence of natural low-temperature pyrite formation probably happened during the Holocene period when brackish, sulfate-rich waters from the Litorina Sea infiltrated the fracture network, providing substrate for sulfate-reducing bacteria.

Sample selection and analysis

Samples were collected from fracture systems that were open to fluid circulation at a depth range of 11 to 1174 meters below the sea level. The main focus of the collection was on calcite and associated pyrite samples gathered from the top 60 meters of the drill core. The fracture mineral samples were composed mainly of calcite, which was almost pure $CaCO_3$, with a minor amount of Mn. The latest calcite generations identified with CL-imaging were of special interest. The isotopic composition of fracture-filling calcite and pyrite was analysed in situ with a secondary ion mass spectrometer (SIMS), the content of trace elements was determined by wavelength-dispersive electron probe microanalysis (EPMA), and one sample from the latest calcite generation was carbon-14 dated using the Accelerator Mass Spectrometry (AMS) method.

Results and discussion

The $\delta^{13}C$ and $\delta^{18}O$ values of fracture calcite ranged from -25.8 to +7.9 ‰ and -18.4 to -4.7 ‰ (VPDB), respectively. The $\delta^{34}S$ values of pyrite associated with calcite fillings ranged from -8.2 to +27.9 ‰ (VCDT). The isotopic composition of most calcite fillings imply low-temperature equilibrium with waters similar to the present-day precipitation in the area. However, calcite fillings at the uppermost 60 m contained a calcite generation enriched in ^{18}O.

The presence of high $\delta^{18}O$ values of calcite, reaching up to -4.7 ‰ in the upper ~60 m of the bedrock, indicates that the precipitation occurred in the presence of the pure end-member composition inferred for the Littorina Sea water. This is also supported by the ^{14}C age of this calcite generation, which is less than 10,000 years.

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New results of the platinum group mineral nuggets in the Finnish Lapland

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Introduction

Platinum group mineral (PGM) nuggets have been excavated from gold panning areas as a side product in Finnish Lapland. Source of these nuggets and their genesis are still poorly understood. This project focused on detailed mineralogical study for these nuggets in order to reveal their mineral paragenesis and favourable source rocks. Most important PGM's are isoferroplatinum and Sperrylite. The aim of this study was to analyse inclusions and surface from isoferroplatinum and make conclusions concerning their genesis. The mineralogy and compositions of the inclusion will be compared with platinum group element (PGE) deposits worldwide.

Samples were collectet from Lemmenjoki, Ivalojoki and Tankavaara-Mäkärä-Roivainen gold panning areas from local gold panners. Polished sections were prepared from the samples and a total of 50 platinum group mineral grains were examined by Zeiss Ultra Plus field emission scanning electron microscope (FESEM). The analyses were carried out on the energy dispersive spectrometer (EDS) of the instrument and the interpretation was performed by calculating the ionic ratios of the mineral from the analysis. A total of 1000 inclusions were analysed. Electron backscatter diffraction technique combined with EDS (EBSD-EDS) was employed using JEOL JSM-7900F FESEM equipped with Oxford instruments Symmetry EBSD and Oxford EDS detector. Combined EBSD-EDS mapping were carried from 10 nuggets.

22 different PGM minerals and alloys were found in the samples. The most common inclusions were Ru-Os disulphides laurite and erlichmanite, which form zonal inclusions within the isoferroplatinum, followed by PGE-sulfarsenides with irarsite being the most common. Rhodarsenide, hollingworthite occur as a smaller inclusions in the ruthenium alloys and irarsite. Ru-Os-Ir alloys occur as small inclusions in the grain interiors, some of which formed crystallographically oriented exsolutions. From the thiospinelli group, cuproiridsite-malanite occurs in grain boundaries and as inclusions. Pt-Pd-Au-Cu mixtures appeared as their own grains. Pt-Fe-Cu mixtures appeared as inclusions and at the margin of isoferroplatinum, in addition, one grain contained an unnamed Pt2Cu mineral surrounded by hongshiite. Base metal sulphides cubanite, pyrrhotite and chalcopyrite were present in one isoferroplatinum nugget. Isoferroplatinum nuggets contained silicate inclusions. Most common inclusions were quartz, plagioclase, kaolinite. Some multiphase silicate inclusions were also observed.Detailed investigations from isoferroplatinum surface revealed weathering products from primary minerals. EBSD mapping revealed that most of nuggets are monocrystalline.

We suggest that the Os-Ir-Ru alloys, laurite-erichmanite minerals were formed magmatically at high temperature. As the temperature decreased, crystallographically oriented cuproiridsite, kashinite exolutions formed. During later magmatic and hydrothermal events, PGE-sulfarsenides, atokite, cooperite and speryllite inclusions were developed. Nuggets were affected by weathering processes which formed secondary platinum, kaolinite and rutile in surface.

Potential sources for isoferroplatinum nuggets may be Ophiolitic source, Ural-Alaska type intrusions or Layered Intrusions. The ruthenium-rich grains indicate an Ophiolite source and the sulphide-poor ones a Ural-Alaska type intrusion. The source of speryllite grains may be Ni-Cu-PGE deposit or a layered intrusion. The most favourable rock types for the deposits are located in the Tenojoki-belt outside the granulite belt.

Regional-scale prospectivity analysis of northern Finland for CRMs hosted in ultramafic-mafic orthomagmatic deposits

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Metals such as nickel (Ni), cobalt (Co), platinum group metals (PGMs), vanadium (V), and copper (Cu) are termed either critical raw materials (CRMs) or strategic raw materials by the European Union due to rising projected demand in modern industrial value chains in strategic and environmentally friendly industries and potential short supply (European Commission, 2023). Therefore, it is crucial to be self-reliant and produce such raw materials locally. The SEMACRET project aims to develop responsible exploration techniques for such CRMs to ensure a consistent supply for the transition to green energy.

Northern Finland is known to host the above-listed CRMs in ultramafic- mafic intrusions of two sub-types: conduit-type, sulphide-rich Ni-Cu-(PGM)-(Co) deposits and layered mafic intrusion type, relatively sulphide-poor PGM-Cr-V-(Co)-(Ni)-(Cu) deposits. This study describes computer-based prospectivity analyses for both these deposit types using Fuzzy Inference Systems (FIS), a supervised, knowledge-based symbolic artificial intelligence technique. The multi-stage FIS used in the study rely on generalised conceptual mineral systems models for each of the two deposit types. These mineral systems models are also used to identify the targeting criteria for the two deposit types. The main components of the conduit-type mineral system include (1) Primitive, mantle-derived, magnesium-rich rocks (ultramafic and mafic rocks), which are the primary source of metal; (2) trans-lithospheric faults and chonoliths that serve as pathways of magma, locally enhanced by varying compressional/extensional tectonic regimes; and (3) dilatational zones of high, fracture-related permeability and localised structures that act as physical traps; along with abundant sulphur-rich crustal rocks that can provide the external sulphur required to form immiscible sulphide melts (Cawthorn et al., 2005; Maier, 2005; Maier and Groves, 2011; Joly et al., 2015). The mineral systems model of the layered mafic intrusion type deposits differs only in the third: traps component, wherein the magma is trapped within the cratonic lithosphere as large magma chambers, forming a layered sequence of ultramafic to mafic rocks due to fractional crystallisation under low regional stress and limited magma-induced sagging. Mineralisation occurs as contact style (or marginal type at the base of the intrusion) and reef type between the lower ultramafic zone and the upper mafic zone and among mafic rocks (Cawthorn et al., 2005; Maier, 2005; Maier and Groves, 2011).

Targeting criteria representing the crucial processes of the respective mineral system were mapped using their spatial proxies from various geoscientific datasets. They were then represented as GIS predictor maps, derived using spatial analyses and geoprocessing tools. New innovative predictor maps have been attempted in this study. The predictor maps of the two mineral systems were integrated into their respective multi-stage FIS structured on their mineral systems model to obtain the prospectivity maps. The resultant prospectivity maps show good agreement with their respective deposits. Remarkably, despite the two mineral systems being broadly similar, the prospectivity models can distinguish between the two types and demarcate promising regions for further detailed exploration.

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From the mantle source to crustal sink: petrogenesis and sulphide saturation of the Central Lapland Greenstone Belt komatiites, Finland

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In northern Finland, the Central Lapland Greenstone Belt (CLGB) hosts widespread komatiites that formed ca. 2.05 Ga. The CLGB komatiites erupted mostly underwater on a sedimentary basin containing abundant sulphur-rich rocks. The komatiites are spatiotemporally and possibly genetically linked with the Kevitsa and Sakatti Cu-Ni(-PGE) deposits, which formed as the magmas assimilated the sulphur-rich crustal rocks. To help identifying chemical signs of assimilation-induced sulphide saturation in the natural rock record, we conducted computational simulations to constrain the komatiite petrogenesis from the mantle source to crustal sink. We calculated the parental melt composition (major elements, Ni, Cu, and REE) by adding olivine ("reversed fractional crystallization") to a chilled margin of a komatiitic dyke until the melt was in equilibrium with Fo_{92} olivine. We used REEBOX PRO together with data from mantle melting experiments to show that 15–20 wt.% melting of a pyrolytic mantle source is sufficient to generate the parental melt. Using the parental melt composition and the pressure-temperature conditions in the mantle, we calculated maximum sulphur solubility and constrained initial sulphur content of the parental melt to 750–1172 ppm. The estimated range in sulphur content is compatible with chromite melt inclusion data from the CLGB komatiites.

We simulated closed-system fractionation of the komatiitic parental melt (MgO = 20.6 wt.%) at crustal conditions using Magma Chamber Simulator. To evaluate the simulation results, we compiled a whole-rock and olivine chemistry database from literature and supplemented it with new whole-rock data of komatiites from Sattasvaara area of the CLGB. The CLGB komatiite data is largely compatible with closed-system fractionation of a single parental melt composition. The natural rocks represent either melt compositions or mixtures between melt and accumulated olivine ± Cr-spinel. Our simulations reproduce the most Ni-rich olivine compositions from Kevitsa and Sakatti and the slight variation can be explained as variable amounts of orthopyroxene fractionation in lower crustal level. Some olivine grains from Kevitsa and Sakatti have lower Ni content than predicted by the simulation, which we interpret as a sign of crystallization from a melt that had reached sulphide saturation (sulphides scavenge Ni causing the observed depletion in olivine). Depending on the initial sulphur content, the komatiite can precipitate Ni-rich (Ni/Cu = 1.9) or Cu-rich (Ni/Cu = 0.4) sulphides upon closed-system fractionation. The simulation results can be used as a baseline to identify chemical signs of early sulphide saturation in the CLGB komatiites and related intrusive rocks.

Age determination of Au-precipitating fluid activity in SW Finland

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Introduction

One of the cornerstones of mineral exploration is the understanding of ore genesis with respect to the regional geological evolution. This is challenging in extensively deformed Precambrian terrains such as in southern Finland, where increasing number of gold and other metal occurrences, prospects and mines (e.g., Eilu, 2012; Tiainen et al., 2017) has caused a growing interest in exploration. However, the basic knowledge of the age of the ore forming events, fluid activity, host rock features and the spatial correlation of the mineralisations within different geological domains are still obscure (e.g., Tiainen et al., 2017; Kara et al., 2021). Petrologically controlled monazite, xenotime and titanite U-Pb age determination on thin section is a powerful tool determining the age of fluid activity events in orogenic gold deposits (e.g., Fielding et al., 2017; Molnar et al., 2018). This method has not yet been tested in the ore deposits in SW Finland. We have sampled several gold occurrences in SW Finland. After thin section preparation and SEM imagining, we performed multimineral U-Pb age determinations on monazite, titanite, zircon and garnet, which allow us to study multiple geological processes behind the ore formation in high precision. The SEM and U-Pb analyses were performed in the Finnish Geosciences Research Laboratory at the Geological Survey of Finland in Espoo.

Results and discussion

The titanites from the Haveri Au-Cu deposit in the Tampere belt show two types of textural variation: i) separately occurring euhedral grains and ii) anhedral vague grains, which occur as clusters and are usually in contact with sulphides. These two populations yield U-Pb ages of c. 1885 Ma and c. 1830 Ma, respectively. The older age is suggested to represent the metamorphic peak in the Tampere belt, whereas the younger age represent the age of the fluid activity. The zircons from the Kultakallio Au-occurrence from the Pirkanmaa belt yield three age populations at c. 1885 Ma, c. 1860 Ma and c. 1805 Ma. These can be correlated to zircon (c. 1885 Ma) and monazite (c. 1805 Ma) U-Pb ages of the nearby Välimäki Au-occurrence. The youngest ages in both locations are correlated to the younger cross-cutting quartz veins so the ages are suggested to represent the age of the hydrothermal activity. Also, the garnet U-Pb age determination was tested on Kultakallio, which yielded a reasonable age of c. 1815 Ma. The error limits of the garnet age, however, are huge making the age uncertain. Titanite U-Pb ages, from hydrothermal titanites associated with sulphides, confirm the age of the Au-precipitation within the Satulinmäki Au-deposit in the Häme belt at c. 1795 Ma. A similar age has been previously suggested by Saalmann et al. (2009).

The age data suggest that fluid activity took place and ceased slightly earlier in the north compared to south. Within the Tampere belt gold precipitation/remobilization took place at c. 1830 Ma, within the Pirkanmaa belt at c. 1810–1800 Ma and within the Häme belt at c. 1800–1790 Ma. These events can be correlated with the emplacement of gold-critical quartz veins.

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Snow geochemistry as a mineral exploration tool – Example from Saramäki Cu-Co-Zn deposit, eastern Finland

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One of the newest sample materials used in mineral exploration is snow. Exogenic geochemical signal formed into the snow can be used in analysis of the elemental composition of underlying bedrock and tracing the potential mineralizations in the bedrock (e.g., Taivalkoski et al. 2019). The method is based on the so-called Mobile Metal Ion (MMI) theory, in which metal ions from mineralisation in the bedrock migrate through the surficial part of the bedrock and transported cover. In summer, metal ions accumulate in the surficial soil horizons although some part continue migration into the air together with carbon dioxide and water vapour as well as various volatile hydrocarbons. Even in winter, the movement continues, but the gases and ions accumulate in the bottom layers of snow cover (in the areas where snow cover exists), where they adhere and bind to snow crystals.

The lower part of the snow cover serves as the best ion binding layer, since the geochemical signal accumulation time is the longest, and the upper layers of snow protect against atmospheric contamination during the winter. In addition, the lowest layer is in contact with the ground and is affected by gases and heat from the underlying soil and bedrock. In the northern regions, snow covers the ground surface for several months a year, so the method is usable on moderately large areas of the Northern Hemisphere and mountainous areas. Snowfall and snow properties are regionally constant, which provides a good basis for extensive and comparable geochemical exploration.

During the winter 2022-2023 snow geochemistry was tested in a sulfide Cu-Co-Zn mineralization in Saramäki, eastern Finland. The mineralisation is a fault-controlled, hydrothermally altered, vein-type and/or VMS-type deposit which is within ultramafic rocks related to the Outokumpu association (GTK 2024). The deposit has small suboutcrop under till cover, but the main body (thickness 5-15 m) is dipping towards east in 25^{o} angle. In this snow geochemistry project two sampling lines were planned to cross transversally the deposit in 200 m distance. The first line crossed the suboutcrop part of the deposit, and the second line in the area where the deposit should be located about 100 m depth from the surface. Snow sampling was carried out three times for one winter period: 1st time at the end of December after about 1 month since the permanent snow was coming to the area, 2nd at the end of February, i.e., about three months from the beginning of snow season, and 3rd time in the middle of April. In each times samples were collected from the bottom part (10-20 cm from the soil surface) and during the other two times also from upper snow layer (30-40 cm). Snow samples were collected directly into acid-treated plastic cans and stored and also delivered to the laboratory as frozen. Samples were analysed using HR-ICP-MS analyser in the mineralogical laboratory of the Geological Survey of Finland in Espoo.

Preliminary results clearly indicate that the known Cu-Co-Zn deposit is seen snow geochemistry. For example, Cu, As, Fe, Pb, S, Ti concentrations are the highest above the sulfidic deposit in both lines during each sampling periods. Particularly, sulfur gave nice anomalous pattern on top of the deposits. Furthermore, there was also strong elevation of the element concentration over the fault structure separate from the sulfidic deposit in the bedrock. The results also prove that the concentrations are clearly lower in the higher level of snow (i.e., 30-40 cm) than the lower layer. This confirm the assumption that the best sampling layer for snow samples to get the strongest geochemical signal is the lower part (10-20 cm) of the snow package. In addition, pH value patterns support the geochemical patterns.

There are also evidences that certain hydrocarbons in the snow can be used in tracing the mineralization in the bedrock (Taivalkoski et al. 2019). For this testing the replicate snow samples were collected and stored to be analyzed for hydrocarbons. This is still waiting confirmation for the extra funding. The project has got funding from the R.H. Renlund's Foundation.

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Kittilä Mine, within the Palaeoproterozoic Central Lapland Greenstone Belt (CLGB)

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Introduction

The palaeoproterozoic Central Lapland Greenstone Belt (CLGB) was metamorphosed and deformed during the 1.91-1.80 Ga Svecofennian orogenic events.

Kittilä gold deposit was discovered in 1986 by the Geological Survey of Finland. Gold mineralization is refractory with the gold occurring mainly within arsenopyrite and pyrite. Mining started in 2008 as an open pit operation. Since November 2012, production has been solely from underground. At current production rates the predicted life for the Kittilä Mine is until 2034.

Location

Kittilä Mine is located in northern Finland approximately 900 km north of Helsinki and about 50km north-east of the town of Kittilä (Figure 1). The infrastructure (roads and airport transportation; and telecommunications) is excellent in the area.

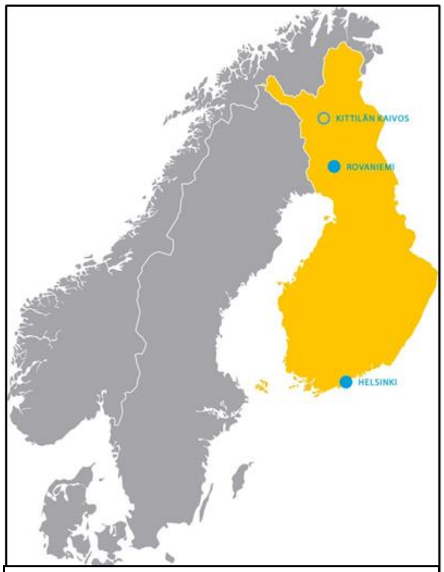

Figure 1. Kittilä Mine, located 900 km north of Helsinki.

Local Geology and Mineralization

The Suurikuusikko mineralized domain is about 5km long and open at depth and is located along the N-S oriented Kiistala Shear Zone. At Kittilä Mine, gold mineralization is refractory, and the gold mainly occurs within arsenopyrite and pyrite. Altered, sheared and brecciated mafic volcanic rocks are the most common host rock for ore. The mineralized rocks are intensely altered. The most typical alteration includes carbonatization, albitization, sericitization and silicification. In the ore zone (shear zone), intense albitization occurs and the dominant carbonate minerals are ankerite and dolomite. Outside the mineralized domain carbonatization is characterized by calcite veins. The gold enriched domains are narrow and elongated and plunge approximately 30-40° to North. These lenses occur parallel to each other and have an observable pinch-and-swell structure. The footwall consists of pillow lavas whereas in the hangingwall there are mafic lavas and altered pillow lavas.

Mine Site Exploration

Since the first discovery, over 1,000 km of diamond drilling has been carried out within the mining lease area. The goal is to extend the mine life and to upgrade ounces from inferred to indicated and indicated to measured and to confirm the resource outlines. Directional drilling with multiple daughter hole has been carried out for over ten years. Making multiple branches from a mother-hole dramatically reduces both the time spent drilling and the cost. The deepest ore-grade intersections have been reported at approximately 1,900m below surface. The most recent exploration discovery, the Parallel Zone (Sisar Zone), forms the easternmost zone striking parallel to the main ore zone.

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Geological hydrogen in Finland – aspects and prospects

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Introduction

Hydrogen (H_2) is traditionally used in industrial processes, but as global climate and energy crises have intensified, hydrogen with high energy content per unit of weight has also become an increasingly valuable resource as a versatile energy carrier. Yet, industrial hydrogen production itself is energy-intensive, and its carbon footprint dependent on the energy source used. However, hydrogen also occurs naturally in the form of molecular or "gold" (also known as "white") hydrogen, which holds promise as a primary energy source.

The formation of a hydrogen reservoir requires a deliberate balance between geological and microbiological production and consumption of H_2 combined with adequate porosity and effective barriers to diffusive and advective fluid flow. Four main mechanisms suggested to form H_2 at low temperatures in the Earth's upper crust are hydration of iron-rich minerals, radiolysis of water, mechanical stress, and microbial reactions (Milkov, 2022). Nearly pure (98%) hydrogen gas reservoir has been discovered in Mali, West Africa (Prinzhofer et al., 2018), and old cratons in Australia, North America, and Fennoscandia are likewise seen as potential areas for hydrogen exploration (Zgonnik, 2020). Despite the recent surge in research surrounding the hydrogen economy and natural hydrogen, there are still significant unknowns related to the origin, volume, and fluxes of geological hydrogen.

Geological hydrogen in Finland

In Finland, hydrogen-rich gases have been identified in bedrock groundwater in geological environments varying from sandstones and uranium-rich gneisses to serpentinites (Silvennoinen 2020). Although some hydrogen can result from corrosion of iron casing and rock grinding during drilling, the substantial volume of H_2 in the gas phase, up to >40 vol-%, and persistent flux of gas suggest major potential for geological hydrogen formation and accumulation. Comparison between the contents of H_2 and He, both originating through radioactive decay processes, indicate serpentinization or other iron-related reactions as additional sources of H_2 in the Outokumpu-Juuka region. Sulfide-rich metavolcanites in Pyhäsalmi and siltstone in Liminka demonstrate notable consumption of H_2 potentially driven by sulfate-reducing bacteria.

The isotopic composition of H_2 (δ^2H_{H2}) in Finnish bedrock groundwaters ranges from -619 to -848 ‰ VSMOW, being among the most deuterium depleted reported from a natural setting. Equilibrium isotope fractionation indicate temperatures below 106°C for the H_2O-H_2 system, consistent with formation or re-equilibration of H_2 within the upper 7 km of the crust and within temperatures suitable for subsurface life. However, samples from the basal parts of the sandstone and siltstone units show unrealistically low equilibration temperatures down to -37°C, which could be due to non-equilibrium processes or migration of H_2 from a source where isotopic composition of water differs from the in-situ values used in the model. Thus, these units could serve as hydrogen traps for gas formed in the granitic basement.

Present status and future directions

On-going projects around geological hydrogen at the University of Helsinki, Department of Geosciences and Geography include DAFNE-22, funded by the Research Council of Finland, which targets especially mechanochemical and microbial formation of hydrogen down to 6.4 km at Otaniemi, Espoo, in the St1 deep geothermal site, and DODGE, funded by the SAFER2028 program, with focus on novel isotopologue techniques applied to molecular H_2 and geological hydrogen in the context of nuclear waste disposal safety. In addition, Helsinki Hydrogen Hub (https://www.helsinki.fi/helsinki-hydrogen-hub) launched in January 2024 will, among other aspects of future hydrogen economy, promote the research on geological hydrogen.

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Cobalt deposits in Finland

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The global transition towards a low-carbon society has significantly changed the role of cobalt as a raw material, especially in electric vehicle batteries. For the EU, cobalt has been classified as a critical raw material since 2010, due to its high economic importance and a relatively high supply risk.

Recycling of cobalt has only started in significant volumes and does not cover much of the demand anywhere. Also the forecasted volume of recycled cobalt will cover only a small part of the forecasted demand, both globally and in Finland (Hund et al., 2020). Obviously, exploration and mining for cobalt needs to increase.

Finland has a significant role in primary supply of the cobalt for the EU having: 1) the largest know Co resources in Europe (about 500 kt), 2) the only active mines producing Co, and 3) being the second largest producer of refined cobalt, after China (Törmänen & Tuomela, 2021; Idoine et al., 2022).

Currently, the only Finnish mines producing Co are Kevitsa (Boliden), and Sotkamo (Terrafame). The known Finnish Co resources cover around 3 % of the known global resources (USGS 2022). There also are several ongoing exploration and mine development projects, such as Rompas-Rajapalot, Juomasuo, Sakatti, Hautalampi, and Suhanko. In all these projects, cobalt is an important by-product, except at Hautalampi where it is one of the main commodities. Exploration potential is also highlighted by several known and assumed Co-enriched mineral systems around the country (Rasilainen et al., 2017; Konnunaho et al., 2023; Nykänen et al., 2023).

Currently, altogether 250 Co-bearing deposits and occurrences are known from Finland. Most of these go into four genetic deposit types: (1) Orthomagmatic sulphide, (2) Outokumpu type, (3) Talvivaara type, and (4) Supracrustal rock-hosted (epigenetic) deposits. In addition, some deposits go into less common types or are just poorly known to be properly classified; these include, e.g., a handful of Co-rich IOCG deposits. This diversity of mineral systems reflects the extensive geological evolution of the Archean and Paleoproterozoic lithosphere of Finland (Konnunaho et al., 2023).

The orthomagmatic sulphide type has historically been among the most important sources for cobalt in Finland; also, one of the currently active mines, Kevitsa, is of this type. These deposits have been found around the country and their exploration potential is still high. Also, the Outokumpu-type VMS deposits have historically been significant, and one current mine project, Hautalampi, is of this type. Black-shale-hosted polymetallic, Talvivaara-type, deposits host the largest known cobalt resource in Europe, and are represented but the Sotkamo mine (Terrafame), the biggest cobalt producer in Europe during this Century. Supracrustal-hosted epigenetic deposits are known from northern Finland. They are important for gold, but some of them also host significant cobalt grades (Konnunaho et al., 2023).

Cobalt is a potential by-product in all these deposit types and typically the Co grades are low (Konnunaho et al., 2023). The highest Co grades have been detected in Outokumpu and epigenetic deposit types (0.05–0.2 %) and the lowest in mafic-ultramafic intrusion-related Ni-Cu-Co-PGE deposits (≤0.02 %).

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Critical raw materials in closed extractive waste sites: a case study from Finland

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Introduction

The growing concern regarding the availability of critical raw materials in the European Union has shifted attention towards extractive waste sites as potential secondary resources. The FutuRaM project, funded by the Horizon Europe programme, was established to investigate the resource potential of these sites and to provide guidance and information about secondary resource assessments.

According to uncertain preliminary data based mainly on indirect evidence on waste amounts, the largest historical extractive waste sites in Finland could contain substantial amounts of critical raw materials, including cobalt (14,100 tonnes), copper (103,800 tonnes), nickel (76,600 tonnes), and vanadium (16,800 tonnes).

Challenges related to remining of the extractive waste

Despite the seemingly significant amounts of critical raw materials in Finnish extractive waste, the preliminary assessment has also highlighted notable challenges. The extraction of these raw materials could be challenging due to their apparent low concentrations, usually ranging between 0.002% and 0.2%, which are lower than conventional ore grades. Furthermore, there is little knowledge regarding the heterogeneity and continuity of potential recoverable grade values in the waste material, or which minerals host the valuable elements. Therefore, more detailed exploration and innovative beneficiation techniques are required to access these raw materials.

At most historical extractive waste sites, the available data is highly uncertain due to the limited number of samples or outdated analysis techniques. So far in Finland, only one site, the Otanmäki tailings facility, has been recently assessed more thoroughly and classified according to the United Nations Framework Classification for Resources (UNFC). It's worth noting that the idea of remining extractive waste is not new, and relatively comprehensive investigations were already conducted in the early 1980s at sites such as Aijala, Haveri, Orijärvi, and Kotalahti tailings facilities. In these investigations, remining was deemed to be unfeasible. However, currently there is more interest in wider scale of elements and minerals, and beneficiation techniques have evolved.

Potential solutions and future perspectives

As interest in the potential of extractive waste resource is high, the EU and the Finnish government have invested in a thorough investigation of the old extractive waste sites and raw materials extraction. The EU-funded RePower project, starting in early 2024, aims to assess 10-15 extractive waste sites in the next two years. Additionally, two sites will be assessed in 2024 as part of the government funded KAJAK program. The experience from the Otanmäki tailings site, which serves as a case site for the FutuRaM project, will be documented and used as an example for future resource assessments, along with other guidance created in FutuRaM.

Apart from the need for e.g., new innovative beneficiation techniques, as metal extraction alone might not be economically feasible, a more comprehensive approach in extractive waste site resource estimation and management should be applied. This includes considering bulk mineral utilization and rehabilitation costs of the site that might be needed to be done in any case, which could enhance the overall feasibility of the remining project. Additionally, the environmental impacts of remining a historic extractive waste site and newly generated waste should be assessed in detail.

Summary

Finnish extractive waste sites have apparent potential as secondary resources of critical raw materials. However, notable uncertainties exist concerning reliable resource estimation and raw materials beneficiation. Resource estimation will be improved in the near future as the resource potential of several extractive waste sites is assessed in EU and government-funded projects. To improve the economic feasibility of a remining project, a more comprehensive approach in extractive waste site resources estimation and management should be applied.

Magnesium extraction from mine tailings in Siilinjärvi

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Climate change and its consequences constitute a complex and pivotal subject, demanding comprehensive comprehension to facilitate the necessary actions for addressing and mitigating its impact effectively. A central contributor to climate change is identified as carbon dioxide (CO_2), with a current atmospheric concentration of 421 ppm, marking a substantial increase from pre-Industrial Revolution levels. Human activities, particularly the combustion of fossil fuels, are identified as the primary source of CO_2 emissions. In response to these challenges, numerous attempts have been made to capture CO_2. e.g. Carbon Capture and Storage (CCS), rehabilitating forests etc.

We have focused on Carbon Capture and Mineralization (CCM) to develop a process for diminishing CO_2 emissions called “the ÅA route", specifically route 4 (Fig. 1). This approach involves the utilisation of a magnesium-rich mineral, phlogopite, to capture CO_2. For that case, the “alkali” in the process scheme could be potassium (K), with potassium sulphate as a significant by-product.

The raw material used in this study is mine tailings from the Siilinjärvi apatite mine. This tailing consists of ~20 wt % MgO situated principally in phlogopite. During the aqueous extraction experiment 5 g tailings were leached in 80 ml 1M sulfuric acid (H_2SO_4) in 80°C for 2 hours. The grain sizes of the tailings had an effect on the leaching results. A grain size > 250 µm extracted up to 63% of the magnesium from the tailings while a grain size < 63 µm extracted up to 85 % of the magnesium. These results show that a phlogopite rich source is an excellent source for CCM. Our results indicate that 167 kg of CO_2 can be sequestrated per 1000 kg of tailings on < 63 µm grain size. With the grain size > 250 µm it is 123 kg of CO_2 per 1000 kg of tailings.

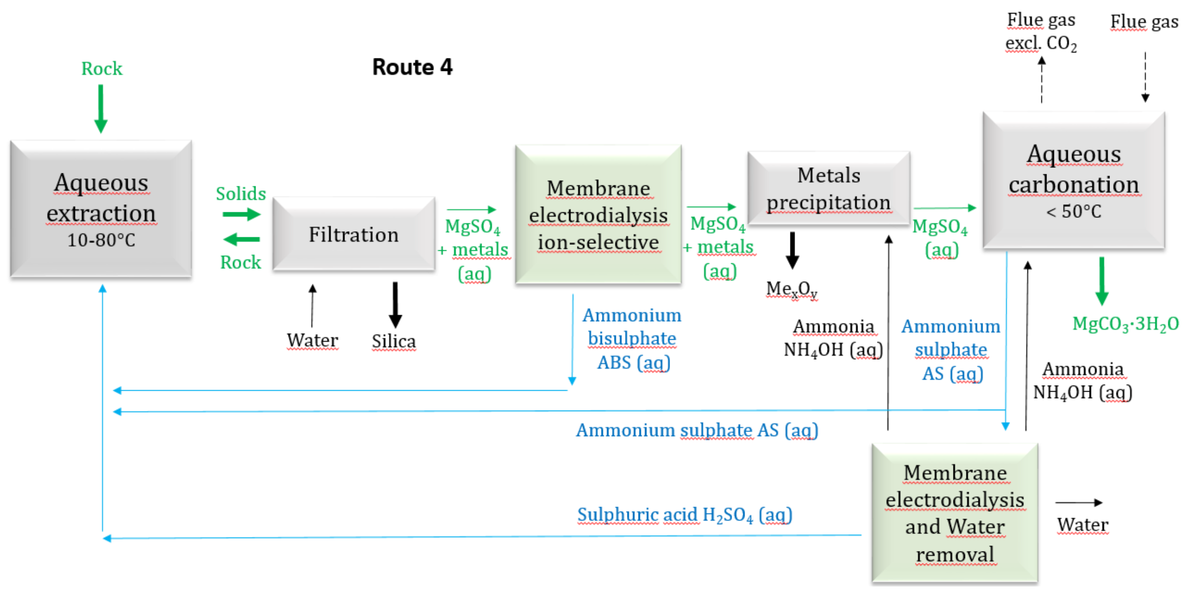

Figure 1. $MgCO_3$ production follows a sequential process involving extraction, precipitation, and carbonation.

Continuously compressing crushers and non-toxic flotation chemicals – Elimination of critical bottlenecks in the global clean energy transition

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Introduction

The ore contents of the mined deposits have been decreasing over the last decades and the extraction of valuable minerals from them is getting challenging. Valuable minerals are still found deeper in the Earth's crust and even from the bottom of the oceans, which makes their mining very challenging. In addition to this, valuable minerals are often found in complex geological and mineralogical formations, which also makes their processing very challenging. This means more mining and mineral processing which consume more energy, water, and chemicals, thus increasing the amount of mining wastes and environmental pollution (Nkuna et al., 2022; Ghorbani et al., 2023).

Various climate technologies like solar panels, electric vehicles, wind turbines, and other are built in this world faster than ever, due to which a sustainable supply of critical raw materials like lithium, cobalt, copper and REEs is crucial to the clean energy transition. Responsible mining practices and research into alternative technologies are needed to ensure a sufficient and sustainable supply of critical materials, because the clean energy transition also means the clean mining and mineral processing. More sustainable and more controlled separation methods of minerals are becoming the next state-of-art technologies of interest in mining and processing industries. This is a result of the requirements set by the clean transition for the development of less water, energy, and chemicals consuming mineral processing methods. Many methods and chemicals used in the mineral processing are more than 100 years old and have not been developed on a sustainable basis originally. Only now, as the world is in crisis and with the increase in the price of energy, attention has started to be paid more intensively to this.

The aim of the study

In this study, supported by the K.H. Renlund Foundation, our aim is to develop two innovative mineral processing methods, namely the continuously compressing crusher (CCC) based on the free crushing of ores (Paasovaara et al., 2022), and non-toxic froth flotation based on synthesized bisphosphonate collectors (Hartikainen et al., 2023). By combining these two novel methods, our aim is to develop the value chain of mineral processing so, that it will not be the critical bottleneck of the sustainable mining value chain.

In the free crushing, the rate of feed is such that the crushed material passes freely through the crushing unit without contact between liberated particles. This prevents the formation of overfine particles and reduces energy consumption. During the free crushing in CCC, microcracks are formed at the natural boundaries of mineral crystals resulting in the liberation of cleaner mineral particles with larger surface area. This can be utilized in the more sustainable comminution and beneficiation processes of ores, especially in dry physical separation, froth flotation, chemical leaching, and bioleaching. In this study, CCC was used for dry separation of minerals from different ores.

In this study, novel non-toxic bisphosphonate collectors are developed to replace toxic chemicals (e.g., xanthates and dithiophosphates) in froth flotation processes. Synthesized aminobisphosphonates were used as a highly selective non-toxic collectors in the flotation of massive Cu-Zn-Fe sulphide ore. Batch flotation tests were carried out with 1 kg ore samples by using Outotec GTK LabCell™ flotation device. The results demonstrate that synthesized aminobisphosphonates can be considered as potential next generation of non-toxic collector chemicals.

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The 2nd GeoDays of Finland is held at the Educarium of the University of Turku, 12th–14th March 2024. The event gathers around 170 participants from different fields of geosciences to present and learn from the latest research and innovations. This publication contains the program and submitted abstracts for all the oral and poster presentations held at the meeting. The organizing committee would like to express gratitude to all the authors for their contributions.

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