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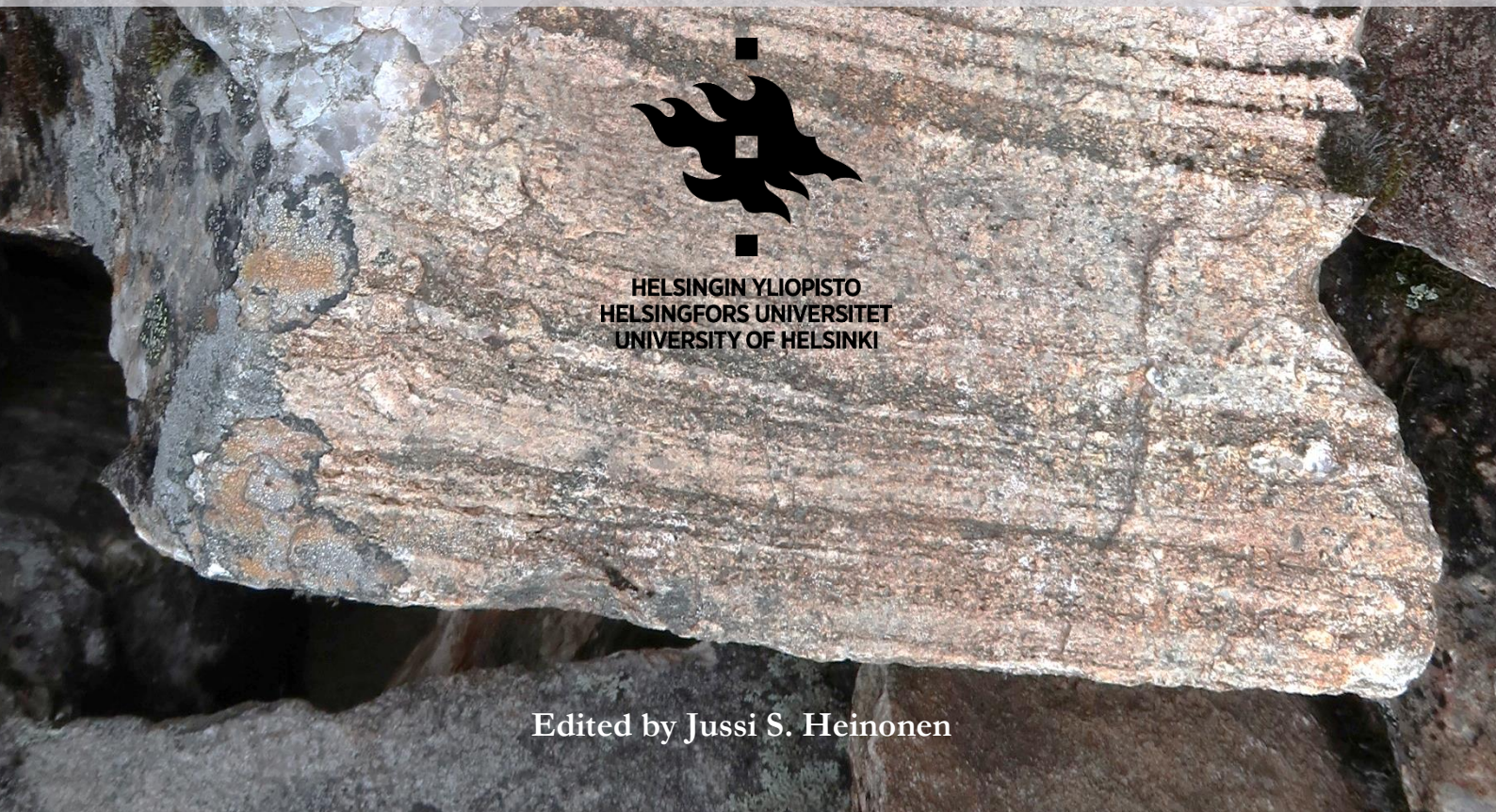


Proceedings of

THE GEOLOGICAL SOCIETY OF FINLAND

Volume 3

Abstracts of
the 1st **GeoDays**
14th–17th March 2023, Helsinki, Finland



Edited by Jussi S. Heinonen

The 1st GeoDays
14th–17th March 2023, Helsinki, Finland



Organizing committee (in alphabetical order)

Jussi Heinonen, University of Helsinki
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Pertti Sarala, University of Oulu & Geokemian rengas
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Foreword

Geosciences play an essential role in the study of planetary processes, global change, and the sustainable use of natural resources in the future. This role is not always understood or appreciated in the public discourse or among decision-makers. The GeoDays meeting is a new initiative to bring together different fields of geosciences in Finland. It builds on the foundation of the National Colloquium of Geosciences (previously the National Geological Colloquium) and aims to bring together a wider range of experts also from outside of the universities. It is intended to connect people from students to professors to people working in the private sector. The meeting consists of talks and a poster session, workshops, short courses, and research and working group meetings. We trust that GeoDays will strengthen our field and create a suitable channel for networking and discussion also in the future. Welcome!

The organizing committee

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Tuesday 14.3.2023	Wednesday 15.3.2023		Thursday 16.3.2023		Friday 17.3.2023
	Registration (8:30-9:00) *Exactum Lobby*		Registration (8:45-9:00) *Exactum Lobby*		
	Wednesday Plenary *Exactum A111*		Thursday Plenary *Exactum A111*		
Workshop on Geoanalytical techniques: Mineralogy & isotope geochemistry (9:00-12:00) *Physicum D105*	Opening (9:00-9:15) Annakaisa Korja/UH		Opening of the 2nd day (9:00-9:15) Saku Vuori/GTK		Open FIN-GEO Working Group Meeting (9:00-11:00) *Exactum C123*
	Keynote: Henrik Drake/LNU		Keynote: Simon Michaux/GTK		MinExTarget Workshop (9:00-14:00) *Exactum C124*
	Bomberg M.		Eerola T.		
	Coffee (10:00-10:30) *Exactum Lobby*		Coffee (10:00-10:30) *Exactum Lobby*		
	Schenk F.		Aranha M.		
	Luostarinen T.		Karlsson T.		
	Invited: Tom Jilbert/UH		Invited: Pertti Lamberg/AA Sakatti Mining		
	Break (11:30-12:30)		Break (11:30-12:30)		
Break (12:00-13:00)	Session 2a *Exactum B123*	Session 2b *Exactum CK112*	Session 5a *Exactum B123*	Session 5b *Exactum D122*	
	Invited: Mats Willner/ELY	Hillers G.	Guo F.	Invited: Kirsti Korkka-Niemi/GTK	
		Sadeghi-Bagherabdi A.	Ayoglu O.		
Short course on scientific writing (13:00-17:00) *Physicum D105*	Hermans M.	Rintamäki A.	Invited: Christoph Beier/UH	Seitsamo-Ryynänen M.	Workshop on Geoanalytical techniques: Lab visit to GTK, Espoo (13:00-15:00)
	Paul Mareike K.	Atobra K.		Turunen K.	
	Virtasalo J.	Häkkinen M.	Kotomaa L.	Invited: Anne Rautio/AA Sakatti Mining	
	Kotilainen A.T.	Pesonen L.	Heinonen J.S.		
	Coffee (14:00-14:30) *Exactum Lobby*		Coffee (14:00-14:30) *Exactum Lobby*		
	Session 3a *Exactum B123*	Session 3b *Exactum CK112*	Session 6a *Exactum B123*	Session 6b *Exactum D122*	
	Bohm K.	Invited: Mathias Forss/GeoPool	Järvinen V.	Invited: Pietari Skyttä/UT	
	Salonen J. Sakari		Nenonen J.		
	Trasune L.	Invited: Pertti Sarala/UO	Loukola-Ruskeeniemi K.	Kohonen J.	
	Moisio K.		Heilimo E.	Tuikka L.	
	Awards (15:30-16:00) *Exactum B123*		Invited: Pasi Heino/FMG/Sokli	Ruuska E.	
				Ding Y.	
	Poster session (16:00- 18:00) *Exactum Lobby*		Closing remarks (16:00-16:15) *Exactum B123*		
Registration (17:00-18:00) *Physicum Lobby*					
Ice breaker (17:30-19:30) *Physicum Atrium (valopiha)*					

Program of the 1st GeoDays, Kumpula Campus, Helsinki (detailed)

Tuesday 14th March

9:00-12:00 Workshop on Geoanalytical techniques Part 1: Mineralogy & isotope geochemistry (Physicum D105)
13:00-17:00 Short course on scientific writing (Physicum D105)

17:00- Registration (Physicum Lobby)

17:30-19:30 Ice breaker (Physicum Atrium, Valopiha)

Wednesday 15th March

8:30-9:00 Registration (Exactum Lobby)

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Annakaisa Korja, Head of Department, Geosciences and Geography, University of Helsinki

Wednesday Plenary Session: Living and Sustainable Earth – Past and Present (Exactum A111)

Chair: Riikka Kietäväinen

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9:45-10:00 The Finnish deep biosphere – are there common factors?
Malin Bomberg, VTT Technical Research Centre of Finland page 12

10:00-10:30 Coffee break (Exactum Lobby)

10:30-10:45 A paleoclimate perspective on recent European heatwaves and droughts
Frederik Schenk, University of Helsinki, Geosciences and Geography & Stockholm University page 13
10:45-11:00 Origins of sedimentary sea-ice proxies in the Arctic
Tiia Luostarinen, University of Helsinki, Environmental Change Research Unit (ECRU) & Helsinki Institute of Sustainability Science (HELSUS) page 14
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Tom Jilbert, University of Helsinki, Geosciences and Geography page 15

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Chair: Tom Jilbert

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Mats Willner, Centre for Economic Development, Transport and the Environment, Turku & Åbo Akademi page 16
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Martijn Hermans, University of Helsinki, Geosciences and Geography & Stockholm University page 17

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K. Mareike Paul, University of Helsinki, Geosciences and Geography page 18

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Joonas Virtasalo, Geological Survey of Finland page 19

13:45-14:00 Shaking the Earth beneath the sea – a case study from the Baltic Sea

Aarno Kotilainen, Geological Survey of Finland page 20

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Gregor Hillers, University of Helsinki, Institute of Seismology page 21

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Amir Sadeghi-Bagherabdi, University of Helsinki, Institute of Seismology page 22

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Annukka Rintamäki, University of Helsinki, Institute of Seismology page 23

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Kwabena Atobra, University of Helsinki, Institute of Seismology page 24

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Miisa Häkkinen, University of Helsinki, Geosciences and Geography page 25

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Lauri Pesonen, University of Helsinki, Department of Physics page 26

14:00-14:30 Coffee break (Exactum Lobby)

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Katja Bohm, University of Helsinki, Geosciences and Geography & Uppsala University page 27

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J. Sakari Salonen, University of Helsinki, Geosciences and Geography page 28

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Liva Trasune, University of Helsinki, Geosciences and Geography page 29

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Kari Moisio, University of Oulu, Oulu Mining School page 30

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Mathias Forss, GeoPool Oy page 31

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Pertti Sarala, University of Oulu, Oulu Mining School page 32

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Thursday 16th March

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9:00- 9:15 Opening of the day (Exactum A111)

Saku Vuori, Director, Science and Innovations, Geological Survey of Finland

Thursday Plenary Session: Minerals for Green Transition: From Ores to Societal Challenges (Exactum A111)
Chair: Aku Heinonen

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Simon Michaux, Geological Survey of Finland page 78

9:45-10:00 Mining and mineral exploration disputes in Finland: implications for the social license to operate
Toni Eerola, Geological Survey of Finland page 79

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10:30-10:45 Exploration targeting of critical raw materials (CRMs)
Malcolm Aranha, University of Oulu, Oulu Mining School & Indian Institute of Technology Bombay page 80

10:45-11:00 Extractive waste as a source of secondary resources in Finland – current state
Teemu Karlsson, Geological Survey of Finland page 81
11:00-11:30 Invited: Sakatti – A FutureSmart Mine of Anglo American
Pertti Lamberg, AA Sakatti Mining Oy page 82

11:30-12:30 Break

Session 5a: Solid Earth: Processes, Resources, and Composition – Part 1 (Exactum B123)
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Fangfang Guo, University of Oulu, Oulu Mining School page 83
12:45-13:00 Characterization of magnetite-bearing Cu ores in Viscaria, Northern Sweden
Olcay Ayoglu, University of Oulu, Oulu Mining School page 84
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Christoph Beier, University of Helsinki, Geosciences and Geography page 85
13:30-13:45 Classification of the phosphorus-rich Lieksa 4 iron meteorite
Laura Kotomaa, University of Turku, Geography and Geology page 86
13:45-14:00 Using portable XRF to analyze geochemistry of basaltic rocks in the field: example from Antarctica
Jussi Heinonen, University of Helsinki, Museum of Natural History & Department of Geosciences and Geography page 87

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Chair: Seija Kultti
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Kirsti Korkka-Niemi, Geological Survey of Finland page 88
13:00-13:15 Fracture mineral investigations beneath the Baltic Sea near Olkiluoto, Finland
Minja Seitsamo-Ryynänen, University of Helsinki, Geosciences and Geography page 89
13:15-13:30 Origin of brackish bedrock groundwater at Finnish mining development site
Kaisa Turunen, Geological Survey of Finland page 90
13:30-14:00 Invited: Insights to hydrogeological studies in Sakatti project
Anne Rautio, AA Sakatti Mining Oy no abstract

14:00-14:30 Coffee break (Exactum Lobby)

Session 6a: Solid Earth: Processes, Resources, and Composition – Part 2 (Excatum B123)
Chair: Jussi Heinonen
14:30-14:45 Single-grain zircon LA-ICP-MS U-Pb age and Lu-Hf isotope systematics of the Archean Takanen greenstone belt in Kuusamo, Northern Finland
Ville Järvinen, Geological Survey of Finland page 91
14:45-15:00 Layman's sample practice - a unique method for mineral exploration
Jari Nenonen, Geological Survey of Finland page 39
Original presentation by Veikko Peltonen et al. on cosmogenic radionuclide dating (see page 92) was cancelled.
15:00-15:15 Risk management of the environmental impacts of black shales in Finland
Kirsti Loukola-Ruskeeniemi, Geological Survey of Finland page 93
15:15-15:30 Re-analysing Co-bearing Layman's samples in Finland
Esa Heilimo, University of Turku, Geography and Geology page 94

15:30-16:00 Invited: Sokli, future raw material source
Pasi Heino, Finnish Minerals Group/Sokli Oy page 95

Session 6b: Structures at Different Scales and Dimensions (Exactum D122)
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Pietari Skyttä, University of Turku, Geography and Geology page 96
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Jarmo Kohonen, Geological Survey of Finland page 97
15:15-15:30 Records of continent-continent collisions in the Paleoproterozoic: exploring the effects of convergence obliquity and temperature
Leevi Tuikka, University of Helsinki, Institute of Seismology page 98
15:30-15:45 Structural characteristics of the bedrock and their bearing on the morphology of the eroded bedrock surface, Turku, South-Western Finland
Eemi Ruuska, University of Turku, Geography and Geology page 99
15:45-16:00 3D seismic modelling and imaging using two seismic profiles of orthogonal geometry at Neves-Corvo mining site, Portugal
Yinshuai Ding, University of Helsinki, Geosciences and Geography page 100

16:00-16:15 Student poster prize and closing remarks (Exactum B123)

Friday 17th March

9:00-14:00 MinExTarget Workshop (Exactum C124)
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9:00-11:00 Geologia.fi Steering Group Meeting (Physicum, A115/Geography Meeting Room) – By invitation
10:00-12:00 Meeting of the Finnish National Committee for Geology (Exactum, Seismon Vintti) – By invitation
11:30-13:30 ILP Committee Meeting (Bistro Bryk) – By invitation
13:00-15:00 Workshop on Geoanalytical techniques Part 2: Lab visit (Geological Survey of Finland, Otaniemi, Espoo, Vuorimiehentie 2) – For registered participants

On the search for deep ancient life in the Fennoscandian shield

Henrik Drake[1*]

[1]*Department of Biology and Environmental Science, Linnæus University, Kalmar, Sweden*
[*]*corresponding author: henrik.drake@lnu.se*

It is becoming increasingly appreciated that deep environments played a crucial role in the early evolution of prokaryotic and eukaryotic life, and that the deep biosphere dominated on Earth for most of life's history. Yet, knowledge of the extent and nature of ancient microbial activity in the continental deep biosphere is still scarce and only exist from a few sites.

In this conference presentation I will present recent findings biosignatures of ancient microbial life are omnipresent in the igneous crust of the Fennoscandian shield, confirming that previous scattered observations are not anomalous. A summary of the diverse isotopic, molecular and morphological biosignatures for deep ancient life in vein mineral specimens from deep boreholes and mines will be presented. The documented preservation of biosignatures in mineral veins over geological timescales and the timing of these microbial processes shed light not only on the evolution and extension of deep life over time on Earth, but also has important implications for astrobiological exploration strategies.

Key findings with far-reaching interest in the research community include recent discoveries and exploration of: 1. Widespread occurrence of extremely isotopically varied pyrite and calcite ($\delta^{34}S_{pyrite}$ and $\delta^{13}C_{calcite}$), including the largest variability of these widely used isotope proxies yet reported on Earth. 2. Widespread evidence of microbial formation and consumption of the greenhouse gas methane in the Fennoscandian shield. 3. Geochronological constraints of microbial processes at an unprecedented level of detail, that allow delineation of metabolic shifts. 4. Organic molecule- and compound-specific C-isotope evidence of bacterial sulfate reduction from the deep igneous biosphere. 5. Fossilized findings of fungi, and proposed syntrophic relationships with prokaryotes. 6. A thermochronological framework for the longevity of deep ancient life in the Fennoscandian shield, and other cratons on Earth. 7. A combined approach of studying isotopic inventories of dissolved gases and liquids, with microbial communities as well as biosignatures of fracture coating minerals from isolated borehole sections.

The Finnish Deep biosphere – are there common factors?

Malin Bomberg[1]

[1] *VTT Technical Research Centre of Finland, Espoo, Finland*
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Introduction

The continental subsurface contains an estimated 2 – 6 x 10^{29} microbial cells, which accounts for 12 – 20% of Earth's biomass. In deep rock environments, this biomass is dwelling in the aqueous spaces, fractures and pores, of the rock and is either attached to rock surfaces in biofilms or free-living in the fluids. Some meta-analyses exist striving to identify a core deep biosphere microbiome, or to identify what parameters affect the microbial community size and composition by collecting available data, but face issues such as difference in sampling procedures, DNA extraction methods, negative control protocols, primers used for sequencing etc., which may introduce false variation. Here the Finnish part of the Fennoscandian Shield was studied by collecting groundwater samples from 7 sites from depths between 100 to 2300 m between 2009 – 2021. Some of the sites have deep groundwater that has been contained in the Earth crust for more than 50 Ma, whereas in other places the groundwater is considerably younger. The same molecular analysis techniques were used for all samples of the study, starting from DNA extraction to primers, enzymes and sequencing technology. All sites contained microbiomes consisting of bacteria, archaea and fungi, and the microbial community composition differed greatly between sites, indicating that rock type and hydrogeochemistry play a great role in moulding the communities. Nevertheless, chemoheterotrophy appeared to be the universally dominant predicted metabolic strategy in all communities. The number of bacteria detected in the groundwater was anywhere between < 1 to more than 5 000 000 16S rRNA gene copies mL^{-1} but did not necessarily reflect the sampling depth, but rather the concentration of DOC and DIC. Finally, samples collected from the same location at 100 m depth over a period of 10 years showed that the microbial communities did dot remain static but varied in size (up to 100-fold) and composition over time in a cyclic manner, interchanging between mainly two distinct community compositions.

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A paleoclimate perspective on recent European heatwaves and droughts

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The frequency and persistence of unusually extreme European heatwaves & droughts observed since ~1990 – that continue regionally as hydrological droughts until today – exceed by far the expected level relative to the current warming trend. The severity and persistence of these anomalous conditions lead to significant damage in, e.g., forestry and have enforced reductions in the use of nuclear power plants during summer in Europe. Observations indicate that these major European heatwaves & droughts coincide with years of unusually cold North Atlantic Ocean temperatures. This link can be also found on millennial timescales where reconstructions for N-Scandinavia exhibit higher forest fire activity (charcoal) during cold anomalies in the N-Atlantic (Drobyshev et al. 2016).

To understand driving mechanisms and impacts behind these extreme events, we present new results from climate reconstructions and paleoclimate modelling of comparable but more extreme ocean states where we explore the impact of a partial collapses of the Atlantic Meridional Overturning Circulation (AMOC, "Gulfstream system") at the end of the ice age around 15,000 to 11,000 years ago. Consistent with the persistent Scandinavian heatwave & drought in 2018, we find modelling and proxy-evidence for a "cold-ocean-hot/dry-summer-mechanism". In the simulation, cold ocean states trigger intensified atmospheric blocking of westerly winds in summer causing warm and dry European summers that counteract winter-cooling (Schenk et al. 2018; 2020). The normally maritime to sub-continental climate abruptly switches to a highly continental climate with major disruptions in ecosystems wiping out large parts of forested areas in parts of Europe as indicated by abrupt decreases in tree pollen. Using lake proxies, we are now able to reconstruct these continentality shifts in response to abrupt shifts in AMOC activity and N-Atlantic cooling that are prone to major heatwaves & droughts (Fig. 1). The projected weakening of AMOC under future warming may additionally increase the risk for more extreme events like 2018. The results add to evidence for abrupt climate disruptions in a warming world that were found in Sokli, N-Finland during the Eemian Interstadial ~125,000 years ago when Earth was slightly warmer than today (Salonen et al. 2018).

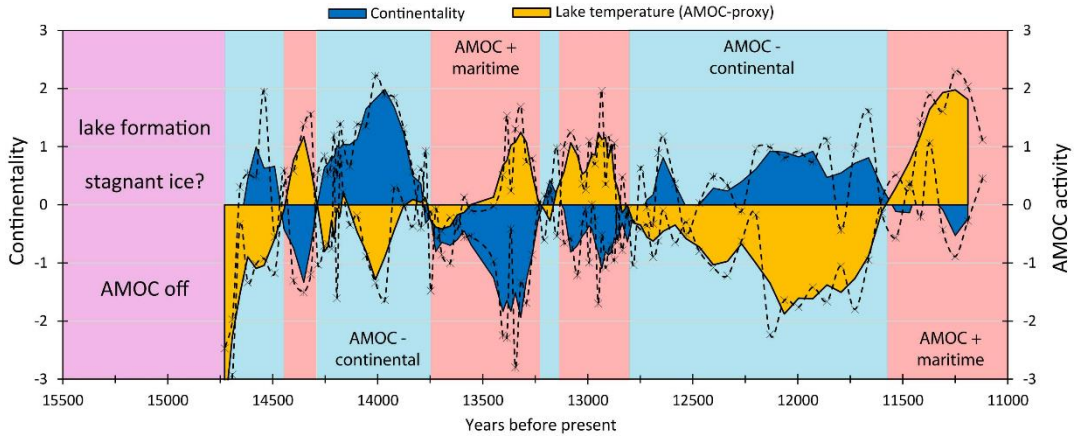


Figure 1. Proxy-based reconstruction of lake temperatures and continentality for the SW-Swedish lake Atteköpsmosse for the period ~15k to ~11k years ago. Strong AMOC activity is associated with warmer lake temperatures and more maritime conditions while weak AMOC cause highly continental conditions (anti-correlation) with major climate and ecosystem disruptions. Data shown as z-scores. Continentality and lake temperatures are reconstructred from Chironomids.

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Origins of sedimentary sea-ice proxies in the Arctic

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Introduction

The rapid decrease of Arctic sea ice is one of the most prominent signs of climate change, with >40% loss of sea-ice since the beginning of the satellite era in 1979 (AMAP, 2017). The decreasing volume of sea ice affects the oceanic and climatic circulations, and has severe effects on marine and terrestrial biodiversity and ecosystems, that reach well beyond the Arctic. To understand and predict current and future sea-ice decline and its implications, it is important to understand past sea-ice variability spanning beyond the instrumental era. This is often achieved using marine sediment records. The state-of-the-art methods to reconstruct past sea-ice changes rely on remains of biological organisms, i.e. biogenic proxies. These include remains of micro-organisms, including diatoms and dinoflagellate cyst microfossils, and biomarkers, such as highly branched isoprenoid lipids (HBIs). Although the development and application of sea-ice proxies has boomed over the past decade, their use as sea-ice indicators is limited by the inadequate understanding of their modern ecologies, seasonal characteristics, and habitat sources (Heikkilä et al. 2022). Mechanistic understanding of proxy links to sea-ice cover is critical for production, interpretation, and use of past sea-ice reconstructions.

We studied sea-ice proxy (diatoms, dinoflagellate cysts, HBIs) production at various sub-Arctic and Arctic settings in Greenland and Canada over seasonal timescales and across the ice-water-sediment continuum to disentangle seasonal production windows (under-ice, ice-edge, open water), habitat sources (ice, water) and vertical transport to the sediment. The sea-ice conditions across the study sites differed markedly: from completely ice-free Godthåbsfjord, SW Greenland, to ca. 4-6 month annual ice cover in Hudson Bay, Canada, to an annual ice-cover of ca. 9 months in Young Sound, NW Greenland. Previous knowledge on the seasonality of the proxy production is sparse, and our results shed light on the habitat sources of the species and their exportation to the underlying sediments. While certain species have been linked with sea-ice cover based on surface sediment distributions (e.g., Oksman et al. 2019; Weckström et al. 2020), their seasonal bloom windows vary across the study sites. Many diatom species living in the ice are not preserved in the sediments, and the reconstructions therefore rely on species living at the ice-edge or underneath the ice. In contrast, dinoflagellate cysts routinely used as sea-ice indicators were not detected in the ice or over the melt season and appear to bloom later in the season. All four HBIs (ice-associated IP_{25}, and $IPSO_{25}$ and open water -associated HBI III and HBI IV) were detected in the ice. Interestingly HBI IV, which is routinely used as an open water proxy, was the most common HBI found in sea ice.

Together, these results indicate that the use of the common sea-ice proxies is not as straightforward as their routine use may imply. We highlight the importance of careful site-specific and ecological consideration when interpreting sediment sea-ice proxy records. More studies on proxy behaviour in modern environments across the Arctic are critically needed and will crucially benefit understanding the past and future changes in sea-ice cover.

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Early diagenesis in human-impacted sedimentary systems: a multidecadal perspective

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Introduction

In unconsolidated sedimentary environments of modern aquatic systems, a network of microbially mediated redox reactions controls the burial and regeneration of carbon, nutrients and other sedimentary components. The principal driver of this reaction network is organic matter, accumulating in sediments from the overlying water column and undergoing remineralization. Microbes derive energy from the primary redox reactions by which organic matter is respired, and from secondary reactions in which the products of remineralization are utilized. Abiotic precipitation and dissolution of mineral phases may also occur dependent on Eh-pH phase equilibria in porewaters. A key characteristic of early diagenetic processes in aquatic sediments is a vertical gradient of chemical zones, reflecting the sequence of electron acceptors available for primary redox reactions and the signatures of secondary processes. In human impacted systems such as eutrophic lakes and the coastal oceans, this gradient has been disturbed by eutrophication and increased loading of organic matter, which has elevated the demand on electron acceptors, in particular oxygen and sulfate. The consequences of this disturbance vary per system and are not fully understood, but are critical to understanding the role of modern sediments in long-term carbon storage and nutrient cycling.

Understanding human impacts on multidecadal timescales

In this presentation I will show some examples of our recent research demonstrating human impacts on sediment biogeochemistry in coastal marine and boreal lake systems. I will focus on processes affecting the cycling of carbon, nitrogen and phosphorus, the key bioactive elements, but also touch on the use of other elements as tracers of environmental change and human impacts. A running theme will be question of how to address legacy effects of past (e.g. multidecadal timescale) human impacts when interpreting observations from modern environments, and how to simulate future changes on similar timescales. Early diagenesis controls, among other phenomena, the carbon sink function of sediments, production and release of methane, and regeneration of the nutrients that drive *internal loading* and harmful algal blooms in eutrophied aquatic systems. Therefore, an improved understanding of early diagenetic processes is essential for environmental management and the attainment of global sustainability goals.

Searching for the fingerprints of gypsum - from the soil to the drainage water and out to the Baltic Sea

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Introduction

The Baltic Sea suffers from high human induced nutrient loads, which cause eutrophication and as consequence large algal blooms are a yearly occurring sight, especially around the coastline in southwestern Finland. It is calculated that approximately 70 % of the human induced phosphorus loads from Finland to the Baltic Sea originate from agriculture (Laamanen et al. 2021). A significant part of the phosphorous load that ends up in rivers and the Baltic Sea is bound to particles that have eroded from farmlands especially on fine-grained clay soils that are sensitive to erosion.

Application of easily soluble gypsum on agricultural fields increase Calcium (Ca2+) in pore waters and is thus expected to enhance flocculation of clay colloids into larger less erodible clay particles and aggregates (Aura et al. 2006). However, an excessive increase of Ca^{2+} may, in theory, also replace important nutrients such as magnesium (Mg^{2+}) and potassium (K+) on cation exchange sites and leach environmentally toxic aluminum (Al^{3+}) into water courses (e.g. Shainberg et al. 1989). Concerns have also been raised about the fate of the excessive sulfates ($SO4^{2}$) that are introduced with gypsum. Studies on farmlands around the river Savijoki catchment area in southwestern Finland showed that the use of gypsum enhanced river water quality by reducing the phosphorous loads from agricultural fields to river Savijoki by up to 30-50 %, without causing Mg and K nutrient deficiencies in fields on both fine-grained and coarse-grained soils (Ekholm et al. 2022). Similar phosphorous reducing results has been observed in other gypsum studies in Finland e.g., within the TraP and SAVE -projects.

So far, the results show that the use of gypsum is a safe and efficient way to reduce the phosphorus loads to the Baltic Sea from agricultural fields. Therefore, the use of gypsum on agricultural fields is an important method to lower phosphorus loads to our rivers. As a result, the Finnish government provides farmers the opportunity to apply for free use of gypsum on their farmlands through the government and EU funded gypsum -project (KIPSI-hanke). The gypsum -project started for farmers around southwestern Finland but expanded to include almost the entity of the Finnish Baltic Sea coastal areas. As a result, free gypsum is now available also for farmers in areas with other types of soils with lower clay content, more organic material as well as acid sulfate soils (a.s. soils).

While results show that gypsum enhances the water quality without causing harm for crops and farmland, less is known about the mechanisms responsible for this on a soil-profile level, particularly how gypsum is affecting deeper soil-layers and the mobility and transport of elements within and out of the soil. We also lack knowledge about how well largescale use of gypsum will reduce nutrient loads to rivers in areas dominated by a.s. soils and coarser grained soils. The studies conducted within the gypsum -project aim to increase our knowledge about the effects of large-scale gypsum use on 1) river water quality in areas with agricultural fields on a.s. soils and coarse-grained soils, 2) effects on farmland drainage water from different soil-types and 3) effects on mobility and transport of e.g., Mg, K, SO_4 and Al in the soil profile. The studies are conducted together with our partners from e.g., Finnish Environment Institute (SYKE) and Åbo Akademi University.

KIPSI-hanke – gypsum free of charge for farmers around the coast of Finland

The gypsum project (KIPSI-hanke) started in 2019 around the Archipelago Sea in southwestern Finland and expanded to other coastal areas in the summer of 2022. The project is funded by the Finnish government and from the sustainable growth program for Finland (NextGenerationEU). The goal for the project is to reduce nutrient loads to rivers and the Baltic Sea by applying gypsum on 100 000 ha of agricultural fields around the coastal areas in Finland. The project is active until the end of 2024. The use of gypsum is totally free of charge for all suitable farmers who apply for subsidize for use of gypsum on their fields.

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Assessing the coupled iron, phosphorus and sulphur feedbacks in response to changes in bottom water oxygen in the Baltic Sea: a modelling approach

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Introduction

Marginal marine systems, such as the Baltic Sea, are naturally susceptible to bottom water de-oxygenation due to strong stratification and restricted horizontal water exchange. In recent decades, bottom water de-oxygenation has been further exacerbated in coastal areas due to excessive anthropogenic nitrogen (N) and phosphorus (P) inputs. Feedback mechanisms in the coupled biogeochemical cycling of P, iron (Fe) and sulphur (S) play a major role in controlling bottom water oxygen (O_2) conditions. Phosphorus release from the seafloor amplifies when bottom water O_2 is low due to reductive dissolution of Fe oxide-bound P and preferential P regeneration from organic matter. This feedback mechanism has been suggested to play a key role in the rapid transitions at the onset and end of multidecadal hypoxic events in the Baltic Sea.

Currently, the coupled biogeochemical cycling of Fe, P and S is not explicitly described in Baltic Sea models. For example, BALTSEM, the principal model used in decision making under the Baltic Sea Action Plan, does not include a representation of coupled Fe, P and S cycling and therefore utilises simplified parameterisations to mimic feedback mechanisms. A critical deficiency is that such parameterisations are calibrated for present-day state only, and do not consider large-scale changes in the spatial distribution of Fe, P and S over long timescales. Therefore, it can become difficult to predict possible future changes or to reproduce past events. Here, we introduce a new model extension for BALTSEM, so-called *Fosferrox* (Fig. 1), that simulates the coupled dynamics between Fe, P and S in response to changes in bottom water oxygen for present day (1850–2100 A.D.). The implementation of such a mechanistic coupled biogeochemical cycling between Fe, P and S, and its associated feedback mechanisms in Baltic Sea models is fundamental to better understand how changes in, for example, P loading might impact water column redox conditions, as well as to improve hypoxia abatement strategies. The main impetus is to extend the functionality of *Fosferrox* to gain a better mechanistic understanding of how the coupled Fe, P and S feedback mechanisms drive the multidecadal oscillations in Baltic Sea hypoxia.

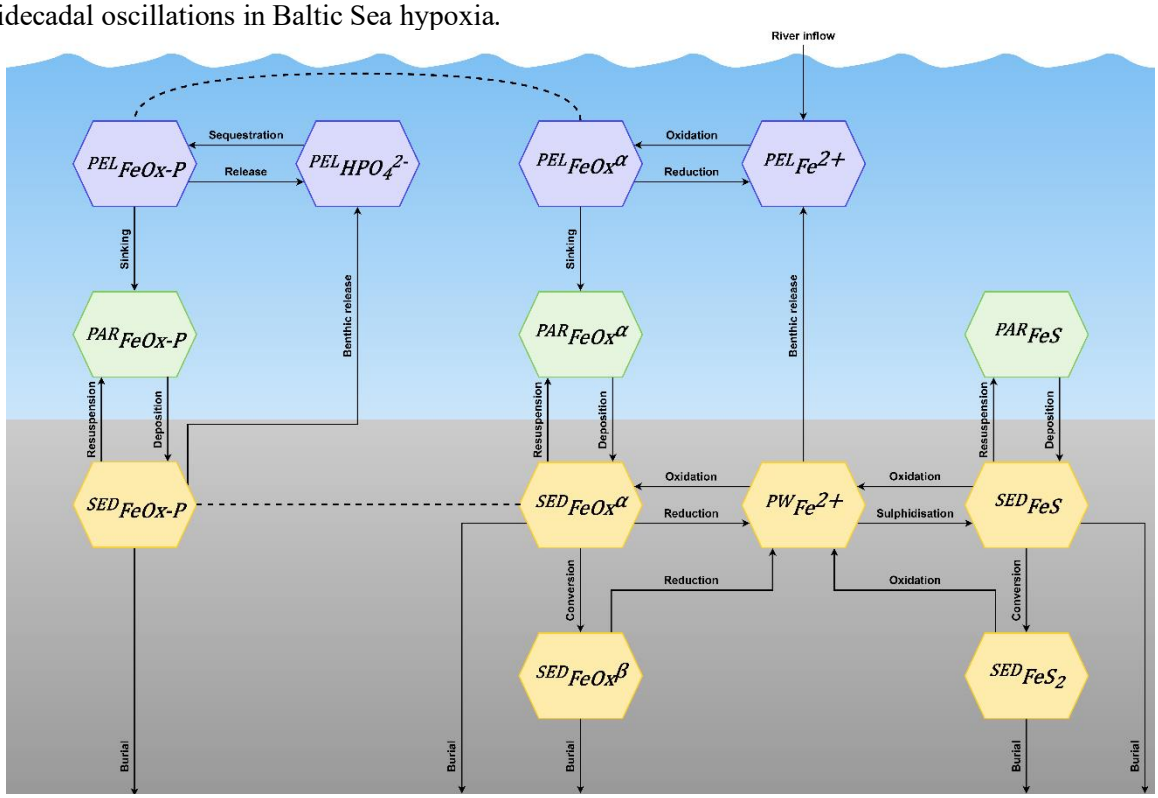


Figure 1. Schematic of the state variables and main processes introduced in *Fosferrox*.

Applicability and constraints of molybdenum and uranium-based paleo redox proxies in coastal marine environments

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Coastal marine environments are highly vulnerable to anthropogenic and climatic pressures, which has led to bottom water deoxygenation in many areas. Sedimentary molybdenum (Mo) and uranium (U) enrichments are widely used as redox proxies to investigate such changes in bottom water oxygen in marine environments. However, these redox proxies may not be equally reliable across a range of coastal settings with varying bottom water redox and depositional environments.

Here, we investigate the validity of Mo and U-based redox proxies at 18 coastal sites with varying bottom water redox conditions, divided into five "redox bins", ranging from persistently oxic to persistently euxinic across a variety of depositional environments. Our results demonstrate that Mo- and U-based redox proxies can be used to differentiate bottom water oxygen among a range of modern coastal depositional environments. In contrast to common understanding, we found that Mo, rather than U, is the more sensitive and reliable bottom water redox proxy in mildly reducing depositional environments.

Constraints on the use of Mo and U as redox proxies can partially be explained by the impact of secondary depositional environmental factors, i.e., particulate Fe-/Mn (oxy)(hydr)oxide "shuttling", the depth of the sulfide front in the sediment, basin reservoir effects, or a combination of these (Paul et al., 2023). We will discuss these factors in the context of the full array of study sites. Additionally, we will present results of a detailed geochemical study of recent sedimentation and early diagenesis in two sill fjords on the Swedish West Coast. This case study highlights how environmental and post-depositional factors can obscure the direct information about past redox conditions stored in Mo and U enrichments.

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Submarine Groundwater Discharge and Its Impacts on the Seafloor Biogeochemical Processes and Microbial Community at Hanko Lappohja

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Submarine groundwater discharge (SGD) has resulted in the formation of pockmarks in the front of the Lappohja beach in Hanko at the water depth of ca. 11 m and ca. 200 m from the shoreline (Virtasalo et al., 2019). We have successfully modelled the geological structure of the SGD site and groundwater flow pathways to the pockmark area (Luoma et al., 2021). In addition, we have investigated the impact of SGD on 3 seafloor pockmarks (B, D and E) by reactive transport modelling and investigations of the microbial community structure (Purkamo et al., 2022).

We constructed a simplified two-layer MODFLOW model for steady and transient states. The simulations estimated the mean SGD rate to the sea at 0.22 cm/d (range 0.0–1.21 cm/d) in autumn 2017. The mean SGD rate increased to 0.28 cm/d (0.0–1.60 cm/d) due to a ca. 30 % increase of recharge in spring 2020 (Luoma et al., 2021).

The porewater systems of pockmarks B and D are dominated by groundwater advection, which leads to a focusing of biogeochemical reactions and microbial activity into the thin surface sediment layer. The advection reduces the organic matter accumulation in the surface sediments, resulting in the absence of SMTZ. Reactive transport modelling estimates low depth-integrated fluxes of SO_4^{2-}, CH_4, NH_4^+, DIC. Groundwater influence is expressed by notable populations of ammonia-oxidizing archaea and nitrifying bacteria of groundwater origin.

SGD has ceased and currently permits the rapid deposition of organic-rich mud in pockmark E. Its biogeochemical environment resembles typical organic-rich mud seafloor in the area, with sulfate reduction and methanogenesis as the dominant organic matter remineralization pathways. Methanogens are relatively more abundant in the archaeal community, whereas sulfate reducers dominate the bacterial community. Although the fluxes of SO_4^{2-}, CH_4, NH_4^+ and DIC at pockmark E are orders of magnitude higher compared to pockmarks B and D, this site represents internal recycling in the sea. In contrast, these fluxes at active pockmarks B and D must be considered to be influenced by external inputs to the sea (Purkamo et al., 2022).

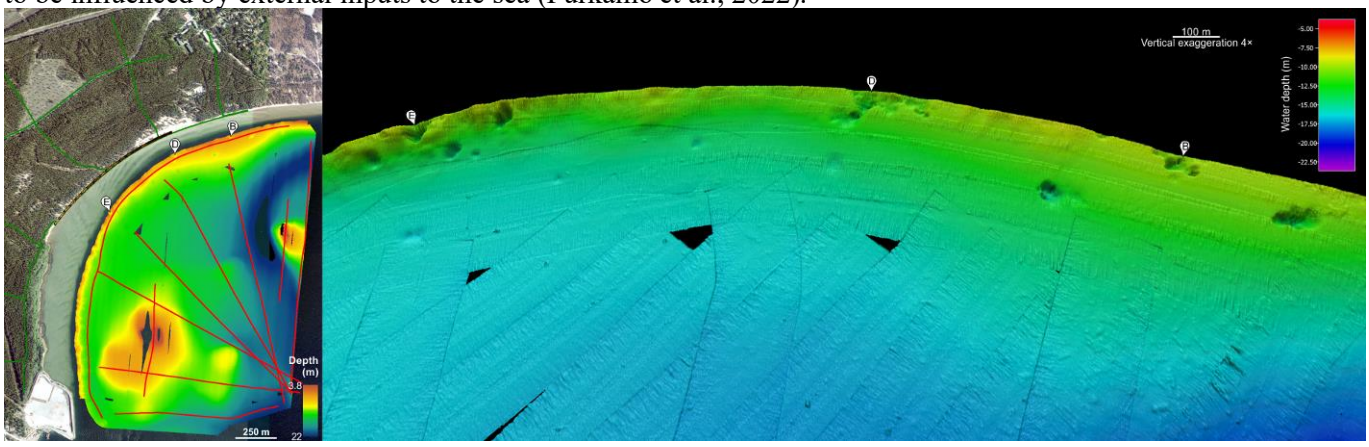


Figure 1. Multibeam bathymetric images of pockmarks at the Hanko SGD site. The studied pockmarks B, D and E are indicated. Green lines indicate ground-penetrating radar survey lines. Red lines indicate marine seismoacoustic survey lines.

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Shaking the Earth beneath the sea – a case study from the Baltic Sea

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Introduction

Large submarine earthquakes and related tsunamis can cause serious human and economic damage. These events are typical for seismically active regions, like the ones close to tectonic plate boundaries. In these areas large magnitude earthquakes are quite frequent (e.g., in February 2023 in Turkey and Syria). The Baltic Sea region is seismically inactive. However, smaller earthquakes occur in this region too.

Study area and methods/data

Here we have used acoustic-seismic data, sediment sampling data, and biological studies to characterize seafloor in the Archipelago Sea, northern Baltic Sea, where seabed deposits suggest possible earthquake triggered event and related seafloor mass movement.

Results

Multibeam echo-sounder bathymetry, side scan sonar data and the acoustic-seismic profiles show the patchy structure of seafloor topography that consists of several smaller depressions and mounds (or blocks). The areal coverage of the seafloor with patchy topography is ca 250 m x 600 m, and difference in depth is ca 2-3 meters. Three distinctive acoustic units (I, II and III) can be seen in the acoustic-seismic profiles. Acoustic unit I is the lowermost unit, and it consists of sediment impenetrable to seismic and echo sounder. Acoustic unit II is up to 10 meters thick, acoustically well stratified unit. It consists of dark, strong, closely based parallel reflectors. The uppermost acoustic unit III consists of chaotic and disturbed reflector structures. In places, blocks and tilted reflectors can be seen. The lower contact of the unit III is erosional. Sediment samples indicate that unit III consists mainly of silty clay and clay.

Discussion and conclusions

The acoustic-seismic and sediment data indicates that the seafloor of the study area is largely disturbed. We suggest that this is due to sediment liquefaction, i.e., the upper part of the seafloor sediment column has changed from a solid state to liquefied state. Liquefaction has resulted into collapse of sedimentary structures and induced mass movement. Possible triggering mechanism for liquefaction and related mass movement could have been earthquake in the region. It could have been accompanied also by gas escapes from deeper seabed subsurface. However, we did not find clear evidence on that in the present study, neither escaping gas seeps or biological evidence. Human activities (e.g., military activities) as a triggering mechanism cannot be ruled out, either.

According to sediment data, the documented mass movement is relatively young. It occurred probably only a few decades ago. If these kind of mass movements have occurred, or could occur, also in the other regions of the Baltic Sea, it will be important to pay more attention to the stability of the seafloor. This is important especially in the areas of high human activities and pressures. Even small-scale mass movements at the seafloor could, in the worst case, cause damage and large expenses to seafloor infrastructure like cables, pipelines, offshore windfarms as well as for the marine environment.

Acknowledgements

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On the lateral resolution of the seismic surface wave focal spot imaging technique

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Introduction

Disadvantages of earthquake tomography associated with limited illumination can now be compensated by ambient noise tomography with its flexible virtual source and receiver configurations. Both approaches invert far-field observations of travel time differences, obtained from earthquake seismograms or from passive Green's function reconstructions, for an optimal model of the velocity structure. Modern dense seismic arrays support alternative local surface wave speed estimations from noise correlation functions, which includes the large scale application of the established frequency domain spatial autocorrelation (SPAC) method (Ekström, 2014). Such dense arrays can now contain on the order of 1000 sensors, which facilitates the proper sampling of the noise correlation amplitude distribution in the near-field. At zero lag time, the time domain representation of the spatial autocorrelation field is referred to as focal spot, which contains the same information as SPAC and can be analyzed using the same mathematical tools (Haney and Nakahara, 2014).

Hillers et al. (2016) first applied Rayleigh wave focal spot imaging in seismology to image lateral velocity variations in a fault zone environment. And although the results of the numerical experiments of Giammarinaro et al. (2023) suggest the overall robustness and utility of the focal spot method for seismic imaging applications, most notably because of the increase in depth resolution, the study could not address lateral resolution. Here we investigate the lateral resolution power of the surface wave focal spot imaging method using numerical experiments of reverberating wave fields in a cavity.

Model setup, test configurations, and results

We study systematically the lateral focal spot resolution using numerical experiments. We perform two-dimensional acoustics simulations to reconstruct the Green's function from reverberating wave fields. The ambient field generated in a chaotic closed cavity yields results that are equivalent to results from open media noise correlation (Derode et al., 2003). The obtained Green's function is identical and is here therefore taken as a proxy for seismic vertical-vertical component Rayleigh wave correlations. We work with a constant number of grid points and a fixed reference frequency.

We implement four test cases and vary the data range or fitting distance *rfit* to investigate the effect on the resolution of the velocity structure. These cases include a homogeneous control experiment, an interface between two half-spaces, circular inclusions, and heterogeneous or random velocity distributions.

Most importantly the resolution depends on the fitting range. This means that focal spot imaging exhibits super-resolution properties provided the data quality supports sub-wavelength fitting ranges. Longer fitting ranges *rfit* still allow imaging of small-scale features at super-resolution albeit with a loss in contrast. In conclusion, seismic surface wave focal spot imaging shows convincing resolution properties that make it suitable for a wide range of imaging applications ranging from feature detection to accurate wave speed estimates. There are hence no fundamental disadvantages compared to established passive surface wave tomography methods. Here as there, the station configuration can be tuned to support image quality and properties for different goals. Here as there, data quality or signal-to-noise ratio ultimately has the largest impact on the resolution, i.e., on the ability to discriminate features, and to accurately estimate their properties.

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Array-derived rocking rate vs. vertical ground acceleration: scaling relations from seismicity induced by the Espoo/Helsinki geothermal stimulation

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Introduction

The accurate measurement and characterization of ground motion in all six degrees of freedom, comprising three components of translational motion and three components of rotational motion, is imperative for obtaining a comprehensive understanding of ground shaking patterns during seismic events. Such accurate measurements are also vital in the development of seismic hazard assessment and engineering design.

Accurate measurements of translational ground motions have been possible since the late 1970s with the advent of digital seismometers. However, the measurement of rotational motions has remained a challenging task due to the sensitivity required to detect such motions. While the necessity for the instruments capable of measuring rotational ground motion was acknowledged as far back as the 1840s (Forbes, 1844), the first successful observations of rotational motion using solid-state rotational sensors and fiber-optical gyroscopes did not occur until the 1990s (Nigbor, 1994; Takao, 1998). The sensitivity of these early developments was limited to strong-motion signals recorded in the vicinity of earthquake sources. With advances in technology, rotational seismometers have become more common, and the recently developed instruments can detect rotational ground motions with high precision. Despite these advances, the accurate measurement of rotational motions remains an active area of research, and the accuracy of current techniques is being continually refined. In this study we focus on the array-derived rotational motions as a low-cost alternative of the rotational sensors.

Array-derived rocking motion from seismicity induced by the 2018 Espoo/Helsinki geothermal stimulation

Diverse seismic networks around the 2018 geothermal stimulation in the Otaniemi district in the Espoo/Helsinki area, southern Finland, recorded the ground motions of 6-km-deep induced events. Key features of the seismic networks are seismic arrays consisting of 3 to 25 three-component 4.5 Hz geophones recording at 400 Hz. The translational seismograms are used to calculate rotational motion for ~400 events with local magnitudes ranging from -0.5 to 1.8 using the using the ObsPy community tool implementation of the seismogeodetic approach (Spudich & Fletcher, 2009).

We evaluate the relationship between array-derived ground rocking rate (GRR) and vertical ground acceleration (VGA) associated with direct P- and S-waves (Lee & Trifunac, 1987). The robustness of the GRR estimates in the 2-15 Hz frequency range are assessed by comparing the VGA waveforms to the GRRs from the full arrays and to the GRRs from subarrays with different wavelength-to-aperture ratios ranging from 2 to 13. With the assumption of a homogeneous earth structure, the rocking motion is only about the transverse component. By rotating the two perpendicular components of the GRRs, we obtained the radial-transverse coordinate system that minimizes the GRR values on the radial component. We find different P- and S-wave propagation directions that deviate from the theoretical back-azimuth of the earthquakes, and variations in the apparent P- and S-wave velocities beneath the arrays that we attribute to local propagation effects. While the deployment of broadband rotational sensors and distributed acoustic sensing systems for wavefield gradiometry analyses is anticipated to become a common practice in the near future, this study provides a low-tech and band-limited experimental verification of the theoretical scaling models (Trifunac, 1982).

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Facture processes during EGS stimulations in the Helsinki area, southern Finland in 2018 and 2020 from centroid full moment tensor analysis of induced event waveforms

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Introduction

Understanding fluid injection induced seismicity is key to safe and successful operation of deep geothermal systems. Efficient geothermal energy extraction by an enhanced geothermal system (EGS) requires increased fluid flow between geothermal wells. The experimental 6-km-deep EGS in the Helsinki capital region, southern Finland, is an intriguing natural laboratory in a cool Precambrian shield setting that yields excellent seismic data quality. We investigate the source processes of earthquakes induced by weeks-long EGS stimulations in 2018 and 2020 via a probabilistic waveform fitting method. Detailed resolution of full moment tensor solutions and their opening components can reveal crucial information on earthquake nucleation and fluid flow patterns.

Seismic waveforms are linearly related to the seismic moment tensor, which is a seismic source representation that resolves shear and opening components. The standard decomposition of the moment tensor includes three components: the isotropic (ISO, equivalent to explosion or implosion), the double-couple (DC, equivalent to shear failure on a plane), and compensated linear vector dipole (CLVD, equivalent to shear failure on conical surface, or opening in one dimension without volume change) component (Jost and Hermann, 1989). Typically, fracture opening is understood as mode I fracturing, i.e., tensile failure, which has a moment tensor with ISO and CLVD contribution. In the case of fluid driven fracture opening, however, the volume increase is often aseismic and the co-seismic fracture opening occurs under constant volume and is manifested as a CLVD contribution in the moment tensor (e.g. Kanamori et al. 1993, Konstantinou et al. 2003).

Centroid full moment tensor and fracture processes of induced seismicity

We present results of a centroid full moment tensor analysis for ~250 events from 2018 and 16 events from 2020 in the moment magnitude range 0.5–1.9. We use three-component data of ~30 stations within a 9-km radius of the well-head site. We fit P- and S-phases by modeling synthetic waveforms using Green's functions with a 20 m grid spacing based on a homogeneous velocity model. We employ automatic high signal-to-noise ratio waveform selection and automatically determined channel-wise correction coefficients for time shifts and amplitude scaling to represent small scale crustal variations not reflected in the velocity model. With the application of both waveform selection and channel corrections, the uncertainty of the moment tensor decreases on average by ~60 % and the location uncertainty by ~85 %. This results in a catalog of well-resolved moment tensors and centroid locations.

The obtained high-quality solutions are dominated by reverse faulting mechanisms with variable compensated linear vector dipole (CLVD) contribution and non-significant isotropic component. The 3D event distribution reveals largest positive CLVD contribution in seismic sources close to the injection well, which indicates localized fracture opening under constant volume with a simultaneous adjacent shear event. Farther from the well, seismic sources have pure double-couple mechanisms or even negative CLVD contribution which may be indicative of fracture lengthening or closing under constant volume at later stages of the stimulation. Events with positive CLVD component occurring close to fluid-filled fractures are potentially nucleated by direct contact with the injected fluid and the associated pore pressure change. In contrast, events with zero or negative CLVD component on the outer parts of the seismicity distribution are likely induced by poroelastic stress transfers without a direct hydraulic contact to the injected fluid. Our findings suggest that the full extent of injection induced seismicity may not be indicative of fluid flow and thus it should be used with care to assess the extent and connectivity of an artificially created fracture network of a geothermal reservoir.

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Physics-based machine learning for characterizing induced seismicity in Enhanced Geothermal Systems (EGS)

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Introduction

Geothermal energy is in many ways an advantageous source for local heat and electricity production. However, the associated stimulation process involves making earthquakes that are felt and heard in the adjacent regions. The event sequences associated with EGS stimulations in Switzerland (2006), South Korea (2017), and France (2020), resulted in earthquake ground motions that exceeded the limits considered to be acceptable, which demonstrates the challenges that have to be overcome before the EGS approach can be widely implemented. On a more fundamental level, each EGS stimulation constitutes a controlled, in-situ rock physics experiments in an intermediate-scale natural laboratory.

We use a unique seismic data set collected around the 2018 deep Otaniemi/Espoo geothermal natural laboratory to explore new ways of conceptualizing rock deformation, fluid-rock interactions, and earthquake physics in the context of sustainable geo-energy technology. Our original combination of machine-learning controlled computer simulations of the rock response has the potential for novel insights into damage mechanics that are essential for developing monitoring strategies for natural and engineered rock failure.

The implementation of the inference system and first results

We work towards understanding the response of EGS systems by utilizing physics-based machine learning models using the Helsinki pumping data and seismicity observations. This involves simulating induced seismicity patterns in a hydraulically stimulated reservoir using a 3D viscoelastic damage rheology model (DRM) (Shalev & Lyakovsky, 2013) to produce a forward model of the reservoir response which allows simulation of fluid diffusion, damage, elastic and plastic deformation, stress drop etc. We report on results obtained during the first phase of the project that focuses on the development of an appropriate 3D DRM for the Otaniemi geothermal reservoir. The forward model is implemented on a 3D spherical domain for computational efficiency with the stress state defined by the principal stresses and a stimulation over pressure. We show results from calibrating test runs using a homogeneous domain to illustrate fundamental features and processes. The DRM outputs a synthetic catalog containing the location, time and potency tensor of the events produced in response to the hydraulic stimulation as well as time series data of the evolution of stress and the fluid pressure field within the reservoir.

We sketch the approach of the machine learning based inversion in the next stage. The goal is to determine the posterior distribution of unknown reservoir and material properties using Likelihood-free inference methods designed for problems with intractable likelihoods such Approximate Bayesian Computation (ABC) and Bayesian Optimization for Likelihood-Free Inference (BOLFI) conditional on the induced seismicity patterns observed during the hydraulic stimulation experiment. ABC and BOLFI are available in ELFI, a machine learning engine for likelihood-free Inference (Lintusaari et al., 2018). We discuss the advantage of this approach to further our understanding of rock failure phenomena by increasing the resolution of the feedback processes at depth. New insights into the reservoir response contribute timely to the conversation of a diverse community concerned with calibrating stimulation protocols and monitoring systems.

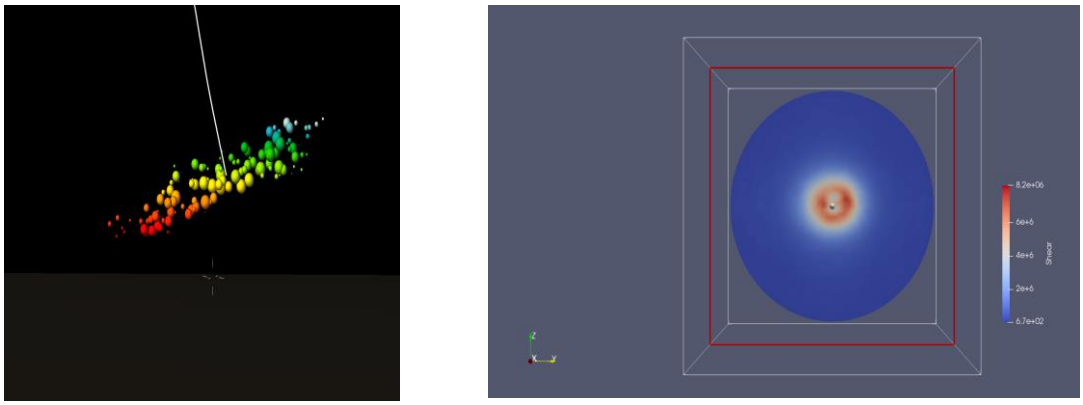


Figure 1. LEFT Example of synthetic events around the injection well. **RIGHT** Example of shear stress evolution in the reservoir from 13 days of pumping.

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Tentative metamorphic paths for southern Svecofennian rocks

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Introduction

A large part of northern European continental crust was created between c. 2.0 and 1.8 Ga during a series of orogenic events jointly termed the Svecofennian or Svecokarelian orogeny. Several models have been proposed for the evolution of the orogeny, including a single or multiple island arcs, subduction below a continental margin, continental or microcontinental collisional stages and oroclines (Hietanen, 1975; Lahtinen, 2014; Nironen, 2017; Stephens, 2020). There is a considerable level of uncertainty for tectonic interpretations of this age that results in part from the incomplete understanding of early Earth geodynamics and tectonics in general. Models for the orogeny are grounded in geochemical and geophysical data, such as the possible provenance of magmas based on chemical composition and isotopic tracers, the seismically mapped crustal structures, and the curious z-form crustal conductance pattern curving around the central Finland granitoid complex.

Metamorphic pressure-temperature paths are a staple of modern tectonic modelling because ideally, they have a unique capacity to track the burial, exhumation and thermal histories of orogens. For the Svecofennian region, this data is scarce, and the metamorphic evolution is poorly known beyond the general high T – low P grade (Hölttä and Heilimo, 2017). The terrain is challenging to study in this sense because of the high temperatures that tend to a large degree annihilate and confuse traces of previous metamorphic conditions and because of the uncertainties that relate to the thermodynamic modelling of partially molten rocks. This project nevertheless tackles the task in an attempt to gain new insight into the evolution of the orogen from the metamorphic perspective.

Project

The study area is Southern Finland and this project particularly targets the late Svecofennian (1.84 Ga and younger) high T metamorphism. Some more detailed studies of the region's metamorphic evolution were made in the westernmost and easternmost parts of the study area (Turku and Sulkava) in the 80 's and 90's by K. Korsman and P. Hölttä. I will present preliminary models for the metamorphic evolution of metapelitic samples of variable grade collected from an approximately N-S transect from the central part of the region (HKI-Sysmä, roughly), where no such studies have previously been published.

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Earth´s evolution in the framework of Precambrian supercontinents and supercycles

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There is ample evidence that supercontinent cycles on Earth have been operating since Late Paleoproterozoic and perhaps even Neoarchean times (≤ 2.8 Ga). Evidence for the supercontinent cycles arise from multidisciplinary observations such as geology (rock record), geochronology (U-Pb zircon age distribution), geophysics (e.g. paleomagnetism, seismology, heat flow), isotope geology (e.g. ^{13}C, $^{87}Sr/^{86}Sr$) and geochemistry (e.g. trace-elements Hf, Nb, Th; nutrient elements P, Se). This presentation summarizes current views of the Precambrian supercontinent cyclicity. In addition, updated paleogeographic reconstructions based on global key paleomagnetic poles and kinematic models of Archean-Paleoproterozoic supercraton clans (e.g. Superia, Sclavia, Vaalbara), Paleo-Mesoproterozoic Nuna supercycle, Meso-Neoproterozoic Rodinia supercycle, and the Phanerozoic Gondwana/Pangea supercycle are explored. The lifecycle of supercontinents is tested by geological, isotopic and geophysical data coupled with secular evolution trends of Earth. Six main conclusions can be drawn. *1.* the results suggest that the supercontinent cyclicity has a characteristic (quasi-)period of ~ 700-500 million years, supported by planetary secular evolution trends, but other periods are also present. *2.* supercontinents Nuna, Rodinia, and Gondwana/Pangea have different configurations and secular evolution trends possibly due to different tectonic styles of assembly.*3.* the cratonic configurations of each supercontinent assembly changes slightly during the three phases of supercontinent cycle: amalgamation, tenure and break-up. *4.* the plate velocity during the Prrcambrian reveals wave-like pattern with peaks and lows corresponding with features in several secular evolution indices including the U-Pb age distribution, passive margins, metamorphic events, tectonic proxies and magmatic activity. *5.* the data suggest three tectonomagmatic lulls during the Proterozoic, but the proposed Mesoproterozoic quiescent period, coined as “boring billion” years of Earth history (1.8-0.8 Ga), appears to be seen mainly by atmospheric and biospheric data rather than tectonomagmatic activity. *6.* the tectonic processes driving supercontinent cyclicity are interactive, with feedbacks from all sixs spheres of the Earth–the geosphere (core,mantle, lithosphere), cryosphere,hydrosphere, biosphere, atmosphere and magnetosphere.

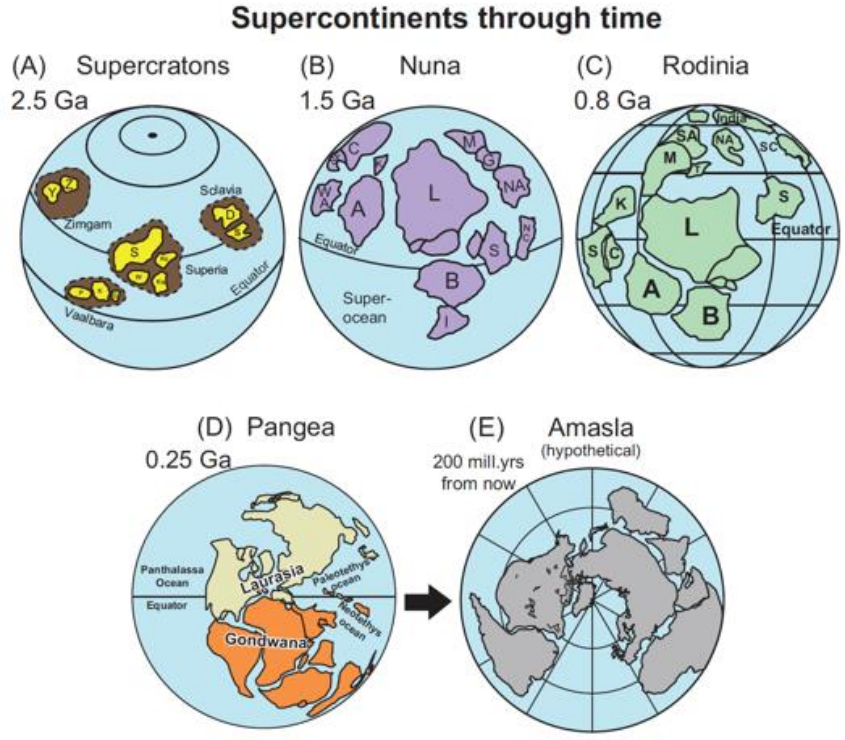


Figure 1. Precambrian supercontinent cycles, events and secular trends (Pesonen et al., 2021).

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Long-term constancy of Asian atmospheric circulation revealed by Paleogene to Neogene dust provenance

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Understanding atmospheric circulation in the geologic past under warm climates is essential for predicting the effects of ongoing global climate change. Atmospheric mineral dust deposits on the Chinese Loess Plateau (CLP) and adjacent areas offer an exceptionally vast amount of material to study Central-East Asian atmosphere and environment through the Holocene to Paleogene. Furthermore, provenance research on these deposits is one of the few ways to reconstruct past atmospheric circulation patterns, aridification history, and the effects of climate changes and tectonics on dustiness in the region.

In this study, we analyse the provenance of Paleogene to Neogene dust deposits in and near the CLP at latitude ~40°N. We present multi-technique provenance data from the Paleogene Ulantatal loess sequence (c. 34–29 Ma) in Inner Mongolia, China, approx. 400 km northwest of the central CLP, and from the Neogene Baode Red Clay (c. 7–2.6 Ma) in the northern CLP. We combine detrital zircon U-Pb ages with detrital rutile trace element geochemistry to reveal the long-term resilience of East Asian winter monsoon as the main carrier of dust since the Paleogene. Our data also indicate shorter-term late Neogene provenance changes, which, e.g. in the late Miocene (c. 8–7 Ma) when dust deposition extended to the eastern CLP, suggest an at least 1–2 Myr dominance of westerly winds over the winter monsoon, enhanced dust production in the Northern Tibetan Plateau, and/or contribution of silt-sized material by a proto-Yellow River.

Although the long-term temporal variability of dust provenance is small through Paleo-Neogene in the northern CLP latitudes, spatial dust provenance patterns during Paleogene are analogous to those of the Neogene Red Clay and Quaternary loess in the CLP region: the Ulantatal dust provenance differs from the Paleogene southwestern CLP dust provenance. This spatial variability confirms previous conclusions that relatively local sources define most of the dust provenance signals in the silt fraction, complicating the interpretation of possible global climate forcing in the Central-East Asian dust cycle, and reinforcing the need for multi-technique provenance analysis of loess dust.

Reconstructions of European climate during the Eemian: millennial trends, latitudinal contrasts, and abrupt events

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The Eemian interglacial (130–115 ka) is a vital global warming analogue for climate science, employed in tuning model simulations of 21st-century warming and estimates of future ice sheet melt and sea level rise. Based on paleoclimate proxy data, the global mean annual temperature anomaly of the Eemian has been estimated at ~ 0.8°C above preindustrial (Fischer et al., 2018). However, the characterization of Eemian climate has been hampered by the paucity of proxy data from the high-latitude continents – due to subsequent glacial erosion of Eemian deposits during the last ice age – as well as by the seasonal bias (summer focus) of the sparse data that is available.

Recently, the lack of high-latitude data has been partly remedied by the high-resolution Eemian sequence from Sokli, NE Finland. Climate reconstructions prepared from the Sokli fossil pollen data (Salonen et al., 2018) show opposite seasonal trends, with a fall in July temperature (Fig. 1a) and a rise in January temperature (Fig. 1b) over the Eemian, consistent with the trends in summer and winter insolation forcing. The strong winter warming is likely also driven by the vigorous Atlantic Meridional Overturning Circulation (AMOC) in the late Eemian (Salonen et al., 2021). In the mid-to-late Eemian, the mean of summer and winter reconstructions yields a mean annual anomaly of ~ +2°C, aligning with the global anomaly when accounting for the amplification of warming expected in the low Arctic. However, these first-order climate trends at Sokli are disrupted by two abrupt cooling events (Tunturi and Värriö events; Fig. 1a,b) intersecting the Eemian warmth. Correlations between Sokli and North Atlantic proxies suggest a linkage of these cold snaps to Greenland meltwater bursts and AMOC disruptions (Salonen et al., 2018).

Comparison of the Sokli seasonal trends with European mid-latitudes highlights stark latitudinal contrasts in the Eemian climate evolution (Salonen et al., 2021). January temperature reconstructions from SW European pollen data show a fall of up to 10°C over the Eemian (Fig. 1c), opposite to the Arctic trend, while the collapse of the Mediterranean forest vegetation (Fig. 1d) indicates a concurrent winter drying trend. Cryptically, these southern trends run against the major forcings including rising winter insolation and strengthening AMOC. However, climate model simulations for early and late Eemian (Salonen et al., 2021) reveal a possible contributor to these divergent latitudinal trends, indicating a deepening pressure gradient over the North Atlantic (Fig. 1e) and intensifying westerlies (Fig. 1f), suggesting a shift towards a positive mode of the North Atlantic Oscillation during the Eemian.

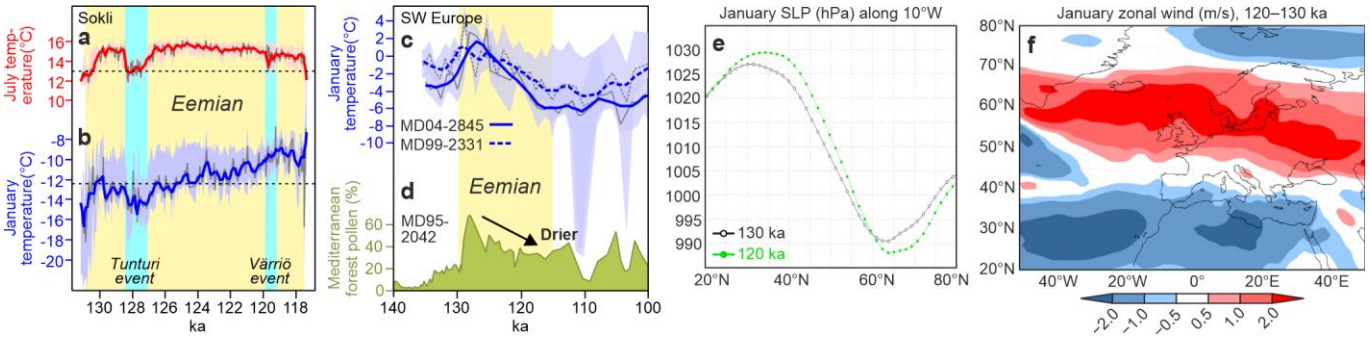


Figure 1. Summary of Eemian proxy data and model simulations: Sokli pollen-based reconstructions for July (**a**) and January (**b**) temperature; (**c**) January temperature reconstructions from marine sediment pollen sequences from Bay of Biscay (core MD04-2845) and the Galician margin (core MD99-2331); (**d**) Mediterranean forest pollen sum in SW Iberian margin marine sediment core (MD95-2042); (**e**) Winter sea level pressure (SLP) gradient over the North Atlantic at 130 and 120 ka and (**f**) the strength of winter westerlies at 120 ka vs. 130 ka, in CCSM3 model runs. (Adapted from Salonen et al., 2018, 2021)

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Younger Dryas summer temperature trends in the Baltic States region based on plant macrofossil data

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The Younger Dryas (YD; ca. 12.8–11.7 ka) cold reversal is a major climate shift event of the rapid Lateglacial warming. The YD has characteristics of generally dry and continental conditions with distinct cooling patterns in the winter season. Furthermore, studies, for example, by Lowe et al. (1994) and Heiri et al. (2014), have also shown similar cooling trends in summers. However, other studies have observed a warm summer presence in some localities in Europe (e.g., Schwalb et al., 2013; Bromley et al., 2014; Birks & Birks, 2014; Schenk et al., 2020). The conflicting evidence of warm or cold summers further causes different explanations of characteristics and causes of the YD cold reversal. Climate simulations done by Schenk et al. (2018) have proposed an explanation of the YD effect on Europe's climate. The study suggests colder and longer winter presence during the YD, when compared to the previous warm Bølling-Allerød, and shorter summers with their temperatures remaining relatively constant or even experiencing a slight increase due to atmospheric blocking mechanisms over Fennoscandia.

Here we reconstruct and study the YD summer trends of the Baltic States region, for which there is conflicting climate evidence: simulations showed summer warming in the Baltics by ~0.5–1.5 °C, while, e.g., a chironomid study by Heiri et al. (2014) showed temperature decrease by ~2–3 °C. Our aim, therefore, is to study the Baltic States region using additional climate proxies to understand the characteristics of the YD's summers. As climate change influences plant realized niches and thus fossil and subfossil plant assemblages found in the sediments, here we reconstruct mean July temperature patterns of the YD using local climate proxy — plant macrofossil — data from 13 sites of the Baltic States and surrounding area. We use two climate reconstruction methods that implement the Probability Density Function approach: CRACLE (Harbert & Nixon, 2015) and CREST (Chevalier, 2022).

As a result, our reconstructions represent both the local and regional climate of the Baltic States. Local July temperatures for each site show conflicting trends of both an increase and a decrease in the summer temperatures — relative changes between the YD and Bølling-Allerød for each site range from approximately -2 °C to 2 °C. However, no distinct changes in summer temperature can be observed on a regional scale. Regional July temperatures in the Baltic States do not fully coincide neither with the warm-summer hypothesis nor with the study by Heiri et al. (2014). Plant macrofossil-based regional July reconstructions show a slight decrease by approximately ~0–1 °C during the YD, thus indicating relatively stable and continuously warm YD summers in the Baltic States region.

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Urban environment and climate change in the Arctic; thermal stress release and frost quakes

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Introduction

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. This project combines geophysics, geology, hydrology, and computer science and aims to develop a methodology for monitoring and prediction of seasonal changes of conditions that could result in damage to pavements and roads. To understand the seismic behaviour behind frost quakes seismic registrations were implemented in the areas where occurrence of these events were confirmed by 'eyewitness' reports. Also, other geophysical activities were done to obtain knowledge about the geological structure and mechanical properties of the areas.

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Mineral Exploration; challenges and opportunities in disruptive markets

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Introduction

Exploration and mining have increased globally since 1950. In 1995 Finland joined the European Union opening up for foreign investments. Since mid-1990´s there has been a disruptive change in form of metal demand. The Finnish, and Nordic bedrock is favourable when it comes to metals needed in this new era.

If, how do these aspects change the exploration industry in Finland, and what opportunities has Finland to offer. How does exploration affect different stakeholders in different parts of Finland. There hasn't been a new mine according to the latest Mining Act since 2011 in Finland, still there is a need to update the Mining Act. How does the European Union Critical Raw Materials Act affect, not only the Mining Act of Finland but the whole exploration industry within the European Union and globally? Is the industry resilient and agile to the market disruption.

About Mathias:
Mathias, M.Sc Geology and Mineralogy, is the founder and CEO of GeoPool and has been consulting companies in the exploration and mining industry in matters ranging from permitting or fieldwork to finding solutions for practical issues. GeoPool builds bridges between companies and the authorities, the landowners and society at large.

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Surface geochemical and mineralogical methods for the environmentally friendly exploration in the glaciated terrains

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Advanced surface geochemical sampling and analysis techniques offer a cost-effective and environmentally friendly set of ore prospecting methods for glaciated areas. Traditionally in the glaciated areas, conventional methods based on the secondary transport of the glacier have been used to determine the origin of surface boulders, heavy minerals and till geochemistry. Due to the variable glacial history, the directions of glaciers' movement, and the complex stratigraphy, tracing the origin can be difficult. Instead, surface geochemical techniques based on the elements' composition of different sample media such as upper sediments and organic soils, plants and even snow provide a direct signal of underlying surface sediment-covered or blind mineralization.

Techniques which are based on the migration of mobile metal ions from mineralization in the bedrock through the top of the bedrock and the sedimentary cover to the upper part of the soil can be use in exploration for all type of elements and their associations. Great benefit is that practically all type of materials, i.e., mineral and organic sediments, plants and even snow are suitable sample media. Easy sampling and sample processing procedure with relatively low analytical costs make these techniques effective in mineral exploration.

Different sample materials and geochemical analysis methods have been studied recently for mineral exploration in vulnerable northern areas. Good examples are the EU-funded projects 'New exploration technologies' (NEXT) and 'Sustainable exploration for orthomagmatic (critical) raw materials in the EU: Charting the road to the green energy transition' (SEMACRET), where the target areas have been in southern and eastern Finnish Lapland. The mobile metal ion based geochemical signal is seen in upper soil horizons (mineralized and organic), in different parts of plants, and in snow. Migrated metal ions accumulate first to the upper soil onto the surface of mineral grains and organic materials forming the exogenic geochemical signal. The so called trap sites can be variable, such as the surface of mineral grains, clay minerals, different hydroxides, and organic compounds. Weakly bounded ions are possible to dissolute with weak or selective leaches. There are plenty of commercial leaching methods available for extracting metal ions from certain mineral traps. The same layer, i.e., upper soil is also a main source for nutrients which plants are collecting using roots forming the basis for biochemistry. In the areas of shallow transported cover roots also can uptake nutrients directly from the bedrock. Plants use major and trace elements as construction materials for trunk, branches, and leaves/needles.

One of the latest advances in sample media is snow. During wintertime, the same mobile ions continue moving upward from the upper soil with water vapour, carbon dioxide and hydrocarbons to accumulate and trap into snow crystals. The bottom part of the snow cover gives the most stable sampling media because of the longest deposition history and the coverage of the upper snow layers which act as a shelter from atmospheric contamination. In addition, the lowest layer is in contact with the ground and is influenced by the gases and heat coming from the underlying soil and bedrock. Snow covers the landscape several months each year in large areas in the Northern Hemisphere. Snowing periods and the snow properties are constant in a regional scale, which gives a good foundation for large and comparable geochemical exploration.

In addition to the leaching-based geochemistry, there are huge amounts of new portable geochemical as well as mineralogical analysers available to support exploration work. Development of those analysers, such as pXRF, pLIBS, pXRD, hyperspectral analysers, and pRAMAN have been intense during last 10-15 years. Benefit of portable analysers is direct analysis in the field, which providecthe quick and reliability analysis of the large group of elements and minerals without significant sample pre-processing. This diminishes need for the laboratory analyses which lower the analytical costs and provides real-time directing of sampling and research. This is supported by the on-site indicator mineral concentration techniques. The development of these techniques as a part of surficial geochemical exploration was done, for example, in the ERDF-funded on-site analytical development projects of the indicator mineral research for the critical metals and minerals, and Au (Indika and Indika Au projects). However, advanced laboratory analysis techniques are needed to confirm the analytical results. For example, field emission scanning electron microscope (FE-SEM) and mineral liberation analysers (MLA) support the automated identification of indicator minerals. In addition, high-resolution and laser ablation inductively coupled plasma mass spectrometers (HR-ICP-MS and LA-ICP-MS) provide trace element and isotope analyses. Those techniques are largely used nowadays and are required, for example, in the recent development work related to sulfidic mineral fingerprinting as a part of indicator mineral research, the development which is done in the EIT Raw Material funded project 'Enhanced use of heavy mineral chemistry in exploration targeting' (MinExTarget).

Exploring the potential of radar data for monitoring tree plantation plans

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Monitoring tree plantation progress in tropical forests is crucial. On-site inspections pose limitations for organizations, making them reliant on alternative methods such as satellite data. Remotely sensed indices derived from optical satellite data, e.g., the normalized difference vegetation index, are widely employed to monitor vegetation changes. However, the high frequency of cloud cover hinders the ability of satellites to obtain high-quality images in monitoring the tropical rainforests. To address this issue, we utilized radar data obtained from Sentinel-1, which can penetrate cloud cover and provide insights into changes in ecosystems, to quantify the radar vegetation index (RVI) between 2016 and 2021. We employed the breaks for additive season and trend (BFAST) method to monitor if and when the tree plantation in our area of interests began. Figure 1 illustrates two sites in Madagascar, where our approach successfully identified the timing of tree plantation. Our findings highlight the importance of selecting appropriate satellite data, indices, and methods for monitoring tree plantation projects. This study not only presents the potential of radar data in addressing challenges related to tree plantation projects but also enhances the transparency and accountability of tree plantation initiatives.

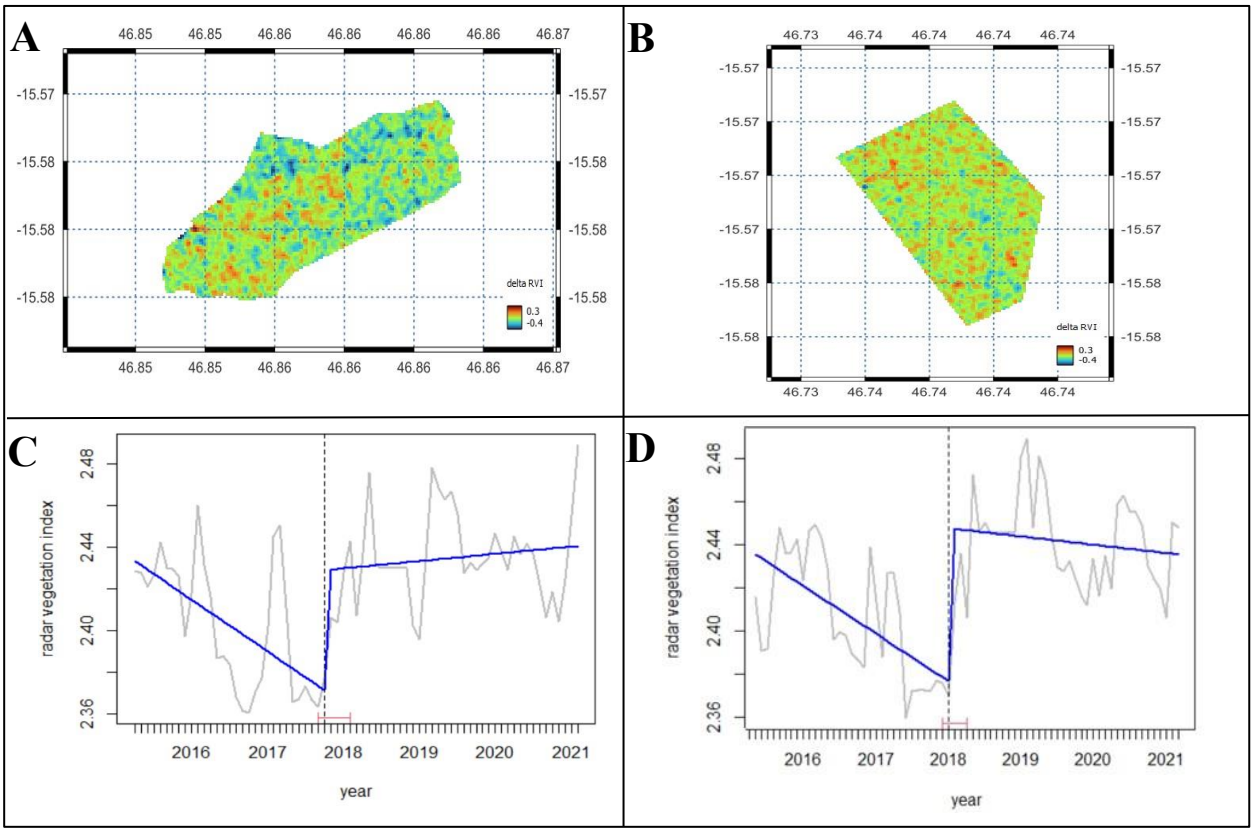


Figure 1. Exploring the potential of radar data for monitoring tree plantation plans in two sites in Madagascar. A and B: Map of the change in radar vegetation index (RVI) before and after tree plantation (delta RVI) in Madagascar, where latitude is the yaxis and longitude is the x-axis in a geographic coordinate system. C and D: Averaged RVI over the entire pixels in sites A and B between 2016 and 2021. The breakpoint in the time series of RVI is calculated using the breaks for additive season and trend (BFAST) method. The blue line represents the trend, and the grey line refers to the actual data. The dashed vertical line indicates the date of the breakpoint.

Phosphorus removal and retention mechanisms of Polonite and Rådasand from hypolimnetic water of lake Hönsan, Sweden

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Phosphorus (P) is a key nutrient element whose release into the environment through human activities has caused eutrophication of aquatic systems worldwide. Hypolimnetic withdrawal (HW) is a method for restoration of eutrophic lakes that aims to extract P from nutrient-rich deep waters and improve water quality. In closed-circuit applications, it also allows for recovery of P for potential use in agriculture. The goal of this study is to investigate phosphorus (P) retention mechanisms in two different filter materials used in HW applications (Polonite and Rådasand), under anoxic and oxic conditions. A saturated, upwards flow-through experiment with four columns was run with hypolimnetic water at KTH SEED laboratory in Stockholm, Sweden.

The columns (acrylic, 40 cm height, 11 cm diameter) were filled as follows: Column 1 – Polonite anoxic; 2 – Polonite oxic; 3 – Sand anoxic and 4 – Sand oxic. 200 L of water was taken from lake Hönsan, Hedemora, during eutrophic conditions in early November 2022. Water was distributed from two vessels, where one was kept anoxic through nitrogen purging and the other was kept oxic (dissolved oxygen ca. 6 mg/L) with a bubbling device. Water flowed from each vessel to the columns through a peristaltic pump (Ismatec, independent flow rate of 12.5 mL/min).

Each column was sliced in 10 segments for sequential P extraction following an adaptation of the five-step SEDEX method (Ruttenberg 1992). Phosphorus content was determined through Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The results show that most P in all treatments is retained either sorbed to the filter materials or precipitated as iron-bound P (Fe-P). Results from the first stage of the extraction (NH_4Cl) confirm the initial expectation of a high sorption performance of Polonite, due to its considerable content of calcium oxide (40%, Renman and Renman (2022)), which is highly reactive with P. Results from the second stage (citrate-bicarbonate-dithionite, CDB) confirm that precipitation of Fe-P is an important pathway by which filter materials physically capture P in HW systems, as high contents of CDB-extractable P are observed in both Polonite and Sand treatments. This confirms observations of Silvonen et al. (2022). The limited differences between oxic and anoxic treatments suggest that even minimal exposure to oxygen can initiate precipitation of oxide particles that bind P in such systems.

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EGT-TWINN
International research cooperation for the green transition in Estonia

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The EGT-TWINN project aims to enhance research and technical capacity at the **Geological Survey of Estonia (EGT)** to accelerate Estonia transition from fossil fuel energy to green energy.

The capacity building will mainly be focused on developing state-of-the-art geological, geochemical, and geophysical survey skills, data management workflows, and subsurface modelling capability for the exploration and geological resource assessment of European critical raw materials and geothermal energy as a future potential green energy source for Estonia. The EGT geological capacity enhancement will be implemented via range of joint activities such as knowledge exchange and scientific conferences as well as through the delivery of targeted training programmes provided by three leading geological surveys in Europe – the **Geological Survey of Finland (GTK)**, the **British Geological Survey (UKRI/BGS)** and the **Geological Survey of Denmark (GEUS)**. A further partner is the **University of Oulu (UOULU)**, more specifically the **Oulu Mining School (OMS)**, which provides a unique state-of-the-art platform for mining-related research and education.

The project will contribute to the development of multidisciplinary research and innovation in geological studies in Estonia and enables EGT to enhance the scientific excellence of its personnel and to collaborate with experts from leading international research institutions. One of the project priorities is to support early-career researchers at EGT who will gain state-of-the-art experience in the geology fields crucial to Estonia. This project is funded by the Horizon Europe funding programme for research and innovation, Grant Agreement no. 101079459.

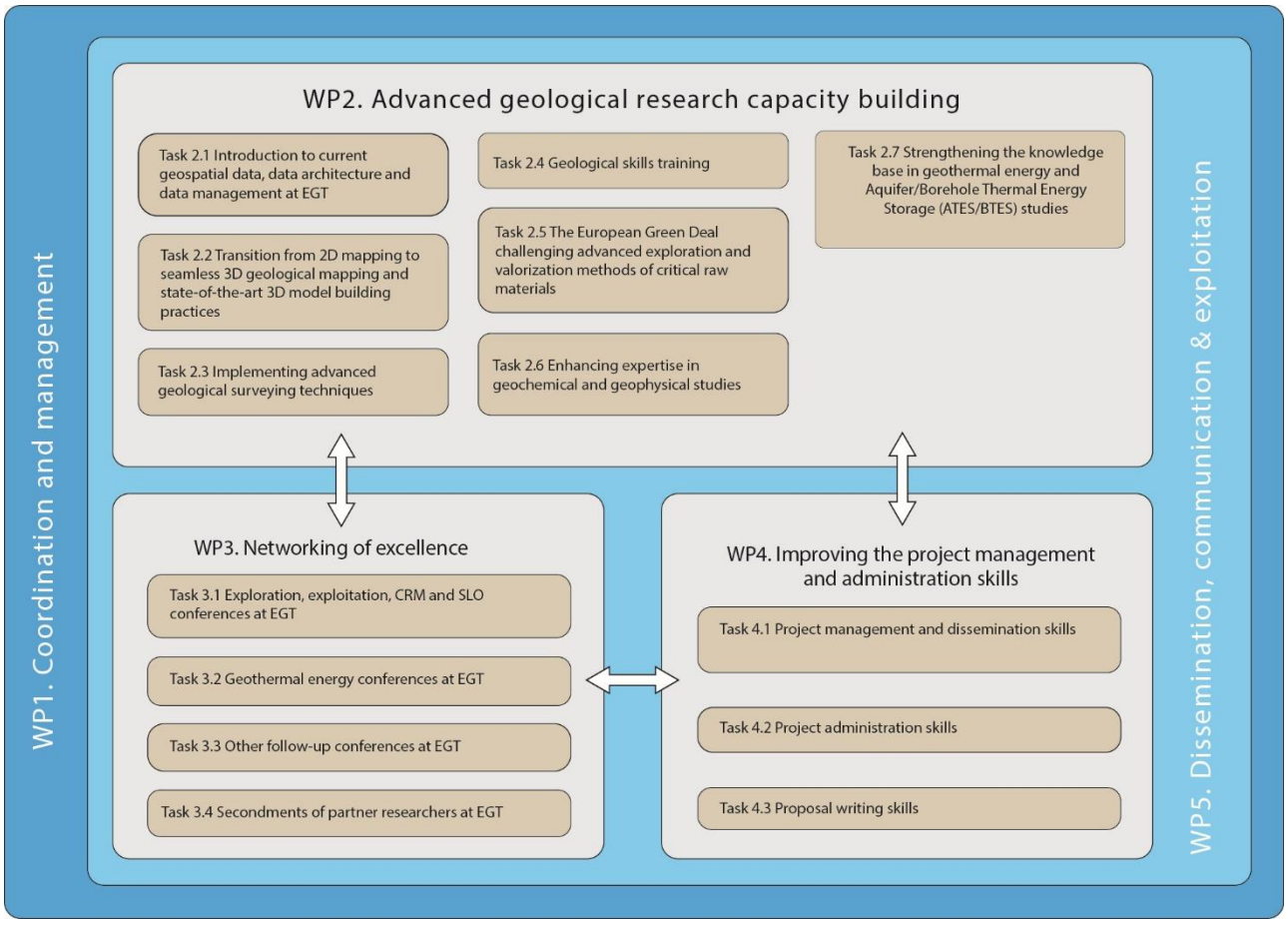


Figure 1. EGT-TWINN project work packages and planned activities.

Stalagmite-inferred hydroclimate in northern Africa during 80-41 ka

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Introduction

The extratropical northern tips of Africa are in the belts of mid-latitude westerlies, receiving the main precipitation from westerlies in winter. During the last glacial period, the multi-centennial-to-millennial-scale Heinrich events, registered in the North Atlantic with occurrences of ice-rafted detritus (IRD) episodes, had significant impacts on global climate and Mediterranean westerlies. The events were linked to global climate variability by adding large amounts of meltwater to the North Atlantic, which in turn slowed the density-driven thermohaline circulation, including the Atlantic Meridional Overturning Circulation (AMOC), caused cold conditions in the Northern Hemisphere, and changed the westerly routes. Numerous studies have shown cold/dry conditions in the northern Mediterranean region during the Heinrich events. However, the lack of terrestrial records from North Africa, the southern Mediterranean territory, hampers understanding the position and strength of the westerlies and their impact on northern Africa's climate during the Heinrich events.

Here we present stalagmite-inferred hydroclimate records from 80-41 thousand years ago (ka, relative to 1950 AD) from Tunisia, located in the southern Mediterranean realm, to understand the regional hydroclimate variability. The associated position and strength of the westerlies during the Heinrich events and the link with the AMOC variation are also investigated.

Methods

A broken stalagmite, LAM2-1, 14 cm in length and 9 cm in diameter, was collected from La Mine Cave, Tunisia, in 2018. It was halved and polished. Twenty-seven powdered subsamples from LAM2-1 were drilled for U-Th chemistry and instrumental analyses. The chemistry procedure was performed on class-100 benches in the class-10000 geochemical clean room at the High-Precision Mass Spectrometry and Environment Change Laboratory, Department of Geosciences, National Taiwan University (Shen et al., 2003, Anal Chem, 75, 1075-1079). The instrumental analyses of U and Th isotopic compositions were conducted on a multiple-collector inductively-coupled-plasma mass spectrometer (MC-ICP-MS), Thermo Neptune (Shen et al., 2012, GCA, 99, 71-86). The half-life values used in age calculation are listed in Cheng et al. (2013, EPSL, 371-372, 82-91).

Results and discussion

The dating results show that LAM2-1 deposited from 187.4 ± 2.4 to 41.4 ± 0.3 ka, with four hiatuses during 185.6 ± 3.5 to 112.3 ± 1.1 ka, 73.1± 0.6 to 60.4 ± 0.7 ka, 58.7± 0.8 to 54.0 ± 0.4 ka, and 51.9 ± 0.6 to 44.5 ± 0.3 ka. In comparison with previous marine sedimentary core and terrestrial stalagmite records, we found that the stalagmite growth period-inferred wet intervals generally match with the wet/warm intervals revealed by both the African humidity index record reconstructed from the marine sediment core GEOB7920 to the coast of Mauritania, northwest Africa, and the stalagmite records from Villars Cave in southwest France during 80-41 ka. This coincidence indicates that the depositional intervals of the local Tunisian LAM2-1 stalagmite were dominated by westerly hydroclimatic conditions.

The last three hiatuses at 73.1 ± 0.6 to 60.4 ± 0.7 ka, 58.7 ± 0.8 to 54.0 ± 0.4 ka, 51.9 ± 0.6 to 44.5 ± 0.3 ka, observed in LAM2-1 record match the occurrence of the IRD events in the North Atlantic during the Heinrich events 6, 5a, and 5, and low sea surface temperature values in the eastern North Atlantic and the Mediterranean. The results suggest that the multi-centennial-to-millennial droughts could be attributed to the weak AMOC by the IRD events in the North Atlantic, which shifted the westerlies northward and away from northern Africa. The agreement of the marine records and the similar climate variations in the northern and southern Mediterranean territories suggests that shifted westerly routes by oceanic circulations were an essential factor in controlling northern Africa's hydroclimate during the last glacial period.

Incorporating gas sampling in studying carbon accumulation from lake sediment and northern peatlands

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Carbon dioxide (CO_2) and methane (CH_4) are important greenhouse gases which play a role in the global carbon cycle. Through production of these gases, peatlands and freshwater boreal lakes contribute to the carbon emissions from natural sources to the atmosphere. However, carbon may also be stored in peatlands and lake sediments. Understanding carbon cycling in these environments is thus essential when discussing the net storage and release of carbon under a changing climate. Here we present two ongoing Master's theses focusing on the methods of gas sampling from porewater collected from lake sediment and peat cores.

Sampling for dissolved CO_2 and CH_4 concentrations in saturated peatland soils and lake sediment porewaters is a basic starting point in estimating emissions from such environments. Using Fick's Law to estimate diffusive fluxes of CO_2 and CH_4 requires that concentrations gradients are well-constrained. However, determination of dissolved gas concentrations, especially CH_4, is vulnerable to losses during sample processing and methods for sampling CH_4 in soils, sediments and water columns are not standardized. Here we test various sampling protocols in the sediments and water column of Lake Pääjärvi, Lammi, and at Puukkosuo fen near the Oulanka research station in Kuusamo. In addition to the CH_4 samples, a range of other geochemical data was collected from dissolved and solid phase materials. A key goal of the Lake Pääjärvi study is to determine the controls on the distribution of methane production in the lake sediments. In the case of the Puukkosuo fen study, a key goal is to analyse the development of the long-term carbon storage, carbon accumulation rates, and overall peat geochemistry.

Peat samples were gathered by a piston corer and the lake sediment by a gravity corer. Two principal methods for sampling and analysis of dissolved gases were tested, based on the protocols from Jilbert et al. (2018), Myllykangas et al. (2020) and Jilbert et al. (2020). In both cases, soil or sediment was collected into a plastic tube with pre-drilled holes, of 16 mm diameter for syringes and 4 mm for the Rhizons filters. After the sediment or peat core was collected, it was held in a vertical position to keep all the layers stable. The gas samples were taken from the sample core with two separate methods; 1) as a porewater subsample directly extracted with the Rhizon filters under vacuum. The subsample was subsequently allowed to equilibrate with a N_2 headspace prior to analysis of the headspace for CH_4 by gas chromatography; and 2) as a sample of wet sediment with a cut-off syringe. The wet sediment was subsequently immersed in saturated salt solution to evolve dissolved gases into a nitrogen filled headspace, from which CH_4 was determined by gas chromatography. In each case, gas-phase samples were stored in pre-evacuated Exetainer® tubes pressurized for analysis with N_2 gas.

In this presentation, we will discuss the comparison of the different sampling methods as well as briefly discussing the results of the ongoing studies. Together these projects contribute to the expanding field of research concerning natural GHG emissions. Understanding carbon dynamics in peatlands, lakes and smaller ponds is of growing importance when estimating national and global GHG emissions.

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Peraluminous I-type magmatism of the postkinematic Heinävesi suite in southern Savonia: Petrological constraints from the Suvasvesi intrusion

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The 1.87 Ga Suvasvesi granite located in southern Savonia (Fig. 1a) intrudes the paragneisses of the Paleoproterozoic Viinijärvi formation. The intrusion comprises a peraluminous I-type granitoid coeval with the postkinematic granitic rocks of the Svecofennian domain. Inner parts of the lithologically zoned intrusion (Fig. 1b) are variably alkali feldspar porphyritic biotite granitoids and the margins are composed of a more biotite-rich equigranular granitoid variety. The metasedimentary rocks of the Viinijärvi suite are also intruded by leucocratic pegmatite dikes related to the Suvasvesi intrusion.

The association of the Suvasvesi granite with the regional, dominantly granodioritic, Heinävesi suite is confirmed in this study based on lithological and geochemical evidence. The granitic rocks of the suite as a whole are magnesian, calc-alkalic, and peraluminous with average ASI value of 1.08 (n=73). Although the Heinävesi suite is postkinematic in age, it shows very few geochemical similarities to other rocks of the age group within the Central Finland granitoid complex. Apparent I-type characteristics suggest a major igneous or metaigneous source component for the suite but previously determined Nd-isotope compositions (ε_{Nd} -3.7 at 1887 Ma) and abundant paragneiss enclaves within the Suvasvesi intrusion indicate that the involvement of a metasedimentary assimilant is also possible.

Preliminary rMELTS models further preclude primary supracrustal (S-type) sources and enable the evaluation of potential regional infracrustal (I-type) source materials for the Heinävesi suite magmas. Possible sources include Archean TTG-series rocks and amphibolites. The origin of a quartz dioritic lithology associated with the Heinävesi suite remains uncertain, but it may not tap the same source as the granitic rocks of the suite.

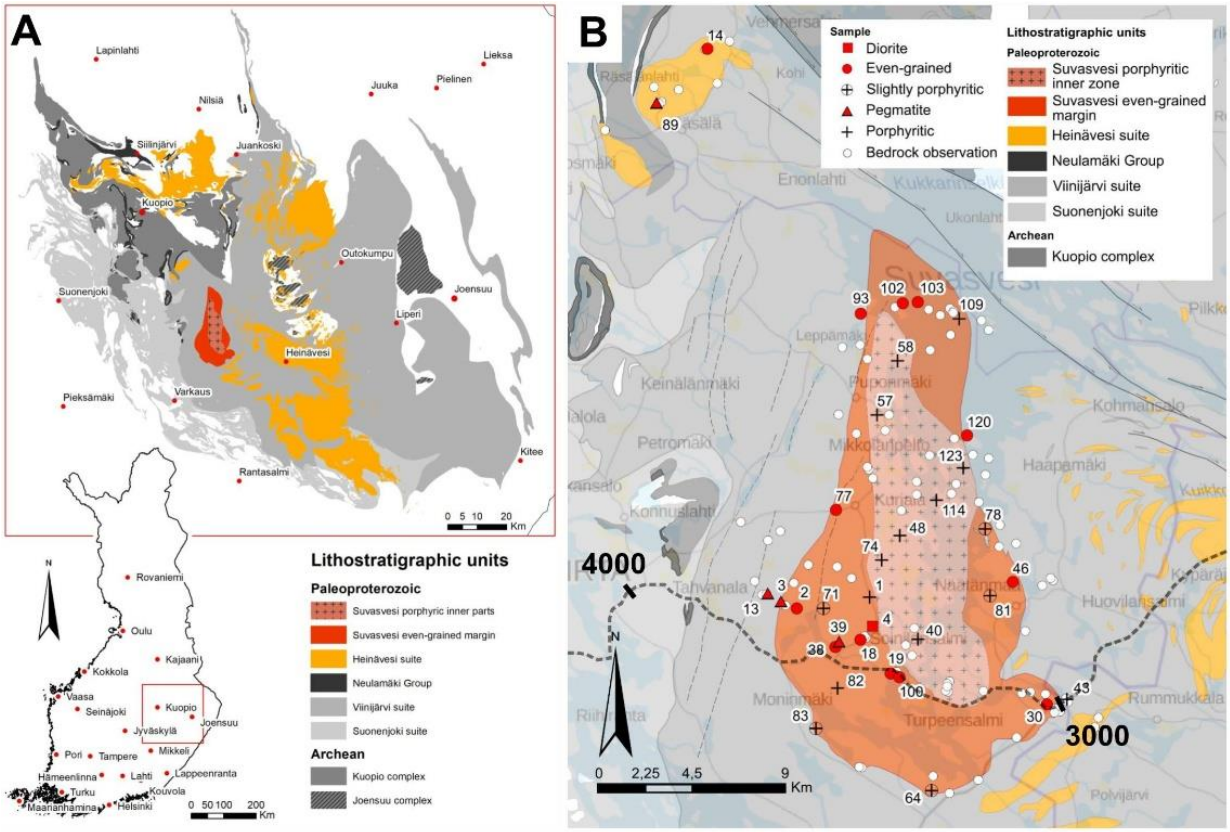


Figure 1. Location of the Suvasvesi intrusion and the Heinävesi suite. **b.** A generalized lithological map of the Suvasvesi intrusion with sampling and observation locations. The stippled line indicates the trace of the FIRE 3A transect.

Layman's sample practice - a unique method for mineral exploration

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Introduction

The Layman's Sample service of the Geological Survey of Finland (GTK) is a unique national method in raw material exploration and research. Its main purpose is to develop knowledge related to Finnish raw material resources. The scope of this service is unusually large compared to other similar operations around the world. In Finland, citizens' rights and the Mining Law legislation provide a practical opportunity for this activity.

The Layman's Sample Office of the Geological Survey of Finland (GTK) receives thousands of samples from all over Finland every year. A sample of rock, or mineral is sent by a member of the public (often a by a rock hobbyist) to a geologist or other geological expert. The office handles ore samples, industrial minerals, dimensional stone, precious stone and gemstone discoveries, and metals of technological interest. Battery mineral samples are of particular interest.

History and meaning

The concept of layman's sample service reflects the action of its history and original purpose. The service started in the 18th century and has continued uninterrupted since then. Historically, thirty four of the metallic mines in Finland have been discovered on the basis of examining a layman's sample further (Fig. 1). Currently, new mining operations are being launched, where the first reference sample has been sent by the public. As a mineral research method Layman's sample practice has proven to be very useful for all glaciated areas in Finland.

In addition to the economic benefit, the Layman's Sample Office also has other tasks. The office answers geology related questions sent in by the general public and provides competent and up-to-date information on the importance of raw materials to the society. The new mobile application OmaKivi (Own Stone) helps the rock hobbyist to send the rock sample information directly to layman's office. This application also inspires young people to the rock collecting hobby in general as well as increases the geological knowledge of the general public.

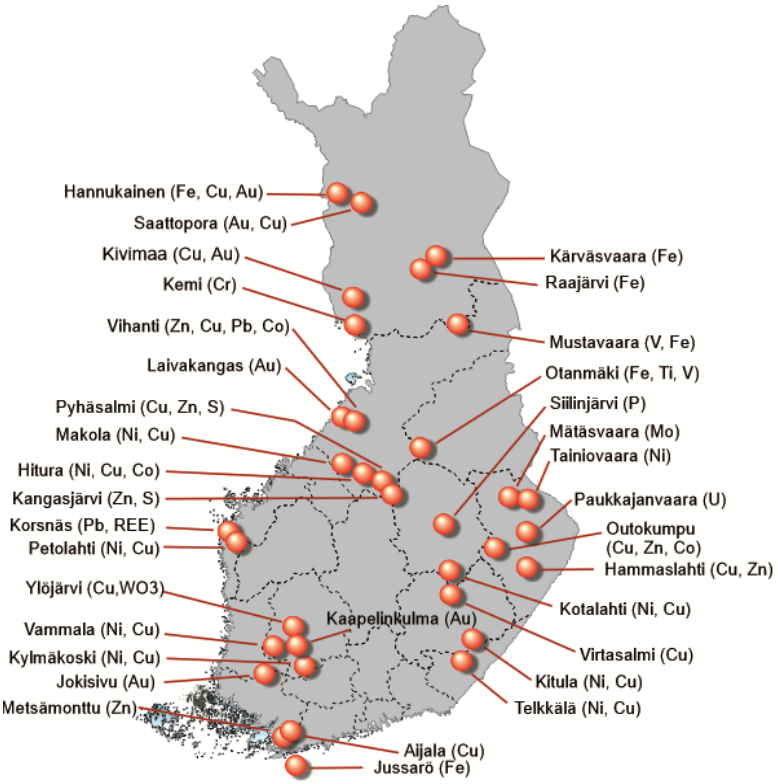


Figure 1. Thirty four of the metallic mines in Finland have been discovered on the basis of examining a layman's sample further.

The digital archive of layman's samples contains information on more than 60 000 bedrock and boulder samples. These samples aggregate and integrate the information of bedrock properties and potential economic deposits. The Layman's Sample Office service is important to citizen education.

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Layman's sample findings for undiscovered about 2440 million years old PGE and chromite deposits

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Introduction

The layman's sample practice of the Geological Survey of Finland (GTK) is a unique national practice in raw material exploration and research. Its main purpose is to increase knowledge related to Finnish raw material resources. This poster is meant to remind us of two things: 1) the importance of geological data received by the layman's sample practice, and 2) the layman's samples could be used as a trace material for deposits still undiscovered in Finland. One of the best examples is from the Kainuu and North Karelia area, where chromite-bearing peridotitic (black star; Fig. 1) and PGE-bearing gabbroidic boulders (red star; Fig.1) are known as layman's samples, but the source rock is still unknown. The most important of these samples are identified as follows: K/20498, K/22953, K/11011, 7483-7031, and 984933 (Table 1).

The best PGE-bearing layman's sample (984933) may originate from the Junttilanniemi layered intrusion (Halkoaho & Niskanen 2013). The chromite-rich boulders found earlier from the north and north-northwest part of the intrusion indicate that there is still at least one undiscovered Palaeoproterozoic layered intrusion, which may also be the source of the PGE-rich layman's boulder. Across the PGE enriched zone of the Junttilanniemi intrusion have been made only one drill hole profile. The exploration should be directed northwest side of the Junttilanniemi intrusion towards the municipality of Vaala because the chromite-bearing boulders found in the Junttilanniemi area cannot be originated from the Junttilanniemi layered intrusion.

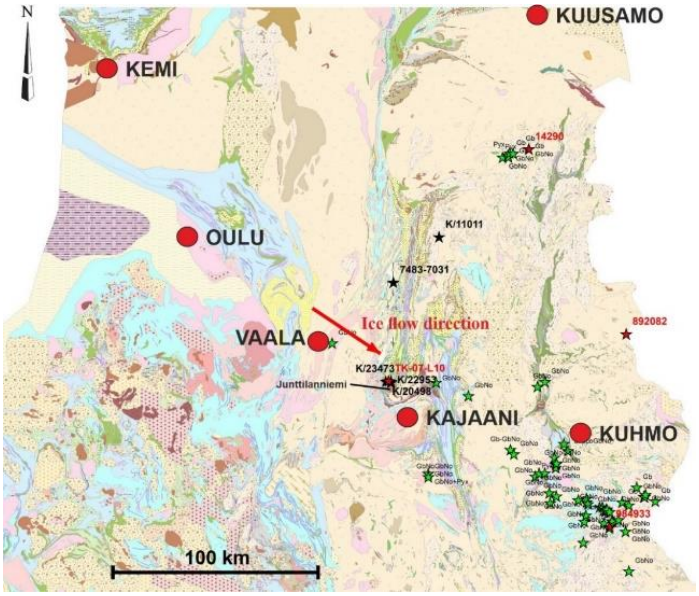


Figure 1. Chromite-bearing peridotitic (black star) and PGE-bearing gabbroidic boulders (red star), which the source is still unknown on the geological map. The green stars represent the cumulate rock (mafic layered intrusion) boulder observations.

Table 1. Cr- and PGE-rich Layman's sample boulders.

Chromite-bearing boulders		**PGE-bearing boulders**	
K/20498	Cr 9,17 %	TK-07-L10	Ni 0,07 %, Cu 0,07 %, S 0,36 %, Pd 196 ppb, Pt 117 ppb and Au 26 ppb
K/22953	Cr 9,3 %	14290	Ni 0,38 %, Cu 0,47 % S 1,6 % and Pd 0,57 ppm
K/23473	Cr 18,98 %	984933	Ni 0,14 %, Cu 0,38 %, S 0,7 %, Pd 6,8 ppm and Pt 1,6 ppm
K/11011	Cr ?? %	892082	Ni 0,36 %, Cu 0,88 %, S 1,5 %, Pd 0,6 ppm and Pt 0,64 ppm
7483-7031	Cr 14,09 %, Ni 0,07 %		

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Numerical simulations of seismo-acoustic nuisance patterns from an induced M1.8 earthquake in the Helsinki, southern Finland, metropolitan area

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Introduction

The mitigation of damaging earthquake ground motions is essential in geo-engineering applications, in particular for enhanced geothermal systems where seismicity is essential to increase the reservoir flow rate. Audible earthquake signals have been reported in epicentral areas of large and small events. Compared to the ground shaking that is potentially linked to stimulations, the excitation of annoying audible effects typically appears to be of minor or no concern. However, the 2018 and 2020 deep geothermal stimulation experiments in the Helsinki metropolitan area led combined to more than 300 macroseismic reports of felt and heard earthquake effects (Ader et al., 2019; Hillers et al., 2020; Rintamäki et al., 2021; Lamb et al., 2021). This demonstrates that persistent earthquake noise can negatively affect the public attitude towards stimulation activities. Research into local audible sound excitation mechanisms of small earthquakes can therefore support a smoother implementation of geothermal systems that are ideally developed near a large, albeit potentially irritable, consumer base.

Realization and impact of fully coupled 3D high-frequency seismo-acoustic earthquake scenarios

Inspired by consistent reports of felt and heard disturbances associated with the stimulation of a geothermal system in 2018 below the Otaniemi district of Espoo, Helsinki (Hillers et al., 2020), we conduct fully-coupled 3D numerical simulations of wave propagation in solid Earth and the atmosphere. We assess the sensitivity of ground shaking and audible noise distributions to the source geometry of small induced earthquakes, using the largest recorded event in 2018 of magnitude ML1.8. Modeling the high-frequency seismo-acoustic wavefields in 3D requires highly resolved numerical simulations that need substantial computational resources on supercomputers. We use the open-source seismic wave propagation software SeisSol that achieves sustained performance in the petascale range (Uphoff et al., 2017) and that has just been extended to simulate coupled elastic-acoustic wave propagation (Krenz et al., 2021). These advances allow us to model seismo-acoustic frequencies up to 25 Hz therefore reaching the lower limit of human sound sensitivity. Our results provide for the first time synthetic spatial nuisance distributions of audible sounds at the 50-100 m scale for a densely populated metropolitan region. In five here presented scenario simulations, we include the effects of topography and subsurface structure, and analyse the audible loudness of earthquake generated acoustic waves. We can show that in our region of interest, S-waves are generating the loudest sound disturbance. We compare our sound nuisance distributions to commonly used empirical relationships using statistical analysis. We find that our synthetics are generally smaller than predicted empirically, and that the interplay of source-mechanism specific radiation pattern and topography can add considerable non-linear contributions. Our study highlights the complexity and information content of spatially variable audible effects, even when caused by very small earthquakes. The numerical laboratory can be used to not only model past events but also to perform a "what if"-analysis to assess the impact on different neighborhoods. We consider that discomfort maps can be valuable addition to seismic hazard maps. This can inform the public which in turn can be beneficial for their acceptance of enhanced geothermal energy system development and operation.

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Induced earthquake source parameters, attenuation, and site effects from waveform envelopes in the Fennoscandian Shield

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Introduction

Induced and natural earthquakes display a wide range of complex behavior but are understood to be governed by the same physics. Estimates of earthquake source properties are potentially biased by incomplete or uneven observations of natural seismic activity. In contrast, the stimulation of an enhanced geothermal system for energy production constitutes an in-situ laboratory, and the controllable aspects of an injection experiment including source region and timing facilitate the tuning of seismic monitoring networks for consistent analysis of the induced seismicity. Observations of small induced event sequences using modern dense networks can thus have general implications for earthquake science and for the structural properties of the stimulation environment.

In this study we analyze earthquake data from the ~6 km deep stimulation experiments in the Helsinki, Finland, metropolitan area, that were performed in 2018 and 2020 to establish a geothermal district heating system (Kwiatek et al., 2019; Leonhardt et al., 2022). We apply the Qopen method (Sens-Schönfelder and Wegler, 2006; Eulenfeld, 2020) that provides an internally consistent radiative transfer based Green's function modeling approach to estimate earthquake source spectra, average medium attenuation parameters, and site effect terms.

Application of the Qopen method to induced event seismogram envelopes

We analyze envelopes of 233 and 22 ML0.0 to ML1.8 earthquakes induced by two geothermal stimulations in the Espoo/Helsinki metropolitan area. The data were collected by a heterogeneous monitoring network consisting of surface and borehole stations (Hillers et al., 2020; Rintamäki et al., 2021). We separate earthquake source spectra and site terms and determine intrinsic attenuation and the scattering strength of shear waves in the 3 Hz to 200 Hz frequency range using radiative transfer based synthetic envelopes.

Displacement source spectra yield scaling relations with a general deviation from self-similarity, and systematic stress drop variations between the stronger 2018 and weaker 2020 stimulation. The 2020 earthquakes tend to have a smaller local magnitude compared to 2018 earthquakes with the same moment magnitude. We discuss these connections in the context of fluid effects on rupture speed or medium properties. Site effect terms demonstrate that the spectral amplification relative to two reference borehole sites is not neutral at the other borehole and surface sensors. The largest variations and the most diverse patterns are observed at surface stations and at frequencies larger than 30 Hz. Intrinsic attenuation in the Fennoscandian Shield is exceptionally low with 1/Qi values down to 2.4×10^{-5} at 20 Hz, which allows for the unique observation of a diffuse reflection at the ~50 km deep Moho. Scattering strength is in the range of globally observed data with 1/Qsc between 10^{-3} and 10^{-4}. Together, the compact source region, the relatively homogeneous medium, the quality network, and the application of a diverse range of analysis techniques using ballistic and scattered wavefields have the potential to better constrain feedback mechanisms between engineered subsurface changes and induced event properties. The diverse results have implications for scaling relations, hazard assessment and ground motion modeling, and imaging and monitoring using ballistic and scattered wave fields in the crystalline Fennoscandian Shield environment. The application of the employed Qopen analysis program to the 2020 data in a retrospective monitoring mode demonstrates its versatility as a seismicity processing tool.

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Horizon Europe project AGEMERA: Combining novel methodologies for agile exploration and geomodelling of critical raw materials deposits

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Introduction

The name of the AGEMERA project stems from the words "Agile Exploration and Geo-modelling for European Critical Raw Materials" (grant agreement N° 101058178). AGEMERA (Holma et al., 2022; Peytcheva et al., 2022) has 20 partners from 10 European countries (Finland, Estonia, Poland, Germany, Netherlands, Hungary, Bulgaria, Croatia, Bosnia-Herzegovina, Spain) and 1 external country (Zambia). The project's goal is to improve the regional and local mineral system models for ore deposits associated with critical raw materials (CRMs) in (1) the Peräpohja-Kuusamo schist belts in Finland (*orogenic Au deposits with atypical Co-enriched metal association)*, (2) the Fore-Sudetic Monocline district in Poland (*Kupferschiefer-type stratabound Cu and Ag deposits with Co, Zn, Ni, Mo and V enrichments*), (3) the Jajce and Posušje districts in Bosnia-Herzegovina (*karst bauxite deposits*), (4) the Apuseni-Banat-Timok-Srednogorie belt in Bulgaria (*locally PGE-enriched porphyry Cu, epithermal Au, and Fe-oxide Cu-Au deposits*), (5) the Iberian Pyrite Belt in Spain (*Ni-Cu-Co mineralisation*), (6) the Erzgebirge district in Germany (*Li and Sn mineralisations, associated with, e.g., post-magmatic greisens*), and (7) four districts in Zambia (*sediment-hosted stratiform Cu-Co in the Copperbelt and North-Western domes regions and Ni, Mn, Li and REE in the Central and Luapula provinces*). The Assarel open-pit porphyry Cu and Lubin underground Kupferschiefer-type Cu mines are among the most notable deposits studied in the project.

Study methods and goals

Several geological, geochemical, and geophysical field methods will be applied to provide input for laboratory-based studies and computer-based modelling of the selected mineral systems. The studied topics include dating the mineralisation processes and establishing improved models for fluid and magma pathways, such as transcrustal-scale terrane boundaries, thrust zones, oroclinal bends, basin-controlling master faults, and local structural controls (for example, see Palinkaš et al., 2022). Additional data will be sourced from the literature and databases. The ultimate objective is to identify new areas for CRM exploration, especially in previously overlooked regions. In geophysics, the project focuses on developing further three novel non-destructive survey methods: 1) passive seismic methods, 2) multi-sensing drone system combining magnetic, radiometric, and electromagnetic sensing and 3) multidetector cosmic-ray muon imaging (muography) for density mapping in various dimensions. The other goal is to use acquired geophysical data to improve the understanding of mineralisation footprints and develop regional and local exploration tools.

The collaboration also focuses on data fusion, small-group interviews, public awareness events, social-licence-to-operate studies, launching university courses, results dissemination, and science outreach. As a whole, the project's goals are: (i) Identify new areas and re-evaluate old mining sites for their CRM potential; (ii) develop new innovative, environmentally, and socially-friendly methods for mineral exploration; (iii) survey the local communities' concerns and hopes related to mineral exploration and mining; (iv) improve the knowledge of the importance of critical raw materials in our day-to-day lives; (v) evaluate the perception of SLO and SLE within the target regions; and (vi) Promote the utilisation of UNFC and UNRMS for the future experts.

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Applications of cosmic-ray muon imaging in Earth Sciences

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Introduction

Primary high-energy cosmic radiation bombards Earth's atmosphere everywhere and at all times, generating a constantly present source of highly-penetrating elementary particles called muons. Once the almost light-speed fast muons reach the ground, they start losing energy faster than they do in the relatively thin air. The unique properties of muons allow density imaging of materials in a new way: muographically. (Cosmic-ray) muography – or muon imaging – is a novel particle geophysical method that works analogously to X-ray imaging in that muon radiation, like X-rays, is attenuated as a function of the material density. In Earth Sciences, muon imaging is conducted chiefly as muon attenuation radiography that provides 2D density images. If the same volume is observed from multiple directions, the produced density models can obtain a 3rd dimension. This technique is muon attenuation tomography. In addition, lengthy radiography or tomography measurements can be used for monitoring density changes over time.

Muon imaging in Earth Sciences

Applications include volcanoes (Oláh & Tanaka, 2022; Leone et al., 2021), aquifers (Lázaro Roche et al., 2022), rock strata and structural geological problems (Holma et al., 2022b), ore deposits (Holma et al., 2022c), mining and tunnelling operations (Zhang et al., 2021), glacier-bedrock interfaces (Scampoli et al., 2022), and karst mapping (Hamar et al., 2022). A few studies have focused on the oceans (Tanaka et al., 2021, 2022a) and even the atmosphere (Tanaka et al., 2022b). Applications employed on the Moon, Mars and asteroids have also been proposed.

The talk aims to bring muography and its many Earth Science applications better known in Finland. Proposed Earth Sciences applications in Finland include groundwater, mineral exploration and mining, Quaternary geology, weathering studies, impact craters, geothermal research, environmental studies and soil and rock characterisation. A recently commenced series in the Finnish magazine "Geologi" represents the principles, background story and applications of muography in detail for the first time in the Finnish language (Holma et al., 2022a). Finnish geoscientists are encouraged to consider muography as an additional tool in their respective research fields.

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Behavior of Li, S and Sr isotopes in the subterranean estuary and seafloor pockmarks of the Hanko submarine groundwater discharge site in Finland, northern Baltic Sea

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Introduction

The main aim of this study was to gain understanding about the isotopic fractionation processes of the selected terrestrial solutes (Sr, Li, S) during transport through a silicate mineral-dominated subterranean estuary in the boreal climate zone (Luoma et al., 2021; Moore, W.S., 1999; Virtasalo et al., 2019). The δ^2H and $\delta^{18}O$ were also analysed from the water samples and the isotopic compositions of hydrogen and oxygen were used as a benchmark for the conservative behavior in the groundwater seawater mixing.

Results and conclusions

Varying degrees of non-conservative behavior was seen in the isotopic results of Sr, Li, and S (Figure 1). A weak shift to values above those expected for the conservative mixing of groundwater and seawater was observed for 87Sr/86Sr and associated with the preferential release of 87Sr from silicate minerals in the aquifer by geochemical weathering. δ7Li values were shifted lower than those expected for the conservative mixing due to the preferential release of 6Li from clay minerals in the aquifer, whereas early-diagenetic mineral formation in organic-rich mud of an inactive pockmark not influenced by groundwater resulted in the enrichment of 7Li in porewater. δ34S values were shifted towards negative and positive values in the groundwater-seawater mixing zone by the combined effects of microbial sulfate reduction and the reoxidation of the produced sulfide or its capture into iron sulfide minerals or organic matter.

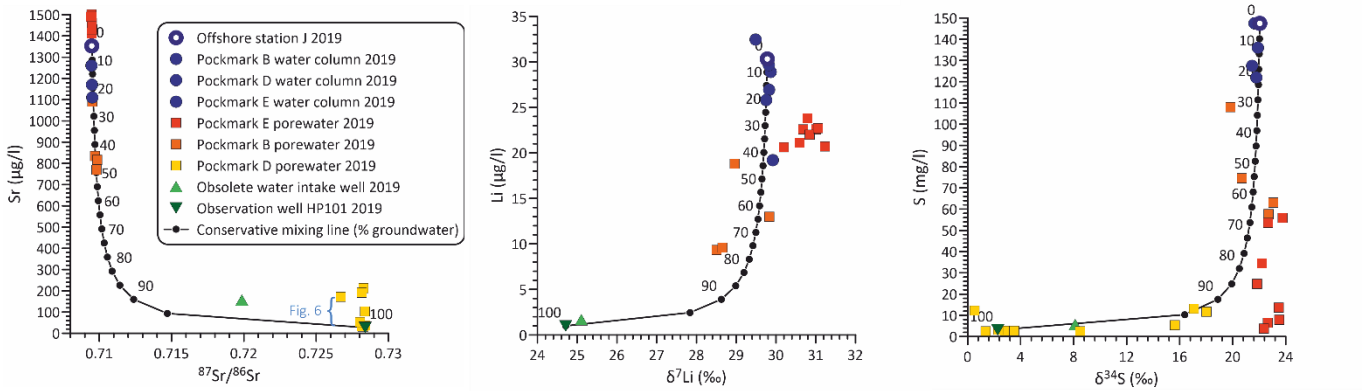


Figure 1. Sr, Li and S concentrations, and $^{87}Sr/^{86}Sr$, δ^7Li and $\delta^{34}S$ values in September 2019 samples plotted with conservative mixing lines as estimated using two-component mixing models (Faure 1986). Numbers along the black mixing lines indicate the fraction of groundwater in the mixture. Light blue bracket in the Sr panel highlights an example deviation from the conservative mixing line.

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Access to point spread function enhances seismic surface wave focal spot imaging

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Introduction

Seismic imaging results have long been exclusively derived from signals at long distances from the source. The advent of dense seismic arrays, together with the insight that deterministic signals can be obtained from continuous records of scattered and diffuse wave fields using cross-correlation, now allow the reconstruction of wave field features at small distances around the virtual source such as the so-called focal spot.

For improved characterization of the imaged subsurface features it is important to quantify the resolution. Various resolution concepts have been explored for the established far-field seismic tomographies, but they all have in common that the metrics derived from the resolution matrices are tied to the implementation of the imaging inverse problem. In contrast, the seismic surface wave focal spot technique compiles images locally without solving an inverse problem. More importantly, this method provides access to the point spread function, which is the fundamental operator that describes how an imaging device such as a microscope, telescope, or camera affects an image. With this contribution we open a new research direction in seismic imaging. We establish the idea of enhancing seismic focal spot imaging results by deconvolving the point spread function.

Image deblurring using the focal spot point spread Bessel function

Focal spot imaging has been a mature medical elastography technique before its first application to dense seismic array data (Hillers et al., 2016). It can be considered another knowledge transfer between different domains concerned with imaging, including acoustics, astronomy, and seismology, that ultimately all rely on wave physics principles. The emerging insight is now that the seismic focal spot is in fact the point spread function of this technique, similar to the point spread function of an imaging device. This poses a fundamental advantage over the established tomographic methods.

Image enhancement by undoing the mostly blurring effects of the point spread function is a mature and active field of research (Hansen et al., 2006; Jansson, 2014). Image deblurring is a linear ill-posed problem often modeled as $\mathbf{b} = \boldsymbol{A}\mathbf{x} + \mathbf{n}$, where $\mathbf{b}$ is the blurred image, $\boldsymbol{A}$ is the blurring operator, and $\mathbf{n}$ models additional noise. The goal is to recover the target image $\mathbf{x}$. Regularization of the problem is often enforced in different ways depending on the particular application. Here we show first results from two image deblurring approaches that are applied to synthetic focal spot imaging configurations (Giammarinaro et al., 2023) using two-dimensional acoustics simulations in a closed cavity.

The first Total Variation regularization (Rudin et al., 1992) approach favours piece-wise constant solutions while the second approach, Total Generalized Variation (Bredies et al., 2010) prefers piece-wise smooth results. We use various synthetic configurations involving simple half-space models, circular inclusions of different sizes, and random but correlated velocity distributions. For these we explore the effectiveness of the two approaches to undo the blurring of interfaces, and to reduce image fluctuations that all depend on the size of the two-dimensional focal spot point spread Bessel function J_0. We conclude with a discussion of established alternative enhancement techniques. We evaluate benefits and disadvantages for focal spot imaging enhancement considering computational costs, and the differences between the new subsurface imaging application and the established contexts.

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Freshwater blue carbon: carbon accumulation in Finnish lake sediments

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Lake sediments provide natural sinks for organic carbon accumulation on timescales of thousands of years. This way a part of the carbon is permanently removed from active biogeochemical cycling, making lake sediments potentially important nature-based solutions for carbon drawdown, and thus provide opportunities for climate change mitigation. To protect and better manage these natural carbon sinks, however, it is critical to understand the factors that control their formation. Simultaneously there is a need to open a dialogue with decision makers and water management authorities to ensure that the blue carbon is considered in national and regional climate and water management plans and strategies, which to date have largely overlooked the potentially important store of carbon. A holistic approach that considers carbon flows at the catchment level and between different ecosystems and environments should be considered in future.

Here as part of the Academy of Finland funded *BlueLakes* -project, we present previously unpublished sediment data on modern carbon accumulation rates in over 200 lakes from Finland, covering range of lake types and sizes, and give future perspectives on how blue carbon can contribute toward climate mitigation on regional and national level.

Neural network for determining silicate composition from reflectance spectra

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Introduction

Olivine and pyroxene can be easily identified in near-infrared reflectance spectra because of multiple absorption bands around 1 and 2 μm. The band properties differ with compositions and relative abundance of olivine and pyroxene. Legacy methods of spectrum unmixing (e.g., Reddy et al., 2015) are sensitive to spectrum quality and have a limited range of validity. We introduce a neural network model that allows us to derive mineral modal and chemical compositions of silicate-rich rocks, including asteroids, with a precision better than 10 percentage points (Korda et al., 2023).

Overview

A neural network model is an empirical model. Parameters of the model are fitted to data. With only a few hundred reflectance spectra of olivine, pyroxene, and olivine-pyroxene mixtures, the model can predict the composition of other minerals based on new spectral measurements.

We applied the model to the surface-resolve reflectance spectra of the Itokawa asteroid (Korda et al., 202x). The model predictions roughly agree with laboratory measurements of returned samples from Itokawa. Moreover, the model detected fresh and space-weathered areas.

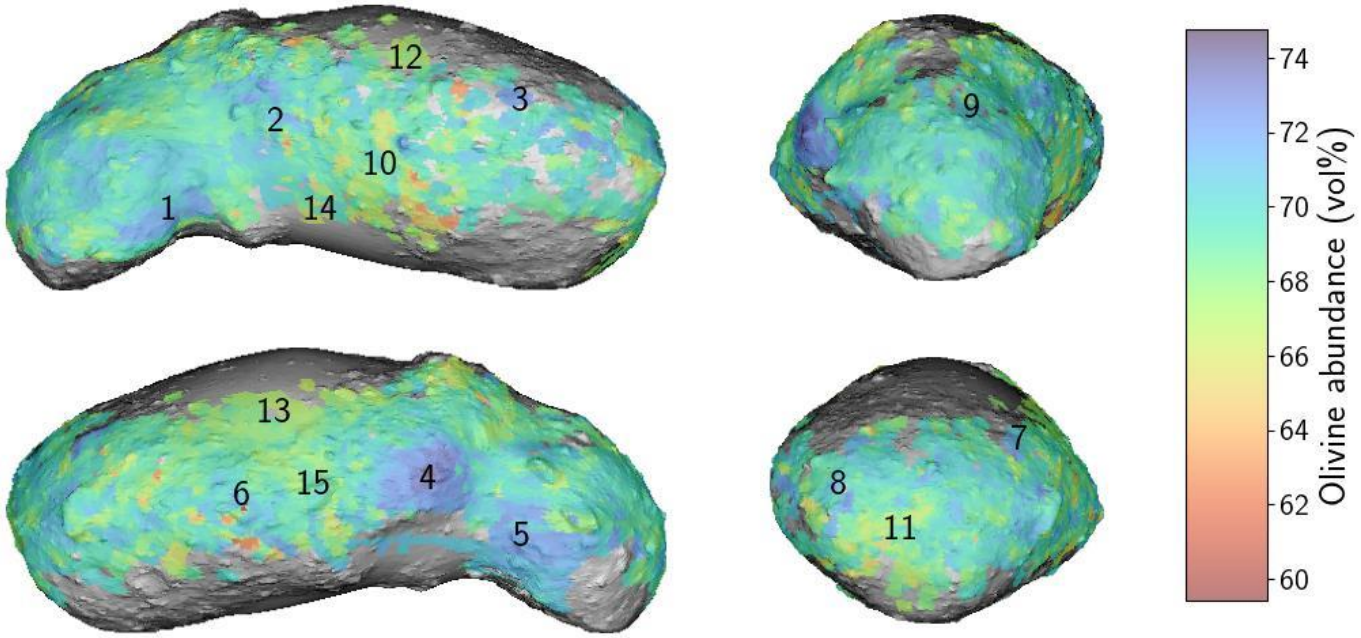


Figure 1. Predicted olivine abundance on the surface of the Itokawa asteroid.

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EMODnet Geology – seabed geological data for the sustainable use of world ocean

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The marine environment is under a growing pressure and effects from rapid population growth, increased anthropogenic activities in coastal and marine areas (e.g., offshore windfarms), and climate change. That pose great challenges to successful maritime spatial planning and coastal zone management. Seabed geological information is an integral part of planning for marine management and sustainable use of marine areas/resources.

Already in 2008 and in response to these needs the European Commission established the European Marine Observation and Data Network (EMODnet) to combine dispersed marine data into publicly available datasets covering broad marine areas. As the data products are free of restrictions on use, the program is supporting any European maritime activities in promotion of sustainable use and management of the European seas.

The EMODnet-Geology project, now in its fourth phase (2021-2023), is delivering integrated geological data products that include seabed substrates, sediment accumulation and seabed erosion rates, seafloor geology including lithology and stratigraphy, Quaternary geology and geomorphology, coastal behaviour, geological events such as submarine landslides and earthquakes, marine mineral resources. Moreover, data products include also submerged landscapes of the European continental shelf at various time-frames including LGM, 9000 years and 6000 years. All new map products are presented at a scale of 1:100,000 all over or finer but also at coarser scales to ensure maximum areal coverage. Thus, partner updates of single-scale products at 1:250,000 and 1:1,000,000 were encouraged and these data products have been uploaded when available. A multi-scale approach is adopted whenever possible.

The EMODnet Geology project is executed by a consortium of 40 partners and subcontractors which core is made up by 23 members of European geological surveys (Eurogeosurveys) backed up by 16 other partner organizations with valuable expertise and data. The EMODnet concept is, however, not restricted to the European seas only, as also the Caspian and the Caribbean Seas are included in the geographical scope of the EMODnet Geology project. Selected methods were shared also with the EMODnet PArtnership for China and Europe (EMOD-PACE) project (2019-2022).

The EMODnet provide the marine data, information and knowledge needed to deliver on the objectives of the EU Mission ‘Restore our Ocean and Waters by 2030’ and the wider goals of the EU Green Deal. In January 2023 EMODnet reached an important milestone as it launched its fully centralised marine data service, integrating all of its thematic services into one single portal. The increased interoperability of EMODnet’s data services is also crucial to underpin new developments such as the European Digital Twin of the Ocean. Moreover, the EMODnet support the Sustainable Development Goals of the UN Agenda 2030 and is a key partner to the UN Decade of Ocean Science for Sustainable Development.

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Repeated fires in forested peatlands in sporadic permafrost zone in Western Canada

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Wildfires have a crucial role in northern boreal peatland ecosystems as drivers of ecosystem functioning affecting vegetation composition and biomass, peat accumulation patterns and soil carbon (C) stocks. Northern permafrost peatland ecosystems are under pressure due to the climate warming and increasing anthropogenic stress. The frequency and severity of wildfires is predicted to increase in the future, and therefore knowledge of long-term natural fire dynamics and their effect on peatland functioning provide relevant information for peatland management and preservation policies.

To investigate long-term fire history and its effect on peat accumulation and peatland vegetation succession we analyzed macroscopic charcoal and plant remains from peat cores from five boreal peatlands located in western Canada covering the past 700−7000 years. Records of the most recent fire events were derived from fire scars and documented fires on the study area. The regional long-term peatland fire patterns were examined by pooling together macroscopic charcoal records and calculating 100-year moving averages.

All studied sites, except the northernmost palsa mire, demonstrate repeated fires throughout the past 1500 years suggesting that fires have been integral part of these peatland ecosystems in Western Canada. Compiled charcoal records indicate peak in fire activity with highest abundance of charcoal for the period from 1300s to 1550s and decreasing fire activity during the recent centuries. The clear and consistent post-fire increase in the abundance of *Sphagnum* mosses suggest relatively rapid recovery of peatland ecosystems after burning. The regeneration pattern, where pre-fire vegetation repeatedly re-establishes suggests that in a long-term perspective fires do not necessarily have negative effect on peatland functioning and peat accumulation. In conclusion, peatlands can remain as effective carbon sinks if natural state is secured.

Our results demonstrate that knowledge of long-term ecosystem dynamics, such as past disturbances and vegetation composition and succession, obtained from paleorecords should be acknowledged in peatland management plans in the future.

A modified - DRASTIC vulnerability mapping method for shallow groundwater areas in Finland

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Abstract
DRASTIC was modified from the previous intrinsic vulnerability assessment method of an aquifer proposed by Luoma et al. (2017) to incorporate the land use and land cover data that lies above the shallow groundwater areas. In this study the "Soil media" parameter was modified based on the uppermost soil layer and land use from the SYKE-CORINE Land cover 2018 dataset. The vulnerability rating was based on the attenuation capacity of the land cover and permeability of the soil zone. The method was applied to the Lahti and Hanhikangas- Mikkeli groundwater areas in southern Finland (Eskelinen et al., 2021). The results showed the relative DRASTIC index varies between 23 and 230 (Fig. 1), while adding the land use and land cover data, the index captured more details of the impacts from the urbanization. Vulnerability analysis can be applied to groundwater protection by combining potential risk activities to groundwater quality with the vulnerability maps. By adding groundwater flow directions to the map, the risk analysis can be used to assess the probability of contaminant transport to the water intake wells.

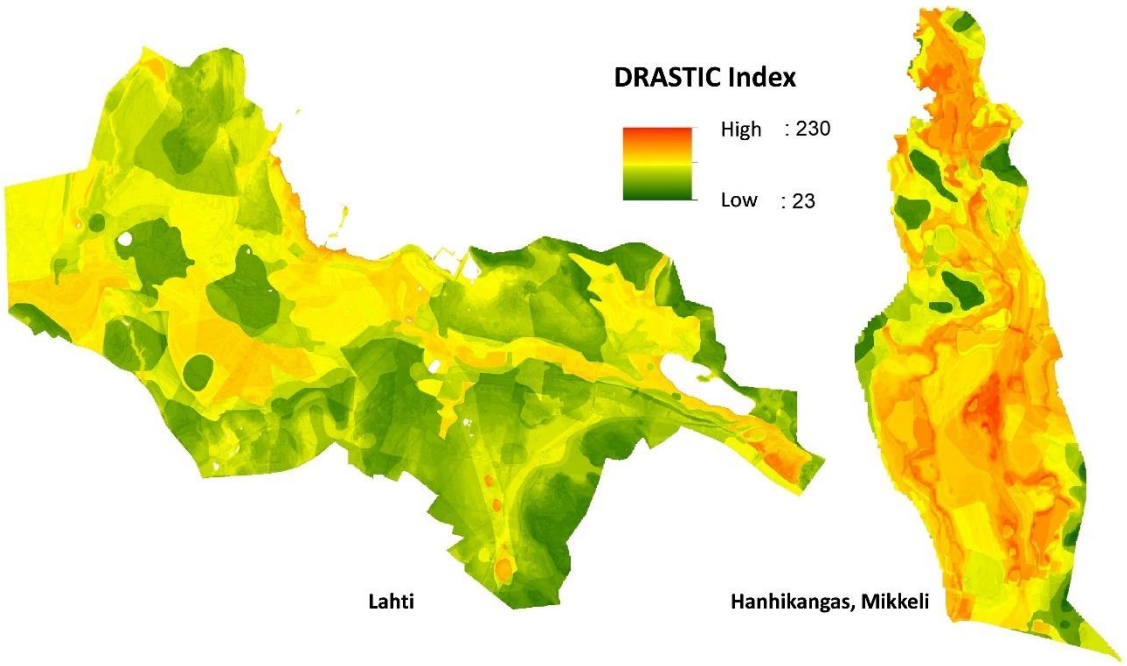


Figure 1. The relative DRASTIC vulnerability index maps of the shallow groundwater areas in Lahti and Hanhikangas, Mikkeli.

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A new high-quality 1885 Ma paleomagnetic pole for Fennoscandia from Svecofennian gabbros of central Finland

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Introduction

As an only quantitative method providing information of ancient latitudes and azimuthal orientations recorded in rocks, paleomagnetism is an essential tool in paleogeographic reconstructions. Most of the global high-quality paleomagnetic data is obtained from mafic intrusions. However, as mafic intrusions are inherently episodic events, there are significant gaps in the global high-quality paleomagnetic record.

High-quality paleomagnetic data for Fennoscandia is mostly derived from gabbro intrusions in Finland and Sweden. Many of these intrusions have been dated radiometrically, and are therefore promising targets for paleomagnetic investigations. Paleomagnetism of some of these gabbros have been studied previously (Pesonen & Stigzelius, 1972; Neuvonen et al., 1981), but sampling scheme back in the days does not meet the present-day statistical requirements. In this work we aimed to provide a new high-quality paleomagnetic pole to fill a gap in the paleomagnetic record of Fennoscandia at ca. 1930–1870 Ma.

Sampling and geological background

Sampling was conducted during two field campaigns in central Finland. In the Ylivieska municipality, samples were collected from six outcrops of well-dated 1883±8 Ma (Patchett & Kouvo, 1986) Ylivieska gabbro and from eight outcrops of smaller undated gabbro unit. Study area forms a part of the accretionary arc complex of central and western Finland (Korsman et al., 1997). In Kiuruvesi municipality, samples were collected from five outcrops of well-dated 1886±5 Ma (Marttila, 1981) Kiuruvesi gabbrodiorite, located on the Raahe-Ladoga tectonic zone separating the Svecofennian domain from the Archean Karelian Province.

Results and discussion

Data from this study was combined with previous studies on Ylivieska gabbro and Kiuruvesi gabbrodiorite (Pesonen & Stigzelius, 1972; Neuvonen et al., 1981). Combined data meets the present-day statistical quality standards and is statistically shown to average out the paleosecular variation. The new pole has a well-determined rock age of ca. 1885 Ma (Marttila, 1981; Patchett and Kouvo, 1986). Typical cooling rates of similar gabbro intrusions and comparison of the new pole to the high-quality paleomagnetic poles of Fennoscandia indicate that the magnetization age is likely close to the rock age, though the new data lacks the paleomagnetic field tests to prove the primary nature of magnetization. The new pole is overlapping the cluster of ca. 1870–1790 Ma paleomagnetic poles of Fennoscandia, indicating a long-time stable position for Fennoscandia at low to moderate latitudes. This is further supported by coeval paleoclimatic indicators in Finland and Sweden.

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Copper in the Rajapalot Au-Co Deposit

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Overview

Orogenic gold deposits are commonly referred to as gold-only in their classification (Goldfarb & Groves, 2005) with limited association of other metals. However, many Finnish orogenic deposits are associated with base metals and are referred to as gold deposits with 'atypical metal association' (Eilu, 2015).

The Rajapalot Au-Co deposit in the Peräpohja Schist Belt is one such 'atypical Au' deposit (Molnár 2019, Ranta et al, 2021), due to the prevalence of cobalt. In addition to cobalt, Rajapalot is variably enriched in copper.

Preliminary observations see copper enrichment to the north of the deposit, in the Palokas prospect, whereas gold grades are highest towards the south, in the Rumajärvi-Raja prospect. The alteration style changes gradationally from Mg-Fe chlorite-amphibole-tourmaline dominated, 'Palokas-type' to K-Fe muscovite-biotite-chlorite 'Rumajärvi-type'. In Palokas, host rocks are ultramafic-mafic in character, and more sulphides (ccp, po) are observed, in Rumajärvi-Raja metasediments are more prevalent, and sulphides less so. Gold is disseminated and vein-hosted (Ranta et al 2018), cobalt bearing minerals at Rajapalot are cobaltite, cobalt-pentlandite and linnaeite. It is currently understood that the cobalt mineralisation preceded the gold mineralisation event (Raič et al 2022).

Aims and Methods

We aim to examine why copper grades are elevated in Palokas and determine what the main controls are on copper grade; if lithology, structure, alteration style, or a combination dictates its spatial distribution. In addition, we will assess the relationship of copper with cobalt and gold (if any), and potential source rocks for copper both local and regional.

Petrography will be utilised to understand textural relationships of Cu-bearing minerals in relation to cobalt and gold phases, and EPMA analyses to examine mineral chemistry in detail and to aid Cu-mineral paragenesis, and then compared and integrated with paragenesis done for cobalt bearing minerals by Farajewic (2018).

Potential local and regional sources of the Cu will be identified and reviewed through the use of the extensive geochemical multi-element assay database, to see if local candidates are depleted in Cu. Regional samples will be collected spring 2023.

Further Implications

If the copper and cobalt relationship is linear, this may have implications for a sedimentary copperbelt setting with an orogenic gold upgrade. Findings may have implications regarding the broader question of; if base-metal enrichment in Finnish Au deposits can be explained by basin pre-conditioning or do other gold bearing models need to be considered, such as altered VMS, skarn, or epithermal deposits. A better understanding of these 'atypical' gold deposits will aid exploration efforts in the Peräpohja Schist Belt, and in the Central Lapland Greenstone Belt and Kuusamo Belt where similar are found.

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Rock surface attaching deep biosphere microbes and their functionality

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Introduction

Finnish deep bedrock and groundwaters create a niche that hosts diverse microbial life. Life in the deep is considered extreme as microbes face elevated pressure, absolute darkness, high salinity as well as low nutrient and carbon concentrations. Deep groundwater microbiomes have been studied in depth compared to the microbial communities residing on bedrock surfaces due to for example sampling technical issues. Now we characterized sessile mica schist microbial communities originating from the deep biosphere of Outokumpu, Finland (Nuppunen-Puputti et al., 2021; 2022; 2023).

Deep biosphere rock surface biofilms were studied both through *in-situ* incubations in the scientific deep drill hole in Outokumpu at the depths of 500 m and 967 m, and with microcosm experiments in the laboratory conditions. Microbial communities were characterized with amplicon sequencing of bacteria, fungi, and archaea. Rock surface community functionality was studied through metagenomics, and microbial marker gene copy counts were estimated with qPCR. Rock surface biofilms were visualized with scanning electron microscopy (SEM).

Rocky metagenomes hosted genes for heterotrophic metabolism, sulfur and carbon cycling as well as arsenate and selenate reduction. In addition, low molecular weight carbon compounds were shown to affect the structure of formed biofilms communities. A variety of genes linked to degradation of complex compounds were detected in the rock surface metagenomes suggesting potential for efficient recycling of necromass in deep subsurface biofilms. Sulfate reducing bacteria (SRB) were common on mica schist surfaces indicating that rocks could act a source of sulfur for deep subsurface microbes. SEM of mica schist surfaces showed that microbial cells had various attachment strategies linked to production of extracellular polymeric substances (EPS), long tubular or hair-like structures and stalks.

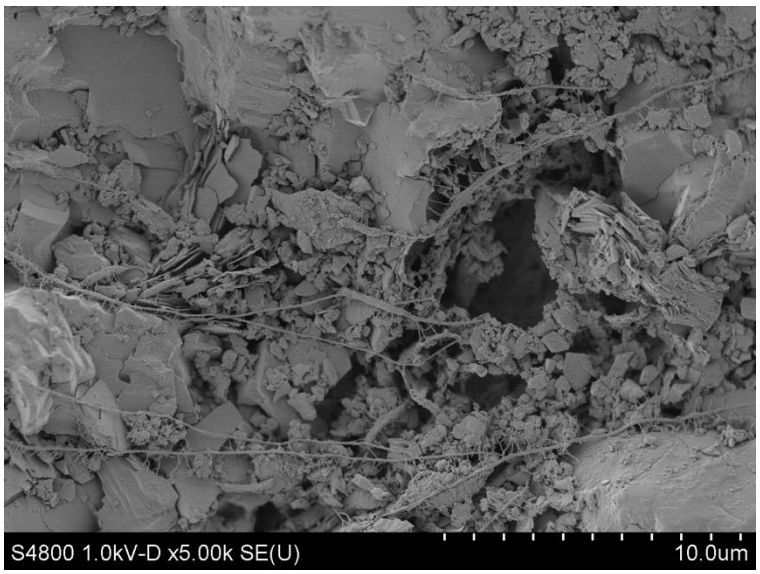


Figure 1. Attached filamentous microbial cell-like structures over mica schist surfaces after 8-month microcosm incubation of deep groundwater originating from the depth of 500 m from Outokumpu, Finland.

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Role of low energy ion particles in space weathering of asteroid spectra: laboratory simulation of solar wind irradiation using low energy H^+

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Space weathering can be defined as the combination of physical and chemical changes that occur in material exposed to an interplanetary environment on the surface of airless bodies. This process results in alterations in material spectroscopic features. Eventually it can lead to misinterpretation of remotely sensed data in the visible-near-infrared (VIS-NIR) wavelength range. The goal of this research is to simulate solar wind effect on asteroid spectra through low-energy 1 keV hydrogen ion irradiation of meteorite powder samples and measure the changes in their reflectance spectra. We simulated solar wind irradiation on three meteorites: Bjurböle (L/LL4), Avanhandava (H4) and Luotolax (Howardite).

Ion irradiation was carried out on meteorite pressed-powder samples under three fluences; 2×10^{17} and 5×10^{17}, 1×10^{18} H^+ cm^{-2} which corresponds to ~490 years, ~1200 years, and ~3100 years of exposure time, respectively at 2.3 au (approximately at inner asteroid belt). Reflectance spectra in VIS-NIR region (250 nm to 2500 nm) were measured for fresh and irradiated samples. The changes of reflectance spectra were evaluated using reflectance parameters such as band centre, band strength, full width at half maximum (FWHM), and band slope. These parameters were extracted by deconvoluting the absorption bands using Modified Gaussian Model (MGM).

In Bjurböle and Avanhandava, shows a clear evolution of the reflectance spectra from fresh towards irradiated samples while in Luotolax, the differences among the irradiated samples are less apparent but clearly distinct from the fresh sample. Two major absorption regions at 1 μm which results from olivine and pyroxenes and 2 μm which results from pyroxenes are identified in all samples. The most prominent changes in all three meteorites are (1) decrease of 550 nm reflectance, (2) reddening in 1-μm region, and (3) monotonous decrease in absorption band strengths in Bjurböle while these are rather insignificant or random in other meteorites. No significant changes were observed in the 2-μm region.

The results imply that at short timescale (10^2-10^3 years) radiation damage as amorphisation and vesicle formation caused by low-energy solar-wind (Chrbolková et al., 2022) is the dominant space weathering factor in all three meteorite compositions causing spectral changes predominantly in the 1-μm region. Only on longer timescales the spectral changes proceed into 2 μm region due to increasing cumulative effect of slower processes such as heavy ion and micrometeorite bombardment and associated occurrence of $npFe^0$. This will be more prominent in olivine-rich materials (A- or S-type asteroids) compared to pyroxene rich basaltic (V-type) asteroids.

Acknowledgements
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Detecting spatial patterns and phenology of peatland vegetation with remote sensing

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Introduction

Peatlands have stored about 650 gigatons of carbon, as one of the largest terrestrial carbon pools (Hugelius et al., 2020; Harris et al., 2021). Currently, Finland has a total peatland area of 9.1 million ha, covering about of its 30% of land areas (Turunen and Valpola, 2020). Vegetation links human beings and nature, indicating the sustainability and vulnerability of ecosystems. Under climate change, peatland vegetation patterns have shifted greatly. However, due to the lack of long-term in-situ observations, remote sensing with various strategies provides effective data support. Besides that, as high spatial heterogeneity exists in peatlands, ultra-high spatial resolution data, i.e., unmanned aerial vehicles (UAVs), are required for achieving precise monitoring. In addition, best to our knowledge, the hyperspectral sensor mounted UVA data was understudied in peatland management. In this project, we aim to (1) depict peatland vegetation patterns from various scales, i.e., field-aerial-satellite, by using state-of-the-art image analysis methods; (2) monitor the vegetation seasonal development, showing the possibility of using satellite data to trace ground vegetation phenology.

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Diverse microbial communities reflect the geochemistry of groundwater in Kurikka aquifer system, Finland

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Introduction and methodology

Groundwater provides an essential water supply worldwide. In Finland, 65% of water distributed by waterworks is groundwater. In Kurikka region, ancient Ostrobothnian buried river valleys host a substantial groundwater resource. Area has a complex groundwater route from the high-standing recharge areas towards the valley floor's coarse-grained aquifer, consisting of the interplay between permeable sediments and fractured crystalline bedrock. Current research done in collaboration with the Water Services Public Utilities of Vaasa (Vaasan Vesi), the Water Services Public Company of Kurikka (Kurikan Vesihuolto OY), Centre for Economic Development, Transport and the Environment in South Ostrobothnia (Etelä-Pohjanmaan ELY-keskus) and Geological Survey of Finland, aims to find enough groundwater to evaluate the possibility of large-scale water abstraction in the region to meet the demands of 150,000 people and the industries in cities of Vaasa and Kurikka. However, the flow paths and potential mixing of shallow and deeper groundwater, with potential input from the deep bedrock groundwaters are still poorly understood. Here we tested the potential of using a microbial fingerprint, i.e., the natural groundwater microbial community structure in different locations of the aquifer to distinguish between the origins of groundwater.

Microbial community structure was defined using an environmental DNA metabarcoding method. Groundwater samples from nine boreholes, one representing bedrock groundwater and others shallower, soil-related groundwater were retrieved. As groundwater is naturally oligotrophic environment, the microbial cell numbers are low. To collect enough biomass, 100 L of groundwater from each borehole was filtered ultrafiltering cartridge. Filter was rinsed, biomass concentrated, DNA extracted and quantified in THL laboratory (Kuopio, Finland). Sequencing the partial phylogenetic marker gene of bacteria, archaea and fungi, and analysis of the microbiomes were done in Eurofins Genomics Ltd. (Konstanz, Germany).

Results and discussion

Microbial diversity differed between the samples (Fig 1). The bedrock borehole R56 did have some bacterial members that were not detected in other groundwaters. For example, *Hydrogenophaga* -affiliating bacteria have been detected previously in deep drillhole fluids from Fennoscandian bedrock (e.g., Purkamo et al. 2013). Sulfate reducers were detected from most samples, iron oxidizers were common in some but not for example in R56. Most diverse microbial community was in HARJA10. MIETO17 and LOHI30 communities had abundant Nitrospirae population. Archaeal communities were mainly composed of euryarchaeal methanogens, but bedrock borehole R56 and NOPPA15 had also significant thaumarcheotal populations.

These preliminary results show that the groundwater microbial communities are indeed diverse and composed of different populations in different boreholes along the aquifer in Kurikka. The bedrock-related microbial community has some special features compared to the shallower, soil-related groundwater.

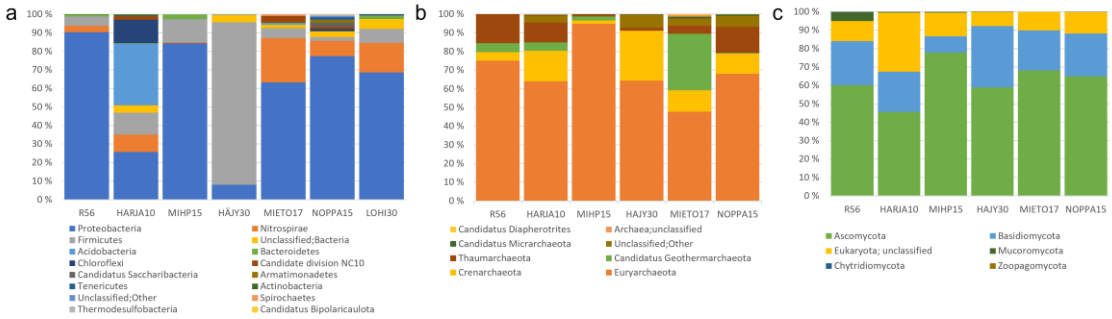


Figure 1. Bacterial (a), archaeal (b) and fungal (c) community structure in groundwater samples from different boreholes along the Kurikka aquifer. The x-axis names correspond to borehole names where microbial communities were successfully sequenced, and the colours in bars represent the relative abundance of the corresponding phylum presented in the legend below each barplot.

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Characterization of suspended particles in estuarine seawater at Pohjanpitäjänlahti using hyperspectral backscatter method

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Introduction

Suspended particulate matter in estuaries contributes to eutrophication dynamics in coastal and open sea waters, through cycling of carbon and nutrients (Asmala et al. 2022). Particles are a mix of minerogenic material and autochthonous or allochthonous organic matter, which can also form aggregates (Eisma 1993). Particles may be transported laterally or sink to the seafloor, thus redistributing carbon and nutrients within the coastal zone. By studying the dynamics of the particles in coastal systems, understanding of their role in eutrophication is enhanced. Pohjanpitäjänlahti is a semi-closed bay area in southern Finland, whose steady hydrological conditions enable research into particle dynamics in stratified coastal water columns. Previous studies (e.g. Asmala et al. 2022, Hjort 2020) have been done on the area to evaluate the particle size distribution in the water column using laser diffraction particle size analyzer and to determine the composition of particles with chemical analyses. However, these methods are limited in their ability to deconvolve the main components of suspended particulate matter.

Approach and preliminary findings

In this study, the particle size and compositional studies are supplemented with hyperspectral studies to evaluate the colour spectrum of suspended particles. The goal is to better understand the main components of the material, including the minerogenic matter, in order to understand how these components interact and influence sedimentation. We test whether the hyperspectral backscatter method can reveal the major components of the particle population through comparison of field data with spectra acquired from a range of suitable reference materials. Additional field data was collected using the LISST particle size analyzer and CTD sonde. Also, water samples were collected and filtered and the filters were studied with scanning electron microscopy (SEM-EDX) and trace element analysis (ICP-MS) to investigate the elemental composition.

The hyperspectral studies showed that it is possible to evaluate the minerogenic and organic matter distribution in the suspended matter and in some cases to specify the likely clay and oxide mineral assemblages. Uncertainties are caused by the unknown matter in the water and the effect of salinity and dissolved organic matter on the results. We will discuss these findings in the presentation.

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The making of monogenetic lava shields: a case study of the mid-Holocene Trölladyngja eruption, Iceland

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Monogenetic lava shields—gently sloping, conical lava mounds that erupted from a central vent—are some of the grandest and most iconic expressions of basaltic magmatism in Iceland's volcanic rift zones, with volumes of single eruptions exceeding 10 km^3. Shield eruptions differ in several significant ways from the more frequent, and more extensively studied fissure eruptions. Lava shields are thought to form by lower intensity, but longer duration effusive eruptions than fissure eruptions, and tend to be compositionally more primitive (higher MgO) and variable (Sinton et al., 2005). Moreover, many of Iceland's lava shields formed in the early Holocene, suggesting a causal link to deglaciation and associated increase in magma production rates. These differences appear to require fundamentally different geodynamic conditions and magmatic supply chains governing lava shields and fissure eruptions (Eason and Sinton 2009). However, the details of how and why lava shield eruptions occur remain poorly understood due to the lack of adequately characterized eruptions.

In this ongoing work, we investigate the influence of petrological processes on the formation of monogenetic lava shields by carrying out a detailed geochemical case study of the mid-Holocene ~15 km^3 Trölladyngja lava shield in the Northern Rift Zone of Iceland. We present an initial dataset comprising whole-rock major, trace element and Pb isotope data from 44 samples which cover much of the spatial extent of the lava apron and the central crater. Compared to adjacent fissure eruptions, the Trölladyngja lavas show greater variability in terms of both crystal content (from aphyric to plagioclase-olivine-phyric) and major element compositions (from primitive to moderately evolved basalts; MgO ≈ 7–12 wt.%). Similarly, the observed range in trace element (e.g., La/Sm, Nb/Zr) and Pb isotope ratios—that preserve signatures of mantle source, melting degree and magma mixing—suggest variable contributions from geochemically enriched and depleted mantle sources. Together, these initial observations indicate that the Trölladyngja eruption was not fed from a single well-homogenized magma reservoir—a conventional model for fissure eruptions—but rather, appears to involve variably evolved melts from a dynamic plumbing system that may have experienced recharge of mantle-derived primitive melts during the course of the eruption.

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Characterization of the lesser Himalayan soils as source or sink of semi volatile persistent organic pollutants (POPs): Inferences for source and environmental processes

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After decades of imposed regulations about reducing the primary emissions of persistent organic pollutants (POPs), these pollutants are still present in the environment. Soils are important repositories of semi-volatile persistent organic contaminants, and it is assumed that organic pollutants sequestered in these reservoirs are being re-mobilized due to anthropogenic influence. The study was designed to assess the impact of different land cover i.e., glacial, remote/mountainous and urban region of the Lesser Himalayan Region (LHR) in soil-air exchange flux of semi-volatile POPs and partitioning of these pollutants between two environmental matrices i.e., soil and air.

Six lakes in Lesser Himalaya Region (LHR) were selected based on altitudinal gradient and demographic set-up for collection of soil and air samples. Among the selected lakes, two were glacial lakes (Shounter and Ratti Galli Lake), Banjosa and Baghsar were high altitudinal alpine lakes, while Subri Lake and Mangal dam were categorized as urban reservoirs. Air samples were collected near the lakes during an eight-week period (3rd March – April 30, 2018) by using Polyurethane Foam–Passive Air samplers. Soil sub-samples were taken every fifteen days from each site and then combined to make a composite sample representing the air sampling period. The collected air and soil samples were analysed by three groups of POPs including organochlorine pesticides (OCPs), Polychlorinated biphenyls (PCBs) and Polybrominated Diphenyl Ethers (PBDEs). The extraction, analyses and quantification of collected air and soil samples were carried out at the Department of Environmental Science, Stockholm University, Sweden.

The concentrations of OCPs, PCBs and PBDEs in soils and air ranged between 0.01 and 2.8, 0.81–4.8, 0.089–0.75 ng g^{-1}; 0.2–106, 0.027–182, and 0.011–7.26 pg m^{-3}, respectively. The levels of POPs in the soil were correlated with soil organic matter indicating that organic matter is a substrate for the organic pollutants in soils. The Clausius-Clapeyron plots between lnP and inverse of temperature (1000/T) suggested that long range atmospheric transport was the major input source of PBDEs and higher chlorinated PCBs over the LHR. Uneven and wide distribution of local sources in LHR and up-slope enrichment of POPs explained the spatial variability and altitudinal patterns. The soils near mountain and urban lakes act as local sinks of POPs such as β-HCH, *pp′*-DDT, CB-28, -118, −153, BDE-47, -99, and −154, with soil-air exchange fluxes tending more toward deposition. However, the soils near glacial lakes acted as local sources of more volatile congeners of α-HCH, γ-HCH, *op′*-DDT, *pp′*-DDE and lower to medium chlorinated PCBs such as CB-18, -28, −53, −42 and BDE-47, -99, with soil-air exchange tending more toward volatilization flux (shown in Figure 1). It was found that both local emissions and atmospheric transport were major input sources for OCPs and PCBs while long range atmospheric transport was the predominant source of PBDEs in LHR. Lateral remobilization and land use changes may explain the different distribution pattern of POPs in soils near lakes of LHR.

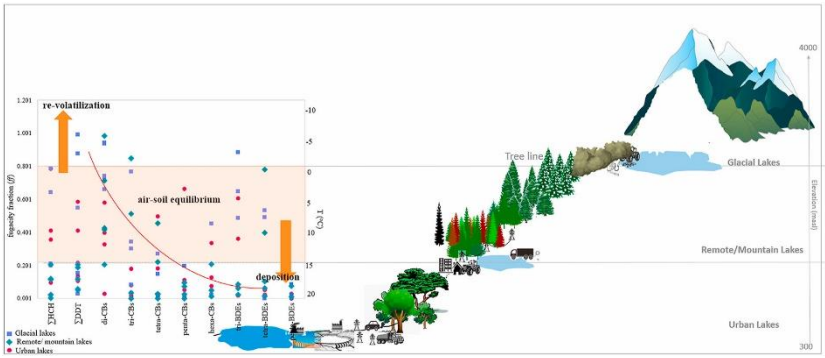


Figure 1. Soil-air exchange calculated via fugacity fraction (*ff*) at different lakes of LHR with different land cover. Dashed lines indicate the equilibrium interval (0.2–0.8).

Orgaanisen hiilen määrä ja alkuperä pohjoisissa rannikkosedimenteissä

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Pohjoiset ja arktiset alueet ovat erityisen herkkiä ilmaston muuttumiselle. Ilmaston lämpenemisen ja sen aiheuttamien lieveilmiöiden sekä ihmistoiminnan vaikutuksesta pohjoisten alueiden hydroklimatologiset olosuhteet tulevat muuttumaan. Tämä johtaa esimerkiksi merijää- ja lumipeitteen pienenemiseen sekä sulannan ja maalta meren päätyvän makean veden määrän lisääntymiseen. Näin ollen myös rannikkoalueille kulkeutuvan orgaanisen aineksen määrä kasvaa. Lisääntyneen orgaanisen aineksen määrän vaikutus pohjoisiin ekosysteemeihin tunnetaan huonosti ja näiden vaikutusten arvioimisen tarve on suuri. Hiilen alkuperän selvittäminen on tärkeää, koska eri alkuperää oleva hiili toimii ravintoverkoissa eri tavoin. Tulevaisuuden olosuhteiden ennustamiseksi on tärkeää ymmärtää hiilen kiertokulkua ja tietää, miten hiili liikkuu ilmakehän, terrestrisen eli mantereisen alueen ja merten välillä. Tätä varten on tärkeä tietää esimerkiksi se, onko orgaaninen hiili peräisin pääasiallisesti maalta vai meristä.

Tämän maisterintutkielman tarkoituksena on selvittää, miten ilmaston lämpeneminen ja ihmistoiminnan vaikutuksen lisääntyminen, lisääntynyt sulanta sekä orgaanisen aineksen kulkeutuminen vaikuttavat pohjoisten rannikkoalueiden sedimentteihin kertyneen hiilen määrään ja mikä on niihin kulkeutuneen hiilen alkuperä. Tutkimusalue on Perämeren rannikot maantieteellisellä akselilla Kemi-Liminka. Lisäksi tutkimuksen tarkoituksena on selvittää, miten Perämeren rannikkoalueiden sedimentteihin kertyneen hiilen määrä on muuttunut ajan kuluessa ja ilmaston lämmetessä sekä miten valuma-alue vaikuttaa rannikkosedimentteihin kertyneen hiilen määrään ja alkuperään.

Orgaanisen aineksen, erityisesti hiilen ja typen, määrää voidaan tutkia rannikkoalueiden merisedimenteistä hyödyntäen isotooppi- ja alkuaineanalyysejä. Tässä tutkimuksessa analysoidaan Perämeren rannikkosedimenteistä kerätyt 21 pintasedimenttinäytettä ja 37 sedimenttikoorinäytettä (yhdestä 37 cm koorista). Näytteistä selvitetään orgaanisen hiilen (TOC) ja typen kokonaismäärät (TN), niiden välinen hiili-typpisuhde (C:N) sekä stabiili-isotooppisuhteet $\delta^{13}C$ ja $\delta^{15}N$ jatkuvan virran EA-IRMS-analyysaattorilla (alkuaineanalyysi-isotooppisuhdemassaspektrometri). Sedimenttikoorin näytteet ajoitetaan radiometrisesti lyijyn stabiileilla isotoopeilla $^{210}Pb/^{137}Cs$ ja $^{206}Pb/^{207}Pb$ Tutkimuksen ensimmäisen hypoteesin mukaan orgaaninen hiili on alkuperältään terrestristä erityisesti lähellä Perämeren rannikkoa ja suurten jokien suita. Näillä alueilla meren ja jään perustuotannosta peräisin oleva hiilen merkitys on vähäisempi ja vaihtelevampi. Toisen hypoteesin mukaan Perämeren rannikkosedimentteihin kertyneen orgaanisen hiilen määrä on lisääntynyt ilmaston lämmetessä ja lämpenemisen aiheuttamien lieveilmiöiden seurauksena. Tutkimus valottaa orgaanisen aineksen jatkuvia muutoksia pohjoisissa ekosysteemeissä ja tarjoaa arvokasta vertailuaineistoa muita pohjoisia rannikkoalueita koskeviin tutkimuksiin.

The High Arctic Large Igneous Province in Svalbard: understanding its magmatic evolution using geochemistry and geochronology.

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Large Igneous Provinces (LIPs) are widespread in the geological record and can have a significant impact on the global climate and environmental conditions. The apparently long-lived and multi-phase High Arctic Large Igneous Province (HALIP) was emplaced during the Cretaceous (ages ranging between ~140-80 Ma). Both intrusive and extrusive remnants of this large-scale magmatism can be found across the circum-Arctic. Recent community efforts to unravel the timing and nature of HALIP have emerged, however, additional geochronological data combined with petrological and geochemical studies are needed to understand the evolution of the HALIP. On Svalbard, the HALIP is represented by the Diabasodden Suite intrusions (122-125 Ma), which are still mostly unexplored despite the relative accessibility of outcrops. To bridge crucial knowledge gaps of the evolution of HALIP on Svalbard and beyond, a PhD project was developed in collaboration crossing several Nordic institutions. The project utilizes both existing geological samples and is supplemented by several field campaigns in strategic locations to cover the exposed, onshore extent of the Diabasodden Suite. The additional sampling and analysis will, in particular, enhance our understanding of the magma evolution and emplacement mechanisms at these localities which can then be extrapolated to a circum-Arctic scale. This project will thus contribute new geochemical, isotope, and age data from Svalbard to better understand the magmatic history of the HALIP as a whole.

The project so far contributed with new U-Pb baddeleyite ages from Ekmanfjorden, central Spitsbergen, based on 6 mafic units sampled in 2020 and 2021. In 2022, detailed sampling campaigns at Wallenbergfjellet and Botneheia yielded 180 dolerite samples that are currently being analysed for whole-rock geochemistry at the University of Helsinki together with MSc student Lauri Malinen. Some of the coarsest samples will be chosen for additional U-Pb geochronology, which will be done at Lund University, Sweden. This year, further sampling in central Spitsbergen and along the northern shores of Nordaustlandet will take place, and in 2024 we will cover the east coast of Spitsbergen and surrounding islands. This will ultimately lead to a comprehensive database of geochemical data from the HALIP on Svalbard and a better understanding of the complexity of the Diabasodden Suite. The geochemical data will also be used to develop a model of the magma evolution processes in LIPs and especially at the marginal position of the HALIP. Further U-Pb geochronology is also planned, with the aim to get high-precision high-accuracy age estimates with a good geographical spread. The combined new data will be used to study how the emplacement of the HALIP relates to the break-up of the Arctic Basin, by testing various models using plate tectonic reconstructions.

Strontium isotopes in identification of food forgeries in Finland

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Introduction

Discovering new methods to detect food forgeries is crucial to maintain food security, support the local production and providing novel tools for the food authorities in the European Union. Food forgeries are an increasingly observed world-wide problem including both the forging of origin and consistency of food. The development of strontium isotope method in identification of food forgeries (SIKRUT) is a research project of Finnish Food Authority funded by Jane and Aatos Erkko Foundation. The focus of this study is the forging of origin of food, and the aim is to develop a reliable method based on strontium isotopes for identifying the forgeries of food origin in Finland.

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) provide a powerful tool for tracing the origin of different organic materials based on the $^{87}Sr/^{86}Sr$ variation in the bedrock. It has been used in provenance analysis in ecology, food science, archaeometry, forensics, and environmental sciences (e.g. Åberg, 1995). The method is well-known and applied to different environmental and food matrices ranging from wine (e.g. Rapa et al., 2022) to tree leaves (Pallavicini et al., 2018). However, due to lack of local baseline and comprehensive previous studies, the method has not yet been widely applied in Finland. Moreover, further knowledge of the possible interfering factors of the $^{87}Sr/^{86}Sr$ ratios such as liming, glacial sedimentary formations (Andreasen & Thomsen, 2019), and pH (Johnson et al., 2022) is needed.

This is the first study where the $^{87}Sr/^{86}Sr$ ratios are extensively applied on provenance analysis of foodstuff and organic materials in Finland. The study covers a large part of the cultivated areas of Finland and considers the effects of bedrock, soil, later glacial sedimentary formations, pH, liming, and irrigation to the variation of the $^{87}Sr/^{86}Sr$ ratios in the agricultural context. Elemental concentrations and the $^{87}Sr/^{86}Sr$ ratios are analysed from different matrices using a sector-field inductively coupled plasma mass spectrometer (ICP-SFMS), and a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS), respectively (Rodushkin et al., 2016).

The first part of the research studies the variation of $^{87}Sr/^{86}Sr$ in Finnish strawberries (*Fragaria x ananassa*) and agricultural soils. Fresh berries would be one example of forged food in Finland since it is relatively effortless to forge the origin of the berries only by changing the packaging labels. The $^{87}Sr/^{86}Sr$ ratios are measured from 120 strawberry samples collected from different strawberry farms in Finland and compared to the $^{87}Sr/^{86}Sr$ ratios of soil samples from 30 farms. The effects of rock and soil type, geospatial location, pH, and irrigation to the variation of the $^{87}Sr/^{86}Sr$ ratios in strawberries and soils are studied. The becoming sub-studies aim to study the effects of liming of agricultural soils and the acidity of soil to the $^{87}Sr/^{86}Sr$ ratios.

As a result, this study aims to define $^{87}Sr/^{86}Sr$ baselines for Finland and create an isoscape, a map of bioavailable strontium, that would cover the majority of Finland. This data can be used as baselines in different applications, like identifying the potential source of foodstuff, plant-based materials, and human and animal individuals. Consequently, the results of this research can be used to develop a method based on the $^{87}Sr/^{86}Sr$ to identify food forgeries in Finland and distinguish Finnish food products of those of foreign origin.

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Possibilities of peatlands in mitigating climate change – a transformation from emission sources into carbon sinks

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Introduction

Peatlands are the most carbon-rich ecosystems in the world. They contain as much as 25 % (i.e. 600 Pg) of the global carbon storage, even though peatlands cover just 3 % of the land area of the Earth (see Loisel et al. 2021). Actual emissions of degrading peatlands are globally in average 1.91 Pg CO_2-eq a^{-1} (Leifeld and Menicetti 2018). Conservation of the natural peatlands, and restoration of the degraded drained peatlands converted back to the peat accumulative ecosystems, are effective measures for carbon capture and removal from the atmosphere.

The climate policy of the European Union is based on the UN Convention on Climate Change, the supplementary Kyoto Protocol, and the Paris Agreement. According to the European Climate Law member countries should be carbon neutral till 2050. The Land Use, Land Use Change, and Forestry (LULUCF) sector is responsible in practise for the carbon sinks. However, in 2021, the LULUCF sector of Finland seems to have transformed into an emission source. In 2020, greenhouse gas emissions from forest organic soils, and cropland organic soils were 3.80 Mt CO_2-eq, and 6.56 Mt CO_2-eq, respectively. In addition, emissions from peat extraction sites are 2.6 t CO_2 per ha. (Statistics Finland 2022).

Materials and methods, and preliminary results

We discuss the possible effects of the management of cutover peatlands, forest-drained peatlands, and peat-soiled croplands on mitigating climate change. We have established intensive observation stations on 1) Naarasneva (Soini) cutover peatland area to study climate impacts of afforestation; and 2) on Rottasniitunsuo (Tammela) forest-drained fertile peatland to study impacts of peatland restoration. Greenhouse gas fluxes are measured by the Eddy Covariance method. Soil gas emissions are measured by the chamber method. Aerosol particulates are investigated by applying the Neutral cluster and Air Ion Spectrometer (NAIS). Ecological changes in the vegetation of the sites, as well as changes in the water quality of the drainage area, are monitored on the field. Methane production and oxidation potential are examined through incubation experiments in the laboratory by Gas Chromatography analyses.

Cutover peatland turned out to be an occasional carbon sink even in the same year that the afforestation was implemented. The reason for carbon sequestration, which exceeded the emissions due to the decomposition of the peat, was the growth of understorey vegetation, not only the growth of the pine saplings. Restoration measures require raising the water table. That causes the formation of methane in anoxic conditions, which in short term, has a warming impact on the climate. Carbon sequestration by an accumulation of peat, in the long run, can compensate for the climate warming effect of greenhouse gas emissions. The same problem of increasing methane emissions is encountered when rewetting the organic agricultural soil. Nevertheless, wetland farming can be a part of a solution when tackling the problem of LULUCF sector unexpected imbalance with greenhouse gas emissions and sinks.

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International Union of Geodesy and Geophysics (IUGG)

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Structure and strategy

The International Union of Geodesy and Geophysics (IUGG), founded in 1919, is a non-governmental scientific organization dedicated to advancing, promoting, and communicating knowledge of the Earth, its space environment, and the dynamical processes causing change. IUGG promotes and coordinates scientific studies (physical, chemical, and mathematical) of the Earth and its environment in space and encourages application of this knowledge to societal needs, such as mineral commodities, mitigation of natural hazards, and environmental preservation. In particular, IUGG focuses on the physics and chemistry of the Earth's interior, surface, fresh waters, cryosphere, oceans and atmosphere, as well as relevant studies of other planets.

Currently, IUGG has 73 member countries in Africa, Asia, Europe, North and Central America, Oceania, and South America and scientists in the member countries can participate in IUGG activities through the National Committees of IUGG. IUGG is composed of eight semi-autonomous Associations: International Association of Cryospheric Sciences (IACS), International Association of Geodesy (IAG), International Association of Geomagnetism and Aeronomy (IAGA), International Association of Hydrological Sciences (IAHS), International Association of Meteorology and Atmospheric Sciences (IAMAS), International Association for the Physical Sciences of the Oceans (IAPSO), International Association of Seismology and Physics of the Earth's Interior (IASPEI), and International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). IUGG also has Union Commissions and a Working Group that promote research on particular interdisciplinary problems: Climatic and Environmental Change (CCEC), Data and Information (UCDI), Geophysical Risk and Sustainability (GRC), Mathematical Geophysics (CMC), Planetary Sciences (UCPS), Study of the Earth's Deep Interior (SEDI), and the Working Group on History (WGH). Through the Associations and Commissions, IUGG undertakes research, assembles observations, gains insights, coordinates activities, liaises with other scientific bodies, plays an advocacy role, contributes to education, and works to expand capabilities and participation on a global scale.

Endeavours

The IUGG Associations and Commissions run frequent symposia and workshops on timely topics in the respective disciplines and the IUGG General Assembly is arranged every four years. IUGG has initiated many collaborative efforts that have led to highly productive interdisciplinary research programs, e.g. the International Lithosphere Program (ILP – a joint activity of IUGG and the International Union of Geological Sciences), Global Geodetic Observing System (GGOS), Extreme Natural Hazards and Societal Implications (ENHANS), International Year of Deltas (IYD), Mathematics of Planet Earth (MPE), World Data System (WDS), World Climate Research Program (WCRP), and International Geosphere-Biosphere Program (IGBP). IUGG also runs publishing activities, the Special Publication Series of IUGG (Cambridge University Press) as well as Association-affiliated journals and books, among them the Journal of Geodesy (IAG), the Hydrological Sciences Journal (IAHS), and the Bulletin of Volcanology (IAVCEI).

To best respond to the challenges of the changing Earth environment and society, special attention is paid to (1) encouraging early career scientists to participate in international science activities, e.g. through appropriate Association-level strategies and travel grants; (2) enhancing the possibilities of countries and agencies to provide free access to data and information, and to initiate collaborative projects with a regional and global scope; and (3) contributing to the education of future generations of geoscientists, taking into account challenges and inequities such as gender inequalities, the need to offer education for individuals with diverse backgrounds, and the need for greater cross-disciplinary knowledge. The Finnish National Committee of Geodesy and Geophysics has representatives for each of the Associations of IUGG and Finland has been actively involved in the activities of IUGG from the outset.

Colloidal gold transport in the Paleoproterozoic orogenic gold deposits: Outlining objectives of the PhD project

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Orogenic gold deposits host major part of the world's gold reserves and are the most important gold deposit type in metamorphic terrains. Deposits are strongly structurally controlled and form relatively deep in the crust (5-20 km) from metamorphic fluids. Recent studies from orogenic gold deposit in Australia show that in addition to gold transport in solution as dissolved species, hydrothermal fluids can carry colloidal particles as a suspension load (Petrella et. al 2022). These findings have enormous implications how formation of orogenic gold deposits is understanded. However, more research focusing on nanoscale processes of gold is needed globally.
In our study, nanoscale processes of gold are studied from orogenic gold deposits located within Paleoproterzoic Central Lapland belt (CLB) and Peräpohja belt (PB). Reference deposits include Ikkari Au (CLB) and Rajapalot Au-Co (PB). Analytical workflow starts with proper selection of samples containing native gold and preparation of polished thin section, Selected samples are studied under reflective light and subsequently with FE-SEM (Field Emission- Scanning Electron Microscope), followed by preparation of micron scale lamellaes from within native gold using FIB-SEM (Focused Ion Beam- Scanning Electron Microscope). These lamellaes are suitable for nanoscale research with the TEM (Transmitted Electron Microscope) instrument. Study is part of Tapio Soukka´s PhD research, focusing on nanoscale processes of gold and platinum minerals in primary and secondary mineral deposits as well as developing robust workflow of nanoscale research in the Material Analytical Center in the University of Oulu.

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Detecting mode of sediment transportation and fine scale shifts in provenance by Dynamic Image Analysis: a methodological study

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The sediment transportation medium, mode, energy and distance are linked to the observed grain-size and grain-shape distribution in a sedimentary deposit. Grain-size analysis has been a well-established technique for almost a century now but within the last few decades also grain-shape analysis has been gaining a firm footing in deciphering past climates and environments. By combining these two techniques, more details can be obtained. Dynamic Image Analysis (DIA) is a novel method that enables to simultaneously measure the grain-shape and grain-size properties from a sedimentary sample. Especially when studying fine sediments, this method has proven to be efficient in separating not only different depositional environments but also the wind speeds when considering aeolian deposition (Shang et al., 2018; Yang et al., 2019; van Buuren et al., 2020; van Hateren et al., 2022). Here, we aim to use DIA data in endmember modelling of size-shape distributions (EMM-SSD) introduced by van Hateren et al., (2020) to detect the mode of sediment transportation and fine-scale shifts in provenance.

We analyzed topmost 10.35 m (ca. 32 ka) of a high-resolution sample set (sampled in 5-cm intervals) from the northern edge of Mangshan Loess Plateau, China. This sequence was chosen because of the high sedimentation rate (approx. 32 cm ka^{-1}; Peterse et al., 2011) enabling detection of rapid climatic and environmental changes. The research is on-going, and we are working with the preliminary results from the EMM-SSD.

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Trace element mobilization during pyrite-goethite alteration in supergenic oxidation processes in till: usability in the fingerprinting analysis of the mineral deposit's formation

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Introduction

Compositional information on sulfide minerals, especially the trace element content of pyrite has proven to be an effective discriminating tool to identify mineralization stages and separate relating or non-relating pyrite of the formation of the mineral deposit in question (e.g., George et al., 2017; Duran et al., 2019; Raić et al., 2022). The concept of mineral fingerprinting is based on trace element and isotope analyses of minerals having different geochemical signatures related to their crystallization environment. Pyrite (FeS_2) is one of the most common sulfide in various mineral deposits and can form under various conditions (e.g., Berner 1970).

In studies of pyrite from bedrock samples, LA-ICP-MS (Laser Ablation Inductively Coupled Mass Spectrometry) technique enables in-situ analyses of individual sulfide grains providing robust information of the compositions in different textural associations within the samples. The information gathered from the pyrite in primary mineral deposits can be used to compare compositions of pyrite grains found in the glacial tills. However, in the case of transported sediments, the successful recovery of fresh pyrite grains from the sediment fractions can be difficult as the pyrite grains are often highly oxidized, resulting alteration partly or totally goethite. Usability of goethitized pyrite grains for fingerprinting has not been studied and the trace element mobility during the transition is poorly known. Preliminary trace element analyses of goethite rims show enrichment of some elements (e.g., Co, Ni, and Mn) compared to the unaltered pyrite core. In this study, multiple micron scale lamellae are prepared from partially goethitized pyrite using FIB-SEM (Focused Ion Beam Scanning Electron microscope) and followed by TEM (Transmission Electron Microscopy) investigations of the nanoscale characteristics of the alteration. Nanoscale Information is combined with in-situ major- and trace element analyses of the grains in order to understand the geochemical properties, i.e., the mobilizing and immobilization of different elements during oxidation. Finally, the usability of oxidized pyrite grains in till for mineral deposit fingerprinting, is evaluated.

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Geokemisk jämförelse av sidoberg och pegmatiter i Österbottens skifferbälte, Seinäjoki och Kuortane regionen, Finland

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Introduktion

Inom EU har man listat 16 st. rare Earth elements, som är så kallade kritiska grundämnen och är viktiga för bl.a. högteknologiska branscher. Bland de kritiska grundämnen räknas också Li, Ta, Be, Nb, Hf och Ga som kan utvinnas bl.a. från pegmatiter (Blengini et al., 2020). De är så kallade LCT-familjens pegmatiter (Li, Cs och Ta anrikade). Enligt Simmons et al. (2008) kan pegmatiter uppkomma via partiell uppsmältning av sedimentära bergarter, dvs. från sidoberget. Detta tyder på att där vi har anrikade sidoberg borde det även finnas anrikade pegmatiter (Simmons et al., 2008).

Österbottens skifferbälte är belägen i Svekofenniska domänen mellan Vasa komplexen och mellersta Finlands granitoidkomplexen i västra Finland. Detta skifferbälte karakteriseras av metasedimentära bergarter, pegmatitiska granitintrusioner och olika utvecklade pegmatitgångar. Längst utvecklade pegmatiter (LCT) förekommer i centrala och östliga delen av skifferbältet med låg metamorfosgrad (Alviola et al., 2001), men också en låg blottningsgrad, vilket gör prospektering av pegmatiter i området problematiskt.

I denna studie testar vi om anrikningen av pegmatiter kan ses i sidoberget. Vi jämför geokemisk data av sidoberget bestående av glimmerskiffer med olika utvecklade pegmatiter i Seinäjoki och Kuortane regionen i Österbottens skifferbälte. Provtagning i fältet gjordes av glimmerskiffer (sidoberg) i områden med låg metamorfosgrad i profiler vinkelrätt mot skiffrigheten. Denna studie kan introducera en ny metod för pegmatitprospektering genom analys av sidobergets geokemi och petrografi.

Geokemisk klassificering

Pegmatiter i studieområdet indelades geokemiskt till anrikade, intermediära och icke-anrikade enligt Li, Cs och Rb halter, eftersom dessa grundämnen utgör ett intresse inom prospektering av pegmatiter ifall de överskrider tre gånger medelvärdet i övre jordskorpan (Selway et al., 2005). Ifall Li, Cs och Rb förekom <3 gånger medelvärdet definierades pegmatiten till icke-anrikad, ifall åtminstone ett av dessa grundämnen förekom 3–6 gånger över medelvärdet till intermediär och om Li, Cs eller Rb förekom >6 gånger medelvärdet till anrikad. Ytterligare gjordes också petrografisk beskrivning av sidoberget.

Resultat och diskussion

Provtagningsprofiler av glimmerskiffer analyserades skilt i varje grupp för att observera fluktuering av Li, Cs och Rb halter i förhållanden till olika anrikade pegmatiter. Anrikade glimmerskiffergrupper hade en stor fluktuering av Li, Cs och Rb, finkornig textur och glimmerrik mineralsammansättning. Icke-anrikade grupper hade jämn fluktuering av Li, Cs och Rb, medelkornig textur, sillimanit och låg glimmermineral halt. Intermediära gruppen hade jämn fluktuering och relativt låga halter av Li, Cs och Rb, medelkornig textur, granat och låg glimmermineral halt.

Resultat indikerar fluktuering av Li, Cs och Rb i sidoberg i områden med anrikade pegmatiter medan jämn fluktuering förekommer i områden med icke-anrikade pegmatiter. Petrografiska resultat kan tyda på lokala variationer i metamorfosgrad, högre i icke-anrikade och intermediära grupper jämfört med anrikade grupper med lägre grad. Om detta stämmer kan det vara nyttig i pegmatitprospekteringsarbete att också fokusera på sidobergets mineralogi – åtminstone i Österbottens skifferbälte.

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Zircon ages of two felsic volcanic rocks from the Orijärvi area, southern Finland

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Introduction

The Uusimaa belt in southern Finland consists predominantly of migmatitic rocks but the Orijärvi area within the belt contains well-preserved volcanic rocks metamorphosed at lower temperatures compared to its surroundings. This makes it a key study area for resolving the stratigraphy and understanding the crustal growth of the Svecofennian Orogen.

The stratigraphy of the Orijärvi area is divided into four formations: the Orijärvi, Kisko, Toija and Salittu formations (Väisänen and Mänttäri, 2002). The Orijärvi formation is the lowermost overlain by the Kisko formation and represent the growth of a volcanic arc. The Toija and Salittu formations are considered to represent younger arc rifting. Previous age determinations are indicated in Fig 1c. In this study we present two new zircon ages on felsic volcanic rocks and aim to provide more detailed view of the chronostratigraphic relations in the Orijärvi area.

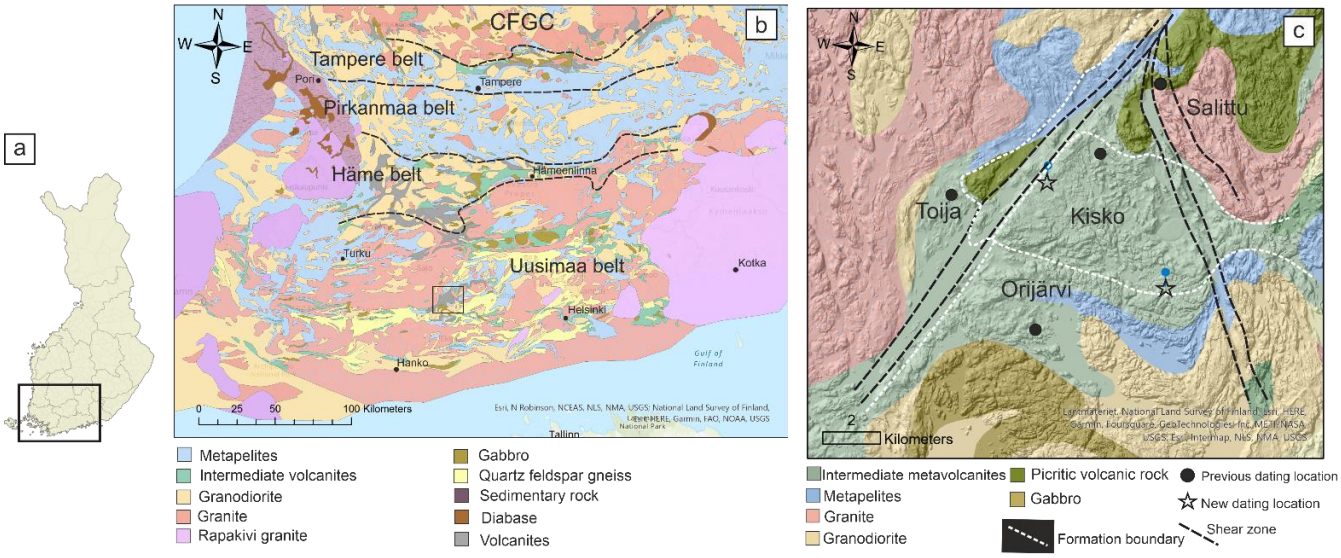


Figure 1. a-b. Geological overview of southern Finland c. Main geological units of the study area. Previous age determinations: the Orijärvi formation 1895±3 Ma and the Kisko formation 1878±4 Ma (Väisänen and Mänttäri, 2002), and the Toija Formation 1878±4 Ma (Väisänen and Kirkland, 2008) are shown. Based on field relations the age of the Salittu formation is interpreted to be approximately 1875 Ma (Nironen et al., 2016).

Results and discussion

Two samples were collected from the Kisko formation for zircon LA-ICP-MS U-Pb age determinations: the Kavasto rhyolite from the nortwestern part of the formation and the Sorvasto rhyolite from the southern margin of the formation (Fig. 1c). The Kavasto rhyolite contains prismatic to small and rounded grains with several age populations, between 1.89 and 3.0 Ga which we interpret as inherited zircons. The youngest population that yields an age of 1.88 Ga is interpreted as the age of the felsic rock. The Sorvasto rhyolite contained mostly prismatic grains with some older inherited material as well, but the main zircon population yielded an age of 1.89 Ga. These ages confirm the previous idea on the growth of the area where the volcanism of the Orijärvi and Kisko formations becomes younger towards the north.

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Focal spot imaging sensitivity to asymmetric array configurations and combined anisotropic energy flux

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1. Introduction

Seismic imaging is an important part of Geoscience research as it provides information about the internal structure of the Earth, ranging from plate tectonic scales over complex fault zone systems to near-surface environments for geophysical exploration purposes. The target of seismic imaging is the seismic velocity structure that is primarily obtained from travel time properties of seismic waves observed with seismic sensors.

In this work, we explore the imaging potential of refocusing surface waves reconstructed from noise correlation functions. At zero lag-time, converging surface waves create a large amplitude feature at the origin referred to as focal spot, with properties governed by the medium. Focal spots have long been used in acoustics and medical imaging (Catheline et al., 2008). We treat dense seismic arrays equivalent to medical ultrasound transducers that allow the reconstruction of focal spots at short distances. The equivalence between the time-domain focal spot and the frequency-domain spatial autocorrelation allows the application of classic SPAC results (Aki, 1957; Haney et al., 2012) for local Rayleigh-wave phase velocity estimates. We focus on demonstrating the general applicability of the method using the USArray dataset, and we investigate the biasing effect of the non-isotropic energy flux of the ambient field on the estimation of the velocity velocity.

2. Numerical studies and application to USArray data

The SPAC formulation entails that azimuthal averaging yields accurate surface-wave phase velocity estimates from spatial autocorrelation fields for anisotropic energy flux. We explore the effect of frequently observed directional noise on configurations that do not allow the reconstruction of the focal spot homegeneously at all azimuths. Such configurations are related to stations located towards the edges of quadratic or circular dense arrays, or to stations in arrays with irregular shapes. First, we perform numerical experiments where we test different cases of the focal spot position in a rectangular array, the aspect ratio of the array, the strength and direction of the anisotropic incidence. For realistic scenarios, the application of a formulation that explicitly accounts for the effects of anisotropic incidence (Nakahara, 2006) yields always smaller errors than the classic SPAC parameterization. The difference in error between the two parameterizations depends on the configuration, and it ranges between 1.2% and 12%. Second, the two solutions are applied to focal spots that are reconstructed from USArray noise correlations in the period range 60 s to 100 s, where the noise energy flux has a dominant NW-SE direction (Rhie et al., 2006). In the corresponding synthetic test case, the difference between the error values from the two parameterizations is 1.2%, which implies that the classic SPAC approach still provides relatively accurate results. We obtain spatial phase velocity distributions from focal spots using rectangular station geometries with variable aspect ratios similar to the numerical tests. Again, the high similarity between the velocity distributions obtained with the two parameterizations indicates that the classic and computationally more convenient formulation is a robust approach for estimating the velocity for the specific background illumination that governs USArray focal spots.

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High-latitude peatlands under changing climate – from new initiation to regime shifts and degradation

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Introduction

Northern peatlands are an important part of the global carbon cycle, as they store approximately 415 Pg of organic carbon. Because of climate change, peatland ecosystems are changing, which further affects to their carbon cycle. Such changes could lead both mitigating or accelerating climatic feedbacks, but more research is needed to better estimate the upcoming changes and their magnitude.

My doctoral studies are linked to the Academy of Finland funded DISPEAT-project, coordinated by Minna Väliranta. DISPEAT-project aims to increase understanding of climate change-related peatland dynamics and feedbacks over the high-latitudes. My project is multidisciplinary, focusing on these processes from various angles. The three sub projects create an interesting continuum from new peatland initiation to regime shifts and peatland degradation.

Firstly, I will study new peat initiation and carbon accumulation in a high arctic environment. Material was collected from Greenland. Soil profiles will be dated by radiometric methods and property analyses (loss on ignition, bulk density, carbon, nitrogen) will be carried out. Secondly, I will focus on on-going peatland regime shifts, more specifically on the fen-bog transition of Finnish peatlands. I will use aerial photographs and compare current environmental conditions and abundance of the key plant species with the results of field surveys done in 2011 to track the recent changes in habitats and their distributions. Finally, I will study recent permafrost peatland temperature development and the driving factors, such as snow cover, in Northern Fennoscandia. For this I am using on-site temperature measurements and camera monitoring data.

Groundwater and surface water PFAS in the River Vantaa catchment area

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Introduction

Per- and polyfluoroalkyl substances (PFAS) are persistent environmental pollutants associated with multiple adverse health effects and they are widely found in the Finnish aquatic environment (Junttila et al. 2019). However, little is known about the occurrence of PFAS in groundwater as well as their transport via surface water-groundwater interactions. The present study takes place in the River Vantaa watershed (southern Finland) where the highest PFAS concentrations and yield have been observed (Junttila et al. 2019) in surface water. The objectives of this study were to expand the knowledge on the PFAS concentrations in groundwater as well and to form a first insight in the relationship between groundwater and surface water PFAS content in different areas.

The occurrence of 50 individual PFAS in groundwater and surface water was investigated in two study areas Herajoki and Rekolanoja where aquifers and surface water bodies are hydraulically connected. Sampling took place in 29 locations in early summer/late spring, late summer and early autumn to account for different river flow conditions and possibly to detect the interaction between groundwater and surface water more explicitly. Altogether 78 samples were collected and analysed for hydrogeochemical parameters and PFAS.

More detailed understanding of the sources and transport pathways of the PFAS is needed in order to estimate the transport of PFAS in the aquifers and between surface and groundwater. Sampling was targeted to cover locations that have potential PFAS sources and at locations where the presence of PFAS would pose a risk for groundwater usage for consumption.

Detectable concentrations of PFAS were found in 91% of all samples in concentrations between 0,6–3900 ng/l. Of all 50 different PFAS that were analysed, 20 different substances were present in the samples. The majority of the detections comprised of 10 different substances. The eight carbon containing perfluoro sulfonic and carboxylic acids (PFOS and PFOA) were the two most often detected substances, present in 67 and 58 samples respectively.

There was a noticeable difference in the sum concentration of PFAS between the separate sites as well as between surface water and groundwaters (Figure 1). Surface water samples showed higher average concentrations of PFAS in both study sites compared to groundwater samples. Surface water samples were dominated in both areas by Per/polyfluoro-carboxylic acids (PFCA), and especially short-chained PFCA's. Groundwater samples had a notable per/polyfluoro-sulfonic acid (PFSA) component in addition to the PFCA, especially in the Rekolanoja study site. The Rekolanoja study site showed higher average concentrations of PFAS both in surface waters and in groundwaters. Both study sites had a noticeable component of fluorotelomer sulfonic acids (FTSA) in the surface water samples as well, especially in August and October. Both study areas showed one groundwater sampling site containing abnormally high PFAS. In the Rekolanoja study site, the highest total PFAS concentration in groundwater was 3900 ng/l and in the Herajoki site 74 ng/l. The Rekolanoja outlier data point was omitted from the graph below.

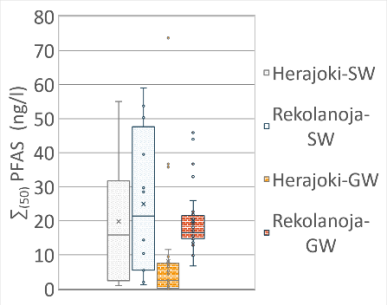


Figure 1. Boxplot showing the sum of 50 PFAS concentrations in groundwater (GW) and surface water (SW) in the two study areas .

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Repeated fluid activity in the cordierite-orthoamphibole rocks in Orijärvi, southern Finland

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Introduction

The Orijärvi region in southern Finland contains several VMS-type ore deposits, the most famous being the depleted Orijärvi mine. The mineralisations are often hosted by altered cordierite-orthoamphibole rocks. We sampled two such cordierite-orthoamphibole rocks (COR) close to the Orijärvi mine and the Iilijärvi mineralised zone, respectively. We separated monazites, zircons and xenotimes for multiple grain in-situ laser ablation U-Pb analyses. We also analysed monazite and xenotime 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. Here we present the preliminary findings and discuss their implications on the metamorphic evolution of the Orijärvi area.

Results

The zircons from the COR close to the Orijärvi mine occur in many morphological types and the grains are metamict and rich in inclusions. Most analyses are discordant and their $^{207}Pb/^{206}Pb$ ages form a declining trend of ages from 1901 Ma to 1786 Ma. Five oldest analyses form a distinct group and yield a weighted average age of ~1.89 Ga. The monazites comprise elongated and rounded grains. The analyses from the separated material and thin sections both yield a concordia age of ~1.80 Ga. The xenotimes are all rounded in shape and yield a concordia age of ~1.82 Ga.

Only a few zircons were recovered from the Iilijärvi COR and they all are highly discordant and geologically meaningless. The monazites are mostly rounded save a few prismatic grains. The analyses are mostly concordant and yield a concordia age of ~1.82 Ga. Population is, however, rather scattered with oldest analyses approaching ages of 1.84 Ga. The thin section analyses yield a more homogenous population with a concordia age of ~1.82 Ga. Older ages are absent in the thin section analyses. The Iilijärvi xenotimes are rounded in shape and yield a concordia age of ~1.785 Ga for both the separated sample and the thin section analyses. Many of these xenotimes are found in the vicinity of joints and cracks in the thin section.

Discussion

The ~1.89 Ga zircons from the Orijärvi COR most likely represent the igneous age of the protolith. The decreasing age trend for the rest of the grains is attributed to hydrothermal and metamorphic activity. The monazite and xenotime yield ages of ~1.80 Ga and ~1.82 Ga which we regard as metamorphic. The Iilijärvi monazite yielded a similar metamorphic age of ~1.82 Ga as the Orijärvi monazite. The xenotime, however, has a younger age of ~1.785 Ga. The Iilijärvi COR has been affected by a more intense hydrothermal activity than the Orijärvi COR based on their appearance in thin section. The 1.82 Ga age of metamorphism is common in the area (Mouri et al. 2005, Väisänen and Kirkland 2008). The 1.80 Ga ages are more ambiguous but not unique (e,g., Väisänen and Kirkland 2008). In general, 1.80 Ga magmatic activity is common in southern Finland (e.g., Rutanen et al. 2011).

The ~1.79 Ga U-Pb ages found in southern Finland are often associated to shear zone activity (e.g., Torvela et al. 2008, Torvela and Kurhila 2022). Orijärvi is flanked by two major shear zones, Jyly and Kisko. Iilijärvi COR shows evidence of more intense deformation in thin sections compared to Orijärvi COR. This might indicate that local smaller scale shearing has affected the Iilijärvi xenotimes.

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The Finnish National Lithosphere Committee

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The Finnish National Lithosphere Committee (aka ILP committee) is the national committee of the International Lithosphere Program (https://www.iugs.org/ilp) in Finland. It promotes research of lithosphere in all scales in Finland and beyond, and advances communication between those involved in it. The website of the committee (https://www.seismo.helsinki.fi/ilp) is hosted at the Institute of Seismology, University of Helsinki.

The International Lithosphere Program has national representatives in different countries. The Finnish representative of the committee is the chairperson Suvi Heinonen. The current configuration of the Finnish national committee consists of chairperson, vice chairperson (Kaisa Nikkilä), and eight other regular members from Finnish universities and other research organizations. Beyond its regular members, the committee has a secretary (Toni Veikkolainen), who is responsible for external communication and administrative meetings.

The committee has organized the biennial Lithosphere Symposium for twelve times. The symposium has taken a stand among the renowned geoscientific events in Finland, gathering professionals and students of geoscience from academia and industry. The most recent symposium took place at the Åbo Akademi University, Turku, Finland, on November 15-17, 2022. The proceedings of these symposia are published in the form of abstract volume (e.g. Skyttä et al., 2022).

Beyond the Lithosphere Symposium, the committee is experiencing a revival process after the COVID pandemic, aiming at new scientific openings in relation to the international host organization.



Figure 1. At the twelfth Lithosphere Symposium, Professor Ilmo Kukkonen was honoured for his longstanding work in lithospheric research. Credit of photo: Päivi Haapanala, University of Helsinki.

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Detecting Induced Seismicity of an Enhanced Geothermal System Using an Automatically Picked Catalogue for Template Matching

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Introduction

The energy company ST1 Oy planned to construct an Enhanced Geothermal System (EGS) using two boreholes drilled down to ca. 6 km depth under the Aalto University campus Otaniemi, Espoo. In order to achieve a water reservoir and circulation between the boreholes, the company conducted two high pressure stimulations, a larger one in June-July 2018 and a shorter, smaller counter-stimulation in May 2020. These stimulations induced tens of thousands of small earthquakes (Kwiatek et al., 2019, Leonhardt et al., 2021). Both stimulation periods were monitored by a dense network of over 100 stations consisting of Institute of Seismology (ISUH) operated permanent seismic stations, temporary stations installed by ISUH and borehole stations operated by the company ST1; while the interim and the post-stimulation periods were, and still are, monitored with a sparser, but still a relatively dense, seismic network consisting of ~20 stations (Hillers et al., 2020; Rintamäki et al., 2022).

In order to study relatively weak seismicity with a dense but temporally variable seismic network, we have developed a template matching event detector based on EQCorrscan (Chamberlain et al., 2017). The detector is run on a continuous waveform archive using templates created from existing event catalogues inserted into a NorDB database (Veikkolainen et al., 2021). The four-stage detector – templating, detection, event filtering, and relocation – is able to run on variable station configuration and handle other intermittent issues such as gaps in the data. To quickly examine the results of the template matching, we have also developed a visualisation tool which can be used to analyse and fine-tune the parameters during the process.

In this work we focus on the results obtained from running the detector using an automatically detected (Kortström et al., 2016) and automatically repicked (Gal et al., 2021) event catalogue. The event catalogue consisting of 484 events (Vuorinen et al., 2023) was inserted into NorDB, and the detector was run on the continuous waveform archive collected from the start of the dense monitoring phase in May 2018 to the end of 2022. This provides us with a view on the anatomy of the EGS induced seismicity, from pre-stimulation to post-stimulation. We also further reflect on the use of the automatic event picking over manual analysis on such datasets.

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Understanding nutrient retention in two-stage channels

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Introduction

Mobilization of nutrients from agriculture and in the associated negative impacts on water quality of have increased interest in finding ways to reduce the nutrient loads from fields into the environment. Two-stage channels (TSC) are nature-based solutions that aim to decrease nutrient run-off from fields while maintaining the necessary drainage systems for agriculture. Compared to normal drainage ditches, a TSC has constructed floodplains that are flooded during wet periods, accumulating suspended sediments. During dry periods floodplains are above water level, reducing the nutrient leaching and sediment erosion caused by the main channel stream flow. However, few studies have attempted to describe and quantify nutrient retention in TSCs.

In this study, nutrient retention processes were investigated by comparing the characteristics of three different study sites (Ritobäcken, Uuhikonoja, Loppi) including sediment accumulation rate, soil geochemistry and phosphorus speciation. Sediment traps were installed on the floodplains of each study site for 9 to 12 months and accumulated fresh sediments were analysed for geochemistry, nutrients (C, N, P), and phosphorus speciation. At the Ritobäcken site, sediment cores were also used to study longer sedimentation history and subsurface processes. Five phosphorus species (exchangeable P, Fe-P, Al-P, Ca-P, and residual organic P) were analysed with a tailored sequential extraction method. Catchment sizes were determined with GIS methods and connected to open access services soil type data. Various statistical analyses such as principal component analysis (PCA) used to explain and visualize differences between and within the study sites.

Results

Preliminary results show that the three study sites have relatively different catchment soil types and sediment geochemistry, but similar phosphorus speciation distribution. Clear differences can be seen between Uuhikonoja, that had mostly clay-rich soils indicated by high contents of minerogenic elements (K, Mg, Na), and Loppi, which is in a forested peatland area and has high contents of organic-matter associated elements (C, Mo, N, S) in soils. Compositional contrasts between the sites were clearly visible in PCA, showing that soil type explains most of the variance in geochemistry between the study sites. PCA also detects the within-site spatial distribution differences. Differences between sites can also be seen in sediment and nutrient accumulation rates, where Loppi had lowest sediment and nutrient accumulation rates while highest rates were observed in Uuhikonoja, and Ritobäcken was intermediate. Still, Loppi had the highest nutrient accumulation relative to sediment accumulation. Despite the clear soil type differences, the phosphorus speciation distribution was dominated by Fe-P (>50%) at all sites, marking its importance in phosphorus retention processes in soils. However, additional data from Ritobäcken sediment core profiles suggests that the forms of P accumulation may have changed slightly in response to construction of the TSC. The core profile shows bulk Fe and Al contents decreasing towards the soil surface, while Ca and P contents are increasing. We will discuss the implications of these results in terms of sediment accumulation and biogeochemical processes in floodplains.

Challenges and Bottlenecks for the Green Transition

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Abstract

A study was conducted to examine what is going to be required to fully phase out fossil fuels as an energy source and replace the entire existing system with renewable energy sources and transportation. This is done by estimating what it would be required to replace the entire fossil fuel system in 2018, for the US, Europe, China, and global economies. This report examines the size and scope of the existing transport fleet, and scope of fossil fuel industrial actions.

To replace fossil fueled ICE vehicles, Electric Vehicles, H_2 cell vehicles for cars, trucks, rail, and maritime shipping was examined. Fossil fuels consumption for electricity generation, building heating and production of steel were all examined for replacement. Calculations reported here suggest that the total additional non-fossil fuel electrical power annual capacity to be added to the global grid will need to be around 37 289.7 TWh. To phase out fossil fuel power generation, solar, wind, hydro, biomass, geothermal and nuclear were all examined. If the same non-fossil fuel energy mix as that reported in 2018 is assumed, then this translates into an extra 607 052 new power plants will be needed to be constructed and commissioned.

The quantity of metals to manufacture the first generation of renewable technology units (wind turbines, solar panels, EV's etc.) to completely phase out fossil fuels. This metal quantities were compared to mining production and mineral reserves.

Conclusions were drawn after comparing all these different aspects. It was proposed that the phasing out of fossil fuels will not go to plan.

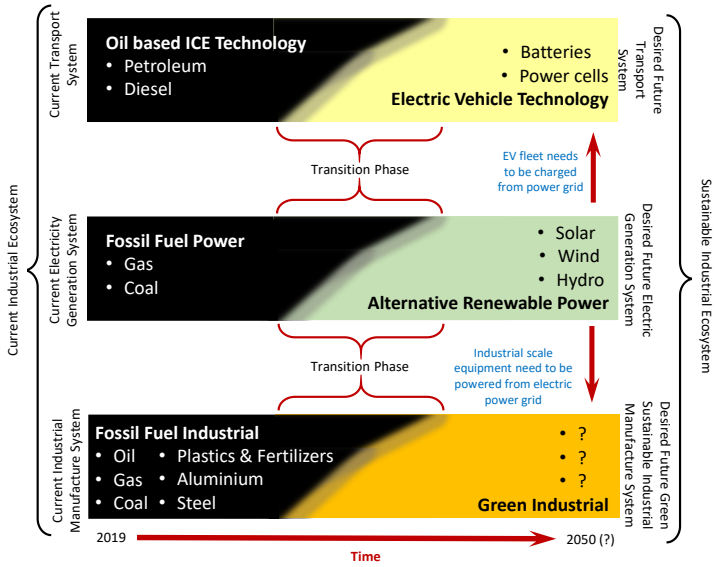


Figure 1. The proposed Green Transition

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Mining and mineral exploration disputes in Finland: implications for the social license to operate

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Introduction

The Finnish mining struggles of the 2000s started with the uranium dispute (2006-2008) during the global mining boom. The Finnish mining skeptical movement originated by focusing on projects associated with uranium (Juomasuo, Rompas, Talvivaara, Sokli). One of these projects, the Talvivaara polymetallic mine, became the key event of the following mining dispute because of its gypsy pond leakage in 2012 (Sairinen et al. 2017). Many mining and mineral exploration disputes (MMED) have persisted for years, while others have ended, and new ones have appeared. This paper presents the results of a recent mapping of ongoing Finnish MMEDs based on Eerola (2022). The topic is intimately related to the social license to operate (SLO), which means acceptance/approval of any activities by a local community or the society (Thomson & Boutilier 2011).

Methodology

Protest event analysis (PEA; Koopmana & Rucht 1999) was applied to identify and map out MMEDs in Finland. Companies with permits and their applications in Finland were listed and their online media records were looked by using the Retriever media monitoring software. Media reports and literature were scrutinized to detect MMEDs and the involved companies, their projects, issues, indicators, and actors. The methodology was described in more detail by Eerola (2022).

Results

Twenty ongoing MMEDs were identified involving seventeen companies (23%) from a total of seventy three. Fourteen of the cases were related to mineral exploration, four to mine projects, and two to mines. The long-term MMEDs are mostly focused on mines and mine projects in northern Finland, whereas the most recent disputes are mostly related to mineral exploration in southeastern Finland. The main reasons for disputes are the conflicting use of land (indigenous Sámi homeland, lake regions with holiday homes, nature conservation, reindeer herding, and tourism destinations), an association with uranium, corporate conduct (communication and stakeholder engagement) and/or reputation.

Conclusions

Twenty ongoing MMEDs were identified in Finland by applying PEA. They concentrate in northern and southeastern Finland. The main reason for their generation seems to be related to project location in sensitive contexts. As even the most recent literature on the SLO has mainly been focused on procedural and distributional fairness (e.g., Jartti et al. 2020, Eabrasu et al. 2021), this paper emphasises the importance of project location and associated land use as one of the main factors for the SLO in Finland, but probably elsewhere as well. Companies must be aware of that and try to avoid such locations when possible. Such sensitive contexts are recommended to be taken into account in their planning and target selection as part of environmental and social governance (ESG).

The identification, mapping, and monitoring of MMEDs in Finland will support future studies regarding the analysis of their causes, dynamics, evolution, actors, and possible solutions. Their investigation can help to understand and avoid MMEDs, conciliate diverse interests, and solve disagreements.

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Exploration targeting of critical raw materials (CRMs)

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Metals such as nickel, cobalt, platinum group metals (PGMs), rare earth elements (REEs), and lithium are projected to be widely used in environmentally sustainable industries, but their present levels of supply fall far short of their projected demand. Therefore, they are considered strategically important and have been classified as 'critical raw materials' (CRMs; European Commission, 2020). Because of their significance in industrial value chains and strategic and green sectors, it is essential to have local production of these raw materials.

This study proposes a desktop-based workflow for exploration targeting of REEs, which are one of the most important CRMs. The workflows are demonstrated by application to delineation of REEs related to carbonatite-alkaline complexes in Northeastern India. The workflow used two diverse, but complementary, algorithms for prospectivity modelling: (a) Fuzzy Inference Systems (FIS), which is a supervised, knowledge-based symbolic artificial intelligence technique; and (b) Self-Organizing Maps (SOM), which is an unsupervised machine learning clustering algorithm based on neural networks.

The supervised approach uses a multi-stage FIS based on a generalised conceptual REE mineral systems model, which is also used to identify the targeting criteria for REE deposits. The major components of the REE mineral systems include (1) regions of metasomatised subcontinental lithospheric mantle (SCLM) that act as fertile source regions for fluids bearing REE; (2) extensional geodynamic settings; (3) permeable lithospheric architecture for tapping REE-rich fluids from the SCLM and focusing them to near-surface levels; and (4) post-emplacement tectonic regimes that preserves the deposits (Aranha et al., 2022). The targeting criteria were represented by mapping their spatial proxies in GIS layers, generated using spatial analysis and geoprocessing tools. Systemic and stochastic uncertainties associated with the approach were accounted for using Monte Carlo simulations and assigning confidence values to the predictor maps. The REE prospectivity in the study area was mapped at three probability levels, namely, 10%, 50% and 90%. The outputs were visualized by draping over a confidence surface.

The application of SOM involved unsupervised clustering of primary gridded data, namely, air-borne magnetics, gravity and topography, without manual pre-processing and generating derivative predictor maps. This led to the elimination of possible subjective bias, as well as time-consuming and labour-intensive data pre-processing. The SOM-based approach involved automated feature extraction and selection, as opposed to the supervised FIS-based approach in which the REE mineral system model was used to guide the feature selection and extraction. Nevertheless, both approaches returned comparable results.

The study yielded several key findings. Firstly, the unsupervised approach was deemed a dependable and resilient tool for streamlining prospectivity modelling, particularly in underexplored areas with limited geological data. The combined approaches successfully identified multiple REE targets in the study area. The key recommendations were as follows. (1) Detailed ground exploration be conducted on a project scale for the Sung Valley and Jasra Complexes, which were highly prospective at all confidence levels. (2) Additional data collection is recommended for the Mikir Hills in the regions surrounding the Samchampi and Barpung Complexes. (3) Further data collection is recommended in the western part of the study area, where there are swarms of dikes in the Garo Hills.

In summary, the present study proposes the first comprehensive workflow, including a new model of carbonatite-alkaline-complex-related REE systems and applications of complementary prospectivity modelling algorithms, to delineate potential REE targets. This workflow could potentially be extended to explore other critical raw materials (CRMs) in the SEMACRET project, which strives to facilitate sustainable exploration of CRMs within the EU to ensure uninterrupted supply for its industries during the green revolution. The project focuses on the exploration of CRMs such as cobalt, nickel, platinum-group metals, and others, which are hosted in mafic orthomagmatic rocks.

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Extractive waste as a source of secondary resources in Finland – current state

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Introduction to extractive waste

Global demand for minerals and metals is expected to increase significantly in the coming decades due to clean energy transition. At the same time more emphasis is placed on supply, security, and environmental issues which has led to more interest in extractive waste as a source of secondary resources. The amounts of extractive waste, which include e.g., waste rocks and tailings, are large. In Finland alone, around 100 Mt of extractive waste is being produced annually, forming 74 % of the total amount of all waste streams. Since the 16th century, around 1 113 Mt of waste rock has been mined at Finnish mines, of these 96 % during 1969-2021 and around half during the last ten years. The amount of tailings, that have been generated by metal mining since the flotation process was adapted in Finland in 1911, is estimated at over 500 Mt.

Extractive waste as secondary resource in Finland

The level of utilization of extractive waste as a source of secondary resources is low in Finland, as also in global scale. The current utilization consists mainly of using waste rocks in earth construction and cavity filling at the active mine sites. One key aspect preventing utilization is the lack of systematic national resource management of extractive waste. Resource management would require information concerning e.g., generation, amount, location, and quality of the extractive waste. Although some usable information exists, it is scattered (deposit data, risk assessments, compliance monitoring by authorities) and an incentive to collect it, not to mention a central database where to store the information, is missing. In new mining projects, the utilization of extractive waste should be investigated and planned in an early phase.

Old extractive waste sites provide new attractive targets as the beneficiation processes were not as efficient as today and may contain valuable commodities which were not detected by contemporary analytical methods or were considered to have no economic value during the life of mine. In general, the resource potential of closed extractive waste sites has not been studied. Of the 10 largest (by total extraction) closed Finnish mine sites, which include Outokumpu-Keretti (total extraction 34.9 Mt), Otanmäki (33.1 Mt), Vihanti (30.8 Mt), Vuonos (15.6 Mt), Kotalahti (13.7 Mt), Rautuvaara (12.9 Mt), Laukunkangas (8.4 Mt), Hammaslahti (7.9 Mt), Raajärvi (7.8 Mt), Saattopora (5.7 Mt) and Hällinmäki (5.3 Mt), only the Otanmäki tailings area has been investigated for remining potential. The Otanmäki Mine Oy started the investigations at the waste site in 2017. The investigations include systematic drilling and sampling, resource modelling, and pilot-scale beneficiation tests at GTK Mintec.

FutuRaM project in enhancing the resource management of extractive waste

The Horizon Europe project Future Availability of Secondary Raw Materials (FutuRaM) is tackling some of the challenges related to the utilization and management of extractive waste. The aim of the project is to construct a database on the quality, availability, and recoverability of secondary raw materials within the European Union. Furthermore, the project will establish a methodology, reporting structure, and guidance for sustainable management of secondary raw materials projects in the future. Finnish extractive waste sites will be included in the database through GTK, which is one of the 28 partners implementing the project during 2022-2026.

In the FutuRaM database, the secondary resources will be classified according to the United Nations Framework Classification for Resources (UNFC), which is a global classification system for sustainable management of energy and mineral resource endowments. Finland is the first country in Europe to classify and unify its primary mineral resources according to the UNFC system, which forms a solid base to make similar classification for secondary resources. The Otanmäki tailings facility, in where the UNFC classification was also applied, serves as a case site in the FutuRaM project and an example for future utilization projects.

Summary

Large amounts of extractive waste exist and is being produced annually. Information about the resource potential of extractive waste is scattered and lacking. Therefore, more systematic investigations of old mine waste sites is needed, and the utilization of future extractive wastes should be better considered in an early phase of the mining project.
The FutuRaM project will develop a database, methodology and guidance to improve resource management and utilization potential of secondary raw materials in Europe.

Sakatti – A FutureSmart Mine of Anglo American

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Anglo American is a leading global mining company producing essential ingredients in almost every aspect of modern life. Our portfolio of world-class competitive operations provides many of the future-enabling metals and minerals for a cleaner, greener, more sustainable world and that meet the fast growing every day demands of billions of consumers. Sakatti Ni-Cu-PGE mine project in Norther Finland is to be company's FutureSmart mine and demonstrates how sustainability can be applied to re-imagine mining to improve people's lives. The biggest challenge in the Sakatti project is to design the operations to minimize the impacts on the Natura 2000 protected mire located above the ore. The ore is 200-1000 m below the surface and therefore the mine will be fully underground and no infrastructure will be placed on the protected area. The processing plant will be placed several kilometers away and the 5 km long access tunnel will reach the ore in a depth of 500 m. Some of the processing operations will be underground making the footprint of the mine small. The underground fleet will be fully electric reducing the CO2 emissions directly but also through reduced ventilation need. As the ore is exceptionally high-graded in processing coarse waste rejection and coarse particle recovery techniques can be applied. As a consequence the CO2 emissions of Sakatti will be one of the lowest in base metals mining. The waste will be utilized locally. Waste rock will be used largely in construction. The processing tailing will be divided into two. The high-sulphur tailing will be used fully as mine back-fill. Also, excess waste rock and 40% of the low-sulphur tailing will be placed underground. The remaining of the low sulphur tailing will be deposited as dry stacking eliminating the pond risks and reducing the water usage compared to normal wet tailing areas. These concrete design criteria demonstrate how sustainability is taken as practice in Sakatti mine.

Rifting-related mafic-ultramafic magmatism and ore potential in NE Fennoscandia

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Multiple stages of Paleoproterozoic rifting have been recorded in several cratons, which resulted in the break-up of the Kenorland supercontinent and later to disruption of individual cratons. These extensional tectonic events were associated with wide-spread mafic-ultramafic magmatism producing important ore deposits of Cr, Ti, V, Ni, Cu and PGE. We studied the geochemistry of Paleoproterozoic mafic-ultramafic volcanic rocks from different belts in NE Fennoscandia (Fig. 1) to constrain the fertility and sulfide saturation history of the magmas and their potential to form magmatic sulfide deposits.

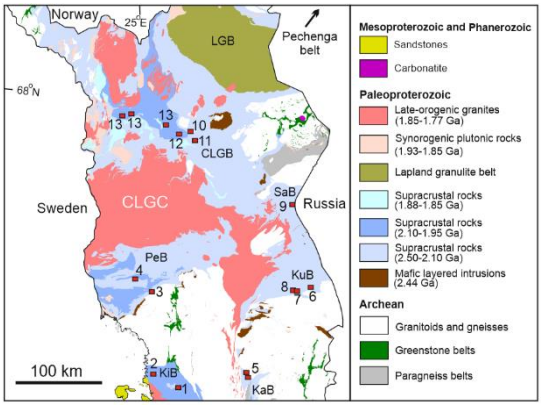


Figure 1. Sampled volcanic formations shown by red squares on a simplified geological map of northern Finland (based on DigiKP, the digital map database of the Geological Survey of Finland, Version 1.0; available at: www.geo.fi/en/bedrock.html). 1 = Kiiminki Fm, 2 = Haukipudas Fm, 3 = Runkaus Fm, 4 = Jouttiaapa Fm, 5 = Vintaselkä and Matinvaara Fms, 6 = Kuntijärvi Fm, 7 = Petäjävaara Fm, 8 = Ruukinvaara Fm, 9 = Mäntyvaara Fm, 10 = Möykkelmä Fm, 11 = Sattasvaara Fm, 12 = Kautoselkä Fm, 13 = Vesmajärvi Fm. Abbreviations for geological units: CLGB = Central Lapland greenstone belt, CLGC = Central Lapland Granitoid Complex, KaB = Kainuu belt, KiB = Kiiminki belt, KuB = Kuusamo belt, LGB = Lapland granulite belt, PeB = Peräpohja belt, SaB = Salla belt, ÖiGB. The Pechenga belt is located outside the map in the Kola Peninsula, NW Russia.

The 2.5-2.45 Ga magmatism formed large layered intrusions in the Kola and Karelian cratons which are thought to be products of a large mantle plume event. The lowermost volcanic rocks in the Kainuu, Central Lapland, and Salla and Kuusamo belts belong to this event. They show relatively primitive magma compositions with high MgO contents and clear signatures of crustal contamination, comparable to the co-eval mafic dyke swarms. This group of volcanic rocks display moderate PGE contents with Pt ranging from 5 to 10 ppb. Primitive rocks show mantle-like Ni/Pt ratios, whereas more evolved rocks show clearly elevated Ni/Pt ratios indicative of sulfide saturation. The volcanic rocks in different belts show rather similar geochemical signatures, suggesting similar histories of magmatic evolution. The Runkaus basalt formation was probably derived from a similar magma that produced the 2.31 Ga mafic dykes in Russian Karelia (Stepanova et al. 2015). This group of basalts has relatively low PGE contents and low MgO contents, indicating that the magma has equilibrated with sulfide, probably in the source mantle due to low degree of partial melting in upwelling asthenosphere. Hence, this pulse of magma may have less ore potential to form economic PGE deposits.

The Jatulian stage volcanic rocks can be related to mafic dyke swarms across the Karelian craton. Volcanic rocks from different belts show variable geochemical features with either depletion or enrichment in LREE and were probably derived from diverse mantle sources. The basalts from the Peräpohja belt were evidently derived from a depleted mantle source, which has experienced different degrees of previous melting extraction. New PGE data show that the magma was rich in Pt and Pd, broadly similar to fertile basaltic rocks globally. These rocks show mantle like Ni/Pt ratios without signs of PGE depletion, indicating no sulfide saturation prior to final emplacement. Based on a similar approach, the post-Jatulian stage magmatism (e.g., Central Lapland, Kiiminki and Pechenga) is assessed to show a high ore-formation potential for magmatic sulfide deposits.

Different stages of magmatism across different belts generally show similar features. With the exception of the Runkaus formation, most magma pulses show broadly fertile PGE contents. The key factors controlling ore-formation may include the capability to form large magma chambers or dynamic feeder conduits and the access of external sulfur to form sulfide deposits.

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Characterization of magnetite-bearing Cu ores in Viscaria, Northern Sweden

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The Viscaria copper ore deposit is the largest and most economically viable deposit situated only 3 km away from the giant iron (Fe)-apatite Kiruna deposit. Magnetite is an early oxide phase occurring in all mineralized zones across the Viscaria deposit, most abundantly in the D-zone. The D-zone mineralization mainly contains magnetite and chalcopyrite. Also, pyrite and pyrrhotite are found in this zone.

The main goal of this research is to develop a textural and mineralogical understanding of magnetite liberation because magnetite occurs in variety form with varying grain sizes. It is important to understand the liberation and compositional features of magnetite grains because of the relevant Fe grades and spatial association with Cu ores to be extracted. Furthermore, the specific objectives include determining the mineralogical and chemical compositional heterogeneity and the mineral inclusions in magnetite, as well as evaluating the source of potential deleterious elements that might be present within the different magnetite-bearing orebodies and might affect the quality of the magnetite concentrate.

Given the variation in ore types across the deposit, a set of samples with good spatial coverage were designed. In total, 25 drillholes and 33 samples were chosen for the research work. In this project, optical microscopy, electron probe microanalysis, and scanning electron microscope analysis were used to characterize deleterious element carrier minerals associated with magnetite.

The mineralogical and textural characterization of the magnetite grains from the D-zone showed that the grain size varies from 5 µm to up to 1.4 mm, and from the B-zone magnetite grain size vary between 10 to 200 µm. The common inclusions were chalcopyrite, pyrite, and pyrrhotite. The presence of pyrite and pyrrhotite was observed more in the B-zone. In addition, different generations of pyrite are distinguished, which are small inclusions occurring in magnetite and big particles locking small magnetite grains. Also, ilmenomagnetite (magnetite with ilmenite lamellas) and goethite were observed in the drill core of VDD0239 from the D-zone.

The chemical composition characterization studies by electron probe microanalysis (EPMA) of the samples from the D-zone showed a high amount of V_2O_3 and TiO_2 when the ilmenomagnetite was detected. Moreover, rare earth elements (REEs) such as Yttrium (Y), Dysprosium (Dy), and Erbium (Er) were observed in REE-phosphate mineral with ilmenomagnetite. In the D-zone, it was observed that pyrite occurrence preceded the main copper mineralization stage such as early pyrite inclusions without Cu sulphides and later pyrite inclusions intergrows with Cu sulphides. Additionally, hematite was detected in the D-zone. Finally, amphibole and apatite occurrences were mainly detected as gangue minerals.

From the crust to the mantle and back: Subduction in progress

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Introduction

Subduction zones are regions of major mass exchange between the Earth's crust and mantle. Understanding the geodynamic processes and geochemical signatures in modern subduction zones is key to understand and interpret the processes and geochemical signatures in the Paleoproterozoic Finnish bedrock. The convection of the mantle wedge above the subducting slab drives the flow of hot mantle material towards the mantle wedge. The combination of slab rollback and mantle flow results in a divergent plate boundary movement and triggers mantle upwelling and adiabatic decompression melting in the backarc behind the arc. The magmatic activity in arcs is the result of the release and ascent and addition of volatiles from the subducting oceanic crust to the overlying mantle wedge.

Arc lavas are generally characterised by an enrichment of the fluid mobile (large ion lithophile, LILE) elements (e.g., Ba, Rb, Sr, Pb) relative to the immobile elements, combined with a depletion of the fluid immobile (high field strength elements, HFSE) elements (e.g., Hf, Ta, Nb, Zr, Ti). The trace element and isotope geochemical variability of arc magmas has been interpreted to result from changes in the dehydration process of the subducting slab causing melting in the mantle wedge, mixing of melts and lithologies from distinct melt regimes, processes such as magmas transfer through the crust, or a combination of these processes. The transition between fluid induced melting underneath the arc to decompression melting in the backarc spreading centre is generally associated with a change from arc-like magma compositions to those that are closer to normal mid-ocean ridge basalts in composition.

The Tonga-Kermadec subduction zone in the western Pacific extends for almost 2550 km's from New Zealand (~35°S) northward to 15°S, and rates of subduction range from 5 cm/yr in the south to 24 cm/yr in the north. Slab rollback of the subducting Pacific plate has resulted in the formation of the Havre and Lau Backarc spreading centres. The westward subducting Cretaceous Pacific plate consists of altered, igneous oceanic crust covered with ~70 m of pelagic sediments. At ~25°S the subduction of the intraplate Louisville seamount chain separates the Kermadec and Tongan arcs and introduces a unique geochemical tracer into the subduction zone. Here, I focus on two peculiar examples from the Tonga arc-backarc system, a) the two northernmost islands of the Tonga arc, Tafahi and Niuatoputapu and b) the Valu Fa and Lau backarc spreading centres. The different geochemical signatures in both settings are the result of changes in source composition, melting dynamics and subduction zone geometry.

The islands of Tafahi and Niuatoputapu display a unique isotope and trace element geochemical signature that resembles a mixture of altered igneous oceanic crust, sediments and altered lavas from the Louisville seamount chain which is currently subducted ~1000 km further south. The occurrence of this peculiar geochemical signature at the northern terminus of the Tonga arc allows deciphering the quantities, nature (fluid vs. melt) and temporal order of the slab and mantle contributions. We can show that the slab component consists of fluids from the igneous oceanic crust, and from altered, Louisville seamount lavas mobilising even Nb and Ta. The seamount signatures were emplaced in a metasomatized, lithospheric mantle and were re-activated due to slab-rollback contributing to the ascending magmas about 4 Myr after subduction. Our model shows that the input compositions into the subduction zone, as well as the extensional regime in northern Tonga results in the preservation of a unique geochemical signature suggesting that even the immobile HFSE can be mobilised.

The Valu Fa Ridge, and the Lau backarc spreading centres are situated just north of the current Louisville subduction. The backarc is situated at an increasing distance to the arc front from as close as ~ 30 km at the southern tip of the Valu Fa Ridge at ~22°44'S to as far as ~110 km at 19°30'S, exceeding 150 km as one approaches the Central Lau spreading centre in the North. The geochemical variability observed along and across island arcs and between the arc and the backarcs is commonly associated to reflect changes in the residual source composition of the underlying mantle wedge combined with fluids or melts originating from the metamorphic dehydration reactions in the subducting slab. Our new geochemical data indicate that the geochemical signatures at less than 100 km between the arc and the backarc are the result of overlapping melting zones and do not easily reflect the dehydration processes in the subducting slab. At distances >100 km between the ac and backarc, the arc-related signatures in the backarc are best explained by along-axis mixing of melts.

Classification of the phosphorus-rich Lieksa 4 iron meteorite

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Introduction

A total of five suspected iron meteorites were found from Lieksa, eastern Finland in 2017. One of these, Lieksa, is the first official iron meteorite find from Finland (Kuva et al. 2017, Kinnunen et al. 2018). No official research data are available of Lieksa 2, 3, and 5, but they have been reported to consist of meteoritic mineral phases (Moilanen 2018). Lieksa-4 consists of ~ 84 wt% Fe, and 11 wt% Ni. In addition, it's highly enriched in P, and depleted in S. Roughly 75 wt% of the meteorite consists of kamacite, 20 wt% schreibersite, with < 1 wt% troilite. Trace elements Ga, Ge, Au, and Ir occur in low abundances. The meteorite is fine grained, with round kamacite granules surrounded by a web-like matrix rich in schreibersite. The kamacite phase hosts microscopic Neumann deformation lines. These features strongly suggest that Lieksa 4 is a meteorite (Kotomaa 2022, Kotomaa et al. 2022).

Comparison with other P-rich irons

Only a handful of P-rich iron meteorites have been discovered. Six other irons rich in P comprise the IIG group, but they have much lower Ni abundances, and their textural features suggest slow cooling (Wasson & Choe 2009), whereas the texture of Lieksa 4 suggests a rapid cooling (Kotomaa et al. 2022). The ungrouped, structurally anomalous Soper iron (Buchwald 1975) has a close textural and mineralogical affinity to Lieksa 4. The meteorites' trace element compositions match closely to one another, but the Soper iron consists of lower concentrations of Ni.

Classification

Iron meteorites are classified according to their structural and chemical characteristics. The structural classification is based on the presence or absence of the Widmanstätten pattern, formed by kamacite-taenite intergrowth, and the bandwidth of the kamacite lamellae (e.g., Goldstein & Short 1967). Ni together with trace elements Ga, Ge, and Ir provide the basis for the chemical classification of iron meteorites (Scott & Wasson 1975).

Lieksa 4 consists of approximately 11 ppm Ga, 5 ppm Ge, and 2 ppm Ir. In addition, the meteorite consists of < 0.5 wt% Co, < 400 ppm Cr, and < 1 ppm Au. Furthermore, the meteorite consists of > 3 wt% P and < 1 wt% S. The meteorite's unusually high concentration of P differ clearly from other iron meteorites. The meteorite does not contain any taenite and thus, no Widmanstätten. However, the Neumann deformation lines in the kamacite phase were observed. Neumann deformation lines are most common in hexahedrites with low Ni (≤ 6.5 wt%) concentrations, and their occurrence becomes more uncommon with the increase of the Ni concentration (e.g., Buchwald 1975). Based on the major and trace element abundances of the Lieksa 4 meteorite, its classification into the existing iron meteorite groups is not advisable. Moreover, the meteorite is structurally anomalous. Therefore, we suggest that Lieksa 4 should be classified as an ungrouped iron meteorite.

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Using portable XRF to analyze geochemistry of basaltic rocks in the field: example from Antarctica

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Developments in portable X-ray fluorescence (pXRF) technology have made it a viable tool for acquiring reliable geochemical data in the field (e.g., Sarala, 2016; Kruger & Latypov, 2020). During a recent expedition to Antarctica (FINNARP 2022), the authors tested the method in analyzing the geochemistry and lava stratigraphy of Jurassic continental flood basalt successions at Vestfjella (Fig. 1a), western Dronning Maud Land, Antarctica. Before the expedition, the device (Olympus Vanta VMR-CCC-G3) was optimized for analysis of major and trace elements common in natural rocks and calibrated with basalt samples for which laboratory XRF data exist (in-house standards).

For the analysis, small (< 1 kg) samples were collected with a hammer and they were cut with a rock saw at the research station (Fig. 1b). The cut surfaces were then polished using sandpaper. We analyzed the polished surfaces with the pXRF (Fig. 1c) and averaged data for 3–6 different spots in each sample. Within-sample variation was usually < 10 % for most of the elements. The analysis of the natural and in-house standard data shows that the method was able to rather accurately analyze major and minor elements Si, Ti, Al, Fe, Mn, Mg, Ca, and P, and trace elements V, Ni, Cu, Zn, Sr, Zr, and Y. Data for K, Cr, Co, Rb, and Ba showed more variation.

Previous work has demonstrated that the minor and trace elements Ti, P, Zr, and Y are crucial in distinguishing the different flood basalt types and linking them to different extinct volcanic centers in the area (Fig. 1d). The on-site use of pXRF facilitated rapid analyses of a large number of samples and thus provided critical support to fieldwork. Geochemical data for over 350 individual lava units and complementary field observations on, for example, flow thicknesses and directions enabled detailed assessment of the composition, structure, and evolution of the volcanic succession. Moreover, the on-site data guided the selection of samples for further more detailed research.

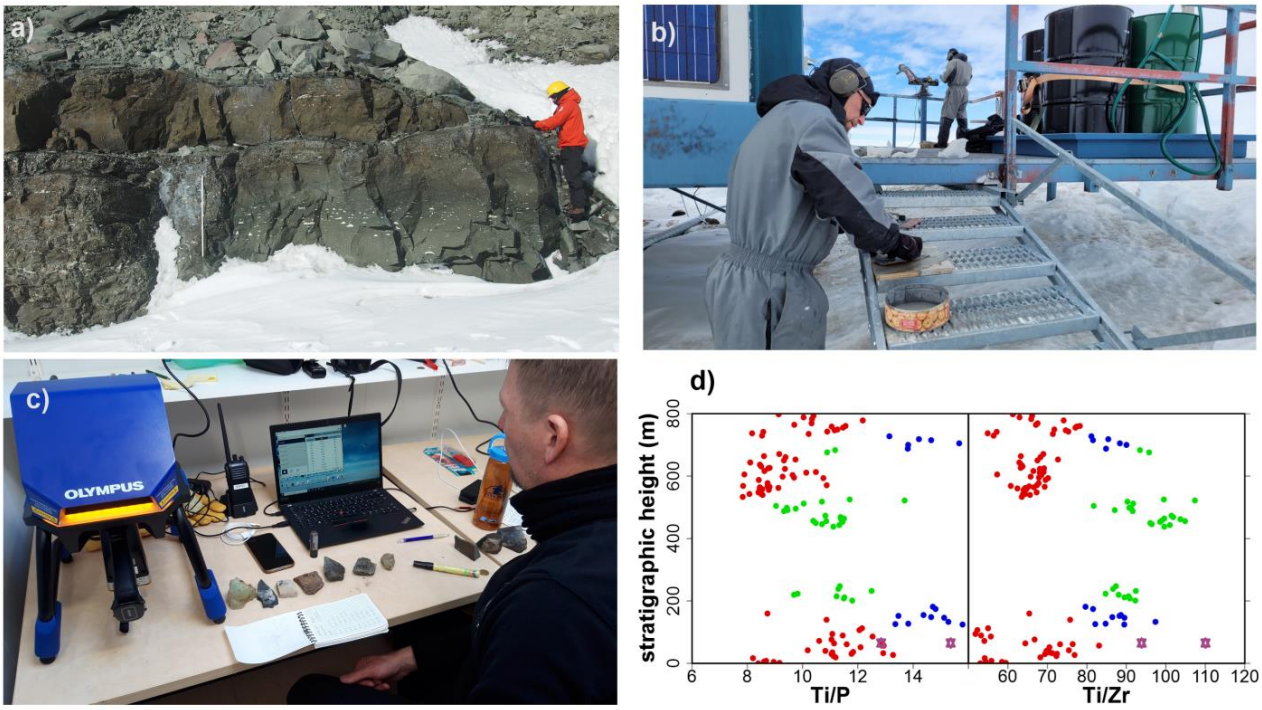


Figure 1. a) Sampling flood basalts at Basen nunatak. b) The sawing and polishing facilities at Finnish Aboa research station. c) pXRF in action at Aboa. d) Geochemical stratigraphy of flood basalts from Plogen nunatak analyzed with pXRF. The different colors refer to different volcanic sources. Photos: a by AVL, b by Antero Kukko, c by JSH (FINNARP 2022).

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Hydrogeological studies in the mining environments

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In the mine area, a wide variety of waters must be managed: dewatering water of mine/quarry, process water, leachate, wastewater, etc., but above all, it must be understood that the mine is part of the natural surface and groundwater system of the area. In Finland, the water balance is always positive; there are more precipitation than evaporation, runoff is high especially during the spring thaw and there is groundwater recharging.

Mining activities influence the quantity and quality of the water within the mine area and its surroundings. Dewatering of mine decreases the regional groundwater level and affects the flow directions: the waters flow into the mine, where they turn into mine waters requiring treatment or monitoring. On the other hand, through groundwater and water bodies, the potential environmental impact of mining can be spread beyond the actual mining area.

Attention should be directed to understanding of the geological complexity of mining environments from a hydrogeological perspective. Each mining environment is individual in terms of its glacier deposits, bedrock structure, groundwater occurrence and flow patterns as well as groundwater surface water connections. Comprehensive regional water balance calculations include precipitation, evaporation, runoff, groundwater recharge, stream discharge, surface water basins, groundwater reserves, effects of quarrying, dewatering as well as water in tailings and waste rock areas in different stage of the mine and in changing climate.

The characterization of sedimentary and bedrock water units and structures that conduct water differently needs drilling data and near surface geophysical data, such as gravity, ground penetrating radar, or seismic sounding as well as borehole geophysical and hydrogeological studies such as BMR or packer tests. Mining development sites and mine sites occasionally host aquifer systems with notable connections to natural surface water bodies. Thermal methods, stable isotopic composition of water etc. can be applied to identify hydraulic connections between aquifers, and surface water bodies or wetlands.

Hydrogeochemical characterization is essential in different stages of the mine life cycle. Hydrogeochemical baseline study, including main water quality parameters, trace elements, isotopic compositions and groundwater dating results, can increase the understanding of the water flow patterns, indicate the natural hydrogeochemical anomalies and can be used in optimizing the future monitoring. Hydrogeochemical studies are necessary during the monitoring of active mine, during the closure of the mine, as well as while monitoring the abandoned mine site.

The conceptual hydrogeological model of the area is often sufficient to characterize the hydrogeological properties. However, numerical 3D geological modeling and 3D groundwater flow modeling are powerful tools that can be utilized in planning and positioning of mining activities and in predicting the effects of future actions. Understanding the flow patterns and shallow groundwater connections to surface water, wetlands and fractured bedrock already in early phase of mining projects increases the transparency and thus the social license to operate in often environmentally sensitive areas.

Fracture mineral investigations beneath the Baltic Sea near Olkiluoto, Finland

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Fracture mineral samples from drill cores OL-KR58 and OL-KR58B drilled beneath the Baltic Sea, near Olkiluoto Island, South-West Finland, were collected for geochemical, isotope geochemical and mineralogical investigations. The aim of the study was to deepen our understanding of the paleohydrogeological evolution in crystalline bedrock. The results of this study are compared to those previously obtained from the repository site for spent nuclear fuel at Olkiluoto. Unlike the groundwaters at Olkiluoto Island, meteoric fresh water has not infiltrated the shallow depths during the Holocene Epoch at the drill site. The lack of influence of modern-day precipitation enables possibility to detect a previously only indirectly observed signal of the earlier Littorina Sea stage of the Baltic Sea from the fracture minerals.

The samples were collected targeting fracture systems open to fluid circulation at a depth range of 11 to 1174 m below sea level. The main interest was in the calcite and associated pyrite samples collected from the uppermost 60 m depth range. Fracture mineral samples consisted mainly of calcite that was compositionally nearly pure $CaCO_3$, with minor amount of Mn. Special interest was focused on latest calcite generations identified with CL-imaging.

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 seem to represents a 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 (Fig. 1).

Unusually high $\delta^{18}O$ values of calcite, up to -4.7 ‰ in the upper ~60 m of the bedrock suggest precipitation in the presence of the pure end member composition inferred for the Littorina Sea water. The $\delta^{34}S$ values of fracture pyrite showed large variability providing evidence for bacterial sulfate reduction in a closed system conditions.

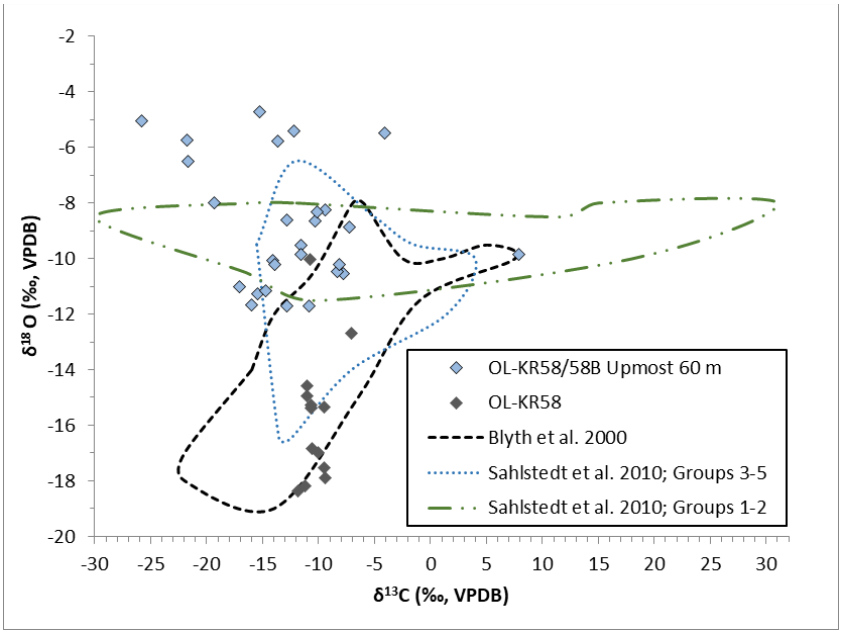


Figure 1. $\delta^{13}C$ and $\delta^{18}O$ values of calcite in the precipitate compared to reported values in fracture filling calcite at Olkiluoto. Groups 1-2 in Sahlstedt et al. (2010) represent latest calcite generations. Groups 3-5 represent older calcite generations.

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Origin of brackish bedrock groundwater at Finnish mining development site

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Introduction

Anomalous electrical conductivity horizons were discovered when studying bedrock groundwater at mining development site in Western Finland. Because the anomalies could not be explained thoroughly with the geological variations, the major and trace element geochemistry and isotopic composition (δ2H, δ18O, 87Sr/86Sr, 3H, 14C-DIC, δ13C-DIC) of groundwater were investigated further.

The origin of the salinity

The main reason for abrupt rise in electrical conductivity was abnormally high concentrations of Cl, Na and Ca in several exploration boreholes suggesting the salinity originating either from old brines or climatic and shoreline changes of the Baltic Sea of the last deglaciation phase. However, the studied boreholes are a lot shallower than the ones in which salinity is identified to originate from brines (Nurmi et al. 1988, Blomqvist 1999, Kietäväinen et al. 2017). Furthermore, the isotope results indicate long residence times (up to 10000 years BP), but no strong water-rock interaction. Most of the similar saline or brackish wells have been observed below the highest Litorina shoreline (Hyyppä 1984, Lahermo and Lampen 1987), the former Baltic Sea stage which preceded the present Baltic Sea stage about 7500-2500 years ago. However, despite of similar characters with sea water, a typical Litorina SO_4 layer was missing.

The mismatching results indicating long residence times, but no Litorina origin could be explained by the fact that, even a small amount of ancient brine or ancient sea water mixing with fresh modern groundwater layer would greatly affect the water geochemistry, while the isotopic composition would stay immutable. Furthermore, the pumping and slug tests indicate low hydraulic connectivity of the bedrock, which prevents the upper fresh groundwater horizon mixing with the brackish groundwater horizon deeper down. Therefore, it is likely that the dilution and infiltration of surface water is causing the lower saline element concentrations and the salinity will presumably increase deeper down. The brackish groundwaters of the site are a mixture of multiple end-member water compositions, most likely modern meteoric water, pre-Litorina Sea stage groundwater, the glacial melt water and possibly partly also of ancient brine (Pitkänen et al. 1994, 1996 and 1999).

The salinity affects the water quality and treatment possibilities of the forthcoming mine, as the high salinity should be removed before discharging the water to the environment to avoid any adverse impact on ecology, but possibly also for reuse purposes of water.

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Single-grain zircon LA-ICP-MS U-Pb age and Lu-Hf isotope systematics of the Archean Takanen greenstone belt in Kuusamo, Northern Finland

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Takanen is a small (10×3 km^2) east-west oriented supracrustal belt located in the northern Lentua Complex (near Kuusamo). Previous work in Takanen includes diamond drilling (32 holes; including the 1500-m-deep hole R339) and results of whole-rock analysis (203 XRF and 154 ICP-MS) (Iljina 2003; Iljina et al. 2006). Here, and in Karampelas (2022), drill core loggings, geochemical data, and 223 thin sections have been reviewed. In addition, two new U-Pb single grain zircon age determinations have been made in addition to Lu-Hf isotope analyses of the same crystals.

Takanen forms a 500–800-m-thick syncline (*Fig. 1*). Stratigraphically, it is composed of intercalated mafic volcanic and felsic volcanogenic rocks and minor komatiites crosscut by granitoid dykes. Volcanogenic rocks are typically banded or layered (rarely with graded bedding). Massive Fe-sulfide layers are typically associated with felsic volcanogenic rocks (low base and precious metal values). Komatiitic rocks include olivine-cumulates and thin undifferentiated units. Geochemically, felsic rocks are calc-alkaline and LREE-enriched, whereas mafic–ultramafic rocks are PM or MORB normative with flat REE-patterns, however, some mafic rocks show LREE-enrichment. Rock association and textures suggest shallow marine deposition environment with some redeposition, with plume-input (komatiites), and possibly some crustal contamination (LREE-enriched mafic rocks).

Based on zircon LA-ICP-MS analyses, the base and the top of the Takanen stratigraphy are aged 2.95 Ga and 2.70 Ga, respectively. Lu-Hf isotope systematics suggest that the 2.95 Ga sample contains material from older source, possibly ~3.2 Ga basement complex. In contrast, the 2.7 Ga sample is isotopically juvenile. Based on these results, the lowermost parts of the Takanen stratigraphy can be correlated with the ~2.95 Ga Luoma-group in the nearby Suomussalmi greenstone belt. The 2.70 Ga juvenile felsic volcanic unit does not have known equivalent in Finnish greenstone belts.

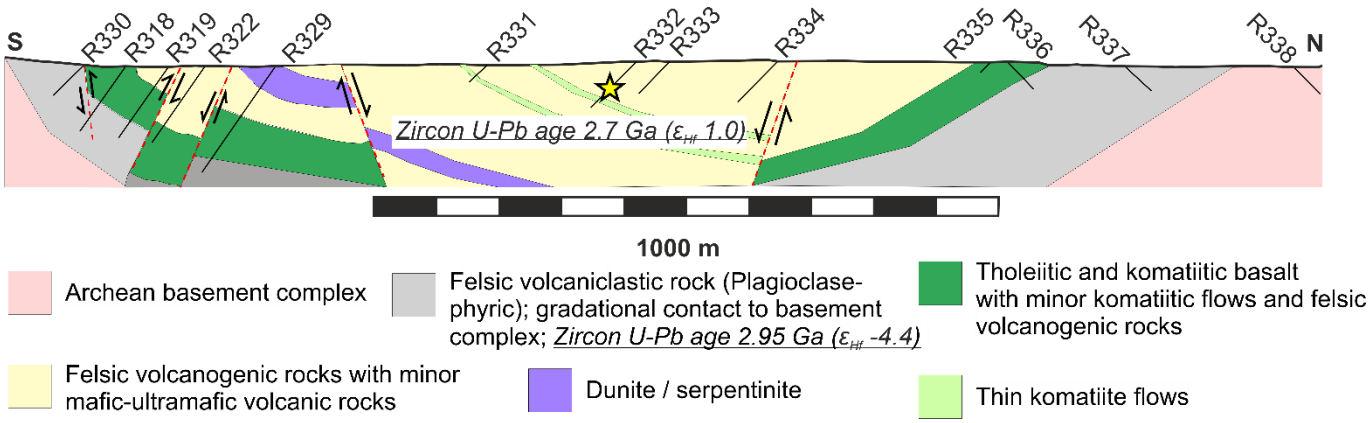


Figure 1. Schematic cross-section across the Archean Takanen greenstone belt. Two felsic volcanoclastic rock samples have been dated here with single-grain zircon U-Pb method, with results marked in figure and in label (grey unit; sample from drill hole R339 outside of profile).

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Reducing Uncertainty in Source Area Exploration of Mineralized Glacial Erratics Using Terrestrial Cosmogenic Radionuclide Dating

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Introduction

Mineral exploration typically utilises sedimentary geochemical indicators during some of the early steps of exploration campaigns. In glaciated regions the majority of the sediment material is related to glacial or fluvial processes, and related displacements. Quantifying the displacement in order to constrain probable source areas for sediment hosted metal or mineral anomalies is a typical task in mineral exploration. However, the tracing process has been observed to being particularly challenging in areas of weak glacial erosion.

In this study we explore the usability of Terrestrial Cosmogenic Nuclide (TCN) dating as a mean to reduce the uncertainty in source area tracing in mineral exploration. The method is used together with 1. stratigraphic investigations, 2. an erratic boulder sample database and literature sources of regional glacial history and 3. ice flow directions near the study site at Kaarestunturi, Finnish Lapland. The study site hosts a mineral exploration project that traces the source of gold mineralized quartz vein erratics, deposited atop multiple till beds.

TCN dating two of the mineralized erratics show that they contain a lengthy exposure history (apparent ages of 35.9 ± 1.3 and 30.3 ± 1.1 ka) that greatly precedes the latest deglaciation at c. 10 ka in the region. Dated local bedrock outcrops also retain large TCN inventories (apparent ages of 48.9 ± 1.9 and 85.3 ± 2.8 ka). The bedrock TCN results show that glacial erosion at the location has been very weak; this also implies slow ice movement velocities and therefore relatively short transportation distances. The erratic boulder TCN ages contain exposure from not only the Holocene, but also prior ice-free time periods. It is possible that the erratics have been transported during the late-Weichselian glaciation and during earlier glaciation(s). Combined results suggest a source area NNW of the current position of the studied mineralized erratics.

Risk management of the environmental impacts of black shales in Finland

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Introduction

Black shales are sedimentary rocks containing > 0.5% of organic carbon. Organic matter and S-rich compounds primarily deposited on seafloor together with silt- and clay-size detritus. Sulphide mineralogy, rock assemblage, textures and chemical characteristics vary from one black shale unit to another due to differences in the deposition environment and subsequent metamorphic and tectonic deformation and alteration processes. GTK has mapped the distribution of black shales using airborne geophysics and geological, petrophysical and geochemical studies (Loukola-Ruskeeniemi et al., 2023).

The distribution of sulphide-rich black shales should be taken into consideration during regional planning as they may generate acid drainage if exposed to weathering especially during anthropogenic activities such as road construction and peat production. Sulphide-rich black shales and related soils may affect the quality of groundwater and surface waters. For example, it is not recommendable to drill wells into black shale. (*e.g.*, Kousa et al., 2022; Loukola-Ruskeeniemi et al., 2003; Parviainen & Loukola-Ruskeeniemi, 2019)

How to apply the Black Shale Dataset for regional planning and environmental permit procedures?

One of the key issues is related to the scale limitations given by airborne geophysics. In many cases, more detailed geological, geophysical and geochemical studies will be needed to locate S-rich black shales and soils in a site. Moreover, due to scale issues the thickness of the black shale is in most cases exaggerated for the maps and the unit seems to be wider than in the real world.

Environmental risks will increase if the thickness of the black shale unit exceeds 3 m and sulphur concentration is > 3% and, in addition, if black shale is outcropped in the banks or bottom of a stream or a river. During glaciation, over 9000 years ago, ice consumed the upper layers of the bedrock. As black shale represents a 'soft' rock type compared with granitoids and quartzites, for example, glacial till rich in black shale materials can be found following the direction of the ice flow. To the opposite direction the possibility to find black shale -related materials in glacial till is lower.

If ditches have been deepened in a black shale area during land reclamation for agriculture or forestry, more detailed studies may be needed such as chemical analyses of till samples. (Loukola-Ruskeeniemi et al., 2022b)

Development of the risk management procedure for S-rich black shales and related soils will benefit especially from the lessons learnt during the development of risk management for naturally As-rich bedrock and soils in Germany (*e.g.*, Loukola-Ruskeeniemi et al., 2022a) and acid sulphate soils in Finland (*e.g.*, Autiola et al., 2022).

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Re-analysing Co-bearing Layman's samples in Finland

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Introduction

The demand for cobalt is increasing, it is one of the materials defined by the EU as critical raw material based on economic importance and supply risk. Cobalt as raw material has chemical and metallurgical uses. Cobalt is a critical component in the cathode of rechargeable lithium-ion batteries. Lithium batteries are used in electric cars and portable computers and smartphones. Other chemical uses of cobalt include the plastic industry, ceramics, paint, and pigment industries. In metallurgy, cobalt is used in high-temperature metal alloys used in turbines, defense industry, energy industry, medical science, catalysts, prosthetics, steel, carbides, diamond tools, and magnets. Currently, over half of the world's cobalt supply is consumed in rechargeable Li batteries.

The most significant known cobalt resources are located in the African copper zone, in the territory of the politically unstable Democratic Republic of Congo. Currently, in Europe, cobalt is produced only from two Finnish mines: Kevitsa Ni-Cu mine and Talvivaara/Terrafame Ni-Zn-Cu-Co mine, which is the largest known cobalt resource in Europe (Eilu, 2012; Törmänen & Tuomela, 2021). Finland's cobalt deposits are divided into four types of deposits, the orthomagmatic Ni-Cu-PGE, the orogenic Au-Cu-Co, VMS, and the so-called polygenetic deposits. Known sources of cobalt also include Outokumpu – type ores (e.g. Peltonen et al., 2008).

This study

During the master thesis of Bruun (2022), we discovered that Co concentrations vary significantly between old analytical methods and up-to-date wavelength dispersive X-ray fluorescence (XRF) analyses at Geohouse, Turku. Therefore, we have collected an extensive dataset of Co bearing samples from the Geological Survey of Finland Layman's sample archive. The dataset contained ca 150 analysed cobalt-bearing samples covering the Raahe -Ladoga zone, Outokumpu region, and other areas, mainly from Central Finland. The old analyses were done between the 1960s and 1990s (the methodology was mostly undocumented, but XRF was at the time common). Our new dataset was produced adhering to a strict QA/QC program, including recurring analyses of multiple international ore standards. The results showed that cobalt concentrations are significantly different compared to older analyses.

The median cobalt concentration of the re-analyses was 119 ppm, and for the old analyses, the average was 228 ppm, both datasets had variation from below the detection limit to over 10 000 ppm concentrations. The new results indicate lower concentrations in the samples; however, significantly higher concentrations were also observed from re-analyses. As we suspect XRF indeed was the preferred analytical method at the time, we propose that most of the high Co concentrations reported in the old data set are a result of an analytical error where correction of the overlap of Fe Kb and Co Ka lines was neglected. Our results highlight the need for close inspection of legacy data and probably a need for re-analysis to update the suitable showings for cobalt and other resources in Finland. Although there is a cost inferred for re-analysis, this should help to better aim the exploration with higher accuracy, and work can be focussed on areas of practical potential.

Acknowledgments

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Sokli, future raw material source

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Introduction

The Sokli carbonatite complex can be considered as a World-Class multi-commodity deposit with known P, Fe, REE and Nb resources. Sokli is currently underexplored and has a significant mineral resource development potential in e.g., phosphate, iron, rare earth elements, niobium, tantalum, uranium, copper, silver, zirconium and vermiculite.

In general, carbonatite-related deposits are the main sources of Nb and LREE; significant sources of Zr, Fe, Cu, vermiculite, phlogopite, fluorite, apatite, calcium carbonate, and sodalite; and have historically produced U and Th. Overall, less than 1 in 1000 discoveries become a profitable mine. Given that 9 out of 100 carbonatites and alkaline-carbonatite complexes contain currently producing or historic mines, carbonatites represent outstanding multi-commodity deposits and exploration targets (Simandl & Paradis, 2018).

There are several mineralisation types in the Sokli carbonatite complex, which hosts various commodities. The mineralisations are related both to the magmatic carbonatite and to the overlying regolith (laterite). Phoscorites are the main carriers of apatite (hard rock phosphate), magnetite (iron), pyrochlore (niobium, tantalum, uranium) and zirconium minerals. Late magmatic carbonatite dykes host e.g., LREE-carbonates and -phosphates, pyrochlore (Nb, Ta, U), chalcopyrite (copper) and silver. LREE-minerals like monazite and ancylite are rich in e.g., neodymium, praseodymium, lanthanum and cerium.

Weathering has concentrated e.g., francolite and apatite (phosphate), magnetite (Fe), pyrochlore (Nb, Ta, U), Mn-oxides, baddeleyite (Zr), vermiculite and LREE-minerals like rhabdophane in the overlying weathered layer, regolith, which has been locally preserved as a high-grade lateritic mineralization with a thickness from few meters to over 100 meters.

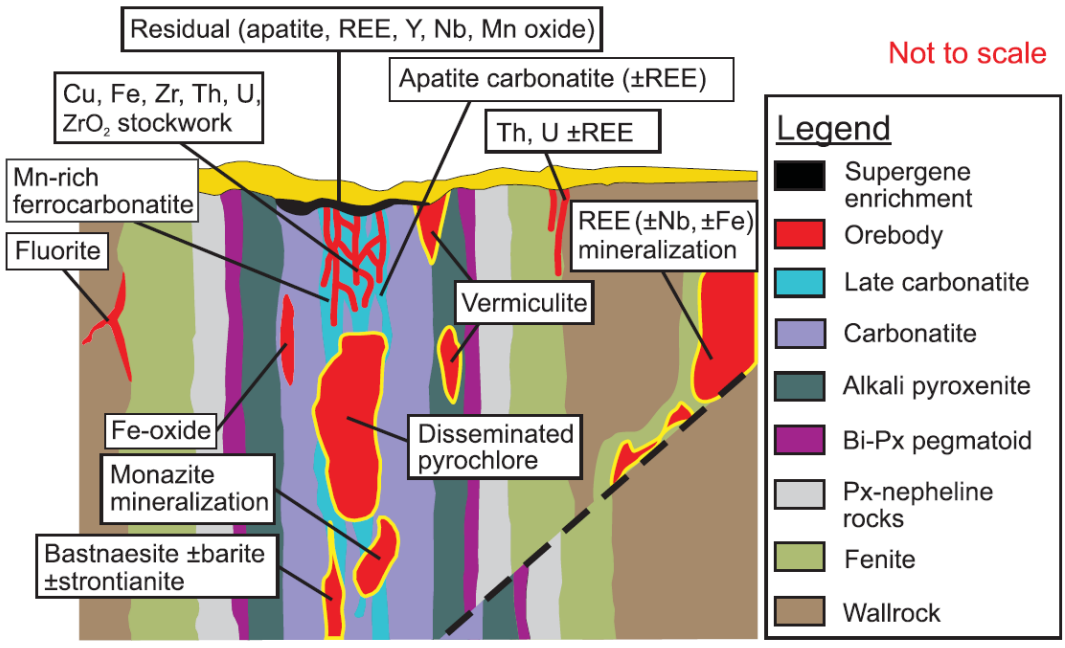


Figure 1. Vertical section of a hypothetical carbonatite mineralising system displaying the relationship between metallic and industrial mineral deposits relative to lithological units and geological contacts. The 'distal' carbo-hydrothermal fluid-related mineralisation or hydrothermally remobilised mineralisation (away from alkaline carbonatite complex) and residual deposits within weathered crust above the carbonatite complex are also highlighted. Bi – biotite, Px- pyroxene. (Simandl & Paradis, 2018)

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Konseptuaaliset mallit ja epävarmuudet geologisessa 3D-mallinnuksessa

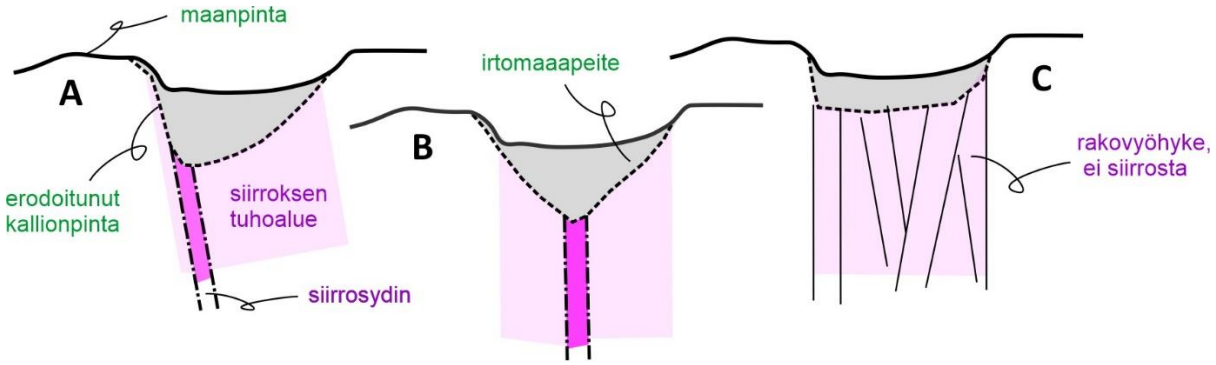
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Geologisissa tutkimuksissa käytettävien lähtöaineistojen laatuun, saatavuuteen, alueelliseen kattavuuteen ja jakautumiseen liittyy tyypillisesti merkittävää vaihtelua, joka omalta osaltaan aiheuttaa tuloksina syntyviin malleihin tulkinnallisuutta ja epävarmuuksia. Esimerkiksi kallioperäkartalla esiintyvien kivilajiyksiköiden muodot ja jatkuvuudet kyetään tulkitsemaan luotettavasti alueella, jolla on runsaasti kalliopaljastumia tai karttatulkintaa tukevia laadukkaita geofysiikan aineistoja. Vastaavasti peitteisiltä alueilta tuotettujen karttojen luotettavuus on lähtökohtaisesti aina heikompi.

Geologisen 3D-mallinnuksen yhteydessä epävarmuudet edelleen korostuvat, koska lähtöaineiston kattavuus suhteessa mallinnettavaan tilavuuteen on lähes aina varsin heikko. Kolmiulotteisen geologisen mallinnuksen epävarmuudet voidaan liittää neljään eri tekijään: konseptuaalinen malli, matemaattisen mallin rakenne, matemaattisen mallin parametrit, (interpoloinnin) lähtöpisteet (Wellmann ja Caumon, 2018). Konseptuaalisen mallin valinta, määrittely tai kehittäminen on mallinnuksen ensimmäinen työvaihe, ja sen tarkoitus on kuvata mallinnettavaa geologista ilmiötä ja prosessia (Kuva 1). Konseptuaalinen malli on työn lopputuloksen kannalta hyvin merkittävä, koska se tavallisesti ohjaa kaikkea myöhempää mallinnusta. Konseptuaalisen mallin epävarmuudet liittyvät kohteen geologiseen ymmärtämisen, mallintajan ammattitaitoon ja näiden tekijöiden yhteisvaikutuksena tehtyihin valintoihin. Konseptuaaliselle epävarmuuksille ei voi määritellä lukuarvoja (kuten lähtöaineiston tarkkuudelle) vaan sitä tulee tarkastella vaihtoehtoisilla ratkaisumalleilla tai esimerkiksi kinemaattisen-geometrisen restoroinnin kautta.

Tässä esityksessä annan muutamia esimerkkejä konseptuaalisen mallin valinnan merkityksestä i) alueellisen geologisen mallinnuksen, ii) siirroksiin liittyvien rakosysteemien, ja iii) siirrosten kontrolloiman maanpinnan eroosiotopografian ja maapeitteiden paksuuden mallinnuksessa.



Kuva 1. Kolme eri konseptuaalista mallia siirrosvyöhykkeeseen liittyvän maanpinnan topografisen painanteen ja sen alapuolella olevan erodoituneen kallionpinnan tulkintaan. Huomaa, että tässä esimerkissä vain maanpinnan morfologia tunnetaan (esim. LiDAR-aineiston perusteella), kun taas maanpinnan alapuoliolista osaa maankamaran koostumuksesta ja rakenteesta ei tunneta. A: Siirrosydin ja voimakkaan epäsymmetrinen tuhoalue. B: Siirrosydin ja symmetrinen tuhoalue. C: Rakovyöhyke, jonka yhteydessä ei ole selvää siirrosydintä.

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Jormua-Outokumpu suture – fact or fiction?

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Introduction

Suture is a concept joining separate tectonic units that have different plate tectonic, metamorphic and paleogeographic histories. The presence of a suture implies that the tectonic units were once widely separated either by oceanic lithosphere or extremely thinned continental lithosphere. *Suture zone* is the area where two tectonic plates were juxtaposed through a collision. A suture zone is characterized by a complex network of shear zones and exotic tectonic lenses typically including *ophiolitic fragments* or eclogites. Theoretically, a suture zone separates the domains representing upper and lower plates within the collision zone. In practice, the collisional structures are typically modified and overprinted by later deformation, multiple re-activation of faults and post-collisional intrusives. Thus, the spatial depiction of a suture zone is not a straightforward task.

A narrow 'oceanic' basin between the Archean blocks in eastern Finland is not a novel idea (e.g. Park et al., 1984), and presently *Jormua–Outokumpu suture* (J-OS) refers to the boundary of two tectonic provinces (Karelia province and Iisalmi-Pudasjärvi subprovince; see Kohonen et al., 2021). The basin developed ca. 1.97 – 1.93 Ga ago as a response to extreme crustal extension manifested by the sheeted dyke complexes and the exhumation of the lithospheric mantle. The central part of the basin was floored by the Archean sub-continental mantle (e.g. Peltonen, 2005) and the developing basin was filled by orogenic Upper Kalevian sediments ca. 1.95 – 1.91 Ga ago (e.g. Kontinen, 1987; Kohonen, 1995).

To be or not to be?

The evidence for a basin floored by exhumed subcontinental (Archean) mantle is convincing, but the tectonic setting and original location of the basin are more controversial. Presently, a major deformation zone, corresponding to the assumed J-OS, links together the Outokumpu-Rääkkylä and Kainuu belts. The zone is characterized by ophiolitic serpentinite lenses, tightly infolded outliers of Paleoproterozoic cover and excessive crustal shortening. Basically, the deformation zone (J-OS) can be explained either (i) a tight syncline preserving the allochthonous rocks (Upper Kalevian sediments and enclosed ophiolites) derived from further west or (ii) a crustal-scale scar representing the original location of the closed proto-oceanic rift basin.

Structural observations and the derived new modelling support closure of a remnant-ocean basin along the present J-OS. The southernmost tip of the Kainuu belt exposes the deep levels of the synclinal structure where the central part and the both margins of original basin can still be identified. The location of the suture zone is here marked by the ultramafic bodies (e.g. Alanen serpentinite) and associated Upper Kalevian greywackes, representing the depositional basement and turbiditic fill in the central part of the remnant-ocean basin, respectively. It appears that the Jormua-Outokumpu suture zone is a good spatial approximation of the Svecofennian collision zone between the two Archean crustal blocks. However, the mechanism (subduction or no subduction) and other details of the basin closure remain enigmatic.

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Records of continent-continent collisions in the Paleoproterozoic: exploring the effects of convergence obliquity and temperature

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In the Paleoproterozoic era (2.5-1.6 Ga ago), the mode of the plate tectonics was shifting from Archean plume-lid tectonics to modern tectonics, with colder and deeper subduction due to a decreasing mantle potential temperature. Hence, the geodynamic regime was different as well; subduction was more episodic and characterised by frequent slab breakoffs, while weaker lithosphere resulted in wider and lower-relief orogens. Metamorphic rocks also recorded a fingerprint of these conditions, generally lacking evidence of UHP(-LT) metamorphism. However, studying Paleoproterozoic orogens is challenging, as metamorphic rocks at the present-day erosional level often represent the middle-to-lower crustal orogenic interior. We aim to overcome this issue using pressure-temperature-time (*P-T-t*) paths extracted from generic, geodynamic continent-continent collision models and comparing them to *P-T-t* paths reconstructed from metamorphic minerals. The models were run using the 3D thermo-mechanical, finite-element geodynamic modeling code DOUAR (Braun et al., 2008), which uses the landscape evolution model FastScape. The work explored the effects of various continental collision obliquity angles, temperature conditions, and crustal thicknesses. The spatial dimensions of the models are 1000×1000×70 km and crustal thickness values of 35 km and 45 km were used. The models reflect continent-continent collision between colder and hotter continental blocks, which is implemented in the models by including a temperature difference of 100ºC along the model base at 70 km depth. Along this boundary, heat production is varied laterally to explore three different temperature scenarios. The convergence obliquity angle is also varied between 0º, 30º and 60º, while the subduction dip angle is constant at 45º. With the thinner 35 km crust, the models do not show much difference in the dynamics between the temperature scenarios, as the crust is too thin to develop wide orogens, and eventual partitioning of strain due to oblique collision. Similarly, the *P-T-t* paths represent only straightforward retrograde metamorphism, due to simple model dynamics and the lack of large-scale internal orogenic heating. Increasing the crustal thickness to 45 km significantly affects the orogenic development. The Paleoproterozoic temperature scenario with a 45 km crust creates both wide and lower-relief orogens, also producing clear strain partitioning for the 60º obliquity angle. This difference in dynamics further results in more variation in the recorded *P-T-t* paths. Ongoing work is exploring which stable mineral assemblages these *P-T-t* paths would correspond in metamorphic rocks.

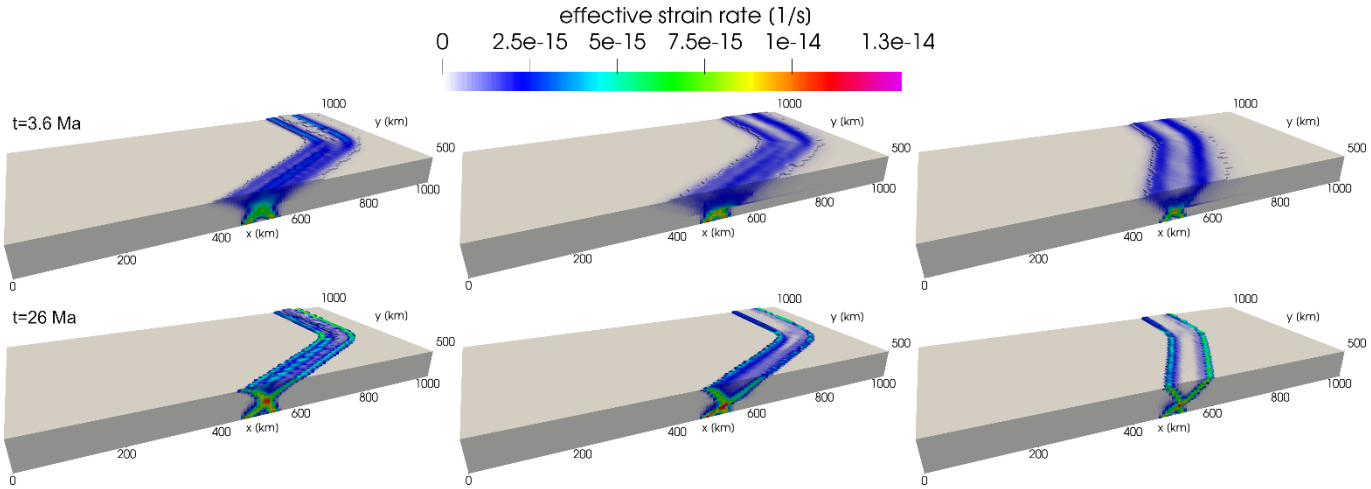


Figure 1. Evolution of the strain rate from 3.6 Ma to 26 Ma. All the models are high temperature cases, while the one on the left has the crustal thickness of 35 km, and two others 45 km. The two leftmost models have 60º obliquity convergence angle and the right one 30º.

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Structural characteristics of the bedrock and their bearing on the morphology of the eroded bedrock surface, Turku, South-Western Finland

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Bedrock structures within the Turku area have been characterized both at the scale of individual sites and at more regional levels. However, the link between these scales is largely missing. Knowledge about the structures of the bedrock in urban areas like the city of Turku is crucial for city planning, the construction industry, and public infrastructure. In particular, the contribution of bedrock structures to the erosional signatures, the resulting morphology of the bedrock surface, and the overburden thickness need to be acknowledged.

In this study, we highlight the characteristic bedrock structures and their contribution to the morphology of the partially exposed bedrock surface within the Turku area (Fig.1).

First, our study demonstrated the dependency of the bedrock structures from the regional to the local scale as shown by a cross-section (Fig. 1c) illustrating the variation within the geometry and the associated strain of the ductile structures, and their control over the overprinting brittle structures. The ductile structures in the study area show homogeneous nature trending strongly ENE-WSW with minor deviations related to refolding of early sub-horizontal structures (Fig.1a). Within the study area, smaller deformation zones tend to follow the orientation of the major deformation zones (ENE-WSW and c. N-S). In contrast, brittle structures are more heterogeneous and no single trend emerges (Fig.1b). However, major fracturing follows the orientation of deformation zones in their vicinity but diversifies rapidly further away from deformation zones

Second, we generated digital elevation models of the bedrock (Bedrock DEMs; Fig.1b) using almost 600k data points from geotechnical drills and LiDAR. Interpolations of the bedrock DEM honour the input XYZ data points and the local scale bedrock structures based on field mapping conducted within the study area. Bedrock-DEMs address the influence of the bedrock structures since bedrock depressions and abrupt changes in the elevation are located along significant structural features in the bedrock such as the deformation zones. This highlights the link between regional and local scale bedrock structures since regional scale deformation zone structures control the local scale's abrupt changes in the bedrock surface.

The network of bedrock depressions creates several challenges for society in the Turku region. The bedrock depressions are favourable surroundings for potentially unstable sedimentary layers, such as sulfidic clays (Fig.1c). Furthermore, the stability of the bedrock is weak along the deformation zone due to dense fracturing and groundwater flow. These unstable conditions in the ground can create severe issues to the land-use industries without proper investigations.

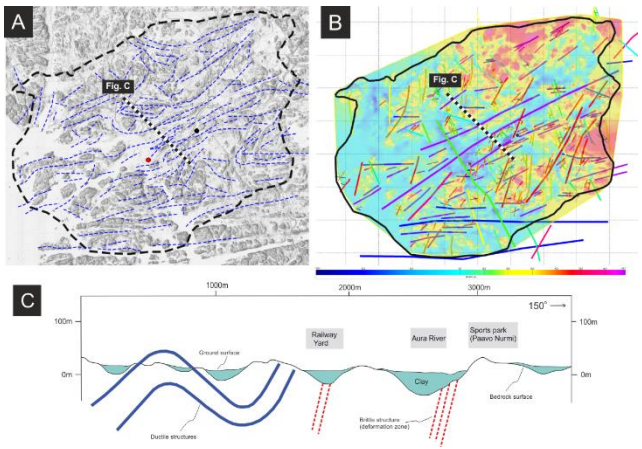


Figure 1. A) Ductile structures of the bedrock. Ground surface topography (LiDAR) map on the background (GTK). Red dot=Turku castle, black dot=Turku cathedral. B) Brittle structures of the bedrock (colours of the polylines are representing dip azimuth of the fractures). Preliminary Bedrock-DEM on the background (colour map scale on the bottom). C) Cross-section sketch highlighting major brittle and ductile structures across the city of Turku.

3D seismic modelling and imaging using two seismic profiles of orthogonal geometry at Neves-Corvo mining site, Portugal.

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1. Introduction

For exploring the natural resources in the subsurface using seismic methods, it is desired to image the target in a 3D seismic volume. To obtain such seismic volumes, 3D seismic imaging needs to be performed using data acquired from a 3D seismic acquisition. Traditionally, 2D seismic data is rarely utilized to produce a seismic volume due to its ambiguity in differentiating the signals from either side of the single 2D line. However, using the 2D datasets to perform a 3D imaging task is possible when two seismic lines are deployed orthogonally in a survey. Additionally, reducing the symmetrical artifacts by migrating the 2D seismic data in 3D can be realized when the acquisition line is crooked. Using two seismic profiles deployed at Neves-Corvo mining site in Portugal (Brodic et al., 2021; Donoso et al., 2021), I show that applying 3D seismic migration algorithms to 2D seismic data can be advantageous for better imaging the spatial distribution of mineral deposits in 3D.

2. Numerical and field studies

Before applying the 3D imaging migration to the field datasets, I first conducted a numerical study to investigate the potential and limitations of 3D seismic imaging constrained by the 2D seismic acquisition and the geometry of the target. The target is represented by the available ore block model derived from the core samples. The elastic wave modelling is done in a constant 3D velocity model (Vp = 4680 m/s, Vs = 2900 m/s, rho=3000 kg/m^3) in which the ore block (Vp = 6000 m/s and Vs = 3718 m/s, rho =3846 kg/m^3) is embedded. The seismic source is a vertical force. And the wavelet is a Ricker having the dominant frequency of 50 Hz. The recorded data are the displacements in the vertical direction. Applying the 3D Kirchhoff prestack time migration (PSTM) to the synthetic datasets recorded by two receiver lines individually, I obtained two seismic image volumes correspondingly. By investigating the two image volumes, I found that (1) the crooked line in the seismic acquisition contributes to reducing artifacts caused by migrating the 2D data in the 3D space, and (2) non-PP reflections from the ore block are not migrated to its true positions in the migration algorithm targeted for PP signals.

Aided with the information obtained from the numerical study, I applied the 3D Kirchhoff PSTM to the field datasets to image the mineral deposits. Two seismic volumes were obtained using the field data from two receiver lines individually. The reflectors in the two seismic volumes were picked out individually and combined to depict the ore deposits (**Figure 1**). To evaluate the accuracy of the picked 3D reflector delineating the deposit, an illumination analysis was performed based on the ore block model.

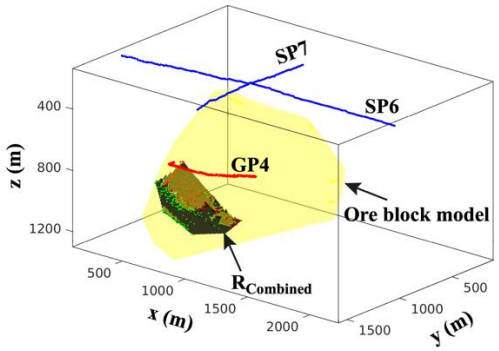


Figure 1. The 3D picked reflector ($\boldsymbol{R}_{Combined}$) of the ore deposits using data acquired from two surface receiver lines (SP6 and SP7) due to the tunnel source line (*GP4*). The red dots and green dots constructing the black surface ($\boldsymbol{R}_{Combined}$) are picked from the seismic volumes due to seismic profiles SP6 and SP7 respectively. The yellow surface shows the ore block model.

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The 1st GeoDays of Finland is held at the Kumpula campus of the University of Helsinki, 14th–17th March 2023. The event gathers over 100 experts 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 event. The organizing committee would like to express gratitude to all the authors for their contributions.

Visit www.geologinenseura.fi for information regarding the next GeoDays!

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