Proceedings of

THE GEOLOGICAL SOCIETY OF FINLAND

Volume 5

Abstracts of
the 3rd **GeoDays**
11th–13th March 2025, Oulu, Finland

Edited by Pertti Sarala & Tiina Eskola

The 3rd GeoDays
11th–13th March 2025, Oulu, Finland

Organizing committee (in alphabetical order)

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Contents

Foreword

Various geological raw materials are the pillars of society. Their sufficient and diverse supply requires continuous research and resource maintenance, as well as cost-effective utilization. Environmental aspects must also be considered so that the utilization of various natural resources can be done in a respectful and acceptable manner. These aspects are emphasized, for example, in the latest Finnish Mineral Strategy. However, it is worth noting that geosciences are much more than just the research and exploitation of mineral and raw material resources. The scope of geosciences will be well highlighted at this year's GeoDays, for example, in the meetings of various committees, in the diverse presentation and poster coverage, and in the extensive presentation of project activities. It is also gratifying to see many students and university researchers, as well as companies and sponsors from the field, actively participating in the GeoDays. This is likely to increase the flow of information and networking, which contributes to high-quality interaction between development activities, teaching, and research.

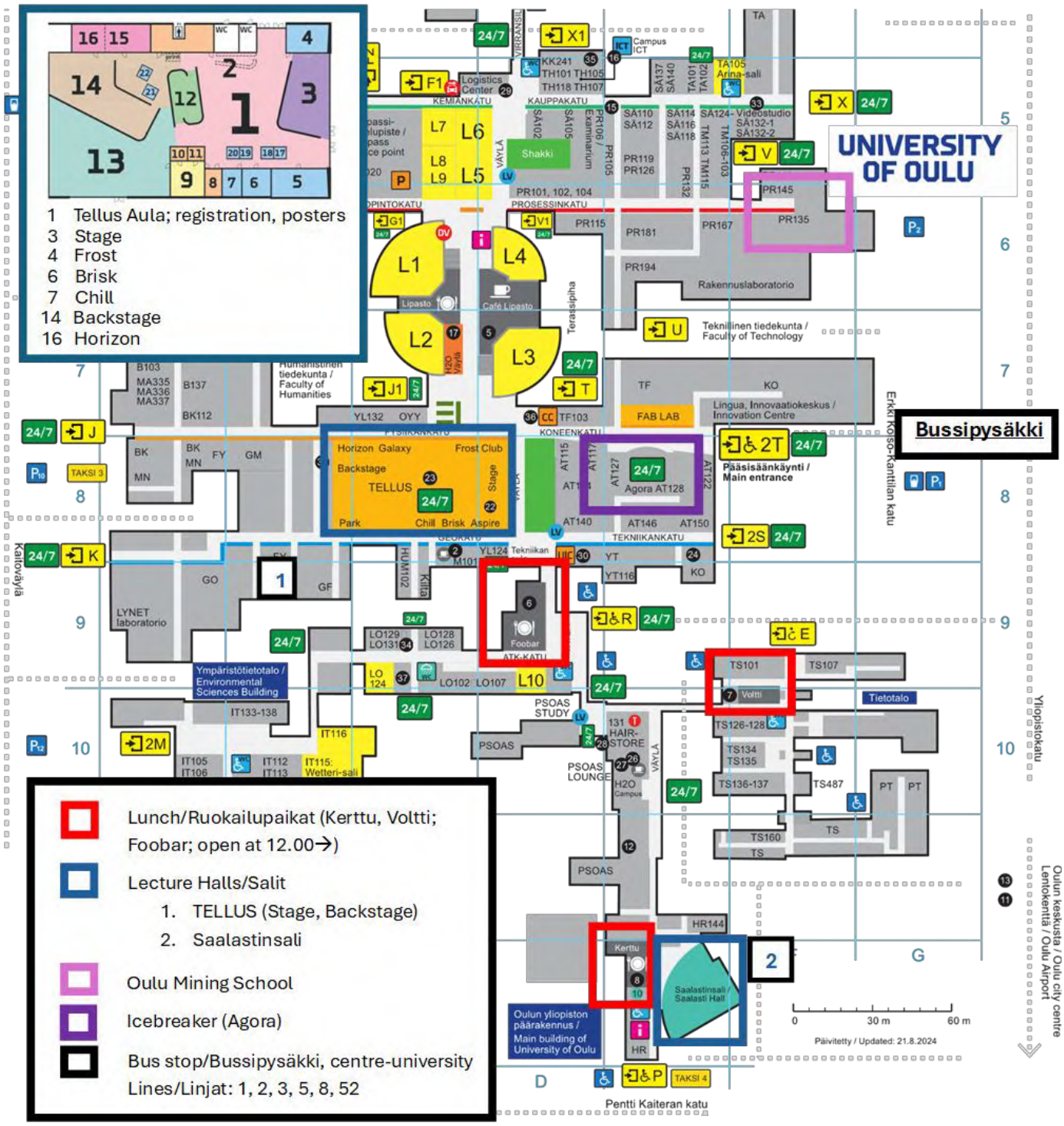
Esipuhe

Erilaiset geologiset raaka-aineet ovat yhteiskunnan tukipilareita. Niiden riittävä ja monipuolinen saanti vaatii jatkuvaa tutkimusta ja resurssien ylläpitämistä sekä tietysti kustannustehokasta hyödyntämistä. Myös ympäristönäkökohdat tulee huomioida, jotta erilaisten luonnonvarojen hyödyntämistä voidaan tehdä luontoa kunnioittaen ja hyväksyttävästi. Näitä näkökohtia korostetaan mm. tuoreimmassa Suomen mineraalistrategiassa. On kuitenkin hyvä huomioida, että geotieteet ovat paljon muutakin kuin pelkkää mineraali- ja raaka-ainevarojen tutkimusta ja hyödyntämistä. Geotieteiden laajuus tulee hyvin esille tämän vuotisilla Geopäivillä esimerkiksi erilaisten komiteoiden kokoontumisina, monipuolisena esitelmä- ja posterikattauksena sekä laajana projektitoiminnan esittelynä. Ilahduttavaa on nähdä myös suuri joukko opiskelijoita ja yliopistojen tutkijoita sekä alan yrityksiä ja sponsoritahoja osallistumassa aktiivisesti päiville. Se on omiaan lisäämään tiedonkulkua ja verkottumista, joka edesauttaa laadukasta kehittämistoiminnan, opetuksen sekä tutkimuksen vuorovaikutusta.

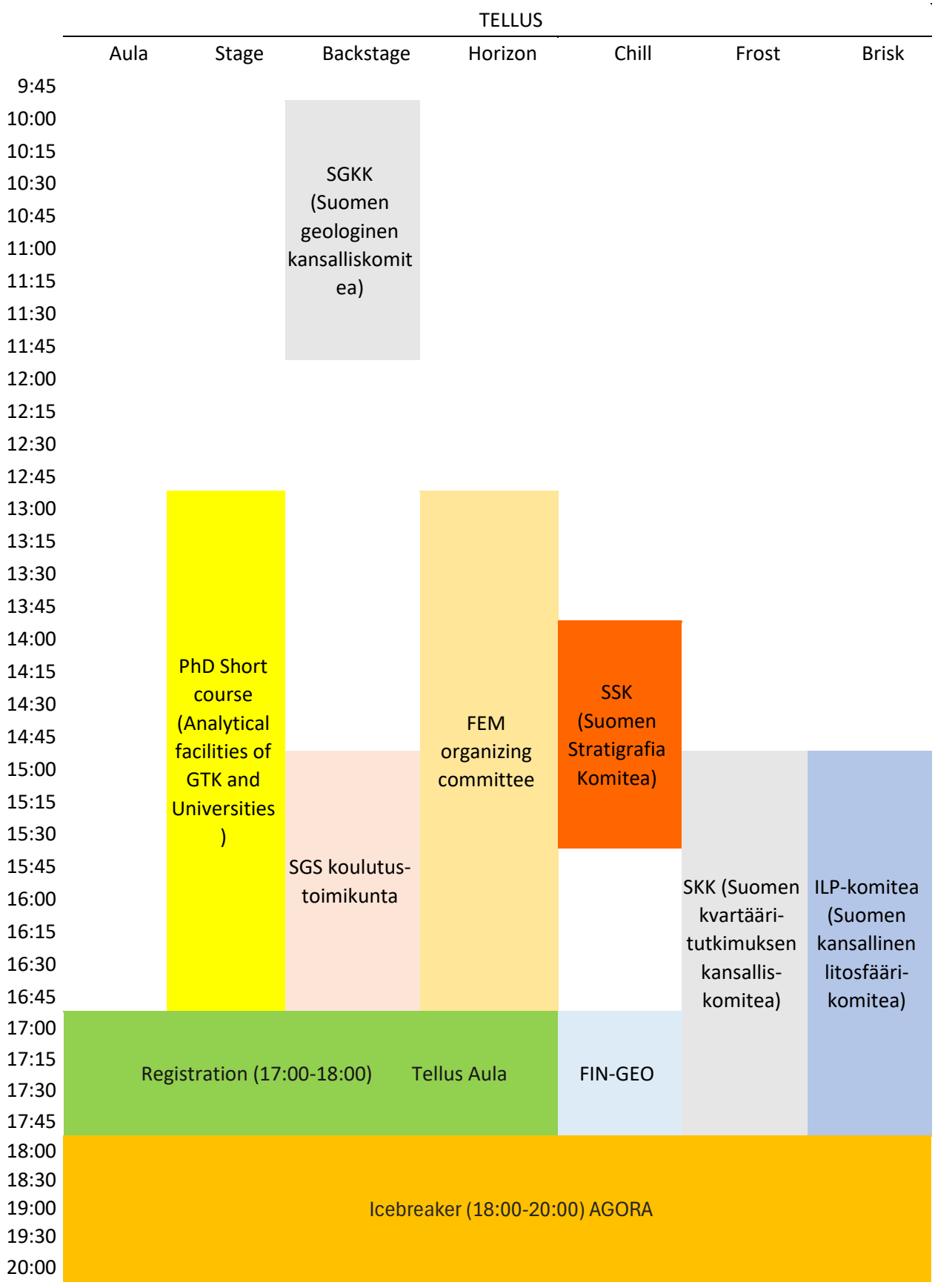
Förord

Olika geologiska råvaror är samhällets pelare. Deras tillräckliga och mångsidiga utbud kräver kontinuerlig forskning och resursunderhåll, samt naturligtvis ett kostnadseffektivt utnyttjande. Miljöaspekter måste också beaktas så att utnyttjandet av olika naturresurser kan ske på ett respektfullt och acceptabelt sätt. Dessa aspekter betonas, till exempel: i den senaste finska mineralstrategin. Det är dock bra att notera att geovetenskap är mycket mer än bara forskning och exploatering av mineral- och råvaruresurser. Geovetenskapens bredd kommer väl att lyftas fram under årets GeoDays-mötet, till exempel genom möten i olika kommittéer, det mångsidiga utbudet av presentationer och affischer och den omfattande presentationen av projektaktiviteter. Det är också glädjande att se ett stort antal studenter och universitetsforskare, samt företag och sponsorer inom området, aktivt delta under GeoDays-mötet. Det kommer sannolikt att öka informationsflödet och nätverkande, vilket bidrar till högkvalitativ interaktion mellan utvecklingsverksamhet, undervisning och forskning.

Map of the 3rd GeoDays, 11.–13.3.2025, Oulu © University of Oulu



Schedule of the 3rd GeoDays, 11.3.2025, Oulu (Tue)



Schedule of the 3rd GeoDays, 12.–13.3.2025, Oulu (Wed & Thu)

	Wednesday 12.3.2025		Thursday 13.3.2025	
8:30	Registration (8:30-9:00) Saalastinsali			
8:45			Registration (8:45-9:00) Saalastinsali	
9:00	Opening (9:00-9:15) - Saalastinsali		Opening (9:00-9:15) - Saalastinsali	
	Session 1 (9:15-10:15) - Saalastinsali		*Session 5 (9:15-10:15) - Saalastinsali*	
9:15	**Keynote: Teo Kangaspunta (TEM) ETÄYHTEYS**		**Keynote: Tapani Rämö (HY)**	
9:30				
9:45	**Invited:** Xuan Liu (GTK)		**Invited**: Anu Kaakinen (HU)	
10:00	Fangfang Guo (OU)		Samuli Helama (LUKE)	
10:15	Coffee (10:15-10:45) - Saalastinsali		Coffee (10:15-10:45) - Saalastinsali	
10:30				
	Session 2 (10:45-11:45) - Saalastinsali		*Session 6 (10:45-11:45) - Saalastinsali*	
10:45	**Keynote: Frederik Schenk (StockUniv/HU)**		**Invited:** Markku Pirttijärvi (Radai Oy)	
11:00			**Keynote:** Mari-Leena Talvitie (OKM)	
11:15	Aarno Kotilainen (GTK)		**Invited**: Jari Joutsenvaara (OU)	
11:30	**Invited:** Kirsti Korkka-Niemi (GTK)		**Palkintojen jako/Awards**	
11:45	Lunch (11:45-13:00)		Lunch (11:45-13:00)	
12:45				
	S3A (13:00-14:30) - Stage	*S4A (13:00-14:30) - Backstage*	*S7 (13:00-14:15) - Stage*	*S8 (13:00-14:15) - Backstage*
	Kurikka buried valley scientific research/Groundwater	Crustal evolution and ore geology	Palaeoclimate and processes	Eploration and modelling
13:00	**Invited:** Niko Putkinen (GTK)	Oliver Teräs (ÅA)	Natalia Saburova	Shenghong Yang (OU)
13:15		Patrik Jänkävaara (TU)	Áquila Mesquita (HU)	Malcolm Aranha (OU)
13:30	Timo Ruskeeniemi (GTK)	Eemu Ranta (HU)	Jie Zhang (E China N Univ)	Charmee Kalubowila (OU)
13:45	Annika Åberg (GTK)	Viivi Yliknuussi (HU)	Pirita Stark (HU)	Kari Moisio (OU)
14:00	Tiina Eskola (OU)	Brandon Datar (OU)	Liva Trasune (HU)	Fereshteh Khammar (HU)
14:15			Meri Mäkelä (HU)	Oltingey Lindi (OU)
14:30	Coffee (14:30-15:00) - Tellus lobby		Coffee (14:30-15:00) - Tellus lobby	
14:45				
	S3B (15:00-16:00) - Stage	*S4B (15:00-16:00) - Backstage*	*S9 (14:45-16:00) - Stage*	*S10 (14:45-16:00) - Backstage*
	Kurikka buried valley scientific research/ Groundwater	Crustal evolution and ore geology	Cooperation and networking	Geosciences
15:00	Marie-Amelie Petre (GTK)	Minna Markkanen (TU)	Juha Kaija (GTK)	Iida Kostamo (HU)
15:15	Juuso Ikonen (GTK)	John Kalimenze (TU)	Jari Joutsenvaara (OU)	Veikko Peltonen (HU)
15:30	Aleksi Tuunainen (GTK)	Petri Pulli (OU)	Matti Kinnunen (GTK)	Sakari Salonen (HY)
15:45	Nizar Abouzaki (Geovisor)	Pelayo Barrón (ÅA)	Mirkka Visuri (SYKE)	Kirsti Loukola-Ruskeeniemi (GTK)
16:00	Poster session (16:00-17:45) Tellus Aula		Matti Kinnunen (GTK)	Teemu Karlsson (GTK)
16:15			Closing	
16:30				
17:30				
18:30	18:30 -> Restaurant Bistro, Radisson Blu Hotel Volunteer dinner			

Program of the 3rd GeoDays, Linnanmaa Campus, Oulu

Tuesday 11th March

Workgroup/project meetings:
10.00–12.00 SGKK (Suomen geologinen kansalliskomitea) Tellus Backstage
13.00–17.00 FEM organization committee, Tellus Horizon
14.00–15.30 SSK (Suomen Stratigrafiakomitea) Tellus Chill
15.00–17.00 SGS koulutustoimikunta, Tellus Backstage
15.00–18.00 SKK (Suomen kvartäärityutkimuksen kansalliskomitea) Tellus Frost
15.00–18.00 ILP-komitea (Suomen kansallinen litosfäärikomitea) Tellus Brisk
17.00-18.00 FIN-GEO, Tellus Chill

Short course:
13:00-17:00 Short course for PhD students: Geochemical and mineralogical analytical facilities of the universities and the Geological Survey of Finland (Tellus, Stage)

17:00-18:00 Registration (Tellus lobby)
18:00-20:00 Ice breaker (Agora)

Wednesday 12th March

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

9:00- 9:15 Opening of the meeting (Saalastinsali)

The organizing committee

Wednesday Plenary, Session 1 (Saalastinsali): Mineral strategy and natural resources

Chair: Pertti Sarala

9:15-9:45 **Keynote: Kansallinen mineraalistrategia – National mineral strategy**
Teo Kangaspunta (Ministry of Employment and the Economy) page 14
9:45-10:00 **Invited**: CRM geotraceability: present and future
Xuan Liu (Geological Survey of Finland) page 15
10:00-10:15 PGE geochemistry of Palaeoproterozoic mafic and ultramafic volcanic rocks from northern Fennoscandia: implications for exploration of magmatic sulphide deposits
Fangfang Guo (University of Oulu) page 16

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

Wednesday Plenary, Session 2 (Saalastinsali): Dynamic hydrological systems

Chair: Tiina Eskola

10:45-11:15 **Keynote: Model vs. Proxy-Evidence for the Severity of Past AMOC Disruptions**
Frederik Schenk (Stockholm University & University of Helsinki) page 17
11:15-11:30 Mapping the seabed sedimentation rates – the winds of change also on the seabed?
Aarno Kotilainen (Geological Survey of Finland) page 18
11:30-11:45 **Invited:** Hydrogeology: Recent advances and challenges ahead
Kirsti Korkka-Niemi (Geological Survey of Finland & University of Helsinki) page 19

11:45-13:00 Lunch break

Session 3A: Kurikka buried valley scientific research/Groundwater 1 (Tellus Stage)

Chair: Kirsti Korkka-Niemi & Niko Putkinen

13.00-13:30 **Invited:** The significance of scientific research on the Kurikka Buried Valley in the field of Finnish geology and hydrogeology

Niko Putkinen (Geological Survey of Finland) page 20

13:30-13:45 Searching for bedrock groundwater in Kurikka, western Finland

Timo Ruskeeniemi (Geological Survey of Finland) page 21

13:45-14:00 3D modelling code scheme development in Kurikka buried valley

Annika Åberg (Geological Survey of Finland) page 22

14:00-14:15 A closer look of the preliminary pollen results and lithostratigraphy of a long sediment sequence from Kurikka, western Finland

Tiina Eskola (Oulu Mining School) page 23

14:15-14:30 (no presentation)

Session 4A: Crustal evolution in the Fennoscandia 1 (Tellus Backstage)

Chair: Jukka-Pekka Ranta & Tapio Soukka

13.00-13:15 A comparative study of granitic pegmatites and their country rock metapelites from Ostrobothnian Schist Belt, western Finland

Oliver Teräs (Åbo Akademy) page 24

13:15-13:30 Effect of the anisotropy and scalability of brittle structures on crystalline rocks

Patrik Jänkävaara (University of Turku) page 25

13:30-13:45 Late-stage magmatic fluid compositions in mafic intrusions constrained by fluid inclusion analysis

Eemu Ranta (University of Helsinki) page 26

13:45-14:00 Origin of enderbites and their role in the metamorphic and deformational history of the Lapland Granulite Belt

Viivi Yliknuussi (University of Helsinki) page 27

14:00-14:15 In-situ trace elements and Sr isotopes in plagioclase in the Koillismaa intrusion, Finland, and implications for the formation of Fe-Ti-V oxide ores

Brandon Datar (University of Oulu) page 28

14:15-14:30 (no presentation)

14:30-15:00 Coffee break (Tellus lobby)

Session 3B: Kurikka buried valley scientific research/Groundwater 1 (Tellus Stage)

Chair: Kirsti Korkka-Niemi & Niko Putkinen

15.00-15:15 Age Indicator (^{3}H) and Hydrochemistry to Understand Groundwater Flow in the Kurikka Buried Valley Aquifer System, Western Finland

Marie-Amelie Petre (Geological Survey of Finland) page 29

15:15-15:30 Microbial communities and isotopes as novel tracers for groundwater flow paths in the multi-layered aquifer system in Kurikka, western Finland

Juuso Ikonen (Geological Survey of Finland) page 30

15:30-15:45 Towards regional groundwater flow modeling of the Kurikka aquifer system

Aleksi Tuunainen (Geological Survey of Finland) page 31

15:45-16:00 Innovative hydrogeological monitoring system - HydroVisor A smart solution for water sustainability

Nizar Abouzaki (Geovisor) page 32

Session 4B: Crustal evolution in the Fennoscandia 2 (Tellus Backstage)

Chair: Tapio Soukka & Jukka-Pekka Ranta

15.00-15:15 Hydrothermal alteration and its effects on Ti-V deportment and processing of the Middle Ore Layer (MOL) from the Mustavaara V-(Ti-Fe) deposit, Finland

Minna Markkanen (University of Turku) page 33

15:15-15:30 Geological characteristics of Rytkynkylä volcanic rocks in central Finland: constraints from whole-rock geochemistry

John Kalimenze (University of Turku) page 34

15:30-15:45 Mineral systems analysis for Lithium-bearing pegmatite prospectivity in Central Lapland Granitoid Complex and its surroundings

Petri Pulli (University of Oulu) page 35

15:45-16:00 Understanding the role of brittle deformation on the formation of crystalline reservoirs and geothermal resources: a case study from Turku city

Pelayo Barrón (Åbo Akademy) page 36

Poster session (Tellus Lobby)

16:00-17:45

Session order (3, 4, 7, 8, 9, 10; no posters for sessions 1, 2, 5, 6) and then alphabetical order by first author

Sessions 3A and 3B:

1. *S. Heikura (OU)*: Geochemical composition and magnetic susceptibility of thick organic inter-till sediments from Kurikka, southern Ostrobothnia (page 37)
2. *T. Lahtinen (GTK)*: Current trends in the use of machine learning in groundwater research (page 38)
3. *S. Silvennoinen (HU)*: High-resolution multi-proxy study of Northern Baltic Sea sediments from Kurikka: Insight into paleomagnetic record and paleoenvironmental changes (page 39)
4. *J. Wikström (HU)*: Investigating the suitability of groundwater dating tracers in Finnish aquifers (page 40)

Sessions 4A and 4B:

5. *R.F. Abioye (OU)*: Mineralogy and geochemistry of the Terrafame black shale, and its implication of hosting minerals of rare earth elements and their source (page 41)
6. *U. Farid (OU):* Sedimentological characterization of evaporite bearing Petäjäskoski Formation, Peräpohja belt, Finland (page 42)
7. *K. Hiltunen (HU)*: Metamorphic evolution of felsic granulites in the Ivalo-Nellim region, Lapland Granulite Belt (page 43)
8. *K. Luolavirta (Geopool Oy)*: A Machine Learning framework for target-scale 3D mapping of geological features with special (page 44)
9. *L.M.L. Maunu (HU)*: The geochemical and petrological variability of the oceanic crust and upper mantle in the Macquarie Island ophiolite (page 45)
10. *A. Tisora (OU)*: Geochronological study of the Savukoski group in Central Lapland Belt northern Finland and its implication for regional mineral exploration (page 46)

Session 7:

11. *F. Aragão (HU)*: Optimization of filtration protocols in hypolimnetic withdrawal and treatment systems (HWTS) (page 47)
12. *T. Junna (GTK)*: Land use as a driver of increased organic carbon burial in boreal lakes (page 48)
13. *A.M. Kaskela (GTK)*: The European Marine Observation and Data Network (EMODnet) and advancing Marine Geoscience (page 49)
14. *E. Kiiski (HU)*: Seasonality of Holocene climate change in Northern Europe (page 50)

15. *E.H. Kivilä (JU)*: Daphnia ephippia as time capsules – using dormant eggs to detect browning-induced shifts in lake biogeochemistry (page 51)
16. *M. Korppoo (SYKE)*: Simulating carbon fluxes in a boreal, eutrophic lake (page 52)

Session 8:

17. *S. Alborzian J. (HU)*: Multivariate statistical analysis of till geochemical data: identifying potential areas for gold exploration in northern Finland (page 53)
18. *A.B. Haivio (HU)*: Electrical conductivity studies on varying graphite distributions hosted in synthetic rocks using 3D printing technology (page 54)
19. *M. Raatikainen (OU)*: Self-organizing map modelling and prospectivity mapping of surface geochemical data (page 55)
20. *T. Suutari-Jääskö (OU)*: Gravimetric Survey in Mineral Exploration (page 56)

Session 9:

21. *L. Palamakumbure (HU)*: Predicting the surface age of asteroids using the space weathering features in reflectance spectra: small data machine learning (page 57)
22. *A.E.K. Ojala (HU) – represented by P. Sarala (OU)*: Stratigraphic framework in Finland – formal classification and practical guidance (page 58)
23. *P Sarala (OU)*: International applied field techniques course for developing multidisciplinary geological skills in promoting green transition in Estonia (page 59)
24. *M. Yadi (OU)*: REMHub Consortium Project: University of Oulu's Role in Pioneering Sustainable Solutions for a Resilient European REE Supply Chain and Advancing Clean Energy and Green Transition (page 60)

Session 10:

25. *M. Arancibia – represented by J. Korteniemi (Muon Solutions Oy)*: Muon imaging for waste rock pile characterisation using borehole detectors (page 61)
26. *J. Korteniemi (Muon Solutions Oy)*: Muon imaging of a bauxite deposit: Results from Jajce, Bosnia and Herzegovina (page 62)
27. *N. Paasovaara (OU, XAMK)*: Developing continuously compressing crushing of critical minerals – Testing of dry processing method for graphite ore (page 63)
28. *T. Soukka (Centre for Material analysis, OU)*: New characterize method for ore minerals with combining FIB-SEM and SC-XRD (page 64)

Thursday 13th March

8:45-9:00 Registration (Saalastinsali lobby)

9:00- 9:15 Opening of the day (Saalastinsali)

Thursday Plenary, Session 5 (Saalastinsali): On the verge of ultimate questions

Chair: Esa Heilimo & Jussi Heinonen

9:15-9:45 **Keynote: Source constraints on the Late Cretaceous, strongly peraluminous magmatism of U.S. Cordilleran Interior; the White Rock Wash pluton, Nevada, and its corollaries**

Tapani Rämö (University of Helsinki) page 65

9:45-10:00 **Invited:** Early human palaeoenvironments in Nihewan, Northern China

Anu Kaakinen (University of Helsinki) page 66

10:00-10:15 NOMA: Pentti Eskola

Samuli Helama (Natural Resources Institute Finland) page 67

10:15-10:45 Coffee break

Thursday Plenary, Session 6 (Saalastinsali): New technologies and future

Chair: Esa Heilimo & Jussi Heinonen

10:45-11:00 **Invited:** Drone magnetic and electromagnetic surveys of Radai

Markku Pirttijärvi (Radai Oy) page 68

11:00-11:15 Ministry greetings

Mari-Leena Talvitie (Ministry of Education and Culture)

11:15-11:30 Muon imaging in underwater geology: Insights from the Mine.io project

Jari Joutsenvaara (Muon Solutions Oy) – Abstract: Korteniemi et al. page 69

11:30-11:45 Awards: Best Masters' theses in 2024 by K.H. Renlund Foundation, and Best Ph.D. theses by the Geological Society of Finland

Veli-Pekka Salonen (K.H. Renlund Foundation), Esa Heilimo (Geological Society of Finland)

11:45-13:00 Lunch break

Session 7: Palaeoclimate and processes (Tellus, Stage)

Chair: Anu Kaakinen & Aarne Kotilainen

13.00-13:15 Paleoecological reconstructions for Crimean Cretaceous-Paleogene boundary

Natalia Saburova page 70

13:15-13:30 The aeolian dynamics in the Pre-vegetated Earth and its stratigraphic record

Áquila Mesquita (University of Helsinki) page 71

13:30-13:45 Avulsion of the Yellow River into the South Yellow Sea during the early to middle Holocene: Evidence from Clay Provenance of the Yangtze Paleo-valley

Jie Zhang (East China Normal University) page 72

13:45-14:00 Using Dynamic Image Analysis of size-shape distributions to determine the mode of aeolian sediment transport and provenance shifts

Pirita Stark (University of Helsinki) page 73

14:00-14:15 The potential of Dynamic Calibration Region approach in plant macrofossil-based palaeoclimate studies

Liva Trasune (University of Helsinki) page 74

14:15-14:30 Diatom and dinoflagellate cyst species dynamics over four years in seasonally ice-covered Young Sound fjord, Northeast Greenland

Meri Mäkelä (University of Helsinki) page 75

Session 8: Eploration and modelling (Tellus, Backstage)

Chair: Shenghong Yang & Kari Moisio

13:00-13:15 Sustainable exploration for orthomagmatic ore deposits, progress of the HEU SEMACRET project

Shenghong Yang (University of Oulu) page 76

13:15-13:30 Exploration targeting of anorthosite-related Fe-Ti-V mineralization around Suwałki, northeastern Poland

Malcolm Aranha (University of Oulu) page 77

13.30-13:45 Determination of till depth intervals with highest potential for mineral exploration in central Lapland, Finland

Charmee Kalubowila (University of Oulu) page 78

13:45-14:00 Joint application of passive seismic coda wave interferometry and gravimetry in brownfield exploration of massive orebodies

Kari Moisio (University of Oulu) page 79

14:00-14:15 Delineating IOCG potential areas, Kolari region, Finland, Application of machine learning methods

Fereshteh Khammar (University of Helsinki) page 80

13:15-14:30 Transforming drilling operations: The power of machine learning for cost reduction and precision
Oltingey Lindi (University of Oulu) page 81

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

Session 9: Cooperation and networking (Tellus, Stage)

Chair: Jari Joutsenvaara & Juha Kaija

15.00-15:15 UNDERCOVER – Redefining the deep mineral exploration
Juha Kaija (Geological Survey of Finland) page 82
15:15-15:30 AGEMERA: An Integrated Approach to Sustainable Mineral Exploration
Jari Joutsenvaara (*University of Oulu*) page 83
15:30-15:45 Kaivannaisalan kehittäminen Keski-Pohjanmaan alueella KAKE-KP-projektin esittely
Matti Kinnunen (Geological Survey of Finland) page 84
15:45-16:00 Happamien sulfaattimaiden hyödyntäminen - FiksuHasu
Mirkka Visuri (Finnish Environment Institute) page 85
16:00-16:15 Geologiliiton uudet tuulet, esitelmä Geologiliiton toiminnasta ja tulevaisuuden suunnitelmista
Matti Kinnunen (Geological Survey of Finland) page 86

Session 10: Geosciences (Tellus, Backstage)

Chair: Seija Kultti & Timo Ruskeeniemi

15.00-15:15 Magnetic minerals in atmospheric Saharan dust
Iida Kostamo (University of Helsinki) page 87
15:15-15:30 Re-assessing combined age determinations from the MIS-2 period in Finland
Veikko Peltonen (University of Helsinki) page 88
15:30-15:45 Holocene megadroughts in eastern North America: patterns and drivers
Sakari Salonen (University of Helsinki) page 89
15:45-16:00 Land degradation related to historical mining industry: risk management options for the Outokumpu mining town in Finland
Kirsti Loukola-Ruskeeniemi (Geological Survey of Finland) page 90
16:00-16:15 Smart Circular Economy Field-testing Facility for Extractive Waste and Side Streams – preliminary results of concept testing
Teemu Karlsson (Geological Survey of Finland) page 91

16:15-16:20 Closing
The organizing committee

Kansallinen mineraalistrategia

T. Kangaspunta

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Mineraalisten raaka-aineiden tarpeen odotetaan kasvavan merkittävästi ja raaka-aineiden toimitusvarmuuden merkitys on korostunut viime vuosina. Elinkeinoministeri Wille Rydman asetti joulukuussa 2023 ohjausryhmän valmistelemaan kansallista mineraalistrategiaa, jossa tarkastellaan Suomen mineraalialan nykytilannetta ja kehitysmahdollisuuksia sekä teollisuuden raaka-ainehuollon turvaamista ja kansainvälistä yhteistyötä. Ohjausryhmä laati mineraalistrategian vuoden 2024 aikana (Kangaspunta et al. 2024). Strategiassa on laadittu yhteinen näkemys mineraaliklusterin nykytilanteesta, politiikan tavoitteista, päälinjoista sekä tarvittavista toimenpiteistä. Tavoitteiden saavuttaminen edellyttää pitkäjänteistä, yli hallituskausien ulottuvaa politiikkaa sekä hallinnonalojen rajat ylittävää ja yksityisen ja julkisen sektorin välistä yhteistyötä ja investointeja.

References

Kangaspunta, T., Tasa, S., Kokko, M., Eskola, M., Heininen, E. (2024). Kansallinen mineraalistrategia. Valtioneuvoston julkaisuja 2024:65, 51 s. Elektroninen julkaisu, saatavana: https://julkaisut.valtioneuvosto.fi/handle/10024/165994

CRM geotraceability: present and future

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Introduction

Traceability has emerged as an upstart in sustainability endeavours in recent years. It is regarded an imperative technique in ensuring transparency and accountability of globalized supply chains of critical raw materials (CRM). The capability of tracing and tracking CRMs transportation and transformation requires creation and identification of reliable and verifiable traceability information. The relevant information can vastly include digital/paper documents exchanged in the supply chains as well as geochemical knowledge of the CRMs themselves within the value chains. A tracing system based on supply-chain information is known as document- or paper-based traceability, whereas one based on value-chain knowledge is often called geo-based traceability.

Geotraceability has become the focus of research in many institutions and universities in the EU. At the Geological Survey of Finland (GTK), CRM geotraceability has been selected as a focus area for the years to come given tremendous success and experiences from several finished and ongoing projects, including BF Battrace project (2020-2023), NI Nordic Sustainable Minerals (2022-2024), HE MaDiTraCe (2023-2026), and HE REMHub (2024-2028). In the Geodays seminar, we will give a critical overview of the concept and methodology and present some of the recent results of tracing REE minerals and magnets. We will also outline challenges and provide perspectives into the future.

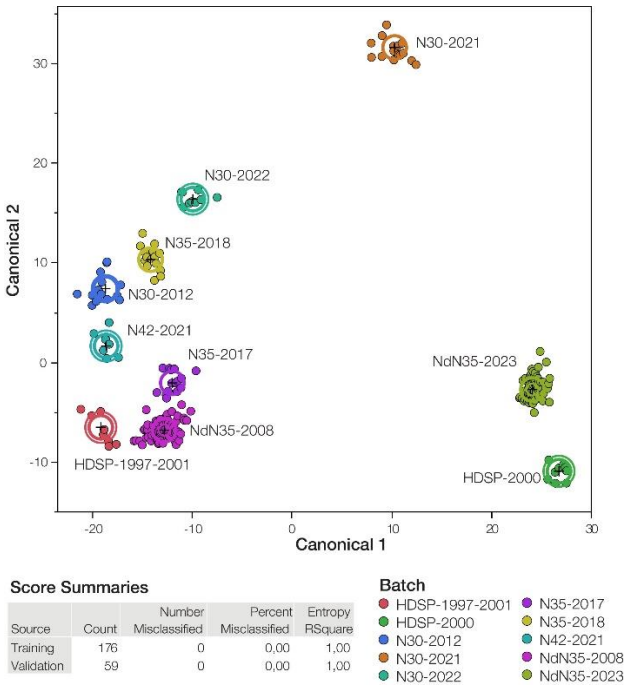

Figure 1. Linear Discriminant Analysis (LDA) applied to REE and metal content to distinguish Nd-Fe-B magnets batches produced in different years

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PGE geochemistry of Palaeoproterozoic mafic and ultramafic volcanic rocks from northern Fennoscandia: implications for exploration of magmatic sulphide deposits

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The Paleoproterozoic break-up of the Kenorland supercontinent was associated with wide-spread mafic-ultramafic magmatism. Here we report on the geochemistry of mafic-ultramafic volcanic rocks from several rifting-related belts in NE Fennoscandia to constrain the platinum-group element fertility and sulphide saturation history of the magmas and their potential to form magmatic sulphide deposits. Magmatism associated with early-stage rifting (2.5–2.45 Ga) formed large layered intrusions in the Kola and Karelian cratons. The coeval volcanic formations have variable PGE contents, with Pt+Pd contents ranging from 1.3 to 15 ppb. Relatively unevolved rocks show mantle-like Cu/Pd ratios whereas more evolved rocks show elevated Cu/Pd ratios indicative of sulphide melt saturation. The middle-stage rifting event (2.2–2.1 Ga) produced volcanic rocks exposed in several belts. Some of the lavas, notably in the Peräpohja and Kuusamo belts, are unusually rich in Pt and Pd, with up to ~24 ppb Pt and up to ~36 ppb Pd. The magmas have seemingly not reached sulphide saturation, as reflected by Cu/Pd ratios below the primitive mantle value. In contrast, a relatively late-stage rifting event at 2.06–1.98 Ga formed significant Ni-Cu-(PGE) sulphide deposits at Kevitsa, Sakatti and Pechenga. We suggested that magmatic ore formation in Fennoscandia has been controlled, in part, by lithospheric structure. During the early rifting stage, the lithosphere was relatively thick and conducive to the formation of large magma chambers in which sulphide saturation occurred during advanced fractionation. This resulted in PGE reefs, and relatively low PGE levels in coeval lavas. During the middle-stage rifting, the lithosphere was weaker and thinner, preventing efficient magma storage and resulting in relatively small intrusions undergoing limited fractionation and ore formation while feeding PGE-undepleted magmas to the surface of the Earth. The late-stage rifting is also characterised by advanced lithospheric thinning facilitating magma ascent into the upper crust without intermittent storage and metal extraction. However, a key difference to earlier magmatism is that the late stage magmas could assimilate external S from sedimentary units deposited after the middle-stage rifting. Our study thus highlights the importance of holistic geochronological/ geodynamic models in magmatic ore exploration.

Model vs. Proxy-Evidence for the Severity of Past AMOC Disruptions

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Uncertainty in observed and projected climate impacts

Despite significant media concerns, empirical evidence for a potential collapse of the Atlantic Meridional Overturning Circulation (AMOC) remains limited and contested. The severity of such an event is often highlighted, but efforts to quantify these impacts are limited due to the theoretical nature of model experiments and lack of data.

In model experiments, the severity and spatial extent of climate impacts related to AMOC disruptions depend on the type of model experiment and CO2 levels. Drastic impacts, as experienced in past climates, are simulated by abruptly enforced AMOC collapses with unrealistic freshwater forcing. Hence, the realism of these impacts is difficult to evaluate from models alone.

Severity of past AMOC disruptions

We provide an overview of our attempts to (re-)quantify climatic impacts for abrupt climate shifts at the end of the last deglaciation (~15,000-11,000 years ago) in Europe. We compare high-resolution CESM1 snapshot simulations (Schenk et al. 2018) to multi-proxy records (chironomids, plant macrofossils, pollen, GDGTs, dD from n-alkanes, cryogenic cave carbonates). We demonstrate that the impact of winter severity rules supreme and must be considered in temperature calibrations. This can be achieved by first reconstructing the seasonal temperature amplitude linked to AMOC shifts, and then quantifying absolute temperatures. We propose the direct inference of a continentality index (latitude-normalized difference of warmest minus coldest month) from proxy data (chironomids) to classify past climate states and their most similar modern calibration regions (Trasune et al. 2024).

For sites in S-Sweden, the British Isles and Baltic States, simulated and reconstructed continentality is extreme during AMOC disruptions, equivalent to a (sub)-Siberian climate with winters below -25°C in England and as cold as –40.7±7°C in SW-Sweden. Using continental calibration regions, proxies yield little to no summer cooling for AMOC disruptions. Instead, we find evidence for paleo-heatwaves or droughts near the ice sheet edge, consistent with a cold-ocean-warm-summer feedback in CESM1 simulations through atmospheric blocking. Cold winters and warm and dry summers are amplified by low evaporation and hence low cloud cover. Conditions are not directly comparable to ongoing and future changes but confirm the model's ability to realistically simulate extreme impacts.

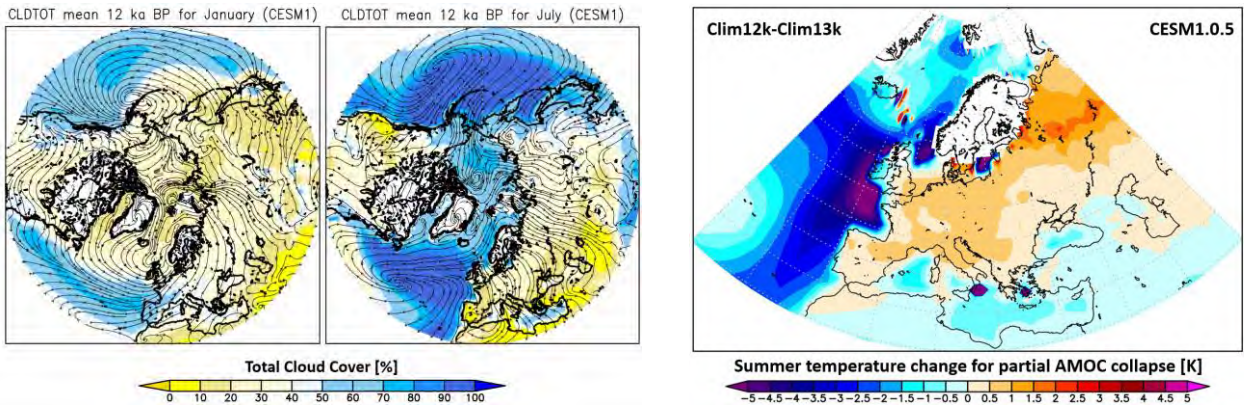

Figure 1. Simulated mean cloud cover and wind patterns for a climate state with a partially collapsed AMOC ~12,000 years ago and related summer temperature change. Strong oceanic cooling and expansion of sea-ice reduces evaporation and cloud cover over land. This amplifies winter severity and dry warm summers. The reduction in cloud cover is currently observed and amplifies CO2-driven warming over land (the humidity paradox = increase in absolute humidity but decrease in relative humidity).

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Mapping the seabed sedimentation rates – the winds of change also on the seabed?

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Introduction

Sediment deposition and resuspension in marine environment are key processes shaping the seabed environment. Information on sedimentation rates is needed in several fields. For example, data on the location and rate of sediment accumulation is important for carbon cycle and carbon budget studies, monitoring pollutants and microplastics, and understanding changes in sediment dynamics.

Data and Methods

EMODnet (The European Marine Observation and Data Network) Geology project is collecting and delivering harmonized data showing sedimentation rates at the seabed. The data is compiled from all available information on the rate of sedimentation in European maritime areas, provided by EMODnet Geology project partners from their national waters (including EEZ). Here we present data collected in various projects such as BONUS Inflow, SmartSea, MAAMERI, SeaMoreEco, and EMODnet Ingestion.

The focus is on the present-day sedimentation rates. That means sediment accumulation to the seabed over the past decades, since AD 1900 or so. Estimations of modern sedimentation rates can be based e.g., on established historical records of anthropogenic radionuclides (e.g., 137Cs and 241Am), lead (Pb), mercury (Hg) and stable lead isotope (206/207Pb ratios) (e.g., Moros et al., 2017; Kotilainen et al., 2021). Sedimentation rate estimates can be based also on varve/laminae counting, radionuclide 210Pb and 14C decay dating methods, as well as monitoring the seabed change (e.g., by multibeam echosounder surveys). In addition, local stratigraphic marker horizons, like in the Baltic Sea, horizons formed by documented Major Baltic Inflow (MBIs) events, can be used in the estimations.

Here, the information on sedimentation rates for recent sediments is presented as point-source information. This data product, sedimentation rates data, consists of more than 1600 data points at this moment.

Results and Discussion

According to data, the rate at which sediments accumulate to seabed differs greatly from place to place. Accumulation does not occur everywhere, e.g., in the Baltic Sea Basin it has been estimated that sediment accumulation areas cover approximately one-third of the seafloor. Generally, sedimentation rates in the accumulation areas of the European Seas varies from some mm/year up to some cm/year. Sedimentation rates are highest in the estuaries as well as in some deep(er) basins/depocenters. In some estuaries the sedimentation rates can be up to several cm/year.

Furthermore, the data supports recent observations of significant changes in some sea areas, marked by an increased deposition of organic carbon-rich sediments on the seabed (e.g., Moros et al., 2024).

Acknowledgements

The EMODnet Geology project is executed by a consortium of 40 partners and subcontractors from 30 countries, which core is made up by members of EuroGeoSurveys (EGS) backed up by other partner organizations with valuable expertise and data. The present work is part of: EMODnet Geology project funded by The European Climate, Environment, and Infrastructure Executive Agency (CINEA) through contract EASME/EMFF/2020/3.1.11 - Lot 2/SI2.853812_EMODnet – Geology; EMODnet Ingestion Project funded by CINEA; and SeaMoreEco project funded by Interreg Aurora, Lapin liitto, and Swedish Agency for Marine and Water Management. The study utilized research infrastructure facilities provided by FINMARI (Finnish Marine Research Infrastructure network).

Discover Europe's seabed geology at: https://emodnet.ec.europa.eu/en/geology

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Hydrogeology: Recent advances and challenges ahead

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Recent advances in hydrogeology include the integration of remote sensing and GIS for improved groundwater mapping and monitoring by enabling the collection and analysis of spatial data. Advances in isotope hydrology provide new insights into groundwater age, recharge rates, and flow paths, aiding in the understanding of aquifer sustainability. Improved hydrogeochemical modelling has enhanced predictions of groundwater quality and contaminant behaviour. The application of machine learning and artificial intelligence in hydrogeology has improved the prediction and management of groundwater resources. These technologies can help in analyzing large datasets and can be used to identify patterns that are not easily noticed through traditional methods.

The main future challenges in hydrogeology are adapting to climate change, which affects groundwater recharge and availability, groundwater – surface water interactions, as well as water quality. Groundwater contamination remains a challenge, with contaminants of emerging concern (CEC) becoming an increasing concern. Groundwater quality research and the assessment of associated health risks will be in focus in future. Over-extraction of groundwater continues to deplete aquifers and reduced water quality. Effective water governance and sustainable management practices are essential to address these challenges. Future groundwater management will require the use of managed aquifer recharge techniques and the integration of advanced technologies like remote sensing, isotopic analysis, and machine learning for effective monitoring and management.

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The Significance of scientific research on the Kurikka Buried Valley in the field of Finnish geology and hydrogeology

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Introduction

For over a decade, groundwater studies supporting the water supply of the cities of Kurikka and Vaasa have been conducted in a buried ancient valley near the Kyrönjoki River. Over the years, the geology of the valley has been revealed through more than 200 drillings, borehole geophysics, ground-penetrating radar surveys, seismic profiling, as well as muon and gravimetric measurements. Meanwhile, hydrogeological investigations have been carried out using conventional groundwater mapping methods aimed at water extraction, including various types of pumping tests, slug tests, water sampling, and environmental monitoring. These studies have been documented in more than ten project and technical reports on projects implemented with Kurikka Vesihuolto Oy, Vaasan Vesi, the EPO-ELY Centre and the Geological Survey of Finland (GTK). In addition, unpublished scientific research has been conducted to improve understanding of the groundwater system and provide local communities, administrative authorities and water companies with evidence that large-scale groundwater abstraction is safe and feasible from all perspectives. This research encompasses geology, hydrogeology, geochemistry, isotopes, microbiology, as well as multi-layer aquifer system modelling in multidiscipline approaches.

Geology of the Buried Valley

The 1.5 Ga old valley has been preserved to this day through a prolonged period of minimal erosion, having alternately been buried and eroded over millions of years cycles (Hall et al., 2021). The valley was exhumed approximately 40 ka ago, followed by an extended period of terrestrial erosion under a humid climate, until the Quaternary glaciations covered Scandinavia around one million years ago (e.g. Gibbard & Levin, 2016). According to the latest results, Kurikka valley seems to contain till deposits from still unknown stages of Quaternary period, along with a discontinuous record of intra-till sedimentary layers, until a more continuous stratigraphic sequence can now be reconstructed from the Saalian glaciation onward.

Geodays Groundwater session

The Geodays 2025 groundwater session will present different aspects of the ongoing scientific research in Kurikka. Timo Ruskeeniemi will present the characteristics of bedrock structures, their significance, and their influence on groundwater flow from upland recharge areas to the valley-floor sedimentary aquifers. Marie-Amélie Petre will focus the origin, movement, and age of groundwater using geochemical and tritium analyses, while Juuso Ikonen will present the use of microbial communities and isotopes as novel tracers in groundwater flow pathways. Tiina Eskola will conduct research at the Kurikka key site on the Last Interglacial, providing regional control on stratigraphy. Annika Åberg will present multidimensional and conceptual modelling of Quaternary deposits, incorporating frameworks such as those proposed by Lunkka et al. (2024). Aleksi Tuunainen will showcase a workflow belongs to numerical groundwater flow modelling using Kurikka as a case study.

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Searching for bedrock groundwater in Kurikka, western Finland

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Introduction

The Precambrian bedrock of Finland is predominantly composed of metamorphic and igneous lithologies. These rocks have low porosity and therefore groundwater can occupy and flow only in fractured bedrock. Brittle deformation caused by tectonic or near-surface processes is common. However, the geometry of fractured units and particularly their hydrogeological properties have turned out to be difficult to predict. Therefore, the more detailed information is required, the more investigations must be done to reach an understanding of the bedrock groundwater system. In Kurikka the target was to assess the potential contribution of bedrock groundwater for the water balance of the Quaternary sediment aquifers.

Studies in the Kurikka site

Kurikka region is characterized by wide valleys and elevated hills. Bedrock is sporadically exposed in these hills. All nearby outcrops have been carefully mapped for lithologies and structural features (Ruuska et al., 2023). However, major part of the study area is covered by thick sediments. Geophysical methods have been applied to observe the subsurface geology including the depth of bedrock surface. Even a densely fractured rock with fresh groundwater has only a weak physical contrast compared to intact bedrock, and they are usually concealed by other geological anomalies. So, little was known about the hydrogeological potential of the underlying bedrock.

To find answers it was necessary to access the buried bedrock and its groundwater. Three diamond drilling campaigns were launched between 2020 and 2023. This was a cost-effective approach because each campaign did reveal hydrogeologically important features helping to develop research methodology and to plan next drillings. In total 20 drillings were done. Out of these 14 provided full research boreholes, core was obtained in three others and three drillings failed to reach bedrock. Drilling of holes was terminated once brittle fracturing became scarce. Realized borehole depths varied from 90 to 140 m vertical. Drillhole data represent an area of 6 x 8 km. Drilling water was spiked by sodium fluorescein to distinguish possible drilling water residues in groundwater samples.

Comprehensive drillcore studies supported by acoustic or optical borehole imaging revealed water conducting fractures from the shallow bedrock. Determining characteristics for these fractures were 1) tensional opening, 2) rusty fracture surfaces indicating flow of oxic water, and 3) subhorizontal orientation. Highest hydraulic conductivities (K) were systematically measured in sections where all three ‘geoindicators’ were observed. This relationship was consistently found in all boreholes. Pumping tests showed significant yields (avg. 50 m^3/day) from narrow boreholes indicating that fractures are networking and extending laterally. Under the main aquifer the fracture network is over pressurized and extends at least down to 140 m. In the surrounding areas this unit is 20–70 m thick. Bedrock groundwater in this dynamic flow system is fresh and slightly evolved compared to the groundwater in Quaternary sediments (Ruskeeniemi et al., 2023; Ruskeeniemi et al., 2025).

Conclusions

Type of fracturing, fracture orientations and the fact that the fracture network is controlled by the bedrock surface suggests that this hydrogeologically active system has formed in extensional stress field under unloading conditions, possibly during Quaternary glaciations. Conceptually, it can be considered as a semi-regional groundwater flow system which has capacity to support water extraction from the Quaternary sediment aquifers.

Acknowledgements

The work is done in collaboration with Vaasan Vesi, Kurikan Vesihuolto Oy, GTK and Etelä-Pohjanmaan ELY-keskus.

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3D modelling code scheme development in Kurikka buried valley

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Introduction and methods

A classification scheme, modelling code, was utilized to classify ca. 200 boreholes in a buried bedrock valley of Kurikka, western Finland. The base of the modelling code lies in the principles of lithostratigraphy (Lunkka et al. 2024) and a geological conceptual model improved by drilling data and grain size samples. Each lithological unit receives a code representing a lithological unit, unit number, and a suffix of genetic deposit type (GDT) representing the geomorphological setting/depositional environment. The GDT suffix of the classification depends on lithology, geophysical profiles, and hill-shaded digital elevation models. The numbering of the modelling code is settled by using marker sediments that can be distinguished through the site. In Kurikka, geophysical data, including seismic profiles and borehole log measurements e.g. natural gamma, were used to verify the classification. A 3D modelling software, GOCAD, was used for visualizing the boreholes, seismic profiles, and the previously constructed hydrostratigraphic 3D model (Putkinen et al., 2024) to understand the architectural elements (cf. Miall 1985; Boyce & Eyles 2000) of Kurikka.

Results

Altogether ca. 50 modelling code units were distinguished from the boreholes. These units were further grouped in major architectural elements in the buried valley of Kurikka. The architectural elements represent various till units (8), interbedded sorted deposits, organic deposits (17), and the uppermost Holocene deposits (2). Different till deposits and interbedded sorted deposits, including glaciofluvial, marine, lacustrine, and littoral deposits, span a time period of approximately 300 ka.

Conclusions

The strength of the hierarchical modelling code classification of Kurikka lies in its use of actual lithology data, rather than interpreted units. This allows for direct interpretation of sediment environments from the borehole data. The modelling code scheme is applicable for formerly glaciated terrains and can be further developed for other unconsolidated sediment areas. The classification enables direct conversion into hydrostratigrahic units.

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A closer look of the preliminary pollen results and lithostratigraphy of a long sediment sequence from Kurikka, western Finland

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Over the past decade, the Geological Survey of Finland has conducted extensive research and drilling surveys in Kurikka, Southern Ostrobothnia, to study a large and complex aquifer system. These investigations have revealed a 1.5 Ga old, 100 m deep valley filled with Pleistocene sediments (Hall et al., 2021). The drillings have uncovered exceptionally thick organic-rich sediments beneath Holocene sand and fine-grained sediments, and multiple till beds. The discovery of these organic sediments led to continuous sediment sampling in 2022, which was complemented in early 2025. This over 10 m thick sediment sequence provides unique opportunity to study the palaeoenvironmental history in detail, complementing existing knowledge of pre-Late Weichselian ice-free periods and their associated vegetational and basin evolutions.

So far, there are only a limited number of known sites in the central area of the former Fennoscandian/Scandinavian Ice Sheet where organic interglacial or interstadial sub- and inter-till sediments from the last glacial cycle have been preserved. Many of these sedimentary records are thin, fragmented, and lack robust age control, often failing to represent the full duration of the interglacial or interstadial interval.

As part of the ongoing research, sediment cores were logged and subsampled for microfossil analyses. Pollen samples were processed using the LST Fastfloat heavy liquid method (Eskola et al., 2021). To place the sediments in a chronological framework, two samples were 14C (AMS) dated at the Poznan C-14 Laboratory in Poland, and three OSL samples taken from above, below, and in the middle of the organic-bearing sediments were dated at Lund University's OSL dating laboratory. The dating results indicate the organic and fine-grained sediments were deposited between the Saalian glaciation and the Middle Weichselian glaciation. This study presents the lithostratigraphic and pollen results of the logged sediment cores, which provide valuable insights into the palaeoenvironmental history and stratigraphy of the Kurikka area and beyond.

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A comparative study of granitic pegmatites and their country rock metapelites from Ostrobothnian Schist Belt, western Finland

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Pegmatites are generally considered to derive from large, parental granite intrusions via fractionation (Černý, 1991) or directly by anatexis as a result of regional high-grade metamorphism (Müller et al., 2017). In the case of the Ostrobothnian Schist Belt (OSB), Mäkitie et al. (2001) suggest that the leucogranites and granitic pegmatites are formed from partial melting of metapelites at the end of the Svecofennian orogeny, thus post-dating the high-grade metamorphism. These pegmatites intruded their country rock metapelites, which underwent earlier high- to medium-grade metamorphism during 1.89–1.87 Ga (Chopin et al., 2020). Zircon U-Pb dating of syn-orogenic granodiorites suggests that extensive anatexis occurred during metamorphic peak conditions at 1.87 Ga, whereas leucogranite and granitic pegmatite emplacement occurred later, around 1.80–1.79 Ga (Alviola et al., 2001). Differences between the granodiorites and leucogranites in terms of field characteristics, mineralogy and geochemistry, suggests distinct sources or degree of melting. Since the Ostrobothnian granitic pegmatites are not directly related to the granodiorites or their residual melts, partial melting of metapelites is often considered to be a more viable explanation.

To test this hypothesis, we have used whole-rock geochemistry of non-mineralized pegmatites and their host metapelites and geochemical modelling of batch melting to explain pegmatite formation from a metapelitic source rock. Preliminary results suggest that the Ostrobothnian granitic pegmatites formed by the incongruent melting of muscovite from a pelitic source. Pegmatites show REE-depleted patterns (ΣREE = ~5.1 ppm), with slight LREE/HREE fractionation ($(La/Lu)_N$ = ~ 1.6) and notable positive Eu anomalies ($(Eu/Eu^*)_N$ = 1.95), compared to the average metapelitic protolith from the OSB (ΣREE = ~138; $(La/Lu)_N$ = ~9.4; $(Eu/Eu^*)_N$ = 0.84). This suggest that apatite/monazite (the main REE carriers) did not dissolve to the melt phase, but remained in the residual, indicating low-degree (<750 ˚C) melting conditions. This conclusion is very similar to those from experimental studies (García-Arias et al., 2012). The positive pressure-temperature slope of muscovite breakdown in a water-absent system supports decompression melting as a key mechanism for generating anatectic melts in the OSB, aligning with retrograde metamorphic reactions observed in mica gneisses as well (Alviola et al., 2001).

In terms of other minor and trace elements, the studied OSB granitic pegmatites show enrichment in Cs, Ta, Be, U and Sn compared to their suggested pelitic protoliths. They also show high K/Na, P/Ti, Rb/Sr and Sm/Nd which are compatible with melting reactions that favour apatite and muscovite dehydration but not monazite dissolution (see Zeng et al., 2005). One of the main issues to be solved in the future is that how these non-mineralized pegmatites are related to mineralized pegmatites that are also found in the area.

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Effect of the anisotropy and scalability of brittle structures on crystalline rocks

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Introduction

Brittle structures, such as faults and fractures, control rock stability of the crystalline bedrock. Further, the formation of brittle structures is controlled by pre-existing structures or other anisotropies such as foliation or rock composition (e.g. sedimentary rock vs. crystalline rock) in addition to the orientation of the stress field (e.g. Crider, 2015)**.** The anisotropy can also be scale-variant (Crider & Peacock, 2004)**.** The studies about effect of anisotropy on the formation of brittle structures on different scales in crystalline bedrock are limited. Recent studies of crystalline Rapakivi granites indicate scalability of brittle structures in larger scales (>10 m), but the scalability in scales from meso- to microscale is poorly known (Ovaskainen et al., 2023)**.** In this study, we compare the formation of brittle structures in different rock types with different evolution of ductile deformation, thus variations in anisotropies.

Material and methods

We have selected three outcrops in vicinity of large-scale ductile shear zones and study them at three different scales. The selected outcrops locate in SW of Finland, and each of them have been initially characterized structural measuring and sampling. The material consists of; 1) outcrops, representing mesoscale (10^0 m), 2) rock samples taken from fault zones, representing centimeter scale (10^{-2} m), 3) thin section from same spots as rock samples, representing microscale (10^{-3} m). From each scale, high-resolution photographs are taken; UAV orthomosaic of outcrop, panoramaphotograph of rock sample and scanned thin section photograph. The ductile and brittle features were digitized from these high-resolution photographs with ArcGis and analysed using the python package Fractopo.

Results

Outcrop FLOP_02 consists of mafic layered supracrustal rock with NE – SW trending foliation and ptygmatic veins. The outcrop is crosscut by semi-ductile NWW – SEE dextral shear, which has deflected asymmetrically the foliation and veins. The brittle faults are subparallel to the semi-ductile shear, but also some minor faults crosscut the foliation. Outcrop FLOP_03 consists of NE – SW trending ash and lava layers with foliation parallel to the layers. The outcrop contains 12 brittle faults subparallel to the foliation, which have localized to the ash layers. The outcrop FLOP_05 contains homogenous tonalite without foliation. The outcrop is crosscut by two N – S trending brittle faults, and fractures in between the faults.

Discussion

The combined effect of the previous ductile deformation together with correctly oriented stress field compared to ductile features affects to the formation of brittle structures. When the angle of strike is acute to the main foliation, the brittle structures localize within pre-existing ductile structures. Regardless of scale, similar brittle structures can be observed form mesoscale to microscale as in the FLOP_02, the fault lenses have similar convergent angles and length – width ratio in both meso- and microscale presenting fractal nature.

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Late-stage magmatic fluid compositions in mafic intrusions constrained by fluid inclusion analysis

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Late-stage magmatic fluids separating from cooling intrusions act as the final transport-medium of mantle-derived volatiles and metals to the crust and surface. However, their compositions remain poorly constrained by empirical data due to the difficulty of sampling pristine magmatic fluid prior to chemical modifications resulting from interaction with the crust or mixing with external fluids. Here, we present preliminary major and trace element and triple halogen (Cl-Br-I) LA-ICP-MS data from fluid inclusions hosted in miarolitic quartz within an exposed gabbroic intrusion, belonging to the 3–4 Ma Vesturhorn intrusive complex in south-east Iceland. Our aim is to characterise the magmatic fluid component forming in mafic intrusions at divergent plate boundaries.

The fluid inclusions were trapped during phase separation (boiling) into assemblages hosting both low-salinity vapor (H_2O, minor CO_2 and trace H_2S) and high-salinity brine. The fluid inclusions formed at high temperatures (> 600 °C)—suggested by high homogenisation temperatures and high host quartz Ti contents—and are interpreted to represent magmatic fluids. Compared to magmatic fluids associated with granitic plutons, the Vesturhorn brines have higher K-Fe contents relative to Na and distinctly high Fe/Mn and Ba/Mn ratios. The Na-normalised Zn, Cu, Mo and Ag concentrations of the brine phase are comparable to brines associated with porphyry ore deposits. Notably, both Br/Cl ($4\pm2\times10^{-3}$; all ratios given as mol/mol) and I/Cl ($70\pm30\times10^{-6}$) of the brine are higher relative to corresponding basaltic melts and oceanic basalts in general. We show that this signature matches with experimentally predicted halogen compositions for magmatic fluids, occupying a unique field in the Br/Cl vs I/Cl space that is distinct from modern seawater (Br/Cl = 1.5×10^{-3}, I/Cl = 0.87×10^{-6}), marine sediments (I/Cl >> 100×10^{-6}) and known ore-forming brines in granitic systems (Br/Cl < 2×10^{-3}).

Our results provide a baseline composition for 'barren' late-stage magmatic fluids in mafic intrusions and can be used to constrain mantle-to-surface elemental fluxes and ore-forming processes in geological settings dominated by mafic magmatism. Our work demonstrates that triple halogen measurements are a potent tool for resolving magmatic fluid contributions from other common fluid sources in hydrothermal settings in general.

The origin of enderbites and their role in the metamorphic and deformational history of the Lapland Granulite Belt

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The Lapland Granulite Belt (LGB) is a Paleoproterozoic complex in the northern Fennoscandian shield comprising granulite facies migmatites and mafic sills of norite and enderbite (Lahtinen and Huhma, 2019; Cagnard et al., 2011; Eskola, 1952). The mafic bodies have been studied by field observations and geophysical data but are lacking sample specific microscopic-scale petrographic and geochemical analysis. Lahtinen and Huhma (2019) and Cagnard et al. (2011) have constructed two different versions of the formation of the LGB, both proposing formation within a backarc basin, but with opposite directions of subduction. The whole area is overlain by a thick layer of till, making field observations and sample collection difficult. Highway 969 from Ivalo to Nellim was recently widened, offering new fresh rock surfaces in the form of roadcuts ideal for structural mapping and analysing contact relationships. This study utilises new data from structural and sample analysis based on these and other road cuts in the area to construct a refined metamorphic and deformational history of the LGB. The focus of this study is the role of the enderbitic sills and mafic granulites.

Structural measurements and observations were made in August 2024 during a field trip to northern Lapland in Finland. Previously made thin sections of enderbites and mafic granulites have been analysed by electron probe micro analyser (EPMA) and X-ray fluorescence (XRF). XRF data show clear differences in whole rock composition and within certain elements, such as P_2O_5 and CaO, between enderbites and felsic granulites. This suggests a different origin for the rock types, coinciding with structural observations made in the field, as well as observations made by Eskola (1952). In the field bigger enderbite bodies had selvedge zones around them that included an abundant amount of garnet and sillimanite. The enderbite bodies appeared as elongated oval shaped masses. Foliations of granulitic gneiss were consistent throughout the LGB and it showed small scale folding with an assumed (all visible folds were on a 2D surface) fold axis parallel to the strike of the foliations. Enderbite bodies showed folding with fold axis' perpendicular to foliation of granulite. Foliation of Angeli anorthosite was consistent with foliation of adjacent LGB granulite and their contact suggests that the anorthosite underlies the granulite.

Our working hypothesis is that the melt zone, where the Angeli Anorthosite accumulated from, is the source of the enderbite and norite sills, as well as the provider of the heat needed to induce granulite facies metamorphism of such large area. The whole unit has then experienced extension and shortening, leading to the deformation of the unit to what we see today.

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In-situ trace elements and Sr isotopes in plagioclase in the Koillismaa intrusion, Finland, and implications for the formation of Fe-Ti-V oxide ores

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Mafic layered intrusions are well-known hosts of base- and precious metal deposits throughout the world. The formation of Fe-Ti-V deposits in layered mafic intrusions remains a subject of interest to petrology and to the extractive industries. The 2.44 Ga magmatism in the Fennoscandian shield was caused by a mantle plume event and the initiation of rifting of the Archean craton, causing the emplacement of several mafic-ultramafic intrusions, mafic dykes and volcanic rocks. Many of these 2.44 Ga intrusions host significant mineralization, including Cr, Cu-Ni-PGE, and Fe-Ti-V. The Koillismaa intrusion belongs to this group of intrusions, and hosts significant contact-, and reef-type PGE mineralization in the lower and middle portions of the intrusion, respectively, and an Fe-Ti-V oxide deposit (Mustavaara) in the upper portion. The Mustavaara Fe-Ti-V deposit is a historically important source of V, having accounted for a significant portion of global V production from 1976-1985. The deposit contains an estimated 64 Mt of proven reserves, and 35 Mt of probable reserves, grading 14 wt. % oxide minerals of 0.91 wt.% V (Karinen et al., 2022, and references therein). The Mustavaara deposit is hosted by a magnetite gabbro with disseminated oxide of about 18.8 wt% in the studied drill hole, without significant massive ores, in contrast to the massive magnetite seams in the Bushveld complex, but similar to magnetite-rich zones in other Finnish intrusions (e.g., Akanvaara). Clinopyroxene grains are intensely altered, but fresh plagioclase domains are normally present.

In this study, systematic analysis of in-situ trace elements and in-situ Rb-Sr isotope of plagioclase from samples taken across the whole stratigraphy of the Koillismaa intrusion has been conducted. These new data, together with published bulk rock geochemical and mineralogical data, are presented in constraining the parental magma composition, and elucidating the fractionation of magma, magma replenishment and oxygen fugacity conditions, providing a better understanding of the genesis of the Fe-Ti-V deposit in Mustavaara. The parent magma of the Koillismaa intrusion is identified as belonging to the 2.44 Ga siliceous high-magnesium basalt (SHMB) series present in the Fennoscandian shield, on the basis of initial $^{87}Sr/^{86}Sr$ ratios in plagioclase. The model of closed-system fractionation of the Mustavaara deposit, as previously proposed by Alapieti (1982) and Karinen et al. (2022) is discussed with regards to the new data. The presence of disseminated oxide ore in an isolated zone within the hanging wall is explained, with reference to plagioclase An and whole-rock contents of Cr and V. In addition, the origin of the subeconomic Rometölväs Reef, an occurrence of PGE-bearing sulfides in the Middle Zone of the Koillismaa intrusion, is discussed, with emphasis on the magma replenishment identified in the Middle Zone, and the fractionation of the magma as observed in whole-rock data.

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Age Indicator (^{3}H) and Hydrochemistry to Understand Groundwater Flow in the Kurikka Buried Valley Aquifer System, Western Finland

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Introduction

The Kurikka buried valley aquifer system (Western Finland) hosts significant groundwater resources in coarse-grained sediments alternating with till layers. Over the past 10 years, this multilayered aquifer system has been the object of growing interest to increase the water supply to the cities of Vaasa, Kurikka and nearby municipalities.

In this context, it is important to understand the groundwater flow system to assess its sustainable exploitation rate and implement sustainable management of this resource. The goal of this study was to assess groundwater quality in the Kurikka aquifer system and interpret the geochemical and tritium (^{3}H) data to better understand groundwater flow patterns.

Methods

To achieve the goal of the study, a geochemical characterization of groundwater was carried out and the obtained data was interpreted using multivariate statistical analysis. The study area (600 km^2) encompasses 4 buried valleys connected to the main Kyrönjoki valley. Compilation of historical geochemical data (56 samples) from 2011-2021 was completed in June-August 2023 by a large groundwater sampling campaign (42 samples) from observation wells, bedrock boreholes, production wells and springs, covering all parts of the study area.

Samples were analyzed for major ions, minor and trace elements and tritium analyses were performed on a subset of 47 samples. Multivariate methods (Hierarchical Clustering and Principal Components Analysis) were applied on 18 physicochemical parameters for 98 samples. Additionally, 30 groundwater samples for tritium analysis were collected at different depth intervals along a vertical profile in 9 bedrock wells in April 2024.

Results

Five water groups emerged from the hierarchical classification. The first three clusters (C1-C2-C3) represent water from sediments, cluster 4 corresponds to water from the bedrock in the upgradient areas and cluster 5 represents water from the bedrock deep beneath the buried valleys.

The major recharge area is located to the west of the study area, in the topographic highs where less evolved, modern tritiated waters were found (C3). From the recharge area, groundwater flows to the north, east and south-east. A similar groundwater evolution from Ca-HCO_3 to Na-HCO_3 water types was observed in both sediments and bedrock in the recharge area (C4). This suggests there is either an evolution within the buried valleys themselves or the buried valleys act as discharge for the evolved bedrock waters that combine with waters present in sediments. Groundwater from the northernmost buried valley and the northern part of the Kyrönjoki valley (C1) are geochemically distinct from the rest of the study area and contain tritiated waters, reflecting a different context of modern esker with a shallower system. Bedrock groundwaters (C4-C5) are characterized by a lower pCO_2 value and higher pH reflecting geochemical evolution.

Groundwater from the sediments is generally free of tritium below 60 m and range from 2 to 4 TU above 60 m, indicating the presence of a modern water component.

While a few bedrock boreholes in the topographic highs and beneath the central Paloluoma buried valley showed a more evolved water type and were tritium-free, most bedrock boreholes contained fresh and tritiated waters (from 2 to 9 TU) up to a depth of 135 m, suggesting deep active flow in bedrock.

Future work

Additional data on radiocarbon (^{14}C) as a groundwater residence time tracer and isotopic signatures (^{87}Sr, ^{18}O/^{2}H) will complement this study to provide more insight on groundwater origin and the processes influencing groundwater flow and geochemical evolution in the Kurikka aquifer system.

The work is made in collaboration with Vaasan Vesi, Kurikan Vesihuolto Oy, GTK and Etelä-Pohjanmaan ELY-keskus

Microbial communities and isotopes as novel tracers for groundwater flow paths in the multi-layered aquifer system in Kurikka, western Finland

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Hydrogeological studies of the Kurikka region's aquifer system (Fig. 1) have been ongoing for more than ten years with the focus on identifying groundwater resources capable of supporting large-scale water abstraction for 150,000 people and local industries. This research evaluates the potential of using microbial community structures and isotopic compositions as novel natural tracers to understand groundwater origins and flow dynamics in the multi-layered aquifer system in Kurikka. The multitracer approach that integrates hydrogeochemistry, including isotopes, and microbial community analysis, can prove to be effective in identifying connectivity and flow paths within the complex multi-aquifer system of the Kurikka region. Groundwater samples were collected from various aquifers, including the deepest sedimentary aquifer, a bedrock observation well, and a superficial sedimentary aquifer. The study utilizes microbial community structures that were defined using an environmental DNA metabarcoding method (Couton et al., 2023). The isotopic compositions of hydrogen (δ^2H), oxygen ($\delta^{18}O$), strontium ($^{87}Sr/^{86}Sr$), and sulfur ($\delta^{34}S$) were analyzed from the water samples to support and to compare the microbial findings in tracing water origins and pathways and in characterizing water types and assessing mixing processes (Ikonen et al., 2022). The results show that the groundwater microbial communities are indeed diverse and composed of different populations in different boreholes along the aquifer system in Kurikka. Furthermore, the bedrock-related microbial community has some special features compared to the shallower, soil-related groundwater. The isotopic data revealed insights into the biogeochemical processes and the local geochemistry. The study highlights the importance of extensive monitoring, including chemical parameters and seasonal sampling, to fully understand the processes influenced by local geology and hydrogeology in a complex aquifer system. This research demonstrates the value of combining hydrogeochemical and microbial analyses to enhance the understanding of groundwater systems. The innovative use of microbial community structures as natural tracers, combined with hydrogeochemical analysis, offers a novel approach to assessing aquifer connectivity and flow dynamics. The findings provide crucial information for informed groundwater management and potential contamination remediation, particularly in regions with complex geological and hydrological settings.

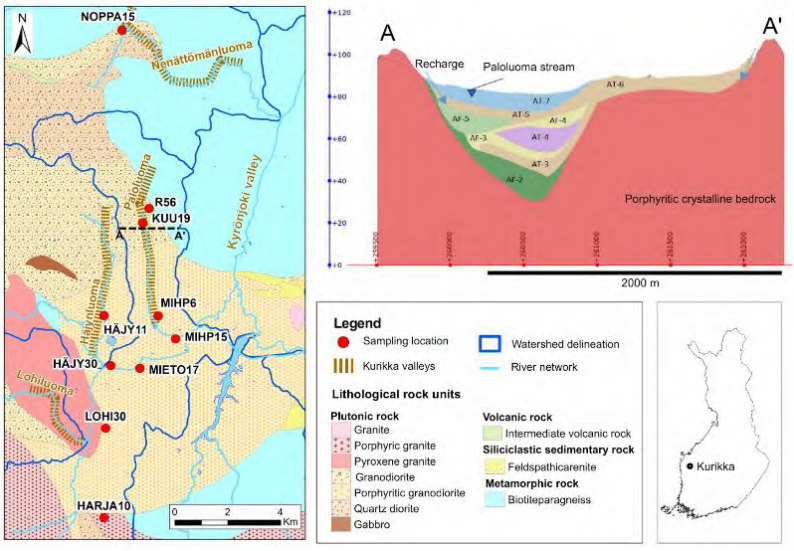

Figure 1. Left, geological map of the study area and groundwater sampling locations; right: general cross-section of the Paloluoma buried valley (modified from Rashid 2022). AF- and AT- refers to aquifer and aquitard, respectively.

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Towards Regional Groundwater Flow Modeling of the Kurikka Aquifer System

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Beneath the South Ostrobothnia landscape in the region of Kurikka, under thick Quaternary sediments, lies a buried valley aquifer system serving as an important groundwater resource. This study aims to ensure the sustainable use of the Kurikka Aquifer System by estimating quantities of groundwater available for extraction through groundwater monitoring and modeling. The primary objectives include calculating water budgets, modeling flow paths from recharge to discharge areas under natural conditions, and assessing the response of the aquifer system to pumping stresses. Numerical groundwater flow modeling integrates an aquifer system architecture and groundwater flow dynamics, which allows the prediction of changes induced both by natural and artificial drivers (Alley et al., 1991). Such modelling is especially important when dealing with a complex system as in Kurikka.

Using the workflow presented by Lunkka et al. (2024), a conceptual hydrostratigraphical model of sediments was developed on the basis of years of fieldwork and boreholes in Kurikka. This geological model is the main input data to develop the groundwater flow model, together with hydraulic tests and groundwater level time series. The numerical model will be then calibrated against static and dynamic groundwater level time series measured in boreholes to accurately represent the natural dynamics of the aquifer system. This model of natural conditions will also help estimate areal groundwater recharge, a parameter that is generally difficult to determine (Scanlon et al., 2002), but is of paramount importance for evaluating the sustainability of the aquifer system.

Using numerical groundwater flow modeling, this study addresses key questions, such as the source of water found in the aquifer system, flux rates, and the potential system responses to intensive future groundwater extraction at the regional scale. Answering these questions will provide a basis for determining the sustainable use of the groundwater resources and assess possible environmental impacts. Additionally, the model can be progressively enhanced with increased complexity in the future, thus allowing for simulations of various abstraction scenarios and the potential impacts of climate change. Post-audits of the model will also be feasible by incorporating monitored groundwater level and pumping rate data. The work is sponsored by Kurikan Vesihuolto Oy.

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Innovative Hydrogeological Monitoring System - HydroVisor: A Smart Solution for Water Sustainability

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Sustainable water management is essential for minimizing environmental impact and ensuring regulatory compliance across various industries. Geo-research house Geovisor Oy provides comprehensive hydrogeological services, including hydrological testing, water sampling, laboratory analysis, data interpretation, and process optimization support. These services enable detailed assessments of groundwater behavior, contaminant transport, and treatment efficiency, providing actionable insights for industries seeking to implement responsible water management strategies. Geovisor's new HydroVisor service is an advanced water monitoring system that integrates real-time data acquisition with hydrogeological measurement technologies to enhance decision-making and optimize resource utilization. Service is based on utilizing Liqum Oy innovative electrochemical liquid sensing system. By continuously monitoring parameters such as water quality and hydrogeological conditions HydroVisor enables industries to improve operational efficiency while reducing their environmental footprint. Its applications extend to mining operations, industrial wastewater treatment, surface water monitoring, environmental impact assessments, and water resource management, where precise and real-time data supports compliance with environmental regulations and enhances sustainability efforts. A key feature of HydroVisor is its cloud-based platform, which allows continuous access to monitoring data. Clients can remotely track water quality, detect anomalies, and receive real-time alerts, enabling on-the-spot decision-making and rapid response to changes. This connectivity enhances proactive water management by ensuring that critical data is always accessible, facilitating more efficient resource allocation and risk mitigation. Beyond real-time monitoring, the integration of continuous monitoring with advanced analytical capabilities marks a significant advancement in hydrogeological research and industrial water stewardship. By facilitating proactive management and rapid response to changes in water conditions, HydroVisor represents a dynamic and innovative approach to sustainable water resource management in the mining.

Hydrothermal alteration and its effects on Ti-V deportment and processing of the Middle Ore Layer (MOL) from the Mustavaara V-(Ti-Fe) deposit, Finland

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Introduction

The Mustavaara V-(Ti-Fe) deposit located 53 km southwest of Kuusamo, northern Finland, represents a significant vanadium resource hosted within the Koillismaa (2.44 Ga) layered intrusion complex. As part of the Horizon Europe AVANTiS (HE AVANTiS)-project, this study investigates the impact of hydrothermal alteration on titanium and vanadium deportment within the Middle Ore Layer (MOL) of the Mustavaara deposit. The research contributes to AVANTiS's goal of developing innovative solutions for sustainable vanadium and titanium production in Europe by providing a detailed understanding of the distribution of critical and strategic elements within the Mustavaara and other oxide deposits in Europe.

Preliminary results

The mineralogical investigation of two drill cores (MV-63-2011 and MV-64-2011) reveals distinct alteration patterns. MV-63 shows extensive hydrothermal alteration with elevated content of V and Ti hosted in silicate minerals. In contrast, MV-64 exhibits better-preserved ilmenomagnetite grains and titanite at magnetite-ilmenite contacts. The presence of secondary calcite and epidote suggests the involvement of Ca-rich hydrothermal fluids. Based on mass balance calculations, magnetite and ilmenite remain the primary hosts for Ti and V, although a significant amount of V (30%) is located in silicate minerals, particularly in secondary amphiboles and epidotes (Figure 1).

The findings highlight that a considerable amount of Ti and V are mobilized and reprecipitated in secondary silicate phases. This hydrothermal mineralization may complicate ore processing and pose recovery challenges that could necessitate adjustment of processing strategies. While primary recovery should focus on oxide-hosted portions, the significant titanite amount represents a potential secondary source of titanium. Vanadium recovery strategies must account for substantial silicate hosting which can be a resource for the future. Future work within the AVANTiS framework will focus on optimizing processing strategies and enhancing the cost-efficient and sustainable extraction of these critical raw materials.

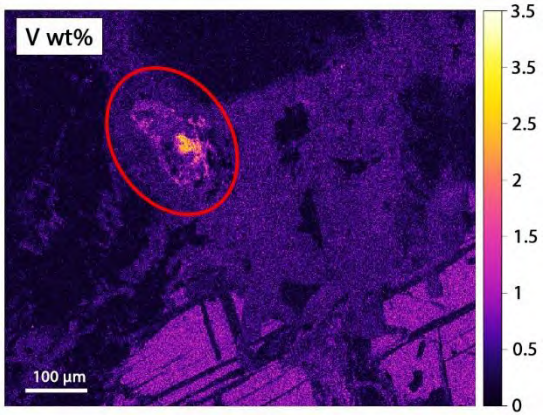

Figure 1. EPMA elemental mapping revealing vanadium-enriched epidote from drill core MV-63-2011, sample -253. The presence of V in silicate phases, particularly epidote, indicates significant hydrothermal alteration and remobilization of vanadium from primary oxide minerals. This observation has important implications for processing strategies, as a substantial portion of vanadium is located in silicate minerals rather than being confined to oxide phases.

Acknowledgments

This research is a part of the doctoral study project of M. Markkanen, which is funded by the HE AVANTiS project. HE AVANTiS is funded by the European Union. The doctoral study project and HE AVANTiS project are implemented in close collaboration with the Geological Survey of Finland.

Funded by the European Union

Geological characteristics of Rytkynkylä volcanic rocks in central Finland: constraints from whole-rock geochemistry

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Introduction

The Rytkynkylä volcanic sequence is located within the Svecofennian Domain and is part of the Raahe-Ladoga shear complex, a significant geological structure in central Finland. This region has a complex tectonic history that has played a crucial role in forming and distributing hydrothermal mineral deposits (e.g., Mikkola et al., 2024; Kärki et al., 2012). The Raahe-Ladoga shear complex consists of a network of dextral faults and shear zones that have experienced multiple phases of deformation and metamorphism (e.g., Lahtinen et al., 2011; Kärki et al., 2012). The geological history of this area is defined by a dynamic interaction of volcanic, sedimentary, and metamorphic processes, primarily occurring during the Paleoproterozoic era, approximately 1.93 to 1.86 billion years ago.

Results

The Rytkynkylä region presents volcanic rocks that are integral to understanding the geological history of the area. This study precisely investigates the geological attributes of these volcanic rocks, with a primary focus on whole-rock geochemistry aimed at elucidating their composition, origin, and evolutionary processes. Additionally, this research evaluates the potential of these rocks for hosting economically significant minerals, thereby justifying future exploratory endeavors. Extensive fieldwork was conducted to gather rock samples in 2023 with K.H. Renlund Foundation funding, followed by laboratory analyses to characterize the petrological and geochemical properties of the samples. The findings indicate that the volcanic rocks predominantly belong to the calc-alkaline series, while also encompassing a spectrum that includes tholeiite, high-K calc-alkaline, and shoshonite varieties. The most felsic and shoshonitic varieties are likely the result of later silicification and K-metasomatism. Based on elemental geotectonic classification diagrams, these volcanic rocks are situated within divergent plate tectonic settings and intraplate environments, specifically associated with volcanic arc systems and polygenetic island arc crust. The studied Rytkynkylä volcanic sequence and nearby granitoid rocks host an array of ore minerals, including pyrite, chalcopyrite, arsenopyrite, pyrrhotite, magnetite, hematite, rutile, and ilmenite. Notably, bismuthinite is observed as a vein or fracture-filling mineral, sphalerite occurs as inclusions in ilmenite while chalcopyrite typically appears as discrete grains, with additional ore minerals disseminated throughout the rock matrix. Elevated concentrations of economic elements—including Au (up to 96 ppb), Cu, Co, Ni, Pb, and Zn—are documented.

Moreover, petrographic examinations reveal evidence of two to three stages of ore paragenesis, marked by marcasite rims, indicative of late hydrothermal processes occurring at relatively low temperatures (ca. 125 °C). The hydrothermal nature of the deposit is further substantiated through the binary plot of the Ishinakawa Alteration Index (AI) against the Chlorite-Carbonate-Pyrite Index (CCPI), which yields comparatively high values: CCPI ranges from 59.54 to 97.73 and AI from 32.73 to 47.25, highlighting a clear zone of hydrothermal alteration. This study enhances the understanding of volcanic activity and mineralization processes in Rytkynkylä but also contributes meaningfully to the overall geological knowledge of the volcanic provinces located in central Finland.

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Mineral Systems Analysis for Lithium-Bearing Pegmatite Prospectivity in Central Lapland Granitoid Complex and its Surroundings

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The aim of the research is to evaluate existing generic prospectivity modeling tools and data resources for assessing lithium-bearing pegmatite potential in Central Lapland Granitoid Complex (CLGC, Fig. 1) (Lahtinen et al 2018), which is potential, but as of today, little-researched area for lithium in northern Finland. Methodologically, existing scientific mineral systems models for lithium, available from New Zealand (Turnbull et al 2018) and Australia (Duuring 2020), are applied together with existing Mineral Prospectivity Modeling (MPM) tool, and geological data provided by Geological Survey of Finland (GTK). Mineral systems models define mapping criteria for the following: sources (energy, fluid, ligand, ore), pathway (enrichment and focusing mechanism), trap, and preservation (surface expression), and their computational proxy data sets, derived from regional geological and geophysical information. Methodologically MPM tools use prospectivity modeling based on fuzzy logic computation on available geological data as defined by the mineral systems models. The availability and accuracy of the geological data is of key importance for mineral systems approach. The genesis of lithium-bearing pegmatites is scientifically not fully understood yet, and there are several theories of the set of geological conditions that make possible formation of pegmatites, such as pluton magma fractioning, anatectic partial melting, and multiphase melting. The tectonics history of CLGC is analysed with respect to different genesis theories and compared to known lithium bearing pegmatite rich areas in Finland, such as western side of Central Finland Granitoid Complex (CFGC, Fig. 1).

Existing mineral systems models for lithium are dependent largely on such types of geological data which are either not available in CLGC area or not computationally adapted for MPM tool evaluated in this research. Especially till data elements needed for geochemical indicators or as pathfinders for lithium minerals, are computationally lacking, most notably Li itself and Al, B, Be, Ca, Cl, Cs, F, Mg, Mo, Nb, Rb, REE, Sn, Sr, Ta, W. As prominent source, S-type granites are specifically enriched by Ba, Be, Cs, F, Ga, K, Li, Nb, Rb, Sn, Ta, most of which are also computationally lacking in MPM till data. A major result of the study was that computationally both available and relevant till data elements in MPM are restricted to Ba, Ca, K, La, Mn, P, Th. Another major result was that geological structures and geophysical gravity worms data were found computationally useful for lithium. Results are presently inconclusive as regards to lithium potential in CLGC. Further research is needed to identify and connect more appropriate geological data e.g. mapped granite-types, fertility indicators, metamorphic and erosion levels, and needed geochemical indicator and pathfinder elements computationally to mineral systems model, and selection of more open and powerful tools for prospectivity modeling. There is also a need to improve the mineral systems models themselves to better match the data sources available for any specified target area in Finland.

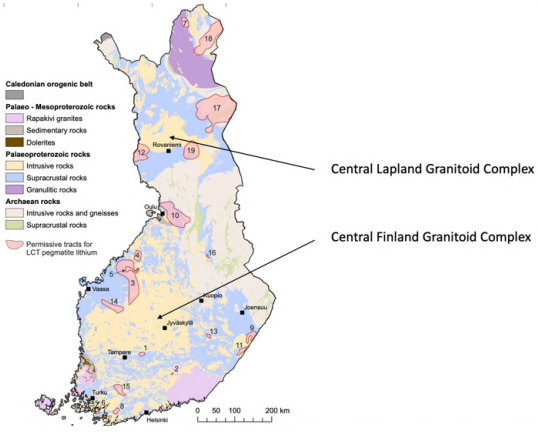

Figure 1. Location of the LCT pegmatite lithium permissive tracts in Finland adapted from Rasilainen et al (2018).

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Understanding the role of brittle deformation on the formation of crystalline reservoirs and geothermal resources: a case study from Turku city

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Introduction

The potential of geothermal energy production in low-enthalpy deep crystalline bedrocks, like Finland, is significant (Bischoff et al. 2024), with an estimated 4 000 000 TWh of power stored in the Finnish bedrock at depths between four to seven kilometres (GTK 2022). Nevertheless, bedrock permeability becomes a critical factor, as it increases the rock volume from where the heat is extracted. Genesis of elevated degrees of porosity (~17 %) and permeability (~5 × 10-14 m^2) in the Finnish bedrock (~1.5 kilometres deep) have been found related to brittle structures and linked mineral alteration (Bischoff et al. 2024). Yet, there is limited knowledge on the events that have created large and deep geothermal reservoirs, and more specifically which brittle structures control these highly porous zones. This study aims to help bridge this knowledge gap, extending the studies performed in the Deep-HEAT-Flow and FLOP projects, with a multiscale structural analysis of faults with associated mineral alteration and secondary porosity in the city of Turku. This will allow a better understanding of the relationships between brittle deformation and secondary porosity within crystalline rocks.

Material & Methods

We conducted in-situ field studies and drone photogrammetric mapping across three different areas in Turku. In total, 85 field observations and 20 samples were collected from 18 outcrops. The field observations comprised rock types, and measurement of the orientation of 79 fault and fracture planes, 15 fault kinematics and two foliations. Furthermore, during field studies a semi-quantitative degree of alteration and porosity was gathered. Samples were collected in the fault cores, damage zones and host blocks, of which, 17 thin sections were made, and 14 cylindrical (2 x 4 cm) cores were sent for petrophysical analyses. Drone photogrammetry mapping was performed for 7 outcrops. Drone mapping analysis is being done to test field observations, and further expand the structural analysis with a better overview on structure behaviour and relationships.

Preliminary results and discussion

Field observations, drone mapping and preliminary regional lineament analysis reveal four major strike-slip fault Sets, trending: Set 1) NE-SW; Set 2) N-S; Set 3) E-W; and Set 4) NW-SE. Sets 1 and 2 are predominantly sinistral, while 3-4 are dextral. Sets 1-3 are the most common trends, reaching significant fracture frequency and density, while Set 4 shows low frequency and is rarely observed. Based on field and drone observations, Set 2 is the oldest, followed by Set 1 and later Set 3, while Set 4 is unclear. Significant mineral alteration related porosity associated to brittle structures was found at two locations in two of the study areas. In one, hydrothermal induced porosity appears along Set 3 planes, while on the second along Set 1. Until now, only the first porous location has been studied more in depth. In here, significant secondary porosity was observed at a lithological contact in the crosscut of Sets 3 and 2. Here, the heavily altered felsic rock reaches ~18 % of porosity and permeability of ~3x10-12 m^2 while the mica gneiss shows low porosity. This appears to indicate that the porosity creating hydrothermal event/s occurred during or after the genesis of the youngest fault set (Set 3), and preferentially leached the granite unit. Moreover, it also indicates the possibility of lithological contacts and crosscutting structures for the enhancement of hydrothermal flow, alteration and geothermal reservoir creation.

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Geochemical composition and magnetic susceptibility of thick organic inter-till sediments from Kurikka, southern Ostrobothnia

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This Master thesis focuses on portable X-ray fluorescence (pXRF), magnetic susceptibility and loss on ignition results carried out from a thick, organic-rich inter-till sediment core from Kurikka, southern Ostrobothnia. pXRF is used to analyse the elemental composition of the sediments. Different elements can be associated with some environmental processes and give insight to the provenance of the deposited sediments (Hillaire-Marcel &Vernal 2007). Magnetic susceptibility gives insight of magnetic minerals in the sediment core, and it can be used to determine interfaces between environmental changes (Mahoney & März 2022). Loss on ignition is a basic research method for assessing the content of organic material in the sediments (Heiri et al.2001).

The bedrock in the area is composed of Precambrian rocks; mainly Paleoproterozoic granodiorites and paragneisses. Groundwater surveys made in Kurikka discovered 100 m deep valley system which cut through the Paleoproterotzoic gneisses. Valley system was formed about 1.5 Ga ago and was filled with Mesoproterotzoic sandstones until it eroded during the early Cenozoic and later filled with the Pleistocene sediments. (Ruuska et al 2023, Hall et al. 2021).

Sediment core was drilled from 31-43 m depth near the Kyröjoki River channel. Based on the preliminary results, the sediment input has changed during the time of deposition and represents the deposition of both glaciofluvial/fluvial sands and thick organic-rich, partly varved silts and clays. Preliminary age results suggest the organic sediments were deposited between the Saalian glaciation and the Middle Weichselian glaciation.

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Current trends in the use of machine learning in groundwater research

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This research explores the current trends of using Machine Learning (ML) for groundwater research. It is based on a literature analysis and an accompanying computational bulk analysis of 1719 scientific articles from the Web of Science. To find out where ML research is being conducted, abstracts of all publications were scraped for country names and keywords using Named Entity Recognition (NER). Results show that since circa 2015 the use of ML in groundwater research has expanded almost exponentially. From a Finnish perspective, the results paint an alarming picture of the current global distribution of research. China, Iran and India were found to be the top ML study locations. In addition, United States and Bangladesh seem to be research hotspots, while most of Europe and especially Finland (0 articles out of 1719) are quickly falling behind.

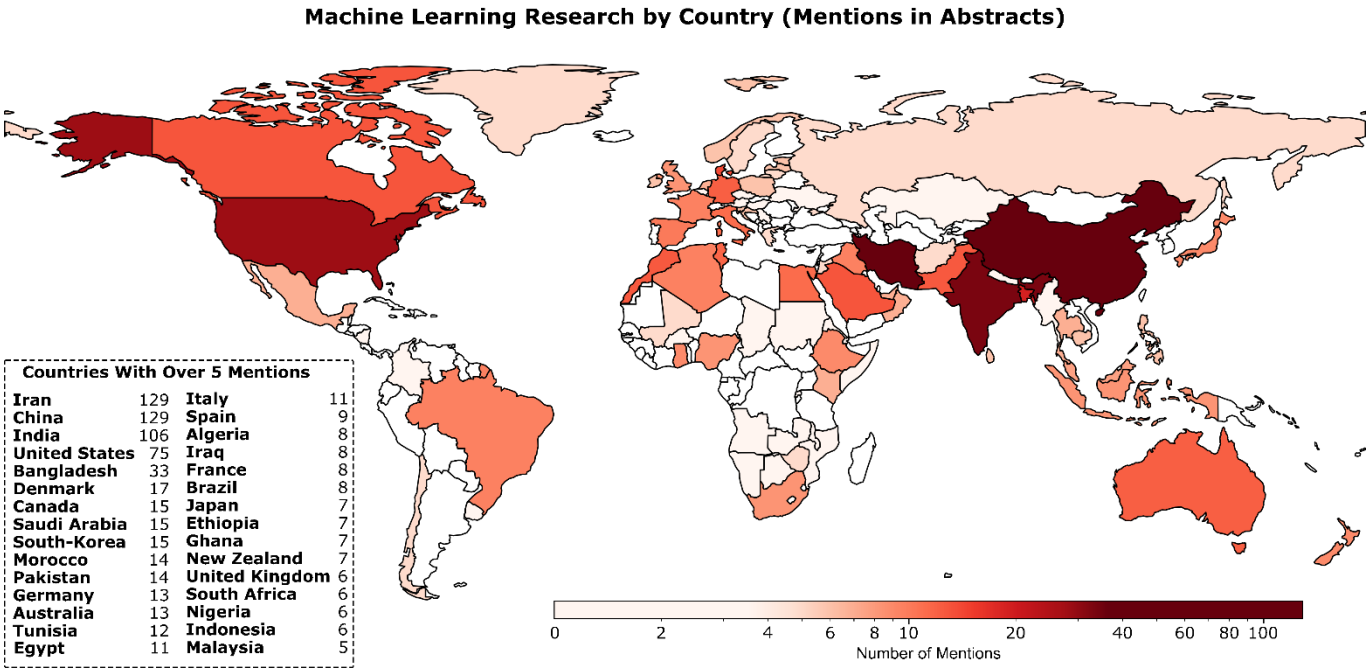

Figure 1. Country names mentioned in article abstracts. Name of a country was mentioned in total 824 times on the article abstracts. Note the logarithmic colour scale.

The research also highlights the currently most popular methods such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Deep Learning (DL). Active ML-groundwater research areas were found to be groundwater level forecasting (see e.g. Boo et al. (2024)), quality assessment (e.g. Haggerty et al. (2023)), recharge estimation and flow and transport modelling (see e.g. Luo et al. (2023)). More specifically, ML is used to answer a wide range of questions related to e.g. drinking water acquisition, management of sea water intrusions, droughts, land subsidence and groundwater contamination cases.

Machine learning has quickly transformed the field of groundwater research by providing more flexible, data-driven alternatives to traditional hydrogeological research methods. However, challenges such as lack of real-word research cases, difficulty in interpretating the models' function, and challenges in research reproducibility and acceptability remain. Multidisciplinary co-operation between hydrogeologists and data scientists, use of remote sensing methods and hybrid modelling techniques should play key roles in future research.

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High-Resolution Multi-Proxy Study of Northern Baltic Sea Sediments from Kurikka: Insight into Paleomagnetic record and paleoenvironmental Changes

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The central Baltic Sea has the one of the largest hypoxic zones in the world, and during the past decades, increasing hypoxic conditions have also been observed in the coastal zone. While the Holocene development of repeated hypoxia in the Baltic Sea basin is well studied in multiple central and southern Baltic deep-sea cores, less is known about the development of the coastal zone during the Holocene thermal maximum (HTM). Understanding the coastal hypoxia during HTM is topical, providing an analogy for assessing future development of hypoxia in a warming climate. Kurikka, located in Southern Ostrobothnia, offers a unique sedimentary archive spanning from the local deglaciation to the isolation of the basin from the sea (~10.8–4.5 ka BP). This record encompasses the transition from the Ancylus Lake phase to the Littorina Sea phase, characterized by shallow sea and coastal sediments, with an average temporal resolution of ~1.5 a/cm. Previous study indicate that deoxygenation was common, but frequently interrupted during the HTM in the shallowing coastal Bothnian Sea (Silvennoinen et al., 2025). They also identified intermittent deoxygenation and fluctuating oxygen conditions during the Littorina phase, but significant gaps remain in understanding the paleoenvironment, full extent and timing of these events. This study seeks to address these gaps through a detailed multi-proxy approach.

The sediment core, comprising 21 meters of Littorina sulphide silts and 13 meters of Ancylus silts, is subjected to a comprehensive suite of analyses. As temporal framework is crucial for understanding the nature of the deoxygenation events, dating of the sediments will be done using both paleosecular variation and radiocarbon techniques. Changes in the paleoenvironment will be reconstructed using sedimentological, geochemical, biostratigraphical and environmental magnetic analyses. While biostratigraphy is applied to reconstruct salinity levels, environmental magnetic methods aim to distinguish the authigenic mineral formation environment.

Preliminary results from geochemical and paleomagnetic measurements will be presented, alongside an initial paleosecular variation record from the sediment core. This PSV record, obtained at a 5 cm resolution, will serve as a chronological framework to date the sediment sequence and estimate sedimentation rates. Notably, the magnetic mineral assemblage, comprising magnetite and greigite, offers a rarely utilized opportunity in paleomagnetic research. Geochemical data is collected at 5 cm interval from the Littorina sulphide silts and at 10 cm interval from the Ancylus silts with ITRAX core scanning method

The ultimate goal of this study is to achieve a dating accuracy of up to a few decades. When successful, this will offer a more detailed reference curve for future paleomagnetic research. Combined with geochemical analyses, the results enable us to test our hypothesis regarding the variable oxygen content in the shallowing Kurikka bay during the Littorina sea phase. Furthermore, the high-resolution PSV data can contribute to magnetic field modelling, which is essential for advancing our understanding of the processes in the Earth's core and the evolution of the magnetic field.

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Investigating the suitability of groundwater dating tracers in Finnish aquifers

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Introduction

Groundwater dating utilizes tracers' geochemical properties to record the duration which the recharged groundwater spends in the saturated zone. The use of groundwater dating tracers in Finland has been scarce excluding few studies (e.g., Favorin 2007, Koskimaa 2020, Turunen et al., 2024), with some uncertain results. Globally tracers have been applied to study groundwater residence times, fraction of modern (>1950) groundwater recharge and mixing, used to calibrate flow models, study aquifer vulnerability, and identify flow paths or hydraulic connections. Previous research has shown uncertainties in involving modern tracer degradation of chlorofluorocarbons (CFCs) in anoxic conditions, and in-situ subsurface gas production for sulphur hexafluoride (SF_6), which leads to unrealistic groundwater dating results (e.g., Busenberg & Plummer, 2000). This study investigates the use of groundwater dating tracers in five aquifers to improve our understanding on tracers' suitability in Finland's old crystalline bedrocks and young glacial sedimentary deposits.

Total of 31 samples were analysed for variety of groundwater tracers (T, $^{3}He_{tritigenic}$, ^{14}C, CFCs, SF_6, and ^{4}He) from shallow crystalline basement and glacial sedimentary aquifers by Geological Survey of Finland over 2021–2023 in HYGLO- project and compared with their respective historical atmospheric concentrations, displaying large contrast between CFCs, SF_6, Tritium, and T/^{3}He apparent ages (Fig. 1). Furthermore, some CFCs, SF_6, and initial tritium ($\Sigma T+{}^{3}He_{tritigenic}$) concentrations were above their historical atmospheric concentrations. Declining atmospheric tracer concentrations means that same tracer concentration can have multiple possible recharge dates, making precise dating difficult or impossible.

Preliminary results show largely contrasting recharge dates for each tracer (Fig. 1). Tritium results with <0.5 TU are often interpreted as premodern waters (<1950) but should be viewed critically as most of our samples also had >5 TU of initial tritium concentrations, which indicates modern recharge. Tritium decays to stable ^{3}He, with known decay rate (t½ =12.32 years) which is used for T-^{3}He dating. Few of the samples had T-^{3}He ages above 100 years, which exceeds the historical tritium concentrations and is considered impossible.

The uncertainty with individual tracers highlights the importance of using multiple tracers together and that our crystalline bedrock might make CFCs and SF_6 tracers unsuitable for dating purposes. Qualitative identification between modern and premodern waters is possible but in future will be less informative as the 'modern' recharge is anywhere between 0–100 years.

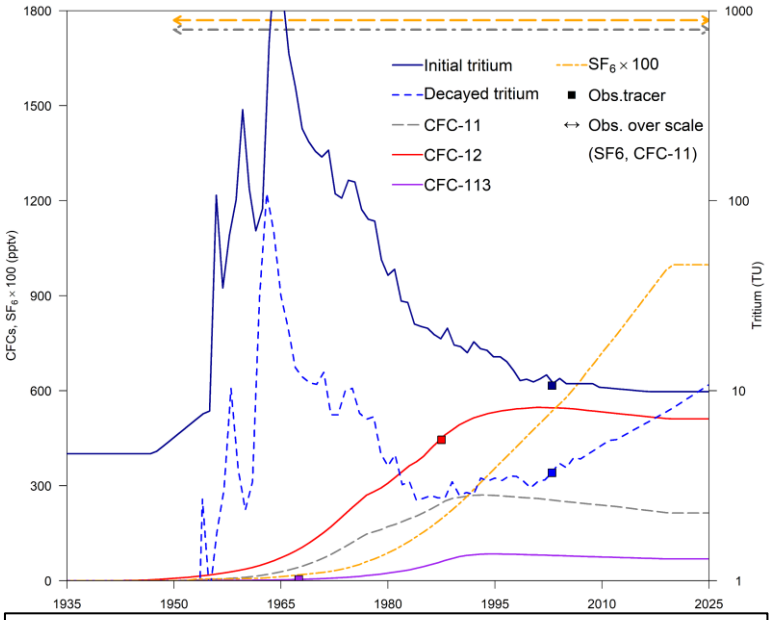

Figure 1. Example case from one sample with different recharge ages for individual tracers. Coloured squares show the recharge dates interpreted from the tracer concentrations. Dashed arrow lines on top show the measured SF_6 and CFC-11 concentrations above the figure scale with undetermined ages. Non-unique ages possible for tritium and initial tritium concentrations.

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Mineralogy and geochemistry of the Terrafame black shale, and its implication of hosting minerals of rare earth elements and their source

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Black shales are important hosts of many important (critical) raw materials, including base metals (Ni, Cu, Co, Zn), precious metals (platinum group elements), and V. The Paleoproterozoic Terrafame deposit in Eastern Finland is the largest black shale-hosted Ni-Cu-Co-Zn deposit in Western Europe, significantly contributing to raw material production. Recently, rare earth elements (REE) have also been recovered from Terrafame bioleaching liquid, making it a potential REE producer for the EU. This positive result suggests that black shale deposits could be a resource of REE, supplementary to the main resources from carbonatite, alkaline rocks and laterite. Despite extensive geological and environmental studies, little research has focused on the REE hosting minerals in black shale. In this study, we have applied petrographic methods like FE-SEM automated mineralogy, EPMA analysis, whole-rock geochemical analyses, and in-situ trace element analyses by LA-ICP-MS to understand the distribution and origin of REE in the Terrafame black shale.

Chondrite-normalized REE patterns of one group of apatite show a generalized depletion of LREE and HREE, and slight enrichment of MREE but with a clear negative Eu anomaly. The other group of apatites show lower HREE content with a negative slope from LREE to HREE. Allanite has high REE contents with chondrite-normalized REE patterns showing strong enrichment in LREE relative to HREE. Titanite accounts for a portion of the REE budget in the Terrafame black shale, with a higher content of the more valuable HREE compared to the LREE. All the titanite grains exhibit a negative Eu anomaly, pointing to an igneous origin. Clinozoisite is LREE-enriched compared to HREE, with a slight negative Eu anomaly. Xenotime, monazite and bastnäsite were found through SEM scanning and confirmed by EPMA analyses showing high REE contents. Despite their extremely low modal abundance, based on their high overall REE content, these two minerals may contribute significantly to the total REE budget. Conversely, LA-ICPMS data show that other minerals such as rutile, feldspars, amphibole, and phlogopite exhibit much lower REE concentrations.

SEM modal analysis of the samples shows that the main REE-bearing trace minerals, including apatite, titanite, allanite, and bastnäsite, xenotime and monazite occur only in trace amounts (<5%, or even down to <0.1%) in the black shale. We use the modal percentage of these minerals, multiplied by their average REE contents, to assess the contribution of different minerals to the total budget of REE. To estimate the role of unanalysed REE-bearing phases like xenotime, monazite, or uraninite, REE concentrations from the literature were used. SEM modal results revealed that apatite content varies from 0.1% to 4%, contributing 1% to 39% to the total REE budget. In samples with over 1 modal% apatite, the REE contribution from apatite exceeds 10%. Titanite, allanite, xenotime, and monazite, bastnäsite are present in much smaller amounts, generally below 0.1 modal%. However, due to their high REE contents, their combined contribution to the total REE budget is significant, typically ranging from 5% to 15%, representing important REE carriers in the Terrafame black shale. Uraninite and rutile are present in very small amounts, contributing less than 1% to the total REE budget. Main minerals like phlogopite, plagioclase, and graphite are more abundant, generally exceeding 5 modal%, but their low REE abundances result in a minimal contribution to the total REE budget. Other minerals rutile, tremolite, clinozoisite, and chlorite are 1 modal% or less and sequester little REE. Based on these calculations, the main REE-hosting minerals include apatite, titanite, allanite, xenotime, and monazite. These preliminary results provide the first clues to the main hosts of REE in black shale, and may also have implications on the beneficiation and recovery of these metals from this rock type.

Sedimentological characterization of evaporite bearing Petäjäskoski Formation, Peräpohja belt, Finland

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The Paleoproterozoic Peräpohja belt (PB) in north-western Finland is an intra-continental rift-passive margin basin and host of atypical orogenic gold and base metal occurrences and prospective areas. The occurrence of evaporites within the Paleoproterozoic supracrustal sequences are discussed previously by e.g. Kyläkoski et al. (2012), Ranta et al. (2018) and Tapio et al. (2021). Evaporites are potential source for basinal brines which can leach and transport copper, cobalt, gold, lead, iron, zinc, uranium, and antimony in a multitude of deposits like IOCG and sedimentary hosted Cu-Co and also can provide external sulphur to sulphur poor mafic-ultramafic magmas which can aid in the formation of Ni-Cu sulfide deposits (Virtanen et al., 2021). The sequence development and study of depositional environment of evaporite bearing Petäjäskoski formation in three drill cores were done by examining lithologies, textures and sedimentary structures. The following lithofacies from bottom upwards were identified: 1) Sub-arkosic sandstone (Facies 1), mature sediments, with oxidation pigmentation, parallel and low angle cross bedding deposited in shallow marine, often subaerial, foreshore-shoreface conditions (Köykkä et al., 2019). 2) Dolomite/dolomitic breccia (Facies 2), sheared and brecciated dolomite and tuffitic fragments that lies on top of sandstones. Dolomite shows occasional enterolithic texture, thin mud laminations and some dolomite clasts are coarse-grained and recrystallized suggesting their secondary nature. The depositional environment for these is intertidal carbonate flats (Melezhik et al., 2013). 3) Evaporite collapse breccia (Facies 3), which is 17m thick and is made up of clast of mudstone with thin layers/laminations and dolomite. These breccias have slightly pitted, solution pitted/rounded contacts with surrounding clasts and fine matrix. The undersaturated pore water dissolved a buried salt bed resulting in collapse of overlying and/or interbedded lithologies, claystone and dolomite in this case, and with the formation of local cavities, sudden collapse of roof strata resulted in the formation of pack or float breccias containing dolomite and claystone fragments. Vanished evaporites in this case were formed in tectonically induced, hydrographically isolated, draw□down basins /lagoons /depressions in an early stage of an epeiric platform (Kendall, 2010; Warren, 2016). 4) Brecciated sandstone/quartzite (Facies 4), on top of Evaporite collapse breccias lies crackle sandstones/quartzite breccias with sporadic thin mud/clay layers, formed by dissolution of underlying evaporite layers and deposited in intertidal sandflats. 5) Sandstone and claystone (Facies 5), contains coarse grained, massive sandstone/ quartzite and thin fine laminated claystone with occasional nodules and tail-twin pseudomorphs after gypsum suggesting deposition in Intertidal sandflat with occasional emergence and saline conditions (Brasier et al., 2011). 6) Claystone with silt-clay couplets (Facies 6), contains tidal bundles, flaser and lenticular bedding and pseudomorphs of gypsum rosettes, nodules, tail-twin morphology of gypsum, platy gypsum, all potentially after gypsum/anhydrite and are suggestive of the saline mud flats in supratidal sabkha conditions (Brasier et al., 2011; Kendall, 2010; Melezhik et al., 2013). Sedimentological and diagenetic features indicates that the deposition of Petäjäskoski formation started in restricted saline lagoonal conditions and shifted afterwards from intertidal and supratidal conditions on a shallow epeiric platform.

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Metamorphic evolution of felsic granulites in the Ivalo-Nellim region, Lapland Granulite Belt

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The Lapland Granulite Belt (LGB) is a Paleoproterozoic metamorphic complex comprising granulite facies metapelites and enderbite–norite series mafic sills. The LGB is bordered to its northeast by the Kaamanen Complex of the larger Neoarchean Inari Terrain (Meriläinen, 1976). To the southwest, the LGB is flanked by Archean gneisses and greenstones of the Karelia province (Meriläinen, 1976; Korja et al., 1996). The southwestern margin of the belt is a mixture of highly strained, banded rocks of the Tanaelv Belt (Tuisku et al., 2006), that also bounds the Angeli anorthosite massif (Meriläinen, 1976).

The arc shape of the LGB is one of its most prominent features and two contrasting theories have been proposed to explain the formation of it. According to Tuiksu et al. (2006) the arc-shaped LGB formed above a northeast-dipping subduction zone after which it was thrust on top of the Karelia province. Lahtinen and Huhma (2019) have since proposed that subduction was instead to the southwest, and that the arc's curvature formed by post-subduction oroclinal buckling. The intrusion of enderbite–norite sills has been an important source of heat to reach the granulite facies conditions (Tuisku et al., 2006).

This study concentrates on a recently-excavated roadcut transecting the LGB–Kaamanen Complex boundary zone between Ivalo and Nellim. Thin sections of three LGB samples and one Kaamanen complex sample have been modelled to produce sample specific P-T pseudosections. The samples were mapped for major element chemistry by electron probe micro-analyzer (EPMA) at HelLabs, University of Helsinki. The maps were quantified with XMapTools (Lanari et al., 2014) to calculate the bulk compositions and almandine and pyrope contents of zoned garnets. Local bulk compositions of the four thin sections were modelled in MAGEMin (Riel et al., 2022) to produce P-T pseudosections.

Modelled almandine and pyrope contents of garnets and P-T pseudosections indicate peak metamorphic conditions of 800–870 °C at 6–8 kbar for the LGB and 720–800 °C at 4–6 kbar for the Kaamanen complex**.** The Kaamanen complex is colder than the LGB based on pseudosection estimates, thin section analyses, and field studies. The peak metamorphic P–T conditions agree broadly with the previous work of Tuisku et al. (2006).

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A Machine Learning framework for target-scale 3D mapping of geological features with special emphasis on hyperspectral data

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In recent years, the need for new metal supplies has been actively discussed in the context of the green transition and raw material dependence in Europe. Since 2010, the discovery rates of new ore deposits, however, have been declining (Shodde 2019) while despite improvements in the reuse and recycling, demand for metals is predicted to increase (e.g. Herrington 2024). Hence, new approaches are welcomed to improve exploration success.

Currently, there are many data collection methods available and in use in mineral exploration, and new technologies are being constantly developed and introduced to the industry. Hence, the understanding of different methods, their correlations, and integrations are of significant importance to efficiently exploit multi-sourced and multi-dimensional data in mineral exploration. Data-driven techniques and particularly, machine learning approaches, have been adopted in the mining industry to tackle the issues related to the complex nature of geological datasets.

Hyperspectral (HS) imaging of drill cores is a non-destructive technique that allows for automated mineral identification and mapping of alteration minerals, variations, and hydrothermal footprints. HS imaging has been integrated into core logging, yet its integration into a three-dimensional (3D) target-scale environment is rare (De La Rosa et al. 2021). This may be due to the challenges in large-scale data management and analysis and fusion of hyperspectral data into other sources of data.

The GeoPool ambition is to tackle these challenges by applying machine learning algorithms to integrate and model complex datasets involving geological, geochemical, geophysical, and hyperspectral data. This will involve the development of workflows for efficient handling (database management), processing, and fusion of large datasets to sophisticated geological models. The 3D modeling approach has applications in better delineation of drilling targets and improving the understanding of the target geology and deposit models aiding decision-making.

This Geopool R&D project is part of a Business Finland-funded AIMEX - Artificial Intelligence in Mineral Exploration project coordinated by the Geological Survey of Finland (https://projektit.gtk.fi/aimex/).

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The geochemical and petrological variability of the oceanic crust and upper mantle in the Macquarie Island ophiolite

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Introduction

Macquarie Island represents a mid-ocean crust ophiolite and is a subaerial fraction of oceanic crust, which is unique amongst global ophiolites in that it lacks evidence for supra-subduction or continental crustal geochemical signatures. The Macquarie Island ophiolite includes both upper mantle section and crustal units from cumulate intrusive rocks to extrusive basalt and hyaloclastite, providing a unique opportunity to study the petrogenetic relations between the different units. This work investigated the genetic link between the plutonic and extrusive rocks, as well as the geochemical and petrological variations within the ophiolite sequence. The samples were studied both petrographically and for whole-rock major and trace element geochemistry, and selected samples were studied for Cr-spinel, silicates, and apatite major and minor element geochemistry.

The results indicate geochemical variations and complex relationships between the different units. The whole-rock major element compositions display three compositionally distinct groups: ultramafic harzburgites, mafic crustal rocks, and a group comprising picrite, wehrlite, and troctolite with compositions that fall between the ultramafic and mafic compositions. The whole-rock trace element data indicate that the harzburgites are not a simple residue of the crustal rocks, but based on the Cr-spinel data, are genetically linked to the dolerite and extrusive rocks of the island. Plagioclase-bearing wehrlites have recrystallized as a consequence of melt infiltration of basaltic melt into former, potentially lherzolitic, mantle source. The whole-rock major and trace element data of the mafic crustal rocks do not support the idea of a continuous plumbing system in which gabbroic melts intrude to fractions formed by extensional forces, leading to the formation of the dolerite dyke conduit system, through which the basalts erupt to the sea floor. In the plumbing system, the expected results would be an enrichment in trace elements from gabbros to dolerites to basalts, along with a decreasing mafic composition. In Macquarie Island the extrusive basalts are more enriched in REE contents compared to gabbroic rocks, but they are more primitive in MgO and SiO_2 contents.

The gabbroic rocks of the slow-spreading mid-ocean ridges are currently considered to form as a result of the solidification of a crystal mush dominated system, where interstitially ascending melts interact with the crystal framework and modify the major and trace element chemistry of both the crystals and ascending melts (*e.g.* Lissenberg & McLeod 2016). These processes could be one explanation for the complex geochemistry observed in Macquarie Island samples. The formation of gabbros and dykes on slow-spreading ridges also appears to have alternative options for the plumbing system, as at Macquarie Island the field relations show that gabbro section might have significantly crystallized and cooled prior to dyke injection from a potentially different magma pulse with a different geochemical history and composition (Dijkstra & Cawood 2004).

Research plan for future work

The research of Macquarie Island formation and further of the accretion of the oceanic crust on slow-spreading mid-ocean ridges continues. The next step with these samples will be systematic core to rim composition analyses of plagioclase and clinopyroxene crystals to consider the effects of melt-rock reactions to the geochemical characteristics of Macquarie Island rocks and melt inclusion research to trace the melt evolution. Recently, Goscombe et al. (2024) proposed that the northern part of Macquarie Island represents a new type of oceanic core complex with off-axis magmatism and exhumation of the mantle rocks. The implications of suggested processes to the formation and geochemistry of the samples will be considered.

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Geochronological study of the Savukoski group in Central Lapland Belt northern Finland and its implication for regional mineral exploration

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The Savukoski Group in the Central Lapland Belt (CLB) represents a key sedimentary sequence for understanding Paleoproterozoic tectonic, sedimentary, and ore formation processes. This study focuses on the Matarakoski Formation, a sulfur-rich black shale unit, with the aim of precisely constraining its depositional timing and investigating its paleoenvironmental conditions. Determining the age of these black shales is critical for refining the stratigraphy of the Savukoski Group and for assessing their role in sulfur assimilation processes during the emplacement of mafic-ultramafic magmas, such as the Kevitsa deposit.

The study employs a combination of petrographic analysis, Re-Os isotopic dating, and geochemical characterization. Eight thin sections spanning the depth interval of 49–103 meters were analyzed to assess the mineralogical and textural characteristics of the black shales. Re-Os isotopic analysis was conducted on fine-grained black shale samples, while U-Pb dating was attempted on detrital zircons from coarser sandy intervals though the separation of zircons was not successful.

The results yield an isochron age of 2088 ± 66 Ma (Figure 1A) for the Matarakoski Formation, consistent with the intrusive contact between the 2056 Ma Kevitsa intrusion and the black shale. The extremely high $^{187}Re/^{188}Os$ makes it possible to calculate model age, ranging from 2108 ± 23 Ma to 2143 ± 23 Ma with a weight mean value of 2129 ± 17 Ma (Figure 1B), providing the most precise depositional age to date and aligning with the Lomagundi-Jatuli Event. Mineralogical analysis indicates a high degree of homogeneity, dominated by clay minerals (clinochlore, muscovite), quartz, scapolite, and graphite, with sulfides primarily comprising pyrrhotite and chalcopyrite. Geochemical evidence from redox-sensitive elements (RSE, Re, Mo, V, U) suggests anoxic to euxinic depositional conditions with localized oxygenation events. Compared to the slightly younger black shale in Terrafame and Onega, the black shale in CLB show clearly lower contents of these RSE, indicating a lower oxygen level in the atmosphere.

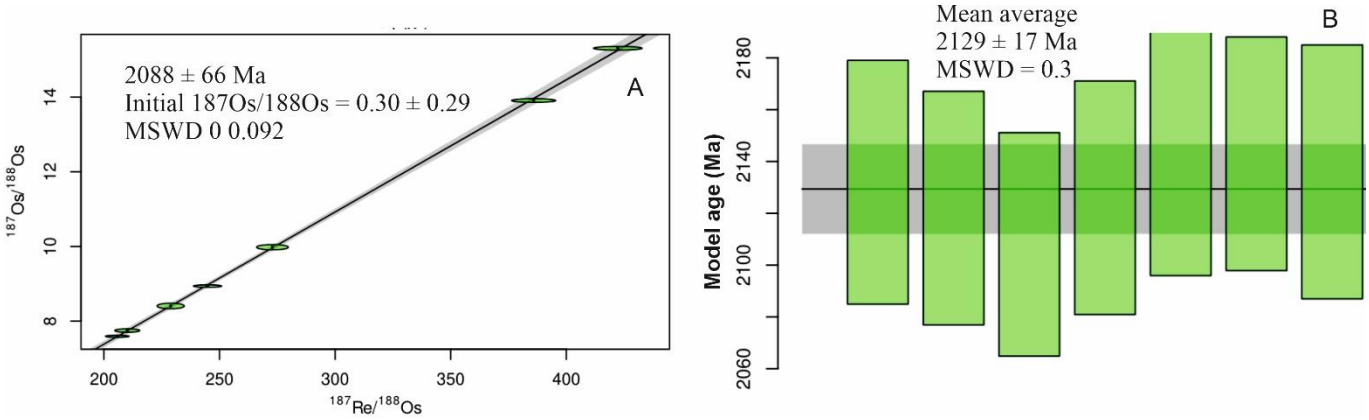

Figure 1. A, Re-Os isochron diagram of the black shale samples of Matarakoski Fm, calculated with IsoplotR. B, Re-Os model age of each sample, assuming a chondritic initial $^{187}Os/^{188}Os$ of 0.1127. The weight average model age is calculated using IsoplotR.

These findings have significant implications for understanding the metallogenic evolution of the CLB. The sulfur-rich nature of the Matarakoski Formation likely influenced the sulfur budget, and probably also provided reduction material, during mafic-ultramafic magmatism, with potential implications for the genesis of magmatic sulfide deposits. The study provides a robust temporal and paleoenvironmental framework for the Savukoski Group, contributing to broader efforts to clarify the geological history of Paleoproterozoic sedimentary basins and their economic potential. The methods and findings are broadly applicable to similar settings worldwide, highlighting the value of integrated geochronological and geochemical approaches in sedimentary basin analysis.

Optimization of filtration protocols in hypolimnetic withdrawal and treatment systems (HWTS)

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Hypolimnetic Withdrawal is a technique aimed at lake restoration, which consists of removing nutrients from the anoxic hypolimnion when phosphorus is released from the lake sediments. This approach has been applied at Lake Kymijärvi, Lahti, Finland, where the water is pumped through a treatment system of filtration units and a wetland, after which it flows back to the lake. The system´s main sand filter however clogs quickly due to the accumulation of precipitates, which reduces its longevity. The goal of this study is to investigate phosphorus retention mechanisms, filtration efficiency and longevity of three filter materials used in water treatment: calcium silicate (Polonite), washed sand (Rådasand) and ordinary construction sand (Kymisand), with two flow-through column experiments. The columns were filled with these materials and fed with hypolimnetic water from Kymijärvi in summer 2023. Water samples were collected from the columns´ inflow and outflow, and solid phase samples were collected after slicing the columns at termination of the experiment, and geochemical analyses of P extraction were performed. Results confirm that P is retained in the filters due to coprecipitation with Fe oxides formed when the hypolimnetic water is aerated, with overall retention being highest in Kymisand and Polonite, the latter of which is also able to sorb remaining soluble P due to its highly reactive CaCO3 surfaces. There is an observed tradeoff between the materials' longevity and efficiency of phosphorus removal, and each one removed different P forms in varied proportions, with phosphate being the one with highest reduction overall. Choice of materials for treatment systems in future hypolimnetic withdrawal projects should take into account water chemistry, in particular the concentration of dissolved iron.

Land use as a driver of increased organic carbon burial in boreal lakes

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Lakes are active environments in the global carbon cycle, where terrestrially derived organic carbon (OC) from the surrounding catchment and in situ produced OC can either pass through system, escape to the atmosphere as CO2 or be stored in the sediments. Due to high number of lakes in boreal areas such as Finland, lakes host a large pool or carbon, making lake sediments a potentially significant, permanent carbon sink. While estimates of carbon accumulation rates over the past few millennia in Finnish lakes have been made, several studies around the world have reported increases in both carbon availability and burial rates in the recent past.

We have calculated modern (post 1986) rates of carbon accumulation across a variety of Finnish lakes in order to identify potential drivers and controls of modern carbon burial. Using ^{137}Cs dating and C:N analysis, we calculated the post year 1986 carbon accumulation rates from lake sediment cores collected from 213 individual lakes in southern and central Finland. The linkages between carbon accumulation rates, lake morphometry and catchment land use were investigated.

Our results show that the rate of modern carbon accumulation in lake sediments has increased on average by a factor of four since mid-Holocene and is linked to the rate of sediment mass accumulation and land use. The highest rates of carbon accumulation were generally measured lakes where the catchment area comprises higher amounts of wetlands and agricultural land. However, in relation to the rate of total sediment accumulation, the burial rate of carbon was proportionally higher in smaller, shallow lakes with elevated C:N ratios and lesser amounts of agricultural activity in the catchment area. Our results suggest potential preferential remineralization of fresh autochthonous, algal OC and preferential deposition and permanent burial of allochthonous, terrigenous OC, increasing the relative significance of forest- and wetland catchment lakes as carbon sinks.

The European Marine Observation and Data Network (EMODnet) and advancing Marine Geoscience

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Introduction

Since 2009, the European Marine Observation and Data Network (EMODnet), funded by the European Commission, has been providing high-quality marine data from across Europe to support research, policy-making, and sustainable resource management. Accessible through its Central Portal (https://emodnet.ec.europa.eu/en), EMODnet covers themes such as geology, bathymetry, biology, chemistry, human activities, physics, and seabed habitats. Third-party data submission is supported through EMODnet Ingestion (www.emodnet-ingestion.eu).

EMODnet Geology

Here we present EMODnet Geology that integrates marine geological data to offer comprehensive coverage of European seas, recently expanding to include the Caspian Sea and the Caribbean Sea. It provides information on seabed substrate, sedimentation rates, seabed erosion, sea floor geology, Quaternary geology and geomorphology, coastal behavior, geological events, marine mineral resources, and submerged landscapes. The project is coordinated by the Geological Survey of Finland (GTK) and executed by a consortium of 40 organizations, primarily members of the EuroGeoSurveys (EGS) network, supported by other organizations with valuable expertise and data.

Seabed substrates and their characteristics, such as sedimentation rates, seabed erosion and other complementary information are among the key deliverables of the thematic. These datasets are crucial for applications including habitat mapping, resource management, and environmental monitoring. For instance, the Multiscale Seabed Substrate, using a modified Folk classification system harmonized from national data by sediment grain size, has been used to produce a seabed habitat map for the European marine areas. Additionally, the seabed substrate database includes information on seabed surface characteristics significant to the marine environment but not solely defined by grain size (e.g., seagrass meadows, moving sediments, ferromanganese concretion bottoms, and bioclastic features).

Over its fifteen years of existence, EMODnet Geology has become a leading producer of publicly available marine geological datasets, covering broad European areas and beyond, with a widely recognized methodology. The continuous development of data products ensures the ongoing relevance of EMODnet data for future applications.

The EMODnet Geology project is funded by The European Climate, Environment and Infrastructure Executive Agency (CINEA) through contract EASME/EMFF/2020/3.1.11 - Lot 2/SI2.853812 EMODnet – Geology.

Seasonality of Holocene Climate Change in Northern Europe

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This project tackles a well-recognized shortcoming of Holocene paleoclimate data, namely, the poorly constrained temperature seasonality of high northern latitudes like northern Europe and the long-term evolution of both warm and cold season temperatures. This problem results from the inherently weaker ecological signal of winter temperature in the proxy data compared to summer temperature. However, with recent advances in the availability of both high-resolution proxy data and of well-validated proxy–climate calibrations for summer and winter temperature, the time is now ripe to fill this vital knowledge gap.

The temperature seasonality of northern Europe is directly connected to assessing the Holocene Temperature Conundrum: the fundamental mismatch between the paleoclimate proxies, indicating a mid-Holocene temperature maximum, compared to climate model simulations which show a monotonic warming trend over the Holocene. In climate models, a massive winter cooling of up to 30ºC below preindustrial is seen in high-latitude Europe in the early Holocene, resulting in strong annual temperature minimum in northern Europe not recorded in existing paleoclimate reconstructions. This remarkable modeled winter anomaly contributes alone a significant portion of the global data–model mismatch, indicating northern Europe as a hotspot region for resolving the temperature conundrum.

To implement a regional test of the Holocene temperature conundrum, we present a synthesis of new Holocene climate reconstructions for northern Europe, spanning from the Alps in the south to the Arctic Ocean in the north. The climate reconstructions are underpinned by recently published pollen–climate calibration models, developed using machine-learning based approaches, allowing robust reconstruction of July and January temperatures in northern Europe. The source proxy data for the climate reconstructions are fossil pollen sequences retrieved from the Neotoma paleoecology database.

The Neotoma database currently includes ca. 600 fossil pollen sequences for the northern European sector spanned by the pollen–climate calibration data. After filtering for temporal resolution and dating control, the 180 datasets were selected for climate reconstruction. The reconstructions reveal a general maximum in both July and January temperatures over approximately 8–3 ka, however with significant regional differences in temperature trends.

Daphnia ephippia as time capsules – using dormant eggs to detect browning-induced shifts in lake biogeochemistry

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Introducing the Hippicap -project

Increasing water colour (browning) and the associated shifts in lake biogeochemistry are a global concern due to concurrent complex changes to aquatic ecosystem functioning, yet we know little about such shifts especially in the long-term context. Monitoring data provides limited information on the historical associations among lake water colour, elemental composition, and biological communities, especially in small lakes, even though they dominate the global lake area and serve as hotspots for biodiversity and biogeochemical processing. Furthermore, paleolimnological methods for reconstructing elemental cycling and composition of lake water are currently limited.

The new Hippicap -project (2024-2028, PI Academy Research Fellow Minna Hiltunen) aims to establish elementomes (i.e., relative concentration of all biogenic elements in an organism) from resting eggs (ephippia) of Daphnia spp. water fleas as a new tool in paleolimnology, which can then be applied in future studies of changes in lake biogeochemistry, not only for browning but also in the context of other environmental changes (e.g. climate change, eutrophication).

We are conducting laboratory and surface sediment studies to test associations among lake water concentrations of biologically important elements (e.g. Ca, N, P) and Daphnia ephippia elementomes. Current stage involves optimising the method for trace element analysis of ephippia with inductively coupled plasma mass spectrometry (ICP-MS), with promising initial results. Concurrently, experimental studies of Daphnia exposed to manipulated water chemistry treatments are being carried out. Experimental relationships observed between ephippia and water, are to be confirmed with surface sediment and lake water data, and further applied to down core. Eventually, we will apply this new tool in combination with other novel paleolimnological proxies to study how biogeochemistry, structure, and function of small lakes have changed over time through acidification and browning. We will utilize spectral reconstruction of lake water dissolved organic carbon (DOC) and chlorophyll-a concentrations, estimate DOC origin and composition, use stable isotopes of sediment organic matter and Daphnia ephippia to gain insights into the biogeochemistry and trophic ecology, and study phytoplankton and Daphnia community structure using sedimentary pigments and Daphnia remains. Our study of multiple proxies from dated sediment cores of Boreal, sub-Arctic, and Arctic lakes will provide novel information on how the physical, chemical, and biological properties of lakes are affected by browning.

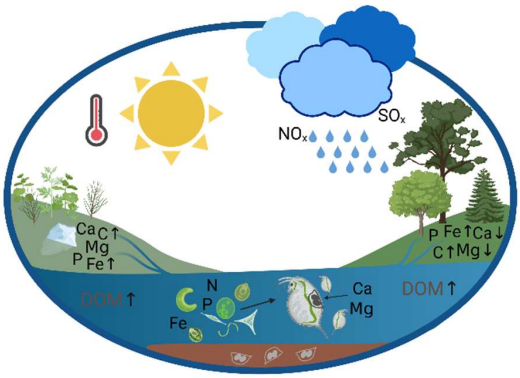

Figure 1. Conceptual figure presenting the drivers of lake browning in sub-Arctic/Arctic (left) and Boreal (right) landscapes, and how the flow of central elements is altered in each ecosystem. Daphnia ephippia integrate the signal of multiple elements from water and diet, hence the subfossil ephippia can be used to reconstruct past lake elementomes.

Simulating carbon fluxes in a boreal, eutrophic lake

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The intricate interplay between eutrophication and carbon accumulation in aquatic ecosystems remains a subject of limited understanding, posing challenges for effective river basin management. In this study, the operational, national-scale nutrient loading model, WSFS-Vemala (Vemala, Huttunen et al., 2016), simulating 67500 lakes and used for river basin management planning in Finland, was developed to include total carbon cycling in the aquatic ecosystem. Vemala v3 (Korppoo et al., 2017) simulates past, present and future nutrient leaching and transport on land, as well as in rivers and lakes. A field scale model is applied for phosphorus and nitrogen terrestrial leaching from agricultural areas. The total organic carbon (TOC) and total inorganic carbon (TIC) leaching are defined by soil types and land uses. The model also includes point loads, urban runoff, atmospheric deposition, and load from settlements. The lake biogeochemical model simulates total and bioavailable nutrient species and carbon. The processes affecting carbon cycling are mineralisation, photosynthesis, respiration, sedimentation and exchange of CO_2 through the water-air interface. It predicts the co-impact of dissolved inorganic nitrogen and phosphate on phytoplankton growth and, therefore, on eutrophication, carbon sequestration in sediments and CO_2 concentrations and emissions from lakes. Vemala v3 has been tested in Tuusulanjärvi lake, a eutrophic lake in Southern Finland, to better understand the role of aquatic environments in carbon cycling. The carbon budget for the lake (Figure 1) shows that most of the carbon (77%) is flowing downstream of the lake. However, a significant amount of carbon is released to the atmosphere annually (21%) with an average annual CO_2 emissions rate of 27 $gCm^{-2}yr^{-1}$ while a smaller portion is sedimented on the long-term (2%). From the total carbon losses, TOC and TIC loss is 7% and 15%, respectively, showing the importance of the carbon cycling in the lake, with about half of the CO_2 emissions being fuelled by TOC loading to the lake.

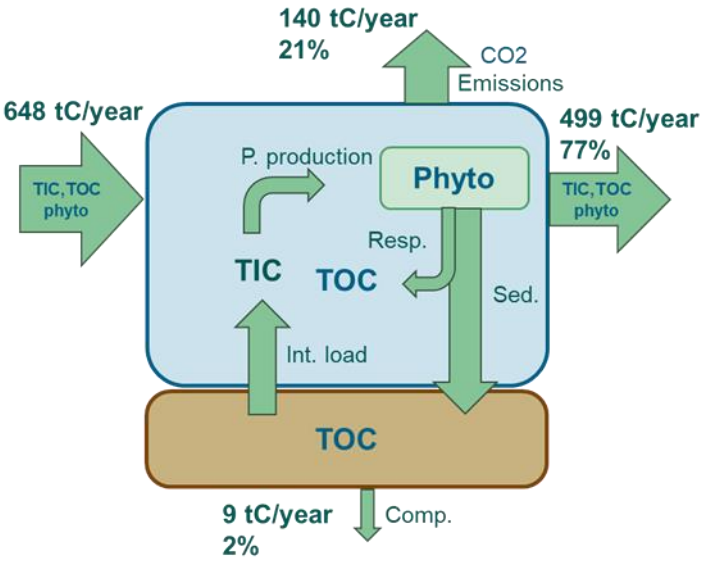

Figure 1. Tuusulanjärvi carbon budget with TIC (total inorganic carbon), TOC (total organic carbon), phyto (phytoplankton, cya= cyanobacteria, dia= diatoms), P.production (primary production), Resp. (respiration), Sed. (sedimentation), Comp. (compaction), Int. load (internal loading)

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Multivariate statistical analysis of till geochemical data: identifying potential areas for gold exploration in northern Finland

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Multivariate statistical methods of geochemical data, e.g., compositional data analysis (CoDa), Robust Principal Component Analysis (RPCA), and K-Means clustering assists in the advancement of mineral exploration, mineralization tracing and clustering, especially in glacial terrains. This study focuses on till geochemical data (1,093 samples across 4,600 km²) from the Central Lapland Belt (CLB), Finland, a region with multiple orogenic gold mineralisations. In order to address till data complexities, we applied a workflow consisting of: (1) replacement of censored data (zeros, values below detection limits) using the k-nearest neighbours (KNN) technique; (2) CoDa transformations (central log-ratio, CLR and isometric log-ratio, ILR) to mitigate dimensionality and closure effects; and (3) performance of RPCA and gap statistic-optimized k-means clustering to identify element associations and regional-scale geochemical patterns. This study demonstrates that ILR-transformed data combined with RPCA and K-means clustering can effectively reveal mineralization-related signals and clustering. Using this unsupervised classification approach, till samples were grouped into distinct elemental associations including Cr–Mg–Ni–V and Au–Mn–Fe. However, Au formed a unique cluster, displaying a distinct behaviour from the other elements. The clusters were validated using known mineralization locations and till anomalies, and the identified gold clusters suggest new potential targets for exploration. This methodology is particularly valuable in early-stage exploration, providing insights into elemental mobility, dispersion, and source targeting in glaciated terrains.

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Electrical conductivity studies on varying graphite distributions hosted in synthetic rocks using 3D printing technology

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Introduction

As the European Union aspires to become more self-sufficient and transition to green energy, the development and execution of mineral exploration of critical raw materials is essential. One such material is natural graphite: known for its anisotropic properties and use in lithium-ion batteries. However, sufficient natural graphite resources are not readily available, and more research is needed to further the understanding of the mineral and so improve prospecting.

In this study, we explore the potential of 3D printing technology in replicating layered flake graphite formations as a method in determining the correlation and trend between carbon content and electrical conductivity, inspired by Kukkonen (1984). 3D printing is relatively new in geosciences, with limited previous studies involving petroleum flow studies and porosity (e.g. Ishutov et al., 2015; Kong et al., 2021) as well as geomechanics (Kong et al., 2017).

Understanding the relation between carbon concentration, its layered distribution and electrical conductivity, may provide a link between known conductive layers in the field and flake graphite. This benefits both mineral exploration and studying the graphite potential, as well as for advancing scientific understanding by further constraining the origins of lower lithospheric conductors and whether they are a result from the presence of graphite (Korja & Koivukoski, 1994).

Pilot 3D printed graphite-bearing samples – electrical resistivity results

The 3D printed samples were produced using an FFF (Fused Filament Fabrication) 3D printer and two separate material components: (1) the insulating PLA (Polylactic acid) for the host-rock section and (2) the conductive flake graphite and PLA composite for the graphite layers. A variety of layers were modelled into a CT-scanned porosity model, 3D printed (Fig. 1a, b) and measured for electrical conductivity using the SCIP (Sample Core Induced Polarisation) Tester (Instrumentation GDD). Results of initial test samples indicate a promising increasing conductivity trend with increasing graphite content (Fig. 1c) and, with further testing and polishing of the method, conductivities closer to those of real graphite bearing rocks may be reproduced.

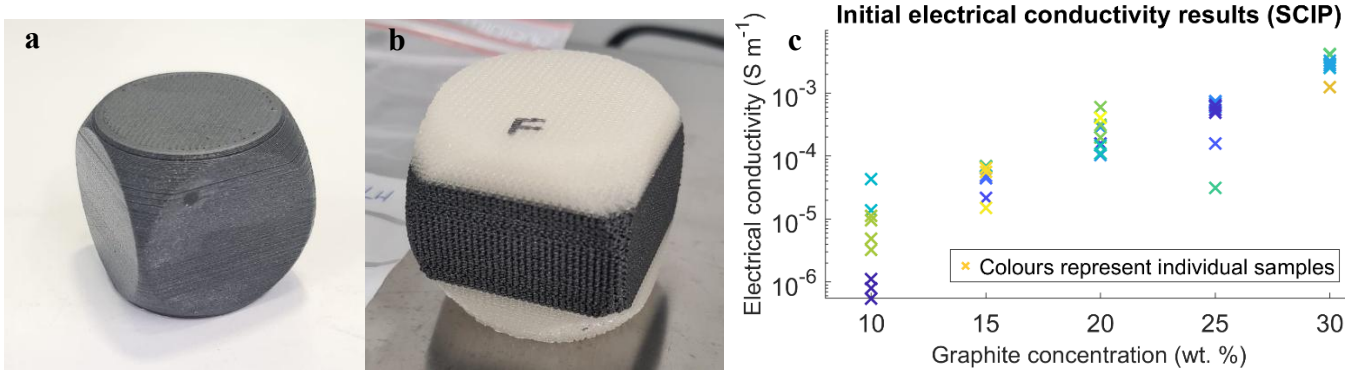

Figure 1. 3D printed (a) graphite/PLA composite and (b) layered graphite/PLA composite between pure PLA, and (c) electrical conductivity results.

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Self-organizing map modelling and prospectivity mapping of surface geochemical data

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Introduction

In glaciated terrains, such as Finnish Lapland, till and weathered bedrock geochemical data sets provide the basis for data analysis and modelling. This can be attributed to the fact that central-Lapland has been subject to multiple glaciations. During these glaciation events central-Lapland has been the location for ice divide zone, multiple times. Due to this there are large areas of well-preserved pre-glacially weathered bedrock. These weathered bedrock areas are further been protected by relatively thick till cover (Hirvas, 1991). There is vast amount of geochemical data recorded from the till and weathered bedrock by Geological Survey of Finland (GTK) (see for Gustavsson et al., 1979). Commonly these types of data sets are referred to as legacy data. Varying in quality, however with proper statistical and levelling methods different quality data can be used for mineral exploration.

In case where the data is based on map sheets that do not overlap, Daneshfar and Cameron (1998) proposed a method for levelling. Where two datapoint selection bands are created for adjacent maps. Then x amount of sample points is selected from both maps. Then one map sheet is determined correct and the other is subsequently corrected using the function of the regression line. This is then continued so that the previously corrected map is now the correct map, and new adjacent map is selected. This is continued until all map sheets are levelled. Adjacency is best decided by lack of bedrock unit change within the selection bands. In this study, levelling is followed by self-organizing maps (SOM) and k-means clustering.

SOM is an unsupervised clustering method part of the neural networks (Kohonen, 2001). This was achieved by using GTK's GisSOM software (Hautala et al., 2021). The SOM method was used due to its capability of handling multivariate data. In other words, its capability of morphing d-dimensional data into lower dimensions such as 2D format. Here 13 elements were chosen out of 17. The selected elements were Ti, V, Ni, Co, Cr, Cu, Si, Fe, Mg, Ca, Na, Mn and K. The SOM calculates these 13 elements as vectors. From here an output layer is created for which m number of data points are randomly selected. Rest of the data points are tested against these initial vectors also known as codebook vectors (Kohonen, 2001) or seed vectors (Fraser and Dickson, 2007). The results of a SOM are feature maps for each element inserted, if clustering function was used, a cluster map and a u-matrix map. K-means clustering is used for further or more clear cluster assignment.

Based on the SOM and k-means clustering results, the resulting clusters were possible to associate with element associations. The results were divided into till and weathered bedrock results. For till there were eight clusters in total. For weathered bedrock there were seven clusters in total. Of these cluster associations most, exploration wise, interesting clusters were focused on. For till there were two interesting clusters with element associations Ni–Co–Cr and Cu–V–Co. For weathered bedrock there were three clusters with element associations Ni–Co–Cr, V–Cu and Cu–Co. These clusters spatially indicated well known deposits within the study area in Sodankylä.

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Gravimetric Survey in Mineral Exploration

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Introduction

Introduction This abstract and poster will present my Bachelor's Thesis conducted in collaboration with Geovisor Oy

Gravity survey is a passive geophysical method based on detecting variations in Earth's gravitational field. For example, dense metallic ores cause positive anomalies in the gravitational field, facilitating their localization and delineation. The method is typically employed in the exploration of high-density ores and the study of geological structures related to mineral prospecting. Instruments based on the microgravimetric method such as the Autograv CG-5 and CG-6 gravimeters are commonly used for these measurements; these are compact devices designed for field use. These relative gravimeters measure changes in gravity relative to a known reference point, where absolute gravity has been precisely determined. The elevation and location of each measurement point on the field are typically determined using an RTK-GPS system.

Gravimetric survey is typically conducted at determined gravity stations evenly spaced to form a grid. The spacing between stations varies depending on the goal of the survey but it is usually between 10 and 500 meters. The survey on the field is relatively straightforward and can be performed by one person; however, measurements are typically carried out by teams of two, with one operating the gravimeter and the other handling the RTK-GPS system. At each determined gravity station, readings are taken, and environmental observations (like thickness of the snow) are recorded. Variations in soil and bedrock, as well as wind, can affect the data, and these factors are later considered during gravity data processing. Predefined base stations are used, where readings are typically taken before and after the measurement day, and if necessary, at midday. Repeat stations are selected from the previous day's stations, and readings are taken from repeat stations at the start of the next measurement day. Base and repeat stations aim to ensure the functionality of the equipment and the comparability and accuracy of the measurement data.

Once accurate measurement data have been collected from the survey area, a geophysicist applies necessary corrections and reductions to the gravimetric data. The goal is to eliminate instrument errors and anomalies not caused by density variations in the Earth's crust. After removing irrelevant gravity variations, the relative Bouguer anomaly can be determined, allowing interpretations of the area's bedrock composition based on density variations.

Predicting the surface age of asteroids using the space weathering features in reflectance spectra: small data machine learning

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The surfaces of airless planetary bodies, such as S-type asteroids, undergo space weathering (SW) due to exposure to the interplanetary environment, resulting in alterations to their reflectance spectral features (e.g., spectral slope, albedo, and absorption band characteristics) **(**Chapman 2004, Bennett et al. 2013, Pieters & Noble 2016). This study aims to estimate the surface age of S/Sq/Q-type asteroids as a function of SW agents and dose by employing two machine learning models, Ensemble model (combining multiple machine learning algorithms) and a Gaussian process (GP) model.

These models were trained on published reflectance spectra of olivine, pyroxene, their mixtures, and chondritic meteorites. Both used reflectance spectra and SW conditions as inputs, with surface age at 1 AU as the target. To address data limitations, k-fold cross-validation was applied. Validation evaluated their ability to capture SW progression across S/ Sq/Q-type asteroids, as well as the relationship between asteroid size and surface age.

Both the Ensemble and GP models provide reliable predictions of asteroid surface ages. However, the GP model exhibited higher variability in predictions for the asteroid dataset. Both models successfully identified relatively fresh surfaces in Q-type asteroids and mature surfaces in S-type asteroids, as well as younger surface ages for asteroids with diameters less than 5 km (Figure 1). While both models effectively captured relative surface age trends, limitations in data availability between 10^3 and 10^7 years hindered precise predictions of asteroid surface ages. These models have significant potential for future applications, such as determining the surface age for individual asteroids and identifying asteroid families, offering valuable tools for advancing our understanding of asteroid evolution and SW processes.

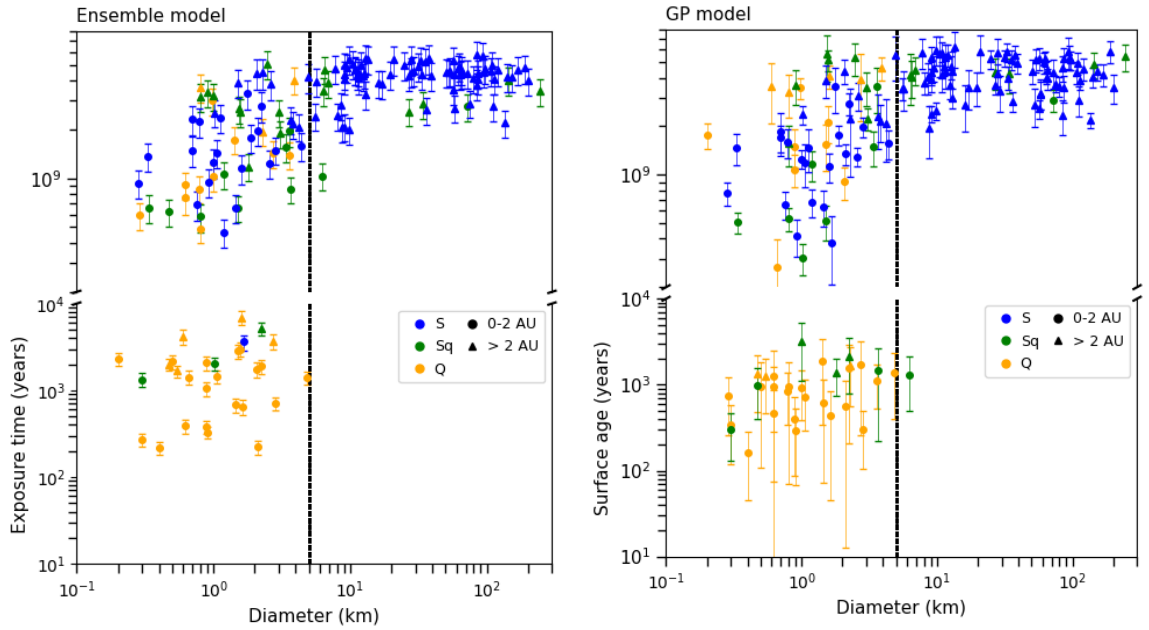

Figure 1. Surface ages distribution for S/Sq/Q-type asteroids plotted against the diameter of the asteroids. GP = Gaussian process, AU = Astronomical unit

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Stratigraphic framework in Finland – formal classification and practical guidance

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Stratigraphy is one of the most fundamental and integral part of geology. It encompasses all the properties of rock strata, including their lithology, fossil content, organisation, correlation and age relationships, and categorises the rock strata into stratigraphic units. Stratigraphic research is a prerequisite for interpreting the origin of rocks and sediments, their depositional conditions and sedimentary environments, as well as the evolution of life and geological history. Stratigraphic work has been carried out for generations, and the stratigraphic classification categories have been developing step by step over time.

The increasing importance of stratigraphy, and geological classification systems in general, is due to the ongoing (i) national and international efforts to harmonize geological information, (ii) digitalization, i.e. the establishment of geological databases, which requires strictly defined and hierarchical classification systems, and (iii) globalization, because of the global working environment where data exchange and interoperability are no longer only necessary for individual leading scientists, but for everybody working in the broad field of geology and geological map data.

In Finland, the stratigraphy has not been a popular topic and the use of stratigraphic terminology has been mixed and inconsistent. Furthermore, the applicability of the formal bedrock lithostratigraphic approach is restricted for plutonic rocks, but also for gneissic and other highly metamorphic rocks without reliable control of the superposition of the mapped lithological units. The classification of Quaternary deposits in Finland encompasses similar challenges in lithostratigraphy, but for different reasons. The establishment of meaningful and mappable glacial and interglacial units is challenging due to their insufficient lateral continuity and connectivity. Recent developments in geological and geomorphological mapping, new concepts and understanding of rock/sediment and landform classification and advances in geochronological methods have led to a need to review the classification of Finnish bedrock and Quaternary strata.

We present here a recently published Geological Survey of Finland, Bulletin 418 called "Stratigraphic framework in Finland – formal classification and practical guidance" (Köykkä et al. eds. 2024), which communicates how modern stratigraphy is best applied in Finland and forms the backbone for the work of the Precambrian and Quaternary subcommissions of the Stratigraphic Commission of Finland. This publication was compiled to: (i) support consistent geological unit nomenclature in Finland, (ii) assist regional geologists and other geoscientists in practical geological work and stratigraphic challenges related to complex, metamorphic bedrock terrains and Quaternary landforms and sediments, and (iii) facilitate the development of the national geological unit database (digital lexicon). The first article by Kohonen et al. (2024) discusses the stratigraphic challenges typical for Precambrian shield areas, with the main emphasis on litho-based classifications. The authors present novel ideas regarding the efficient use of lithodemic units in map database structures. They also propose a new approach related to regional chronostratigraphic nomenclature. The second article by Köykkä et al. (2024) is a completely revised edition of the 'Guidelines and procedures for naming bedrock units in Finland'. This new version aims to offer practical advice on the use of different bedrock unit classification systems in Finland, providing an update and revision of Strand et al. (2010). It also describes the current status regarding how various aspects of regional geology are covered by parallel but distinctly defined unit classifications. The last article by Lunkka et al. (2024) is the 'Stratigraphic framework for the classification of Quaternary deposits in Finland'. This paper introduces practices for the mapping and classification of superficial Quaternary deposits in Finland. It is not a formal stratigraphic guide or a stratigraphic code but aims at introducing applicable approaches and practices through which different classifications have been and are currently applied to benefit both scientific interests and more applied research in Quaternary geology.

International applied field techniques course for developing multidisciplinary geological skills in promoting green transition in Estonia

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The EGT-TWINN project aims to improve the research and technical capacity of the Geological Survey of Estonia (EGT) in order to accelerate Estonia's transition from fossil fuels to green energy. The project will promote the development of multidisciplinary geological research and innovation in Estonia and enable the enhancement of scientific excellence of EGT staff and cooperation with experts from leading international research institutions. One of the project's priorities is to support early-stage researchers at EGT in important geological areas to Estonia.

The competence development mainly focuses on developing state-of-the-art geological, geochemical and geophysical research skills, data management workflows and subsurface modelling capabilities for research. The aim is to promote the assessment of geological resources for critical raw materials in Europe, but also for geothermal energy as a potential future source of green energy for Estonia. The improvement of EGT's geological capacity will be implemented through several joint activities, such as information exchange and scientific conferences, as well as through targeted training programmes offered by three leading European geological surveys – the Geological Surveys of Finland (GTK) and Denmark (GEUS) and the British Geological Survey (UKRI/BGS). The Oulu Mining School (OMS) of the University of Oulu is also a partner, providing training in applied field methods for surface geochemical and geophysical exploration and a unique state-of-the-art platform for mining research and education.

One of the field training courses organized by OMS focuses on multidisciplinary, applied exploration methods for ores and minerals in glaciated areas. It emphasizes in a practical way how (i) sampling and various field survey techniques can be commonly used in generative green field exploration campaigns in areas covered by the glacial sediments and (ii) understanding the use of surficial geochemical, indicator minerals and geophysical field methods in ore exploration. The importance of understanding the regional geological context is the main theme of the course. In addition, the mechanisms of elemental dispersion in different glacial environments are described. The course content includes the use of *in situ* geochemical and mineralogical analysers, mobile metal ion techniques and geophysical survey methods.

This project is funded by Horizon Europe, Grant Agreement no. 101079459.

REMHub Consortium Project: University of Oulu's Role in Pioneering Sustainable Solutions for a Resilient European REE Supply Chain and Advancing Clean Energy and Green Transition

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Introduction

As the world transition towards cleaner energy and sustainable practices, the demand for critical materials, such as Rare Earth Elements (REEs), has seen unprecedented growth. These 17 metals are indispensable for modern technologies sectors, including renewable energy, environmental and process technologies and national security applications, which serve as the backbone of numerous high-performance products and processes. However, the accessibility of economically viable REE deposits is limited, posing significant challenges to their supply. Addressing this pressing issue is the cornerstone of the Rare Earth and Magnets Hub for resilient Europe (REMHub) project, funded by Horizon Europe.

Despite their name, REEs are relatively abundant in the Earth's crust; however, economically recoverable deposits are rare and often concentrated in a few geographic locations resulting in the highest supply risk in the critical raw material list of the EU. In this work, it outlines the aims of the REMHub project, with particular focus on the University of Oulu's (UOULU) capabilities. Three research units at UOULU are involved. Each unit is engaged in several strategic initiatives: Environmental and Chemical Engineering (ECE): Innovating REE refining and separation technologies from primary sources and recovering REEs from waste streams using ion-exchange-assisted hybrid-membrane separation technology, advancing LREE substitution, and conducting sustainability assessments throughout the REE value chain; Oulu Mining School (OMS): Developing novel processing technologies, including continuously compressing and crushing (CCCs) for REE ore crushing, flotation and leaching, and Industrial Engineering Management (IEM): Focusing on stakeholder engagement, quality assurance and risk management, KPIs and monitoring strategy, capacity building, and contributing to the development and implementation of the Innovation Hub.

By advancing cutting-edge technologies and promoting sustainable practices, the project not only addresses the immediate challenges of REE scarcity but also paves the way for a cleaner and greener future. As we continue to embrace renewable energy sources and environmentally friendly technologies, initiatives like REMHub are crucial in ensuring that we have the necessary materials to support this global transformation. Ultimately, the project's success will contribute significantly to the clean energy and green transition, reinforcing commitment to a sustainable and resilient Europe.

Muon imaging for waste rock pile characterisation using borehole detectors

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Introduction

Old mining waste rock piles are a significant yet often overlooked resource, potentially containing economically viable minerals. However, identifying resource-rich zones within these heterogeneous and extensive heaps remains challenging. A non-invasive and scalable method is needed to support sustainable resource recovery and reduce reliance on primary extraction, with innovative technologies playing a key role in the green transition.

Muon imaging is a non-invasive method for assessing density variations at metre-to-kilometre scales using naturally occurring atmospheric muons. As these high-energy particles pass through materials, their attenuation reveals density distributions within the target. By analysing directional muon flux, density maps can be generated. Muon imaging has been used in, e.g., volcanology, underground void detection, and mineral exploration (Tanaka et al., 2023). It is a promising tool for waste rock assessment, reducing reliance on costly drilling campaigns.

Borehole muon detectors for enhanced subsurface imaging

In the XTRACT project (https://xtract-project.eu), we are developing an advanced borehole-fitting muon detector system with enhanced resolution for waste rock characterisation. Designed to fit standard 75.7 mm NQ boreholes and scan low-contrast targets like legacy stockpiles, our probes offer improved sensitivity to density variations (Fig. 1a). The detectors enable targeted imaging and higher-resolution density maps for more precise resource assessment.

The first pilot deployment of our improved borehole muon detector is set for mid-2025 at the São Domingos Mine in the Iberian Pyrite Belt, one of the world's largest VMS provinces. São Domingos is one of Portugal's most notable mines, with mining history spanning from Roman times to 1966. Extensive waste rock piles accumulated over centuries of extraction make the site ideal for our tests (Fig. 1b). Field trials will assess real-world performance, guide technology refinement, and validate its potential for cost-effective and sustainable resource recovery.

Muon imaging provides a transformative approach to assessing legacy mining waste, facilitating resource recovery while minimising environmental impact. The XTRACT project's borehole muon detectors represent a major advancement in mining. By improving waste rock analysis, this technology has the potential to unlock valuable secondary resources and support a more circular and sustainable mining future.

Figure 1. a) Muon borehole probe test-fitted inside an NQ-size borehole at the São Domingos pilot site. b) Stockpiles and associated highly acidic waters (pH 0) at the São Domingos pilot site in Portugal. Images: Muon Solutions.

Acknowledgements: XTRACT is funded under the Horizon Europe research and innovation programme (grant agreement #101138432). The team is grateful to Empresa de Desenvolvimento Mineiro (EDM; https://edm.pt/en) for providing access to borehole data.

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Muon imaging of a bauxite deposit: Results from Jajce, Bosnia and Herzegovina

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Introduction

Muon imaging is a non-invasive method for remotely detecting density anomalies. It uses natural high-energy muons that penetrate all matter, including bedrock, and attenuate based on density. Detectors beneath or beside the target record muon trajectories over weeks to months, effectively imaging a cone-shaped region above them. The data enable statistical reconstruction of the internal density structures of the target by analysing muon attenuation.

The Dinaric Alps in Central Bosnia feature extensive carbonate platforms and karstic terrain, where bauxite has accumulated in palaeokarst depressions formed by prolonged weathering and erosion. The bauxite deposits in the Jajce area were formed during periods of subaerial exposure between the Late Albian and the Coniacian–Maastrichtian. The L-34 ore body of the Bauxite Mines Jajce (BMJ) consists of <10 m thick bauxite lenses on karstic surfaces, overlain by 40–50 m of limestone. Detecting the bauxite there is almost impossible using conventional surface geophysics (e.g., seismic and electrical surveys); thus, current exploration relies mainly on drilling. However, the density contrast between limestone and bauxite (0.3–0.4 g/cm³) makes this deposit wellsuited for muon imaging.

Muon imaging of bauxite deposits

As part of the AGEMERA project (Joutsenvaara et al., 2025), we applied muon imaging to locate bauxite ore bodies at the Jajce underground mine in 2023–2024. We used a muon telescope with a 50×50 cm detector area and an angular resolution of ca. 5 mrad (~0.3°) to scan for bauxite deposits from five locations in a mine adit at 1 037 m above sea level, 50–110 m below the local ground surface (Fig. 1a). At most locations, the detector was tilted towards the expected location of the bauxite ore body L-34 to improve focusing. In total, the measurements took ~12 months.

For data analysis, we classified the identified muon trajectories into ~10 000 angular direction bins. In each, we determined muon flux values and converted them to density-lengths. These data were used in a linearised discrete tomographic inversion to identify the rock density distribution responsible for the measured muon attenuation. Regularisation with a prior geological model stabilised the inversion. The scanned volume was then divided into a 55×55×47 matrix of equidistant, geographically fixed voxels (volumetric "3D pixels" with edge lengths of 2.3–2.7 m). Each voxel represents a discrete volume with a single assigned density value.

Our scans identified the bauxite lens, though smaller than expected. Geological inhomogeneity is the likely cause, which could be tested with post-survey muon simulations. To improve clarity, we applied post-processing to filter noise and enhance spatially coherent density anomalies. The results are shown in Figs. 1b and 1c.

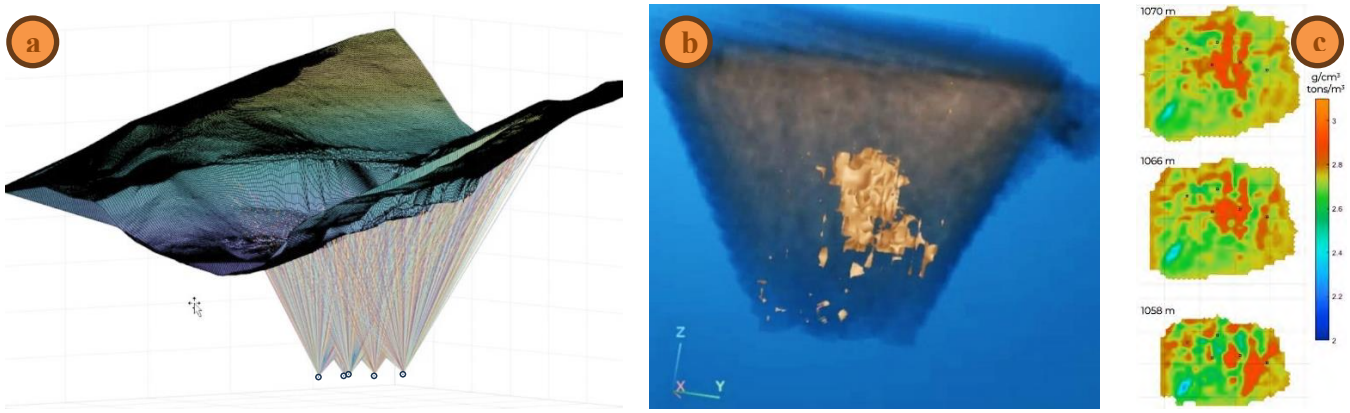

Figure 1. (a) 3D model of the muon detector locations (dots) in relation to the local surface topography. Scene width is ~120 metres. (b) 3D model of the identified bauxite deposits. (c) Horizontal slices of the density model. Images: Muon Solutions.

Acknowledgements: AGEMERA is funded under the Horizon Europe research and innovation programme (grant agreement #101058178).

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Developing continuously compressing crushing of critical minerals – Testing of dry processing method for graphite ore

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Introduction

Sustainable supply of critical raw materials such as lithium, cobalt, copper, nickel, phosphorus, graphite, and rare earth elements are crucial for the clean energy transition. However, many crushing and grinding methods used in mineral enrichment are more than 100 years old and were not originally developed on a sustainable basis.

More sustainable and controlled separation methods are becoming increasingly interesting and valuable investments for the mining and mineral processing industry. This is due to the requirements of the green and clean transition to promote innovative mineral processing technologies that consume less water, energy, and chemicals. The green and clean energy transition must cover the development and implementation of more efficient and cleaner processes in the whole value chain of critical raw materials.

Aim of work

Our aim is to develop a Continuously Compressing Crushing (CCC) method, which is based on the theory of free crushing. In free crushing, the rate of feed is such that the crushed material passes freely through the crushing unit without contact between the liberated particles. This prevents the formation of overfine particles and reduces energy consumption.

During the free crushing in the CCC method, microcracks are formed at the natural boundaries of mineral crystals resulting in the liberation of cleaner mineral particles with larger surface area. This can be utilized in the more sustainable comminution and beneficiation processes of ores, especially in dry physical separation, froth flotation, chemical leaching, and bioleaching.

Results and discussion

In this study, the CCC method was successfully tested for the dry separation of coarse-grained graphite flakes, which are favored in the battery industry (Paasovaara et al., 2024).

Compared to the conventional crushing methods, the CCC method produced more intact and cleaner graphite flakes from the graphite bearing schist, which in many ways facilitate the next steps of beneficiation of natural graphite as a valuable raw material. The CCC method also produced less fine and ultrafine particle waste compared to conventional crushing methods (Paasovaara et al., 2024).

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New characterize method for ore minerals with combining FIB-SEM and SC-XRD

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Introduction

Platinum group minerals (PGM) are often very small and difficult to examine. This study presents a new method for analysing micron-sized inclusions. Micron-sized inclusions are important links in ore genesis, ore exploration and mineral processing. Their small size often makes it impossible to measure their crystal structure. By combining different analytical instruments, field emission scanning electron microscopy (FESEM) and electron backscatter diffraction (EBSD), focused ion beam electron microscopy (FIB-SEM) and single crystal X-ray diffraction (SC-XRD), it is possible to measure the crystal structure.

EBSD is becoming an important method in geology and mineralogy. Unlike Energy Dispersive Spectrometry (EDS), which only shows the mineral composition, EBSD shows the crystal orientation of a selected sample. In this study, a JEOL JSM-7900F FESEM and Oxford instruments symmetry EBSD were used to study polished Pt-Cu nuggets. The measured Pt-Cu nugget contained several crystals, which is not an ideal sample for SC-XRD. For crystal structure measurements, the sample must be single crystal without other crystals or minerals. For the measurement, a small 20x20.20um cube of the selected crystal was prepared using FEI Helios DualBeam FIB-FESEM (Figure 1a). The EBSD map was used to locate the single crystal. The prepared cube was transferred to a thin needle holder (Figure 1b) and measured using a Bruker D8 Venture SC-XRD.

SC-XRD work revealed Pt3Cu is Ordered Orthorhombic Cmmm structure. Parameters for this structure are a = 7.708, b = 5.4504, c = 2.7252 Z=4. Combining this result to data from Cabral et.al (2019) crystal measurement was successful.

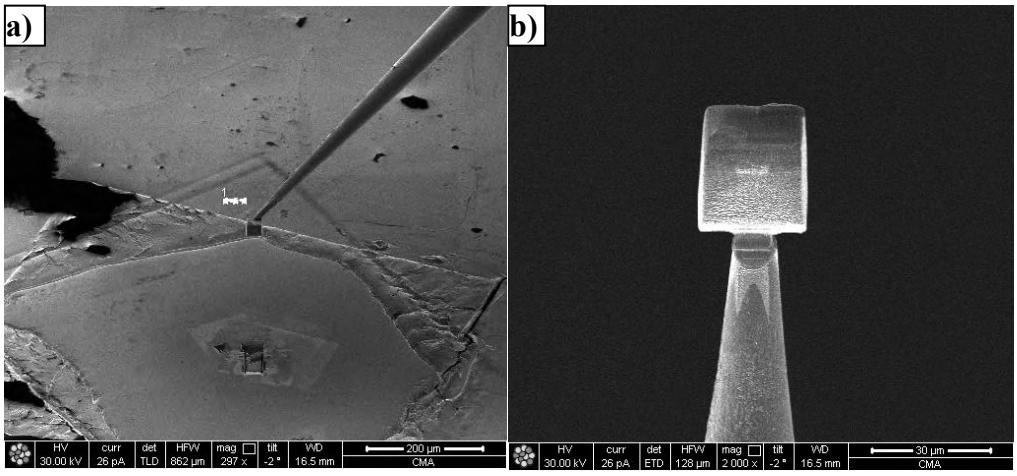

Figure 1. a) Moving prepared FIB-Cube to holder b) Prepared FIB-Cube in needle holder.

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Source constraints on the Late Cretaceous, strongly peraluminous magmatism of U.S. Cordilleran Interior; the White Rock Wash pluton, Nevada, and its corollaries

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The Cordilleran Interior (CI) of the United States, underlain by broadly autochthonous Precambrian lithosphere, was the locus of widespread magmatic-arc plutonism from mid-Mesozoic through Paleogene, with the most intense plutonic activity having occurred later than in the Sierra Nevada and Peninsular Ranges (Fig. 1). In the Newberry Mountains of southern Nevada, the CI Precambrian basement was intruded by the 68.5-Ma, two-mica White Rock Wash pluton (WRWP) (Miller et al. 1997; Haapala et al. 2005). WRWP is a circular stock, ~ 5 km in diameter, cuts sharply across its wall rocks, and includes marginal pegmatite. Geochemically, it is peraluminous, high in SiO_2, Sr, and Sr/Y, very low in HREE, and similar to other Late Cretaceous-Paleogene peraluminous plutons of the region. WRWP is, however, leucocratic throughout and not bimodal as, for instance, the Iriteba pluton in the Eldorado Mountains (Kapp et al. 2002). WRWP has an ε_{Nd} (at 65 Ma) of -15.6 to -16.4 (granite), Sr_i of 0.71215-0.71255 (granite) and 0.71369-0.71731 (pegmatite), and S&K μ_2 of 9.64-9.74 and ω_2 of 41.8-43.0 (feldspar from granite and pegmatite). WRWP feldspars define, together with whole-rock and feldspar fractions from the basement rocks of the Newberry and Eldorado Mountains, a $^{207}Pb/^{206}Pb$ isochron of 1692 ± 170 Ma. This is compatible with a major Precambrian crustal (Mojavia-type) source component. The Precambrian wall rock of WRWP is, however, less radiogenic in Nd [ε_{Nd} (at 65 Ma) -18.7 to -21.7] and more radiogenic in Sr [$^{87}Sr/^{86}Sr$ (at 65 Ma) 0.7269-0.7349] and thus the Mojavia (upper) crust cannot have been the sole source of WRWP. A minor less mature source component has been suggested for the Iriteba pluton, based on Jurassic cores of zircon (Kapp et al. 2002). Variation in lower crust isotope composition (and overall mantle separation age) across CI, portrayed by several strongly peraluminous plutons from southern California to northern Idaho (Fig. 1), may also have been the cause of the observed variability. Varying Sr/Y values probably imply varying source depths for these strongly peraluminous CI magmas.

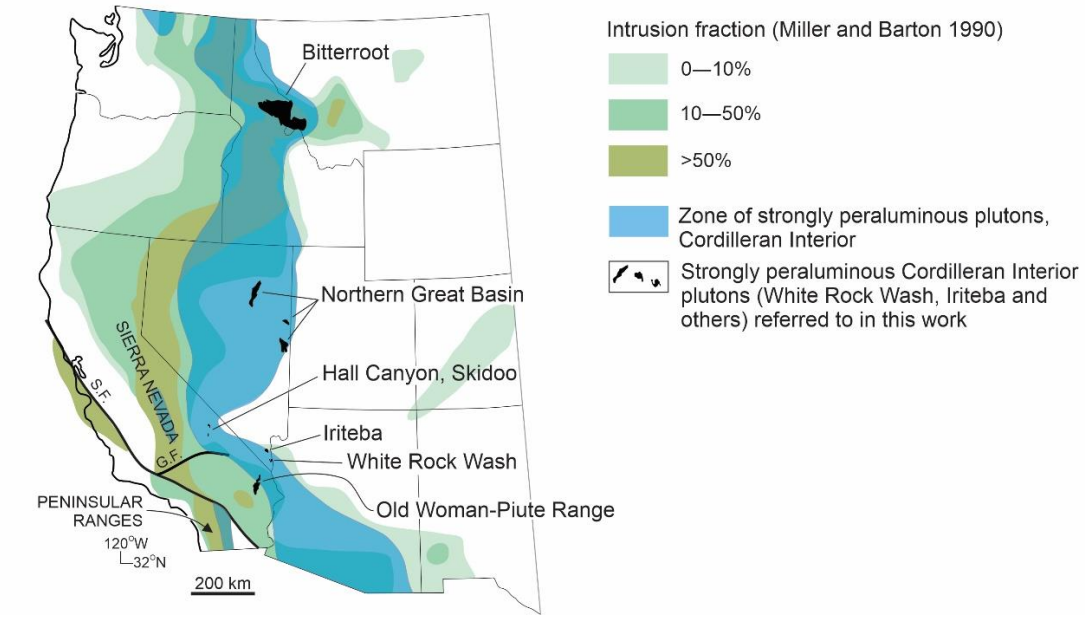

Figure 1. Distribution of Cordilleran Cretaceous-early Paleogene plutonic activity in the western United States with intrusion fraction and location of strongly peraluminous CI magmatism and CI plutons examined in this work indicated.

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Early Human Palaeoenvironments in Nihewan, Northern China

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The Nihewan Basin in Hebei Province, Northern China, provides a key terrestrial archive of faunal, environmental and climatic changes throughout the Pleistocene, and preserves one of the most important successions of Paleolithic archeological sites in Eurasia. So far, the earliest indications of human presence in the Nihewan area are dated to ca 1.66 Ma. This study, part of a consortium project bringing together archaeologists, palaeontologists, geologists, and computer scientists, refines the stratigraphic framework of the region, investigates depositional environments, and examines the relationship between climatic shifts, faunal evolution and human occupation in the area.

The classic Nihewan Fauna, representing the early Pleistocene Asian Land Mammal Age (Nihewanian), has long been central to bio- and chronostratigraphic correlations, yet its precise stratigraphic context remained unresolved. By reassessing 30 original excavation sites through field surveys and museum collections, our study provides the first calibrated stratigraphic profile of the Nihewan Formation in Xiashagou and suggests an age of ~2.4–1.8 Ma for the classic Nihewan Fauna.

Building on this chronological framework, the second part of this study focuses on the Shanshenmiaozui sequence, where a high-resolution stratigraphic investigation reveals a temporal span from ~1.8 Ma to the present. Crucially, this work establishes the earliest well-dated archaeological finds in the region at 1.8 Ma, marking a major contribution to East Asian Paleolithic and hominin research. The timing of early human dispersal into East Asia remains one of the most debated topics in archaeology, and reliable dating of Early Pleistocene Paleolithic sites is essential for addressing this issue. The Nihewan Basin now provides one of the most robust records of early hominin presence in the region.

Lithofacies analysis indicates that the classic Nihewan fauna mainly yields from deposits consisting of fluvial and alluvial fan sediments, whereas the Shanshenmiaozui site with artefacts represents distal fluvial fan–floodplain setting transitioning to marginal lacustrine environments, with a constant eolian dust supply. Faunal and dental ecometry data suggest a shift from more diverse temperate conditions with elements of forest and shrublands before 1.8 Ma to an increasingly arid shrubland-dominated environments thereafter. These findings offer critical insights into palaeoenvironmental changes during early hominin occupation in East Asia, shedding light on the ecological contexts that shaped early human dispersals.

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Johdanto

Stephen Jay Gould (1941-2002) oli Harvardin yliopistossa toiminut yhdysvaltalainen paleontologi. Gouldin lukuisat tutkimukset, kirjat ja lyhemmät esseistiset kirjoitukset käsittelivät usein evoluutiota. Tieteenalasaavutustensa lisäksi Gould tunnetaan kehittämästään NOMA-mallista, joka on lyhenne ilmauksesta ”Nonoverlapping magisteria”, tieteen ja uskonnon erillisyyteen tai itsenäisyyteen omina oppituoleinaan viitaten (Gould 1997, 1999). Oppialojen tasolla ilmenevän limittymättömyyden lisäksi NOMA-malli kuitenkin kehottaa myös henkilökohtaisella tasolla käytävään vuoropuheluun tieteen ja uskonnon välillä (Helama 2020, 2024). Integroivan ajattelun tavoitteena on Gouldin mukaan pyrkimys kohti viisautta.

Pentti Eskola (1883-1964) toimi Helsingin yliopiston geologian ja mineralogian professorina vuosina 1924-1953. Hänet tunnetaan eräänä merkittävistä geologisen tutkimuksen uudistajista, eritoten julkaisuista, joissa Eskola toi geologiaan käsitteen metamorfinen fasies. Elämäntyöstään Eskola sai Vetlesen-palkinnon vuonna 1964, mutta tieteen kansantajuistajana toimien hänen panoksensa luonnontieteille oli puhtaasti tieteellisiä meriittejä monipuolisempi (Marmo 1965; Korsman 2015). Tässä työssä Eskolan maailmankuvaa arvioidaan erityisesti hänen kristillistä katsomustaan käsittelevien näkemysten kautta. Kyseistä puolta ajattelustaan Eskola toi esiin kirjassaan Maailmankuvaa etsimässä (Eskola 1954), sekä eteenkin kirjassa Perimmäisten kysymysten äärellä (Arnkil et al. 1962) julkaistun kirjeenvaihdon lomassa. Viitekehyksen tarkastelulle antaa Stephen Jay Gouldin NOMA-malli. Kyseiseen malliin sovelletun tulkinnan mukaisesti tarkastelussa ovat paitsi tiede ja uskonto, faktat ja etiikka, myös vuoropuhelu näiden välillä, sekä viisauden käsite.

In English:

Stephen Jay Gould (1941-2002) was an American palaeontologist who worked at Harvard University, and whose numerous studies, books, and shorter essays often dealt with evolution. In addition to his scientific achievements, Gould is known for his NOMA model, which is an abbreviation of the expression "Nonoverlapping magisteria", referring to the separation or independence of science and religion as their own domains (Gould 1997, 2002). In addition to the non-overlappingness at the level of disciplines, the NOMA model calls for a dialogue and even integration of scientific and religious inputs at the personal level (Helama 2020, 2024). According to Gould, the goal of this integrative thinking is the pursuit of wisdom.

Pentti Eskola (1883-1964) was professor of geology and mineralogy at the University of Helsinki between 1924 and 1953. He is known as one of the remarkable developers of geological research, especially from publications in which he introduced the concept of metamorphic facies to geology. Eskola received the Vetlesen award for his lifetime achievement in 1964, but acting as a populariser of science, his contribution to the natural sciences was even more diverse than purely from scientific merits (Marmo 1965; Korsman 2015). In this study, Eskola's outlook on life is evaluated especially through the views and thinking on Christianity. Eskola publicised this aspect of his thinking in his book Maailmankuva etsimässä (Eskola 1954), and especially in the correspondence published in the book Perimmäisten kysymysten äärellä (Arnkil et al. 1962). Stephen Jay Gould's NOMA model provides a framework for the consideration. According to the interpretation of the NOMA model, not only science and religion, facts and ethics, but also the dialogue between them, and the concept of wisdom, are examined.

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Drone magnetic and electromagnetic surveys of Radai

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Introduction

Radai company was established in Rovaniemi, North-Finland in 2013 by Ari Saartenoja (CEO) and Dr Arto Karinen (CTO). In ten years, Radai has established a reputation of a leading-edge company specialized in drone geophysical surveys.

With the help of a staff of 10-15 persons, including three certified drone pilots, Radai typically makes over 20.000 line-km of magnetic surveys per year. Unlike most other companies, Radai utilizes 3-component fluxgate magnetometers that are installed rigidly onto a fixed-wing drone. The vector components of the magnetic field are obtained from the orientation information recorded by an inertial measurement unit (IMU). The vector magnetic data provides more information for 3D magnetic inversion than the total magnetic intensity does.

Radai has recently started to use Coot VTOL (vertical take-off and landing) drones show in Fig. 1. Coot has an endurance of 2 hours, which means that each flight is about 140 km long. Using simultaneously two drones it is possible to reach over 1000 line-km in a single day. The use of a special fluxgate calibration method to compensate for the magnetic effects of the drone and equivalent layer modelling method in data post-processing provides a noise level of few nano-teslas.

Radai is also developing a drone-based electromagnetic (EM) survey method. This so-called Louhi system operates at three frequencies (2.3, 4.6, 9.2 kHz). The EM source is either a fixed ground loop (100 m by 100 m) or a small transmitter loop (∅ 0.9 m) that is attached to a Coot VTOL drone that tows the 3-component EM receiver birdie. The first commercial field surveys with the semi-airborne system were made in 2024. The first field test with the single-drone (Slingram) system will be made this year.

Successful application of the drone-EM data requires numerical modelling and inversion. Radai's Lempo3D software is based on an approximate integral equation method. It can be used for simultaneous inversion of both ground and airborne data from different EM systems. In the future, Radai will be providing EM data interpretation as a service.

Figure 1. Coot (Nokikana) VTOL drone used in Radai's magnetic and electromagnetic surveys. A digital 3-component fluxgate magnetometer is installed inside the extended tail-pipe. The drone has electric engines and an endurance of about two hours.

Muon imaging in underwater geology: Insights from the Mine.io project

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Introduction

Flooded mines pose significant challenges for geological characterisation and resource assessment. Traditional geophysical methods are often ineffective in a subaqueous environment due to signal attenuation and interference. Direct access via divers or remotely operated vehicles is costly, complex, and limited by safety concerns. The lack of effective remote imaging solutions hinders efforts to assess structural integrity, locate remaining ore resources, and repurpose flooded mines. Here, we present a new geophysical method for studying these sites.

Muon imaging as a solution

The Mine.io project (Holma et al., 2023; https://mineio-horizon.eu) integrates muon imaging with autonomous robotics for innovative underwater geological exploration. We develop and deploy specialised muon detectors designed to operate reliably on battery power in high-pressure aquatic environments.

Muon imaging utilises atmospheric muons to non-invasively probe structures ranging from metres to kilometres in scale. While high-energy muons can penetrate all materials, their flux is gradually attenuated depending on density and thickness. By detecting these variations, muon imaging generates density-based images and three-dimensional models. Muon imaging has proven to be particularly useful in geological applications, such as volcano monitoring, mineral exploration, and void detection (Tanaka et al., 2023).

In Mine.io, the muon detectors jointly developed by the HUN-REN Wigner RCP (https://wigner.hu/en) and Muon Solutions Ltd (https://muon-solutions.com) generate 3D density maps of submerged geological formations, enabling the exploration of mine cavities, ore-bearing features, and potential hazards such as faults. The detectors are deployed at the study sites by AI-driven autonomous underwater vehicles developed by INESC-TEC (https://www.inesctec.pt/en) and capable of self-navigating complex flooded mines (Fig. 1).

With R&D now complete, the underwater robots and muon detectors are being integrated. Pilot studies on deployment and functionality are planned for mid-2025 at a Mine.io-designated site in Portugal. Following successful field validation, we will proceed to autonomous operation and rock density assessment.

Figure 1. Concept art depicting INESC-TEC's EVA robot deploying muon detectors (pink cylinders) in a flooded open-pit environment. The regions being scanned by the detectors are coloured in pink. Image: Muon Solutions.

Acknowledgements: This work is funded by Horizon Europe (GA #101091885) and the Hungarian NRDI Fund (GA TKP2021-NKTA-10).

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Paleoecological reconstructions for Crimean Cretaceous-Paleogene boundary

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Introduction

The thesis is devoted to the reconstruction of paleoecological conditions that existed at the Cretaceous-Paleogene boundary on the current territory of the Crimean peninsula. Earlier, sections of sediments with the same geological age, have been discovered in Nature Centre Stevns Klint (Denmark), geological outcrops of the cities of Gubbio (Italy), Zumaia (Spain), northeastern Brazil, the Tampico region of Mexico, etc. (Egorov 2012). Global climate change, distinguishing the geological time, entailed irreversible processes that became the most important factor for the further development of life on the Earth.

The study of the boundary horizon which is about 65 million years away from us has enjoyed growing interest for decades because at that time many important groups of organisms became extinct: dinosaurs, ammonites, belemnites and others. The upper Cretaceous deposits are a complex of exclusively clay-carbonate rocks (marls) in which fossils of marine animals - ammonites and belemnites - are found, which are not found higher up in the Paleogene deposits. Clay-carbonate rocks are the result of the great late Cretaceous transgression of the sea (Arkadiev, 2010).

In addition the object of research is connected with the insufficient study of this geological time. Previously obtained information and existing hypotheses including the asteroid fall do not reveal the primary cause of the mass Cretaceous-Paleogene extinction. Identification of geochemical features of the boundary horizon using geochemical indicators (Sklyarov et al., 2001) allows us to reconstruct the environmental conditions and identification of geomorphic mechanisms controlling the formation of sedimentary layers that were existing in water and land systems of the occurrence of the extinction at the end of Mesozoic and beginning of Cenozoic eras.

Material and methods

Previously, in August 2008, the boundary horizon, represented by clay sediments and located on the Crimean peninsula near Simferopol, v. Skalistoe, Baklinskaja cuesta, was discovered by Prof. E.M. Nesterov. The location characterised as one of the unique places on the Earth in which can be traced sequential alternation from Mesozoic era changing to supposed Cretaceous-Paleogene boundary and Cenozoic era. Later, in summer 2015, as a part of a scientific expedition a presumed clayey boundary horizon was investigated and samples of sedimentary rock and related fossils collected and transported to a laboratory.

The section of Cretaceous-Paleogene boundary and the layers adjacent to it studied in detail, made a stratigraphic description and detailed macro- and microscopic analysis. Particular attention was paid to the study of microfossils in the samples using electron microscope MIKMED-5 LOMO. Found fossil samples determined using the atlas of Crimean geology (Arkadyev & Bogdanova, 1997).

Sample preparations for geochemical analysis using X-ray fluorescence method was carried out according to the developed methods of the state standard (GOST 17.4.4.02-84) in laboratory conditions. The obtained data was interpreted using geochemical indicators (Sklyarov et al., 2001) as a tool in reconstructions of environmental conditions and identification of geomorphic mechanisms controlling the formation of sedimentary layers at the end of Mesozoic and beginning of Cenozoic eras.

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The aeolian dynamics in the Pre-vegetated Earth and its stratigraphic record

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The Proterozoic Earth witnessed unique paleoenvironmental conditions as compared to those following the post-development of land plants in the Silurian. The most obvious difference lies in the absence of vegetation, which likely made the bare continental surface more susceptible to weathering and erosion, encouraging the widespread development of complex aeolian systems due to high sediment supply. Therefore, it is reasonable to assume that the mechanism of aeolian dynamics, construction and accumulation throughout the Precambrian were more complex than those developed in Phanerozoic environments, reflecting in different stratigraphic records. Based on Phanerozoic and present-day cases, aeolian systems are categorised into dry, wet and stabilising types. It is questioned here whether the depositional architecture highlighted by these models are different to Proterozoic systems. Facies and architectural-element analyses have been applied to the Mesoproterozoic aeolian succession of the Galho do Miguel Formation (SE Brazil). The aim is to identify and discuss what controlling factors govern the construction and preservation of Proterozoic aeolian systems, and to explain how these differ from Phanerozoic examples.

The sedimentary succession comprises deposit of megadunes (draas), large-scale isolated dunes with dry interdunes, small-scale isolated dunes with damp or wet interdunes and salt flats. These architectural elements suggest the development of two main aeolian sub-environments, which coexisted and alternated temporally and spatially. The construction of megadunes, large-scale dunes and dry interdunes occurred in topographically elevated areas, usually above the water table, but that were occasionally flooded; isolated dunes with damp and wet interdunes, and salt flats formed in low-lying areas with water table at or close to the surface. The dry sub-environment was composed of interconnected interdune corridors between large and well-developed bedforms (simple dunes and megadunes). The water table did not influence the construction of climbing dunes and dry interdunes, but this was fundamental for long-term aeolian accumulation. Due to the proximity of the water table to the depositional surface, the dry interdune flats were eroded only up to the groundwater level, where the wetness inhibited sand removal during dune migration. This condition enabled the accumulation of thick packages of dry interdune deposits (up to 3 m thick). The wet sub-environment is represented by extensive interdune flats, sand flats, non-climbing dunes, and a continuously near-surface water table. In this context, the interdune deposits underwent only minimal reworking associated with dune migration. This setting allowed the progressive rise of the interdune substrate and the amalgamation of interdune deposits of different generations, thereby producing thick wet-interdune stratal packages (up to 8 m thick). The accumulation of thick packages of interdune strata in both sub-environments was generated by: (i) high rates of vertical accumulation of the interdune substrate due to high rates of sediment input for aeolian construction in Precambrian systems, and (ii) progressive relative rise of the water table. These conditions enabled the long-term accumulation and successive preservation of Precambrian aeolian systems, in which the stabilising effects of vegetation did not operate. Therefore, the aeolian architecture of the Galho do Miguel Formation suggests that: (i) Precambrian aeolian systems probably produced thicker dry and wet interdune deposits than their Phanerozoic counterparts, and (ii) hybrid dry-wet aeolian systems likely provided the most favourable conditions for long-term accumulation and successive preservation of these types of deposit in the Proterozoic. The proposed model also accounts for the relative scarcity of complex aeolian systems in Proterozoic records, compared with the Phanerozoic. The barren surface of the Proterozoic Earth, under the expected conditions of sand supply and wind action, should have experienced the construction and temporary accumulation of widespread ergs in dry environments. However, in absence of stabilising factors, like vegetation and wetness, sand-undersaturated wind and other exogenous agents were able to rework the aeolian bedforms hindering their preservation. Thus, in the Proterozoic, the accumulation and preservation of ergs may have hinged critically on the occurrence of a groundwater table close to the depositional surface.

Avulsion of the Yellow River into the South Yellow Sea during the early to middle Holocene: Evidence from Clay Provenance of the Yangtze Paleo-valley

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The location of the Yellow River estuary controls the pattern of mud dispersal and therefore influences the ecology of China's marginal seas. However, little is known regarding the Holocene history of Yellow River avulsion. The Yangtze estuary, south of the Yellow River estuary, may provide some clues, as a large amount of Holocene sediments has accumulated in a major paleo-valley in this area, incised during the Last Glacial Maximum (LGM). In this research, we identify clay contributions from the Yellow River in the three Holocene cores (TZ, DY, and HM) of the Yangtze estuary using provenance analogues of clay geochemistry associated with the modern rivers, and reveal the history of Yellow River avulsion into the South Yellow Sea. The results show that clay geochemistry in the Holocene cores is similar to that of the Yangtze River, except for the period of ~9.5–7.0 cal. kyr B.P. when it is represented by lower element contents more closely similar to those of Yellow River clays. Provenance end-member analysis shows 40%–60% clays of the Yangtze paleo-valley was derived from the Yellow River during this period. These findings indicate that, at least, one channel of the Yellow River avulsed southward into the South Yellow Sea during the early to middle Holocene (~9.5–7.0 cal. kyr B.P.). Fine-grained sediments from the Yellow River paleo-estuary could be transported southward to the Yangtze paleo-valley by enhanced marine energy during the early to middle Holocene. This study, not only, provides new evidence for Yellow River avulsion in the Holocene, but also sheds light on the impact of the Yellow River sediments on the depositional system along the coast of China, especially in the Yangtze delta.

Using Dynamic Image Analysis of Size-Shape Distributions to Determine the Mode of Aeolian Sediment Transport and Provenance Shifts

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The sediment transport medium, mode, energy, and distance are recorded in the observed grain-size and grain-shape distribution (SSD) in a sedimentary deposit. Grain-size analysis has been a well-established technique for almost a century, but within the last few decades also grain-shape analysis has been gaining a firm footing in inferring sedimentary and transport processes to decipher past climates and environments. Combining these techniques provides more detailed insights.

Dynamic Image Analysis (DIA) is a novel method that enables simultaneous measurement of size and shape characteristics of sedimentary particles in a sample, and hence, producing the SSD. This method has proven particularly efficient in studying silt- and sand-sized sediments, as the shape of the SSD can differentiate between various sedimentary and transport processes, as well as the transport mode in aeolian deposition.

Here, we aim to further develop analytical procedure in size-shape analysis by analysing topmost ~10 m (c. 32 kyr) of a high-resolution loess-paleosol sequence from the northern edge of Mangshan Loess Plateau, located next to the upper part of the lower Yellow River in China. First, a series of samples is analysed to examine the ideal sample concentration, DIA measurement settings, and potential effects of contamination. Subsequently, the entire sample set is analysed using the optimised settings. This high-resolution DIA dataset is then used in endmember modelling of SSDs (EMM-SSD) to identify the mode of sediment transport.

Our EMM-SSD results indicate that the Mangshan Loess is a mixture of three endmembers (EMs). The SSD of EM1 shows no clear trend and is the coarsest of the endmembers. The SSDs of EM2 exhibit a clear decreasing trend in aspect ratio (grain elongation) as well as convexity (grain irregularity) with increasing grain-size. The SSDs of the finest endmember, EM3, exhibit similar decreasing trend in aspect ratio but the convexity values become more concentrated rather than decrease. The decreasing aspect ratio suggests aeolian suspension as a transport mode for both EM2 and EM3. Further, the overall aspect ratio of EM3 is lower than that of EM2, suggesting that EM3 sediments have travelled a longer distance than those of EM2. No clear trend in SSDs of EM1 points to a short-range transport as bedload from a nearby source, such as the Yellow River floodplains.

The potential of Dynamic Calibration Region approach in plant macrofossil-based palaeoclimate studies

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Introduction

When reconstructing past climate conditions from (sub-)fossil proxy records, a vital step is the creation of the modern-day calibration using modern climatic values and modern proxy sample data. The choice of modern calibration region (CR) has a strong potential to change the climate reconstruction results (Salonen et al., 2013; Trasune et al., 2024), and thus should be carefully considered. In practice, however, the choice of the most appropriate CR has largely been based on the location of study site and limited by the availability of modern calibration data. Moreover, the use of one static CR – a classic approach in proxy studies – ignores the likely influence of temporal variations by other vegetation-affecting environmental factors, e.g., moisture regime, growing season length, continentality regime etc., which could potentially compromise the applicability of the CR for past conditions.

To address these limitations of classical reconstruction methods, a Dynamic CR approach should be considered (Birks, 1998; Trasune et al., 2024). In this approach, a range of CRs are used through the reconstruction timeline to mirror the shifts in a secondary environmental factor. Similar attempts have been made in pollen studies (Bartlein and Whitlock, 1993; Salonen et al., 2013), however, the Dynamic CR requires an extensive set of modern analogue samples, which has limited the application of Dynamic CRs for microfossil proxies. Quantitative plant macrofossil-based climate reconstruction approaches, on the other hand, can be calibrated with global modern-day taxon-occurrence and climate datasets. Modern-day plant occurrence datasets have a wide spatial coverage, and using them for calibration of palaeoclimate reconstruction could, in theory, enable the implementation of the Dynamic CR approach.

I test the Dynamic CR principle by focusing on seasonal temperature trends of the Baltic States from 14.7 to 11 ka BP. During this period, evidence from proxy data and palaeoclimate model simulations points towards major shifts in the continentality regime (Buizert et al., 2018; Schenk et al. 2018). The continentality – defined as the difference of the warmest minus coldest month temperatures, normalized by the sine of the latitude (Gorczyński, 1922) – impacts the reconstructed temperatures through shifts in the temperature optima of each plant taxa across the continentality gradient. I use January and July mean air temperature reconstructions of the Baltic States region calculated from a range of CRs, each representing different continentality regime (Trasune et al., 2024). The final reconstruction is calculated by weighting the reconstructed temperatures based on the different CRs using palaeo-continentality estimates reconstructed from chironomid data from the Atteköpsmosse sequence of southern Sweden. The resulting climate reconstruction suggests major winter temperature variations through time, with events like the Younger and Older Dryas now showing considerable shifts in winter conditions. The Dynamic CR approach shows a high potential to better resolve non-stationarity in proxy-climate relations if changes in secondary climate variables are considered in palaeoclimate reconstructions.

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Diatom and Dinoflagellate Cyst Species Dynamics over four Years in Seasonally Ice-covered Young Sound fjord, Northeast Greenland

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Arctic near-shore ecosystems are rapidly changing due to climate change impacts on marine and terrestrial environments. Retreating sea-ice, increasing precipitation and the melting of Greenland's glaciers are warming and freshening the sea surface and impacting light availability in the coastal Arctic Ocean. To predict future cryosphere change and its impacts on e.g., phytoplankton and ice-algal communities, it is essential to understand climate and ecosystem variability beyond the instrumental era. Sedimentary proxies are commonly used to reconstruct past ocean conditions and study the long-term environmental change. Diatoms and dinoflagellates are responsible for most of the planktic marine primary production together with coccolithophores. Their microfossil remains have been abundantly used in palaeoceanographic studies. Our understanding of the environmental responses of diatom and cyst (resting stage) producing dinoflagellate species is predominantly based on sediment core studies and the spatial distribution of the species in surface sediments in relation to surface ocean conditions across the Northern Hemisphere. However, we need to know more of their physical (ice, water) habitats, seasonal ecologies in relation to the annual sea-ice cycle, and how species' interactions, such as predation, impact the diatom and dinoflagellate cyst abundances in the water column and in the sediment.

Here we present diatom and dinoflagellate cyst succession at 2 to 12 week intervals over four years (2013-2015 and 2016-2018) in seasonally ice-covered Young Sound fjord in Northeast Greenland. An automated sequencing sediment trap was installed near the fjord entrance (74.322°N; 20.269°W) at 60-m water depth, 15 m above the seafloor. We found highly seasonal and mainly concomitant diatom blooms and dinoflagellate cyst production, likely due to narrow open-water season. Yet, there was no clear separation in the timing of production between sea-ice indicating and open-water species. The annual variation in the diatom and dinoflagellate cyst production was generally not linked with the timing of sea-ice breakup nor the nutrient status. Instead, we linked the most prominent diatom blooms with the years of relatively low river discharge. Yet, the fluxes of heterotrophic dinoflagellate cysts were highest during the years of relatively enhanced river discharge, and thus, they could indicate land-derived meltwaters and/or light limitation. Hence, terrestrial inputs can have an overriding the impact on the seasonal responses of diatom and dinoflagellate cysts species. Thus, the common use of these microfossil species as sedimentary proxies for past sea ice and sea-surface temperature, should be considered carefully in Arctic fjord settings.

Sustainable exploration for orthomagmatic ore deposits, progress of the HEU SEMACRET project

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The SEMACRET project aims to develop socially and environmentally responsible exploration methods for green transition (Critical) Raw Materials (PGE, Co, V, Ti, Ni, Cu, Cr) hosted by ultramafic-mafic orthomagmatic mineral systems. The primary focus is on refining ore deposit models following the mineral systems approach, optimising regional-scale exploration targeting, and developing efficient local scale exploration methods. There are 4 reference sites serving as case studies for testing these methodologies, including Lapland in Finland, the Beja area in Portugal, the Ransko area in the Czech Republic, and the Suwalki and Sleza areas in Poland.

The project has refined multiple geochemical proxies to identify the key source (mantle) component and degree of melting for generating metal rich magmas, in both rift and orogenic belts settings. Using computational modelling, magma transportation on a whole-crustal scale and within the upper crust have been modelled. High temperature experimental studies and thermodynamic modelling have been applied to constrain the metal precipitation mechanisms. All these provide fundamental clues for guiding mineral exploration in both regional and local-scale exploration.

Regional exploration targeting for orthomagmatic mineral deposits involves the compilation of mineral system models for Ni-Cu-rich conduit-type and PGE-Cr-V-rich layered mafic intrusion systems, supplemented by the insights gained from geological modelling. We applied deep penetration geodata as predictor proxy in the modelling. These predictor maps are then integrated using a knowledge-driven approach for prospectivity modelling. The implication for future upscaling is to build up a GIS based deep penetration geophysical database across Europe from dispersed sources, as part of the European Geological Data Infrastructure, to facilitate the utilization of these data for guiding mineral exploration. In addition, an innovative outliner detection method has been developed which can be applied for identifying occurrence of mineral deposits.

Local-scale exploration focuses on creating an integrated solution that combines innovative methods to identify high potential areas at the deposit scale to be applied in brownfield exploration. The project developed innovative geophysical inversion methods. These include 3D inversion for electromagnetic (EM) data of sulfide ores taking into account induced polarization (IP), and joint inversion of EM and ground IP data in QGIS plug-in, advanced modelling algorithms of full tensor magnetic gradiometry (FTMG) data and 3-component passive seismic modelling. Novel environmentally friendly surficial geochemistry tools based on upper soil horizons and plant geochemistry are also being explored. In addition, machine learning-based resource modelling and 3D prospectivity modelling are under development. Many of these technologies have potential for future upscaling. Different technologies can be integrated and combined with litho-geochemical modelling, for an optimized solution for the best practice on different mineralization styles.

Sustainable mineral exploration needs to promote social awareness on the significance of raw materials. In SEMACRET, social community events, interview and machine learning based social media analyses have been carried out to understand the attitudes towards exploration and mining from different stakeholders. Mineral source data on key raw materials hosted in orthomagmatic mineral systems have been collected across Europe, and conversion to UNFC code is on going.

Exploration targeting of anorthosite-related Fe-Ti-V mineralization around Suwałki, northeastern Poland

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The Suwałki Anorthosite Massif in northeastern Poland hosts significant Fe-Ti-V mineralisation associated with anorthosite-related mafic intrusions (Mikulski et al., 2022), commodities that are considered critical by the European Union (European Commission, 2023). Deposits in this area lie under a thick sedimentary cover of about 800 metres. Computer-based prospectivity modelling is a cost-effective and robust tool for delineating areas with high mineral potential, integrating diverse geospatial datasets. This study employs knowledge-driven fuzzy inference systems (FIS) to assess and model the mineral potential of Fe-Ti-V deposits in the region.

FIS is a symbolic artificial intelligence technique that enables a computer to apply geological reasoning by incorporating expert knowledge and defining fuzzy membership functions for key mineralisation indicators, such as magnetic anomalies, gravity data, and structural features. The GIS predictor maps, or evidence layers, are derived based on a mineral systems model, which also determines the structure of the FIS. The mineral system model for Fe-Ti-V mineralisation related to ultramafic-mafic intrusions includes (1) Primitive, mantle-derived, metal-rich magmas emplaced in an extensional setting, serving as metal sources; (2) trans-lithospheric faults and suture zones acting as magma pathways; and (3) dilatational zones of high, fracture-related permeability and localised structures that physically trap the mineralising fluids, allowing fractional crystallisation to generate evolved, oxide rich anorthosites. The evidence layers are then combined using logical if-then rules defined by the mineral systems model to produce a continuous prospectivity map.

Data availability is a serious challenge in this particular case where the mineralisation is deep-seated. Modelling warrants innovative data engineering to extract valuable features from any geoscientific data available. Geophysical data in the form of magnetic and gravity data is available for the entirety of Poland. Besides, a 3D model of p-wave velocities is compiled from seismic data by Grad et al. (2016). From these datasets, several features, such as a potential deep-seated magma reservoir, fluid transporting structures, fluid trapping structures, and intrusive bodies, were mapped. Predictor maps were then obtained and integrated as per the mineral systems model in the FIS. The resulting prospectivity map highlights previously untested targets, aiding mineral exploration efforts in the Suwałki region.

This work is co-funded by the European Union and UKRI (SEMACRET, GA101057741).

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Determination of till depth intervals with highest potential for mineral exploration in central Lapland, Finland

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Discovering new mineral deposits is essential to meet the increasing global demand for mineral resources. The glacigenic sediments, particularly till almost fully cover the bedrock in glaciated terrains like Finland. Moreover, till serves as one of the most appropriate natural sampling medias as it is derived directly from the bedrock. The targeting till geochemical data set of Finland was collected during 1970s and early 1980' by the Geological Survey of Finland (GTK). It covers central Lapland, some areas in Ostrobothnia and eastern Finland. Targeting till geochemistry survey samples comprise soil samples collected by GTK along sampling lines in 1971–1983 and the point density of soil sampling varies between 6–12 samples/km2 . The line interval is 500–2000 metres, and the point interval 100–400 metres. The samples were collected using percussion drilling with a flow-through bit and the sampling depth varies greatly, having on average 2 metres, where the maximum depth is 25.3 m and the minimum depth is 0.1 m. A size fraction < 0.063 mm was sieved from the samples, and the concentrations of 17 chemical elements were analysed with an emission quantometer (EKV). Since this data set contains elemental concentration for various depths, the aim of this study was to identify the best suitable depth interval for detecting orthomagmatic deposits. Thus, specific area from central Lapland was selected to study the depth profile of the samples. After data pre-processing, elements with acceptable quality were selected for further analysis emphasising on the elements those associate with the orthomagmatic deposits. Then, two methods were used to determine the appropriate depth intervals. First method involved detecting changes in both variance and/or mean of selected elements while the second method was based on fixed one metre intervals. Different depth intervals were compared to check the most appropriate depth interval for detect mineral deposits. Fuzzy logic was initially applied to generate predicted maps. Appropriate elements and their membership functions were identified based on the correlations of principal component analysis (PCA). Receiver operating characteristics (ROC) and area under the curve (AUC) were ultimately used to determine the best depth interval that has highest potential for exploration.

Joint application of passive seismic coda wave interferometry and gravimetry in brownfield exploration of massive orebodies

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The development of cost-effective and environmentally friendly methods for the exploration of critical raw materials (CRM) is important in the modern world as such platinum-group metals (PGM) as nickel (Ni), cobalt (Co), vanadium (V), copper (Cu) are irreplaceable in a wide set of EU strategic sectors such as aerospace, digital industry, and defence sectors. Within the SEMACRET project ("Sustainable exploration for orthomagmatic (critical) raw materials in the EU: Charting the road to the green energy transition"), an innovative passive seismic method based on coda wave passive seismic interferometry has been developed (Afonin et. al., 2024). To test this method, we used three-component seismic data recorded within two passive seismic experiments in Finland: in the Akanvaara Cr-V-PGE and in the Otanmäki Fe-T-V deposits. In both experiments, we used GSB-3 seismic recorders with 5 Hz three-component seismic sensors manufactured by Geospace Technologies Ltd. (USA). These instruments were provided for the experiments by the FINNSIP (Finnish Seismic Instrument Pool, www.finnsip.fi).

The passive seismic experiment in Otanmäki was conducted in October-November 2021. The profile with a length of about 3600 m, crossed the orebody projection in the ground surface and consisted of 342 seismometers which were recording continuously seismic data for one month. To evaluate the Empirical Green's Tensor (EGT) at each profile point, we selected recordings of the P-wave coda from 275 regional seismic events originated on epicentral distances between 250 to 800 km and with a local magnitude higher than one. We applied the data processing procedure described in Afonin et al. 2024 to obtain the EGT's. Interpretation of these results turned out complicated because the EGT's included a lot of arrivals of converted and trapped seismic waves. To improve this interpretation, we involved the modelling results of the gravimetric measurements done in the summer of 2020 funded by the K.H. Renlund Foundation. Joint interpretation of the EGT's and the density models allowed the detection of the converted arrivals originating from the deepest part of the orebody. Using travel times of the converted PS waves and seismic shear wave velocity model of the orebody, which was obtained from the same seismic data by inversion of the dispersion curves of surface wave parts of the empirical Green's functions, we estimated the vertical size of the orebody to about 3700 m, instead of the 3000 m initially estimated by the gravity modelling. Moreover, the several structural features of the deposit were found by this joint interpretation.

In the second passive seismic experiment in the Akanvaara, seismic data was continuously recorded along two profiles, crossing the mineralized zones of the deposit. In total, we used 746 three-component seismometers. The instruments were recording seismic data in first profile from 2.11.2023 to 9.12.2023 (606 instruments) and in the second one from 28.08.2024 to 2.10.2024 (140 instruments). Results of the seismic data processing by the developed method show converted arrivals originated from mineralisation zones and from other structural features of the deposit. To interpret these arrivals, the available gravity data was used similarly. This data was measured by the Geological Survey of Finland during the 1990's. Joint interpretation of the density models and seismic sections shows a good correlation between structures with different densities and converted arrivals, which makes the results interpretable.

Both case studies, show that the joint application of passive seismic coda wave interferometry and gravimetry looks promising for brownfield exploration of massive orebodies. Further development of this approach, which includes joint inversion of EGTs and gravimetry may result in the innovative cost-effective and environmentally friendly method for greenfield and brownfield exploration of massive ore deposits.

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Delineating IOCG potential areas, Kolari region, Finland, Application of machine learning methods

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Machine learning (ML) methods have considerably enhanced exploring and identifying new potential areas across various geoscience applications. Some ML techniques, such as random forests, support vector machines, and convolutional neural networks, have been employed in mineral prospectivity mapping (MPM) to delineate exploration targets. However, the number of training points significantly affects model performance, potentially leading to either reliable predictions or overfitting. In this study, we addressed the challenge of limited available training points by using the Synthetic Minority Oversampling Technique (SMOTE) machine learning method to increase the dataset from 34 points (17 positive and 17 negative) to 102 points, mitigating the risk of overfitting. We then applied the random forest algorithm on 12 evidence layers, such as gravity worms, thrusts, major faults, and albitised rocks, corresponding to the Iron-Oxide Copper Gold (IOCG) mineral system in the Kolari region of Northern Finland. The prospectivity map identified both known deposit locations and new areas with similar characteristics. The model demonstrated high accuracy, achieving F1, precision, and recall scores of 0.94, 0.95, and 0.97, respectively, indicating robust and reliable predictions.

Transforming Drilling Operations: The Power of Machine Learning for Cost Reduction and Precision

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Drilling in mineral exploration or during active mining stages is crucial for successful mining operations. It facilitates the study of the shape and subsurface characteristics of potential ore bodies, yielding essential information such as mineral grade (Revuelta, 2017; Dumakor-Dupey & Arya, 2021; Jung & Choi, 2021). Current geostatistical methods typically necessitate closely spaced drill holes to accurately estimate variables in unsampled regions. However, constraints related to budget and technical capabilities hinder the execution of detailed drilling (Sadeghi & Cohen, 2023; Lindi et al., 2024).

Unlike traditional geostatistical approaches that rely on the data within a spatial search window for interpolation, machine learning (ML) techniques offer a promising alternative by leveraging learned patterns and behaviors from datasets (Cevik & Ortiz, 2020; Jung & Choi, 2021). This study aims to employ ML for mineral resource estimation by minimizing the volume of data needed for analysis through quadratic sampling. The focus will be on datasets from the Ransko Ni-Cu-(PGE) deposit in Czech Republic, where systematically reduced data will serve as a basis for training and evaluating the performance of various ML models.

The research specifically investigates the application of ML methods, such as Extreme Gradient Boosting and Random Forest, to enhance mineral resource estimation in the Ransko Ni-Cu-(PGE) deposit. These ML techniques represent a significant advancement by predicting target variables in unsampled locations while utilizing sparse and distantly located data, thereby minimizing environmental impact and costs associated with drilling exploration. Furthermore, ML can effectively integrate geological interpretations and address spatial continuity, which potentially improves the accuracy of resource estimates and leads to more efficient and sustainable exploration practices. By employing distant exploration drill holes, the overall costs of mineral exploration can be substantially reduced, paving the way for innovative strategies within the industry.

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Undercover – Redefining the deep mineral exploration

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Recent EU initiatives for a circular 'Net Zero' economy emphasize the growing need for raw materials, particularly critical mineral resources (CRMs). Traditional mineral exploration methods are limited in scale and depth, often missing large CRM deposits under thick cover (500-1000 m).

The UNDERCOVER (Unified Novel Deep ExploRation for Critical Ore discoVERy) exploration research project aims to revolutionize deep CRM exploration by extending the mineral systems concept to exploration-relevant spatial scales. UNDERCOVER project is funded by the European Union Horizon Europe research and innovation -funding programme. The consortium, comprising 16 partners from leading research institutes, academia, service providers, and industry, includes members from five European Union member states (Finland, Germany, France, Czech Republic and Portugal), one from Namibia and one from Canada.

The project integrates advanced technologies developed by EU academia, research organisations and companies. It includes low-cost, full 3D lithosphere-scale surveys for target prospective regions, and regional scale mapping using innovative airborne techniques to identify exploration targets beyond 1 km depth. The project also enhances cost efficiency for high-resolution, deeply penetrating seismic and EM methods for deposit study and environmental planning. Additionally, AI and joint inversion methods are used to integrate multi-scale, multi-method geological, geochemical, and geochronological data, resulting in a 4D multi-scale mineral systems model. An integrated exploration strategy incorporates these technologies along with Environmental, Social, and Governance (ESG) studies to increase social acceptance and adoption of UNDERCOVER methodologies.

This new exploration strategy will emphasize the importance of both existing and new data, expert knowledge, and advanced modeling, inversion, and AI software solutions to optimize the predictive power of exploration models across various scales and stages. It will also address social and environmental issues. The introduction of UNFC guidelines is integral to our novel exploration strategy as part of the Value of Information. Case studies in the Kuusamo Schist Belt (Finland), Iberian Pyrite Belt (Portugal), and Kalahari Copper Belt (Namibia) demonstrate the strategy by identifying several new deep exploration targets.

AGEMERA: An Integrated Approach to Sustainable Mineral Explration

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Introduction

The AGEMERA project, funded by Horizon Europe, advances sustainable mineral exploration by integrating non-invasive geophysical technologies, a 3D visualisation platform, education, and social engagement. As demand for critical raw materials (CRMs) grows, AGEMERA supports the EU's goal of a resilient, responsible supply chain while minimising environmental and societal impacts. (Holma et al., 2022; Joutsenvaara et al., 2023)

Social Scientific Tools

AGEMERA promotes societal acceptance of mineral exploration through community engagement methodologies, including surveys and participatory dialogue, to assess public perceptions of CRM exploration and extraction. By involving local communities, the project enhances transparency, trust, and informed discussions on sustainable resource development. (Suopajärvi & Tulilehto, 2023).

Data

AGEMERA integrates multi-source geological and geophysical datasets to refine subsurface models and enhance mineral system models for CRM exploration. The project applies multi-scale 3D modelling, incorporating borehole data, geological maps, remote sensing, geochemistry, and geophysical parameters to validate geophysical methods and improve mineral system predictions. (Holma et al., 2022; Peytcheva et al., 2022).

Technologies

AGEMERA employs non-invasive geophysical methods, including muography, ambient noise seismology, and drone-based EM surveys, to characterise bedrock while minimising environmental impact. These techniques enhance subsurface characterisation, mineral system models, and resource targeting. The AGEMERA platform integrates diverse datasets into a cloud-based system, enabling advanced interpretation and 3D visualisation via a natural language interface. The project was recognised as a Horizon Europe Technology Success Story at EU Raw Materials Week 2024. (Joutsenvaara et al. 2025; Stimac Tumara and Matselyukh 2024).

Education and Knowledge Transfer

In addition to its technological and social components, AGEMERA places a strong emphasis on education and knowledge transfer. The project develops university courses, public engagement events, and an interactive online game to raise awareness about CRMs' role in modern society and promote responsible resource management.

Acknowledgements

The project receives funding from the Horizon Europe programme (Grant agreement ID: 101058178).

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Kaivannaisalan kehittäminen Keski-Pohjanmaan alueella KAKE-KP-projektin esittely

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Alkavan kaivostoiminnan myötä Keski-Pohjanmaa on liittymässä Euroopan tärkeimpien kaivannaisalueiden joukkoon, ja toimiala palveluverkostoineen on jo ennestään merkittävä elinkeino alueella. Euroopan unionin (EU) vihreän kehityksen ohjelman (Green deal) tavoitteet, EU:n kriittisten raaka-aineiden lainsäädäntökokonaisuus (CRMA) ja viimeaikaiset geopoliittisen tilanteen muutokset ovat tuoneet selkeästi esiin sen, että on ensiarvoisen tärkeää kasvattaa EU:n raaka-aineomavaraisuutta. Suomi yhtenä EU:n malmipotentiaalisimpina alueina voi vastata esitettyyn haasteeseen, mutta vain, jos maakuntien ja toimialan sisäistä ja keskinäistä yhteistyötä saadaan tehostettua.

Hanke vastaa tunnistettuun tarpeeseen kehittää maakuntien välistä kaivannaisalan yhteistyötä, erityisesti yhdessä Itä- ja Pohjois-Suomen maakuntien kanssa ja jatkaa näiden kaivannaisalueiden keskinäisen EU-tason vaikuttamiseen tähtäävää dialogia. Hanke on liitännäisprojekti Kaivannaisalan kehittäminen Lapin, Pohjois-Pohjanmaan ja Kainuun alueilla (KAKE) -hankkeelle.

Projektin vetovastuussa on Geologian tutkimuskeskus (GTK) ja yhteistyökumppanina KPEDU. Projektin toiminta-aika on 1.8.2024-31.7.2026.

Euroopan unionin osarahoittama

KESKI-POHJANMAAN LIITTO
MELLERSTA ÖSTERBOTTENS FÖRBUND

GTK

kpedu

Happamien sulfaattimaiden hyödyntäminen – FiksuHasu

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Rakentaminen happamilla sulfaattimailla aiheuttaa monenlaisia haitallisia ympäristövaikutuksia. Maaperän sulfidiyhdisteiden hapettuminen johtaa maaperän ja sen kanssa kosketuksissa olevien valumavesien happamoitumiseen ja metallikuormitukseen. Happamat sulfaattimaat ovat myös rakennusteknisesti haastavia niiden huonojen geoteknisten ominaisuuksien ja happamuuden rakenteille aiheuttamien korroosio-ongelmien takia.

Maarakennushankkeiden massatasapaino on tyypillisesti alijäämäinen eli rakennusalueiden ylijäämaita kuljetetaan läjitettäväksi muualle, ja niitä korvataan pääasiassa luonnonmateriaaleilla esimerkiksi soralla ja hiekalla. Happamien sulfaattimaiden läjittäminen on happamuusongelmien vuoksi tarkoin säädeltyä ja läjitettäviä massoja joudutaan käsittelemään esimerkiksi kalkitsemalla. Materiaalien uusiokäyttö läjityksen sijaan olisi järkevää ympäristön ja rakentamisen kestävyyden näkökulmasta sekä taloudellisesti.

Sulfaattimaiden hyötykäyttöä voitaisiin lisätä neutraloimalla ja stabiloimalla massat, jolloin niitä voidaan hyödyntää turvallisesti rakennuspohjana, meluvallien materiaaleina ja muussa rakentamisessa. Stabilointi ja neutralointi estävät happamuuden muodostumisen maaperässä, vähentävät happamien valumavesien muodostumista ja sulfaattimaiden käytön aiheuttamia ympäristöongelmia sekä rakenteiden korroosiohaittoja.

Massojen neutralointia ja stabilointia tehdään nykyisin sementti- ja kalkkipohjaisilla materiaaleilla, joiden käyttö lisää rakentamisen hiilidioksidipäästöjä. Kierrätysmateriaalien käyttö maarakentamisessa on vielä vähäistä, vaikka neutraloinnin ja stabiloinnin on todettu onnistuvan myös sivuvirtamateriaaleja kuten tuhkia ja kuonia käyttäen, jolloin hiilidioksidikuormitusta saadaan merkittävästi pienennettyä. Kierrätysmateriaalien turvallinen käyttö edellyttää kuitenkin vielä lisätutkimuksia niin laboratoriossa kuin käytännön mittakaavassakin.

Kaivettujen, happoa tuottavien massojen neutralointi ja stabilointi edellyttävät, että käsiteltävän massan ominaisuudet tunnistetaan luotettavasti, jotta tarvittavat materiaalimäärät voidaan laskea oikein. Tietoa kaivetun massan ominaisuuksista tarvitaan usein nopeasti, eikä niitä aina pystytä täysin selvittämään ennen kaivuutöiden aloittamista. Tällä hetkellä happoa tuottaville massoille on käytössä erilaisia pikatunnistus- ja riskinarviomenetelmiä, joiden soveltuvuutta käytäntöön massojen neutralointiin, stabilointiin ja korroosiotutkimuksiin ei ole tutkittu.

Korroosiotutkimukset tehdään Suomessa nykyisin Liikenneviraston (2017) ohjeistuksen mukaan, joka ei ota huomioon maaperän mahdollisia olosuhdemuutoksia, kuten pohjavedenpinnan ja hapetus- ja pelkistysolosuhteiden vaihtelua. Nämä voivat vaikuttaa kuitenkin merkittävästi korroosioon ja sen voimakkuuteen.

Rakennushankkeissa happamien sulfaattimaiden tutkimukset ja korroosiotutkimukset ovat tyypillisesti erilliset osakokonaisuudet. Niihin otetaan näytteet usein saman aikaisesti, ja todellisuudessa juuri monet happamien sulfaattimaiden ominaisuudet ovat kriittisiä korroosioriskin arvioinnissa. Siksi useita happamien sulfaattimaiden analyysimenetelmiä voitaisiinkin hyödyntää suoraan korroosioriskin tarkastelussa, ja siten saada kustannus- ja aikatauluhyötyä hankkeille.

Happamille sulfaattimaille kehitettyjen analyysimenetelmien avulla maaperän muuttuvat olosuhteet olisi mahdollista ottaa huomioon ja tuottaa siten uutta tietoa korroosiotutkimuksiin.

FiksuHasu-hankkeessa (2024–2026) kehitetään happamien sulfaattimaiden tutkimusmenetelmiä maaperän korroosiohaittojen tunnistamisen ja maa-aineksen uusiokäytön suunnittelun näkökulmasta. Hankkeessa tutkitaan myös paikallisten kiertotalousmateriaalien käyttömahdollisuuksia happamien sulfaattimaiden neutraloinnissa ja stabiloinnissa, tuotetaan uutta tietoa happamien sulfaattimaiden aiheuttamasta korroosioriskistä ja sen vähentämisestä rakentamisessa ja päivitetään nykyistä korroosiotutkimusohjeistusta tarvittavin osin.

Geologiliiton uudet tuulet, esitelmä Geologiliiton toiminnasta ja tulevaisuuden suunnitelmista

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Geologiliitto on ammatillis-aatteellinen yhdistys, joka pyrkii parantamaan ammattikunnan toimintamahdollisuuksia ja geologien äänen kuulumista yhteiskunnassa. Geologiliitto toimii kotimaisena hakukanavana European Geologist - lisenssille. Geologiliitto perustettiin ajamaan geologien asiaa 1953 ja sen jäsenmäärä kasvoi geologien määrän lisääntymisen ja geologien korkean järjestäytymisasteen myötä saavuttaen 600 jäsentä 90-luvun alussa. Työmarkkinajärjestönä Geologiliitto oli kuitenkin pieni ja yleinen kehitys työmarkkinakentällä johti pienimpien liittojen toimintojen yhdistämisiin ja tässä tapauksessa suuremman ammattiliiton perustamiseen 1993. Samalla Geologiliitto erosi Akavasta ja ohjasi jäsenistöään liittymään perustettuun uuteen edunvalvontaliittoon. Geologiliitto jatkoi kuitenkin toimintaansa itsenäisenä ja määritteli toimenkuvansa tarkemmin ammatillis-aatteelliseksi. Ammatillisena järjestönä Geologiliitto on osallistunut alan tapahtumien järjestämiseen yhdessä muiden järjestöjen kanssa ja toimittanut muun muassa Geologimatrikkelin vuonna 2001. Vuonna 2024 Geologiliitolle valittiin uusi hallitus, joka on kehittänyt toimintaa vuosien hiljaiselon jälkeen. Tavoitteena on muun muassa opiskelijoiden ottaminen mukaan toimintaan, koulutukset, seminaarit, opintomatkat eli ekskursiot ja kansainvälisen toiminnan edistäminen.

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Magnetic minerals in atmospheric Saharan dust

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Atmospheric dust is an important component of the global climate system. It has large-scale effects on the planetary radiation budget, the albedo of snow/ice, and biogeochemical cycles. Despite this, particularly the magnetic minerals in atmospheric dust have been poorly described in aerosol models. The absorption effects of magnetic particles can be comparable to black carbon, they promote ice nucleation and therefore play a role in cloud formation, and they increase the input of iron into ocean ecosystems. We aim to contribute to characterizing these dust particles and their source areas, long-range transport, and scattering effects.

The research material consists of Saharan dust deposited on snow in Finland, collected as an extensive citizen science campaign by the Finnish Meteorological Institute during 2021. The first results regarding the dust samples were published by Meinander et al. (2023). The multidisciplinary study showed that the dust originated from the Sahara and the Sahel regions (south of Sahara), based on the magnetic properties of the particles, and the System for Integrated modeLling of Atmospheric coMposition (SILAM) model. The results form the basis for the present project.

A detailed magnetic characterization of the dust samples is one of the main objectives. Identifying properties such as the types and grain sizes of the magnetic particles is crucial in indicating the source area of the dust and improving the light scattering and absorption models of dust. Magnetic measurements, including initial susceptibility with two frequencies, anhysteretic remanence, and isothermal remanence, have been carried out for a set of 47 dust samples. The preliminary results are in good agreement with the previously published magnetic analyses (Meinander et al., 2023), showing signs of the presence of both Saharan and anthropogenic dust.

In the future, the scattering and absorption of light by the dust particles will be studied both experimentally and theoretically. The existing numerical methods will be extended for the treatment of magnetic particles, particularly.

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Re-assessing combined age determinations from the MIS-2 period in Finland

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The understanding the deglaciation dynamics of the past continental Ice sheets, such as Fennoscandian Ice Sheet, is topical and enlighten the present-day deglaciation patterns.

The timing of the glacial conditions is not easy to assess. Instead, a proxy methods that imply ice free conditions is used to evaluate the length of the glacial period. These methods can be used to approximate burial time of the sediment (optically stimulated luminescence dating, OSL), age of the exposure of the rock (terrestrial cosmogenic nuclides, TCN), or time of the death of living organism (radiocarbon dating, ^{14}C). Targeted studies have discovered and dated late glacial events and formations in Finland. South Finland hosts Younger Dryas Salpausselkä end formations, ice retreat during the Allerød, stages of the Baltic ice lake, and the topic of Heinola deglaciation (cf. Lunkka et al. (2021), Rainio (1993)). The ice-divide zone, minimal glacial erosion and a late deglaciation in the early Holocene on the other hand are often used to characterize Northern Finland.

In this study, we compile previously published MIS-2 aged age determinations from multiple sources, and discuss about the results. The aforementioned dating methods are accompanied by their respective sources of error. Although the less pervasive climate events can occur in the smaller data sets of targeted studies, they can easily be disregarded as outliers. In a larger compilation the outliers can form aggregations. The aggregations can ultimately grow to a size where they should be considered as true events, rather than multiple outliers. Our results imply that such aggregations could exists in Northern Finland at Bolling-Allerod and near the Last Glacial Maximum. In Southern Finland, the results generally agree with the current consensus of the MIS-2, although small sampling of TCN and ^{14}C age determinations are found in the proximal side of the Salpausselkä formation which post-dates them. The preliminary results imply that the deglaciation and glaciation were possibly more dynamic than what they are often viewed as.

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Holocene megadroughts in eastern North America: patterns and drivers

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Paleoclimate proxy data for eastern North American moisture conditions indicate strong and persistent multi-millennial droughts during the Holocene. However, climate model simulations often fail to reproduce the proxy-inferred droughts (Liefert & Shuman, 2020). Diagnosing the data–model mismatch can offer valuable insights about the drivers of hydrological variability and different regional sensitivities to past and future climate forcing.

Here we present a new proxy–modeling synthesis for Holocene climates in the eastern North American mid-latitudes, including water balance reconstructions prepared from fossil pollen sequences (Fig. 1a) using machine-learning-based calibration models (Salonen et al., 2019) and high-resolution climate simulations. Prior to 8 ka, our data reveal an earlier drying in the northeast U.S. compared to the mid-continent, followed by drier-than-preindustrial conditions in all regions over 8–4 ka (Fig. 1b). In addition, our high-resolution proxy data and simulations show clear multi-centennial climate variability, including periodicities with wavelengths falling generally at about 0.2 ka.

Notably, our results resolve the prior-generation inconsistencies between paleoclimate data and climate models, showing consistent spatiotemporal patterns of Holocene moisture change, and enable assessment of the underlying driving mechanisms. Our modeling suggests that the Holocene summer insolation trend, combined with the Laurentide Ice Sheet (LIS) deglaciation and its effect on atmospheric circulation, explain the timing and spatial extent of drier than modern climates. The early-Holocene pattern with a wet mid-continent but dry Atlantic seaboard (Fig. 1b) can be linked to the glacial anticyclone over the LIS, which diverted humid air away from the Northeast towards the Midwest. Based on our simulations, the mid-Holocene multi-millennial drought (Fig. 1b) is largely driven by the Holocene temperature maximum which led to high evapotranspiration, rather than changes in precipitation. The mid Holocene may thus present a reasonable natural analog for the drying trajectory projected for mid-latitude North America in the 21st century (IPCC, 2021), which is also primarily driven by rising temperatures.

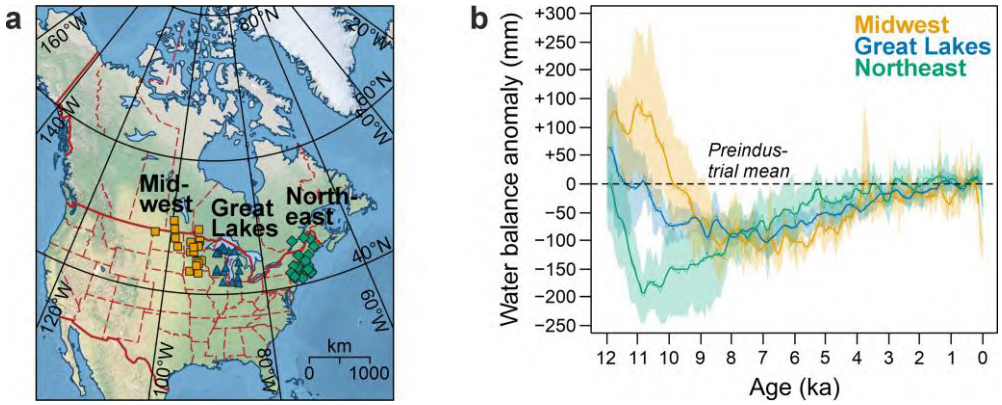

Figure 1. (**a**) Locations of 66 fossil pollen sequences used to reconstruct Holocene paleoclimate, divided in three spatial clusters: Midwest, Great Lakes, and Northeast. **(b)** Holocene annual water balance reconstructions for the three spatial clusters.

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Land degradation related to historical mining industry: risk management options for the Outokumpu mining town in Finland

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Introduction

Mining and metallurgical industry started at Outokumpu in 1910 resulting in soil and water contamination and acid mine drainage. Outokumpu is the only sulphide ore mining site in Finland where the tailings areas and waste rock piles are located in a town. However, in Europe and beyond, some historical mining towns and cities host a large population, Daye in China with a population exceeding 870 000 as an example (Yuan et al., 2023).

When evaluating the environmental impact of sulphide ore mining, we recommend using the abbreviation SOEC for sulphide ore extraction -related contaminants instead of, for example, potentially toxic elements, as acid mine drainage also generates compounds such as sulphates and causes acidity.

The 'Soil planning area' concept

We propose nominating the historical mining area at Outokumpu as a 'Soil Planning Area' with specific land-use regulations (Solismaa et al., 2025). In the Freiberg mining town in Germany, this procedure has been successfully implemented (e.g., Saxon State Directorate 2011a,b, Loukola-Ruskeeniemi et al., 2022). Ramboll Finland (2022a, b) carried out a study that revealed soil contamination in the Outokumpu centre due to the utilization of mine tailings in road construction. According to Ramboll, comprehensive site-specific risk assessment and subsequent risk management would cost hundreds of millions of euros.

Outokumpu is one of the test areas of the EU Soil Mission project ISLANDR (https://www.gtk.fi/en/research-project/islandr-information-based-strategies-for-land-remediation/). The ISLANDR project (1.5.2023–30.4.2026) intends to present some recommendations to support the proposed Soil Monitoring Directive of the European Union.

Acknowledgements

The research was funded by the Information-Based Strategies for Land Remediation (ISLANDR) European Union research project under Grant Agreement 101112889.

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Smart Circular Economy Field-testing Facility for Extractive Waste and Side Streams – preliminary results of concept testing

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Introduction to extractive waste testing and the SMARTTEST project

Extractive waste management requires reliable data on the long-term behaviour of waste materials and the performance of closure solutions, such as cover structures. Such data has traditionally been produced at laboratory scale, but recently there has been increasing focus on developing field tests to better simulate the behaviour of wastes, waste mixes and cover structures under local climatic conditions and to improve the scalability of the test results to operational scale. Also, the use of extractive and industrial side streams in closure solutions offers a possibility to reduce the use of virgin materials and disposed waste and to increase the circularity and sustainability of the extractive industry. However, the use of side streams in cover structures requires verified data on their geotechnical and environmental performance to ensure their suitability.

To facilitate reproducible and effective testing of extractive waste and industrial side streams, a flexibly customizable and comprehensively instrumented field-testing site and concept is being developed and set up by the Geological Survey of Finland (GTK) at the GTK Mintec mineral processing pilot plant. The concept includes smaller scale tests to study long-term behaviour of extractive waste and side streams and to test a selection of closure structures, whereas larger scale tests will be applied to mimic operational conditions of selected closure solutions. Combining a mineral processing pilot plant with the field-testing facility allows early testing of extractive wastes, supporting design-based waste management and promoting circular-based side streams. The concept is being tested and validated as part of the Smart Circular Economy Field-testing Facility for Extractive Waste and Side Streams (SMARTTEST) project of GTK, funded by the European Regional Development Fund (ERDF) from the Regional Council of North-Karelia, Agnico Eagle Finland Oy, EPSE Oy, Fatec Oy, Nord Fuel Oy, Kemira Oyj, Mawson Oy, Sokli Oy, and Geological Survey of Finland.

Field test construction and preliminary results

In Autumn 2024, various test structures were built to demonstrate different testing scenarios. In work package (WP) 2, a large-scale test was constructed to evaluate the performance of dry stacked tailings. WP3 focuses on promoting circular economy through innovative cover structures. For this purpose, three smaller-scale tests and one larger-scale test were constructed, using less harmful tailings and chemically stabilized tailings as cover materials. In WP4, the behaviour of waste rocks and a mix of waste rock with steel production side streams is being investigated through six smaller-scale tests and one larger-scale test. Geochemical and geotechnical processes in the test materials are being monitored using e.g., drainage water and pore water sampling, online sensors and 3D lidar imaging, offering a wide range of different parameters. The collected data will be utilized in WP5, which focuses on modelling of the test setups, providing insights into the different processes and further scaling up of the results.

The preliminary results indicate that the field-scale testing concept is feasible. Thus far, the test structures are performing as expected, and valuable data is being generated. The tests will provide interesting and useful data regarding the environmental properties and performance of the tested materials, cover structures and novel waste disposal methods. This information can be utilized in designing mine waste management and closure strategies for mining projects.

The 3rd GeoDays of Finland is held in the University of Oulu, 11th–13th March 2025. The event gathers around 110 participants from different fields of geosciences to present and learn from the latest research and innovations. This publication contains the program and submitted abstracts for all the oral and poster presentations held at the meeting. The organizing committee would like to express gratitude to all the authors and sponsors for their contributions.

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

Citation:
Sarala, P. & Eskola, T. (eds.) (2025) Abstracts of the 3rd GeoDays, 11th–13th March 2025, Oulu, Finland. Proceedings of the Geological Society of Finland, vol. 5.

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