# Common Mid Point (CMP) surveying for depth calibration of ground penetrating radar data

Pinola, Hannu

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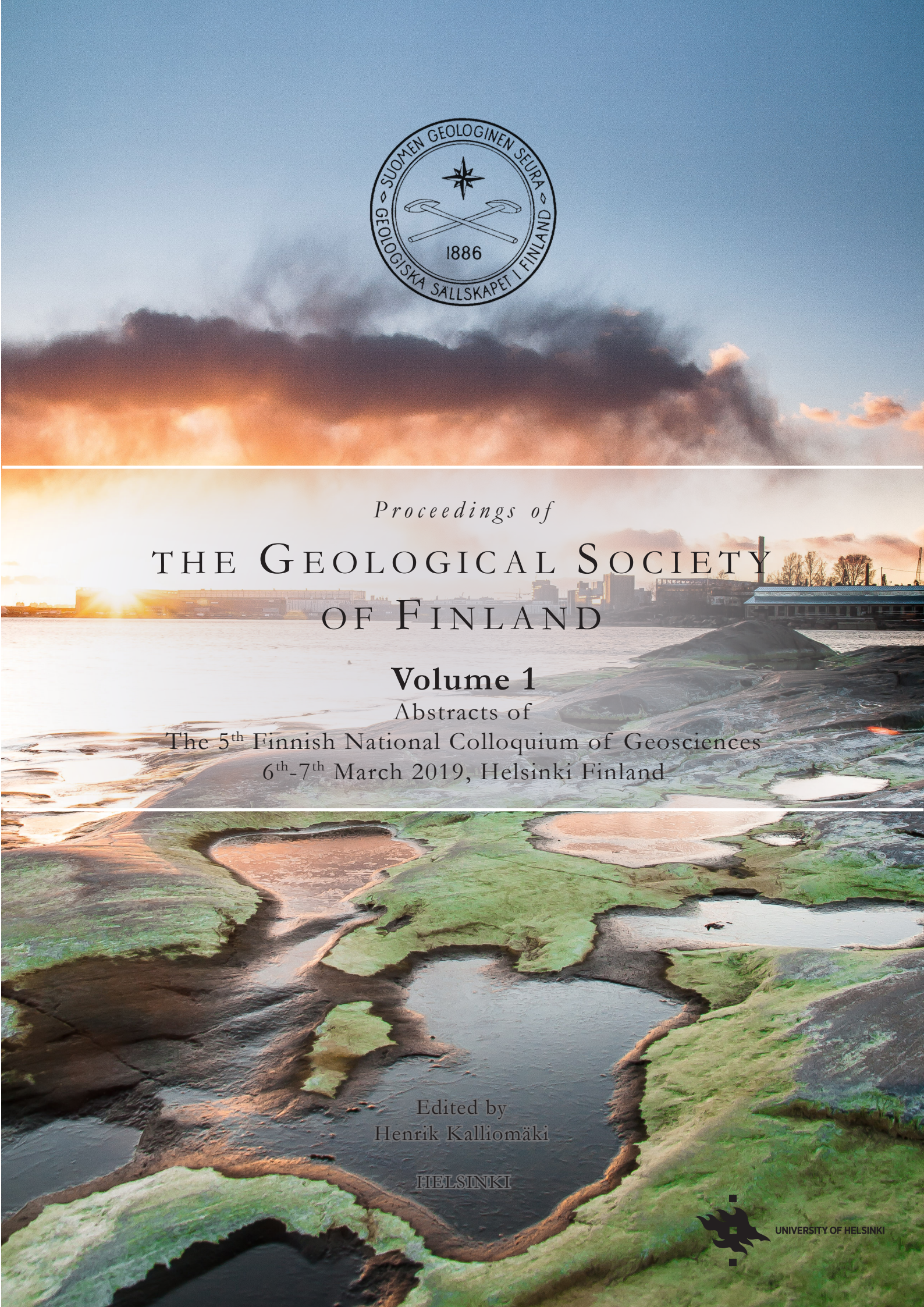


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## Volume 1

Abstracts of
The 5th Finnish National Colloquium of Geosciences
6th-7th March 2019, Helsinki Finland

Edited by
Henrik Kalliomäki

HELSINKI

UNIVERSITY OF HELSINKI

# The 5th Finnish National Colloquium of Geosciences
# 6th-7th March 2019 Helsinki, Finland

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# Dozen in a pocket: Summanen, a new meteorite impact structure in Finland

PESONEN, L. J[1], HIETALA, S[2]*, PLADO, J[3], KREITSMANN, T[3], LERSSI, J[2], AND NENONEN, J[2]

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## 1. Introduction

Impact cratering is a ubiquitous process in our solar system affecting all planetary surfaces throughout geologic time. On Earth, there are currently 190 confirmed impact structures, which are distributed unevenly. The Fennoscandian Shield houses 16.8 % of them.

A dozen (12) impact structures have been discovered in Finland. The latest, Summanen (62°39'00"N, 25°22'30"E) was found in 2017 (Plado et al., 2018). It is located within the Paleoproterozoic Central Finland Granite Belt and covered with the Lake Summanen and, thus, is not directly observable. The first hint of an impact generated structure is based on airborne geophysical mapping by the Geological Survey of Finland in the early 2000`s (Lerssi et al., 2007) that revealed a circular ~2.6 km wide striking aeroelectromagnetic resistivity anomaly.

## 2. Research methods and results

A few tens of erratic porphyritic granite boulders with shatter cones and brecciated rocks, were discovered during field-work in 2017. Most shatter cones were found within a distance of 5 km SE from the geophysical anomalies near the center of the lake. Surfaces of shatter cones are curved and distinctly conical. The striations are diverging from the apex with angles between 45° and 75°. The best-developed shatter cones occur in fine-grained aplitic granite.

In two shatter cone samples planar deformation features (PDFs) were identified. Measurements of PDF orientations were done at the University of Tartu, with a LOMO FS universal stage mounted on a polarizing microscope. A standard technique was followed in measuring the orientation of the c-axis, and poles to planar deformation features (PDFs) relative to the orientation of the thin section (Langenhorst 2002). Results were analyzed using the PDF indexing algorithm ANIE (Huber et al. 2011). Altogether 64 measurements of the angles between quartz c-axes and poles to PDFs were made in 60 quartz grains. In most cases, there was one set of PDFs per grain. Eighty-three percent of the measured angles are between 20° and 35°, which correspond to {10-13} or {10-12} axes in most cases. All PDFs were decorated with average spacing between 5 and 8 μm. In addition to PDFs, planar fractures (PFs) were common, and in rare cases, feather features (FFs). Kink bands in biotite were also abundant.

## 3. Future studies

The impact age of Summanen is undefined but must be younger than the target rock age which is 1.88 Ga. Radiometric and paleomagnetic dating techniques will be applied to date the Summanen event. Additionally, there is a need for a detailed gravity mapping and 3D modellings. Seismic reflection and wide-band EM surveys may also provide additional information of the structure including the estimate of its erosion level. The Summanen structure would be an ideal target for drilling, providing data for multidisciplinary (geology, geophysics, geochemistry and environmental) research.

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Plado J., Hietala S., Kreitsmann T., Lerssi J., Nenonen J., Pesonen L.J., 2018. Summanen, a new meteorite impact structure in Central Finland, Meteoritics & Planetary Science, 53.

# Asteroid Prospection Explorer (APEX) CubeSat for Hera mission

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*2 Swedish Institute of Space Physics (IRF)*

Asteroid Prospection Explorer (APEX) is a 6 unit-sized CubeSat for Hera spacecraft (ESA) with a unique set of instruments designed to provide a global characterization of the Didymos binary asteroid system – target of the joint ESA-NASA Asteroid Impact and Deflection Assessment (AIDA) mission. The instrument set includes ASPECT (Asteroid Spectral Imager), ACA (Asteroid Composition Analyzer), and MAG (Magnetometer).

Both ASPECT and ACA provide crucial information of the Didymos surface composition. While ASPECT can provide the mineral composition information at high resolution (2 m/px or better) from mineral absorption bands, ACA complements this by the elemental composition of sputtered ions from asteroid surface ejected by solar wind. Combining the information from these two instruments we can obtain a complex picture of the Didymos system composition and detect the compositional variations between Didymos I and II as well as along the bodies itself. MAG complements this information by searching for an intrinsic magnetization of the building blocks of the asteroids, thus being potentially able to distinguish between monolithic and various levels of rubble pile structure.

APEX scientific observations are planned in two stages. First, a global mapping phase is scheduled on 4.2 km, slightly inclined orbit around barycenter of the Didymos system. From this orbit, global composition and magnetic field mapping will be achieved at uniform resolution utilizing all three payload instruments. In the second phase, APEX will gradually transfer to locations nearby L4 and L5 points of the Didymos binary system. From here, APEX will engage in a high resolution compositional and magnetic mapping of both Didymos I and II. At the end of the mission, a landing of APEX on one of the Didymos asteroids will be tried.

APEX concept with its unique instrument set and capabilities can be applied in any future asteroid characterization projects from purely science and planetary defense driven missions to characterization of the asteroid ISRU potential.

# The Earth´s magnetic environment dancing in the rhythm of solar storms

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The Earth´s magnetic environment is highly dynamic and strongly modulated by its heliospheric surrounding. The main source of the variability is the Sun with its 11 and 22 years long solar cycles. Solar dynamics modulates the content and structure of the solar wind, which furthermore drives geomagnetic activity at the polar and equatorial regions. Solar wind hosts disturbances that vary in wide variety of time scales from seconds and hours to years and solar cycles. Auroral regions are dancing in the rhythm of these variations and producing the northern and southern lights for the Arctic and Antarctic regions. Magnetic environment have been monitored since the discovery of the magnetometer before the mid 1800´s. Finland was one of the first countries starting the continuous recordings at Kaisaniemi observatory in 1844. We have analyzed geomagnetic disturbances recorded in Finland for the last 170 years and show the observed year-to-year, annual and seasonal variability. We found out that the largest geomagnetic disturbances occur typically after the solar activity maxima when the solar wind is the fastest and embedded with the Alfvénic magnetic field fluctuations. Because the Sun is the stormy star it can produce the extreme disturbances at any time making their predictability a challenging task. The Sun –Earth magnetic coupling studies have teached that the rhythm of the Sun is, however, somewhat systematic. The morphology of the solar magnetic field at the active regions and the shape of the solar coronal holes seem to play the crucial role in this modulation.

We will present results that are based on the long time series of measurements as well as introduce new platforms, concepts and methods for better monitoring the magnetic environment in the future. New platforms and concepts include drones capable of carring payloads up-to few kilograms, and flexible portable instruments for ground-based, aerial and underwater observations. The role of pattern recognition and other artificial intelligent methods are discussed related to resolving how to best handle large amount of data, and for better understanding the rhythmic changes in the magnetic environment.

# Alpine hydrogeology: The critical role of groundwater in sourcing the headwaters of the world

Keynote lecture by Masaki Hayashi

*(NGWA Henry Darcy Distinguished Lecture)*

Many of us have been awed by the stunningly beautiful view of alpine lakes and streams – and they are not just beautiful. Nearly half of the world population relies on rivers originating in high mountains for water supply. Source areas of mountain streams have rugged topography with sparse soil and vegetation covers, and were once considered "Teflon basins" that have minimum capacity to store groundwater. Over the past decade or so, a new understanding of alpine hydrogeology has been emerging based on detailed field observations around the world. Alpine basins actually have important aquifer units that provide temporary storage of rain and melt waters from snowpack and glaciers. Gradual release of water from these aquifers sustains stream flow during dry or cold periods, and is critically important for water supply and aquatic habitats in downstream regions. Due to rugged terrain and severely limited vehicle access, alpine hydrogeologists need to rely on creative methods to investigate groundwater, such as geophysical imaging techniques or observation of surface-groundwater interaction. This lecture will demonstrate how we can gain valuable insights into groundwater in challenging environments and develop conceptual understanding of hydrological systems. These ideas and approaches will have broad applicability in a variety of environments, where hydrogeologists are faced with challenging conditions.

Masaki Hayashi, Ph.D., is a professor in the Department of Geoscience at the University of Calgary. He received his B.Sc. and MSc. in earth sciences from Waseda University and Chiba University, respectively, in Japan and his Ph.D. in earth sciences from the University of Waterloo in Canada. His main research interests are in the connection among groundwater, surface water, and atmospheric moisture in various environments ranging from the prairies to the mountains.

# Geochemical and isotopic constrains on the origin of brackish groundwater in crystalline bedrock at Syväjärvi site

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Brackish (total dissolved solids, TDS 1–10 g/l) to saline (TDS 10–100 g/l) groundwater is common in crystalline basements worldwide and almost everywhere in Fennoscandian Shield these can be found especially in depths of 1 – 2 kilometres or more, but high salinities have been detected also in shallow groundwater (e.g. Nurmi et al. 1988, Frape et al 2003). These layered sequence of groundwater can be related to climatic and shoreline changes from modern time through former Baltic stages to the deglaciation phase about 10 000 years ago and even to preglacial times (e.g. Fritz and Frape 1982, Clark and Fritz 1997).

Clear anomalous electrical conductivity horizons were identified in several boreholes at Syväjärvi mining project site during winter 2016-2017. As these anomalies could not be explained thoroughly with geological variations and the elevated salinity affects the water quality and possible treatment method of the mine, further studies on the origin of the anomalies were suggested. As the Syväjärvi site is located below the highest Litorina shoreline where most of the saline wells have been observed, it was speculated that the abrupt rise in electrical conductivity shows a limit of waters of different ages, the deeper horizon originating from the Litorina stage of the Baltic Sea which has a very slow hydrologic cycle compared to upper horizon. Another hypothesis was the solid compounds leaching from the fractures or the fluid inclusions and possible release of these to groundwater. In order to characterize groundwater at the site, stable isotopes (δ2H and δ18O), dissolved trace element geochemistry and physico-chemical characters of water were used to constrain the origin of anomalous electrical conductivity horizons in selected boreholes.

According to the geochemical studies the Syväjärvi brackish groundwaters are a mixture of at least two end-member water compositions. Based on the TDS values (129-3025 mg/l), none of the waters can be classified as saline (TDS > 10g/l) or brine (TDS>100g/l), at most as brackish (TDS1-10g/l). Most of the deep groundwater samples are Ca-Na-Cl type, whereas the top layer is fresh HCO3-type water and has a meteoric origin. There is a clear indication of salinity originating most likely from Litorina stage of the Baltic Sea, but the isotopic composition of the groundwater at Syväjärvi site is congruent with the local groundwater composition and indicates also surface water infiltration. Thus, it is assumed that the dilution and infiltration of surface water is causing the lower saline element concentrations and the salinity will presumably increase deeper down in bedrock.

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# Geochemical processes and modelling of an unconfined esker aquifer in Karhinkangas, west Finland

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The shallow aquifer in the Karhinkangas esker in western Finland contains naturally high concentrations of dissolved Fe (up to 29.9 mg/L) and Mn (up to 0.29 mg/L) and the concentrations of other dissolved elements are greater than the reference values for the Finnish aquifer. This study investigated the geochemical processes controlling the groundwater geochemistry and mobility of Fe and Mn in groundwater by using the hydrogeochemical PHREEQC program for 157 profile samples from 6 monitoring wells along groundwater flow path. The esker aquifer is about 20 - 25 m thick with low hydraulic gradient and flow velocity. Overall groundwater contains low pH (5.2 - 6.8 with median of 6.3) and is supersaturated with respect to hematite. The geochemistry of groundwater shows spatial variations both in vertical and horizontal. The oxidation zone is found in the upper part of the aquifer with high dissolved $O_2$ and low dissolved Fe, Mn and other dissolved elements. The reduction zone is found in the lower part with high concentrations of dissolved Fe, Mn, other dissolved elements, high $CO_2$ and TOC. Concentrations of nitrate and ammonia in groundwater are very low or absent. Groundwater shows sharp redox boundary, which suggests that redox process may occur at the faster rates compared with the groundwater flow rate. The kinetic oxidation of dissolved iron also showed that the oxidation of ferrous iron can be completed very quickly in the oxidation zone and less than a month in the reduction zone.

The main geochemical processes controlling the groundwater geochemistry and mobility of Fe and Mn in groundwater include the oxidation - reduction reactions, the dissolutions of iron-bearing minerals and the precipitation of iron oxide. The thermodynamic equilibrium phase calculated for the iron-bearing minerals (e.g. K-feldspar, biotite), and organic matter with the atmospheric $CO_2$ and $O_2$ showed better correlation with water samples than without organic matter and the atmospheric equilibrium. For non-calcareous aquifer such as in Karhinkangas, apart from sulfide oxidation, organic matter could possible act as an electron donor and enhance more reduced groundwater to the aquifer.

**Acknowledgements**

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# Submarine groundwater discharge at the Hanko Peninsula, south Finland

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A submarine groundwater discharge (SGD) site was recently documented at the Hanko Peninsula in south Finland, northern Baltic Sea. The local stratigraphy and aquifer geometry were studied using a multifaceted dataset of offshore seismic sub-bottom profiles, multibeam and sidescan sonar images of the seafloor, radon measurements of seawater and groundwater, and onshore ground-penetrating radar and refraction seismic profiles. The aquifer is hosted in the distal sand-dominated part of a subaqueous ice-contact fan that belongs to the First Salpausselkä ice-marginal formation.

The SGD takes place predominantly through pockmarks on the seafloor, which are present on the edge and slope of a sandy shore platform, at the water depths of ca. 11 meters. Elevated Rn-222 activity concentrations in the near-bottom water at the pockmark locations strongly indicate groundwater influence, and permit calculating a rough estimate of 1 cm/d for the discharge rate.

Porewater profiles of elements of marine affinity such as Cl show strong vertical gradients in sediments underlying the pockmarks. The isotopic ratios $\delta^2H$ and $\delta^{18}O$ measured for local groundwater, pockmark porewater and local seawater demonstrate that waters discharged from the pockmarks are mixtures of the groundwater and seawater end-members. The share of fresh groundwater in the pockmark porewaters is ca. 83%, whereas it is ca. 9% in the full water column above the pockmarks.

SGD has been implicated as a significant source of nutrients and harmful substances to coastal sea areas. The volumes of SGD are generally small compared to riverine influx; however, concentrations in SGD typically are much higher. The purpose of this study is to improve the understanding of SGD-associated fluxes of nutrients and harmful substances to the Baltic Sea, which are largely missing in the current ecosystem models.

This work resulted from the BONUS SEAMOUNT project supported by BONUS (Art 185), funded jointly by the EU, the Academy of Finland (Grant No. 311983), and the Federal Ministry of Education and Research, Germany (Grant No. 03F0771B).

**Related publication**

Virtasalo, J.J., Schröder, J.F., Luoma, S., Majaniemi, J., Mursu, J. & Scholten, J.: Submarine groundwater discharge site in the First Salpausselkä ice-marginal formation, south Finland. Solid Earth Discuss., https://doi.org/10.5194/se-2018-131.

# Meso-Neoarchean geodynamics: examples from the Fennoscandian and Indian Shields

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In spite of a tremendous progress in Precambrian studies in the past decade, early Earth's geodynamics remains the subject of animated discussion [4]. The point is that, on the one hand, Archean complexes and the lithospheric segments they make up display some distinctive features: a) the structural characteristics (Archean cratons have a thick lithosphere with mantle keels), b) rock constituents (TTG-granitoids, komatiites, sanukitoids [2], BIF) and c) the absence of some complexes (e.g. no Archean glaucophane schists have been reported), of the oldest oceanic complexes show that the Archean oceanic crust was thicker (25-30 km) than the modern ones (7 km) [6].

On the other hand, the results of Archean paleomagnetic studies clearly indicate that lithospheric plates were moving at that time at near-modern speeds [3]. Furthermore, many Archean structures, e.g. those in the Karelian and Belomorian provinces of the Fennoscandian Shield [1] and the Bundelkhand Craton of the Indian Shield [5] are dominated by nappean, accretionary structures, also widespread are indicator igneous and metamorphic complexes such as volcanics of calc-alkaline, boninite and adakite series, eclogite-facies metamorphic complexes for subduction processes; S-granites, kyanite-facies metamorphic complexes, and tectonic nappes for collisional processes. Archean ophiolites were also revealed on the Fennoscandian Shield [1, 6]. Basaltic-komatiitic complexes, indicative of plume processes, are common in Archean greenstone belts. Archean structures, correlatable with continental rifts, are also known from these shields [1].

Thus, Meso-Neoarchean geological complexes in the Fennoscandian and Indian shields indicate that from 3 Ga onwards subduction, collisional, plume, continental-rift-related and spreading (at least in back-arc basins) geodynamic processes on the Earth have been active. They were very similar to Phanerozoic processes but seem to have occurred under hotter-mantle conditions that were also responsible for a considerable thickness of the oceanic lithosphere [6].

The study was funded by RFBR Project 17-55-45005-a.

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# Time-gated Raman in analysis of REE-bearing rocks

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Mineralogical analysis from REE-bearing minerals with Raman spectroscopy can be a challenge because of a high fluorescent background. The fluorescence can be reduced by photobleaching, in which the sample is irradiated with high laser power before the measurement. This is easily achieved with one sample point, but if and when multiple measurements are needed for thorough mineralogical analysis, the total measurement time increases too much. Excitation wavelength can also be chosen differently to avoid transitions to the fluorescent states, typically to longer wavelengths. However, the Raman signal is inversely proposal to wavelength and thus results to lower acquired intensities. A new promising option for analysis of fluorescent materials is time-gated (TG) Raman, in which the sample is irradiated with sub-nanosecond laser pulse and Raman signal is collected before the formation of strong fluorescence background. In this research[1], TG Raman is applied to the analysis of REE-bearing minerals from the Norra Kärr deposit in southern Sweden. Minerals of interest in the nepheline syenite samples are eudialyte [$Na_4(Ca,Ce)_2(Fe^{2+},Mn,Y)ZrSi_8O_{22}(OH,Cl)_2$] and catapleiite [$Ca/Na_2ZrSi_3O_9 \cdot 2H_2O$]. Mineralogical information obtained with TG Raman mapping is combined with elemental information given by laser-induced breakdown spectroscopy (LIBS) in respect to the location of REEs.

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# Constraining assimilation in magmatic systems

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Because of the high temperatures involved, magmas readily interact chemically and/or physically with their surroundings. Terms such as mixing, hybridization, mingling, and assimilation are commonly applied to these magmatic interactions, but discrepancies and overlaps abound in the way they are used and defined by different researchers. Can melts or magmas be "assimilated" by other melts? How does "assimilation" differ from "mixing" or is there any difference? In this contribution, we concentrate on two issues: 1) defining assimilation in a fresh conceptual sense and 2) reviewing geochemical and thermodynamical models used to computationally replicate it.

We define the cornerstones of magmatic interaction (pure mixing, pure mingling, pure assimilation) by constraining an initial ($t_0$) state and a later ($t_n$) state for a system that at $t_0$ consists of chemically and physically separate active melt (A) and passive melt/homogeneous wallrock (B). The effective variables are the melt fraction (F) of B at $t_0$ and the intensity of segregation of the liquid ($I_l$) at $t_n$. Pure assimilation is defined as a magmatic interaction with an initially completely solid B (at $t_0$, $F_B = 0$) and complete hybridization of melt A with melt derived from B (at $t_n$, $I_l = 0$). Note that this definition also allows partial melting of the wallrock. In nature, pure assimilation forms a hypothetical "solid-solution" with pure mixing (at $t_0$, $F_B = 1 \rightarrow$ at $t_n$, $I_l = 0$) and pure mingling (at $t_0$, $F_B = 1 \rightarrow$ at $t_n$, $I_l = 1$; or in the case of mingling with wallrock melts: at $t_0$, $F_B = 0 \rightarrow$ at $t_n$, $I_l = 1$).

The first geochemical models of assimilation used simple mixing equations (as would also apply to pure mixing of liquids) and suggested an important role for assimilation in igneous systems. Thermodynamic considerations have shown, however, that bulk assimilation of large amounts of solid wallrock is considerably limited by the enthalpy content of the resident magma. Although crystallization is generally the most important factor in the major element evolution of igneous systems, the most recent models that combine thermodynamical and geochemical aspects confirm that simultaneous assimilation of partial melts of chemically distinct wallrock may indeed have a considerable effect on the trace element and isotopic compositions of igneous rock series.

# Formation of sulfide melt droplets in experimentally molten black schist and its relevance to Ni-Cu-PGE mineralizations

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Assimilation of sulfur bearing country rocks by a metal laden mafic-ultramafic magma is an important process in formation of economically important Ni-Cu-PGE mineralizations. The excess sulfur from the wall rock enhances formation of immiscible sulfide melt, which then scavenges the metals from the silicate melt. In the 1.1 Ga Duluth Complex, northern Minnesota, mafic magma assimilated sulfur and carbonaceous material rich Paleoproterozoic black schists (Virginia Formation), creating one of the largest, though currently subeconomic, Ni-Cu-PGE mineralization in the world, with estimated 4000M tons of reserves at 0.2wt.% Ni content. Despite extensive research, the sulfur transport mechanism from the black schist to the magma is still poorly understood. It is unknown whether the sulfur was mobilized as a fluid or as a melt and whether it derived mainly from the intact wall rock or from the numerous xenolithic blocks that the magma pulses have taken up from the country rocks along the major conduits.

We performed a set of pioneering partial melting experiments on a natural black schist sample from the Virginia Formation. The experiment conditions ranged from 1 to 2 kbar pressure and 700 to 1100°C temperature, which are fair estimates of the conditions experienced by the Virginia Formation black schist along the contact with the Duluth Complex. Our results show that sulfide melt droplets form readily within the partially molten black schist between 900 and 1000°C, and show elevated Cu and Ni contents already prior to reacting with the mafic melt. These results indicate 1) that sulfide melt droplets could have been transferred to the magma from the partially molten proximal part of the sulfur rich wall rock as well as from the xenoliths, and 2) that black schists may support mafic-ultramafic magmas not only by sulfur but metals too.

# Mafic-felsic interaction, crystallization conditions, and parental magma composition of the Ahvenisto anorthosite

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Massif-type anorthosites, usually Proterozoic in age, are known from many anorthosite-mangerite-charnokite-granite (AMCG) suites generated in bimodal (mafic-felsic) magmatism. The origin and parental magma composition of massif-type anorthosites has been debated for decades without reaching a widely accepted consensus. In recent years the 1.64 Ga Ahvenisto AMCG complex in southeastern Finland has become the primary Fennoscandian locus of studies on massif-type anorthosite petrology. The suite comprises of a granitic intrusion surrounded by an anorthositic arc with rock types varying from gabbro-anorthositic rocks to minor monzodiorites. Prominent mafic-felsic magma interaction structures between the monzodiorites and granites of the complex are common and have the focus of recent research activities (cf. Fred et al., 2019).

Petrography and bulk geochemistry of show that different monzodiorite types observed in the complex represent discrete stages in the evolution of residual magmas after fractionation of plagioclase (which formed the anorthositic cumulates). These compositionally different residual liquids also exhibit distinct interaction styles (i.e. mingling and hybridization) with coeval granitic magmas suggesting that evolution of the monzodioritic melt played an important role in the generation of diverse interaction structures. This also supports the previously presented hypothesis that unlike the anorthositic cumulates, the monzodiorites represent melt compositions and, thus, their most primitive (high Mg#) compositions can be used for evaluating composition the anorthosite parental magmas.

To this end, new samples of the most mafic anorthositic rocks (leucotroctolites) and different olivine-bearing monzodiorite types have been collected for bulk (XRF & -ICP-MS) and mineral chemical (EMPA) analysis. Compositions of plagioclase, K-feldspar, amphibole, and ortho- and clinopyroxene will be analyzed from 1)the rock types related to the different interaction processes: hybrids, monzodiorites, and hbl-granites, and 2) from the most primitive (high Mg#) members of the anorthositic and monzodioritic rocks in order to trace their parental melt compositions and evolution. Geothermobarometric methods will be employed to evaluate crystallization conditions (P,T) of all pertinent magmas.

The geochemical and thermobarometric data will serve as material for future thermodynamic modeling studies. By using the state-of-the-art modeling tools, the rhyolite-MELTS and Magma Chamber Simulator (MCS), we aim to produce a comprehensive melt evolution model for mafic magmas in the Ahvenisto complex and AMCG suites in general. These models can also in the future be applied to estimate the ore-potential of AMCG suites.

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# Nd, Sr, Pb, and Os isotopes suggest a primitive mantle source for the Luenha picrites in the Karoo large igneous province

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The mantle sources of the Karoo large igneous province (LIP) are a subject of continued scientific interest. Research on them is limited by the rarity of primitive lava or dike compositions not influenced by differentiation processes.

The Luenha picrite lava series from Central Mozambique includes samples that have not been significantly modified by differentiation processes. In addition, they contain high-Mg olivine, which together with the whole-rock geochemistry suggests derivation from picritic to komatiitic primary melts. Chondrite-like ratios of lithophile incompatible elements in the most primitive samples of the Luenha picrites indicate a mantle source similar to primitive mantle. In terms of radiogenic isotope compositions, the most primitive sample shows only slightly superchondritic initial $\varepsilon_{Nd}$ (+1.4) and bulk-silicate-Earth-like (BSE) initial $^{87}Sr/^{86}Sr$ (0.7041). The initial $^{187}Os/^{188}Os$ ratio (0.12585) falls between primitive upper mantle and depleted MORB mantle ranges. The initial Pb isotope ratios, $^{206}Pb/^{204}Pb$ of 17.75, $^{207}Pb/^{204}Pb$ of 15.73, and $^{208}Pb/^{204}Pb$ of 38.0 can be closely replicated by a single-stage 4.55 Ga evolution model of a primordial reservoir, which bears chondritic $^{238}U/^{204}Pb = 8.77$ and nearly chondritic $^{232}Th/^{204}Pb = 36.81$. Each of the studied isotope systems is therefore consistent with a primitive mantle source for the Luenha picrites.

Other picrite types previously identified in the Karoo LIP are not petrogenetically related to the main volume of the Karoo flood basalts and have likely sampled depleted mantle, subcontinental lithospheric mantle, and anomalous recycled sources. The Luenha picrites may provide the first piece of evidence of magmatism related to a mantle plume that sampled ancient mantle sources with primitive, undifferentiated mantle, compositions. This source may also have been important in the generation of the main volume of flood basalts in the Karoo LIP.

# Distribution and characteristics of suspended inorganic particles in Pohjanpitäjänlahti estuary

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Suspensions of eroded minerals and organic matter, as well as particulate and dissolved elements such as Fe and Mn, are transported from land to sea and ultimately deposited in sediments. These materials have a strong impact on biogeochemical processes in coastal sediments, hence it is important to understand the factors controlling their accumulation. For example, redox driven precipitation and re-mobilization of iron (Fe) and manganese (Mn) oxides is an important process in coastal environments. The Fe and Mn are dissolved under anoxic/hypoxic conditions in sediments or near-bottom water. The dissolved Fe and Mn in the porewater may then move upwards in the sediment or further to the water column until they reach oxidizing conditions, and precipitate as oxides. These oxides are used as electron acceptors in organic matter respiration.

As a part of a larger project, in which suspended particles (SP) and estuarine biogeochemistry are studied, the aims of this study are (1) to quantify and characterize suspended inorganic particles (SIP) in the Pohjanpitäjänlahti estuary, (2) to facilitate the use of a LISST-100X suspended particle size analyzer in in situ marine studies, and (3) to understand the redox driven Mn cycling in the estuarine environment. The study site is the inner and outer Pohjanpitäjänlahti estuary in southern Finland (Gulf of Finland). A total of 12 study sites (A-C, C2, D-K) were visited along the estuarine transect during the FINMARI cruise in October 2018 onboard the r/v Geomari of the Geological Survey of Finland. Continuous particle size distribution profiles of the water column at the study sites were obtained by the LISST-100X instrument, which measures in-situ sizes and volume concentrations of particles suspended in the water column by laser diffraction method. End-members of different particle-size populations were obtained by processing the LISST data using the R package EMMAgeo. Continuous salinity and temperature profiles were collected by an EXO2 multiparameter sonde. Water samples from selected depths were collected at each station and filtered with a precombusted 0.7 μm fiberglass filter. From the retentates collected on the filters, particle sizes, particle compositions and element associations were characterized with scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS). The suspended particles were a mixture of mineral grains, diatoms and organic material, all with sizes below 10 μm dominating. Larger particles were typically aggregates of clay minerals and organic matter. Manganese nodules of varying sizes (1 – 10 μm) and with distinctive cauliflower and star-shaped morphologies were also found in sections of the estuary.

# Repeated relative gravity measurements in an underground structure resolve the variation in local subsurface water storage

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Repeated gravity measurements are a well-established method in hydrology to study large changes in terrestrial water storage, e.g. the depletion of hydrothermal fields. In geodesy, the gravity effects of variation in subsurface water storage are often a nuisance: a noise that contaminates the signal of interest, say the trend in gravity due to the post-glacial rebound. Both the signal and the noise may then be relatively small. To get an idea of the magnitudes involved: the standard uncertainty of measurement with a modern free-fall absolute gravimeter is about 2 μGal (i.e., 2 ppb of gravity). This equals the gravity effect of 1 cm of vertical motion in postglacial rebound, or the attraction of a water layer 5 cm thick. Correcting time series of absolute gravity (AG) measurements for local hydrology is still rare as it may require a lot of work: observations of groundwater level and soil moisture at the site, and geological studies to determine the hydrological properties of the soil/rock.

At the AG station in Riga the station geometry allows the determination of water storage variation directly from local relative measurements. The station is situated about 10 m underground, at the bottom of a silo-like concrete structure on the limestone basement. During the first AG measurement in 1995 by the FGI two excentre stations were established on the surface and tied to the AG station by relative measurements. It was realized that repeating the relative ties at every AG measurement would give an opportunity to isolate the gravity effect of the variable water storage in the sediment layers and to correct the AG results for it. At the AG station at bottom the attraction is upwards, at the surface stations downwards, and in the gravity difference it appears approximately double.

The relative measurements were repeated at subsequent AG station occupations by the BKG, by the National Geospatial Intelligence Agency (St. Louis, USA) and again by the FGI. However, it turned out that they were too few for validating the results. Therefore, after the fifth AG measurement performed by the FGI in 2013 a monthly series of relative campaigns was started by the LGIA, using two Scintrex CG-5 gravimeters. The network comprises two underground stations at different depths, two stations at ground level, and one station in the silo structure 5 m above ground level.

Assuming a one-dimensional model (i.e., the variation in soil water content is a function of depth only) we can invert the time series of observed gravity differences for both variation in total water mass and for the mean depth of the layers where the variation is taking place, without any hydrological observations. Correlating gravity with the single hydrological observation at the site, a groundwater time series, we obtain a scaling coefficient to determine the variation in water mass (groundwater+soil moisture) from the water table fluctuation. Then the groundwater time series together with the 1-D model can provide hydrological corrections to AG measurements made long before the establishment of the time-series of relative gravity.

# Paleohydrogeological implications from stable isotope compositions of fracture minerals, Kyläniemi, Finland

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Fracture mineral samples from Kyläniemi, central Finland, were collected for geochemical, isotope geochemical and mineralogic investigations. The aim of the study was to bring forward our understanding of the paleohydrogeological evolution in deep crystalline bedrock. The results of this study are compared to those previously obtained from the repository site for spent nuclear fuel at Olkiluoto. Unlike the Olkiluoto Island, the Kyläniemi region has not been overlain by the Baltic Sea since the last glaciation. Thus, possible effects of marine water intrusions during the Holocene Epoch can be excluded.

The samples were collected targeting fracture systems open to fluid circulation at a depth range of 55 to 430 m. Fracture mineral samples consisted mainly of calcite and some pyrite. Calcite was compositionally nearly pure $CaCO_3$, with minor amount of Mn. Special interest was focused on latest calcite generations. The $\delta^{13}C$ and $\delta^{18}O$ values of fracture calcite ranged from -24.5 to 34.2 ‰ and -19.3 to -4.4 ‰ (VPDB), respectively. The isotopic composition of most calcite fillings represent a low temperature equilibrium with waters similar to the present-day precipitation in the area. Calcite filling at depth of 100 m contained a calcite generation highly enriched in both $^{13}C$ and $^{18}O$. These values indicate microbial methanogenesis in a low temperature environment, and could be associated with a marine water intrusion during one of the earlier interglacial periods. More investigations are still needed in order to fully understand the paleohydrogeological evolution at the Kyläniemi site.

# Geothermal energy research in Finland

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Geothermal energy utilisation provides new, innovative and sustainable energy solutions for markets. Therefore, geothermal energy is modernising the geological research environment and generating new opportunities for researchers to grow as top experts in the field of applied geology.

Geothermal energy utilisation can be divided to two main categories; a) deep geothermal energy which source is the earth's internal energy and systems normally operates in temperature regime of over 100 °C and b) shallow geothermal energy which source is partly earth's internal heat and partly solar energy, which is absorbed by and stored to the upper part of the ground. Shallow geothermal energy system's operational temperature is much lower than in deep geothermal energy systems.

Geothermal energy research was started approximately 40 years ago in Finland. The research was mainly concentrated to the shallow geothermal energy applications. The main scientific institutes were current Tampere University and Åbo Akademi. Geological Survey of Finland (GTK) published high quality geophysical research which was more related to geothermics than energy utilisation research.

Modern geothermal energy research is closely related to develop innovative energy solutions to the market instead of purely scientific studies. However, a few purely academic publications has also been published lately and at least three doctoral research is currently ongoing. GTK has a major role in geothermal R&D projects in Finland. The key developing areas in GTK are a) Closed-loop shallow energy systems in bedrock, b) Underground energy storage, c) Shallow aquifer energy utilisation and d) Deep geothermal energy in crystalline bedrock.

Geothermal energy research requires expertise related to thermogeology, geophysics, environment geology and hydrogeology. Geothermal energy research is cross scientific and hence expertise related to energy transfer, heating and cooling techniques, construction and drilling are also needed.

# Modelling widespread geological resources

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Modern society demands a multitude of geological reserves. So-called widespread geological resources form a significant part of these. These are widely occurring usable materials, whose use is controlled by economical and legislative factors more than the specific sites in which they occur. Examples of widespread geological resources include aggregates, groundwater, and peat. In my doctoral dissertation, I aim to study their availability, extent and amount. While they are widely available, their use is typically limited in other ways. Limiting factors include legislative, societal, environmental, and natural limitations. These limitations range from bodies of water to buffer zones around residential areas.

A knowledge-based approach to using these materials requires that there is a way to estimate them. As the resources are widespread, the study needs to be on a regional scale. Therefore, a geographical information system (GIS) is required. In this presentation, I outline a tool for the estimation of widespread geological resources: the 2.5D model. This tool estimates the extent, depth, and possible sterilization of their occurrences. The total amount of material available is determined by modelling the extent and the depth of the chosen resource, then removing the sterilized areas, and calculating the final amount.

In the first of my studies, I have used the 2.5D model for the estimation of rock aggregates. My study area was the Helsinki metropolitan region in Finland. The parameters used were outcrops for the extent of possible aggregate locations, groundwater level for the maximum extraction depth, and various sterilization layers for the limiting factors. Finally, the results were validated by fieldwork. The study demonstrated that the model is viable. Currently the model is being applied to groundwater energy resources. The modelling process involved with this is more complex, requiring the estimation of several variables, including groundwater level and temperature as well as ground cover depth.

In general, when modelling widespread geological resources it is important to find correct parameters. This is important because the use of each individual widespread resource is limited in different ways. The 2.5D modelling tool is functional, but its accuracy is limited by the input data and parameters. While it is suited for targeting exploration, on-site studies are still required for exploitation at specific locations. The model is best used in regional estimation of widespread geological resources.

# Muon radiography and muon tomography – the two common versions of muography, and their applications in geosciences

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The density distribution of any material can be extracted using cosmic-ray induced high-energy muon particles. Once the attenuation and angular distribution of the subatomic muons passing through any geological matter is measured, a map of average density distributions in the media – be it solid rocks, loose soil layers or whatever – can be illustrated. This is based on the facts that muon flux is fairly constant and muons are more sensitive to density variations than other geophysical methods, including that of gravity. The method is called muography and in principle it is reminiscent of the X-ray imaging (see, for example, Tanaka 2013). However, radiation sources are not needed in muography.

The muographic images can be produced as lower resolution 2D density profiles (muon radiography, which is similar to X-ray and gamma-ray radiography) or highly detailed 3D density images (muon tomography, which is similar to CT scanning in medical imaging). The modes have different instrumentation and applications. The third option is to use radiography or tomography for time-sequential imaging which facilitates, for example, studies of geological processes that affect densities. Currently, muon tomography can resolve features to the sub-meter scale (Bonal et al. 2016).

In terms of the density imaging of underground rock volumes, muon tomography is a suitable solution whenever the object can be studied from a variety of directions, for example via caves, tunnels or boreholes (Holma & Kuusiniemi 2018). However, this is not always possible due to lack of such cavities, or there is simply no need for 3D images. In this case the density variations can be extracted, albeit with lower resolution, by muon radiography technique. This method works even with a single muon detector – in other words, even if there is no access but just one side of the object. An additional resolution and even partial three-dimensionality can be obtained by adding more detectors or just changing their positions and hence the field of view.

Muography is currently commercially available only for few applications. These are, for example, a scanning of cargo containers at national borders and imaging of shielded nuclear waste containers for security controlling purposes (Kaiser 2019). In geosciences, muography has so far been applied most widely in volcanology (Tanaka 2019), but successful field tests and research pilots have also been conducted in the fields of ore exploration and groundwater studies, to name but a few (Holma 2018). It is anticipated (see, for example, Kaiser 2019) that the usage and commercial availability of muography will expand in the future and muographic surveys will be as essential to geophysics as any of the more traditional methods. However, it is not clear when this point is reached. Such a development is driven by technological advancements, increased research efforts, growing research community, increased awareness and acceptance of the method within the geosciences community and, finally, the growth of the private sector that will provide the services in this particular field. In this respect, muography is developing in a similar manner as any new technology.

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# Finland in international earth science olympiad

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Finland had a team in International Earth Science Olympiad for the first time in 2018. The 12. International Earth Science Olympiad (IESO 2018, Earth Science For All) was held on August 8-17, 2018 in Thailand. Altogether 154 high school students from 38 countries competed in individual written and practical tests and in international team tasks. International team competitions were organized in form of practical Field Investigation and Earth System Project based on online materials. The competition was extremely valuable experience for four selected high schools students, two high school teachers and two university lecturers participating the competition as member of the team, mentor or observer. In 2018, team Finland was granted to the competition by K.H.Renlund Foundation and Geological Society of Finland.

Geoscience is not a subject in the basic education plan in high schools in Finland, which is the case in many other countries. National competition and coaching camps to qualify for team Finland to participate in future IESOs are means to raise awareness of higher education possibility in geosciences among high school students. In addition, Bachelor's program in geosciences at the University of Helsinki automatically grants admission to the university studies for the members of Team Finland, which opens direct career path possibility in geosciences for them.

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# Source and extent of the late Neogene aeolian Red Clay deposits of East Asia

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The thick sequences of late Neogene (11–2.5 Ma) aeolian Red Clays underlying the Quaternary loess on the Chinese Loess Plateau (CLP) are important archives of past terrestrial climate and dust changes. The onset of the Red Clays is related to the intensification of the East Asian summer monsoon (EASM) system and the fossiliferous Hipparion Red Clays (Zdansky 1923) record a regional anomaly of high precipitation in a global trend of increasing aridity (e.g. An et al. 2001, Fortelius et al. 2002). The late Neogene is one of the most recent periods of significantly warmer climate and has been considered as an analogue of future warmer climates.

Despite its importance, detailed knowledge of the origin of the Red Clay deposits is lacking. This project aims to identify the late Neogene dust source areas and transporting winds, and their variation. One of the main objectives is to develop single-grain geochemistry as a provenance tool for the fine-grained aeolian dust. While zircon U-Pb dating has been shown to be an effective tracer of dust from multiple sources of different ages (e.g. Stevens et al. 2013), despite a number of promising studies (e.g. Nie et al. 2014, Shang et al. 2016) this technique in Red Clays is hampered by the small number and size of suitable zircon grains. Therefore, independent single-grain proxies on Red Clay provenance are needed in addition to zircon U-Pb. In this study, the geochemistry of quartz, rutile, tourmaline and garnet are considered.

Another essential part of this study is to apply the novel single-grain proxies to modern mineral dust collected during dust storms in the CLP area. The data will then be combined with dust-trajectory models that simulate present-day dust emission, transport and deposition, and with available satellite imagery. This combination allows us to perform a systematic evaluation of both established and novel provenance proxies while the specific source results can be used to help qualify estimates of late Neogene dust sources and inferred climatic conditions.

Finally, the extent of the Red Clays in East Asia is examined. Observations have been made of potential new Red Clay sites in Ulanhua (Inner Mongolia) and Nihewan (Hebei province), which would be the northeasternmost known occurrences of Red Clays, extending the known area the EASM influenced during Neogene significantly. The new sites will be studied using conventional sedimentological methods and magnetostratigraphy.

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# Petrographic and geochemical characterization of fenites in the northern part of the Siilinjärvi carbonatite-glimmerite complex, Central Finland

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The Siilinjärvi carbonatite-glimmerite complex is located northeast of the town of Siilinjärvi. The 2.6 Ga complex is a 16 km long and 1.5 km wide N-S oriented lenticular body which has intruded the 2.8 Ga basement gneiss of the Karelian Archean Province (O'brien et al., 2015). The carbonatite-glimmerite intrusive body is surrounded by a fenite halo. It was formed by alkali metasomatism of the granite gneiss country rocks. Here the focus is on the fenites in the northern part of the Siilinjärvi complex.

Fenites appear around carbonatites and magmatic alkali intrusives such as nepheline syenites and ijolites. In Siilinjärvi, the alkali metasomatic fluids, which caused the fenitization of the basement granite gneiss, are derived from the carbonatite. Although carbonatites usually occur with alkali silicate rocks (Le Bas, 2008) none are found in the Siilinjärvi carbonatite-glimmerite complex, which leads to the conclusion of carbonatites being the source for the fenitizing fluids.

The northern area of the complex is characterized by a forking of the fenite aureol into an eastern and a western branch. In this study samples from both branches and the point of the branching has been studied under a petrographic microscope and analyzed with a micro-XRF (μXRF). The main minerals observed in the fenites are microcline, orthoclase, aegirine-augite and perthite. Accesory minerals found are quartz, apatite, calcite, titanite and opaques. The altered feldspars and unique textures observed in the field have been analyzed with the μXRF to understand which elements have been mobile during the fenitization. The feldspars are without exception K-feldspars with some displaying only a slight degree of perthitization. This is a clear indication of potassium being the dominant alkali in the fenitization process of the basement granite gneiss. The absence of Na-rich pyroxenes and amphiboles, with one outlier, supports the notion of potassic fenitization. That is not to say that Na has not been present at all. Rims of pyroxene grains have been altered to a blue to teal pleochroic Na-amphibole, presumably richterite. According to O'Brien et al. (2015) richterite is abundant in the entire complex. In addition the rims of some observed feldspars also show a depletion of K and an enrichment in Na.

With the help of an element map generated by the μXRF, it is evident that the most mobile elements in the fenites have been Sr and Ba along with the main alkalis. Cores of K-feldspars in three specific samples are enriched in Sr and Ba where as none of these elements were observed in the rims. Ti also displayed similar patterns even though it is usually assumed to be immobile during fenitization. This could indicate two fenitization pulses where the latter pulse has redistributed these elements from the rims of the K-feldspars as a consequence of pervasive fenitization.

The presence of both blue amphibole along the rims of pyroxenes and K-feldspar rims enriched in Na along with slight perthitization supports the assumption of two strong and distinct fenitizing pulses in the northern part of the Siilinjärvi complex.

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# The Vaasa migmatitic complex

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The Vaasa migmatitic complex (VMC), which is a part of the Paleoproterozoic Svecofennian accretionary orogen, has been studied by geological and geophysical methods. Lithological, structural, geochronological (U/Pb) and geophysical (MT and seismic reflection sections, aeromagnetic and gravity maps) data are used to interpret the structure and formation of this large migmatitic complex. The VMC consists of supracrustal rocks that have been deformed, metamorphosed and partially melted, and the complex is flanked by 10-30 km long shear zones in the east and south. The seismic and MT sections show crustal-scale structures that image an ancient accretion prism.

The data suggest that the first metamorphic foliation was developed before anatexis at 1.90-1.85 Ga. The observed inverse metamorphic gradient, i.e. partially molten rocks on top of gneiss and schists, is interpreted as a ductile flow of partially molten supracrustal rocks within the accretion prism. The exhumation of migmatites was disrupted by lateral shortening (todays N-S direction) and was materialized at regional scale by a huge orocline at 1.88 Ga->, highlighted by conductive material. In the center of the complex, in the most melted part, domes of diatexites and granitoids are finally exhumed along vertical shear zones by mechanical instability at 1.87-1.86 Ga

# Southern Europe climate oscillations at marine isotope stage 5a

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The orbital parameters during marine isotope stage (MIS) 5a, 85.8-76.0 thousand years ago (ka, before AD 1950), after an abrupt global temperature rise from MIS 5b, 95.0-85.8 ka, are similar with those during Holocene. However, it is still a controversial analogue for comparison of the climate fluctuations in MIS 5a and Holocene. Lack of paleoclimate records with good age-control and high resolution in MIS 5a hampers our understanding of regional climatic change and corresponding global links on centennial-to-millennial scales. Here, we present a $^{230}$Th-dated stalagmite $\delta^{18}$O-inferred precipitation time series during 83.7-80.2 ka from Observatoire Cave (43°44'N, 7°25'E), Monaco, southern Europe. The record shows a millennial-scale decreasing trend in precipitation from 83.7 to 82.5 ka punctured by an abrupt 200-year wet event at 82.7 ka and a rapid shift from aridity to wetness during 82.5-82.4 ka, followed by relatively stable conditions until 80.2 ka in southern Europe. A strong connection between land and marine in the Mediterranean was improved by the general agreement between our stalagmite $\delta^{18}$O and G. ruber abundances in the core from the central Mediterranean. Our record provides detailed climate oscillations in southern Europe at the late stage of the sea water stratification event, sapropel 3 lasting from 85.8 to 80.8 ka, in the eastern Mediterranean. The decreasing precipitation trend from 83.7 ka is consist with declined vanadium and barium in the western Mediterranean, indicates a lower export productivities and less reducing condition during sapropel 3. Compared with near-surface water variability inferred from the foraminiferal $\delta^{18}$O and $\delta^{13}$C, we concluded regional arid period caused an interruption in sea water stratification at the onset of 83.7 ka. The high similarity of climate oscillations with multidecadal-to-multicentennial cycles inferred from stalagmite $\delta^{18}$O records in southern Europe at MIS 5a and Holocene implies similar physical process and forces control the climate change at these two time windows, which suggest climate fluctuations in MIS 5a is a good analogue for comparison in Holocene.

# Metal concentrations of sediments in Vanhankaupunginlahti dam basin, river Vantaa

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The city of Helsinki has been considering the demolition of the Vanhankaupunginkoski dam so that the rapid in river Vantaa could be restored for a refreshment area. Demolition of the dam would also have positive affect in nature by advancing the natural habitat and enlarging the breeding area of the fishes that flourish in rapids. The demolition of the dam would however loosen the river sediments that have accumulated behind the dam. Because of the heavy agriculture, industrialism and human influence on the entire river Vantaa drainage basin the sediments may contain elevated concentrations of metals, which causes risks for sensible coastal ecosystems in Vanhankaupunginlahti. This study examines the quantity and quality of sediment in the dam.

The quantity of the sediment was examined by GPR-profiles and drillings. Sediment samples were collected from fourteen locations behind the dam upstream of the river. No sedimentation was found in the proximity of the dam whereas sediment thickness upstream varied between 70 and 195 cm. In two sediment cores taken farthest from the dam, we were able to see a transition from littoral sediments to river sediments which reflects sedimentation history that is effected by shoreline displacement caused by glacial isostatic uplift.

Metal concentrations were partial soluble ($HNO^3$) and analyzed with inductively coupled mass spectrometer and with a portable X-ray fluorescence analyzer. The ICP-MS analysis was conducted to 113 samples that were taken from every sediment layer of all of the seven sediment cores for the contents of As, Cd, Co, Cr, Cu, Ni, Pb, V, and Zn. The pXRF-analysis was also conducted to all seven sediment cores but the measurement was conducted within every centimeter instead of every sediment layer. In total, there were 673 pXRF-measurements.

The measured metal concentration in the sediment were compared to the allowed concentrations that are regulated by the Finnish Government (PIMA act 214/2007). The act is divided into values that exceed the threshold value, the lower guideline value and the upper guideline value by every metals.

Typically the metal concentration are low, however some elevated concentrations were found. None of the samples exceeded the upper guideline. The lower guideline was exceeded with chromium in 6, with lead in 8 and with zinc in 20 samples. The threshold value was exceeded with arsenic in 93 samples, cadmium in 14, cobalt in 4, chromium in 33, copper in 4, lead in 38, nickel in 7 and zinc in 18 of the total of 113 samples. Also from the tested metals there was not any sample that exceeded the threshold value within antimony or vanadium. Slightly elevated arsenic values reflects regional geology in the catchment area. The pXRF measurements follow the same trend than the ICP-MS measurements.

# Characterization of lithocap related epithermal to porphyry transitional deposit at Ronaldo prospect, Huancavelica department, Peru

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The Ronaldo prospect is located in the Huancavelica department in central Peru, at an elevation of 4500 meters above sea level. It comprises an extensive area of argillic alteration dominated by smectite, with some lithocap root remnants displaying pyrophyllite and dumortierite; everything is crosscut by late epithermal silica veins which locally host bonanza (up to 4100 ppm Ag and 17 ppm Au) mineralization. A structurally-controlled creek transects the tenement, revealing deeper parts of the hydrothermal system. The two topographically elevated hills surrounding the creek show colour anomalies caused by focused advanced argillic and widespread argillic hydrothermal alteration. The principal objective of the mapping and surface sampling project was to provide evidence that the overlying hydrothermally altered rocks and related epithermal mineralization hosting silica veins are related to concealed, porphyry mineralization.

Results from the Ronaldo prospect reveal that the epithermal mineralization in the prospect is low-sulphidation by nature. Evidence includes textures such as cavity filling veins, banded chalcedony veins, druse-lined cavities, lattice-textured bladed calcite replaced by quartz and abundant Ag mineralization compared to Au mineralization. Locally sphalerite, galena, chalcopyrite and pyrite bearing polymetallic veins occur in the creek. These veins are either fault controlled subepithermal Zn-Pb-Cu-Ag±Au veins or intermediate-sulfidation epithermal Zn-Pb-Au+-Cu±Au veins, both types which occur distal to porphyry stocks.

An occurrence of a banded molybdenite-quartz (BMQ) vein is clear evidence of proximal porphyry Cu (Mo-Au) style mineralization, but the sparsity of BMQ vein occurrence is not encouraging for significant porphyry Cu (Au-Mo) mineralization. Some magmatic-hydrothermal breccias in the creek host large remnant magnetite aggregates and abundant sericite, which are interpreted as evidence of sericitic overprinting of potassic alteration. Other encouraging findings are the presence of hydrothermal biotite in igneous breccia clasts and the nature of the sericitic alteration as the latter is only confined to narrow zones, representing deep, structurally controlled root structures of the previously extensive lithocap. Trace element concentrations (e.g. elevated Te, Bi, As and Sb) suggest that Ronaldo is, in a hydrothermal porphyry Cu system, spatially situated in transition from the deep sericitic to shallow sericitic zone.

We propose that the Ronaldo prospect has been formed through a sequence of events: 1) Porphyry stock related lithocap and magmatic-hydrothermal breccia emplacement, 2) waning of hydrothermal system causing sericitic alteration to overprint the root structures of the lithocap and underlying potassic alteration in addition to telescoping of the system 3) erosion causing the silicified and sericitized ridges to be exposed at surface and the exposure of the top of hydrothermal-igneous breccias along the creek 4) late low-sulfidation epithermal mineralization controlled by a major E-W structure forming banded silica veins due to laterally flowing meteoric water.

Taking all the afore mentioned factors into account, it seems that the Ronaldo prospect does not exemplify convincing evidence of significant porphyry Cu (Mo-Au) mineralization at economically reasonable depth. The prospect does show potential for a low- or intermediate-sulphidation epithermal mineralization project: further studies, especially on the continuity of the silicified ridges, are required to advance understanding of the mineralization at the Ronaldo prospect.

# Geology of natural stone deposits in Finland

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The main types of natural stone produced in Finland are granite, schist, and soapstone with focus on granite and soapstone. The main granite production centre is the rapakivi granite area in southeastern Finland while soapstone is produced mainly in the municipality of Juuka in eastern Finland.

Granite is extracted from approx. thirty sites as rough blocks for export and domestic markets. The granites are typically red, brown, grey, green, or black. Geologically, the most important group is rapakivi granites, which cover approx. 60 % of all granite production in Finland. The rapakivi granites are quarried from the Wiborg batholith in southeastern Finland with stone qualities like "Baltic Brown", "Carmen Red", "Eagle Red", and "Karelia Red". The age of these rocks is ca 1640 Ma. "Balmoral Red" is a rapakivi granite quarried from the Vehmaa batholith in southwestern Finland with an age of ca 1570 ma. The undeformed rapakivi granites form composite intrusives, consisting of smaller intrusions with a variety of different granite types, post-dating regional ductile deformations. The anorogenic rapakivi granites are homogeneous and sparsely fractured and have the highest potential for granitic natural stone in Finland. Other granite qualities often include coarse-grained porphyritic stones, which are mostly quarried from the Central Finland Granitoid Complex, which comprises synkinematic and weakly foliated or undeformed post-kinematic intrusions. The ages of the quarried granites vary from 1875 to 1890 Ma.

Migmatitic rocks, which are commercially classified as granites, are mainly extracted from the South Finland Migmatite Zone, characterized by granite sheets with intense and penetrative subhorizontal regional deformation, and high-grade metamorphism. These quarried migmatites have the ages of 1830–1870 Ma.

Most schist quarries are located along the ca 1900 Ma Tampere Schist Belt in the south-central Finland (e.g. "Orivesi Schist") and in eastern Finland in the early-Proterozoic Jatulian orthoquartzites ("Nilsiä Quartzite").

Soapstones are low to medium-grade metamorphic rocks, formed through complex metamorphic and carbonatization processes. Soapstones are quarried mainly in two geological environments in eastern Finland: Archean greenstone belts and Proterozoic ophiolite complexes. The soapstones occur typically as folded, elongated, and lenticular bodies inside the greenstone belts and ophiolite complexes, closely connected to serpentinites. The principal location of quarries is situated in North Karelia in Nunnanlahti, Juuka. The main stone qualities are "Tulikivi Classic" and "Mammutti Soapstone".

# Auroral substorms for last 20 years

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The Earth is in a constant interaction with the solar wind. The influence of the varying solar wind and interplanetary magnetic field (IMF) extends from the near-Earth space down to the surface. Disturbances, observed as geomagnetic storms and substorms, arise from the solar wind energy input and dissipation in the magnetosphere and ionosphere. In order to be able to prepare for space weather effects, we need to understand their variation in different time scales, as well as the dependence on the conditions in the Sun and near-Earth space. We present results on the substorm occurrence rate, strength, duration and energetics for over last 20 years since 1993 to 2015. Substorms and their properties are found to largely vary within the year as well as from year to year. The largest number and the most intense substorms are found in 2003-2005 and 1994 while the longest substorms occur in summer season. The substorms during solar cycle 23 (1998-2009) are longer, on average, and dissipate almost 50 % more energy than substorms of cycle 24 (2010-2015). We present results based on data from geomagnetic activity indices such as IL index and individual observatories such as Sodankylä.

# Building Digital 3D Learning Environments To Support the Teaching in Geosciences

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Geological features are three-dimensional. However, by necessity these features are typically displayed on a two-dimensional surface that can result in loss of information or be unintuitive to comprehend. Furthermore, the ever-growing industry demand for 3D modelling and interpretation skills on the field of geosciences emphasizes the need to increase 3D modelling education. Thus, incorporating 3D learning environments, materials and exercises into geological education serves to make learning more effective by allowing the intuitive study of complex, three-dimensional supra- and subsurface structures while simultaneously teaching essential skills required by modern geoscientific industry and academia alike.

In the University of Helsinki, both Bachelor's Programme in Geosciences and Master's Programme in Geology and Geophysics are participants in the "Digiloikka" ("Digital Leap") project that provides resources to study programs to digitalize teaching. Along with other learning materials such as educational videos and ultra-high resolution imagery, the project uses data collected within the project in combination with open geospatial data to produce 1) 3D and virtual reality (VR) learning materials that can intuitively tie together complex structures from photogrammetry-based outcrop models and subsurface structures that have been observed using geophysical methods 2) an application framework and workflow that will allow a single teacher or a researcher to produce 3D model and VR environments from their own imagery, and 3) a physical learning environment that allows the full utilization of 3D materials and VR-environments in different classrooms.

Different 3D and VR models and environments can then be used to augment teaching in a multitude of ways ranging from displaying quaternary phase diagrams to expanding field observations to subsurface structures. Furthermore, working in with 3D models and in VR environments gets students invested in working with 3D software and familiarizes them with the associated workflow. The procedure allows each teacher to create their own learning materials and exercises in 3D and use them in various learning spaces. This will create a foundation that is easy to expand upon and cuts down the resource requirements needed to create and develop further 3D materials.

The outcomes of the project are not aimed only at university students: the material will be made available for a broader audience through the geologia.fi internet portal and can be utilized for marketing geoscience studies for possible applicants. Collaborating with the project, the Helsinki based company Teatime Research Ltd specializes in designing virtual and augmented reality applications and services with plans to advance integrating geoscientific outreach and virtual reality. The project welcomes input and cooperation from everyone interested in developing geological teaching materials and environments and furthering popularization and general knowledge on geosciences

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

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

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

An extensive Finnish research terminology database will help those researchers, translators, journalists and others who write about research and its results in the arts and sciences and in Finnish. With periodical status and ISSN number, work in the HTB can be included in a list of publications and research data systems.

Currently, the HTB includes 45 subject fields. Geology field in the HTB started in August 2018 with the grant from the Kordelin Foundation as a part of Major cultural projects. Existing geology-related terms and their definitions have been checked and updated if necessary, and this is still on-going process. The Geological Society of Finland admitted permission to use the geological glossary in "Suomen kallioperä – 3000 vuosimiljoonaa" book and therefore geological terminology in the HTB is currently concentrated on terminology related to petrology and Finnish bedrock.

Geological term work in the HTB has many potential uses. Updating and creating established terms in Finnish serves for example scientist, teachers from university levels to elementary schools, and journalists. In addition, by gathering the scientific terminology in one place, the database also improves the possibilities for multidisciplinary discussion and research. We are looking for researchers from wide array of geology and geosciences who would like to contribute to term work. Come to see our poster and test the HTB on site!

# Seismic properties of rocks in Kylylahti Cu-Au-Zn mine

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As a part of the COGITO-MIN (COst-effective Geophysical Imaging Techniques for supporting Ongoing MINeral exploration in Europe) project, new petrophysical laboratory measurements were made to provide a solid base for accurate interpretation of geophysical data, in particular new seismic exploration data collected in 2016, from the Kylylahti mine site in the Outokumpu district, eastern Finland. The petrophysical sample set consisted of 209 samples from the Kylylahti mine and 30 ore samples from several mining sites in the Outokumpu district. Kylylahti samples covered the most common rock types found in the district: rocks of ophiolite-derived ultramafic massifs, the so called Outokumpu assemblage rocks, and also black schists and mica schists surrounding the massifs. The ultramafic massifs in the area contain several polymetallic (Cu-Co-Zn-Ni-Ag-Au) semimassive-to-massive and disseminated sulphide mineralizations.

The petrophysical parameters measured were density, seismic P-wave velocity, porosity, magnetic susceptibility, intensity of remanent magnetization, inductive resistivity, galvanic resistivity and chargeability. Additional parameters calculated from the measurements were seismic impedance, Königsberger (Q) ratio and induced polarization (IP) estimates. The emphasis of the COGITO-MIN project was on seismic exploration methods, thus the petrophysical properties needed for interpretation of seismic data, density and P-wave velocity, were on the focus of petrophysical data analyses.

According to their density, the Kylylahti rocks can be divided in three categories: 1) Massive and semi-massive sulphide mineralizations with an average density of 3750 kg/m$^3$, 2) Outokumpu assemblage rocks with densities close to 3000 kg/m$^3$ and 3) Kalevian rocks, mica schist and black schist, with densities a bit under 2800 kg/m$^3$. Sulphide disseminations are common in both Outokumpu assemblage carbonate-skarn-quartz rocks and black schists, elevating the densities when abundant. The average P-wave velocities for almost all Outokumpu assemblage rock types, including the sulphide mineralizations, are a bit over 6 km/s. Soap stones, mica schists and black schists have lower P-wave velocities, around 5.5 km/s.

Comparison of physical properties of ore samples from different mine sites in the Outokumpu district reveals the differences in their mineralogy. Throughout the Outokumpu district, the physical properties of ore samples change with changing proportions of pyrite, pyrrhotite and magnetite. This change follows the metamorphic zoning in the Outokumpu district, also evidenced by the physical properties of Outokumpu district serpentinites. Metamorphic grade in the Outokumpu district varies from low amphibolite facies in the east to upper amphibolite facies in the west.

Based on the results, the sulphide mineralizations in Kylylahti should produce a detectable reflection against any background due to their high density. Also the other Outokumpu assemblage rocks have a clear contrast against the mica schists and black schists. Furthermore, soap stones in contact with other Outokumpu assemblage rocks form a reflecting contact.

# Geological and hydrogeological characteristics of a complex ice-marginal formation in Hanko, south Finland

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Geological and hydrogeological characteristics of the bedrock topography and the Quaternary deposit of the First Salpausselkä ice-marginal (SSI) formation in Hanko groundwater area were intensively investigated based on all available geological, geophysical and hydrogeological data. The depositional sequences of the SSI formation in the study area consist of glacial till, primary deposit of the ice-marginal sediments, fine-grained deposits of the glaciolacustrine, and the littoral coarse-grained deposits. The Precambrian crystalline bedrock surface formed a sharp contact with the Quaternary deposits and varies between +31.0 and -49.0 m a.s.l. Three deep NE-SW trenches of the bedrock surface associated with three main parallel ridges of the ice-marginal formations indicated that the SSI formation could probably formed in at least three sub-phases. These deep trenches could act as a ground-line of the ice-marginal controlling the deposition of the sediments. The high elevation of the bedrock surface areas were often found associated with the coarse-grained sediments deposit in the proximal area close to the ice-marginal ground-line. The deep trenches or kettle-holes were often filled with the fine-grained sediments. A narrow tunnel filled coarse-grained materials was observed in the NNW-SSE direction. However, there is unclear whether these coarse-grained units are connected as a long tunnel filled from north to south or only restricted in a short distance in front of the local ice-marginal ridges. LiDAR-DEM reveals landforms of the SSI formation and remnants of the littoral processes from wave action along the ancient shoreline during the submerged terrain was uplifted to the shore level due to the isostatic land uplift and changes of water levels in the Baltic basin. The maximum ancient shoreline in the Hanko area lying between 12-14 m a.s.l. at the present depth. The littoral sediments are, therefore, expected to be found in the areas between the maximum ancient shorelines and the coastlines. Based on the geological and hydrogeological data, Hanko groundwater area is divided into two main aquifers. The east aquifer is unconfined with the groundwater levels vary between zero and 12 m a.s.l. The west aquifer consists of two main groundwater levels: the perched- and the main (lower) groundwater levels. The perched groundwater is accumulated above the fine-grained unit in the northern part of the west aquifer and has groundwater levels very between 1.51 and 11.58 m a.s.l., which is similar water levels to the east aquifer. The main groundwater level in the west aquifer is semi-confined with partly bounded by the fine-grained unit. The groundwater levels vary between less than zero and 6.70 m a.s.l., approximately 1.24-7.64 m lower than the perched water level.

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# Modified-DRASTIC method for groundwater vulnerabilty assessment of the Finnish shallow aquifers

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The shallow permeable aquifers in Finland consist of sand and gravel from the Quaternary deposit and are vulnerable to contamination from sources that are located on the ground surface and climate change. The intrinsic vulnerability of an aquifer is the relative degree of natural protection of an aquifer based on the hydrogeological characteristics of the aquifer. For the sustainable management and quality protection of groundwater resources, an assessment of intrinsic vulnerability should be performed for any aquifer area in order to use this information as an indicator of aquifer vulnerability and the need for detailed investigations. DRASTIC method is well-known for the intrinsic vulnerability assessment of an aquifer in clastic sedimentary environments. However, the rating classification of DRASTIC does not sufficiently represented the hydrogeologic parameters of the shallow aquifer in Finland. A vulnerability assessment method that can be applied for the whole depositional environments of shallow groundwater areas and a method that can provide the same standard for all shallow aquifers in Finland is still needed.

This study presents the modification of the DRASTIC method for the vulnerability assessment of the shallow aquifer for the Finnish conditions. DRASTIC method assesses the vulnerability of the groundwater area based on seven hydrogeological parameters that control the groundwater pollution potential: Depth to the groundwater table (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone media (I), and hydraulic Conductivity (C). The modified-DRASTIC method has been developed based on the classification of the superficial deposit to better suit the hydrogeological conditions in Finland. The vulnerability index map using the modified-DRASTIC in the Hanko case study area showed better identification of the vulnerable areas compared with the original method, which seemed to be overestimated. The modified-DRASTIC method can still be improved following the new data from different study areas. Although this method does not take into account for chemical nor dynamic properties of the contaminant, it provides a simple and the most representative of parameters for the Finnish conditions. The vulnerability index map provides sufficiently information that can be used to prioritize the most vulnerable groundwater areas to contamination and the areas that are needed for detailed investigation. Furthermore, it provides useful information for land use planning, risk management, groundwater management and protection plans for the groundwater area.

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# Revisiting mafic dykes of Bornholm – implications for Baltica in supercontinent Nuna at 1.3 Ga

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Earth's history has likely been dominated by cycles of supercontinent assembly and breakup. These cycles have had major consequences on Earth's geologic, climatic and biologic record; such as diversification of life, unique climatic conditions including numerous glaciations, global changes in ocean chemistry, and long-lived mantle convection patterns giving rise to plumes, large igneous provinces (LIPs) and episodic and unevenly distributed Earth resources.

Recently the paleogeographical reconstruction of Mesoproterozoic Nuna (1.8 – 1.3 Ga) supercontinent has been taking the shape. There is a strong line of geological and paleomagnetic evidence that the juxtaposition of Baltica and Laurentia at 1.76 – 1.26 Ga forms the core of Nuna. It has been proposed that this unity may have lasted until 1.12 Ga. To shed light on this, we carried out paleomagnetic study on the well dated (1326±10 (2$\sigma$) Ma, Holm et al., 2005) Kelseå mafic dyke and on a set of undated and not previously sampled narrow mafic dykes of Bornholm island, Denmark. Based on earlier paleomagnetic data (Abrahamsen and Lewandowski, 1995) the narrow dykes were thought to be of 1220 Ma in age. This new data fills the gap in the paleomagnetic record of Baltica and provides a possibility for testing the existence of the supercontinent Nuna.

Stable reversed polarity paleomagnetic results were obtained for 1.32 Ga Kelseå dyke. These results contradict earlier results of Abrahamsen and Lewandowski (1995), which we now interpret to represent Paleozoic remagnetization commonly obtained as secondary component in several paleomagnetically studied Fennoscandian intrusions (e.g. Salminen et al., 2017). Reversed polarity magnetization was obtained for three and normal polarity magnetization for eight of the narrow dykes, which provide a positive reversal test. Results of the narrow dykes agree with earlier results of different narrow dykes of Abrahamsen and Lewandowski (1995). We obtained a full positive baked contact test for the normal polarity narrow dyke of the Klippeløkken quarry, which for the first time indicates that the obtained magnetization is original. Additional partial positive baked contact test was obtained for reversed polarity Kelseå dyke. The paleomagnetic poles for Kelseå and combined narrow dykes are within error bar of each other, indicating coeval magnetization age (ca. 1.32 Ga).

Paleomagnetic poles of this study are positioned between Mashak pole (1.38 Ga) and mean pole of post-Jotnian intrusions (1.26 Ga) and close to Lake Ladoga pole (1.46 Ga), indicating stable position of Baltica near equator at 1.46 – 1.26 Ga. When rotated according to NENA configuration the Bornholm poles are in between 1.39 Ga Pilcher and 1.31 Ga Nain poles of Laurentia, supporting the juxtaposition of Laurentia and Baltica.

Based on coeval 1.38 – 1.32 Ga LIPs obtained at Baltica, Laurentia, Congo, Siberia, North China, and Australia, we propose that these continents were at close proximity at the supercontinent Nuna and may indicate initiation of its break-up.

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# Petrography and mineral chemistry of the Kuohenmaa orbicular rock from Kangasala

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Orbicular rocks are igneous rocks that consist of conspicuous, often multi-shelled orbicules embedded in an even-grained or partly pegmatitic matrix. Their petrogenesis is controversial and several theories have been suggested to explain how the orbicules were formed. The two prominent theories suggest their origin to relate either to generation of local diffusion-controlled enrichment fronts onto the orbicules crystallizing from magma or cyclic changes in crystallization pressure or temperature.

The orbicular quartz monzonite from Kuohenmaa, Kangasala, nearby Tampere is one of the most beautiful and well-known orbicular rocks in the world. Small group of Kuohenmaa orbicular rock boulders were discovered already in 1915 and there have been several attempts to locate its outcrops, but without success. The orbicules of Kuohenmaa orbicular rock are multi-shelled and consist of a core and several alternating radial plagioclase-rich shells and tangential biotite-rich shells. Two distinct varieties of Kuohenmaa orbicular rock are known, one with small and one with large orbicules.

The goal of this project is to make detailed petrographic observations about the mineralogy of the Kuohenmaa orbicules and to analyze the major element compositions of the main orbicule-forming phases, plagioclase and biotite, in order to trace possible compositional gradients. Preliminary petrographic observations have also indicated potential for the study of melt inclusions and refractory phases such as monazite as evolutionary tracers of orbicule formation processes. The ultimate goal is to generate a dataset which allows for testing the applicability and validity of existing orbicule-forming theories relative to these petrographic and mineral chemical observations.

So far, the shell structures of 21 small and two large orbicules were studied. All of the small orbicules have a very similar structure and amount of shells, 54 shells on average. Plagioclase-rich shells are 0.1 to 1 cm thick and biotite-rich shells are up to 0.2 cm thick and often discontinuous. Center regions of the large orbicules correspond structurally very closely to the small orbicules but in total have about five times more shells than the small ones. The interpretation is that over 200 alternating shells have grown on the small orbicules in order to produce the larger orbicules.

A very important petrographic observation regarding the small-orbicule variety is that the internal shell structures of individual orbicules are identical. On a sawn surface the orbicules seem different but a closer examination reveals this merely to be a 3D-effect of random sectioning. This observation of uniformity suggests that the diffusion-controlled local origin model cannot explain the genesis of the Kuohenmaa orbicules and a further petrogenetic evaluation is warranted.

# Sea level changes in the Kattegat region from 18 thousand to 4 thousand years ago

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In my master's thesis I am doing a bathymetric model of Kattegat region from 18 thousand to 4 thousand years ago. To gain a better understanding of the sea level changes in the region during the timeframe I have gathered a dataset of 35 raised beaches and isolated lakes in the area. The dataset contains the altitude, location and date of these locations and will be used for a GIS based bathymetric model for the Kattegat region.

During the late Weichselian 18.5-18 thousand years ago rising sea levels melted the flow of the ice from Norway to Denmark and later approximately 17 thousand years ago the glacier in Denmark was fully isolated from the rest of the glacier. What followed was a rapid retreat of the glaciers from the Kattegat region. By 14 thousand years ago glaciers had retreated approximately to the modern day Swedish coast of Kattegat and by 12 thousand years ago during older Dryas deglaciation had reached central Sweden.

The weight of Weichselian ice sheets led to isostatic depression of the areas it covered by up to hundreds of meters. In Kattegat the rebound rates have been fastest in the northeastern areas in Swedish coast and are lowest in southwestern areas in Danish coast.

The Holocene warm period also led to an increase in sea level as continental ice sheets melted. The coastal areas where the postglacial isostatic rebound was slower than sea level rise were left under water and the areas where it was faster emerged from the sea. For example a coastal lagoon in central Kattegat formed around 11000 years ago and is now over 30 meters below sea level. Simultaneously in northeastern Kattegat, beaches were formed that are now 47 meters above sea level and further to the north, around the neighboring Skagerrak, lakes were isolated that are now more than 130 meters above sea level.

During the Holocene the rate of eustatic sea level change has varied. Before 7,500 years ago eustatic sea level increased at rates in excess of a centimeter per year leading to transgression in many parts of the Kattegat region, for example in southern Kattegat sea level rose 25 meters in 1400 years. Later the increase slowed down and in combination with isostatic rebound this led to regression in the area revealing for example the islands in the area such as Anholt 7700 years ago, Samsø 5000 years ago and Laeso 4900 years ago. Since from approximately 4000 years ago the eustatic sea level change has only changed slightly; around that time the global sea level almost reached the current level and has remained within few meters of current level since.

Additionally the rate of isostatic uplift in the area has also changed. It was fastest around the time the glaciers melted from the area and since then the rate of uplift has declined significantly. Today rate of uplift is slow even in northeastern part of Kattegat, where the rate remains below a millimeter per year, and uplift has entirely ceased from southwestern part.

# New Paleoproterozoic mafic-ultramafic rocks of the Oum Abana suite and Elmalhat complex of the NW Reguïbat shield (Western Sahara)

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The West African Craton (WAC) comprises two large shields where Archean and Paleoproterozoic terranes outcrop out at the southern and northern borders of the Neoproterozoic and Mesozoic Taoudeni basin; the Leo-Man Shield in the south and the Reguibat Shield to the north, spanning Western Sahara, Mauritania and Algeria.

The Elmalhat Complex (Lehbib, 2016, Combs, 2018), located in the Paleoproterozoic portion of the Reguïbat Shield, belongs to the Oum Abana terrane (Marchand et al.,1985) and represents a potential area for chromite, Cu-Ni-PGE and Ti-V magnetite mineralization typical of deposits found in mafic-ultramafic complexes.

Our fieldwork together with the observations of Lyche (2012), Combs (2012, 2018 and Hanno Resources has revealed several occurrences of chromitites aligned in a NE–SW orientation within the Northern Limb of the Elmalhat Complex. The chromitites are associated with amphibolites and meta-serpentinites, ultramafic meta-cumulates, mafic rocks and gabbro-anorthosites.

The age of Elmalhat Complex has not been directly dated, however, Combs (2018) establishes that the complex was emplaced at about 2.13 Ga, and comprises two principal outcropping lobes. The largest complex (6–8 Km wide and 12 km long) located about 15 km northeast of Bir Elmalhat is surrounded by Ultramafic bodies (commonly carbonate-altered to form listwanite), granites, orthogneisses and amphibolites, but the petrographic study of thin sections made from the rock samples taken and the geochemical analysis results (Lehbib, 2016), states that granulitic metagabbros, serpentinized metadunites, and amphibolites within these units have geochemical affinities to tholeiitic and boninitic volcanic rocks found in oceanic island arcs that coincide with Marot et al. (2003).

Chromitites crop out as lenses of several metres width and tens of metre length. They often occur within leuco-amphibolite layers. Chromitites are either massive, brecciated or disseminated within the host cumulates. Some layered chromite pods have also been observed within anorthosite or gabbro-anorthosite.

# New insights on the case of Tahmelanlähde spring, Pispala, Tampere: building a hydrogeological model

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The condition of Tahmelanlähde spring in city of Tampere has been under discussion for two decades. Between 1906-1966, the spring was being used for municipal water supply and water quality was good. The quality of discharging groundwater has since deteriorated, bearing now high concentrations of iron, manganese, nitrogen, phosphorus and very low oxygen. The cause of this deterioration has remained unclear. The aims of this study are to create a hydrogeological model for Tahmela-Pispala area in order to get a better understanding of the sources of the groundwater discharging at the spring area, to assess the cause for the spring deterioration and to give suggestions to a rehabilitation plan.

Tahmelanlähde spring is located on a clay or silt soil under artesian circumstances, down the southern slope of Pispalanharju Esker formation. The esker forms a longitudinal neck between Lake Näsijärvi and Lake Pyhäjärvi, rising up to 160 meters above sea level. The water level of Lake Näsijärvi is approx. 95 m a.s.l. and the water level of Lake Pyhäjärvi approx. 77 m a.s.l. Considering the distance of only a few hundred meters between these two lakes, the difference of 18 meters in the lake water levels is quite unusual in Finland's geological context, especially because the lakes are separated by an esker formation (Ahonen et al. 2013).

For the construction of the hydrogeological model we had field campaigns including ground penetrating radar (GPR) survey, thermal infrared survey using unmanned aerial vehicle (UAV-TIR), measuring of water tables as well as water sampling from springs, surface water bodies, groundwater observation wells and groundwater discharging into the Lake Pyhäjärvi. 23 water samples were analyzed for main ion composition, stable isotopic ($\delta^{18}O$ / $\delta D$) composition, pH, EC and trace elements such as iron and manganese. 14 samples were additionally analyzed for $COD_{Mn}$, N, P, O and microbial indicators.

Some previous studies have suggested infiltration of Lake Näsijärvi water into the esker (Ahonen et al. 2013, Ahonen et al. 2018). Our results reveal that most of the groundwater in the Pispalanharju area contains a variable amount of surface water component. The samples east from the spring present good-quality groundwater and show non-existent surface water impact. This indicates that the regional groundwater flow patterns are complex and there are at least two water components with different origins discharging at Tahmelanlähde. The results imply that the primary cause for the spring deterioration could be a major shift in the groundwater – surface water interaction in the northern esker area, probably driven by urbanization and the heavy construction during the last few decades.

We are working on a hydrogeological model for the study area. The aim is to build a conceptual and possibly a numerical 3D model using water table, hydrogeochemical, drilling and GPR data. Groundwater discharge locations into the Lake Pyhäjärvi and on the land surface will be pointed out, as well. The study is a collaboration between the City of Tampere, Pirkanmaa Center for Economic Development, Transport and Environment (ELY Center) and University of Helsinki, Department of Geosciences and Geography.

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# The environmental history of lakes Hältingträsk and Storträsk

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Hältingträsk and Storträsk are two small lakes located in Östersundom, eastern Helsinki, southern Finland. The City of Helsinki current zoning plan includes up to 100 000 new homes for residents in Östersudom, this includes sites as well for nature reserve and recreation. The catchment of Storträsk is in Sipoonkorpi National Park, but the effects of recreational activities and liming must be evaluated. The area near Hältingträsk will be subject to intensive building construction.

The aim of the study is to investigate the environmental history of the lakes, using the paleolimnological approach. To investigate the responses and resilience of the lakes to human influence, the water pH evolution was traced through time using fossil diatom assemblages. In addition, the geochemistry of heavy metals was analyzed to detect anthropogenic impact. Both proxies are framed with an age-depth model based on $^{210}Pb/^{137}Cs$ and $^{14}C$ dating. The assessment of the past conditions will allow set up reference conditions and estimate how the future human activities will influence the lakes.

The preliminary results indicate a transition from a marine environment to a freshwater one, as well as acidic lake water pH in the modern times in Hältingträsk. For Storträsk, the results show low variability in pH in the recent times, suggesting little effect of liming. Hältingträsk record displays the trends of the era of intensive human influence with a peak in the top of the heavy metals sequence, and variability in the environment in the fossil diatoms.

# 3D geological and groundwater modelling for the public water supply management – A case study from Karhinkangas aquifer, west Finland

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Shallow groundwater is an important source for public water supply in Finland. However, geological complexity of glaciofluvial and ice-marginal deposits could cause the greatest challenges for aquifer body identification and groundwater resource estimation. During the past 20 years, the Geological Survey of Finland (GTK), in collaboration with the municipalities, waterworks and local ELY-centres, has carried out 3D geological mapping of the aquifers for groundwater resource assessment with the integration of various geological and geophysical techniques including site investigation with gravimetric survey for identification of the bedrock surface, GPR survey for the internal structures of sediments with confirmation of the drilled borehole data. 3D geological model provides not only geological framework for groundwater flow model, but also useful data for the vulnerability and risk assessments for water supply management of the groundwater area. The applications and visualization of 3D geological and groundwater flow modelling have facilitated the authority and non-geologist user understanding of geological structures and flow paths of aquifer which could establish information sharing and more reliable on groundwater resource estimation.

This study presents the applications of 3D geological and groundwater flow models from a case study in Karhinkangas groundwater area that locates in the low-lying terrain in the west-coast of Finland. 3D geological model revealed the main superficial units: glacial till, sand and coarse gravel of esker sediments, glaciomarine fine sediment, littoral deposit and peat, and outlined the location of aquifer body and groundwater divides. New water intake wells were planned in the optimized locations and depths, while groundwater flow model estimated water budgets, flow paths and travel times to the intake wells based on the pumping scenarios of the expected increase in demand of groundwater supply in the future.

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# Composition of olivine and magma-sulfide interaction in Sakatti Ni-Cu-PGE deposit (Central Lapland)

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The goal of this work is to study the fractional crystallization, and the sulfide segregation processes during the formation of the magmatic Sakatti Ni-Cu-PGE deposit. By studying olivine composition, fractional crystallization of the olivine in the deposit can be examined, and the MgO content of parental magma can be determined. Olivine Fo-Ni systematics provide important insight into the timing of sulfide saturation, and magma-sulfide interaction.

Samples used for this study were selected from drill cores and 57 thin sections were prepared. Those 57 thin sections together with seven already existing thin sections from the different units of the Sakatti deposit, were used as a sample set. The units selected for the study are different parts of peridotite (mineralized and unmineralized), olivine-pyroxenite, komatiitic lava and dunite. The target was to find fresh olivine; therefore, units with a lot of alteration had fewer useful samples. Samples from upper peridotite body and southwest did not have any fresh olivine, therefore these unmineralized peridotite bodies had to be excluded for now. Petrographic analysis was carried out with a polarized light microscope. In total 19 samples, one to three samples from each unit and one to three olivine grains from each sample, were selected for detailed study with Electron Probe Micro-analyzer (EPMA).

One of the main targets for the study is to do a profile from one drill core; eight samples were selected from drill core that goes through sulfide lenses, providing a great dispersion throughout the peridotite body. Early results show that the forsterite ($Mg/(Mg+Fe^{2+})$) content of the olivine in the profile increases from $Fo_{87}$ to $Fo_{91}$ as moving deeper. The Nickel content varies from 3380ppm to 2840ppm, decreasing as going deeper and being the lowest in the bottommost part of the peridotite body. However, the content increases when migrating from peridotite to dunite. Forsterite content of the olivine distinguish the different units considerably. The Fo-content is lowest in the komatiitic lava unit and in the olivine-pyroxenite, with average value of $Fo_{85}$. Dunite has the highest Fo-content ($Fo_{91}$), however, some peridotite samples reach almost the same values ($Fo_{90}$). Nickel content varies between the units, and moreover within the units. The lowest nickel content is in olivine-pyroxenite, however the content in komatiitic lava unit and peridotite fluctuates quite much.

Work in progress: The results from olivine in the profile will be compared to the chromite compositions; For the most part comparing the nickel contents in olivine and chromite. Also LAMS determination of trace elements, Ca > Ca geobarometry will be examined.

# Common Mid Point (CMP) surveying for depth calibration of ground penetrating radar data

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Accurate depth calibration is essential when interpreting Ground Penetrating Radar (GPR) data. Inaccurate depth estimation may lead to significant miscalculations if geological setting is not known or soil water content varies. Depth calibration is needed to transform the two-way travel times of the recorded GPR signals to actual depths. Depth calibration can be done in numerous ways: using velocity tables, hyperbola fitting to common-offset data, laboratory measurements, known reflector as a reference, CMP (Common Mid Point) surveying, WARR (Wide Angle Reflection and Refraction) surveying, transillumination test etc. Using velocity tables is the easiest and most used method but may lead to miscalculations. Therefore, empirical studies are always recommended.

Purpose of this study is to use a CMP survey for depth calibration in selected locations. Objective is to compare results with other methods and evaluate whether CMP results provide a more accurate method for depth estimation. GPR system used was Geophysical Survey Systems Inc. SIR-3000 unit and MLF 3200 unshielded antenna with either 80 MHz or 40 MHz center frequency. Data processing is done using ReflexW signal processing software. Surveys were done in early February 2019. In CMP survey both the transmitter and receiver are moved away from fixed center point, i.e., the Common Mid Point (CMP), in constant step distance. In this study 10 cm steps were used over 30 m distance to collect a CMP survey profile. Collected profiles are then processed in ReflexW and semblance analysis is applied to determine radio wave velocities compared to depth. After processing CMP results are applied to common-offset profiles. CMP survey results are compared to depth estimations with velocity tables, hyperbola fittings and known reflector as a reference.

Test fields are located in Southern Finland at Salpausselkä 1 in Hollola and Patola forest in Helsinki. In Patola forest geological setting is a shallow 0-5 m moraine, sand and landfill bedding. Bedrock is clearly visible with fractures through the common-offset profiles. In Hollola, bedding is deep glacial delta system. Delta foresets and groundwater surface are observed on common-offset lines. A benefits of the CMP method is getting empirical in-situ information of the profiled media. CMP also gives velocities throughout the vertical profile unlike other depth calibration measurements. On the other hand, data acquisition is time consuming and surveying on folded or dipping beds may give misleading information.

In poster presentation CMP method is discussed in more detail and examples presented from Hollola and Patola study sites.

# Microbial ecology of surface- and groundwaters in the forefield of a rapidly retreating glacier in Iceland

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Climate change has devastating effects on glaciers all around the globe. Catchment areas where glacier melt forms a component of the river flow are inhabited by over 1 billion people worldwide. These rivers provide ecosystem services that may be disrupted when glacier dynamics change. Glacial deposits can form significant aquifers and contain groundwater stores that have important role in buffering changes in river discharge induced by melting of the glaciers. The meltwaters contain significant amount of organic carbon and other nutrients, thus providing a suitable environment for microbes. Microbes are the most diverse and dominant functional drivers in almost every ecosystem. They play a significant role in biogeochemical cycles and are considered to be sensitive and relevant indicators of environmental disruptions. The study site, the sandur in front of Virkisjökull glacier in Iceland, provides an excellent opportunity to observe structural differences in the microbial community in the glacial meltwater and sandur aquifer. We collected samples from altogether eight shallow boreholes (<15m) in the upper, middle and lower sandur. In addition, Virkisá River, two springs, the glacier lake outlet and a hill stream in the proximity of the glacier were sampled. Geochemistry variables were measured in the field (temperature, pH, dissolved oxygen, electrical conductivity and redox potential) or in laboratory (anions, cations, O and H stable isotopes). Microbial biomass was collected by filtration of water samples (50-500 ml), DNA extracted and bacterial and archaeal 16S rRNA gene amplicons sequenced with Illumina MiSeq platform. Sequencing data were processed using analysis pipeline of the sequencing provider (MrDNA). Operational taxonomic units (OTUs) were defined by clustering at 97% similarity and classified with BLASTn against a curated database derived from commonly used ribosomal databases (Ribosomal Database Project and NCBI). Further statistical analyses were done with PAST program.

Bacterial community structure varied between the boreholes according to their location. The microbial community in the upper sandur aquifer was dominated by Proteobacteria, Firmicutes and Bacteroidetes phyla, while in middle and lower sandur samples Nitrospira was relatively more abundant compared to Bacteroidetes. Lentisphaera and Planctomycetes were also more abundant in middle and lower sandur samples compared to the upper sandur. Diatoms (Thalassiosirales, Fragilariales) dominated in springs and shallow stream samples, while the microbial community of the river sample shared features of both the groundwater (Proteobacteria, Bacteroidetes) and surface water communities (Bacillariophyta, Cyanobacteria). Euryarchaeota (Methanococcaceae, Methanosaetaceae, Methanobacteraceae) and Thaumarchaeota were most dominant archaeal phyla in the samples. Thaumarchaeal Nitrosopumilaceae OTUs were relatively more abundant in the surface water samples. No archaea could be detected from river and glacier lake outlet samples. As expected, microbial communities detected from the borehole water differ from those sampled aboveground within both bacteria and archaea. Interestingly, river bacterial community appears to be a mix of surface and groundwater communities.

# Using aerial thermal infrared (TIR) imaging for river baseflow estimation in Lake Pyhäjärvi catchment, Southwestern Finland

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The objective of this study is to examine the applicability of thermal infrared (TIR) imaging for river baseflow estimation in two input rivers of Lake Pyhäjärvi catchment. The temperature anomalies and longitudinal temperature profiles of two input rivers Pyhäjoki and Yläneenjoki were studied.The aerial TIR data for this study was collected in summer 2011 in Lake Pyhäjärvi catchment in SW Finland. A FLIR ThermaCAM P60 TIR camera together with an HDR-CX700 digital video camera were used to data acquisition. Cameras were held in a near vertical position on the side of the helicopter and the flight altitude varied from 70–350 meters (above ground level) and ground resolution varied from 0.15 to 0.5 meters.

The temperature anomalies of two input rivers Pyhäjoki and Yläneenjoki were studied from TIR data. In Lake Pyhäjärvi area, the groundwater and surface water temperature difference is largest in mid-summer when the average groundwater temperature is 6°C and the surface water temperature is around 20-24 °C. The meteorological data used during TIR data processing was collected from Kokemäki weather station situated nearly 20 kilometers from the Lake Pyhäjärvi. It was used in locating the temperature anomalies and potential groundwater discharge sites as well as in defining the minimum radiant temperature of the river water.

The study revealed that the mosaic TIR images combined from individual TIR images can be used to illustrate different groundwater discharge classes and to represent wide diffuse patterns in the river systems. Based on the TIR images, groundwater is discharging into the both rivers and River Pyhäjoki seems to be more groundwater dominated than River Yläneenjoki. The River Pyhäjoki is dominated by wide diffuse discharge of groundwater and had less than 10 springs detected from the TIR images. The River Yläneenjoki had more discrete groundwater discharge anomalies and over 30 springs were detect along the river.

In this study, only relative temperatures were used and the values are not compared to reference temperatures. In River Pyhäjoki, minimum radiant temperature of river water changes from the upstream to the Lake Pyhäjärvi over 5-6 °C, from 12 to 19 °C. The River Yläneenjoki minimum radiant temperature varies spatially and it has three significant patterns where the river temperature falls remarkably. In these spatial patterns the river temperature diminishes approximately 3-5 °C.

The TIR can only detect the skin layer of the surface water (0.1 mm) (Torgersen et al. 2001). Therefore, the TIR surveys has to be completed with other hydrogeological research methods. The floating vegetation and riparian vegetation can produce challenges and false interpretations to the TIR studies. Also, the data processing, meteorological conditions and photo quality affects to TIR results (for example the shadows, unfocused photos) bringing issues for the interpretation. To confirm the TIR results, baseflow of the rivers will be calculated using hydrograph separation. The results will be compared to the results of mass balance based study by Rautio and Korkka-Niemi (2015) and study of Wiebe et al. (2015), where PART-adjusted runoff water balance method was used.

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# Introduction to the laboratory services in the Department of geosciences and geology at the University of Helsinki

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# Modelling performance of the Topographic Wetness Index is affected by grid resolution and flow-routing algorithm

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Topographic Wetness Index (TWI) is a commonly used proxy for soil moisture. It is known that TWI is affected not only by the accuracy and resolution of the digital elevation model (DEM), but also the algorithms used. Yet, their joint-effect is largely unquantified, as is how it affects TWI relationships with soil moisture. Here, we tested how well TWI predicts field-quantified topsoil moisture in oroarctic tundra by using different flow-routing algorithms, at resolutions varying from 1 to 30 m.

Generalized Additive Models (GAM) were used for analyses. Field data consisted of 1040 plots, measured at two response scales (1 m2 and ~ 100 m2). In addition, sensitivity of each flow-routing algorithm to the DEM errors was examined by adding random height-errors and calculating the correlation between the original and error-added data for different resolutions and algorithms.

The R2 of the soil moisture-TWI-models ranged from 0.0 to 22.2% for the micro-scale, and 0.0 to 26.3% for the local-scale response (10-fold cross-validation). The highest R2 was obtained with 2 m and 3 m DEM for the micro- and local-scale, respectively. In the error-sensitivity analysis, the addition of random height errors revealed differences among algorithms, specifically at high resolution. The multiple-flow-direction algorithms outperformed the single-flow-direction algorithms, particularly at high resolutions (< 10 m).

Our results show that using higher-resolution DEMs alone does not improve soil moisture estimates. We conclude that careful assessment of DEM quality, proper resolution, and flow-routing algorithms are critical when using TWI as a proxy of soil moisture.

# Composition of chromite in Ni-Cu-PGE deposit in Sakatti, Central Lapland – petrogenetic implications

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In addition to major elements, chromite (Fe++, Mg)(Cr, $Al)_2O_4$ is composed of a variety of trace elements. It often occurs as an accessory component in cumulate rich olivine rocks. The melt composition and pressure of crystallization can be recorded into chromite. Chromium can be dissolved only in limited amounts of komatiite melt depending on the given temperature and oxygen fugacity, until it exceeds this limit and starts to crystallize chromite. If the parental magma is high in MgO, chromite would not be on the liquidus. Moreover, the composition of chromite can be used as a proxy for the petrogenesis of the magma, provide vital information how the sulfur saturation occurred, and in particular to record thermal conditions of the cooling cumulates.

The Sakatti Ni-Cu-PGE deposit may be classified as an ultramafic intrusion or komatiitic channel cumulates. The objective of this thesis work is to study the composition of chromite from the Sakatti Ni-Cu-PGE deposit, which can then lead to better understanding of the classification of the deposit and thus also its parental magma composition.

Two or three thin sections were selected from each of the deposits (SW, NE and Upper bodies) and thirteen thin sections from the Main body deposit, where nine of the sections are representing a profile through the main deposit. The chromite grains were classified by their optical features under polarizing microscope and they are usually fresh and euhedral having thin ferrian-chromite alteration rims around grain boundaries and cracks. The chromite grains occur either as intercumulus positions relative to olivine grains, but they are also found inside fresh olivine grains. The alteration rims are thicker at the NE and SW body samples compared to main body samples.

The elemental composition, including $SiO_2$, $TiO_2$, $Al_2O_3$, $Fe_2O_3$, FeO, $V_2O_3$, MnO, MgO, ZnO and Ni, of the chromites were analyzed using electron probe micro analysis (EPMA). In the Cr/(Cr+Al) vs. Mg/(Mg+Fe) diagram, the Sakatti chromites plot within both, layered intrusion and komatiitic lava compositional fields. Nickel contents of Sakatti chromites range approximately from 150 ppm to 400 in the SW body, from 200 ppm to 1800 ppm in the NE body and from 150 ppm to 2000 ppm in the Main body.

# Glacial landform interpretation utilizing LiDAR DEM

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During the previous decades, technological advantages in remote sensing alongside with significant developments in GIS (Geographical Information System) capabilities have provided a revolutionary tool to study glacial landforms and sediments. Deglaciated landscapes are now revealed in a detailed resolution, shifting the paradigm in palaeoglaciological reconstruction and geomorphological mapping. Utilizing data produced with LiDAR (Light Detection And Ranging) technology, complemented with existing geological data offers an unprecedented methodology to interpret and categorize glacial landforms rapidly and cost-efficiently. These landforms include lineated features such as flutings, drumlins, and mega-scale glacial lineations; horizontal deltaic surfaces; and continuous, sharp-crested esker ridges delineated by kettle hole systems.

The interpretation of glacial landforms is utilized as a framework when applying Quaternary geological knowledge to land use management, including groundwater resources, mineral exploration, and environmental impact assessment procedures. Analysing geological characteristics from high-resolution elevation models should be based on comprehensive theory-based knowledge about sedimentary environments, landform-sediment assemblages and their relations to the glacial processes and systems. The core of glacial dynamic interpretation is based on spatiotemporal understanding of a variety of phenomena and interacting processes during glacial advance, readvance phases and deglaciation.

Basing glacial landform interpretation merely on elevation data is insufficient without proper lithological and Quaternary mapping datasets. Effective use of LiDAR DEM (Digital Elevation Model) in mapping glacial morphologies relies on a wide array of geological data collected in the past decades. Therefore, using the LiDAR DEM is not a stand-alone interpretation approach, but the newest step in a continuum of multi-disciplinary tradition of glacial interpretation combining among others glaciological, geomorphological, geophysical, and sedimentological data. Geological data complementing the LiDAR DEM include Quaternary geological maps, topographic databases, the ancient shoreline database, bedrock outcrop observations, lithology and fault zone maps, sediment logs, drill cores, scientific publications, old topographic maps, aerial imagery data as well as aerial and ground-based geophysical surveys.

Several factors may complicate LiDAR interpretation. For example, areas that are lacking or have a scarcity of supporting geological data makes interpretation precarious. Complementary data may also contradict with LiDAR interpretation. Certain landscapes are inherently difficult to interpret even with abundant geological data. Hummocky moraines of low relief draped over uneven bedrock topography present remarkable difficulties in reliably differentiating moraine hummocks from bedrock outcrops. Pro-glacial lakes and sudden fluctuations in their water levels may cause a significant influx of meltwaters to reshape glacial landforms. Palimpsest features formed by ice readvance or during different glacial cycles make categorization of landforms difficult. Postglacial phenomena influence local morphologies, obscuring and disturbing glacial or glacifluvial deposition. Such phenomena include littoral, aeolian and anthropogenic reworking of glacial topography and sediments.

Finally, the LiDAR-based mapping of glacial landforms needs to be supplemented with field observations, especially from key locations essential for glaciodynamic reconstructions, in order to increase objectivity and verify the interpretations. The high resolution of the LiDAR DEM makes it possible to pinpoint the most useful locations for this purpose.

# Heat flow and heat production in relation to geoneutrino signal near Pyhäsalmi mine

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This study gives an overview of thermal environment within 150 km distance from the 1444 m deep Pyhäsalmi zinc-copper mine where ore production will end in late 2019. Projects related to nuclear physics have been undertaken in the mine, and in the new laboratory hall at a depth of 1430 m, the share of cosmic rays in total radiation is limited to muons. Therefore radiation from geoneutrinos could be detected more easily than at upper levels. We have analysed geoneutrino flux Φ in the crust around mine using a cylindrical model with 150 km radius. We generated one-dimensional geotherms for a two-layered crust, applying upper crustal depth d = 10 km and Moho depth $z_m$ = 55 km, Moho heat flow $Q_m$= 9...15 mWm$^{-2}$ from xenolith thermobarometry surface heat flow Q = 32.1...46.1 mWm$^{-2}$ from borehole data and upper crustal heat production values $A_H$ = 0.2...2.3 μWm$^{-3}$ from the rock geochemical database of Finland. Our most plausible cylindrical model of the crust around Pyhäsalmi has Q = 39.0 mWm$^{-2}$, $A_H$ = 1.21 μWm$^{-3}$ and $Q_m$ = 12.1 mWm$^{-2}$. Crustal differentiation index is $D_i$ = 2.47 and geoneutrino flux Φ = 11.7 × 10$^6$ cm$^{-2}$ s$^{-1}$ in this case. An undifferentiated crustal cylinder with similar surface-Moho heat flow contrast, and similar mean heat production, would only produce Φ = 6.2 × 10$^6$ cm$^{-2}$ s$^{-1}$. The share of upper crust is 42% in the undifferentiated and 45% in the differentiated case. The total geoneutrino flux is affected by lithospheric and asthenospheric mantle, but crustal differentiation results in most obvious changes to total geoneutrino flux.

Unlike in the surroundings of Sudbury neutrino observatory in Canada, the upper crust in the immediate vicinity of Pyhäsalmi is not locally enriched in radiogenic isotopes, when compared to upper crust beyond 150 km, but separate investigations of near-field crust remain important to assess geoneutrino flux. The actual estimation of total geoneutrino flux requires knowledge of the crustal structure also beyond the 150 km distance and integration over domains of different, often poorly known heat production constraints. The lithospheric part of geoneutrino flux should in principle be almost exclusively a result of heat production in crust, because xenolith pressure-temperature data imply very small mantle heat production globally. Adding lithospheric mantle part to the modelling , even with a heat production of 0.02 μWm$^{-3}$ and an anomalously large thickness of 195 km, adds up to the total geoneutrino flux only 4.2% in case of undifferentiated and 9.0% in the case of differentiated crust. Although the stable intraplate location makes Pyhäsalmi a good spot for nuclear physics observations, the forthcoming Hanhikivi nuclear power plant in Pyhäjoki, 130 km from the mine site, will cause a large artificial increase to the geoneutrino flux in the area.

# Ice flow directions and DEM in Central Lapland: Evidence of Middle Weichselian deposits in Sodankylä

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Till fabric observations assigned to the Middle Weichselian stadial (71–57 ka) in Central Lapland in northern Finland, have been distinguished in the west, in Kittilä and Kolari areas (Aalto et al. 1992, Sutinen 1992, Salonen et al. 2014, Sarala et al. 2015) or in the east, in Savukoski area (Johansson 1995, Helmens 2014). These areas are separated by the valley of the River Kitinen in Sodankylä, where confirmed Middle Weichselian deposits are lacking (Sarala et al. 2015), remains of glacial erosion are rare and till fabric observations are diverse (Hirvas 1991) indicating varying ice flows from SE to NNE. Here we present the first evidence of a till unit in the valley of the River Kitinen, Kärväsniemi, Sodankylä that is tentatively assigned to MIS4 glacial event.

Previous observations on till fabric and esker chains were collected in a GIS format in order to trace ice flow patterns. A hill-shaded LiDAR DEM and DEM with 32 m resolution were applied for the inspection of glacial landforms in Central Lapland. In addition, a set of OSL-age determinations were performed.

Sedimentological and stratigraphic work on the Kärväsniemi site exposures revealed the presence of three till beds (Åberg et al. 2017). The till fabric from middle till indicates an ice flow direction from NNE-NE. OSL ages of above (40 ky) and below (67 ky) the middle till suggest glacial advance in Kärväsniemi region during Middle Weichselian. Furthermore, the till fabric of the middle till corresponds to the average ice flow direction of the Middle Weichselian in eastern Lapland (Johansson 1995). On the basis of the previous studies and this work, there were two ice lobes in Central Lapland: one in Kittilä and another in Savukoski. The latter likely extended to Kärväsniemi depositing the middle till. The absence of streamlined landforms in the valley of the River Kitinen indicates the deposition during the last glaciation was largely by cold-based ice with various flow directions. Moreover, it is likely that scattered Middle Weichselian fluvial deposits were preserved in the valley of the River Kitinen.

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# The regulation of the River Kitinen to flood affected Mire Viiankiaapa, Sodankylä

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Costruction of hydro-electric power plants and regulation of the river since the 1970s ended the regular spring floods of the River Kitinen in Sodankylä, northern Finland. These floods affected the hydrological conditions of the Natura 2000 protected Viiankiaapa mire, which supports habitats of endangered groundwater dependent ecosystems (GDE). Groundwater table elevation due to the regulation raised the water tables of the mire area. The aim of the study was to understand how the change in the hydrological setting has affected the Viiankiaapa mire and its groundwater discharge patterns, which most probably affects the distribution of some endangered species.

An understanding of the natural or pre-development stage is important because a promising Ni-Cu-PGE showing has been discovered (Brownscombe et al. 2015) below the ground of the Viiankiaapa mire. It is important to understand the structure of the surficial deposits and the surface water – groundwater interactions before planning of the future exploration and possible mining activities to diminish possible environmental risks.

Viiankiaapa is located in the area where complex sedimentation and weak glacial erosion has produced a complex hydrostratigraphic system. The surficial deposits of the study area consist of varying layers of tills and sorted sediments, which have deposited mainly during the last glaciation (Åberg A. et al. 2017). It is possible that the subpeat sediments of Viiankaapa mire provide groundwater discharge to the mire and that the sedimentation can be linked to the distribution of GDEs (Åberg S. et al. 2018).

Viiankiaapa is a habitat of the endangered species Hamatocaulis vernicosus, which is according to Borkenhagen and Cooper (2018) resistant to flooding and based on the sediment core studies (Zibulski et al. 2013) it has been observed to spread during the high-intensity flooding periods. On the contrary, another endangered species Saxifraga hirculus L. that is also found in Viiankiaapa mire has poor resistance to high flood stages (Meškauskaitė and Naujalis 2006). Therefore, the definition of the pre-regulation flooding is needed for understanding the effect of the regulation to GDEs in the Viiankiaapa. Groundwater flow modelling (MODFLOW-NWT, Niswonger et al. 2011) and flood modeling (HEC-RAS, Brunner 1995) was tested to understand the past and present flow patterns.

Historical records indicate that floods generated by spring break-up jams could lead to at least five-meter rise in the stage of the Kitinen river. Preliminary modelling results indicate that regular flooding affected the SW part of the Viiankiaapa mire and that the discharge patterns in the mire have been changed due to regulation indicating that Viiankiaapa is not at its natural stage anymore. However, further or more advanced modelling is needed for better understanding of connections of GW discharge and flooding to GDEs.

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