FoU-dag vid SGU, 11 april 2019

FoU-seminarium

Sammanställd av Nelly Aroka, Lars-Ove Lång

maj 2019

SGU-rapport 2019:10

SGU
Sveriges geologiska undersökning

Omslagsbild: Personer som tittar på en vägg
med vetenskapliga affischer.
Fotograf: Nelly Aroka.

Ansvarig chef: Kaj Lax
Projektnamn: FoU - Gemensamt
Projekt-id: 35001

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Innehåll

FÖRORD

SGU har ansvar att med ett anslag om ca 5,9 miljoner kronor stödja geovetenskaplig tillämpad och riktad grundforskning vid svenska universitet och högskolor. Syftet är att utveckla och använda nya kunskaper och metoder inom geologin för att bättre tillfredsställa samhällets behov och verka för en hållbar utveckling. Angelägna forskningsfält spänner över ett brett område: naturresurser, mineral, bergarter, metaller, grundvatten, jord, grus, energiråvaror, geotermi, koldioxidlagring samt georisker av olika slag. Generellt inkommer ca 30 ansökningar om projektfinansiering till den årliga öppna utlysningen, varav normalt ca. 4–8 projekt beviljas finansiering.

SGU bedriver även egenfinansierad forskning och utveckling (”FoU”) samt deltar i olika typer av internationella samarbetsprojekt i linje med verksamheten. Dessa internationella projekt erhåller oftast finansiering från EU, via t.ex. GeoEra, H2020, Interreg och EIT RawMaterials.

För att stödja FoU vid SGU så har en FoU strateg och samordningsgrupp tillsatts under 2018. Det är i år denna grupp som tagit tillfället i akt att anordna en seminariedag där utvalda projekt täckandes SGUs olika verksamhetsområden presenteras, för att informera om och väcka intresse för de FoU-projekt som SGU finansierar, driver eller deltar i. Den 10:e april bjöds det därför in till en öppen FoU dag på SGU i Uppsala. Dagen besöktes av ca 40 personer som fick tillfälle att lyssna till 19 presentationer, studera posters som presenterade andra intressanta projekt och mingla med varandra. Denna rapport innehåller sammanfattningar från de presentationer som gavs under dagen och vi hoppas att de som inte hade möjlighet att deltaga personligen i år kommer att finna dessa sammanfattningar upplysande och att de väcker mer intresse för geovetenskaplig forskning och utveckling!

Uppsala den 24 maj 2019

Kaj Lax	Therese Bejgarn
avdelningschef	FoU-strateg

Foto: Nelly Aroka, SGU.

PROGRAM FÖR SGUS FOU-DAG 11 APRIL 2019

Öppen seminariedag om externfinansierade projekt och pågående FoU-verksamhet vid SGU.

Tid: 08.30–15.45. Plats: Hörsalen, SGU Uppsala.

Kl. 08.30–09.00. Fika/mingel

Välkommen till SGU

Kl. 09.00–09.10. Avdelningschef Verksamhetsstöd: Göran Risberg.

Markanvändning och hållbar infrastruktur

Kl. 09.10–10.10. Moderatorer: Colby Smith och Fredrik Mossmark.

- Mats Åström (Linnéuniversitetet). Geochemical, mineralogical and microbiological characterization of acid sulfate soils – towards improved water quality on the coastal plains
- Per Möller (Lunds universitet). Submoräna sediment och deflationsytor i södra Sverige – vad är deras betydelse för förståelsen av den glaciala utvecklingshistorian för detta område?
- Gustaf Peterson (SGU). Tunnel valleys and glaciofluvial meltwater corridors in Småland
- Charlotte Möller (Lunds universitet). Understanding the variation of bedrock material properties with metamorphic condition.

Kl. 10.10–10.40. Kaffepaus och posterutställning.

Blå tillväxt

Kl. 10.40–11.30. Moderator: Sarah Josefsson.

- Anna Apler (SGU). Fiberbankar – från kartläggning till risk för spridning av miljöföroreningar.
- Lars Arneborg (SMHI). Regional spreading of pollutants from fibre banks in the Bothnian Sea.
- Marcelo Ketzer (Linnéuniversitetet). Ackumulering av metaller i Östersjöns sediment: betydelse för miljöövervakning och åtgärdsinitiativ/metal accumulation in the Baltic Sea sediments: implications for environmental monitoring programs and mitigation actions.
- Gunnar Jacks (Kungliga Tekniska högskolan). Kvicksilver i fisk – minskar selen upptaget?

Kl. 11.30–12.30. Lunch.

Grundvatten och geofysik

Kl. 12.30–13.50. Moderator: Peter Dahlqvist.

- Lisbeth Hildebrand (SGU). Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA).
- Roland Barthel (Göteborgs universitet). The status and future of coastal groundwater – implications for groundwater quality and quantity under increased pressures and climate change.
- Auli Niemi (Uppsala Universitet). Quantification of coupled hydro-mechanical processes in deep hydraulically transmissive fractures by downhole field tests and modeling.
- Thorkild Maack Rasmussen (Luleå tekniska universitet). Geophysical investigation of the Arvidsjaur volcanics and the Archean-Proterozoic boundary.
- Mehrdad Bastani (SGU). Results from 2D and 3D modelling of airborne geophysical data. Examples from Sweden and Norway.

Kl. 13.50–14.20. Fika och posterutställning.

Primära och sekundära råvaror

Kl. 14.20–15.45. Moderator: Lena Persson.

- Joel Andersson (Luleå tekniska universitet). Structural vectoring of mineralized systems in northern Norrbotten.
- Helen Thomas (Luleå tekniska universitet). Textural and chemical characterization of sulphide minerals for improved beneficiation and exploration, Skellefte district, Sweden.
- Susanne Grigull (SGU, Uppsala universitet). Dating brittle deformation events in faults from central Sweden: Preliminary results from the Söderström fault (Stockholm)
- Åke Johansson (Naturhistoriska riksmuseet). Cleaning up the record – reanalysing zircon samples from southwest Sweden and the Protogine Zone by SIMS
- Erik Jonsson (SGU). Kritiska metaller och mineral: aktuell verksamhet och framtida möjligheter.
- Ronald Arvidsson (SGU). MinLand project – Access to land a key issue for mining, and the X-Mine project.

Kl. 15.45. Avslut.

MARKANVÄNDNING OCH HÅLLBAR INFRASTRUKTUR

Foto: Claes Mellqvist, SGU.

Geochemical, mineralogical and microbiological characterization of acid sulfate soils – towards improved water quality on the coastal plains

MATS ÅSTRÖM, LINNÉUNIVERSITETET

The largest occurrences of acid sulfate soils in Europe are found in Sweden and Finland. In these two countries, acid sulfate soils develop on fine-grained sulfide-bearing sediments that were once deposited on lake and sea bottoms. Since their deposition, isostatic land uplift has resulted in them being distributed on coastal plains. Under natural conditions, these sediments are to a large extent located under wetlands where they are near pH neutral and environmentally harmless due to the inherent stability of the sulfide minerals. However, when artificially drained which has occurred to an ever larger extent and by more and more efficient techniques over the last two centuries (e.g. utilization of subsurface drainage pipes), the sediments are exposed to the atmosphere which triggers a reaction between the sulfide minerals and O2. In this reaction, sulfuric acid is formed via complex biogeochemical mechanisms, eventually leading to development of acid sulfate soils that typically attain a pH of less than 4.0 (Boman et al. 2010, Burton et al. 2009). Although this kind of sediment has occasionally been drained in forests and areas of urban/infrastructure development, they are overwhelmingly found in coastal localities reclaimed and drained for agricultural activities.

Acid sulfate soils typically support healthy crops. The reasons for this are that the soil: (i) has been limed and thus the pH of its top layer (uppermost 30-40 cm) has been considerably raised; (ii) has a physical structure that favors a good water balance; and (iii) has high natural nutrient contents. Below the uppermost 30–40 cm, where the lime does not reach, the soils extend and remain acidic down to a depth of 1–2 m. In these acidic horizons, percolating rain and snow-melt water are severely acidified and loaded with a variety of potentially toxic metals such as Al, Ni, Cd, Mn, and Be released via mineral weathering in the acidic horizons (Astrom and Bjorklund, 1995). Thus, the water residing in the pores of this soil (“soil water”) is of exceptionally poor quality, frequently with a pH down to 3 and very high con-tents of dissolved metals. Hence, the waters eventually discharging from acid sulfate soils are very acidic and rich in a variety of metals. For example, calculations have shown that the metal quantities leached from the Finnish acid sulfate soils are considerably higher than from the entire industry in the country (Sundstrom et al. 2002). In consequence, the “good chemical status” required by the EU´s Water Framework Directive is typically not reached in acid sulfate soil affected areas.

There is thus an urgent need to developed methods and management practices in order to decrease the leaching of acidity and metals from acid sulfate soils, which occur primarily on the coastal plains around the Gulf of Bothnia but also elsewhere such around Mälaren and in the Kristianstad area. However, the task is not trivial and therefore has remained unsolved, mainly for two reasons: (i) the acid sulfate soils are largely in agricultural use and therefore, any mitigation measures need to be developed and used in a context of farming activities and, (ii) for point sources such as industrial effluents and emissions (including those in mine areas) regulations can and have been created, but for the acid sulfate soils the acid/metal leaching occurs through thousands of small drains spread over thousands of square kilometers and therefore are much harder both to identify and ultimately control. The task of the project is to contribute to a solution to this serious and difficult-to-control environmental problem by state-of-the-art biogeochemical research and a close collaboration with environ-mental organizations in landscapes where these soils are as most severe.

The study is located to the counties of Västerbotten and Norrbotten in Sweden and Österbotten in Finland where acid sulfate soils are particularly widespread and problematic, and experimental fields on these soils have been set up by local organizations. On these fields, various treatments with the potential to minimize acid and metal leaching from acid sulfate soils are being tested and evaluated. The local organizations are carrying out the basic characterization and monitoring of the sites, whereas the research carried out by the Linnaeus University focuses on characterization of the fundamental geochemical, mineralogical, and microbiological processes within the soils in response to the various treatments applied. The determination of the fundamental processes is a key factor on which the short- and long-term potential and performance of the various treatments can be evaluated.

References

Astrom, M., Bjorklund, A., 1995: Impact of acid sulfate soils on stream water geochemistry in western Finland. *Journal of Geochemical Exploration, 55(1-3),* 163–170.

Boman, A., Frojdo, S., Backlund, K., Astrom, M.E., 2010: Impact of isostatic land uplift and artificial drainage on oxidation of brackish-water sediments rich in metastable iron sulfide. *Geochimica Et Cosmochimica Acta, 74(4),* 1268–1281.

Burton, E.D. et al., 2009: Iron-Monosulfide Oxidation in Natural Sediments: Resolving Microbially Mediated S Transformations Using XANES, Electron Microscopy, and Selective Extractions. *Environmental Science & Technology, 43(9),* 3128–3134.

Sundstrom, R., Astrom, M., Osterholm, P., 2002: Comparison of the metal content in acid sulfate soil runoff and industrial effluents in Finland. *Environmental Science & Technology, 36(20),* 4269–4272.

Submoräna sediment och deflationsytor i södra Sverige – vad är deras betydelse för förståelsen av den glaciala utvecklingshistorian för detta område?

PER MÖLLER OCH HELENA ALEXANDERSON, LUNDS UNIVERSITET

Under lång tid var den allmänna uppfattningen bland geologer att inlandsisen var som en bulldozer som gick fram över landskapet och skrapade bort jorden och ersatte den med ett nytt: dagens landskap skulle således avspegla bara vad som hänt under och efter den senaste istidens maximum för ca 20 000 år sedan. Men i slutet av 1980-talet visade SGU-geologen Robert Lagerbäck att i norra Sverige finns sediment och landformer som har bevarats i mer än 75 000 år, trots att de har körts över av minst en inlandsis. Senare forskning har i stort sett bekräftat den här bilden och har visat att bevarandet av gamla landformer bland annat beror på hur temperaturen i botten av inlandsisen har varierat över tid och rum.

De gamla landformerna har framför allt hittats i norra Skandinavien, där senare istäcken under en stor del av deras existens varit kallbaserade. Men i en ny rapport argumenterar Lagerbäck (2018) för att samma mönster kan ses också i södra Sverige, särskilt i Småland. Han beskriver hundratals observationer i gamla grustäkter av vad han tolkar som en begravd markyta täckt av morän (fig. 1). Den begravda markytan karakteriseras av vindslipade stenar och spår av permafrost, vilket skulle tyda på att den bildades under en kall och blåsig period då södra Sverige var isfritt. Men när ägde denna period rum? Lagerbäck föreslår att markytan bildades för mer än 75 000 år sedan, i början av den senaste istidscykeln (tidig-Weichsel), men har inga faktiska åldersbestämningar som stödjer detta. Sedimenten (glacifluviala åsbildningar) som markytan utbildats över föreslås vara avsatta i samband med deglaciationen av Saale-isen (för ca 130 000 år sedan). Vi anser däremot att det är mer sannolikt att den begravda markytan är betydligt yngre, kanske likåldrig med andra moräntäckta isälvs- och issjösediment i Småland. Dessa har i nyligen genomförda undersökningar visat sig vara ca 55 000–30 000 år gamla (mitt-Weichsel; Möller & Murray 2015, Möller m.fl., in prep.).

Vi kommer att testa vilken av dessa hypoteser som är riktig genom att åldersbestämma markytan och dess sediment med hjälp av ett nytt dateringskoncept med en kombination av luminiscensdatering och kosmogen exponeringsdatering. Genom att datera både de vindslipade stenarna och de eoliska sediment som ibland täcker dem kan vi få fram både tidpunkten då markytan bildades och hur länge den isfria perioden varade. Vi kommer också att göra detaljerade sedimentologiska undersökningar för att bekräfta, eller motbevisa, tolkningen av markytan och sedimenten under och ovan den.

Oavsett om det är vår eller Lagerbäcks hypotes som visar sig vara korrekt kommer resultaten att ha stor betydelse för vår förståelse av södra Sveriges nedisningshistoria och ge en helt ny bild av hur upprepade nedisningar bildat det landskap vi ser idag i form av sediment och landformer bildande en glaciationsmosaik snarare än ett enhetligt, likåldrigt landskap. Sådan kunskap är intressant i sig, men är också användbar för t.ex. klimatmodellering och för riskbedömning av förvaring av kärnavfall.

Referenser

Lagerbäck, R., 2018: Den senaste nedisningen i södra Sverige – och tiden dessförinnan. *Rapporter och meddelanden 143,* Sveriges geologiska undersökning, 87 s.

Möller, P. & Murray, A.S., 2015: Drumlinised glaciofluvial and glaciolacustrine sediments on the Småland peneplain, South Sweden – new evidence on the growth and decay history of the Fennoscandian Ice Sheets during MIS 3.*Quaternary Science Reviews 122,* 1–29.

Figur 1. Vindslipad stenhorisont under överlagrande morän (figur 84 i Lagerbäck, 2018).

Tunnel valleys and glaciofluvial meltwater corridors in Småland

[1,2]GUSTAF PETERSON AND [2]MARK JOHNSON

[1]GEOLOGICAL SURVEY OF SWEDEN AND [2]UNIVERSITY OF GOTHENBURG

Northern Europe was covered by ice sheets multiple times during the Pleistocene. The last glacial maximum (LGM) of the Fennoscandian Ice Sheet (FIS) at around 22 Ka BP reached as far south as 52° latitude (Hughes et al. 2015, Stroeven et al. 2016, Svendsen et al. 2004). As the last ice-sheet receded, a landscape emerged, shaped by the processes of the FIS. By studying this landscaped we can learn about the processes active below ice sheets. With the assumption that these former glacial beds are analogous to contemporary ice sheets it is possibly to address questions important to understand the rapid melt seen on Greenland and Antarctica today (IPCC 2013a).

During FIS retreat after the LGM, there where periods of colder and warmer climate, the latter was most pronounced during 14.7–12.9 Ka BP, the Bølling-Allerød interstadial (Rasmussen et al. 2014). During this interstadial there is evidence for rapid ice-sheet melting and increased sea-level rise on a global scale (Deschamps et al. 2012). This warm period enhanced ice-sheet retreat, not dissimilar to the current global warming's effect on contemporary ice sheets (IPCC 2013b, Hanna et al. 2008, Rignot et al. 2011, Schoof 2010). Therefore, understanding of the processes active beneath ice-sheets, and in particular the processes connected to glacial melt-water drainage, is crucial for a fundamental understanding of ice sheets and how they react in a warming climate.

Investigating sediments and geomorphology of drainage systems below ice sheets is complicated; however, formerly glaciated regions are easily accessible. New datasets, in the form of LiDAR-derived digital elevation models (DEM), have made it possible to map formerly glaciated regions in an unprecedented detail (Johnson et al. 2015). We have mapped an area in southern Sweden, the south Swedish uplands (SSU), that make up a fair bit of the formerly south-central part of the Fennoscandian Ice Sheet (FIS) (Peterson, Johnson, and Smith 2017). This region was deglaciated during the Bølling-Allerød warm period, just prior to the Younger Dryas cold event (Hughes et al. 2015, Stroeven et al. 2016, Svendsen et al. 2004).

On the SSU we have mapped elongate zones of hummocks, which we refer to as corridors (Peterson & Johnson 2017, Peterson, Johnson & Smith 2017) These elongate zones have distinct borders with the surrounding lineated till plain; in some places they show an anastomosing pattern The corridors have an overall radial pattern that is sub-parallel to overall ice-flow and in places the corridors cut through glacial lineations A.

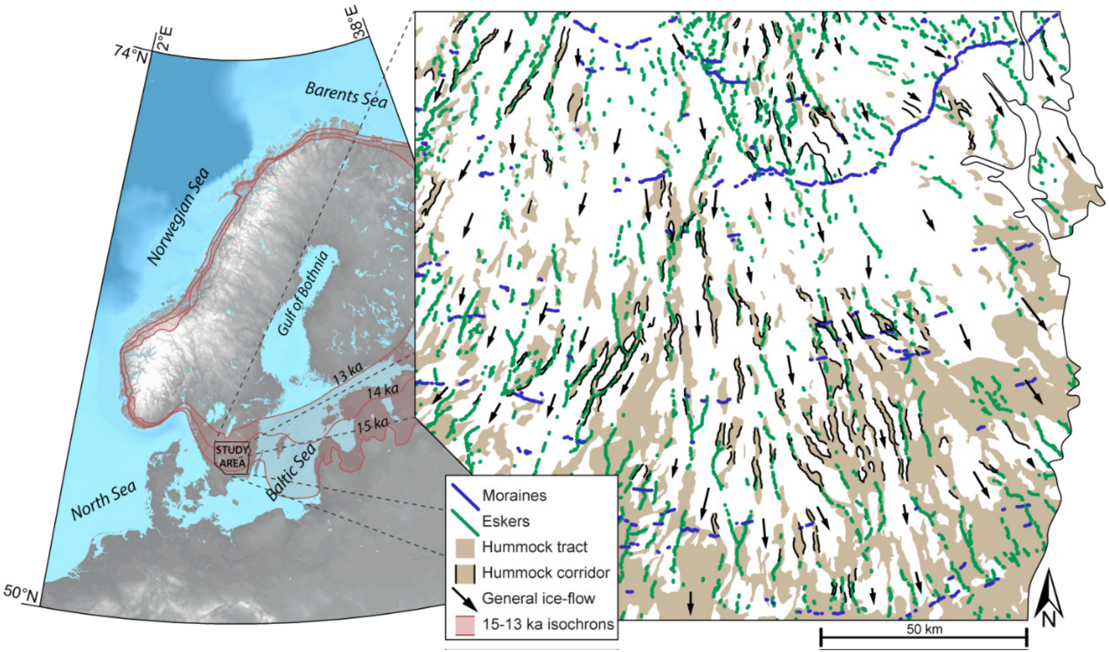

Figure 1. Overview map of study area with generalized glacial geological map. Modified from Peterson & Johnson (2017).

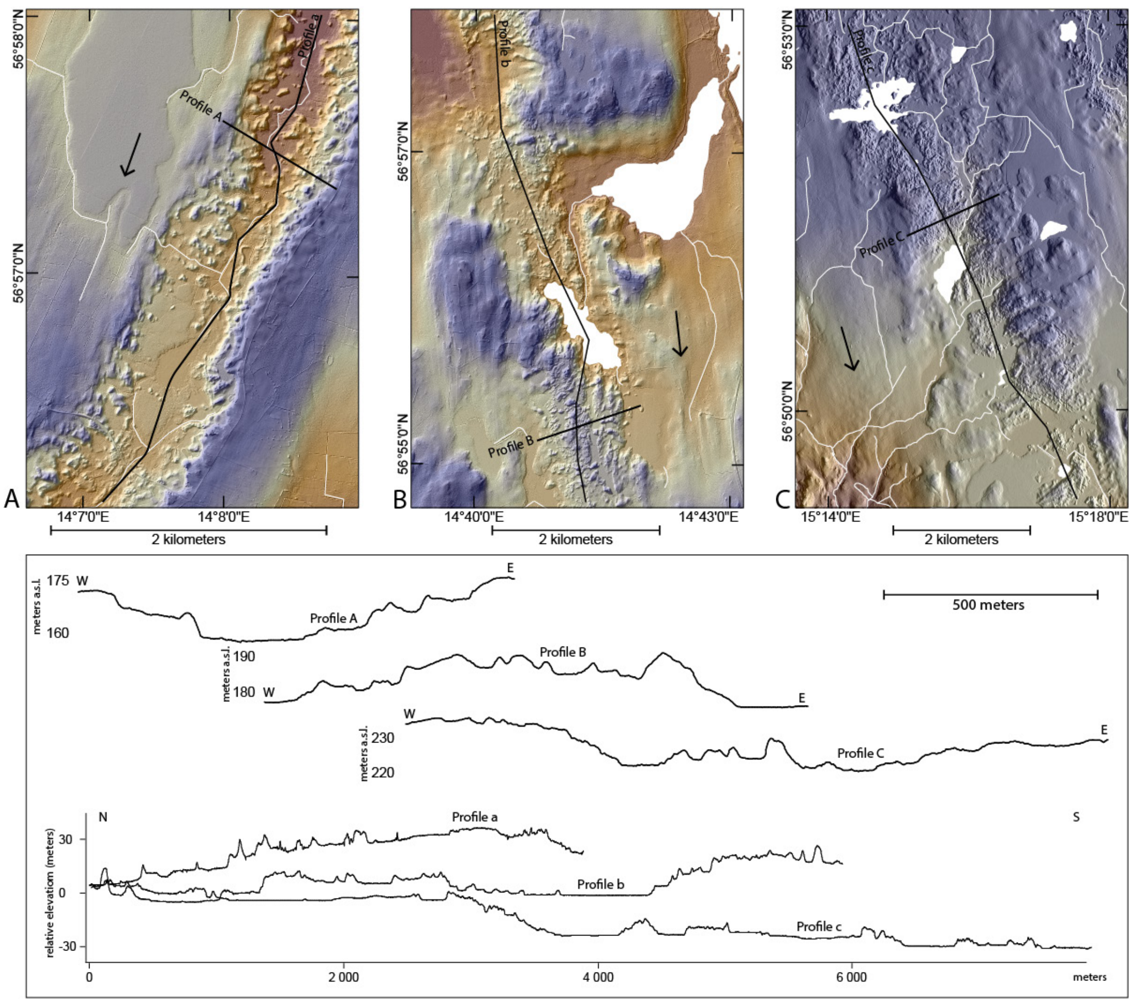

Figure 2. **A, B,** and **C** present LiDAR elevation models of hummock corridors with cross- and long-profiles. Modified from Peterson et al. (2017).

We analyzed the morphometry of these corridors. Many show adverse, up-to-the-margin slopes (Fig. 2). Corridor width varies 0.2 and 4.9 km, their lengths are up to 11.8 km and the spacing between corridors is around 10 km, values comparable to data on tunnel valleys (TV) and glaciofluvial corridors (GFC) reported elsewhere (van der Vegt, Janszen & Moscariello 2012, Storrar, Stokes & Evans 2014). About 2/3 of the corridors display negative cross-profiles (they are incised in the regional till plain), others are positive forms. In the floors of some negative corridors eskers occur that are superposed on hummocks (Peterson et al. 2018).

With machine dug sections of hummocks within one of these corridors we show that at least two of these hummocks consist of subglacial traction till with deformed interbedded sorted sediments (Peterson et al. 2018). Moreover, we show that the material in these hummocks belong to MIS 4 or 3, using OSL (Peterson et al. 2018). Based on the morphometrics and our excavations, we interpret the negative corridors to be tunnel valleys (e.g. Clayton, Attig & Mickelson 1999, Cofaigh 1996, Ussing 1903) and the positive corridors to be glaciofluvial meltwater corridors (e.g. Fisher, Taylor & Jol 2003, St-Onge 1984, Utting, Ward & Little 2009).

The radial pattern and regular spacing of the corridors imply the positive forms also have a subglacial meltwater genesis. Using a recent reconstruction of the deglaciation of the FIS (Stroeven et al. 2016) we attribute an age to the mapped corridors. Comparing the frequency of corridors per time interval with climate variations from Greenland ice-cores (Rasmussen et al. 2014) we suggest that the formation of corridors on SSU can be connected to delivery of abundant supraglacial meltwater to the bed during the Bølling-Allerød warm period (Peterson and Johnson 2017) (Fig. 3).

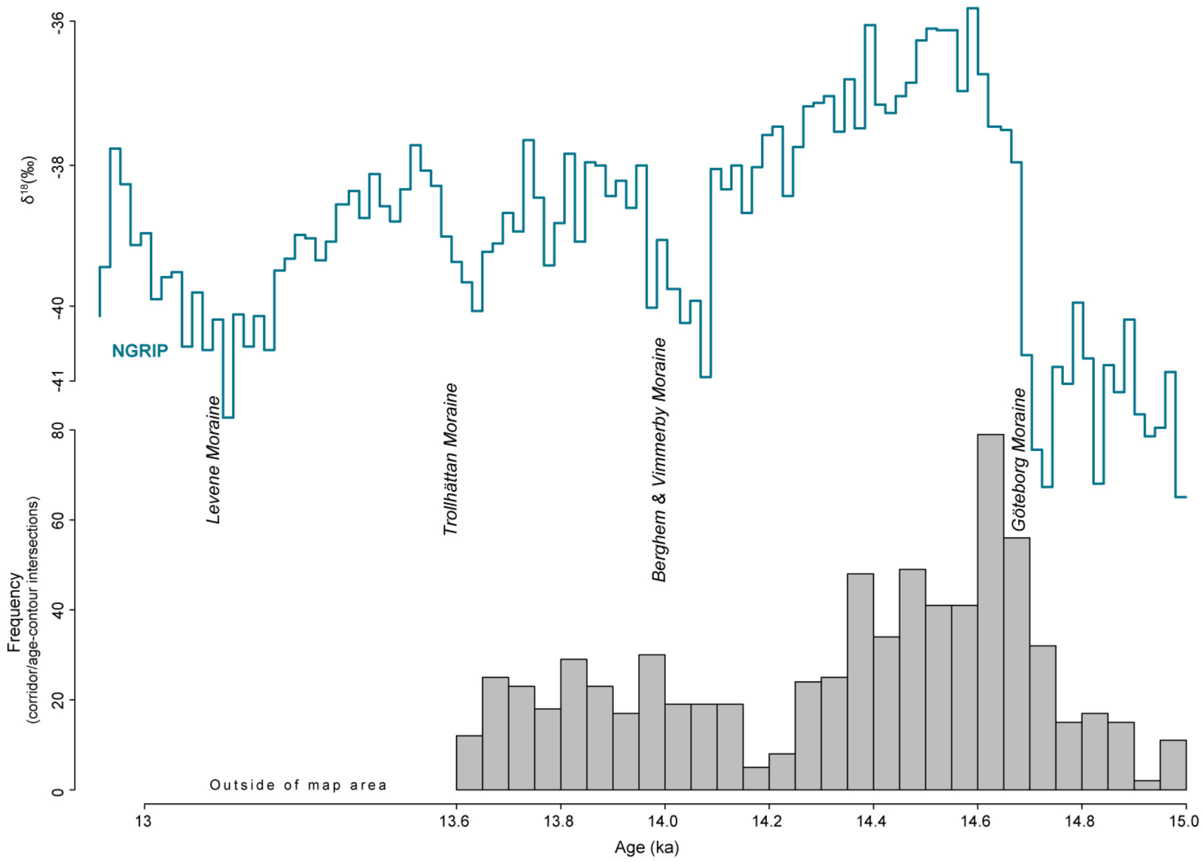

Figure 3. Visual comparison of ice core δ18O values and frequency of hummock corridors per 50-year break. Upper: The NGRIP δ18O values are modified from (Rasmussen et al. 2014). Modified from Peterson & Johnson (2017).

References

Clayton, L., Attig, J.W. & Mickelson, D.M., 1999: Tunnel Channels Formed in Wisconsin during the Last Glaciation. *Geological Society of America, Special Paper 337,* 69–82.

Cofaigh, C. Ó., 1996: Tunnel Valley Genesis. *Progress in Physical Geography 20 (1):* 1–19. doi:10.1177/030913339602000101.

Deschamps, P., Durand, N., Bard, E., Hamelin, B., Camoin, G., Thomas, A.L., Henderson, G.M., Okuno, J., & Yokoyama. Y., 2012: Ice-Sheet Collapse and Sea-Level Rise at the Bølling Warming 14,600 Years Ago. *Nature 483 (7391).* Nature Publishing Group: 559–564. doi:10.1038/nature10902.

Fisher, T., G, Taylor, L.D. & Jol, H.M., 2003: Boulder-Gravel Hummocks and Wavy Basal till Contacts: Products of Subglacial Meltwater Flow beneath the Saginaw Lobe, South-Central Michigan, USA. *Boreas 32 (2)*, 328–336. doi:10.1111/j.1502-3885.2003.tb01087.x.

Hanna, E., Huybrechts, P., Steffen, K., Cappelen, J., Huff, R., Shuman, C., Irvine-Fynn, T., Wise, S. & Griffiths, M., 2008: Increased Runoff from Melt from the Greenland Ice Sheet: A Response to Global Warming. *Journal of Climate 21 (2),* 331–341. doi:10.1175/2007JCLI1964.1.

Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J. & Svendsen, J. I., 2015: The Last Eurasian Ice Sheets – a Chronological Database and Time-Slice Reconstruction, DATED-1. *Boreas 45,* 1–45. doi:10.1111/bor.12142.

IPCC, 2013a: *Ice Sheets.* In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. L. Bamber, P. Huybrechts, and P. Lemke, 317–382. New York: Cambridge University Press. doi:10.1017/CBO9781107415324.012.

IPCC, 2013b: *Changes in Temperature*. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. Hurrel, J. Marengo, F. Tangang, and P. Viterbo, 159–254. New York: Cambridge University Press. doi:10.1017/CBO9781107415324.008.

Johnson, M. D., Fredin, O., Ojala, A.E.K. & Peterson., G., 2015: Unraveling Scandinavian Geomorphology: The LiDAR Revolution. *GFF 137 (4).* doi:10.1080/11035897.2015.1111410.

Peterson, G. & Johnson, M. D., 2017: Hummock Corridors in the South-Central Sector of the Fennoscandian Ice Sheet, Morphometry and Pattern. *Earth Surface Processes and Landforms 43 (4),* 919–929. doi:10.1002/esp.4294.

Peterson, G., Johnson, M. D., Dahlgren, S., Påsse, T. & Alexanderson, H., 2018: Genesis of Hummocks Found in Tunnel Valleys: An Example from Hörda, Southern Sweden. *GFF 140 (2),* 189–201. doi:10.1080/11035897.2018.1470199.

Peterson, G., Johnson, M. D. & Smith, C. A., 2017: Glacial Geomorphology of the South Swedish Uplands – Focus on the Spatial Distribution of Hummock Tracts. *Journal of Maps 13 (2).* Taylor & Francis, 534–544. doi:10.1080/17445647.2017.1336121.

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., et al, 2014. A Stratigraphic Framework for Abrupt Climatic Changes during the Last Glacial Period Based on Three Synchronized Greenland Ice-Core Records: Refining and Extending the INTIMATE Event Stratigraphy *Quaternary Science Reviews 106,* 14–28. doi:10.1016/j.quascirev.2014.09.007.

Rignot, E., Velicogna, I., van den Broeke, M. R., Monaghan, A. & Lenaerts, J., 2011: Acceleration of the Contribution of the Greenland and Antarctic Ice Sheets to Sea Level Rise. *Geophysical Research Letters 38 (5),* 1–5. doi:10.1029/2011GL046583.

Schoof, C., 2010: Ice-Sheet Acceleration Driven by Melt Supply Variability. *Nature 468 (7325).* Nature Publishing Group, 803–806. doi:10.1038/nature09618.

St-Onge, D.A., 1984: Surficial Deposits of the Redrock Lake Area, District of Mackenzie. Current Research, Geological Survey of Canada 84–1A (Part A).

Storrar, R. D., Stokes, C. R. & Evans, D. J. A., 2014: Morphometry and Pattern of a Large Sample of (>20,000) Canadian Eskers and Implications for Subglacial Drainage beneath Ice Sheets. *Quaternary Science Reviews 105 (December).* Elsevier Ltd, 1–25. doi:10.1016/j.quascirev.2014.09.013.

Stroeven, A. P., Hättestrand, C., Kleman, J., Heyman, J., Fabel, D., Fredin, O., Goodfellow, B. W., et al., 2016: Deglaciation of Fennoscandia. *Quaternary Science Reviews 147,* 91–121. doi:10.1016/j.quascirev.2015.09.016.

Svendsen, J. I., Alexanderson, H., Astakhov, V. I., Demidov, I., Dowdeswell, J. A., Funder, S., Gataullin, V., et al., 2004: Late Quaternary Ice Sheet History of Northern Eurasia. *Quaternary Science Reviews 23 (11–13),* 1229–1271. doi:10.1016/j.quascirev.2003.12.008.

Ussing, N.V., 1903: Om Jyllands Hedesletter Og Teorierne for Deres Dannelse. *Oversigt over Det Kongelige Danske Videnskabernes Selskabs Forhandlinger 2*, 1–152.

Utting, D. J., Ward, B. C. & Little, E. C., 2009 Genesis of Hummocks in Glaciofluvial Corridors near the Keewatin Ice Divide, Canada. *Boreas 38 (3),* 471–481. doi:10.1111/j.1502-3885.2008.00074.x.

van der Vegt, P., Janszen, A. & Moscariello, A., 2012: Tunnel Valleys: Current Knowledge and Future Perspectives. *Geological Society, London, Special Publications 368 (1),* 75–97. doi:10.1144/SP368.13.

Understanding the variation of bedrock material properties with metamorphic conditions

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The goal of this project is to understand the variations of bedrock material properties with metamorphic conditions. Our chosen test area is the Eastern Segment of the Sveconorwegian Province, for which there is a new overview metamorphic map (Fig. 1; Möller & Andersson, 2018). We will provide a high-quality petrological data set coupled with test data that can be used for prediction of technical properties. A second aim is to provide a quantitative model of the regional variations in pressure, temperature and timing of the metamorphism in the Eastern Segment. Based on this knowledge, we will outline a regional-scale metamorphic domain map that is intended to serve as a basis for finding rock materials suitable for aggregate production. Our data will portray the systematic changes in bedrock properties in a part of Sweden's bedrock that is the tectonic analogue to the India plate, buried at increasing depth and temperature in a collision zone. The model is intended to demonstrate systematic links between metamorphic processes and bedrock material properties.

Aggregates produced from geological materials are by far the most widely exploited natural resource in Sweden. A sustainable production relies on good fundamental understanding of the variation of bedrock material properties. Quarrying of "the right" materials greatly reduces (a) the consumption of energy and water during aggregate production, (b) the use of chemicals (e.g. for production of concrete), and (c) transports. The study area of this project is a region in which there are immediate plans for new infrastructure (e.g. Europabanan, Götalandsbanan, E20, Skåne region) and where suitable bedrock materials have to be made available.

We need to deepen our knowledge of the variation of rock properties with different geological conditions so that accurate predictions can optimize the exploitation and use of rock materials. Rock properties change radically when the bedrock is subjected to tectonism and metamorphism. In SW Sweden, the bedrock is characterized by a strong metamorphic gradient from ENE to WSW, grading from less than 300 °C in eastern areas (Lammhult-Växjö) to 850 °C (Varberg-Halmstad). The metamorphic conditions have steered the development of radically different mineral assemblages (affecting hardness, brittleness, density, etc.) and textures, the latter including variations in (a) degree and type of recrystallization, (b) hydration, (c) grain sizes and shapes of grains, and (d) internal strain in crystals. Moreover, felsic and mafic rocks have responded in different ways to metamorphism and deformation and can therefore be used for different purposes. These petrographic variations will be systematically documented so that bedrock material properties can be better understood and accurately predicted.

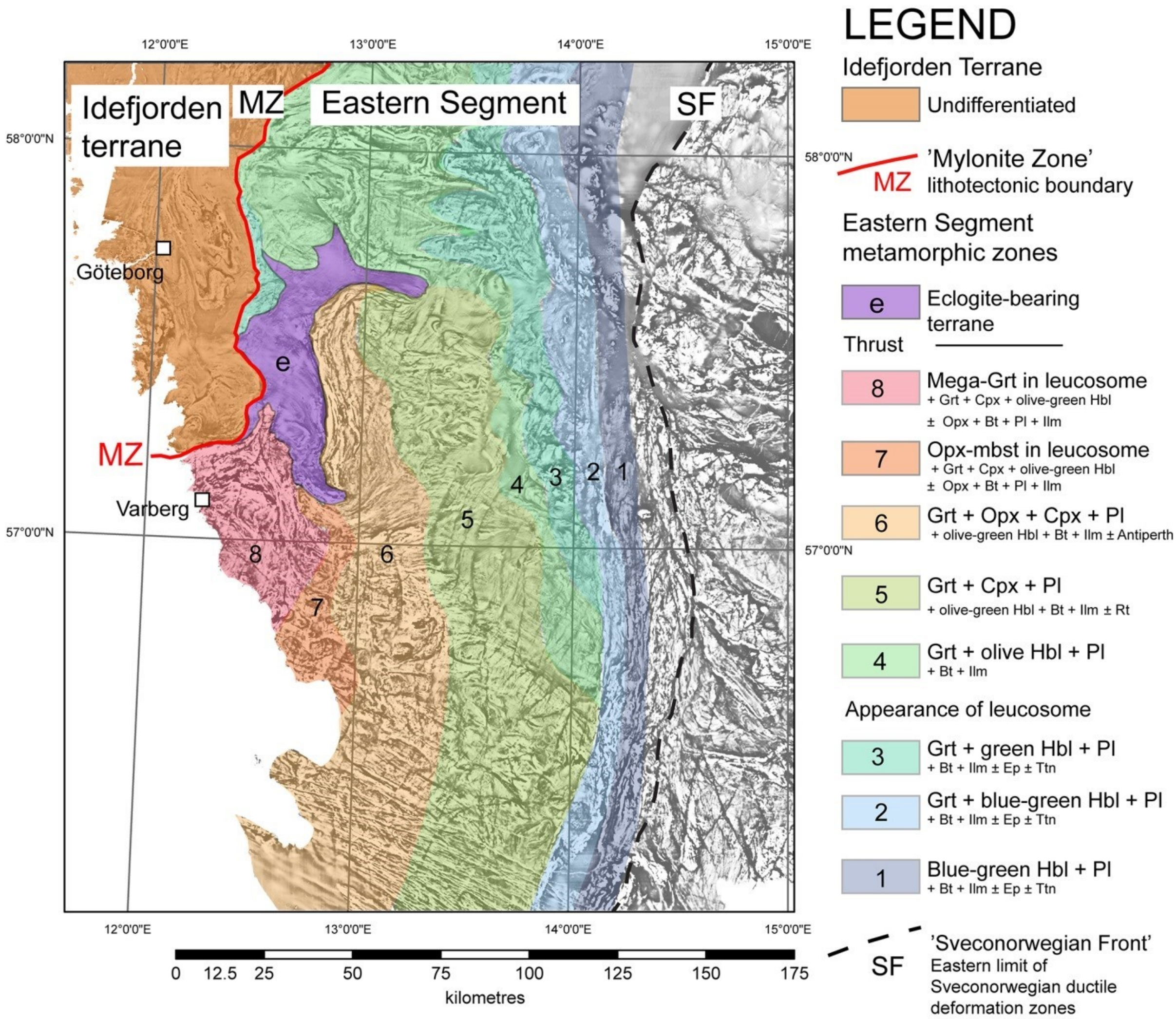

Figure 1. Metamorphic zones of the Eastern Segment, overlain on greyscale airborne magnetic anomaly map (differential field; source: Geological Survey of Sweden; softened contrast). Zones 1–8 represent gradually increasing metamorphic grade, from ~550 °C in the east to ~ 850 °C in the west. Metamorphic zones are based on assemblages in Fe-Ti rich metagabbro (n=276) of a ~75 km wide profile between the coastal areas and 130 km towards ENE; zones are preliminary extrapolated to areas north and south of this profile. The gently west-dipping Mylonite Zone (MZ, red line) is the lithotectonic boundary between the Eastern Segment and the western Sveconorwegian terranes, with the Idefjorden Terrane (shaded orange) positioned structurally immediately above the Eastern Segment. Sveconorwegian Front (SF) marks the eastern limit of non-penetrative Sveconorwegian deformation and metamorphic recrystallization. From Möller, C., Andersson, J., 2018. Metamorphic zoning and behaviour of an underthrusting continental plate. Journal of Metamorphic Geology 36, 567–589.

The project is designed as a PhD-project, based at the Department of Geology, Lund University, with contributions from collaborating advisors. The project will make use of existing data and samples from SGU's databases and archive, data and samples at LU, and run in close collaboration with SGU. The test area is a ~30 km wide and 120 km long profile from Värnamo to Varberg, along which we have defined qualitatively the metamorphic gradient. The project is designed as work packages comprising analysis of petrographic and technical properties of felsic and mafic rocks, respectively, and quantitative determination of temperature, pressure, and time of metamorphism for different metamorphic zones. These results will be extended into a prediction model of bedrock quality for a larger area of the Eastern Segment.

Improving the Weichselian chronology of northern Sweden

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Northern Sweden is a key area when it comes to reconstructing Late Quaternary environmental changes and the history of the Fennoscandian ice sheet (Lagerbäck 1988, Lagerbäck & Robertsson 1988). It is a core area of the former ice sheets and most of Sweden's known pre-LGM (Last Glacial Maximum) interstadial sites are found here (Lundqvist & Robertsson 2002, Kleman et al. 2008). However, several of these sites, which mainly contain fragmented records, are not dated by numerical methods or have only poor or partial age constraints. This makes correlation both between sites in the area and to other N European/N Atlantic or global records difficult, and in turn, hampers our possibility to understand ice-sheet dynamics and environmental variability during the Weichselian glacial period.

The aim of this project is to improve the geochronological constraints on the Late Quaternary glacial history and environmental change in northern Sweden 1) by developing luminescence dating methods that can provide better precision and 2) by dating new stratigraphic sites or re-dating known sites.

Some existing optically stimulated luminescence (OSL) ages from interstadial sites in northern Sweden have yielded ambiguous results. Our previous experience from dating two sites (Riipiharju and Rauvospakka) suggests that one reason for the poor results is the properties of the dated material (quartz), which have not been compatible with the standard analytical protocols that have been used. If we can more specifically identify the problems with the quartz in these areas, we may be able to develop an approach to work with these kinds of deposits. Feldspar has been attempted but preliminary results also seem at least partly inconclusive.

Empirical data from elsewhere in the world (e.g. Preusser et al. 2009, Jeong & Choi 2012) suggest that the luminescence characteristics of quartz – and thus its suitability for dating – is related to the geological history of the quartz grains, e.g. their origin and transport history. To evaluate this, we need to have a larger dataset and cover a larger area than our currently available data from northern Sweden. We have therefore re-analysed luminescence data from 65 samples (1921 subsamples) from Sweden and Norway that have previously been dated at the Lund Luminescence Laboratory. These samples come from Late Quaternary deposits and contain quartz of different bedrock origin and different (Quaternary) transport histories.

The first results of the luminescence data analyses show that there is large variability in the luminescence characteristics of quartz from Sweden and Norway, and that there is a spatial component to this variability. Much quartz appears quite dim, i.e. it has a relatively weak luminescence signal. This does not necessarily affect the accuracy of an OSL age, but may reduce precision, limit the possibility to do analyses of small-aliquot or single-grain dose distributions and increase the number of measurements rejected due to poor quality. Quartz from Quaternary deposits located within the area of the Caledonian orogen seem to be particularly dim, while quartz originating from Proterozoic provinces appears much brighter (stronger signal). Quartz from northern Sweden (Svecokarelian orogen) is also quite dim. Other factors that have been analysed include the shape of the luminescence signal. For an accurate OSL age, the luminescence signal should be dominated by a fast signal component (~have a strong peak). This is the case for a majority of Swedish-Norwegian samples, but there are exceptions. The regional differences in luminescence properties of quartz makes it interesting to further explore this as a provenance tool.

To increase our dataset from northern Sweden we carried out fieldwork in October 2018 and cored three basins in Veiki moraines in the Junosuando area. Only one core has so far been opened and revealed alternating sandy and organic beds. At the base there was a grey diamicton in which the corer stopped. OSL ages from the sandy beds and radiocarbon ages from plant macrofossils from the organic beds are pending.

References

Jeong, G. Y. & Choi, J.-H., 2012: Variations in quartz OSL components with lithology, weathering and transportation. *Quaternary Geochronology 10,* 320–326.

Kleman, J., Stroeven, A. P. & Lundqvist, J., 2008: Patterns of Quaternary ice sheet erosion and deposition in Fennoscandia and a theoretical framework for explanation. *Geomorphology 97,* 73–90.

Lagerbäck, R., 1988: The Veiki moraines in northern Sweden – widespread evidence of an Early Weichselian deglaciation. *Boreas 17,* 469–486.

Lagerbäck, R. & Robertsson, A.-M., 1988: Kettle holes – stratigraphical archives for Weichselian geology and palaeoenvironment in northernmost Sweden. *Boreas 17,* 439–468.

Lundqvist, J. & Robertsson, A.-M., 2002: Istider och mellanistider. In Fredén, C. (ed.): Sveriges Nationalatlas: Berg och jord, 120–124. Tredje utgåvan.

Preusser, F., Chithambo, M. L., Götte, T., Martini, M., Ramseyer, K., Sendezera, E. J., Susino, G. J. & Wintle, A. G., 2009: Quartz as a natural luminescence dosimeter. *Earth-Science Reviews 97,* 196–226.

BLÅ TILLVÄXT

Foto: Fredrik Theolin, SGU.

Fiberbankar – från kartläggning till risk för spridning av miljöföroreningar

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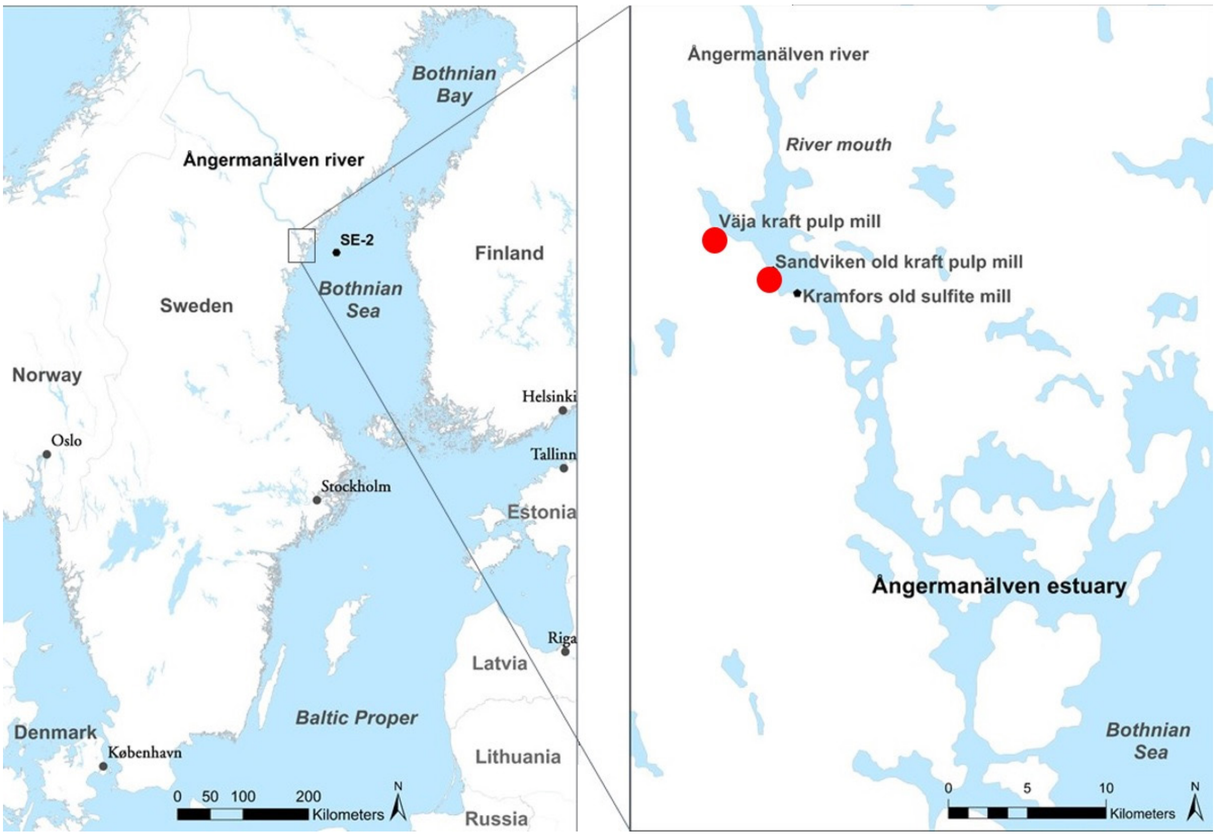
Östersjön är känt som ett av världens mest förorenade hav. På grund av dåligt vattenutbyte samt stor befolkningstäthet i havets avrinningsområden har under årens lopp stora mängder miljögifter ansamlats i sedimenten där de på många ställen begravs på stabila ackumulationsbottnar. Kartläggningar utförda av SGU (år 2010–2017) har avslöjat att omkring 29 km^2 av Norrlandskustens grunda havsbottnar täcks av en annan, sedan innan okänd typ av sediment: fiberhaltiga sediment (Apler m.fl. 2014, Larsson m.fl. 2017, Norrlin m.fl. 2016).

De fiberhaltiga sedimenten består i olika omfattning av trä- och cellulosafibrer som släppts ut med avloppsvatten av massaindustrin innan miljölagstiftning trädde i kraft år 1969. Avloppsvattnet innehöll också processkemikalier såsom tungmetaller och organiska klorerade ämnen. Idag ligger dessa gamla miljöföroreningar kvar på grunda vatten i s.k. fiberbankar bestående av uteslutande cellulosa eller i fiberrika sediment som är naturliga leror uppblandade med cellulosafibrer.

SGUs kartläggningsprojekt dokumenterade höga halter av miljöföroreningar i de fiberhaltiga sedimenten (Apler m.fl. 2014, Larsson m.fl. 2017, Norrlin m.fl. 2016). År 2014 initierades ett doktorandprojekt vilket också blev det första SGU-finansierade forskningsprojektet om fiberbankar. Projektet syftar till att studera om spridning från sediment till ovanliggande vatten sker och om det akvatiska systemet som studeras ser ut att kunna återhämta sig på naturlig väg. Under två fältkampanjer (år 2015 och 2017) med SGUs undersökningsfartyg S/V Ocean Surveyor, har sediment, porvatten och bottenvatten samlats i två studieområden, Väja och Sandviken, i Ångermanälvens mynningsområde (fig. 1). Dessa två områden ligger utanför sulfatmassafabriker som släppt ut fibrer till vattnet fram till 70-talet och där fiberbankar och fiberrika sediment finns representerade på botten.

I båda studieområden togs prover i sedimenttyperna fiberbank, fiberrikt sediment och naturlig postglacial lera för att studera skillnaderna mellan de olika bottentyperna. Proverna har därefter analyserats med avseende på tungmetallerna arsenik, kadmium, kobolt, krom, koppar, kvicksilver, nickel, bly och zink. Resultaten från den första provtagningskampanjen har publicerats och visar att metallerna kadmium och bly förekommer i halter som överstiger de gränsvärden då negativa effekter förväntas uppkomma i bottenlevande organismer (Apler m.fl. 2019).

De högsta halterna detekterades i fiberbankssediment, det vill säga i de sediment som består uteslutande av träfibrer. Analyserna av porvatten tyder dock på att metallerna sitter hårt fast i sedimentfasen på samtliga stationer då halterna var mycket låga eller under rapporteringsgränsen. Bottenvattnets halter av lösta och därmed biotillgängliga metaller var också mycket låga och sjönk ännu mer då bottnen under resuspenderats innan provtagning. Vid resuspensionen ökade halten partikelbundna metaller i koncentration och nivåerna av krom ökade till att överstiga vattenförvaltningens gränsvärde för god ekologisk status i ytvatten. Detta visar på risken med resuspension (orsakad av t.ex. strömmar eller båttrafik) som kan medföra försämrad vattenkvalitet samt spridning av partikelbundna föroreningar till nya platser i det akvatiska systemet.



Figur 1. Doktorandprojektets två studieområden, Väja och Sandviken, ligger i den inre delen av Ångermanälvens mynning ut mot Bottenhavet.

Referenser

Apler, A., Nyberg, J., Jönsson, K., Hedlund, I., Heinemo, S.-Å. & Kjellin, B., 2014: Fiberbanksprojektet – Kartläggning av fiberhaltiga sediment längs Västernorrlands kust. *SGU-rapport 2014:16.* Sveriges geologiska undersökning, 598 s.

Apler, A., Snowball, I., Frogner-kockum, P. & Josefsson, S., 2019: Distribution and dispersal of metals in contaminated fi brous sediments of industrial origin. *Chemosphere 215,* 470–481.

Larsson, O., Norrlin, J., Nordgren, P. & Dahlgren, A., 2017: Bottenkartering av misstänkt förorenade områden, Norrbotten. SGU diarienummer: 316-907/2017, 19 s.

Norrlin, J., Josefsson, S., Larsson, O. & Gottby, L., 2016. Kartläggning och riskklassning av fiberbankar i Norrland. *SGU-rapport 2016:21.* Sveriges geologiska undersökning,765 s.

Regional spreading of pollutants from fiber banks in the Bothnian Sea

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High levels of hazardous substances such as persistent organic pollutants (POP) and heavy metals in the environment imply health risks for humans and animals. Such substances have been found in residues, such as cellulose fibers, originating from discharged pulp and chemicals from old pulp and paper mills in Västernorrland, Sweden. These residues were transported with the rivers and accumulated forming large banks of fibers in calm waters and now cover large areas of lakes and the sea in the vicinity of these old factories. The fiber banks and fiber rich sediment distributions have been mapped in previous projects. These projects also studied the release, bioaccumulation and dispersal of pollutants from the banks and sediment on a small scale. It was found that the banks contain large amounts of heavy metals such as lead, mercury, cadmium, chrome and zink, as well as POP such as polychlorinated biphenals (OCBs), dichlorodiphenyltrichloroethane (DDT) and hexachlorobenzene (HCB).

The aim of this project is to study the dispersion of these substances on a larger scale using two different complementing types of models: 1) a multi-basin one-dimensional coastal zone model with high vertical resolution to study the dispersion of pollutants in the Ångerman river estuary, and; 2) a three-dimensional open ocean model, based on NEMO 3.6, with relatively high spatial resolution to study the dispersion in the open Bothnian Sea. The model study is supported by observations of currents and stratification in the outer parts of the Ångermanälven estuary.

During the first year of the project, the main emphasis has been on the observational part and on the dispersion modeling outside the estuary. Instruments were deployed in August to November 2018 when they were successfully recovered. The data show a general circulation that shifts between a standard estuarine circulation and an inverse estuarine circulation on time scales from days to weeks. This is related to varying density fields outside the estuary and has consequences for the circulation of pollutants within the estuary and for the export to the open sea. Ongoing work is focusing on obtaining forcing fields for the second half of 2018 to run the coastal zone model, so it can be validated against the observations. Model results from earlier years show similar patterns, so there is a good chance that the model works well. When the model is validated it will be run for a longer period of years and for different scenarios of pollutant release from the sediments, to study the spreading and how it may be influenced by biological productivity and sedimentation of organic matter.

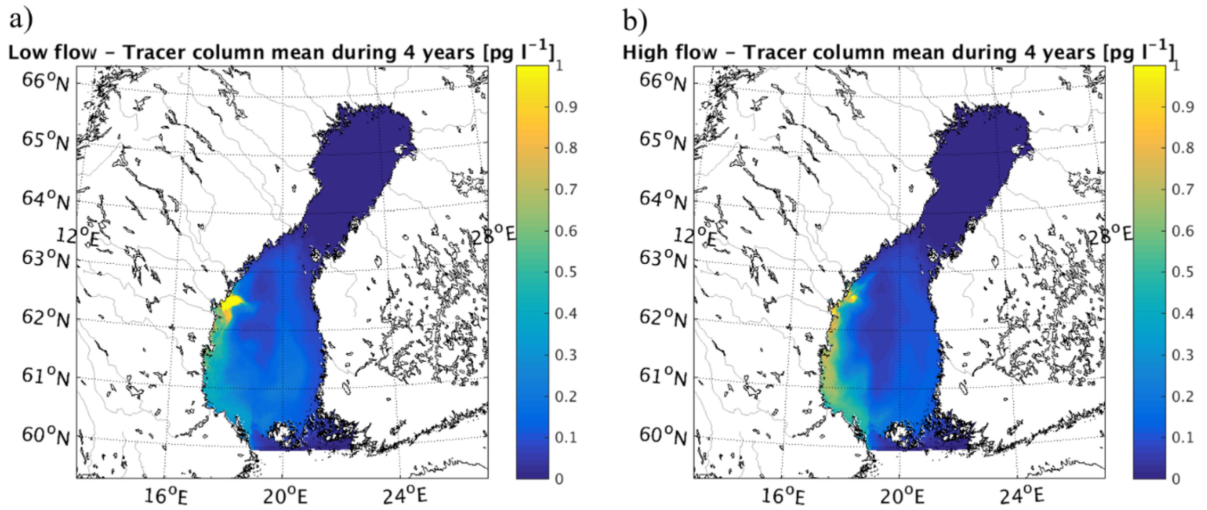


Figure 1. Mean concentration of tracer averaged over the first four years after the tracer release during low (a) and high (b) river discharge, respectively.

Preliminary dispersion studies have been performed with the regional three-dimensional model to see how pollutants exported from the estuary spread along the coast and dilute out into the Bothnian Seas. These studies have been performed with a passive tracer that is released momentaneously at the mouth of the Ångerman river and then left to advect and mix with the water currents. Figure 1 shows two examples where tracer has been released at low and high flow condition in the Ångerman river. The shown concentrations correspond to a release of 1 kg pollutant. For a pollutant with a 1 mg/kg dry weight concentration in the sediments this corresponds to a volume of about 2000–7000 m^3 wet sediment, or a lump of about 100 m x 10 m x 5 m of sediments that has collapsed and released its pollutant into the water. Some preliminary conclusions from these simulations are (i) that it takes about 2 years to spread out the pollutant over the whole Bothnian Sea, but that gradients are still present by then, and (ii) that low river flow during release causes higher impact close to the source, whereas the high river flow situation causes generally lower concentrations but higher impact on the coasts south of the source point.

In the continuation of this work we will define relevant pollutant release scenarios and include settling processes to estimate fluxes to the sediments both at the local estuary and regional scales. We will also need help to interpret these results in terms of ecological impacts and risks.

Ackumulering av metaller i Östersjöns sediment: betydelse för miljöövervakning och åtgärdsinitiativ/metal accumulation in the Baltic Sea sediments: implications for environmental monitoring programs and mitigation actions.

MARCELO KETZER OCH MATS ÅSTRÖM, LINNÉUNIVERSITETET

Sammanfattning

Belastningen av spårelement på Östersjöns vatten och sediment är ett stort miljöproblem, som är kopplat både till metallinflöde och till geokemin (t.ex. redox förhållanden) i vattnen och sedimenten. I detta projekt skall vi studera fördelningen (koncentrationer och species) av spårelement (bl.a. As, Hg och Cd) i porvatten och fasta fasen av sediment i Östersjön via sedimentproppar som kommer att samlas in i monitoreringskampanj som utförs av SGU på beställning från Naturvårdsverket.

Vi kommer att studera spårelementfördelningen in rum (ytliga och djupa vatten) och tid (pre-industriell tid till nutid) och kommer också att genomföra ett laboratorieexperiment in syfte att studera hur förändringar i geokemin (bl.a. redox) i vattnen påverkar metalltillgänglighet i Östersjön generellt, med särskild fokus på framtiden.

Geokemiska förändringar, som kan relateras till klimatförändringar, eutrofiering, inflöde av syrerikt vatten från Nordsjön och/eller föreslagna tekniska lösningar för att återställa syrerika bottenförhållanden, kommer att ha stor betydelse för huruvida spårelement fälls ut eller fastnar på fast fas (t.ex. inne i strukturen eller på ytan av mineral). Geokemiska förändringar kan emellertid också mobilisera spårelement till exempel via oxidation av sulfidmineral.

Projektet kommer att bidra till att bredda och förstärka pågående monitorering av Östersjön samt öka kunskapen om hur metaller beter sig vid förändrade geokemiska förhållanden. Det senare kommer att vara till stor hjälp vid prediktion av spridning av föroreningar (spårelement), risker för djur (och människan), och framtida miljöförhållanden i Östersjön i stort.

Abstract

The load of trace metals to Baltic Sea waters and their accumulation in the sediments is a major environmental problem, which is possibly connected to the geochemistry (e.g., redox conditions) of water and sediments. We propose to study in this project the distribution (concentration and speciation) of trace metals (such as As, Hg, and Cd) in pore waters and as solid phases in sediments of the Baltic Sea using sediment cores that will be obtained during the monitoring campaign to be performed by SGU to Naturvårdsverket in 2020.

We will study trace metals distribution in space (shallow and deep waters) and time (from pre-industrial times to present-day) and will also conduct laboratory experiments to investigate how changes in geochemical (e.g., redox) conditions in the water will affect metal availability in the Baltic Sea in the future.

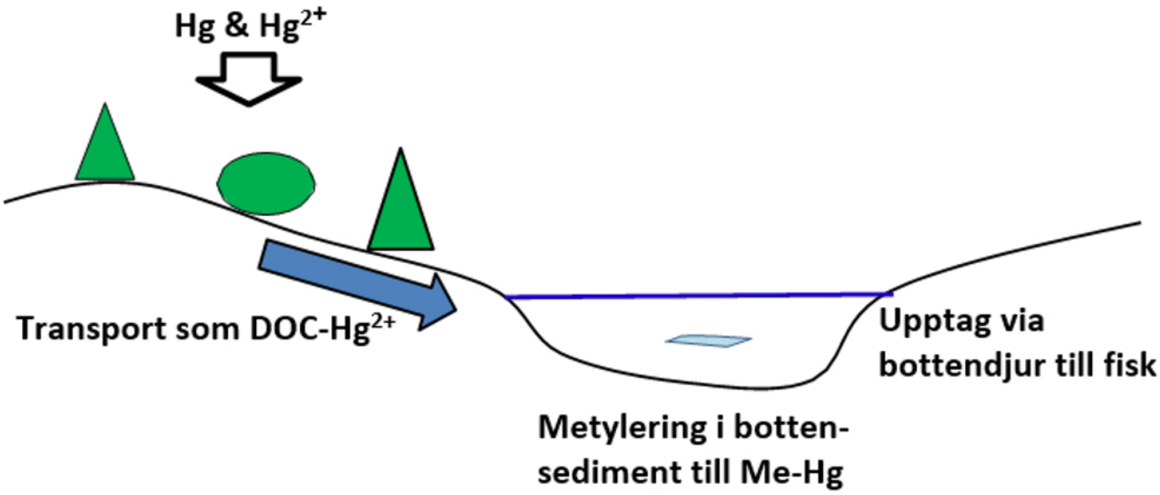
Changes in geochemical conditions, which can be related to climate change, eutrophication, invasion of oxygen-rich North Sea waters, and/or proposed engineering mitigation options to re-establish oxic condition of bottom waters, will play a key role in determining whether certain trace metals may be precipitated and immobilised in a solid phase (e.g. in the structure of a mineral or adsorbed in a solid surface) or in a more mobile phase (dissolved in waters). Changes

in geochemical condition may, however, mobilise trace metals that are in more stable phases if geochemical conditions are altered owing to, for instance, oxidation of sulphide minerals.

We strongly believe that our project will add value to current monitoring efforts in the Baltic Sea and will improve our understanding of the geochemical behaviour of trace metals in sediments and water. The latter will be of great help to predict spreading of contaminants (trace metals), risks of contamination to animals (and humans), and the future environmental conditions of the Baltic Sea in general.

Kvicksilver I fisk – minskar selen upptaget?

GUNNAR JACKS, KUNGLIGA TEKNISKA HÖGSKOLAN, ELIN NILSSON, MALÅ KOMMUN



Andel sjöar i Norden med för höga kvicksilverhalter i gädda

Region	Andel sjöar med > 0,5 mg/kg Hg i gädda
Södra Sverige	70 %
Mellersta Sverige	80 %
Södra Finland	50 %
Norra Finland	10%
Södra Norge	60 %
Mellersta Norge	25 %

Sedan industrialismens genombrott har stora mängder Hg transporterats från Central-Europa till Norden och deponerats i marken där det bundits till organiskt material. Halten i markens ytskikt är i dag ca 5 gånger det preindustriella värdet eller 0,35 mg/kg. Från markens ytskikt kan kvicksilvret transporteras till vattendrag och sjöar i form av organiska komplex. I sjösediment kan detta kvicksilver under reducerande betingelser metyleras metyleras, sannolikt av sulfatreducerande bakterier. Detta Hg-Me kan sedan via födoämneskedjor transporteras till fisk ock ackumuleras där. Vi har i Sverige rekommendationen att kvinnor i fertil ålder inte bör konsumera fisk med mer än 0,5 mg/kg.

Selen och kvicksilver har många relationer Arcagni m.fl. (2013). Flera undersökningar har visat att selen kan motverka ackumulation i fisk (Hultberg 2002). Sverige och Finland är selenbrist-områden. I Finland har man sedan 25 år tillbaks tillsatt selen till handelsgödsel. Detta har visat sig påverka djurhälsan och öka selenhalt i bröstmjölk (Alfthan m.fl. 2015). Vi har i Sverige miljöer med förhöjda selenhalter, alunskiffrar (Jacks m.fl. 2018), prekambriska svartskiffrar (Jacks m.fl. 2013) och områden där sulfidmalmsavfall deponerats (Lindeström & Grahn 1982).

Syftet med detta projekt är att analysera fisk från sådana miljöer för att se om denna fisk har lägre halter kvicksilver. Ett antal lämpliga projekt har identifierats i Västerbotten vid Norsjö och Malå där ett antal sjöar påverkade av sulfidmalmsavfall finns. Samma sak gäller ett par sjöar i

Bergslagen (t.ex. Lindeström & Grahn 1982). Vid en exkursion med studenter från KTH till en gruvsjö i Bergslagen köpte vi en gädda och analyserade den och den visade sig 1/10 av den förväntade kvicksilverhalten. I Jämtland finns stora områden påverkade av Kambrisk alunskiffer och där jämte andra metaller även selen finns i måttligt förhöjda halter (Jacks & Mörth 2018).

Förhoppningsvis kan detta projekt identifiera an lämplig halt av selen för att påverka kvicksilverhalten i fisk. En fortsättning på detta projekt kan då vara att konstruera en ”slow release”-anordning för att förhöja selenhalten till lämplig nivå i sjöar med fisk som har förhöjda halter av kvicksilver.

Referenser

Alfthan, G., Eurola, M., Ekholm, P., Venäläinen, E-R., Root, T., Korkalainen, K., Hartikainen, H., Salminen, P., Hietaniemi, V., Aspila, P. & Aro, A., 2015: Effects of nationwide addition to fertilizers on foods and animal and human health in Finland. *J. Trace elements in Med. and Biol. 31,* 142–147.

Arcagni, M., Campbell, L., Arribére, MA., Marvin-DiPasquale, M., Rizzo, A., Guevara, SR., 2013: Differential mercury transfer in the aquatic food web of a double basined lake associated with selenium and habitat. *Sci. Tot. Environ. 454–455,* 170–180.

Hultberg, H., 2002: Treatment with low-low dosage of selenium in lakes to decrease the content of Me-Hg in fish. *IVL-rapport B 1487,* 39 pp.

Lindeström, L. & Grahn, O., 1982: Antagonistic effects to mercury in some mine drainage areas. *Ambio 11*, 359–366.

Jacks, G., Slejkovec, Z., Mörth, CM., Bhattacharya, P., 2013: Redox-cycling of arsenic along the water pathways in sulphidic metasediments in N Sweden. *Appl, Geochem. 35*, 35–43.

Jacks, G. & Mörth, CM., 2018: Assessment of environmental risks in a black shale area in Central Sweden. Eco-Tech Conference, Kalmar, Sweden. 19–21 Nov. 2018.

Skyllberg, U., 2003: Kvicksilver och metylkvicksilver i mark och vatten – bindning till humus avgörande miljörisk. *Fakta Skog nr 11,* SLU, 4 s.

Skyllberg, U., 2008: Competition among thiols, inorganic sulphides and polysulphides for Hg and Me-Hg net production. *J. Geophys. Res. Biogeosciences 113*, 14 pp.

GRUNDVATTEN OCH GEOFYSIK

Foto: Patrik Johansson, SGU.

Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)

LISBETH HILDEBRAND, GEOLOGICAL SURVEY OF SWEDEN

GeoERA is a so-called ERA-NET (H2020 ERA-NET Cofund Action). This means that it is not a single research project but rather a research programme. This programme is established and run by a group of 33 national and 15 regional geological survey organisations from Europe. Together these organisations constitute the GeoERA consortium.

The programme is funding 15 transnational research projects. The projects have been selected through a two phased call process. Funding of the projects is partly covered by the GeoERA consortium members (70%) and partly by European Commission (30%). The programme has a total budget of 30.3 M€, and the projects will run for three years, started in July 2018. Only members of the GeoERA consortium are beneficiaries of the GeoERA projects.

The objective of GeoERA

GeoERA is part of the strategic vision of EuroGeoSurveys, which is to deliver a Geological Service for Europe. This vision aims to establish a common European geological knowledge base and joint research focusing on European policy.

GeoERA will contribute to the optimal use and management of the subsurface, by maximising its added value for **energy, raw materials, and groundwater**, while minimizing environmental impacts and footprint. Therefore, GeoERA is funding projects that support 1) a more integrated and efficient management and 2) more responsible and publicly accepted exploitation and use of the subsurface. GeoERA projects should address the development of (parts of) the following deliverables:

- Interoperable and transnational data and information services on the distribution of **geo-energy, groundwater and raw material resources** in Europe and harmonized methods to assess those;
- common assessment frameworks and methodologies supporting better understanding and management of the water-energy-raw materials nexus and potential impacts and risks of subsurface use;
- a geological knowledge base, existing of objective and seamless data, information and expertise to service European, national and regional policy makers, industry and other stakeholders and facilitate them in policy and decision-making processes.

SGU is participating in the following nine projects:

Raw Materials

1. FRAME – Forecasting and Assessing Europe's Strategic and Raw Materials Needs. http://www.frame.lneg.pt/
2. EuroLithos – European Ornamental stone resources. http://geoera.eu/projects/eurolithos1/
3. Mintell4EU - Mineral Intelligence for Europe. http://geoera.eu/projects/mintell4eu7/
4. MINDeSEA - Seabed Mineral Deposits in European Seas. Metallogeny and Geological Potential for Strategic and Critical Raw Materials. http://geoera.eu/projects/mindesea/

Groundwater

5. HOVER - Hydrological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems. http://geoera.eu/projects/hover8/
6. RESOURCE - Resources of groundwater harmonized at cross-border and pan-European scale. http://geoera.eu/projects/resource9/
7. TACTIC - Tools for Assessment of Climate change Impact on groundwater and adaptation Strategies. http://geoera.eu/projects/tactic/

Geoenergy

8. MUSE - Managing Urban Shallow geothermal Energy. http://geoera.eu/projects/muse/

Information platform

9. GIP-P - GeoERA Information Platform. http://geoera.eu/projects/development-of-an-information-platform-to-support-management-and-provision-of-data-for-the-three-other-themes/

These links are available April 18, 2019.

GeoERA will end in December 2021, but efforts to sustain and further develop a Geological Service for Europe under the next framework program is under progress.

The status and future of coastal groundwater – implications for groundwater quality and quantity under increased pressures and climate change

ROLAND BARTHEL, UNIVERSITY OF GOTHENBURG

The overall objectives of the project are (i) to improve the understanding of the complex hydrogeological conditions in coastal areas in Sweden, thereby contributing to a well-organized knowledge-base of coastal groundwater in Sweden; (ii) to support the development of guidelines to decrease the pollution and draught vulnerability of private and other small-scale water supply systems; and (iii) to provide Swedish coastal communities with specific tools needed for the planning and management of water supply, wastewater and problems related to contamination of groundwater. The specific research questions to be answered by this research are:

1) What is the actual status of saltwater intrusion and related problems in Sweden?

2) How can we predict the future behavior and impact on human-environmental systems of coastal groundwater in view of increasing development and climate change?

3) Which are the most relevant investigation strategies and tools for planning and management of coastal groundwater resources on a municipal level and in coordination with national and EU policies?

The initial focus of the project before project start was on the problem of "salt water intrusion" which is the result of a specific situation in coastal areas: groundwater below the sea floor typically has salinity similar to seawater. This salty groundwater extends also beneath the shoreline under the terrestrial system. On land, fresh rainwater can infiltrate into the ground and form a stable layer of fresh groundwater that floats on the saltwater due to its lower density. This phenomenon allows fresh groundwater to be pumped and used even on small islands or very close to the shoreline. However, the freshwater layer is sensitive to changes of the pressure in the groundwater system (e.g., because of changes in groundwater recharge or pumping from groundwater) and to sea level change. According to a relatively simple physical law based on the different density of fresh- and seawater a rise of the sea level or a drop of the groundwater level will cause the interface between salt and freshwater to move upwards and landwards, i.e., locations that previously had fresh groundwater the water will become salty. Less than 1% of saltwater (~250 mg/l Cl-) will thereby result in groundwater that can no longer be used as drinking water. While natural changes (climate change, sea level rise) occur quite gradually, over-pumping can locally lead to a very fast salinization of fresh water aquifers. To reverse this situation, i.e. to remove the salt from an aquifer by natural recharge, is almost impossible within human timeframes.

In the meantime, after about half of the project time has passed (the project started with a delay as it was difficult to employ a post-doctoral research fellow to perform the main part of the work), the focus has shifted from seawater intrusion to other questions. Sea water intrusion can occasionally form a problem in Swedish coastal areas, but other problems are also abundant: water scarcity (most groundwater usage in coastal areas is small-scale from very local aquifers), contamination (often microbiological due to lack of proper sanitation) and proximity of wells (in particular on islands). Furthermore, municipalities struggle not so much with the hydrogeological conditions, but with the lack of guidelines, regulations and laws. Therefore, a bigger focus than initially planned has so far been on legal, societal and economic questions.

Another finding of significance is that, in particular with respect to drilled wells in bedrock, the situation is so complex and location-specific, that the goal of creating general methodology seems unrealistic. It may be argued that this was clear from the beginning, but we can now show, mainly due to an intensive field measurement campaign on the Koster islands, that this is the case.

Work carried out so far:

An extensive literature analysis and data collection was performed. On the international level, the literature review of peer reviewed scientific literature is ongoing and almost completed. A manuscript will be submitted to an international journal (Hydrogeology Journal). On the national level, a large number of reports, guideline documents and other literature were retrieved and partly evaluated using thematic analysis.

Two main surveys were sent to all coastal municipalities in Sweden asking about their perception of groundwater related problems in coastal areas and how they deal with such problems. The main objective was to evaluate if there are any standard methodologies, which are applied in more than one municipality. The surveys were followed up by telephone interviews and backed up by literature studies. This work was supported by a Master's Thesis (Geuze 2018). One focus was on Uddevalla municipality as a case study. The collaboration with Uddevalla was backed up by a Master's Thesis and on Bachelor's Thesis in fall 2017 and spring 2018 (Jillerö 2018, Kling-Jonasson and Müller 2018).

The field observations focused on the Koster Islands were a number of Bachelor's and Master's Theses were performed and completed in 2017 and 2018 (Andersson & Engdahl 2017, Fredriksson & Wennerbäck 2017, Granberg 2017, Ljungkvist & Ekström 2017, Merisalu 2017). The results of those theses are now being combined in two scientific articles that cover 1) the natural hydrogeological conditions on Koster, 2) the relation between the natural conditions and the socio-economic framework. In total the work on Koster resulted in more than 300 from about 80 wells water samples that were fully analyzed, a large number of continuous measurements of water level, temperature and electric conductivity, borehole logs, geophysical measurements and more.

In addition, we are working on a typology of Swedish coastal aquifers. This typology of Swedish coastal aquifers is a by-product of a project financed by FORMAS which was not initially planned but will contribute to the present research.

References

Andersson, H. & Engdahl, H., 2017: Evaluation of the potential of artificial groundwater recharge on a small island in western Sweden – a pilot study. Bachelor Thesis Thesis, Gothenburg University, 61 pp.

Fredriksson, F. & Wennerbäck, M., 2017: Groundwater on the Koster Islands With a Special Focus on Groundwater Chemistry, University of Gothenburg, 53 pp.

Geuze, I., 2018: Standardising coastal groundwater resource assessments in sweden – a feasibility study. Master's Thesis Thesis, Univerity of Gothenburg, 69 pp.

Granberg, M., 2017: An assessment of the inorganic groundwater quality in a heterogeneous hydrogeological island environment – a case study on the Koster Islands, Sweden (Draft). Master's Thesis Thesis, University of Gothenburg.

Jillerö, I., 2018: Enskilda brunnar och dricksvattenförsörjning – En fallstudie med fokus på att generera en överblick av problem, handläggning, reglering och kunskap i en västsvensk kustkommun. Master's Thesis Thesis, University of Gothenburg, 77 pp.

Kling-Jonasson, I. & Müller, R., 2018: En hydrogeologisk undersökning av förutsättningarna för småskalig vattenförsörjning på Sveriges västkust - en fallstudie i Munkeby. Bachelor's Thesis Thesis, University of Gothenburg, 97 pp.

Ljungkvist, A. & Ekström, L., 2017: Groundwater Quality and Quantity on the Koster Islands: a preliminary study with focus on Saltwater Intrusion, Universtity of Gothenburg.

Merisalu, J., 2017: Sustainability of groundwater resources in coastal areas – a case study on the Koster islands, Sweden. Master's Thesis Thesis, University of Gothenburg.

Quantification of coupled hydro-mechanical processes in deep hydraulically transmissive fractures by downhole field tests and modeling

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Understanding the coupled hydro-mechanical processes in deep hydraulically transmissive fractures is of key importance for many major applications, such as Enhanced Geothermal Systems (EGS), unconventional hydrocarbon exploration, nuclear waste disposal, geological storage of CO2 and mining. In many geo-energy related applications the fluid-injection related induced seismicity is also of particular concern.

A key question to be addressed is how fracture aperture and permeability respond to fluid pressure changes under in situ stress conditions. Increasing pressure may lead to fracture shearing, fracture propagation, and new connections to nearby fractures. Fracture propagation may cause local micro-seismicity. Currently a great need is the understanding of the time-evolution of the coupled pressure-flow and fracture-deformation-and-propagation process, which may lead to micro aseismic and seismic events

To address the HM coupled processes in deep fractures, this project brings together two major infrastructures and capabilities, namely the ICDP drilled 2.5 km deep scientific investigation borehole COSC-1 in Åre, whose geohydrological properties have carefully been investigated in an earlier SGU project, and the newly enhanced SIMFIP (Step-Rate Injection Method for Fracture In-Situ Properties) hydro-mechanical measuring method and specialized tool developed at Lawrence Berkeley National Laboratory, USA, that allows real-time in-situ determination of hydraulic and mechanical properties and their time evolution using coupled pressure/deformation measurements in boreholes. Cutting edge HM measurements will be carried out at COSC-1 in carefully selected hydraulically transmissive fractures and the HM response will be determined, along with monitoring of the seismic response through sudden changes in pressure and flow data. This is a joint Uppsala University –Lawrence Berkeley National Laboratory project, where Uppsala work is supported by SGU and LBNL work by US DOE.

Previous results from COSC-1 borehole have identified hydraulically transmissive fractures with one example shown in Figure 1 below. In this project six separate deep zones has been tentatively selected for testing with an enhanced SIMFIP tool, namely (i) three deep hydraulically transmissive fractures, identified at 506 m, 696 m, and 1210 m and (ii) two deep hydraulically non-transmissive fractures, identified at 595 m and 1214 m, where the latter is a steep dipping fracture and (iii) one zone without any apparent open fracture, identified at 715 m.

For each chosen interval, simultaneous measurements of time-evolution of pressure, flow rate and fracture-deformation-and-propagation process will be conducted. Microseimic events may be recognized by sudden changes in pressure, flow rate and rock deformation, which will be studied in detail. Actual seismic signals are expected to be small. Positioning SIMFIP tool at target depth section is done by matching γ log profiles to old EC/T/γ data used to identify inflow fractures. Furthermore, prior and after the actual HM measurements, we will also carry out hydraulic conductivity measurements with FFEC techniques, to characterize the fracture conductivities before and after the test. The exact positioning of the tool and the additional hydraulic measurements have required additional developments to the SIMFIP tool. The actual experimental campaign is planned for June 2019, to be followed by data analysis and modeling of the results.

The results will be analyzed and modelled with state-of-the-art modeling in order to obtain an improved understanding of the coupled HM processes in deep hydraulically transmissive fractures and related key processes which may lead to induced seismicity. The issues to be addressed in the modeling include: (i) Change of fracture aperture and deformation of borehole rock wall due to injection pressure at increasing and then decreasing pressure levels; (ii) Potential for fracture shearing with shear dilation with accompanied 3D rock wall deformation; (iii) Potential for fracture propagation, including sudden cracking with accompanying sudden pressure and flow rate changes; (iv) Estimation of micro seismic energies; (v) Calculation of flow and pressure signatures associated with propagating fracture intersecting another transmissive fracture or zone; and (vi) Effect of temperature difference between injection water and in situ rock.

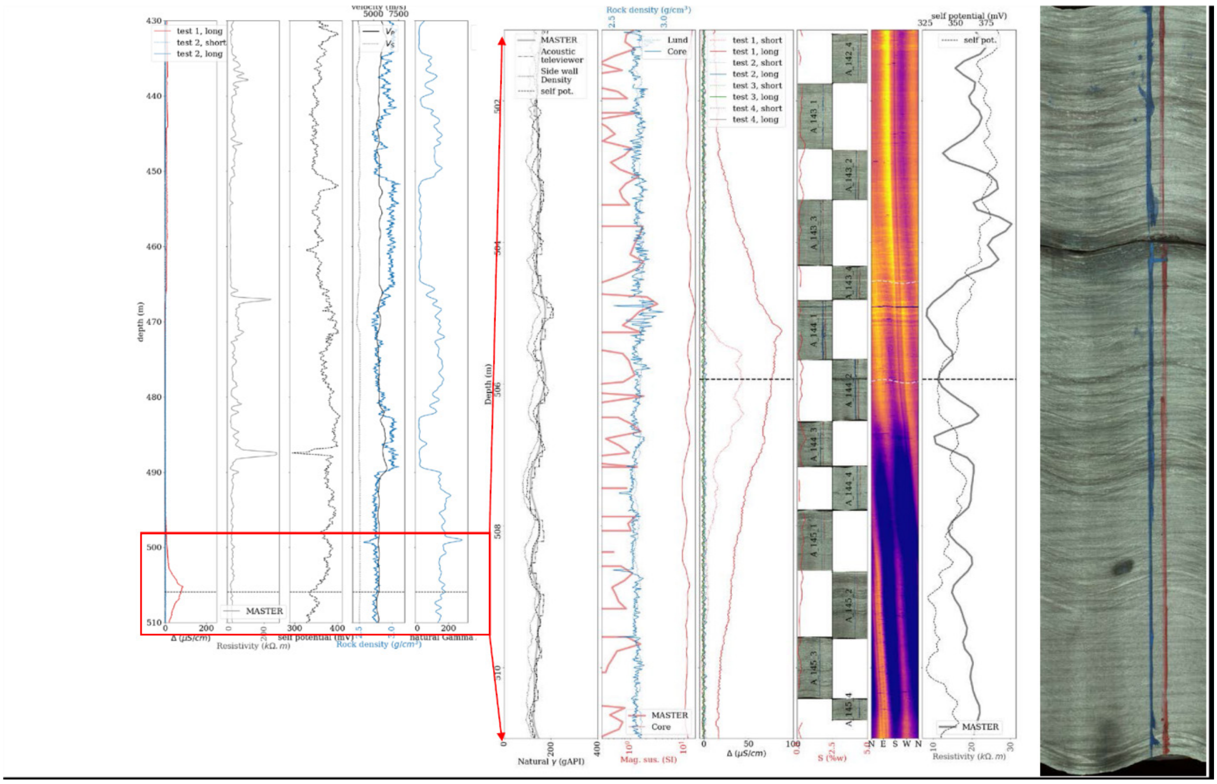

Figure 1. Example of a zone to be studied: 506 m – a hydraulically transmissive fracture. Panels on the left-hand-side show the location of the hydraulically conductive fracture (in red box) to be tested along with geophysical profile (Master) used to position the SIMFIP tool. Panels on the right-hand-side show the zoom-in to the test interval, with the most right-hand-side figure showing a picture of a 0.4-m core section containing the target fracture.

Geophysical investigation of the Arvidsjaur volcanics and the Archean-Proterozoic boundary

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The discovery of a large volume, low grade Cu-Au-Mo mineralization at Lill-Laverberget in Norrbottens län was reported by Boliden Mineral AB in 2012. The mineralization is located approximately 1 km south of the old Laver mine that was in production from 1934–1946. SGU reported in December 2014 that the Laver area is of specific geological interest in relation to the supply of minerals.

The new Laver deposit may serve as a proxy for similar types of ore bodies and it is therefore important that the new Laver deposit is sufficiently well documented with respect to geophysical signature before this is put into production. Models derived from these data may afterwards be evaluated based on comparisons to the information derived from future mining activity. Such a comparison will enable validation of the geophysical methods and thereby serve as valuable guidelines in the exploration for similar deposits. The mineralizations are likely related to hydrothermal activity caused by the intrusion of the porphyritic intrusions, but the mineralizations are not specific to a particular host rock type. The mineralizations are vein- and alteration-related and are therefore much more difficult targets for geophysical exploration compared to exploration for massive sulphide.

The geophysical data utilized in this study are airborne magnetic data provided by SGU and 22 new magnetotelluric (MT) stations acquired for this project during September 2018 Three out these stations were excluded in the modelling due to problems with noise.

SGU airborne magnetic data have been processed and analyzed in order to extract structural information about the subsurface. Various techniques based on pseudo gravity gradient tensor estimation were performed. Result of using an “edge”-detection technique is shown in Figure 1. The “edge” detection technique highlights boundaries between structures having differences in magnetic susceptibility.

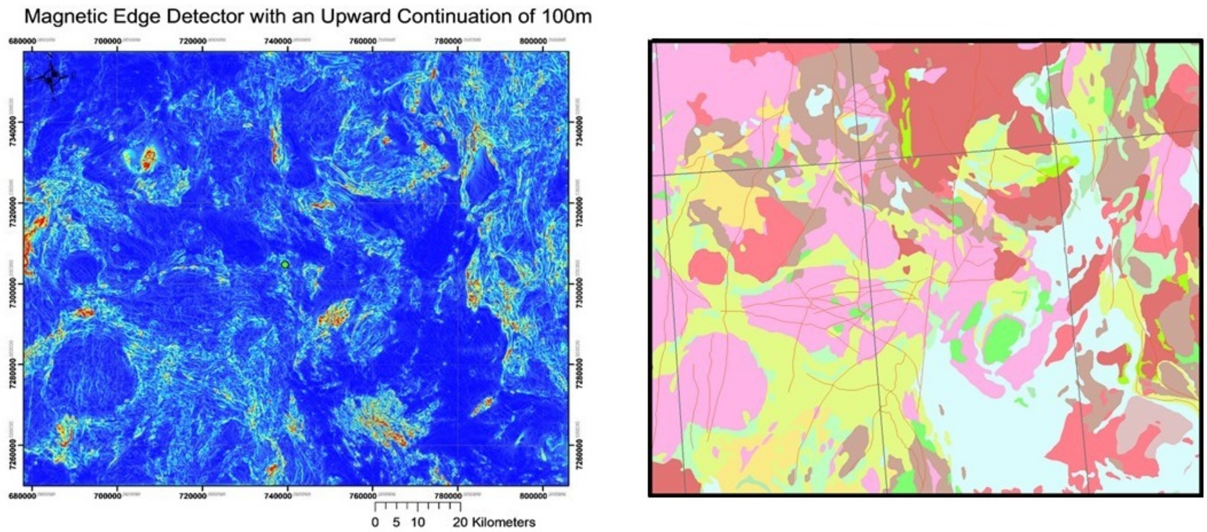

Figure 1. (Left panel) The Edge detection function applied on the magnetic pseudo gravity anomaly field. The green dot is the location of Laver. (Right panel) The interpreted structures (red lines) from the ED function on top of the geology map.

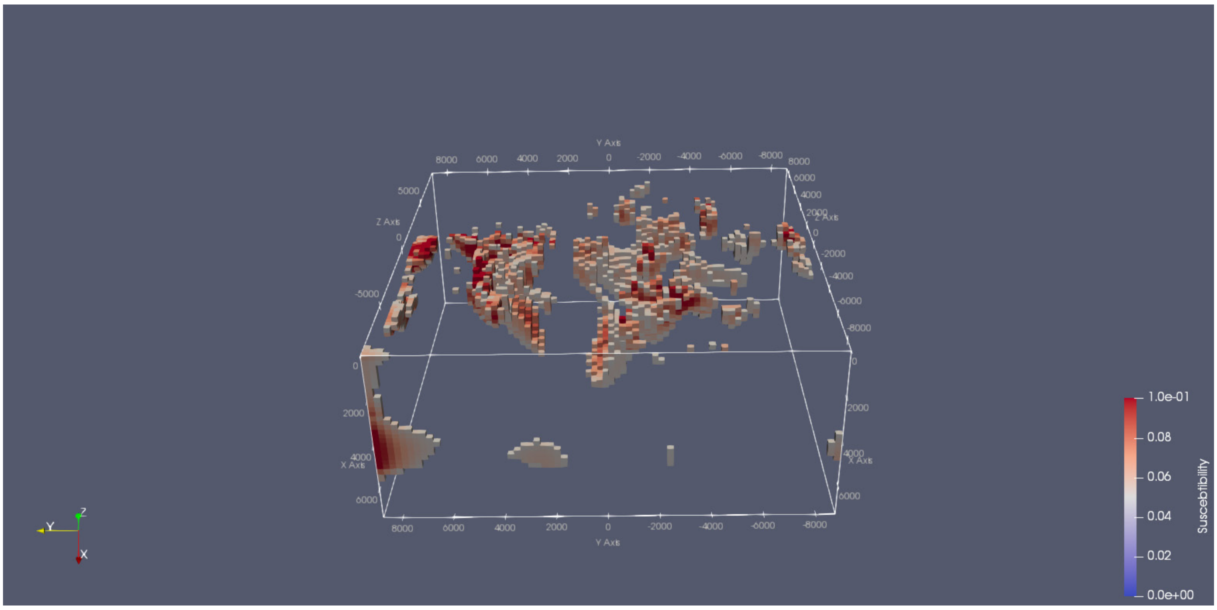

Figure 2. The Magnetic susceptibility model for the Laver area created in the SimPEG software and visualised in Paraview. The cells that are shown are a reduced dataset consisting of cells with a magnetic susceptibility higher than 0.05. The coordinate system shows X as the depth, Y points towards west and Z towards north.

The magnetic data from the Laver region has been modelling in 3D using the SimPEG open source software. Results from the data inversion are shown in Figure 2.

The MT data (Fig. 3) are indicative of fairly resistive structures (> 3000 Ohmm) but three sites (NO. 1. 19 & 22) have indications of near surface good or moderate conductive structures. Site no. 1 is close to the old Laver deposit whereas 19 and 22 are roughly 8 km towards SE and NW of Laver respectively. Site 19 points towards the most conductive structure. A 3D inversion of the MT data has been performed. The site separation is not sufficiently dense to provide a detailed model of the 3D conductive structure close to the surface. More work is needed with respect to modelling of the data. Results from 2D modelling is shown in Figure 3.

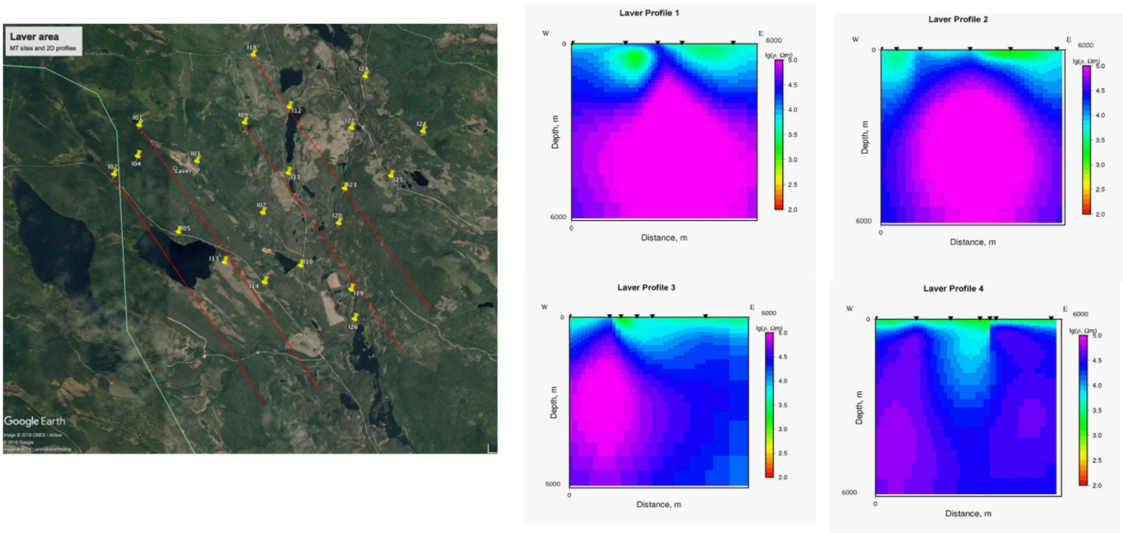

Figure 3. Left panel shows location of MT stations and four profiles (red lines) used for 2D modelling. Right panel shows the resistivity structures along profiles 1-4 ordered sequentially from SW to NW.

The presented work is based on a MSc thesis by Erik Bjänndal supervised by Maxim Smirnov and Thorkild M. Rasmussen. More field work with controlled source EM and MT is planned in order to get more detailed information about the conductivity structures in the Laver area.

Results from 2D and 3D modelling of airborne geophysical data. Examples from Sweden and Norway

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Airborne geophysical data are routinely used for mapping and modelling geology in a wide range of applications and scales. This includes near surface engineering studies, groundwater modelling, mineral prospecting, bedrock mapping and deep crustal studies. In many cases the acquired airborne data are modelled with a technique called inversion where a model that fits the observed data to a pre-determined level is sought by using an iterative scheme. Geological settings and their complexity determine the inversion's complexity which in turn affect the assumptions made about the dimensionality of the problem as well as the computation time.

In this study two examples from inversions of airborne geophysical data are presented. The first example is about comparison between resulting models of one-dimensional (1-D) and two-dimensional (2-D) inversions of frequency-domain helicopter electromagnetic (FHEM) data. Synthetic resistivity models including complex 2-D scenarios are modelled using 1-D and 2-D inversions to study the differences caused by improper dimensionality assumptions. Both 1-D and 2-D inversion routines where then tested on a real FHEM dataset acquired by the Geological Survey of Norway (NGU) in Byneset, Norway (Baranwal et al. 2017). Main aim of the survey is to use FHEM data in mapping clay layers/marine sediments and cross-check it with 2-D resistivity and refraction seismic. Compared to 1-D inversion, the 2-D FHEM inversion results show better correlation with a model retrieved from the ground based 2-D electrical resistivity tomography and refraction seismic data along parts of a flight-line in the area.

The second example demonstrates utilization of existing borehole and geological information in the 3-D inversion of airborne magnetic field data. Lelièvre et al. (2009) discuss the importance of inclusion of geological knowledge in the inversion of geophysical data as constraints or a-priori information. The priori knowledge is usually gained by the laboratory measurements of the physical properties of rock samples, for example magnetic susceptibility, or in some cases the known values extracted from other surveys with similar geological settings. We have processed and modelled in 3-D the existing airborne magnetic data acquired by the Geological Survey of Sweden (SGU) over the Blötberget mine with known iron oxide-apatite orebodies. The mine is in the Bergslagen, a historical mining district in Sweden. The 3-D modelling is carried out in two steps. First the data are modelled using just different types of regularization parameters e.g. smoothing regularization and upper-lower susceptibility bounds. We then use the existing information from the boreholes drilled in the mining area in the form of a reference susceptibility model in the inversion process. The resulting susceptibility models in both cases are then compared. The comparison reveals that use of borehole information in the 3D inversion of the magnetic field data as a-priori information has considerably improved the 3D model in resolving the deeper parts of the iron orebody as well as its geometry. Moreover, compared to the unconstrained models, use of constrains at the borehole locations has limited the depth extent of high susceptibility zones at areas adjacent to the mining area. This means some of the artefacts imposed by smoothing regularization are eliminated in the final model.

References

Baranwal, V. C., Rønning, J. S., Solberg, I.-L., Dalsegg, E., Tønnesen, J. F. & Long, M., 2017: Investigation of a sensitive clay landslide area using frequency-domain helicopter-borne EM and ground geophysical methods. *Landslides in sensitive clays, Springer international publishing,* 475–485.

Lelièvre, P. G., Oldenburg D.W.& Williams N.C., 2009: Integrating geological and geophysical data through advanced constrained inversions. *Exploration Geophysics (Collingwood, Australia), 40,* 334–341. doi: 10.1071/EG09012.

PRIMÄRA OCH SEKUNDÄRA RÅVAROR

Foto: Erik Jonsson, SGU.

Structural vectoring of mineralized systems in northern Norrbotten

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Northern Norrbotten is one of the most active mining- and exploration areas in Europe and hosts several large and world-class metal deposits of different types. Prominent examples are the Kiirunavara and Malmberget massive magnetite deposits and the Aitik Cu-Ag-Au (-Mo) deposit. Many of the deposits in northern Norrbotten have been studied over the past century in terms of mineralogy, petrology and geochemistry with the aim of clarifying their individual genesis (e.g. Geijer 1910, Parak 1975, Wanhainen 2005). Despite these abundant deposit-scale studies, only few authors dealt with the structural control on mineralizations in northern Norrbotten or with the tectonic framework in which these deposits occur.

This project aims at defining the tectonic framework for ore formation in northern Norrbotten, showing structural controls on individual hydrothermal events and the effects of deformation during later overprinting events. Abundant field mapping and structural analysis was performed in key areas throughout northern Norrbotten with the focus on the coupling between structures and alterations. The key areas for this study include the Kiruna area, the Svappavaara-Kiskamavaara area and the Eustiljåkk-Allavaara areas. Results from this study were furthermore reflected in the light of previous projects on the Nautanen and Fjällåsen-Allavaara areas (Andersson 2019, Bauer et al. in prep.) and key areas from the Barents project (Lynch et al. 2018, Bergman 2018).

Results show multiple deformational, metamorphic and hydrothermal events in northern Norrbotten. The most obvious features are a series of sub-parallel, crustal-scale shear zones that area spatially related to a majority of mineralizations (Fig. 1). A combined study on stratigraphy and structures in the Kiruna area (Andersson 2019) indicates an early extensional event at approximately 1.89 Ga, coinciding with the emplacement of massive magnetite orebodies, which is correlatable to a regional-scale extensional event inferred from geochemical signatures of intrusive rocks (Sarlus et al. 2017, 2018). The earliest recognizable fabric in northern Norrbotten is a penetrative tectonic cleavage (S1) that is interpreted to result from a regional deformational (D1) and related metamorphic (M1) event. Cross-cutting relationships with early Svecofennian intrusive rocks suggest an approx. 1.89–1.87 Ga timing (Lynch et al. 2018). This coincides with the inferred porphyry copper formation at Aitik (Wanhainen et al. 2012) and with studies from the Skellefte-district where an age of 1.87 Ga is suggested for a regional deformation event (e.g. Skyttä et al. 2012). Deformation intensity and metamorphic grade varies drastically across northern Norrbotten and abrupt changes of conditions can be observed across some of the crustal-scale shear zones. A distinct association of amphibole-magnetite-scapolite shows clear relationships to the D1 deformation and is suggested to have form prior or early during deformation.

The S1 fabric was subsequently folded into F2-folds that generally lack an axial-planar parallel cleavage. A spaced cleavage with brittle-ductile characteristics can be observed sparsely in few localities. The F2 folding was accompanied with reactivation of the crustal-scale shear zones as either shearing or brittle reactivation locally forming pseudotachylites, resulting in the truncation of the F2 folded, early Svecofennian supracrustal units at Nautanen and Kiskamavaara. This D2 deformation event is accompanied by syn-tectonic mafic and felsic intrusion activity that implies an age around 1.80–1.78 Ga (Sarlus et al. 2017, 2018). Especially the felsic Lina-type intrusions show a clear relationship to remobilisation of minerals and a spatial relationship to a regional potassic alteration. Hydrothermal alterations are characterized by K-feldspar, sericite, epidote, garnet, amphiboles, magnetite, pyrite, bornite, chalcopyrite and calcite and appear as irregular patches growing across the S1 fabric or as veins and coatings on brittle fractures (Andersson et al.

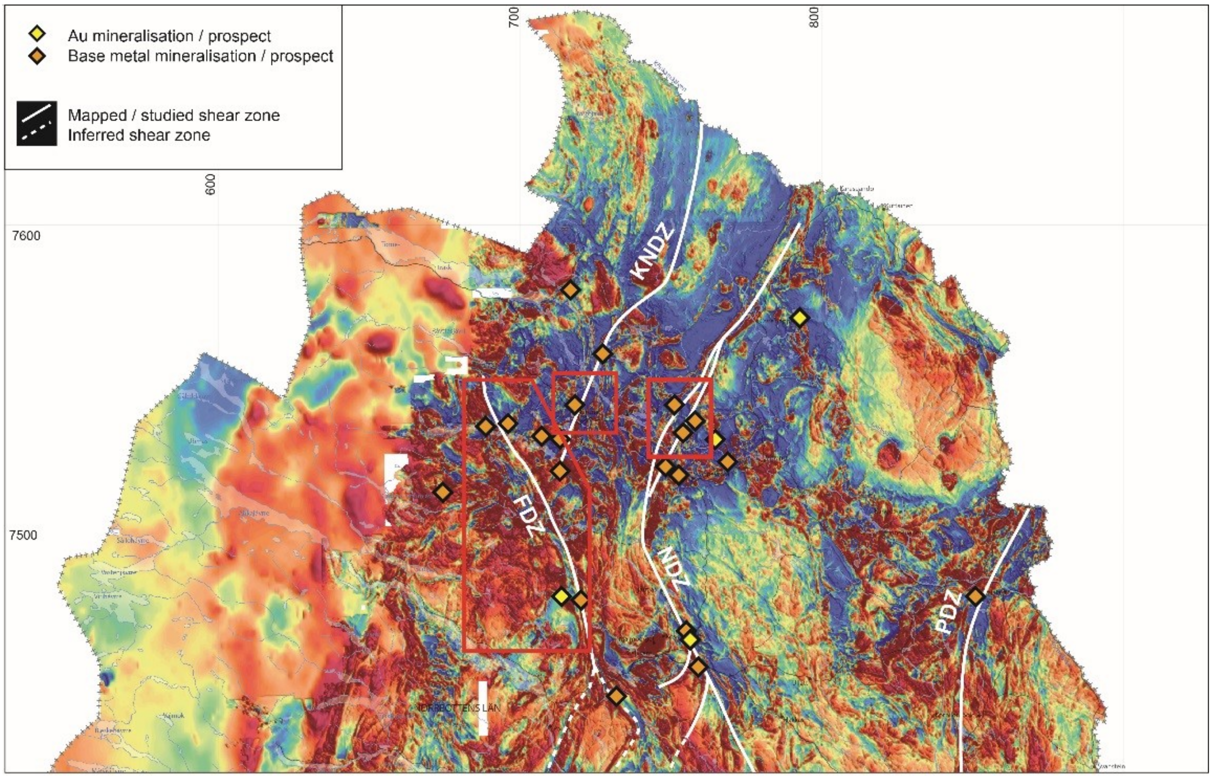

Figure 1. Structural overview map of northern Norrbotten showing the key areas Kiruna, Eustiljåkk-Allavaara and Svappavaara-Kiiskamavaara. Major shear zones: FDZ: Fjällåsen deformation zone, KNDZ: Kiruna Naimakka deformation zone, NDZ: Nautanen deformation zone, PDZ: Pajala deformation zone. Modified after Wedmark (2012), Andersson (2019) and Metzger (2019). Coordinate system: SWEREF99.

2019, Lynch et al. 2018, Bauer et al. in prep.). Due to the close relationship to the abundant intrusive rocks and the upper crustal character of deformation we assign this event to a phase of regional-scale contact metamorphism and related hydrothermal activities.

References

Andersson, J.B.H., 2018: Structural evolution of two ore-bearing Palaeoproterozoic metasupracrustal belts in the Kiruna area, northwestern Fennoscandian Shield: Licentiate thesis, Luleå University of Technology.

Bergman, S., 2018: Geology of the Northern Norrbotten ore province, northern Sweden. *Rapporter och meddelanden 141.* Sveriges geologiska undersökning, 432 p.

Geijer, P., 1910: Igneous rocks and iron ores of Kiirunavaara, Luosavaara and Tuolluvaara, Scientific and practical researches in Lapland arranged by Luossavaara-Kiirunavaara Aktiebolag: Stockholm, Norstedt & Söner, 278 p.

Lynch, E.P., Bauer, T.B., Jönberger, J., Sarlus, Z., Morris, G.A. & Persson, P.-O., 2018: Petrological and structural character of c. 1.88 Ga meta-volcano sedimentary rocks hosting iron oxide-copper gold and related mineralization in the Nautanen–Aitik area, northern Sweden. In: Bergman, S., 2018: Geology of the Northern Norrbotten ore province, northern Sweden. *Rapporter och meddelanden 141.* Sveriges geologiska undersökning, 432 p.

Metzger, N., 2019: Structural controls on the shear zone hosted, IOCG-style Kiskamavaara Cu-Co-Au mineralization. MSc-thesis, Luleå University of Technology. 82 pp.

Parák, T., 1975: The origin of the Kiruna iron ores. *Geological Survey of Sweden C709,* 209p.

Saruls, Z., Andersson, U. B., Bauer, T. E., Wanhainen, C., Martinsson, O., Nordin, R. & Andersson, J. B. H., 2017: Timing of plutonism in the Gällivare area: implications Proterozoic crustal development in the northern Norrbotten ore district, Sweden: Geological Magazine, p. 1–26.

Sarlus, Z., Martinsson, O., Bauer, T., Wanhainen, C., Andersson, J. & Nordin, R., 2018: Character and tectonic setting of plutonic rocks in the Gällivare area, northern Norrbotten, Sweden: GFF, p. 1–20.

Skyttä, P., Bauer, T. E., Tavakoli, S., Hermansson, T., Andersson, J. & Weihed, P., 2012: Pre-1.87 Ga development of crustal domains overprinted by 1.87 Ga transpression in the Palaeoproterozoic Skellefte district, Sweden: *Precambrian Research, v. 206–207,* p. 109–136.

Wanhainen, C., 2005: On the Origin and Evolution of the Palaeoproterozoic Aitik Cu-Au-Ag Deposit, Northern Sweden. A Porphyry Copper-Gold Ore, Modified by Multistage Metamorphic-Deformational, Magmatic-Hydrothermal, and IOCG-Mineralizing Events. Doctoral thesis, Luleå University of Technology. 151 pp.

Wanhainen, C., Broman, C., Martinsson, O. & Magnor, B., 2012: Modification of a Palaeoproterozoic porphyry-like system: Integration of structural, geochemical, petrographic, and fluid inclusion data from the Aitik Cu-Au-Ag deposit, northern Sweden. *Ore Geology Reviews, v. 48,* p. 306–331.

Wedmark, M., 2012: Magnetic anomaly map of Sweden, scale 1:1 million. *Sveriges geologiska undersökning K 424.*

Textural and chemical characterization of sulphide minerals for improved beneficiation and exploration, Skellefte district, Sweden

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A recently started project at LTU focusing on sulphides in and around the Rävliden North VMS deposit, jointly funded by Boliden Mineral and the Geological Survey of Sweden. The project will be carried out by a PhD student supervised by Dr. Nils Jansson, Prof. Christina Wanhainen and Dr. Helen Thomas with industrial advisors consisting of representatives from Boliden Mineral's departments of Exploration and Mineral Technology.

The project aims to produce a spatial model of the distribution and geochemistry (major and trace elements + sulphur isotopes) of sulphides in and around the Rävliden North deposit in the western Skellefte District. The model will be integrated with a temporal model of the history of crystallization, growth, recrystallization and remobilization of sulphides. Special emphasis will be placed on understanding the mineralogical and textural controls on the distribution of base, precious, critical and deleterious elements in the deposit, and how this impacts on the recoveries of these elements during ore processing. The results will also complement ongoing exploration in the area by increasing the understanding of the deposit genesis, as well as investigating the development of primary or secondary geochemical and mineral chemical haloes.

The Rävliden North deposit constitutes one of the major discoveries in the Skellefte District during the 21th century, yet no description of the deposit exists in the scientific literature. The project will contribute to national or international programs aiming at documenting Fennoscandian ore deposits such as Malmdokumentation and FODD by providing detailed data on the different ore types.

The inclusion of critical elements in this study represents a unique opportunity to assess the deposit-scale variations in critical element content in sulphide minerals, as well as the potential of these elements as by-products during planned mining. This may complement ongoing initiatives specifically aiming to secure the European supply chain of critical elements.

Work so far during the start-up phase of the project has involved recruiting a PhD student, selection of detailed study profiles and reconnaissance petrographic work. A reference collection from earlier work (e.g. Johansson, 2017) and legacy data have been assembled to serve as an early framework for the study. This work has greatly aided during detailed planning of the first sampling and logging campaign.

References

Johansson, S., 2017: Ore mineralogy and silver distribution at the Rävliden N volcanogenic massive sulphide deposit, Skellefte district, Sweden. MSc thesis, Luleå University of Technology, 117 p.

Dating brittle deformation events in faults from central Sweden: Preliminary results from the Söderström fault (Stockholm)

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In Sweden, timing of brittle deformation of many important faults remains poorly constrained, as only very few studies providing absolute geochronological constraints exist. This SGU supported study focuses on dating brittle structures (faults) in central Sweden, with study areas in central Jämtland, Lovisagruvan and central Stockholm. The last study area is the focus of this presentation, from where we present new although preliminary results aiming to better define the age of brittle deformation accommodated by the Söderström Fault by dating authigenic and synkinematic illite separated from the fault rocks using K-Ar dating. The fault transects Svecokarelian (2.0–1.8 Ga) migmatites of sedimentary and granitoid origin previously deformed in the ductile regime.

The Söderström Fault is recognized as a key brittle deformation zone that strikes east-west through Söderström, a water body that separates the capital suburbs Gamla Stan and Södermalm in central Stockholm. Relatively little is known about this fault, but there are indications for still active dextral strike-slip motion along the fault. Reverse S-side-up movement of up to several hundreds of meters has been reported. Samples from this fault were obtained from a drill core that cross-cut the fault and preserve clay-rich gouge. Sample preparation allowed separation of clay minerals in five different size fractions (<0.1 µm, 0.1–0.4 µm, 0.4–2 µm, 2–6 µm and 6–10 µm).

Dating of two samples (SGL18-0001A and SGL18-0003A) shows a range of ages from ca 360 to 660 Ma and ca 450 to 760 Ma, whereby the younger ages are from the finer- and the older ages from the coarser size fractions. The younger sample (SGL18-0001A) yields distinct ages in the two finest grain size fractions, <0.1 and 0.1–0.4 µm, at ca 360 Ma and ca 390 Ma, respectively. SGL18-0001A also exhibits similar ages in the coarsest grain size fractions, 2–6 and 6–10 µm, with ca 650 Ma to ca 660 Ma, respectively. Similarly, sample SGL18-0003A yields consistent ages in the two coarsest grain size fractions, with ages of ca 790 Ma and ca 760 Ma, whereas the three smaller grain size fractions yield gradually younger ages, from ca 670 Ma to ca 550 Ma and ca 450 Ma. A detailed study of the identification of the clay mineral fractions is still ongoing, and it will help constrain the actual amount of authigenic illite in the finest fraction as well as the polytypism of the clay crystallites.

These preliminary dates indicate a protracted brittle deformation history of the Söderström Fault. Gouge formation postdates the Sveconorwegian orogeny (1.1–0.9 Ga), and is more likely related to extensional events during the opening of the Iapetus Ocean. The youngest ages coincide broadly with the age of the Caledonian orogeny and may represent the influence of the far-field orogenic stress. A similar timing of brittle deformation has also been observed by Alm et al. (2004) and Drake et al. (2009) in eastern and northern Sweden, and in southeastern Sweden, respectively, by dating specific mineral growth events. Further work is ongoing, with respect to dating of structures in Lovisagruvan and central Jämtland, where we expect the first results to be generated during the spring of 2019.

References

Alm, E., Sundblad, K. & Huhma, H., 2004: Sm-Nd isotope determinations of low-temperature fluorite-calcite-galena mineralization in the margins of the Fennoscandian Shield, *SKB Report R-05-66,* 58 pp.

Drake, H., Tullborg, E.-L. & Page, L., 2009: Distinguished multiple events of fracture mineralisation related to far-field orogenic effects in Paleoproterozoic crystalline rocks, Simpevarp area, SE Sweden, *Lithos, 110,* 37–49.

Cleaning up the record – reanalysing zircon samples from southwest Sweden and the Protogine Zone by SIMS

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The technique for radiometric age determinations in Sweden has evolved from K-Ar and Rb-Sr whole rock dating and early U-Pb studies in the 1960:ies, through U-Pb multigrain zircon dating by TIMS (thermal ionization mass spectrometry) in the 1970:ies and 80:ies, to spot analyses in single zircons or other minerals using SIMS (secondary ionization mass spectrometry) from the 1990:ies and onwards, and most recently also LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry). This development has lead not just to increased precision of ages, but above all, increased accuracy inasmuch as real magmatic or metamorphic ages can be separated from spurious mixed ages or ages affected by inheritance.

In this project, zircon samples from the southern part of the Sveconorwegian province (Eastern segment) and the Protogine Zone (PZ) in southwest Sweden, previously analysed by multigrain TIMS, will be reanalyzed by U-Pb spot analyses using the Nordsim ion microprobe (SIMS). This will help in cleaning up the Swedish U-Pb age record, as expressed in the SGU radiometric age data base and the digital bedrock age map, from spurious mixed or otherwise imprecise or erroneous ages. These analyses will also be complemented by Hf isotope analyses of the same zircons by LA-ICP-MS at the Vegacenter, in order to shed some more light on the origin of the magmas forming these rocks. The analyses of initial Hf isotope composition in the zircons complement earlier whole rock Sr and Nd isotope analyses from the same samples, but can give more information on the origin of the magmas forming these rocks, as the Hf analysis of multiple individual zircon grains may give a spread in values, indicative e.g. of mixing of magmas from different sources, rather than not just the average isotope values given by whole rock analysis.

Table 1. Summary of old TIMS U-Pb age determinations from the southern part of the Protogine Zone and the Eastern Segment of the Sveconorwegian province.

Sample	Locality	Rock type	U-Pb TIMS age
Southern part of the Protogine Zone (upper unit of Eastern Segment; Johansson 1990):			
84082	Önnestad	Syenite	1224 +140/-14 Ma
84083	Gumlösa-Glimåkra (Åraslöv)	Gneissic granite	1204 +16/-15 Ma
86010	Gumlösa-Glimåkra (Vanås gods)	Gneissic granite	1232 +80/-46 Ma
76314	Flackarp	Gneissic granite	1531 ± 8 Ma
86011	South of Alvesta	Gneissic granite	1711 ± 3 Ma
Southern part of the Eastern Segment (west of the ProtogineZone; Johansson et al. 1993):			
84093	Mölle, Kullaberg	Granite	1497 +47/-34 Ma
85015	Stenberget, Romeleåsen	Red gneiss	1557 +32/-27 Ma
85016	Beden, Romeleåsen	Granodiorite	1449 +23/-11 Ma
85017	Vägasked	Grey gneiss	1613 ± 6 Ma
85018	Skäralid, Söderåsen	Granite	1575 +77/-61 Ma
85019	Örkelljunga	Charnockite	1452 +347/-47 Ma

As can be seen in the summary diagram of U-Pb zircon ages from southern Sweden in Figure 1, there are some spurious ages not coinciding with known tectono-magmatic events, e.g. the Mullsjö and Flackarp samples in the Protogine Zone (Upper unit of the Eastern Segment). I am responsible for some of these spurious, imprecise or otherwise suspect U-Pb TIMS ages, such as the Flackarp age (Johansson 1990, Johansson et al. 1993; Table 1), and these samples will be reanalyzed (with the exception of the Beden granodiorite, which has already been dated more precisely to 1463 ± 9 Ma by Petersson et al. (2013)). So far, zircons from the remaining ten samples have been handpicked and cast into two polished epoxy mounts for U-Pb and Hf isotope analysis, but no analytical results are available so far. It is, however, believed that this will help in cleaning up the SGU database and the geological record from such spurious age data, as well as cleaning up my own publication record before I retire and somebody else does it.

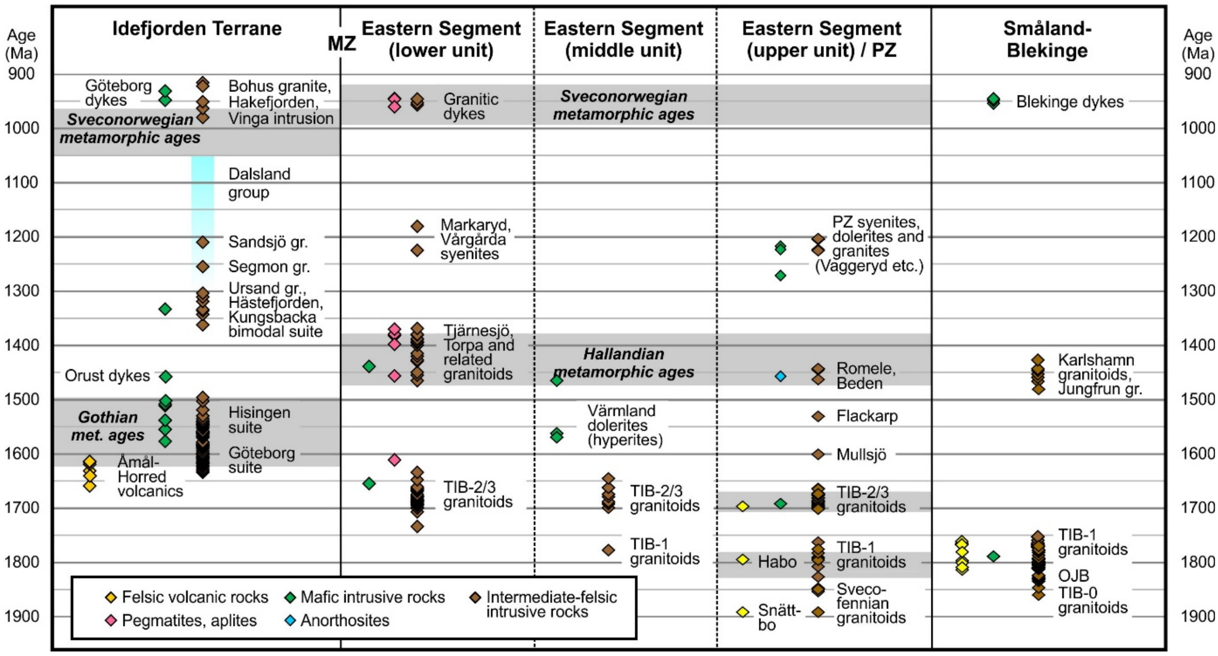

Figure 1. Diagram of U-Pb (and a few Pb-Pb) ages within different lithotectonic units in southern Sweden. Data from the age data base of the Geological Survey of Sweden (SGU). The coloured symbols mark individual magmatic uranium-lead ages (on zircon or in a few cases monazite or baddeleyite), or in a few cases (PZ-intrusions) lead-lead ages on zircon, in different rock types. Only ages interpreted as magmatic (or in some cases uncertain interpretation) with an uncertainty in age below ±20 million years have been included. The grey shaded fields mark intervals of metamorphic uranium-lead ages (on zircon, monazite or titanite) from the database of SGU.

References

Johansson, Å., 1990: Age of the Önnestad syenite and some gneissic granites along the southern part of the Protogine Zone, southern Sweden. In C.F. Gowers, T. Rivers & B. Ryan (eds.): Mid-Proterozoic Laurentia-Baltica. *Geological Survey of Canada Special Paper 38,* 131–148.

Johansson, Å., Meier, M., Oberli, F. & Wikman, H., 1993: The early evolution of the Southwest Swedish Gneiss Province: geochronological and isotopic evidence from southernmost Sweden. *Precambrian Research 64,* 361–388.

Petersson, A., Scherstén, A., Andersson, J. & Möller, C., 2013: Zircon U-Pb and Hf-isotopes from the eastern part of the Sveconorwegian Orogen, SW Sweden: implications for the growth of Fennoscandia. *Geological Society of London Special Publication 389,* 281–303.

Kritiska metaller och mineral: aktuell verksamhet och framtida möjligheter

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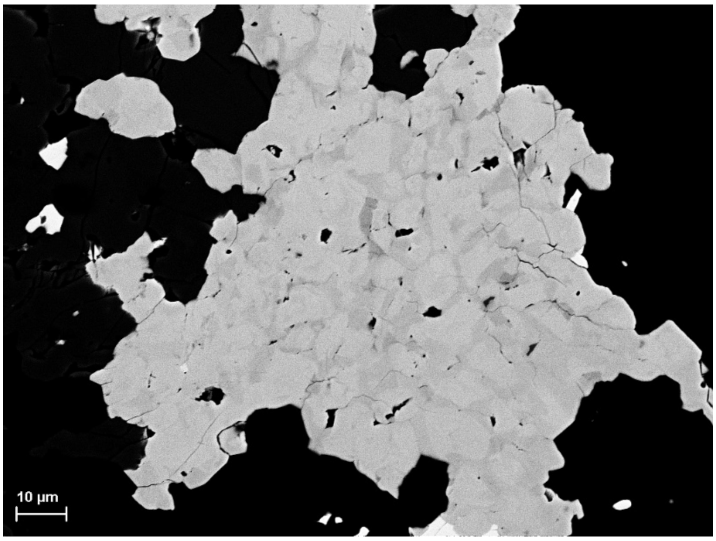
Flera pågående liksom nyligen avslutade samverkansprojekt med SGU, Uppsala universitet (UU) och andra samarbetspartners är inriktade mot kritiska metaller och mineral, deras förekomster, bildningssätt och mineralogiska karaktär. Huvudteman är och har varit sällsynta jordartsmetaller (eng. *Rare Earth Elements, REE; fig. 1*) och deras förekomst i olika typer av mineraliseringar, främst i Bergslagen med metallogenetisk omnejd; apatitjärnmalmer, både såsom varande EUs och Sveriges viktigaste järnmalmer, men också som potentiellt viktiga framtida källor för REE och fosfor; indium, gallium, germanium och andra sällsynta metaller och halvmetaller i paleoproterozoiska mineraliseringar inklusive varphögar. Verksamheten inom dessa områden har lett till flera upptäckter och kunskapshöjningar med avseende på deras mineralogi, bildningssätt och förekomst, genom såväl forskningsinsatser som kursmoment och studentarbeten.

Grunderna till konceptet kritiska metaller och mineral och deras problematik har således också inkorporerats i form av föreläsningar för olika kurser vid UU, inklusive CEMUS. Detta har i sin tur bland annat lett till de tematiska seminariedagar som avhållits på SGU i Uppsala under 2017 och 2018, liksom presentationer i andra sammanhang, som för Näringsdepartementet och under Almedalsveckan. Sedan 2018 har också en helt ny kurs fokuserad på detta tema tagits fram och hållits vid UU inom ramarna för det internationella SINReM-mastersprogrammet. Pågående och nyss avslutade EU-projekt med relevans för dessa råmaterial, som EURARE, X-Mine och FRAME, innefattar också samverkan med främst UU, dels med vissa projektfrågeställningar, men också framtagande och handledning av examensarbeten. Bland mera uppenbara framtida möjligheter till samverkan för forskning och utveckling inom området framstår fortsatt arbete inom mineraliseringstyperna som nämnts ovan, men också satsningar på antimon, kobolt och litium samt konfliktmetaller som tantal och niob som särskilt eftersträvansvärda.



Figur 1. Svepelektronmikroskopbild med s.k. BSE-detektor visar det nyupptäckta mineralet gadolinit-(Nd) som varierande ljusgrå kristallaggregat i en karbonat-silikatgrundmassa (svart) från en järn-REE-mineralisering vid Norberg, Bergslagen. Detta fram till nyligen okända mineral kan vara en lokalt viktig värd för den kritiska metallen neodym (Nd), en av nyckelkomponenterna i bland annat moderna vindgeneratorer och elbilar. Gråskalan i kristallerna styrs främst av förhållandet mellan halterna neodym och cerium i mineralet. Vitt är volframmineralet scheelit, svart är grundmassekarbonater och -silikater. Foto: Erik Jonsson.

MinLand project – Access to land a key issue for mining, and the X-Mine project

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MinLand project

Competition about use of land is fierce within Europe. Currently, the need for metals, construction raw materials and industrial minerals is increasing. Therefore, there is a large need for access to land for exploration and extraction of mineral raw materials. Since land use is not always well synchronized when it comes to extraction of minerals Eu has recognised the need for exploring good practices for sharing between the EU member states for guidelines regarding how to reach a system where land is not sterilised and a harmonised land use and mineral policy strategy that will allow extraction of metals, construction and instrustrial mineral within Europe. In a global context we are also obliged to take a shared burden of extraction and not only consumption.

The H2020 project MinLand therefore deals with:

- Establishing a data base regarding legislation and policy regarding minerals land use and general land use
- Analyse different land use cases of mineral exploration and extraction
- Develop a guideline regarding successful process of exploration and extraction with focus upon an optimised and sustainable land use process and mineral extraction
- The guide line will focus upon good case examples

The project is coordinated by the Geological Survey of Sweden and has a broad participation of partners covering land use authorities, mining inspectorates, industrial and professional organisations, NGOs and a broad stakeholder group.

X-Mine project

The X-MINE project supports better resource characterization and estimation as well as more efficient ore extraction in existing mine operations, making the mining of smaller and complex deposits economically feasible and increasing potential European mineral resources (specifically in the context of critical raw materials) without generating adverse environmental impact.

The project will implement large-scale demonstrators of novel sensing technologies improving the efficiency and sustainability of mining operations based on X-Ray Fluorescence (XRF), X-Ray Transmission (XRT) technologies, 3D vision and their integration with mineral sorting equipment and mine planning software systems.

The project will deploy these technologies in 4 existing mining operations in Sweden, Greece, Bulgaria and Cyprus. The sites have been chosen to illustrate different sizes (from small-scale to large-scale) and different target minerals (zinc-lead-silver-gold, copper-gold, gold) including the presence of associated critical metals such as indium, gallium, germanium, platinum group metals and rare earth elements.

The pilots will be evaluated in the context of scientific, technical, socio-economic, lifecycle, health and safety performances. The sensing technologies developed in the project will improve exploration and extraction efficiency, resulting in less blasting required for mining. The technologies will also enable more efficient and automated mineral-selectivity at extraction stage, improving ore pre-concentration options and resulting in lower use of energy, water, chemicals and men hours (worker exposure) during downstream processing.

The consortium includes 5 industrial suppliers, 4 research/academic organizations, 4 mining companies and 1 mining association.