A Practical Toolkit addressed to Mineral Exploration and Mining Companies

September 2021

Editors

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NEXT
New Exploration Technologies

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As a geologist, dealing foremost with solving day-to-day technical exploration issues, it is easy to forget that it is really important to explain to the public what we are doing. Nowadays, people are much more environmentally conscious and have much easier and faster access to information, so people do expect information about our exploration plans and activities to be shared and explained. At the same time, misinformation can spread easily and consequently it makes it all the more important for the exploration and mining industry to be open. Mineral exploration happens mostly out of sight of most people but there is really nothing to hide. This Toolkit brings practical tips to formulate what, why, how, when and where to communicate with local people. Highly recommended reading for everybody in the exploration and mining industry!

Juhani Ojala, Chief Geoscientist at Geopool Oy, Finland

By providing insights about "What", "Why", "How", "When", "Where" to communicate about a company's mineral exploration activities, this Toolkit should prove a useful contribution for exploration companies to build a respectful and harmonious relationship with stakeholders and local communities. And while it does have a Nordic flavour, the insights provided should be helpful to exploration companies around Europe and beyond.

Stephen Fraser, Managing Director of VectORE Pty Ltd., Adjunct Assistant Professor with the Sustainable Mining Institute at the University of Queensland, Fellow of the Australasian Institute of Mining and Metallurgy Source for information (FAusIMM), Member of NEXT Scientific Advisory Board

Europe needs metals and minerals produced in Europe. This Toolkit brings the NEXT Way to the Discovery of Ore Deposits. The novel technologies, tools and approaches documented in this Toolkit should pave the way for faster, more efficient and less costly mineral exploration with minimal environmental impact. Due attention is paid to provide exploration companies with recommendations for a more socially acceptable way of conducting their activities.

Timo Mäki, Director of Northgold AB, Firefox Gold Corp., and Strategic Resources Inc., Member of the NEXT Scientific Advisory Board

This publication brings a comprehensive overview of the multitude of scientific achievements which the NEXT project achieved. Aside from the project's technological achievements it also elaborates on the outcomes of the research that was carried out on the Social License to Explore theme, which are at the basis of the recommendations addressed to mineral exploration companies for stakeholder engagement. The bionotes accompanying the write-ups in this publication give due credit to all the people who contributed to these achievements.

Vesa Nykänen, Research Professor, Geoinformatics and Information Solutions with the Geological Survey of Finland (GTK), NEXT Scientific Coordinator

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***Front and back cover**:*

Electromagnetic survey with drones, a concept illustration by Ari Saartenoja, Radai Oy, Finland
The NEXT Consortium at the entrance and inside the tin/tungsten underground mine of Zinnkammern Pöhla, Germany, October 2018. Photo credits: Andreas Knobloch, BEAK Consultants GmbH, Germany and Torsten Gorka, DMT GmbH & CO. KG, Germany

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Preface - About the NEXT project and the content of the present Toolkit

The EU funded Horizon 2020 **N**ew **EX**ploration **T**echnologies (**NEXT**) research project ran from the 1st of May 2018 until 30th September 2021, which translates into a duration of almost three and a half years. The project consortium was made up of 16 partners from leading research institutes (3), academia (3), service providers (5) and industry (5). Its members came from 6 European Union Member States (Finland, France, Germany, Malta, Spain and Sweden). With the exception of Malta, which is of sedimentary origin, these countries represent the main metal producing regions of Europe, i.e. the Fennoscandian Shield, the Variscan Belt of Iberia and the Central European Belt. These economically most important metallogenic belts within the European Union have diverse geology with evident potential for different types of new mineral resources.

The mineral deposits in these belts are the most feasible sources of critical, high-tech and other economically important metals in the European Union. Aside from the varying geological and environmental contexts of these belts, the glacial sedimentary cover in the Arctic regions of northern Europe, and the thick weathering crust and more densely populated nature of the target areas in the Iberian and Central European belts influence mineral exploration in different ways. In this context, the project consortium also relied on the expertise brought in by a vast international collaboration network, e.g. 50% of the NEXT project's Scientific Advisory Board members were invited from outside the European Union.

The scope and ambition of the NEXT project primarily focused on the further optimization, testing and validation of environmentally sound exploration concepts and technologies in these diverse mineral deposit types. As a result, the novel exploration technologies and data analysis methods produced by the end of the project now permit much faster and more efficient mineral exploration, at a lesser cost, and with minimum impact on the environment.

Aside from a multitude of presentations of the novel insights gained about ore formation and the novel exploration tools and data analysis methods at international exhibitions, conferences and other fora, the NEXT project also aimed at raising awareness about mineral exploration among the general public, and in particular among local communities living around exploration sites. The latter formed part of the research that was carried out within the NEXT project with the aim to gain a deeper understanding of the factors affecting local attitudes towards mineral exploration (and mining). The research used a comparative case study design including interviews and surveys conducted in local case studies in both Finland (1) and Sweden (2).

The present Toolkit brings a collection of write-ups in which the main scientific and technological outcomes of the project are presented in a manner that is intended to make these outcomes more accessible to the general public. Both the advances in mineral exploration and the outcomes of the research on the Social Licence to *Explore* theme are presented in an easy-to-grasp language. Finally, the present Toolkit also brings recommendations, which are foremost addressed to mineral exploration and mining companies, about why, how, when and where to communicate with local communities during the mineral exploration stages. A concluding write-up describes how a new mapping tool which has been implemented on Cordis (https://cordis.europa.eu/datalab/datalab.php), which now enables to network and establish synergies with past and ongoing EU funded research projects: a virtual goldmine of information is now available at one's fingertips!

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Chapter 1 Exploration companies' expectations from the present Toolkit and what it offers

In this first chapter, we share our understanding of the expectations from this Toolkit, which is foremost addressed to mineral exploration and mining companies. An Exploration Seminar organized by the NEXT project in Rovaniemi in October 2019 provided the opportunity to invite participating exploration and mining company representatives to take part in short, semi-structured interviews. The expectation emerged that the interviewees wished for the content of our toolkit to be process-oriented, i.e. to provide practical answers to the questions of ***what***, ***when***, ***how***, ***where***, and ***why* to communicate with local communities** in areas targeted for exploration activities. Answers to these questions can be found in existing toolkits, such as the toolkit for stakeholder engagement issued by the Finnish Network for Sustainable Mining (FNSM) in 2015[1]. The FNSM also created a specific standard for sustainable mineral exploration including stakeholder involvement, biodiversity conservation, safety and health in 2016[2]. In addition, the recently completed Horizon 2020 Mining and Metallurgy Regions of EU (MIREU) project issued SLO Guidelines for Europe[3] and an accompanying Toolbox[4]. Both the Finnish and the MIREU initiatives bring detailed answers to the questions of when and why to communicate as well as an extensive toolset to guide on how to organize an effective, 2-way dialogue with local communities. Common to these, and similar toolkits from around the world, is the recognition that ensuring local people's views are heard, respected, and reflected in action from the very outset of mineral exploration are key to gaining trust and acceptance from the local community. Clearly, this requires understanding of the local context, its social, economic, and environmental features on top of the institutional factors that regulate and shape the industry. However, none of the currently existing toolkits deal with the role which new technologies may play in acceptance of mineral exploration.

What a reader from the present Toolkit may therefore expect is motivated by two considerations. First, we have sought to fill a void in relation to the question of ***what* to communicate about new technologies**. **In Chapter 2**, a compilation of write-ups informs about the various tools which have been developed in the NEXT project as well as new insights pertaining to mineral ore formation and mineral prospectivity mapping. The major part of Its content is styled as interviews conducted with the main protagonists behind these advances. The motivation for including these write-ups in the context of this Toolkit, is to show that it is not only perfectly possible but of the utmost importance that exploration companies do communicate about the nature of the tools they use in a language that is accessible to local communities around mineral exploration areas and thus to a general public. Moreover, as these write-ups inform about new insights, tools and technologies developed in the NEXT project, it brings ready-to-use material to communicate about these advances when applying these in future exploration activities. Secondly, the present Toolkit collects the outcomes of the research activities carried out on the theme ***Social Licence to Explore (SLE)****, i.e. acceptance* or approval of mineral exploration by local communities and society in general. These research activities included the following tasks: (1) mapping of key factors influencing social licensing at the mineral exploration stage, (2) assessing the importance of the new sensitive technologies and early contacts with local communities to the process of obtaining and maintaining the SLE, and (3) identifying the necessary tools to assess social and safety risks associated with mineral exploration. **In Chapter 3**, we have adopted the same easy-to-understand writing style to share the **main outcomes of these research activities on SLE**. These outcomes serve as the basis for a set of further recommendations **in Chapter 4** of ***why, how, when and where* to communicate** during the mineral exploration phase, complemented with a write up on ***with who*** companies may also wish to communicate through the use of a novel mapping tool implemented on CORDIS.

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[1] https://www.kaivosvastuu.fi/en/toolbox-exploration/
[2] https://www.kaivosvastuu.fi/network-approves-new-standard-for-sustainable-exploration/
[3] https://mireu.eu/sites/default/files/2021-05/D%204.3.pdf
[4] https://mireu.eu/sites/default/files/2021-05/D%204.4.pdf

Chapter 2 Mineral prospectivity mapping: NEXT delivers new tools and knowledge

This second chapter informs about several novel tools which have been developed in the Horizon 2020 New Exploration Technologies (NEXT) project as well as new insights which have been gained pertaining to mineral ore formation and mineral prospectivity mapping. The major part of the content of this chapter has been styled as interviews with the main protagonists behind these advances.

Starting from an interview on the current, state-of-the-art knowledge how mineral ore deposits are formed with an ore geology expert at Luleå University of Technology in Sweden, we delve into how the scientific domain of surface geochemistry can bring both environmental and cost-saving benefits to the mineral exploration phase. To this effect, research teams within the Geological Survey of Finland (GTK) explain how snow sampling can be used for mineral prospective mapping, followed by an interview on GTK's advances of mineral prospective mapping in glaciated terrains.

We also proudly present how independent experts from the European Commission's Innovation Radar ranked Radai's Novel electromagnetic (EM) survey system on UAV for mineral exploration as a top innovation product with high market potential in the near future. This announcement motivated the Finnish company Radai to further develop their drones with a geofence system and a parachute trigger as safety measures.

The data from a range of existing handheld devices for mineral prospectivity mapping were utilized by a research team at the University of Lorraine to produce a novel software. The software has been made available as a free and open-source library that can be downloaded by interested users. Although tested and validated for a specific geologic context, i.e. the Elvira deposit in the Iberian Peninsula, the developers are confident that it will be possible to transfer the use of these new tools to additional geological contexts. Furthermore, new satellite-imagery derived products for mineral exploration and environmental monitoring were tested and validated by the German company EFTAS in Finnish test sites which inspired their concept design of a satellite image crawler.

The data generated by the above-mentioned approaches, combined with previously collected data from traditional exploration technologies, brought the opportunity to mine all of these datasets using artificial intelligence-based concepts. This led to the development of a new software algorithm that takes mineral predictive mapping to a new frontier. The new software developed by GTK produces Self-Organizing Maps (SOM) that allow to pinpoint to areas with high mineral exploration potential based on desktop research of all available data. Crucially, the approach allows to speed up calculations dramatically. Employing this software, the German company Beak Consultants produced a predictive map of the Erzgebirge in just a matter of days, which includes the time that was required to organize all the available input data. Although this area has been the subject of tin mining for centuries, a sample of tin-enriched rock was found in one of the predicted exploration zones which had not been mined to date!

GTK has been at the forefront to produce country-wide mineral prospectivity maps at the regional-, shield- and belt-scales. In the NEXT project, a team of experts in geospatial analysis at GTK successfully transformed regional-scale predictions of mineralization to target-scale detections of mineral deposits.

The concluding interview-styled write-up in this Chapter is with Mawson's Chief Geologist. The Rajapalot area in Finland for which the company Mawson in the NEXT partnership holds the exploration permit, served as a test site for the validation of several of the above-mentioned new tools and approaches. Find out how all of the most recent drilling activities in the Rajapalot test site not only confirmed GTK's predicted mineralization horizons but revealed that the gold-cobalt resource estimate is at least twice the estimate predicted prior the start of the NEXT project. Moreover, satellite imagery was used also to pinpoint to the identification of potential compensation areas, i.e. areas with similar habitats to compensate for the possible loss of habitats should the exploration activities in the Rajapalot area proceed to the application for a mine development.

2.1 How do ore deposits form? NEXT uses mineral systems modeling to improve our understanding

Tobias Bauer, Associate Professor at Luleå University of Technology (LTU) in Sweden, fills us in on how ore deposits are formed and how mineral systems modeling can help to advance our understanding.

How do ore deposits form?

Ore deposits require a whole series of ingredients to form. The vast majority of metals sit in minerals that formed in geological processes over a very long period of time. Geologists try to reconstruct these processes based on available observations.

Most ore deposits formed from hot fluids that circulated through the Earth's crust and carried metals with them on the way. Once these fluids get focused along certain pathways, they might reach conditions where they are no longer stable and metals can precipitate.

What is mineral system modeling?

Mineral system modeling attempts to simulate these processes on multiple scales. The modeling effort considers the following ingredients that are necessary for forming an ore deposit:

- **Fluid source**: this could be infiltrating rain or seawater, water that is pressed out from sediments or fluids from an intrusion, such as a magma chamber.
- **Energy source** that can drive circulation of fluids: this could be the heat from an intrusion or heat and pressure from burial under overlying rocks or heat and pressure from colliding continents.
- **Metal source**: this could be surrounding rocks that are leached by circulating fluids, yet metals can also come directly from intrusions.
- **Fluid pathway**: dense rocks usually do not allow fluids to circulate, so fluid pathways are required to focus the fluid flow. Such pathways can be fracture zones related to geological structures such as faults.
- **Trap**: a chemical or mechanical trap that favours the precipitation of metals. This can be a drop in pressure or temperature, mixing with other fluids or the contact with reactive rocks.
- **Preservation of the deposit**: was the deposit preserved over time or was it modified afterwards, for example if it became overprinted by later metamorphic events.

The important aspect to consider is that an ore deposit can form only if all these ingredients are present!

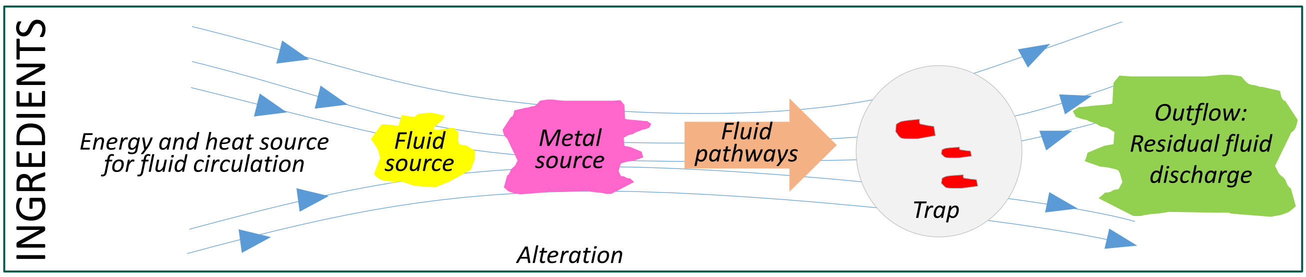


Figure 1: Ingredients of a mineral system (from Knox-Robinson and Wyborn, 1997)

What is required to advance our understanding of how these ore deposits are formed?

In order to improve our understanding of all these ingredients, we need to study rocks on different scales and in different areas. Fluid and energy sources for mineral systems are typically affecting large areas, typically in the magnitude of hundreds of kilometres. On the other hand, traps for mineral precipitation are localized to small areas, such as just tens or hundreds of metres. The latter areas bring target sites in the NEXT project for detailed investigation.

However, it should be borne in mind that all of these ingredients are uniquely different which explains why a wide range of different analytical techniques is needed to understand them.

The EU funding permits us to bring together a highly interdisciplinary team of researchers that includes geologists, geophysicists, geochemistry and ore geology experts, which is really crucial if we are to improve our understanding of how ore deposits are formed.

Where is mineral systems modeling being applied in the NEXT project?

In the NEXT project all these ingredients are being reconstructed for specific types of ore deposits.

These comprise copper-gold deposits that formed from orogenic processes, such as through the collision of continents and the consequent formation of mountain chains. Our target areas comprise both the northern Fennoscandian Shield (Finland and Sweden) and the Iberian Peninsula. The latter is also a target area for massive sulphide deposits that formed on the seafloor in volcanic environments and tungsten-tin deposits that formed on top of intrusions.

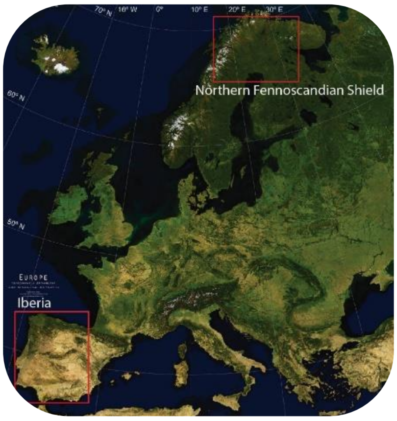


Figure 2: NEXT brings a focus on distinct ore deposit types in: (1) the Iberian Peninsula and (2) the Northern Fennoscandian Shield

How would you describe your ultimate goal?

Our ultimate goal is not only to define conceptual and regional guidelines for targeting orebodies, but also to significantly reduce the cost of mineral exploration and consequently to reduce on the social and environmental impact of mineral exploration activities. For this purpose, our research outcomes are being shared with other research colleagues in the NEXT project who are looking at the economic, social and environmental aspects of mineral exploration.

“Growing up at the foot of the Alps, I could almost every day see a wall of rock from my window. It was just natural that I started to climb in the mountains. And the more rocks and mountains I saw, the more I was wondering how all of this formed. How can it be possible that ancient seafloor ends up at 3000 meters above sea level? So, I decided already during school to become a geologist. My current studies deal with mountain-forming processes, both present but also ancient, 2 billion years old processes. By that, I can reconstruct how the rocks and minerals under our feet formed during geological times.“

Tobias Bauer is an Associate Professor in Ore Geology at Luleå University of Technology (LTU) in Sweden

2.2 Did you ever consider snow sampling could be used for mineral prospecting?

Maarit Middleton, Associate Research Professor within the Information Solutions Unit of the Geological Survey of Finland (GTK) and her research colleagues in the NEXT project are experts in what is known as surface geochemistry. We invited Maarit to explain the research group's passion for snow sampling, but let us start with the context.

What is mineral prospecting?

Mineral prospecting is the first geological phase in exploring for mineral deposits. The goal in exploration is to determine whether an area has any mineral resources. If so, geologists and exploration experts then set out to determine whether the deposit has a viable exploitation potential from an economic point of view.

The starting area of interest may range from hundreds to even thousands of square kilometres. Geologists rely on preliminary studies with airborne geophysical surveys, satellite imagery, as well as field observations of the outcropping rocks on the ground surface to pinpoint to areas where mineral potential is high. However, to reach a decisive conclusion actual drilling and excavations of the bedrock need to be conducted. Commonly, drill holes are spaced in a dense grid of one hundred to even just 10 meters, and tens of kilometres of core may be drilled as part of single prospecting project. At a drilling cost of 120 to 150 euro per meter, plus analytical expenses and working time, this task is clearly expensive. It is also time consuming as it typically takes several years, even decades to make a profitable discovery. To illustrate the magnitude of the risk to investors, only one in a thousand prospecting projects end up in an actual mine development!

How does this fit in with the objectives of the NEXT project?

The overall objective of the Horizon 2020 NEXT project is to develop tools and techniques that would not only reduce the cost of mineral exploration but also minimize the environmental impact during the early stages of mineral exploration. The scientific domain of surface geochemistry is among several approaches that are being investigated as part of the ongoing research activities.

What is surface geochemistry and how does snow sampling come in?

The use of surface geochemistry relies on a multitude of transport mechanisms that enable the migration of ions from the mineralized deposits to reach the surface where the ions become fixed in the top layers of the soil and the vegetation. Obviously, this concerns just very small amounts of metals or other elements and hydrocarbons. The efficiency of this migration is controlled by several factors, and may include a combination of gaseous, microbial or electrochemical ion transportation mechanisms. Other factors include the hydrological regime as well as preferential pathways to the surface, such as geological faults as determined by the hydrogeological setting.

In surface geochemistry, the samples taken from the top layers of the soil and plants are analysed in the laboratory. The ions are released with very weak chemical extractions methods which then permits to determine the chemical element or hydrocarbon concentration of the samples.

When the surface is covered with snow, the flow of gasses continues, and the ions and hydrocarbon compounds accumulate to the base layer of snow. This is why very small amounts of metals or other elements and hydrocarbons can be analysed not only in samples of plant tissues and soil horizons, but also in snow samples.

The surface geochemistry approach thus permits to discover blind deposits even deep in the bedrock or beneath a thick cover of sediments as illustrated in the picture below.

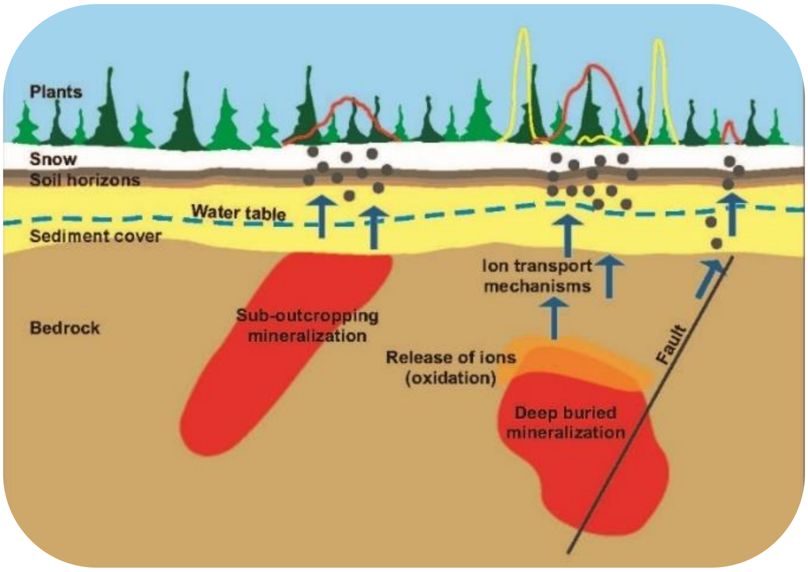


Figure 3: Ions released from mineralized deposits are transported to the surface and become fixed in the top layers of the soil and vegetation as well as in the base layer of snow.

Could you elaborate on what you mean by using surface geochemistry for smart bedrock drill targeting?

Surface geochemistry provides a very powerful approach to reveal the secrets of the underlying bedrock chemistry. In fact, there simply are no other methods available for detecting geochemical signals of mineralization under sediment and bedrock cover. This also explains why the approach has gained considerable importance in guiding exploration geologists to specific locations for bedrock drilling, avoiding the need for the conventional use of heavy-machinery assisted sampling.

How is the sampling approached?

Organic and mineral soil horizons are sampled with a shovel only to a depth of 50 cm or less. Plants twigs are clipped with pruning shears and bark samples are obtained with paint scrapers.

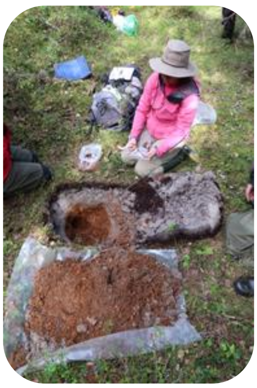


Figure 4: Soil (left) and plant (right) sampling. Photos: Maarit Middleton, GTK

The EU funding of the Horizon 2020 NEXT project brings the opportunity to test unconventional sampling material with extremely low environmental impact, such as snow and transpired fluids from plants or trees, for mineral exploration purposes.

Figure 5: Sampling of Norway spruce transpired fluids (left) and snow (right)
Photos: Maarit Middleton, GTK

The sampling is done simply on foot and under the condition of snow cover on skies, snowshoes or snowmobiles, hence the insignificant environmental impact of the approach.

What would you consider as the main benefits of using surface geochemistry for mineral prospecting?

Surface geochemistry is environmentally friendly and cost-saving. The cost savings for mineral exploration companies derive from land access permitting being simpler and, in general, permit processing times being shorter when compared to sampling conducted with heavy machinery. Sampling is fast and allows covering of larger areas or with higher number of samples in the time given. For northern European conditions, winter exploration activity enabled by snow sampling may speed up the exploration process.

“Mineral prospecting is increasingly challenging and becomes vastly more expensive once the focus of the exploration activities moves deeper into the subsurface. This can be especially the case when the ore deposit is buried under a large sediment cover or otherwise concealed deep in the bedrock. Surface geochemical techniques are based on collecting small samples of upper soil horizons, plants and even snow, which can reveal subtle fingerprints of underlying mineralization. This sampling does not require the use of heavy machinery and has a clearly insignificant environmental impact. Even large areas can be sampled efficiently in this manner and leads to smarter, and also much cheaper, pinpointing of drilling targets. My interest as a researcher is to apply these techniques on a variety of mineralization types to gain an improved understanding of how and when to use these techniques most efficiently. Increasing the sensitivity of surface geochemistry with better analytical methods and the analysis of the data with advanced statistical techniques are also of particular interest to me.”

Maarit Middleton is an Associate Research Professor in geodata data analysis at the Geological Survey of Finland (GTK) specializing in remotely sensed and surface geochemical data

2.3 NEXT advances mineral exploration in glaciated terrains

Pertti Sarala, Research Professor in geochemical exploration at the Geological Survey of Finland (GTK) and the Oulu Mining School, is sampling upper soil in this picture. Upper soil geochemical sampling is one of the advanced, environmentally friendly surface geochemical exploration techniques that has been successfully tested in the NEXT project. We invited Pertti to explain in more detail the advances of mineral exploration in glaciated terrains brought by the NEXT project.

Could you give us a brief history of mineral exploration in glaciated terrains?

For over a hundred years already, studies of surficial geology, surface boulders and heavy minerals are used in mineral exploration of glaciated terrains. Geochemical methods also have been at the basis of mineral potential mapping in these terrains for more than 50 years. Since the 1950s, the development of chemical analyses techniques has been continuous, allowing for the determination of increasingly lower concentrations and for an ever-growing group of elements. Starting from base metals, i.e. copper, lead, nickel and zinc, explored in the 1960s, the mining industry moved from precious metals such as gold and platinum in the 1980s to high technology metals such as gallium, indium and scandium. Rare earth elements and battery technology metals have been under intensive exploration and mining since the 1990s. These analytical development steps have in fact been a boosting factor for mineral exploration around the world.

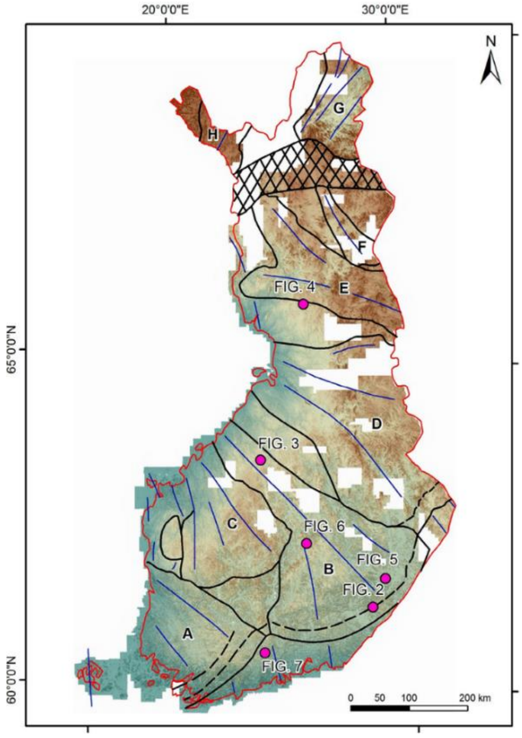


Figure 6: LiDAR-based Preliminary Ice stream lobes Map of Finland (PIMF)

In one of the recent publications on glaciated terrains in Finland to which I contributed, an overview (see Figure 6), is presented of the main ice stream lobes (A. Baltic, B. Lake district, C. West, D. North Karelian/Oulu, E. Kuusamo, F. Salla, G. Inari and H. Enontekiö) of Finland, resting on June 2017 LiDAR DEM coverage. The ice lobe margins (black), the ice divide zone at North (raster), and the main flow lines (blue) are indicated. Detailed illustrations of the figure locations (FIG. 2 to FIG. 7) in the above figure are provided in this publication which appeared in the Bulletin of the Geological Society of Finland, Vol. 89, 2017, pp 64–81.[5] Below are two further illustrations of drumlin fields and landforms in the Kuusamo region of northern Finland. Drumlins are oval-shaped hills, largely composed of glacial drift, formed beneath a glacier or ice sheet and aligned in the direction of ice flow.

[5] Putkinen et al. (2017), High-resolution LiDAR mapping of glacial landforms and ice stream lobes in Finland, https://doi.org/10.17741/bgsf/89.2.001

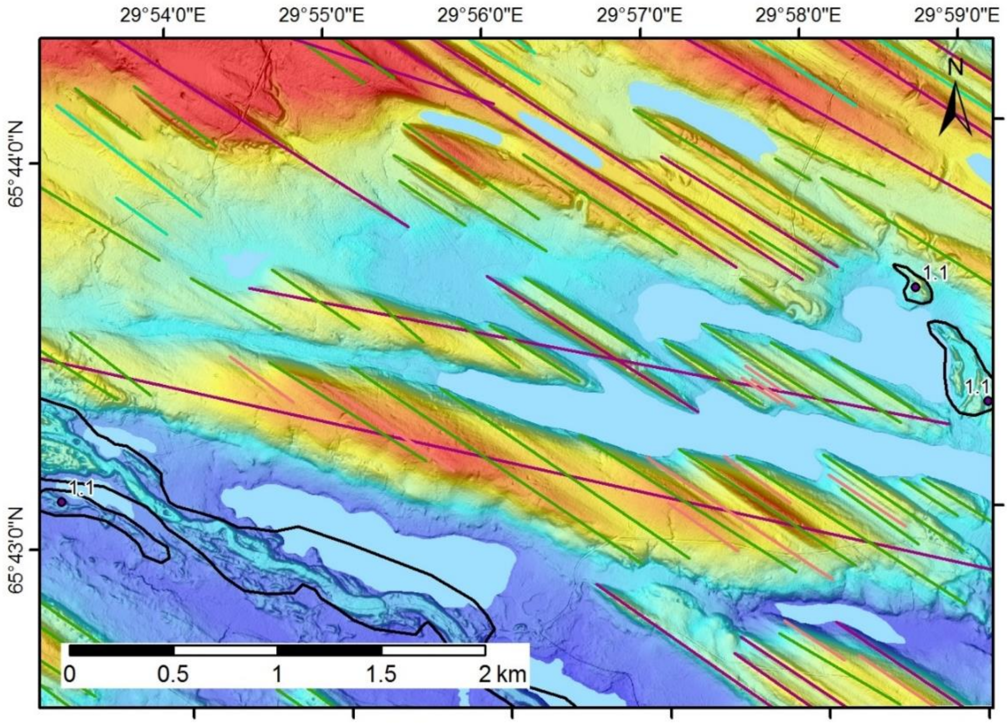


Figure 7: Two over-lapping drumlin fields in the Kuusamo region, northern Finland indicating two different ice flow phases in the area

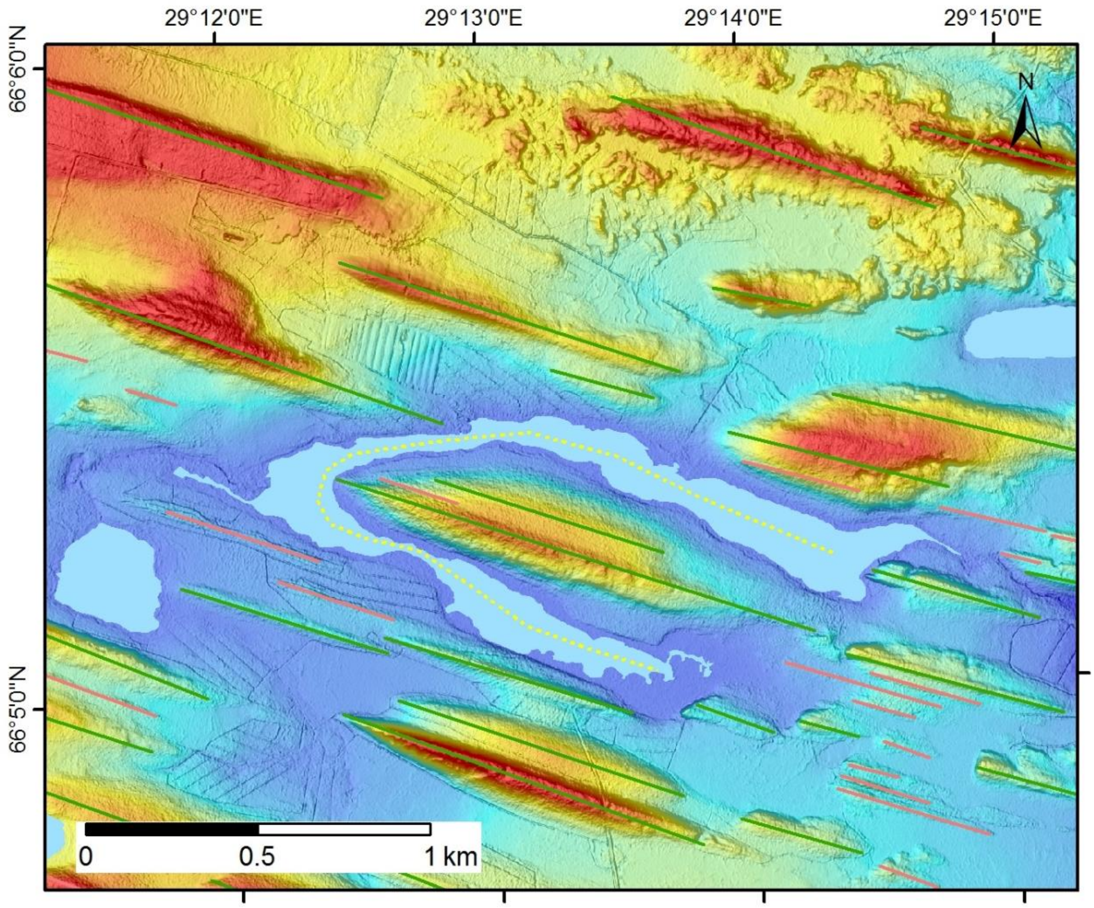


Figure 8: Drumlin landforms in the Kuusamo region, northern Finland

How do these advances relate to our understanding of mineral exploration processes?

Particularly in glaciated terrains, our understanding about transport and deposition processes increased through the use of surface geological research techniques. The development of what is known as morphological interpretation and our improved understanding of formation processes in relation to subglacial conditions and glacial dynamics have brought important contributions to widening our knowledge. As an example, reference can be made to the use of the remote sensing method, known as LiDAR, that is used to examine the surface of the Earth. LiDAR-based elevation models have completely renewed the process of morphological mapping as the increased amount of detail of glacial features supports a much more advanced interpretation. This has brought a wealth of information which permits us to delve into aspects such as the secondary dispersion of mineralized materials in glaciated terrains.

Which features would you consider as being of the foremost importance in the context of mineral exploration of glaciated terrains?

A key feature for mineral exploration is brought by **till** or **glacial till**, which can be described as unsorted glacial sediment, derived from the erosion and entrainment of material by the moving ice of a glacier. As a consequence of this process, till represents a mixture of fresh bedrock, pre-glacial weathered bedrock and other pre-existing sediments. Till debris and rock fragments are always found some distance away from the source or sources from which they were derived. As they disperse in the direction of the ice-flow, they give a larger and more homogenized indication of the source(s) than of the bedrock itself. However, this dispersion is influenced by many different factors, i.e. geology, topography and subglacial conditions with ice-mass variations, and is highly dependent on glaciogenic deposition environments composed of glacial erosion, debris transportation and deposition.

Thick glaciogenic deposits, **large mire areas** and **pre-glacial weathered bedrock** are challenging for mineral exploration and require expensive research methods. These geological environments are typical of large areas in the Northern Hemisphere and are very sensitive to climate and environmental changes and actions of any kind which can disturb the vegetation and soils.

How is sampling traditionally conducted in these glaciated terrains?

Till samples have traditionally been collected using hand-made test pits but more often heavier sampling methods such as tractor excavator, percussion drilling and soil drilling are needed to get more representative samples deeper from the transported cover. Specific till size fractions such as less than 0.063 mm are used in geochemical analyses using partial leaching. To determine the elemental composition of the samples requires methods that are based on atomic emission spectroscopy and atomic absorption spectroscopy. This explains why this traditional sampling procedure is typically both expensive and time-consuming.

It should also be borne in mind that different land-use interests and large conserved areas can restrict the mineral exploration field work using traditional geochemical sampling and analysis methods. For example, the northern, sub-Arctic areas in Fennoscandia and Finland, are typically vulnerable and belong widely to Natura 2000 or other nature conservation programmes. Despite the relatively high current activity of mineral exploration in our part of the world, vast areas in Finland and the Fennoscandian shield are poorly studied for exploration.

Figure 9: Analysis of the element concentrations from the glacial till using portable XRF analyser. (Photo credit: Pertti Sarala)

Could you describe the advances in mineral exploration of glaciated terrains brought by the NEXT project?

Our goal is to assess the effectiveness of geochemical research methods which offer an easy way to collect samples with low-to-negligible impact on nature and would also be cost-efficient. To move away from the use of heavy sampling beneath the transported cover of glaciated terrains, new sampling and analytical methods are required that will give us a geochemical signal directly from the underlying bedrock.

Our use of **advanced surface geochemical exploration methods** is based on **metal ions migration through the sediment deposits**. As my research colleague in the EU funded Horizon 2020 NEXT project, Maarit Middleton explained in her earlier write-up, upper soils, plants and snow provide relatively easy, fast and cost-effective sampling media with a very low environmental impact. In fact, traces of such sampling are hard to even spot in the field. Moreover, with only minor pre-processing requirements, supported by numerous weak or partial leaching techniques, these methods are highly cost-effective for many ore types in different terrains. In addition, new on-site geochemical analysis techniques such as a field electrochemical probe instrument that is being developed in the NEXT project as well as other modern field analysers, such as portable XRF, can support surface geochemical exploration by giving element concentrations directly in the field. This is a huge benefit as it offers the possibility of obtaining sampling results in real-time instead of first having to send the samples to a laboratory and having to wait for several days to obtain the results.

How would you describe the benefits of the new surface geochemical methods in NEXT?

The development of new sampling techniques and analysis methods using upper soil layers, plants and snow enables cost-effective and nature-friendly mineral exploration in environmentally sensitive areas like the Arctic. In these areas, the transported cover typically consists of thick glaciogenic overburden and large, peat-covered areas that present a challenge to traditional exploration methods. Furthermore, large areas have restricted access due to large uninhabited expanses. There are also many nature reservation areas which makes the use of heavy machinery for mineral exploration highly inappropriate.

It is also worthwhile to note that thick transported cover can be found frequently and these techniques are perfectly suitable also in these terrains. The surface geochemical methods have been proven to be effective in recognizing many types of buried ore bodies or mineralized lithological units and structures from the bedrock. This is a significant benefit when it comes to the selection of targets for further exploration studies. In addition, I do believe that the reduced environmental impact and exploration footprint by using these technologies can help increase the social acceptance of mineral exploration in these terrains.

"I have always been interested in nature and in matters related to geology in particular. After upper secondary school it was quite natural for me to decide to study geology at the University of Oulu, where mineral exploration using surface sediments and geochemistry were my preferred subjects. My doctoral thesis focused on a better understanding of glacial processes as a part of element and heavy mineral distribution in glaciated terrains. Having gained a broad knowledge in Quaternary and glacial geology, geomorphology, applied geochemistry, till and weathered bedrock geochemistry and mineral exploration processes gave me the opportunity to successfully apply for a research professorship in geochemical exploration. The development of surface geochemical exploration methods to decrease the environmental impact in sensitive nature in the sub-Arctic and Arctic areas continue to be an important part of my research interests."

Pertti Sarala is Research Professor in geochemical exploration at the Geological Survey of Finland (GTK) and the Oulu Mining School (OMS) of the University of Oulu

2.4 Radai's pioneering research on non-invasive mineral exploration technologies on the European Commission's Innovation Radar!

Independent experts of the European Commission´s **Innovation Radar** have ranked the "**Novel electromagnetic (EM) survey system on UAV for mineral exploration**", as a top innovation product with high market potential in the near future. The Finnish companies Radai together with Loop and Line and the Geological Survey of Finland (GTK) are behind the product's development. Whereas Radai is the main developer, GTK has been an active supporter and facilitator in the development. Here we elaborate on how Radai's pioneering solution fits perfectly with Finland's pacesetting approach to recycling and metals and earth minerals as well as the country's global leadership in sustainable utilisation of mineral resources.

Recycling of metals and earth minerals in Finland

Finland is considered as one of the world's pacesetters in the domains of nature conservation as well as recycling. In fact, the country boasts one the world's most efficient recycling methodologies. However, it is also a reality that only a small percentage of the metals and earth minerals that are needed to produce today's advanced communication tools, such as mobile phones, can be covered by recycled materials.

A global leader in sustainable utilisation of mineral resources

The Finnish government duly recognizes the challenges posed by the growing demand in mineral resources and aims to develop its mining sector by encouraging the use of sustainable solutions. To this effect, the government actively supports the development and use of non-invasive, eco-friendly solutions for mineral resource exploration and exploitation. The Geological Survey of Finland (GTK) considers Finland as "*...a global leader in the sustainable utilisation of mineral resources and the minerals sector is one of the key foundations of the Finnish national economy."*

Radai's pioneering research

Among the pioneers in the development of eco-friendly, non-invasive geophysical surveys is the Finnish Radai Oy. The company offers precise, high quality geo-mapping surveys through the use of its UAV based geophysical survey technology. Through this in-house developed Unmanned Aerial Vehicle, Radai is in a position to conduct surveys that have a lower carbon footprint compared with any other existing mineral exploration technologies.

Developed in the EU funded Horizon 2020 research project entitled New Exploration Technologies (NEXT), Radai's solution makes it possible to carry out different types of measurements during one single flight.

Radai's UAV carries in-house developed sensors to measure ground surface, soil and bedrock structures. This brings a comprehensive image of the surveyed area, and allows geophysical experts to then determine the most promising areas for mineral exploration. Effectively, Radai's solution eliminates the need for extensive, long-term and invasive exploration over large areas.

Additional applications of Radai's solution

Although developed in the context of bringing to market novel mineral exploration technologies, Radai's technology has already proven to be highly versatile. In fact, a very broad spectrum of environmental monitoring applications such as carbon emissions can be monitored in a very efficient manner. Other applications include the detection of water leaks in dams, or the monitoring of chemically polluted areas, which clearly play a vital role in protecting communities that live nearby. As water has the potential to become a scarce resource even in traditionally water-rich countries, Radai's solution can be used in locating additional water sources.

By using lightweight UAVs, driven by electric motors and, during summer months by solar energy, Radai’s technology is not invasive (its small electric motor can be barely heard), has a low carbon footprint and also offers a much-reduced cost compared with conventional exploration technologies in the mining sector.

Figure 10: Radai's team fitting out its pioneering drone

Figure 11: Radai's team prepares for launch of its pioneering drone

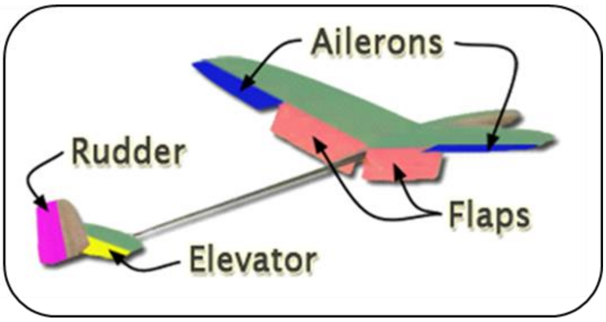
2.5 Radai adds further safety features to its novel drone prototypes

Ari Saartenoja, CEO & Founder of the Finnish company Radai, is the main developer of a novel electromagnetic (EM) survey system on unmanned aerial vehicles (UAVs) for mineral exploration that has been developed in the NEXT project. For this write-up we invited Ari to provide us with an update on the company's advances since it was first picked up the European Commission's Innovation Radar as "a top innovation product with high market potential in the near future".

Could you tell us more about Radai's most recent advances with respect to the use of UAV for mineral exploration?

During the last 12 months, we have achieved significant progress in the development of our drone-based magnetic field survey system. In fact, our **VM Prototype-3 UAV survey system** has not only significantly improved the hardware capabilities of UAV's orientation measurement system we have also paid special attention to the autopilot system software that controls the plane and flight mission.

Figure 12: Aircraft surfaces that enable to control the route and altitude of a flight



As you can see from this schematic diagram, the flight route and altitude of a flight can be controlled through aircraft surfaces that include ailerons, rudder, elevator, and flaps. As we are dealing with an unmanned aerial vehicle (UAV), we depend on the development of an autopilot which consists of sophisticated algorithms that fully control these respective aircraft surfaces as well as its motor. This enables us to make the drone flight much more stable and predictable and improves the overall safety of a flight.

Aside from flight safety, how would you rate the drone operators' safety and the environmental risks of your UAV?

Radai assigns the highest value to the safety of its drone operators and avoids causing damage to the environment in which operates at any cost. For these reasons, we have added an additional safety layer which consists of an in-house developed **geofence system and a parachute launch trigger**. These have been implemented by adding new instruction commands into the VM Prototype-3 datalogger, allowing the data logger to give direct commands to the autopilot. The geofence is a GPS-based virtual perimeter that determines the area in which the plane is expected to operate and orders the drone to take corrective action whenever it reaches the boundaries of this virtual perimeter. Should the drone still go beyond the predesigned perimeter, a further command triggers its parachute to be launched and effectively stops the drone from continuing its flight.

Figure 13: UAV outfitted with a parachute as a further safety measure

What motivated you to start a company which has clearly been highly successful in developing a new generation of drones?

"My interest in flying machines and technology goes back to my teenage years. Together with a friend, I started to innovate and find applications for drones back in 2012. Both of us were keen to develop something new. We meticulously went through the scarce information we were able to find and started building our first drones and sensors in my garage. It proved an intense period of my life, characterized by initial failures and starting all over again. Then, at some stage, the outcome of our passionate efforts proved to work surprisingly well. Looking back, our ambition to put into practice some of our innovations, which were quite many at this initial stage, came quite naturally I would say. We kept pushing our development work forward and little by little our first prototype of a drone-based survey system was completed. Our teenage obsession that things can always be improved is part of our small company's culture today: striving all the time to do better, never being happy with mediocre results.

Through the European Commission's financial assistance provided to the NEXT project, we came up with a breakthrough solution for the mineral exploration industry, but things can be done better in so many other domains… and drone technology opens up to so many new possibilities… so hopefully, in the future, we will add our bit in improving the outcome of other industries.

At Radai, we much look forward to keeping 'playing' with flying machines and technology as I did in my teenage years, and in the process, our team definitely will maintain its focus on innovating!"

Ari Saartenoja is CEO & Founder of the Finnish company Radai Ltd

2.6 NEXT produces a novel software to process data obtained from handheld devices for mineral prospectivity mapping

Jean Cauzid, Assistant Lecturer at the University of Lorraine explains about the purpose and functionality of a set of novel handheld devices for mineral prospectivity analysis which have been developed in the EU funded Horizon2020 New Exploration Technologies (NEXT) project.

How would you describe the general purpose of handheld or portable devices in the domain of mineral prospectivity mapping?

Already for several years now, manufacturers have been designing tools for producing chemical analyses outside of the laboratory environment. In reality, these devices are equivalent to the tools that are typically used inside the laboratory. However, they are downsized, autonomous in energy and their use is simplified so that only a limited knowledge of the physics on which they rely is required on the part of the operator.

They often look like fat guns and are known as “handheld” or “portable” devices. Each device is capable of providing a limited amount of information for two reasons. To start with, their use is simplified to be fit-for-purpose to non-expert operators. As a consequence, no fine tuning of the analytical conditions nor extensive signal interpretation can be performed. The second reason is that a single tool cannot provide a full characterization of a sample. Even in the lab, one has to run several experiments on several devices to obtain a comprehensive set of data.

On the other hand, these handheld devices present several interesting features. They are cheap compared to their lab equivalents; they are designed to be run by non-specialists and are capable of producing data of an incredibly good quality. In fact, much more information can be extracted from the obtained data compared to what is usually arrived at in a laboratory set-up. This is not due to a lack of effort on the part of the manufacturers, it is due to the way these handheld devices are supposed to be used: by a non-expert, on a large range of possible applications and without input from other techniques.

Could you tell us more about the specific aims of your new software solution in the NEXT project?

Our aim is to extract the most from these tools by combining the data measured by the handheld devices in a new software solution with the following considerations: the software should remain fit-for-purpose use by non-experts, and we wish this software to become available as freely as possible. Beyond these considerations, there are two constraints which are necessarily faced and shape the development of the software: first, several analytical techniques must be used jointly and second, the application will be restricted to a limited geological context. The challenge is to make the change from one geological context to a different geological context as easy as possible.

Which analytical techniques have you been focusing on?

Because of the fact that several analytical techniques need to be used jointly to produce a duly comprehensive data set, we have been working with no less than six analytical techniques. Each of these are available as portable tools and are labelled XRF, LIBS, XRD, Raman, FTIR and VNIR-SWIR.

Photos the handheld devices we are using together with a brief description of the sample preparation requirements for each device and of the data these provide are shown below.

Table 1: Characteristics of the handheld devices used for data collection

 **Olympus TERRA portable XRD** The sample has to be powdered to a grain size smaller than 150µm and then inserted in the slit in the middle of the case. This technique provides data on the nature of the crystallized solids. (Photo YongHwi KIM)	 **Spectral Evolution SR6500 VNIR-SWIR spectrometer** The sample can be unprepared, freshly cut or powdered. This device provides data on minerals, mainly the hydrated species through the cation-OH vibration, carbonates, and some sulphates. (Photo YongHwi KIM)
 **Thermofisher Niton Xl3t GOLDD+ XRF spectrometer** The sample can be unprepared, freshly cut or powdered. This device provides quantitative data on elemental concentrations from Magnesium to Uranium. (Photo Jean Cauzid)	 **EnSPectr RaPort Raman spectrometer** The sample can be unprepared, freshly cut or powdered. Most minerals can be measured with this device, however with some lower detection limits compared to FTIR and VNIR-SWIR for some mineral species. (Photo Marie-Camille Caumon)

Table 1 (continued): Characteristics of the handheld devices used for data collection

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SciAps LIBS Z300 spectrometer

The sample can be unprepared or freshly cut. Powders are preferably pelletized before analysis. This device provides mainly qualitative data on all elements from Hydrogen to Uranium. Quantification can be attained via the measurement of standards and the building of calibration curves.
(Photo YongHwi KIM)</td>
<td>
Bruker Bravo Raman spectrometer

The sample can be unprepared, freshly cut or powdered. Most minerals can be measured with this device, however with some lower detection limits compared to FTIR and VNIR-SWIR for some mineral species.
(Photo Marie-Camille CAUMON)</td>
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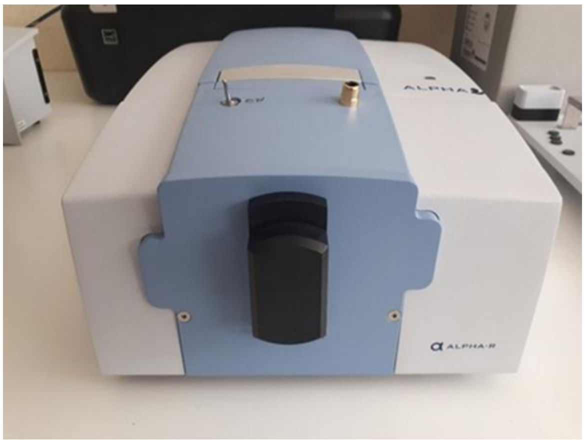
<td colspan="2">
Bruker Alpha FTIR spectrometer
The sample can be unprepared, freshly cut or powdered. The front side of the device can be changed to access various modules of IR analyses. Most minerals can be measured with this device, which however remains sensitive to water content.
(Photo YongHwi KIM)</td>
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This approach derives from the assumption that the strengths of one technique will address the weaknesses of the others. Errors and uncertainties from one analysis are reduced by the use of accurate values from another. In adopting this approach, it becomes clear that individual measurements complete, validate and sustain each other; which guides our entire efforts to be based on the concept of reconciliation.

With the first two techniques, we are analysing the elements in the sample (silicon, iron, lead, etc.). With the other four techniques, we are analysing the minerals (quartz, pyrite, dolomite…). Each mineral is made from a series of elements and rocks consist in assemblages of several minerals. Among these techniques, XRF only provides a quantitative analysis of a sample. Under some conditions, the other techniques can be made quantitative but the result from their portable version is not quantitative by default. Our approach is to obtain the list of the minerals in the sample from the four techniques and quantify the amount of each mineral from the XRF measurements. LIBS is there to address some constraints concerned with the elements which XRF cannot detect.

On which geological context have you been testing your new tools?

In NEXT, we focused on the Elvira deposit, a base polymetallic resource from the Iberian Pyrite Belt. A large portion of our work consisted in being sure that in Elvira, each mineral can be recognized without ambiguity with at least one of the four mineralogical techniques. This was done in parallel with the modeling of the Elvira deposit by colleague partners in the NEXT project. The latter enabled to obtain a listing of the minerals that can be found in Elvira which was not fully known at the beginning of the project. Consequently, we started working on automating the data extraction from the devices. It cannot be fully automated as all these devices are commercial and data extraction relies on a specific software, which is usually not open source. We also finalized the automatic identification of each mineral in a measurement point. Currently, we are working on the automation of the mineral quantification from the list of detected minerals and the XRF data.

How do you see the final product of your efforts and the commercialization prospects of the advances you have achieved?

The final product will be a software available as a free and open-source library that can be downloaded by the final users. However, in the process, we are creating a new space for commercial business as anybody skilled in analytical techniques will be able to advise final users, help them in choosing the best set of techniques and provide them with a software solution. All of this can be achieved without breaching manufacturer intellectual property.

Evidently, it should be borne in mind that by and large the knowledge gained and the advances achieved have been strictly in relation to the specific geological context of the Elvira deposit. Yet, we are highly confident that it will be possible to transfer the use of our new tools to additional geological contexts.

“During a year of studies in Australia back in 1988, I decided to switch from environmental studies to mining. After helping local communities in Africa how to go about contracting new schools and wells for water supply as part of my National Service, I seized the opportunity to start a PhD. This involved getting myself into a synchrotron, a machine as big as a building. Surely not a coincidence that since then I have been lecturing on, and also searching for, ever smaller devices, trying to make analytical tools directly available to users who really need the data. I use all the skills I developed earlier: managing complexity as in environmental sciences, staying grounded as in mining, targeting the longer term as in a PhD and explaining things unusual to my audience as contracts in the bush.”

Jean Cauzid is Assistant Lecturer at the University of Lorraine, France

2.7 NEXT develops new satellite-imagery derived products for mineral exploration and environmental monitoring

EFTAS Remote Sensing and Transfer of Technology GmbH is an SME based in Münster, Germany, which provides geoinformation and IT services based on remote sensing and GIS from a single source.

Sebastian Teuwsen, Project Manager at EFTAS, explains about the remote sensing related research activities in the EU funded Horizon 2020 New Exploration Technologies (NEXT) project.

Could you elaborate on the contribution of remote sensing to the ambitions of the NEXT project?

Even before the start of the NEXT project, we gave a lot of attention to how we could help our colleague partners in the consortium with the many tasks foreseen, by building on our experience from previous exploration projects. We foremost took into consideration that a minimal impact on the environment was requested by the Horizon 2020 Call for proposals to which NEXT was submitted. Indeed, the Call specifically expected proposals to develop new and more sensitive environmentally sound exploration technologies and solutions.

Furthermore, the Call requested to communicate the added value of a proposal to the local communities around the exploration sites as well as to society at large for improving public acceptance. Thus, one of the primary goals of the Call was to achieve a reduction of the anthropogenic footprint in the field of exploration technologies and thereby strengthen and increase the acceptance, and in this instance, of the *Social License to Explore* (SLE) on the part of the public.

Remote sensing, through the use of unmanned aerial vehicles (UAVs) or satellite technology, clearly presents itself as an ideal tool to achieve the goal of reducing the anthropogenic footprint. However, it quickly became apparent that our technology would be of particular interest in new areas identified for exploration and whose viability would normally first be assessed in the field and in the laboratory. The fact that the Finnish study area partly includes an area that is under the guidelines of the EU Natura 2000 directive played a very significant role in this regard.

Could you elaborate on the nature on the remote sensing activities in the Finnish study area?

Throughout the 3-year duration of NEXT, we worked in close cooperation with the mineral exploration company Mawson Oy, the permit holder of the Finnish study area. This approach ensured that the methods and approaches used for exploration and monitoring purposes were strictly oriented towards keeping in line with the environmental directives set by the responsible authorities in Finland. This enabled us to develop several methods that can be used in the future and are in full compliance with environmental protection regulations in sensitive natural areas, including Natura 2000 sites. Although this effort required a substantial amount of research, we were very much aware that exploration activities in these sensitive areas are hotly debated not only in Finland but in all such areas around Europe.

Which, if any, particular difficulties did you encounter to test the remote-sensing based technologies?

In fact, from the very outset of NEXT, we faced difficulties to adequately apply our remote-sensing based technologies for the purpose of mineral exploration due to the dense vegetation cover, particularly in the Finnish study area and to a large extent also in the Spanish one. This is mainly because satellite-based remote sensing technology, regardless of which optical sensors are used, can only be applied primarily in arid and sparsely vegetated areas. This is due to the fact that signals from the vegetation cover and the tree canopy hide the signals coming from the open ground or from the outcrops under investigation. Hence the presence of a dense vegetation does not permit investigations with regard to outcropping rocks and their mineralogy.

The pros and cons of these test sites had already been a point of discussion among the consortium at the initial meeting in Brussels in November 2016, i.e. at a time when the NEXT research proposal was still being developed. Nevertheless, in the course of the project, together with our colleague partners, we were able to test and develop good and, above all, very useful methods and products from the field of satellite remote sensing in these densely vegetated areas.

Could you elaborate on type of satellite sensor data used and how these are linked to the various methodologies you developed in NEXT?

Our methodologies are mainly based on the data collected by the sensors of the Sentinel family of the EU-Copernicus programme, which also corresponds to a primary goal of the Horizon 2020 Call for proposals to which the NEXT project proposal was submitted.

However, aside from Sentinel-1 and Sentinel-2 sensors we also relied on LandSat, ASTER and Hyperion satellite imagery. The table below brings an overview of the various methods we developed using the Sentinel-2 and Hyperion sensors for environmental monitoring in general and for mineral exploration in particular.

Table 2: Overview of elaborated methods/datasets for mineral exploration and environmental monitoring

Method	Sensor	Application	Description
Vegetation Type Mapping	Sentinel-2	Environmental Monitoring	Automated classification of vegetation types
Vegetation Change Analysis	Sentinel-2	Environmental Monitoring	Checking vegetation vitality changes over a period of time in the area of interest
Map Check	Sentinel-2	Environmental Monitoring	Automated check, to verify if there are any differences between the outcomes of a field campaign and the remote sensing derived products
Vegetation Structure Analysis	Sentinel-2	Environmental Monitoring	Analysing compensation areas nearby the exploration area to detect areas with similarly valuable environmental stockings
Element Concentrations	Sentinel-2	Mineral Exploration	Analysing principal components of the outcropping rocks in the area of interest
Iron Feature Depth (IFD)	Sentinel-2	Mineral Exploration	Analysing iron contents in the area of interest
Surface Reflectance	EO1-Hyperion	Mineral Exploration	Cluster mapping relating to the spectral reflectance of the bare soils in the area of interest

In the figure below, our products derived from the application of these methodologies are grouped, firstly in relation to their application for mineral exploration and mining purposes (top), and then with respect to their usefulness in environmental monitoring (bottom).

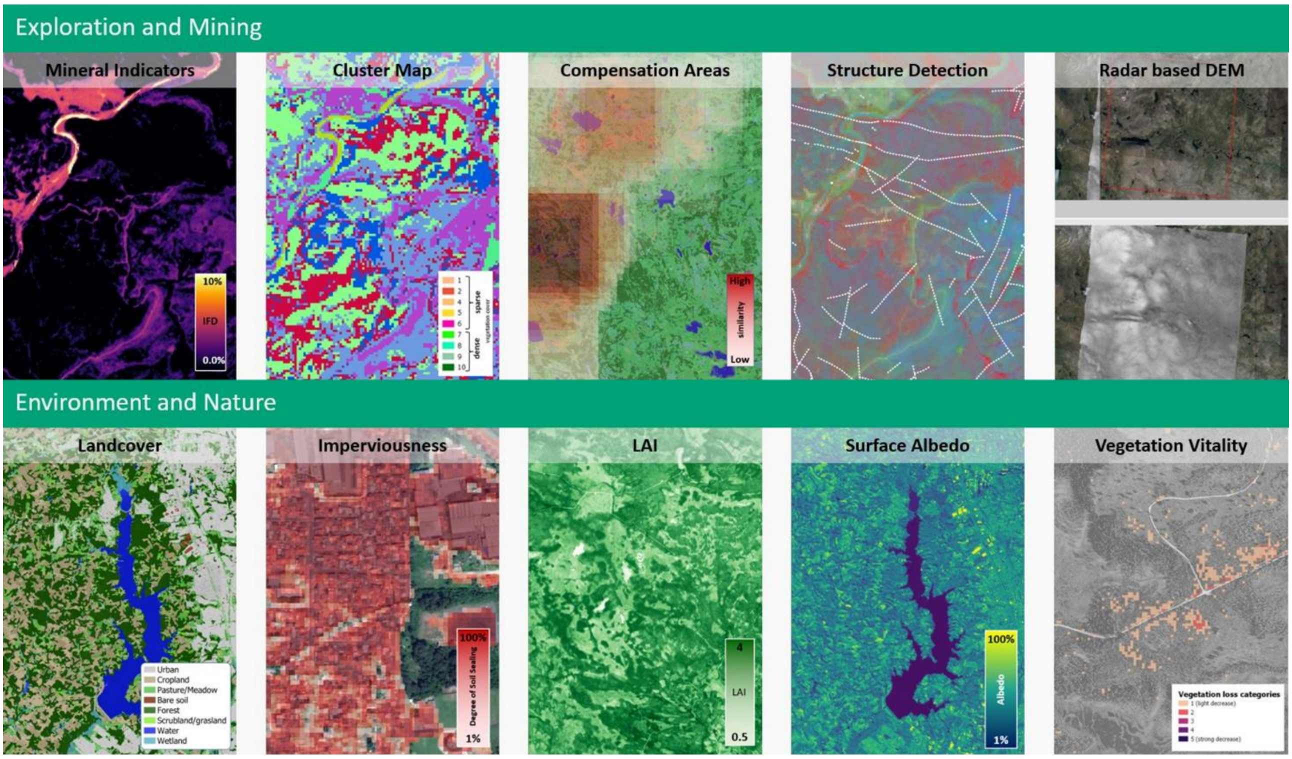

Figure 14: Remote sensing derived products related to Exploration and Mining (top) and the monitoring of the Environment and Nature (bottom)

"Many people, including acquaintances, friends and family, ask me how I came to be a geologist, because this profession it is widely considered to be something special or even extraordinary in Germany. I grew up in a tranquil, rural suburb of a medium-sized city in Westphalia. Already as a young boy I was keenly exploring the wonders of nature in the nearby forests and countryside. Later at school, I focused more and more on subjects that are concerned with the natural processes occurring on our planet and how these shape our lives. After completing my secondary education and a year of civilian service I moved to the beautiful city of Münster. There I studied geology/palaeontology and geophysics, and after a few external internships I was lucky to get a job at the company where I still work every day with pleasure and fulfilment. Our application world of energy, mining and resource management is highly multifaceted. Our remote sensing applications range from soil contamination to water management and supply, pore storage projects, ground movement monitoring and mineral exploration projects. The range of activities covered under the umbrella of remote sensing is really incredibly vast!"

Sebastian Teuwsen is Project Manager in Research and Development; Energy, Mining and Resource Management at EFTAS Remote Sensing and Transfer of Technology GmbH, based in Münster, Germany

2.8 NEXT unveils Concept Design of a Satellite Image Crawler

In this follow-up to the previous interview, **Sebastian Teeuwsen** shares further details how the outcomes of various remote sensing-based methodologies that were applied in Finnish test sites, inspired the concept design of a Satellite Image Crawler.

Could you elaborate on the purpose and outcomes of the remote sensing-based methodologies you have applied in the Finnish test sites?

To start with, I would like to point out that the development of our remote sensing-based methodologies was particularly boosted as a result of the active cooperation that was extended to us by the company Mawson, which gave us full access to the results of earlier field campaigns they conducted at their exploration site in Finland. These data proved essential to test and validate our algorithms which are applied to data captured by satellite sensors, such as those of Sentinel-2. Sentinel-2 is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is a constellation with two twin satellites, Sentinel-2A and Sentinel-2B.

As I explained in my earlier interview, numerous data products can be derived from Sentinel-2 imagery, including but not limited to vegetation type mapping, vegetation change analysis and vegetation structure analysis. All of these products were successfully validated for the Finnish study area, known as Rajapalot. However, Rajapalot presented itself foremost as a test site to develop remote sensing-based methods that would effectively minimize the environmental footprint of mineral exploration activities in sensitive natural areas, such as Natura 2000 sites. Thus, we were particularly interested in developing methods that would enable us to document environmental changes that could possibly be attributed to (earlier) exploration activities, especially during the winter months.

In parallel to this effort, we also made a thorough evaluation of what is required to produce an up-to-date and very quickly processed digital elevation model (DEM). This was motivated by the fact that a DEM is essential for the flight planning of drones and unmanned aerial vehicles (UAVs). It should be noted that due to its geographic location, only a very low-resolution elevation model based on Shuttle Radar Topography Mission (SRTM) data from the year 2000 turned out to be available in some regions with regard to global coverage. Based on these data, the horizontal resolution of the DEM is about 30 metres and the elevation accuracy is about 6 metres. This very low resolution presented a serious obstacle for the company RADAI, as they could not afford to lose their drones equipped with new sensor technology developed in NEXT due to an unforeseeable natural obstacle in the terrain.

To produce a much higher resolution DEM in the test sites shown below, which were selected together with RADAI, we relied on Sentinel-1 radar imagery. As its name implies, Sentinel-1 was the first of the Copernicus Programme satellite constellation to be put in orbit by the European Space Agency. In this video-link[6], the European Space Agency explains how Sentinel-1 can image the surface of the Earth through cloud and rain and regardless of whether it is day or night.

The figure below shows the results of processing a rapid and current DEM from Sentinel-1 data for three selected test sites in Finland.

[6] https://www.esa.int/ESA_Multimedia/Videos/2014/03/Sentinel-1_seeing_through_clouds

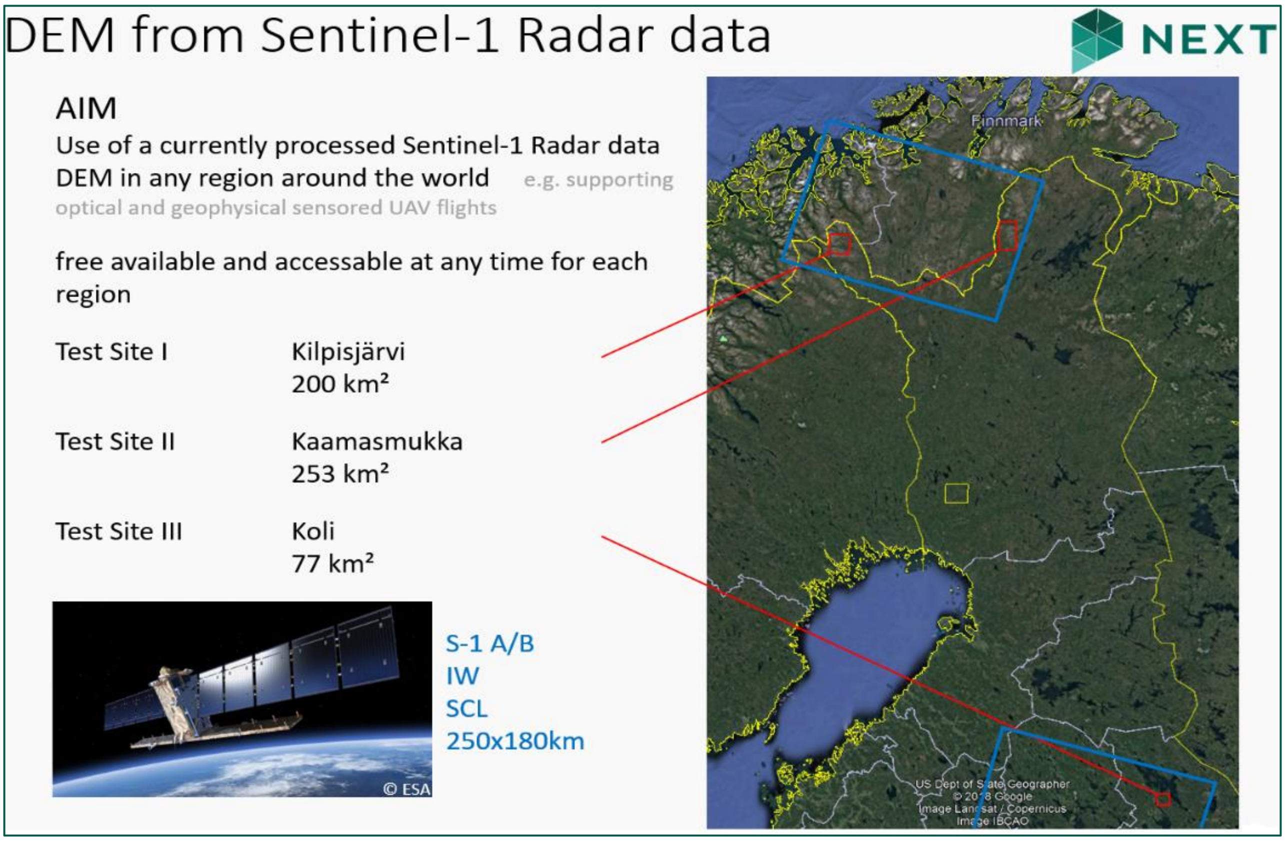

Figure 15: Location of the three test sites in Finland

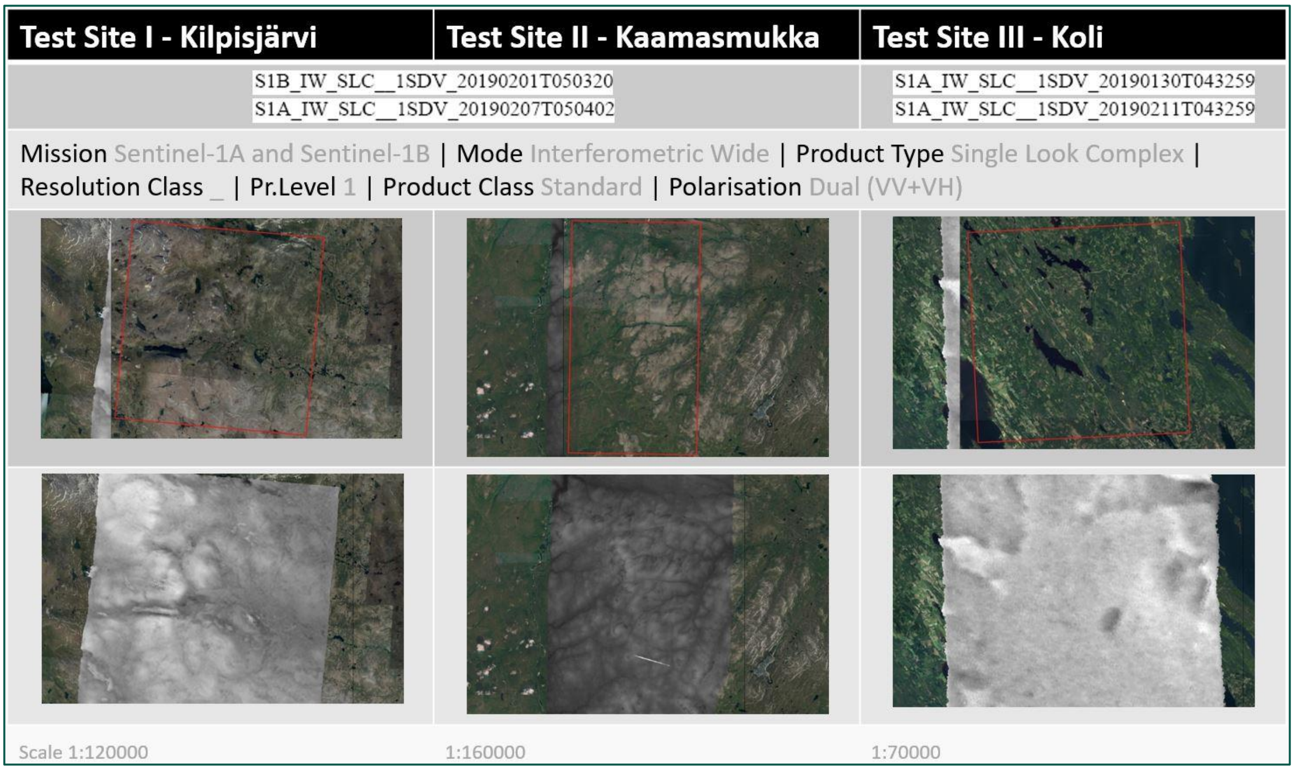

Figure 16: Processing a rapid and current DEM from Sentinel-1 data in the selected test sites

Which factors led to the idea of developing a Satellite Image Crawler in NEXT?

Our original plan was to develop an automated downloader for satellite data that would serve the needs of the exploration as well as of the mining industry. Back in 2016, this was still a mostly uncharted technical territory. As ever newer technologies in the domains of IT, neural networks, cloud processing and machine learning emerged, the market witnessed a very rapid increase in suppliers of fully automated download software and it did not take long for even publicly accessible and open-source software solutions to become available as well.

In consultation with the NEXT Advisory Board, we shifted our originally intended focus of software development to developing a stand-alone, web-based tool that would offer users access to our results in NEXT. We realized that over time such an online portal will permit us to showcase results also for other areas with new challenges and therefore also with new parameters to be taken into account. This implied that we had to envision this new concept with an appropriately flexible user-oriented functionality, which in itself presented us with a multitude of new questions and challenges.

Our Satellite Image Crawler (SIC) is currently being developed as a post-processing service and is intended as a tool that masters and combines the functions of both searching and analysing. Thus, this universal software tool for data search, acquisition, analysis, storage and post-processing can be used as a one-stop service by customers. Its uniqueness lies with the fact that it showcases the technical added value of our developments in an easy-to-interpret way. This makes it an especially worthwhile offer to customers such as smaller companies and start-ups in the exploration industry.

Prospective customers will be able to access the system via a web-based user interface. Once logged in, they can define their area of interest on the basis of an OpenStreetMap layer, enter the time period for the satellite scenes to be used, with the option to select a single one-time analysis or a complete time series analysis, among additional parameters. On completion of these preliminary steps, the user is invited to select from our portfolio of satellite image derived products. This last step triggers off the start of an automated data search on the European Space Agency (ESA) Hub and of any satellite data already stored on our server. Finally, the user will receive a notification when the desired product has been generated and is ready for download.

Once fully developed, our Satellite Image Crawler will fulfil the requirements that we envisioned back in 2016 and therefore much before the start of the NEXT project, i.e. a fully automated downloader of satellite imagery. However, the added functionality of automated post-processing is expected to attract the active interest of exploration and mining companies alike.

The bionote of Sebastian Teuwsen is included with the previous write-up, entitled ‘2.7 NEXT develops new satellite-imagery derived products for mineral exploration and environmental monitoring’.

2.9 NEXT advances mineral predictive mapping with Self-Organizing Maps

Through its involvement in the NEXT project, the company Beak Consultants GmbH, based in Freiberg, Germany has been able extend its “advangeo® 2D Prediction” software suite through the integration of Self-Organizing Maps. **Andreas Brosig** who is a geologist and 3D Modeling Team Leader at Beak Consultants, explains about the scope of mineral predictive mapping and the functionality of these Self-Organizing Maps.

What is predictive mineral mapping about?

Predictive mineral mapping enables the rapid targeting of areas that are a priori likely to have deposits and therefore offers a means to significantly reduce on exploration costs and also on lead times to the eventual opening of a new mine or the extension of an existing mine. At BEAK, we have been working with this approach for ten years now. Our application to a wide range of target areas and hence also different data sets enables us to continuously develop our in-house “advangeo® 2D Prediction” software. Essentially our software suite is built on the basis of data science concepts such as artificial intelligence which combines novel data mining approaches with machine learning.

We understand NEXT has brought the opportunity for BEAK to add a new algorithm to its prediction software suite. Could you give us more details about this new algorithm?

As our research colleague in NEXT, Tobias Bauer explained in your earlier interview, the challenge to predict the location of ore deposits is huge and complex. The ingredients that are necessary for their formation are uniquely specific, as they are influenced by processes that occur not only at the regional scale but also at the very local scale. The new algorithm we have now added to our in-house “advangeo® 2D Prediction” software is based on the concept of Self-organizing maps. Self-organizing maps (SOM) are a useful tool to analyze and interpret the available datasets that have been collected, such as geophysical data that are brought in through field surveys and geochemistry data of stream sediments produced in a laboratory environment.

To start with, all these datasets are transformed from the ‘usual’ geocoded geographic space to the SOM space as illustrated in the schematic illustration of the work flow below.

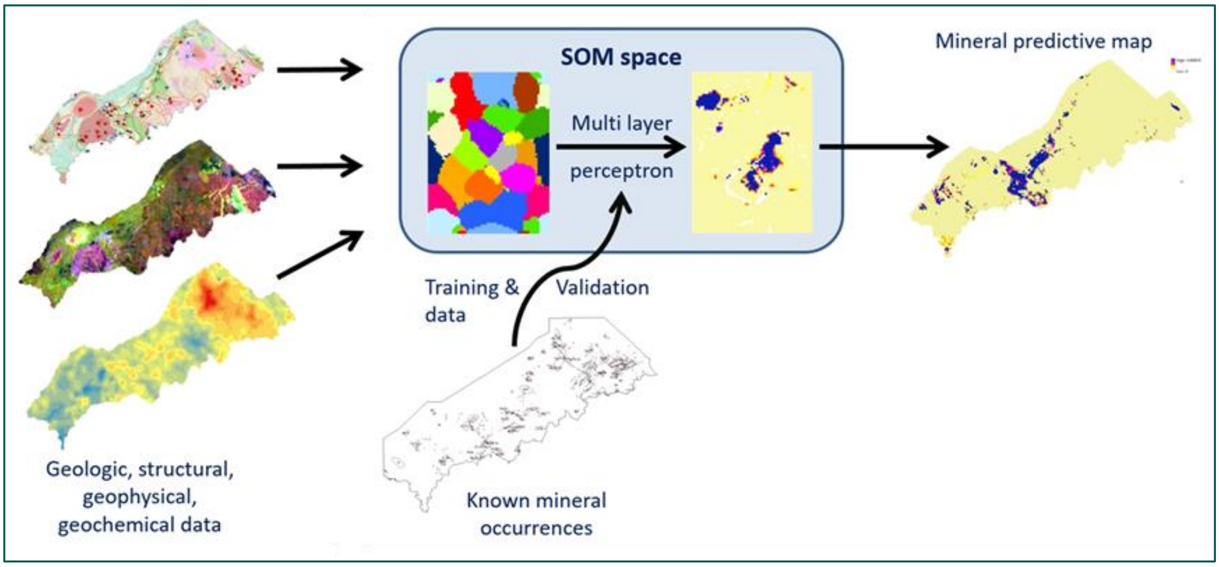

Figure 17: Schematic illustration of the workflow to obtain a mineral predictive map

Within this SOM space, the data are then clustered according to overall similarity. By transforming the clusters back to geographic space, a novel means of geological interpretation of these clusters is facilitated. As shown in the schematic illustration of the workflow, the final outcome generated by our new algorithm takes the form of a mineral predictive map.

In machine learning our algorithm is known as a perceptron. A perceptron is an algorithm for supervised learning of binary classifiers. There are two types of perceptrons: single layer and multi-layer. Single layer perceptrons can learn only linearly separable patterns. As we are dealing with multi-layer inputs, we take advantage of the known mineral occurrences as our training data in the SOM space. It is precisely the application of a multi-layer perceptron in the SOM space that enables us to produce mineral predictive maps.

Can you tell us more about applications that confirm the validity of your new algorithm?

To date we have applied the method to tin deposits in the German part of the Erzgebirge. The training and validation data were compiled from available mining and exploration records. As input data for the SOM space we used reprocessed gravimetric, magnetic, stream sediment geochemistry, geologic and tectonic data sets. Potentially ore-controlling spatial relationships, such as the distance to different types of partly covered granite intrusions, were derived from a regional scale 3D geological model.

The resulting mineral prediction map allows the definition of as yet undocumented areas that reveal a high mineral potential and which thus present themselves as prime locations for detailed exploration activities.

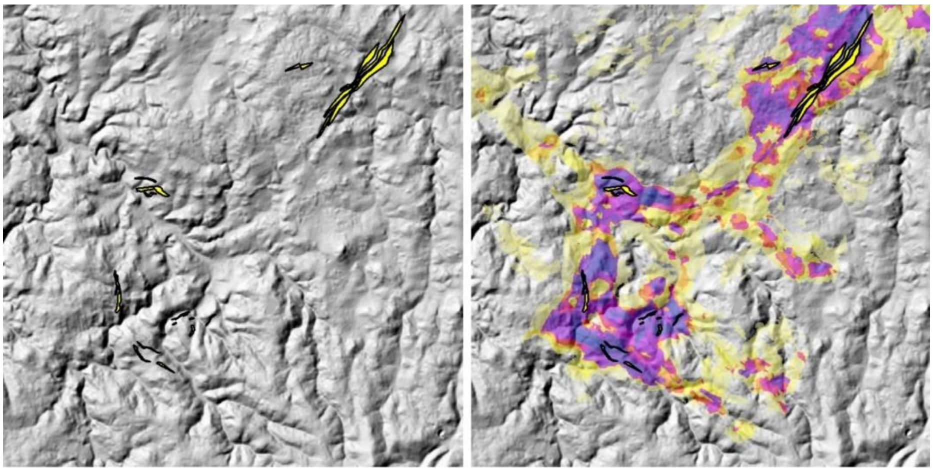

Figure 18: Left: A map of a part of the western Erzgebirge with known tin deposits. Right: Our mineral predictive map shows the locations where additional deposits could exist.

As you will agree, the results are very promising and we are looking forward to validate our new algorithm in other locations, such as the Rajapalot gold deposit in Finland which is one of the sites in the NEXT project for the testing and validation of novel mineral exploration technologies.

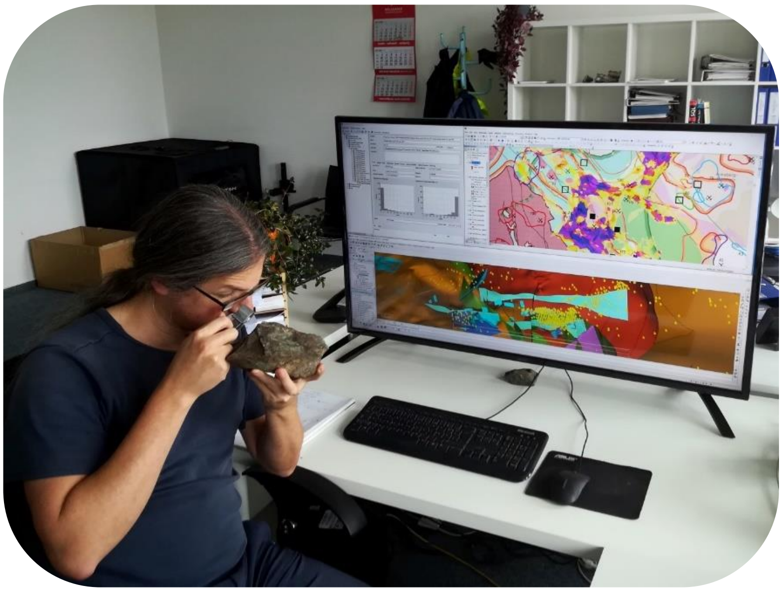

Figure 19: Andreas Brosig examines a sample of metalliferous rock collected in one of the mapped exploration zones. (Photo credit: Gerald Volkmer)

How would you describe the main advantages brought by your application of predictive mapping?

To start with, I would consider that in comparison to other modeling approaches, our application makes the most of the available data sets as input data. The SOM space in particular allows us to speed up calculations dramatically. In the example of the Erzgebirge, we were able to produce the predictive map over a period of just a few days, including the time to organize all the input data in the geographic space. However, the ability to pinpoint to areas with a high mineral exploration potential based on desktop research is a clearly very promising advantage.

Figure 20: A sample of tin-enriched rock found in one of the predicted exploration zones. (Photo credit: Peter Bock)

"As a child I was deeply into mineral and fossil collecting. During school holidays, I would badger my parents for short trips to the Alps or the Franconian Alb to hunt for fossils. Over time, I began to wonder how much harder it must be to discover minerals in the deep underground, compared to collecting samples from the surface. Later I learned that it is indeed a complicated, but also a very captivating topic as it involves many natural processes interacting over incredibly long time scales. Examining the remaining traces of these processes brings the opportunity to improve our understanding of what happened in the deep past. With this new approach to mineral predictive mapping, it is possible to find new mineral deposits even in areas where mining activities in past centuries are thought to have exhausted the hitherto known deposits."

Andreas Brosig is a geologist and 3D Modelling Team Leader at BEAK Consultants Gmbh in Germany

2.10 Transforming Regional-Scale Predictions to Target-Scale Detections – Empowered by Advanced Statistical and Machine Learning Methods

Bijal Chudasama, Postdoctoral Research Scientist and **Johanna Torppa**, Senior Scientist within the Information Solutions Unit at the Geological Survey of Finland (GTK), explain about new advances in mineral prospectivity analysis based on their expertise with statistical and machine learning methods.

Could you give us an introduction to the scope and purpose of mineral prospectivity analysis?

Mineral prospectivity analysis aims at distinguishing areas with high mineral potential from those with low potential. The resulting prospectivity maps show the variation of predicted mineral potential in a study area. These are used, for instance, in mineral exploration targeting by mining companies as well as in land-use planning by the public sector. The two essential parts of mineral prospectivity analysis are (1) conceptual mineral systems modeling and (2) mineral prospectivity modeling. Conceptual mineral systems modeling refers to gaining a geological understanding of the processes that form a mineral deposit of a certain type. Mineral prospectivity modeling involves generating a mathematical model based on the geoscientific variables representing mineralization processes and predicting prospectivity values based on this model. In addition, there are several phases of data processing and statistical analysis to support the analysis. Prospectivity analysis is commonly performed on a regional scale, as well as on shield- and belt-scales, depending on the intended use of the maps.

The Geological Survey of Finland (GTK) has, over the years, developed methods for prospectivity modeling and systematically implemented modeling of mineralization in Finland and abroad. These studies have been conducted at regional scales, belt scales and also at, smaller, camp-to-target-scales for various mineral systems. Through this effort, Finland has been at the forefront of country-wide mineral prospectivity modeling and mineral resources assessment, and particularly for modeling of gold mineralization. There are regional-scale studies covering, for instance, the entire Fennoscandian Shield in northern Finland (Figure 21a and 21b), followed by belt-scale studies for each of the important Palaeoproterozoic Belts such as the Central Lapland Belt (Figure 21c) and the Peräpohja Belt (Figure 21d) within the Fennoscandian Shield in Finland.

Aside from regional-, shield- and belt-scales, you also mentioned camp- and target-scales. Could you guide us on the motivation for this additional focus?

The regional scale prospectivity map of the Peräpohja Belt (Figure 21d) highlights the smaller camp-scale Rompas-Rajapalot area with high prospectivity but does not provide enough detail to target the actual mineralization. To produce a more detailed prospectivity map in camp or target scale, different aspects have to be considered as compared to when modeling at the regional scale. Regional scale studies are driven by the mineral systems approach. As a consequence, a strong emphasis is made on the identification of all the components associated with the formation (sources, pathways and traps) and preservation of mineralization.

To explain this in more detail, it is well-known in our field of expertise that for a region to be prospective for mineral deposits today, it must necessarily show evidence of all the critical ingredients that are required for the formation and preservation of those deposits. This means it requires (1) source(s) of ore components, transporting fluids, and energy to drive the system, (2) pathways or conduit(s) along which metals and fluids were transported from source to a sink, (3) traps signifying the physical and/or chemical mechanism(s) that deposited ore components at the sink and (4) preservation, i.e. processes permitting the preservation of mineralization in the crust up to the present time. If any of these ingredients are absent from a region, its mineral prospectivity will be low.

All of these components associated with mineralization can be mapped at a regional and belt-scale. Once prospective regions have been identified from regional- and belt-scale studies, more detailed prospectivity analyses can be carried out in camp- or even smaller target-scale.

In these smaller exploration areas, signal from the trap component only can mainly be observed because its significance outweighs that of the sources and pathways. Essentially, this difference in the significance of the mineral system components is what distinguishes a regional-scale study from a camp- or target-scale study.

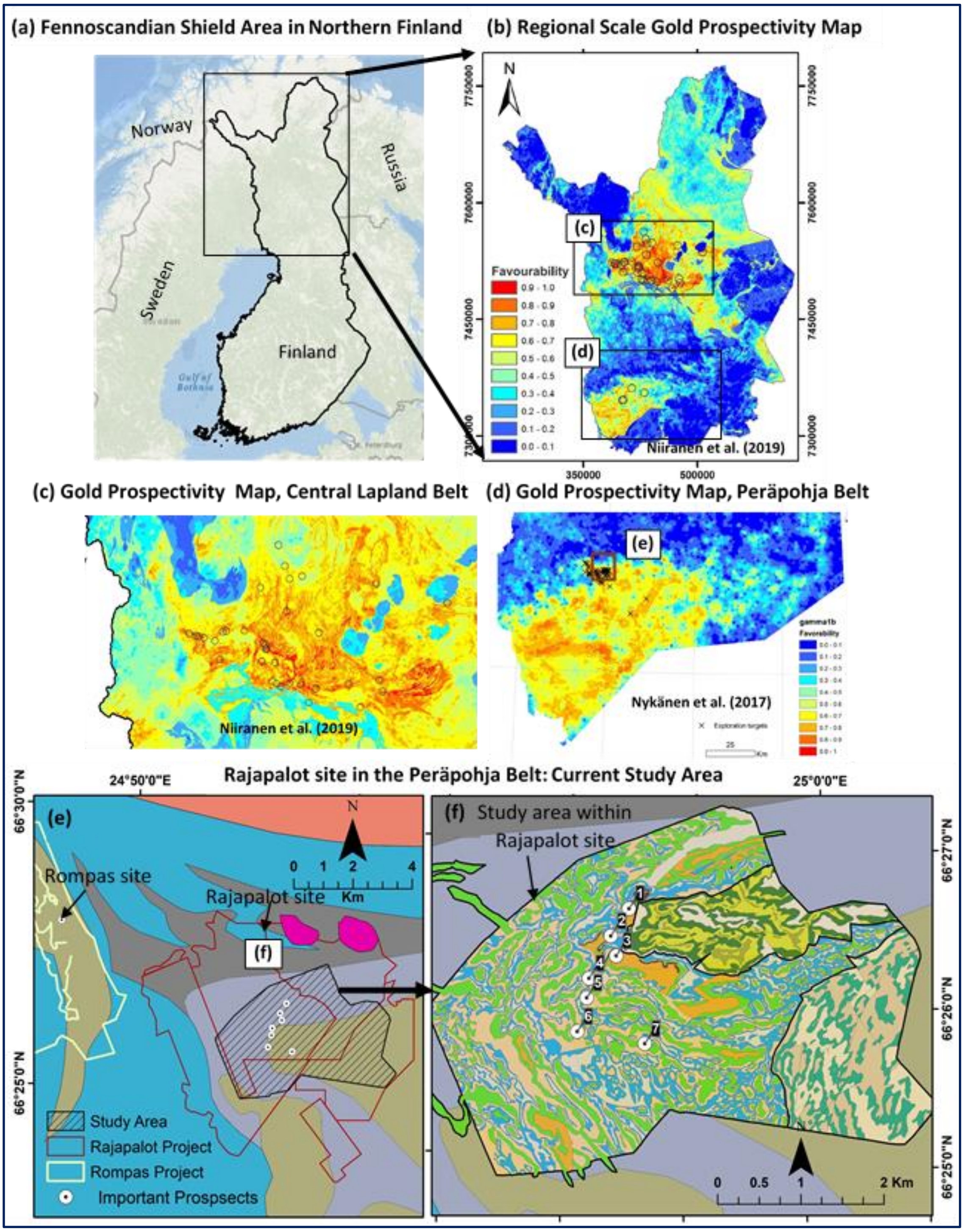

Figure 21: Prospectivity maps at different scales

In the above illustration, previous regional- and belt-scale studies for gold mineralization in Finland are shown in Figure 21(a) to 21(d). The Rajapalot area, see Figure 21(e) and 21(f), within the Peräpohja Belt is the target-scale study area for identification of ground exploration targets in the NEXT project.

In the NEXT project, our emphasis has been on identifying the trap regions and the associated geological processes. The Rompas-Rajapalot area actually comprises two different local subtypes of mineralization – the Rompas style and the Rajapalot style. In NEXT, we particularly focused on target-scale prospectivity modeling of gold mineralization in the Rajapalot project area to identify drilling areas with high mineral potential.

Could you share more details about the approaches and methods you employed for this research?

We approached our ambition to gain new insights about the geological processes operating in the trap components of a mineral system in a systematic and highly comprehensive manner. For this reason, we used several methods which generally fall under the umbrella of, respectively (1) mineral system modeling, (2) statistical testing of geological hypothesis and (3) mineral prospectivity modeling (see Figure 22).

For defining the mineral system model, we used the extensive knowledge derived from existing literature as well as the results obtained for the Rajapalot target area through field surveys conducted by research colleagues in the NEXT project to feed into a conceptual mineralization model. This enabled us to identify the trap-related favourable settings and the constituent geological processes leading to mineralization. Based on these insights, we formulated several geological hypotheses of the mineralization processes and derived the corresponding evidence layers from available geoscientific datasets.

Our second step involved the statistical testing of the geological hypotheses formulated on the basis of the conceptual mineralization model. We used both parametric and non-parametric statistical tests, such as the T-test, the Wilcox-test and the Kolmogorov-Smirnov test. This was aimed at checking if the evidence layers could distinguish the drill core sections with gold mineralization from those with very little or no gold. In turn, this helped us to identify the most representative evidence layers that then served as inputs to the advanced statistical and machine learning algorithms for prospectivity mapping. This second step was crucial because what the machine-learning algorithm 'learns' is very sensitive to what the input data represent. Hence, the main objective was to curate the input datasets in such a way that they paint a holistic picture of the mineralization settings to which the machine-learning algorithm was then applied.

In the final, third step, we used both unsupervised and supervised machine learning methods for mineral prospectivity modeling. The unsupervised method used was self-organizing maps (SOM). This was implemented using the open source GisSOM application[7] developed by GTK in the framework of the NEXT project. SOM is an effective method for generating a low-dimensional (usually 1 up to 3 dimensional) representation of multi-dimensional/ multivariate input data. Through this conversion of the input data to the SOM-space, geological patterns can be identified, considering only the distribution of the geoscientific input variables and neglecting the spatial aspect. Additionally, distinct populations in the input dataset can be identified through the implementation of K-means clustering of the results obtained in the SOM-space. The reason for implementing this clustering is that the geospatial domains corresponding to specific populations can, by means of visual interpretations and statistical evaluations, be related to the mineralized drill-core sections, thus representing prospective mineralization areas. The transformation of the input data to the SOM-space itself does not require direct use of any training data. However, we can further apply supervised classification upon the SOM-space results using an artificial neural network (ANN). This approach of running an ANN on the SOM results was developed by the German company Beak Consultants GmbH in the NEXT partnership. More details about this further approach can be found in the previous write-up by Andreas Brosig, who is the 3D Modeling Team Leader at BEAK.

[7] https://github.com/gtkfi/GisSOM/releases

For those more acquainted with this field of specialization, we wish to highlight that in addition to the above methods, we also implemented Fuzzy Inference Systems (FISs) and a hybrid Adaptive Neuro Fuzzy Inference System (ANFIS) for knowledge-based prospectivity modeling. Additionally, modeling uncertainties related to parametrization of the membership functions of the FIS were quantified by running Monte Carlo Simulations (MCS). The MCS-based FISs generated prospectivity maps at varying confidence levels. In the ANFIS approach, the parameters of the system were learnt by an artificial neural network in a hybrid learning environment using the gradient descent algorithm and least square estimators.

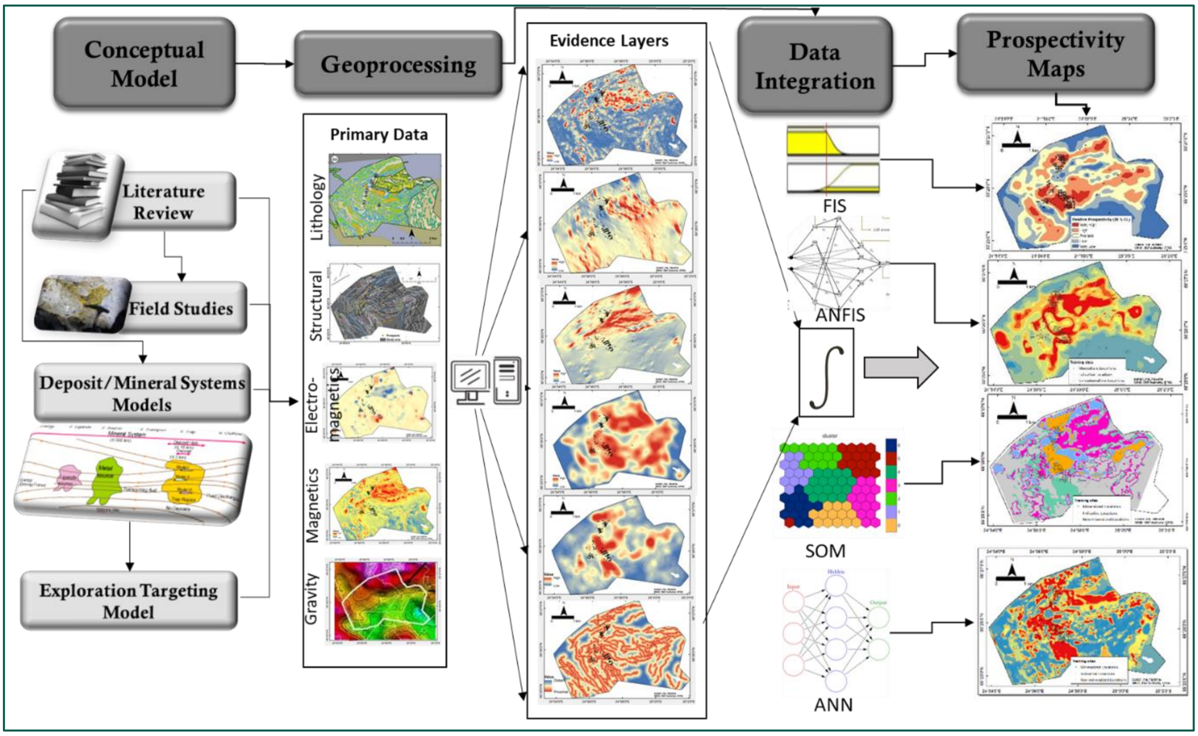

Figure 22: Prospectivity Modeling Workflow and Results

Clearly, the range of methods employed has been extensive. Based on the outcomes would you favour one method over another, or do you see the need to adopt a composite workflow in which you would essentially mix and match all of these distinct methodologies?

Usually, exploration models tend to get somewhat biased by existing discoveries. Especially data-driven machine learning based methods lead to discoveries similar to the ones already known, because the machine learning algorithm is caught up in learning only those features and patterns that are present in the training data. Hence, we are not able to identify new sub-types of mineralization or characterize the diverse controls on mineralization. Since mineral systems are formed as a consequence of tremendous interaction between different geological processes, the same mineral system can contain different types of mineralization. In such situations the knowledge-driven approaches become particularly useful, because they can target geological processes forming the deposit rather than geological features associated with the deposit. Machine learning can be applied in knowledge-based approaches as well but, in this instance, the machine is learning also from the knowledge of the geoscientist and not only from the data.

Hence, the reasoning behind using unsupervised SOM together with supervised knowledge- and data-driven methods was to be able to:

- identify mineralization-related patterns in the input data without the use of training data
- delineate prospective areas based on the conceptual understanding of the mineralization processes by implementation of the knowledge driven approach, and

- recognize mineralization features represented in the training data and facilitate learning of these patterns by data-driven models.

Most importantly, we conclude from this study that mineral prospectivity studies can be transformed from predictive tools at the regional scale to an aid to detection tools at the target scale for identifying targeted drilling areas. The results presented here were submitted to the journal Ore Geology Reviews and the manuscripts are being processed.

The outcomes of the advanced statistical and machine learning methods presented in this write-up were submitted as part of two manuscripts to the journal *Ore Geology Reviews* and are under review.

"Geological science is full of ambiguities and uncertainties. Exploration of mineral deposits is a challenging yet an exciting task. Nevertheless, with most of the larger deposits already discovered and exploited, finding new deposits is the need of the hour. However, the complex interactions and overprinting of several geological processes since billions of years, have led to their manifestation as highly stochastic phenomena. The non-deterministic nature of earth system processes makes the fitting of mathematical models to geological data even more complicated. Yet, precisely these notions continue to stimulate my interest to gain a better understanding of these systems. Today's advanced modeling approaches come to the rescue to identify hitherto hidden patterns. Interpreting the outcomes of our modeling is like revealing the story the data have all along been trying to tell us! With my background in geology, and my expertise in geoscientific data analysis, data integration, machine learning and mathematical modeling, I try to unravel the enigmatic processes that may have contributed to the formation of mineral deposits on Earth."

Bijal Chudasama is a Postdoctoral Research Scientist in the geoinformatics and geoscientific data analyses team at the Geological Survey of Finland (GTK)

"Like many others, I started from observing the surrounding environment on the surface of our little Earth. It was obvious that a lot is happening there that as humans we cannot directly observe. At the end, the answer to everything always seemed to be in physics and chemistry. Driven by my interest in physics, I took a tour a little further, to the Solar System and beyond. Among many things, it was exciting to model the physical properties of asteroids, seen only as tiny dots in images taken from Earth. It was also inspiring, in a few rare cases, to compare the model to the real shape and spin state of an asteroid imaged by a spacecraft. After landing back on Earth, I started digging below the Earth's surface. How can we know what is in there, below us, without actually going there? Although the target of study is really close compared to an asteroid or a distant galaxy, we just cannot easily get there. What we do is the same as in astronomical problems: find a model that describes the target with parameters that we can measure from the Earth's surface and above. This playground is where I feel at home; working with numbers and functions, and trying to get them organized with the help of physics and chemistry that have always been known to somehow be involved."

Johanna Torppa is a Senior Scientist in the geoinformatics and geoscientific data analyses team at the Geological Survey of Finland (GTK)

2.11 NEXT shares findings of its new exploration technologies applied to the Rajapalot test site in Finland

The exploration company Mawson who owns permits for exploration at the Rajapalot test site in Finland is a partner in the EU funded Horizon 2020 New Exploration Technologies (NEXT) project. For this write-up we invited **Nick Cook**, Chief Geologist of Mawson to share the findings of the new exploration technologies which have been tested and validated in the Finnish test site.

Could you elaborate on your company's exploration activities prior to the start of the NEXT project?

As a company, we have been carrying out ground exploration activities for ore-body delineation, expansion of known prospect areas, and ore resource estimation since 2012. We employed traditional exploration technologies including high spatial resolution ground geophysical measurements such as magnetics, gravity and induced polarization, and also comprehensive drill-core geochemistry. The geophysical and geochemical data, together with the interpretation of the rock types and structural data, revealed that the formation of the mineralization in Rajapalot was driven by epigenetic-hydrothermal processes. This means that the geologic processes involved occurred close to the Earth's surface, and that the mineralization occurred later than the enclosing rock formations. Hydrothermal mineral deposits are accumulations of valuable minerals which formed from hot waters circulating in Earth's crust through fractures. At Rajapalot, this circulation eventually created the rich metallic fluids concentrated in a selected volume of rock, which became supersaturated and then precipitated as a high-grade gold-cobalt deposit.

What motivated your company to join the NEXT project?

The aim of developing more environmentally friendly exploration technologies is of great interest to us. In particular, the ambition to develop new exploration methods that do not leave any trace in the environment is highly supported by Mawson. The Rajapalot area, being a designated NATURA 2000 site, further accentuates our motivation to join the NEXT partnership. At the same time, it was only natural for the research teams in NEXT to welcome the fact that we could offer high-quality geoscientific datasets on which they could test and validate their new approaches and methodologies. Given the extensive ground exploration data available, the Geological Survey of Finland (GTK) considered the Rajapalot area as an ideal scenario to test their novel machine learning-based prospectivity modeling methods.

Could you guide us on the findings of these machine learning-based prospective modeling methods?

In the previous interview, Bijal Chudasama (Postdoctoral Research Scientist), and Johanna Torppa (Senior Scientist) of the Information Solutions Unit within the Geological Survey of Finland (GTK), explained about their motivation to test whether the previously developed regional- and belt-scale prediction methods by GTK could also be used to guide the selection of drilling targets at the scale of a deposit.

From their knowledge driven approaches (FIS and ANFIS), the general NE-SW trend of the mineralization becomes evident, being shown as high prospectivity zones in the corresponding prospectivity map (Figure 23a). These trends conform to the structural settings that strongly control mineralization. For instance, the known prospects are located near the hinge of a kilometre scale open fold, with a NE-SW trending axial trace. These trends are mapped in the prospectivity results also along the hinge and the limbs of this fold. The clusters identified as prospective from the unsupervised SOM also point to geospatial domains of prospective mineralization zones (Figure 23b). In addition to this, the GTK's data-driven approaches identified localized high prospectivity areas near the, as yet, underexplored prospect areas.

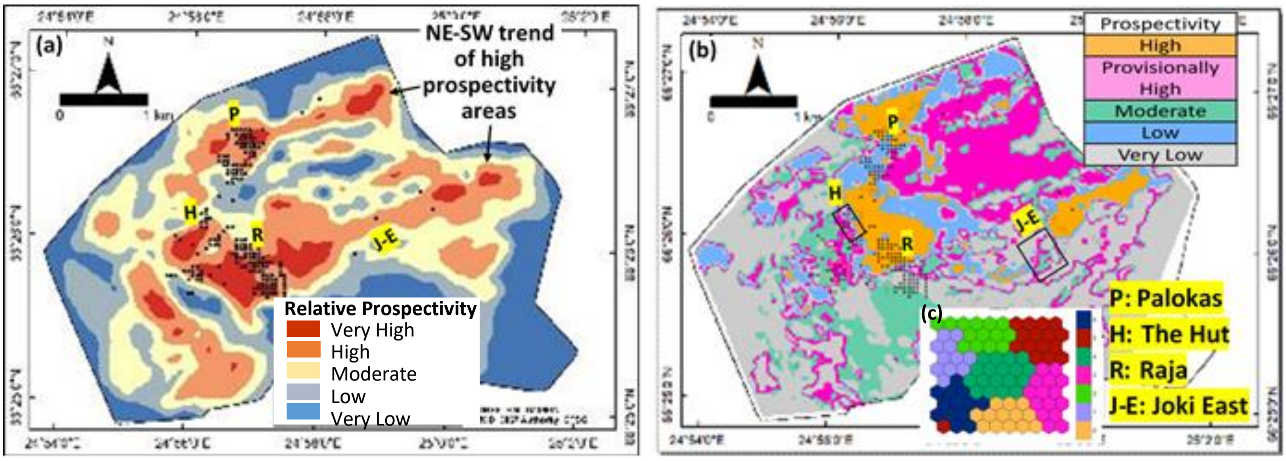

Figure 23: (a) FIS Results showing the NE-SW trend of high prospectivity areas; (b) Geospatial locations of the k-means clusters defined for SOM, (c) the corresponding k-means clusters on SOM

The Joki East (J-E in Figure 23b) area shows moderate to high prospectivity in GTK's SOM results. This area also distinctly appears as a high prospectivity zone in GTK's ANFIS result (Figure 24). This was confirmed by us with the outcomes of targeted drilling as described in our company website posts[8,9,10,11].

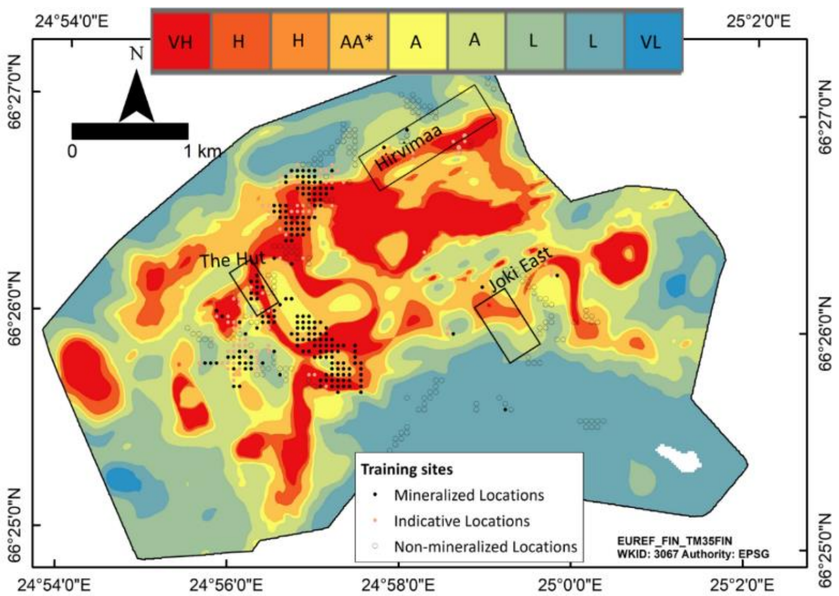

Figure 24: Identification of new possible mineralized areas for drilling. Base map: Prospectivity map from ANFIS model

Similarly, the area around the hitherto less explored Hut prospect (H in Figures 23a and 23b) showed high prospectivity in GTK's SOM, FIS and ANFIS results. Also here, targeted drilling confirmed mineralized horizons[12]. Furthermore, our recent drilling activities at Raja confirmed GTK's predicted mineralization horizons. All of these outcomes continuously add to the existing resources[13].

[8] Mawson Discovers High-Grade Gold At Joki East| Mawson Gold Ltd.
[9] Mawson Drills Further High-Grade Gold at Joki east | Mawson Gold Ltd.
[10] Mawson Drills 1.3 Metres @ 25.3 g/t gold at Joki East | Mawson Gold Ltd.
[11] Mawson Drills 5.5 Metres @ 6.9 g/t gold | Mawson Gold Ltd.
[12] Mawson Defines Two New Areas in Finland | Mawson Gold Ltd.
[13] Mawson Drills 20.7 metres @ 7.4 g/t gold at Raja Prospect | Mawson Gold Ltd.

We understand the Rajapalot area was also a test site for the validation of remote sensing derived products and services developed by the company EFTAS in the NEXT partnership. Could you elaborate on the purpose and outcomes of this Earth Observation based approaches?

As a Natura 2000 designated site, the Rajapalot area hosts flora and fauna habitats which are accorded special protection. To this effect, the potential impact of any type of human activities, including those for mineral exploration purposes, on the environment is subject to monitoring and reporting obligations under EU legislation. For this reason, we were keen to learn more about the remote sensing-based approaches developed by EFTAS which include, among other, the mapping of the vegetation type and the analysis of vegetation change over a period of time. As Sebastian Teuwsen, Project Manager in Research and Development; Energy, Mining and Resource Management at EFTAS explained in your earlier interview, the Rajapalot areas has a completely closed vegetation canopy which presented itself as a major challenge to derive this information from satellite imagery.

However, we were able to give EFTAS a head-start by providing them with a dataset which contains some 40 categories of vegetation types that was obtained from field surveys. This information was used by EFTAS to determine which of these vegetation types occurred with a sufficient magnitude to be used as a training set for the interpretation of satellite imagery. EFTAS applied this machine learning approach for vegetation type mapping using Sentinel-2 imagery. Next, EFTAS proceeded to analyse whether vegetation change occurred over a given period of time. Vegetation change monitoring forms an integral part of our environmental monitoring obligations already during the permit application process and then of course also during the entire term of the mineral exploration permit. Figure 25 depicts the vegetation loss derived from the analysis of Sentinel-2 images on, respectively, 13 June 2017 and 16 June 2019. Aside from the visualization of a light decrease of biomass and/or vegetation vitality along the tracks used by vehicles and machinery for exploration purposes, the strongest decrease in vitality is observed in the top left of Figure 25 within and around a surface water body. This loss in vitality is likely to be induced by changes in water level and the distribution of aquatic plants and algae. Hence it can be attributed to the natural terrestrial surface water dynamics of wetlands rather than mineral exploration activities.

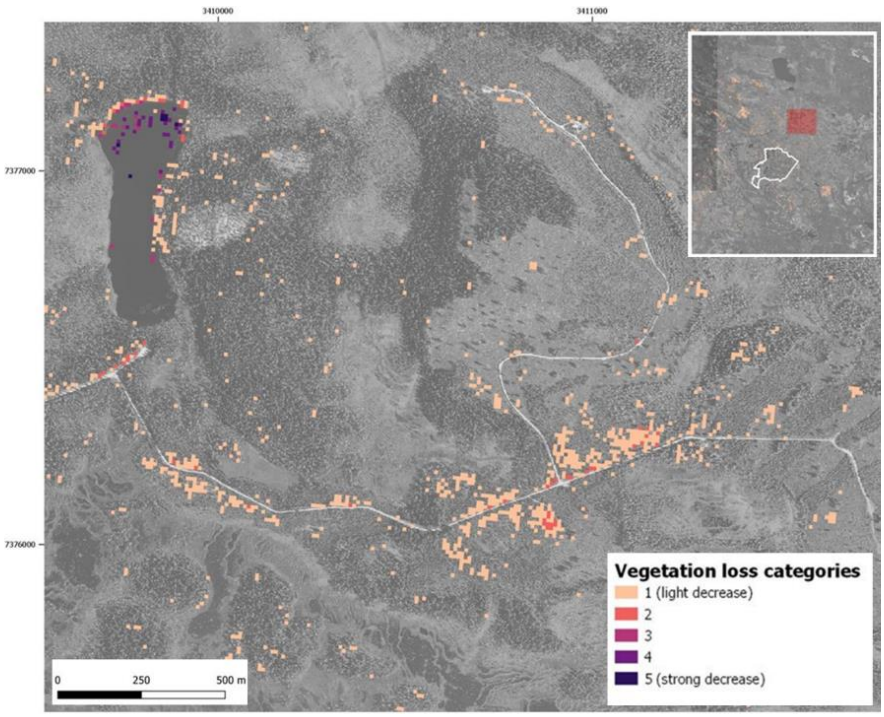

Figure 25: Vegetation vitality changes in the Rajapalot area derived from Sentinel-2 imagery

How would you describe your main appraisal of the novel approaches to mineral exploration developed in the NEXT project?

The mathematical modeling of prospectivity performed by GTK fully convinced us that these predictive tools can be used for selecting new drilling targets at the camp-to-target-scale. At the same time, our recent drilling activities enabled GTK to further improve the understanding of how these methods can lead to optimum results.

We also asked EFTAS whether their approaches could be used to identify land compensation areas. Once again, this was motivated by the fact that the environmental legislation in force requires us to find similar habitats to the ones at Rajapalot to compensate for the possible loss of some its habitats should the exploration proceed to the application for a mine development. Meeting our request, EFTAS provided us with a satellite image map shown in Figure 26, which covers a much larger area around the designated Natura 2000 site. The reddish areas indicate regions matching the reference pattern in terms of vegetation composition of the Rajapalot area which is shown in the centre of the map. Obviously, these areas would need to be ground truthed, but as with GTK's predictive tools, this map clearly gives us a head-start to identify suitable compensation areas.

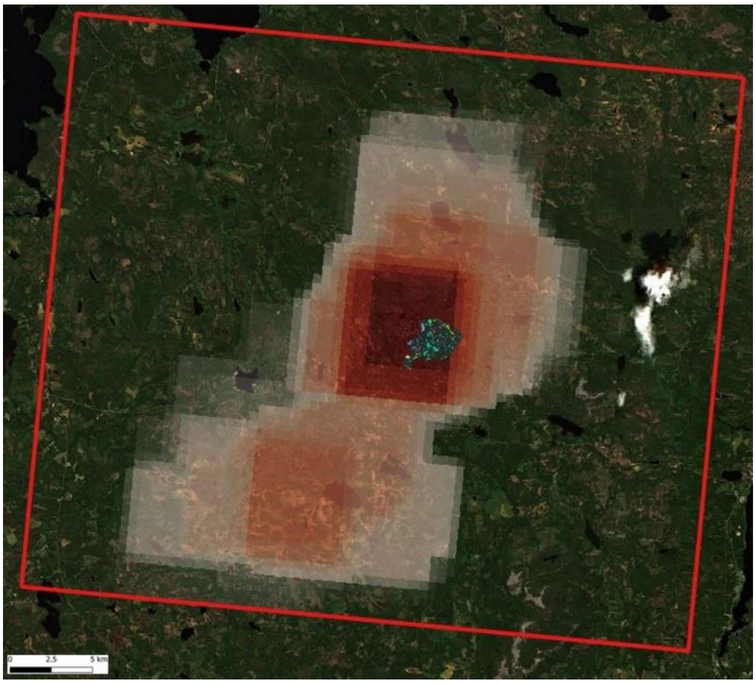

Figure 26: Identification of potential compensation areas derived from Sentinel-2 imagery

"I am a keen hands-on geologist with a long history in Proterozoic terranes, both as an academic and exploration geologist. Currently, I am involved in leading the Finnish geological team in building the Paleoproterozoic Rajapalot Au-Co resources in Lapland. I am also heavily involved in cooperative research projects with the Geological Survey of Finland (GTK) including the EU-funded MinExTarget, and Business Finland funded BATCircle and BATTrace."

Nick Cook is Chief Geologist of Mawson Oy

Chapter 3 Findings from the *Social Licence to Explore* research activities in NEXT

The present chapter summarizes the main outcomes of the research activities carried out on the theme ***Social Licence to Explore*** (SLE) in the NEXT project. These research activities included (1) mapping of key factors influencing social licensing at the mineral exploration stage, (2) assessing the importance of the new sensitive technologies and early contacts with local communities to the process of obtaining and maintaining a SLE, and (3) assessing social and safety risks associated with mineral exploration.

Two locations were selected to gain further insights about the perceptions on the new technologies and their role in social licensing pertaining to the mineral exploration phase. In Finland, Mawson's Rajapalot exploration site on the border of the Ylitornio and Rovaniemi municipalities, in southwest Lapland, is the case-study area. In Sweden, Boliden's exploration in the Gällivare municipality is used as a comparative case. Boliden's long-standing exploration and mining activities are used as a base-line when assessing the effects of Mawson's use of new technologies and proactive community engagement practices. A third case was added in Jokkmokk municipality located some 100 kilometres south of Gällivare. No mines exist in Jokkmokk, but the company Jokkmokk Iron Mines AB (JIMAB) is exploring with conventional technologies and have plans to establish an iron mine. However, in contrast to Gällivare municipality where little opposition to exploration and mining has been documented, the opposition to mineral exploration and mining in Jokkmokk is well documented[14,15].

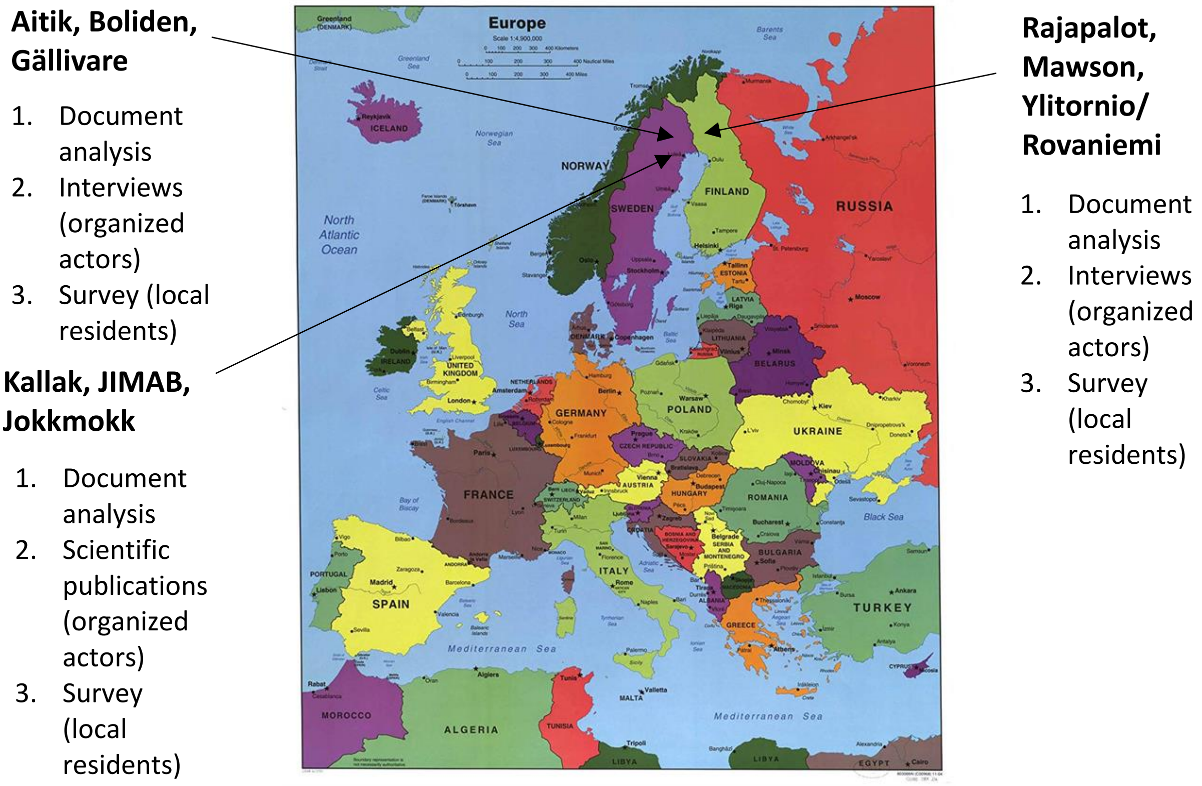

Figure 27: Nature of the research activities pertaining to the Social License to Explore theme in the three selected case studies

[14] Beland Lindahl, K., Zachrisson, A., Viklund, R., Matti, S., Fjellborg, D., Johansson, A., Elenius, L., 2016. Konflikter Om Gruvetablering: Lokalsamhällets Aktörer Och Vägar till Hållbarhet (Conflicts about mine establishment: Local actors and pathways to sustainability). Report no. 2/2016. Länsstyrelsen i Norrbottens län, Luleå, Sweden

[15] Beland Lindahl, K., Johansson, A., Zachrisson, A., Viklund, R., 2018. Competing pathways to sustainability? Exploring conflicts over mine establishments in the Swedish mountain region. J. Environ. Manage. 218, 402–415.

Figure 27 shows the three case study locations and summarizes the methods used to explore each case. For a complete presentation of the outcomes, which include also the Jokkmokk case study, the reader is referred to the Report on the role of exploration technologies and associated social and safety risks for social licensing[16] and the associated policy brief[17].

In this chapter we have once again adopted the approach of sharing these outcomes in the form of easy-to-understand write-ups, which is meant to make the material fully accessible to a general public and therefore also to people in the local communities who actively participated in the NEXT project research activities.

We start this chapter with a write-up on the outcomes of interviews with representatives of mineral exploration and mining companies who attended the Exploration Seminar organized in Rovaniemi, Finland in October 2019. These interviews were foremost aimed at finding out what exploration companies themselves would wish us to address and present in this Toolkit for it to be fit-for-purpose. By and large, they converged on being given answers to the questions with who, what, why, when and where to communicate with local communities in the areas where they conduct exploration activities.

To find out to what extent and how exploration companies in Finland communicate about their use of new exploration technologies and their SLE-related commitments and strategies, a survey of their websites was conducted in 2018 and then repeated in 2020. Overall, these findings suggest that when operating in sensitive contexts and faced with the risk to lose the SLE, or challenges to gain the SLE, companies make efforts to strengthen their image, including through informing on their website about their stakeholder engagement practices and the very low to negligeable impact on the environment when using new exploration technologies.

A second set of interviews, this time with organized actors in both Finland and Sweden, aimed at exploring local actors' understanding of mineral exploration and identifying factors affecting local acceptance, including social and safety risks. The outcomes show how both the way of communication and the quality of interaction can lead to improved understanding and knowledge about exploration technologies and, in some cases, to a higher level of acceptance towards exploration by local actors.

However, in both the survey of company websites and the interviews with local organized actors, the research concluded that other factors than the use of new technologies were more important to actors' attitudes. In fact, the interviews indicated that the most important factors are actors' visions of the future, their understanding of sustainable development and their perceptions of impacts of mineral exploration and mining.

Expectations, uncertainty and risks are key issues when debating about mineral exploration activities. This was highlighted during an Info Day organized in June 2019, and reaffirmed by interviews with residents of local communities in South West Finnish Lapland. Since the lifestyle here is closely tight with nature, perceived environmental risks often turn to social risks when changes in the environment are predicted to worsen every-day-life of local people, or concerns about the future of the home-area emerge. The concluding write-up in this Chapter summarizes these findings and delves into local peoples' perceptions about mineral exploration with the new tools and approaches that were applied in the Rajapalot test site in Finnish Lapland.

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[16] https://www.new-exploration.tech/media/pages/media-news-events/deliverables/downloads/d5-3-role-of-exploration-technologies-and-associated-risks/a7f6cc0c22-1634114921/d5.3_report-on-the-role-of-exploration-technologies-and-associated-social-and-safety-risks-for-social-licensing.pdf

[17] https://www.new-exploration.tech/media/pages/media-news-events/publication/downloads/next-policy-brief-on-factors-affecting-local-attitudes-to-mineral-exploration/afca330bf7-1631285539/next_policy-brief_factors-affecting-local-attitudes-to-mineral-exploration_en.pdf

3.1 NEXT shares outcomes of interviews with mineral exploration companies

On the occasion of the Exploration Seminar that was organized by the Horizon 2020 New Exploration Technologies (NEXT) project in Rovaniemi on 9 October 2019, the participating representatives of exploration and mining companies were invited to take part in short semi-structured interviews.

The interviews were conducted by **Dirk De Ketelaere**, Senior Researcher at Integrated Resources Management Company Ltd., IRMCo, an environmental research company based in Malta, and **Toni Eerola**, Senior Specialist at the Geological Survey of Finland, GTK.

Figure 28: Markku Iljina, who runs an independent exploration company based in Finland, being interviewed by Dirk De Ketelaere (Photo by Toni Eerola)

What was the main motivation for your interviews with exploration and mining companies?

The delivery of a Toolkit addressed to exploration companies presents itself as the final, practical outcome in the research that is being conducted under the umbrella of the Social License to Explore (SLE) theme in the Horizon 2020 NEXT project. Hence, we wished to obtain first-hand knowledge what the expectations of such a toolkit would look like on the part of our target audience.

How many interviews were conducted and what was the area of expertise of the participants?

We conducted a total of ten interviews, with mainly exploration geologists (nine) and one geophysicist accepting to take part. The interviewees represented Finnish, Swedish and Australian companies, among which seven were exploration and three consultancy companies.

How would you describe the main outcomes from your interviews?

Many of the interviewees were not aware whether their corporate websites address Social License to Explore (SLE) related aspects, and referred to other people in the company for a detailed answer.

Half of the company representatives considered SLE-related issues as an important topic to be considered in the first place when going to a new area to explore, while the other half considered the technical aspects to be more important.

The new technologies were mainly reflected upon regarding their cost and time efficiency, but also in relation to a further reduction of the environmental footprint. The ones most mentioned were drones. The interviewees held the view that local communities may be interested in drones and their lower environmental impact may help companies to be accepted in their mineral exploration activities.

Some company representatives stressed the importance of considering land use issues when planning and selecting targets to explore, i.e. to avoid operations in nature conservation areas, Sámi homeland, tourism destinations, to avoid the risk of conflicts and increase the chances of obtaining SLE.

The stakeholder engagement of the companies seems to be restricted mainly to information sharing. Interviewees largely converged on the need to first meet with the landowners, residents, and other stakeholders, and then to organize meetings with the local communities. However, none of the interviewed company representatives mentioned participation and collaboration as important for obtaining an SLE at the local level. The stakeholders mentioned included reindeer herders, mayors, landowners, community, road maintenance associations, and municipalities.

The need for raising public awareness about mineral exploration was recognized by many, as well as the need for guidance on how to communicate and ensure active stakeholder engagement.

If we can draw two main conclusions from these interviews, these would be that already existing toolkits were not known and need to be disseminated in a more effective way, particularly among the mineral exploration companies in Finland, and, secondly, there was a clear expectation for any toolkit to be process-oriented, i.e. provide answers to the questions of what to do, when, where, how, and why.

To conclude this interview, Dirk and Toni invited us to share this summary overview of the ten main points that were the subject of their interviews with mineral exploration companies

1) **Types of technologies**: Conventional technologies and methods are mentioned by most of interviewees. Drones are mentioned by some as a new technology that they have been using. Two mentioned the technologies developed and tested within NEXT, such as snow and soil sampling and the use of drones.

2) **The first issues to consider in exploration of a new area**: Around half of the respondents mentioned data collection, choice of technologies, study of structural controls and elaboration of geophysical models, selection of target and commodity, fulfilling shareholders' expectations and reconnaissance with geophysics and soil sampling. The other half emphasized social aspects, such as interaction with the local community and landowners, consideration of land use and social and environmental impacts.

3) **Meaning of Social License to Explore (SLE) for the company**: Specific reference to the term SLE did not feature often in the interviews. However, for some interviewees, social acceptance is a big issue. This was not the case for one Swedish company representative, who considered the authorities as the main issue in Central Sweden. However, another Swedish representative did not share this view and asked the NEXT project to offer guidance for their community relations in Northern Sweden. Consideration of competing land uses in the selection of exploration targets, e.g., to avoid Natura 2000 and Sámi areas, is mentioned by representatives from Finland, while others emphasize co-existence and active company-community engagement, including interaction, contacting landowners, meeting the local community, and informing what they are doing and consideration of the environment and existing land use to avoid conflict. Some also stated that foreign companies need to be better informed about the local issues at hand. The need for information sharing was considered as the main issue, whereas active engagement and collaboration were not specifically mentioned.

4) Strategies for SLE: A consultant with only junior experience "reflected about" SLE related topics and actions to be taken in response to the contractor's request for pro-active engagement with the local community; to be open, to be the first person to inform about activities, to talk with mayors with a view to organize Information Days.

5) Personal interaction with the local actors: Some of the interviewees stressed the need to have the required skills when contacting local people. Several interviewees advocated sharing information. The use of "common sense", i.e. starting by meeting landowners and then organizing community meetings when applying for the exploration permit and contracting local people were recommended to be part of the exploration activities. Even if the way of contacting may vary with the type of project; gaining social acceptance was essentially seen as fundamental to running the operations. In relation to the nature of personal interaction, talking with the municipalities and road maintenance associations, presence at community meetings, discussions with reindeer associations about their expectations / issues; and the organization of geology courses were mentioned.

6) Communication channels:

a) ***Targeting investors***: carried out by specialized personnel, websites (usually in English), newspapers, quarterly newsletters.

b) ***Targeting local actors***: direct contacts, announcements in local newspapers to "spread the word" about community meetings, maintain websites to make the data on water and soil sampling publicly accessible and guide people to send their CV for job applications, and the use of email to contact landowners. The consultants interviewed held the view that although they may have their own company website, this could not bring information about their clients' projects. On the other hand, they stated that they could meet landowners and send letters to the municipalities explaining about activities; bring announcements in the local newspapers, but would not rely on journalists.

7) SLE-related issues addressed on the company website: On this topic the answers were quite evasive: many informed they were not aware whether SLE-related content featured on the websites of the company they represented. Some of the interviewees stated that the respective companies they worked for did not have its own corporate website, but that of the parent company; some preferred not to use the terms SLE or SLO at all because it might not be known by the local people - "technological research and development are the main focus on our website". One company mentioned the SLO-concept directly in its Swedish pages (pages also in Norwegian for general audience and in English for investors); another interviewee held the view that since most of the people are elderly in the exploration area, they do not visit a website.

8) Influence of new technologies on SLE, and SLO in the longer term: Interviewees mostly agreed that technologies matter a lot. Some mentioned their use of surface soil sampling as a technology not leaving any traces of activities behind. Others considered that the local community would be interested to learn more about the use of the drones that are being developed in NEXT. An interviewed consultant stated he would advise his clients to both use and advertise new technologies in their websites after learning about the new technologies in the NEXT seminar, and expressed the view that if it is possible to demonstrate that the technologies reduce the environmental impact, this would bring a clearly positive aspect to share with the local community.

9) Other benefits of new technologies: Responses varied between: maybe too early to answer; they are cost-effective and faster, cost is the main issue when it comes to mineral exploration; it would drive innovation in the sector; it is important to train local people in the use of such technologies in order to be able to be hire them. Moreover, the aspect of efficiency is emphasized; new technologies are developed to minimize the environmental footprint (probe to detect cosmic ray particles in boreholes and use of solar and thermal energy to reduce energy consumption); the choice of technologies should be considered on a case-by-case basis, drones do not serve all purposes.

10) **Assistance needed for community engagement**: Communication is seen as the main issue. Any toolkit should be process-oriented, i.e. provide answers to the questions of what to do, when, where, how, and why. There are companies that come to an area just for a quick trip to check out mineral potential and then move on, not spending time with community issues. Companies need to be guided how to conduct stakeholder engagement, and there should be guidance on tools to communicate and inform people better about exploration as they do not know about that. A toolkit about general practices and standards would be welcome and companies can advertise that they are following such standards. It is important to keep the local community informed also because they can offer services and, in this context, it is important to have a local person on the ground who speaks the local language, and be the company's face for the community.

"Whilst a majority of our company's research projects over the past 25 years have dealt with various aspects of water resources management, my involvement in the Horizon 2020 NEXT project and in the FP7 ProMine project reinforces my viewpoint that there is a clear need to directly involve local communities in all matters that pertain to their land and water resources. responsibilities set by companies are simply not sufficient to ensure and safeguard the social well-being of society. As a hydrologist, I do not see access to water as a source of conflict but rather a means to build lasting bridges among competing users. To think of it, access to land should be viewed in the same way."

Dirk De Ketelaere is a Senior Researcher at Integrated Resources Management Company Ltd., IRMCo, an environmental research company based in Malta

"My work as a geologist in Finland and abroad made me observe and learn the importance of stakeholder engagement and communication with local communities and other stakeholders since I was student and trainee in the field. I have been practicing and developing stakeholder engagement and related toolkits and standards not only through the Horizon 2020 NEXT and MIREU projects, but also directly with mineral exploration companies, and through collaboration with the Finnish Network for Sustainable Mining and the Finnish Mineral Exploration Network of the FinMin."

Toni Eerola is a Senior Specialist at the Geological Survey of Finland (GTK)

3.2 Outcomes of a survey of websites of companies practicing mineral exploration in Finland

The present write-up brings the outcomes of a survey of websites of companies practicing mineral exploration in Finland. The survey was performed by **Toni Eerola**, Senior Specialist at the Geological Survey of Finland (GTK) in 2020. The motivation for this survey is because a website is considered an important tool in modern corporate communication. Corporate websites are typically monitored by investors, and by non-governmental organizations (NGOs), and are also sources for local communities and landowners who search for information on companies operating in their region.

The main surveyed topics were companies' communication on their websites concerning the use of new low impact mineral exploration technologies (NLIMET) and contents relevant to Social Licence to Explore (SLE)-related topics, i.e. references to acceptance and/or approval of mineral exploration by local communities. The purpose was to examine to what extent and how companies communicate their use of NLIMET and SLE-related commitments and strategies.

The contexts in which companies operate and ongoing or previous company-community disputes were also investigated. The overall goal of the survey was to find out how companies communicate about NLIMET and SLE and how these strategies may be affected by the contexts where they operate.

From a total of 73 companies, 20 mention SLE-related topics in their websites (see Table 3). The survey revealed that most companies do not mention the SLE directly on their website but address it in terms like stakeholder engagement or company-community relationship.

Table 3: Company websites referring to the social license to operate/explore (SLO/SLE)

Company (own/parent company's nationality)	Activities	Main project(s)/deposits	Commodities
A.A. Sakatti Mining Oy (UK)	Mine development, mineral exploration	Sakatti	Nickel, copper, gold, platinum group elements
Agnico Eagle Finland Oy (Canada)	Mining, mineral exploration	Kittilä	Gold
Anglo American Exploration B.V. (UK)(*)	Mineral exploration	Sakatti	Nickel, copper, gold, platinum group elements
Boliden (4 subsidiaries; Sweden)	Mining, mineral exploration	Kevitsa, Kuhmo, Kylylahti,	Nickel, copper, cobalt, zinc
Karelian Diamonds Resources Oy (Ireland)	Mineral exploration	Kuhmo	Diamonds
Hannukainen Mining Oy (Finland)	Mine development, mineral exploration	Hannukainen	Iron, copper, gold
Keliber Oy (Finland)	Mine development, mineral exploration	Läntä	Lithium
Kultatie Holding Oy (Australia) (*)	Mineral exploration	Satulinmäki	Gold
Kultatie Oy (Australia) (*)	Mineral exploration	Satulinmäki	Gold
Latitude 66 Cobalt Oy (Australia)	Mine development, mineral exploration	Juomasuo	Gold, cobalt, uranium (**)
Mawson Oy (Canada) (*)	Mineral exploration	Rompas-Rajapalot	Gold, cobalt, uranium (**)
Muon solutions Oy (Finland)	Mineral exploration	Ylivieska, Nivala	Nickel, cobalt, copper
Oy Fennoscandian Resources Ab (UK)	Mineral exploration	Heinävesi, Tuusniemi	Graphite

Pyhäsalmi Mine Oy (Canada)	Mining, mineral exploration	Pyhäsalmi	Copper
Rupert Resources Finland Oy (Canada)	Mineral exploration, mine development	Pahtavaara	Gold
Sakumpu Exploration Oy(*) (Australia)	Mineral exploration	Aarnivalkea, Aakenusvaara	Gold, copper
Stonerol Oy (Germany)	Mineral exploration	Simo	Gold
Arctic Platinum Oy (UK)	Mine development, mineral exploration	Suhanko	Platinum group elements
Terrafame Oy (Finland)	Mine, mineral exploration	Talvivaara	Nickel, copper, cobalt, zinc, uranium (**)
Yara Suomi Oy (Norway)	Mining, mine development, mineral exploration	Siilinjärvi, Sokli, Savukoski	Phosphorus, iron, niobium (**), uranium (**)

(*) Parent company website
(**) Elements found in association with the main commodities

Only nine companies report on the use of NLIMET (see Table 4). Those which do, report mostly on the use of drones. Eight of the companies addressing NLIMET, also mention SLO/SLE.

Table 4: Company websites referring to new low-impact mineral exploration technologies (NLIMET)

Company	Activities	Main project(s)	NLIMET
A.A. Sakatti Mining Oy	Mine development, mineral exploration	Sakatti, Sodankylä	Closed-circuit drilling
Anglo American Exploration B.V. (*)	Mineral exploration	Sakatti, Sodankylä	Closed-circuit drilling
Boliden	Mining, mineral exploration	Sodankylä, Kuhmo, Kylylahti, Pieksämäki Joroinen	Deep-penetrating electro-magnetic survey
Latitude 66 Cobalt Oy	Mine development, mineral exploration	Juomasuo, Kuusamo	Drone
Magnus Minerals Oy	Mineral exploration	Several locations	Manual XRF analysis
Mawson Oy (*)	Mineral exploration	Rompas, Yli-Tornio	Drone, snow, and plant sampling
Muon Solutions Oy	Mineral exploration	Ylivieska, Nivala	Muography
Oy Fennoscandian Resources Ab	Mineral exploration	Heinävesi and Tuusniemi	Drone
Rupert Resources Finland Oy	Mine development, mineral exploration	Pahtavaara, Sodankylä	Drone

(*) Parent company website

Out of the nine companies referring to NLIMET in Finland, seven were found to operate in sensitive contexts (nature conservation areas, tourism destinations and/or exploration activities associated with uranium), as shown in Table 5. Exploration activities in such contexts are more likely to trigger resistance or conflicts in Finland. Actually, those seven companies also face some form of opposition from local communities and/or NGOs. In one case, a bad reputation of the parent company originating from previous disputes in Sweden and poor corporate conduct in the form of insufficient communication and stakeholder engagement also seems to play a role (see Table 5).

Overall, these findings suggest that when operating in sensitive contexts and faced with the risk to lose the SLE, or challenges to gain SLE, companies make efforts to strengthen their image, including through informing on their website about their stakeholder engagement practices and the very low to negligeable impact on the environment when using NLIMET. Hence, addressing NLIMET on the website may be motivated by SLE related challenges associated with sensitive contexts. However, this research also suggests that other issues - such as project location, commodity, and corporate reputation and conduct (attitudes, activities, communication, stakeholder engagement) – are typically more important to local community attitudes than the technology.

Table 5: Companies mentioning NLIMET on their websites and operating in sensitive contexts.

Company and activity	Main project(s)	Commodity	Sensitive context and issues
A.A. Sakatti Mining Oy, mine development, mineral exploration	Sakatti (Sodankylä)	Nickel, copper	Natura 2000, mire conservation, reindeer herding
Anglo American Exploration B.V. (*), mineral exploration	Sakatti (Sodankylä)	Nickel, copper	Natura 2000, mire conservation, reindeer herding
Boliden Finnex Oy, mineral exploration	Pieksämäki and Joroinen	Gold, copper	Groundwater area
Latitude 66 Cobalt Oy, mine development, mineral exploration	Juomasuo (Kuusamo)	Cobalt, gold, uranium (**)	Tourism, uranium, reindeer herding
Magnus Minerals Oy, mineral exploration	Joensuu, Kontionlahti and Ilomantsi	Eighteen Commodities	Holiday homes, lake area, claim reservation size
Mawson Oy (*), mine development, mineral exploration	Rompas (Yli-Tornio)	Cobalt, gold, uranium (**)	Natura 2000, reindeer herding, uranium
Oy Fennoscandian Resources Ab, mineral exploration	Heinävesi, Tuusniemi	Graphite	Lake region, holiday homes, tourism destination, bad reputation (***), poor corporate conduct

(*) Parent company website
(**) Elements found in association with the main commodities
(***) Parent company Beowulf Ltd.

A manuscript on the results of this survey has been accepted for publication in the Journal of Cleaner Environmental Systems[18].

[18] Eerola, T. New low-impact mineral exploration technologies and the social license to explore: insights from corporate websites in Finland. Submitted to Journal of Cleaner Environmental Systems (forthcoming)

3.3 Sharing outcomes of interviews with local organized actors in Finland and Sweden

Earlier studies have consistently shown that mineral exploration can bring hopes but also fears to different actors depending on their personal or collective preferences. The aim of the interviews with local organized actors, as part of the Horizon 2020 New Exploration Technologies (NEXT) project was to better understand local actors' perceptions of exploration and other factors that are likely to affect their views on exploration and mining, including their views on regulations and exploration companies' communication and engagement efforts.

The interviews were conducted by **Karin Beland Lindahl** from Luleå University of Technology in Sweden, and **Leena Suopajärvi** from the University of Lapland in Finland. They interviewed mining companies, municipality and business representatives, village associations, (Sami) reindeer herders, and NGOs in Gällivare municipality, Sweden which has a long history of mining and in Ylitornio, Finland where to date only mineral exploration activities have taken place. Two interviews in Finland were also conducted in a nearby village located in the neighbouring Rovaniemi municipality.

Table 6: Socio-economic conditions in the two case study areas. Sources: Statistics Sweden 2020, Statistics Finland 2020

Case Study	Gällivare	Ylitornio
Area of municipality	16,818 square km	2,213 square km
Population and demography	17,529 in 2019 Declining Elderly population	Around 4000 Declining Elderly population
Unemployment	Stable low/declining 1.8 % in 2019	Varying, but currently lower than in 2000s. About 12.6 % in 2020
Largest employers	Gällivare municipality: 23.5% LKAB (mining): 13% Boliden Mineral AB (mining): 7.5% Norrbotten County (health care): 9.1%	Ylitornio municipality: 30% Decentralized small businesses (appr. 300 enterprises) in tourism, industrial production, traffic, welfare services etc.
Average income	Above the national average due to well-paid jobs in the mining industry	Low especially in "Lake Villages" where the majority of the residents are retired
Indigenous peoples and minorities	Swedish majority but with relatively large Sami and Finnish minorities.	Finnish population Not part of Sami homeland in Finland

An ageing and declining population bring similarities to both case studies. However, significant differences are observed when it comes to employment opportunities. With over 20% of the local workforce employed by two mining companies, the unemployment in Gällivare is much lower as compared to Ylitornio, where the unemployment rate stands at 12.6%. Well-paid jobs in the mining industry explain why the average income is above the national average in Gällivare. In Ylitornio, 40% of the residents belong to the lowest income group in Finland as their income is primarily derived from their retirement pension. Another difference lies with the fact that Gällivare municipality is home to indigenous people, including four Sami Reindeer Herding Communities (SRHCs) who practice traditional Sami reindeer herding.

To date, there has not been any mining activity in Ylitornio, but the locality has witnessed ten years of mineral exploration using new and more environmentally sensitive technologies. In Gällivare by contrast, active mining has been ongoing for decades and Boliden is continuously exploring new deposits primarily using conventional exploration technologies. The exploration company operating in Ylitornio, Mawson Oy, has been very proactive in their communication with the affected local community. Overall, actors in Ylitornio considered themselves as being well informed and perceived the quality of interaction as good. Swedish Boliden has an established relationship with the community and communicates as required by the legal framework in Sweden, but has not engaged in particular outreach about exploration or exploration technology. The company is in constant contact with landowners, the municipality and the SRHCs, and interaction regarding exploration is hard to separate from their communication about many other mining related issues. Also, relationships have shaped over many decades. Boliden has been communicating directly with local actors that are affected by their exploration and planned mining operations. Sami RHCs are always informed by mail about exploration activities and provided with the specific working plans by the responsible authority. However, most local actors are informed through the use of the local media, public notices and sometimes through the organization of public meetings. Overall, the actors interviewed held varying opinions on the quality of this communication. The SRHCs experienced an overload of written notices and work plans and considered themselves to not having the resources to follow-up on all of them. Lack of responsiveness on the part of the companies, uneven power relations and unequal access to resources were common themes particularly among Sami RHCs and landowners that were directly affected by exploration and mine development. While some actors thought communication with the company worked very well, others felt there is room for improvement both in relation to communication strategies and company responsiveness.

In general, exploration technology was not a topic that engaged the informants and the informants' state of knowledge on this topic varied. In Ylitornio, the use of drones and other new technologies for the purpose of mineral exploration was familiar to some actors since Mawson had proactively informed local people about their use of new exploration technologies. In Gällivare, some actors, notably representatives of village associations, reported no, or little, knowledge about which exploration technologies are in use, while other actors considered themselves to be well-informed about the exploration technologies used by Boliden.

The majority of actors in Sweden and Finland stated that less intrusive technologies are considered positive, especially if impacts, and in particular the reliance on drilling, can be reduced. However, several actors also stated that technology is not a major issue, and that other factors, such as the impacts of a possible mine, are more important in influencing their attitudes to exploration.

Most local actors that were not directly affected by exploration or mine development stated that their knowledge about the regulatory system is limited, but that they trust it is adequate. In Ylitornio, most of the actors did not have direct experiences of the regulations, so their knowledge was limited, but they anyhow considered the Finnish regulatory framework to be sound and working well. In Gällivare, actors had more experiences of exploration and mining, and their perceptions of the regulations was clearly influenced by their personal experiences and attitudes towards exploration and mining. While some actors trusted the system, others did not consider it fair and legitimate albeit for different reasons. Landowners deemed it inadequate to protect land- and property owners' rights; business representatives were concerned with lead times being too long and inconsistent implementation; Sami RHC representatives did not trust the system because of its inadequate treatment of Sami rights and inability to address existing land use conflicts; several actors found it biased in favour of mine development. Unclarities as to how different regulations "talk to each other", how responsibilities are distributed between different state actors, as well as inconsistencies, delays, or biases, in implementation were issues which came to the fore in both case studies.

Most actors in the Ylitornio/Rovaniemi case experienced the environmental impacts of Mawson's exploration activities as very limited. This, together with their expectation that the possible opening of a mine would bring income and employment opportunities, are likely underpinning the generally positive attitudes to exploration that was found among most of the Finnish actors. However, negative positions were also expressed, particularly with regard to exploration in protected nature conservation areas. Some actors typically conditionalized their approval of a possible mine resulting from the exploration activities: *if* environmental issues are taken care of and *if* mining could bring work opportunities, it could be accepted.

Those who strictly opposed mining in nature conservation areas or thought that mining would bring lasting harm to other livelihoods, for example to the traditional reindeer-herding, stated they would oppose the opening of a mine.

A significant factor in shaping the attitudes in Gällivare is that employment in the municipality is highly dependent on mining, a fact which was recognized by all actors during the interviews. At the same time, their personal positions on exploration varied significantly reflecting different experiences of the impacts. Whereas some actors approve exploration for new mines, others do not wish to have exploration aiming for the establishment of *new* mines in the area. A further segment of actors, e.g. Sami RHCs, stated they would prefer to see a restriction on all new exploration activities. Several actors also stated that their acceptance is due to the community's ongoing dependence on mining and lack of alternatives. Some pointed out that their own, or others' acceptance, could be higher *if*, for example, procedures for fair compensation and distribution of benefits were in place.

The interviews showed how both the way of communication and the quality of interaction can lead to improved understanding and knowledge about exploration technologies and, in some cases, to a higher level of acceptance towards exploration by local communities. However, our research also demonstrated that the most important factors affecting local actors' attitudes are their visions of the future, their understanding of sustainable development and their perceptions of impacts of mineral exploration and mining.

"Drawn by a love for forests and a strong interest in environmental issues, I graduated from university with a bachelor's degree in biology. But after some years of lichen, fungi and wetland inventories, I started to ask myself what really matters for the environment. What is most needed right now, more knowledge about the forest living species, or a better understanding of the social system governing the natural resources? So, I shifted to political science and started a graduate project which looked at local peoples' relations to forests and forest conflicts in Sweden. Today my research continues to focus on the politics of natural resource management and conflicts, particularly related to forests, minerals and energy. Understanding how local people are affected, and actively consulting and involving them in all aspects related to natural resource management, are key for the legitimacy of resource-based businesses and the State governing the resources."

Karin Beland Lindahl is an associate professor in political science at Luleå Technical University in Sweden

"As a little child born in Lapland, I always got very worried whenever adults discussed about hydro-power generating projects. How was I going to get back home if the water would cover the entire road to our village? Hardly coincidence I guess that I went on to study disputes about hydro-power construction in Lapland from master theses to doctoral theses. All along, I increasingly started asking myself what is the role of local people in natural resource governance? And for sure it cannot be coincidence either that I have been delving into the social and environmental impacts caused by mining projects ever since Lapland witnessed a mining boom at the start of the present millennium."

Leena Suopajärvi lectures on environmental sociology at the University of Lapland in Finland *(Photo credit: Marko Junttila)*

3.4 Social risks of mineral exploration: perceptions of local residents in Finnish Lapland

When debating about mineral exploration activities, people tend to focus on expectations, risks and the uncertainty about the outcomes. In the 17 interviews conducted by **Leena Suopajärvi** from the University of Lapland in Finland with residents of the Ylitornio Municipality and in the southern parts of Rovaniemi Municipality, all respondents speculated whether the company Mawson's exploration site in the Rajapalot area would become the object of a mining application and what the prospect of a mine would bring for the local communities, economy, and environment.

In general terms, risks are negative predictions; expectations based on today's knowledge that negative impacts or issues might happen because of today's choices and actions based on those decisions. On the other hand, there may be risks realizing in the future that cannot be foreseen - they cannot be predicted with today's knowledge.

Social risks of mineral exploration are risks that may affect local people and stakeholders in the vicinity of the exploration sites. In the northern, rural areas of Finland, people's lifestyle reflects their relationship with nature. As a result, environmental risks often turn to social risks when changes in the environment are expected to worsen every-day-life of local people, or when concerns about the future of the home-area emerge. This may typically include negative emotions like fear or despair.

Environmental risks were considered to be minor among the local respondents. In the early stages of the exploration activities, when the French company Areva S.A. was operating in the area, there were speculations about uranium radiation or impacts to the water system. Over the years, these doubts faded away. Also, the environmental footprint of drilling was considered to have been taken care of in recent years, and a concluding remark of a villager living nearby the exploration area was: "yes, it is strongly exaggerated that it would somehow destroy that environment". Local people who had been visiting the Open-Days organized on an annual basis by Mawson, vouched that there had not been even smallest oil spills resulting from the exploration activities in the area. They also argued that there might be accidents involving or caused by the machinery used, but held the view that risks of injury are present in every work site and so far, no serious accidents were reported. In general, respondents referred to the company's own risk assessments and safety measures and described how authorities monitor and restrict activities so that environmental risks are limited.

The main concern caused by the mineral exploration was a feeling of uncertainty among the locals. And "uncertainty is the worst thing", as one reindeer herder pondered. Some stated that they will not live to see the result: "this current generation who lives here will not be witnessing the opening of a mine". Therefore, the main argument put forward was that exploration should be continued without any delays so as to know whether there is an economically viable-to-mine deposit or not. Most of the respondents hoped for a mine and they were kind of desperate: "if it ever will come". On the other hand, some village association representatives thought that the risk of opening a mine would prevent young, nature-oriented families to move to a region with probable environmental damage.

It is also noteworthy that none of the interviewed persons limited their considerations only to mineral exploration. All reflected longer term, if there would be a mine, what then? Some were worried about the environment, especially possible negative impacts to surface and ground water bodies and the loss of a unique nature habitat, whereas others expected workplaces and working-aged people moving to this declining area, where the population is elderly, and many houses are empty and abandoned. Whatever the opinion, all respondents referred to the Finnish Talvivaara accident where a toxic leak resulted in major downstream pollution in the autumn of 2012 as a hazardous risk. "We don't want another Talvivaara here", everybody argued.

3.5 Peoples' perceptions about mineral exploration with new technologies in Finnish Lapland

New exploration technologies are at the core of the NEXT project, which also generated new, cost-effective and environmentally sensitive tools for the collection of geophysical and geochemical data, combined with novel approaches for their interpretation. From the layman's perspective the variety of new technologies, tools and approaches is huge, ranging from data products and services derived from the use of satellite imagery to the detection of very tiny concentrations of metals and hydrocarbons in transpired fluids from plants or trees, such as from spruce twigs. For this write-up, **Anna Spiteri**, Managing Director of Integrated Resources Management Company Ltd. (IRMCo), an environmental research company based in Malta, invited **Leena Suopajärvi** from the University of Lapland in Finland to share her insights about local peoples' perceptions about the use of the new technologies developed in the NEXT project.

Could you guide us on how you collected peoples' perceptions about the use of new technologies?

The first source was provided through interviews with local residents which are referred to in the previous write-up in which I shared insights about peoples' perceptions of social risks associated with mineral exploration in Finnish Lapland. However, a second source was provided through an Info-Day in Lohijärvi Village, Ylitornio Municipality, which I organized in June 2019, together with GTK, Mawson and Radai. This event gave the opportunity to explain about the developmental work carried out by the NEXT research teams in the Rajapalot area where the company Mawson holds the exploration permits. More than 70 local residents attended the meeting, in which they were introduced to the new exploration tools and methods. The highlight of the event was a flight show demonstration by the Finnish company Radai of its drone equipped with an electromagnetic survey system.

How would you describe the outcomes obtained from the interviews and the Info-Day?

When discussing about mineral exploration, most people associate it with drilling, and this was also the case in the first round of interviews conducted with local residents in 2019. However, as many of these interviewees had previously attended the Info-Day, they had learnt about the new sensitive technologies developed by NEXT. This had enabled them to not only learn about, but also to evaluate first-hand, the new exploration methods that were being developed by the research teams in the NEXT partnership. The second round of interviews, organized during 2020, revealed that local residents maintained an active interest in the subject of mineral exploration, and had been closely following up on developments in the Mawson exploration site.

Could you give us some examples of specific insights gained of peoples' perceptions?

One of the respondents who had been closely following up on the developments at the Rajapalot test site, made reference to the cost of the drilling operations and estimated that "if the findings are going to show that it had been worth exploring in that place, it is like you would have known about the lottery numbers beforehand". To put this viewpoint in its proper context, respondents were generally well aware of the typically huge investment that goes into mineral exploration. Yet, this respondent would appear to also be aware that statistics show that only one in a thousand prospecting projects lead to an actual mine development!

Respondents sitting at a restaurant table and talking about the NEXT research work concluded: "It is much easier to take samples from snow and vegetation". A conversation partner continued: "And drones fly and take magnetic fields and so on, so it is really much cheaper and leaves no traces". The active interest in drones may also be because since the 2010s, drones became available in Finland for everyday utility uses as well as hobbies. Actually, it is sometimes difficult to distinguish between utility and hobby since harvesting in the form of game hunting or berry picking are both a utility and a hobby in the rural livelihood of Finnish Lapland. Certainly, finding a cloud berry mire without even a step from home or cottage would be nice and easy. On the other hand, even environmentally sensitive methods must adapt to the natural conditions. According to the local respondents, the bird nesting season is an especially vulnerable period of time.

Local respondents were also realistic. Besides new technology, they realized that drilling is also needed: should no deposit be found, "You have to go deeper than exploring the surface of the ground and then it eventually requires drilling. Sampling of plants, trees or even snow may not tell the whole story".

How would you describe the added value of having organized a NEXT Info Day in Finnish Lapland?

The tools and methods developed in the NEXT project, their practical uses and meaning are difficult to understand without expert knowledge and therefore not likely to become a topic of everyday, matter-of-fact discussion. To my view, the Info-Day convincingly demonstrated that it is possible to have a meaningful dialogue with lay people in local communities about new exploration technologies. Perhaps, this had very much to do with the initiative of a couple of ladies from the local community, who welcomed the NEXT researchers to the Info-Day with a highly compulsory pea soup in the Finnish tradition of hospitality. Still, it was clearly most heartfelt, when some of the local attendees concluded the Info-Day with a clear show of appraisal stating that: ''Eminent professors and high-level experts have come down to meet up with us in our village to explain about the research that is going on in our area. For this, we are grateful."

Leena Suopajärvi's bionote is included with the write-up on the outcomes of interviews with local organized actors in Finland and Sweden. The bionote of **Anna Spiteri**, who conducted this interview is provided below.

"Our planet is a truly wondrous place and I was always fascinated with so many disciplines that it was only natural that 'geography' 'chose' me at London University. My curiosity to learn how landscapes form and how they are represented on maps led me to go for earth observation studies at the International Institute for Geo-Information Science and Earth Observation (ITC) in Enschede, the Netherlands. Back then, this subject was still very much in its infancy but it was taught at ITC in a grand way, complete with simulation cockpits and exotic fieldtrips! This was at a time when the phrase remote sensing evoked images of water divining… a potentially valuable skill nowadays that is still on my list of things to learn. Having the privilege to work in a multitude of international research projects ranging from precision farming and coastal zone management to knowledge management of mineral extraction, and always in several exciting countries still makes my understanding of geography come alive. Its interconnectedness with a range of other disciplines enables me to visualize holistic scenarios. In turn, this has led to a deeper understanding of what is at stake and many times enabling knowledge bridges to cross over to different themed projects. Most importantly, this brings the recognition that people's aspiration for a better life are basically the same everywhere, together with the realization that writing reports and papers are of no consequence if the voices of the local community are not recorded. Moreover, it has allowed me to keenly observe that people's relationship with the land changes in proportion to the distance of where they live… and evidently people living in rural areas are more in tune with the cycles of nature than those living in cities. All of these notions became manifest foremost when our company started adopting Public Participatory GIS, known as PPGIS. As I learned to adopt and adapt this approach, it enabled us to capture wide-ranging viewpoints. By and large, this crowdsourcing approach encourages participants to think spatially and to draw a vision of the land they live on. It empowers local communities, resurrects hidden and local tacit knowledge and their views of the world. Moreover, it fosters a new type of land and water governance through stewardship. In all of our work I always try to keep in front of me that we have the responsibility to be accountable to the seventh generation."

Anna Spiteri is Managing Director at Integrated Resources Management Company Ltd., IRMCo, an environmental research company based in Malta

Chapter 4 Recommendations for stakeholder engagement

4.1 Why to communicate

The Social License to Operate has become recognized in recent years as the **number one business risk** for the mining industry (Mitchell et al., 2020)[19]. Whereas several risks were 'new' on the radar of a 2020 survey by Ernst & Young (see Figure 29), the License to Operate maintained its number one position.

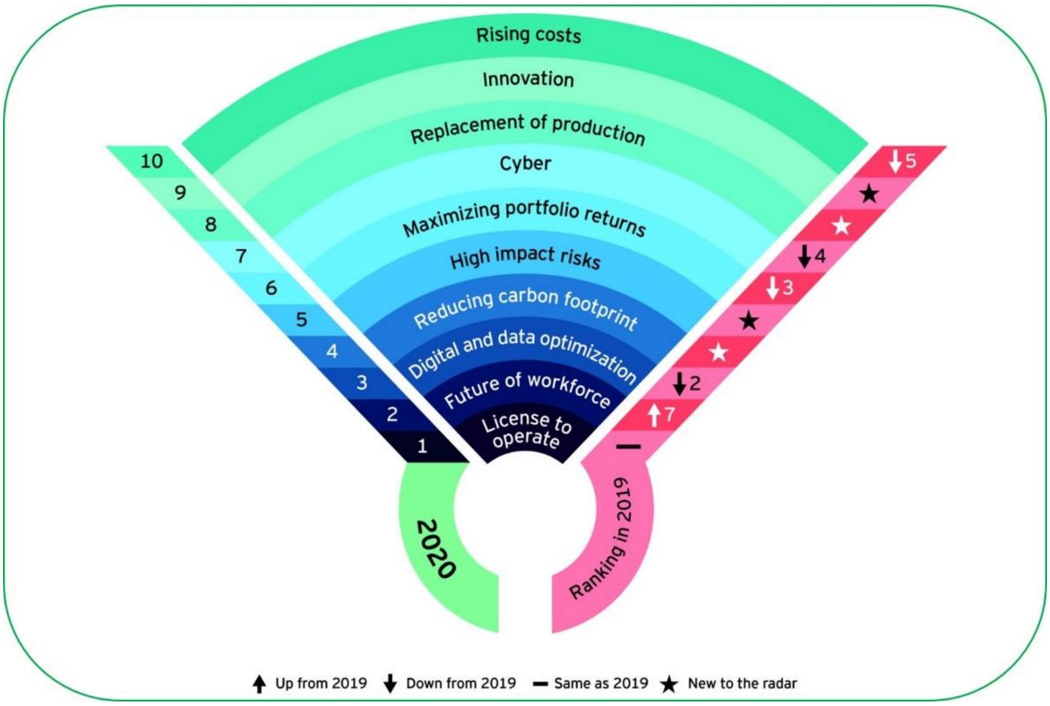


Figure 29: Top 10 business risks facing mining and metals[20]

Mineral exploration is a long, costly, competitive, and high-risk activity characterized by uncertainty and ambiguity covering large areas. Field work and financing are often undertaken by junior exploration companies operating with limited resources.

It is also quite common that the license owner companies change during the mineral exploration phase, and especially from the stages of mineral exploration to mine planning, construction and operation, which in itself can create further challenges for a good and long-term company-community relationship.

The interviews with local organized actors and the surveys among local residents in the NEXT Case Studies in both Finland and Sweden concluded that both the way of communication and the quality of interaction can lead to improved understanding and knowledge about exploration technologies and, in some cases, to a higher level of acceptance towards exploration by local communities. However, the research on the Social Licence to Explore theme also demonstrated that the most important factors affecting local actors' attitudes are their visions of the future, their understanding of sustainable development and their perceptions of impacts of mineral exploration and mining.

[19] Mitchell, P, Downham, L and van Dinter, A. Top 10 business risks and opportunities – 2020. Ernst & Young Global. https://go.ey.com/39jdgbi
[20] https://www.ey.com/en_za/mining-metals/10-business-risks-facing-mining-and-metals

Exploration companies should therefore give due consideration to make sure that local actors and residents are correctly informed, i.e. to enable them to act and respond to planned and ongoing exploration activities in an informed way.

Such interaction is crucial to identify concerns, potential risks, perceived impacts (positive as well as negative), as this will then enable the exploration company to design and develop a sound communication strategy. This foremost requires a proper understanding of the local context, which the research conducted in the NEXT project has shown to be a very significant, if not predominant factor in shaping peoples' perceptions and affecting their attitudes towards mineral exploration and mining. In turn, this reinforces the notion of the importance of having a stakeholder engagement that is driven by the ambition to establish a 2-way dialogue, aimed at building trust and through which mutually beneficial aspirations can be identified. Any form of direct involvement of the local community in the exploration activities should be actively explored and, where such interest within the community exists, put into action.

Obviously, exploration companies have to comply with national legislation which typically set specific requirements regarding who to inform and involve. In addition, companies remain subject to scrutiny by any citizen due to the rights given to the public through the Aarhus Convention. The United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters was adopted on 25 June 1998 in the Danish city of Aarhus (Århus) at the Fourth Ministerial Conference as part of the "Environment for Europe" process. Since its entry into force on 30 October 2001, the follow-up process, together with updates are documented on the UNECE Convention website[21].

The Aarhus Convention has been drawn up on three axes:

a) **Access to environmental information**: establishes the right of everyone to receive environmental information that is held by public authorities. This can include information on the state of the environment, but also on policies or measures taken, or on the state of human health and safety where this can be affected by the state of the environment. Applicants are entitled to obtain this information within one month of the request and without having to say why they require it. In addition, public authorities are obliged, under the Convention, to actively disseminate environmental information in their possession;

b) **Public participation in environmental decision-making**: establishes the right of everyone to participate in environmental decision-making. Arrangements are to be made by public authorities to enable the public affected and environmental non-governmental organisations to comment on, for example, proposals for projects affecting the environment, or plans and programmes relating to the environment, these comments to be taken into due account in decision-making, and information to be provided on the final decisions and the reasons for it; and

c) **Access to justice**: establishes the right to review procedures to challenge public decisions that have been made without respecting the two aforementioned rights or environmental law in general.

The Aarhus Convention complements EU legislation addressed to sustaining and encouraging natural biological diversity and complexity as well as maintaining natural areas and functions on the land, including wildlife habitat conservation.

The right of any individual or association to be 'stewards' of the land also applies to the exploration and mining sector.

[21] https://ec.europa.eu/environment/aarhus/

4.2 How to communicate

The overall target of 'how to communicate' must be to achieve and maintain an active interaction in the form of a mutually appreciated and beneficial two-way dialogue, whether in physical meeting events, through a company website, social media channels or through other fora.

Physical meetings should foremost be viewed as creating the opportunity to demonstrate the exploration company is fully prepared ***to listen*** to the views, expectations, needs and concerns of the local community This process can be aided by including sessions that are dedicated to brainstorming about topics that are likely to be a concern. However, communicating relevant and honest information about the exploration activities and their expected impacts is also important.

The Info-Day organized in Finnish Lapland, described in more detail in sections 3.4 and 3.5 of this Toolkit, showed that a touch-and-feel experience of a new technology - in this instance of the drone equipped with an electromagnetic survey system - is likely to generate active interest among the participants.

Geologists working in mineral exploration are usually among the first personnel who meet community representatives in the field and in the localities where the company they belong to operates. Usually, stakeholder engagement is not part of the academic curriculum of geologists. Several toolkits and guidelines have been developed for companies to reduce this gap and to help them to engage with local communities in different contexts. Particularly in events such as open hearings, exploration companies may wish to consider the engagement of a professional facilitator.

A number of existing toolkits and guidelines delve deeper into, not only the importance and suggested nature, but notably also the "**how-to aspects" of community engagement**. Among these initiatives, the examples cited below bring a specific focus on those addressed to the ***mineral exploration stage***. Some of these toolkits take on a global dimension, while others bring a national, regional or a corporate dimension to the fore.

The series of publications, *Preventing conflict in exploration - A toolkit for explorers and developers*, and *First engagement – A guide for explorers*, issued by the **Prospectors and Developers Association of Canada** (PDAC), is an example of a toolkit which takes on a global dimension. An example of a toolkit with a corporate dimension is *A strategic approach to early stakeholder engagement – A good practice handbook for junior companies in the extractive industries*[22]*,* issued by the **International Finance Corporation**.

As guidelines such as those mentioned above mostly deal with the Global South context, there are several aspects that do not necessarily fit into e.g., the European Union's (EU) context. For this reason, organizations in countries such as Finland and Sweden, developed their own guidelines and toolkits for stakeholder engagement in mineral exploration, adapted to their specific contexts. In **Finland, t**he Finnish Network for Sustainable Mining (FNSM) created a toolkit for stakeholder engagement in 2015[23], and a specific standard for sustainable mineral exploration including stakeholder involvement, biodiversity conservation, and safety and health in 2016[24], which has since been further developed and improved. In **Sweden**, the industry association of mines, mineral and metal producers, SveMin, released the Guidance on Exploration[25] in 2018 for all interested parties on stakeholder engagement, regulatory framework and consultation practices related to mineral exploration in Sweden. This is being adapted to Finland by the FinMin's Mineral Exploration Network.

[22] https://www.extractiveshub.org/servefile/getFile/id/1183
[23] https://www.kaivosvastuu.fi/en/toolbox-exploration/
[24] https://www.kaivosvastuu.fi/network-approves-new-standard-for-sustainable-exploration/
[25] https://www.svemin.se/english/publications-and-downloads/

Most recently the EU funded Horizon 2020 Mining and metallurgy regions of EU (**MIREU**) project issued **SLO Guidelines for Europe**[26] and an accompanying **Toolbox**[27]. As illustrated in Table 7, the MIREU SLO Toolbox brings an array of tools guiding Authorities, Communities and Companies in the context of relationship building activities. The tools are intended to guide these respective actors on how to gain SLO, including through, among other, 'fun-styled activities' such as an SLO Card Game, financial mechanisms and community agreements. Although not uniquely targeted to the exploration phase, the same type of activities are actively encouraged by MIREU to already start from this first phase in the mining cycle.

Table 7: Overview of the available tools in the MIREU SLO Toolbox

SLO TOOLBOX				
RELATIONSHIP-BUILDING ACTIVITIES	TOOLS	TOOLS FOR AUTHORITIES	TOOLS FOR COMMU-NITIES	TOOLS FOR COMPANIES
Activity 1 Familiarise	Tool 1.1: PEST Analysis Template			Tool 1.1
	Tool 1.2: Regional Approaches			Tool 1.2
	Tool 1.3: Stakeholder Mapping and Stakeholder Frames	Tool 1.3		Tool 1.3
Activity 2 Introduce	Tool 2.1: Checklist for First Meetings Between Community-Company		Tool 2.1	Tool 2.1
	Tool 2.2: Checklist for First Meetings Between Community-Government	Tool 2.2	Tool 2.2	
	Tool 2.3: SLO Video	Tool 2.3	Tool 2.3	Tool 2.3
Activity 3 Reach out	Tool 3.1: Community-Company Vision Statement		Tool 3.1	Tool 3.1
	Tool 3.2: SLO Card Game	Tool 3.2	Tool 3.2	Tool 3.2
	Tool 3.3: Financial Mechanisms to Encourage SLO	Tool 3.3		
Activity 4 Establish	Tool 4.1: Community Engagement Plan		Tool 4.1	Tool 4.1
	Tool 4.2: SWOT analyses – template and examples	Tool 4.2		Tool 4.2
	Tool 4.3: Grievance Mechanism	Tool 4.3	Tool 4.3	Tool 4.3
	Tool 4.4: SLO Indicators	Tool 4.4	Tool 4.4	Tool 4.4
Activity 5 Strengthen	Tool 5.1: Community-Company Environmental Monitoring Plan		Tool 5.1	Tool 5.1
	Tool 5.2: Community Agreements	Tool 5.2	Tool 5.2	Tool 5.2

It should also be highlighted that the set of 5 relationship building activities (see Table 7) are not intended as a timeline, but rather as a mix-and-match while always maintaining the focus on the local context, prior experience of the local community with exploration activities and mining operations among other important aspects to consider.

[26] https://mireu.eu/sites/default/files/2021-05/D%204.3.pdf
[27] https://mireu.eu/sites/default/files/2021-05/D%204.4.pdf

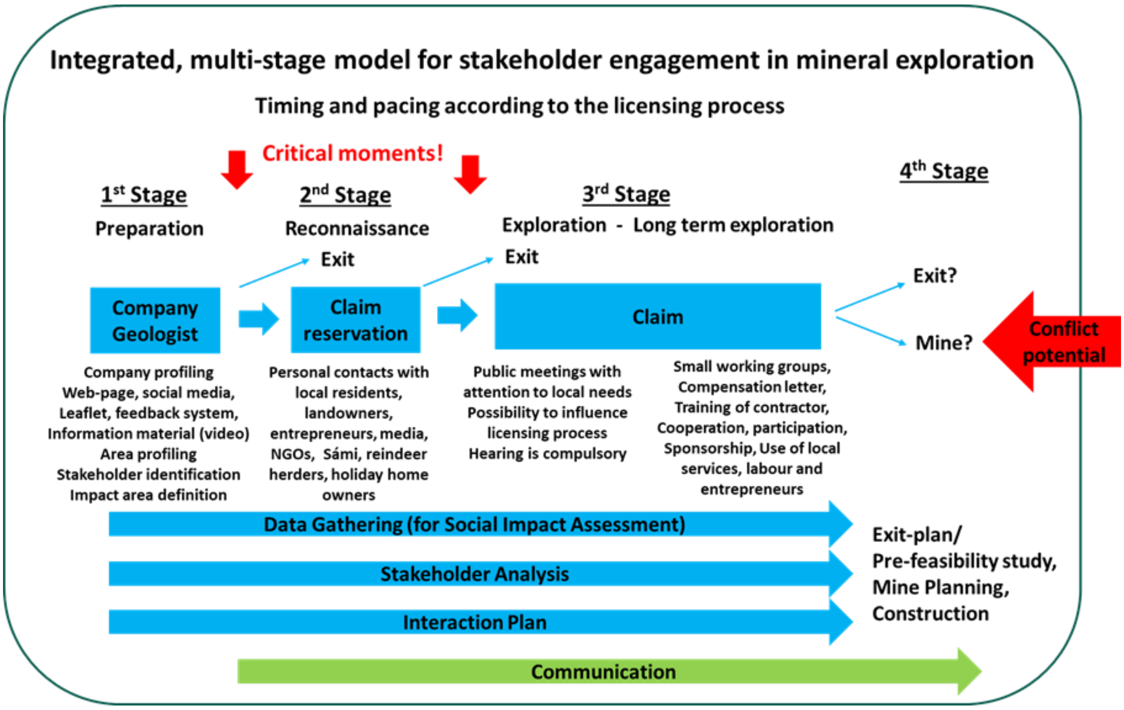
4.3 When to communicate

Exploration differs from mining both as a concept as well as in practice, as the latter is a productive activity which bears far more significant environmental and social impacts to the locality. Yet, an important aspect of community engagement during mineral exploration is the management of expectations and uncertainty. This can best be achieved by giving timely and relevant information to the local actors and decision-makers and engaging in a dialogue with them **from the very beginning of the mineral exploration activities**.

The **Prospectors and Developers Association of Canada** (PDAC) was the first entity to develop guidelines and toolkits addressed to mineral exploration, the *e3 Plus: A Framework for Responsible Exploration*[28], which is recommended to be applied all around the world by PDAC's member companies. With respect to the timing of community engagement, it considers four stages of mineral exploration[29]: 1) **Before You Leave** (for the project site), 2) **When You Arrive**, 3) **While You Explore** and 4) **When You Leave**.

The **Finnish Network for Sustainable Mining** (FNSM) created a toolkit for stakeholder engagement in 2015[30]. As it was designed according to the Finnish mineral exploration permit process, it also distinguishes between four stages, as illustrated in Figure 30.

Figure 30: The Finnish toolkit for stakeholder engagement in mineral exploration[30]



With regards to the timing of your events and meetings, try to find out during what timeslots of the day, and which days of the week the relevant actors and general citizenry of the local community are most likely to be available. While organized actors, such as municipal organisations, business associations and larger interest groups may be best approached during working hours, organisations operating on a voluntary basis and working people may prefer evening activities. To access actors with unregular working hours and activities in several places, like Indigenous Sami reindeer herding communities, companies must be flexible in terms of meeting localities and timing. Generally, flexibility and patience is needed to reach out to a broad range of actors and residents. If you decide to organise an event around lunch- or dinner time, consider providing refreshments.

[28] https://www.pdac.ca/priorities/responsible-exploration
[29] https://www.pdac.ca/priorities/responsible-exploration/e3-plus/community-engagement-guide/introduction
[30] https://www.kaivosvastuu.fi/en/toolbox-exploration/

4.4 Where to communicate

As we have outlined before, communication involves many different kinds of interaction, including digital communication, formal consultations with rightsholders (e.g. land owners and Indigenous people), direct contacts and meetings with different interest groups and business organisations, negotiations with municipalities and potential local business partners, as well as open hearings and information meetings with the general public.

Regardless of the format however, “where” to meet, negotiate and interact matters. Large public meetings or events can be instrumental to demonstrate sensitivity, flexibility and transparency. Yet, there will always also be persons who would rather stay away from such type of events for a variety of reasons. Thus, also smaller meetings and even individual consultations to listen to the needs of e.g. reindeer herders and local farmers, do have a place. Clearly, it is critical not to “divide and rule” by negotiating separately without transparency between the actors involved, so a mix of both type of meetings is likely to be a better option.

The selection of a venue for events as may be organized by the exploration company itself, does matter too! Choose a venue that characterizes the area where the exploration activities are taking place, be it a local community centre, local school or historical site. A clearly good choice can be a venue where the local community is used to meet up. The latter could be a venue that is used for indoor sport events, as was the case for the NEXT Info-Day organized in Lohijärvi Village in southwestern Finnish Lapland (see Figure 31). Also consider how easy it is to reach the venue, and whether it is easily accessible for participants through different transport forms, e.g. by public transport, by bicycle or by car. Avoid meeting rooms that are tucked away inside buildings, and lack fresh air and light. A venue that has a pleasant atmosphere, natural light, and a source of fresh air, are all factors which greatly contribute to the well-being of the participants and hence to a productive outcome of the event. Putting up flowers and having plants in the room can also help towards creating a welcoming atmosphere.

Seating arrangements matter too! Ideally, participants should be seated so everyone faces each other, such as in a circle or oval shaped manner. This seating arrangement is more conducive to having a two-way communication throughout the event and definitely instrumental in making everyone feel and be treated as equals.

Figure 31: The venue where the NEXT Info-Day took place (photo credit: Leena Suopajärvi)

4.5 With who you may also wish to communicate

On 15 September 2021, to mark the occasion of the NEXT project Final Event, a new open-access module "Projects map" was launched on the CORDIS portal. The new mapping tool allows users to explore synergies and to optimize clustering in the "jungle" of EU funded research and innovation projects. This new module was developed by the research team at the University of Lorraine (UL) in the NEXT partnership in collaboration with the CORDIS team of the European Commission. We invited **Anne-Sylvie Andre Mayer**, who is Professor in Economic Geology and Head of the GeoResources Laboratory at UL to bring us up to speed about the functionalities of this new mapping tool.

Could you guide on the scope of the CORDIS portal and how to access the new open-access module?

CORDIS is the acronym of the European Commission's Community Research and Development Information Service. The portal is a primary source of results of projects funded by the EU's framework programmes for research and innovation. The repository covers the entire sequence of EU funded research and innovation projects since the First Framework Programme (FP1) in the 1990's to the current Horizon 2020 Framework Programme to which the present NEXT project proposal application was successfully submitted for funding. In fact, also the portal itself is currently funded through the Horizon 2020 budget allocation and is managed, on behalf of the European Commission, by the Publications Office of the European Union based in Luxembourg.

The CORDIS portal is accessed through the link https://cordis.europa.eu/. Scrolling down to the bottom of the homepage, a map of Europe is shown which invites to "Go to the Collaboration Network map". This link, https://cordis.europa.eu/datalab/datalab.php, opens up with a map of Europe, where one can select the layer depicting the H2020 Hot Spots as shown in the screenshot below. When clicking the Collaboration Network icon (encircled in red in Figure 32), a search window appears which invites the user to 'Search organisations'. This gives a user access to the details of any and all organizations which took part as a coordinator or as a participant in H2020 funded research.

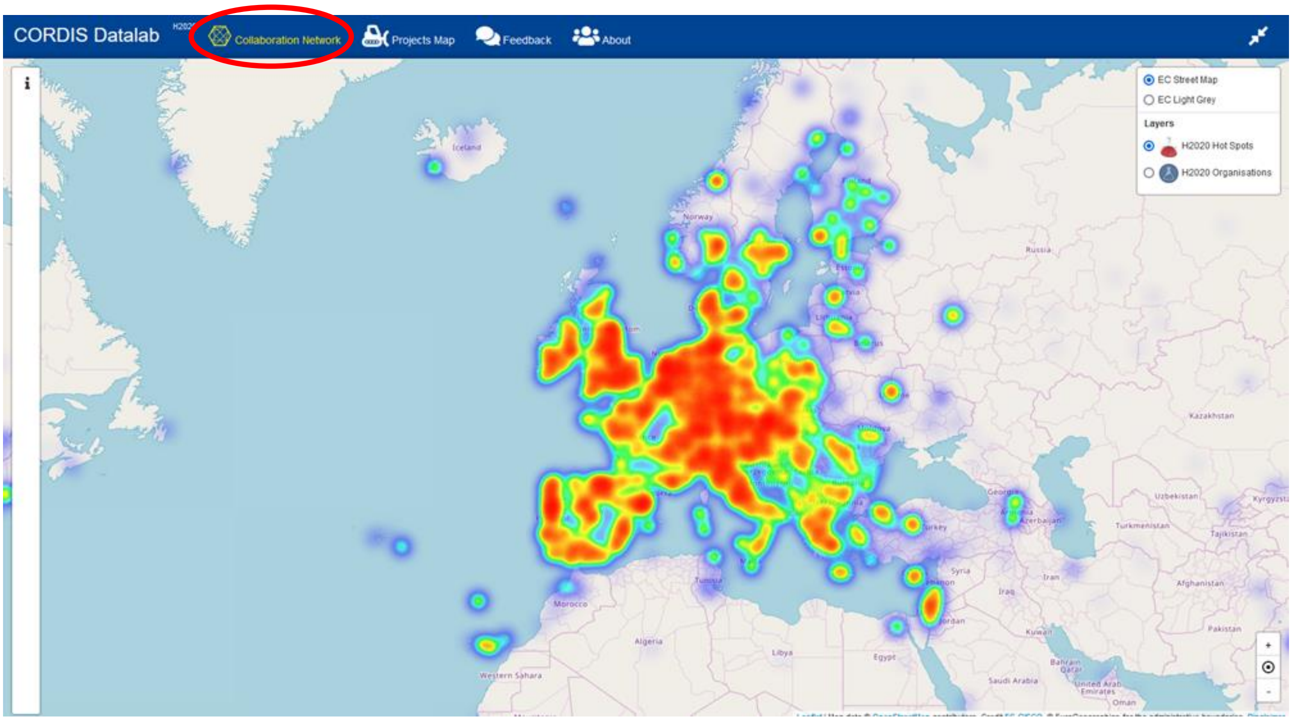


Figure 32: H2020 Hot Spots map of Europe

Could you guide on the functionality of the new mapping tool that was implemented on the Cordis portal?

The new open-access module, which was launched publicly in September 2021, is the icon having the description ‘Projects Map’ (encircled in red in Figure 33). Here, the user is invited to ‘Search project names, institutions, scientific fields …’. This new module, which we named P2Co, enables users to identify which organizations participated in projects related to a particular scientific field. The user is therefore invited to type his/her query on the search bar so as to display the organizations who participated in a given theme.

As an example, a query on ‘lithium’ returns a map informing how many organizations took part in lithium related research and how many such projects received EU funding. Normally, this information is provided in near-real time, but may take longer depending on how many active requests the portal is dealing with. Should the display time take more than a few seconds, this can be reduced by clicking the down arrow to the right of the search window, where it becomes possible to search the CORDIS database based on a project’s ’Title’, ’Acronym’ and/or ’Objective’.

To further refine a search, it is also possible to add keywords in the search bar. In the screenshot below, the search has been refined to ‘lithium and battery’.

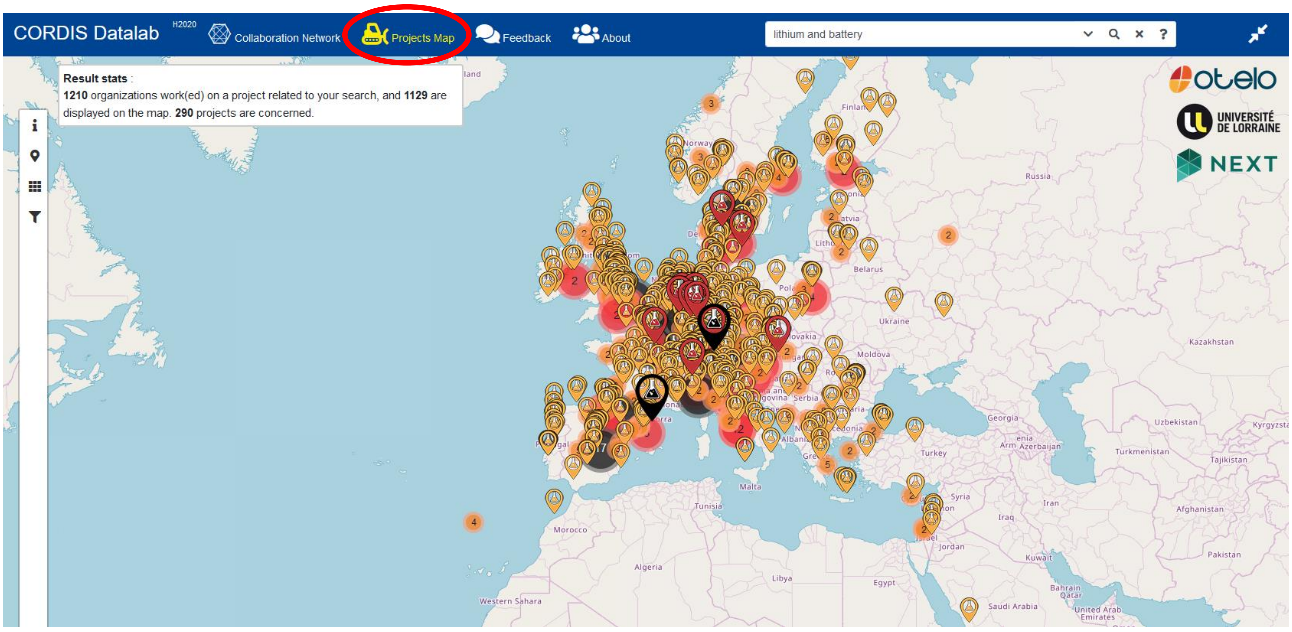


Figure 33: Query of CORDIS database based on ‘lithium and battery’

As shown in Figure 33, aside from a map of Europe displaying the location of organizations who participated in ‘lithium and battery’ related research, also the result statistics are provided, informing how many organizations took part, how many of these are displayed on the map and how many projects are concerned. The symbols shown on the map as Points of Interest (POI) are shown in different colours to further differentiate among these POIs. A POI's colour and size depend on the number of projects in which the organization has been involved in, either as coordinator or as a participant, based on the legend:

 : the organization is involved in more than 10 projects

 : the organization is involved in 5 to 10 projects

 : the organization is involved in 1 to 4 projects

In order to obtain more specific information about these projects, a filter icon (encircled in red in Figure 34) has been added. By clicking this icon, the user is informed how many of these projects pertained to a particular scientific field, how many pertain to a given funding scheme, how many partner organizations took part in a given country, etc.

The same filter icon also informs about the evolution in time, i.e. how many projects were funded in a given year. This information is obtained by clicking (and maintaining the click) on the square on either the left or to the right of the time bar. The latter option is illustrated with the red up-arrow in Figure 34.

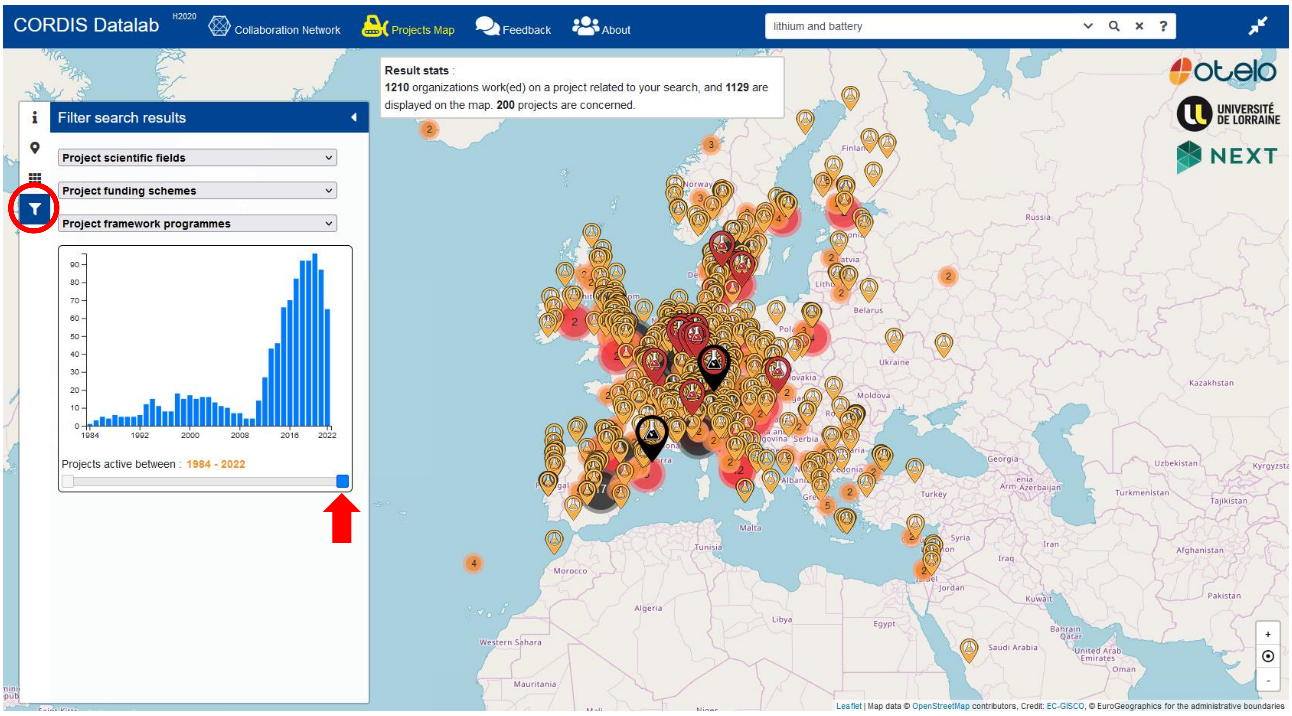


Figure 34: Evolution of EU funded 'lithium and battery' related projects over time

In our example search, we can see that the number of projects on 'lithium and battery' related projects increased dramatically since around 2010, reaching a peak of more than 90 projects that received funding in 2020. Although lithium is used in the field of mental health, where lithium carbonate is a common treatment of bipolar disorder, helping to stabilize wild mood swings caused by the illness, the reason for the observed increase is rather related in this instance to its use in the manufacture of aircraft and in certain types of batteries. This conclusion is reached given that our search was based on the use of the operator 'and'. The help function, represented by the question mark to the right of the search bar, gives an extensive overview about the use of a full range of operators. In our example, we would have obtained the same search results if we had used 'lithium + battery', while obviously 'lithium or battery' will return a much larger set of relevant projects.

The same filter icon also informs about the amount of funding received. When moving the square handle on the left of the budget bar to the very end, i.e. to the maximum of 470.80 Million Euro, as illustrated in Figure 35, we can see that the diagram continues to retain a project which had 30 partners across Europe. On further verification during the development phase, this concerned the nuclear-physics EUROfusion project. Its partners established a joint programme to implement the Roadmap towards the realization of fusion energy that was adopted by the European Fusion Development Agreement (EFDA) at the end of 2012. This Roadmap aims at achieving all the necessary know-how to start the construction of a demonstration power plant (DEMO) by 2030, in order to reach the goal of fusion electricity in the grid by 2050.

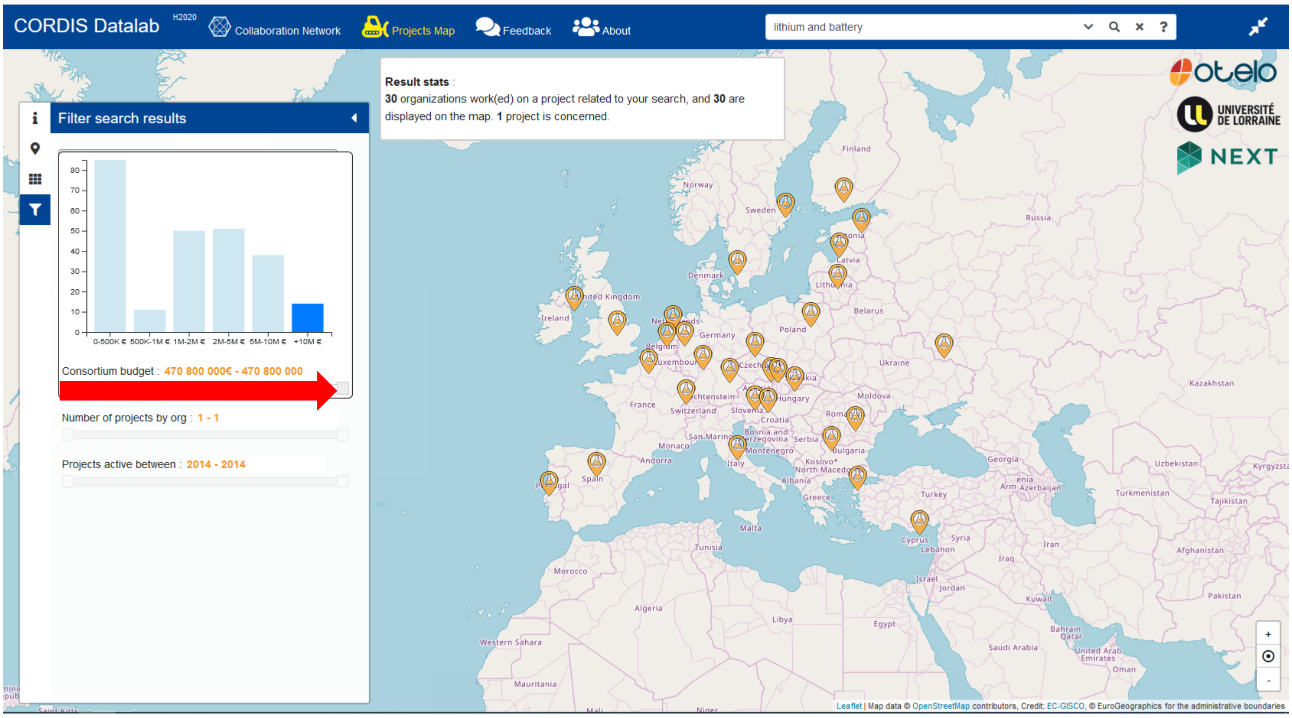


Figure 35: Refining a search based on the amount of allocated EU funding

For the purpose of exploring synergies with ongoing H2020 funded 'sister' projects of NEXT on the Social Licence to Operate/Explore theme, we were foremost interested to keep up to date with the outcomes from these projects. Although this turned out to have been a very useful exercise, it did require us to visit the individual project websites on a regular basis and thus proved quite time consuming. Can this new mapping tool be used to provide a faster and more efficient access to also this type of information?

To provide a clear answer to your question, I suggest we return to the first step, and use the new mapping tool, i.e. the Projects Map module, to find out which projects bear a link to the 'social acceptance of mining'. It is important to mention that the faster way to find these projects is to once again use the 'and' operator, so that the search correctly takes into consideration that we are interested in projects which dealt with 'social AND acceptance AND mining'. If not, the search will return with any and all projects that were linked to 'social OR acceptance OR mining', which would result in a much larger number of such projects.

Using the budget bar functionality, we can see a dramatic increase in just the past 5 years of projects related to the SLO/SLE theme. This may well be correlated with the fact that the mining industry is nowadays considering the risk of losing the social licence to operate as the foremost risk faced by the industry. Since your own search was specifically focusing on 'sister' projects of NEXT, we can use the filter icon and indicate that we wish to know about projects that were funded under the H2020 programme, which reduces the number of relevant projects from 90 to 80.

To get to the results of these projects, and in particular their 'deliverables' that were earmarked for public assess, we use the icon that is just above the filter icon. This icon, encircled in red in Figure 36, opens us the metadata of the retained, i.e. 80 projects. These metadata include the project acronym, budget allocation, start and end date, and their topic, i.e. the reference to the 'Topic of the Call for Proposals'. Scrolling down the list of entries, we find the NEXT project included with the first 25 entries, as illustrated in Figure 37. Just below the acronym, we obtain the 'project id', a unique identification number which is used to identify the Grant Agreement of each project, and is linked also to the Cordis database of projects. Thus, by clicking on the 'project id', we gain access to the 'Fact Sheet', 'Reporting' and also the 'Results' of any given project as illustrated in Figure 37.

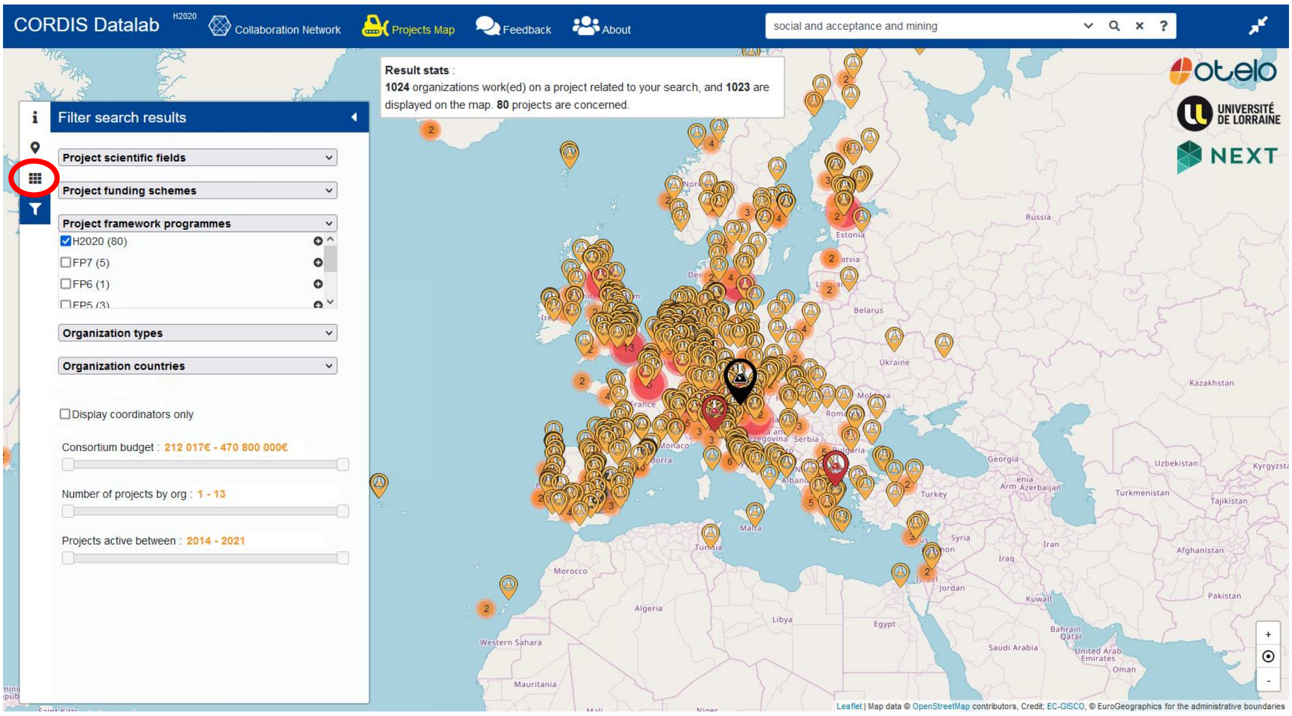


Figure 36: Searching the CORDIS portal for 'sister' projects of NEXT

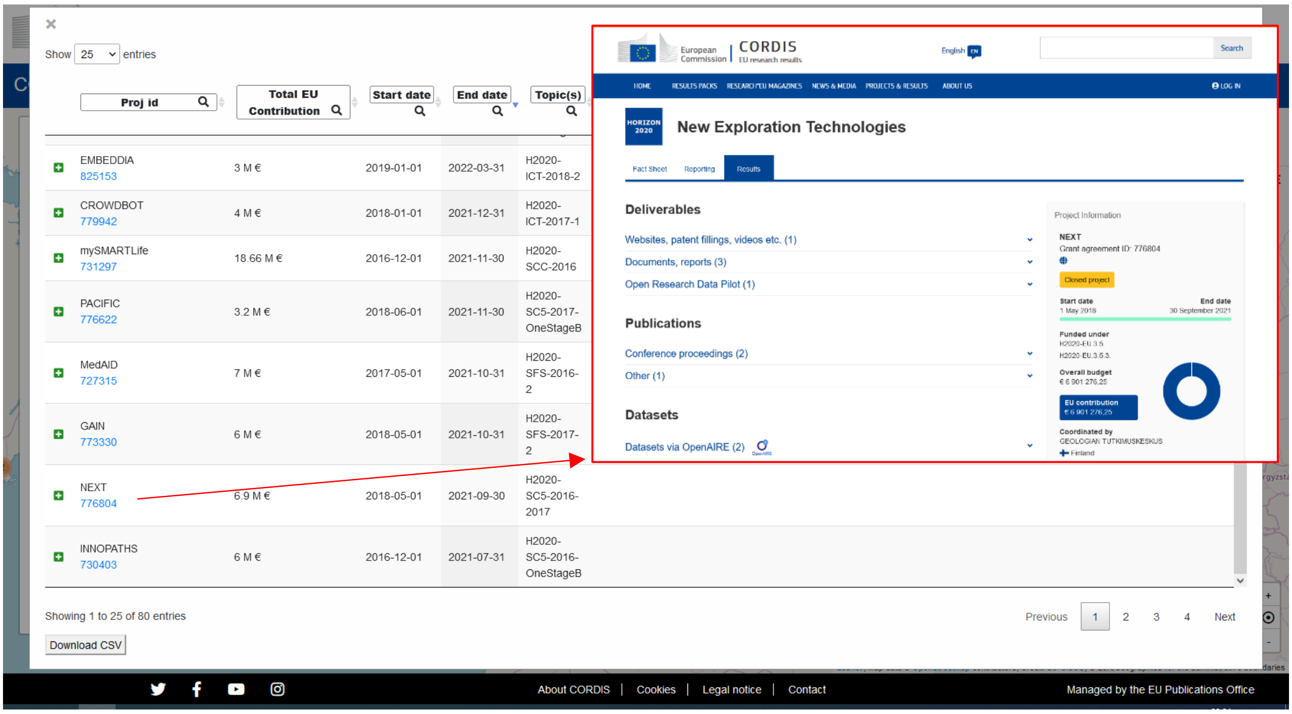


Figure 37: Searching the CORDIS portal for 'sister' projects of NEXT and link to NEXT project on Cordis database

It should be noted that the Results of projects do not become available in the CORDIS database until after their acceptance which is an integral part of a formal review process. As results of projects typically tend to be reached more towards the end of a given project duration, the reader should anticipate that the Results page for the NEXT project will see many more entries towards the end of 2021 and even more likely in the first half of 2022, when taking into consideration that the formal review process of NEXT is scheduled for December 2021.

To conclude our interview, how would you describe the value of this outcome of the NEXT project?

I should like to point out that this effort was not among the originally foreseen research activities of the NEXT project. However, I believe that this new mapping tool brings an immensely valuable addition to the CORDIS portal. As I hope to have shown, these new search functionalities can be applied to any scientific domain or field of expertise a user may be interested in.

This should prove useful not least to young researchers who now have a means to navigate the CORDIS database in a highly efficient and streamlined manner. It also opens up more efficient and time-saving ways for all entities, including SMEs and industry, to find out about recent research advances and who is behind these advances. This should prove highly instrumental for establishing an active collaboration.

Of course, I hope this will also aid the buying into of advances such as those achieved in the NEXT project by mineral exploration and mining companies. For all these reasons, I indeed consider that this new mapping tool brings a very tangible legacy of the NEXT project, and for this, I am most grateful for the fruitful collaboration of my research team with the CORDIS team.

We fully subscribe to the notion that the CORDIS portal already enabled to look up organizations and their research activities, yet this new mapping tool truly makes this goldmine of information more easily accessible! Networking and establishing synergies with entities around the world is now simply at one's fingertips!

"I was born and grew up in city in the region of Lorraine. The much sought-after iron ore which is found in this region brought its mining history. However, by the mid-1970s, the iron ore market became international. This signalled the end of the iron ore miring at Lorraine's "La minette". The low grade of around 30 to 35% rendered the mining of its iron ore to no longer being economically viable. Yet, coincidence or not, my involvement in a succession of international research and educative projects spurred my interest in all aspects dealing with mineral exploration and its related challenges. Recently I have been focusing my research on the understanding of the relationship between metal endowment, particularly Gold, Uranium and Rare metals, and the formation and reworking of the continental crust in Proterozoic times.

Anne-Sylvie André-Mayer is a Professor in Economic Geology and Head of the GeoResources Laboratory at Université de Lorraine in Nancy, France

Acknowledgements

We are foremost grateful to the representatives of Finnish and Swedish exploration companies for accepting to be interviewed, which enabled to document their expectations from the present Toolkit at an early stage in the project. We hope that the material contained in the present Toolkit does bring practical and useful answers to these expectations.

We are much indebted to Karin Beland Lindahl who masterfully planned and oversaw the progress of the research activities in the NEXT project which pertained to the Social Licence to *Explore* theme. We are also grateful for the active support of our colleagues in this research, Leena Suopajärvi, Toni Eerola, Hannu Panttila, and Gregory Poelzer, who were always at hand to give us their fullest support in producing this publication - and just as Karin – provided their time to answer to our many questions. On behalf of our colleagues, we wish to convey our gratitude to all the local actors and residents who took part in the NEXT project interviews and surveys pertaining to this research.

Even if the new insights on the Social License to *Explore* theme were sourced from surveys and interviews that were conducted in case studies pertaining to Finland and Sweden, we do believe these can be useful to companies located anywhere in Europe and also beyond.

Yet, if anything, we are especially grateful to all partners and colleagues in the NEXT project who provided us with material that allowed us to document the NEXT Journey, and what a great honour it has been for us to have been invited to join in this journey by Juha Kaija, the highly experienced Project Manager of the NEXT project.

We have ventured to document this journey in a way that will hopefully raise awareness about all of the scientific and technological advances achieved by this EU funded research project. We are confident that the write-ups on these advances should now pave the way for much faster and more efficient mineral exploration, at a lesser cost, and with minimum impact on the environment.

As environmental researchers, the latter is what we personally care for the most!

Dirk De Ketelaere and Anna Spiteri, Integrated Resources Management Company Ltd. (IRMCo), Malta

Editors

NEXT Publications and other related outputs

1) **Popular publications, peer reviewed journal articles and abstracts of presentations at conferences on the topics of:**

a) Mineral Systems Modeling

Krispinsson J (2020) A Microstructural Analysis of the Alconchel Cu-Au Deposit, Southwestern Iberia. 41 pp.

Gisbert et al. (2019) Elvira: a new shale-hosted VMS deposit in the Iberian Pyrite Belt. *Boyce A (ed) Life with Ore Deposits on Earth, 1256-1259*.

Losantos et al. (2019) Iberian Pyrite Belt massive sulphide deposit stockworks: styles and comparison. *Boyce A (ed) Life with Ore Deposits on Earth, pp 1864-1867*.

Gisbert et al. (2021) Vectors to ore in replacive volcanogenic massive sulfide (VMS) deposits of the northern Iberian Pyrite Belt: mineral zoning, whole rock geochemistry, and application of portable X-ray fluorescence. *Solid Earth 12: 1931-1966*.

Gisbert et al. Vectors to ore in replacive volcanogenic massive sulphide (VMS) deposits of the northern Iberian Pyrite Belt: major and trace elements mineral chemistry. Submitted to *Ore Geology Reviews*.

Raic et al. Application of lithogeochemical and pyrite trace element data for the determination of vectors to ore in the Raja Au-Co prospect, northern Finland. Submitted to *Solid Earth*.

Losantos et al. Synthesis of W-Sn mineral systems in Iberia. (In preparation)

Tornos et al. The Alconchel Cu system: the role of previous ironstones in the formation of “IOCG” deposits. *Mineralium deposita*. (In preparation)

Logan et al. (in preparation) Geochronology, lithogeochemistry, and Rb-Sr Sm-Nd analysis of bimodal magmatism in the Kiruna Mining District and implications for ore deposit formation. *Economic Geology*.

Logan et al. Trace element and sulfur isotope analysis of Kiruna District sulfide ores: implications for regional sulfur sources and geochemical changes during the Svecokarelian orogeny. *Mineralium Deposita*. (In preparation)

Logan et al. Micro-scale sulfide remobilization signatures used as regional scale vectors: example from Kiruna Mining District, Sweden. *Mineralium Deposita*. (In preparation)

Logan et al. Iron oxide apatite deposit protolith in the Kiruna Mining District: Insights from zircon trace element analysis. (In preparation)

Logan L, Bauer TE (2021): Microstructural Constraints and Characterization of Remobilized Sulfides and Associated Alteration at Pahtohavare, Kiruna District, Sweden. *Nordic Geological Winter Conference*.

Logan et al. (2021). Sr and Nd Sources for Epigenetic Cu ± Au and IOCG Deposits in the Kiruna Mining District Based on Rb-Sr and Sm-Nd Isotopic Data. *SEG 100 Conference*.

b) Novel Exploration Technology

Pospiech et al. (in preparation) Uncertainty Estimation - A practical Guide for Geochemists.

Pospiech et al. (2021) Discriminant Analysis for Compositional Data Incorporating Cell-Wise Uncertainties. *Mathematical Geosciences 53, 1–20 (2021).* (https://doi.org/10.1007/s11004-020-09878-x)

Hackel et al. Field electrochemical detection of Co(II)/Ni(II) by Cathodic Stripping Voltammetry (CSV) and Pb(II)/Zn(II) by square wave anodic stripping voltammetry (SW-ASV). To be submitted to *Journal of Geochemical Exploration*.

Hackel et al. Trace level quantification of Lead, Cadmium and Zinc by Stripping Chronopotentiometry (SCP) using screen printed electrodes. (In preparation)

de Junet et al. Field soil extraction protocol for an onsite trace and rare earth elements quantification. To be submitted to *Journal of Geochemical Exploration*.

Middleton et al. Norway spruce (Picea abies L. Karst) transpired canopy fluid geochemistry exhibits signs of K-Na albitization to aid target scale Au-Co mineral exploration in Northern Finland. To be submitted to *Geochemistry: Exploration, Environment, Analysis* (*GEEA*).

Poszwa et al. Development of environmentally-friendly soil extraction techniques prior to onsite metal quantification. (In preparation)

Sarala et al. Upper soil geochemistry in Au-Co mineral exploration in the glaciated terrain, southern Finnish Lapland - Compositional statistical data analysis approach. (In preparation)

Taivalkoski et al. How data processing enhances the utilization of snow in mineral exploration – case study in northern Finland. (In preparation)

Pirttijärvi et al. (2019). Louhi - novel UAV-based EM system. Abstract, *XXI National meeting of Applied Geophysics*, 19.-20.11.2019, Rovaniemi, pp. 37-40.

Karinen et al. (2020) UAV-based vector magnetic survey system. *1st EAGE workshop on UAVs*, 2-4 December 2019, Toulouse, France, MoUAV06.

Pospiech et al. (2020) Compositional modelling of the impact of source lithology on the plant Ionome. *Goldschmidt2020 Virtual 21-26 June*. (https://doi.org/10.46427/gold2020.2107)

Pospiech et al. (2021) Compositional modelling of element cycling in soil and plants - a case study from Northern Finland. *Goldschmidt, Virtual 4-9 July, 2021*. (https://2021.goldschmidt.info/goldschmidt/2021/meetingapp.cgi/Paper/6037)

Pospiech et al. (2021) Snow as environmentally low-impact sampling media for mineral exploration - a case study from Northern Finland. *EGU General Assembly 2021*, online, 19-30 April 2021, EGU21-5174, (https://doi.org/10.5194/egusphere-egu21-5174)

Sarala et al. (2021) Mineral exploration in the glaciated terrain using upper soil horizon geochemistry and compositional statistical data analysis, *EGU General Assembly 2021*, online, 19-30 April 2021, EGU21-10191. (https://doi.org/10.5194/egusphere-egu21-10191)

Pirttijärvi et al. (2021) Drone-based electromagnetic survey system for geophysical applications. Manuscript submitted to *Open Research Europe* (https://open-research-europe.ec.europa.eu/) on June 30, 2021.

c) Data Fusion

De La Rosa et al. Mineral quantification at deposit scale using drill-core hyperspectral data: a case study in the Iberian Pyrite Belt. Submitted to *Ore Geology Reviews*.

Kim et al. (2021) Identification and composition of carbonate minerals of the calcite structure by Raman and infrared spectroscopies using portable devices. *Spectrochimica Acta* Part A: Molecular and Biomolecular Spectroscopy, 261, 119980.

Chudasama et al. (2021, under revision). Target-scale prospectivity modeling for gold mineralization within the Rajapalot Au-Co project area in northern Fennoscandian Shield, Finland. Part 1: Application of knowledge-driven- and machine learning-based-hybrid- expert systems for exploration targeting and addressing model-based uncertainties. Submitted to *Ore Geology Reviews.*

Chudasama et al. (2021, under review). Target-scale prospectivity modeling for gold mineralization within the Rajapalot Au-Co project area in northern Fennoscandian Shield, Finland. Part 2: Application of self-organizing maps and artificial neural networks for exploration targeting. Submitted to *Ore Geology Reviews*.

Brosig et al. Hybrid mineral predictive mapping with self-organizing maps and artificial neural networks: Methodology and application in the Erzgebirge, Germany. Submitted to *Ore Geology Reviews*

Kim et al. (2021) Access to quantitative analysis of carbonates using a portable LIBS instrument: First applications to single minerals and mineral mixtures. Submitted to *Spectrochimica Acta* Part B: Atomic Spectroscopy.

Brosig et al. Contributions to the Geochemistry and Metallogeny of the Erzgebirge/ Vogtland area (Germany). To be submitted to *Solid Earth.*

Knobloch et al. (2019): Geological information systems and mineral potential mapping - Important preconditions for mineral sector diversification. *DMT Mining Forum / Bergbau Forum 2019*.

Knobloch et al. (2019) Mineral predictive mapping (MPM) in selected target areas in DR Congo using hybrid approach: Combination of knowledge-driven genetic models and data-driven artificial neural networks (ANN). *EGU General Assembly 2019.* Geophysical Research Abstracts. Vol. 21, EGU2019-5318, 2019.

Barth et al. (2020) New Data, Metallogenic models & Mineral Predictive Mapping open new Perspectives for the Historical Mining District of the German Erzgebirge. *AIMS 2020*. First International Conference. Mineral Resources for Future Generations. http://publications.rwth-aachen.de/record/786983/files/786983.pdf

de La Rosa (2020) 3D modelling of a mineral deposit using drill core hyperspectral data. EGU General Assembly 2020, 4-8 May 2020, Online. *Vienna EGU General Assembly 2020*

Chudasama et al. (2021). Machine learning methods for assisting identification of drilling targets within the Rajapalot project area in the northern Fennoscandian Shield, Finland. *Proceedings of the Mineral Prospectivity and Exploration Targeting (MinProXT-2021) Webinar.* 12-13 and 26-27 October 2021. Geological Survey of Finland.

Torppa et al. (2021). GisSOM and its application to geoscientific data. *Proceedings of the Mineral Prospectivity and Exploration Targeting (MinProXT-2021) Webinar.* 12-13 and 26-27 October 2021. Geological Survey of Finland.

Karinen, A. (2021) Magnetic vector inversion using XYZ measured by fluxgate magnetometer in UAV, *EGU General Assembly 2021*, online, 19-30 April 2021, EGU21-13006, https://doi.org/10.5194/egusphere-egu21-13006, 2021.

Brosig et al. (2021) Hybrid mineral predictive mapping with self-organizing maps and a multilayer perceptron applied to tin deposits in the Erzgebirge, Germany. *EGU General Assembly 2021.* EGU21-15874, updated on 29 Apr 2021. https://doi.org/10.5194/egusphere-egu21-15874.

Brosig et al. (2021) Battery metal exploration targets in the Erzgebirge from stream sediment geochemistry and mineral predictive mapping with self-organizing maps. ID: 458. *GeoKarlsruhe 2021*.

d) Social License to Explore

Suopajärvi et al. (2019) Social License to Explore: Key factors influencing social license to operate during the mineral exploration phase. Report and Research Brief, NEXT H2020.

Beland Lindahl et al. (2021) Report on the role of exploration technologies and associated social and safety risk for social licensing: factors affecting local attitudes to mineral exploration. Report and Research Brief, NEXT H2020.

De Ketelaere, D. and Spiteri A. (Editors) (2021). A Practical Toolkit addressed to Mineral Exploration and Mining Companies. Book, NEXT H2020.

Boutilier et al. Four factors of the social license – Back to the origins of the SLO model. Mining: Industry of Controversies. The article is aimed for a book edited by the University of Eastern Finland and suggested for Routledge. (In preparation)

Eerola, T. New low-impact mineral exploration technologies and the social license to explore: insights from corporate websites in Finland. Submitted to *Journal of Cleaner Environmental Systems*

Suopajärvi et al. Social Aspects of Business Risk in the Mineral Industry: Political, Reputation, and local acceptability risks. Submitted to *Mineral Economics*.

Eerola, T. CSR indicators of website communication towards the social license to explore by companies practicing mineral exploration in Finland. (In preparation)

Beland Lindahl et al. Social License to Explore? Factors affecting local attitudes to mineral explorations. (In preparation)

2) **NEXT Results available on CORDIS (https://cordis.europa.eu/project/id/776804/results)**

Deliverables

Websites, patent fillings, videos etc. (1)

Corporate Design, Project Website, Brochures, Leaflets, Newsletter

Documents, reports (3)

Mapping key factors influencing effectiveness of social license during the exploration phase
Report on Activities of the Press Bureau
Report on Social Media

Open Research Data Pilot (1)

Open-source stand-alone SOM software along with system concept / class diagram / software design, Testing report, User's manual

Publications

Conference proceedings (2)

Iberian Pyrite Belt massive sulphide deposit stockworks: styles and comparison. Proceedings of the 15th biennial meeting SGA. Vol 4, 1864-1867.
Author(s): Losantos, E., Gisbert, G., Tornos, F.
Published in: Proceedings of the 15th biennial meeting SGA., Issue Vol 4, 2019, Page(s) 1864-1867
Corporate Design, Project Website, Brochures, Leaflets, Newsletter
Elvira: a new shale-hosted VMS deposit in the Iberian Pyrite Belt.
Author(s): Gisbert, G., Losantos, E., Tornos F.
Published in: Proceedings of the 15th biennial meeting SGA, Issue Vol. 4, 2019, Page(s) 1256-1259

Other (1)

Policy Brief on Social License to Explore: Policy brief on the importance and effectiveness of practices used to assess social impacts and interact with local communities at the exploration stage.
Author(s): Suopajärvi, L. Eerola, T., Panttila, H., Poelzer, G., and Beland Lindahl, K.
Published in: NEXT Policy Brief, 2019

Datasets

Datasets via OpenAIRE (2)

Benchmark hyperspectral field and laboratory data against X-ray diffraction (XRD), Portable X-ray fluorescence (pXRF) and Scanning Electron Microscopy with Mineral Liberation Analysis (SEM-MLA) data.

Authors: De La Rosa Fernandez, Roberto Alejandro; Tolosana Delgado, Raimon; Gloaguen, Richard

Published in: Rodare

Louhi EM test data

Authors: Pirttijärvi, Markku; Saartenoja, Ari; Korkeakangas, Pekka

Published in: Zenodo

3) **Forthcoming NEXT results to become available on CORDIS Portal (pending a formal review process)**

Publicly available spectral database of the mineralogy of the study areas
Initial Data Management Plan
Final Data Management Plan
EM surveys with drones
Drone vector magnetic surveys
HR-ICP-MS sample preparation and analytical protocols
EM surveys II with drones
Vector magnetic surveys with drones
Recommendations and best practices for the use of tested surface geochemical sampling media
Field spectroscopic techniques - Best practices

Open-source stand-alone SOM software along with system concept / class diagram / software design, Testing report, User's manual
Mineral prospectivity maps for target areas
Report on the role of exploration technologies and associated social and safety risks for social licensing
Policy brief on the importance of exploration technologies, social and safety risks, early participation of civil society
A practical NEXT toolkit for exploration and mining companies
Synthesis of Clustering Activities
Recommendations to feed the RM Strategic Implementation Plan

4) Other publications, blogs, data repositories and software releases

a) MSc Thesis

Krispinsson J. (2020) A Microstructural Analysis of the Alconchel Cu-Au Deposit, Southwestern Iberia. 41 pp.

b) Not peer-reviewed articles

Rotureau et al. (2021) Electroanalytical metal sensor with built in oxygen filter. *Analytica Chimica* Acta 1167 (2021) 338544

Hackel et al. (2021) Developing on-site trace level speciation of Lead, Cadmium and Zinc by Stripping Chronopotentiometry (SCP): fast screening and quantification of total metal concentration. *Molecules 26 (2021) 5502* (https://doi.org/10.3390/molecules26185502)

Torppa et al. GisSOM and its application to geoscientific data. Open File Research Report, Geological Survey of Finland. (In preparation)

c) Geological Survey of Finland's Geoblogi

Torppa J. (2021) GisSOM for clustering multivariate data – Multivariate clustering and a glance to self-organizing maps, (https://www.gtk.fi/en/gissom-for-clustering-multivariate-data-%E2%80%92-multivariate-clustering-and-a-glance-to-self-organizing-maps/)

Torppa J. (2021) GisSOM for clustering multivariate data – self-organizing maps (in press)

Torppa J. GisSOM for clustering multivariate data – GisSOM. (In preparation)

Chudasama B. Self-organizing maps for mineral deposits-related pattern recognition and gold prospectivity modeling in the Rajapalot project area in Finland using GisSOM. (In preparation).

d) Data repositories

Rohstoffe Erzgebirge Web Portal. Retrieved at https://rohstoffe-erzgebirge.de/en and https://rohstoffe-erzgebirge.de/en/next

Metallogenic Map of the Erzgebirge / Vogtland Area. Retrieved from https://rohstoffe-erzgebirge.de/metallogenic-map

Geochemical Atlas of the Erzgebirge / Vogtland Area. Retrieved from https://rohstoffe-erzgebirge.de/mapsgeochem

e) Software releases

Pospiech S, van den Boogaart K.,G, (2020). Discriminant analysis incorporating individual uncertainties. R-package version 0.1.3. https://CRAN.R-project.org/package=vdar

ArcGIS SOM: https://github.com/Beak-Consultants-GmbH/ArcGISSOM

GisSOM: https://github.com/gtkfi/GisSOM

The NEXT Consortium at the entrance and inside the tin/tungsten underground mine of Zinnkammern Pöhla, Germany, October 2018