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Smart Exploration: Innovative ways of exploring for the raw materials in the EU

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Summary

Europe has a favourable geology for a wide variety of commodities necessary for improving our modern life sustainably and environmentally friendly. The Smart Exploration initiative answered one of the seven societal challenges offered by the European Innovation Partnership on Raw Materials on new solutions for sustainable production of raw materials – new sensitive exploration technologies. The project involves 27 partners from nine European countries comprising of 11 research institutions, 11 small and medium enterprises and 5 stakeholders. It primarily focuses on developing cost-effective, environmentally friendly tools and methods for geophysical exploration in highly challenging brownfield areas to meet the ever-increasing community (social acceptance) and environmental issues, as well as reduce the return time (from exploration to production). The aim is to not only generate new technological and methodological markets, but also to create results that will also allow for improved exploration in the EU countries and beyond. Planned prototypes and their potential to impact the market as well as methodological developments will be introduced. Furthermore, the value of legacy data through the use of both traditional and innovative approaches, reviving these datasets and illustrating their potential for deep (+500 m) targeting of mineralized bodies will be discussed.

Introduction

Mineral exploration industry while is booming again due to the market prices and as a prospect towards more and more green-type technologies requiring more and variety of minerals, it is still suffering to make a breakthrough exploration of the so-called Tier-1 and world-class deposits at depth. If successful, this will generate wealth for a considerable period of time as well as creating better market to attract investors (Schodde, 2006). Although adoption from other sectors such as hydrocarbon and digital industries can be helpful, geological complexity and variability imply greater challenges requiring more innovative and dedicated solutions. Mineral camps and deposits should be studied together in a broader scale to pinpoint regions of great potential for deep targeting. To sustain current mining and to lower environmental impacts (improving social acceptance), in-mine and near-mine will dominate exploration expenditure. This while has some positive aspects, it may not lead to significant new discoveries particularly in greenfields, hence issues with mineral resources sustainability in the long term. New deposits outside the known mineral camps will only be found where there are adequate data to interpret, although obvious, one that seems to get forgotten when new areas are suggested for exploration. Lack of skilled personnel and flow of young professionals into the sector with revolutionary and entrepreneurship thinking further complicate this story.

To partly cover some of these aspects and in response to a number of societal challenges identified by the European Commission namely, and relevant here, climate action, environment, resource efficiency and raw materials, 27 partners from nine European countries were successfully the Smart Exploration project, in late 2017. The project is a research-innovation action with a diverse group of organizations and expertise working together and complementing each other. The dissemination and communication aspects of the project are handled by EAGE and coordination by Uppsala University. The project has so far employed over 15 MSc, PhD and post-doc researchers and is at a stage of disseminating its early technical results. Figure 1 shows different component of the project through a triangle and how various partners contribute in the project with their expertise.

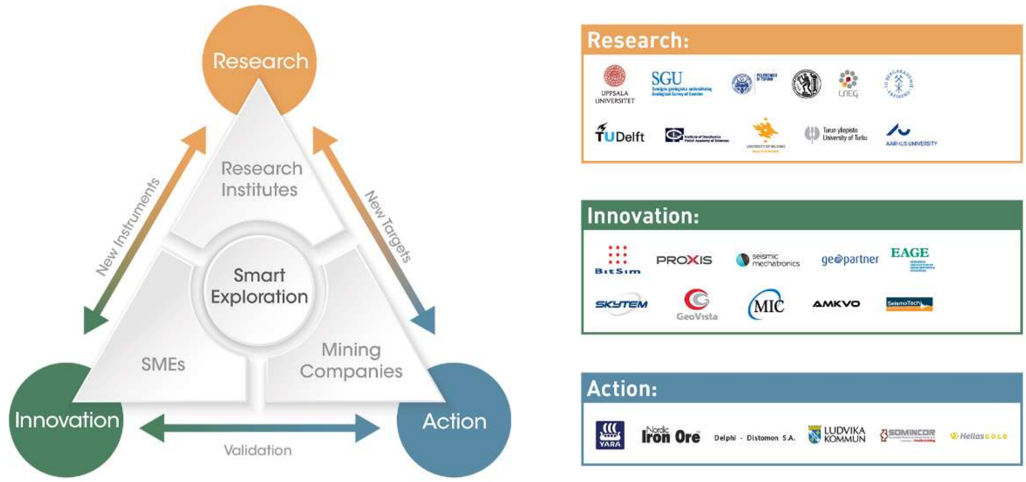

Figure 1 *Overall structure of the Smart Exploration project and how different partners contribute to its overall goal on pioneering cost-effective and innovative solutions for mineral exploration. This includes new processing and modelling algorithms, new prototypes and validation at relevant exploration sites. Six exploration sites covering a number of critical raw materials (CRM) for the EU and different exploration scenarios (in-mine, near-mine and greenfield) are used during the validation stage of the project.*

Incremental or transformational innovation in mineral exploration

While inventing a single way of exploring at depth appears unthinkable, adopting and learning from existing solutions may be the only way of progressing. In doing this, a number of pilot tests and practical solutions needs to be provided realizing that continuous utilization of shallow-target (200-500 m) exploration strategies will fail in securing an acceptable rate of new exploitable deposit discoveries in the future. Smart Exploration was initiated by fresh ideas, but also by acknowledging and employing known technologies available within other fields outside the mineral exploration sector. The main concept is to provide cost/time-effective exploration solutions while minimizing environmental impacts both during the exploration phase, but also when mining commences. The minimization will be through the use of non-invasive and improved geophysical methods (e.g., less forest clearing because of optimized acquisition methods) and less fuel consumption and CO2 emission because of improved or new technologies, but also providing critical information already during the exploration stage for locating tailing dams, mining shafts and general mining infrastructures that may be highly relevant to the environment around a future mine. Overall we aim for a target technology readiness level (TRL) of 5-6 in the project.

Planned prototypes and examples

Drilling is by far the most exploration expenditure (60-80%) and yet boreholes (or core samples) are mainly used for assay analysis and logging, and in best cases downhole measurements such as EM are employed to search for missed conductors. Most exploration boreholes are slim in diameter (NQ-HQ, 48-64 mm, respectively), hence a limitation to employ conventional downhole systems used in the hydrocarbon sector for mineral exploration. Moreover, existing and often sophisticated downhole systems are either highly advanced requiring skilled knowledge or remarkably expensive for routine mineral exploration purposes and budgets available. An even less utilized an operating mine is the noise generated by machineries and mining operations as well as the underground spaces used for mining including drifts, slopes and cross cuts. Broadband seismic recording, which has already been recognized by the hydrocarbon industry could open new possibilities including improved imaging capabilities as well as extracting property information such density and velocities. These if successfully obtained can de-risk drilling targets and help to distinguish e.g. a massive sulphide deposit from a mafic intrusion (Bellefluer et al., 2012). Knowing that most mineral deposits are conductive, improved solutions for deep penetrating airborne and UAV-based EM systems (e.g., Malehmir et al., 2017) are required leading to a new market in the mineral exploration industry.

Following prototypes are currently being developed in the project:

- Helicopter-based deep penetrating time-domain electromagnetic system,
- Broadband frequency UAV- and ground-based modular geophysical system,
- Broadband frequency seismic vibrator,
- For slimholes, digital- and modular-based geophysical system,
- Array-based GPS-time system for deep mines.

We present two of the prototypes, namely the broadband seismic source and the array-based GPS-time systems. Figure 2 shows an example shot record obtained in a pilot test in a geologically known site in the Netherlands where the broadband seismic source (Noorlandt et al., 2015) that uses completely electronic systems was used to generate the data. Clear reflections and broadband nature of the data are clear already in this raw shot record encouraging to be employed in hard rock environment. An up-scaling survey is planned early 2019 and preliminary results or the survey set-up will be presented.

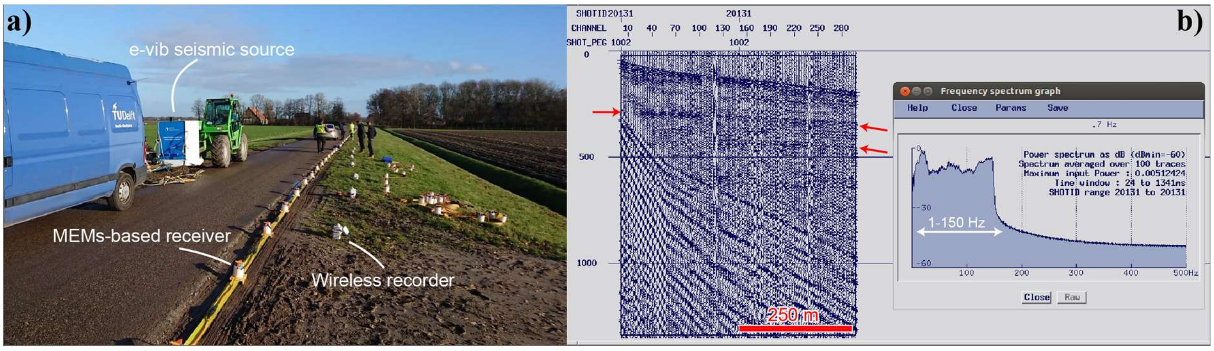

Figure 2 *(a) Broadband seismic source (e-vib) adopted for hard rock surveys in the project and (b) example shot record with clear reflections obtained using a sweep range of 1-150 Hz. This pilot survey was conducted during December 2018 in a geologically known site in the Netherlands.*

Without doubt much more can be done to utilize underground workings for mineral exploration and mine planning applications. A few years ago, we realized this offered a unique opportunity (Brodic et al., 2017) with important applications and benefits of providing e.g. synchronized array-based seismic surveys in underground mines with standard receivers typically used at the surface but technical limitations were hindrances. Thanks to Smart Exploration project, we have now been able to pioneer a system (Malehmir et al., 2018) that can provide accurate GPS-time (micro-second accuracy) to an array of receivers placed at different tunnels and different depth levels. Laboratory tests have been successful, however, the full potential will be demonstrated using an up-scaling project planned for early 2019. Figure 3 shows an example sketch of possibilities for simultaneous tunnel-surface-tunnel seismic data acquisition and how for example the entire volume around the tunnels and under can be imaged using over 100-1000s receivers from one depth level to another.

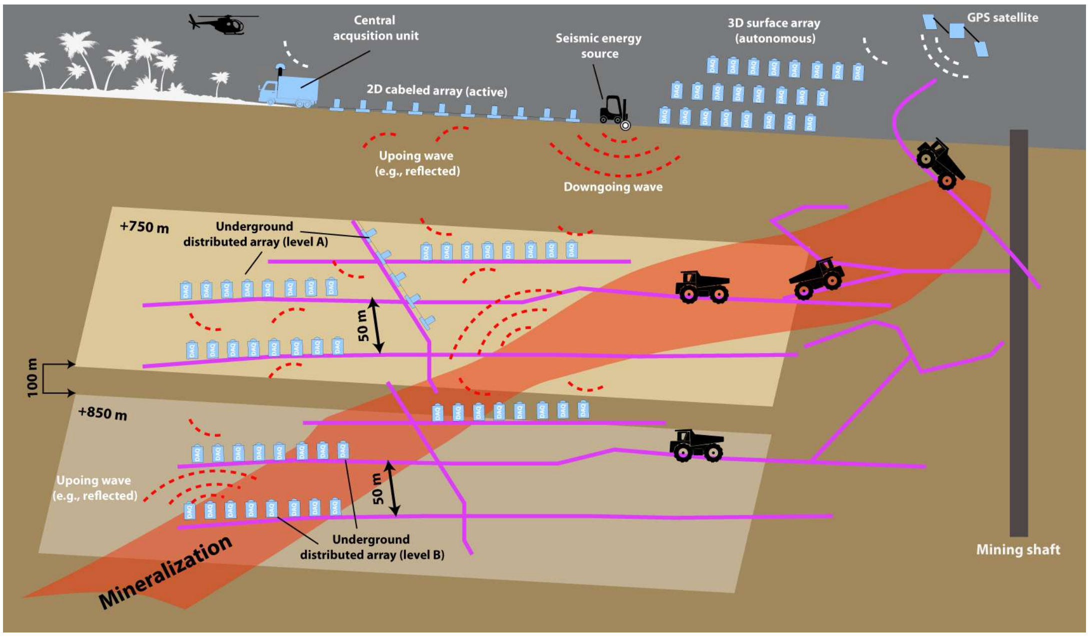

Figure 3 *Sketch showing potential of the array-based GPS-time synchronized system for geophysical surveys and rock mass characterization in deep mines (based on Malehmir et al., 2018).*

Planned methodological developments

Academic partners because of their in-depth attentions to details and technical expertise typically best scrutinize hardware and software solutions. In the project, much effort is put in developing new 3D modelling algorithms for both time- and frequency-domain EM data, imaging algorithms geared towards hard rock environment including improved solutions for refraction statics as well as exploring potential of combined passive-active seismic data and various imaging algorithms for mineral exploration and optimizing survey cost and design.

Examples of legacy data

Data is the number one item that every mineral explorationist has to work with. With no data, no action and decision can be made. In recognition of the value of legacy data, Smart Exploration identified exploration sites that possessed extensive legacy datasets to be re-examined in planning for new exploration programmes and generating new targets for detailed follow-up investigations. The legacy data not only offer an opportunity to reinterpret the original data but through integration with other available geoscientific information it can guide future exploration. There is nothing more cost-effective than re-visiting an existing data set and realization that additional and useful information can always be extracted. Notably, reprocessing and reworking legacy data for Neves-Corvo, Portugal (base-metal), Ludvika Mines, Sweden (iron-oxide) and Gerolekas, Greece (bauxite) using modern algorithms and incorporating knowledge of the mineral deposits and the surrounding geology have provided valuable information about the geometry and potential extensions of the deposits. This knowledge will be used to optimize the planned geophysical surveys to identify targets for drill testing. Figure 4 shows an example of reprocessing legacy 2D seismic data (year 1996) from the Neves Corvo (Donoso et al., 2018) deposits and comparison with another attempt made in 2007. The Lombador world-class (ca. 150 Mt massive sulphide) deposit is remarkably imaged in the reprocessed seismic section as well as steeply dipping structures near the surface.

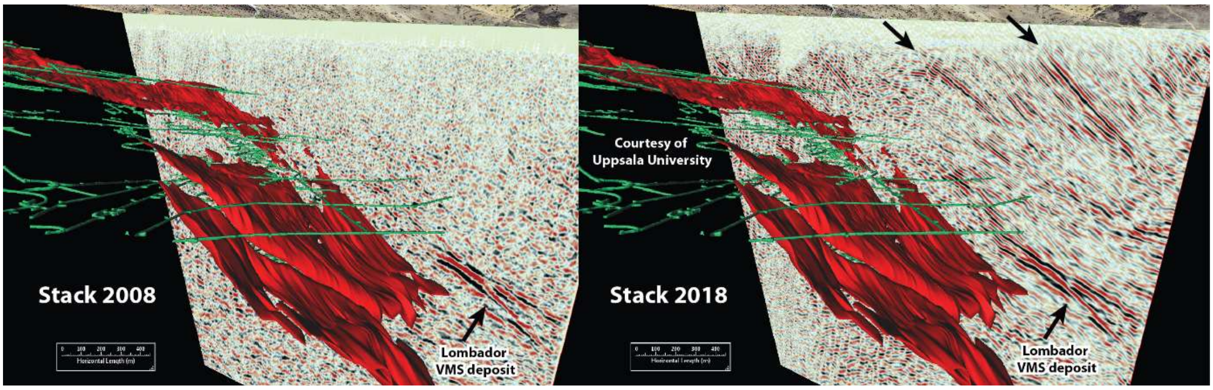

Figure 4 *Example of reprocessing legacy 2D seismic data from the Neves Corvo mining site in Portugal and how much improvement and additional information can be extracted from these legacy data (from Donoso et al., 2018).*

Mineral exploration and a collaborative approach among geoscience community

To successfully explore new mineral exploration, more and more collaborative approaches are needed. Mineral exploration industry needs to progress in all fronts and in doing this researchers, high-tech industries as well as mining companies need to work together complementing each other. There is no single-type methodological solution for mineral exploration therefore a wide range of geosciences as well as engineering and social sciences (social licence to operate) should interact with each other helping this to succeed. Smart Exploration is hopeful that by exemplifying this approach through its case studies advances mineral exploration a step forward.

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