BOOK OF ABSTRACTS

Online workshop

New imaging technologies for mineral exploration: state-of-the-art and the EIT SIT4ME project

10 & 11 November 2020

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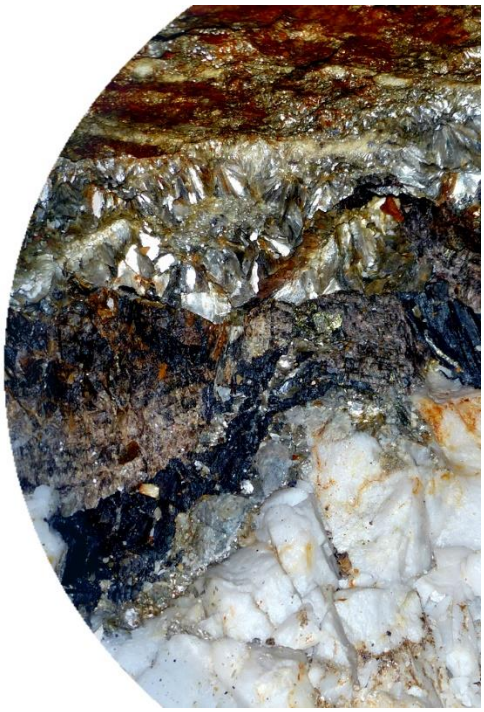

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Session 2 Chair

Dr Irene De Felipe
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Session 3 Chair

Schedule

Day 1 (10th November)				
Session	**Time**	**Speaker**	**Affiliation**	**Title**
0	10:00	Juan Alcalde	Geosciences Barcelona, CSIC	Introduction to the workshop
1	10:20	Gregor Borg	Martin-Luther-Universität Halle-Wittenberg	The VeRo Liberator technology - a potential game-change in energy-efficient comminution
1	10:40	Felix Hlousek	TU Bergakademie Freiberg	Advanced active seismic imaging techniques for mineral exploration
1	11:00	Paula Rulff	Uppsala Universitet	3D electromagnetic forward modelling
1	11:20	Nick Arndt	University Grnoble Alpes/SISPROBE	Passive Seismic Methods for Mineral Exploration and Tailings Dam Monitoring
5' BREAK				
1	11:40	Sergio Llana-Fúnez	Universidad de Oviedo	Petrophysical characterization of rocks applied to mineral exploration
1	12:00	Liam Bullock	University of Oxford	Platinum-rich gold in Irish coal: an exploration target for low-temperature concentrations of precious metals
1	12:20	Mehrdad Bastani	Geological Survey of Sweden	EM field measurements in the frequency range 1-350 kHz onboard a UAV.
5' BREAK				
2	12:40	Musa Manzi	Wits University	Reflection seismics for mineral targeting and risk mitigation of mining-induced seismic events in deep and overstressed mines: case studies from South African mines
2	13:00	María José Jurado	Geosciences Barcelona, CSIC	The INNOLOG project: Innovative Geophysical Logging Tools for Mineral Exploration
1	13:20	Andreas Brosig	Beak Consultants	A 3D subsurface model of the Erzgebirge for 3D mineral potential mapping of Sn-W deposits with Artificial Neural Networks

Day 2 (11th November)				
Session	**Time**	**Speaker**	**Affiliation**	**Title**
0	10:10	Juan Alcalde	Geosciences Barcelona, CSIC	Reconvening
2	10:20	Giorgia Stasi	Geological Survey of Belgium	ROBOMINERS – changing the ground rules
2	10:40	Paul Mardsen	Nordic Iron Ore AB	Geometry of iron-oxide deposits at Blötberget (Nordic Iron Ore AB, Ludvika Mines) Sweden and Key Findings
2	11:00	Joao Carvalho	LNEG	Generating new targets in Neves-Corvo through 3D TEM modelling, gravity inversion and innovative in-mine-surface seismic survey
5' BREAK				
2	11:25	Gaye Bayracki	National Oceanography Centre (NOC) Southampton, UK	Seismic strategies to constrain the physical properties of extinct Seafloor Massive Sulphide deposits
2	11:45	Fernando Tornos	IGEO	"iTarg3T" Innovative targetting of W-Sn-Ta-(Li-Nb) deposits
3	12:05	Ramón Carbonell	Geosciences Barcelona, CSIC	Introduction to the SIT4ME project
5' BREAK				
3	12:30	Yesenia Martínez	University of Salamanca	Seismic exploration of Sotiel-Coronada site
3	12:50	Alba Gil	Uppsala University	Seismic exploration of Zinkgruvan site
3	13:10	Tim Hupe	DMT GmbH & Co.	Combination of 3D Borehole radar and Underground Reflection Seismic - A case study for In-Mine Exploration

List of talks

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Abstracts

Welcome and introduction to the SIT4ME workshop

Juan Alcalde (*Geosciences Barcelona, CSIC – Spain)*

Mineral resources are used in larger quantities than ever before in history, and are the basis of our modern society. Exploration is the first step in the mineral resources cycle. Most of the giant deposits at shallow depths have been already explored and mined out and the industry is moving towards deeper and more complex mineral systems, which brings significant exploration challenges. The exploration sector needs time-saving, cost-effective, and, particularly in Europe, environmentally friendly and socially acceptable techniques to ensure sustainable access to mineral resources. This workshop will bring in experts in mineral exploration from a broad range of topics (e.g. geophysics, remote sensing, geology, modelling) and will be divided in three sessions: (1) advanced exploration techniques and results; (2) international exploration projects; and (3) results of the EIT Raw Materials SIT4ME project.

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The VeRo Liberator technology - a potential game-change in energy-efficient comminution

Gregor Borg (*Martin-Luther-Universität Halle-Wittenberg – Germany)*

Mining and mineral processing industry are under pressure from political and social stakeholders to deliver products more sustainably with a much smaller environmental impact. Technical innovations to achieve these goals include reduction in energy consumption, waterless mineral processing, improved particle liberation, and safe dry stacking of tailings. Traditional abrasional comminution in robust ball and SAG mills is known for its inefficiency with respect to breakage and energy consumption. Earlier theoretical predictions and numerical modelling postulated that more efficient impact breakage should occur at higher impact energies from higher operational velocities. The VeRo Liberator impact crusher operates in such a mechanical high-velocity regime and achieves very high particle size reduction ratios and degrees of particle liberation at very low energy consumption and without using process water. These step-changing comminution results are achieved from high frequency, high-velocity impacts with an efficient momentum transfer that leads to the effective disintegration of the feed material. The VeRo Liberator technology has currently achieved TRL 7 and several units operate currently at mining operations and test facilities in South Africa.

Advanced active seismic imaging techniques for mineral exploration

Felix Hlousek (*TU Bergakademie Freiberg – Germany)*

Reflection seismic methods are a key technology which are able to investigate and characterize mineral deposits prior to drilling or mining. However, these deposits are often embedded in a hard-rock environment, causing difficulties such as strong scattering, steep and various dips of the imaging targets, a low signal to noise ratio of the recorded data and an irregular distribution of sources and receivers in land seismic acquisitions. We will show how we handle these challenges and how our focusing pre-stack depth imaging methods can produce good and reliable structural images of the target areas in such conditions.

3D electromagnetic forward modelling

Paula Rulff (*Uppsala Universitet – Sweden)*

We conducted a forward modelling detectability study to prepare for controlled-source electromagnetic measurements above a ferrous mineral deposit in central Sweden. The aims of our detectability study are to test the applicability of our newly developed 3D forward modelling algorithm on a real field example and to investigate practical aspects such as preferred station locations for the field campaign. The presentation will give some insight into the functionality of our software and illustrate the benefits of three dimensional modelling. The work is funded by the Smart Exploration project. Smart Exploration has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 775971.

Passive Seismic Methods for Mineral Exploration and Tailings Dam Monitoring

Nick Arndt (*University Grenoble Alpes/SISPROBE – France)*

Sisprobe, a small France-based company, and PACIFIC, an H2020 project, are developing passive seismic methods for mineral exploration. Sisprobe's main activity employs ambient-noise surface-wave tomography to image the upper few hundred metres at mineral exploration sites. Seismic noise sources generated by ocean waves, freight trains or minor tremors are used to determine the geological context of ore deposits, the structures that control the mineralisation, and the thickness and geometry of younger cover. Successful projects include magmatic PGE-Cu-Ni, porphyries, VMS and sedimentary Mn-Fe deposits. Sisprobe also uses optic fibres and Distributed Acoustic Sensing to monitor tailings dams. The PACIFIC project develops more advanced techniques such as extraction of body waves from the ambient noise signals in order to apply reflection seismic techniques, and the combination of down-hole and surface sensor arrays. The main test sites are the Marathon PGM-Cu deposit in Canada and the Kallak iron deposit in Sweden.

Petrophysical characterization of rocks applied to mineral exploration

Sergio Llana-Fúnez (*Universidad de Oviedo – Spain)*

The research group GEOCANTABRICA, in collaboration with TerraDat, is developing a program for petrophysical characterization of rock that includes, among other properties, seismic velocities (P and S - waves), electromagnetic conductivity, magnetic susceptibility, electrical chargeability and resistivity, as well as density (porosity) and mechanical properties. Some of the materials we work with show anisotropic behavior to some of these properties. Our analysis aims to determine which microstructural component controls the anisotropic behavior, whether mineral orientation, compositional banding or microfracturing. The petrophysical analysis must underlie the development of exploration strategies in the field, since it allows to identify which methods are best suited for ore exploration. Prior knowledge of physical properties of rock materials under study, for instance their anisotropy or their structural control, will facilitate the design of exploration strategies. For our petrophysical work we collaborate with several of the industries operating in northwestern Spain, which provided the samples for laboratory work, either in blocks or in core samples. We have so far studied roofing slates, dolostones, limestones and several types of sandstones (for instance, quartzarenites and iron rich sandstones).

Platinum-rich gold in Irish coal: an exploration target for low-temperature concentrations of precious metals

Liam Bullock (*University of Oxford – United Kingdom)*

Gold grains, up to 40 µm in size and containing variable percentages of admixed platinum, have been identified in coals from the Leinster Coalfield, Castlecomer, SE Ireland, for the first time. Gold mineralisation occurs in sideritic nodules in coals and in association with pyrite and anomalous selenium content. Mineralisation here may have reflected very high heat flow in foreland basins north of the emerging Variscan orogenic front, responsible for gold occurrence in the South Wales Coalfield. At Castlecomer, gold (–platinum) is attributed to precipitation with replacive pyrite and selenium from groundwaters at redox interfaces, such as siderite nodules. Pyrite in the cores of the nodules indicates fluid ingress. The underlying Caledonian basement bedrock is mineralised by gold, and thus likely provided a source for gold. The combination of the gold occurrences in coal in Castlecomer and in South Wales, proximal to the Variscan orogenic front, suggests that these coals along the front could comprise an exploration target for low-temperature concentrations of precious metals.

EM field measurements in the frequency range 1-350 kHz onboard a UAV

Mehrdad Bastani (*Geological Survey of Sweden – Sweden)*

Since the beginning of 70's the Geological Survey of Sweden (SGU) has been collecting the signal from distant powerful very low frequency (VLF) data in Sweden. In the past decade we have also gained experience on the LF signal from transmitters by measurements across Europe. The signals provide a unique possibility to utilize a very fast and cheap tool to map variation of electric resistivity over reasonably large areas. A controlled transmitter at frequencies down to 1 kHz has been utilized at a few locations to increase the investigation depth with a factor of ca. 3. In this presentation a new concept and data acquisition system mounted onboard a UAV for the EM measurements in the frequency range 1-350 kHz are demonstrated.

Reflection seismics for mineral targeting and risk mitigation of mining-induced seismic events in deep and overstressed mines: case studies from South African mines

Musa Manzi (*Wits University – South Africa)*

South Africa hosts some of the world's richest ore bodies, the gold-bearing conglomerates of the Witwatersrand Basin. These ore bodies extend to depths exceeding 3.5 km, the greatest mining depths in the world by far. The deep mines are also characterized by high-stress levels that give rise to intensive mining-induced fracturing within the rock mass, resulting into rockbursting. Rockbursts have remained one of the most serious and least understood problems facing deep mining operations. In this paper we demonstrate how the reflection seismic method has been successfully used to explore some of the world's largest gold deposits and map the gross structural architecture that controlled the formation of these ore bodies and support mine planning, and improve safety. We further demonstrate how reflection seismics can be combined with source parameters of mining-induced earthquakes to improve mine safety. We analysed more than 2000 seismic events (main events and aftershocks) with local magnitudes between -3.0 and 3.0 that caused damage to the surrounding stopes in the deep underground gold mines. Superposition of large seismic events (> 1.5 ML) on the reflection seismic data suggests that sub-vertical structures (faults and dykes) are most likely to trigger seismicity. The integration of source parameters and reflection-seismic defined structures indicates that mining activities may lead to a burst or a slip on pre-existing geological structures. We argue that the integration of reflection seismics with mine seismology may increase mine safety and make it possible to explore and mine successfully at depths exceeding 3.5 km.

The INNOLOG project: Innovative Geophysical Logging Tools for Mineral Exploration

María José Jurado (*Geosciences Barcelona, CSIC – Spain)*

The main objective of the INNOLOG project is to improve the performance of the existing downhole geophysical logging tools in the identification of specific minerals in the subsurface and mineral deposits evaluation. Innovative borehole logging tools based on recently developed sensors and innovative processing capabilities provide new opportunities for development of efficient downhole exploration tools suitable for detection and quantification of minerals and raw materials in the subsurface. Extensive testing of the tools' performance first at research facilities and in mines is planned to demonstrate the efficiency of the new geophysical logging tools as high cost-effectiveness raw materials exploration tools and mineral diagnostic performance.

A 3D subsurface model of the Erzgebirge for 3D mineral potential mapping of Sn-W deposits with Artificial Neural Networks

Andreas Brosig (*Beak Consultants – Germany)*

Since the 12th century, the Erzgebirge has been an important center of metal mineral mining, especially for Ag, Fe, Cu, Sn, W and later U. Because of the long mining history and the large amount of geological, geochemical, geophysical and mineral data, the Erzgebirge was selected as the test case for developing advanced mineral predictive mapping approaches. The developed 3D model covers an area of 9500 km^2 to a depth of 3000 m below sea level, providing an excellent framework for predictive mapping of minerals mineable in the near future. It focusses on the ore controlling litho-stratigraphic and tectonic framework with detailed consideration of intrusives and the close integration of known Sn and W occurrences. Geological primary (bore holes) and derived (maps, sections) datasets, as well as geophysical and geochemical data were used for geological modeling. Hidden granite intrusions were constrained by 3D inverse gravimetry modeling. Enveloping bodies of known Sn-W occurrences were modeled using data either from literature or provided by exploration companies. They are classified according to commodity content and genetic type for later use as training data in the neural network. Secondly, a software utilizing voxel datasets for artificial neural network based predictive mapping (advangeo® 3D Prediction Software) was developed. The 3D model software was used in generating a voxel-based Sn-W predictive model for the Central Saxonian Lineament with its underlying hidden granite intrusive. Key to predictive modelling is the creation of separate models according to the genetic types of deposits (e.g. Sn in skarns or pneumatolytic veins) to fully account for the different geological factors controlling different types of ore genesis. Field reconnaissance led to the discovery of Sn-W-mineralisations in predicted areas. The model is the starting point for new discoveries supporting the Saxon mineral exploration sector and the development of advanced mineral predictive mapping technologies.

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ROBOMINERS – changing the ground rules

Giorgia Stasi (*Geological Survey of Belgium – Belgium)*

< If you can't grow it, you have to mine it > The rise of request for raw materials in all the industry sectors and the willingness to move towards a more sustainable mining industry are two of nowadays' main topic of interest. Those needs to be supported with new objectives and strategies to facilitate EU access to mineral raw materials. For this purpose, the ROBOMINERS project aims to create an innovative bio-inspired robot capable of mining underground mineral deposits. The main goals of the project are (1) to construct a modular robot prototype to mine difficult to access deposit, (2) to design a new mining system via simulation and modeling, (3) to validate and showcase all key function of the miner at a TRL-4/5 level, (4) use the prototype to study and advance future research

Geometry of iron-oxide deposits at Blötberget (Nordic Iron Ore AB, Ludvika Mines) Sweden and Key Findings

Paul Mardsen (*Nordic Iron Ore AB – Sweden)*

The presentation catalogues the positive outcomes for Nordic Iron Ore's involvement (test site and data verification) with the 27 organisational collaboration of Smart Exploration; an EU sponsored 3-year programme of developments of advanced equipment and technologies applicable to deep level exploration techniques, led by Uppsala University. Importantly it also highlights the high standards and leading examples set out for greater communication with society and to reinforce responsible social and environmental practices.

Generating new targets in Neves-Corvo through 3D TEM modelling, gravity inversion and innovative in-mine-surface seismic survey

Joao Carvalho (*Laboratório Nacional de Energia e Geologia (LNEG) – Portugal)*

Neves-Corvo is currently one of the largest base metals producing mines in Europe. Discoveries of new deposits in the last 20 years suggest that the area still holds good potential for reasonable size deposits. These will probably be placed at depth and in a complex geologic environment, opening the way to the use of geophysical methods to complement geological outcrop and sparse drill-hole data. With the goal of discovering new targets for exploration, under the scope of the SmartExploration project, a new 3D geological model for a constrained gravimetric inversion was generated for the Neves-Corvo region. The geological model was built using available legacy seismic and TEM data, updated drill-hole and geological data. To supplement the geophysical information, drill-hole geochemical data were integrated into the modeling workflow using neural networks algorithms in order to provide additional predictive parameters for deep targeting at the near-mine area. To assess the possibility of the down-dip extension of one of the major deposits, 1D inversion and 3D electromagnetic forward modeling of ground-loop, time-domain data, 3D gravity inversion and a novel seismic survey took place. The seismic survey had as major goal to test the possibility of acquiring data inside the exploration drifts in an active mine. Two prototypes were successfully tested: (i) a GPS-time synchronization system for satellite denied environment and (ii) electrically driven broadband vibrator seismic source. Furthermore, the known deposit could be mapped and other reflectors are currently being investigated.

Seismic strategies to constrain the physical properties of extinct Seafloor Massive Sulphide deposits

Gaye Bayracki (*National Oceanography Centre (NOC) – United Kingdom)*

Ultramafic-hosted seafloor massive sulphide (μSMS) deposits are found in magma-poor ridges, where lower-crust and upper-mantle ultramafic rocks are exhumed by 'detachment' faults forming oceanic core complexes (OCCs). The μSMS deposits are estimated to contain larger amounts of Cu and Zn than the active SMS deposits at volcanic plate margins, and to have sub-seafloor ore bodies where hydrothermal fluids have mixed with serpentinising fluids. The Semyenov Hydrothermal Field, located on the Mid-Atlantic Ridge at 13°30'N, hosts five μSMS deposits and, therefore, is an ideal laboratory to study the mineral, chemical and physical controls on the formation and evolution of μSMS deposits. Studying the physical properties of μSMS deposits and quantifying the extent of sub-seafloor mineralisation using seismic techniques is challenging due to their small (few 100's m) size, burial beneath shallow sediments, within a hard-rock host, and in a deep sea environment. In this talk we discuss the short comings of conventional ship-towed airgun seismic surveys in constraining such targets and develop new strategies such as "inverse vertical seismic profiling" and "borehole seismic" imaging using short-offset "seismic-while-drilling" techniques and an ROV mounted deep-towed high-frequency source to overcome these challenges.

"iTarg3T" Innovative targetting of W-Sn-Ta-(Li-Nb) deposits

Fernando Tornos (*IGEO-CSIC – Spain)*

The aim of the iTarg3T (Innovation Targeting of Tin-Tungsten-Tantalum) EIT RM project is to promote the exploration of these critical and technological metals in RIS countries by providing innovative tools that facilitate the transition from conventional brownfields to greenfields exploration. These techniques include the development of mineral system models for the different styles of mineralization, numerical prediction of ore accumulation, geochronology and isotope geochemistry as pathfinders to ore and geophysical detection of hidden cupolas and mineralized structures. These geological-geophysical studies are complemented by advances in two other pillars that support mine exploration, which are advances in our understanding of the social license to operate and in geometallurgy.

Introduction to the SIT4ME project

Ramon Carbonell (*Geosciences Barcelona, CSIC – Spain)*

Deep mineral resources need to be discovered and accessed to ensure the ever increasing needs of minerals in our society. Seismic methods have proven their capacity to image important targets in deep, crystalline environments, but their use is not yet a standard within conventional mineral exploration activities. The EIT-RawMaterials Programme has funded the “Seismic Imaging for Mineral Exploration - SIT4ME” project, aimed to develop seismic imaging approaches for mineral exploration within crystalline settings, at a reduced cost. The aim of this transnational initiative is to test the efficiency of seismic methods to image target ore structures by comparing control and natural source seismic data-sets in two real case-studies, the Zinkgruvan mine in Sweden and the Sotiel mine in Spain. This work describes the main objectives and activities carried out as part of the project, and outlines the expected outcomes of this initiative.

Seismic exploration of Sotiel-Coronada site

Yesenia Martínez (*University of Salamanca – Spain)*

In the Iberian site, located at the southeastern of the Iberian Pyrite Belt (SW Spain), a multi-method seismic dataset (i.e. 3D-3C controlled source and natural source) was acquired. The target of this experiment is a pyrite-rich massive sulfide orebody interbedded with felsic volcanic rocks and shales, located at 300 – 500 m depth. The acquisition comprised 653 seismic receivers, distributed in a 3D mesh and six 2D-crooked lines, that registered 875 vibration points in an area of approximately 6 km2. The processing workflow involves standard commercial processes such as static corrections, surface-consistent deconvolution, amplitude equalization, frequency filtering and velocity analysis. Here, we present the results of this processing flow in a few 2D-seismic sections crossing the study area in the north-south and east-west directions. The seismic images present coherent reflectivity down to ~2000 ms two-way traveltime (TWT). The North-South line shows a ~400m long highly reflective zone of in the center at 130 ms, characterized by high amplitude, north-dipping reflections. The east-west transects show a soft folded structure (antiform and synform) which can be observed down to ~235ms TWT. Towards the north, these structures are difficult to identify as the transects become parallel to the subsurface structures. These lines will become the framework for the processing and interpretation of a dense 3D grid acquired at the location of the target orebody. Future processing will involve pre-stack depth migration and P-wave travel-time tomography.

Seismic exploration of Zinkgruvan site

Alba Gil (*Uppsala Universitet – Sweden)*

The Zinkgruvan mining area is located in the south-eastern part of the Bergslagen district, one of the three most mineral prospective regions in Sweden. In this study, we present the results from two recently acquired approximately 6000 m-long reflection seismic profiles crossing the Zinkgruvan mining area. Profile P1 was acquired using cabled geophones with 10 m receiver and source interval and crossed a major NE-plunging fold. Profile P2 was acquired perpendicular to P1, used wireless recorders with 20 m receiver and 10 m source intervals. Despite the notably complex geology, the processed seismic sections clearly reveal a series of moderately-to-steeply dipping reflections associated with the mineral-bearing Zinkgruvan formation. The results from this seismic survey are encouraging regarding the potential of the seismic method for mineral exploration purposes and its high resolving power on complex geological structures in a cost-effective and environmentally friendly way.

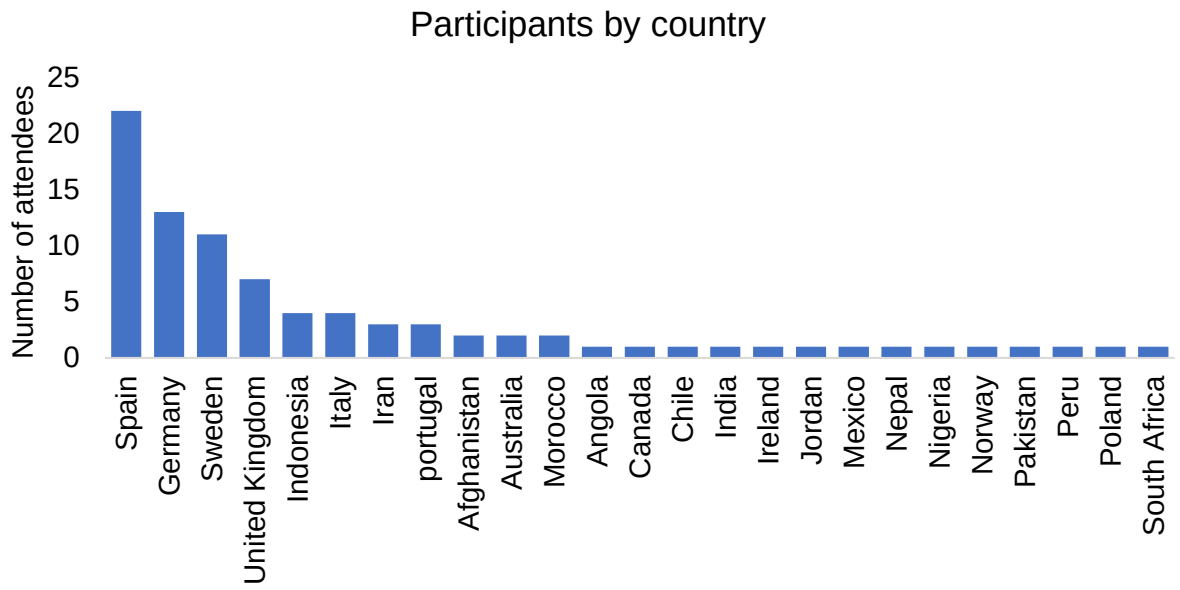
Combination of 3D Borehole radar and Underground Reflection Seismic - A case study for In-Mine Exploration

Tim-Julian Hupe (*DMT GmbH & Co. – Germany)*

As part of the SIT4ME research project, a hybrid method consisting of in-mine reflection seismic, tunnel VSP and 3D borehole radar investigations is introduced. In this scope, both, active and continuous seismic measurements as well as 3D borehole radar measurements in the Asse II mine (Germany) were performed. The Asse II mine is a former salt mine used as a deep geological repository for radioactive waste, operated by the federal company for radioactive waste disposal (BGE). However, due to water penetration from the geological overburden and endangered stability of the mine workings, the German government ordered the retrieval of all waste material stored in the Asse II mine. For the retrieval, the operator plans to sink a shaft in direct proximity to the former emplacement chambers beyond the limits of the local salt dome. Consequential, the objectives of this study comprise the localization of the salt dome limits, the verification of known geological structures and the discovery of unknown stratigraphical and structural geological conditions.

Attendance

- 20 international speakers
- 87 people registered from 25 countries



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