EXPLORATION

Strategy and Vision **(will be included in part 1 of the roadmap**, 423/300-400 words)

While Europe contributes to more than 20% of the global consumption of metals and minerals, we only produce around 3%. It is generally considered that this relationship between consumption and production to a large extent is due to the lack of many commodities in European crust, i.e. that the geological potential is lacking. However, this is mainly based on models that rely on the current knowledge base of known deposits and not on a sound geological estimation of undiscovered resources.

In Europe, the mineral exploration expenditure was about 4% of the global expenditure. The amount of money invested in exploration per square kilometre is much lower in Europe compared to elsewhere in the world and this indicates that Europe's import dependence will increase. Based on results from mining-related research projects, among others the FP7 ProMine and REEcover projects, it can be demonstrated that Europe possesses several structurally complex world class mineral districts and has a very high potential for the extraction of critical metals. Europe is also a leading technology provider for exploration as well as for underground mining and drilling.

In Europe, especially in the central and southern parts, competition for land-use is a major concern for the extractive industry, and projects related to this issue, e.g. the H2020 MinLand project, is ongoing. At the same time, fewer and fewer new "world class" discoveries are made on the surface, and exploration will in the future be focused to a larger extent on deep, hidden resources. This is now a global trend, and since the potential for finding new economic mineral deposits are very high in Europe, the fact that most of these will be mined in underground mines will also decrease the burden for land utilisation by extractive industry. In northern Europe, where outcrops are sparse, large areas are still unexplored, and new methods based on indicator mineral and micro-chemical in situ approaches are still to be tested.

In order to explore for deep seated and complex ore deposits not only direct targeting through bedrock and structural geology mapping, geophysical surveys, and geochemical analysis can be applied but also indirect targeting is needed. Indirect targeting is based on proxies such as geological setting of mineralizations and therefore requires good knowledge of the mineral system. By building on this mineral system approach it is needed to develop new deep penetrating geophysical technologies, new approaches to geochemical data interpretation, and advanced mineral chemical analytical techniques and integrate these technologies into a better understanding on how and where the mineral deposits have formed in Sweden.

Summary/purpose of the thematic area 524/300 words

In any region, sustainable extraction is in the long run dependent on exploration. Since any one mineral deposit is by nature non-renewable, extraction without exploration will inevitably exhaust known mineral resources. Even if this is partly mitigated by increased recycling and substitution, urbanisation and population growth in the modern high-tech society will inevitably lead to the fact that if there is no exploration investment in a region, self-sufficiency will decrease instead of increase. A proposal is made for an *Exploration* agenda owing to the need to improve the required

supply demand of primary mineral raw materials from domestic resources. Exploration should target ferrous, base, precious and critical commodities, bearing in mind that within the time frame of the project the criticality aspect for some currently critical materials may change. The *Exploration* agenda encompasses six main areas:

"*Technology*". Development of new drilling technology for deep (>1,000 m) drill holes.

Deep, >1,000 m diamond and percussion drill holes with master and daughter drill holes.

Fan or cone type drilling patterns at depth, developed and implemented MWD.

"*Location*". Development of 3D/4D geo-modelling of mineral resources.

Three-dimensional models of the Swedish bedrock in all areas of high potential for deep mineralisation with a target depth of 1–5 km.

Models of the evolution of geology and related mineral deposits over time: Four-dimensional modelling.

"*Penetration*". Development of new, deep penetrating geophysical techniques.

Develop new electromagnetic and induced polarization methods with improved resolution at a range of depths, from shallow to below 1,000 m.

Develop new seismic techniques with data acquisition in 3D utilising three-dimensional infrastructure such as mines and drill holes. Target: good resolution in 3D in the top 5 km.

Development of improved and joint 3D inversion techniques for magnetic, gravimetric, electromagnetic and geo-electrical geophysical data.

Fully integrated geophysical and geological modelling.

"*Formation*". Conceptual modelling of mineral deposit types.

Establish genetic and exploration models for major ore types in Sweden, including models for deposits containing critical raw materials with economic potential.

Define potential exploration targets, and the geological, geochemical, mineral chemical, and geophysical vectors to ore for the most pertinent ore types in Sweden at depth. A major target is increased investment in deep exploration in Sweden.

Compare and contrast major Swedish ore deposits and mineral belts with equivalent deposits and belts internationally in order to better define and model mineral deposit systems, ore genesis and vectors to ore.

"*Education*". Building knowledge and developing skills in Europe.

Define a knowledge base of metals and minerals in Sweden. A target is to implement the teaching of economic geology and geophysics based on Swedish resources in Swedish universities.

Improving skills in the staffs of industry and survey organisations for future forefront predictive targeting of resources in Sweden.

Improving the awareness (public and government) of the need for minerals and metals for a sustainable and green society.

"*Integration*". Integration of data into real-time exploration and geometallurgical tools.

Developing tools for data collection while drilling: 3D camera, geochemical assay while drilling (AWD), down hole

geophysical measurements while drilling (GWD).

Integration of structural, mineralogical and geochemical data sets in one software system in real time.

Integration of early-stage exploration data in geometallurgical modelling.

Objectives and KPI 131/150 words

Deep exploration calls for interpretations based on improved drilling technology, more efficient depth penetration and resolution of geophysical data, advanced geochemical/mineral chemical techniques and utilization of machine learning, and more accurate targeting based on a three-dimensional knowledge base and a genetic concept of ore forming processes. The vision for these areas is expressed as established targets and Key Performance Indicators (KPIs) for 2030 and beyond:

- Reduction of energy
- Increase in resources base and commodity diversity focused on critical minerals
- Increased use of new deep drilling technology
- Improved ore genetic models for Swedish mineral resources
- Improved geophysical, geochemical and mineralogical targeting methods
- Improved integrated interpretation of geochemical/geophysical data through machine learning
- Increased efficiency through applied real-time exploration
- Improved awareness of the need for minerals and metals for a sustainable and green society

Research and innovation needs, and strategies and actions 308/350 words

Short-term

Based on the results of recent exploration research projects, define similar projects in areas of Sweden offering a great potential for new discoveries. Start to develop the ore genetic models by defining deposit types in these areas with a focus on both main mined commodities and related critical minerals. Develop exploration models by defining the geological, geochemical, mineral chemical, and geophysical vectors to ore at both the regional and local mine scale. Establish procedures for ensuring a fully integrated data and knowledge driven approach. Specifications for new efficient exploration technologies exist but the proposed methodologies need financial support in order to be implemented and developed further. Launch a technology-based project for new and innovative drilling, geophysical and geochemical techniques.

Build visualisation centres and publish predictive 3D models for Sweden.

Improve the awareness of the need for minerals and metals for a sustainable and green society, both publicly and throughout the whole of government – this is crucial for the objectives to be achievable.

Medium-term

Intensive fieldwork, pilot actions on new exploration techniques, feeding 3–4D models with data and further adjustment of acquisition parameters. Continue to develop genetic ore- and exploration models for Sweden's major ore deposit types. Testing and validation of genetic- and exploration models with predictive models in pilot areas.

Development of new geophysical methods for deep penetration from surface, airborne and borehole observations.

Development of new geochemical and mineral chemical vectors to ore, through advanced microanalysis and data interpretation.

Potential pilot-scale verification of 3D models, and new geophysical and geochemical equipment by deep drilling in test areas. Start to utilise results in training across Europe.

Long-term

Training of decision makers for better resource governance, and actively promoting results among exploration industry at large. Proven new deep drilling, deep geophysical, deep geochemical/mineral chemical techniques, and "real-time" mineralogical and geochemical analysis, as well as 3D structural modelling.

Expected impact 219/200 words

Technical

Providing Sweden with innovative, world-class technology for minerals exploration of deeper-seated ore bodies.

Providing Sweden with a first nationwide 3D model of the bedrock down to several kilometres, to be used for decision making on land planning issues.

Economical

Deeply located deposits can be defined and economically evaluated.

Improved self-sufficiency and a stable supply of base, critical and other metals for the Swedish and European economy.

Foster the development of Swedish-based downstream industries on domestic mineral resources, e.g. battery manufacturing.

Create wealth and growth in many less densely populated areas of Sweden.

Environmental

Definition of deeply buried resources to minimise the effect of mining.

Define where the mining potential is in Sweden for the coming century to be used as a tool for decision making on land use, protection etc.

Social

Fewer problems with access to land in densely populated areas. Exploring deeper and under cover may meet rising community and environmental concerns.

An awareness of the need for minerals and metals for a sustainable and green society, both publicly and throughout the whole of government.

Increased employment opportunities in less populated and rural regions of Sweden with a good potential for the extraction of minerals and metals.

Training of decision makers on resource geography and potential and predictive models will lead to improved governance of Swedish resources.