

CENTRE OF ADVANCED MINING AND METALLURGY

Pär Weihed

Professor in Ore Geology

Director CAMM (Centre of advanced
mining and metallurgy)

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Prioritized area Mining & Metallurgy

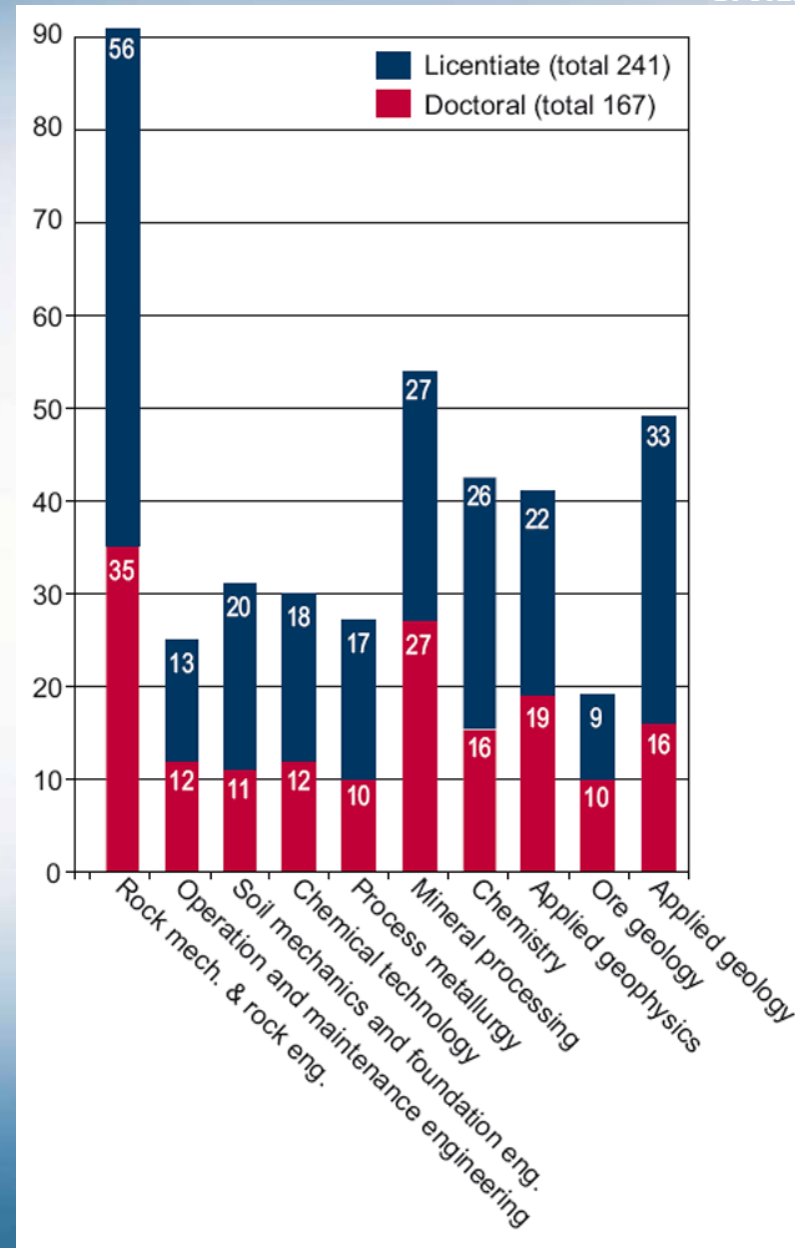
- **Dept. Civil, Environmental & Natural resources**, mainly
- >12 research subjects
- >20 full professors, ca. 50 senior researchers
- >70 PhD students, 6–10 dissertations/year
- Turnover ca 150 MSEK/year 20% of the LTU budget

Vision for Mining and Metallurgy

- One of the most complete mining universities in Europe (crystalline rocks)
- Research along the full value chain exploration-mining-processing-smelting-remediation
- Strength
 - Research in cooperation with industry
 - Modern & applied education with theoretical depth

Dissertations

During years 2000 – 2010, 68
PhDs within mining and
metallurgy



External funding in Mining and Metallurgy, contracted R&D until 2014 (preliminary)

	SEK	Euro
HLRC	50	5.5
LKAB EC	50	5.5
Vinnova	37	4.1
Boliden	28	3.1
Jernkontoret	11	1.2
LKAB	13	1.4
Formas	3	0.3
CAMM	75*	8.3
ProcessIT-Innovations**	52	5.8
Totalt	319***	35.4

* Räknas som fakultetsanslag, behandlas av Vinnova, exkl. MEFOS 9 MSEK

** Flera olika finansiärer

*** Detta är ett lägstvärde, fler projekt finns inom LTU



CENTRE OF ADVANCED MINING AND METALLURGY



The "hard rock-heavy metal" chain at LTU



Find and characterize mineralizations and ores

Construction, extraction and maintenance

Process and refine minerals and metals

Remediation, environmental aspects of mining

Exploration Geophysics
Ore geology

Rock mechanics
Rock engineering

Mineral processing
Process metallurgy
Chemistry

Applied geology
Soil Mechanics and
Foundation Engineering

Operation and Maintenance Engineering
Industrial production environment
Sound and Vibration
Fluid mechanics



Vision: Technological leadership is utilized for resource-efficient production of raw materials and innovative products with high value added in order to enhance quality of life by creating prosperity in harmony with nature and society. LTU is recognized as a world leading university in mining and metallurgical research and education.



**CENTRE OF ADVANCED MINING
AND METALLURGY**

Centre for Advanced Mining and Metallurgy **CAMM**

Board CAMM (styrgrupp)

Chairman (ordförande) from LTU (appointed by VC cons w. HoD (TKG)) - **DeVC Prof Erik Höglund**
Three WP leaders (forskningsledare) from LTU (appointed by HoD (TKG))
Two representatives from industry (appointed by Bergforsk)
One representative from Mefos

Appointed for a 2 year period

meets minimum 2 times/year

Executive management CAMM (ledningsgrupp)

Director (verksamhetsledare) (appointed by VC cons w. HoD (TKG)) - **Prof Pär Welhed**
6 Work package leaders (forskningsledare) (appointed by the director)

Director appointed for a 3 year period

Work packages (forskningsområden)

1. Geometallurgy and 4D geological modeling	<i>WP leader Prof. Jan Rosenkranz</i>
2. Deep mining	<i>WP leader Prof. Ering Nordlund</i>
3. Lean mining	<i>WP leader Prof. Uday Kumar</i>
4. Particle technology	<i>WP leader Prof. Jonas Hedlund</i>
5. Green mining	<i>WP leader Prof. Björn Öhlander</i>
6. Raw materials for future Iron- and steelmaking	<i>WP leader Prof. Bo Björkman</i>



The board decides on strategic financial approval:
 - work plan for C-CAMM Annual
 - budget (annual)

The manager reports to the board and shall for each year provide:
 - work plan for C-CAMM Annual
 - budget (annual)
 - annual report

Mefos

Research Institute

Research partner WP 6

CAMM Strategy

”JV” with Swedish mining industry

- International collaboration
- More focus on senior research
- EU platform (ETP SMR) for international R&D networks for FP7+8 success
- More mobility

Work packages

- Geometallurgy and 4D geological modelling
- Deep mining
- Lean mining—development of production systems
- Particle technology
- Green mining—reducing the environmental footprint
- Raw materials for future iron- and steelmaking

Research leader: Professor Jan Rosenkranz (mineral processing)

Despite continuous improvements in exploration, mining operation and extractive metallurgy the overall production process from the in-situ ore to the final metal product is in many cases not optimal. This is often due to poor quantitative characterization of the ore's mineralogy and shortcomings in mineral process design and optimization accordingly.

A new research field that brings together geological sciences, mineral processing and process metallurgy in order to overcome these deficits is called Geometallurgy. Geometallurgy is an interdisciplinary, holistic approach with a significant potential for utilizing non-renewable mineral resources more efficiently and sustainably, thereby reducing the economic risks for the mining industry.

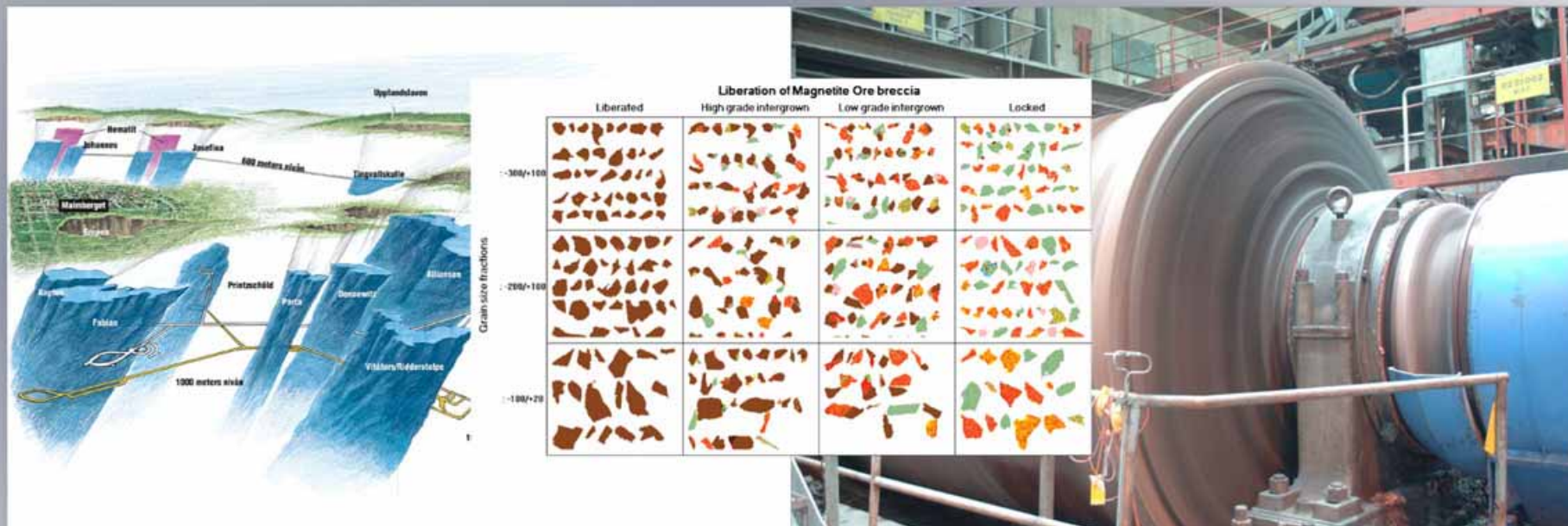


Fig. 1: Liberation analysis of iron ore



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1. Ore characterization: Development and implementation of analysis methods to characterize mineral composition and texture of ores as well as test routines for technological properties. Results from mineral & metallurgical processing tests will be correlated to mineralogy.

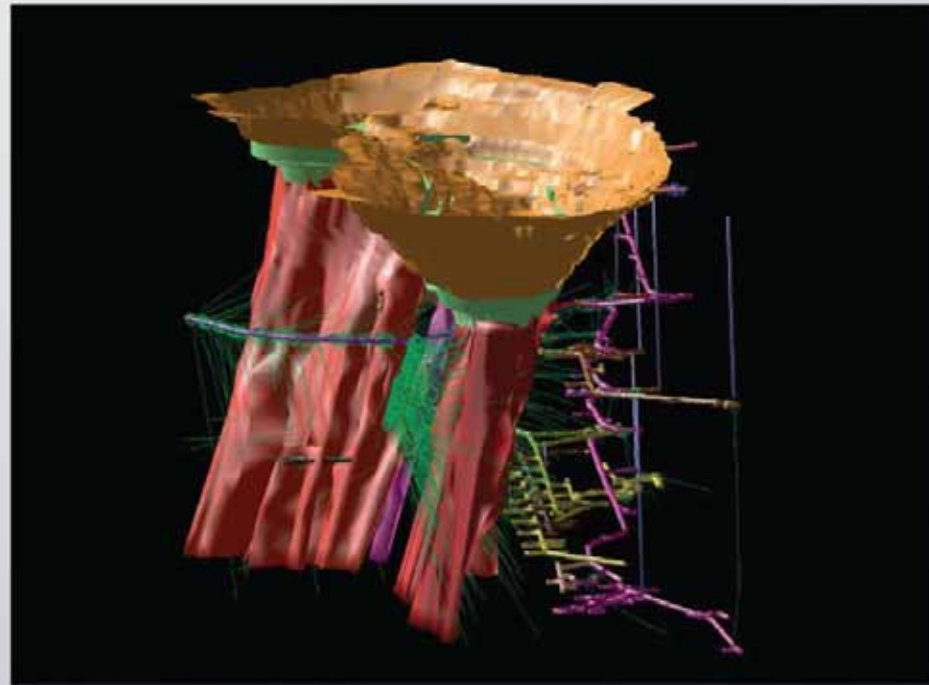


Fig. 3: Geological model – 3D ore model



2. 3D property modelling: Description of ore properties based on spatial patterns. Data models will be aligned with mine planning. Modelling comprises ore body geometry and topology, interpolation to predict unmeasured ore properties and correlations between mineralogy and technological parameters.

3. Production modelling: Provision of reliable process models (structured model library) comprising different mining methods, unit operation models for ore beneficiation (crushing and grinding, flotation and other physical separation) as well as metallurgical process models.

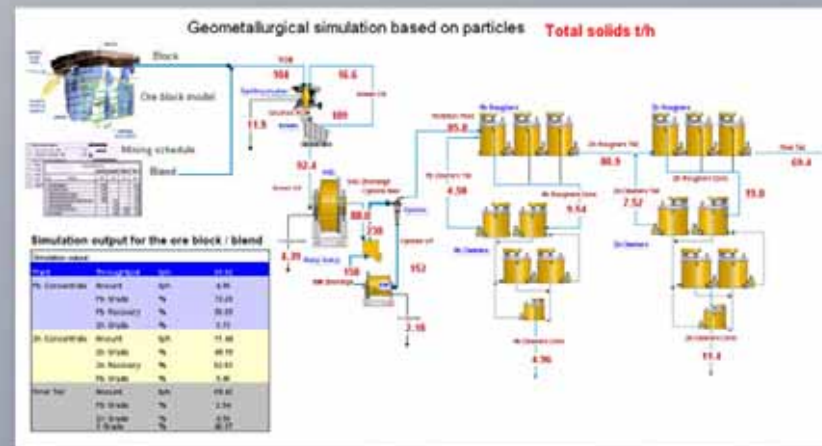


Fig. 4: Particle based simulation



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4. Enhanced product program: Identification of new products based on improved mineral analysis, new applications for established products by adjusting quality and product distribution.

Deep Mining



Research leader: Professor Erling Nordlund (rock mechanics)

GROUND CONTROL

OBJECTIVE

Improve the understanding of:

- Failure mechanisms and clarify how well a fallout could be predicted with the aid of continuum and discontinuum models,
- The interaction of underground openings and seismic waves and the response of the opening to seismic waves with respect to stability,
- The interaction between the rock support systems and the rock mass under dynamic loading as well as squeezing conditions,
- The performance of underground openings in a complex geological environment.

Methods for:

- Probabilistic analysis of stopes,
- Estimation of fallouts and the performance of underground openings using numerical analyses,
- Dynamic testing of rock support.

Rock support systems for deep mining



SUBSIDENCE

OBJECTIVE

Improve the understanding of:

- The main failure modes of hangingwalls and crown-pillars,
- The influence of the geological structures on the deformation/subsidence of the hangingwall,
- The long-term stability of crown-pillars and hangingwalls in sublevel caving mines.

Develop:

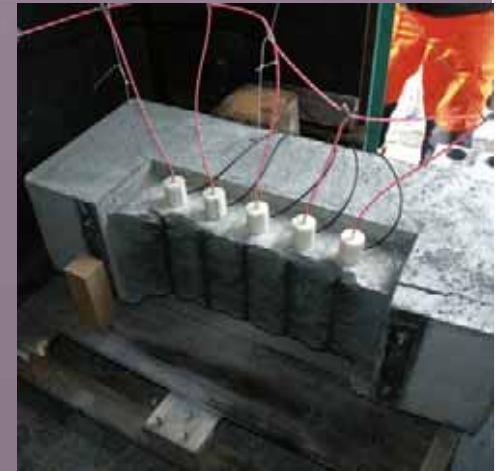
- Criteria defining onset of continuous and discontinuous subsidence,
- Analyses methods for hangingwalls and crown pillars,
- Methods for prognosis of ground deformation and fracturing.

BLASTING & FRAGMENTATION

OBJECTIVE

Improve the understanding of:

- Fragmentation by blasting under different conditions,
- Properties of explosives,
- The detonation process.

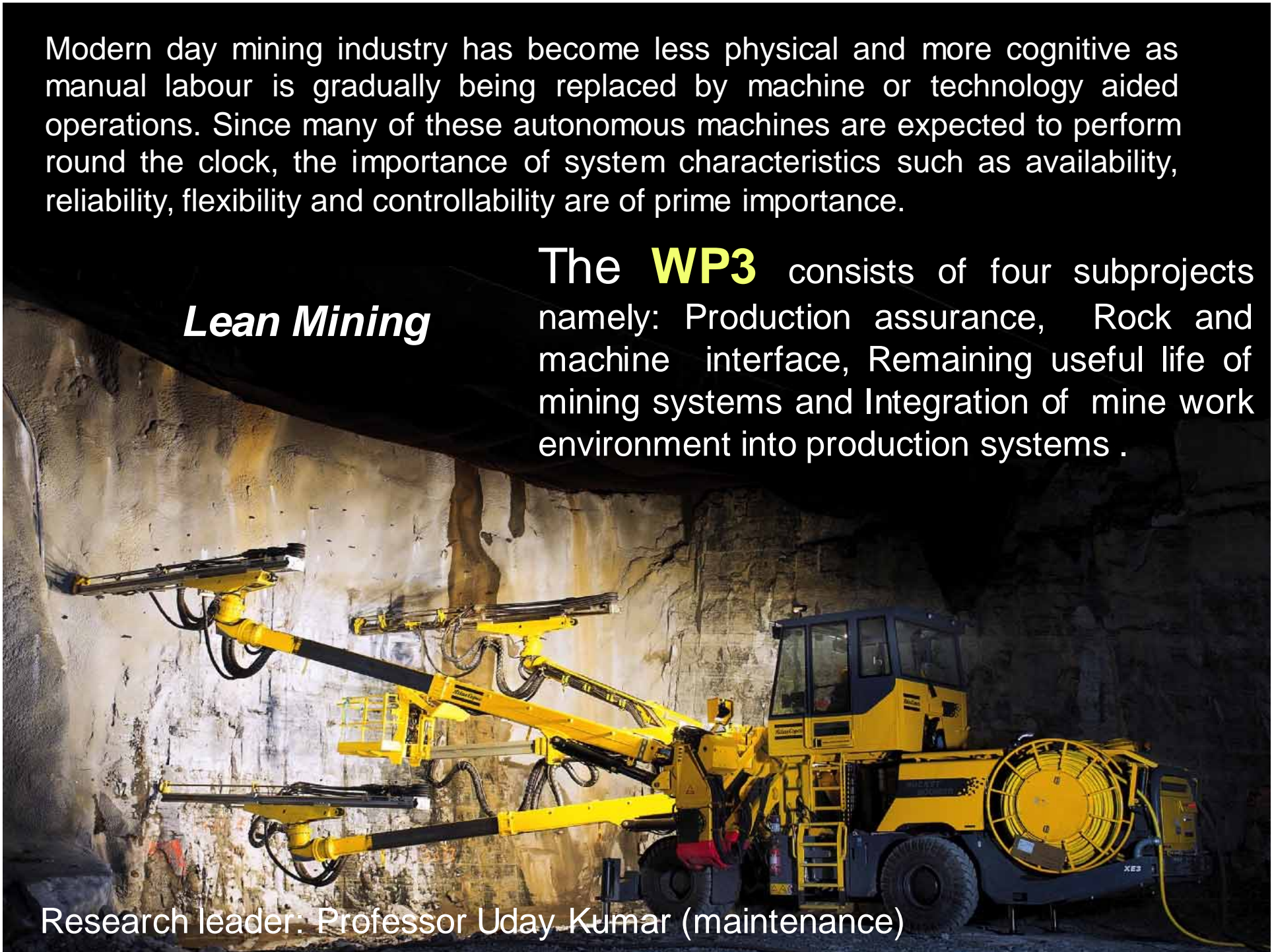


Modern day mining industry has become less physical and more cognitive as manual labour is gradually being replaced by machine or technology aided operations. Since many of these autonomous machines are expected to perform round the clock, the importance of system characteristics such as availability, reliability, flexibility and controllability are of prime importance.

Lean Mining

The **WP3** consists of four subprojects namely: Production assurance, Rock and machine interface, Remaining useful life of mining systems and Integration of mine work environment into production systems .

Research leader: Professor Uday Kumar (maintenance)



1 Improvement of production availability and delivery assurance

- Development of production plant integrity index (PII).
- Development of a generic link and effect model which will locate bottle necks and identify areas for investment and development.
- Development and use of generic models for production assurance.
- Research to integrate *front end processes* (customers' need) to *back end processes* (maintenance need, ore quality, etc).



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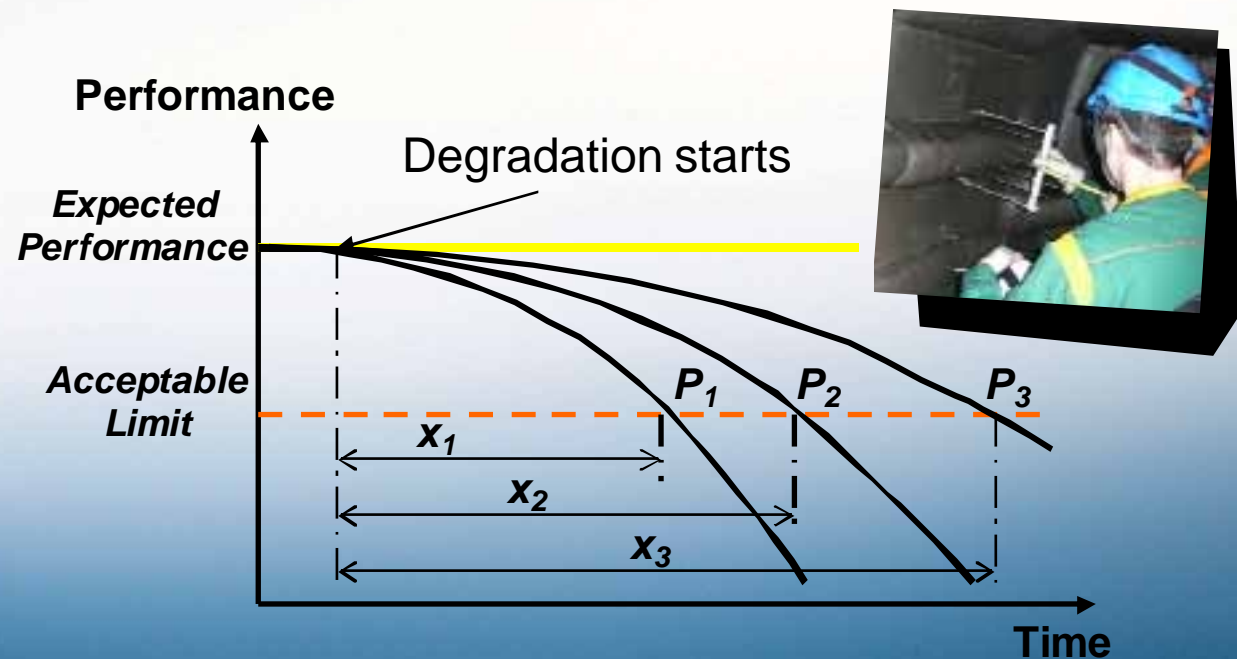
Rock and machine interface

Research to understand and communicate rock mass behaviour in real time to all the collaborative partners with a special reference interface between rock mass/ore body and production machines and system.



3 Remaining useful life of mining systems

Models for Remaining Useful Life of system, prediction of number of hours/days the production system, components, etc can run at acceptable performance level without risk.



4 Integration of mine work environment into production systems

Develop models for integration of organisational, human factors and work environment perspectives into production and technical development processes to make mines safe working place.



Research leader: Professor Jonas Hedlund (chemical technology)

The research in Particle Technology is divided into three general projects of fundamental and multidisciplinary character: Mechanisms of flotation, Mechanisms of agglomeration, and Mechanisms of comminution.

Competence in Mineral Processing, Chemistry of Interfaces, and Chemical Technology will be combined to reach the highest possible scientific level.

In all projects, a combination of carefully designed experiments, advanced instrumental techniques, and modeling will be used. To ensure high industrial relevance, conclusions drawn from model systems will be verified or rejected using industrial multi-component mineral systems.



- Comminution
- Flotation
- Agglomeration

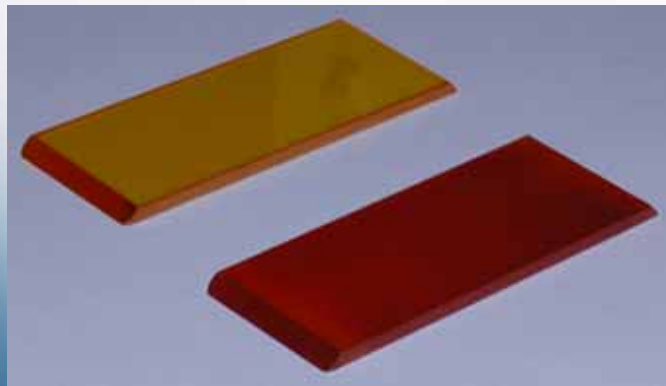


1. Mechanisms of flotation:

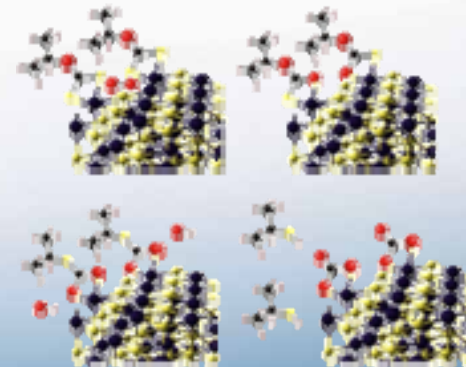
Selectivity and recovery of mineral particles in flotation of iron oxide and sulphide ores can be improved through a deeper understanding of the molecular interactions taking place during the adsorption of flotation chemicals on mineral surfaces.

To assure industrial relevance, the research will focus on complex flotation systems.

The experimental techniques include wet chemistry and flotation tests, in combination with ex-situ and in-situ FTIR-spectroscopy and FTIR-spectroelectrochemistry, XPS, solid-state NMR, and theoretical ab-initio quantum mechanical calculations.



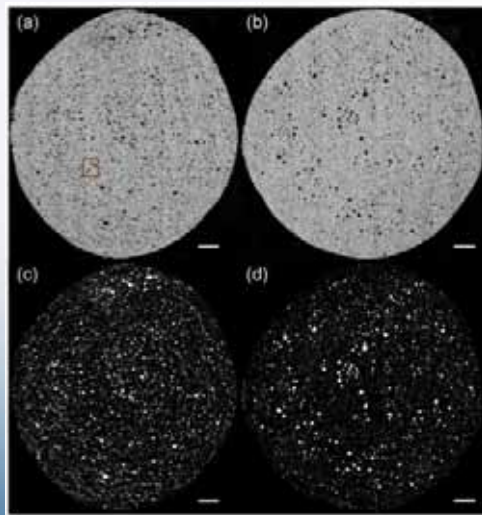
Thin film of synthetic hematite on a ZnSe substrate for in-situ adsorption studies using FTIR-spectroscopy.



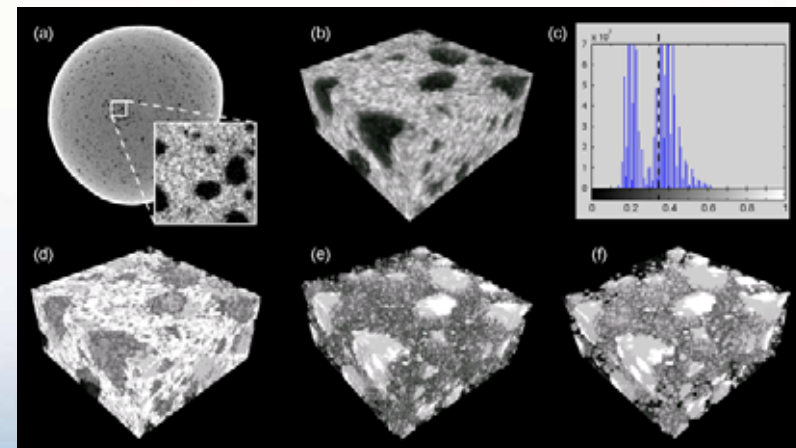
Schematic illustration of xanthate decomposition after adsorption on synthetic PbS. Solid state NMR can be used to identify different species of collectors adsorbed on a mineral surface.

2. Mechanisms of agglomeration:

Our aim is to provide the fundamental knowledge needed for improvement of industrially important processes such as briquetting, pelletization and filtration. We will perform advanced morphological characterization (optical and electron microscopy and X-ray tomography), measure porosity and, depending on the type of agglomerate, measure the relevant key properties such as permeability and/or strength.



HR-SEM images of iron ore pellet cross-sections illustrating flotation effect on porosity.



3D X-ray micro tomography images of iron ore pellet segment illustrating bubble porosity.

3. Mechanisms of comminution:

The goal of the project is to enhance understanding of particle breakage, which shall lead to improved comminution systems and more efficient utilization of energy for particle size reduction and mineral liberation.

Research leader: Professor Björn Öhlander (applied geology)

There has been a tremendous development of reducing the environmental footprint of mining the last decades, but mining operations may still have detrimental effects on soil, water and biota. The mining industry is a major energy consumer. Leakage of the nutrient nitrogen from undetonated explosives and from cyanide leaching for gold extraction is common. Dust and noise problems are common at mine sites. However, these effects occur only as long as a mine is active. The major potential long-term environmental effect of mining is formation of acid rock drainage (ARD) in sulphide-bearing mine waste, which can last for hundreds or even thousands of years. Therefore, such deposits are nowadays carefully stored, with the major aims to reduce the amount of oxygen and water reaching the sulfides in the waste. The most common method is to apply some sort of soil cover on the waste or to cover it with water.



The industrial area at LKAB's Kiruna mine, with waste rock dumps and tailings.

1. Remediation of mine waste deposits, and prevention of formation of ARD: The research plans involve studies of the use of incineration ashes, waste from wood and paper industries, waste from other industries, sewage sludge, and combinations of these materials, for construction of sealing layers and for other applications such as passivation of surfaces on reactive minerals such as pyrite by coatings.

An innovative suggestion that will be tested in this sub-project is depyritization. The remaining tailings could potentially be sufficiently low in Fe-sulfides that direct deposition will not be environmentally hazardous.

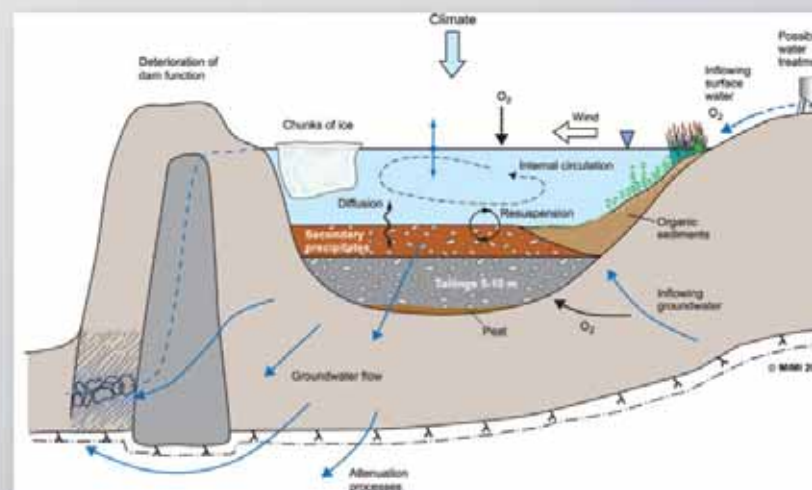


ARD at the Kristineberg mine, Västerbotten.

2. Construction of mine dams :

Important research questions are:

- What type of material can resist seepage without getting internal erosion during these very long time periods?
- Does a given material have a maximum value for the hydraulic gradient in order not to get internal erosion?
- If a maximum value exists, how can this be determined?
- How can safety be described and assessed during for these very long time periods?



Sketch of water covered tailings, illustrating the importance of the dam construction as well as of the complex geochemistry.

3. Natural metal release in mineralized areas :

The planned research aims at understanding in detail the complex interactions between weathering release, distribution, transport, attenuation and speciation of metals from natural metal occurrences as well as from mine sites.

Included in this sub-project are also studies of release of nitrogen from mining areas. The main goals are to quantify the environmental significance of nitrogen effluents from the mining industry in relation to the natural load of nitrogen in streams and rivers, and to improve the possibilities to reduce effluents of mining-related nitrogen through efficient water management.



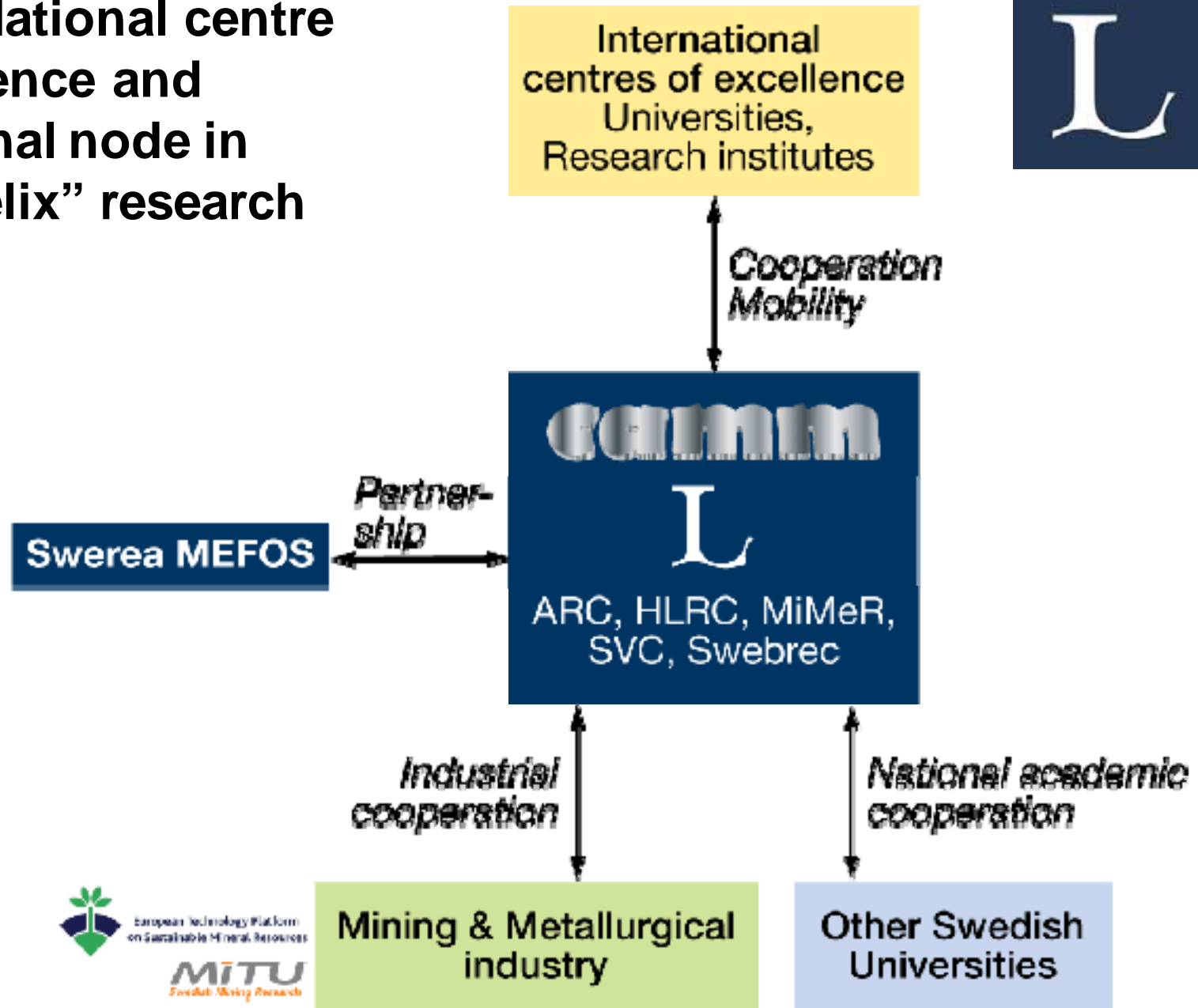
Field work in the nitrogen project.

Raw materials for future iron- and steelmaking with Swerea MEFOS

- **Subproject 1:** Iron carrying raw materials for future blast furnace ironmaking routes.
- **Subproject 2:** Iron carrying raw materials as scrap substitutes
- **Subproject 3:** Zero waste steel production.

Research leader: Professor Bo Björkman (process metallurgy)

CAMM: National centre of excellence and international node in "triple helix" research

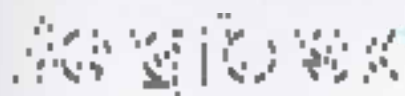




CENTER OF ADVANCED MINING AND METALLURGY



EUROPEAN TECHNOLOGY PLATFORM ON SUSTAINABLE MINERAL RESOURCES



**WP 1 – Geomining
4D-Geomining**

C. Wanhainen, C. Samuelsson, F. ...

Despite continuous improvements in separation, the production process from the in-situ ore to the final metal is still characterized by poor quantitative characterization of the ore's mineralogical composition.

A new research field that brings together geological and mineralogical data in order to overcome these deficits is called 4D-geomining. This approach has a significant potential for utilizing raw materials more efficiently, thereby reducing the economic risks for the mining industry.



Fig. 1. Location of the mining site.

The use of advanced resource characterization, 3D geomodeling and geostatistics, as well as mineralogical testing and process simulation provides the basis for optimized extraction processes along the entire production chain in order to:

- Optimize recovery of valuable minerals and final product quality.
- Identify valuable associated minerals and design process for their production.
- Detect and remove undesired minerals.
- Predict tailings and identify ways to recover valuable or reduce harmful components from mine waste.

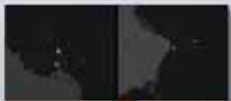


Fig. 2. SEM and QEMSCAN images of quartz-hosted gold grains in proximity to main sulphide minerals.

Providing the described geomining modelling framework applicable to different ore types and various processing options, requires the development of efficient test methods and analyses as well as a comprehensive methodology.

Research within WP 1 therefore aims on the development of suitable tools and methods and their utilization within an integrated approach to predictive geomining modelling.

To ensure consistency and completeness of the methodology the developed procedures will be validated by two industrial relevant case studies, covering complex sulfide ores (Göteborg Mineral AB) as well as oxide ores (LKAB).

The research work is divided into four sub-projects:

**WP 2 - D
E. Nordlund**

**GROUND
OBJECTIVE**

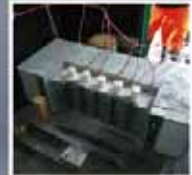
Improve the understanding of the

- Failure mechanism of rock in the underground
- The interaction between stress and strain in the rock
- The interaction between the rock and the rock mass
- The performance of rock mass

Methods for:

- Prohibitively an
- Estimation of the underground op
- Dynamic testing

Rock support system



WP 3 – Lean M

U. Kumar, H. Schumessan, B. Ghoshal



Modern day mining industry has become less physical labour is gradually being replaced by machine or robotic. Since many of these autonomous machines are expected to be used in the future, it is important to study the importance of system characteristics such as its controllability and of prime importance.

The Workforce of the future will be autonomous.



**1 Improvement of production availa
and delivery assurance**

- Development of production plant integrity index (PII)
- Development of a generic risk and effect model which will include both risks and effects which will be used to assess the risk of failure of the production plant
- Risk and process integration for the assessment of both risk and processes for the risk, the quality, etc.

2 Rock and machine interface

To improve the rock and machine interface, it is necessary to study the interaction between the rock and the machine. This will be done by studying the failure mechanism of the rock and the machine.

**3 Remaining useful life of mining
systems**

Methods for Remaining Useful Life of system, prediction of number of hours/years the production system, components, etc. can run at acceptable performance level without risk.

**4 Integration of mine work
environment into production
systems**

Develop models for integration of organizational, human factors and work environment perspectives into production and technical development processes to make mining safe working place.



WP 4 – Particle t

E. Petropova, A.-C. Larsson, K. H. R.

The research in Particle Technology is divided into the multidisciplinary character: Mechanisms of flotation, Mechanisms of comminution.

Competence in Mineral Processing, Chemistry of Interf. combined to reach the highest possible scientific level.

In all projects, a combination of carefully designed techniques, and modeling will be used. To ensure it, flow from model systems will be verified or replaced mineral systems.



- Comminution
- Flotation
- Agglomeration

Fig. 1. Particle technology.

1. Mechanisms of flotation:

Selectivity and recovery of mineral particles in flotation of iron oxide and sulphide ores can be improved through a deeper understanding of the molecular interactions taking place during the adsorption of flotation chemicals on mineral surfaces.

In order to understand the complex interactions between the mineral surface and the flotation chemicals, the research will be carried out in a multidisciplinary way. The research will include FTIR-spectroscopy with ex-situ and in-situ FTIR-spectroscopy and FTIR-spectroelectrochemistry, XPS, solid-state NMR, and theoretical ab-initio quantum mechanical calculations.



Fig. 2. Thin film of synthetic ferrite on a ZnSe substrate for in-situ adsorption studies using FTIR-spectroscopy.

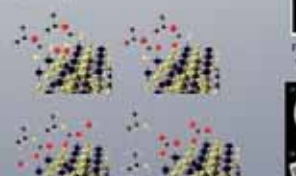


Fig. 3. Schematic illustration of sulphate adsorption after adsorption on synthetic FeS₂. Zinc ions (Zn²⁺) can be used to identify different species of adsorption obtained on a mineral surface.

3. Mechanisms of comminution:

The goal of the project is to enhance understanding of improved comminution systems and more efficient reduction and mineral liberation.

**WP 5: Green Mining – Reducing the
Environmental Footprint**

B. Öhlander, L. Alakangas, C. Maurice, A. Widorlund, F. Ecke, S. Knutsson and T. Edeskär, LTU

There has been a tremendous development of reducing the environmental footprint of mining, but the environmental effects of mining may still have detrimental effects on soil, water and biota. The mining industry is a major energy consumer. Leaking of the tailings bearing mine waste, which can last for hundreds or even thousands of years. Therefore, such deposits are considered globally, apart from the major aim to reduce the amount of oxygen and water reacting the surface in the waste. The most common method is to apply a cover of soil cover on the waste to prevent it with water.



The treatment area at LKAB's Kiruna mine, with water treatment tanks and settling.

Soaking layers are usually constructed by using a natural soil. It is however generally thought that the function of such conventional soil covers is reasonably well understood, but there is an urgent need of research on the use of alternative materials such as industrial and municipal wastes for mine waste remediation. This would solve two problems at the same time, and soil and fill quarrying would decrease.

Can construction is very important for mine waste management both during production and after mine closure.

Water and air from mine also often have considerably higher concentrations than background values. The environmental effects and the extent of natural removal of the nitrogen in mine-water requires are unclear.

Sulphate-bearing mine waste may generate ARD with release of heavy metals into the environment is also a natural process, and environmental effects of man-made materials from mining operations should be assessed in relation to the natural weathering and release of metals from different rock and soil types.

Together with Göteborg AB, LKAB and other industrial partners, these issues are covered in CAMM WP 5. The research is divided into three sub-projects:

1. Remediation of mine waste deposits, and prevention of formation of ARD. The research plans involve studies of the use of alternative wastes, waste from wood and paper industries, waste from other industries, storage sludge, and construction of these materials, by construction of soaking layers and so on. Applications such as prevention of sulphate on reactive minerals such as pyrite by coatings.

An innovative suggestion that will be tested in this sub-project is mineralization. The remaining tailings must naturally be sufficiently low in Fe-sulphate that direct distribution will not be environmentally hazardous.



ARD at the Gällvare mine, Sweden.

2. Construction of mine dams:

Important research questions are:

- What type of material can resist seepage without getting internal erosion during these very long time periods?
- Does a given material have a maximum value for the hydraulic gradient in order not to get internal erosion?
- If a maximum value exists, how can this be determined?
- How can safety be described and assessed during the these very long time periods?



Sketch of water covered tailings. Illustrating the importance of the dam construction as well as of the complex groundwater.

3. Natural metal release in mineralized areas:

The planned research aims at understanding in detail the complex interactions between weathering release, distribution, transport, attenuation and application of metals from natural metal sources as well as from mine sites.

Included in this sub-project are also studies of release of nitrogen from mining areas. The main goals are to quantify the environmental significance of nitrogen effluents from the mining industry in relation to the natural load of nitrogen in streams and rivers, and to improve the possibilities to reduce effluents of nitrogen through efficient water management.



Water management at the Gällvare mine.