MiMi

Mitigation of the environmental impact from mining waste

Programme plan for the period 2002-2003

Mitigation of the environmental impact from mining waste

Photo: Lars Olof Höglund

November 2001

ISSN 1403-9478
ISBN 91-89350-17-0

A MISTRA FUNDED RESEARCH PROGRAMME

MiMi

Mitigation of the environmental impact from mining waste

Programme host

Luleå University of Technology
971 87 Luleå

Publisher: MiMi Print, Luleå

Cover photo by Lars Olof Höglund:
Surface runoff from till covered tailings,
Impoundment 1, Kristineberg mine, Northern Sweden.

ISSN 1403-9478
ISBN 91-89350-17-0

For more information please contact:

Lars Olof Höglund, Programme director
Kemakta Konsult AB
P.O. Box 12655
112 93 Stockholm
SWEDEN

Phone: +46 8 617 67 17
Fax: +46 8 652 16 07
E-mail: loh@kemakta.se

Contents

Vision

Twenty years from today the mining industry in Sweden is still strong and flourishing, using technologies that are internationally competitive and environmentally acceptable. The environmental standards are set high, since most of the ore deposits and mining activities are situated in sparsely populated areas with a very sensitive nature of high ecological and recreational value. Applying economic methods for processing and reuse of waste products, the release of heavy metals from waste deposits is kept low, the impact on the environment is small and restricted to the close vicinity of the mining areas. Methods used for waste disposal and remediation are efficient, robust and reliable so that, when any remediation is completed, a deposit can be left without the need for supervision or maintenance.

The MiMi programme has made it possible to predict the extent of environmental impact and has provided tools and methods to control and design processes and waste treatment systems already from investigation of the mineralogical and chemical composition of the ore and the wall rocks, and the local hydrology and topography. Furthermore, it is possible to design cost-efficient treatment systems for existing deposits of mining waste.

Preface

MiMi (Mitigation of the environmental impact from mining waste) is a multidisciplinary research programme devoted to development of safe methods for remediation of mining waste and reliable prediction of the long-term function of the disposal sites. MiMi was funded for a first phase (1998-2000) by the Swedish Foundation for Strategic Environmental Research (MISTRA) with contributions from the Swedish mining industry. The programme is now in its second and final phase (May 2001-December 2003).

The programme consists of six projects, each focussing on studies of specific remediation methods. Significant efforts have been made to strengthen and vitalise the scientific input in synthesis work and co-ordination. To this end, an operative scientific advisory panel has been appointed. A new method for the synthesis work will be applied for the second phase, based on the performance assessment methodology, which has been successfully applied to disposal of radioactive waste and toxic mercury waste. The work within Performance assessment has been organised as a project, integrating the different parts of the programme. Significant resources have also been allocated to strengthen the work in the field of microbiology.

This programme plan is a steering document, which describes the work planned for the second phase of MiMi, and in further detail the specific work planned for the year 2002.

1 Background

1.1 Introduction

Today, Sweden is the leading metal producer within the EU1. A large share of Europe's iron and metal ore resources and mines is in Scandinavia. Significant mineral exploration is currently taking place in Sweden, opening new possibilities for future mining operation. In a European perspective, the security of metal supplies and the long-term protection of the environment are prioritised areas.

Future exploitation of ore reserves identified during exploration demands knowledge that enables internationally competitive mining operation, with due consideration of increasing environmental demands. Mining operations generally require large areas of land, however, and associated conflicts arise that are primarily related to competing land uses, fugitive dust, vibrations and inevitably, large amounts of mine waste. This waste needs to be managed using principles that control the environmental impact in both short and long term, as well as meet the safety requirements on the deposits over long periods of time. Finding appropriate methods to solve the problems related to mine waste disposal is a prioritised research task, which is addressed by the MiMi programme. While a certain impact on the local environment by disposal of significant amounts of mine wastes within the mine site is inevitable, the impact on the surroundings needs to be negligible. This puts high demands on the management of the mining operation, as well as on the use of appropriate methods for waste disposal and remediation. A factor of particular importance is the need for methods that ensure safe disposal over very long periods of time.

To meet this demand, a research programme is required to establish the necessary scientific and technical basis for mine waste disposal and remediation. The purpose of the MiMi programme is to provide this basis.

The strategic importance of the mining industry for Swedish society has been recognised in a recent forward-looking study presented by the Swedish Academy of Engineering Sciences (IVA, 2000).

1.2 Achievements during MiMi Phase I

The initial phase of the MiMi programme has established a research organisation consisting of several scientific and engineering specialists working together on a common task. A common field site has been selected, the Kristineberg mine, and a field-monitoring programme has been established and maintained. A number of research students have been recruited. During Phase I, one PhD thesis and three licentiate theses have been presented and publicly defended.

State-of-the-art reports have been produced on a number of important areas. In addition, scientific results have been published in peer-reviewed international scientific journals, as well as at international conferences.

The network of researchers, engineering specialists and industry representatives established during Phase I, provides a platform necessary for the work in Phase II.

---

1 (2000): *Iron 95 %, 1st; Silver 66 %, 1st; Lead 46 %, 1st; Copper 41 %, 1st;*
Zinc 26 %, 3rd after Ireland and Spain; Gold 20 %, 3rd after Finland and France

Soil Covered Tailings

Detailed studies on Impoundment 1 in Kristineberg show that the soil cover is efficient with respect to limiting the oxygen intrusion. Any remaining oxidation is now occurring under dysoxic conditions, possibly with Fe^{3+} as oxidant. A diverse microbial community that may play a role in this context has been observed. An extensive study of the groundwater geochemistry indicates that the rate of sulphide oxidation has decreased, but that it will take another 5-10 years until the overall groundwater quality has been improved. A raised groundwater table results in wash out of weathering products retained in the tailings. Hydraulic conductivity tests on compacted low permeable till barriers indicate that their efficiency is very sensitive to compaction during construction. Repeated freezing and thawing also indicate that such barriers may be affected by frost action, if not protected by a sufficient cover. Furthermore, modelling results show that deterioration or quality variations in a low permeable barrier may have a significant effect on the overall intrusion of oxygen.

Water Covered Tailings

One method to limit the supply of oxygen to mine waste is to cover the waste with water. Flooding by raising tailings impoundment dams is an important remediation method. Detailed geochemical studies of the flooded, sulphide-rich tailings at Kristineberg and Stekenjokk show that flooding is an efficient method from a geochemical point of view, and that there is little leakage of metals from the tailings to the pond water. Washout of old weathering products may, however, be a problem for water covering old waste. At Kristineberg, the flooded pond is limed and functions as an efficient trap for metals released from upstream impoundments. If flooding should be a real walk-away solution, long-term dam stability is critical. The high pH in the limed pond has a strong inhibitory effect on bacteria, whereas nutrients are not lacking. If plants are established in a pond, the water depth may be shallower than otherwise. Introductory studies show that it may be possible to establish vegetation in flooded impoundments. Studies of metal uptake show that different species have very different metal accumulation capacities.

Biogeochemical Barriers

A pilot - scale barrier system has been installed for the treatment of groundwater discharging from Impoundment 1, and has been monitored at regular intervals. Analyses of treated water indicate that acid neutralisation is proceeding as expected. However, the maintenance of a viable population of sulphate - reducing bacteria has proved to be difficult, probably because of the relatively low water residence time in the system. Laboratory experiments, nevertheless, have yielded encouraging results and demonstrate that by reducing water flow in the field system and by inoculating with bacteria, it should be possible to maintain a population of sulphate-reducing bacteria for an extended period of time.

Co-disposal Technique

Full-scale pumping tests with tailings and crushed waste rock have shown that drained deposits with inherent stability and natural landscape forms can be achieved. However, co-disposal including pumping of waste rock was not economically competitive to traditional disposal techniques. Pilot scale tests with co-disposal utilising traditional transport methods have shown favourable results with regard to stability. However, the retention of tailings sand in coarse waste rock structures needs to be improved.

Wetlands as Metal Traps

A field-monitoring programme was established to study metal removal in the wetland system down - gradient from Impoundment 4. Results from this study demonstrated that water flow in the wetland system is highly channellised, with a major fraction of the metal flux concentrated during snowmelt when the wetland is still frozen. Little metal precipitation occurs in the wetland sediments. Metal attenuation in the wetland is due primarily to dilution, while increases in metal concentration can be attributed to metal sources in mineralised regions of the catchment area. A conclusion of this study is that the studied wetland system is inefficient for capturing metals, but that a constructed wetland may be properly designed for sufficient water treatment. A method was developed for the determination of aqueous metal complexes with organic matter, and indicated that copper, for example, occurs primarily in complexes with natural organic matter.

Surface Water Systems

Particles play a significant role in the distribution of metals in surface waters within the mining area and in the recipient (R. Vormbäcken). The particulate phase consists of organic and inorganic matter, such as secondary iron precipitates formed by oxidation of ferrous iron, with particle sizes ranging from colloids (<0.22 µm) to suspended solids. The uptake of contaminants to particles is determined by the chemical conditions. Association of contaminants with particles forms a potential basis for utilisation of natural attenuation processes in active as well as passive treatment systems. It was estimated that, under optimal conditions, the adsorption capacity of the secondary iron precipitates is sufficient to immobilise a significant fraction of the heavy metals released by sulphide weathering.

2 Problem Description and Structure

While mine waste-related environmental problems and required remediation techniques may be complex, the fundamental source of these problems is simple. The key issues that are the root of these environmental problems are:

- Mine waste often contains metal sulphides
- Sulphides oxidise when exposed to oxygen and water
- Sulphide oxidation creates an acidic metal-laden leachate water
- Large amounts of waste result in leachate generation over long periods of time.

The primary consequence of these key issues is that the applied prevention and control methods must have a very long functional lifetime. Furthermore, the methods used for the construction of waste deposits with covers and dams need to result in stable structures. The crucial question for the disposal of mining waste is to demonstrate in a solid scientific - technical way the effects of the selected prevention and control actions over very long time periods. In this context, the relevant time scales are on the order of hundreds or even thousands of years.

Also for mine wastes that do not contain sulphides, like tailings from iron oxide mining, the long-term stability of waste containment, is a critical factor.

In order to demonstrate that the effects of selected remediation methods are viable over very long periods of time, different prediction tools are required. Two types of tools are necessary for this: –experimental methods to characterise the waste material, – and quantitative models for predictions of metal release and transport over long time periods.

Data and Predictions

Performance assessment studies for the final storage of radioactive and other toxic wastes have addressed similar questions for decades. The application of a simple, but robust methodology, based on fundamental and well-established scientific principles such as thermodynamic and mass-balance approaches, has been very successful. Thus, the same basic concept has been found appropriate as a working methodology for the synthesis work during the second phase of the MiMi-programme and will be further detailed in Chapter 5. The basic problem formulation can be divided into three parts, *i) the Source term*, *ii) the Near field*, and *iii) the Far field*, as illustrated in Figure 2.1.

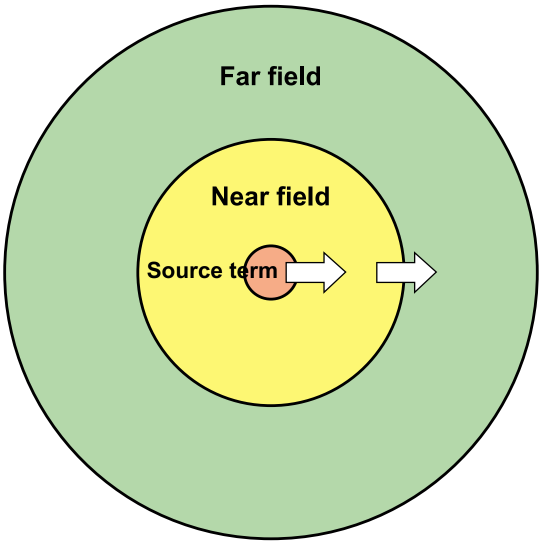

Figure 2.1 Illustration of the propagation of mobilised metals from the source term to the far field.

The investigated problem can be conceptually simplified to: *"by reducing the amount of leachable metals in the source term, and by reducing the inflow of oxidants in the near field, we can thereby decrease the metal release rate. In addition, metals and acid that do escape from the near field are retained in the far field by accounting for the capacity of natural attenuation processes."*

The *Source term* concerns different aspects of the waste that is produced, such as the amounts and characteristics of the waste, the possibilities to alter its chemical and mineralogical composition, and different aspects of the reactivity of the waste.

The *Near field* covers all aspects of the waste deposits and the engineered barriers. The fundamental remediation approach for the near field can be denoted *passive prevention*, i.e. methods applied to preclude oxidation of the waste and thereby avoiding subsequent problems. Critical questions include the mobilisation of metals from the waste, the longevity and sustained function of the cover layers and of dam constructions built to confine the waste and to prevent oxygen from reaching the waste.

The *Far field* comprises the area outside the constructed deposits that receives drainage water from the deposits. It is important to understand and be able to quantify different natural attenuation processes in the far field for the assessment of the environmental impact of a constructed deposit. Studies of the far field also include different *passive treatment* methods for mine drainage water that can be efficient in combination with the containment methods applied in the near field.

Studies will be undertaken within the MiMi programme on the feasibility of different methods to reduce the source term strength and to mitigate the release of contaminants from the source term and transport in the near-field, as well as exploration of the possibilities to increase the natural attenuation in the far field. Figure 2.2 gives a schematic illustration of the origin of acid mine drainage and various treatment options at a mine site. It is obvious that the use of integrated system solutions for reclamation of complex mine sites is an important application that must be studied in a holistic way.

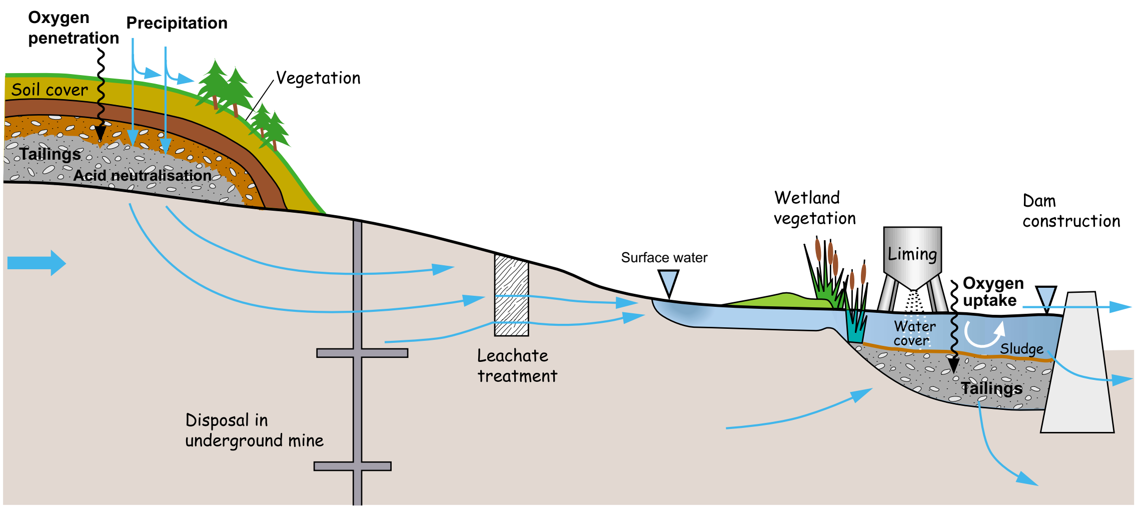

Figure 2.2 A schematic illustration to causes and remedies for generation of acid mine drainage studied during MiMi Phase II.

3 Program Goals and Deliverables

3.1 Programme Goals

The **overall goal** for the second phase of the MiMi programme is:

> ***To devise methods for the safe disposal of mining waste and for the reliable prediction of their function over very long periods of time.***

In order to achieve this goal, the research activities will focus on the following main tasks:

I. *To develop scientifically sound conceptual models as a means to understand the importance of different processes in disposed mine tailings and in the far field.* The conceptual models should serve as a projection of important processes and their interaction, thereby increasing the scientific comprehension. The development of conceptual models requires input from multidisciplinary research.

II. *To devise methods for characterisation* of the disposed mine tailings in *order to define basic measurable input data* necessary for *the performance assessment* of the function of different disposal methods *over long periods of time*. When required, ideas for improvements of techniques and characterisation methods will be explored.

III. *To use studies of natural analogues to evaluate the importance of processes acting over long time-scales*, inaccessible by experiments and other means of observations, with the purpose to apply the findings to mine waste disposal.

IV. *To apply a performance assessment methodology for reliable long-term prediction, based on a synthesis of conceptual models, data acquired by characterisation of the disposed tailings, and studies of natural analogues*. The performance assessment methodology, based on solid scientific methods such as thermodynamics and mass-balance approaches, has proven to be suitable and robust for analysis of complex systems. It provides the possibility to focus on the most important issues, and can act as tools for quantification of the long-term function of different disposal methods. It has thus been judged an appropriate methodology for the second phase of MiMi.

V. *The training of PhD students* and the involvement of *senior researchers and engineering specialists* acting as *carriers of competence*, as well *as established technical and scientific networks*. These will all *contribute to fill the future competence needs* of industry and society, and *to assure appropriate implementation of results*.

3.2 Programme Deliverables

The following deliverables are planned for MiMi´s second phase:

- A methodology will be presented for performance assessment of mine waste deposits suitable for evaluation of the short- and long-term function of selected remediation methods.
- Conceptual models will be presented, reflecting the increased understanding of the function of different remediation methods, focussing on important biogeochemical and physical processes in the near field.
- Conceptual models will be presented, reflecting the increased understanding of the function of different methods, focussing on natural attenuation processes in the far field.

- A toolbox of simple and robust quantitative models will be presented, based on the formulated conceptual models, suitable for addressing the short- and long-term function of selected remediation methods for mine waste.
- Co-disposal techniques of tailings and waste rock will be demonstrated in large-scale applications, and an evaluation of the feasibility for different applications will be presented.
- The feasibility of low-maintenance methods for short- and medium-term leachate treatment in the far field will be evaluated.
- Criteria for applicability for different methods aiming at stimulation of natural attenuation processes in the far field will be determined.

To build general knowledge, appropriate scientific resources and related infrastructure and networks for industry and research organisations, the following deliverables are planned for:

- Six PhD theses and six Licentiate theses will be presented.
- The research results will be presented in peer-reviewed international scientific journals, as well as at international conferences. The achievements of the MiMi programme during Phase I will be presented to the end-users and the research community at the international conference "Securing the Future" held in Skellefteå in 2001. MiMi is represented in both the organising and the scientific committees.
- Scientific and technical networks established among the researchers, engineering specialists, representatives from the industry and the authorities, will be strengthened and expanded by participation in different activities on the European Community level. Thereby, the MiMi programme will provide a platform for future research, technical development and development of regulatory policies within the mining area.

Current status of progress

Deliverables	**Status**
A methodology will be presented for performance assessment of mine waste deposits suitable for evaluation of the short- and long-term function of selected remediation methods.	A draft methodology has been worked out, with emphasis on the long-term issues.
Conceptual models will be presented, reflecting the increased understanding of the function of different remediation methods, focussing on important biogeochemical and physical processes in the near field.	A draft conceptual model for a Base case has been developed for different near field situations.
Conceptual models will be presented, reflecting the increased understanding of the function of different methods, focussing on natural attenuation processes in the far field.	A draft conceptual model for a Base case has been developed for different far field areas.
A toolbox of simple and robust quantitative models will be presented, based on the formulated conceptual models, suitable for addressing the short- and long-term function of selected remediation methods for mine waste.	Present focus is on long-term function. Both simple and more complex model tools are currently used.
Co-disposal techniques of tailings and waste rock will be demonstrated in large-scale applications, and an evaluation of the feasibility for different applications will be presented.	Large-scale tests are currently progressing.
The feasibility of low-maintenance methods for short- and medium-term leachate treatment in the far field will be evaluated.	First tests completed. Additional tests under planning.
Criteria for applicability for different methods aiming at stimulation of natural attenuation processes in the far field will be determined.	Work initiated.

4 Technologies and Methods Studied – Open Important Scientific Questions

A selection of remediation methods is currently studied, of which some are in common use in full-scale applications in Sweden today. The practical experiences of these methods are satisfying and the Swedish know-how of their application is in world-class. However, in view of increased demands to understand the development and consequences over long time periods, a number of open questions exist regarding the fundamental understanding of the function of these methods. The development of a methodology, to understand and predict the long-term effects of the selected remediation methods on the release and transport of metals, is therefore reflected by the overall goal of the MiMi programme. The approaches taken in the programme also comprise studies aiming at reducing the source term strength and methods to increase the inherent geotechnical stability of waste deposits and dam constructions.

Source Term – Strength Reduction and Pre-Treatment

During mining operations, various treatment options exist that can influence the amounts and properties of the disposed waste. This may be achieved, for example, by withdrawing sulphide-rich fractions from the wastes and depositing them in the excavated mine for underground storage. Further, the potential source strength of the waste may be changed by pre-treatment of the waste, e.g. by bioleaching of certain sulphide-rich fractions. Such possibilities are scrutinised and evaluated during the second phase of MiMi.

Examples of open scientific and technical questions of importance for the second phase of MiMi are:

- Which types of waste have the capacity to cause an environmental problem?
- What possibilities exist to control the amount of highly reactive waste that needs to be disposed selectively?
- Can pre-treatment of the waste be used to reduce the waste reactivity, and thereby reduce the future environmental risks?
- How can a system approach be applied to improve the overall economic and environmental performance for a mine site in the short and long term?

Near Field – Design, Function and Disposal Techniques

Passive prevention methods are applied in the near field and aim at reducing the primary release of metals from the waste material by minimising oxygen intrusion into the waste and by reducing the water flow rate through the waste. The passive prevention methods must be designed to be efficient over very long periods of time and, therefore, mechanical integrity and resistance to different degradation processes such as weathering, erosion etc must be ascertained. Two methods for passive prevention, soil covers and water covers, are commonly being used today in Sweden, as well as world-wide. Soil covers are generally more expensive, whereas flooding is limited to areas where the local topography and the hydrogeological conditions are favourable. Studies of these methods constitute a central part of MiMi, where particular emphasis is put on methods for prediction of the long-term functions with respect to metal release and transport and properties of the applied covers and dam constructions.

In a different technical area, significant knowledge and experience have been gained through large field experiments carried out during the first phase of MiMi to improve the disposal methods for low reactivity mine waste, i.e. waste from iron ore production. In particular, treatment through the co-disposal of tailings sand and waste rock suggests interesting future developments in disposal techniques with inherent geotechnical stability; these methods will be studied during the second phase of MiMi and the possibilities to use them for sulphide bearing waste will be evaluated.

Examples of open scientific questions of importance for the second phase of MiMi are:

- How can we assess and predict the long-term function of the deposits? How is the generation of acid mine drainage affected by changes in the environmental conditions, such as oxygen availability, water saturation, and water flow rate in wet- and dry-covered tailings impoundments? How effective are the methods to prevent oxygen intrusion on short and long term? How long time will be required before the applied methods become effective?
- How stable are the cover and dam constructions over time, considering possible long-term effects, such as frost penetration, root intrusion and climate changes?
- When sulphide oxidation is limited by O_2 availability, such as under a saturated tailings cover, will O_2 continue to play a dominant role in sulphide oxidation, or will other oxidants (e.g. Fe^{3+} or nitrate) prevail? Are there variations in the spatial and temporal distribution of iron- and sulphur-oxidising bacteria in a tailings impoundment, and if so, are these variations related to the geochemical, hydrological, and/or physical characteristics of the tailings?
- Establishment of vegetation in shallow ponds may result in the formation of a sediment layer rich in organic material on water covered tailings. To which extent will decay of this organic matter further reduce the oxygen flux, and will the changes of the physiochemical environment caused by the organic matter be positive for metal immobilisation?
- How stable over time are the secondary minerals, formed due to weathering and precipitation, as well as by treatment of drainage waters? What is the fate of the trace metals associated with these secondary minerals?
- The washout effect of metals and other elements when oxidised waste is covered with water is probably important, but can it be quantified?
- The geochemistry of pit lakes is not yet understood in detail. Can they be used as recipients for acid mine drainage and for disposal of sulphide-bearing waste?
- Which fundamental processes govern the function of drained co-disposal structures? Can generic criteria for design of such deposits be set up?
- Can co-disposal techniques be applied to sulphide bearing mine waste? Would such techniques be feasible for heap-leaching of certain waste streams?

Far Field – Leachate Treatment and Natural Attenuation

Design of the Near Field can aid the attenuation in the Far Field. To some extent, the Far Field can also be engineered for enhanced function. Leachate may be intercepted by different barrier methods applied in the downstream groundwater zone. Further, it may be possible to devise ways to create self-sustaining natural systems that provide means for metal attenuation in the far field area. During the second phase of MiMi, studies are undertaken of such biogeochemical treatment systems, including reactive barriers, constructed wetlands and manipulated pit lakes.

Natural attenuation processes govern the balance between transport of metals and retention in the far field. Some of these processes may be very important for overall metal transport in the long-term perspective and metal availability in the recipient system; these processes are therefore of primary importance in determining the environmental effects of the leachates released from the near field area. Examples of such natural attenuation processes that are studied during the second phase of MiMi are the adsorption of metals by secondary iron precipitates and the chemical speciation of metals in waters rich in humic acids, as well as their binding to peat soils.

During MiMi Phase I, it was demonstrated that metals in surface waters in the Kristineberg area to a large extent are associated with organic and inorganic particles. Associations with secondary minerals, above all iron-containing phases, are here considered to play a significant role. It was also shown that the retention of contaminants in the downstream River Vormbäcken area is not significant. The large quantities of dissolved iron (Fe(II)) present in the waste leachates may be utilised in a passive treatment of groundwater and surface water discharges. Such a constructed structure can form an integrated component in a system of passive prevention and passive treatment measures. Examples of open scientific questions of importance for the second phase of MiMi are:

- How reliable is natural attenuation? Can it be quantified?
- Which geochemical and physical conditions are optimal for an effective attenuation of metals by particle formation under oxidising conditions, association of contaminants to the particulate phase, aggregation and particle retention by sedimentation?
- How effective is the attenuation provided by a passive treatment system on a long-term basis?
- How can the transport and attenuation of metals be manipulated?
- Can a wetland be constructed for the effective treatment of mine leachate in a cold climate? Can the performance of a passive treatment system be enhanced by a final treatment in a wetland (natural or constructed)?
- Can pit lakes be used for collection of leachate water and can the biogeochemical conditions be manipulated to create an efficient trap for metals and acidity? Is the functional life-time long enough to allow up-stream passive prevention methods to become effective?

5 Performance Assessment

The prediction of the environmental impact from mining waste over long periods of time is complex and requires an integrated approach, with due consideration to multiple and interacting processes, e.g. chemical, microbial, physical and mechanical processes. The performance assessment methodology has been developed to handle such complex systems and has been shown to be reliable.

Performance assessment is a methodology developed by researchers in the area of radioactive waste management. The primary question addressed here is: *How can we assess the performance of a proposed disposal design over a period of time that by far exceeds the period for which experimental evidence can be provided?*

The approach relies on basic and well established scientific knowledge, such as found for thermodynamic processes in combination with mass-balances, to scrutinise the function of a proposed design from any possible angle, successively increasing the complexity of the addressed issues when found necessary. In essence, the Performance Assessment uses a toolbox of conceptual and mathematical models that describe and quantify the main processes that govern the release, transport, as well as the chemical and biochemical reactions of the contaminants in the whole chain from the Source term to a final recipient. Such a methodology can be used to study how changes in for example design of the Near Field influences the final release. It also allows the identification of crucial mechanisms and design issues. To support the evaluation of the long-term effects of different processes, studies of natural analogues can give valuable additional information. In Sweden, many quaternary geological formations such as dense till formations and sulphidic clays, as well as weathering of massive sulphide rocks, are available that can give valuable information over periods of 5 000-10 000 years.

The intrusion of oxygen in the deposits will inevitably cause an oxidation of the sulphide minerals in the waste. If the deposit is large, the oxygen intrusion rate will, therefore, most likely determine the overall oxidation rate. Thus in this very simple case the overall reaction rate can be assessed from the oxygen transport rate.

The presence of significant amounts of oxidised iron compounds in the waste may act as oxidants of the remaining sulphides. Oxidised iron compounds may form due to accumulation of reaction products of previous weathering of the waste material or may be present as natural components of the mined rock. Microbial catalysis may be expected to play an important role in such systems. The total amount and potential impact of oxidised iron compounds in the waste needs to be assessed. This is particularly important since the presence of oxidised iron compounds in the deposits can not be influenced by existing remediation methods in the same way as the oxygen intrusion without excessive costs.

It is important to describe the studied systems in a clear and transparent way to make it possible to distinguish between significant and negligible processes. Such evaluations also need to be made at different times. For a mine waste deposit three different stages are of interest:

- The operational stage (e.g. during the first decades)
- The short – mid-term stage (e.g. within the first hundred years after closure)
- The long-term stage (i.e. hundreds to thousands of years after closure)

The MiMi programme has its main focus on the long-term stage, although the short- and mid-term stage will also be addressed. A systematic approach to address the complex interaction of different processes can greatly facilitate the performance assessment work. One method developed for performance assessment is the so-called interaction matrices used to assist in structuring and documenting the work needed for establishing conceptual models of complex systems. The method is also suitable for keeping record of priorities given to different processes, as well as documentation of the underlying scientific basis. The interaction matrix method can also be used as a platform for studies of the impact on the function of studied remediation technologies by changes in the design, as well as changes of the external conditions, e.g. changes of climate. Systematic studies of such changes are commonly denoted scenario analysis, which is an integrated part of the performance analysis. The use of e.g. interaction matrices provides a structure to formulate and document reasonable scenarios.

By the performance assessment approach, a successive development of the conceptual understanding and quantification of a complex system is enabled. An illustration of a simple conceptual model for a mine site where a system of remediation methods has been applied is presented in Figure 2.2. The experience from radioactive waste management in using this methodology has shown that it is an effective pivot for synthesis of research results and for identification of critical tasks which need further scientific research. This can create a dynamic research process where the performance assessment is used to set priorities for the research activities.

During the second phase of MiMi the performance assessment methods will be used as a methodology to carry out the overall synthesis work, to provide a tool box for evaluation of the studied technologies and methods and to provide guidance and priorities for the on-going research work. The performance assessment studies reflect the overall programme goal and constitute the core of the main task IV. The process is illustrated in Figure 5.1.

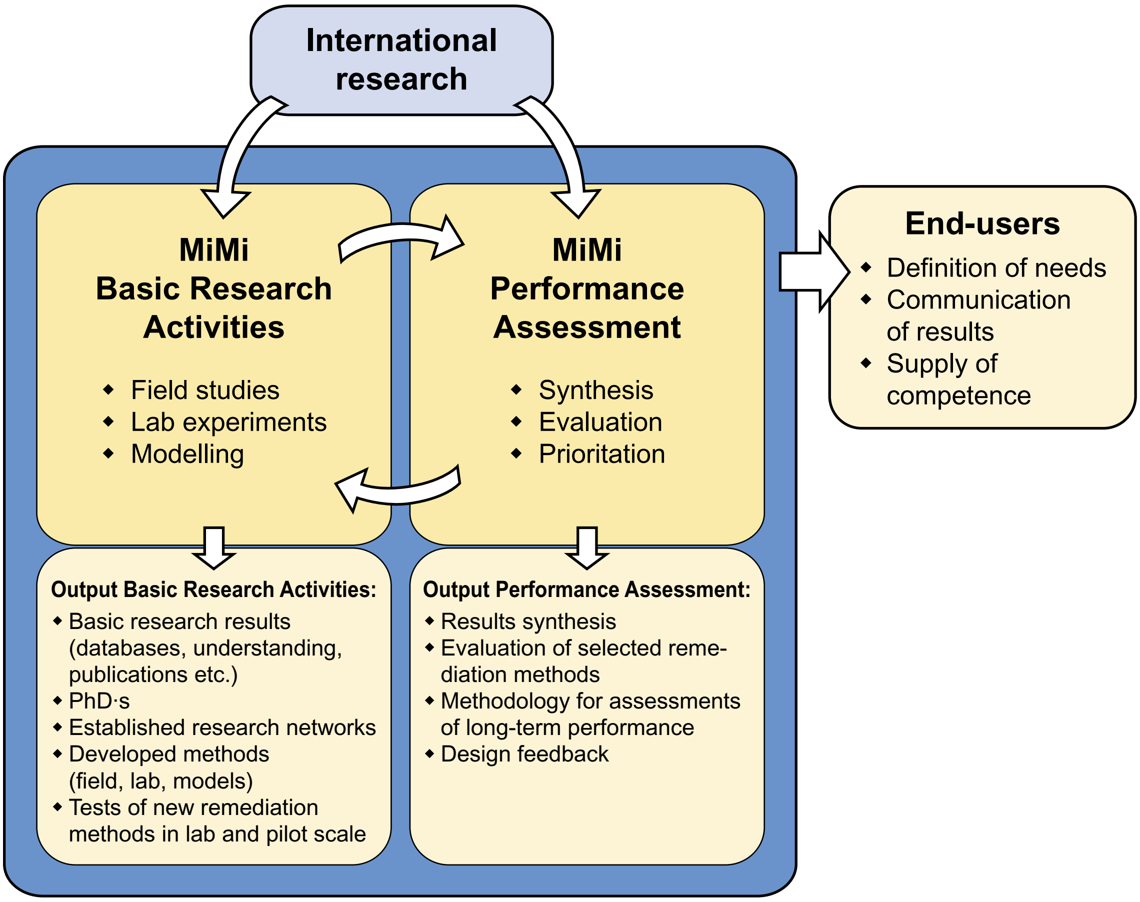

Figure 5.1 A systematic performance assessment methodology in the MiMi synthesis work will provide a toolbox for evaluation and guidance for on-going research work.

The performance assessment will involve all MiMi research projects in the different phases; to identify and document the processes judged important for the different technologies and methods studied, to establish conceptual models based on the scientific comprehension of the interacting processes, to set up simple mathematical tools to evaluate the importance of different processes, and to successively include additional processes in more elaborate prediction models. Whenever applicable, available models will be used for exploratory calculations. For specific needs, further developments and adaptation of the existing models may become necessary. At all levels of the performance assessment the models will be used to study the sensitivity to the fundamental assumptions, systematically testing alternative model concepts, as well as the sensitivity to uncertainties in the basic input data.

With its main focus on sulphidic tailings and long-term performance, a methodology for the performance assessment work has been developed which is briefly described below. For each of the studied remediation methods the continuous and recurrent methodology includes:

- A schematic description is made of the anticipated function of the studied method.
- A Base case definition is set up for each of the studied remediation methods. Only very basic features and processes are included in the Base case definition to ensure simplicity and transparency.
- Simple models, both conceptual and mathematical, are applied to study and to quantify the effectiveness of the method. Initial evaluations, process by process, are made for idealised conditions.
- Process descriptions are set up and interactions between processes are identified and documented in a structured way.
- The complexity is gradually increased by considering additional processes, as well as by accounting for process interactions.
- Throughout the evaluations, processes of quantitative importance should be pin-pointed, as well as the conditions for which they are of importance.
- Compare the quantitative performance assessments with field and laboratory observations, making use of identified deviations for refining and improving the understanding and for improving the system definitions.
- Use observations of natural analogues to address long-term processes and if possible for validation.
- Perform sensitivity calculations for different processes to study the impact on the overall performance.
- Apply and compare alternative conceptual and mathematical models, and when applicable alternative data sets.
- Apply a structured methodology, e.g. so called interaction matrices, to define scenarios, such as due to changed environmental conditions, and to document assumptions and judgements.
- Make predictions for the defined scenarios and synthesise the results and independent observations.
- Identify assessment results that provide important feedback in the design process for new and improved remediation techniques.

At this stage, draft base case definitions have been set up for the projects *Soil cover*, *Water cover*, *Biogeochemical barriers* and *Natural attenuation*. Initial assessments of some subsystems have been made and will be further elaborated in the continued work.

6 Projects

The practical scientific work of MiMi´s second phase programme will be carried out within a number of separate projects. The projects have been carefully developed in order to – together – provide the necessary input to a synthesised result reflecting the overall goal and the focussed main tasks. This will mainly be done through the integrated performance assessment work. Further, the projects are organised to assemble the necessary competence to address the open scientific questions identified during the first phase. The projects can be classified as three different types:

- *Studies focussing on issues related to the Source term strength reduction and pre-treatment*
  –Source term strategies –How to minimise the amounts and reactivity of the waste?
- *Studies focussing on issues related to the Near field design, function and disposal technology*
  –Soil covers – How to optimise and demonstrate the longevity of soil cover constructions?
  –Water covers – How to construct and demonstrate the longevity of dams and water covered tailings?
  –Alternative disposal techniques – How to construct inherently stable deposits?
- *Studies focussing on issues related to Far field attenuation*
  –Barrier technologies – What are the limits of applicability of different technologies for treatment of acid mine drainage?
  –Natural attenuation – How to stimulate and quantify the natural attenuation processes in the long-term?

In the following, brief descriptions of the six projects are given. The presentation is focussed on the goals, working hypotheses and deliverables during the second phase of the MiMi programme. Additional information, such as detailed work plans, personnel and project budgets, can be found in the Appendix.

Certain fundamental scientific studies are of common interest within the programme. To simplify the project structure and co-ordination, these studies have been allocated to two of the projects, the Soil cover project and the Far field attenuation project.

6.1 Source Term - Methods and Tools for Prevention and Source Strength Reduction

Proper source term management takes into account the properties of the material in every stage of the extraction, also considering every opportunity for reuse or safe deposition of intermediate products. Valuable information has already been generated during the exploration stage of a project.

Included in the source term approach is the evaluation of various pre-treatment options. Obvious alternatives are extraction of sulphide rich fractions and separate deposition of the inert material in facilities that require only limited protection measures.

In the process of developing sound source term strategies, methods for classifying and separate management of various fractions of waste will be addressed as well as new laboratory experiments to obtain data for estimation of the environmental impact of the produced leachate and secondary waste.

6.2 Near field - Methods and tools for optimised soil covers

The research activities within the project reflect the open scientific questions that have been identified regarding the efficiency of soil covers, and thus need to be investigated in order to provide the necessary scientific foundation for a performance assessment evaluation of this reclamation method. In accordance with this the project is organised in two sub-projects, *Design of soil covers for long term performance* (sub-project A), with the focus on formulating design requirements for physical integrity of constructed barriers over time, and *Sulphide weathering and the quantification of the effect of remedial activities and the role of bacteria* (sub-project B), with the focus on quantifying the effects of limiting the intrusion of oxygen, in terms of the generation of acid mine drainage.

The application of soil covers, most often including a low permeability barrier, has become an established reclamation method for decommissioned mine waste deposits in Sweden. The method aims at maintaining a high degree of water saturation in a zone in the cover, thereby decreasing the transport of oxygen and water infiltration into the waste. However, the response of the mine drainage – generating processes to an actual decrease in oxygen availability has not been thoroughly investigated, and hence remains uncertain. In the absence of oxygen, sulphide weathering may be controlled by microbial activity in combination with other oxidants that can be present in tailings and waste rock, such as ferric iron, nitrate etc. Large amounts of Fe^{3+} may be present as oxides due to pre-reclamation sulphide oxidation while nitrates can originate from undetonated explosives.

Within the project, studies are performed with the purpose of quantifying sulphide mineral weathering kinetics and the mobilisation of buffering substances at conditions relevant for remediated mine waste sites. This will include the quantification of oxidation rates at reduced oxygen concentrations with or without the presence of other oxidants than oxygen (e.g. ferric iron) for partly oxidised and unoxidised tailings, and the importance of microbial activity to these processes.

With a time perspective of hundreds to thousands of years, all constructions are subject to degradation processes that may pose a threat to their long time performance. Damage to the engineered soil cover barriers may lead to an increase in oxygen transport to the waste and a corresponding increase in metal discharge from the deposit. There are several processes that may be active and are very difficult to describe and predict. For Swedish conditions, two processes have been prioritised, namely frost penetration and root penetration in compacted low permeability barriers. In addition, the effect of potential climate change on the efficiency of covers needs to be considered. To assess the effect of these processes and formulate design criteria for soil covers with respect to their long-term performance, accelerated studies are performed in laboratory and compared to field results from the field site in Kristineberg as well as studies of natural analogues in northern Sweden.

6.3 Near Field – Methods and Tools for Optimised Water Cover

Water covers have been shown to strongly reduce the oxidation rates of sulphide-bearing mining wastes since the amount of oxygen reaching the waste is restricted to the oxygen gas dissolved in the water. Before the applicability of water covers as a remediation method is completely understood, it is necessary to study how the water cover affects weathering and transport processes in mine waste both in short and long term perspectives

Water coverage may be obtained by raising the dams of tailings pond (sub-project A), the most common method, by deposition of waste in pit lakes (sub-project E) and by deposition of waste in natural lakes (sub-project D). If water cover should be a real walk-away solution in the cases when dams are constructed, the long-term stability of dams is of utmost importance (sub-project B).

If plants are established in water covered impoundments, the pond may be shallower than without plants since the risk for resuspension of tailings decreases (sub-project C). Establishment of vegetation in shallow ponds may also result in formation of a sediment layer rich in organic material on top of the tailings, which may further reduce the oxygen flux.

6.4 Near Field - Alternative Disposal Techniques

The mining industry has for several years, worked with the development of alternative methods of transporting and depositing of tailings. The general objectives of this development have been to increase dam safety and to bring down the significant operational and investment costs of dam constructions.

At the Swedish iron ore producing company LKAB, pilot tests of co-disposal of coarse waste rock –60 mm and fine –4 mm tailings were conducted. The evaluation showed that the operation was not competitive to traditional transportation techniques mainly due to significant wear costs. The resulting co-disposal showed that the slurry stream formed a rounded moraine-like formation. The use of available volume was more efficient. In addition, it was concluded that if measures are taken in order to control the ground water level in the deposit, stable and high deposits may be created with this disposal method.

The promising properties of the co-deposited waste rock and tailings have encouraged work to achieve the advantages of co-disposal combined with traditional transportation techniques. The MiMi-programme and LKAB have, in co-operation, developed the concept of drained-cell disposal. After the initial pilot test during MiMi phase 1, further laboratory-scale and in pilot-scale test has been conducted during 2001 in Malmberget and in Kiruna. During 2002, a scientific evaluation of sedimentation and consolidation processes will result in practical design criteria for drained cell disposal. The result will also be used in an analysis of the cost efficiency of drained cell disposal in Kiruna. Full-scale production tests during winter condition are planned to investigate the influence of cold climate on the stability of the deposit.

This work will be done within the framework of the performance assessment work, to address identified open scientific and technical questions, as well as be tested in practical full-scale application.

6.5 Far Field – Development of Biogeochemical Barriers for Passive Leachate Treatment

The installation of soil covers on mine tailings impoundments reduces the diffusion of oxygen to the tailings, such that the rate of sulphide oxidation is greatly diminished. However, a number of years may pass between tailings deposition and reclamation, so that sulphide oxidation products may accumulate in the deposit. During the period prior to reclamation, and afterwards as the oxidation products are flushed from the deposit, complementary methods are needed to treat leachate that may discharge from mine tailings impoundments. Biogeochemical barriers may be designed and installed to intercept and remediate these waters, prior to discharge to surface water recipients. In this project, reactive barrier systems and biogeochemically – manipulated pit lakes will be studied for mine drainage treatment.

In 2002, laboratory and field tests will optimise the performance of the existing sequential treatment barrier system in Kristineberg. The use of pit lakes will be studied as a method to reduce metal transport from the near field to the far field. The primary goals of these sub-projects are to determine attainable treatment levels in biogeochemical barriers, and to predict the degree of contaminant retention as a function of loading to the systems.

6.6 Far Field – Natural Attenuation

Contaminants in mining waste leachates can be significantly attenuated from groundwaters and surface waters under oxidising conditions by the precipitation of secondary iron-containing phases capable of immobilising metals by adsorption and co-precipitation. An effective removal of the particulate phase by sedimentation can be induced by aggregation of colloidal particles, facilitated by increasing concentrations of dissolved ions. A method will be developed for the passive treatment of discharge water requiring a minimum of supervision and maintenance and utilising the sequence: particle formation, uptake of contaminants, aggregation and sedimentation. As a tool in the assessment of attenuation of contaminants, a quantitative model will be adopted combining biogeochemical and hydrological processes and as far as possible, integrating results from field and laboratory experiments.

This will be achieved by a combination of field and laboratory experiments addressing the different steps in the attenuation sequence individually and in combination, as well as development of a biogeochemical model coupled to a mass transport model. Furthermore, a pilot-scale settling-basin will be constructed to demonstrate optimal conditions for the retention of contaminants by association with a particulate phase, according to the sequence described above.

7 Management, Communication, Use of Results and Research Education

7.1 Management

The MiMi management structure follows the recommendations from MISTRA, see Figure 7.1.

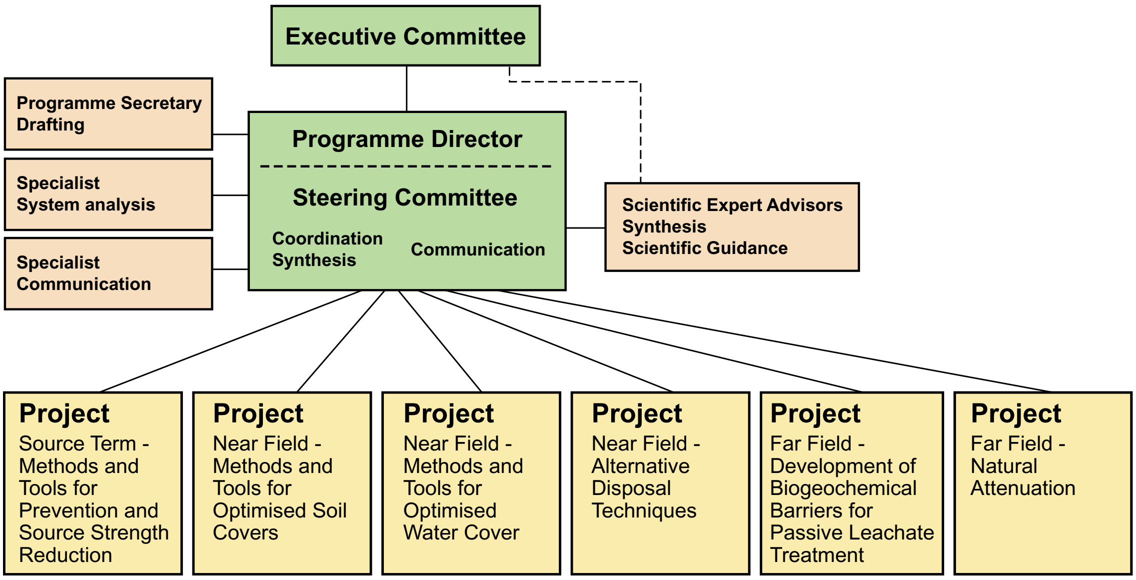

Figure 7.1 Management structure of the MiMi programme for the second phase.

7.2 Communication and Use of Results

MiMi is the largest integrated mining waste research programme running in Europe. Since the MiMi programme will result in scientifically based descriptions of short and long-term environmental consequences of different remediation strategies, MiMi will provide a foundation for a better understanding of the environmental implications of AMD prevention and control activities.

When planning for the finalisation of a programme the following questions should be addressed:

- How is the competence and skill, which has been cultivated and supported within the MiMi programme, best used in the future?
- How can the work be continued in other formats?
- How shall the results be best implemented?

The main deliverables of the MiMi programme may be assigned to following categories:

- Human capital, i.e. trained personnel with relevant knowledge and skilled researchers.
- Generic scientific knowledge, data and comprehension.
- Collaboration and established networks, both on personal and institutional levels.
- Technical solutions, developed methods, knowledge of relevance for legislation etc.

Main beneficiaries

End-users of the results of the research within the MiMi programme are the mining industry, the environmental authorities, consultants and research institutes. The research results may also be of great interest to scientists in other fields of research.

There exists a close working connection between the MiMi programme and the mining industry. The active participation of several industry representatives in the executive committee and in the practical research work is a manifestation of this. These industrial representatives ensure that the major issues addressed by the MiMi programme are both relevant and feasible.

Interaction with planned EU and Swedish directives and legislation

Owing to the increasing political interest in various issues concerning the mining industry, the MiMi-programme may also be an important source of balanced information for legislators in Sweden and within the European Community. To this end:

- MiMi is actively contributing to the preparation of a proposal for the new mine waste directive.
- The European Commission, through its Joint Research Centres, is currently developing a document on Best Available Technology (BAT) on mine waste management. The MiMi results would be an important contribution to this work.
- The implementation of the European water framework directive will underline the importance of the holistic management of drainage basins. Mine waste deposits need to be managed properly to avoid emissions of metals and acid drainage over long periods of time. MiMi results will point at the ability to predict and in time successfully mitigate emissions. It is the intention that MiMi results shall be used in the Swedish implementation of the European water directive.
- MiMi results will contribute to the assessment of the potential impact of mine drainage on the water quality in drainage basins, which has a direct bearing on the implementation of the water framework directive.
- The implementation of the MiMi results will aid in reaching the national environmental goals, particularly concerning water quality. Further, MiMi will provide necessary scientific knowledge and insights into the process of defining and establishing national environmental quality criteria.

Transfer of Results to End-Users - Communication of results

Multiple modes of communication with the identified end-users will be explored to ensure fast, efficient and correct implementation and practical applications of the research findings. Examples of channels for communication are:

- scientific publications and conference presentations
- newsletters to present recent findings both nationally and internationally
- annual reports will present the research results in a popular way
- synthesis reports will highlight interesting findings, improved understandings of the key processes and their interaction, and improved methods for remediation
- compilation of know-how regarding methodologies in fact sheets

- seminars and courses especially directed to the industry, the authorities and other interested parties
- a computer server will be used for communicating electronic information and publishing of updated information on the progress of the programme

The Swedish Mining Association organised an international conference during 2001 on environmental issues related to mining activities. The conference, *Securing the Future*, which was held in Skellefteå June 25- July 1, 2001, was very well received and a major manifestation of Swedish know-how within mine waste management and research. A follow-up is planned for 2005, at which time MiMi will be ended as a MISTRA programme. However, it is expected that the conclusions from the MiMi programme will be highlighted in a series of presentations at this conference.

A benefit of the MiMi programme is the continuous evaluation of the results achieved by putting them into the context of practical mine waste remediation. Such evaluation has only been possible due to the close collaborative work between academia, engineering specialists and personnel from the mining industry. For the second phase, this work would benefit from an increased involvement of the authorities.

To further strengthen the communication with the end-users, representatives from industry and authorities will be invited to consultations, at which the results from the performance assessment studies and the synthesis work will be presented and discussed.

Scientific and technical networks among the researchers, engineering specialists, representatives from the industry and the authorities is an important deliverable of the MiMi programme to society. The MiMi programme has the strategy to make use of existing and well functioning structures within the mining industry to communicate important research results, such as through the Environmental Committee of the Swedish Mining Association. By this, continuity is ensured in the mining research work, also extending beyond the scope of MiMi´s Phase II. Networking will also be further strengthened and expanded by participation in different activities on the European Community level, e.g. the Georange-project and the PIRAMID-project. Through this strategy, the MiMi programme will provide a long-lasting platform for future research, technical development and development of regulatory policies within the mining area.

How should MiMi´s achievements be carried forward?

MiMi´s vision for the future is to maintain competitive large-scale mining operations in Sweden while keeping the protection of the environment at the highest standards. In Sweden today, significant and increasing ore prospecting activities are taking place. In the last few years, this has resulted in feasibility studies for a number of potential new mines, of which a few have showed positive results that may lead to the opening of new mines. MiMi results will facilitate the opening of new mines in the future, to the benefit of Swedish industry, by ensuring a safe handling of the mining waste. This includes the understanding of different remediation methods, the prediction of long term pollution effects, a prioritisation of dam safety, and the training of personnel.

The demand for knowledge is still large, especially concerning the management of old and severely weathered and acid-producing mine wastes. Over the last 6 years, the MiMi programme has been a conglomeration of expertise within the area of mine waste research in Sweden. As MiMi approaches the end of operation, there is a risk for dispersing this integrated task force of unprecedented dignity in Sweden and Europe. Different ways to ensure the productive utilisation of this resource in the future may include various combinations of:

- Continued research activities within the Georange project;
- Engagement in research projects funded by the forthcoming European Union Sixth Frame Work Programme by various groups within the present MiMi organisation;
- Engagement of MiMi researchers in investigations of the ecological consequences of different mine waste management strategies as a basis for the establishment of national environmental quality criteria;
- Industry-financed projects for specific topics, possibly in collaboration with other funding organisations. The MiMi programme has the strategy to make use of existing and well-functioning structures within the mining industry to communicate important research results, such as through the Environmental Committee of the Swedish Mining Association. By this, continuity is ensured in mining research, beyond the scope of MiMi´s Phase II;
- Engagement in future studies of dam safety;
- Industry, authorities, academic researchers and consultants in various future investigations will use methodologies and results from the MiMi programme;
- Supply of human resources by means of trained personnel for industry, authorities, legislators, academic research and consultants.
- A planned follow-up of the Securing the Future conference. The conclusion from the MiMi programme should be summarised at the conference, although it is scheduled after finalising the programme activities.

One example of the continuation of the MiMi research is MiMi´s involvement in the Biometech project during phase 2. Biometech is expected to start its research activities during 2002. The Biometech research project is focussed on advanced process biometallurgy, mining and mineral technology, as well as mine waste treatment. Fundamental research will be performed at Umeå University and at Luleå University of Technology. The industrial testing and applied research will take place in the demo-plant at Biometech in Boliden. The research groups of Dr. E. Börje Lindström, Department of Molecular Biology, Umeå University and Dr. Åke Sandström, Division of Process Metallurgy, Luleå University of Technology, will be responsible for the fundamental and applied research at Biometech. The project will involve an international network of research expertise namely Prof. Douglas Rawlings, Stellenbosch, South Africa, Prof. Olli H. Tuovinen, Ohio, USA, Dr. Barrie Johnson, Bangor, Wales, and Prof. Geoff Hansford, Cape Town, South Africa.

However, a few generic remarks need to be emphasised regarding the importance of the MiMi programme. The MiMi programme results are partly specific to mining waste. However, the scientific basis for the programme, e.g. chemistry of toxic metals, their interaction with soils and subsoils, transport and fate of contaminants are to a large extent general in nature and can be used in other areas of contaminant transport. There are many sites in Sweden classified as being contaminated. The MiMi results can be expected to be useful for the assessment of their potential risks and/or remediation strategies. Very large environmental restoration projects are currently in progress in Sweden and many more are planned over the years to come. The need for synthesised knowledge is still large, in particular knowledge that can assist in bridging the gap between fundamental research and practical methods. Hence, many object-specific knowledge gaps can be foreseen within such restoration activities. The MiMi task force group would serve the purpose of a valuable resource in this area.

The MiMi programme is unique in that it has brought together experts from various fields. It has already attained considerable status as a productive research programme, and has aroused the interest of other researchers and programmes. It is well regarded internationally because it has integrated many of the key aspects of mining waste mitigation and because it is well founded on the underlying scientific principles. MiMi has shown that an inter-disciplinary research programme with well-defined goals and an integrated project structure can successfully address complex scientific questions. The programme management would therefore like to emphasise that a programme of this type could well provide the motivation for similar programmes to be formed to continue this type of work in related fields.

7.3 Training of Research Students

MiMi has an ambitious programme for training of research students, which will be of benefit for the industry and the society. Presently, MiMi engages twelve doctoral students, of which MiMi funds eleven and Boliden one. One PhD-thesis has already been delivered during the first phase. Considering these numbers, the MiMi programme is by far the largest potential supplier of highly qualified personnel within the field of mining environmental management for the industry, consultants and authorities over the coming years.

Research education and courses of general interest are open to all participants in the programme. Research students are encouraged to participate in research exchange on an international level.

During the second phase, advanced courses representing the frontline methodologies have been planned, with international authorities as lecturers. Whenever possible, exchange of courses with other MISTRA-programmes and EU-financed research projects will be encouraged.

Courses on advanced process biometallurgy, mining and mineral technology, as well as mine waste treatments are in demand. The Biometech project will offer international courses, which should underline environmental benefits of hydrometallurgy and the possibility for safe treatment of mine waste.

Thematic workshops will be arranged as part of the performance assessment and synthesis work, to which international experts may occasionally be invited as discussion leaders. This will give important opportunities for the research students to report and partake in the discussions on the ongoing research, as well as to establish international contacts. Additional workshops to discuss specific topics will be arranged for the research students.

The MiMi programme is encouraging the research students to present their results at national and international conferences. The research students are also encouraged to undertake visits to industries, authorities and other parties during their education. This will supply further opportunities for exchange of information and ideas, and for establishing personal networks both nationally and internationally.

8 Programme Budget

The budget covers the period 2002-01-01 – 2003-12-31. A programme reserve has been included to cover unforeseen future investigations.[2]

Project costs	2002	2003	Total
Source term reduction – total	**792 000**	**660 000**	**1 452 000**
Salaries including social overhead	458 000	472 000	930 000
University overheads	134 000	138 000	272 000
Expenses, equipment, analyses, consumables	200 000	50 000	250 000
Soil cover – total	**3 367 000**	**2 217 000**	**5 584 000**
Salaries including social overhead	2 259 000	1 548 000	3 807 000
University overheads	798 000	509 000	1 307 000
Expenses, equipment, analyses, consumables	310 000	160 000	470 000
Water cover – total	**2 585 000**	**2 399 000**	**4 984 000**
Salaries including social overhead	1 778 000	1 830 000	3 608 000
University overheads	427 000	469 000	896 000
Expenses, equipment, analyses, consumables	380 000	100 000	480 000
Alternative methods of disposal – total	**2 043 000**	**798 000**	**2 841 000**
Salaries including social overhead	514 000	527 000	1 041 000
University overheads	166 000	171 000	337 000
Expenses, equipment, analyses, consumables	1 363 000	100000	1 463 000
Biogeochemical barriers – total	**1 341 000**	**975 000**	**2 316 000**
Salaries including social overhead	674 000	576 000	1 250 000
University overheads	237 000	199 000	436 000
Expenses, equipment, analyses, consumables	430 000	200 000	630 000
Natural attenuation – total	**2 231 000**	**1 433 000**	**3 664 000**
Salaries including social overhead	1 461 000	1 006 000	2 467 000
University overheads	493 000	309 000	802 000
Expenses, equipment, analyses, consumables	277 000	118 000	395 000
Performance assessment – total	**2 182 000**	**2 294 000**	**4 476 000**
Salaries including social overhead	1 778 000	1 832 000	3 610 000
University overheads	404 000	462 000	866 000
Communication – total	**525 000**	**570 000**	**1 095 000**
Salaries including social overhead	300 000	320 000	620 000
Expenses, equipment, analyses, consumables	225 000	250 000	475 000
Management – total	**1 050 000**	**1 080 000**	**2 130 000**
Common costs – total	**2 360 000**	**2 555 000**	**4 915 000**
Travel costs	850 000	850 000	1 700 000
EU co-ordination	125 000	125 000	250 000
Courses and seminars	250 000	200 000	450 000
Ad hoc expertise, international co-operation	250 000	200 000	450 000
Evaluation phase 2		200 000	200 000
Other costs	325 000	350 000	675 000
Programme reserve	400 000	450 000	850 000
Programme host	160 000	180 000	340 000
Total direct costs	**18 476 000**	**14 981 000**	**33 457 000**
VAT 8%	1 431 000	1 221 000	38 372 000
Grand total	**19 907 000**	**16 202 000**	**36 109 000**

[2] The budget assumes a 40% university overhead cost, calculated on salaries including social overheads, whereas the requests from the different universities range from 40 up to 56%. An average salary increase of 3% per year has been assumed. An extra 50% senior researcher has been included in the Performance assessment project.

The funding for the second phase of the MiMi programme, including 2001, has the following components.

MISTRA funding Phase 2	38 000 000
Balanced from Phase 1	4 403 000
Industry funding	2 681 000
University funding	2 061 000
Total funding	**47 145 000**

The total costs budget for the second phase is summarised below.

	2001*)	2002	2003	Total
Direct costs	10 296 000	18 476 000	14 981 000	43 753 000
VAT 8%	740 000	1 431 000	1 221 000	3 392 000
Total costs	**11 036 000**	**19 907 000**	**16 202 000**	**47 145 000**

*) Based on prognosis for 2001-05-01 – 2001-12-31

Appendix A –
Detailed Workplans for the Projects

A1 Source Term – Methods and Tools for Prevention and Source Strength Reduction

Introduction

Today's environmental problems connected to mining waste are typically functions of past deficiencies in source term management. Tailings and waste rock have historically been classified exclusively due to it's content of extractable metals, disregarding other constituents such as sulphur, harmful metals or soluble compounds.

External conditions such as hydrology and climate have often been considered as being of secondary importance compared with direct production related issues such as logistics and geotechnical conditions. There are many examples of sulphur rich waste rock used in applications that enhance the deleterious properties rather than prevents adverse effects. Common examples are old roads and dykes constructed with the use of sulphur rich waste rock. Such practises cause great exposure of the material and in many cases today, widespread pollution or demanding costly protective and remediative measures.

Proper source term management takes into account the properties of the material at every stage of the extraction, also considering every opportunity for reuse or safe deposition of intermediate products. Valuable information has already been generated during the exploration stage of a project. For example, mineralogical data on ore and waste rock is an outcome of diamond drilling. Furthermore, geochemical and geotechnical information on the soil are gathered during early stages of the exploration or can easily be included in the exploration programme, to support the project. With minimum effort, hydrogeological data can also be gathered using diamond drillholes.

Combined deposition of various materials with different chemical or physical properties may be used as a tool to prevent environmental impact. The utilisation of quality controlled waste rock may be a way to reduce both the quantity of waste occupying land, at the same time reducing the need for gravel pits, again reducing the footprint.

Included in the source term approach are evaluations of various pre-treatment options. Obvious alternatives are extraction of sulphide rich fractions and separate deposition of the inert material in facilities that require only limited protection measures. In favourable cases, the sulphide free material may find uses as construction material or similar. The sulphide rich material needs to be managed according to it's reactive nature, with separate disposal under water or as backfill in mines, or subject to treatment using e.g. bioleaching intended to both reduce the reactive pyrite content and possibly to extract metals.

In the process for developing sound source term strategies, methods for classifying and separate management of various fractions of waste are required. Further, knowledge and principles for combining various product streams need to be developed, as well as the quantification of the effects. In many cases, standard solutions for waste management may be applied. Generally, strict control of the production is required to secure the product's flow from the sources to the final deposition.

Goals

- A decision model for management of different material streams within a mine site.
- Principles for selective management of various waste rock fractions and separation and management of various constituents in the mill tailings.
- An assessment of the feasibility for biotechnical pre-treatment of sulphidic waste to reduce the future environmental impact.
- Development of strategies for waste management and site layout based on exploration data.

Deliverables for the Period 2001 – 2003

For the second phase of the MiMi programme, the following deliverables are planned:

- Guidelines for collection and management of data of relevance for environmental source term limitation.
- Principles for waste product management using source term limitation considerations.
- Evaluation of the applicability of biotechnical pre-treatment of sulphidic waste, taking into account the management of secondary generated waste.

Deliverables for 2001

Planned deliverables	**Status**
Progress report - Review of present practice on the use exploration data to optimise the environmental performance of a mining operation	Delayed due to late recruitment.
Progress report – identification of critical parameters for selective management	Delayed due to late recruitment.
Deliverables in addition to programme plan	**Status**
Selection and chemical analysis of tailings from different parts of a selected flotation process.	A special flotation process has been selected and analysed.
Laboratory leaching experiments will be performed in order to determine the optimal leaching rates of the selected tailings, using batch stirred tank bioleaching.	Enrichment shake flask cultures have been started, which will be used in the stirred tank bioleaching experiments.

Deliverables for 2002

Planned deliverables	**Status**
Batch stirred tank bioleaching will be continued.	
Estimation of the leaching time for these tailings under accelerated heap leaching conditions. Laboratory column experiments will be used.	
Calculation of the aeration cost during heap leaching and neutralization cost of the leachate and the residual waste for the industrial scale of the process.	

Estimation of the impact of the produced leachate and secondary waste on the Environment.	
Final report – Evaluation of applicability of regular exploration data and assessment of needs and possibilities for additional data extraction	
Final report – Outline of a decision model	

Work Plan

The working hypotheses are:

- The environmental impact and the corresponding operation and decommissioning costs can be greatly reduced when practising proper source term management.
- Implementation of a scheme for interdisciplinary communication of data will enable cost reduction and reduce the environmental impact.
- Pre-treatment of various waste products may be a tool for reduction of the remediative measures required for a waste deposit.

Sub-project A: Pre-treatment of waste using biotechnology

Sub-project co-ordinator: Börje Lindström, Department of Molecular Biology, Umeå University

Generally speaking, mine waste of significance for environmental impact contains sulphides in concentrations and morphology that leads to spontaneous oxidation. The environmental load will be different depending on the relative contents of buffering components and sulphides.

State-of-the-art methods for acid mine drainage attenuation are based on inhibiting further oxidation and hence reducing the pollutant load.

As an alternative, depletion of the sulphide content will be assessed. The principal method will be to accelerate the oxidation of the waste material, to reduce the time scale within which the outflow of pollutants from the deposit is reduced to an acceptable level. An important aspect to consider is the environmental implications of the means required for managing the leachate, and of the secondary waste generated, containing the bulk of metals and sulphate released.

This suggested work is an extension of the previously planned programme. A flotation process will be selected as a model system for this pre-feasibility study. Tailings from different parts of this process will be collected and analysed for mineral and chemical composition. The different tailings will then be used in laboratory experiments in batch stirred tank bioleaching, as well as in column experiments in order to determine the optimal leaching rates of the sulphidic part of the material. These data will then be used in the evaluation of the applicability of pre-treatment of the waste.

Sub-project B Assessment of the potential to use exploration data to optimise the environmental performance of a mining operation

Sub-project co-ordinator: Manfred Lindvall, Boliden AB

Traditionally, environmental management activities are based upon data and experiences gathered during the production phase or as a result of separated environmental projects.

Data of great importance for later environmental management are collected starting during the early stages of exploration. In normal practice, however, exploration is an activity managed separately from environmental management.

There is a need to evaluate the potential in a co-ordinated approach. The aim is to develop tools for interactions between the pioneering activities conducted by the exploration team and the environmental organisation, securing the environmental performance during and after completion of the operations.

The activities within this sub-project will produce a report accounting for the state-of-the-art and identifying practises for improvement.

Sub-project C Decision model for selective management of reactive waste products

Sub-project co-ordinator: Manfred Lindvall, Boliden AB

In sulphide mining context, pyrite is normally the constituent of highest interest of remediation and prevention measures. Depending on the mineralogy and the content, pyrite may be concentrated in a separate product. Previously, large quantities of pyrite were used as a raw material in the sulphuric acid production. Today, this market sector is occupied by other raw materials.

There might still be a financial incentive for separation of pyrite when assessing the costs for additional measures required to address the pyrite content.

The technology for pyrite extraction is well established. What needs to be evaluated is the potential in reducing the reactivity of the bulk of the waste, isolating a more reactive waste product and focusing the remediation measures on this product.

The activities within this sub-project will produce a report accounting for the state-of-the-art and identifying practises for improvement.

Personnel

Manfred Lindvall, Boliden AB	Sub-project B, C, Project management	10 %
Börje Lindström, UmU	Sub-project A	5 %
Microbiologist, Mark Dopson, Post.doc, UmU	Sub-project A, May-Dec, 2001	50 %
Bertil Pålsson, LTU	Sub-project B, C	20 %

Budget

	2002	2003
Salaries	458 000	472 000
University overhead, 40 % on university salaries	134 000	138 000
Expenses, field installations, lab analyses etc	200 000	50 000
Total costs	**792 000**	**660 000**
Deduction – Industry funding	- 124 000	- 127 000
Total MiMi funding	**668 000**	**533 000**

A2 Near field – Methods and tools for optimised soil covers

Introduction

The research activities within this project reflects the open scientific questions that have been identified regarding the efficiency of soil covers, and thus need to be investigated in order to provide the necessary scientific foundation for a performance assessment evaluation of this reclamation method. In accordance with this the project is organised in two sub-projects, *Design of soil covers for long term performance* (sub-project A), with the focus on formulating design requirements for physical integrity of constructed barriers over time, and *Sulphide weathering and the quantification of the effect of remedial activities and the role of bacteria* (sub-project B), with the focus on quantifying the effects of limiting the intrusion of oxygen, in terms of the generation of acid mine drainage.

In recent years, a number of projects involving the installation of dry covers on mining waste have been performed in Sweden and elsewhere. The method aims at maintaining a high degree of water saturation in a zone in the cover, thereby decreasing the oxygen diffusion and water infiltration into the waste. Studies of short-term effects carried out within the programme suggest that the cover applied on Impoundment 1 in Kristineberg strongly reduces the overall weathering rate of the tailings sand. Similar results have been reported from follow-up studies at other sites. However, the response, in quantitative terms, of the weathering processes to the decrease in oxygen transport and water infiltration still is uncertain, and needs to be thoroughly investigated to improve predictions of remediation activities. In the absence of oxygen, sulphide weathering may be controlled by microbial activity in combination with other oxidants that can be present in tailings and waste rock, such as ferric iron, nitrate etc. Large amounts of Fe^{3+} may be present as oxides due to pre-reclamation sulphide oxidation, while nitrates can originate from undetonated explosives. The hitherto studies have also shown that the effect of an applied cover can be strongly affected by heterogeneity. Further, preliminary results indicate that common processes such as frost action and root penetration can affect the properties of a soil cover. The probability for development of heterogeneities in the soil cover with time, depending on the soil cover design, and the consequences of such heterogeneities, must be further evaluated and reflected in the models to predict long term effects of soil covers.

Goals

The primary goal for this project is:

> To *develop tools and design criteria that can be used for the cost-efficient design of soil covers on sulphidic mine tailings*.

This project goal reflects the overall programme goal and will be achieved by:

- Quantifying the effects of soil covers on the abiotic and biotic AMD generation rates over time for tailings sand (reflects the main tasks I, II and IV).
- Quantifying probable effects of frost action and root penetration in low permeability till barriers and determining the necessary thickness of a soil protection layer, designed to prevent such effects over various periods of time (reflects the main tasks I, III and IV).
- Predicting the effects of possible climate change on the efficiency of single layer and multiple layer soil covers (reflects the main tasks IV).

Deliverables for the period 2001-2003

- An evaluation of the efficiency of soil covers, including the quantification of the effects of soil covers on microbial sulphide oxidation and mineral weathering.
- Conceptual and quantitative models as a tool for optimisation of soil covers with long time perspective.
- A compilation of design criteria for soil covers.

Deliverables for 2001-2002

Planned for 2001	***Status***
A conceptual model of changes in groundwater composition due to application of a single layer soil cover in combination with raising the groundwater level for reclamation of partly oxidised tailings. (LTU)	Reported in Corregé (Skellefteå 2001). Planned licentiate thesis during 2001.
A quantification of AMD-generation rate for tailings sand from the Kristineberg site at conditions (e.g. temperature) that are relevant for a Swedish mine waste site, using laboratory experiments. (KTH/SU)	Reported in Salmon and Malmström (Skellefteå 2001)
A quantification of contaminant release rates from pure sulphides and mixtures of sulphides and a comparison with the AMD-generation of tailings sand. (KTH)	Ongoing
A quantification of the effects of frost action and root penetration in soil covers on contaminant source term (LTU, SU, modelling resource).	Delayed to 2002 (ongoing recruiting of modelling resource)
Factors affecting the growth and activity of Acidothiobacillus ferrooxidans, and their role in the carbon cycle in mine waste will be presented (LiU)	Ongoing

Planned for 2002	
Weathering rates in mill tailings: Laboratory study and (bio)geochemical modelling of the effect of temperature, pH, particle size and surface area (KTH)	
Weathering rates in mill tailings: First results and interpretation from laboratory columns and comparison with batch-scale experiments (SU, KTH)	
Quantification of the effect of different sterilisation methods on weathering rates in mill tailings (KTH, SU, LiU in cooperation with Department of Mineralogy and Petrology, Lund University))	
Laboratory column studies of mill tailings: The effect of grain size, temperature, oxygen content and soluble ferric iron on biogeochemical weathering rates (SU).	
A comparison of microbial growth in mill tailings from column experiments (as stated above) (SU)	
A quantification of possible effects of climate changes on the efficiency of soil covers as barriers against oxygen transport and percolation of precipitation (LTU, modelling resource in co-operation with Sweclim).	

Work plan

The working hypotheses are:

- Chemical as well as microbial processes govern weathering and release processes, where the microorganisms may play a significant role. It is possible to identify key processes that contribute to the overall contaminant release. Biotic and abiotic AMD-generation rates can be determined and compared using a consistent methodology.

- Soil covers are efficient in reducing the intrusion of molecular oxygen, provided that they maintain a zone with a high degree of water saturation throughout the year. A decrease in the intrusion of molecular oxygen strongly reduces the oxidation of sulphidic mine waste.

- Column experiments and smaller scale batch and/or flow-through experiments can be used to quantitatively address the dependence of AMD-generation rates on variables, such as oxygen availability and water flow rate, that are altered during remediation of an impoundment (dry and wet cover).

- The long-term efficiency of low permeability barriers can be affected by different processes. For Swedish conditions the most important processes are frost action, root penetration and possible climate changes.

- Field investigations, including the study of natural analogues, in combination with laboratory studies and modelling, enable the prediction of the long-term efficiency of soil covers.

Sub-project A. Design of soil covers for long term performance

Sub-project co-ordinator: Pär Elander, Envipro Miljöteknik AB

The application of a soil cover including a low permeability barrier has become an established reclamation method for decommissioned mine waste deposits in Sweden. As a result of a research programme in the 1980´s, the Swedish Environment Protection Agency in 1993 gave general recommendations regarding design of such covers, mainly based on modelling results. However, comparisons between field data from reclaimed sites and corresponding modelling results, in order to verify modelling results, still need to be addressed. Furthermore, considerable uncertainty exists regarding the optimisation of soil covers with regard to long-term performance and cost-efficiency.

In a long time perspective, all constructions are subject to degradation processes that may pose a threat to their long time performance. Regarding the deposition of mine waste and environmental protection, damage to the engineered barriers may lead to an increase in oxygen transport to the waste and a corresponding increase in metal discharge from the deposit. In order to draw conclusions as to the durability of barrier constructions, the effects have to be related to a time-scale. With a time perspective of hundreds to thousands of years, several processes may be active, which are very difficult to describe and predict the outcome of. For Swedish conditions, two processes have been prioritised, namely frost penetration and root intrusion in compacted low permeable soil barriers. In addition, the effect of potential climate changes on the efficiency of covers needs to be considered.

Previously, the geochemistry of ground water and drainage water in Impoundment 1 in Kristineberg have been studied, to establish a platform for evaluation of the soil cover. Also, a field test area has been constructed including lysimeters for measurements of oxygen flow and water flow through barriers with different protection against frost action and root penetration. In addition, investigations of natural analogues have been started to study the impact of such processes over long periods of time.

During the remaining two years, further studies will be carried out of natural analogues, where low permeable soil layers have been exposed to frost and root penetration for a long period of time. Data collection regarding oxygen and water transport as well as geochemistry at the field installations in Kristineberg will continue. Also complementary laboratory studies, will ongoing determine the effects of frost action and root penetration into compacted low permeable barriers of clayey till. The aim is to study changes with time and evaluate the probability for, and predict the long-term effects of, repeated frost and root penetration into clayey till barriers overlaid by protective covers with different thickness. The final goal is to develop criteria for cost efficient design of soil covers with respect to their long-term performance.

Data on geochemistry, hydrology and an evaluation of possible changes with time, together with laboratory results on weathering from sub-project B will be interpreted and compared to model results for quantification of the pollutant source strength over time.

For covers including a low permeable barrier, collected field and laboratory data together with studies of natural analogues will make it possible to account for and predict long-term effects from frost and root penetration. As a complement, available data from other field sites will be utilised and compared to modelling results regarding oxygen and water infiltration through low permeability barriers as well.

The major part of Impoundment 1 in Kristineberg is covered with a single layer till cover with the aim to keep the groundwater level well above the tailings surface. With regard to its function, this method is different from low permeable barriers and thus needs to be addressed separately. The effects of this type of cover will be evaluated and modelled, using field data from Kristineberg and results from laboratory studies within sub-project B. The sensitivity of this method to site specific hydrogeological conditions and possible long-term effects such as climate changes will be evaluated.

Sub-project B. Sulphide weathering and the quantification of the effect of remedial activities and the role of bacteria.

Sub-project co-ordinator: R. Herbert, Dept of Geology and Geochemistry, Stockholm University
Ass. Co-ordinator: M. Malmström, Dept of Water Resources Engineering, Royal Institute of Technology

Conventional remediation methods commonly aim at reducing the flux of oxygen and/or the infiltration of water to tailings, thereby limiting oxidant availability and leachate production in the waste deposits. However, the response of the AMD-generating processes to an actual (coupled) decrease in these parameters has not been thoroughly investigated, and hence remains uncertain. The objectives of this sub-project are:

1) to assess various sulphide oxidation mechanisms, including microbial oxidation, and quantify the weathering kinetics over a broad range of oxygen concentrations at several experimental scales and under well-controlled conditions; and
2) to quantify the effects of changes in geochemical and physical master variables, as typically due to soil/wet cover remediation, on the dominant geochemical processes in mine wastes, specifically focusing on the generation of acidic, metal-laden leachates.

This study will quantify the sulphide mineral weathering kinetics as well as neutralisation processes at conditions relevant for a remediated mine waste site, including the quantification of oxidation rates at reduced oxygen concentrations with or without the presence of other oxidants than oxygen (e.g. ferric iron) for oxidised or unoxidised tailings. A state-of-the-art review on sulphide oxidation, focusing on dysoxic conditions, was published within the MiMi-programme during 1999 (Herbert, 1999). Laboratory experiments, aiming at quantifying the sulphide weathering rates in tailings from the Kristineberg site (processed before 1991) and from the

Boliden enrichment plant (freshly processed) as well as for pure sulphide specimens were started during late 1999.

In order to minimise the need of costly field investigations at individual mines sites, it is desirable to be able to extrapolate results from laboratory, field and model studies between different mine waste sites, with different characteristics in terms of e.g., mineralogical composition and particle size distributions. Such extrapolations rely on the quantification of the individual processes and conceptual and mathematical methods describing the interaction between those in the waste deposit. For the sulphide weathering reactions, a first step towards the development of such methods would be to determine and compare the weathering rates of the individual sulphides in pure mineral samples (e.g. pyrite, chalcopyrite) and a few mill tailings sands with varying composition. This could be accomplished by using a consistent experimental method and under a few specific conditions, e.g temperature and tailings composition, that are characteristic for remediated mine sites.

In order to assess the possible effect of microbes on sulphide mineral weathering rates, the microbial community in ground water samples from the till - covered tailings impoundment will be characterised in terms of dominating functional groups and the distribution of bacteria in time and space. Utilising the installed BAT-pipes would allow sampling at well defined depths, and also a correlation of the results from the microbial characterisation with results from chemical analysis (including oxygen content). By using so - called MPN series for carefully selected functional groups, which is a technique that has been successfully applied for the characterisation of deep ground waters, good results can be expected also in this type of environment.

The influence of different microbial communities and their interactions on acid generation and the release of metals will be studied in so called microcosm experiments. Tailings sand will be transferred to a laboratory system, within which the physical and chemical conditions, as well as the microbial community, can be well - controlled. The influence of the microbial community will also be studied indirectly by analysis of the effluent water. In a pre-study, the effect of temperature on sulphide weathering by *Thiobacillus ferrooxidans* was performed in 2000. Results from this sub-project will be used in sub-project A for the development of recommendations for the design of soil covers, but will also be of importance to the project *Methods and tools for water cover*, with the aim of developing recommendations for the design of water covers.

Personnel

Pär Elander, Envipro Miljöteknik	Sub-project A, Project management	20 %
Erik Carlsson, LTU	Sub-project A	90 %
Lena Alakangas, LTU	Sub-project A	30 %
Eva Stoltz, SU	Sub-project A	10 %
Sten Berglund, KTH	Sub-project A, B	10 %
Modelling resource	Sub-project A, B	
Maria Malmström, KTH	Sub-project A, B	5 %
Sally Salmon, KTH	Sub-project A, B	45 %
Microbiologist, Mark Dopson, UmU	Sub-project A, B	25 %
Roger Herbert, SU	Sub-project B	
Magdalena Gleisner, SU	Sub-project B	100 %
Gustav Ebenå, LiU	Sub-project B	90 %
Jan Landin, LiU	Sub-project B	20 %
Tina Krantz-Rülcker, LiU	Sub-project B	5 %

Budget

	2002	2003
Salaries	1 982 000	1 263 000
University overhead 40 %	798 000	509 000
Consultant fees	277 000	285 000
Expenses, field installations, lab analyses etc	310 000	160 000
Total MiMi funding	3 367 000	2 217 000

A3 Near Field – Methods and tools for optimised water cover

Introduction

Various methods have been developed or suggested to prevent the formation of acid drainage from sulphide mining waste. One method is to limit the supply of oxygen by covering the waste with water. Based on identified open scentific questions, this project has been set up to use a performance assessment methodology for identification of key processes and prediction of short- and long-term efficiency of various types of water covers.

Water covers have been shown to strongly reduce the oxidation rates of sulphide-bearing mining wastes since the amount of oxygen reaching the waste is restricted to the oxygen gas dissolved in the water, but this does not completely stop the sulphide oxidation. In shallow water covers, wind driven turbulence may increase the supply of oxygen, and resuspension of sulphides in water covered tailings ponds may lead to increased sulphide oxidation. Before the applicability of water cover as remediation method is completely understood, it is necessary to study how the water cover affects weathering and transport processes in mine waste both on short and long time perspectives

Water coverage may be obtained by raising the dams of tailings pond (sub – project A), the most common method, by deposition of waste in pit lakes (sub – project E) and by deposition of waste in natural lakes (sub – project D). Different aspects of these methods are studied during MiMi phase 2. If water cover should be a real walk-away solution in the cases when dams are constructed, the long-term stability of dams is of utmost importance (sub –project B). It remains to be proven that dams built to reasonable costs are effective for time scales of hundreds to thousands of years.

If plants are established in water covered impoundments, the pond may be shallower than without plants since the risk for resuspension of tailings decreases (sub – project C). This reduces the costs. Establishment of vegetation in shallow ponds may also result in formation of a sediment layer rich in organic material on top of the tailings. It is possible that decay of this organic matter further reduces the oxygen flux, and that the changes of the physiochemical environment caused by the organic matter are positive for metal immobilisation.

The most favourable case is when the waste never gets the possibility to be exposed to the atmosphere. However, water cover has a potential to be used also on waste that to some extent has been oxidised and weathered. In that case, there is a potential risk for a washout effect of metals and other elements secondarily retained in the waste at or below the oxidation front. To develop methods and strategies for reclamation of complex mining areas, there is a need to quantify this effect for different scenarios of what will happen when variously oxidised waste with different characteristics is covered with water (sub – project A). The role of Fe^{3+} as oxidant and the role of microbes in this context are also important to quantify.

When a complex mining area will be remediated and covers will be used on upstream waste deposits, it will take several years before the full effect of remediation is reflected by a strong improvement of the quality of drainage waters, in particular if the covered waste has been oxidised. In such a situation, limed downstream tailings ponds may be efficient traps for metals and other weathering products. The metals are retained in a calcite-gypsum slurry developed on the tailings in the pond. The long-term stability of such a slurry and its trapped metals when liming ceases needs to be quantified (sub – project A).

The geochemistry of pit lakes is not yet understood in such detail that it is known how they can be used and manipulated to function as recipient for acid mine drainage and for disposal of sulphide-bearing waste. Field studies of carefully selected pit lakes are necessary before a scientific comprehension and good practice of the use of pit lakes as part of reclamation of mining areas has been developed (sub – project E).

A MiMi pre study identified a programme-common need for pilot scale test cells. As an important part of the EU-financed Georange project, a test field with pilot scale cells has been built in the vicinity of Kristineberg. The cells should be instrumented so that detailed stuies of key processesare are possible. A collaboration between MiMi and Georange allows the test field to be used in MiMi projects which will narrow the gap between field and laboratory scale studies. The test cells will be used in sub – projects A, C and E.

Goals

- To develop conceptual models of various types of water cover such as flooding by raising dams, and deposition of waste in pit lakes and natural lakes. The models shall include detailed understanding of key processes and prediction of long-term efficiency. *This reflects the overall programme goal and the first of the specific programme goals*.

- To develop complementary methods such as the use of vegetation when designing water covers, and the use of limed downstream tailings ponds as metal traps. *This reflects the overall programme goal and the first and fourth of the specific programme goals.*

- To develop improved knowledge of how to use different water cover methods for waste management at mine sites, and for reclamation of complex mining areas. *This reflects the overall programme goal and the fourth of the specific programme goals.*

Deliverables for the period 2001-2003

- By using a performance assessment methodology for identification of key processes including long-term water supply, deliver conceptual and quantitative models of various types of water covers with main focus on flooding

- By using a performance assessment methodology, deliver an evaluation of the long-term efficiency of various types of water covers

- A quantification of wash out effects when weathered waste is covered with water, and a compilation of criteria for how to decide if such waste should be covered with water or not

- An evaluation of the possibilities to use waste disposal in natural lakes

- A compilation of criteria for how and when pit lakes may be used for waste disposal and as recipient for acid mine drainage

- A conceptual model of using establishment of vegetation when constructing water covers,

- An evaluation of the long term efficiency of the use of limed downstream tailings ponds as metal traps, also after cessation of temporary liming

Deliverables for 2001

Planned deliverables	Status
A sequential extraction will be performed on samples of the metal-rich calcite-gypsum slurry developed on the tailings in impoundment 4 as a result of liming, and the results reported.	Achieved
A conceptual model of the geochemistry of impoundment 4 at Kristineberg will be reported.	Achieved
A plan for the detailed studies of water cover in the Georange pilot-scale test field will be presented	Achieved
A detailed research plan for Sub-project B, Construction of tailings dams (associated project), will be presented.	Achieved
The results from the studies at Gillervattnet of establishment of vegetation in tailings ponds will be reported.	Achieved
The possibilities to study tailings disposal in a lake at the Blaiken Zn-Cu mine, and the time plan for that, will be evaluated and reported.	The opening of this mine is delayed and it will probably not be possible to use this site during the MiMi programme period.
A detailed geochemical field study of two pit lakes will be performed, and a preliminary interpretation of the results reported.	Achieved

Deliverables for 2002

A first report of the outcome of using a performance assessment methodology for identification of key processes for short- and long-term efficiency of various types of water covers will be produced.	
The long-term stability of the metal retention in the lime slurry in impoundment 4 at Kristineberg will be evaluated and reported.	
Prelimary evaluations of studies performed in the Georange test field of the initial reactions when fresh tailings saturated with process water meet a water cover will be reported.	
A preliminary evaluation of studies of the influence roots from different plant species have on mine tailings of different origin will be reported.	
A pilot scale test site for studies of vegetation in tailings ponds with shallow water cover will be constructed as a part of the Georange test field.	
The results form the field studied of the pit lakes at Udden and Rävliden will be published.	
Ming Lu will take the lic-degree.	

Work plan

The working hypotheses are:

- Remediation by using water cover strongly reduces the oxidation of sulphidic mine waste on short- and long-term.
- Flooding of waste and disposal of waste in natural lakes are efficient remediation methods
- Disposal in pit lakes may in some cases be a useful complement for remediation of the industrial area at mine sites
- Vegetation can be established in tailings with a shallow water cover to limit resuspension and to retain metals. Further, this may be a cost-efficient and sustainable alternative to deep water covers
- Limed, relatively deep tailings ponds are efficient traps for metals from acidic, upstream drainage waters

Sub-project A The efficiency of flooding as remediation method

Sub-project co-ordinator Björn Öhlander, assistant sub-project co-ordinator Anders Widerlund

The flooded impoundment 4 at Kristineberg was studied during MiMi phase 1. What remains do be performed during is a detailed study of the pore water in the tailings. A sequential extraction has been performed on samples of the metal-rich calcite-gypsum slurry developed on the tailings as a result of liming. This allows a speciation of the metals retained in the slurry, which is necessary for the modelling of the long-term stability of the metal retainment in flooded and limed tailings pond that will be performed. Sampling for analyses of metals content in the outlet from impoundment 4 will continue.

The flooded tailings pond at Stekenjokk has been studied in detail. The tailings at Stekenjokk are sulphide rich but also relatively rich in carbonates. What is still missing is studies of flooded, sulphide-rich but carbonate-poor tailings. This will be performed in pilot-scale at the Georange test field. Also flooding of partly weathered waste will be performed in the test cells. The mining company Boliden uses the artificial lake Gillervattnet for tailings disposal. In collaboration with Boliden, a M. Sc.-thesis has been completed. A geochemical field study of the water column of Gillervattnet was performed (both dissolved and suspended phases were analysed). These data will be used in this MiMi-project.

The detailed data from Kristineberg, Stekenjokk, Gillervattnet and the Georange test field in combination with data from the scientific literature will be used for modelling of the long term performance of water cover on tailings. Various types of tailings with different content of sulphides and different buffering capacities will be used for simulations of remediation with water cover with different depths, various degree of wind driven turbulence in the water and subsequent oxygenation and resuspension, and changed physiochemical condions caused by for example establishment of vegetation in shallow ponds (in this latter case, see subproject C).

At the end of MiMi phase 2, the results of this sub-project will allow a prediction of both the short term and long term efficiency of the use of water cover for remediation of various types of sulphide-bearing mine tailings.

Sub-project B Construction of tailings dams (associated project)

Sub-project co-ordinator Manfred Lindvall

Previous geochemical studies of the use of water cover to prevent oxidation of sulphides in mine waste have given encouraging results. However, if water cover should be a real walk-away solution in the cases when dams are constructed, the long term stability of dams is of utmost importance. Studies with the aim to find new and improved methods for construction of tailings dams are carried out within a project mainly financed by consultants and the mining industry. This sub-project is planned to continue for about eight years.

Sub-project C Effects of the establishment of vegetation

Sub-project co-ordinator Maria Greger

If plants are established in a pond when using wet cover, the pond may be shallower than without plants, which reduces the costs. The plants reduce the risk for resuspension and oxidation of the resuspended particles. Ample vegetation results in the formation of sediments rich in organic matter that reduces the diffusion of oxygen into the tailings. The potential use of vegetation to increase the efficiency of and to reduce the cost of constructing a wet cover is studied in this subproject.

During MiMi phase 1, an inventory of the vegetation at Kristineberg was performed. The possibilities to establish vegetation and the effects in the tailings when plants grow are studied during phase 2. The role of decaying plant material for metal mobility is also investigated.

Important goals are to understand which plants are able to grow on sulphide-rich mine tailings with a shallow water-cover, how the plants handle increased concentrations of heavy metals and other elements, and what happens in the tailings during plant growth. The influence roots from different plant species have on mine tailings of different origin will be investigated. One important question is if it is common that plant roots try to keep the pH around 6 and decrease the metal leakage of drainage water from the tailings. The major goal is, however, to develop and design plant vegetation as an important tool for improving the wet cover method. Pilot-scale studies in the Georange test field will also be performed.

Sub-project D Tailings disposal in natural lakes

Sub-project co-ordinator Anders Widerlund

The best situation is when sulphide-bearing waste never get the possibility to be strongly oxidised, i.e. never come in direct contact with the atmosphere. Disposal of tailings in natural lakes is therefore an attractive method, at least from the geochemical point of view. There are no problems with dam stability if natural lakes are used.

Disposal of fresh tailings directly in water will be studied in detail in the pilot-scale test cells. The initial reactions when fresh tailings saturated with process water meet the lake water will be studied in detail, as well as long-term geochemistry of the lake water.

Subprojects E The use of pit lakes

Sub-project co-ordinator Björn Öhlander

The possibilities to use pit lakes as part of remediation systems will be studied. First of all it is important to understand potential problems from the pit lakes themselves. Oxidation of sulphides in the pit walls as well as drainge waters from surrounding industrial areas may cause low pH and high metals concentrations. Drainage from such lakes is a potential problem. The pit lakes at Udden and Rävlidmyran are studied in detail. Detailed profiles of the water columns in these pit lakes have been sampled and analysed during the whole-year cycle 2001. The effects of disposal of sulphide rich waste, as well as of acid drainage waters in pit lakes with various characteristics will be evaluated.

The possibilities to chemically manipulate the pit lakes to obtain efficient metal attenuation will be studied in the project “Development of biogeochemical barriers for leachate treatment”.

Personnel

The project leader is Björn Öhlander, who will work 30 % of his time with MiMi (he is wholly financed by Luleå University of Technology, LTU).

The sub-project leaders are:

Sub-project A: Björn Öhlander, LTU, assistant project leader Anders Widerlund, LTU.
Sub-project B: Manfred Lindvall, Boliden
Sub-project C: Maria Greger, Stockholm University (SU)
Sub-project D: Anders Widerlund, LTU.
Sub-project E: Björn Öhlander, LTU.

Senior researcher Anders Widerlund at LTU will work 30 % in sub-project A and 30 % in sub-project D. Senior researcher Manfred Lindvall will work 5 % in sub-project B, financed by Boliden. Senior researcher Maria Greger at SU will work 20 % with sub-project C. Senior researcher Elsa Peinerud at LTU will work 25 % in subproject A and 25 % in sub-project D.

Three research students are involved in the project during phase 2. Their affiliation and financing are as follows:

Ming Lu will work with pit lakes at LTU. Financing 2001 and 2002, sub-project A 50 % and the project “Development of biogeochemical barriers for leachate treatment” 50 %. During 2003 LTU 10 %, sub-project A 45 % and the project “Development of biogeochemical barriers for leachate treatment” 45 %

Annika Benckert at Boliden will work 50 % as external research student at KTH in sub-project B, financed by the industry.

Eva Stoltz at SU will work with effects of vegetation. Financing SU 10 %, sub-project C 80 % and the projcect “Methods and tools for optimised soil covers” 10%.

Budget

With an expected salary increase of 3 % per year, the budget is (SEK):

	2002	2003
Salaries (including social costs)*	1 778 000	1 830 000
University overhead, 40 % of salaries*	427 000	469 000
Expenses, field installations, analyses etc.	380 000	100 000
Total	2 585 000	2 399 000

* During 2002 Ming Lu has a scholarship for which the only overhead is room rent. Includes funding by LTU of Professor Björn Öhlander.

A4 Near Field - Alternative Disposal Techniques

Introduction

Coarse dry handled waste rock from sorting and wet handled tailings are generated by LKAB in mineral processing. At the two mine sites, Kiruna and Malmberget, 12 Mton sorting waste rock and 4 Mton of tailings are produced. The dry waste rock is transported with trucks to disposal areas, which normally are inactive open pits or large terrace-formed heaps. The fine-grained tailings originate from wet grinding and different separation processes, such as magnetic separation and flotation in the concentrating plants. The tailings have a solid grade of 2 to 30% and are pumped or transported in flumes to large water-covered deposits surrounded by dams. The construction of the dams varies, but in principle they all consists of a low-permeable core, filters, support fill and erosion protection. The dams are, for safety reasons, classified as hydropower dams. The dams are raised when the tailings and water levels are increased to the highest permitted water level.

LKAB has, for several years, worked with the development of alternative methods of transporting and depositing waste rock and tailings. The objectives of this research have primarily been to bring down the significant investment and operation costs of trucking and of dam constructions.

A major test has been conducted, were a mixture of dry –60 mm waste rock and –4 mm tailings is pumped with heavy duty slurry pumps. The tests and site specific evaluation showed that the operation was not competitive to traditional transportation techniques, mainly due to wear in pumps and pipeline. The resulting co-disposal showed that the slurry stream “designed” a rounded moraine-like formation, similar to those created by melting ice during the withdrawal of the inland ice. The density of the deposited material was found higher than that of conventionally placed material, i. e. the use of available volume is more efficient. In addition, it was concluded that if measures are taken in order to control the ground water level in the deposit, stable and high deposits may be created with this disposal method.

The promising properties of the co-deposited waste rock and tailings have encouraged work to achieve the advantages of co-disposal combined with traditional transportation techniques. The MiMi-program and LKAB have, in co-operation developed the concept of drained-cell disposal. A pilot test in full-scale operation has been conducted in Malmberget during Phase one. Large amounts of data have been collected and the evaluation and further development of this technique will be performed during the Mimi Phase two.

Goals

- To describe the operational, hydraulic and geotechnical aspect of “drained-cell disposal” based on results from pilot-scale tests.
- To develop applicable design criteria for drained tailings disposal.
- To investigate the influence of cold climate on the stability of the deposit. *The three first goals refer to the overall programme goal and programme task 1.*
- To investigate the applicability of co-disposal to sulphide ore operations with regard to weathering, leaching and safety properties. *The last goal is achieved by using performance assessment methodology, which is described under task 4 in the overall programme goal.*

Work plan

The working hypotheses are:

- It is possible to use waste rock in structures that allow drained disposal of tailings.
- Drained cell-disposal is a cost efficient method to build safe deposits.
- Co-disposal of sulphidic waste rock and tailings can result in increased dam stability and decreased sulphide leaching.

Deliverables

For the period 2001-2003 the following general deliverables are planned:

- Design criteria for drained tailing disposal
- An analysis of the cost efficiency of drained disposal in cells constructed of waste rock.
- A feasibility study of the potential in using co-deposition of tailings and waste rock as a method to decrease sulphide leaching.

Deliverables for 2001

Planned deliverables	**Status**
A state of the art report in the area of drained disposal	A state of the art report will be delivered in December
A number of MiMi-reports on compiled data and achieved results from pilot tests in Malmberget	The data has been compiled but not yet reported. See deliverables for 2002
One presentation of results in international scientific publications and/or at conferences	Reported at the conference "Securing the future" Skellefteå 2001
New sets of data will be collected during further development of the technique in Kiruna and in Malmberget	Laboratory and pilot test has been conducted in order to determine dimensioning factors

Deliverables for 2002

Planned deliverables	**Status**
MiMi-reports: Field scale test in Malmberget, Laboratory test indicating hydraulic conductivity and filtering properties of selected waste rock Results from pilot scale test on selected waste rock and geotextiles	
Propose design criteria for drained cell disposal	
Evaluation of sedimentation and consolidation processes	
An analysis of the cost efficiency of drained cell disposal in Kiruna	

Personnel

Anders Lundkvist, LKAB	Project management	10 %
Sven Knutsson, Division of Soil Mechanics, Luleå University of Technology	Professor	5 %
Two resources	Senior researchers	10 % +10 %
Håkan Åkerlund, Division of Soil Mechanics, Luleå University of Technology	PhD –student	80 %

Budget

The MiMi part of the budget (SEK):

	2002	2003
Salaries (Senior researchers and PhD-stud)	414 000	427 000
Expenses (installations, maintenance)	150 000	20 000
Analyses, etc.	113 000	80 000
University overheads (40% of salaries)	166 000	171 000
Total	843 000	698 000

The LKAB part of the budget (SEK):

	2002	2003
Salaries (Project management)	100 000	100 000
Expenses (installations, maintenance)	1000 000	
Analyses, etc.	100 000	
Total	1 200 000	100 000

Total budget (SEK):

	2002	2003
Salaries	514 000	527 000
Expenses (installations, maintenance)	1 150 000	
Analyses, etc.	213 000	
University overheads (40% of university salaries)	166 000	171 000
Total	2 043 000	798 000

A5 *Far Field – Development of Biogeochemical Barriers for Passive Leachate Treatment*

Introduction

The installation of a soil cover or the flooding of a tailings deposit are generally successful in reducing oxygen diffusion to tailings, but the lag-time between tailings deposition and reclamation may be several years to tens of years. During this time, sulphide minerals in the mine wastes may partially oxidise. Even though later reclamation efforts may lead to a significant decrease in sulphide oxidation and leachate production, many years may be required before the accumulated sulphide oxidation products are flushed from the tailings pore space. During this interval, biogeochemical barriers may be constructed to intercept and treat this leachate water. There are, however, a number of open scientific questions that should be addressed, before biogeochemical barriers can be recommended for leachate treatment. For example, how effective is the attenuation provided by a passive treatment system on a long - term basis? How can the transport and attenuation of metals be manipulated? Furthermore, in order to fully evaluate the coupled utility of passive prevention techniques (e.g. soil covers) and biogeochemical barriers, a performance assessment is required to identify critical processes and links. This project will therefore provide data that is necessary for an effective performance assessment.

In order to limit the discharge of leachate waters to far field surface water recipients, biogeochemical barriers may be constructed to intercept and treat the water. Natural biogeochemical barriers include wetlands and peat bogs, while engineered barriers include systems such as permeable reactive barriers, constructed wetlands, and anoxic limestone drains. A common biogeochemical process in all these barriers is microbial sulphate reduction, where sulphate-reducing bacteria catalyse the reduction of sulphate to hydrogen sulphide. Metals are then immobilised in the barrier through the precipitation of metal sulphides (e.g. FeS, PbS). For Phase II of the MiMi programme, reactive barrier systems (sub-project A) and biogeochemically - manipulated pit lakes (sub-project B) will be studied in this project.

Laboratory and field tests will continue during 2002, in order to optimise the performance of the existing sequential treatment barrier system. In particular, column experiments will focus on processes and mechanisms dominating the geochemistry of the barrier system, such as the dissolution of olivine and dolomite, precipitation of gypsum, and degradation of organic matter. In the field installation, barrier performance and design criteria will be evaluated, including the determination of sulphate reduction rates and the measurement of microbial activity. An alternative barrier design will be investigated and implemented at the Kristineberg site, with the purpose of assessing the relative performance of both techniques.

The use of pit lakes, as a method to reduce the transport of metals from the near field to the far field, will be studied. The pit lakes may be used as recipients and sinks for acid drainage, either in an unaltered state or through biogeochemical manipulation. The latter function employing biogeochemical manipulation will be studies in this project, while the former function is studied in the project *Near Field – Methods and tools for optimised water cover* (appendix A3). Additional effects that need consideration are e.g. the large-scale water flow pattern in the pit lakes, and the impact of thermo- and haloclines and particle dynamics in the water phase. As pit lakes are generally deep, with anoxic conditions often occurring in the lower regions, sulphate reduction may be stimulated in these systems. Therefore, sub-projects A and B will investigate similar biogeochemical processes and will benefit from mutual problem definition and method development.

Goals

The primary goals of this project are *to determine attainable treatment levels in biogeochemical barriers, and to predict the degree of contaminant retention as a function of contaminant loading to the systems*. This is directly linked to MiMi's overall goal, in that barriers are systems designed to ensure the safe disposal of mining waste before more long-term solutions are effective. As barrier systems are considered as a complement to long-term prevention techniques (e.g. soil covers), barriers should be considered in conjunction with other methods and assessed accordingly. This project will therefore focus on providing data needed to quantify the performance and capacity of barrier systems, which is reflected in MiMi's main tasks I & IV and will be used in a performance assessment of a coupled passive prevention (e.g. soil cover) – barrier system.

The project goals will be achieved by:

- Developing design criteria for dimensioning reactive barriers, in terms of construction, barrier materials, and flow rates.
- Enhancing groundwater treatment in a reactive barrier system through the optimisation of mineral weathering and sulphate reduction rates.
- Developing methods for the geochemical manipulation of pit lakes for metal retention.
- Quantifying the performance and capacity of reactive barrier systems and pit lakes as geochemical barriers.

Work Plan

The working hypotheses are:

- Anaerobic conditions and a reactive organic substrate can be maintained in a biogeochemical barrier so as to promote microbial sulphate reduction and the subsequent precipitation of iron and other heavy metals as metal sulphides.
- Column experiments and smaller scale batch experiments can be used to test the applicability of reactive materials for an engineered barrier system in a controlled laboratory environment, and to quantitatively determine the rates of dominating reactions at room temperature.
- Pit lakes can be manipulated to retain metals from mine drainage waters.
- Pilot scale test cells can be used to test different methods to manipulate the biogeochemical conditions in pit lakes under field conditions.

Deliverables

The following deliverables were stated in the Programme Plan for 2001 – 2003:

Planned Deliverables 2001 - 2003	**Status**
Design criteria established for the construction and maintenance of a barrier system for optimal groundwater treatment, and the attainable treatment levels with such a design.	In progress.
A barrier system installed and tested for the removal of heavy metals from leachate waters.	Completed. Metal removal capacity is being monitored.
Methods for the manipulation of pit lakes for waste disposal and metal retention, and the attainable treatment levels in such systems.	In progress.
A series of MiMi-reports on the achieved results from each of the sub-projects, and a presentation of results in international scientific publications and/or at conferences.	Results on the studied barrier system reported in Morales and Herbert (2001)[3] A state-of-the-art report on pit lakes is in preparation in collaboration with the Water cover project.

[3] Morales, T.A., and Herbert, R.B. 2001. Sulphur and iron chemistry in a barrier system for the remediation of groundwater contaminated by AMD, Kristineberg mine site, Northern Sweden, In: *Proceedings, Securing the Future*. Skellefteå, Sweden, June 2001 (546 - 555).

Deliverables 2001	**Status**
Column tests, using reactive mixtures inoculated with bacteria and feed solutions similar to the contaminated groundwaters and leachates from the selected field site, will be performed in order to investigate the geochemistry and microbiology of a constructed reactive barrier.	Completed and reported in a Licentiate thesis (Morales, 2001)[4].
A pilot scale barrier system will be maintained for the treatment of leachate from impoundment 1. Results for the year 2001 will be compiled and interpreted in a working report.	Results from 2001 presented in working report (Herbert, 2001a)[5].
A new subsurface permeable reactive barrier consisting of peat from the Kristineberg site will be installed and sampled. (Roger Herbert Jr./SU).	Because of difficulties with the existing barrier system, a new installation is postponed until 2002, pending results.
The geochemistry and hydrology of pit lakes for waste disposal and metal retention will be studied, and methods will be evaluated for the manipulation of lake chemistry. (Ming Lu/ LTU, Lars Olof Höglund/ Kemakta).	Delayed. Background studies have been made in several pit lakes and two have been found suitable for further investigations. It was decided to first collect at least one year of data before any installations are made. These data are collected within the Water cover project.

Deliverables 2002	**Status**
MiMi report on the performance of the pilot – scale barrier system at the Kristineberg site (R. Herbert, T. Morales / SU).	
Working report on the maintanence and monitoring of the barrier system during 2002 (R. Herbert / SU).	
The geochemistry and hydrology of pit lakes for waste disposal and metal retention will be studied, and methods will be evaluated for the manipulation of lake chemistry. (Ming Lu/ LTU, Lars Olof Höglund/ Kemakta).	
Working report on the installations and field measurements during 2002 (Ming Lu/ LTU, Lars Olof Höglund/ Kemakta).	

[4] Morales, T.A. 2001. Groundwater treatment of acid mine drainage – Laboratory and field studies, Licentiate thesis, Department of Geology and Geochemistry, Stockholm University.
[5] Herbert, R.B. 2001a. Performance of reactive barrier system, 2001. MiMi working report.

Sub-projects

During 2002, reactive barrier systems (sub – project A) and pit lakes (sub – project B) will studied in this project.

Sub-project A Barrier systems for groundwater treatment

Co-ordinator: Roger Herbert, Dept of Geology and Geochemistry, Stockholm University

To minimise the discharge of groundwater contaminated by mine waste leachate to nearby surface water bodies, barrier systems may be installed in order to intercept the contaminated groundwater. The construction and design of a barrier will depend on the site characteristics as well as the chemical composition of the contaminated water and desired level of treatment. Thus, the proper design of a barrier system requires carefully planned and conducted laboratory experiments to determine the various reactive materials that are needed in a barrier, and to predict the performance of the barrier system in a controlled laboratory environment.

During the first programme period, a pilot scale reactive barrier was installed between impoundment 1 and impoundment 2 in Kristineberg. Parallel with the field installation, the geochemistry and microbiology of a constructed reactive barrier was studied in batch and column tests. Laboratory and field tests will continue during 2002, in order to optimize the performance of the existing sequential treatment barrier system. In particular, column experiments will focus on processes and mechanisms dominating the geochemistry of the barrier system, such as the dissolution of olivine and dolomite, precipitation of gypsum, and degradation of organic matter. Alternative organic substrates for heterotrophic bacteria will be studied, as well as adsorption and complexation in the same material. The effect of low temperature and temperature variations on iron and sulphate removal rates will be determined. Mineralogical and geochemical studies of the various metal sulphides that are formed will be conducted. The importance of the microbial community for these processes should be considered in close collaboration with microbiologists in other projects.

In the field installation, barrier performance and design criteria will be evaluated, including the determination of sulfate reduction rates and the measurement of microbial activity. An alternative barrier design will be investigated and implemented at the Kristineberg site, with the purpose of assessing the relative performance of both techniques. A field test will investigate how an inoculation of bacteria may accelerate organic matter degradation, and how additives may assist in the establishment of bacterial growth. Additional compartments for sulphate and iron removal in the barrier may be needed, which would prolong the residence time in the system.

Sub-project B Pit lakes for metal retention

Co-ordinator: Lars Olof Höglund, Kemakta

The geochemistry of pit lakes in the Kristineberg area was studied during 2000, with the purpose of understanding the function of such geochemical systems. The use of pit lakes, as a method to reduce the transport of metals from the near field to the far field, will be studied during Phase II. The pit lakes may be used as recipients and sinks for acid drainage, either in an unaltered state or through biogeochemical manipulation. The latter function employing biogeochemical manipulation will be studies in this project, while the former function is studied in the project *Methods and tools for optimized water cover* (appendix A3). Additional effects that need consideration are the large-scale water flow pattern in the pit lakes, and the impact of thermo- and haloclines and particle dynamics in the water phase.

As pit lakes are generally deep, with anoxic conditions often occuring in the lower regions, sulfate reduction may be stimulated in these systems. Therefore, sub – projects A and B will investigate similar biogeochemical processes and will benefit from mutual problem definition and method development. Simple models will be set up and tested against field measurements to describe and quantify the transport and possible attenuation of metals and acid drainage in the pit lakes.

Pilot scale field tests will be performed to evaluate the possibility to manipulate the biogeochemical conditions in pit lakes on short and long term. This sub-project will also benefit from the collaboration with the EU-funded project PIRAMID (Passive In-situ Remediation of Acidic Mine/industrial Drainage), which was launched 1 March, 2000.

Personnel

Roger Herbert (SU)	Sub-project A & Project management	70%
Teresita Morales (SU)	Sub-project A	100% (7 months)
Lars Olof Höglund (Kemakta)	Sub-project B	5%
Ming Lu (LTU)	Sub-project B	50%

Budget

	2002	2003
Salaries	674 000	576 000
Expenses (installations, maintenance)	240 000	
Laboratory and field equipment, analyses, etc.	190 000	200 000
University overheads (40% of salaries)	237 000	199 000
Total (SEK)	1 341 000	975 000

A6 Far Field – Natural Attenuation

Introduction

Contaminants present in mining waste leachates can be significantly immobilised from groundwater and surface waters by precipitation of secondary iron - containing solid phases under oxidising conditions in the far field. These natural attenuation processes may be utilised in a structure for passive leachate treatment forming an integrated component of a system for safe disposal of mining waste. Open scientific questions of fundamental importance for the formulation of a conceptual model for contaminant immobilisation will be addressed. The research will provide important scientific data for the performance assessment of the function of disposal methods.

Particles play a significant role in the distribution of metals in surface waters within the mining waste deposit area at Kristineberg, and in the downstream recipient of drainage water (R. Vormbäcken). The particulate phase consists o f inorganic and organic matter of different composition and with particle sizes ranging from colloidal phases, i.e., compounds small enough to pass a filter with a pore size of 0.1µm and suspended solids that are trapped by filtration. Under influence of high concentrations of dissolved ions, colloids may coagulate and form larger aggregates that can settle and, hence, be retained in natural environments, such as lake sediments and in wetlands. Secondary minerals may serve as primary adsorbing phases for elements released by mineral weathering. These minerals are known to accumulate metals in soils, and their role for the immobilisation of metals in oxidised mine waste and in downstream areas can be expected to be large. Of particular importance are iron oxyhydroxides, but also Mn and Al oxyhydroxides and clay minerals, hydroxysulphates and other accessory minerals may act as metal scavengers.

Thus, contaminants in leachate discharge from mining waste can be significantly attenuated from groundwater and surface waters by formation of secondary solid phases under oxidising conditions and by sorption to surfaces of organic and inorganic particles. To achieve a significant retention of contaminants, it is necessary to remove the particulate phase from the water by sedimentation. An increased sedimentation can be induced by aggregation of colloidal particles as a result of increased pH and concentration of dissolved ions, such as Ca^{2+} (as a result of acid neutralisation) and sulphate. The presence of natural organic acids in surface waters may further enhance particle aggregation. Thus, the mixing of waste leachates with high salinity and natural surface waters with organic substances may strongly affect the particle dynamics in this type of environments.

Natural attenuation processes can be utilised in active as well as passive treatment systems. Since the MiMi program has as an overall objective to contribute to a solution of the environmental concerns of mining waste on a long-term basis, focus will be put on passive systems which require a minimum of supervision and maintenance. Wetlands are being used for passive treatment of leachate discharge at many locations, but with varying success. While there are several examples of well functioning wetland treatment systems, in other cases loads of metals have been too high to maintain an operating ecosystem. For instance, high levels of Fe and Al have resulted in such extensive precipitation of secondary iron/aluminium solid phases that even resistant plants have not survived. Therefore, the metal content must be minimised before the water enters a wetland.

Within the MiMi programme, it has been decided to refrain from studying wetlands as a single method for treatment of leachate water, but rather as a final polishing step in a system of different measures. Preliminary results from a study of the metal retention in the River Vormbäcken area indicate that the attenuation of metals in the R. Vormbäcken area is not very effective. A method will be developed for passive treatment of discharge water utilising the above described attenuation sequence as a primary treatment, i.e. particle formation, exchange of matter between dissolved and solid phases, aggregation and sedimentation. In order to find optimal conditions these processes will be studied in laboratory and field experiments. The influence of hydrochemical conditions on the different processes will be studied. For field demonstration, a pilot-scale settling-basin will be constructed at the Kristineberg site

As a tool in the assessment of contaminant attenuation, a quantitative model will be adopted combining biogeochemical and hydrological processes. Results from the different field and laboratory experiments will be integrated in the model development. The coupled biogeochemical and hydrological model will be useful in the search for optimal conditions for the different steps of the attenuation sequence: particle formation, uptake of contaminants, aggregation and sedimentation

The utilisation of secondary iron phases as a means for attenuation of metals is scope for a collaboration with the EU-funded project PIRAMID (Passive In-situ Remediation of Acidic Mine/industrial Drainage), which was launched 1 March, 2000. Furthermore, a project is planned for a more active treatment of leachates within another research project, Georange, which was launched in February 2001. Within the framework of the Georange project, a constructed wetland is planned at the Kristineberg site. In both cases, a comprehensive understanding of governing processes is of fundamental importance for the success of the remediation methods.

Goals

The main objective of this project is to *develop methods for an optimised utilisation of natural attenuation processes in structures for the passive treatment of drainage water*. This objective reflects the first and the fourth main tasks of the MiMi programme, and includes:

- The definition of design criteria for a metal immobilising system, which takes into account relevant biogeochemical processes, such as formation and accumulation of particulate matter, formation and transformation of metal scavenging secondary solid phases, consolidation of metal containing sediments, and transport processes.
- The development of tools for the quantification of contaminant retardation in waste deposits and surrounding geological formations, including an assessment of the performance of passive treatment systems.

Work plan

The working hypotheses are:

- Contaminants in mine waste leachate can be significantly attenuated by the formation of secondary solid phases and sorption to organic and inorganic particles surfaces, in combination with the removal of the particles from the aqueous phase. The attenuation on a long-term perspective is coupled to structural transformation of secondary minerals
- It is possible to construct a system for passive treatment of discharge water in which formation of colloids and suspended solid phases under oxidising conditions, and their retention by aggregation and sedimentation, can be promoted.
- Natural organic matter present in ground and surface waters may enhance aggregation of particles but may also induce a deteriorating solubilisation of metals by complexation.
- A quantitative model combining biogeochemical and hydrological processes can be set up and used as a tool for quantification of the release, transport and retention of metals in different compartments of a mine waste deposit and for a performance assessment of passive leachate treatment

- Constructed wetlands can be used as a passive leachate treatment method and have potentials as a complementary method to other remediation measures also in cold climates.

Deliverables for the period 2001-2003

- A method for passive leachate treatment by formation of particles under oxidising conditions, followed by sedimentation, will be developed.
- Criteria for the design of discharge water treatment systems will be defined.
- A model, combining transport processes and biogeochemical processes, will be adapted and used for the assessment of the attenuation of contaminants.
- A plan for the construction of wetlands in cold climate will be conceived, based on knowledge gathered within the MiMi-program, as well as on practical experiences obtained at field sites elsewhere in the world.

Deliverables for 2001

Planned deliverables	**Status**
Geochemical characterization of the surface waters within the Kristineberg waste deposit area will be reported based on data collected during the first programme period, including the distribution of elements between the dissolved and particulate phases. (LTU)	Surface water data are presented in revised draft of manuscript Öhlander et al. 2001
The distribution of elements in surface waters (R. Vormbäcken and Impoundment 4) between colloids and suspended particles of different particle size will be determined. (LTU/LiU)	Metal analyses finished (R. Vormbäcken). Paper under preparation.
Characterisation of the uptake of metals to secondary iron phases from water with chemical composition representing conditions. (UmU)	Experimental work to be concluded during 2001. Paper under preparation
Determination of the adsorption properties of flotation reagents (xantates), including degradation products, with respect to association with secondary iron phases. (UmU)	Experimental work finished. Report under preparation
An evaluation using voltammetric methods of the impact of dissolved organic matter and inorganic colloids on copper complexation will be reported. (SU)	Complexation with organic matter reported in Herbert (2001b)[6].
A conceptual model for the contaminant retardation processes coupled to the source processes releasing contaminants, including mass transport processes, will be presented. (KTH)	Ongoing. MiMi working report to be presented in Jan. 2002.
A pilot scale settling basin will be constructed for field demonstration of attenuation processes under oxidising conditions (LiU/LTU/UmU)	Delayed. To be discussed at project meeting in November.

[6] Herbert, R.B. 2001b. Copper complexation in a stream system receiving mine drainage waters, In: *Proceedings, Securing the Future*. Skellefteå, Sweden, June 2001 (259 - 268).

Preliminary criteria for design of a constructed wetland in a cold climate will be presented. (LiU)	Report to be prepared during 2001. A wetland is under construction at the Kristineberg site (SU) in collaboration with GEORANGE.
The applicability of "low-maintenance" wetlands to different types of water chemistry will be concluded. (LiU)	Delayed. Will be concluded and reported during 2002.

Deliverables for 2002

Planned deliverables	**Status**
Factors affecting the partitioning of metals in Impoundment 4 and along a gradient in Vormbäcken downstream Impoundment 4 between dissolved and settling particulate phases, and particulate phases that may be used in a passive treatment system will be investigated and reported. (LTU/LiU)	
The effects of transformation of secondary iron phases on the immobilisation of metals in short-term and in long-term perspectives will be investigated and reported (UmU).	
A State-of-the-Art report on wetland treatment of mine drainage waters will be presented. (LiU)	
Preliminary criteria for design of a constructed wetland in a cold climate will be presented. (LiU/SU/UmU/LTU)	
A pilot scale settling basin will be constructed for field demonstration of attenuation processes under oxidising conditions (LiU/LTU/UmU)	
A modelling methodology, including process representations, for quantification of natural attenuation of acid mine drainage will be reported. (KTH)	
Sensitivity analyses and results of the model for quantification of natural attenuation of acid mine drainage will be reported. (KTH)	

Research tasks

The work within this sub-project will be organised in four research tasks

I. Attenuation of contaminants by formation, aggregation and sedimentation of particles

Co-ordinator: Karsten Håkansson, Swedish Geotechnical Institute
Assisting Co-ordinator: Anders Widerlund, Luleå Technical University

The formation of secondary solid phases as a result of oxidation of Fe(II) when mine waste leachates are exposed to air is largely controlled by the physicochemical conditions. It has been shown that the chemical composition of the aqueous phase strongly influences the composition and structure of the solid material. Attenuation of contaminants in groundwater and surface waters by precipitation/co-precipitation and sorption to particles requires effective separation of the particulate phase from moving water. Increased sedimentation, as a result of an aggregation of colloidal particles, can be induced by a changed pH and an increased salinity. Besides the generally high levels of heavy metals and other toxic compounds, such as arsenic, drainage waters created by oxidation of sulphide minerals also contain high concentrations of divalent Ca^{2+} and sulphate ions. The natural surface waters in the vicinity of most mines are characterised by a low content of Ca and sulphate. On the other hand, these waters generally contain high concentrations of natural organic matter. Presence of organic macromolecules may further enhance particle aggregation, c. f. the use of polymers in many industrial processes (e.g. in waste water treatment). Therefore, the mixing of leachate waters and natural surface waters may strongly affect the particle dynamics in this type of environments.

In this study, the effect of geochemical gradients on composition and flocculation/aggregation of colloids and suspended particles will be studied both by field studies and laboratory experiments in which waters of different origin are mixed. In order to obtain estimates of e.g. what would be a sufficient retention time or volume of a settling basin, the effect of time on these processes will also be studied.

Surface waters in the Kristineberg area, including both surface waters within the waste deposit area and in the downstream recipient (R. Vormbäcken), have been frequently sampled in two different MiMi studies. The distribution of elements between the dissolved and particulate phases has been determined for the samples collected. These investigations will be coordinated and extended to further elucidate the distribution between particles of different classes with respect to particle size.

II. Association of contaminants to particles
Co-ordinator: Lars Lövgren, Umeå University

Secondary iron precipitates formed by oxidation of ferrous iron and in waters with high sulphate concentrations contain significant amounts of structurally bound sulphate. The precipitates contain trace levels of many elements, either adsorbed to particle surfaces or co-precipitated. It was estimated that, under optimal conditions, the adsorption capacity of the secondary iron precipitates is sufficient to immobilise a significant fraction of the heavy metals released by sulphide weathering. The aqueous speciation of many transition elements is dominated by interaction with natural organic compounds. NOM in the aqueous phase may significantly influence the degree of sorption of metals onto mineral surfaces. Depending on the hydrochemical conditions, presence of NOM at high concentrations can increase sorption as a result formation of so called ternary surface complexes or decrease sorption resulting from a pronounced aqueous complexation with metal ions.

The influence of natural organic matter on metal sorption onto Fe-oxyhydroxides has been studied within the MiMi programme. In order to enhance the possibilities to evaluate an equilibrium model that can be used in predictive model calculations focus was put on NOM sorption onto a well-defined phase, goethite (α-FeOOH). The specific effect of NOM on metal sorption with both goethite and secondary phases collected at the field site will be investigated. Furthermore, sorption properties of particulate phases obtained by filtration of surface water samples (c.f. Research task I) will be studied. In another study, the effect on metal mobility of residues of collector reagents from the froth-floatation process (ethylxanthate, as well as important degradation products) will be investigated.

Freshly precipitated secondary iron phases are generally poorly crystalline. Upon ageing these solids are transformed into more ordered structures. Phase transformation can be expected to result in altered sorption properties and hence affecting the solubility of metals. While incorporation of metals into the solids would result in a decreased tendency for remobilisation, reduced active surface areas implies reduced sorption capacities. The chemical composition of the aqueous phase strongly influence sorption processes but also dominating pathways for phase transformation. Long-term alterations leading to virtually irreversible immobilisation of metals by adsorption/transformation or co-precipitation, substitution etc. are important for the long-term performance of remediation actions. Different aspects of phase transformation of secondary iron precipitates will be studied utilising a range of laboratory methods. These investigations address metal retention i) within deposits (oxidised tailings, soil, flooded impoundments, sediments) and in natural or constructed wetlands and ii) by passive treatment systems, i.e. purification of drainage waters with high metal content by precipitation of secondary iron phases.

The influence of hydrochemical conditions and mineralogy, as well as the chemical composition of secondary products, will be considered. Desorption processes will be quantitatively characterised in order to provide kinetic data for predictive modelling and performance assessment. The mechanisms behind non-reversible adsorption will be studied on a molecular scale.

III. Quantification of long-term retention and attenuation of AMD
Co-ordinator: Maria Malmström, Royal Institute of Technology

The objective of this research task is to model the performance and long-term capacity of natural processes for attenuating contaminants (e.g. heavy metals, sulphate, and acidity) from acid mine drainage within mine waste deposits and/or surrounding geological formations. The main focus in this research task will be on the quantitative coupling of hydrological and (bio)geochemical processes. Special attention will be given to the processes that attenuate contaminants (e.g. sorption, precipitation, co-precipitation, and mineral transformation) or affect the hydrogeochemical conditions that govern these processes. The developed model will be used to predict the temporal evolution of the groundwater quality in/around mine waste deposits and to assess the sensitivity of model results with respect to dominant processes and hydrogeochemial conditions. The response of model results with respect to transient, natural processes, such as mineral dissolution and depletion, in a system with spatially variable hydrogeochemical properties will also be assessed.

The modelling methodology will be based on results from research efforts within the Predictive Modelling Project in the first phase of MiMi, other relevant modelling methodologies that have been reported in the scientific literature, and a conceptual model that has been developed within this research task during year 2001. Specifically, this methodology includes selection of relevant sub-system(s) and field site data for modelling and identification of dominant processes, as well as process quantification and coupling.

The developed model will be used to investigate the effect of reduced contaminant generation, as due to application of various prevention and control methods for environmental impact mitigation, on the groundwater quality downstreams from the contaminant source and its temporal evolution.

IV. Systems for passive leachate treatment
Co-ordinator: Karsten Håkansson, Swedish Geotechnical Institute

Wetlands are being used for passive treatment of leachate discharge at many locations, but with varying success. While there are many examples of well functioning wetland treatment systems, the loads of metals have in other cases been too high to maintain an operating ecosystem. High levels of Fe and Al have in several cases resulted in such extensive precipitation of secondary iron/aluminium minerals that even resistant plants have not survived. This has demonstrated the importance of keeping the metal load at a minimum. Based on these experiences it was decided to refrain from studying wetlands as a single method for treatment of leachate water, but rather as a final polishing step in a system of different measures. Thus, a sustainable use of wetlands for treatment of surface waters requires removal of a substantial fraction of the Fe content of the water. As is described above, Fe removal by precipitation and sedimentation can be utilised for contaminant attenuation.

A pilot scale settling basin will be constructed to demonstrate optimal conditions for retention of contaminants by association with a particulate phase, according to the sequence described above: 1) particle formation; 2) sorption; 3) particle aggregation and, 4) sedimentation, i.e. processes that can be optimised by applying a model combining biochemical and hydrological processes.

Natural wetlands retain metals mainly by adsorption on organic surfaces, retention of suspended particles and by the precipitation of metal sulphides, where the latter process is considered a more permanent metal sink if anaerobic conditions are maintained. In a constructed wetland, a design priority would be to create an environment where the maintenance of anaerobic conditions is favoured and the growth of sulfate reducing bacteria thus promoted. This places high demands on such factors as water flow and wetland geometry, while it is important to develop methods to sustain water saturation so as to maintain anaerobic conditions and to control potentially devastating effects of spring floods.

Previous studies within the MiMi programme in the natural wetlands surrounding R. Vormbäcken have concentrated on clarifying processes active in the immobilisation of metals, and the capacity to retain metals in this wetland. Studies have also been initiated regarding the uptake of metals by plants that can be utilised in immobilisation of metals from the wetland peat/sediments, or in a more permanent storage if the plant residues are incorporated in the system. A plan will be proposed for the construction of a wetland, based on field data from the R. Vormbäcken and knowledge on fundamental governing processes collected within the MiMi-programme, as well as on practical experiences obtained at field sites elsewhere in the world. The wetland construction will be a joint project with the research programmes Georange and PIRAMID.

Personnel

Lars Lövgren (UmU)	Project manager	50 %
Elsa Peinerud (LTU)	Senior researcher	10 %
Anders Widerlund (LTU)	Senior researcher	10 %
Jörgen Jönsson (UmU)	PhD-student	80 %
Sally Salmon (KTH)	PhD-student	45 %
Åsa Sjöblom (LiU)	PhD-student	90 % (9 months)
Roger Herbert (SU)	Senior researcher	10 %
Karsten Håkansson (SGI)	Senior researcher	20 %
Maria Malmström (KTH)	Senior researcher	15 %
Sten Berglund (KTH)	Senior researcher	10 %

Budget

Within an expected salary increase of 3 % for each year, the budget is (SEK)

	2002	**2003**
Salaries	1 461 000	1 006 000
Expenses	127 000	58 000
University overhead (40% of salaries)	493 000	309 000
Laboratory and field equipment, analyses etc.	150 000	60 000
Total costs	2 231 000	1 433 000

A7 Performance Assessment

The performance assessment project is the main core of the MiMi programme and is extensively described in Chapter 5. Goals and Deliverables for the Performance assessment project are identical with the programme goals programme deliverables specified in Chapter 3 and will not be repeated here. This project has significant dedicated resources as specified below, but will also make use of the resources in the six method-oriented projects when appropriate and necessary. However, the resources in the performance assessment project are also intended as a central resource available to the other six projects.

Personnel

Lars Olof Höglund, Kemakta	Project manager, Performance assessment methodology	25 %
Professor Ivars Neretnieks, KTH	Scientific co-ordinator, Performance assessment methodology	10 %
Professor Bert Allard, ÖrU	Scientific advisor, geochemistry and natural attenuation	5 %
Associate professor Börje Lindström, UmU	Scientific advisor, microbiology	5 %
Associate professor Luis Moreno, KTH	Scientific advisor, performance assessment and geochemical transport modelling	25 %
Dr. Mark Dopson, UmU	Senior scientist, microbiology	25 %
Dr. Kristina Skagius, Kemakta	System analysis	5 %
Håkan Svensson, Kemakta	Programme assistant, documentation	5 %
Resource, senior scientist	Performance assessment modelling	50 %

Budget

	2002	2003	Total 2002-2003
Salaries including social overhead	1 778 000	1 832 000	3 610 000
University overheads	404 000	462 000	866 000
Performance assessment – total	2 182 000	2 294 000	4 476 000

MISTRA

MISTRA is a foundation and as such must comply with the Swedish Foundations Act. The relevant paragraph from the statutes states that:

- The aim of the foundation is to support research of strategic importance for a good living environment.
- The foundation shall promote the development of robust research environments of the highest international class that will have a positive impact on Sweden's future competitiveness. The research shall play a significant role in solving major environmental problems and contribute to the development of a sustainable society. The potential for achieving industrial applications shall be realised as far as possible.

MISTRA distributes about SEK 250 million a year to environmental research. At the beginning of 2001, the foundation's capital amounted to SEK 4.7 billion. MISTRA applies the same principles of transparency as the government research councils.

MISTRA funds and organises research aimed at solving strategic environmental problems. A MISTRA programme is considered a success when scientifically advanced research has been put to practical use in companies, authorities or other organisations.

MISTRA funds about 20 or so major programmes, each of which should have a time span of between six and eight years. Major investment in interdisciplinary research programmes stimulates innovation, new options and new forms of cooperation, benefiting both Swedish environmental research as a whole and Sweden as a nation.

The Government appoints MISTRA's board and its chairman. The Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences and the Royal Swedish Academy of Agriculture and Forestry constantly audit MISTRA's activities. The audit reports are published.

MISTRA
Foundation for Strategic Environmental Research
Gamla Brogatan 36-38, 111 20 Stockholm, Sweden
Tel: +46-8-791 10 20, Fax: +46-8-791 10 29
E-mail: mail@mistra.org
Internet: www.mistra.org

The vision of the MiMi-programme

Twenty years from today the mining industry in Sweden is still strong and flourishing, using technologies that are internationally competitive and environmentally acceptable. The environmental standards are set high, since most of the ore deposits and mining activities are situated in sparsely populated areas with a very sensitive nature of high ecological and recreational value. Applying economic methods for processing and reuse of waste products, the release of heavy metals from waste deposits is kept low, the impact on the environment is small and restricted to the close vicinity of the mining areas. Methods used for waste disposal and remediation are efficient, robust and reliable so that, when any remediation is completed, a deposit can be left without the need for supervision or maintenance.

The MiMi programme has made it possible to predict the extent of environmental impact and has provided tools and methods to control and design processes and waste treatment systems already from investigation of the mineralogical and chemical composition of the ore and the wall rocks, and the local hydrology and topography. Furthermore, it is possible to design cost-efficient treatment systems for existing deposits of mining waste.

MiMi

Mitigation of the environmental impact from mining waste

Visit us at:

http://www.mimi.kiruna.se

ISSN 1403-9478
ISBN 91-89350-17-0