The Falun copper mine in BERGSLAGEN, Sweden

- Operation started around 1000
- The world´s largest copper mine in the 1600´s
- 30 Mtonnes of ore mined
  (400 ktonnes of Cu, 500 ktonnes of Zn produced)
- Operation closed in 1992

BERGSLAGEN

- a mining region some 60 000 km^2 in south central Sweden. The bedrock is a felsic metavolcanic rock, 1.9 a of age, and containing oxide (Fe) and sulphide (Cu, Zn,Pb) ores, often associated with crystalline carbonates.

Mining for copper is recorded from the 11th century (Falun), and over 100 mines were in operation in the early 20th century (3 today).

Remains from the mining activities are some 500 historic deposits, and traces can be seen at some 3000 places.

Bergskraft Bergslagen

is a programme that started around 2003 with the general objective: *New mining in the Bergslagen region*. Presently some 15 municipalities, several companies and one university (Örebro University) are engaged in *Bergskraft Bergslagen.*

Financiation: From the municipalities, companies, national research foundations and EU (regional development).

Control of metal releases from historic sulphidic mine waste - experiences from the test site at the Ljusnarsberg mine field, Sweden (Project *Bergskraft Bergslagen*)

A project within the *Bergskraft Bergslagen* programme at Man-Technology-Environment Research Center (MTM), School of Science and Technology, Örebro University SE-701 82 Örebro, Sweden

Objectives:

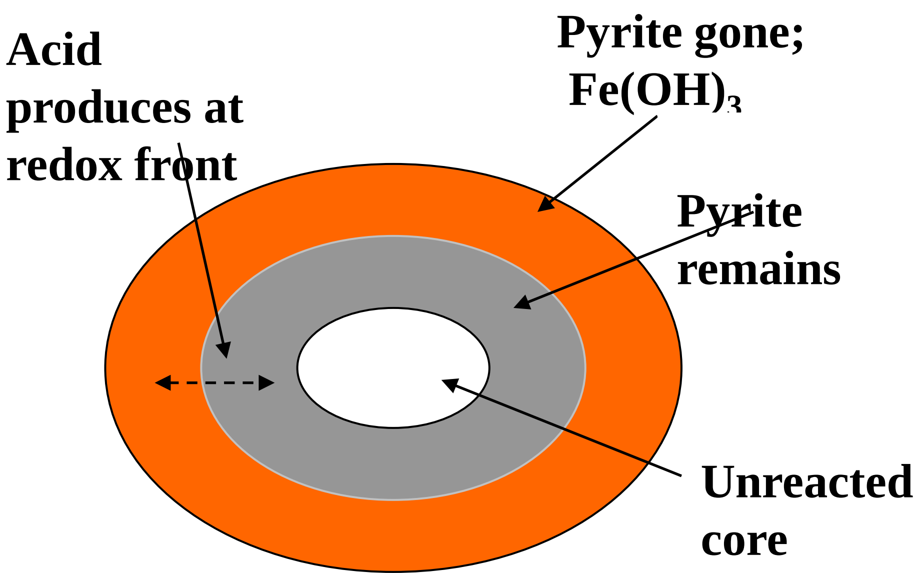
Test of barriers and additives for remediation purposes: Control of the weathering process and the spreading of metals by leachates from the historic mine waste deposit at Ljusnarsberg, Kopparberg

Ljusnarsberg, Kopparberg (”Copper Mountain”)

Sulphidic mine in operation from 13th century to 1905 and from 1940 to 1975.
Mine deposit: Some 300 000 m^3 of waste rock on 120 000 m^2

The weathering process

- Pyrite oxidation by O_2
- Hydrolysis and precipitation of Fe(III)
- Pyrite oxidation by Fe(III)



Historic or *Modern* mine deposits, is there a differens?

Historic or *Modern* mine deposits, is there a differens?

The weathering (=oxidation) of sulphide residues can progress with Fe(III) as electron acceptor in *a historic mine deposit* (containing Fe(III) precipitated on-site)

Covering of the deposit (to reduce in-flow of oxygen/air) does not stop the weathering and release of metals -

How good is a cover on a deposit if an elecron acceptor Fe(III) is present and mixed with unreacted sulphides?

Bergskraft Strategy

Test of barriers and additives for remediation and control of metal releases

- **Control of pH to above neutral level (above 9)**
- **Control of redox potential (to promote iron precipitation)**
- **Enhanced metal adsorption by active adsorbents**

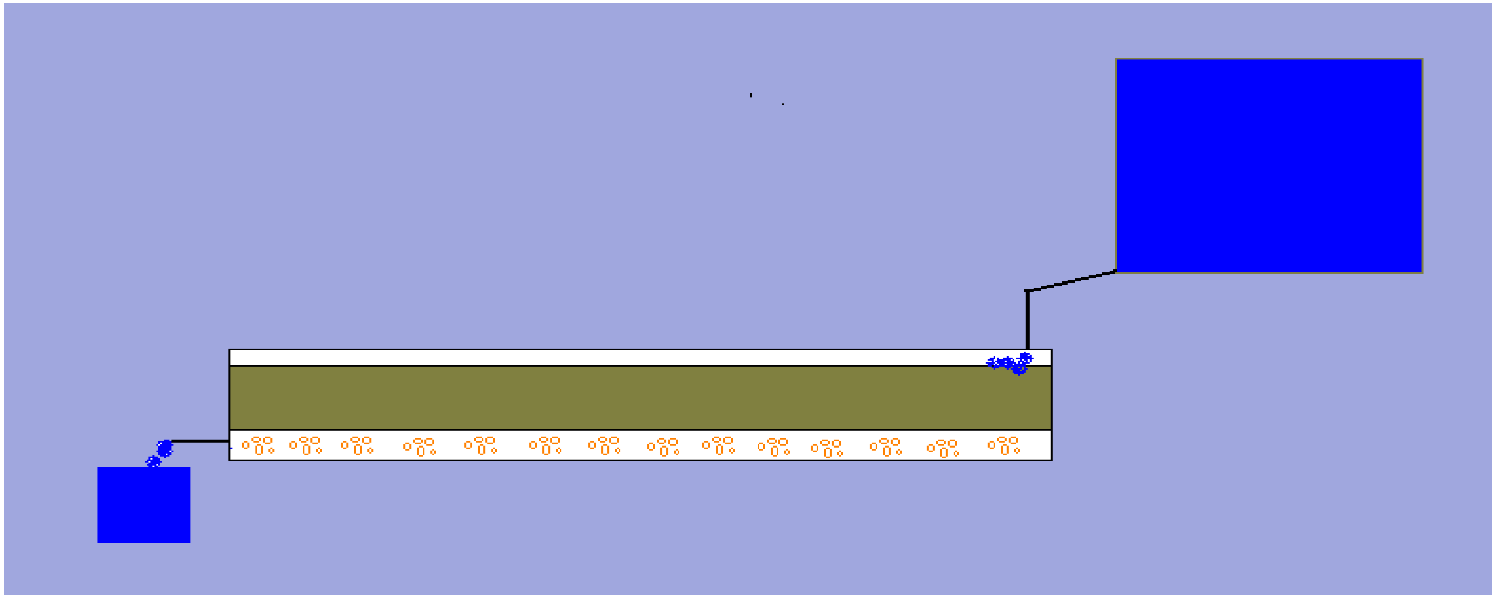
Use of cheap additives and components - waste products if possible

Test in the field (m^3 -scale) and in full scale (planned)

(1) Reactive barriers

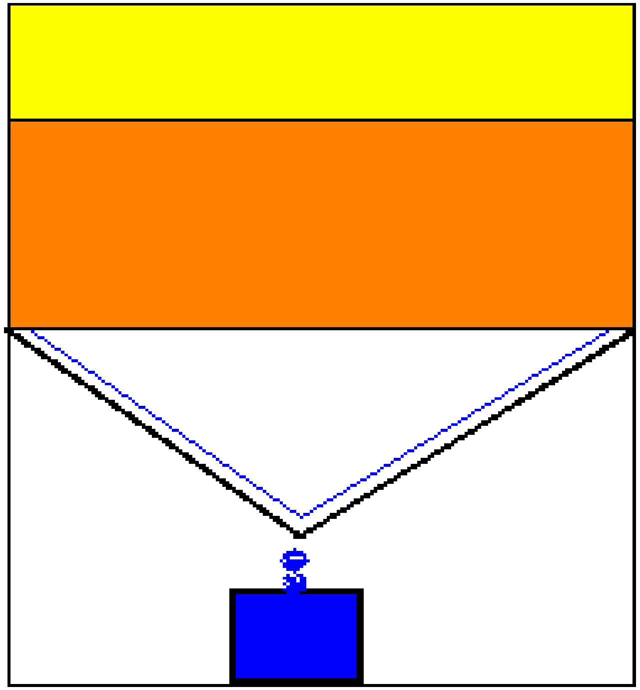
Lechates and mine water is passing through a horisontal filter section with various components:

- **pH-control**
- **Redox control**
- **Adsorption**



(2) Infiltration/injection

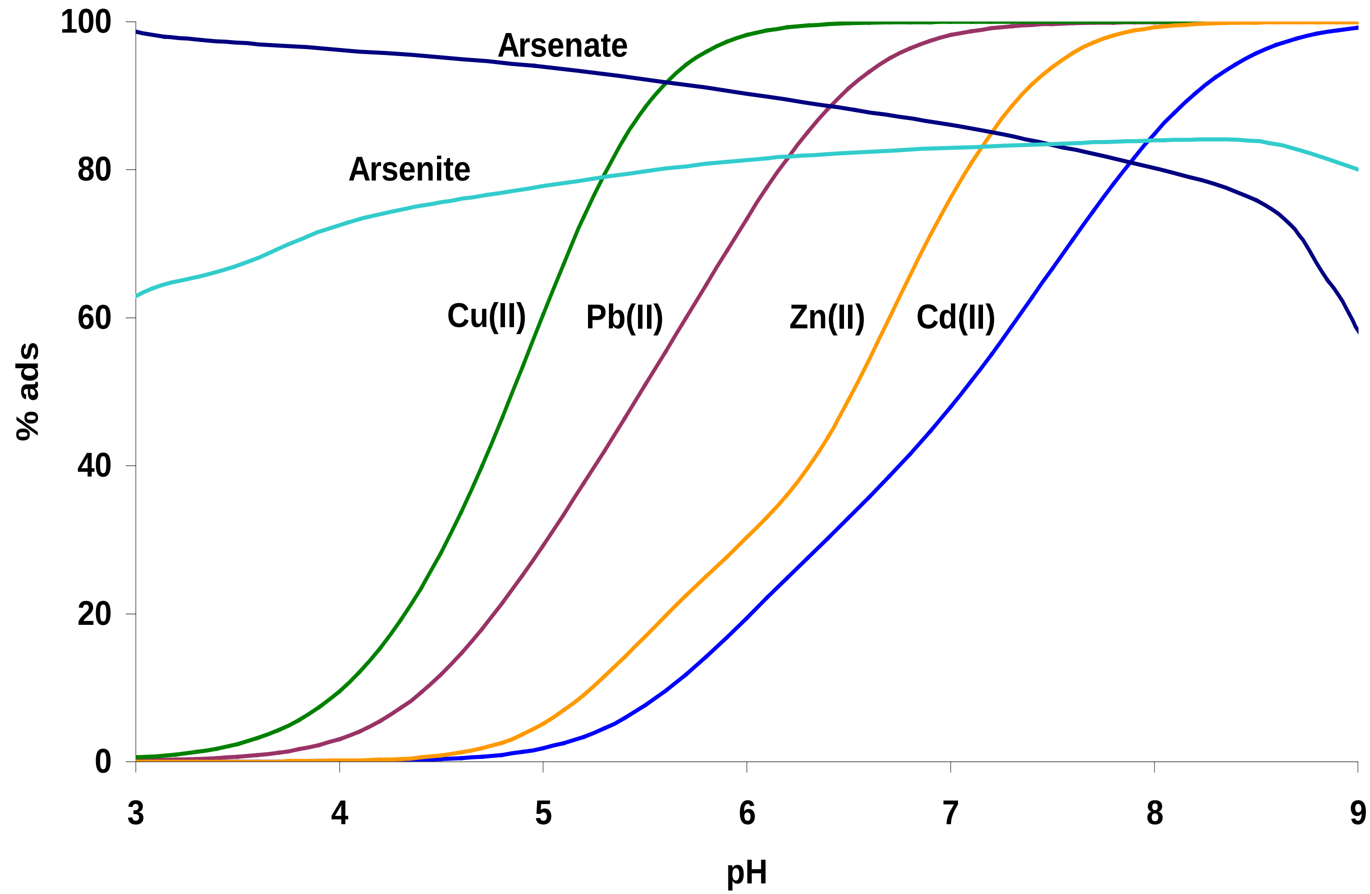
Mine waste is mixed with comonents (homogeneous mixture or layers of different composition) and exposed to water (precipitation)



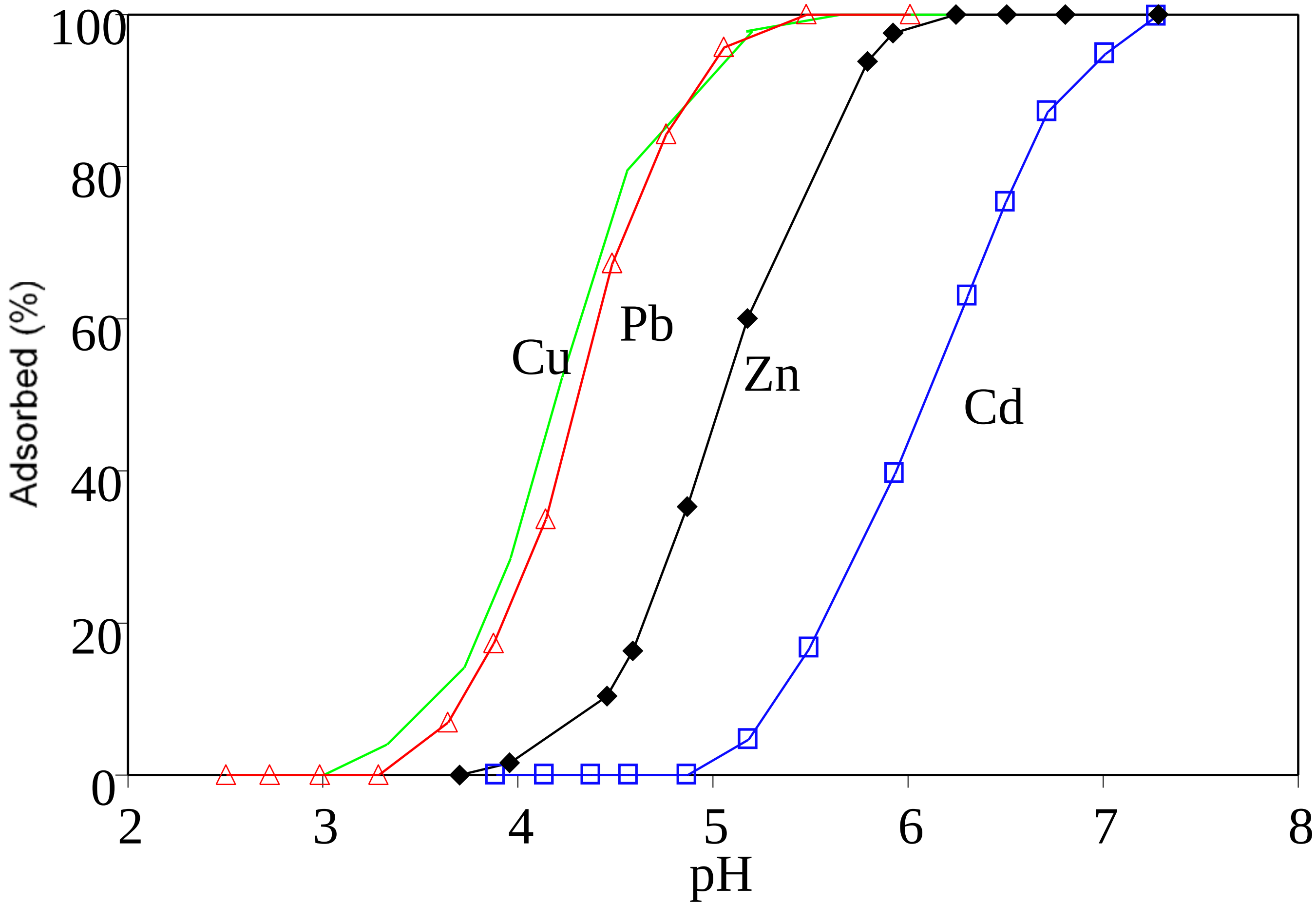
Components

- **Alkaline waste materials**
- **Adsorbing agents**
- **Support**

Adsorption vs pH on goethite



Adsorption vs pH on schwertmannite



Barrier tests

Barrier systems, each with three sections in sequence

Filling of Leca pellets and fly-ash (pH increase and aeration)

Infiltration/injection tests

Different combinations of mine waste and additives; stored at ambient temperature but in shelter

PERFORMANCE ASSESSMENT OF MINE WASTE - TREATMENT ALTERNATIVES

Focus on *remediation of historic sulphidic mine sites:*

- **Stabilisation of sulphidic mine waste - infiltration**
- **Reduction of metal releases by using reactive barriers**
- **Waste products as reactive agents for process control**
- **Recycling of metal-rich leachates into the deposit**
- **Recovery of metals from metal-rich leachates**
- **Performance assessment - choce of ”best practice”**
- **Over-all strategy for remediation of historic mine sites**

Örebro University

Start in 1999; up-grading from university college that started around 1960

- **3 faculties**
  - **Social Sciences and Humanities**
  - **Natural Sciences andTechnology, Business and Economy**
  - **Medical Sciences**
- **Ca 15000 students, (600 PhD students)**
- **Ca 1200 employees (100 professors)**
- **Turn-over ca 100 M E/year**

Man-Technology-Environment (MTM)

Man-Technology-Environment (MTM) **is a research centre and graduate school within the School of Science and Technology, Örebro University.**

History:

- **Project at Örebro University (1994) (=start)**
- **Program and Graduate School (1996)**
- **Research Centre (1999)**

PROJECT GROUP PARTICIPATING IN *BERGSKRAFT* (2010)

Bert Allard, Prof	Chemistry/Environ. Sci.
Mattias Bäckström, Ass. Prof	Environ. Chemistry
Alf Ekblad, Prof.	Soli Ecology
Stefan Karlsson, Ass. Prof	Environ. Chemistry
Andreas Oberstedt, Prof	Physics
Lotta Sartz, PhD student	Environ. Sci.
Viktor Sjöberg, PhD student	Environ. Sci.
NN, PhD student	Chemistry/Environ. Sci.
Stefan Sädbom, geologist	Ore Geology

Results from BERGSKRAFT, the test site

- A steady increase in pH in all systems, but still at neutral or slightly above (8.5 maximum)
- A prounced reduction of metal fluxes from the mine waste
- Appearance of ”new” metals from the additives (anionic; Cr, V, Mo)
- The systems have not reached steady-state after more than 2 years

Continuation:

- Field tests continue for a minimum of three years
- Up-scaling, implementation

FUTURE

- **New mines are opened - or old mines are re-opened, in the Bergslagen region**

- **Remediation of old mine sites are required before start of new operation`?**

PREVIOUS MINING WASTE MANAGEMENT PROJECTS

Bersbo; remediation of a mine site
Field program 1985-90; monitoring yearly since 1990

Ranstad; performance studies at a shale deposit
Field program 1989-92

Kristineberg; strategy for large-scale remediation (MiMi)
Field program 1998-2003

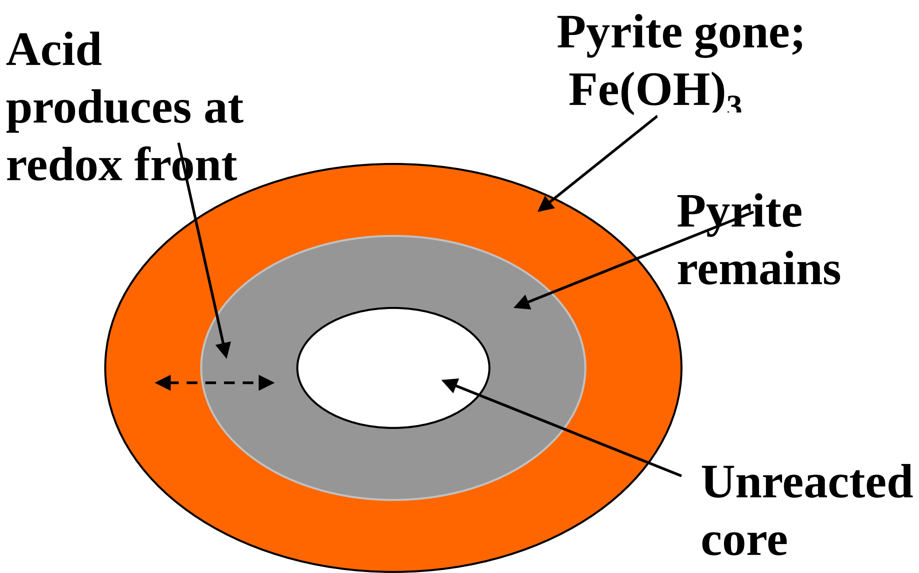
Ranstad; test av barrier system
Field program 1999-2001

The weathering process

- Pyrite oxidation by O_2
- Hydrolysis and precipitation of Fe(III)

Questions:

- **Other electron acceptors available?**
- **Presence of neutralizing agents?**



Pyrite oxidation by O_2

(1) $FeS_2(s) + 3.5O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2\,H^+$

Oxidation and hydrolysis of Fe(II):

(2) $FeS_2(s) + 3.75O_2 + 3.5H_2O = Fe(OH)_3(s) + 2SO_4^{2-} + 4H^+$

Pyrite oxidation by O_2

(1) $FeS_2(s) + 3.5O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2 H^+$

Oxidation and hydrolysis of Fe(II):

(2) $FeS_2(s) + 3.75O_2 + 3.5H_2O = Fe(OH)_3(s) + 2SO_4^{2-} + 4H^+$

Pyrite oxidation by Fe(III)

(3) $FeS_2(s) + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+$

At high pH:

(4) $FeS_2(s) + 14Fe(OH)_3(s) + 26H^+ = 15Fe^{2+} + 2SO_4^{2-} + 34H_2O$

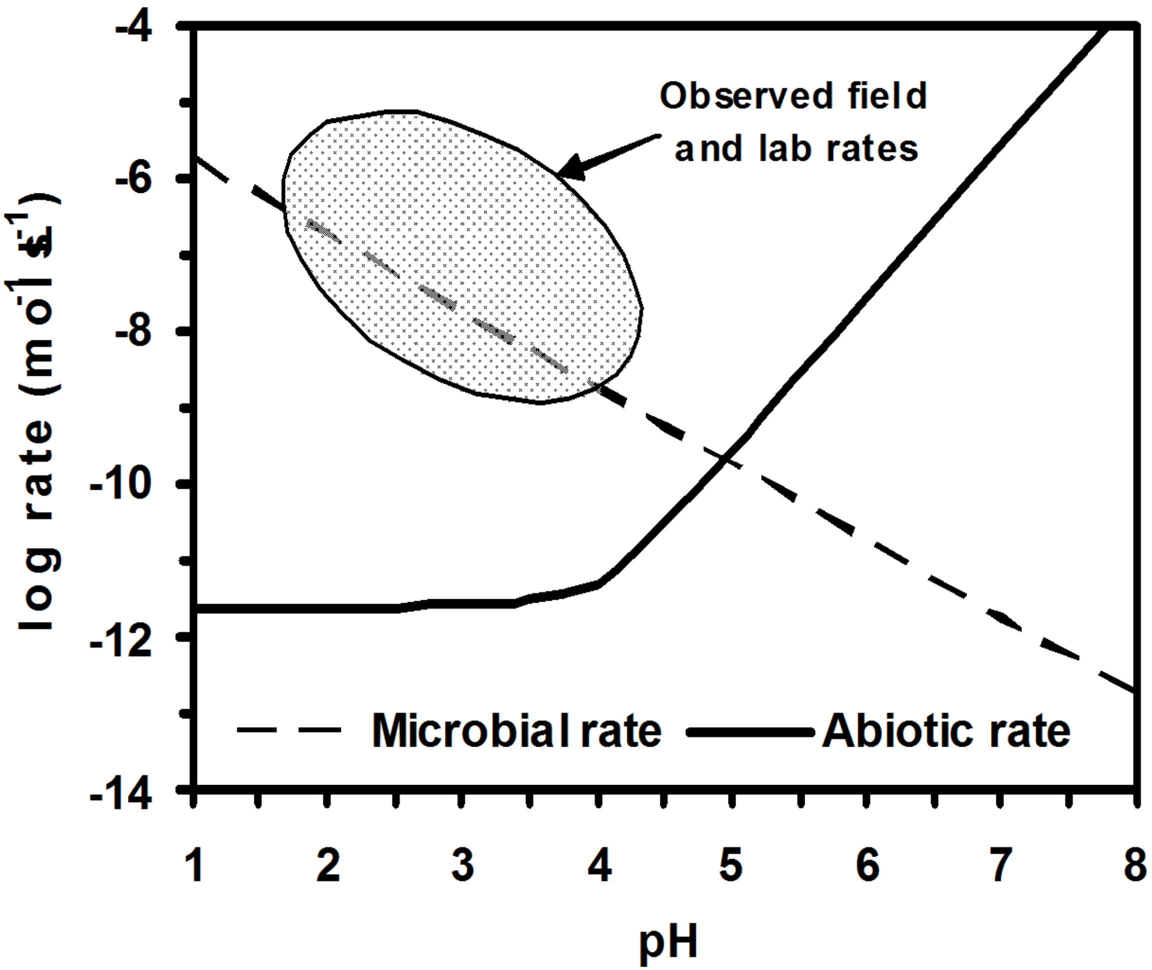
Oxidation, hydrolysis and precipitation of Fe(III)

(5) $Fe^{2+} + 0.25O_2 + 2.5H_2O = Fe(OH)_3(s) + 2H^+$

Critical questions:

- **Where is Fe(II) precipitated as Fe(III)?**
- **How fast is the sulphide oxidation by $Fe(OH)_3(s)$?**
  (rate = const x $[Fe(III)]^{0.6}$?)
- **Can the oxidation of sulphides proceed at *high pH* in the *absence of air*?**

Oxidation (with air) governed by microbial processes?



Components

Alkaline waste materials

- Lime kiln dust (from lime production)
- Green liquour dreg (from pulp and paper production)
- Steel slag (steel production residues)
- Bio-fuel fly-ash (incineration residues)

Adsorbing agents

- Peat nuggets
- Limestone
- Apatite (phosphate)
- Leca pellets (illite)

Support

- Crushed brick

PERFORMANCE ASSESSMENT OF MINE WASTE - TREATMENT ALTERNATIVES

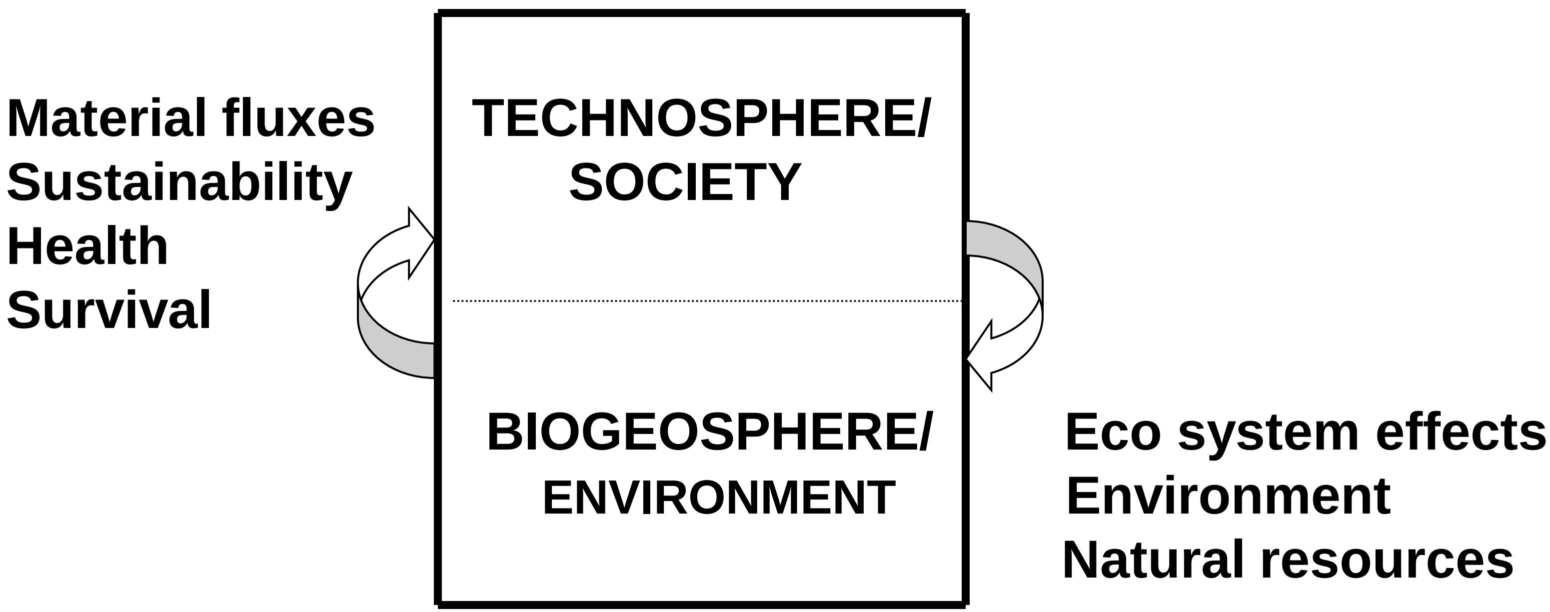
Test and demonstration (ex):

- **Sulphide oxidation by solid ferric oxyhydroxide**
- **Effects of various covers with organic carbon**
- **Accelerated leaching, cost effectiveness**
- **Evaluation of the suitability of various barrier meaterials**
- **Long-term efficiency of remediation measures**

PERFORMANCE ASSESSMENT OF MINE WASTE - TREATMENT ALTERNATIVES

Focus on *transformation and use of mine waste:*

- **Utilisation of mine waste - new products (e.g. pigments)**
- **Conditioning of sludges after precipitation of metals**
- **Recovery of valuable metals from slags**
- **Recovery of valuable metals from low-level waste**


Material fluxes
Sustainability
Health
Survival
TECHNOSPHERE/
SOCIETY
BIOGEOSPHERE/
ENVIRONMENT
Eco system effects
Environment
Natural resources