Biomining in giant mining operations: state-of-the-art and potential for development

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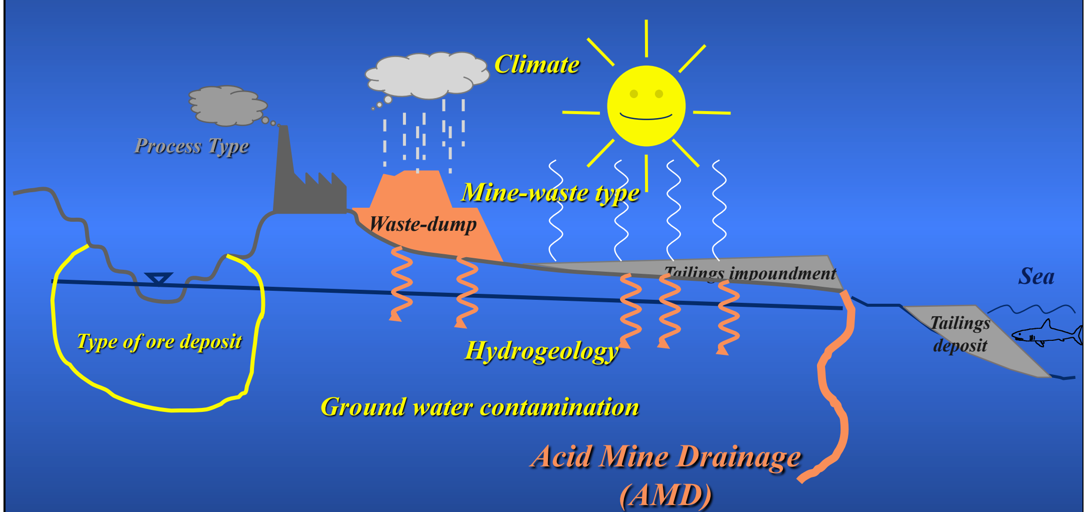
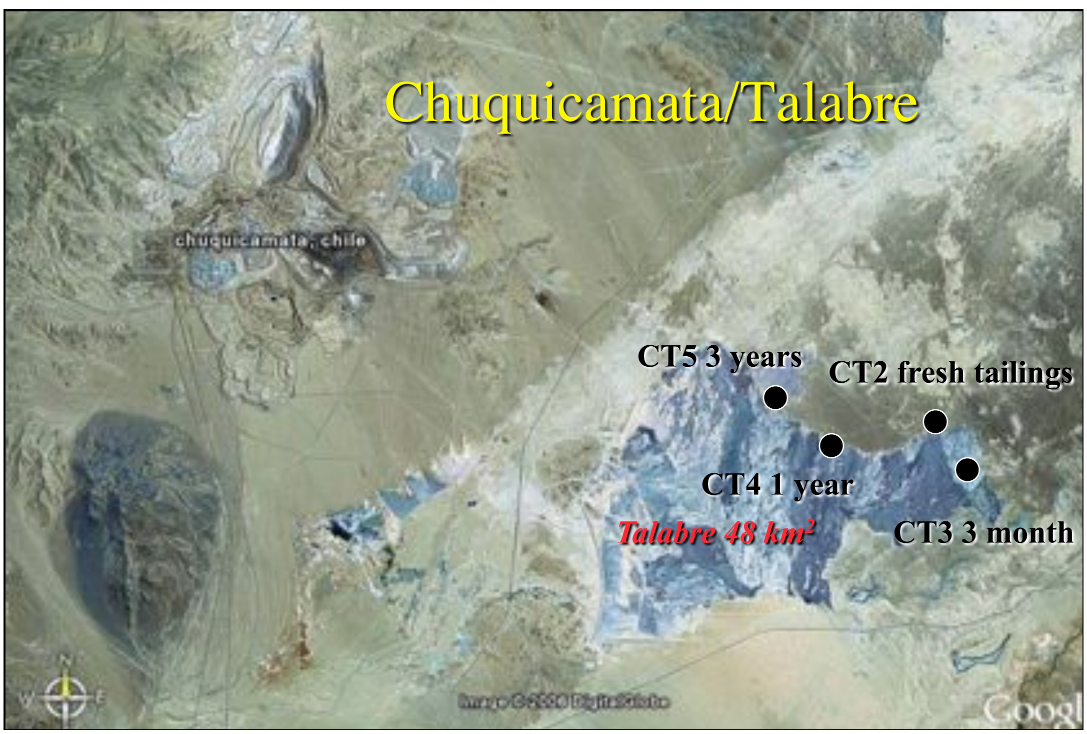
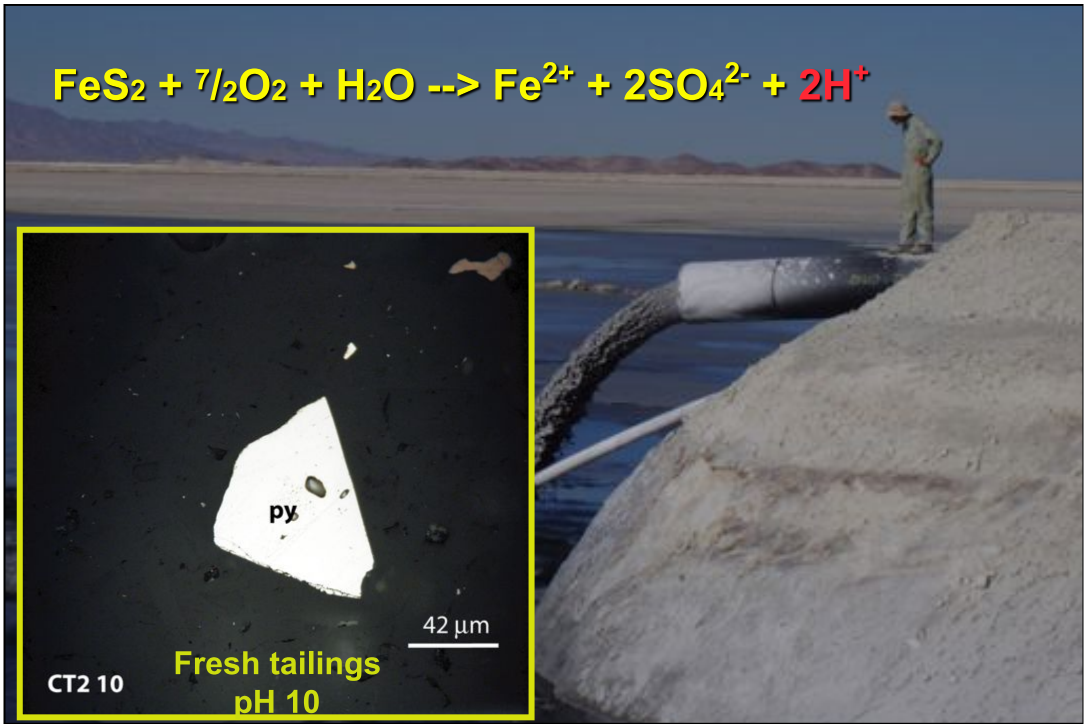
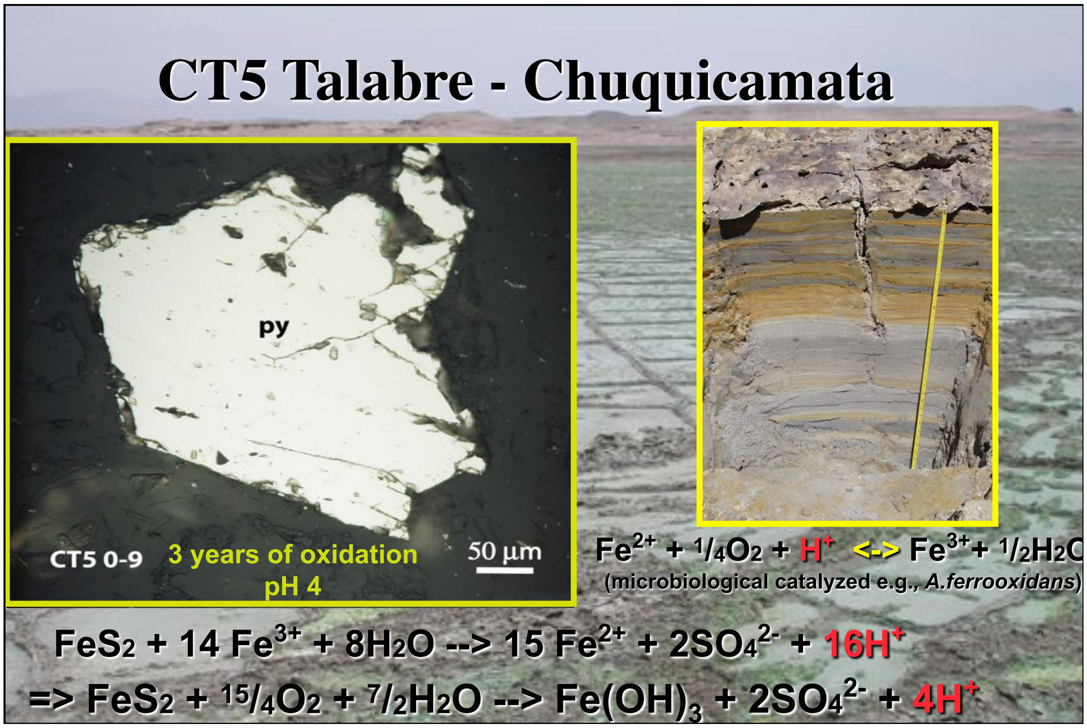
Mining and Environment

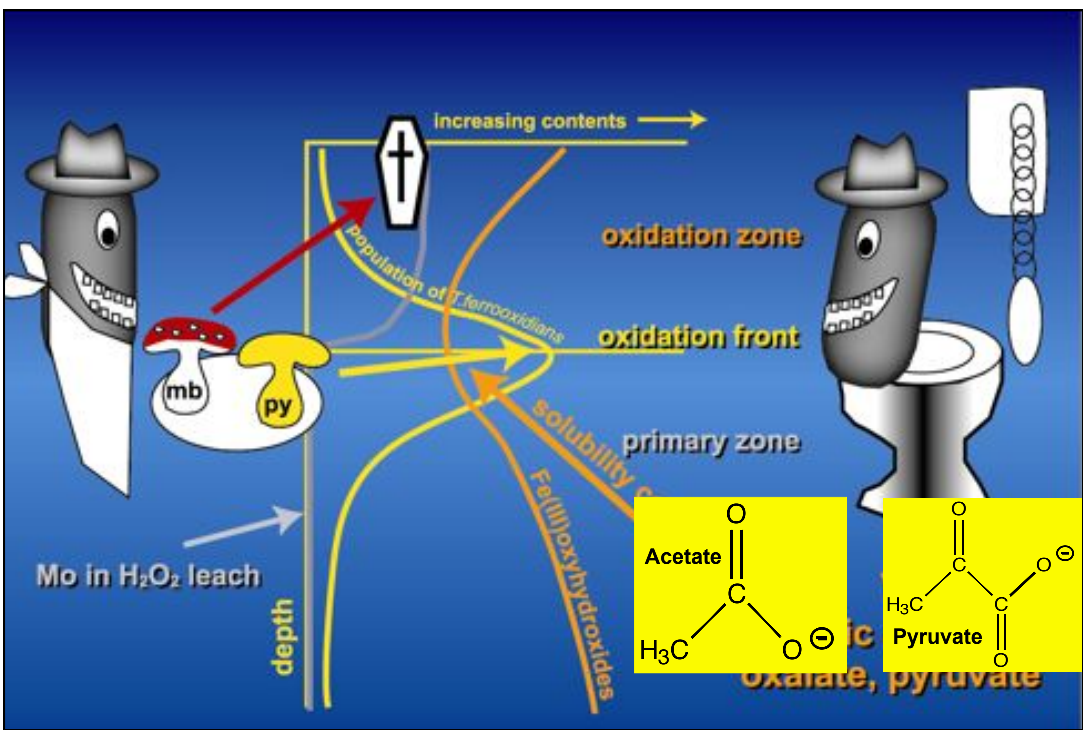


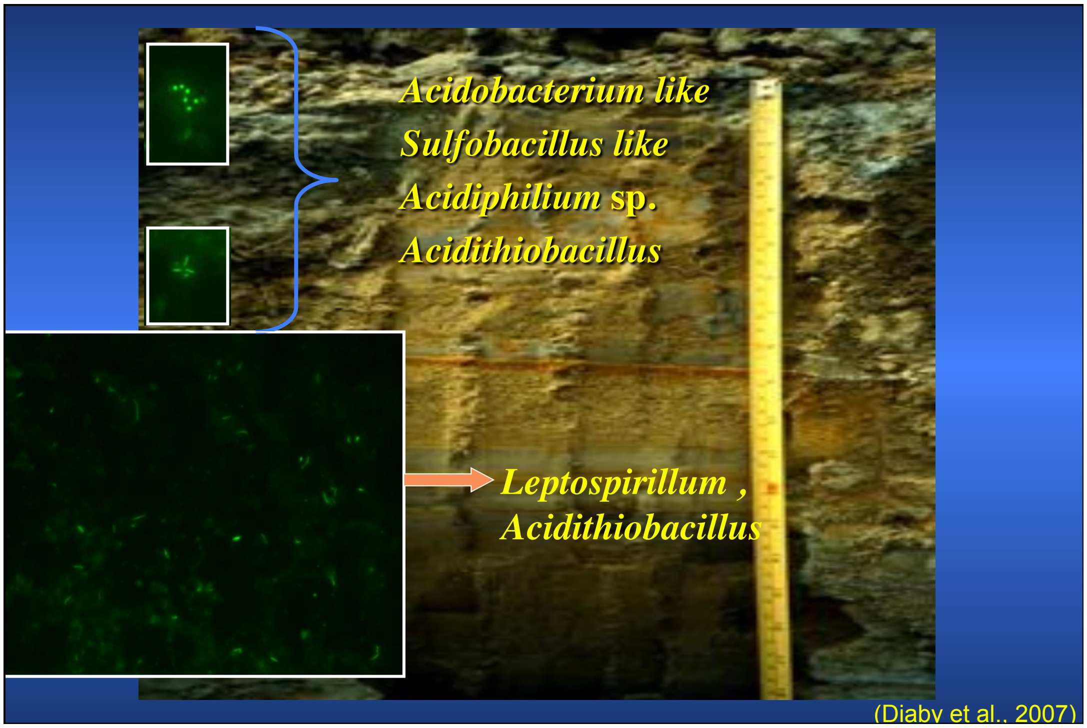

Chuquicamata/Talabre
chuquicamata, chile
CT5 3 years
CT2 fresh tailings
CT4 1 year
Talabre 48 km²
CT3 3 month

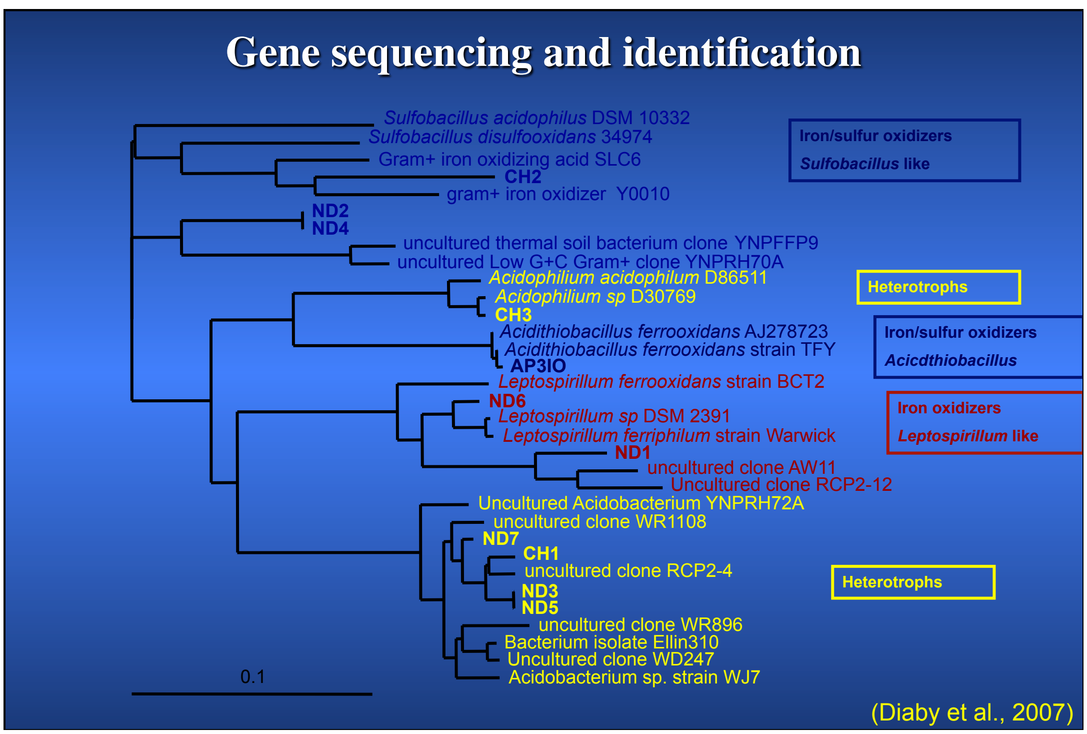

$FeS_2 + {}^7/_2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$
py
42 µm
CT2 10
Fresh tailings
pH 10

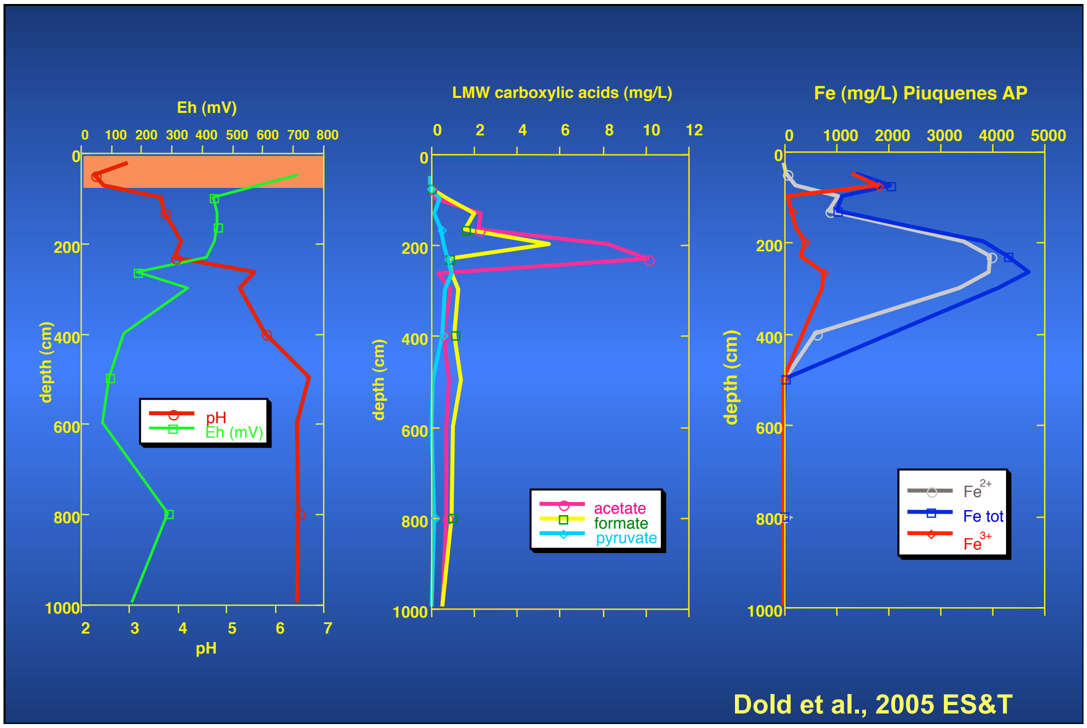

3 months of oxidation
pH 7-8
$Fe^{2+} + {}^1/_4O_2 + H^+ \leftrightarrow Fe^{3+} + {}^1/_2H_2O$
$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$
Fe-hydroxide
py
54 µm
CT3 10-35


CT5 Talabre - Chuquicamata
py
CT5 0-9
3 years of oxidation
pH 4
50 µm
$Fe^{2+} + {}^{1}/_{4}O_2 + H^+$ <-> $Fe^{3+} + {}^{1}/_{2}H_2O$
(microbiological catalyzed e.g., *A.ferrooxidans*)
$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15\ Fe^{2+} + 2SO_4^{2-} + 16H^+$
$\Rightarrow FeS_2 + {}^{15}/_{4}O_2 + {}^{7}/_{2}H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$

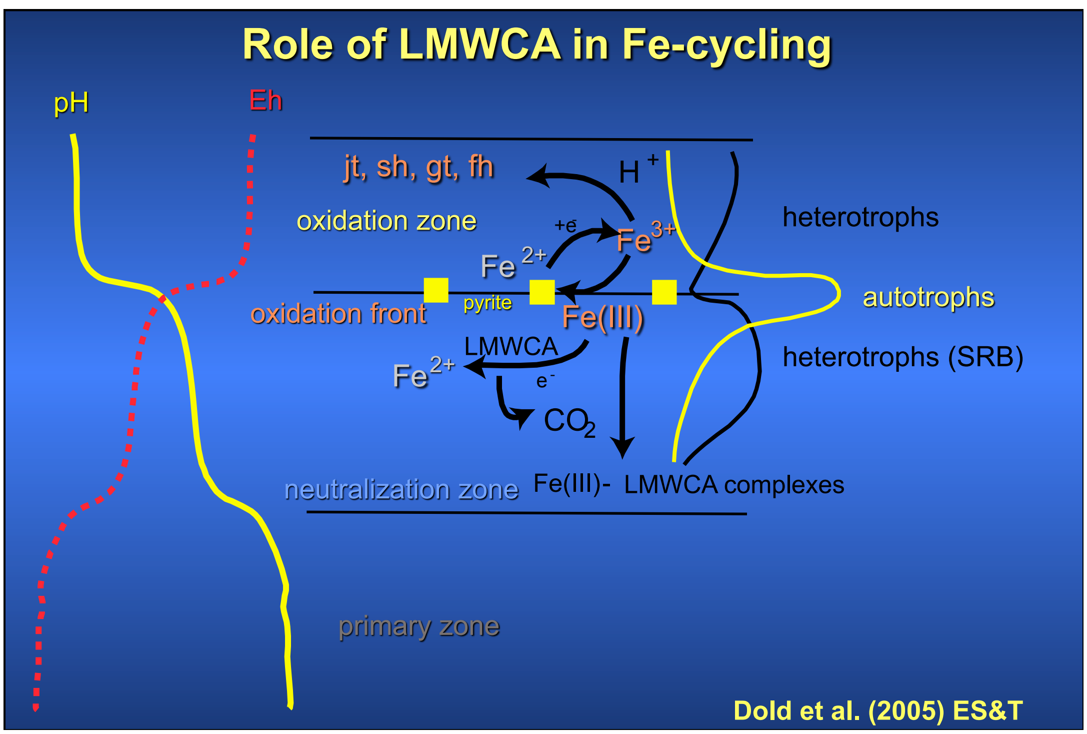

increasing contents
oxidation zone
population of T.ferrooxidans
oxidation front
primary zone
Fe(III)oxyhydroxides
Mo in H_2O_2 leach
depth
mb
py
Acetate
Pyruvate


Acidobacterium like
Sulfobacillus like
Acidiphilium sp.
Acidithiobacillus
Leptospirillum ,
Acidithiobacillus
(Diaby et al., 2007)

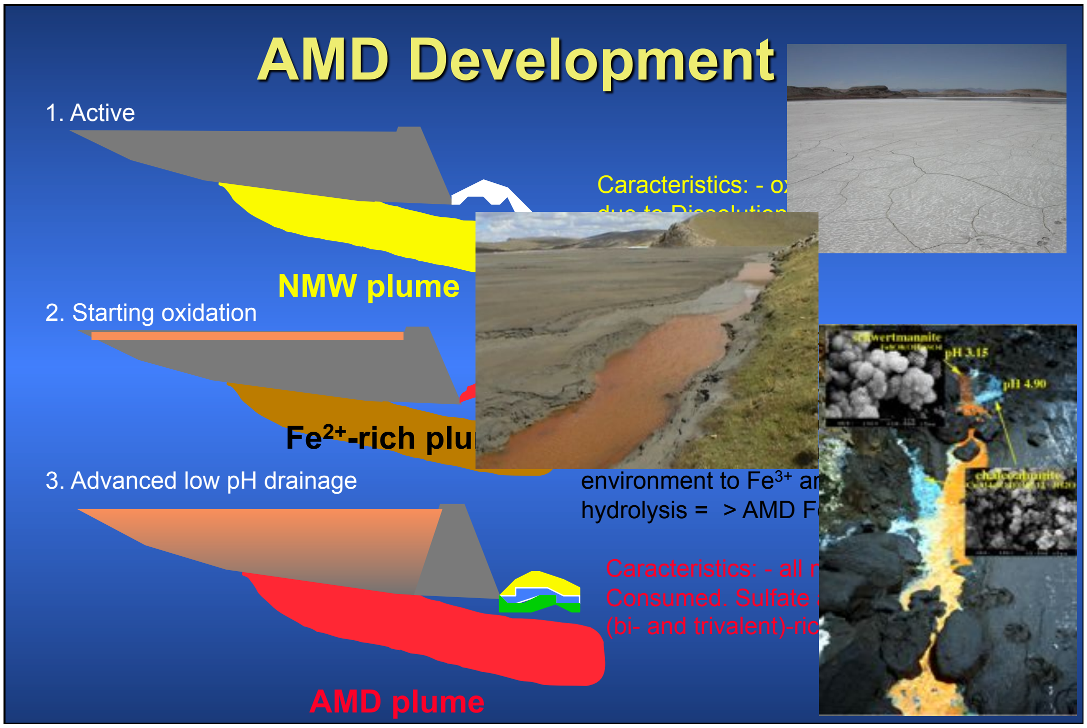

Gene sequencing and identification
Sulfobacillus acidophilus DSM 10332
Sulfobacillus disulfooxidans 34974
Gram+ iron oxidizing acid SLC6
CH2
gram+ iron oxidizer Y0010
ND2
ND4
uncultured thermal soil bacterium clone YNPFFP9
uncultured Low G+C Gram+ clone YNPRH70A
Acidophilium acidophilum D86511
Acidophilium sp D30769
CH3
Acidithiobacillus ferrooxidans AJ278723
Acidithiobacillus ferrooxidans strain TFY
AP3IO
Leptospirillum ferrooxidans strain BCT2
ND6
Leptospirillum sp DSM 2391
Leptospirillum ferriphilum strain Warwick
ND1
uncultured clone AW11
Uncultured clone RCP2-12
Uncultured Acidobacterium YNPRH72A
uncultured clone WR1108
ND7
CH1
uncultured clone RCP2-4
ND3
ND5
uncultured clone WR896
Bacterium isolate Ellin310
Uncultured clone WD247
Acidobacterium sp. strain WJ7
0.1
Iron/sulfur oxidizers
Sulfobacillus like
Heterotrophs
Iron/sulfur oxidizers
Acicdthiobacillus
Iron oxidizers
Leptospirillum like
Heterotrophs
(Diaby et al., 2007)

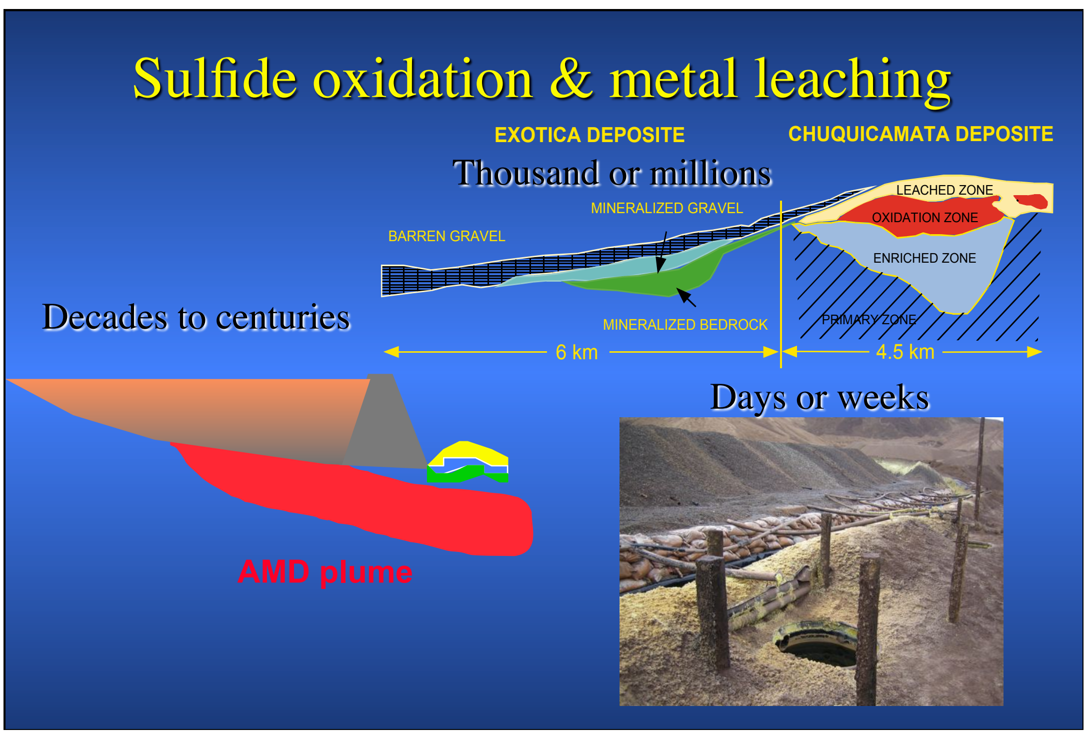


Eh (mV)
0 100 200 300 400 500 600 700 800
depth (cm)
pH
Eh (mV)
pH
LMW carboxylic acids (mg/L)
acetate
formate
pyruvate
Fe (mg/L) Piuquenes AP
Fe2+
Fe tot
Fe3+
Dold et al., 2005 ES&T



Role of LMWCA in Fe-cycling
pH
Eh
jt, sh, gt, fh
H+
oxidation zone
+e-
Fe3+
Fe 2+
heterotrophs
pyrite
autotrophs
oxidation front
Fe(III)
LMWCA
Fe2+
e-
CO2
heterotrophs (SRB)
neutralization zone
Fe(III)- LMWCA complexes
primary zone
Dold et al. (2005) ES&T


AMD Development
1. Active
Caracteristics: - ox
NMW plume
2. Starting oxidation
Fe2+-rich plu
environment to Fe3+ ar
hydrolysis = > AMD Fe
3. Advanced low pH drainage
Caracteristics: - all r
Consumed. Sulfate
(bi- and trivalent)-ric
AMD plume
pH 3.15
pH 4.90


Sulfide oxidation & metal leaching
EXOTICA DEPOSITE
CHUQUICAMATA DEPOSITE
Thousand or millions
LEACHED ZONE
OXIDATION ZONE
ENRICHED ZONE
PRIMARY ZONE
MINERALIZED GRAVEL
BARREN GRAVEL
MINERALIZED BEDROCK
6 km
4.5 km
Decades to centuries
Days or weeks
AMD plume


Goal: Sustainable Mining
Mine waste Management
Acidobacterium like
Acidiphilium sp.
Acidithiobacillus
Controlled Management, Prevention, Remediation
Leptospirillum
Sulfobacillus like,
Acidithiobacillus
Sulfate Reducing Bacteria (SRB)
EXOTICA DEPOSITE
CHUQUICAMATA DEPOSITE
Supergene Enrichment
BARREN GRAVEL
LEACHED ZONE
OXIDATION ZONE
ENRICHED ZONE
Exploration
6 km
4.5 km
Biomining
Increased of Metal recovery
Less contamination of CO_2 and SO_2
and less energy & water

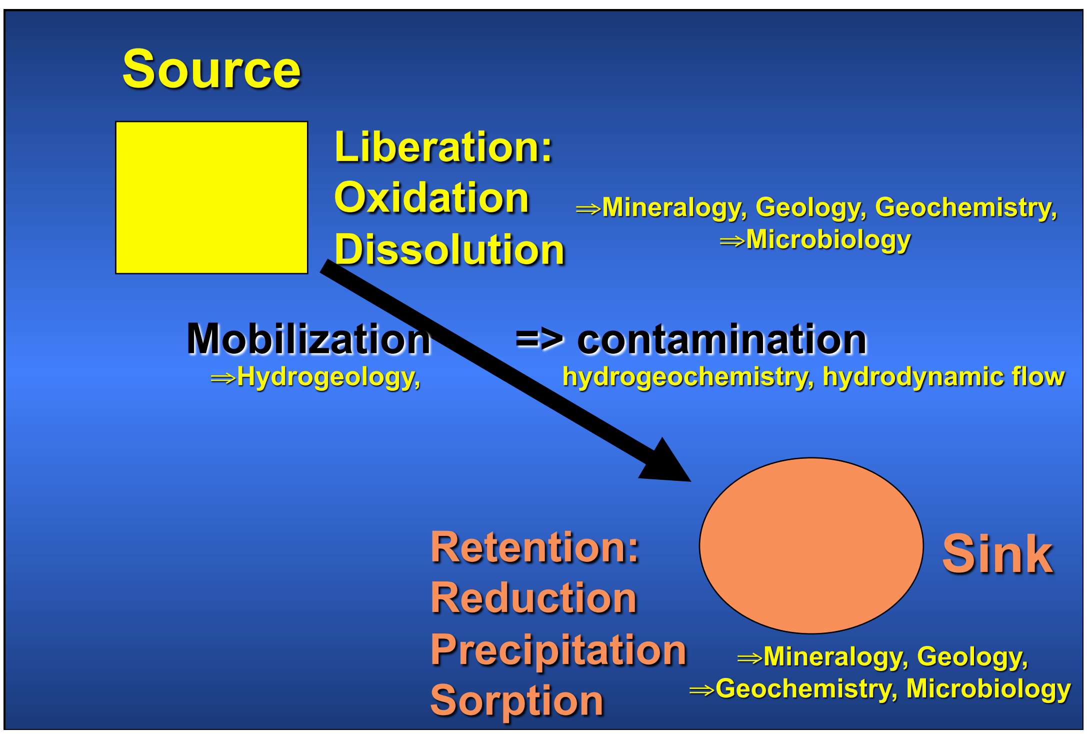
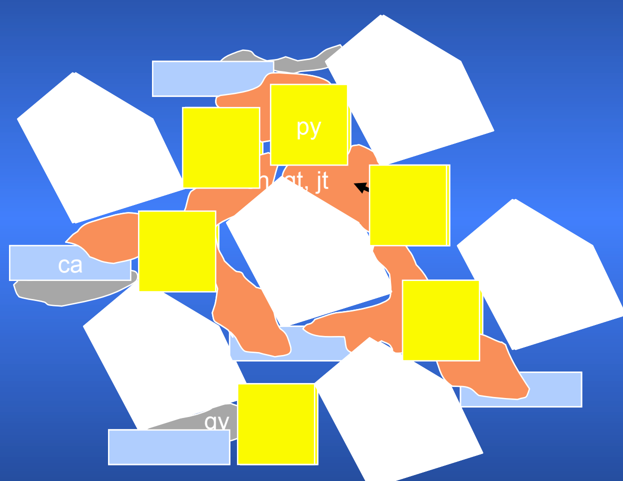

Source
Liberation:
Oxidation
Dissolution
⇒Mineralogy, Geology, Geochemistry,
⇒Microbiology
Mobilization
=> contamination
⇒Hydrogeology,
hydrogeochemistry, hydrodynamic flow
Retention:
Reduction
Precipitation
Sorption
Sink
⇒Mineralogy, Geology,
⇒Geochemistry, Microbiology

Table 1: Average concen trations of metals in the earth crust with the average concentrations exploited by mining and the enrichment factors. Some concentrations of element still present in mine tailings are shown to highlight the still strong enrichment of these elements in the waste material. Modified after (Evans, 1993).

Metal	Ø Crust (%)	Ø by mineral exploitation (%)	Enrichment Factor	Ø In mine tailings	Enrichment Factor tailings
Cu	0.005	0.4	80	0.1 – 0.3	20 - 60
Ni	0.007	0.5	71	0.2	28.4
Zn	0.007	4	571	2 – 4	275 - 571
Mn	0.09	35	389		
Sb	0.0002	0.5	2500		
Cr	0.01	30	3000		
Pb	0.001	4	4000	1 - 2	1000- 2000
Au	0.0000004	0.0001	250		

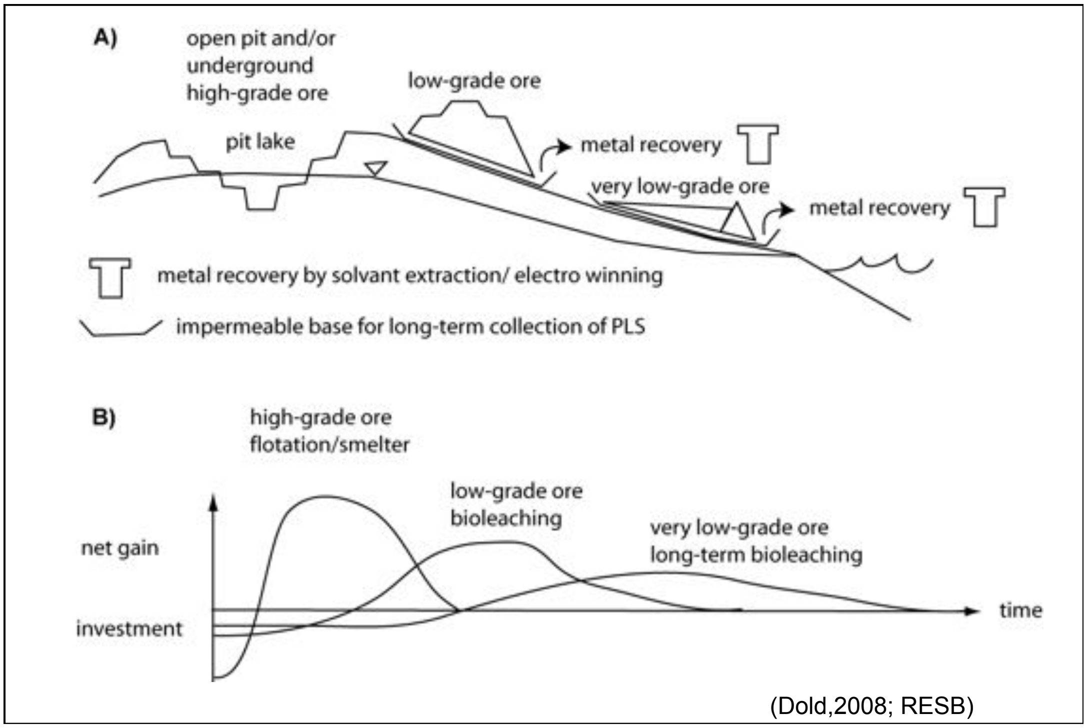
(Dold,2008; RESB)

Sequential Extraction



Classification after Jambor (1994):
- primary mineralogy
- secondary mineralogy
- tertiary mineralogy
- quartinary mineralogy

Dold (2003); JGE


A)
open pit and/or
underground
high-grade ore
low-grade ore
pit lake
metal recovery
very low-grade ore
metal recovery
metal recovery by solvant extraction/ electro winning
impermeable base for long-term collection of PLS
B)
high-grade ore
flotation/smelter
low-grade ore
bioleaching
very low-grade ore
long-term bioleaching
net gain
investment
time
(Dold,2008; RESB)


Morrillo
Cadera
Costillar
Falda
Pecho

Conclusions

Biomining in leach dumps in giant Cu mining is extremely ineffective

(70-90 % of the resource remains untouched!)

Criteria for bioleaching is ore grade, NOT mineralogy!!!

Principally only acid soluble Cu is leached

Real bioleaching of chalcopyrite is not reached.

Leach dumps do not have impermeable basement!

Potential

Convince the mining operation that:

1. They can do better (difficult with the actual metal prices!)
2. Characterization of the ore in order to build segregated deposits for optimized recovery
3. To built the deposit in order to increase temperature to reach 50-60°C (thermophile archea)
4. Additional heat source is needed (pyrite?)
5. Control of Temperature and air flow in the system
6. Control of PLS on long-term
7. Control of secondary mineralogy and chemistry of the solution is needed to prevent precipitation and inhibitation
8. Search for additional values in the material and development of extraction techniques