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Weathering mechanisms and composition of effluents from a sulphide mine waste deposit after covering – Twenty years of field data

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Bersbo

Mining operations

- Began in the 14th Century
- Rational since 1765
- Peak production 1855-70
- Ended in 1902
- Remediated 1987-89

32,000 tonnes Cu
700,000 m³ waste
1.5 MTonnes
0.5 km²

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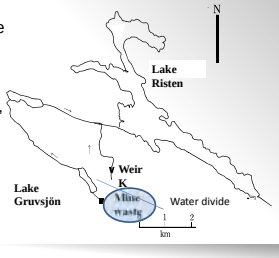
Geology
Leptitic granite with amphibolitic intrusions and mica schists

Late intrusions of young alkaline granite

Sulphidic ore veins of:
Pyrite, chalcopyrite, sphaelerite, galena

The ore contained
25% S, 20% Fe, 0.5-3% Cu, 1-3% Zn, 1% Pb



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Environment

Till on top of glacial clay with calcareous shells (clay underneath the waste rock)

Coniferous forests, agricultural fields downstream of the mine

Bog areas upstream of the mine

Annual precipitation: 650 mm

(70% evapotranspiration, 30% run-off)

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ARD chemistry

Leachate

SO_4^{2-}	500-1000 mg/l
Fe	3-100 mg/l
Zn	60 - 90 mg/l
Cu	8 - 15 mg/l
pH	3.2 - 3.9

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Groundwater chemistry

Ca - SO_4^{2-} - CO_3^{2-} -type
pH 7.1 - 7.8
Alkalinity 2.5 - 3 meq/l
Salinity 500 mg/l
Cu, Zn, Cd, Pb; high levels but within the range of granitic groundwaters

Surface water chemistry

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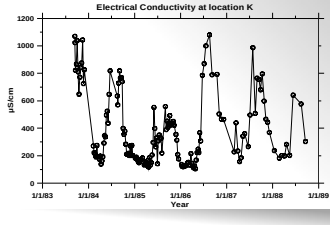
Ca - Na - SO_4^{2-} -type
pH 4.9 - 5.3
TOC 15 - 25 mg/l
Salinity 100 mg/l

Small catchment
High variability
Seasonal
Rainfalls
Redistribution



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Remediation in 1987-89

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- Open shafts were filled
- Waste rock was moved to one continuous area; partial liming (eastern part)
- The deposit was completely covered:
  - West of the water divide: Cement stabilized fly ash from coal fuel, 0.3 m
  - East of the water divide: Illitic clay, 0.3 m
  - Cover of glacial till over the area, 2 m

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Surface water monitoring

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- Weekly sampling from 1983 until 1989
- Monthly sampling from 1989 until 1998
- Sporadic sampling in 2002 and 2009
- Performance study in 2007

Some 15 sampling locations
+ 50,000 quality observations

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Weathering processes

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Presence of air

Oxidation of pyrite with O_2 in two steps -

1) Sulphide to sulphate

$FeS_2(s) + 3.5O_2 + H_2O \Rightarrow Fe^{2+}(aq) + 2SO_4^{2-} + 2H^+$

2) followed by Fe(II) to Fe(III) and hydrolysis

$Fe^{3+} + 3H_2O \Rightarrow Fe(OH)_3(am) + 3H^+$

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Weathering process

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Absence of air

Oxidation of pyrite with Fe(III) in two steps –

1) Sulphide to sulphate with simultaneous reduction of Fe(III) to Fe(II)

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

Or

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

(and subsequent oxidation to Fe(III) by the introduction of air)

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Sulfate/iron-ratio

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	SO_4^{-2}/Fe
$FeS_2 + O_2 = = Fe^{2+} + SO_4^{2-}$	2
$FeS_2 + Fe(III) = = Fe^{2+} + SO_4^{2-}$	0.13
$Fe^{2+} + O_2 = = Fe(OH)_3$	>>2

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Site West A

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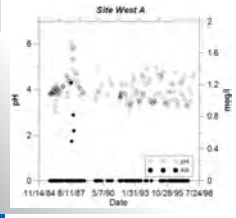
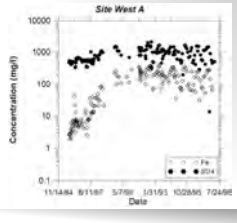
- Time series – monthly averages
  - Non proportional increase of Fe and SO_4^{2-}





Site West A

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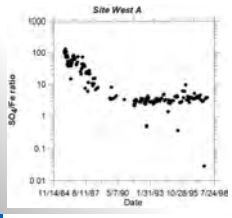
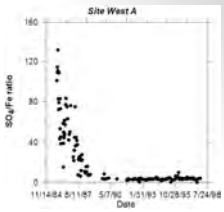
- Time series – monthly averages
  - Fe/SO_4^{2-} lowered





Site West B

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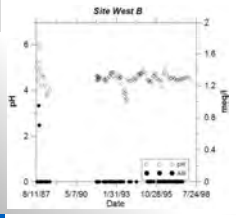
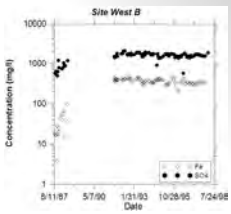
- Time series – monthly averages
  - Non proportional increase of Fe and SO_4^{2-}





Site West B

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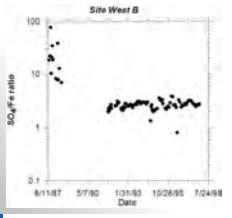
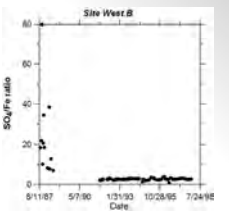
- Time series – monthly averages
  - Fe/SO_4^{2-} lowered





Site East A

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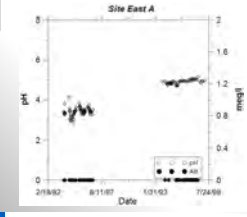
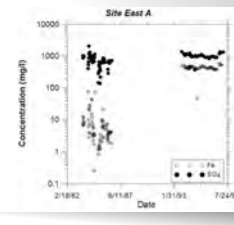
- Time series – monthly averages
  - Non proportional increase of Fe and SO_4^{2-}





Site East A

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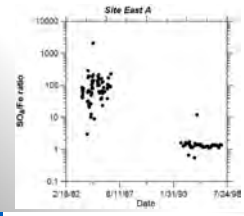
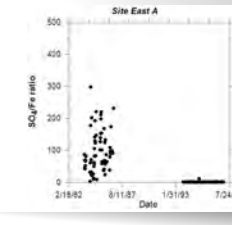
- Time series – monthly averages
  - Fe/SO_4^{2-} lowered





Proportions of other elements – East A & West A

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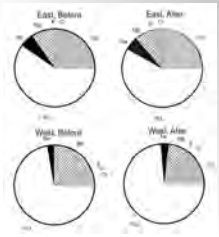
- West– CeFill
  - Mg - lowered
  - Ca – Small increase
- East – Illitic clay
  - Mg – lower
  - Ca – increase
  - SO_4^{2-} - increase
- A result of sealing materials and change in water balance



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Results - Average

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Parameter	West Site A		West Site B		East Site A		East Site B	
	Before	After	Before	After	Before	After	Before	After
Fe (mg/l)	34.3	366	14.2	191	8.9	431	5.0	nd
SO_4^{2-} (mg/l)	790	1619	567	1028	737	1026	602	nd
pH	4.60	4.51	4.17	3.87	3.42	4.91	3.39	nd
SO_4^{2-}/Fe	22.0	2.61	48.6	3.54	122	1.50	89.2	nd
n	24	96	47	105	73	47	61	nd

Lowered Fe/SO_4^{2-} ratios indicate new release mechanisms

A) $FeS_2 + Fe(III) \text{ --- } Fe^{2+} + SO_4^{2-}$ 0.13

B) $FeS_2 + O_2 \text{ --- } Fe^{2+} + SO_4^{2-}$ *2*

C) $Fe^{2+} + O_2 \text{ --- } Fe(OH)_3$ >>2

Before Mechanism B/C

After Mechanisms A and possibly some C

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Conclusions

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According to the Fe/SO_4^{2-} ratio

Oxidative weathering before covering

Anoxic weathering after covering

Periods with Fe(III) as oxidizing agent

Changes in water balance important

Increased loading of iron

Increased acidification

Hydrolysis of released Fe(II)

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Thank you

For your attention

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