Neutralisation distance of acid drainage and migration range of pollutants

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Issues with Acid mine drainage (AMD)

> **What everybody knows about AMD (MEND,...)**
- one of the biggest environmental issues of mining,
- releases massive amounts of solubilised metals, metalloids and salts in surface water
- both active and closed mines, may begin after closure
- close relationship between neutralisation and contaminants release

> **Focus here on former mines**
- naturally occurring neutralisation in the downstream drainage
- effects of passive barriers

Basin management in mining or former mining regions

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Issues with AMD: basin management in mining or former mining regions

> **The Source – Flow – Target scheme**
- AMD source evaluation through Acid Base Accounting (ABA) of solid waste
- Flow evaluation from hydrology and geochemistry: metals, metalloids and salts as solutes, precipitated or further carried away in solid form as sediments
- Target identification and assessment downstream

Location of potential targets depends upon neutralisation and precipitation dynamics

Independent from ABA source assessment

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Issues with AMD neutralisation

> **Neutralisation processes**
- Natural attenuation in watercourses
- Mine water neutralisation with passive barriers
- Mine water neutralisation by active treatment

> **Neutralisation distance**
- Neutralisation is accompanied by the gradual precipitation of most pollutants,
- deposited or further carried away in solid form as sediments.

Good practice in mining management: waste facilities design, mine water management, neutralisation

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Case studies

India
- Subarnarekha: Cu, Ni, U

Greece
- Kirki: Cu, Zn, Pb

Romania
- Calimani, S

France
- Huelgoat: Pb

Litterature references
- Iberic Pyritic Belt
- Cornwall Tin Belt

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Methods

> **Field measurements**
- pH, electrical conductivity (EC), ORP, DO, alkalinity
- Water flow
- Water samples filtration: 0.45 or 0.1 µm
- Periodic monitoring campaigns to evaluate the effects of seasonal variations on the neutralisation range

> **Laboratory analyses**
- Major and trace laboratory analyses, carried out by ICP/AES, ICP/MS and/or AAS
- Sediments by partial extraction or total digestion
- Acid base accounting (ABA) of solid waste
- Reference to acid water and to neutralisation from European Directives: lower guide value of pH 6.5

Data required to calculate acidity and metals flow or balance

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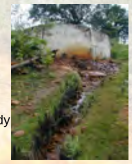
India

> **Site**
- Singhbum copper district – Cu Ni U Zn Ag
- AMD at several mines, especially at Surda

> **Acidity flow**
- Mine drainage flows down a hill slope, then reaches paddy rice fields on the flat alluvial beds of Subarnarekha river
- Brook discharge negligible vs river discharge
- Neutralisation zone (0.6 to 2.3 km from runoff) along the hill slope and at the beginning of the alluvial plain
- Monsoon rains shift slightly downwards the neutralisation front
- Most of the precipitation and sedimentation at the break in slope
- Metal transfer occurs further downstream as particulate transport.

> **Host geology**
- Silicic volcanosedimentary formations
- Fracturation




Fast neutralisation but transfer continues

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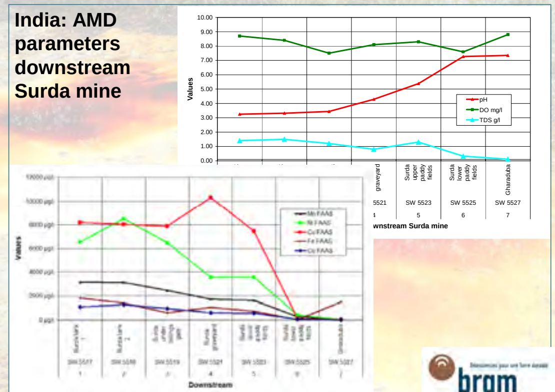
India: AMD parameters downstream Surda mine



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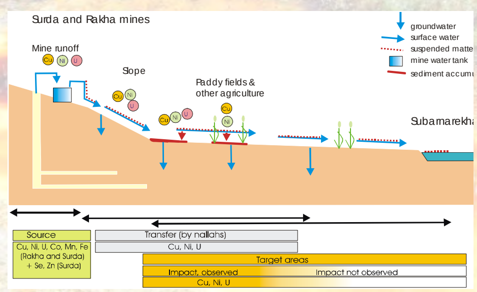
Factors



Neutralisation point and sediment precipitation are close to each other, near the slope break

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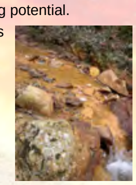
Greece, Kirki

> **Site**
- Kirki abandoned Cu-Zn-Pb mine in NE Greece
- Uncontrolled AMD occurs with Cd pollution
- Mediterranean, with stormy rainfall regime

> **Host geology and geomorphology**
- Silicic volcanosedimentary– high fracturation
- Drainage is channelised into a narrow volcanosedimentary gorge, with little or no buffering potential.
- Extensive formation of biofilms





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Greece, Kirki

> **Acidity flow**
- Acidic water in contact with oxidised mine and pit walls (pH 2.9)
- further acidified (pH 1.5) and enriched in metals (up to 240 mg/l Zn and 2.4 mg/l Cd) while percolating sulphide-rich waste piles.
- Neutralisation range between 600 m and 2 km according to seasonal rainfall and discharge
- Torrential regime, favouring oxidation, neutralisation and flushing, but also transfer of pollutants in solid rather than solute form.
- Despite neutralisation in the downstream gorge, Cd-Zn pollution is observed downstream to the sea

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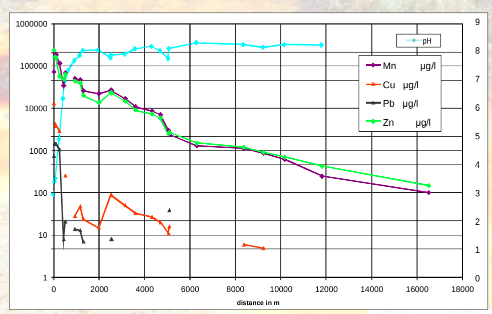
Greece - Kirki



Pb and Cu levels fall down before Zn and Mn

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Romania – Calimani Sulphur, Suceava County

> **Site**
- Native sulphur extracted until 1997 in open pit out of acidic volcanics
- Uncontrolled AMD, no significant metal pollution
- Acid river flow observed far away from the mine (25-40 km)

> **Host geology and geomorphology**
- Steep slopes (elevations from 1900 to 1100 m) favour fast flow and erosion.
- Stormy rainfall regime between spring and autumn favours flushing.
- S-rich silicic volcanics, especially dacites, with little or no neutralisation potential
- High S concentrations available to oxidation as sulphide, allowing weathering to trigger natural acid rock drainage (ARD)
- Widespread fracturation

Almost nothing to slow down the acidic flow

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Romania – Calimani Sulphur, Suceava County

> **Acidity flow**
- Free rainfall percolation through huge pyritic waste heaps
- Severe acid drainage (pH 1.9 to 3.5) and high flow rates
- Acidic pH (4 to 6) also observed in brooks outside the mine area: acid rock drainage (ARD)
- Geochemical background for pH much lower than 6.5
- Rain storms tend to flush massive quantities of acidic water from the waste heaps and to wash pit walls
- Lower pH in river despite the much higher discharge
- Neutralisation front extends well beyond 25 km

It makes no sense to neutralise runoff beyond geochemical background !

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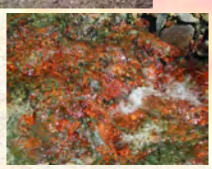
Romania – Calimani Sulphur, Suceava County



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France, Huelgoat: Pb-Ag former mine

> **Site**
- Lead and silver were extracted until 1903 (total production 26000 tonnes).
- Natural runoff is accompanied by uncontrolled AMD with minor Pb-Zn pollution.

> **Acidity flow**
- Mine discharge (15 m3/h) is released in a tributary (20-25 m3/h) of the local river (7500 m3/h).
- Mild acidity only (5.9 to 7.5).

> **Host geology and geomorphology**
- Granite and volcanosedimentary silicic rocks provide dilution potential with fractures network
- The low hills topography at the mine site (elevations from 100 to 200 m) and oceanic climate favour slow flow and steady sediment migration and deposition.

Sedimentation pools control metal migration

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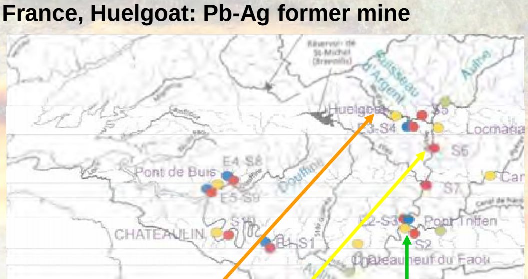
France, Huelgoat: Pb-Ag former mine



Mine discharge => neutralisation zone => sedimentation zone

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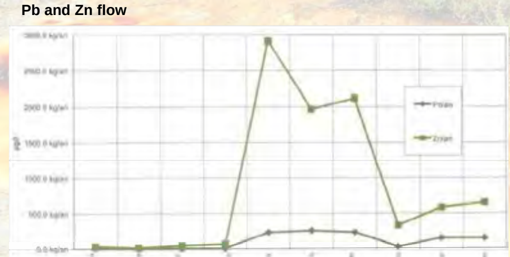
France, Huelgoat: Pb-Ag former mine

Pb and Zn flow



Upstream => Mine discharge => neutralisation => sedimentation

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Factors affecting the neutralisation range


Acidity flow

- acidity of discharge (pH, alkalinity) at runoff points
- flow rate of runoff
- Instant and cumulated H+ emission by time unit

Acidity dilution

- discharge of the receptor watercourse
- receptor watercourse chemistry affects also neutralisation distance, not only through its pH, but especially its alkalinity
- Dilution through infiltration (fracture network)

Mixing of acid water with incoming neutral water breaks the chemical equilibrium of mine water and uses the buffering capacity of dilution water

Factors affecting the neutralisation range

Buffering capacity

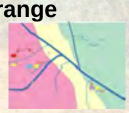
- Chemistry of river bed materials:
  carbonate rocks
  carbonate-bearing sediments and gravel
  organic matter
- Exchange surfaces
- Buffering potential of receiving watercourses

Solute content and coprecipitation ions

- Carbonates, sulphate, phosphate

Precipitation of metals, where and how ?

Factors affecting the neutralisation range

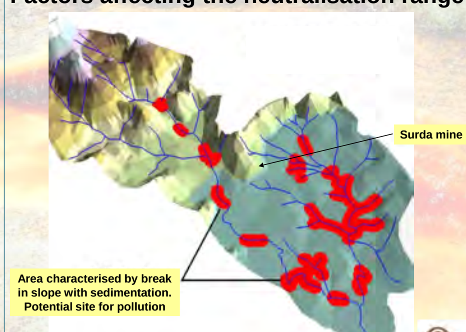


Hydrology and hydrodynamics

- Catchment topology and flow rate
- Topography and slope profile
- Fast and turbulent flow regimes promote oxygenation, CO2 release and exchanges with sediment.
- They accelerate both neutralisation and precipitation of the solute load through reactions with the milieu
- Clearly shown at breaks in slope where neutralisation fronts tend to be located
- Precipitation, sedimentation, water residence and pooling
- Transitory hydrodynamics and rainfall regime (flushing)
- Flow velocity variations must be taken into account for kinetics effects in the neutralisation distance model

Small AMD area, wide metal dispersion

Factors affecting the neutralisation range



Conclusions

- Not enough observations for a quantitative approach to the dependence of AMD neutralisation distance on any parameters, but…
- Observations from a few sites useful for AMD mitigation strategy
- Localisation of the neutralisation front useful for water quality safety
- To be done both in normal and stormy regime
- It will contribute to define in the catchment where the use of surface water is safe, for which uses, and with which precautions.

Observation of the flow and catchment features useful for predictive strategies in case of delayed AMD or rebound

Conclusions

Remediation

- Passive reactive barriers near a break in slope upstream from the neutralisation zone reduce downstream contaminants dispersion.
- Upstream water derivation around AMD sources allows to control downstream quality and discharge dispersion
- PRB implementation should be done in a catchment dynamics perspective
- Interpretation of the position of the neutralisation front relationship must take into consideration any existing ARD background. It would make no sense to mitigate AMD further than background basin pH values.

Complements ABA in the predictive models but for transfer !

Thank you for your attention !

(partners for future projects welcomed)

India, Subarnarekha, Surda mine runoff

Sampling point	Dist km	pH	EC µs/cm	Eh mV	Cu µg/l	Zn µg/l	SO_4^{2-} mg/l	pH monsoon
Surda mine runoff	0	3.3	2210	567	8030	477	45	3.31
Surda backfilling point effluent	0.3	3.5	1844	500	7860	383	4	3.34
Surda brook– graveyard	0.6	4.3	1208	326	10320	316	198	3.51
Surda brook - upper paddy fields	2.3	6.6	482	276	139	36	178	
Surda brook - lower paddy fields	3.6	4.8	1194	279	7450	264	595	
Subarnarekha river confluence	4.3	6.7	163	300	38	13	23	7.86

Other case studies

Some well documented cases…

> **Iberic province**
- Rio Tinto

> **Cornwall tin province**
- Wheel Jane

> **And so many others**
- Metals mining
- Coal mining

Need for comparative databases