Neutralisation distance of acid drainage and migration range of pollutants

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[1]*BRGM, Environment and Process Division, PO Box 36009, 45060 Orléans, France, b.lemiere@brgm.fr*

Abstract Acid mine drainage (AMD) release to surface water is naturally followed by neutralisation and subsequent precipitation of the pollutants load. This occurs between 50 m to 50 km from source, depending on topography, hydrography, geology and chemistry. Factors influencing this distance are discussed in view of a cost-efficient mitigation of AMD pollution. This approach should complement the evaluation of AMD likeliness and potential neutralisation (acid base accounting). In the Source-Transfer-Receptor framework, ABA provides information on source while neutralisation zone modelling provides information on transfer pathway. Remediation targets and facilities depend on the location of potential targets vs neutralisation distance.

Key Words acid mine drainage, AMD, sediments, heavy metals, catchment, figures, reference

Introduction

Acid mine drainage (AMD) is one of the biggest environmental issues of mining, as it releases massive amounts of solubilised metals and salts in surface water where appropriate mitigation actions were not taken on time. It affect both active and closed mine sites and may even begin after mine closure. Good practice in mining management (Environment Australia, 1997; MEND, 2001; US-EPA, 2000, 2004; JRC 2004) includes many aspects aimed at AMD prevention and mitigation. Once AMD reaches the surface water network, the only mitigating process is neutralisation. This process occurs naturally within a variable distance. This is the suject of the present paper. Neutralisation is accompanied by the gradual precipitation of most pollutants, which are deposited or further carried away in solid form as sediments. Knowing better the neutralisation range of AMD is thus a contribution to basin management in mining or former mining regions.

Methods

For most of the studied cases, the geochemical data set is based on field measurements: pH, electrical conductivity (EC) and other parameters, and on trace laboratory analyses, carried out by ICP/AES, ICP/MS and/or AAS on samples filtered and acidified on site. Further details are available through papers given in reference. Most of the results were obtained during periodic monitoring campaigns, allowing to evaluate the effects of seasonal variations on the neutralisation range.

Reference to acid water and to neutralisation is taken from the European Directives on water, which provide a lower guide value of 6.5.

India

AMD occurs at several mines of the Singhbum copper district, Jharkhand, India (Négrel et al. 2007), especially at the Surda mine (Billaud et al. 2003). Mine drainage flows down a hill slope, then reaches paddy rice fields on the flat alluvial beds of the Subrnarekha river. Surda brook (nallah) discharge is of several orders of magnitude smaller than the river discharge, regardless of the season.

***Table 1** AMD parameters at the Surda mine, India*

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	3.36	2210	567	8030	477	45	3.31
Surda backfilling point effluent	0.3	3.53	1844	500	7860	383	4	3.34
Surda brook downstream – graveyard	0.6	4.28	1208	326	10320	316	198	3.51
Surda brook downstream - upper paddy fields	2.3	6.56	482	276	139	36	178	
Surda brook downstream - lower paddy fields	3.6	4.79	1194	279	7450	264	595	
Subarnarekha river confluence	4.3	6.73	163	300	38	13	23	7.86

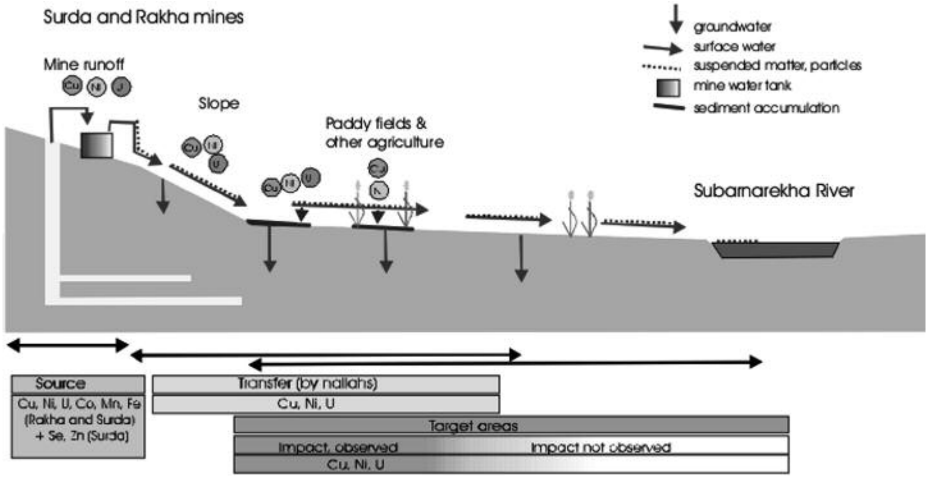

Figure 1 *Neutralisation model at the Surda mine, India.*

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The neutralisation zone (0.6 to 2.3 km from runoff) extends along the hill slope and at the beginning of the alluvial plain (Fig. 1). It coincides with a peak in sulphate values, while EC and ore metals are decreasing. Monsoon rains increase discharge and shift slightly downwards the neutralisation front, but they do not change significantly the neutralisation range. Sediment data (Billaud et al., 2003) show that the break in slope is home to most of the precipitation and sedimentation phenomena. Metal transfer occurs further downstream mainly as particulate transport, until the Subarnarekha river.

Greece

Uncontrolled AMD occurs at the abandoned Kirki Cu-Zn-Pb mine in northeastern Greece, with significant cadmium pollution (Liakopoulos et al., 2010). Acidic water in contact with oxidised mine and pit walls (pH 2.9) is further acidified (pH 1.5) and enriched in metals (up to 240 mg/L Zn and 2.4 mg/L Cd) as it is allowed to percolate the sulphide-rich waste piles. Drainage is then channelised into a narrow gorge in volcanosedimentary formations, with little or no buffering potential. Neutralisation occurs at a variable distance according to strong seasonal rainfall and discharge variations, between 600 m and 2 km. Torrential regime, favouring oxidation, and the extensive formation of biofilms contribute to AMD neutralisation, and to the transfer of pollutants in solid rather than solute form.

Despite an effective neutralisation in the downstream gorge, Cd-Zn pollution is observed in the Eirini river down to the sea (up to 2.7 mg/L Zn). This implies that mitigation is required, beyond the current natural attenuation.

Romania

Sulphur was extracted until 1997 at the Calimani Negoiu Open pit, in the Suceava County, dug out of the steep slopes of Mt. Calimani National Park. out of acidic volcanics in the immediate vicinity of a Mines, tailings storage facilities and waste dumps cover a surface of 375 hectares. Free rainfall percolation through huge pyrite-bearing waste heaps and tailings triggered severe acid drainage (pH 1.9 to 3.5, ICPM, 2007; Ionce, 2010; unpublished data from REPA).

The steep slopes at the mine site (elevations from 1900 to 1100 m) favour fast flow and erosion. The stormy rainfall regime between spring and autumn contributes further to flushing phenomena.

The geological features contribute all to the very long distance observed for neutralisation: the host rocks at and around the mine are silicic volcanics, especially dacites, with little or no neutralisation potential. Acidic pH (4 to 6) was also observed in brooks outside the mine area. The high concentrations in sulphur naturally occurring in these rocks are available to oxidation as sulphide (Clemente et al. 2004), allowing weathering to trigger acid rock drainage (ARD). The actual geochemical background for pH is much lower than the guide value. It would make no sense to request neutralisation beyond this background value.

It was also observed that rain storms tend to flush massive quantities of acidic water from the waste heaps and to wash pit walls, resulting into lower pH in water courses despite the much higher discharge. The neutralisation front could not be fully mapped but it extended beyond 25 km.

Discussion: factors affecting the neutralisation range

Acidic river water is naturally neutralised at all documented sites, as a result of three phenomena: chemical reaction with the river bed and sediments, oxygenation through fast flow, and mixing with neutral water from upstream or incoming tributatries. The required distance for neutralisation is directly controlled by the parameters of these phenomena. Data on the three studied sites are summarised in Table 2 and complemented by data from classic sites (Rio Tinto: Espana et al., 2005; Wheal Jane, UK: Neal et al., 2005, Whitehead & Prior, 2005).

Initial pH at runoff points affects obviously the neutralisation distance, as each pH unit increases the requirement for neutralisation potential by a factor of ten. However, the real significance of this parameter depends on the flow rate of runoff and on the pH and discharge of the receving water courses. Acidic water dilution in the receptor watercourse by near neutral water is first taken into account, but receptor watercourse chemistry affects also neutralisation distance, not only through its pH, but especially its alkalinity (Kirby & Cravotta, 2005). Mixing of acid water with incoming neutral water breaks the chemical equilibrium of mine water and uses the buffering capacity of dilution water.

Chemistry of river bed materials is of prime importance: materials with high buffering capacity, such as carbonate beds or carbonate-bearing sediments and gravel, will allow a faster neutralisation. The presence of carbonate in sediments is especially important due to their high exchange surface.

Fast and turbulent flow regimes promote oxygenation and exchanges with sediment. Therefore, they accelerate both neutralisation and precipitation of the solute load through reactions with the milieu. This is mainly governed by slope. Flow velocity variations must be taken into account, aside rainfall regime, for kinetics effects in the neutralisation distance model. This is clearly shown at breaks in slope where neutralisation fronts tend to be located. This is not only due to precipitation and sedimentation but also to water residence time and pooling.

Conclusions

These observations are still too limited to provide a quantitative approach to the dependence of AMD neutralisation distance on these parameters. The base of case studies needs to be expanded. However, the qualitative conclusions drawn from a few sites are useful for AMD mitigation strategy, and they most often meet commonsense. For instance, implementing passive reactive barriers near a break in slope upstream from the neutralisation zone will reduce the dispersion of contaminants from precipitation downstream the neutralisation zone.

***Table 2** Comparison of neutralisation distances for the studied sites*

Site	Source pH	Solute load at source mg/l	Channel discharge	From source to pH 6.5	Morphology, flow and rainfall regime
India – Surda mine	3.3	1300	2 l/s	2.3 km	Hilly, torrential, monsoon
Greece, Kirki mine	1.5	1269	3 to 6 l/s	0.6 km	Hilly, torrential, stormy
Romania, Calimani	2	≥ 3000	80 l/s	≥ 25km	Mountain, torrential, stormy
Wheal Jane, UK	4.4	3000	200 l/s	3 km	Low hills, steady, oceanic
Spain, Rio Tinto waste drainage	2.6	10000	28 l/s	> 8 km	Hilly, torrential, stormy
Spain, Rio Tinto mine adit	2.3	6000	1 l/s	> 8 km	Hilly, torrential, stormy

A proper localisation of the neutralisation front, both in normal or stormy regime, will be useful for water quality safety. It will contribute to define in the catchment where the use of surface water is safe, for which uses, and with which precautions. 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.

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