Mine Wastes: Past, Present, Future

Karen A. Hudson-Edwards[1], Heather E. Jamieson[2] and Bernd G. Lottermoser[3]

LEFT: Acidic drainage leaking from a former adit, Rheidol Mine, Wales. Above: Zinc- and lead-rich mine wastes at the former Cwmystwyth mine, Wales

1811-5209/11/0007-0375$2.50 DOI: 10.2113/gselements.7.6.375

Mine wastes are unwanted, currently uneconomic, solid and liquid materials found at or near mine sites. Volumetrically they are one of the world's largest waste streams, and they often contain high concentrations of elements and compounds that can have severe effects on ecosystems and humans. Multidisciplinary research on mine wastes focuses on understanding their character, stability, impact, remediation and reuse. This research must continue if we are to understand and sustainably manage the immense quantities of historic, contemporary and future mine wastes, given the trend to exploit larger deposits of lower-grade ores.

KEYWORDS: mine wastes, tailings, metals, metalloids, radionuclides, acid mine drainage, dust

INTRODUCTION

Iconic treasures such as the gold funeral mask of King Tutankhamen and the Koh-I-Noor Diamond would not exist today without mining. Since the dawn of civilization, humans have exploited metals, coal, industrial minerals and rocks for the production of goods, energy and building materials. These mining activities have created great wealth: the Chalcolithic (Copper) Age, for example, took its name from the exploitation of copper ores and the production of copper-based tools, and the "Golden Age" of Spain in the 16th and 17th centuries was built on the gold and silver extracted from mines in the Americas. The importance of mining was recognized by Gregor Reisch in 1503 in his book *Margarita Philosophica* (*The Philosophical Pearl*) in which he illustrated his section on natural objects with a woodcut showing "Mining for Metal" (FIG. 1).

These treasures and associated wealth have come at an environmental cost, because mining has produced colossal quantities of solid and liquid wastes, known collectively as "mine wastes". Nearly every country has or has had a mining industry and, therefore, has a legacy of mine waste. Thus, the large-scale production of mine wastes and their secure disposal or sustainable remediation represent problems of global importance. It has been estimated that, annually, the production of solid mine wastes now matches the amount of Earth materials moved by global geological processes – several thousand million tonnes per year (Fyfe 1981; Förstner 1999). Many of these wastes contain components, such as arsenic, lead and cyanide, in concentrations that may pose serious hazards to ecosystem and human health. The control and mitigation of acid mine drainage (AMD) mine wastes alone is considered to be one of the major environmental challenges facing the mining industry worldwide (International Network for Acid Prevention 2011). The estimated costs for total worldwide liability associated with the current and future remediation of acid drainage are approximately US$100 billion (Tremblay and Hogan 2001).

FIGURE 1 "Mining for Metal", a hand-coloured woodcut from the 1503 textbook for scholars *Margarita Philosophica* (*The Philosophical Pearl*), by Gregor Reisch, ca 1467–1525. The origin of natural objects was one of the twelve sections of the book. IMAGE COURTESY OF THE SCIENCE MUSEUM LONDON/ SSPL

Major issues concerning mine wastes are dealt with in the articles in this issue, but to give these context, we provide in this article necessary background information on the definition of mine wastes, how they are stored or otherwise distributed, their effects on waters, soils, ecosystems and humans, and the potential for their reuse and rehabilitation. Detailed reviews can be found in references such as Jambor et al. (2003) and Lottermoser (2010).

WHAT ARE MINE WASTES?

In this issue of *Elements*, we define mine wastes as "those waste products originating, accumulating and present at mine sites, which are unwanted and have no current

1 Department of Earth and Planetary Sciences
Birkbeck, University of London, Malet St., London WC1E 7HX, UK
E-mail: k.hudson-edwards@bbk.ac.uk

2 Department of Geological Sciences and Geological Engineering, and School of Environmental Studies
Queen's University, Kingston, Ontario K7L 3N6, Canada
E-mail: jamieson@geol.queensu.ca

3 School of Earth Sciences, University of Tasmania
Private Bag 79, Hobart, Tasmania 7001, Australia
E-mail: Bernd.Lottermoser@utas.edu.au

economic value" (Lottermoser 2010) (see Glossary for this and other terms). Mine wastes are heterogeneous materials consisting of ore, gangue, industrial minerals, metals, coal or mineral fuels, rock, loose sediment, mill tailings, metallurgical slag and wastes, roasted ore, flue dust, ash, processing chemicals and fluids. This definition is illustrated by the Kalgoorlie "Super Pit" gold-mining operation (Fig. 2), one of the largest in the world. The mine is surrounded by waste dumps and tailings ponds, the latter of which also contain processing chemicals such as cyanide (Griffiths et al. 2009). The footprint of the Super Pit is greatly exceeded by that of its wastes, mainly because so much rock is mined to extract the parts per million amounts of gold within its ores. For every tonne of metal ore extracted, at least a tonne of waste is generated, and usually orders of magnitude more (Lottermoser 2010).

Figure 2 The "Super Pit" gold mine at Kalgoorlie, Western Australia, with its attendant grey waste dumps and grey-white tailings ponds. The town of Kalgoorlie abuts the mining area. Photo taken 15 February 2010, courtesy of NASA

Figure 3 Mine tailings disposal at Kidd Creek, Ontario, Canada. The Kidd metallurgical facility, which ceased operations in 2010, is shown in the background. Photo by Bernd Lottermoser

STORAGE, REDISTRIBUTION AND ENVIRONMENTAL IMPACT OF MINE WASTES

Solid mine wastes are stored in piles or in tailings impoundments around or near mine sites (Fig. 2). In the past, tailings were discharged to rivers or wetlands. Currently, tailings are used as backfill underground, stored in open pits, dried and stacked, or pumped into tailings impoundments ranging from a few hectares to thousands of hectares in area. In some cases, the tailings are thickened with a flocculant to increase surface tension and maintain saturation during storage. In impoundments, tailings may be exposed to the atmosphere or stored below a water cover. Figure 3 shows the tailings-disposal site at Kidd Creek in northern Ontario, Canada. One of the world's largest and richest volcanogenic massive sulfide deposits, Kidd Creek has produced silver, cadmium, copper, indium, sulfuric acid and zinc since 1966 (InfoMine 2011). By the time the site closes in 2023, more than 130 million tonnes of tailings will be stored in the pond (InfoMine 2011). Global estimates of tailings production are similarly high: in the 1960s, tens of thousands of tonnes of tailings were produced each day, but by 2000, that amount had risen to hundreds of thousands of tonnes per day (Jakubick and McKenna 2003).

Although impoundments are useful and necessary repositories for tailings, they can create environmental problems. Air and soil can be contaminated by the generation and dispersal of dust, and groundwater and surface water can be contaminated by seepage through embankments or through the base of the tailings pile. Most dramatically, tailings dams can fail. Since 1970, over 70 major failures of impoundments have occurred around the world. Many of these have resulted in short- and long-term damage to ecosystems, in significant impact on communities that live beside them and rely on impacted lands for food and livelihood, and most seriously, in the loss of over 1000 lives (WISE 2011). An example is provided by the Aznalcóllar–Los Frailes dam failure in southwestern Spain on 25 April 1998 (Fig. 4). The flood of tailings and acidic water spread out in the flatter, lower reaches of the catchment but was impeded by walls constructed to protect the Doñana National Park, the largest reserve for birds in Europe and a UNESCO Reserve of the Biosphere. These walls, and the emergency removal of the tailings back to the open pit beginning on May 3, 1998, considerably reduced the medium- and long-term impacts on vertebrate wildlife (Guitart et al. 2010). Nonetheless, 37 tonnes of fish, 40 tonnes of amphibians, 20 tonnes of birds and 8 tonnes of mammals were killed by the spill, and agricultural products had to be destroyed (Grimalt et al. 1999). Soils and groundwaters in the area retain considerable quantities of potentially toxic metals resulting from the spill and historical contamination, and the clean-up operations severely destabilized the river channel and floodplain, accelerating erosion and sedimentation downstream (Turner et al. 2008). Such observations have been made in other areas affected by spills of impounded tailings, and the long-term environmental consequences in many of these areas remain unknown.

Mine wastes have been, and still are, discharged directly into marine environments, rivers and lakes, and indirectly through erosion of tailings and waste-rock piles (Lewin et al. 1977). This can cause increased turbidity and sedimentation, and can contaminate suspended, channel, floodplain and lake sediments with metals, metalloids and radionuclides. For example, more than two million cubic metres of metal-contaminated mine waste sediment are stored in the floodplains of the Clark Fork River basin in the United States (Moore and Luoma 1990). In northern England, an estimated area of 12,000 km^2 of river catchments is polluted by historic waste, mainly generated during lead and zinc mining in the 19th and early 20th centuries (Macklin et al. 2006). Of pressing concern is the potential for remobilization of mining-contaminated alluvial sediment from these areas, either by in situ biogeochemical weathering or by physical erosion during

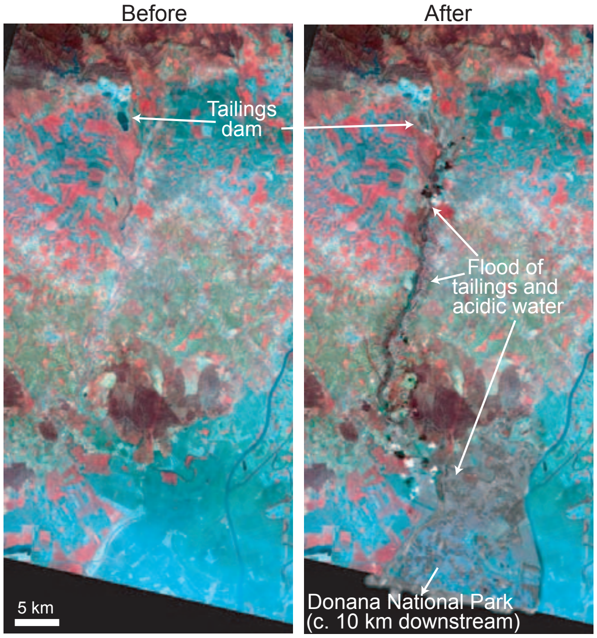

Figure 4 SPOT satellite images taken before (left) and after (right) the Aznalcóllar tailings impoundment spill in southwestern Spain in April 1998. Following the spill, the rivers downstream were covered with two million cubic metres of pyritic, zinc-, lead-, arsenic-, copper-, thallium-, cadmium- and mercury-bearing tailings and acidic water, which spread over 4286 ha and formed a layer up to 4 m thick (Grimalt et al. 1999). Image courtesy of Aurensa

high-flow events. Both processes have the potential to contaminate groundwater and surface waters through dissolution or desorption of contaminants from sediment surfaces. Nagorski et al. (2003), for example, showed that concentrations of arsenic, copper, iron, manganese and zinc in the water of a mining-impacted stream in Montana, USA, were highest following spring runoff and short-term storm events. The greater frequency and severity of floods due to climate change may, in turn, contribute to increasing mobilization of riverborne mine wastes (Goudie 2006).

Surface and subsurface mine waters used in the extraction and disposal of mine wastes, which include mill and process waters, are themselves considered mine wastes. At well-managed mines sites, such mine waste water is stored in settling ponds and used as recycle water in mill processes and open pit and underground operations. At abandoned or improperly managed sites, however, water is discharged deliberately or inadvertently as a result of seepage, run-off or flooding, often spreading several kilometres from the source. In most countries, regulations prohibit the release to the environment of water that does not meet specific water-quality standards. Perhaps the most famous example of mine waste water concerns the Río Tinto ("red river") in southwestern Spain. There, long-term natural weathering and at least 5000 years of mining of massive sulfide orebodies have delivered both natural acid rock drainage (NARD) and AMD to the river, giving it a characteristic red colour and high acidity (pH = ~1.7–2) extending some 60 km downstream from the mining area (López-Archilla et al. 1993). The reason for the persistence of such low pH, which is not seen in other AMD rivers, is due to factors such as the constant input of low-pH water from mine workings, waste dumps and waste-lined railway and road bases, abundant pyrite-oxidizing microorganisms and the dissolution of acid-producing secondary sulfate salts (e.g. Hudson-Edwards et al. 1999). The latter are common, if ephemeral, products of the precipitation of AMD waters

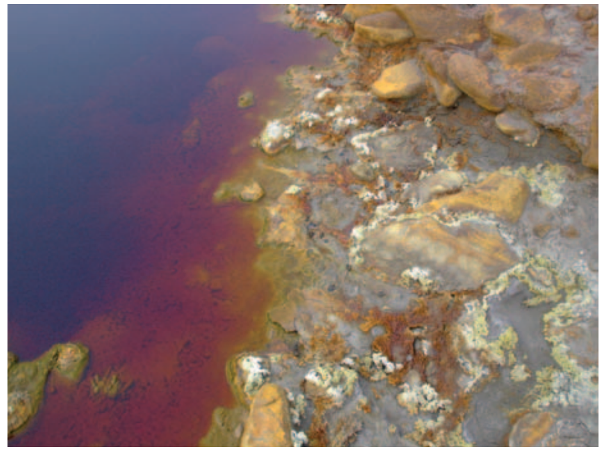

Figure 5 Acidic drainage in the Río Tinto, Spain. Multicoloured efflorescent sulfate minerals have precipitated along the river banks. Field of view is about 2 m on long axis of photo. Photograph by Bernd Lottermoser

(Fig. 5). In addition to acidity, they also contribute pulses of metals and metalloids when they dissolve during rainfall or flood events.

The uptake of toxins from mine waste–affected soils and waters can lead to their bioaccumulation and biomagnification in terrestrial plants and aquatic algae. Plants and crops grown on contaminated soils often contain high concentrations of metals (Miller et al. 2004). Animals grazing on alluvial soils often eat this plant material and sediment, especially after flooding when fresh metal-rich sediment is deposited. This poses risks to their health and that of humans who ingest their meat and milk. Some plants and animals, however, are able to survive and even thrive on contaminated soils. Such plants, known as metallophytes, have developed mechanisms to tolerate high levels of metals and metalloids, by either excluding or incorporating them into their biomass. Rapid invasion of abandoned and rehabilitated mine sites by metal-excluding plants is beneficial to their rehabilitation as it leads to the establishment of a green cover that protects wastes and waste repositories from erosion and leaching.

Fauna, too, can develop metal and metalloid tolerance in mining-affected sites: the earthworm *Dendrodrilus rubidus*, which is native to the mining-contaminated soils at the Coniston copper mine in northern England, was shown to tolerate higher soil copper and exhibit significantly less change in weight than control worms (Arnold et al. 2008). Pathways of metals, metalloids and radionuclides from mine waste to humans include the ingestion of polluted drinking water, soil, and foodstuffs (if grown on contaminated soils), and the inhalation and ingestion of polluted dust (Miller et al. 2004).

RECYCLING, REUSE AND REHABILITATION OF MINE WASTES

The legacy of historic mine waste and the piles that accumulate today and will do in the future present both a problem and a benefit to society. To achieve sustainable growth, humankind ideally requires the products of mining to be extracted without negative environmental impact. Consequently, plans for the rehabilitation of mine wastes are incorporated into plans for new extraction operations. This does not, however, address the issue of historic wastes, which were often not disposed of securely. Remining or reprocessing of such wastes, especially those in which ore extraction was not as efficient as with modern technologies, brings potential financial and waste-reduction benefits. New techniques such as soil amendments and phytoremediation are being explored for mine waste rehabilitation. Some procedures, such as the hydroseeding of slag dumps (FIG. 6), have the added benefits of reducing the visual impact, stabilizing the wastes and preventing waste dispersal.

FIGURE 6 Hydroseeded slag dump, Sudbury, Canada. PHOTO BY BERND LOTTERMOSER

MINE WASTES IN THE FUTURE

Modern society relies on energy and mineral resources, and as a result the volumes extracted are increasing year on year. There are many, however, who think that this rate of extraction cannot continue. Gordon et al. (2006) warned that if all nations consumed the same amount of copper, zinc and platinum as the developed nations, supplies would unlikely to be exhausted in the immediate future, but demands might not be met in the long term, even if near-complete recycling and complete extraction of all the lithosphere's metals were to occur. Studies such as this have led others to coin the term "peak metal" (analogous to "peak oil", a term used in the energy industry), meaning that humankind has extracted more metal to date than is left to mine. Although controversial, these terms highlight the fact that many of the richest mines and energy resources are being or have already been exploited, and companies are now turning to larger deposits with lower-grade ores. Such deposits, as a consequence, generate more mine waste per unit extracted. Thus, the mine waste–related damage to the Earth's surface, which is already extensive, is likely to be exacerbated.

New technologies and declining resources have also created new types of mine wastes. Lanthanide (rare earth) elements such as neodymium and europium are used in lasers, solar panels and televisions, but they are mined from deposits that may contain uranium and thorium; therefore, the associated wastes are potentially both radioactive and toxic. The strong demand for lithium-ion batteries for portable electronic devices and other applications has also increased demand for this metal. Lithium is extracted from salt pans such as the Salar del Hombre Muerto in northwestern Argentina (FIG. 7). Here, as elsewhere in the world, lithium is extracted and concentrated into solution by evaporating water from the brine in solar ponds. In addition to the currently unknown human health risks associated with the waste waters and discarded salty sediments, the effects on local water cycles of large-scale brine extraction in these arid environments are not well understood. Also, the environmental impact of oil sand mining, which generates massive quantities of high-salt tailings and airborne volatile organic compounds, is severe (Kasperski and Mikula 2011 this issue).

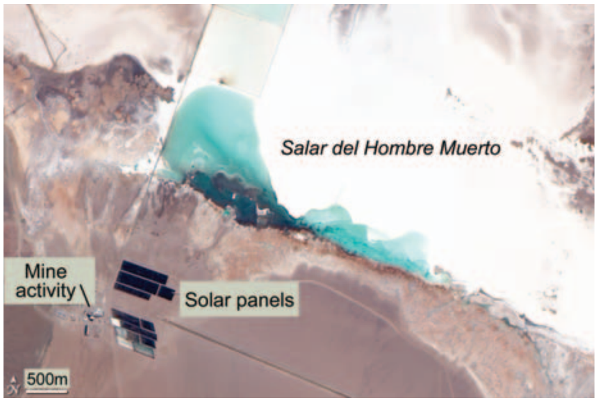

FIGURE 7 Extraction of lithium from the Salar del Hombre Muerto in northwestern Argentina. PHOTO TAKEN MAY 16, 2009, COURTESY OF NASA

The risks associated with mine wastes are directly related to the ways in which the potentially toxic components are released, transported and taken up by flora and fauna. These mechanisms, in turn, depend on the nature of the minerals in the mine wastes and the fluids and organisms they encounter. Geoscientists have the knowledge and the tools to better understand these processes. In the example shown in FIGURE 8, the mineral scorodite ($FeAsO_4 \cdot 2H_2O$) has been identified in weathered, arsenopyrite-rich mill tailings using traditional transmitted- and reflected-light microscopy, together with modern synchrotron radiation–assisted micro-X-ray diffraction. In the future, the synergistic use of these and other emerging techniques, including tomography and CAT scanning, will enable the behaviour of mine wastes to be better understood and predicted.

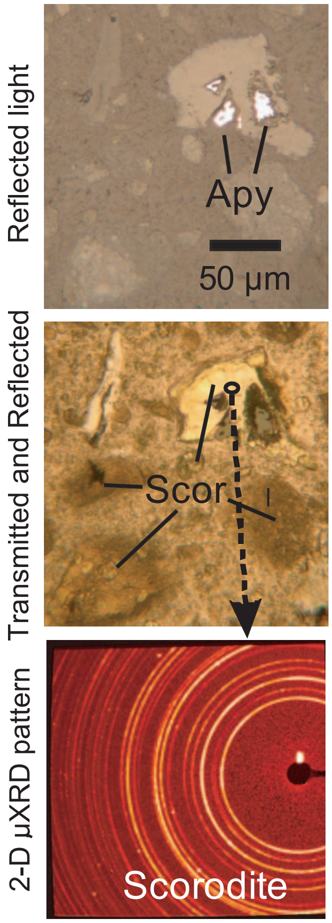

FIGURE 8 Scorodite (Scor) alteration products of arsenopyrite (Apy) in Nova Scotian (Canada) mine tailings. These were identified by combined optical microscopy and synchrotron-assisted micro-XRD. FROM WALKER ET AL. (2009), USED WITH PERMISSION

Similarly, our ability to mitigate the environmental impact of surface-mined oil sands operations will hinge on our ability to characterize particles on the nano scale.

IN THIS ISSUE

The geochemistry, mineralogy, human ecotoxicology, remediation and reuse of mine wastes are explored in this issue. Heather Jamieson discusses the chemistry and mineralogy of solid metallic mine wastes and stresses the need for characterization at the micro- to nanoscopic scale for better behaviour prediction and remediation (Jamieson 2011). This need is echoed by Kim Kasperski and Randy Mikula in their article on the emerging issue of oil sand extraction wastes (Kasperski and Mikula 2011). Kirk Nordstrom discusses the microbiology and geochemistry of acidic to circumneutral mine waters (Nordstrom 2011). The contribution by Geoff Plumlee and Suzette Morman shows how an understanding of the mineralogical and geochemical characteristics of mine wastes can help to anticipate and mitigate potential human health problems (Plumlee and Morman 2011). The final article by Bernd Lottermoser provides a comprehensive overview of the recycling, reuse and rehabilitation of mine wastes, and highlights the necessity for making the most efficient use of all mined resources, while protecting the environment (Lottermoser 2011). Although a plethora of studies have contributed to a good baseline understanding of the character, weathering mechanisms, long-term stability, ecotoxicology, remediation and reuse of mine wastes, much still remains to be discovered. Geochemists and mineralogists have a significant role to play in this endeavour, especially with the challenges associated with historic mine wastes and the growing global mass of new, inherently complex mine wastes.

ACKNOWLEDGMENTS

The authors acknowledge financial support from their respective research funding agencies and industry partners. We thank the contributing authors, reviewers (Dave Craw, Mark Hodson, Alisa Mast, Chris Mills, Peggy O'Day, Anita Parbhakar-Fox, Michael Parsons, Barbara Sherriff, Kevin Taylor, David Vaughan, Katie Walton-Day, Ron Watkins), Tim Drever and Pierrette Tremblay for their assistance in bringing this issue to fruition.

REFERENCES

Arnold RE, Hodson ME, Langdon CJ (2008) A Cu tolerant population of the earthworm *Dendrodrilus rubidus* (Savigny, 1862) at Coniston Copper Mines, Cumbria, UK. Environmental Pollution 152: 713-722

Förstner U (1999) Introduction. In: Azcue JM (ed) Environmental Impacts of Mining Activities: Emphasis on Mitigation and Remedial Measures. Springer, Heidelberg, pp 1-3

Fyfe WS (1981) The environmental crisis: Quantifying geosphere interactions. Science 213: 105-110

Gordon RB, Bertram M, Graedel TE (2006) Metal stocks and sustainability. Proceedings of the National Academy of Science 103: 1209-1214

Goudie AS (2006) Global warming and fluvial geomorphology. Geomorphology 79: 384-394

Griffiths SR, Smith GB, Donato DB, Gillespie CG (2009) Factors influencing the risk of wildlife cyanide poisoning on a tailings storage facility in the Eastern Goldfields of Western Australia. Ecotoxicology and Environmental Safety 72: 1579-1586

Grimalt JO, Ferrer M, Macpherson E (1999) The mine tailing accident in Aznalcóllar. Science of the Total Environment 242: 3-11

Guitart R, Sachana M, Caloni F, Croubels S, Vandenbroucke V, Berny P (2010) Animal poisoning in Europe. Part 3: Wildlife. The Veterinary Journal 183: 260-265

Hudson-Edwards KA, Schell C, Macklin MG (1999) Mineralogy and geochemistry of alluvium contaminated by metal mining in the Rio Tinto area, southwest Spain. Applied Geochemistry 14: 1015-1030

InfoMine (2011) Mining information for Kidd Creek, Ontario, Canada. See www.infomine.com/minesite/minesite.asp?site=kiddcreek

International Network for Acid Prevention (2011) See www.inap.com.au/index.htm

Jakubick A, McKenna G (2003) Stabilisation of tailings deposits: international experience. Mining and the Environment III, Sudbury, Ontario, Canada, 25-28 May, 2003, pp 1-9

Jambor JL, Blowes DW, Ritchie AIM (eds) (2003) Environmental Aspects of Mine Wastes. Mineralogical Association of Canada Short Course Volume 31, 430 pp

Jamieson HE (2011) Geochemistry and mineralogy of solid mine waste: Essential knowledge for predicting environmetal impact. Elements 7: 381-386

Kasperski KL, Mikula RJ (2011) Waste streams of mined oil sands: Characteristics and remediation. Elements 7: 387-392

Lewin J, Davies BE, Wolfenden PJ (1977) Interactions between channel change and historic mining sediments. In: Gregory KJ (ed) River Channel Changes. John Wiley and Sons, Chichester, pp 353-367

López-Archilla AI, Marín I, Amils R (1993) Bioleaching and interrelated acidophilic microorganisms from Río Tinto, Spain. Geomicrobiology Journal 11: 223-233

Lottermoser BG (2010) Mine Wastes: Characterization, Treatment and Environmental Impacts, Third Edition. Springer, Berlin, Heidelberg, 400 pp

Lottermoser BG (2011) Recycling, reuse and rehabilitation of mine wastes. Elements 7: 405-410

Macklin MG, Brewer PA, Hudson-Edwards KA, Bird G, Coulthard TJ, Dennis IA, Lechler PJ, Miller JR, Turner JN (2006) A geomorphological approach to the management of rivers contaminated by metal mining. Geomorphology 79: 423-447

Miller JR, Hudson-Edwards KA, Lechler PJ, Preston D, Macklin MG (2004) Heavy metal contamination of water, soil and produce within riverine communities of the Río Pilcomayo basin, Bolivia. Science of the Total Environment 320: 189-209

Moore JN, Luoma SN (1990) Hazardous wastes from large-scale metal extraction. Environmental Science & Technology 24: 1278-1285

Nagorski SA, McKinnon TE, Moore JN (2003) Seasonal and storm-scale variations in heavy metal concentrations of two mining-contaminated streams, Montana, USA. Journal de Physique IV 107: 909-912

Nordstrom DK (2011) Mine waters: Acidic to circumneutral. Elements 7: 393-398

Plumlee GS, Morman SA (2011) Mine wastes and human health. Elements 7: 399-404

Tremblay GA, Hogan CM (eds) (2001) Mine Environment Neutral Drainage (MEND) Manual 5.4.2d: Prevention and Control. Canada Centre for Mineral and Energy Technology, Natural Resources Canada, Ottawa, 352 pp

Turner JN, Brewer PA, Macklin MG (2008) Fluvial-controlled metal and As mobilisation, dispersal and storage on the Río Guadiamar, SW Spain and its implications for long-term contaminant fluxes to the Doñana wetlands. Science of the Total Environment 394: 144-161

Walker SR, Parsons MB, Jamieson HE, Lanzirotti A (2009) Arsenic mineralogy of near-surface tailings and soils: influences on arsenic mobility and bioaccessibility in the Nova Scotia gold mining districts. Canadian Mineralogist 47: 533-556

WISE (2011) Chronology of major tailings dam failures. World Information Service on Energy. Uranium Project, www.wise-uranium.org/mdaf.html

GLOSSARY

Acid generating potential – the potential for the weathering of mine waste to generate low-pH water; usually calculated from the sulfide and carbonate contents of the rock

Acid mine drainage (AMD) – the process whereby low-pH water (pH < 5.6) is formed from the mining-induced weathering of sulfide minerals. The term is also used to describe the low-pH water itself.

Acidophiles – archaea, bacteria and eukarya organisms that thrive in low-pH water (pH < 5)

Calcination (or calcining) – the thermal treatment of ores at temperatures below their melting point to cause thermal decomposition or phase transitions, and thus release the economic materials

Chemolithoautotrophic bacteria – bacteria that gain their carbon from CO_2 and their energy from the oxidation of inorganic substrates (in mine wastes, usually minerals containing reduced forms of Fe and S)

Coal-mine drainage (CMD) – the process whereby low-pH mine water is formed from the oxidation of sulfide minerals in coal deposits. The term is also used to describe the low-pH water itself.

Efflorescent salts – post-mining oxidation minerals (mainly sulfates), commonly present as cements and crusts in wastes and at or near the wastes' surfaces

Fines – fine-grained particulates remaining after the crushing and processing of ores

Flue ashes and dusts – fine particulates formed during the metallurgical smelting of ores

Gangue minerals – valueless minerals intergrown with ore minerals

Heap leaching – the process in which metals are dissolved from ores by leaching them with a solution. The ores are crushed and usually heaped onto an impermeable base known as a leach pad.

Hydroseeding – a planting process using a slurry containing seed and mulch to stabilize mine wastes

Industrial minerals – rocks or minerals of economic value, excluding metallic ores, mineral fuels and gemstones

Mature fine tailings (MFT) – a term used in oil sand mining for the material formed by the gradual settling of the minerals in fluid fine tailings over three to five years until they reach a content of 30 to 40 wt% solids

Metallurgical slag – the non-metallic top layer that separates during the smelting of ores

Metallurgical wastes – the residues of the leached or smelted ores whose grade is too low to allow further treatment. These include the wastes from hydrometallurgy (e.g. cyanide leaching of gold ores), pyrometallurgy (e.g. smelting of copper or zinc ores to break down their host minerals and release the metals) and electrometallurgy (e.g. the use of electrolysis to liberate metals such as aluminum).

Mine wastes – solid, liquid or gaseous by-products of mining, mineral processing, and metallurgical extraction that are unwanted, have no current economic value and accumulate at mine sites

Natural acid rock drainage (NARD) – the process whereby natural low-pH water (pH < 5.6) is formed from the weathering of sulfide minerals. The term is also used to describe the low-pH water itself.

Oil sand – sand that contains bituminous organic matter incorporated when the sediment was deposited

Ore – an aggregate of metallic or industrial minerals and gangue minerals that is economically valuable

Ore roasting – a metallurgical process carried out to purify metals extracted from sulfide ores, involving oxidation, reduction, chlorination, sulfation and pyrohydrolysis reactions at high temperatures

Physiologically based extraction test (PBET) – a laboratory leach test that models the release of toxicants from various solid and liquid media (including mine wastes) in simulated gastric, gastrointestinal, lung, and other body fluids

Pressure oxidation – oxidative dissolution of sulfide minerals to remove sulfur and concentrate metals, carried out at high pressures and temperatures

Processing chemicals – chemicals that are added to crushed and sized ore to aid the separation of the sought-after minerals/metals from gangue minerals and unwanted metals

Recycling – the practice whereby new valuable resource ingredients are extracted, or the waste is used as feedstock, thus converting the entire mine waste into a new valuable product or application with some reprocessing

Rehabilitation – measures that alleviate environmental impacts during post-mining waste storage

Remediation – the process of removing mine waste–derived pollutants or contaminants completely from water or soil, reducing their concentrations to comply with regulatory requirements, or making them insoluble or unavailable to biota

Reserve – resources that can be economically and legally extracted now

Resource – naturally occurring concentrations of liquids, gases, or solids in or on the Earth's crust in such form and amount that economic extraction of a commodity is currently or potentially feasible

Reuse – the process that involves the new use or application of the total mine waste in its original form for an identified purpose directly without any reprocessing

Settling pond – a pond used to separate mine waste particles into different grain sizes using gravity and, in some cases, with the aid of a flocculant

Slag – the vitreous product of flux addition during smelting, consisting of metal silicates and oxides, and, in some cases, sulfides and native metals

Smelting – a metallurgical process carried out to extract metal from ore. It involves heating and partial melting of the ore, and the addition of a chemical reducing agent to remove oxygen and a flux to remove the gangue as slag.

Tailings – crushed rock and processing fluids (that may contain xanthate or cyanide) from a mill, washery or concentrator resulting from the removal of the economic metals, minerals, mineral fuels or coal from the mined resource

Waste rock – rock material removed to access and mine ore or coal

Zero waste – the concept of total resource utilization, where all the material mined is put to good use and no waste is generated