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Sustainable practices in the management of mining waste: A focus on the mineral resource

Éléonore Lèbre *, Glen D. Corder, Artem Golev

Centre for Mined Land Rehabilitation (CMLR), Sustainable Minerals Institute (SMI), University of Queensland, Australia

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ABSTRACT

The environmental legacies of metal mining are often dominated by large waste facilities, which can be sources of acid and metalliferous drainage, resulting in both local pollution and irreversible loss of some of the soluble minerals. Whether a material is treated as waste or ore depends on a wide variety of factors and circumstances. Three critical aspects – time, the extractive strategy and the economic context - are discussed in this paper. The authors argue that the fine line between waste and ore requires a mine waste management (MWM) hierarchy that properly considers waste as a potential future resource. This hierarchy exhibits four main levels: reduce, reprocess & stockpile, downcycle and dispose, which are illustrated by a review of both academic research and public data on industrial practices. The authors conclude that to generate the most successful outcomes the hierarchy must operate across all levels and is a core component of an overall mine sustainability framework.

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1. Introduction

There are a variety of sustainability frameworks adaptable or specifically designed for the mining industry. These frameworks, originating from academia, governments and industry, are attempting to comprehend the sustainable mining challenge and contribute to the understanding of this complex problem.

The authors have argued that a key element of sustainable mining is the mineral resource itself (Lèbre and Corder, 2015), a resource that is finite and non-renewable. They also argued, along with other authors (e.g. Ayres et al., 2002; Fonseca et al., 2013; Laurence, 2011), that most sustainability frameworks tend to overlook that aspect, which makes the mining industry unique in the sustainability challenge.

Principle 8 of the ICMM principles (ICMM, 2015) connects mining activities to downstream use and disposal of metal-containing products, engaging the mining industry in the global efforts to close material cycles through recycling. However, before extending the extractive industry's responsibility across the entire value chain, it is worthwhile investigating opportunities at the mine site level.

The five capitals framework (Porritt, 2003) includes the mineral resource in the natural capital, and the mining industry will carry out a transfer from this capital to the four other capitals (in particular the manufactured capital, but also the financial, human and social capitals). The question is: how effective is this transfer? At the mine site level, how much of the mineral resource is being effectively extracted and utilised, and how much is left behind? There is evidence that a significant part of the resource is left behind as waste (Laurence, 2011).

The aim of this paper is to review reported practices of management of mining waste and categorise these within a proposed hierarchy with a specific focus on metal mining. This hierarchy prioritises strategies that lead to minimising losses of minerals and enhancing the utilisation of mineralised waste over the life of mine. The paper is structured as follows. First, we overview the origin of mineralised waste at the mine site level and introduce a mind-set change to better distinguish the difference between ore and waste. Second, the MWM hierarchy is presented and illustrated with examples from both academia and industry. The final part of the paper consists of a discussion on how proactive waste management approaches can be coupled with remediation and rehabilitation efforts to deliver improved outcomes.

2. The fine line between resource and waste

In a metal mine, mineralised waste may originate from three main production stages: mining, minerals processing and metallurgical processing. Inefficiencies caused by various factors occur in each stage and result in mineral losses to waste rock, tailings, slag and leached ore. Mine water is a fifth waste stream that comes

* Corresponding author.
E-mail address: e.lebre@uq.edu.au (É. Lèbre).

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into contact with solid waste either naturally or by being introduced during one of the production stages. The resulting waste water is charged with dissolved metals. This last type of waste differs from the others by its mobility, contributing to spreading environmental contamination. Lottermoser (2010) provides a comprehensive overview and detailed description of the various types of mining wastes and their sources, summarised in Fig. 1.

Additionally, any unexploited mineralised material on site may be considered as waste. In particular, a part of the ore body left exposed and unexploited may also come in contact with mine waters, contributing to discharges of dissolved metals. This paper includes all sources of mineral losses in the aim of defining a waste management strategy that maximises the utilisation of the overall mineral resource.

These different types of waste material still contain a certain concentration of the minerals targeted for extraction. Recovering these minerals is generally considered too costly and too intensive from an energy, water or resource perspective, making it undesirable from both economic and environmental perspectives. However, the distinction between waste and ore can sometimes be fuzzy due to various factors not related to the physical properties of the ore body. They can be technical or non-technical, external or internal to the mining project. We describe three main factors (or groups of factors) below. These factors inform the alternative waste management presented later in this paper.

2.1. Factor 1: Time

Time allows for technological innovation to occur, which in turn allows for the economic extraction of minerals and metals from what were once sub-economic resources. As a consequence, mineral waste reprocessing is almost as old as mining itself. One historical example is the Broken Hill mining area in Australia, were zinc was initially not extracted and the first twenty years of operations generated about 7 Mt of tailings grading 19% Zn (Mudd, 2009). Technological advances, notably the invention of the flotation method, then allowed for zinc extraction and the tailings were reprocessed in 1905 (Mudd, 2009).

In parallel, intensive mining has led to a continual decrease in ore grades over time (Gordon, 2002). Ever increasing resource scarcity leads to higher energy and other resources requirements for mineral extraction, and at the same time demanding fast technological adaptation to address rapidly evolving challenges (Rönnlund et al., 2016a). Two conclusions can be drawn from this: firstly, because of technological advances it is possible to re-mine mineral waste material that was not economic in the past, and therefore logically waste of today can become the ore of tomorrow. Secondly, taking into account the need for re-mining mineralised waste deposits may be necessary in a long-term vision of metal supply.

2.2. Factor 2: The extractive strategy

The composition and the amount of mining waste essentially rely on human decisions made upstream in the metal supply chain, and based on economic considerations. The operating costs, the metal prices and the extractive strategy will in particular determine the cut-off grade that separates ore from waste rock. The processing plant design and technological choices are articulated around the specified concentrate grade and recovery rates, which determine the amount of mineral losses to processing waste streams. Table 1 shows estimates of mineral losses to tailings and slag compared to global production for seven different metals.

Furthermore, metallic ore bodies present complex arrangements of minerals and the extractive strategy may, driven by economic considerations, choose to extract only some of them leaving the remainder to report to tailings. The selected extractive strategy and plant design will define whether a particular type of mineral is to be treated as a main product, by-product or as an impurity. The statement from Wills and Napier-Munn (2006) "A valuable product in the 'wrong' concentrate will be considered as impurity" succinctly highlights this issue. In particular, poly-metallic ores are complicated to deal with and decision-making will have to consider trade-offs between the main product(s) and by-products recovery, taking into account operating costs and the operating challenges related to mineral extraction and processing. Not deviating from the company's core business can be a sufficient reason for not exploring the recovery of a particular by-product.

Hunter (2014) points out that these decisions, which obey to the profit maximisation imperative, often do not result in optimal resource extraction. Hunter argues however that governments, as the resources' owners, have the power to - and interest in - influencing the extractive strategy to achieve higher extractive rates.

2.3. Factor 3: The economic context

Finally, materials that were economic to mine may become waste as a result of an unplanned interruption in mining activities. Laurence (2011) evaluates that about 75% of mining projects close prematurely - often due to a drop in commodity prices - leaving some un-extracted resource behind. These unplanned closures do not consider a future use for the remaining mineralised material, which ends up being wasted. A resource whose extraction was planned can therefore become sterilised.

Mining projects are inherently limited in time by the extraction rate of the orebody. However, the (macro)economic context as well as internal business decisions affect the project's economic viability and can either ensure or compromise the continuity of mining activities. Maintaining coherence in the extractive strategy despite a changing economic context in order to complete resource extraction and avoid sterilisation is a crucial aspect in the sustainable mining challenge. Moreover, without economic viability none of the other sustainability dimensions can be satisfactorily addressed.

Incomplete resource extraction causes environmental problems. Hansen (2004), who studied the environmental impacts of mine waste disposal, proposes to view solid waste deposits as an abiotic resource whose environmental impact is due to its non-utilisation rather than its depletion. And the quality of this resource, i.e. its grade, is declining over time through dispersion

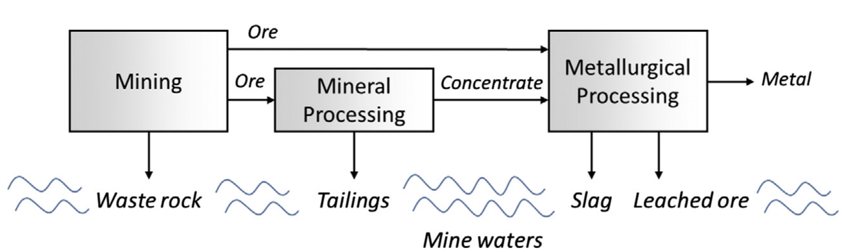

Fig. 1. Origins of mineralised waste.

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