On-Land or Submarine Tailings Disposal? – Pros and Cons

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ABSTRACT

Mine tailings management is a major issue for the mining industry and a limiting factor due to competitive land use for example with agriculture or tourism. Most of mine tailings are stored today in constructed tailings impoundments on-land. This practise results in the exposure of sulfide minerals to oxidizing conditions and subsequent in acid mine drainage (AMD) formation in many cases. Due to the environmental and geotechnical stability problems of this tailings disposal practise, the mining industry is searching for alternatively tailings management options. Currently the deep marine tailings disposal is experiencing a revival as such an alternative option. After negative experiences of marine shore or shallow depositions around the world, the deep marine disposal (below the euphotic zone; i.e. < 150 m depth) is seen as a potentially save option in some sectors. The idea to deposit sulfide minerals in a reducing environment to prevent sulfide oxidation and the subsequent element and acid release is sound and appealing. However, the experiences from the past have shown that only the thorough mineralogical and geochemical characterization of the future tailings to be deposited can give the necessary information if the material is suitable for submarine disposal (The tailings can contain more soluble minerals, which are not stable in the marine environment). Then the disposal site has to be evaluated to ensure stable reducing conditions without currents and upwelling. This paper analyzes the pros and cons of each tailings management strategy and highlights the geochemical processes and characterization methodologies, which have to be considered in each case for decision-making.

Keywords: sulfide oxidation, acid mine drainage, prediction, waste management, reductive dissolution,

INTRODUCTION

Final waste management is a critical issue for mining operations, as around the world new legislations are in place for mine closure and environmental protection (e.g. new mine closure law 20.551 in Chile from November 2012). As nowadays metal mining focuses mainly on sulfidic ore bodies, the associated sulfide oxidation and formation of acid mine drainage in mine wastes like tailings are the mayor environmental issued of the on-land deposition of the mine tailings (Dold, 2010, 2014a). Mine tailings disposal is therefore a critical issue for any mine project and must be thoroughly studied before the most suitable solution of each case is found. Main problems associated to the tailings disposal are the geotechnical stability (Azam and Li, 2010; Rico et al., 2008a; Rico et al., 2008b) and the geochemical stability (Dold, 2010, 2014a).

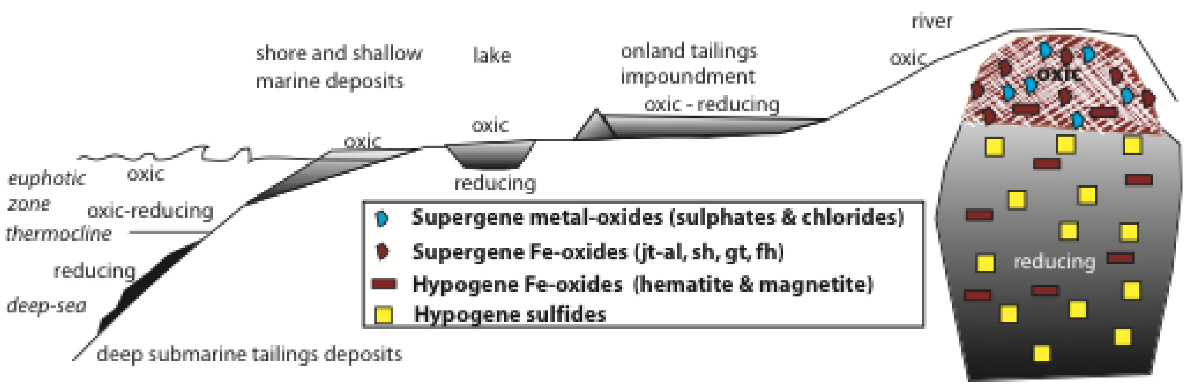

Figure 1: Overview over the different mine tailings disposal options (river, lake, sea and onland disposal (constructed impoundments) and the associated geochemical regimes. On the right the different main mineral assemblages from sulfide to oxide domination in an ore deposit are highlighted.

Historically, mine tailings were dumped first into close-by rivers (Fig. 1), lagoons or lakes (Dold, 2014b; Dold et al., 2009). In some cases the tailings reached the sea and formed so called shore tailings deposits, like at Chañaral/Chile (Bea et al., 2010; Dold, 2006; Korehi et al., 2013), Bahia de Ite/Peru (Diaby and Dold, 2014; Dold et al., 2011) y Bahia Portman/Spain (Benedicto et al., 2008; Martinez-Sanchez et al., 2008; Oyarzun et al., 2013). This practice led to a severe contamination of the associated aqueous systems.

In the years around 1970 at several place around the world, the so called deep submarine disposal of mine tailings started due to the visible problems of marine tailings deposition at the shore line and in the euphotic zone in the Atlas Mine, Filipinas, Island Copper Mine (50 m), Canada, Jordan River Mine, Canada and Black Angel Mine, Greenland. The cases of Island Copper Mine and Black Angel Mine have shown the difficulties of predicting the behavior of the oceanographic system and the importance of mineralogical and geochemical characterization of the tailings before marine deposition. In the latter case, soluble and oxide minerals liberated significant amounts of contaminants into the sea (Perner et al., 2010; Poling and Ellis, 1995), similar to the situation of Ensenada Chapaco (Dold, 2014b), and clearly showed that oxide minerals should not be deposited in a reducing environment.

As this historic overview shows, inappropriate tailings management and a lack of mineralogical, geochemical, and oceanographic characterization of the systems can lead to environmental damage, and has resulted in a shift by the mining industry back to on-land deposition in tailings impoundments.

However, also on-land tailings disposal has many severe problems (e.g. geotechnical and geochemical stability; AMD formation), receiving increasing pressures from society, and therefore, the submarine tailings disposal option is nowadays again being evaluated. This paper shows the factors to be considered for the final decision making for the best tailings disposal option.

METHODOLOGY

In order to be able to predict accurately the environmental long-term behavior of the tailings on-land or submarine, quantitative mineralogy is needed. This give the possibility to predict the behavior of the material in different geochemical conditions and for an accurate prediction of acid mine drainage formation (acid-base accounting). Today advanced technologies are available for automated mineralogical analysis like QEMSCAN® or MLA. If thoroughly calibrated with the ore mineralogy this give an accurate quantification of the complete mineral assemblage, degree of liberation, as well as grain size distributions, important information to increase the efficiency of the extraction process and to predict AMD formation and element release.

However, this methodology does not give detailed information on trace element association to specific minerals or mineral groups. This information is crucial in order to predict if a certain contaminant might be liberated from its host mineral. Therefore, the mineralogical data are combined with high-resolution geochemical data from a seven-step sequential extraction developed for the primary and secondary mineralogy present in typical porphyry copper deposits (Dold, 2003). The leach solutions are then analyzed by inductively coupled plasma–atomic emission spectroscopy. The sequential extractions data can additionally be used to perform a high-resolution ABA (Dold 2010) and should be correlated with the mineralogical data for quality control of the data, and in order to predict AMD formation and element liberation of any mined material. It is important to note that this extraction sequence might have to be adapted to the solubility of the specific minerals (primary and secondary) present in an ore deposit, as this might differ importantly in different ore deposit types.

In order to predict the kinetics of metal release to the environment, so-called kinetic tests are used (Weibel et al., 2011). The tests used in AMD prediction (e.g. ASTM D5744-96) are not suitable for prediction of the behavior of mine tailings in submarine environments, as they expose to an oxic environment. There is currently no kinetic test available to predict the behavior of mine tailings in a reducing environment. Therefore, efforts have to concentrate to develop such a test to simulate the geochemical conditions in the deep-sea environment.

DISCUSSION

Most of the mine tailings are deposited close to the mine site, or at least as close as possible in order to lower costs. However, there are examples were tailings are sent hundred kilometers to a suitable disposal site. An overview of the principal pros and cons of both deposition strategies are given and then discussed in order to give assessment for decision making.

Pros and Cons of On-Land tailings disposal

Commonly Mentioned Advantages of On-Land tailings disposal are:

- Cheapest option, as lowest transport costs through close-by deposition;
- The economic value contained in the tailings might be exploited in future by new exploitations techniques;
- New dam construction techniques ensure geotechnical stability;
- New tailings impoundments contain an impermeabilization to prevent groundwater contamination and/or to recover water and dissolved metals (e.g. pregnant leach solutions; PLS) from the tailings.
- New tailings deposition techniques like dry stacking use less water and increase the geotechnical stability.

Commonly Mentioned Disadvantages and Risks of On-land tailings deposition are:

- Dam failures due to geotechnical instability (especially in seismic and high rainfall areas and for old tailings impoundments, which were not constructed in an appropriate and safe way);
- Formation of Acid Mine Drainage due to sulfide oxidation;
- Competition with other land-uses like agriculture and tourism;
- Groundwater contamination due to the lack of basal impermeabilization;
- Long-term maintenance and monitoring required
- Low social acceptance

Pros and cons of submarine tailings disposal (STD)

Commonly Mentioned Advantages of STD Are:

- Prevention of acid mine drainage: Reducing environment and lower concentrations of dissolved oxygen limit or prevent sulfide oxidation and any acidity produced through sulfide oxidation will be neutralized by the buffer capacity of marine water;
- Tailings are more geotechnically stable and the possibility of catastrophic failure of tailings dams (on land tailings dam heights may reach several hundred meters), especially in areas with high seismic activity and high rainfall is eliminated;
- Minimal land surface is used. This is a strong argument in Norway where, due to the Fjord topography, on-land space for the tailings deposition is very limited;
- Less long-term maintenance required after deposition compared to on-land disposals.

Commonly Mentioned Disadvantages and Risks of STD Are:

- Smothering benthic organisms and physical and geochemical alteration of bottom habitat;
- Reduced number of species and biodiversity of marine communities;
- Risk of liberation of toxic elements from the tailings to the seawater;
- Bioaccumulation of metals through the food chains and ultimately into fish consumed by Humans, with associated human health risks;
- The water content of the tailings cannot be recovered; this is especially critical in dry climates;
- The deposited tailings cannot be recovered (possible loss of valuable resources);
- Larger footprint on the seabed than on land;
- Potential toxicity of the flotation reagents used on the marine ecosystem;
- Plume sharing and dispersal of the fine particles throughout the sea;
- Relocation of the tailings in different compartments of the marine ecosystem due to upwelling and currents.
- If accidents happen it is nearly impossible to control them in the deep-sea environment.
- Low social acceptance

In the past, many mistake in mine tailings disposal have been done, which led to strong environmental contamination and threat through geotechnical instability. This led to an increasingly low acceptance by the public opinion and therefore difficulties in the permitting process. This is true for the on-land disposal as well as the submarine disposal. The main problems in both cases are the insufficient mineralogical and geochemical characterization of the tailings to be deposited and the characterization of the receiving environment. It is known, that when sulfidic tailings are exposed on-land to oxidizing conditions, acid mine drainage can form. In order to predict accurately if AMD will form, a thorough mineralogical and geochemical study has to be performed. Standard acid-base accounting tests and kinetic testing is not sufficient to address the complexity of the ore mineralogy. Additionally, most of the tailings impoundments do not have an impermeabilization in order to prevent the infiltration of the contaminated solution into the groundwater (Dold, 2014a), and the hydrogeology of the receiving environment is often poorly understood.

If the tailings are deposited into the sea, also a detailed study of the mineralogy and geochemistry of the ore is needed, as well as a detailed knowledge of the sea environment is needed. In this case a special attention has to be given to the oxide minerals (especially Fe-oxides like hematite, magnetite, goethite, ferrihydrite among others), which can contain important amounts of toxic elements (Nystroem and Henriquez, 1994) and might suffer reductive dissolution in the reducing environment of the deep sea (Dold, 2014b). Additionally, the long-term stability of the reducing conditions at the disposal site has to be proven by thorough oceanographic studies. These studies have also to show that at the site, there are no currents and upwelling, which could relocated the material into different geochemical conditions.

In the past on-land tailings disposal was done in very simple forms promoting the oxidation, and thus the AMD formation, mostly with direct contact with water bodies (river, lake, sea, or groundwater), with the subsequent pollution of those. If on-land tailings disposal is done by best-practice, an impermeabilization and separation from the hydrological system is necessary (Dold, 2008). Also the formation of AMD might be prevented or controlled by different measures, in order to limit the impact on the receiving ecosystem. The geotechnical stability can be increased importantly by the use of state-of–the-art dam construction techniques. If all these factors are considered in the construction of an tailings impoundment on-land, most of the environmental and geotechnical problems from the past can be avoided, and the tailings are in condition for further exploitation with advanced technologies by future generations (Dold, 2008). However, the on-land tailings deposition still has to compete with other land-uses.

In case of submarine tailings disposal, it has to be proven that the material to be deposited is "inert inorganic geological material" following the London Protocol (Dold, 2014b). The objective of submarine tailings disposal is to deposit the sulfide containing minerals into a reducing environment, in order to prevent the sulfide oxidation. However it is often overlooked, that ore deposit often contain not only sulfide minerals, but also oxides like hematite and magnetite or other soluble minerals, which can contain also toxic trace elements. These minerals are not stable under the reducing, alkaline and organic matter rich environment of the deep-sea. Therefore, the mineralogical and geochemical characterization must be very thorough in order to ensure that the material is effectively "inert inorganic geological material".

CONCLUSION

Te above mentioned arguments show that both option have important pros and cons, and it has to be evaluated in each case, which might be the most suitable option. The examples show that only if we count on an accurate quantitative mineralogy and data on the association of trace elements to these minerals, a correct prediction of the behaviour of the material in the different geochemical compartments for the final deposition of the waste material can be given. This is crucial to ensure the long-term geochemical and geotechnical stability of the waste.

Due to the limitation for submarine tailings disposal that only "inert inorganic geological material" can be deposited into the sea, it can be predicted that only few sites might be suitable for this option. Instead, if on-land disposal uses best-practice methods for pollution prevention and geotechnical stability, this option ensures the possibility that future generation might be able to exploit these resources in the future by optimized exploitation techniques.

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