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Editorial

Editorial for Special Issue "Reutilization and Valorization of Mine Waste"

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Solid waste management is the most important environmental challenge of mining operations worldwide. Indeed, a highly significant volume of mine waste is produced every year, including waste rock (blasted barren rock), tailings (slurried fine material produced by mineral processing), and sludge (from water treatment processes). These solid wastes are generally stored in specifically designed storage facilities for an extended and undefined period of time. The physical and chemical characteristics of these mine wastes can be variable and often induce risks related to geotechnical and geochemical instabilities. Tailings dam failures, acid mine drainage, wind erosion, soil and groundwater contamination are examples of potential impacts caused by poor mine waste storage and management. In the context of sustainable development and responsible mining operations, solid mine waste may offer opportunities for reuse and valorization beyond their traditional long-term disposal. Recent research work identified options to take advantage of the physical, mineralogical, and chemical properties of waste rock, tailings, and sludge, either for reutilization on the mine site itself or for further use ex situ. This special issue consists of eight research contributions, in which mine waste becomes a resource in a circular economy framework. These contributions highlight specific examples and applications of mine waste reutilization at different technology readiness levels, from preliminary studies to laboratory and field scale. The common ground for these contributions is a desire to reduce environmental liabilities related to mine waste long-term storage and management and to favor a reduction in natural resource extraction.

The first contribution discussed the use of gold mine tailings as a source of silica for glass making [1]. Large amounts of silica are mined to fulfill the industrial requirements, such as glass, sand, and abrasives. In parallel, vitrification is a process that can be used to immobilize and encapsulate hazardous materials, and involves the production of a glass-like matrix. South African gold mine tailings were investigated as a potential raw material to replace silica sand in glass making while benefitting from the encapsulation of contaminant elements (e.g., copper, lead, zinc) present in the tailings through vitrification. A detailed physical, chemical, and mineralogical characterization of the gold mine tailings was performed to ensure that the specifications are compatible with glass making requirements. A beneficiation of the tailings was deemed necessary to reduce the amounts of iron oxide, alumina, titanium and potassium oxides. Glass was then produced by addition of calcium carbonate and soda as fluxing agents, at a temperature of 1520 °C. The glass had different levels of white structures and green glassy material, depending on the residual amounts of iron oxide. Further processing was suggested to improve the quality of glass. However, the study showed a definite potential of using gold mine tailings as silica sand substitute for glass making, while reducing the environmental impacts of tailings facilities.

The second contribution evaluated three reutilization prospects of diamond clay tailings from the Lomonosov Mine in northwestern Russia [2]. The mine produces large quantities of saponite, an argillaceous mineral, from kimberlite processing. After a detailed characterization of the chemical and mineralogical properties of the tailings slurry, and considering that the remote location of the site imposed constraints related to supply and demand for by-products, and being in a sensitive cold environment, three potential reuse options for the tailings were selected for testing. First, application as cement clinker for ceramics manufacture was found to give satisfactory results, but its application is quite limited in this underpopulated area. Then, application of the tailings slurry as alkaline amendment to reclaim acidic peat bogs was evaluated in field plots, and was found to be efficient. Third, the slurry was tested as clay-based fluid for drilling; however, the results were not promising due to high fluid loss. This contribution highlights the need to integrate technical, environmental, and socio-economic considerations into the selection of valorization scenarios for kimberlite tailings.

The next contribution also involved kimberlite tailings [3], and proposed a valorization strategy that fulfils two objectives: sequestration of carbon dioxide and partial cement substitute in concrete bricks. Accelerated mineral carbonation was performed on kimberlite tailings (magnesium and calcium silicate) as a carbon capture mechanism. Thin-film carbonation, done using relatively low energy, was shown to be effective to increase the CO_2 content of kimberlite by approximately 3%. The carbonation plays a role in increasing the amount of carbonates in the kimberlite to improve strength development when used as a cement in bricks. Indeed, the bricks produced with carbonated kimberlite fulfill the compressive strength requirements by the Canadian Concrete Masonry Producers Association. The valorization of kimberlite is therefore enhanced by carbon dioxide sequestration, which can provide positive environmental impacts on two fronts: carbon capture and reduction in volume of kimberlite tailings stored in tailings ponds.

Another contribution implied the reuse of tailings from an old lead mine as a component for bricks, along with red clay [4]. After a detailed physicochemical characterization of mining tailings and clay, different groups of samples with variable proportions of clay and mine tailings were conformed and sintered before evaluation of the potential release of contaminants using standardized leaching tests. The work highlighted the importance of considering the potential for contaminants leaching from the bricks when mine tailings are used in brick fabrication. It was found that heavy metals were effectively retained in the ceramic matrix. Some elements, such as copper, showed a slight mobility when the fraction of mine tailings was increased in the bricks; however, the concentration leached was still below the regulation limits. Overall, the process of substituting a portion of red clay by lead mine tailings in bricks was helpful to reduce the environmental impacts of the tailings, which are otherwise left in nature.

On the same topic of brick making, the next study [5] involved the valorization of granite stone cutting sludge from ornamental stone quarries. The focus of this study was on the physical properties of the materials and the resulting bricks' physical, color and strength properties. Slight variations in physical properties, such as shrinkage and porosity, occurred with the inclusion of up to 70% granite stone cutting sludge. Depending on the specific properties of the bricks with different ratios of sludge and clay, the most appropriate application can be selected. For example, lower density bricks are suitable where light construction materials are required. The environmental benefits of replacing part of the red clay by granite stone cuttings in the brick include a reduction of waste material deposited in landfills and a decrease of natural material extraction.

The previous contributions were mostly focused on reuse of mine waste in ex situ applications. There is, however, a large potential to reuse mine waste as a construction material on the mine site itself. While the reuse of inert waste rocks, tailings, or overburden in road construction and backfill is quite common, the reuse of waste as part of acid-generating tailings reclamation scenarios is more complex. Two linked papers, [6,7], explored this aspect. The first part presented a methodology used to evaluate if low sulfide tailings and waste rock have the adequate properties to replace natural geological materials in a cover with capillary barrier effects (CCBE) placed over highly reactive tailings. The work involved detailed physical, hydrogeological, mineralogical, and environmental characterization to assess the suitability of the waste as components of the CCBE. This evaluation was done at the laboratory and field scales. It was found that the low sulfide (desulfurized) tailings were appropriate as a fine-grained material for an oxygen barrier. Waste rocks, with up to 0.6% S, were deemed acceptable as capillary break layers, since their hydrogeological properties have a sufficient contrast with the low sulfide tailings properties. The paper highlighted the importance of assessing both hydrogeological and geochemical properties for potential reuse of mine waste.

The related paper [7] presented the laboratory and field experiments initiated to evaluate the performance of a CCBE made entirely of mine waste placed over highly reactive tailings to prevent acid mine drainage. The cover materials were instrumented to monitor water and gas movement through the cover, and the effluent quality was assessed. The challenge was to sufficiently reduce the oxygen flux reaching the reactive tailings to prevent acid generation and metal leaching. The results showed that the cover made of low sulfide tailings and waste rock was efficient at maintaining the appropriate hydrogeological conditions to minimize oxygen diffusion. However, even with low oxygen flux, the measured metal concentration in the effluents was sometimes above the criteria in the appropriate jurisdiction. The high reactivity of the tailings to be reclaimed was found to require even lower oxygen flux targets than typical tailings for the reclamation scenario to meet effluent quality criteria. Globally, the study showed that mine wastes can be appropriate as reclamation cover materials provided that the oxygen flux target is determined based on the specific characteristics of the tailings to be reclaimed.

The last contribution [8] involved the recovery of a phosphate by-product from niobium mine tailings to maximize the exploitation of mineral resources, while reducing the amounts of mine waste to be disposed of. The conventional desliming/flotation/acid leaching process used for phosphate ores was adapted to mine tailings initially containing 5.1% P_2O_5. Preliminary results showed the potential to recover a saleable apatite concentrate (32% P_2O_5) from niobium mine tailings. Desliming using hydrocyclones was used to remove the fine particles (<38 μm) that consumed chemicals for subsequent steps and entails selectivity challenges during flotation. Reverse flotation approach (flotation of gangue minerals and depression of apatite) appeared to be more efficient than direct flotation of apatite from mine tailings to selectively recover an apatite concentrate (27.4% P_2O_5) from the coarse particles, as the samples contained minerals already subjected to collectors to concentrate niobium. Sulfuric acid leaching successfully solubilized residual carbonate minerals, including dolomite, reducing the final amount of Mg below the target values (<1% MgO). A preliminary technoeconomic analysis highlighted the viability of this process train to recover a saleable apatite concentrate from niobium mine tailings, even if the recovery of apatite is quite low (41%).

Research work presented in this Special Issue pointed out that in situ or ex situ reuse and valorization of solid mine waste (e.g., waste rock, tailings) is of great importance beyond their traditional long-term disposal to reduce environmental impacts of mining activities and maximize the exploitation of mineral resources. The recovery of valuable metals/minerals present in solid mine waste [1–5,8] to produce value-added by-products supports circular economy (e.g., convert mine waste into valuable by-products for another industrial sector) and sustainable mining operations (e.g., reduction of the amount of solid waste to be disposed of on-site). The reuse of mine waste, including low sulfide tailings and waste rocks, as construction materials for mine site reclamation [6,7] is another approach of interest to valorize these low reactive materials, especially for remote mine sites. The success of mine waste reuse or valorization is strongly dependent of adequate physico-chemical, mineralogical, geotechnical and/or geo-environmental characterization. Additional research work in this field is of importance to change our perspective and consider solid mine waste as raw material for further applications.

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