minerals

Editorial

Editorial for Special Issue "Geomicrobiology and Biogeochemistry of Precious Metals"

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The effect of bioorganic and geobiological processes on the mobility of precious metals, especially gold and platinum, has been the subject of scientific debate for more than 100 years [1–3]. While silver mobility under near-surface environmental conditions was widely accepted, the dogma of the immobility of gold and platinum in Earth surface environments and the purely detrital formation of placer gold only fell in the 1980s and early 1990s. This was the result of a series of studies showing nanophase and secondary gold formation on placer gold from New Zealand, Australia and the United States [4–6]. The advent of suitable biomolecular tools in the 2000s combined with high-resolution micro-analytical techniques revealed that microbial biofilms play a critical role in gold and platinum mobility as well as placer particle transformation. The fundamental processes driving the cycling of these elements is now better understood than ever before [7–9]. This current issue builds upon previous research in precious metals by bringing together recent studies in the areas of geomicrobiology and biogeochemistry. Collectively, these studies enhance the fundamental understanding of the process and explore biotechnological applications for precious metal exploration, ore processing and bioremediation.

In their review, Shuster and Reith [10] summarize current processes concerning gold cycling and point to the need to determine the kinetics of these processes to develop applications for the minerals industry. How environmental kinetics can be determined is highlighted in the study by Shuster et al. [11], which assesses biogeochemical silver cycling in acidic, weathering environments at three abandoned open-pit mines in Spain. By using bacterial enrichment cultures combined with micro-analytical tools, the kinetics of silver mobility was estimated for different types of silver-bearing regolith materials: Gossans, terrace iron formations, and mine soils represented a range of years in which biogeochemical silver cycling had occurred. The study by Mechiorre et al. [12] demonstrated that placer gold grains and nuggets from Rich Hill (Arizona, USA), contain detailed records of physical, chemical and biological transformation triggered by wet/dry paleoclimate transitions. Biogeochemical transformations result in changes to the chemistry placer gold, the generation of nano-particulate gold and the production of polymorphic biofilm layers containing manganese-iron-barium oxide. On the other side of the world in New Zealand, Kerr and Craw [13] found that detrital gold in Late Pleistocene–Holocene placers was chemically mobilized and redeposited at the micron scale by biologically mediated reactions along redox boundaries in the sediment–groundwater system. In this environment, microbial sulfur-oxidation and (thio)sulfate-reduction drive gold dissolution and re-precipitation processes. This study, therefore, also points to the need for a better integration of biogeochemical cycles of precious metals with other large biogeochemical cycles, e.g., those of carbon, nitrogen and sulfur. In their application-driven study, La Vars et al. [14] achieve this by assessing *Acidithiobacillus ferrooxidans* and its associated extracellular polymeric substances (EPS). This bacterium forms biofilms on the surface of gold-bearing sulfide mineral pyrite and the resulting EPS may be a viable alternative depressant of pyrite for froth flotation. A large step towards integrating platinum and carbon cycling, especially the decomposition of humic acids was achieved by Bowles et al. [15], who showed that mobile platinum species can catalyze the breakdown of the longer n-alkanes to form $C_{14–22}$ alkanes. Thereby, this mechanism offers additional important evidence for the presence of the platinum complexes in soil solution and confirming platinum mobility in soils.

Crucially important for the development of bioprocessing applications as well as for the emerging field of gold/platinum nano-bioscience, is understanding the mechanism leading to the sorption and reduction of mobile noble metal complexes as well as the biomineralization of nanoparticles by microbial cells. For example, Rizki and Okibe [16] showed that the acidophilic, Fe(III)-reducing heterotrophic bacterium, *Acidocella aromatica*, was capable of forming intracellular gold nanoparticles from highly-acidic Au(III)-complexes containing solutions via a simple one-step reaction. The study by Campbell et al. [17] demonstrated that the known gold-resistant bacterium *Cupriavidus metallidurans* was also capable of precipitating nanometre-scale platinum particles. These were formed primarily along the cell envelope, where energy generation/electron transport occurs. These studies corroborate the important role of bacteria for the transport of gold and platinum in natural systems leading to the formation of dispersion halos, which are widely used in precious metal exploration. Natural nanoparticle mobility of precious metals and the increasing anthropogenic use of gold and silver can lead to the large-scale release into the environment. Therefore, ecotoxicological pathways need to be studied, as was done by González et al. [18], who studied gold nanoparticle toxicity in freshwater diatoms. The results suggested that cell photosynthesis can lead to a decrease in gold nanoparticle adsorption and uptake by cells. This can be considered as a mechanism of passive detoxification driven by the exertion of organic ligands. Using microbiota to reclaim noble metals from electronic waste (e-waste) is currently a hot research topic due to the large environmental and human costs of reclaiming these metals using 'standard' techniques. As e-waste is a highly complex mixture of various toxic heavy metals, noble metals and plastics, understanding the effect of bacterial–fungal interactions on these materials is important to control the release of toxic side products. This was studied by Losa and Bindschedler [19], who assessed the synergistic bioremediation capabilities of bacterial–fungal couples to mobilize and immobilize cadmium in e-waste. They suggested that using microbial consortia, rather than single species, represents an innovative alternative to traditional bioremediation approaches, especially for the development of new biotechnological approaches in urban mining.

Overall, we hope this special issue will contribute further to the understanding of the geobiological cycling of noble metals, enhance the scientific debate and point the way towards making good use of our understanding of the possibility of a sustainable future.

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