

Microbes at the extreme: Mining with microbes



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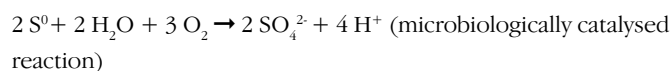
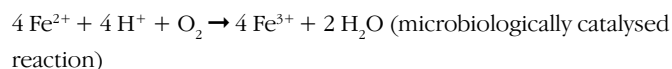
The use of microorganisms to recover precious and base metals from mineral ores and concentrates is called biomining, or biohydrometallurgical processing. Biomining occurs through the natural ability of certain microorganisms to catalyse reactions, leading to the solubilisation of metals from the minerals. This process is used today in commercial operations to recover copper, nickel, cobalt, zinc and uranium from complex ores.

Specific microorganisms have the ability to oxidise reduced sulphide ores and hence enhance the solubilisation of desired metals. In bioleaching base metals are leached into solution, whereas biooxidation is used as a pre-treatment to oxidise the sulphide matrix of gold and silver ores or concentrates before cyanidation. Modern day biomining descends from observations in the 1950s at Kennecott copper mine in USA, where a blue coloured run-off was discovered coming from piles of waste ore. The liquid run-off contained copper sulphate released from the ore, a process normally attributed to powerful oxidising agents¹. The oxidation was found to be catalysed by the bacterium *Acidithiobacillus ferrooxidans*, which is the most studied bioleaching organism. Further investigations have shown that a number of other bacteria and archaea can also enhance mineral dissolution including other *Acidithiobacillus* spp., *Leptospirillum* spp., *Sulfobacillus* spp. and *Sulfolobus* spp.².

Bioleaching microorganisms are mesophiles (lovers of warmth) or thermophiles (lovers of heat) and grow in very acidic conditions

of pH 1.2–2.0 or even lower, allowing these organisms to thrive in very extreme environments. These organisms have a unique ability to oxidise inorganic compounds such as Fe²⁺ and S⁰ to derive energy (chemoautotrophy) for their metabolic processes. Many of them also possess the ability to use atmospheric carbon dioxide as a source of carbon (carbon fixing). Along with high metal tolerance, these characteristics make bioleaching microorganisms very useful for extracting metals from minerals.

Sulphide mineral leaching by microorganisms was previously thought to occur via direct and indirect leaching. In the direct bioleaching model the microorganisms attached to the minerals were believed to directly oxidise the ore enzymatically, thereby gaining energy from the sulphide mineral. As little evidence has been found to support the theory of a direct enzymatic mechanism, the current consensus view is that bioleaching occurs *via* an indirect mechanism³. The indirect bioleaching of sulphide minerals is mediated by microbially-regenerated ferric iron and protons produced in the biological oxidation of reduced sulphur compounds:



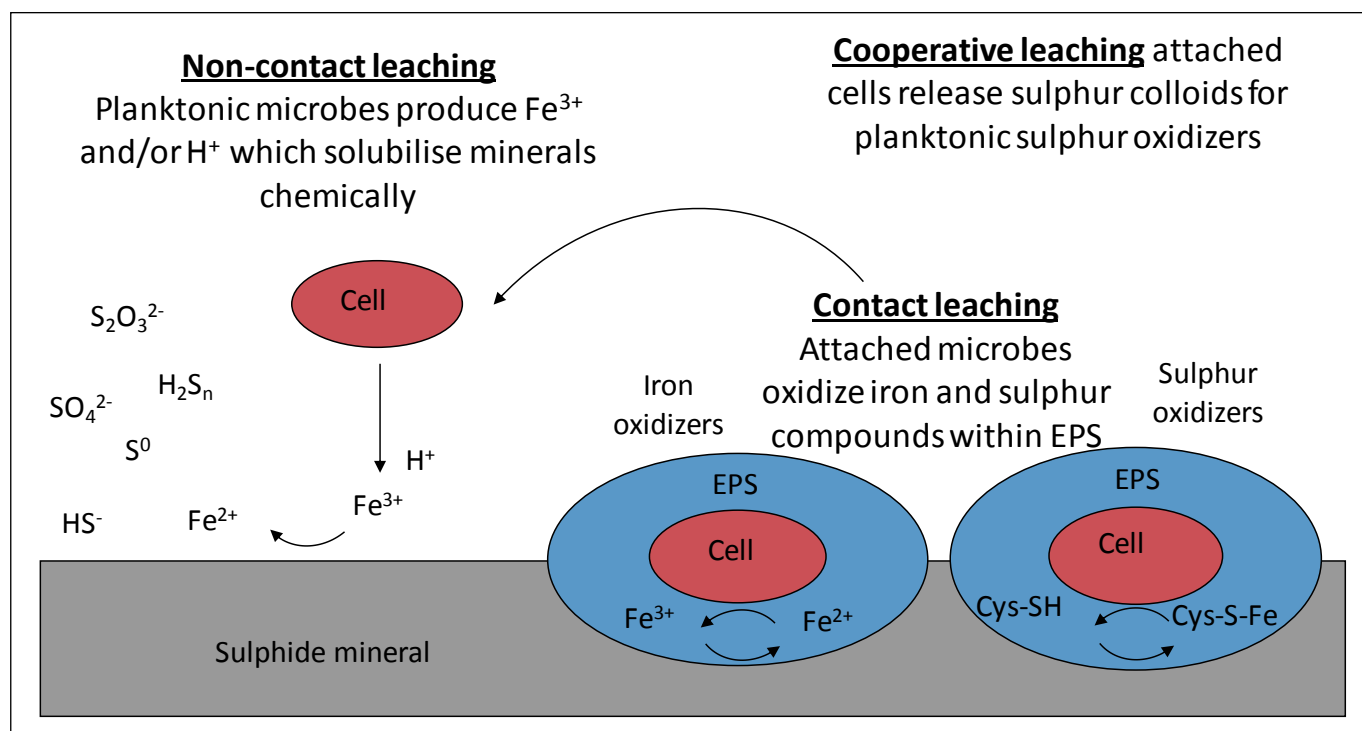


Figure 1. Contact, non-contact and cooperative leaching mechanisms (adapted from reference 4). EPS = extracellular polymeric substances.

Indirect bioleaching has been observed to occur via contact, non-contact and cooperative mechanisms (Figure 1). In contact leaching the microorganisms attach to mineral surfaces and the leaching reactions take place in an extracellular polymeric substance (EPS) matrix produced by the microorganisms. In the non-contact mechanism, planktonic cells produce Fe^{3+} and the H^+ ions, which leach the mineral sulphides. In the cooperative mechanism, attached microorganisms release mineral particles and sulphur compounds, which are utilised by planktonic microorganisms to produce Fe^{3+} and H^+ ⁴.

Metal sulphide leaching can occur via two reaction pathways, the polysulphate pathway and the thiosulphate pathway. The acid solubility of the metal sulphide determines via which pathway the sulphide oxidation will take place. All acid soluble metal sulphides such as chalcopyrite (CuFeS_2), sphalerite (ZnS), and chalcocite (Cu_2S) are leached by both Fe^{3+} and H^+ via the polysulphate pathway with polysulphide as a major intermediate. Acid insoluble metal sulphides, such as pyrite (FeS_2), molybdenite (MoS_2) and tungstenite (WS_2) are leached solely by Fe^{3+} via the thiosulphate pathway with thiosulphate as the main intermediate ^{5,6}.

The main engineering techniques currently used commercially to extract metals from mineral sulphides are *in situ*, in place, dump, heap and reactor (stirred tank) bioleaching or biooxidation (Figure 2). Reactor leaching has been used mostly for concentrates and involves higher costs but shorter leaching times. Heap, dump, in place and *in situ* leaching are more suitable for low-grade ores because the treatment costs are lower, but leaching times are significantly longer. Commercial bioleaching applications are used primarily for copper but also for nickel, cobalt, zinc

and uranium. Bioleaching has been applied in over 20 industrial copper ore operations throughout the world and is currently used to produce over 20% of the world's annual copper. Biooxidation has been mainly applied to refractory gold ores.

The use of bioleaching microorganisms in mining benefits the industry by minimising environmental impacts and allowing the utilisation of low-grade and complex ores, the processing of which would not be feasible with traditional methods. Conventional pyro- and hydrometallurgical ore extraction methods are usually cost- and energy-intensive, not feasible for low-grade ores, and have negative impacts on the environment, for example, tailings (toxic waste carrying heavy metals) from various extraction processes and emissions of chemical reagents, CO_2 and SO_2 ¹. As the grades of available mineral ore deposits decline ⁸, methods that allow extraction of metals from low-grade or other complex ores are required. The lower capital and operational costs make bioleaching a good alternative, particularly for ores containing <0.5% of valuable metals. Moreover, bioleaching can be used for ores for which smelters would impose penalty rates because of hazardous emissions (for example, $\geq 0.15\%$ arsenic in feed intake). Bioleaching organisms also have the ability to oxidise and release metals efficiently at ambient temperatures with low energy consumption enabling the reduction of the carbon footprint. In addition to sulphide ores, the application of bioleaching has been explored for recovering metals from oxide ores ⁹, metallurgical waste ^{10,11}, electronic scrap ¹⁰, wastewater sludge ¹² and municipal solid waste incineration fly ash ¹³. Further research might open avenues for utilising the unique capabilities of these microorganisms in other industries such as toxic waste management and bioremediation.

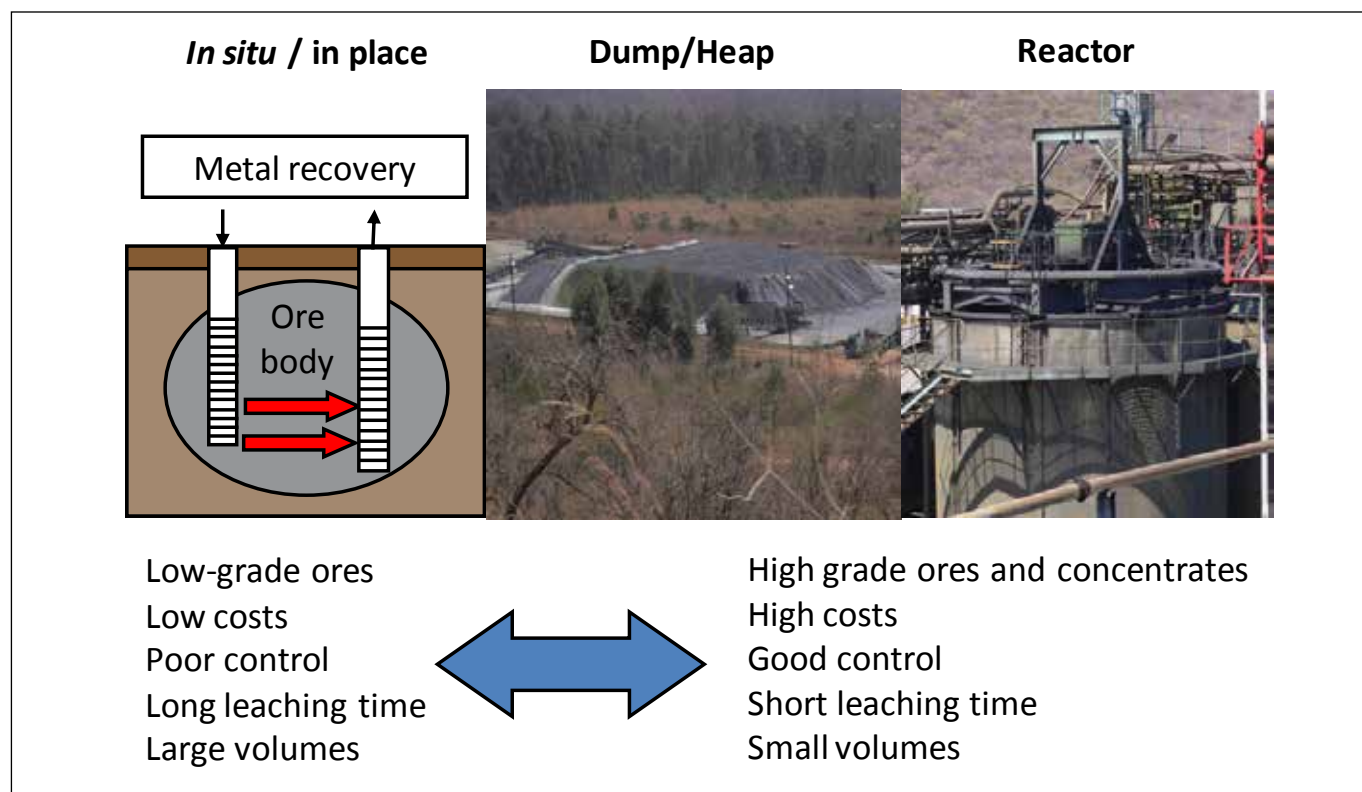


Figure 2. Main bioleaching and biooxidation techniques (adapted from reference 7).

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Biographies

Udeshika Wijewardena is a scientist currently working for Rio Tinto, Technology and Innovation Group. Her area of work is in mineralogy (Exploration and process mineralogy) and bioleaching of copper minerals. Her current work included an honours project in collaboration between the RMIT University and Rio Tinto Technology and Innovation unit. This project provided in-depth understanding of the dynamics in leaching of the interior surface of chalcopyrite ore. Udeshika is a graduate in Biotechnology and cell biology from Latrobe University, also having work experience in analytical chemistry, microbiology and mineral processing.

Ian Macreadie is an Associate Professor at RMIT University where he teaches Biological Chemistry, Protein Technologies and Industrial Microbiology. His research is focused on exploitation of yeast, in particular as a model for Alzheimer's disease. He is an Adjunct Professor of Edith Cowan University and has edited *Microbiology Australia* since 2006.

Dr Anna Kaksonen is a Senior Research Scientist and leads the Environmental and Industrial Biotechnology Team in CSIRO Land and Water. Her research interests include the use of microorganisms and biotechnological processes for environmental and industrial applications in the mining, water supply and wastewater treatment industries. She has expertise in environmental biotechnology and microbiology, biogeochemistry, microbial ecology and taxonomy, and molecular methods for microbial community analysis.