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The role of microorganisms in gold processing and recovery—A review

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ABSTRACT

With a projected steady decline of gold ore grade in mineral resources, mining applications enabling efficient metal extraction from low-grade ores are of increasing interest to the minerals industry. Microbial processes may provide one such solution since they can participate in the biogeochemical cycling of gold in many direct and indirect ways. This review examines current literature on the role of microorganisms in gold processing and recovery. The review covers aspects such as the biotechnical pre-treatment of gold ores and concentrates, microbially catalysed permeability enhancement of ore bodies, gold solubilisation through biooxidation and complexation with biogenic lixiviants, and microbially mediated gold recovery and loss from leach liquors.

1. Introduction

Gold (Au) ore grades in Australia show long-term declining trends over time (Mudd, 2009; Fig. 1). As the quality of gold deposits continues to decrease, it is expected that processes which can economically extract gold from low grade ores will grow in importance to the minerals industry. Biotechnology has the potential to transform uneconomic gold reserves into resources. Bioprocessing can be attractive for: 1) low grade gold ores that are too expensive to process using conventional processes and 2) ores that contain impurities that foul conventional processing equipment (e.g. arsenic in gold ore). Microorganisms can mediate gold solubilisation by oxidising the sulphide matrix of refractory gold ores making the gold more accessible to leaching by chemical lixiviants. Microorganisms can also excrete ligands which are capable of stabilising gold by forming gold-rich complexes and/or colloids (Reith et al., 2007a). The solubilisation of gold can be facilitated by biologically produced amino acids, cyanide and thiosulphate (Reith et al., 2007a). Moreover, microorganisms can participate in the redox cycling of iodine (Amachi, 2008), which is a potential alternative lixiviant for gold leaching. Microorganisms can also decrease gold solubility by consuming the ligands that have bound gold, or by biosorption, enzymatic reduction and precipitation, and by using gold as a micronutrient (Fig. 2) (Reith et al., 2007a). Additionally, microorganisms can influence gold solubilisation indirectly by enhancing the permeability of ore bodies (Brehm et al., 2005; Burford et al., 2003; Ehrlich, 1998; Jongmans et al., 1997; Kumar and Kumar, 1999). Understanding the possible activities of microorganisms is important, especially when considering leaching applications, where the control of operational conditions may be challenging. This literature review aims to identify microbial processes which may be relevant or hold potential for the processing and recovery of gold.

2. Biotechnical pre-treatment of refractory gold ores

2.1. Biooxidation of refractory sulphide ores

2.1.1. Principles of biooxidation

Many gold deposits are sulphidic in nature and contain gold in a form that is inaccessible to lixiviants. Refractory gold ores often contain finely disseminated gold particles encapsulated by a sulphide mineral matrix containing arsenopyrite, pyrite and pyrrhotite (Bosecker, 1997). The inaccessibility of gold to lixiviant has been overcome by biooxidising the sulphides contained in the ore, thereby liberating gold particles from the sulphide matrix and rendering the gold amenable to dissolution using lixiviants (for example cyanidation) (Bosecker, 1997).

The oxidation of the sulphide matrix is based on the activity of acidophilic chemolithotrophic iron and sulphur-oxidising microorganisms which obtain energy by oxidising ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) or elemental sulphur (S^0) or other reduced sulphur compounds to sulphuric acid (H_2SO_4) (Sand et al., 1995):

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \quad (1)$$

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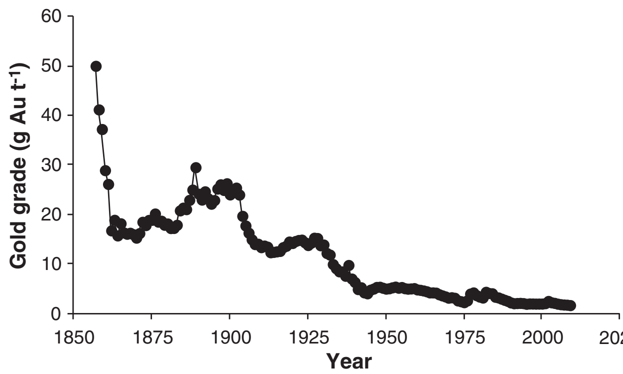

Fig. 1. Gold ore grades over time in Australia (data from Mudd, 2009).

$$2S^0 + 3O_2 + 2H_2O \rightarrow 4H^+ + 2SO_4^{2-} \quad (2)$$

Fe^{3+} and H^+ ions attack the valence bonds of sulphide minerals leading to the breakdown of sulphide matrix as shown below for pyrite (FeS_2) and pyrrhotite ($Fe_{1-x}S$) as examples (Belzile et al., 2004; Morin, 1995; Nagpal et al., 1994).

$$FeS_2[Au] + 2Fe^{3+} \rightarrow 3Fe^{2+} + 2S^0 + [Au] \quad (3)$$

$$FeS_2[Au] + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ + [Au] \quad (4)$$

$$Fe_{1-x}S[Au] + (2-2x)Fe^{3+} \rightarrow (3-3x)Fe^{2+} + S^0 + [Au] \quad (5)$$

$$Fe_{1-x}S[Au] + (8-2x)Fe^{3+} + 4H_2O \rightarrow (9-3x)Fe^{2+} + SO_4^{2-} + 8H^+ + [Au] \quad (6)$$

$$2Fe_{1-x}S[Au] + 4(1-x)H^+ + (1-x)O_2 \rightarrow 2(1-x)Fe^{2+} + 2S^0 + 2(1-x)H_2O + 2[Au] \quad (7)$$

Microorganisms used in biooxidation processes include mesophilic bacteria, such as iron- and sulphur-oxidising *Acidithiobacillus* (*At.*) *ferrooxidans*, sulphur-oxidising *At. thiooxidans*, iron-oxidising *Leptospirillum* (*L.*) *ferrooxidans* and *L. ferriphilum*, moderately thermophilic bacteria, such as iron- and sulphur-oxidising *Sulfobacillus* spp. and sulphur-oxidising *At. caldus* and a variety of archaea including mesophilic iron-oxidising *Ferroplasma acidiphilum*, moderately thermophilic iron-oxidising *Acidiplasma cupricumulans*, and thermophilic *Acidianus* spp., *Metallosphaera* spp. and *Thermoplasma*-like species (Bosecker, 1997; Brierley and Brierley, 2001; Golyshina et al., 2009; Hawkes et al., 2006; Olson et al., 2003; Reith et al., 2007b; Schippers, 2007; van Hille et al., 2013).

In general biooxidation of the gold-containing sulphide ores is a pretreatment which can decrease the consumption of lixiviant for gold solubilisation in subsequent parts of the operation and ultimately increase gold yields. However, since it does not actually solubilise gold biooxidation needs to be used in conjunction with other methods.

2.1.2. Engineering applications

During the past 20 years bio-treatment of refractory gold ores has been developed as an industrial application and applied commercially in bioreactors and heaps. The development of the biooxidation technology has been well reviewed elsewhere (see e.g. Brierley, 2008; Harvey and Bath, 2007; Ndlovu, 2008; Rawlings et al., 2003; van Aswegen and Marais, 2001van Aswegen and van Niekerk, 2004; van Aswegen et al., 2007) and hence will be only briefly mentioned here. The first industrial scale plant was started at the Fairview Mine, South Africa, in 1986 (Bosecker, 1997; Morin, 1995) (Figs. 3–4). Since then, biooxidation operations have been commissioned in a number of countries, such as Australia, Brazil, Ghana, Peru, China, Uganda, USA, Kazakhstan, Uzbekistan and Russia (Table 1).

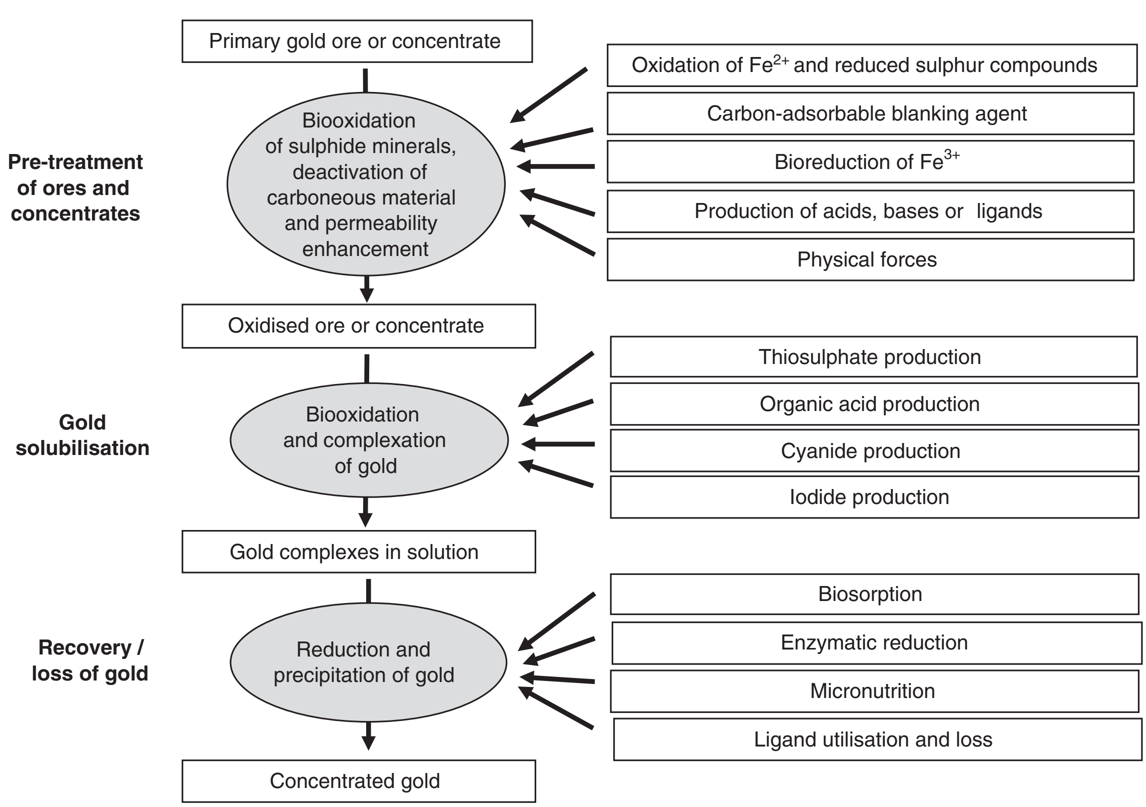

Fig. 2. Potential roles of microorganisms in gold processing and recovery (adapted from Reith et al., 2007a).