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How efficient are they really? A simple testing method of small-scale gold miners' gravity separation systems

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ABSTRACT

This paper demonstrates a simple, minimally-invasive method of estimating the gold recovery rate of gravitational separation equipment used by artisanal and small-scale miners at alluvial gold sites in the Guianas, South America. A local ASM group mining an alluvial gold deposit agreed to allow the research team to collect eight samples of ore material immediately before it was to be processed by their sluice and eight samples taken immediately upon exit from their sluice. Each sample was sieved into three grain size portions (<75 μm, 75–500 μm and >500 μm) and each portion assayed for gold content. The results indicate that the sluice at this site is capturing approximately 91% of the gold that enters the sluicing system, and the grain size distribution of the gold particles suggests that mercury amalgamation methods employed by the miners post sluicing are likely to be very efficient as well. Although this study and sample size is extremely small, and should not be taken as a full replacement of more elaborate geologic sampling and metallurgical analysis, this method could provide a useful tool for practitioners who want to quickly evaluate ASM gold processing methods and consider the effectiveness of introducing alternative processing technologies, especially those that aim to reduce mercury emissions from ASM.

1. Introduction

Artisanal and small-scale mining (ASM) employs approximately 50 million people worldwide and produces 15–20% of the world's non-fuel mineral resources (Veiga and Baker, 2004). The sector is widely credited with supplying an important livelihood to people in developing countries that suffer from high rates of rural underemployment (Hentschel et al., 2002). Unfortunately, the economic benefits of ASM are accompanied by environmental damage, occupational health and safety problems and in some cases, human rights violations. Large-scale mining companies, governments, non-governmental organizations (NGOs) and scholars recognize the importance of ASM to developing economies, but find the sector unyielding when it comes to curtailing the dangers and sometimes illegal activities associated with ASM (Buxton, 2013; Hentschel et al., 2002; Smith et al., 2016).

Although ASM is increasingly active in a wide variety of geologic settings, simple, easy to mine alluvial deposits probably still dominate the ASM sector's worldwide gold production. Alluvial deposits were almost certainly where gold was first discovered and dominated early history's production (MacDonald, 1983), and alluvial gold mining technologies have been well understood for centuries. Although relatively simple to find and recover, valuing alluvial gold deposits and testing the efficiency of alluvial mining technologies has been a more complicated matter.

This paper demonstrates a simple, minimally-invasive method of estimating the gold recovery rate of gravitational separation equipment used by ASM at alluvial gold sites in the Guianas.[1] To accomplish this goal, a local ASM group, mining an alluvial gold deposit, agreed to allow the research team to collect eight samples of ore material immediately before it was to be processed by their sluice and eight samples immediately upon exit from their sluice. Each sample was sieved into three grain size portions (<75 μm, 75–500 μm and >500 μm), and each portion was assayed for gold content. The results indicate that the sluice at this site is capturing approximately 91% of the gold that enters the sluicing system, and the grain size distribution of the gold particles suggests that mercury amalgamation methods employed by the miners are likely to be very efficient as well. This method could provide a useful tool for development practitioners who want to quickly evaluate ASM gold processing methods and consider the effectiveness of introducing

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[1] The Guianas include the South American countries of Guyana, Suriname, and French Guiana; the latter being an overseas department of France.

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alternative processing technologies, especially those that aim to reduce mercury emissions in ASM.

2. Alluvial gold deposits

Gold in alluvial deposits commonly occurs in large, often visible nuggets and in unconsolidated material (MacDonald, 1983; Youngson and Craw, 1995). This condition makes alluvial gold relatively easy to find and recover using simple, inexpensive technology. Miners usually do not have to break or blast hard rock, nor do they have to tunnel or remove substantial amounts of overburden in order to access gold-bearing material. Alluvial gold often occurs as "free gold," or gold that is not chemically or physically bonded with other materials, so prospectors and miners do not have to employ sophisticated milling and roasting processes in order to liberate the gold from gangue minerals and achieve profitable recoveries. Early alluvial miners developed few formal methods of valuing deposits or testing the efficiency of their recovery methods because the capital investments required to mine and the resultant costs of inefficiencies were so low (MacDonald, 1983, pp. 1–12).

Alluvial gold mining began to change in the late 1800s, an evolution that continued until the outbreak of World War II. Large-scale miners in North America and Southeast Asia began to invest in increasingly mechanized mining methods to exploit alluvial deposits, culminating with large-scale dredging systems in the early 1900s (Garnett, 1991; Isenberg, 2005). This level of investment soon required more rigorous deposit valuation systems to justify the investment and mobilization of large machinery. Miners in this period assessed their gold deposits using an "R/E factor" where R is the amount of actual gold recovered from mining a portion of the deposit and E is the amount of gold they predicted they would be able to recover based on pre-mining sampling. An R/E value of 1.00 indicates that the miners recovered exactly the same amount of gold as pre-mining studies predicted (Garnett, 1991).

Geologists estimate the quantity of recoverable gold in an alluvial deposit (the 'E') by taking bulk samples at a fixed spacing. Because the grades of alluvial gold deposits tend to vary widely over short distances, it is difficult to estimate with certainty the true value of a deposit without prohibitively high quantities of tightly spaced bulk samples. Although advances in the application of geostatistical methods, such as Kriging, improved deposit valuation in the late 1900s, alluvial gold deposits often contain small zones of exceptionally high grade – meaning that regular sampling methods often fail to capture values from the highest-grade portions of the deposit. This deposit variability phenomenon and the resulting geostatistical challenge is commonly known as the "nugget effect" (Davis, 1987; Garnett, 1991).

By examining dredging records from the height of North America's alluvial mining period in the early 1900s, it becomes clear how unreliable estimating gold grades and the challenges of the "nugget effect" are in practice. Long-term (multi-year) R/E values ranged from 0.50 to 2.90; a chilling indictment of the reliability of geologic sampling and deposit modeling techniques of the time (Garnett, 1991). As a result of the investment uncertainty and a souring gold market, large-scale mining companies all but abandoned alluvial deposits after World War II, choosing instead to invest in exploring and developing larger, more predictable gold deposit systems (Garnett, 1991). As a result, very little published work on improving alluvial deposit estimation has been conducted since.

Although large-scale companies have been out of the alluvial gold game for decades, the relatively low costs associated with prospecting for, and recovering gold from, alluvial systems is not lost on ASM. While alluvial gold production declined throughout the developed world, ASM gold production began to increase throughout Africa, Asia, and Latin America as government reforms and World Bank-driven economic restructuring liberalized developing economies and gave rural individuals access to the rising gold price (Banchirigah, 2006). In rural gold-bearing parts of the developing world, small-scale mining quickly became an attractive occupation.

Artisanal and small-scale miners' success at exploiting alluvial gold deposits in the 1980s and 1990s quickly led to increased investment in ASM projects from successful miners and local investors, often outside of the formal mining sector (Banchirigah, 2006; Hilson and McQuilken, 2014). Scholars now report that the "small-scale" mining sector is increasingly large, employing relatively expensive and highly mechanized mining and processing techniques which enable them to exploit larger, more geologically complex, and lower-grade deposits (Hilson and McQuilken, 2014; Teschner, 2012, 2014; Verbrugge, 2014; Verbrugge and Besmanos, 2016).

3. ASM gold processing and quixotic western interventions

The ore processing methods used in ASM systems are generally considered to be inefficient and pose serious risks to the environment and human health (Hentschel et al., 2002; Smith et al., 2016). Mercury is often used in ASM gold processing to bind with gold particles to form an amalgam. The creation of this amalgam is a useful method of separating gold particles from other heavy gangue minerals, which fail to bond with the mercury. The gold-mercury amalgam is heated to burn off the mercury, leaving the gold behind in a relatively pure form that is easy to value and sell (Hilson, 2006; Veiga and Baker, 2004). During the burning process, miners often inhale the mercury vapors, exposing them and others in the mining communities to grave health risks. Mercury is a potent toxin that interferes with brain and neurological function; it is particularly harmful to babies and young children (Poulin and Pruss-Ustun, 2008).

Artisanal and small-scale mining is the largest source of anthropogenic mercury emissions worldwide (United Nations Environmental Program, 2013). The United Nations Environmental Program (UNEP) estimates that the ASM sector consumes 640–1350 metric tons of mercury a year – roughly one third of the total global consumption (United Nations Environmental Program, 2008). Unlike other industrial uses of mercury, nearly all of what is used by ASM ends up in the environment. Approximately 40% is released into the air, while most of the remaining 60% is lost into waterways and soil (Telmer and Viega, 2009). Because mercury can travel globally, mercury released by ASM often ends up polluting air, water, and fish all around the world (United Nations Institute for Training and Research, 2005).

Development organizations have spent considerable time and resources attempting to reduce or eliminate mercury use at ASM sites. The UNEP has a goal of reducing mercury use in ASM by 50% by 2020 (United Nations Environmental Program, 2011), and aid organizations, scholars, and a handful of small companies have endeavored to develop gold recovery technologies that reduce or eliminate the need for mercury. These interventions are commonly aimed at persuading miners to adopt new technologies and are deployed under the assumption that alternative technologies will improve miners' gold recoveries and reduce the negative impacts on the environment and human health of mercury-based technologies (Aubynn, 2009; Hylander et al., 2007a,b; Teschner, 2013).

As early as the late 1990s, development practitioners attempted to introduce new gravity separation techniques including centrifuges, shaking tables, and improved sluices. They believed that these systems would draw miners away from more traditional