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Coexistence of Large-Scale Mining with Artisanal and Small-Scale Mining—A Guide for Geologists

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Editor's note: The aim of the Geology and Mining series is to introduce early career professionals and students to various aspects of mineral exploration, development, and mining in order to share the experiences and insight of each author on the myriad of topics involved with the mineral industry and the ways in which geoscientists contribute to each.

Abstract

Artisanal and small-scale mining (ASM) takes place in approximately 80 countries, and it is widespread in parts of Central and South America, Africa, Asia, and Oceania. Estimates range from 40 to 100 million ASM miners operating worldwide, and ASM generates a significant share of global production for commodities such as gold, tantalum, tin, gemstones, and diamonds. Geologists may encounter ASM activity when exploring new areas or when ASM miners move into existing exploration projects or the vicinity of large-scale mines. These interactions can be contentious, leading to conflicts that force project delays or abandonment. Alternatively, both groups can collaborate to generate mutual benefits, enabling mining companies to gain social license to operate and at the same time manage the environmental impacts of ASM, while the ASM miners maintain culturally and economically important livelihoods. Technical and social factors can help to predict the potential for coexistence or conflict with ASM operators, including the geology of the deposit type, the mining method, and the economic, legal, historical, and cultural context of a project. We present a series of case studies on ASM in Latin America, highlighting five coexistence models that have been previously implemented between mining companies and ASM operators. Our intent is to raise awareness of ASM, so that geologists can consciously consider its impacts on early exploration and subsequent decision-making. Secondly, we aim to encourage broader discussion of the role of ASM in mineral production and sustainable development.

Introduction

Artisanal and small-scale mining (ASM) is common in many mineral-rich parts of the globe, particularly in developing countries, and contributes significantly to production of some commodities. Geologists may encounter artisanal and small-scale miners when exploring areas where ASM miners are working or when ASM miners move into existing exploration prospects or the vicinity of large-scale mines. These interactions can be contentious and may jeopardize the livelihoods of ASM operators, while creating risk for the large-scale project or mine. This potential for conflict may partially explain why mining companies and consultancies increasingly report that above-ground risks outweigh technical risks in large-scale mining (Rio Tinto, unpub. report, 2011; Environmental Resources Management, 2016; Upton, 2016; Mitchell, 2018; Teschner and Holley, 2019). A preferable alternative is that ASM and large-scale mineral exploration and mining (LSM) coexist peacefully or even collaborate to generate mutual benefit. Coexistence agreements require careful consideration of the social and technical factors, even at the early stages of mineral exploration when geologists are the only company representatives present at the project site. This article summarizes our primary observations at case study sites and integrates the findings with current events and recent studies on ASM. The goals are (1) to raise awareness of ASM among exploration and mining geologists, empowering them to consider ASM when they are the first "boots on the ground" representatives of large-scale projects and in subsequent decision-making and (2) to encourage broader discussion of the role of ASM in mineral production and sustainable development.

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Background

Economic geologists are employed in LSM, which comprises capital-intensive, often legally complex, government-regulated activities, typically characterized by high rates of ore production (Hilson and Maconachie, 2020; Holley et al., 2020). In contrast, ASM encompasses various scales of labor-intensive mining operations that largely take place with minimal application of the technologies used by LSM (Hilson and Maconachie, 2020; Holley et al., 2020). Artisanal and small-scale mining is commonly practiced in poor and rural areas, where it may be an economically or culturally important livelihood (World Bank, 2009; Sidorenko et al., 2020). Since about 80% of artisanal and small-scale mines are informal and operate outside legal and regulatory frameworks (Fritz et al., 2017), ASM is often associated with hazardous working conditions and deleterious effects on the environment, including the use of mercury for gold amalgamation and the discharge of tailings into waterways (Aubynn, 2009).

Artisanal and small-scale mining takes place in approximately 80 countries worldwide and is widespread in Central and South America, Africa, Asia, and Oceania (Fig. 1). Estimates of the number of miners directly involved

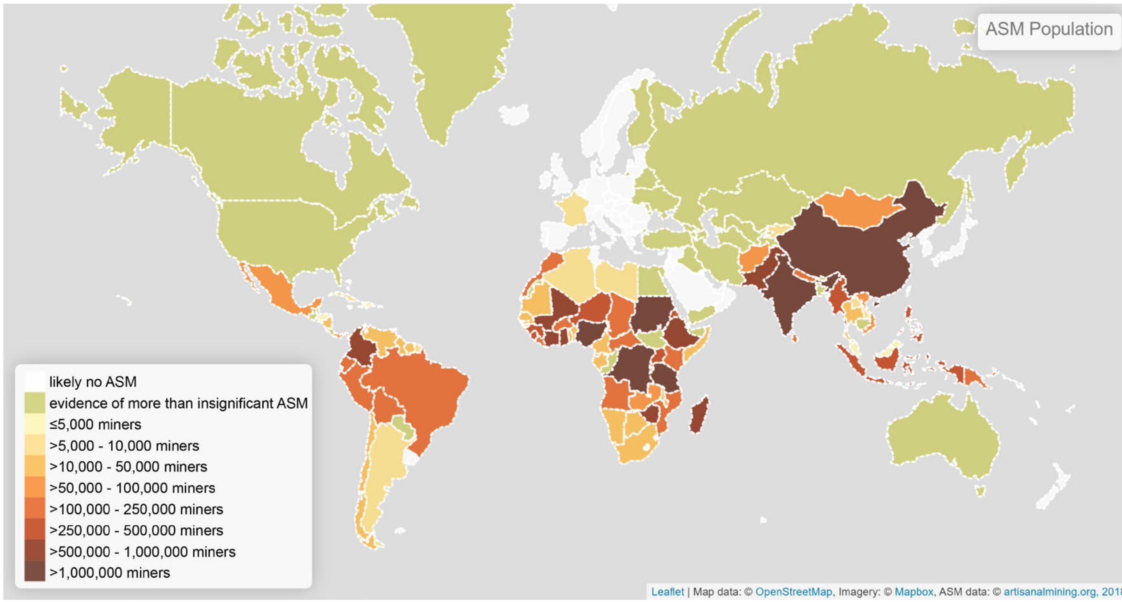

Fig. 1. Estimated number of artisanal and small-scale miners (ASM) per country (Artisanalmining.org, 2018).

range from 40 million to 100 million, and there are millions more people who provide goods and services to the sector and rely on income from ASM activities further down the supply chain (Fritz et al., 2017; Delve, 2021). By comparison, only seven million people (workers and their families) worldwide depend on the LSM industry (World Bank, 2013). Raw materials produced by ASM are generally those that are high value, can be extracted using rudimentary methods, and are easy to transport (Dorner et al., 2012). Globally, the ASM sector accounts for 80% of production of colored gemstones, 10–25% of gold, 15–20% of diamonds, and 20–25% of tantalum and tin (Villegas et al., 2012; World Bank, 2013; Harlow et al., 2019).

Artisanal and small-scale miners are often involved in mining of potential "conflict minerals" because of both geologic and social factors. In conflict-affected areas of Central Africa, ASM is prevalent for tin, tungsten, and tantalum (the "3Ts"), as well as gold, and the illicit supply chains for these commodities fund armed groups that are partially responsible for regional political instability (Smith, 2011). Legislation in the European Union and the USA mandates adherence to Organization for Economic Co-operation and Development (OECD) responsible sourcing standards for these commodities, since they may finance armed conflict or be mined using forced or child labor. Throughout West, Central, and Southern Africa, diamonds have been used to fund armed conflict, motivating the establishment of the Kimberley Process Certification Scheme. About 20% of the Democratic Republic of Congo's cobalt production comes from ASM operations, and child labor is common at these sites (Lawson, 2021). In the southeastern part of the country, ongoing conflict between LSM and ASM cobalt operations has been attributed to extreme inequality in the region (Katz-Lavigne, 2020). Formalization approaches, such as the Cobalt Industry Responsible Assessment Framework, and voluntary certifications, like the Fair Cobalt Alliance or the Fairmined gold assurance label, mandate or provide incentives for transparent and responsible supply chains. However, bureaucratic processes and taxing schemes can force miners back into the informal ASM economy (Martinez et al., 2021).

Artisanal and small-scale mining is associated with numerous environmental and health concerns, including sedimentation and metal contamination of waterways and deforestation (Dethier et al., 2019; Diringer et al., 2020). For ASM gold mining in particular, mercury contamination is a grave concern. In the Madre de Dios placer gold field in southeastern Peru, a combination of both highly and minimally mechanized ASM activities resulted in about 96,000 ha (960 km^2) of deforestation over a 34-year period, from 1985 to 2017 (Caballero Espejo, 2018). Deforestation coincided with a period of high gold prices, as well as with improved access for mining, the latter resulting from paving of the Interoceanic Highway. Similarly, in Ghana, ASM is responsible for about 29,000 ha of deforestation (Barenblitt et al., 2021; Patel, 2021). These activities, known in Ghanaian as *galamsey*, from the words "gather" and "sell," account for 35% of Ghana's gold production (Barenblitt et al., 2021; Patel, 2021). About 1 million people are involved in galamsey directly in Ghana, overall supporting 4.5 million people. From 2005 to 2019, galamsey accounted for 85.7% of mining-related vegetation loss in Ghana, with ~14.3% attributed to LSM activity (Barenblitt et al., 2021).

Various strategies have been employed to address the negative impacts of ASM. Evicting ASM miners from a site or region is a common environmental management strategy, although it commonly leads to conflict (Hilson and Yakovleva, 2007; Smith et al., 2017). In regions where most of the ASM activity is focused on gold, many jurisdictions have banned the use of mercury for gold amalgamation. Through the Minamata Convention, 159 countries have committed to reducing mercury emissions (United Nations, 2021b). Various NGO- and development organization-funded programs have attempted to train or provide incentives for ASM miners to modify practices, including using retorts to minimize mercury loss or storing tailings away from waterways (Veiga et al., 2014; United Nations, 2021a). Other strategies include formalizing ASM miners and operations so that they must adhere to regulations (Hilson et al., 2021; Salas-Urviola et al., 2021) or incentivizing particular environmental and safety practices through fair-trade and fair-mined certification schemes (Childs, 2014a, b; Ribeiro-Duthie et al., 2017; Sippl, 2020). Collaboration between ASM and LSM operations can also serve as a mechanism for environmental, health, and safety management.

ASM matters to geologists

Geologists are typically the first "boots on the ground" in new exploration projects and may be the first company representatives to interact with ASM operators, long before the project team includes trained social-performance or community-outreach specialists. Exploration is a critical stage during which companies can work with communities, build relationships (negative or positive) with local stakeholders, and understand local conditions (Hilson and Murck, 2000). As advocated by Mackenzie et al. (2020), the behavior of geologists and their interactions with communities during exploration have major impacts on the evolution of the project. Geologists require skills and training in the basic principles of stakeholder engagement, particularly as there is increasing international scrutiny of geologists and their interactions with communities during exploration (Mackenzie et al., 2020).

Geologists often use evidence of current or previous ASM activities as a prospectivity indicator in exploration targeting. Many ASM miners are skilled in prospecting and have made notable discoveries, including the Tapajos (Para) and Alta Floresta (Mato Grosso) gold districts of Brazil in the 1970s and 1980s, as well as the Gramalote and Cordoba deposits discussed below. However, this approach can lead to problems, since the economics of ASM are very different from large-scale mining and, more importantly, vectoring based on ASM discoveries inevitably leads to convergence of both ASM and large-scale exploration at the same site. Exploration geologists are uniquely positioned to integrate ASM into prospectivity analyses, and we advocate that a nuanced analysis of ASM is imperative during exploration decision-making. Determining whether potential ASM interactions may be contentious or collaborative requires consideration of both technical and social aspects. Some ore deposit types and mining methods are better suited to coexistence, such as zoned deposits, whereas others commonly produce conflict (Holley et al., 2020).

Social dimensions that foreshadow interactions with LSM include the history, culture, demographics, and livelihoods of people in the project area as well as the regulatory environment. If artisanal and small-scale miners live within the local community or move into the project area, it is critical that the site geologists understand the legal framework for ASM in the jurisdiction and the cultural, historical, and economic context of local ASM activities prior to any interaction. Also important is an understanding of the complex ways in which ASM can intersect with other locally applicable issues such as armed conflict, illicit activities that include drug and human trafficking, and conflicts over land, water, and other resources. We examine these facets of ASM in the following case studies, concluding with practical recommendations for geologists and other technical decision-makers. We focus on Central and South America, where high gold prices and international recognition of the mining potential of the region are increasingly causing ASM and LSM to intersect in the region. Similar studies have been carried out in Indonesia (van Leeuwen, 2014) and the Philippines.

Prevalent Coexistence Models

In Central and South America, five distinct models for coexistence have been piloted and applied by governments, LSM companies, and ASM communities, with varying levels of success:

1. Ore purchase model, as occurs at Bonanza in Nicaragua, with Grupo Minero Horizonte in Peru, and Antioquia Gold in Colombia: In this model, the LSM company purchases ore from ASM and processes it in the LSM plant. The ore is usually sampled and assayed by the LSM company, and the ASM operator is paid according to a previously negotiated contract. This is a well-established model that has operated in many parts of the world for more than a century.
2. Contract mining model, as applied by GCM Mining Corp. and Continental Gold in Colombia and Grassalco in Suriname: In contract mining, the LSM company allocates an area or sector of its mine to be exploited by ASM. This arrangement can include purchase of ore or subcontracts of operation. The ASM miners are not the owner of the mining rights and must follow the safety, environmental, and labor rules of the LSM company. The ASM miners are also responsible for fulfilling their commitments under a commercial services contract agreed upon with the LSM company. These agreements are private, and the relevant government authority is usually not involved.
3. Formalization subcontracts model, as applied by Gramalote Ltd and Continental Gold in Colombia: In this process, the LSM company allocates an area for ASM but retains mining title. The ASM operators are obligated to pay royalties and follow regulations, and the ASM operators are also directly accountable for any labor, environmental, or fiscal breach.
4. Formalization model, as at Merian in Suriname or at Royal Road Minerals' Nariño project in Colombia: Under this model, the owner of the mining rights agrees to give up an area to serve as an ASM mining reserve, with title potentially transferred to the ASM operators. The ASM operators can become formal owners of the mining rights if the area where they work is free of title. In most jurisdictions, ASM miners are required to develop mine and reclamation plans. This can be infeasible for many ASM operators if requirements for the plans are as stringent as for LSM companies.
5. Cooperatives model, as applied at Cerro Rico de Potosi and other mines in Bolivia, where groups of miners legally operate in sections of mines with government sanction: However, they are not companies and therefore lack access to capital.

Selection and application of any of these five models will depend on the legal framework of the country, the stage in the mining cycle in which the LSM company is operating, characteristics of the ASM community, and the geologic nature of the deposit. For the latter, geologic characteristics such as mineralogy, ore type, shape, and location of the orebody are important factors. This implies that the potential for coexistence is a sociotechnical construct, which needs to be evaluated by integrating social and technical considerations.

Case Studies

We present three case studies of ASM-LSM convergence that demonstrate the importance of seeking coexistence, followed by examples of one each of the five coexistence models. The case study locations are shown on a map in Figure 2, and images from these sites are shown in Figures 3–5. Case-by-case discussions are based on publicly available information and conversations with ASM and LSM practitioners in the field. We recognize that some perspectives may not be adequately documented. Moreover, because the described

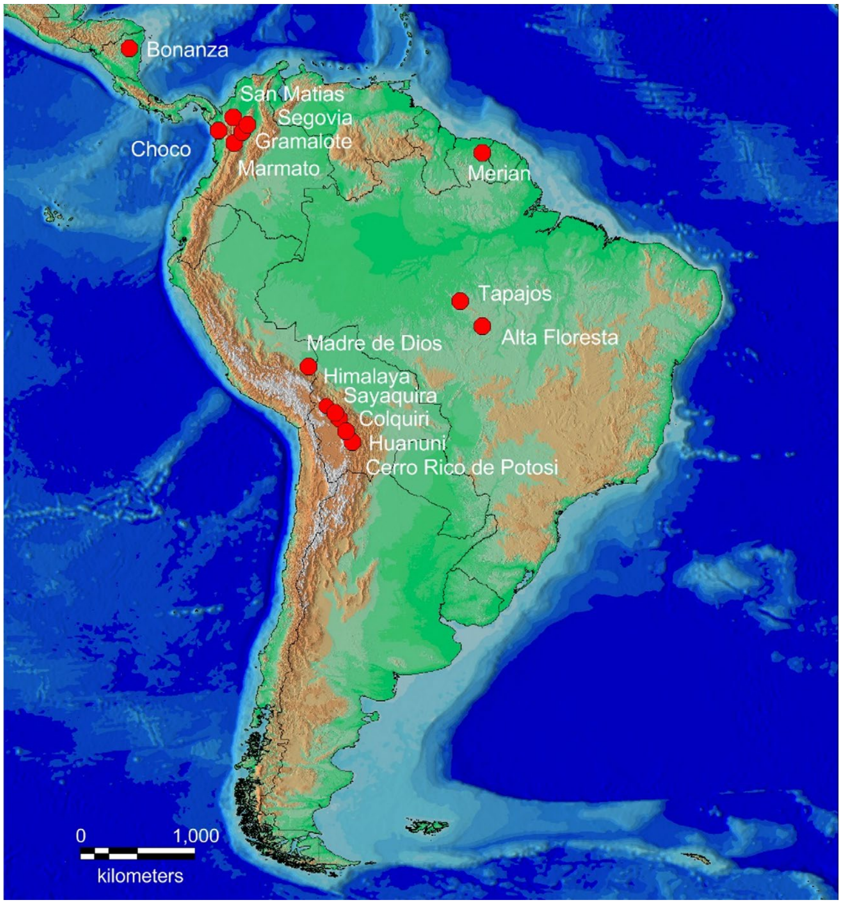

Fig. 2. Map of South and Central America showing the location of the case studies and other sites mentioned in the text.

examples are dynamic, our analysis may not reflect recent changes to conditions. Nevertheless, these case studies provide useful lessons to consider in the development of future coexistence scenarios.

ASM displaced LSM: Chocó, Colombia

The Chocó region is located on the Pacific coast of Colombia and is known for its wet climate and the prevalence of artisanal gold and platinum placer mining. American-owned Compañia Minera Chocó Pacífico S.A. mined the placer deposits with six large Bucyrus bucket-wheel dredges for about 60 years, starting in 1916. In 1974 the company was sold to a newly created Colombian company, Mineros de Antioquia S.A., after which it operated as Mineros del Chocó S.A. Small-scale miners developed various strategies to force the new national company to stop mining—for example, by planting banana trees in front of dredges and then claiming damages to the banana crop. The company was then sold to a miners' cooperative in 1977 and subsequently became bankrupt in 1979. Tens of thousands of small-scale miners of Afro-Colombian, indigenous, and mestizo descent then continued mining the placers (Castillo Ardila, 2013). Production was increased by the use of new technology, such as mechanical backhoes, pumps, washing plants, and mini-suction dredges, which could reach places inaccessible to the large bucket-wheel dredges. The Chocó small-scale mining boom created jobs for a large number of people and drew people from other parts of the country, most notably Antioquia. As a result, in 2001, the government attempted to establish areas reserved for traditional artisanal mining. In contrast, the placer gold concessions of the River Nechi in Antioquia that were sold at the same time as Chocó continue to be mined by the national company Mineros S.A., using large dredges. Mineros S.A. maintains agreements with ASM operators to exploit portions of their mining titles at a lower production rate with smaller dredges. The company is currently Colombia's second largest gold producer.

LSM attempted to displace ASM: Marmato, Colombia

Mining of gold in hard-rock deposits in the Colombian Cordillera Occidental has occurred since about 500 BCE (S.D. Redwood, unpub. report, 2009), and the Marmato gold deposit (Fig. 3) has been mined almost continuously since the 1500s (SRK Consulting, 2017). Artisanal and small-scale miners currently operate hundreds of underground workings in the shallower portions of the deposit, where ore occurs as electrum in sheeted or anastomosing epithermal veins that crop out along the flanks of Cerro El Burro (SRK Consulting, 2017). Electrum and native gold in the deeper parts of the veins have been mined episodically by medium-sized companies since the early 1800s.

In one of the world's few examples of vertically stacked mining rights, the 1954 Colombian National Decree 2223 designated the upper elevations of the mountain at Marmato, the Zona Alta or Upper zone, for shallow ASM and reserved the lower elevations, the Zona Baja or Lower zone, for deeper larger-scale industrial mining methods. Within Marmato proper, the upper limit of the Zona Baja is defined by the road, which varies between 1,207 and 1,298 m, whereas outside Marmato the Zona Baja continues to surface. Various large-scale companies have explored Marmato since the 1980s, investigating the potential for large-scale open-pit or underground mining. A large, potentially open-pit mineable resource was identified in the Zona Alta, but open-pit mining would remove the upper elevations of the mountain where ASM occurs. This possibility, in concert with legal disputes over the validity of Decree 2223, resulted in more than a decade of tension between ASM and LSM at Marmato. The situation escalated in 2006, when the government and Colombia Goldfields attempted to resettle the historic townsite away from the deposit. Major mudslides had recently inundated the central plaza, hospital, and school, which was an unfortunate consequence of the wet climate, steep topography, and the abundance of loose waste rock around the ASM portals. The government declared the area unsafe for habitation, but the ASM community perceived the resettlement as preparatory to open-pit development. A priest who opposed the resettlement was murdered by an unknown perpetrator, and

Fig. 3. Images from case studies at Marmato (Caldas) and Cordoba (Cordoba), Colombia. A) Artisanal gold vein mining at the Marmato deposit is defined by law to be carried out in the Zona Alta, or Upper zone, whose base is marked by the road. The hundreds of artisanal mine tunnels in the Zona Alta leave extensive waste dumps and induce landslides and collapse that have damaged buildings in the town of Marmato (S. Redwood). B) Artisanal gold miners at Marmato push a wooden mine car on wooden rails in a narrow tunnel to extract gold ore (S. Redwood). C) Ancient mining methods are still used by artisanal and small-scale mining: an Antioquian stamp-mill used to crush ore to extract gold at the El Alacrán mine, Cordoba project (S. Redwood). D) Mules transport gold ore from an artisanal pit in the supergene copper oxide zone of the Montiel East porphyry copper-gold deposit, Cordoba project (S. Redwood).

tensions ran high between the community and the large-scale company.

In 2017, Gran Colombia Gold (now GCM Mining Corp.) discovered a deeper zone of veinlets and disseminations beneath the zones currently mined at small and medium scales. In the “Deeps zone” (now called the Lower mine), below 1,000-m elevation, native gold could be mined underground by a new decline from the existing medium-scale Maruja mine portal at 1,165-m elevation. This portal was originally developed by a British company in 1908–1925 and was reopened by Mineros Nacionales S.A. in 1993 (Holley et al., 2020). The new discovery allows the company to leverage larger tonnage mining methods and economies of scale not feasible for ASM. Aris Gold Corporation (44% GCM Mining) started development of the Lower mine and a 4,000-tpd carbon in leach plant in 2022. The company is currently pursuing coexistence agreements with the ASM miners, wherein ancestral and artisanal miners could conduct contract mining of the shallower zones. This is similar to the approach described for Segovia, below (Gran Colombia Gold, 2017). The deposit geology and the legal framework at Marmato are permissive of coexistence, but the culture of traditional mining and the long history of conflict are serious impediments that must be carefully considered.

Need for a coexistence model: San Matias, Cordoba, Colombia

In the tropical Andean foothills of the Department of Cordoba, northern Colombia, the San Matias project includes the Alacran copper-gold deposit that was discovered by artisanal miners in the 1980s (Fig. 3). Various companies were subsequently able to reach agreements with the artisanal miners to explore the deposit. Dual Resources Inc. explored the area from 1987 to 1989, and Cordoba Minerals has been exploring since 2017 (Taylor and Redwood, 2017). The adjacent Montiel porphyry copper-gold deposits were discovered by artisanal miners at a later date, probably in the 2000s. At the Montiel East deposit (originally called Teheran), artisanal miners were extracting material from a small open pit by hand and transporting it by donkey to a stamp mill for crushing and then washing on a Wilfley table to recover gold. The gold mines had been in operation for years prior to any geologic characterization. On the first site visit for Cordoba Minerals in 2011, the artisanal pit was observed to have dense quartz stockwork veining covered in green copper oxides indicative of a porphyry copper-gold deposit (Redwood, 2011). The nearby Montiel West deposit (originally called La Montiel) had been hydraulically mined for gold in saprolite by artisanal miners, who had exposed quartz vein stockwork in a second porphyry copper-gold deposit.

At the San Matias project, approximately 400 artisanal miners continue working while the company explores under an agreement whereby artisanal miners will either be relocated to other areas where they can mine or be retrained as operators in the planned future large-scale mining operation. Although such temporary agreements allow both parties to continue activities during exploration, the situation is tense and constantly evolving. Continued access to ASM livelihoods is at risk for the artisanal miners, and social license to operate a large-scale mine is not guaranteed for the company.

Collectively, these three examples demonstrate the need for coexistence; in the following sections we present case studies of five coexistence models.

Coexistence model 1 (ore purchasing): Bonanza, Nicaragua

The Bonanza gold district is located in the tropical lowlands of the North Caribbean Coast Autonomous Region (RACCN) of Nicaragua. Mining of epithermal gold veins has occurred for approximately 130 years. In an effort to legalize ASM, the Nicaraguan government stipulated that 1% of the area of a concession must be made available to ASM (Horan et al., 2020). About 6,000 artisanal miners work at Bonanza, and about 5,000 of these belong to artisanal mining cooperatives. Miners hand-select quartz-rich ore from weathered veins (Fig. 4), increasing the gold grade to 3–30 g/t, averaging 8 g/t Au (L. Freeman and R. Johansing, unpub. report, 2018). Shallow veins are several meters wide, oxidized, and amenable to mining using hand tools. Large-scale mining in the district is carried out by the company HEMCO Nicaragua, which had agreements in place to purchase ore from artisanal miners and to process it in their plant. In 2010, HEMCO built VESMI-SA, a separate ore-processing plant designed to exclusively process artisanal ore, and in 2012 HEMCO built La Curva, a second plant for ASM ore processing. Each plant has a capacity of 100 tpd and processes ore recovered by about 1,000 ASM miners. The plants do not use mercury and have better recovery rates than the artisanal plants utilized by the remainder of the miners in the area.

Fig. 4. Images from case studies at Bonanza, North Caribbean Coast Autonomous Region (RACCN), Nicaragua, and Gramalote, Antioquia, Colombia. A) Artisanal mining for gold by means of open stoping and winches on the Pioneer vein, Bonanza (S. Redwood). B) Artisanal mining for gold of the Bonanza vein in the Cleopatra sector of the Bonanza district (S. Redwood). C) Artisanal mining of gold in thick saprolite by hydraulic mining using monitors has left a distinctive eroded landscape at the Gramalote deposit (O. Rodriguez). D) After hydraulic mining of gold in the saprolite at Gramalote is exhausted, leaving eroded ridges like that in the background, the artisanal and small-scale miners then mine narrow gold veins in hard-rock granodiorite and tonalite, seen on the foreground waste dump, while the veins are hand-cobbed at the mine shack (S. Redwood).

In 2013, HEMCO was acquired by Colombian mining company Mineros S.A. After acquisition, tensions between the company and the ASM community increased, eventually becoming violent in 2015. After several days of protests, ASM leaders and the company negotiated a sociotechnical solution known as the Bonanza model. The agreement centers on increasing trust between the miners and the company, achieved through modifications to the ore valuation process. Common practices for purchasing ASM ore can lead to mistrust: companies may only assay a single grab sample, using this single value to estimate the value of the entire ASM delivery and calculate the payment for the load. The Bonanza model incorporates automatic disk splitting and computerized random selection of samples, eliminating the possibility of unfair sampling. The company assays one random sample, a second random sample is given to the miner to assay if the miner chooses, and a third random sample is retained for assay by an independent party in case of a discrepancy between the first two samples. The company also weighs the ore while the miners are present, using a set payment price of half of the gold value calculated from the weighing and sampling. The average take-home pay is approximately USD$10/day for the ASM miners, compared with the average daily wage of <$5 for other occupations in the region (L. Freeman and R. Johansing, unpub. report, 2018). The ASM cooperatives and Mineros S.A. have been working together under the Bonanza model since 2016, which underscores the importance of shared trust between the two parties fair procedures for sampling, assaying, and valuation, and also the appropriateness of the determined payment fraction.

Coexistence model 2 (contract mining): Segovia, Colombia

The Segovia gold deposit is located in the tropical foothills of northern Antioquia, about 300 km northeast of Marmato. The deposit has been in continuous production for >170 years and is Colombia's largest gold mine. The district has thousands of artisanal miners and small processing plants operated commercially by groups of artisanal miners and small companies. Under the previous owner, Frontino Gold Mines Ltd., illegal miners would invade the company's operations through tunnels. Some miners even lived underground for days or weeks on end while hiding from company personnel in the labyrinth of old tunnels. In 2001, an estimated 5,000 illegal miners known as *machuqueros* staged a full-scale invasion and occupation of the largest mine, El Silencio. Mining of pillars threatened the stability of the mine, causing roof collapses in the mine and building collapses in the town above. The ventilation and pumps were damaged, resulting in flooding up to level 18, which exacerbated the problems by concentrating ASM in the upper levels. The situation became so critical after about two to three years that the parties were forced to negotiate, and from this arose the first operation contract within the mines.

Fig. 5. Images from case studies in Suriname and Bolivia. A) Hydraulic mining of saprolite for gold in Suriname (E. Holley). B) Deforestation and sedimentation at an artisanal gold mining camp in Suriname (E. Holley). C) Fifteen thousand cooperative miners exploit silver and some tin from the Cerro Rico de Potosi, Bolivia, the world's largest silver deposit, where they coexist with a large-scale mining company. The mountain is honeycombed with mine tunnels from five centuries of mining (S. Redwood). D) Artisanal open-pit and underground mine workings for silver following an inclined epithermal ledge at the Tollojchi deposit near Potosi, Bolivia.

Gran Colombia Gold Corporation (now GCM Mining Corporation) took ownership of the deposit in 2010 and has since developed a formula to work with artisanal miners rather than against them. Under the formalization subcontract model, the company has agreements with 56 third-party miner groups, or collectives, which mine designated areas within the veins being mined by the company and in other veins which the company is not currently mining. The ASM miners carry out extraction in higher-grade stopes by hand. The company pays ASM operators for recovered gold at a fixed price, while the contractors manage the miners and fund their own costs. The company processes the ore at its plant, disposes of the tailings in a permitted tailings facility, and sells the gold. This ASM activity contributes about 15% of the gold production from Segovia mine. The company provides training in health and safety and in the technical aspects of mining (Gran Colombia Gold, 2021).

The contract mining model employed in Segovia generates economic, environmental, and health and safety benefits for both ASM and LSM operators. Working in a legalized framework has meant eliminating child labor, a reduction of mercury emissions, access to legal explosives, and less exposure to extortion, illicit influences, and illegal armed groups throughout the supply chain. However, intermittent community resistance has required the company to request military intervention on occasion (El Colombiano, 2019). The contract mining model is possible in Segovia partly because of several factors that make it difficult for ASM miners to operate independently. These factors include relatively low grade ore, tight regulatory control of explosives in an area plagued by historical armed conflict, the banning of mercury, control and extortion by illegal armed groups, and pressure from regulatory authorities to comply with the contract model.

Coexistence model 3 (formalization subcontract): Gramalote, Colombia

The Gramalote gold deposit is located in the Central Cordillera of Colombia, midway between Medellin and Segovia. Artisanal mining in the region dates back to the 1800s. In the Gramalote Hill area (Fig. 4), ASM miners hydraulically mined the soft saprolite that is up to 80 m thick using monitors (water cannons). In the hard rock exposed below the saprolite, underground ASM mining is focused on narrow veins up to 10 cm wide, which attracted the attention of major and junior companies during the 1990s. The larger deposit was discovered in 2006 when Anglogold Ashanti Colombia intersected quartz veins during drilling. Drill campaigns in 2006 and 2007 identified a resource amenable to mining by open pit. The intrusion-related gold deposit comprises structurally controlled stockwork and sheeted veins (Rodriguez, 2009), with an indicated resource of 78.2 Mt grading 0.85 g/t Au plus an inferred resource of 129.2 Mt at 0.68 g/t, containing a combined total of 4.97 Moz of gold (Garagan et al., 2020). Anglogold Ashanti Colombia has a 50:50 joint venture with B2Gold Corporation through the JV company Gramalote Colombia Ltda. B2Gold is the current operator and is carrying out a feasibility study due for completion in 2022. If approved for development, this operation will be the first LSM open-pit gold mine in Colombia, with the potential to set precedents for LSM-ASM interactions in Latin America.

About 300 ASM miners were working at Gramalote Hill when the Anglogold discovery was made. The proposed open pit would encompass the hill and the ASM operations. Under a subcontract of formalization, Gramalote Colombia Ltda. has reached agreements with the ASM miners to relocate their operations underground to a new area (Garagan et al., 2020). Under Colombian law for subcontracts of formalization, Gramalote Colombia Ltda retains ownership of the mining title. The company is not accountable for environmental or safety issues generated by ASM operators (as opposed to formalization, wherein the company resigns the land to the government, and formalized ASM operators can gain title). The LSM company is obliged to designate a given area for ASM use for a minimum of four years, after which mining rights to the area return to the company unless the company chooses to extend the ASM subcontract. The ASM operators are required to develop a mine plan and obtain an environmental permit. Although the required ASM documentation is not as onerous as that required of LSM companies, most ASM miners do not have the resources or training to produce the necessary plans, and technical assistance from the company is an important prerequisite. In this case, B2Gold has agreed to provide legal and technical support for the formalization subcontract and the ASM transition to underground mining. At present the ASM ore is being processed in a nearby plant owned by Antioquia Gold at the Cisneros mine, and in the future it will be processed by the Gramalote plant.

Coexistence model 4 (formalization): Guianas

In French Guiana, Suriname (Fig. 5), and Guyana, ASM gold mining of alluvium, colluvium, eluvium, and in situ saprolite has increased rapidly since the mid-1980s. Most of the gold is considered to be derived from orogenic lodes (Kieo-A-Sen et al., 2016). Similar to the Amazonian placer gold rush operations, such as Madre de Dios in Peru, ASM in the Guianas has become increasingly mechanized. Mining methods include generator-powered water monitors and open-pit and minor underground development using bulldozers, track-mounted excavators, front-end loaders, and dump trucks. To access more remote locations in the interior of the region, heavy equipment is commonly disassembled, transported upriver by barge in the rainy season, and reconstructed on site. Gold is transported to urban centers by boat, foot, all-terrain vehicles (ATVs), and small airplanes and helicopters.

In some locations, ASM encampments have taken on permanent status, with associated infrastructure including airstrips. Many of the miners are of Brazilian origin and have entered the country illegally. Indigenous and Maroon communities (the latter descended from escaped slaves of West African descent who labored on Dutch colonial plantations) have adopted techniques from Brazilian miners, including mercury amalgamation followed by volatilization of the mercury in shovels held over an open fire. Health, environmental, and other associated effects include deforestation, sedimentation of rivers, mercury contamination of waterways and fish, and malarial-mosquito breeding and infestations in the stagnant water.

Throughout the Guianas, ASM miners typically operate outside the legal framework, and government attempts to exert influence have met with varying success. In 2002 and 2008, French Guiana conducted two military campaigns in an attempt to destroy the logistical and supply chains of the miners. However, the remote jungle locations of the operations proved difficult to access and oversee.

In recent years, the Surinamese government has implemented various formalization strategies. This started with establishment of an ASM reserve in Newmont's Merian deposit area (Anaya et al., 2017). When the deposit was discovered, it was expected to produce 5.5 Moz gold over 11 years; open-pit production began in 2016, and currently the company reports 4 Moz of proven and probable gold reserves (Newmont, 2022). The government and Newmont's subsidiary Surgold collaborated in evictions of about 2,000 ASM miners from the Merian concession in 2011. In 2012 Newmont agreed to a request by the government to relinquish a portion of the concession so that the government could establish a reserve for ASM operations. The reserve was exclusively designated for Pamakas, the local Maroon ethnic subgroup that claims traditional rights to the land; subcontracts to other parties were prohibited. The company agreed to assist the miners in becoming formalized, a process that requires ASM miners to provide the Ministry of Natural Resources with a map created by a surveyor, a work plan, and a budget for their operation. The company also agreed to provide technical assistance to improve gold recovery and decrease environmental and safety concerns, including elimination of mercury use, implementation of erosion control techniques, and minimization of deforestation. It is unclear how the latter requirement is put into practice by ASM miners, however, since removal of vegetation is the first step in alluvial and saprolite mining.

Although the ASM reserve was a watershed move by Newmont, the selected area is allegedly not as gold rich as the Merian deposit itself. This is a common issue in the establishment of ASM reserves; ore deposits are geologic anomalies, and nearby areas may not be similarly endowed. In 2015, the government evicted about 200 miners who had reentered the main part of the Merian concession. In 2016, the company commissioned RESOLVE, an independent nonprofit organization specializing in consensus building, to convene an expert advisory panel to investigate conflict with ASM miners at the Merian project, based on the principles of free prior and informed consent (Anaya et al., 2017). Local contacts have advised that ASM miners are now recovering gold from within the bounds of the initial reserve, but the situation remains contentious.

At numerous other sites in Suriname, the coexistence model has reverted to contract mining. The 75% state-owned mining company, Grassalco, offers contracts to Brazilian, Surinamese, and French ASM miners. The miners are not supposed to use mercury in recovering gold, but there is little government oversight. Mercury amalgamation is the processing method of choice, notwithstanding its serious risk to health. Grassalco takes 15% of the value of the sponge gold that the ASM miners produce after volatilizing the mercury.

Coexistence model 5 (cooperatives): Cerro Rico de Potosi, Bolivia

In Bolivia, miners' cooperatives employ approximately 125,000 miners, which represent 90% of the country's mining workforce. Cooperatives mine selectively by hand, and productivity is very low, meaning that disseminated or stockwork deposits cannot be mined using these methods. As a result, viable ore for ASM in Bolivia is restricted to visible metal-bearing minerals in veins and veinlets of, for example, stibnite, cassiterite, wolframite, silver-rich zinc and lead sulfides, visible gold, and placer gold. Most of this mining is of narrow massive sulfide veins in old mines, deemed to be uneconomic for larger-scale mining. Cooperatives are legal entities constituted according to law DL 5035 of 1958, and most mining cooperatives operate under contracts with Comibol, the state mining company. Cooperatives are organized according to traditional Andean social structures, whereby each member contributes skills, equipment, or materials, and each member shares in the profit. Although cooperatives are legal entities, they are not companies, and they do not have access to capital through banks. Therefore, their capacity to develop mines or to grow in size is limited. Typically, a cooperative will work only certain veins or sectors of a mine, and a large deposit may be worked by many cooperatives.

Cerro Rico de Potosi (Fig. 5) is the world's largest silver deposit and one of the largest tin deposits, with an estimated 3.9 billion ounces silver and 0.65 to >1 Mt tin in production and resources (Arce Burgoa, 2020). Currently there is one type of LSM and three types of ASM mining. After the tin price collapsed in 1985, large-scale tin mining by Comibol was replaced by cooperative mining. Comibol now administers operational contracts rather than carrying out mining. There are >15,000 cooperative miners in 42 cooperatives at Cerro Rico who selectively mine narrow silver-zinc veins by hand. Since 2008, a medium-sized foreign-owned mining company, Empresa Minera Manquiri S.A., owned originally by Coeur Mining Inc. and since 2018 by Andean Precious Metals Corp., has mined surficial oxide deposits of silver-bearing colluvium (*pallacos*) and old mine dumps to recover silver in a 4,800-tpd cyanide leach plant. Cooperatives are involved through a trucking contract, and the company buys additional oxide ore from cooperatives at Cerro Rico and in other mines in the Department of Potosi. The two other types of ASM at Cerro Rico are hand-cobbing of silver-rich sulfides from waste rock on the dumps by women, called *palliris*, and placer mining of cassiterite from colluvium by small groups of miners using primitive alluvial-mining methods.

Despite the prevalence of the cooperative model in Bolivia, conflicts have arisen between ASM miners and large mining companies, both state-owned and private. As the cooperatives increase in number, they seek access to new veins and mines. In 2006, armed conflicts between cooperatives and salaried Comibol miners at the Huanuni tin mine resulted in 18 fatalities and 61 wounded among both groups of miners. The conflict was resolved by the government through two actions. First, it nationalized Posokoni Mountain where the cooperatives mined, above deeper underground levels. Second, the government turned 4,000 cooperative miners into salaried Comibol miners. This further burdened the state mining company with added expense.

In another example, the Colquiri tin-zinc mine, which was privatized to Comsur in 1999 and later bought by Glencore PLC in 2005, was the scene of a violent conflict by a cooperative in 2012, which was resolved by nationalizing the mine and giving the cooperative access to one of the rich veins. In other cases, cooperative miners have invaded privately owned mines, such as the Himalaya tungsten mine in 2007, which had just been prepared for bulk mining, and the Sayaquira tin mine in 2011, both owned by Empresa Minera Barrosquira Ltda of La Paz. In the former case, Comibol cancelled the contract and then awarded it to the cooperative, thus effectively nationalizing the mine. The second case was resolved peacefully after several months by police intervention and the withdrawal of the cooperative miners.

Discussion

Global distribution of ASM

Geologic factors exert important controls on the global distribution of ASM. At lower latitudes, tropical weathering and oxidation render some deposit types particularly amenable to mining by small-scale methods. Where tropical weathering overlaps with ore-forming environments to generate valuable and easily extractable commodities, ASM is more prevalent. This partly explains the geographic distribution of ASM mining of kimberlites in southern Africa, alluvial and beach placer diamonds in the Guiana Shield and West and Central Africa, columbite-tantalite pegmatites in Africa's Great Lakes region, and supergene oxidized porphyry copper deposits in the circum-Pacific. Artisanal and small-scale gold mining is also prevalent in metallogenic environments that generate hypogene free gold, including vein-hosted epithermal and orogenic deposits and their downstream placers. By contrast, there are few ASM operations in high-sulfidation epithermal vein deposits, unoxidized porphyry copper deposits, and volcanogenic massive sulfide (VMS) deposits, because of the refractory nature of the ore.

Social factors also contribute to the prevalence of ASM in particular locations. Informal economies are more common in developing nations due to political instability, limited government capacity to enforce regulations, and limited economic opportunities in rural regions (Lahiri-Dutt, 2018). Mineral exploration booms in developing countries have been linked to surges in ASM activities (Hilson et al., 2020), due to a combination of favorable commodity prices and increased awareness of the mineral potential of those regions. In some locations, artisanal mining has long been an important traditional livelihood. Long traditions of ASM can set the stage for conflict with large-scale mining (Holley et al., 2019). By comparison, the U.S. and Canada have postcolonial mining traditions, strong mining industries, and little informal mining since the early 20th century.

Temporal factors also play a role. The great gold rushes of the 19th century in California, Victoria, Transvaal, and the Klondike occurred in countries that now have major industrialized mining and little ASM. The gold rushes attracted mass migration and settlement (with the exception of the Klondike due to the harsh climate). Mining during the gold rushes resulted in the discovery of new deposits and districts, in some cases leading to progressively larger scale mining. Easily won placers that were soon depleted generated capital that contributed to regional development and funded a formal, large-scale mining industry.

Role of ASM in sustainable development

Artisanal and small-scale mining is an important livelihood in locations where there are few other economic opportunities. It also creates indirect employment by injecting capital into economies where there may be little infrastructure and where other industries may struggle economically (de Haan and Turner, 2018). Often ASM activities serve as a form of livelihood diversification, whereby people engage in mining to supplement agricultural or livestock-based livelihoods during off-seasons (Okoh and Hilson, 2011).

Given the importance of ASM to some rural populations, governments and mining companies have the opportunity to contribute to sustainable development by providing support for ASM operators to become formalized and use cleaner and safer technologies. During creation of the United Nations' Sustainable Development Goals (SDGs) in 2015, mining companies were specifically called on to contribute to meeting SDG targets (United Nations, 2015). We suggest that the coexistence between ASM and LSM contributes to sustainable development in two ways. First, companies can implement strategies that mitigate environmental and safety risks of ASM; such strategies might include mining company-ASM collaboration on tailings disposal or mechanisms to ensure that ASM operators use personal protective equipment. Second, we argue that ASM-LSM coexistence enables resource efficiency, defined by the European Commission (2020) as more efficient use of Earth's limited resources.

In many cases, ASM operators extract mineral resources that cannot be mined economically by a large company. Since the material cannot be extracted economically by large-scale mining methods, it is not included in a mineral resource or reserve (in a NI 43-101 or Joint Ore Reserves Committee classification). The five case studies presented above demonstrate that profitable ASM production is possible because of (1) low production costs (all case studies), (2) ability to mine selectively in placer deposits or narrow veins (Choco, Segovia, and Gramalote in Colombia), and (3) ability to hand sort ore (Bolivian Cooperatives and Bonanza in Nicaragua). In Bolivia, Comibol acknowledges that cooperatives are mining deposits that are no longer economic for it to mine. This can be considered as maximizing utilization of a mineral resource, by extracting additional ore that would otherwise be abandoned. Thus, mines can continue to provide a livelihood and employment to a large number of small-scale miners and continue to produce mineral exports, rather than closing.

Coexistence: Why, where, when, and how

Coexistence agreements can be mutually beneficial for ASM communities and LSM companies. Such agreements can help mitigate the environmental and social impacts of ASM while preserving ASM livelihoods. Coexistence strategies that include formalization (and associated regulations) may lead to improved health and safety for miners, but only if accompanied by appropriate trainings, workshops, and other capacity-building activities aimed at the sector (Smith et al., 2016). Coexistence agreements are also a tangible way to maintain social license for the LSM company. Coexistence can be viewed more broadly as a strategy for community engagement. We have observed that coexistence negotiations can shift anti-LSM movements into positive dialogues that honor local mining traditions and community cohesion, while generating viable solutions for managing safety and environmental risk. However, not all sites are equally suited to coexistence, and there is no one-size-fits-all coexistence strategy. Mining companies have a responsibility to their investors to work in their best interests, and this responsibility must guide a company's decision-making. Possible corporate benefits associated with developing a coexistence strategy could include decreasing the financial and reputational risk of project delays or stoppages (Teschner and Holley, 2019).

Kemp and Owen (2019) offer a classification to categorize interactions between LSM and ASM. Their approach is based on overlap (or nonoverlap) of objectives between the two parties, in terms of commodity and target area (Fig. 6). When commodities or locations of interest differ, coexistence agreements may be mostly straightforward, as in three of the scenarios considered. However, from our observations, coexistence is difficult to achieve in type 4 scenarios, where LSM and ASM exploit the same commodity in the same physical space. For example, at both Marmato and Gramalote Hill, conflict ensued when the LSM companies were pursuing open-pit development of shallow epithermal veins. Discovery of the large-scale underground mining target at Marmato and relocation of ASM activities to underground workings at a different location at Gramalote created possibilities for coexistence.

We extend the typology concept to suggest that particular geologic settings and mining methods are better suited to coexistence than others. For example, zoned deposits may be promising for simultaneous ASM and LSM activity by virtue of being amenable to different mining methods between zones. Deposit types that may be amenable to a coexistence arrangement include mineralized epithermal or orogenic veins that change in thickness at depth or along strike; deposits with oxidized shallow zones, supergene-enrichment blankets,

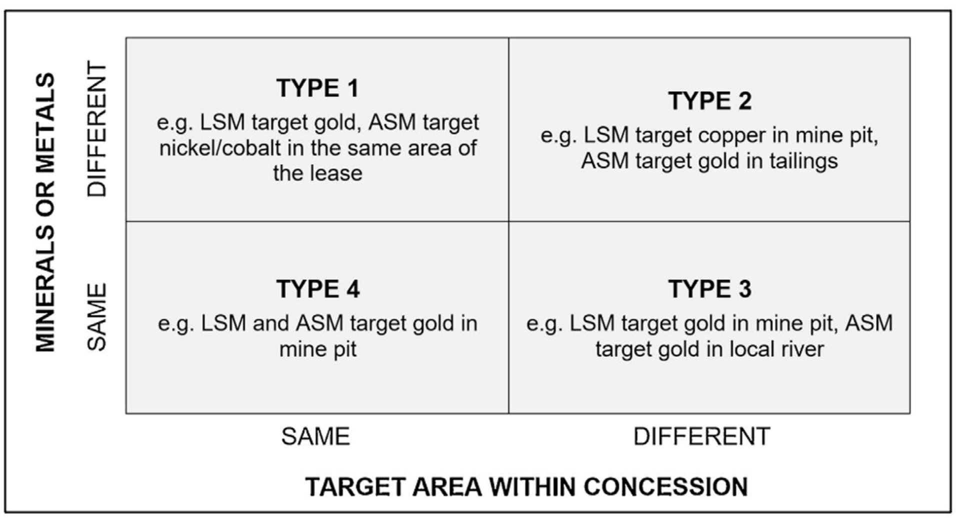

Fig. 6. Classification of interfaces between large-scale mineral exploration and mining (LSM) and artisanal and small-scale mining (ASM) (Kemp and Owen, 2019).

or exotic supergene deposits; disseminated deposits with narrow structurally controlled feeders; genetically related systems such as placer deposits and their nearby source lodes; or porphyry copper deposits with spatially associated higher-grade epithermal and skarn deposits.

Mining methods are an important consideration. Coexisting open-pit mining operations at significantly different mining scales may be viable, as at Yanfolila in Mali, where ASM mining of the Bolon placer occurred 1 km away from the orogenic veins that were exploited in the Kamana East open pit (Teschner, 2014). However, in the absence of satellite deposits or zones, large-scale open-pit mining may limit the possibility for coexistence. Other mining methods such as block caving will create instability in ASM workings near the surface expression of caving, causing major safety issues; coexistence should not be contemplated where LSM methods include mass underground mining of any type. The safety and well-being of ASM and LSM operatives are of critical importance in any coexistence strategy.

Our observations indicate that the stage of the mining life cycle at which a company engages in a coexistence agreement with ASM operators is a major factor. Teschner and Holley (2019) showed that the costs of suspension of a mining project due to social conflict vary based on the stage of project development. Such costs can be huge. In a case study of the Pebble project in Alaska, the authors determined that the social risk-adjusted net present value (NPV) of the project was $4.8 billion dollars less than the traditionally determined NPV. The same study showed more generally that although the risk of project suspension from social conflict is highest in the prefeasibility and feasibility stages, the cost of conflict is highest during mine construction. Once construction begins, future production is the only way to recoup development costs, so social conflict becomes very expensive. This finding adds emphasis to the case studies in the present contribution, underscoring the advantage of having coexistence strategies in place before development and production begin. Strategies must inevitably evolve with the changing needs of the project and the community throughout the mine life cycle, and care should be taken to ensure that the coexistence mechanisms can align feasibly with company and community expectations as the project evolves or potentially changes hands.

Even though coexistence agreements are becoming more common, many have not achieved long-term sustainability (World Bank, 2009). Historically, most agreements have lacked sufficient grounding in the technical and social contexts of the site. These oversights include (1) a lack of mineral resources in the areas allocated for ASM, (2) insufficient government support or overly complex application processes for formalization, and (3) alternative livelihood programs that subsequently collapsed after the departure of the large-scale mining company (Hilson and Yakovleva, 2007; Smith et al., 2017). Agreements are vulnerable to LSM mergers and acquisitions, which introduce new managers and company priorities. To mitigate this potential risk, existing or possible coexistence opportunities should be carefully considered when companies acquire new properties. During that evaluation, social and technical contexts should directly inform development of site-specific coexistence strategies. Hilson et al. (2020) suggested that fluctuating commodity prices may, in fact, make coexistence unsustainable. Ultimately, a coexistence arrangement can only survive if the commodity price enables continued operation of the LSM mine.

Conclusions

Artisanal and small-scale mining generates a substantial proportion of production for commodities such as gold, tantalum, tin, gemstones, and diamonds, particularly for certain countries. It is an important form of livelihood in many parts of the world, providing employment and economic diversification in rural and poor regions where there may be few alternatives for earning income. Various aspects of ASM alternately contribute to and impede sustainable development, and from the outset of mineral exploration, LSM companies need to be aware of the potential impacts of these factors on possible mine development. Coexistence strategies for LSM and ASM are an approach by which mining companies may assist in achieving the United Nations' SDGs, within a commercially viable framework.

Geologists may encounter ASM when entering new areas or when ASM miners move into exploration project areas or active large-scale mines. The nature of early interactions between mining company representatives and ASM communities can influence the trajectory of an exploration or mining project. Numerous projects have become embroiled in conflicts that force project delays or abandonment, in some cases due to mishandled interactions with ASM operators. Geologists are early representatives of the company and need to be empowered to enact stakeholder engagement strategies that are sensitive to the cultural, historical, economic, legal, and technical context of local ASM activities. Strategies also need to consider prior interactions between ASM and LSM operations in the area, as well as the complex ways in which ASM can intersect with other potentially contentious issues, such as the presence of illicit supply chains or access to land and water. Project teams should prepare for encounters with ASM by seeking training specific to the regional and local context. Social performance experts, NGOs, host governments, and industry associations can play a vital role by providing such training.

Coexistence agreements can be mutually beneficial by enabling mining companies to achieve social license to operate, while simultaneously enabling ASM livelihoods to be maintained and also managing the environmental and social impacts of ASM. Geologic factors such as deposit type and likely mining method can be predictors of the potential for coexistence, or conflict, with ASM operators. In regions where LSM and ASM converge, this potential should be considered a fundamental exploration decision-making criterion. Since the cost of project suspension is highest during mine construction (Teschner and Holley, 2019), the exploration stage of a project is the optimum time to determine and develop coexistence strategies where these are applicable.

Case studies such as Chocó, Marmato, and San Matias in Colombia demonstrate the need for coexistence strategies that consider the technical and social context of ASM at the site. Elsewhere in Latin America, previously developed coexistence models include ore purchasing (Bonanza, Nicaragua), contract mining (Gran Colombia Gold, Continental Gold, and Mineros S.A. in Colombia and Grassalco in Suriname), formalization subcontracts (Gramalote and Continental Gold in Colombia), formalization (Merian in Suriname and

Royal Road in Colombia), and cooperatives (Cerro Rico de Potosi in Bolivia). We propose that the selection and application of a coexistence strategy should be based on the legal framework of the project location, the stage in the mining cycle in which the LSM company is operating, the geologic nature of the deposit, and the characteristics of the ASM community.

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REFERENCES

Anaya, J.S., Evans, J., and Kemp, D., 2017, Free, prior and informed consent (FPIC) within a human rights framework: Lessons from a Suriname case study: Washington, D.C., RESOLVE FPIC Solutions Dialogue, 33 p.

Arce Burgoa, O.R., 2020, Yacimientos Metalíferos de Bolivia: Cochabamba, Bolivia, Super Print Impresores, 356 + [86] p.

Artisanalmining.org, 2018, ASM Inventory, http://artisanalmining.org/Inventory.

Aubynn, A., 2009, Sustainable solution or a marriage of inconvenience? The coexistence of large-scale mining and artisanal and small-scale mining on the Abosso Goldfields concession in Western Ghana: Resources Policy, v. 34, p. 64–70.

Barenblitt, A., Payton, A., Lagomasino, D., Fatoyinbo, L., Asare, K., Aidoo, K., Pigott, H., Som, C.K., Smeets, L., Seidu, O., and Wood, D., 2021, The large footprint of small-scale artisanal gold mining in Ghana: Science of the Total Environment, v. 781, article 146644.

Caballero Espejo, J., Messinger, M., Román-Dañobeytia, F., Ascorra, C., Fernandez, L.E., and Silman, M., 2018, Deforestation and forest degradation due to gold mining in the Peruvian Amazon: A 34-year perspective: Remote Sensing, v. 10, article 1903.

Castillo Ardila, A.M., 2013, Los retreros y la gente del Río Condoto: Minería y transformaciones socioambientales en Chocó, 1975–2013: Unpublished graduate thesis, Bogotá, Colombia, Universidad de los Andes, 108 p.

Childs, J., 2014a, A new means of governing artisanal and small-scale mining? Fairtrade gold and development in Tanzania: Resources Policy, v. 40, p. 128–136.

——2014b, From "criminals of the earth" to "stewards of the environment": The social and environmental justice of Fair Trade gold: Geoforum, v. 57, p. 129–137.

de Haan, J., and Turner, B., 2018, Handbook: Developing national ASGM formalization strategies within national action plans: Geneva, United Nations Institute for Training and Research (UNITAR) and United Nations (UN) Environment, 134 p., https://mercury.unitar.org/site/document/1438.

Delve, 2021, Global number of people working in ASM: https://delvedatabase.org/data.

Dethier, E., Sartain, S.L., and Lutz, D.A., 2019, Heightened levels and seasonal inversion of riverine suspended sediment in a tropical biodiversity hot spot due to artisanal gold mining: Proceedings of the National Academy of Sciences, v. 116, p. 23,936–23,941.

Diringer, S.E., Berky, A.J., Ortiz, M.M.E.J., Karatum, O., Plata, D.L., Pan, W.K., and Hsu-Kim, H., 2020, Deforestation due to artisanal and small-scale gold mining exacerbates soil and mercury mobilization in Madre de Dios, Peru: Environmental Science and Technology, v. 54, p. 286–296.

Dorner, U., Franken, G., Liedtke, M., and Sievers, H., 2012, Artisanal and small-scale mining (ASM): POLINARES Working Paper, v. 19, http://pratclif.com/2015/mines-ressources/polinares/chapter7.pdf.

El Colombiano, 2019, Gran Colombia Gold pide acciones miltares en Segovia, Remedios y Marmato: https://www.elcolombiano.com/colombia/gran-colombia-gold-pide-acciones-militares-contra-mineria-ilegal-DE9987489, accessed April 12, 2019.

Environmental Resources Management (ERM), 2016, New realities facing the mining and metals industry: https://www.erm.com/globalassets/documents/presentations /2018/new-realities-facing-the-mining-industry .pdf.

European Commission, 2020, Resource efficiency—environment: https://ec.europa.eu/environment/resource_efficiency/.

Fritz, W.M., McQuilken, J., Collins, N., and Weldegiorgis, F., 2017, Global trends in artisanal and small-scale mining (ASM): A review of key numbers and issues: Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF), http://www.iisd.org/sites/default/files/publications/igf-asm-global-trends.pdf.

Garagan, T., Pemberton K., Rajala, J., and Jones, K., 2020, Gramalote project, Colombia: NI 43-101 Technical Report, prepared for B2Gold Corporation, effective date December 31, 2019.

Gran Colombia Gold, 2017, Gran Colombia Gold announces underground mineral resource for its Marmato project, commencing scoping studies for underground mine expansion: Press Release, http://www.grancolombiagold.com/news-and-investors/press-releases.

——2021, Gran Colombia Gold 2020 sustainability report: https://s27.q4cdn.com/512972177/files/doc_downloads/sustainability/overview/Gran-Colombia-Gold-2020-Sustainability-Report.pdf.

Harlow, D., Hurley, K., Fox, A., Vargas-Guerra, A., and Gibson, J., 2019, Small-scale and artisanal mining impacts on biodiversity in Latin America: https://www.land-links.org/issue-brief/small-scale-artisanal-mining-impacts-on-biodiversity-in-latin-america/.

Hilson, G., and Maconachie, R., 2020, Artisanal and small-scale mining and the Sustainable Development Goals: Opportunities and new directions for sub-Saharan Africa: Geoforum, v. 111, p. 125–141.

Hilson, G., and Murk, B., 2000, Sustainable development in the mining industry: Clarifying the corporate perspective: Resources Policy, v. 26, p. 227–238.

Hilson, G., and Yakovleva, N., 2007, Strained relations: A critical analysis of the mining conflict in Prestea, Ghana: Political Geography, v. 26, p. 98–119.

Hilson, G., Sauerwein, T., and Owen, J., 2020, Large and artisanal scale mine development: The case for autonomous co-existence: World Development, v. 130, article 104919.

Hilson, G., Mondlane, S., Hilson, A., Arnall, A., and Laing, T., 2021, Formalizing artisanal and small-scale mining in Mozambique: Concerns, priorities and challenges: Resources Policy, v. 71, article 102001.

Holley, E.A., Smith, N.M., Delgado Jimenez, J.A., Casasbuenas Cabesas, I., and Restrepo-Baena, O.J., 2019, Sociotechnical context of the interactions between large-scale and small-scale mining in Marmato, Colombia: Resources Policy, v. 67, article 101696.

Holley, E.A., Smith, N.M., Delgado Jimenez, J.A., Cabezas, I.C., and Restrepo-Baena, O.J., 2020, Socio-technical context of the interactions between large-scale and small-scale mining in Marmato, Colombia: Resources Policy, v. 67, article 101696.

Horan, S., Holm, D., Krutzelmann, H., and Wiatzka, G., 2020, NI 43-101Technical Report on the Hemco Property, Region Autonoma De La Costa Caribe Norte, Nicaragua: www.sedar.com/GetFile.do?lang=EN&docClass=24&issuerNo=00051967&issuerType=03&projectNo=03192088&docId=4917760.

Katz-Lavigne, S., 2020, Distributional impact of corporate extraction and (un)authorised clandestine mining at and around large-scale copper- and cobalt-mining sites in DR Congo: Resources Policy, v. 65, article 101584.

Kemp, D., and Owen, J.R., 2019, Characterizing the interface between large and small-scale mining: The Extractive Industries and Society, v. 6, p. 1091–1100.

Kioe-A-Sen, N.M., van Bergen, M.J., Wong, T., and Kroonenberg, S.B., 2016, Gold deposits of Suriname: Geological context, production and economic significance: Netherlands Journal of Geosciences: Geologie en Mijnbouw, v. 95, p. 429–445.

Lahiri-Dutt, K., 2018, Extractive peasants: Reframing informal artisanal and small-scale mining debates: Third World Quarterly, v. 39, no. 8, p. 1561–1582.

Lawson, M.F., 2021, The DRC mining industry: Child labor and formalization of small-scale mining: The Wilson Center, https://www.wilsoncenter.org/blog-post/drc-mining-industry-child-labor-and-formalization-small-scale-mining.

Mackenzie, S., Everingham, J.-A., and Bourke, P., 2020, The social dimensions of mineral exploration: SEG Discovery, v. 121, p. 16–28.

Martinez, G., Smith, N.M., and Malone, A., 2021, Formalization is just the beginning: Analyzing post-formalization successes and challenges in Peru's small-scale gold mining sector: Resources Policy, v. 74, article 102390.

Mitchell, P., 2018, EY: 10 business risks facing mining and metals: https://www.ey.com/en_gl/mining-metals/10-business-risks-facing-mining-and-metals.

Newmont, 2022, Newmont reports 2021 mineral resources of 93 million gold ounces and 65 million gold equivalent ounces: www.newmont.com/investors/news-release/ news-details/2022/

Newmont-Reports-2021-Mineral-Reserves-of-93-million-Gold-Ounces-and-65-million-Gold-Equivalent-Ounces/default.aspx.

Okoh, G., and Hilson, G., 2011, Poverty and livelihood diversification: Exploring the linkages between smallholder farming and artisanal mining in rural Ghana: Journal of International Development, v. 23, no. 8, p. 1100–1114.

Patel, K., 2021, Detecting gold mining in Ghana: NASA Earth Observatory, Image of the day: https://earthobservatory.nasa.gov/images/148376/detecting-gold-mining-in-ghana.

Redwood, S.D., 2011, Cordoba project, Department of Córdoba, Republic of Colombia: NI 43-101 Technical Report for Wesgold Minerals Inc., Vancouver, July 26, 2011, 63 p., www.sedar.com.

Ribeiro-Duthie, A.C., Domingos, L.M.B., Oliveira, M.F., Araujo, P.C., Alamino, R.C.J., Silva, R.S.V., Ribeiro-Duthie, J.M., and Castilhos, Z.C., 2017, Sustainable development opportunities within corporate social responsibility practices from LSM to ASM in the gold mining industry: Mineral Economics, v. 30, no. 2, p. 141–152.

Rodriguez, O.F., 2009, Ore paragenesis of the Gramalote gold deposit: M.Sc. thesis, Kingston, Canada, Queen's University, 79 p.

Salas-Urviola, F.B., Calsina-Paricahua, L.G., and Vilca-Salas, A.C., 2021, Analysis of the formalization process of artisanal and small-scale mining (ASM): Case region Puno-Peru: Resources Policy, v. 73, article 102160.

Sidorenko, O., Sairinen, R., and Moore, K., 2020, Rethinking the concept of small-scale mining for technologically advanced raw materials production: Resources Policy, v. 68, article 101712.

Sippl, K., 2020, Southern responses to fair trade gold: Cooperation, complaint, competition, supplementation: Ecological Economics, v. 169, article 106377.

Smith, J., 2011, Tantalus in the digital age: Coltan ore, temporal dispossession, and "movement" in the eastern Democratic Republic of the Congo: American Ethnologist, v. 38, p. 17–35._

Smith, N.M., Ali, S., Bofinger, C., and Collins, N., 2016, Human health and safety in artisanal and small-scale mining: An integrated approach to risk mitigation: Journal of Cleaner Production, v. 129, p. 43–52.

Smith, N.M., Smith, J.M., John, Z.Q., and Teschner, B.A., 2017, Promises and perceptions in the Guianas: The making of an artisanal and small-scale mining reserve: Resources Policy, v. 51, p. 49–56.

SRK Consulting, 2017, Updated mineral resource estimate for the Marmato project: NI 43-101 Technical Report, prepared for Gran Colombia Gold Corporation, 212 p.

Taylor, I., and Redwood, S.D., 2017, Independent technical report and resources estimation on the El Alacran gold deposit, Department of Cordoba, Colombia: NI 43-101 Technical Report, prepared for Cordoba Minerals Inc., January 5, 2017, 147 p.

Teschner, B., 2014, "Orpaillage pays for everything": How artisanal mining supported rural institutions following Mali's coup d'etat: Futures, v. 62, p. 140–150.

Teschner, B., and Holley, E., 2019, The cost of mine suspension from social conflict: A decision tree model: Resources Policy, v. 74, article 101443.

United Nations, 2015, Sustainable development goals: https://sdgs.un.org/goals.

United Nations, 2021a, Guidance document on the management of artisanal and small-scale gold mining tailings: Environment Programme, https://www.mercuryconvention.org/en/documents/guidance-document-management-artisanal-and-small-scale-gold-mining-tailings.

United Nations, 2021b, Minamata Convention on Mercury, 2021, Parties and signatories: Environment Programme, https://www.mercuryconvention.org/en/parties.

Upton, M., 2016, Quantifying the impact of social license for investment decision-making: https://www.kz.srk.com/sites/default/files/file/MUpton_Current_Trends_In_Mining_Finance_2016.pdf.

van Leeuwen, T., 2014, A brief history of mineral exploration and mining in Sumatra: Sundaland Resources 2014, Masyarakat Geologi Ekonomi Indonesia (MGEI), a commission of IAGI (Ikatan Ahli Geologi Indonesia), Annual Convention, Palembang, South Sumatra, Indonesia, November 17–18, 2014, Proceedings, p. 35–57.

Veiga, M.M., Angeloci-Santos, G., and Meech, J.A., 2014, Review of barriers to reduce mercury use in artisanal gold mining: The Extractive Industries and Society, v. 1, p. 351–361.

Villegas, C., Weinberg, R., Levin, E., and Hund, K., 2012, Artisanal and small-scale mining in protected areas and critical ecosystems programme (ASM-PACE). A global solutions study: http://www.asm-pace.org/images/documents/GSS.pdf.

World Bank, 2009, Mining together: Large-scale mining meets artisanal mining, a guide for action: https://openknowledge.worldbank.org/handle/10986/12458.

——2013, Artisanal and small-scale mining: https://www.Worldbank.org/en/topic/extractiveindustries/brief/artisanal-and-small-scale-mining.

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