A Novel System for Mercury Abatement Within Artisanal and Small-Scale Mining:

Concept, Pilot Project, and Discussion of Findings

MERCURY FREE MINING

Eradicating Mercury for the Health of Our World

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Sponsored by:
The Gemological Institute of America

PRELIMINARY RESEARCH REPORT

*Results and analyses are subject to change with the discovery of new information

Acknowledgments:

This report summarizes years of work and effort on behalf of many organizations and has been catalyzed by Toby Pomeroy, Mercury Free Mining's founder and the person who enabled the project to occur.

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Thank you Cruz Pata Chaquiminas and CECOMIP Ltda for participating in the research program, conducting sampling, and working with our team to ship and pay for materials.

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Lastly, thank you Gemological Institute of America for funding this research. It is the start of a significant and valuable program which will help mitigate the continued use of mercury within ASGM.

Glossary of Abbreviations:

ARM: Alliance for Responsible Mining

ASGM: Artisanal and small-scale gold mining

CE: CECOMIP Ltda.

CO: Concentrated ores

CP: Cruz Pata Chaquiminas

GIA: Gemological Institute of America

OPEX: Operating Expense

QA/QC: Quality Assurance and Quality Control

MFM: Mercury Free Mining

NGO: Non-Governmental Organization

SEM: Scanning Electron Microscope

T: Tailings

W: Waste (same meaning as tailings)

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1. Report Scope and Structure

This is a preliminary report detailing a pilot program launched by Mercury Free Mining to test a novel system for mercury abatement within mining communities. It is built upon and inspired by the lessons of others and was placed into action with two partnering mines, Cruz Pata Chaquiminas and CECOMIP Ltda. It is being funded by the Gemological Institute of America and implemented in partnership with the Alliance for Responsible Mining.

This report includes the information collected to date with additional information coming soon as more gold assays are completed. All parts of the report are subject to change and alteration as additional information is gathered and interpreted.

1.1 Executive Summary

- Mercury use within artisanal and small-scale mining is negatively impacted the wellbeing of millions and believed to be driven by a lack of reliable information regarding the efficacy of alternatives for concentrating gold.
- A system which evaluates potential mercury alternatives was developed and piloted. The system was able to effectively characterize the efficacy of mercury alternatives and provide miners recommendations for improved mineral processing.
- The system was designed to be amenable to a variety of mining contexts to be used across the globe and increase the general understanding of mercury alternatives. Furthermore, it uses a holistic approach in integrating the whole gold supply chain and social governance experts.
- The pilot program showed two alluvial mining cooperatives in Ananea District Peru were interested in gathering more information and were able to deploy the proposed system.
- Future work intends to revise and streamline the methodology to be deployed throughout the globe.

1.2 Graphical Summary

Driving Question:

Is there a system to efficiently produce reputable information on mercury alternatives and helping artisanal and small-scale miners supplant mercury?

This Research:

#1
Created a Theoretical System

- Review ASGM literature and identify best practices
- Create an objective method for characterizing a mining operation and remotely optimizing mineral processing.
- Organize needed resources

#2
Trialed System with a Pilot in Peru

- Two mines in Peru participated
- 5 mercury-alternatives are being assessed
- Ores and gold was characterized/evaluated
- Recommendations for optimized processing made

#3
Reconciled and Improved the System

- Miners were interested in the research opportunity
- Procedures and methods developed could be implemented with higher cost effectiveness
- Both field visits and remote analyses improve effectiveness

2. Introduction and Project Motivation

Globally, people mine to earn an income. There are approximately 23.5 million gold miners across the globe and 22.5 million are artisanal and small-scale gold miners (ASGM), or 95.7% (Seccatore et al., 2014). This majority of miners use a type of mining which is defined by having relatively lower capital expenditure, using rudimentary methods, and are oftentimes operating beyond their host jurisdiction's formalized economic system (Seccatore et al., 2014, OECD 2016, Veiga & Marshall, 2019).

It is important to note early the consensus among experts that illegal mining is not the same as ASGM. As the OECD Due Diligence Guidance Supplement on Gold (2016) suggests, there are 'legitimate' ASGM actors that act in good faith which fundamentally differ from 'illegitimate' illegal gold miners acting on bad faith, trespassing, and/or violate basic human rights (Hunter, 2020a). The following discussion of ASGM assumes the miners are in in the former 'legitimate' category.

ASGM is most common in areas with few alternative income streams. These are also areas with great potential for economic growth and development. ASGM has been mapped onto the UN SDG's and has been considered to be a potential route for millions to earn a reliable and adequate income (de Haan et al., 2020; Fisher et al., 2009; Ross, 2011).

Artisanal and small-scale mining has been a topic of study by development specialists, engineers, NGO's, and institutes for over a half a century yet it is still considered to be causing a global health crisis. The dominant issue perpetuated by ASGM is the use of mercury and the associated mercury pollution. Mercury is a potent neurotoxin with a significant environmental lifecyle (Bernhoft, 2012; Esdaile & Chalker, 2018; Zahir et al., 2005) . It is a unique material that creates an amalgam with gold and enables recovery, albeit poor (~40%) (García et al., 2015). The UNEP found in 2015, that ASGM represented 38% of the 2220 tonnes of mercury emitted into the atmosphere from all anthropogenic sources (UNEP., 2018). Other sources indicate when evaluated all forms of mercury pollution, ASGM can be attributed to about 2,000 US tons annually (Yoshimura et al., 2021).

There is a clear issue of mercury within ASGM and the discussion now shifts to why mercury remains a grand global challenge. Decades of laudable efforts have produced few successes. Experts have been increasingly reflecting on why failure seems endemic and prescribe systems they believe would yield more productive results. Below summarizes the works of Hilson & Maconachie, 2017; Hilson & McQuilken, 2014; Robles et al., 2022; Veiga & Fadina, 2020 in order to highlight some of the key features of previously attempted mercury abatement programs.

A non-exhaustive list of features which have been common with failed programs includes.

- Failures to integrate the large set of dynamic stakeholders and adequately consider their needs, and aptitudes
- Lack of reviewing prior mercury abatement projects to identify mistakes
- Short-term projects lacking continuity in technical assistance and general support
- Significant focus on shifting bureaucratic policy or tracking the environmental and health impacts of mercury without attempts to replace mercury in mineral processing
- Uncoupled geological, mineralogical, and mining engineering evaluations leading to misconceptions about the scalability of mercury alternatives and improper implementation of mercury-free equipment. Commonly known as finding a “silver bullet” for mercury use.

The few notable success stories in mercury elimination generally include the following features

- Using capitalism-based market demand for sustainable goods to produce the capital needed to invest in sustainable mining (Fisher et al., 2009; Martínez et al., 2021)
- Cooperation between large-scale mining and ASGM through cooperative mineral processing, sharing geological information, and utilizing social governance experts (Lessons Learned on Managing the Interface between Large-Scale and Artisanal and Small-Scale Gold Mining, 2022).
- Community mineral processing cooperatives
- Projects with long-term support/training, and technical assistance (Martinez et al., 2021).
- Interdisciplinary projects integrating diverse stakeholders (Malehase et al., 2017; Smith et al., 2016).

Putting these lessons and guidance into action is the motivation of this pilot project. Prior to being able to address all of the above issues related to prior mercury abatement efforts, there is a need to discover reliable information on how mercury alternatives function within the dynamic environment of an ASGM operation. This project is intended to close that knowledge gap.

This pilot tests a system which actively helps miners supplant mercury by eliminating the risk involved with switching to alternatives explained in section 1.1. Ideally, this system can be scaled and transformed into open-source projects for additional groups to utilize. Eventually, there will be enough data points on the efficacy of mercury-alternatives so that extrapolation can replace direct experimentation and minimize the risk for miners throughout the globe.

2.1 The Miner’s Perspective

This section is devoted to understanding why mercury is still being used by ASGM. There are methods and equipment for concentrating gold without mercury and the continued use of mercury is notable. Understanding why mercury is used enables our team to devise a system that addresses the highest priorities for miners we partner with. The summary is non-exhaustive and focuses on the characteristics directly addressed in the proposed system.

Income. In the past, ASGM was considered an “entrepreneurial” activity. Under this banner, miners were thought to be mining to enhance their income. This has shifted. Experts now recognize mining is frequently a means to survival and any change in the mining process is inherently a risk to survival (Betancur-Corredor et al., 2018; Hilson, 2016; Wilson et al., 2015).

Familiarity. Mercury is familiar. It has been used for multiple generations. Even though it generally has a low rate of recovery (~40%), miners know how much gold they will be able to recover from their feed and have a reliable income (Martinez et al., 2021; Veiga & Fadina, 2020).

Ease of use. Mercury alternatives can be complex, require technical knowledge, unreliable, and need additional effort to operate effectively. Therefore, training and continued support essential for any effort to supplant mercury (Martinez et al., 2021; Veiga & Fadina, 2020; Yoshimura et al., 2021).

Inadequate Information. Miners may be unaware of mercury alternatives and/or objective evaluations regarding the efficacy of many mercury alternatives may not exist or be applicable to their operation (Martinez et al., 2021; Smith et al., 2016).

Informality. The “Cycle of Poverty” theory within ASGM asserts that because miners are most often informal, they sell their gold through informal markets. This leaves them to being particularly susceptible to bad actors that will only buy the gold (sometimes at lower than spot price) if the miner buys mercury (Prescott et al., 2022; Ross, 2011).

Financing. Receiving the capital to invest in new equipment is difficult when outside formal markets and income is sparse (Bugmann et al., 2022; Hilson & Garforth, 2012; Hunter, 2020b). Mercury alternatives can cost several thousands of dollars which is often unfeasible for the operation.

2.1 Proposed System for Supplanting Mercury

Following from prior efforts to supplant mercury use in ASGM, the proposed system (in section 2.2 below) was designed with specific features/goals to avoid repeating past failures. This system for supplanting mercury in ASGM is described below:

Integrate dynamic stakeholders and consider an interdisciplinary approach:

- Build support from the end-user/consumer back up the supply chain to the miners in order to integrate changing demands and to leverage increased support for supply chain transparency
- Combine engineering and the physical sciences to understand the processes and methods of mining and prescribe improvements
- Integrate social governance teams into the projects to avoid one-sided approaches to mercury mitigation

Create a system that can scale and have a greater impact than a case study:

- Publish and share the underlying procedures and methods used to minimize the miner's risk in choosing a mercury alternative
- Share data related to each processor evaluated and the ore evaluated
- Repeat case studies to build a repository of information and increase our ability to extrapolate results and be used by other mining specialists and miners

Catalyze sustainable change:

- Supply-chain integration is also intended to help facilitate the development of transparent supply-chains. This enables long-term relationships to form between Mercury Free Mining and the miners which is essential for enabling continuous support.
- Work with local experts to help train miners on equipment, share results, and develop trust.
- The proposed system can be implemented regardless of the use of mercury. It is action-oriented meaning that it is explicitly designed to maximize the development of information related to fostering positive change in ASGM mineral processing.

2.2 Proposed System for Mercury Abatement Within ASGM

This is the proposed system for mercury abatement. It is used in the pilot program and will be revised for future expansion of the MFM research program (revisions mentioned in Appendix D). The system is implemented through "projects" where we partner with mines, conduct the evaluation of mercury alternatives, and create recommendations. This will be used to compile a robust dataset suitable for extrapolation.

Project Phase	Step:	Reasoning:
#1 Planning and Fundraising	1. Gather market-side support and align social-governance expertise.	Market demand for responsibly sourced goods is a potent method for catalyzing positive change in a supply chain (Thorlakson, 2018). This method has not been used previously but when considering other markets like food goods, it has significant potential to transfer to ASGM. Partnering with social governance experts is imperative to understanding the multi-dimensional issues miners face.
	2. Partner with a mining community, offering the opportunity to enhance well-being.	Creating a relationship founded in trust and respect for one another is how our teams can reduce risk, increase transparency, and develop long-term impact. To develop this partnership a community, visit to gather basic observations of the mining operations, infrastructure available, etc is conducted.
	3. Gather buy-in from mineral processing equipment manufacturers	With project support and the community's trust, mercury-free processing equipment, which represents a diverse group of methods believed to be most effective for the context, is selected. Relationship-building between manufacturers and MFM team occurs, and the pre-processing agreement is signed to create accountability.
#2 Sampling and Technical Analyses	1. Sample and ship materials for evaluating mercury alternatives. For example, concentrated ores (pre-	To objectively evaluate the performance of selected mercury-free processors, representative samples of ore materials must be selected for processing. This helps the MFM team understand the mineral processing that is occurring to make

	amalgamation, tailings, and run-of-mine)	suggestions on how the miners can improve their profitability. Sampling is conducted using the methods described in Appendix A.
	2. Receive samples and conduct standardized evaluations to characterize materials.	Ore characterization is necessary to compare ores from different areas. Without characterization, there is not an opportunity to diagnose and understand why a mineral processor's efficacy may differ dependent on the context it is used.
	3. Using a standardized procedure, each mineral processing equipment manufacturer processes the materials.	The standardized procedure for objectively evaluating each of the gold recovery equipment is presented in Appendix B. This procedure is important for ensuring that each equipment manufacturer is compared equally and by using robust metrics.
	4. Processed materials are returned and analyzed.	Materials must be analyzed for gold content to understand the effectiveness of each of the equipment tested. Ore characterizations allow for the team to make conclusions related to the strengths and weaknesses of a piece of equipment evaluated.
#3 Implementation	1. Data is compiled, reconciled, and interpreted.	The data gathered from phases 1 and 2 is reviewed and interpreted to understand why there are variations in performance, provide recommendations, and understand the mining operation.
	2. Miners are informed of the results and can choose to implement a processor.	Miners are the key stakeholders of the project and must be the decision-making group when supplanting mercury. The full analysis, and recommendations are presented to them for consideration.
	3. Implementation and training on chosen processor.	If miners want to implement equipment, the training enables the miners to use it effectively, make repairs, and increase equipment life.
	4. Continued conversations and revisitations to the mining community.	This provides the long-term support necessary to successfully eliminate mercury use within a given mining operation.

3. Test Site and Methodologies

Section 3 describes the specific details of the pilot project used to test the proposed system. This tested the following hypotheses:

H1: *If the information discovered can increase miners' certainty about the efficacy of a mineral processor which increases their income, then the miners will be open to adopting the mercury free technology/ies.*

Underlying this hypothesis are the assumptions that miners are what some economists call "rational actors" and will prioritize their basic needs, like earning a stable income, prior to the "higher level" needs described by psychologists like Maslow.

H2: *A scalable and repeatable system can be developed which enables miners to increase their confidence in mercury-free technology/ies through objective scientific research.*

This hypothesis assumes that a certain piece of mineral processing equipment or method can be shown to have predictable results on the metrics that are important to miners. Additionally, it assumes that this can be done in a fashion that is feasible.

H3: *With supply chain integration, the proposed system can be sustained and repeated with other mining operations across the globe.*

H3 is testing whether the demand for sustainable goods is legitimate and can make the system self-propelling by enabling miners to access formal markets with demand for gold that can be verified as mercury-free.

3.1 System for Mercury Abatement as Implemented in Pilot

Project Phase	Step:	Step As Implemented:
#1 Planning and Fundraising	1. Gather market-side support and align social-governance expertise.	The Gemological Institute of America funded the research and broad public outreach conducted by MFM created a considerable base of support. As a key collaborator, the Alliance for Responsible Mining staff are the social-governance experts for the project.
	2. Partner with a mining community, offering the opportunity to enhance well-being.	ARM experts connected MFM with CECOMIP Ltda. And Cruz Pata Chaquiminas in the Peruvian Andes. Both mining cooperatives expressed an interest in increasing their profitability using new mineral processing technologies. Cruz Pata currently uses mercury within their mineral processing.
	3. Gather buy-in from mineral processing equipment manufacturers	MFM received information on the mines from the ARM team. It was decided to evaluate 6 different equipment: GOLDROP, Gold Cube, Cleangold Sluice, Flinder's Method, ICON Centrifuge, and Carlos Heneos's shaking table. Carlos Heneo was unable to receive the ores hence and the total number of processors analyzed was 5.
#2 Sampling and Technical Analyses	1. Sample and ship materials for evaluating mercury alternatives. For example, concentrated ores (pre-amalgamation, tailings, and run-of-mine)	With ARM, miners randomly sampled and split 90 kg of tailings and 20 kg of concentrated ores. Miners were paid for the concentrated ores based upon the gold recovered from the material that was not reserved for the testing. It was panned and smelted to produce doré. After payment, the samples were transported to Lima for shipping. For more information, please see Appendix A.
	2. Receive samples and conduct standardized evaluations to characterize materials.	Drying procedures are in Appendix C. Ore characterization included particle size distribution, grain counts, and gold grain characterization conducted by Caelen Burand. This is in section 4 of this report.
	3. Using a standardized procedure, each mineral processing equipment manufacturer processes the materials.	The standardized evaluation method developed included a binding document requiring that equipment manufacturers adhere to a common processing procedure. The goal is to isolate specific processes which change the ore's character for MFM to evaluate how that change in ore character impacts profitability. These procedures are in Appendix B.

	4. Processed materials are returned and analyzed.	Equipment manufacturers returned processed material. They were dried and randomly sampled for assays and characterization. These results were then compiled and interpreted.
#3 Implementation	1. Data is compiled, reconciled, and interpreted.	TBD. This report compiles, reconciles, and interprets the data.
	2. Miners are informed of the results and can choose to implement a processor.	TBD
	3. Implementation and training on chosen processor.	TBD
	4. Continued conversations and revisitations to the mining community.	TBD

3.2 Geography, Geology, and Community

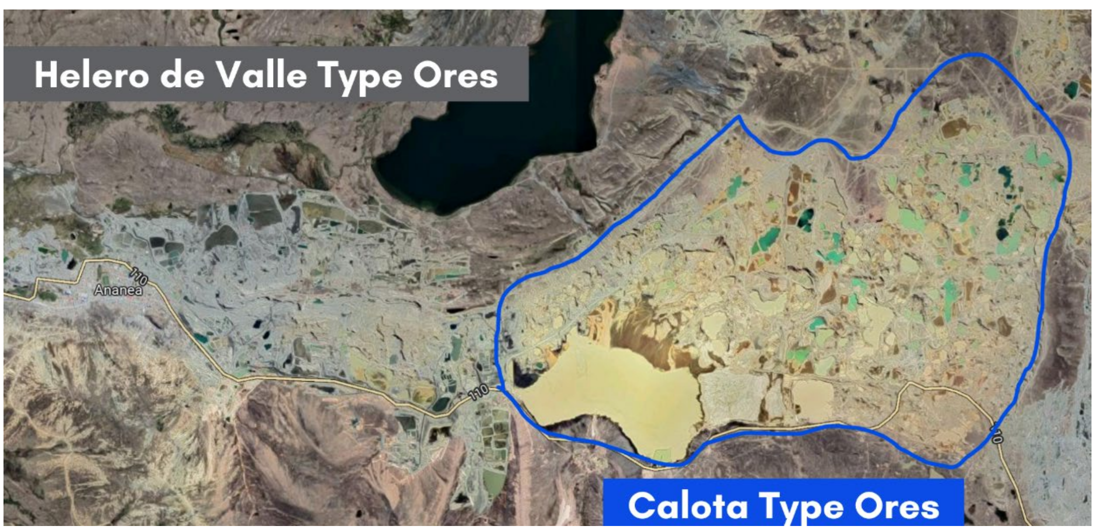
Country: Peru

Region: Puno

Province: San Antonio de Putina

District: Ananea

Altitude: 4650 meters above sea level.



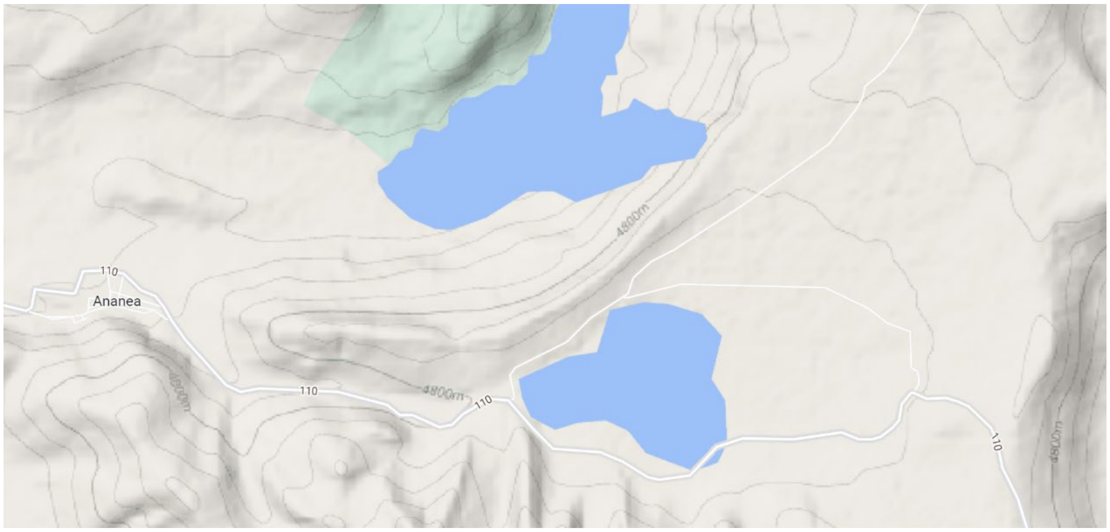


Figure 1: The geographical distribution of "Calota Type" and "Helero de Valle" type alluvial ores. Locals believe that the ores in these two locations vary drastically. The topographic map shows how these deposits are constrained by topography which is important during the latter discussion of the ore character.

Fidel Cabana, mining engineer previously with the Alliance for Responsible Mining, compiled a reconnaissance report which included the process of collecting, transporting, and shipping the ore samples in February 2022. The following is based on his reconnaissance. Please note that this reports on the observations of the miners in the region and is the narrative believed to explain the ore deposits. Some of the claims made are disputed in section 4.

The Ananea District, in Southeastern Peru, is economically driven by cattle ranching, sheep herding, and alluvial gold mining. In all economic sectors, the dominant social structure is the “Social Community” where resources are owned by the community and shared through mining cooperatives and community ranches. The deep valleys where mining occurs are situated between large cordilleras. The mining is conducted in fluvio-glacial deposits from the Quaternary when glaciation undulated with global climate. The surrounding mountains are predominantly slates and schists carved by prior glaciation periods.

It is believed that there are two distinct deposits in the region which were developed during two glaciation periods. The first type is called Calota type which is red in color, with fine gold, and more fine sediments. The Calota type deposit is being mined by CECOMIP. The other type of deposit, called Helero

Figure 2:

Upper left: Miners at CECOMIP Ltda collect ore samples from the sluice tailings. The red material represents Calota type deposits.

Upper right: Miner at Cruz Pata shows the typical scale of cobbles and rocks in a Helero de Valle type deposit.

Please note the difference in color between the deposits is significant.

de Valle, was developed through dominant glacial erosion, not the glacio-fluvial transport dominated Calota. They are believed to have lower amounts of fine sediment, more schist, and coarser gold.

The areas of Ananea and La Rinconanda, to the Northeast, have been mined since the Incan empire. The Spaniards carried out some mining of Placer de San Antonio de Poto using the cochas system but was reduced to the artisanal miners after the founding of Peru. Between 1929 and 1976 Placer de San Antonio was worked by various mining conglomerates, state operations, and private groups which employed hydraulic washing, a dredge, and significant processing plants. Beginning in the 1980's, to today, artisanal miners became the dominant form of mining. Many forming cooperative mining structures like CECOMIP Ltda. and Cruz Pata Chaquiminas.

Cruz Pata Chaquiminas and CECOMIP Ltda. use similar processes to mine and concentrate their gold ores with the only exception being that Cruz Pata uses mercury to create their final product and CECOMIP uses a shaking table and borax smelting to produce their final product.

The first step is ore extraction. Excavators fill dump trucks with the raw ore. It is transported to wooden grizzly screens that removes the largest rocks. The grizzly screen is inclined, and high-pressure water is used to wash the rocks and remove the sediments which contain gold. This produces a slurry of rock, gold, and sediments. This flows through long sluices inclined at relatively high angles. These are regularly cleaned by the miners which means the mats and riffles are removed to collect the "pre-concentrated" ores.

At CECOMIP, these pre-concentrates are converted into concentrates using a shaking table then smelted using borax to produce doré. At Cruz Pata Chaquiminas, the pre-concentrates are amalgamated in a ball mill and the mercury evaporated to produce doré. In both cases this doré is then sold.

This investigation is particularly focused on the step of converting the pre-concentrated ores into concentrated ore sufficient to be smelted into doré. This requires a very high concentration of gold, exceeding 3% Au (Appel & Na-Oy, 2012). This is difficult to achieve while recovering a high proportion of the gold.

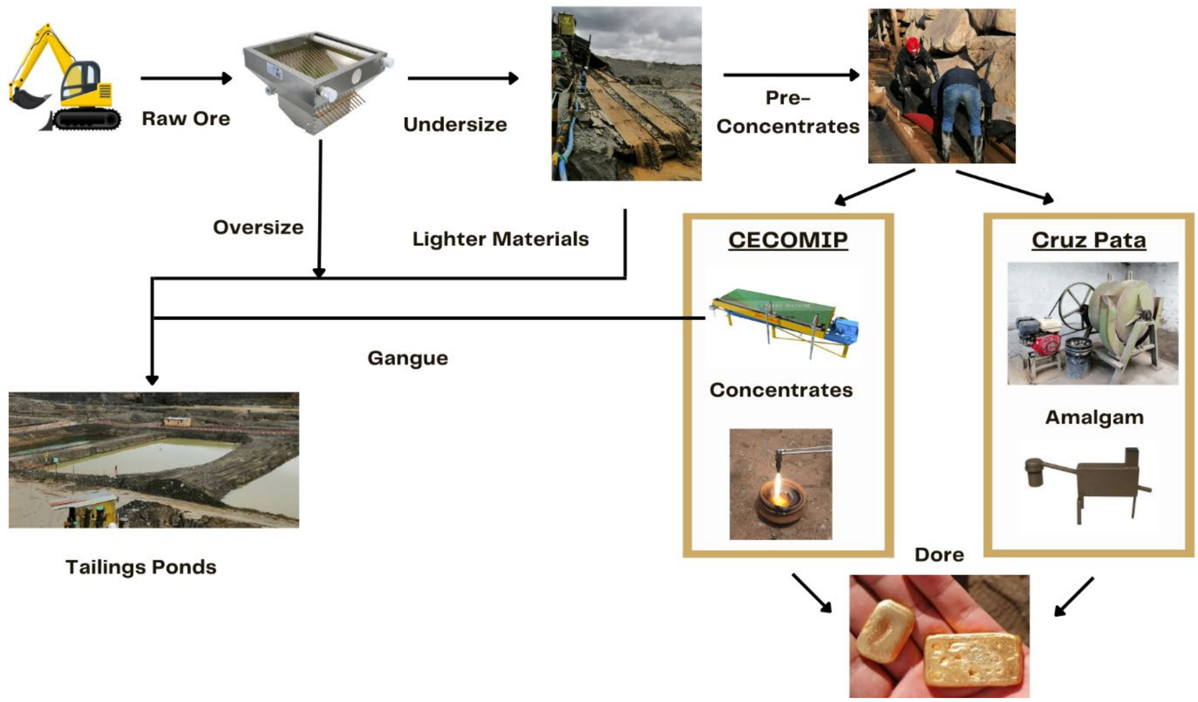


Figure 3: Mineral Processing flowsheet at Cruz Pata Chaquiminas and CECOMIP Ltda. The operations follow similar methods when processing ore except for the final step of producing the sellable doré.

4.0 Results

4.1 Ore Characteristics

The tailings and concentrated ores received are highly heterogeneous and size ranges from silts to cobbles. The largest cobble measured within the tailings was 3.7x3.1x1.9 cm and the largest in the concentrates was 1.2x1.0x.7 cm. Clasts are sub-angular to rounded, indicating significant mechanical weathering although it is thought their transport distance is in the range of tens of km. They are oftentimes oblong in shape, like a platelet, and some show slaty cleavage which makes them particularly thin. These were more common in the CECOMIP materials. Clearly, they were the result of an energetic depositional environment.

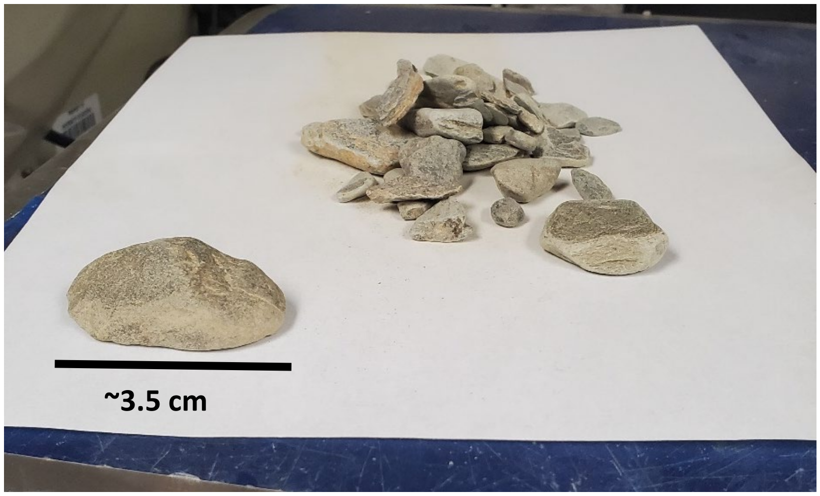
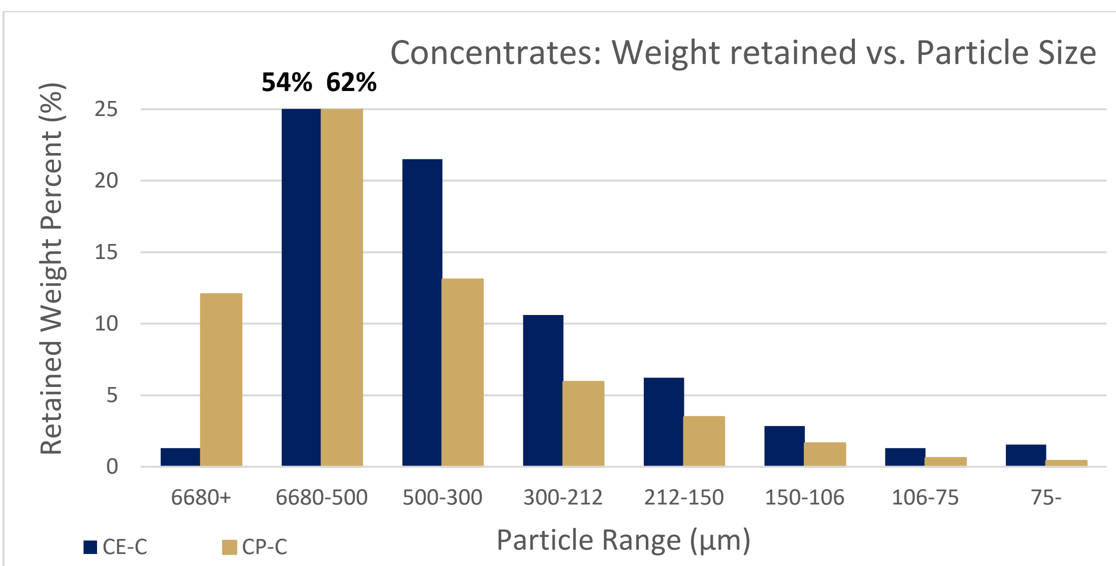


Figure 4: An example of some of the gravel and cobble sized stones in CECOMIP tailings. Note that some of the larger stones have slight slaty cleavage.

The dominant rock types are medium-grade slates with minor components of fine-grained diorites and gabbros. There is very little phyllite. The igneous rocks are significantly more disintegrated than the metamorphic rocks. The conclusion derived from this is that the erosion of the lode source was dominated by fluvial processes and glacial processes. The sediments are similar to those that arise during syntectonic sedimentation in periglacial systems and/or on the distal regions of alluvial fans in this setting. It is difficult to distinguish the precise depositional state given the run of mine material has been previously reworked and destroyed bedforms.

Random samples of .75 kg of concentrated ore and tailings were split into two .375 kg samples. Each of these smaller portions were sieved for 15 minutes using a vibratory and rotational dry sieving machine. The results of the processes are shown in the charts below.



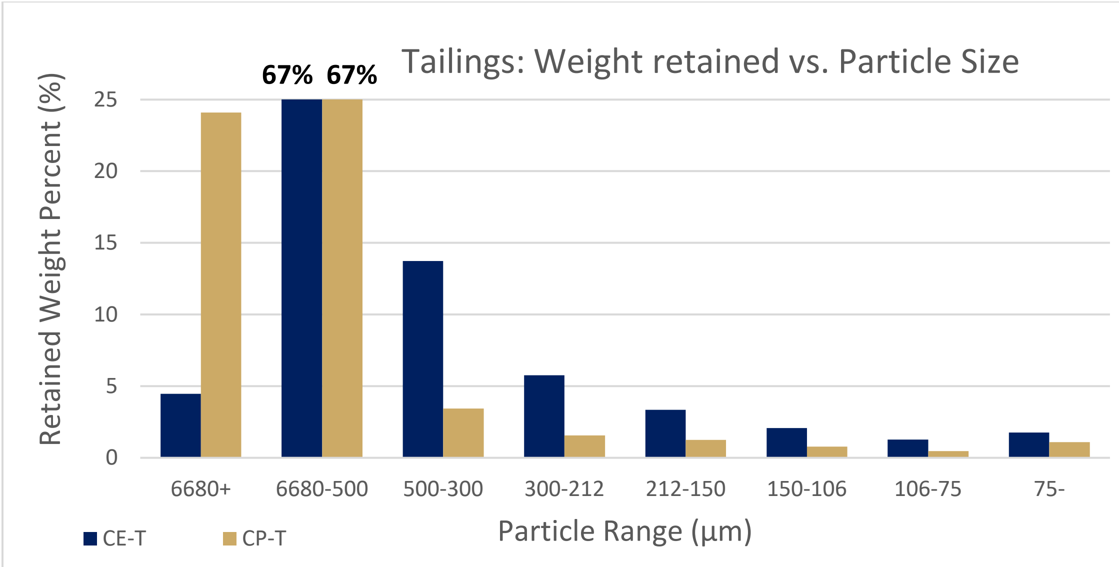


Figure 5: Upper chart shows the % weight retained at each particle size range for the concentrated ores and the lower chart shows the same metric for the tailings.

The cumulative passing vs. particle size curve which typically follows the Gates-Gaudinn-Schumann curve (Macıas-Garcıa et al., 2004), or similarly defined exponential curve which is given by:

$$y = \left(\frac{x}{k}\right)^m$$

Where:

y = Cumulative weight percent passing through a sieve

x= particle diameter

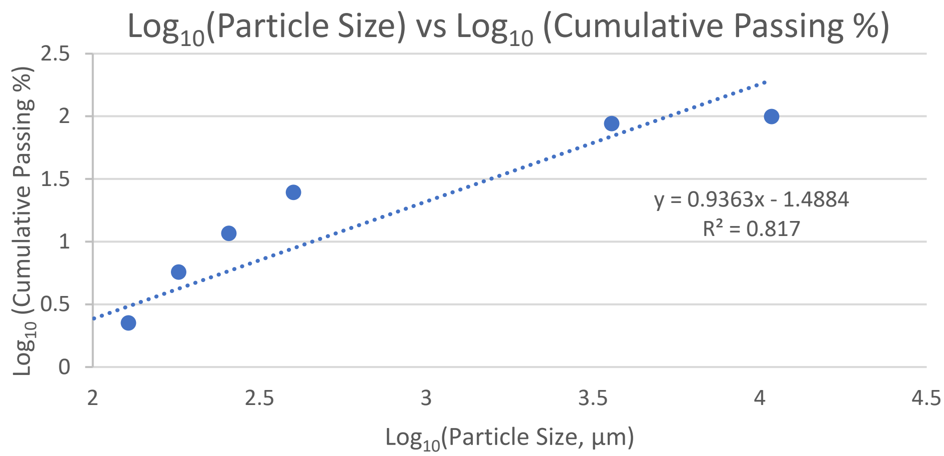
m and k are empirically determined variables

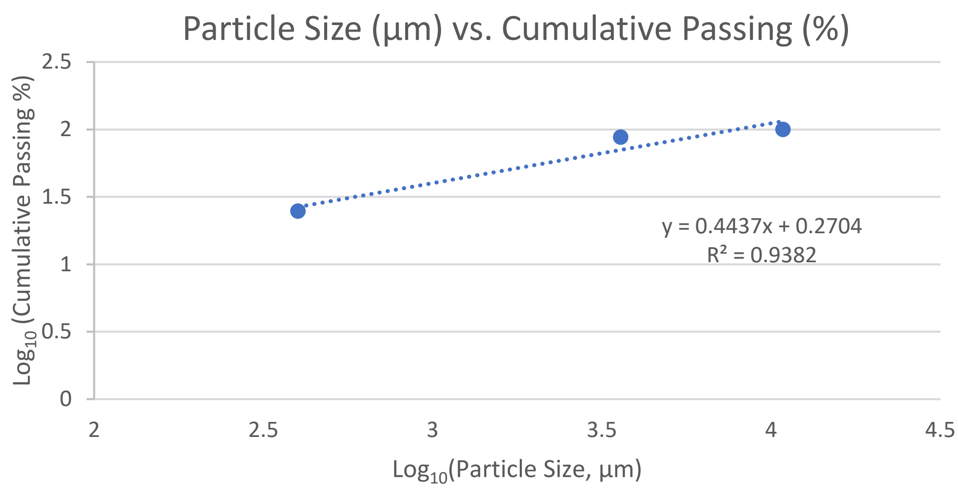
Using simple algebra, it can be shown that

$$\log(y) = mlog(x) - mlog(k)$$

where the greater the value of m means less particle size dispersion or that the sediments are all of equal diameters.

After visual analysis and following the procedure Spencer (1963) outlined, the particle size distributions were found to represent two separate populations. They were dissected into two separate groups in the following steps. This was reiterated for each of the types of ore materials received.





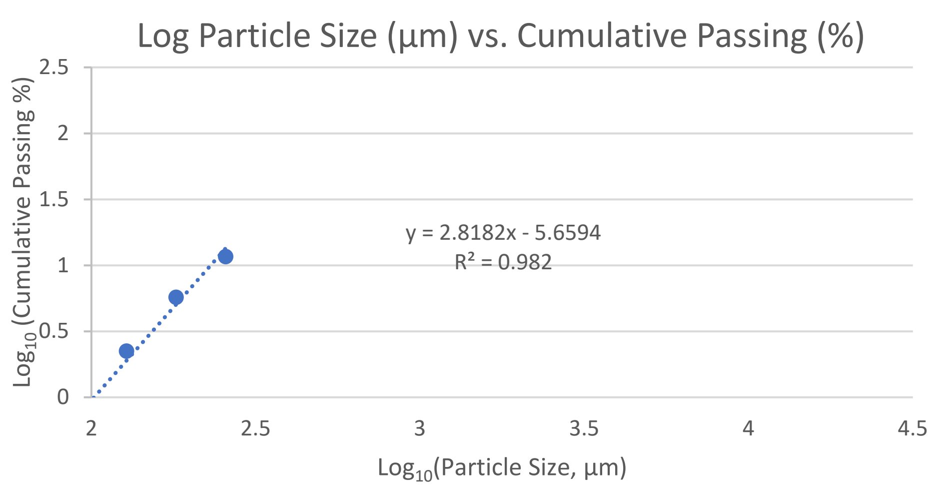


Figure 6-8 shows the steps used to dissect the two populations of ore material such that they fit the exponential function which defines sediment particle size distributions. These best fit descriptions of the ore is used when defining statistical measures. The *plots split showing that there are two populations. One that is well defined and consisting of the smaller particles, and another that is highly heterogenous representing the gravel and cobbles.*

The resultant lines of best fit were then used to calculate the theoretical parameters indicated below to summarize the characteristics of each type of ore. These parameters are described by Spencer (1963) and commonly used to understand sediment morphology (Folk, 1966; Middleton, 1976).

$$Dispersion = \frac{P_{75}}{P_{25}}$$

$$Skew = \frac{(P_{75} * P_{25})}{(P_{50})^2}$$

$$Kurtosis = \frac{(P_{75} - P_{25})}{2 * (P_{90} - P_{10})}$$

Where: P=Particle size and the subscript referring to the percent weight passing based on the best-fit curves produced for each type of material received.

	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse
	CE-C		CE-T		CP-C		CP-T	
Dispersion	1.51	56.85	1.66	13.17	1.48	11.89	1.70	3.83
Skew	0.90	0.35	0.88	0.51	0.90	0.52	0.87	0.70
Kurtosis	0.28	0.25	0.29	0.30	0.28	0.31	0.29	0.32

Figure 9 summarizes the statistical measures of the grain size populations represented in each of the samples received.

The analysis indicates two important characteristics: CECOMIP and Cruz Pata ores are very similar to one another and that the process of using the sluices does little to change the physical dimensions of the ore. This is important because it means that the sluices are either retaining particles based primarily on their composition, not on their size, or the sluices collect gold grains and a random sample of the other run-of-mine materials. If this were not true then there would be a significant difference in the particle size distributions of the concentrated ores and the tailings.

Mineral grain counts were conducted to identify the composition of materials that are in the sand through silt size and were conducted using an AmScope binocular microscope with 90x magnification. These are summarized on the tables below with “metallics” indicating hematite and similar iron oxides and “matrix” indicating the host rocks (mainly gabbros and diorites at this size).

CECOMIP Concentrates: CE-CO		
Mineral Component	Count	Proportion of Total
Metallics	4	.029
Matrix	83	.593
Quartz	51	.364
Other	1	.007
Gold	1	.007
TOTAL	**140**	
Cruz Pata Concentrates: CP-CO		
Mineral Component	Count	Proportion of Total

Metallics	10	.063
Matrix	83	.522
Quartz	64	.402
Other	1	.006
Gold	1	.006
TOTAL	**157**	

CECOMIP Tailings: CE-T		
Mineral Component	Count	Proportion of Total
Metallics	9	.035
Matrix	27	.101
Quartz	228	.86
Other	1	.0038
Gold	2	.0075
TOTAL	**267**	
Cruz Pata Tailings: CP-T		
Mineral Component	Count	Proportion of Total
Metallics	18	.06
Matrix	48	.16
Quartz	229	.78
Other	0	0
Gold	0	0
TOTAL	**295**	

The differences between the two mining cooperatives' ores based on the mineralogical and size distribution analysis can be summarized by:

- Cruz Pata ores contain more cobble-sized rocks.
- CECOMIP ores have finer particles and more "glacial flour". It was determined to be primarily silt using the texture test.
- Cruz Pata ores contained a higher fraction of higher-grade metamorphic rocks (near schistose textures were observed) whereas CECOMIP ores contained a greater proportion of slate.
- Cruz Pata ores had significantly more metallics than the CECOMIP ores and their matrix was lighter, thought to be because of more feldspathic minerals being present.
- Both ores have very low proportions of magnetite and sulfides which likely indicates that they are rather environmentally inert although geochemical analysis would be needed to assert this claim.
- In all samples, small spheres of mercury were noticed and is likely because of the prior century of mining using mercury in the area.

Importantly, CECOMIP and Cruz Pata ores do not vary. It is locally believed their "clay content" significantly differs because of the stark difference in color between the ores as shown in figure 2. CECOMIP ores are tan to red while Cruz Pata ores are grey. This may lead field observers to identify "red clay" at CECOMIP and not Cruz Pata but the results show that the ores are nearly identical. The topography shown in figure 1 shows how a difference in standing water at the two sites could be the reason for the contrasting colors. Standing water would enhance the oxidation of iron, causing the shift in color at CECOMIP. This impacts this report because it means that the optimal mineral processing for one mine is likely to also be optimal for the other.

4.1.1 Gold Grain Characteristics

Analysis of the gold grains and grain counts were conducted using an AmScope binocular microscope with 90x magnification. Gold grains were chiefly observed using the GOLDROP products because of their high concentration of grains which made comparisons more effective.

Samples were randomly drawn, placed on a microscope slide in a monolayer and then observed and counted using the line counting method. Gold grains were visually measured with future endeavors intending to use a digital microscope or SEM to increase the precision but for this pilot, having the broad understanding of the gold grains was considered adequate. For the purposes of this investigation, gold grain character was observed from the materials produced by GOLDDROP because this had the greatest density of gold and mimics typical concentration processes used in gold grain analyses. The following metrics were observed and calculated.

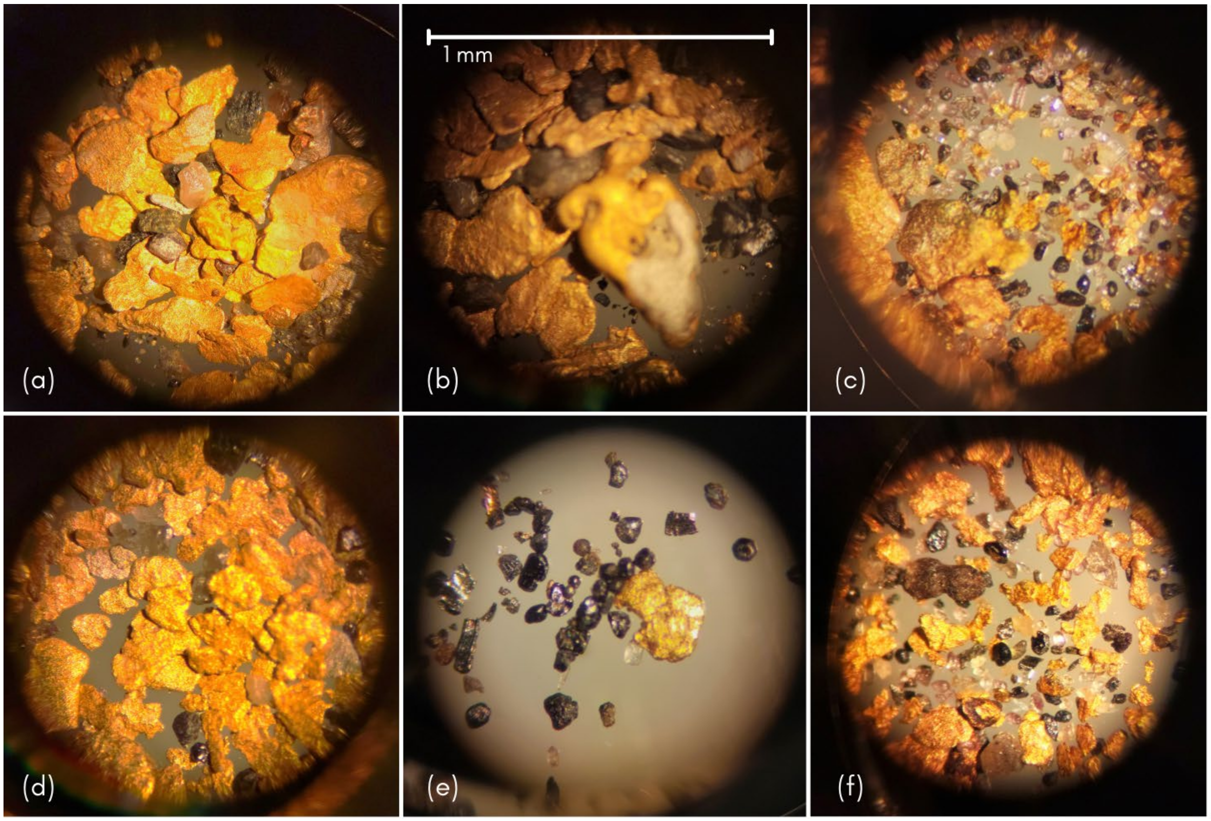


Figure 10: (a) CECOMIP concentrates. This gold was lighter colored, well hammered, reshaped and flat. A significant observation was that CECOMIP concentrates also contained citrine like the piece in the center of a. This was not found in any Cruz Pata ores.

(b) CECOMIP tailings showing a large, interesting grain that clearly is not pure gold. Several of these grains were found in the tailings of both mines.

(c) Cruz Pata tailings. Gold was "pitted" and the quartz in the tailings was well-rounded, like sand, whereas the grains in the concentrates were much more jagged and angular.

(d) Cruz Pata concentrates. Pitted and brighter color. Some of the grains appeared to be less malleable than the CECOMIP ores leading to edges that were more complex.

(e) An example of an isolated gold grain in Cruz Pata concentrates. The grain is partially amalgamated to the magnetite. Several spheres of mercury were identified during inspection.

(f) CECOMIP concentrates. Note that the large dark grain near the center is gold with a rust/patina which was unique to CECOMIP.

Grains were categorized into three categories by morphology. Pristine is defined by, crystalline features, convex corners, points, and no mass redistribution; modified, mass is partially redistributed but the grain retains some complex features; and reshaped, mass has been thoroughly redistributed and it is unclear what the original morphology of the gold grain was. Pristine gold represents the most proximal gold and reshaped the most distal, but the amount of transport and physical interactions with other materials influences how rapidly pristine grains are transformed into reshaped grains (Minter et al., 1993). The number of grains counted in the tailings was limited by the number of grains recovered by GOLDROP.

	Pristine	Modified	Reshaped	Total Number of Grains
CE-CO	0	0.082	0.92	558
CP-CO	0	0.047	0.95	430
CE-T	0.08	0.28	0.64	21
CP-T	0.034	0.31	0.66	29

Figure 11: This is used to show how the majority of gold at both mine sites is reshaped and that the sluices, as implemented, are selective for reshaped grains. The greatest losses to both sites come from impure and less transported gold which are lost in the tailings.

Dimensions of samples of individual grains was approximated using the size of the field of view. These dimensions were record and used to define quantitative parameters describing the gold grains following examples given by authors like Benn & Ballantyne (1993), Ketchaya et al. (2022), and Minter et al., (1993). This is summarized by the charts and graphs below.

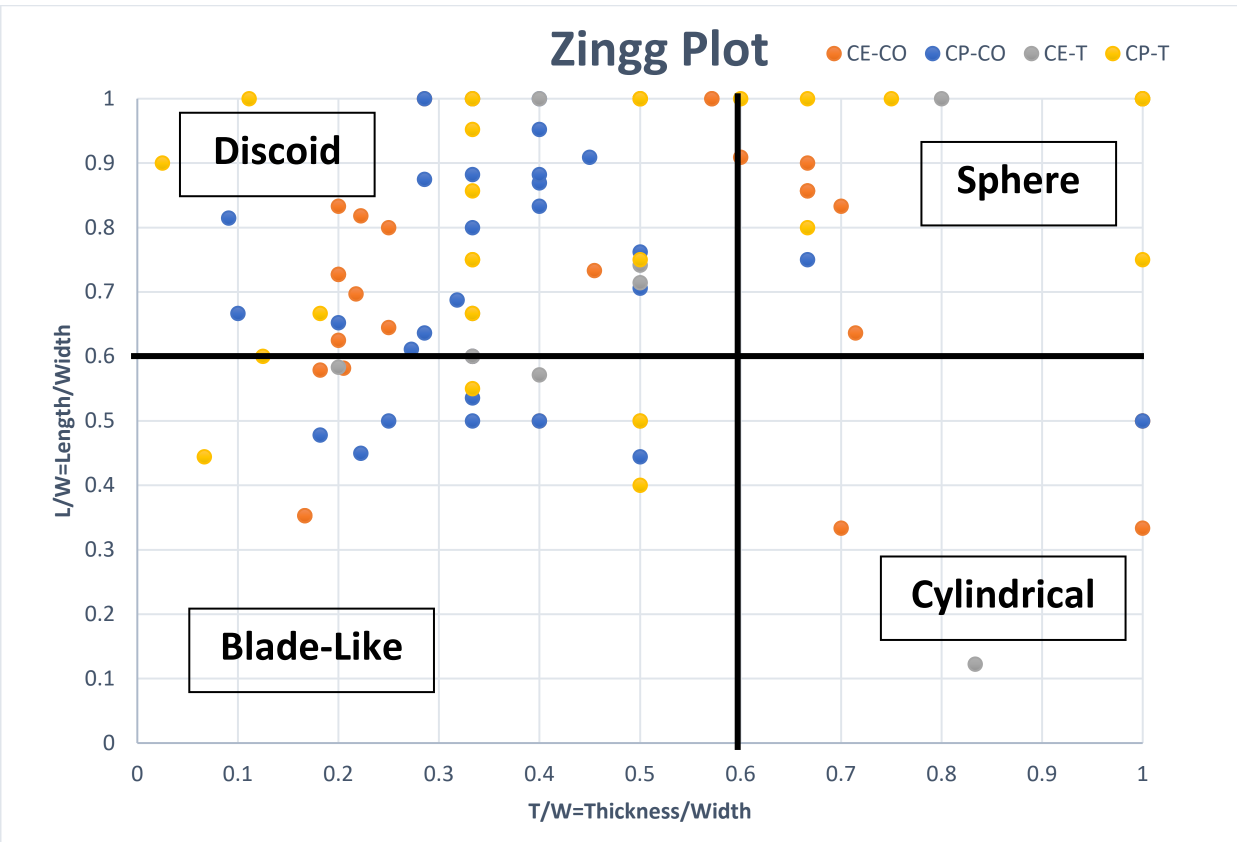
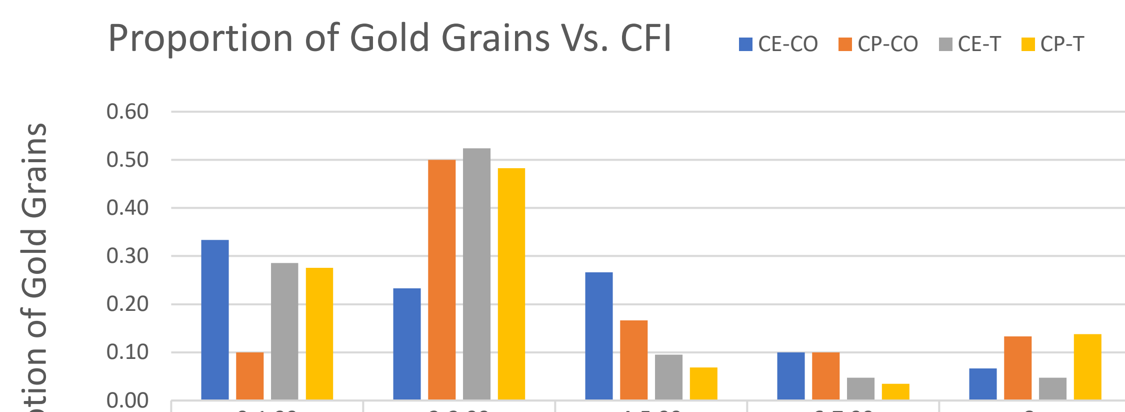


Figure 12: The Zingg plot shows how the majority of grains measured are described as being "discoid" shaped region while more of the tailings are spherical. Cruz Pata concentrates were the most common grains to show blade-like morphology.

$$Cailleux\ Flatness\ Index = CFI = \frac{L + W}{2 * T}$$

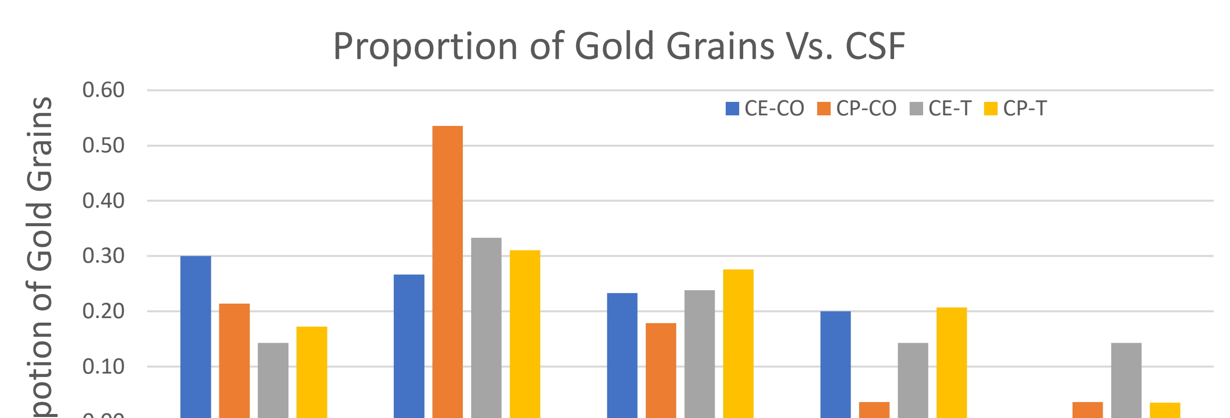


	0-1.99	2-3.99	4-5.99	6-7.99	8+
CE-CO	0.33	0.23	0.27	0.10	0.07
CP-CO	0.10	0.50	0.17	0.10	0.13
CE-T	0.29	0.52	0.10	0.05	0.05
CP-T	0.28	0.48	0.07	0.03	0.14

Cailleux Flatness Index (CFI)

Figure 13: CFI is a standard measure of flatness, and the comparison of the ore types indicate that CECOMIP concentrates (CE-CO) are the least flat and Cruz Pata tailings (CP-T) has the greatest spread. Grains with a CFI between 2 and 4 are not being captured in CECOMIP's sluices.

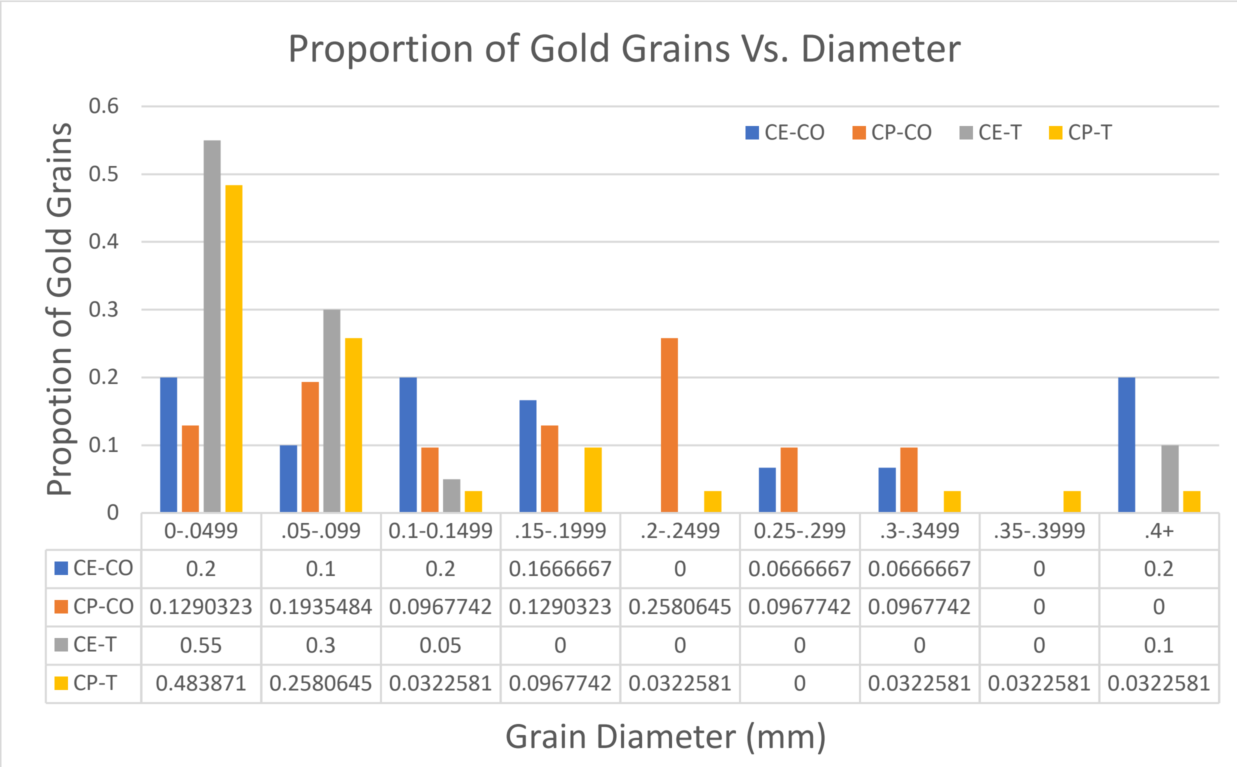
$$Corey\ Shape\ Factor = CSF = \frac{T}{(L * W)^{.5}}$$



	0-.199	.2-.399	.4-.599	.6-.799	.8+
CE-CO	0.30	0.27	0.23	0.20	0.00
CP-CO	0.21	0.54	0.18	0.04	0.04
CE-T	0.14	0.33	0.24	0.14	0.14
CP-T	0.17	0.31	0.28	0.21	0.03

Corey Shape Factor (CSF)

Figure 14: Corey shape factor is used in sedimentology to define the sphericity of a grain. A high CSF is related to a spherical grain. A low CSF is indicative of a flat grain. CECOMIP concentrates include the greatest variety of grains by this classification while Cruz Pata Concentrates select for thin, blade-like grains of gold.



	0-.0499	.05-.099	0.1-0.1499	.15-.1999	.2-.2499	0.25-.299	.3-.3499	.35-.3999	.4+
CE-CO	0.2	0.1	0.2	0.1666667	0	0.0666667	0.0666667	0	0.2
CP-CO	0.1290323	0.1935484	0.0967742	0.1290323	0.2580645	0.0967742	0.0967742	0	0
CE-T	0.55	0.3	0.05	0	0	0	0	0	0.1
CP-T	0.483871	0.2580645	0.0322581	0.0967742	0.0322581	0	0.0322581	0.0322581	0.0322581

Figure 15: Most of the gold measured from samples of tailings is the smaller than the gold captured in the sluices. The sluices can capture a wide range of grain size.

Conclusions from the qualitative and quantitative assessment of the gold grains:

- Most grains were well hammered and elongated, clearly having undergone significant transport or physical interactions with other, less malleable rocks.
    - High presence of well-rounded rocks shows an energetic depositional environment (like an alluvial fan for example) where grains would be beaten by surrounding rocks.
- Tailings samples are more have grains which are round, impure, and have smaller diameters.
    - The tailings included many grains that were clearly a mixture of gold and other metals. This is speculated to be silver, mercury, or a form of telluride and should be verified with geochemical testing.
- Several grains in CECOMIP concentrates had a patina or rust on the outer surface.
    - This would make them potentially susceptible to not being recovered by mercury or gravimetric processes dependent upon the specific properties of the patina.

4.2 Gold Concentration Equipment and Methods

Section 4.2 summarizes the equipment tested during the pilot.

Please note that when interpreting the grain counts in this section, these include the grains present in the sample under analysis and is not volumetric or an indication of the grade of the material. Instead, it is used to understand the types and morphology of materials that are concentrated by the method.

GOLDROP is a reverse circulation elutriation system which works by injecting material into an upward flow of water where the more massive and dense material sinks and the lighter material is forced upwards by the upward flow of water. When new feed is added into the suspended materials, it causes an oscillation of the flow and the gold grains have a net downward travel path.

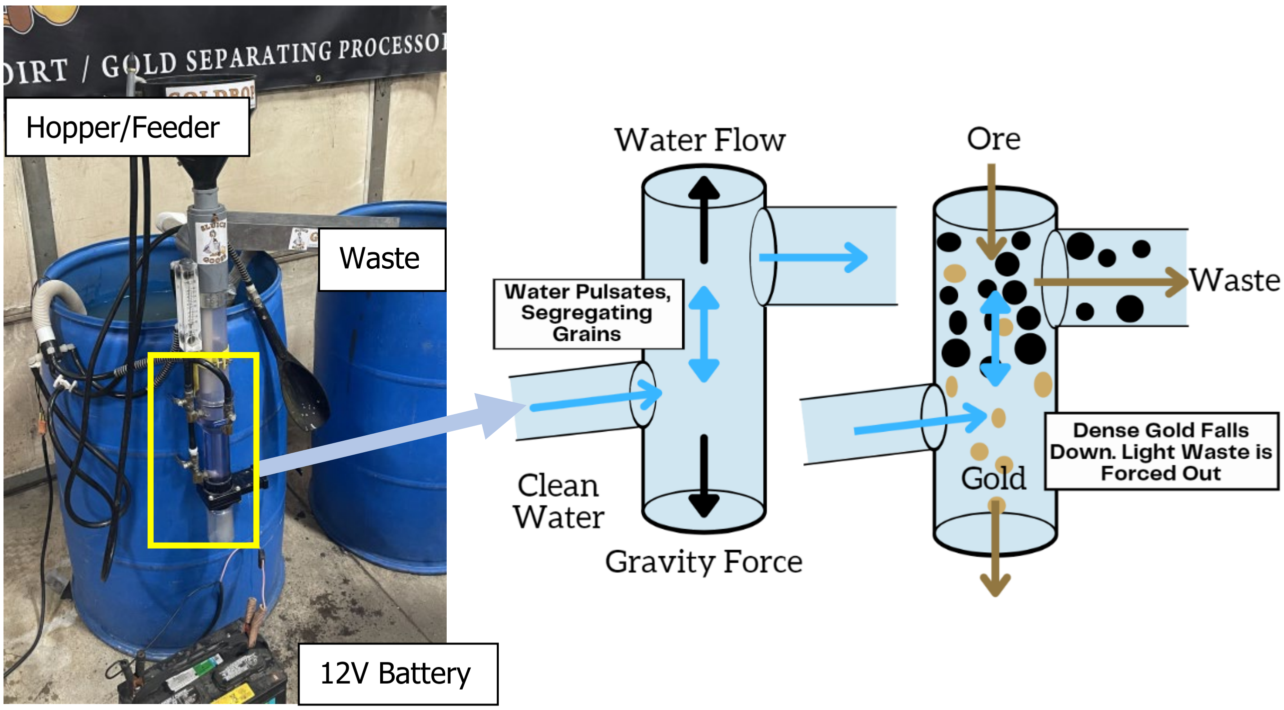


Figure 15: Image of the GOLDROP system with box and schematic diagram of the reverse elutriation processes used to recover and concentrate gold.

Parameter	Value
Required Infrastructure	Two 55 gallon drums (with water) 12 V battery charged with 100 W solar panel
Throughput	3 cf/hr (~240 kg/hr)
Screening Requirements	Yes. -1/8” required and then segregated to ±2 mm and ±.5 mm
Training/Optimization	“5 minutes to mastery” Optimization requires tweaking the rate of upwards flow based on visual analysis. After calibration the system does not need to be changed unless notable changes in ore character occurs.
Tailings	Tailings are kept within one of the two 55 gallon drums making the system closed.
Feed system	Vibratory trommel is hand fed and regulates the feed of material
Cleanup	Seal the jar at the base of the reverse elutriation tube and increase water flow to wash out material. ~2-3 minutes.
Maintenance	Minimal pump maintenance and manual adjustments of water flow

Component	Capital Cost (USD)
100 W solar panel	~150
Two 55 gallon drums (w/ water)	120
12 V battery	100

Goldclaw© Pan	60
GOLDROP Processor	2,000
Screening Equipment	~3,000
Spinitoff	20
TOTAL	**7,300**

CECOMIP Concentrates		
Mineral Component	Count	Proportion of Total
Metallics	245	.257
Quartz	140	.147
Other	9	.001
Gold	558	.586
TOTAL	**952**	
Cruz Pata Concentrates		
Mineral Component	Count	Proportion of Total
Metallics	104	.160
Quartz	53	.081
Other	3	.005
Gold	491	.754
TOTAL	**651**	
CECOMIP Tailings		
Mineral Component	Count	Proportion of Total
Metallics	563	.823
Quartz	66	.096
Other	17	.025
Gold	38	.056
TOTAL	**684**	
Cruz Pata Tailings		
Mineral Component	Count	Proportion of Total
Metallics	357	.769
Quartz	84	.181
Other	12	.026
Gold	11	.023
TOTAL	**464**	

Procedure Used: https://www.youtube.com/watch?v=h7zlnl-cuHI

1. The pump was started water flow tuned prior to adding any material.

2. The GOLDROP was set to .3 gallons/minute and mixing valve at halfway. The elutriation flow was set so the gangue material (quartz and matrix) suspended near the top which was determined optimal when .15 gallons per minute of vertical flow through the drop tube occurred.

3. A handheld trowel was used to feed the material and after all the material was processed the vertical flow was increased, removing gangue mineral, trap shut, and collected mineral removed. Tailings materials flowed through a magnetic sluice for further separation.

4. John Richmond (equipment manufacturer) used a Spinitoff and Goldclaw© pan to further reduce the concentrates. These were sent to MFM as concentrates and the other materials as waste. This final step is a source of error for isolating the effects of GOLDROP.

Analysis:

GOLDROP uses a unique system which may initially seem complex, but it produces a high grade concentrate suitable for smelting, which makes it particularly useful for situations when mercury is only used in the final step of doré production. The ability for one to visually see the gold in the tube as tuning occurs enables it to be used relatively easily and to be adjusted dynamically during operation with ease. Adding an automatic hopper with a three-system screen would enable the miners to continuously operate the machine with greater ease.

Cleangold is a sluice that uses a base of magnetite to replace the typical sluice mats. It is functional and easy to implement when magnetite is present within the ore. It is manually adjusted as needed, similar to a sluice. It consists of a "black sand mat" which is a large magnet where magnetite riffles create the turbulent flow needed for sluices to properly recover gold.

Parameter	Value
Infrastructure Requirements	An inclined surface with steady water flow. Pure magnetite (~$34/kg)
Throughput	Dependent of sluice size, water flow…
Screening Requirements	Yes. -3/16" (3.175 mm)
Training & optimization	Same as a sluice. Works best with standardized ore homogeneity.
Tailings	Sluice discharge (can be contained)
Maintenance	Minimal. No motors.

Component	Capital Cost (USD)
Cleangold sluice	TBD
Magnet for Removing Magnetite	20
Magnetite	~50 (~1 kg/ 60 kg tailings)
Screening Equipment	~1,000
TOTAL	**1070**

CECOMIP Tailings		
Mineral Component	Count	Proportion of Total
Metallics (magnetite)	425	.832
Quartz	84	.164
Other	0	0
Gold	2	.004
TOTAL	**511**	
Cruz Pata Tailings		
Mineral Component	Count	Proportion of Total
Metallics (magnetite)	478	.828
Quartz	98	.169
Other	0	0

Gold	1	.002
TOTAL	**577**	

Procedure Used:

1. Material was dry sieved and the material larger than 3/16” was bagged as waste.

2. The sluice was charged with magnetite on the black sand mat which magnetically holds the magnetite and creates the riffles for capturing gold. The magnetite used is pure magnetite imported and processed to minimize any potential contamination.

3. Steady water flow was used as ore was placed into the center of the head of the sluice.

4. The material moved through the sluice and gold collected in the irregularities of the surface.

5. Concentrated ore and magnetite were bagged and returned for analysis. If being used in an operation, the material would be further reduced by removing the magnetite with a magnet which is assumed to be a process with 100% gold recovery and further testing could verify the accuracy of the statement.

Analysis:

The benefit of Cleangold is, concentrates are easily transformed into smeltable material by removing the magnetite where, based on the observations of the concentrates (sans magnetite), it is nearly completely gold and quartz. Low proportions of matrix simplifies smelting. The gold identified in the analysis was small with representative diameters of .36 mm and .38 mm respectively. The gold was interpreted as being reshaped with a CFI of 1.3 and 1.5 and a CSF of .75 and .67. It was pitted like the Cruz Pata ores. This would indicate that Cleangold works well with fine grains of gold that are rounded although the very small sample size observed during the analysis would need to be supported by additional investigation.

Gold Cube is a stacked sluice which forces blade-like gold underwater and negates the issue of having these thin particles float on the surface of the water. The upper level is a “slick plate” where the material mixes with the water to form a semi-homogeneous slurry. This slurry moves through a “J” shaped separator that submerses particles while stratifying based on density. The material exits onto a matted sluice box where materials are trapped by specific weight. This is repeated.

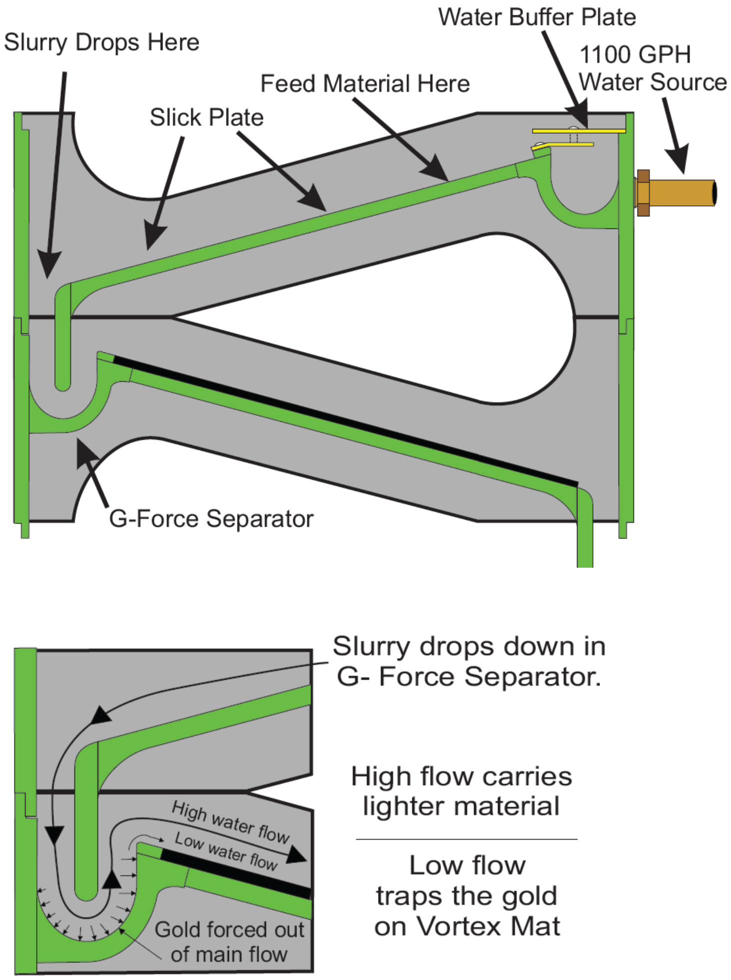


Figure 16: Schematic diagrams of the Gold Cube system courtesy of Mike Pung. The lower image shows the "J" shaped component that submerses all gold grains and minimizes the potential for gold grains to float on the surface of the slurry.

Parameter	Value
Infrastructure Needs	1100 gph sump pump Two 55 gallon drums (with water if self-circulating) 12 V battery charged with 100 W solar panel
Throughput	1000 lbs/hr; 2.5 kg/min
Screening Requirements	Yes. -1/8" required (3.175 mm)
Training/optimization	Flow is fixed and feed is self-regulated although a self-feeding trommel can be purchased.
Tailings	Can be contained in buckets.
Feed system	Hand feeding directly onto upper deck
Cleanup	Washing mats and panning the concentrates
Maintenance	Minimal. Sump pump is the only moving mechanical object.

Component	Capital Cost (USD)
100 W solar panel	~150
Two 55 gallon drums (w/ water)	120
12 V battery	100

Common Pan	~15
Screening Equipment	~1,000
4-stack Gold Cube	536
TOTAL	**$1921**

1. Ore was wet sieved to -1/8” and the +1/8” fraction was scanned with a metal detector to ensure there were not any nuggets and returned as waste

2. Ore was soaked in water before being discharged onto the upper plate. Soaking the ores reduces the possibility of hydrophobic effects impacting the blade-like gold grains by wetting the surfaces.

3. At a rate of 2.5 kg/min, the material was added onto the upper deck of Gold cube and flowed through the system

4. This was completed with all of the material for each of the ores while washing the equipment between tests.

5. Tailings were collected from the discharge of all 4 stacked trays when they exited the base of the Gold Cube.

6. Although the first mat produces higher grade material, all the material, from all 4 decks of the Gold Cube, was mixed and shipped back to understand the net effects as requested by the MFM team.

CECOMIP Tailings		
Mineral Component	Count	Proportion of Total
Metallics	30	.067
Quartz	225	.5
Other (matrix materials)	195	.43
Gold	1	.002
TOTAL	**551**	
Cruz Pata Tailings		
Mineral Component	Count	Proportion of Total
Metallics	55	.119
Quartz	341	.738
Other (matrix materials)	66	.143
Gold	1	.002
TOTAL	**443**	

Analysis: Gold Cube is an easy-to-use piece of equipment which is expected to be best for reprocessing tailings or similar low-grade material. Comparing Gold Cube with the sluices employed at each mine site, which utilize some of the same principles of ore concentration, reveals that Gold Cube is particularly selective at reducing the proportion of quartz within the sample and/or is selectively retaining matrix based on the grain counts.

The gold grains observed were well rounded, bright, well-hammered with representative diameters of .074 and .092 with CFI of 1.25 and 2.5, CSF of .4 and .75. Altogether meaning that the grains observed were more spherical and larger than the other methods.

It should be noted that during the testing, the MFM team did not request that the manufacturer, separate the highest-grade material from the top mat from the lower decks and instead requested that it was mixed. In personal communication, the manufacturer has noted how in future testing that the MFM team should consider this as most of the gold is concentrated in the first mat at a much higher grade than that which was reported.

Flinder's Process: Fundamentally, this a process of leaching the ores and then capturing the gold using a sulfur-based adsorbent. It requires regulating a leaching solution and filtration before adsorbing the gold onto the sulfur substrate. It is the only chemical method tested during the pilot. It is currently within a beta-phase where information about the technology is not publicly available.

Parameter	Value
Infrastructure Needs	A building where the leaching and extraction can occur large scale paddle mixer, filtration system, a furnace to burn the substrate and recover the gold.
Throughput	Dependent on implementation. Limited by filtration equipment and containers to leach ores.
Screening Requirements	None
Training/optimization	General optimization can be pre-determined if materials are relatively homogeneous like with this pilot.
Tailings	Lixiviant solution needs to be retained and properly disposed
Feed system	Batch-feed
Cleanup	Filter material, add substrate, and then burn a substrate to release gold
Maintenance	Maintaining the equipment/buckets for leaching and the vacuum filter which is susceptible to breaking, particularly at low air density, like in the high Andes.

Component	Cost (USD)
Filtration System	3,000
Sulfur Based Substrate	TBA
Standing Mixer	1,000
TCAA and Catalyst for Leaching	TBA
TOTAL	

Procedure:

1. Ore and water is mixed in a high-speed standing mixer in a 2:1 ore:water ratio to create a homogenous slurry.

2. During mixing, the leaching reagents are added. This includes TCAA (trichloroisocyanuric acid) which is not hazardous when diluted and a catalyst. This should be done in a well-ventilated area.

3. Material rests for 24 hours during leaching. The catalyst is added twice during the leaching period, once every 12 hours.

4. Filtration occurs using a vacuum filter. This takes 8-12 hours to sufficiently dry the materials and release the leaching liquor.

5. Leach liquor and substrate are combined. Gold adheres to the substrate which is then removed.

6. Substrate is burnt, and the gold remains.

Analysis: The leaching process is inherently risky because it removes some of the control over where gold is and how it is secured. With the other processes tested, all gravimetric, the gold remains in one form and can be influenced by people relatively easily. With leaching, this is not the case.

ICON Centrifuge: The ICON Centrifuge uses centripetal forces to concentrate gold ores. Feed enters the bottom of a riffled rotating bin. The heaviest materials are pushed towards the outer rim of the spinning bin by the rotation. The heaviest materials are then captured in the riffles on the wall of the bin and the lighter material "climbs" out of the top of the bin.

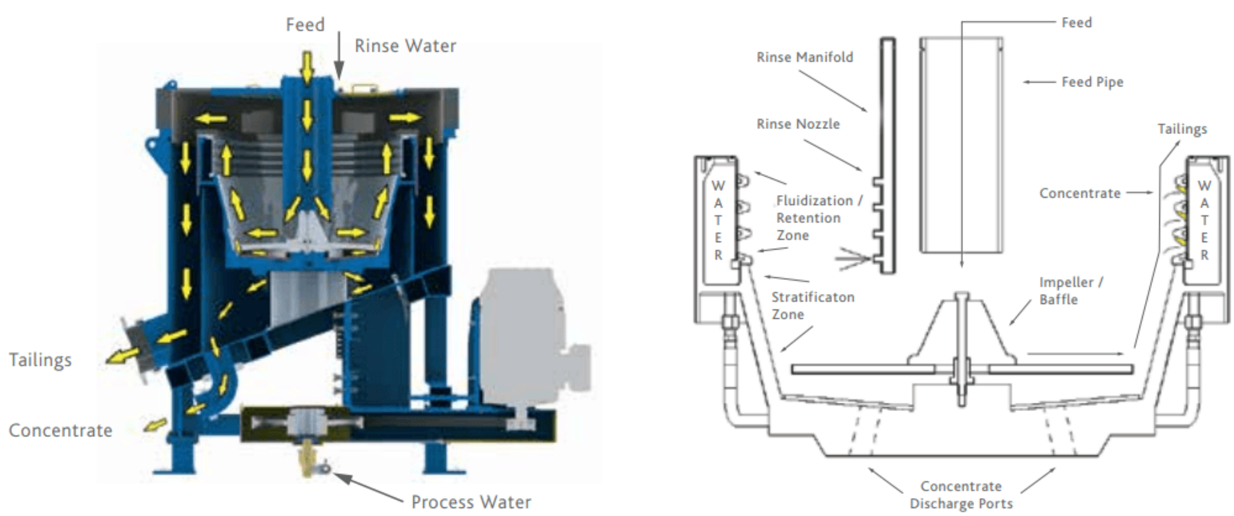


Figure 17: Diagrams of the ICON centrifuge showing the dispersion of material and the basic physical concepts. Diagram on the left shows the flow of feed material during operation and the diagram on the right shows the various components of the ICON centrifuge. Image courtesy of 911metallurgist.com.

Parameter	Value
Infrastructure Needs	Concrete pad, continuous water source, process manager, 220 V (i150) or 208-230 3 phase (i350)
Throughput	I150: 2 tons/hr (max); i350: 10 tons/hr (efficient)
Screening Requirements	Yes. -2 mm required for i150 and -2.5 mm for i350
Training/optimization	Ore flow and water flow is relatively fixed but can be tweaked for optimization. For the ores under analysis, it is unlikely there is significant need to continuously adjust.

Tailings	Slurry which can be contained. No chemicals are added.
Feed system	Hopper
Cleanup	Batch-based cleanup of ores occurring after rinsing the internal area of the centrifuge
Maintenance	Local supplier can aid. Motor is a potential source of issue, and the machine would need regular greasing, tightening, and general maintenance.

Component	Cost (USD)
Centrifuge	~1500 (i150)
Screening System	~12,000 (±5,000)
220 V step-up	650
TOTAL	**14,500**

CECOMIP Concentrates ***MATERIALS HAVE NOT BEEN RETURNED FOR ANALYSIS YET***		
Mineral Component	Count	Proportion of Total
Metallics		
Quartz		
Other		
Gold		
TOTAL		
Cruz Pata Concentrates		
Mineral Component	Count	Proportion of Total
Metallics		
Quartz		
Other		
Gold		
TOTAL		
CECOMIP Tailings		
Mineral Component	Count	Proportion of Total
Metallics		
Quartz		
Other		
Gold		
TOTAL		
Cruz Pata Tailings		
Mineral Component	Count	Proportion of Total
Metallics		
Quartz		
Other		
Gold		
TOTAL		

Procedure:

1. Ore is wet classified to -2 mm

2. The ICON centrifuge is turned on and water pumps initiated. Flow is adjusted so that an even layer of water flows up the edges of the bin and into the tailings refuge.

3. Ore is placed into the hopper and fed into the centrifuge where it enters the base of the spinning bin and the least dense material is screened to the top as the materials move up and out of the rotating bin.

4. After all the material has been processed, the concentrates are removed using a rinse of water (~60-90 seconds for cleanup). This material can be panned further.

5. This process is repeated in batches until all the material has been processed.

4.3 Assays, Recovery, and Concentration Factor

All assays were conducted through American Laboratory Services (ALS). Samples were split into 30-gram representative samples by Caelen Burand and submitted for analysis. 3 samples were submitted for each of the materials. The following page shows the recovery and concentration ratios for the data currently available.

Material	Assay (PPM)
CECOMIP Concentrates	**1501.67**
CECOMIP Tailings	**1.370**
Cruz Pata Concentrates	**1247.33**
Cruz Pata Tailings	**1.567**

Figure 18: The table above shows the grades of the materials as received from each of the mines. The lack of information regarding CECOMIP Tailings is the reason for the unknown recoveries in the following tables.

The table above shows the grades of the materials as received from each of the mines. The importance of this is that the sluices used by CECOMIP and Cruz Pata are effective at concentrating the gold and with proportional quantities of ore to waste recovery and concentration ratio could be calculated. **Please note that the tailings contain the gold that is the most difficult to capture and has already been discarded by multiple sluices. Hence, any recovery of this gold should be noted as admirable given the difficulty of capturing these generally small and impure grains.**

Concentrated Ores				
Processor	Goldrop		Flinder's Method	
Mine	CECOMIP	Cruz Pata	CECOMIP	Cruz Pata
Recovery	90.8%	69.3%		
Concentration Ratio	405.9	474.4	N/A	N/A
Grade of Products	60.9% Au	66% Au	95%+	95%+

Tailings						
Processor	Goldrop		Cleangold		Gold Cube	
Mine	CECOMIP	Cruz Pata	CECOMIP	Cruz Pata	CECOMIP	Cruz Pata
Recovery	87.8%	43.9%	38.8.%	33.9%	57.9%	46.9%

Concentration Ratio	24,088	24,990	26.1	35.1	10.22	6.26
Grade of Products	3.3% Au	3.9% Au	35.75 (with magnetite)	55 PPM (with magnetite)	14 ppm	9.815 ppm

Flinder's Method	
CECOMIP	Cruz Pata
	91%
N/A	N/A

Figure 19: Tables showing the effective recovery and concentration ratios of each of the processes under evaluation. Please note that the black cells indicate that the samples have not been received for assaying or are in the process of being evaluated by ALS laboratories.

The tables include all of the processors being evaluated and include their respective recoveries and concentration ratios as defined below. These are considered to be the two most important key performance indicators (KPI's).

$$Recovery = R\% = 100 * \frac{Gold\ in\ Concentrates}{Gold\ in\ Original\ Ore}$$

$$Gold\ within\ Material = (Gold\ Assay/10^6) * (Mass\ of\ Dried\ Received\ Material)$$

Recovery (R%) is the percentage of gold that is recovered by a given process from the total amount of gold originally within the feed. It is usually negatively correlated with grade (proportion of the material which is gold by mass) (Veiga & Gunson, 2020).

An example calculation follows, if the concentrated ores have 1 kg of mass and an assay value of 1000 ppm then it is known there is 1 gram of gold in the concentrated ores. If an identical calculation shows the feed contains 2 grams of gold, then recovery is 50% or half of the gold was recovered by the mineral processing. This is verified through analyzing if the other gram of gold is within the waste. In practice, variance in assays and sampling can cause discrepancies and when the mass balance of total gold in concentrates and tailings exceeds 10% the feed. The materials were once again randomly sampled and re-assayed.

This does help reduce the potential error that occurs due to variance in sampling because, when testing multiple processors, it creates a series of equations all of which must be true, in this case, by conserving mass of contained gold. This was used during the pilot to improve the confidence of the results.

When the grade of the concentrated products was not determined by fire assay because the grade exceeded laboratory limits and the sample was too small to submit, it was determined via mass balance related to the difference in the amount of material received as concentrates and the amount of gold possible within the sample. For example, if it was possible to have 1 gram of gold in the feed, .5 was in the tailings (assayed and massed), and 2 grams of concentrates were received, then the nominal recovery is 50%, or .5 grams of gold. This is the maximum amount of gold and should be the amount of gold within the concentrates if the assays and masses are accurate. This figure can then be verified through identifying the type and net volume of materials in the concentrates to estimate purity. In this example it would mean that the concentrated materials would be 25% gold and contain a net of .5 grams of gold. This procedure was used when determining the recovery of GOLDROP.

$$Concentration\ Factor = \frac{Grade\ of\ Concentrates}{Grade\ of\ Feed}$$

Concentration factor is the multiple of how much more enriched the concentrates are than the raw feed and is an indication of a process's influence on the feed material. A higher concentration factor corresponds to a greater intensification of grade and a concentration factor of less than one indicates the material becomes diluted. Flinder's process has an N/A for concentration factor because their product has a purity near 100% gold. This would mean that concentration factor is an outrageously large number and no longer retains its value as a comparative indicator.

5. Discussion

5.1 Review of Processors

From the results and the continuous trend of CECOMIP ores having a higher recovery rate than the Cruz Pata ores, it is clear that these ores are more amenable to gravimetric processing and gold recovery. This is thought to explain the difference between the respective recoveries which is seen throughout each of the results and is implicit in the discussion below.

ICON Centrifuge

The ICON centrifuge is the highest capital equipment tested during the pilot. Assays will reveal if this equipment is suitable for the capital expenditure needed to implement. It is also the most mechanically complex of the proposed methods for concentrating ores which can be a barrier to implementation and sustained use. Gold grain and particle heterogeneity is not amenable to centrifuges which is unlikely to lead to this being the ideal equipment employed at either mine in the pilot program.

GOLDROP

GOLDROP excels with ores that are pre-concentrated and is a tool for taking concentrated ores to smeltable grades. The recovery of the tailings is a testament to the fact that it is not the best tool for bulk processing. That said, the Cruz Pata tailings are the least amenable to being recovered by GOLDROP of any of the ores tested. An interesting finding for GOLDROP is that the fine portions of waste received were at an equal grade as the original concentrated ores processed. These could be reprocessed by GOLDROP to increase the recovery.

The difference in recovery between Cruz Pata and CECOMIP concentrated ores are thought to arise because of a difference in the panning procedure. Analyzing the difference in heavy metals, noted in section 4, it is evident that more rigorous panning of Cruz Pata concentrates would decrease the number of small gold grains which substantially reduced recovery and corresponds to less heavy metals as observed. If implemented, it is recommended that panning does not occur to maximize recovery.

Flinder's Process

The process of leaching ores is robust and requires minimal dynamism during mineral processing but creates difficulties due to the long leaching time, use of chemicals, and reliance on chemical, not physical, processes. It is recommended that the miners consider leaching as it would likely increase their gold recovery, but it would also require substantial investment into developing the knowledge to successfully leach the ores. CECOMIP has the most to benefit from leaching because of their ores being more oxidized than Cruz Pata which is amenable to leaching (Udupa et al., 1990). The high recovery of the Cruz Pata tailings is a good indication that similar recoveries will be achieved in future tests.

Flinder's process is notable because the chemicals involved are not particularly harmful and can be purchased by either cooperative. Special training related to the production of the sulfur substrate would be necessary.

Gold Cube

The Gold Cube's grain analysis shows that it is selective against quartz which is notable because quartz will almost always be present when processing ores. Deploying the concept of submersion within alluvial deposits originating from granites and silica rich ore bodies where grains have had significant transport and reshaping is thought to be the situation when it operates at the highest efficiency. Furthermore, deploying the "J" shaped stratification, through consultation with the manufacturers could help the miners reduce the probability of blade-like gold floating. To date, it has the greatest recovery of the gold remnant within Cruz Pata tailings which indicates that it is a superb mineral processing unit but the relatively small concentration ratio does not indicate it is ideal for these operations.

It is advised that further investigation into the amount of gold captured on the upper levels of the system is conducted in order to know if the concentration ratio of these materials is significantly different than the bulk average.

Cleangold

Clearly, Cleangold has potential when magnetite is in the ores being processed. The low amount of gangue material and small particles captured would indicate that Cleangold would thrive in situations near the lode source with high amounts of ferrous material. For the application to these ores, the large, flat particles and low amounts of magnetite hinder the ability of Cleangold to be more effective than the processes currently used based on the results to date. The low amount of gangue material and ease of converting to what is believed to be a smeltable grade is notable and merits Cleangold consideration when the circumstances are amenable.

5.2 Sources of Error and Areas of Further Research

5.2.1 Sources of Error

1. Grain dimensions and count: As with any task done manually, there are errors. This should be taken into consideration when evaluating the results discussed in section 4 and most likely occurred when trying to characterize the smallest grains. Using automated SEM or digital analysis is recommended in future projects to eliminate potential error and increase the precision.

2. Assay variance and the "nugget effect": The ores evaluated are heterogeneous and gold is not dispersed evenly. While every precaution was taken to minimize potential sources of error in the sampling, the inherent stochastic nature of alluvial gold will inevitably influence results. In the future, having additional assays will improve confidence and accuracy. Budget constraints and the need to simultaneously focus resources on both the pilot and creating the system, meant that was not practical for this launch.

3. Sampling variance: Even though the miners followed the peer-reviewed sampling procedure in Appendix C there is the potential for sampling variance. There is random variation in geology that can influence results.

4. Gold grain size distribution: Sieve fire assay analysis could be used to understand the particle size distribution of the gold in better detail by providing exact masses to how much gold is within a given size range of particle. While the counting method used can be extrapolated by finding cumulative volume, this is not considered to be enough evidence to substantiate a claim related to the proportions of gold with diameters of a certain size.

5.2.2 Opportunities for Further Research

There are many revisions to the testing procedure and the system devised which are explained within Appendix D, but additional areas of research related to this pilot or future projects include:

1. Investigating the gold source: Using geochemical analyses accompanied by a more thorough provenance analysis could reveal if there is more than one source of gold in the region. This was not particularly helpful for this pilot given that the focus was on ore processing and the ores were similar, but it could provide the miners with additional information that could improve their ability to efficiently recover the gold and target areas for extraction.

2. Field mapping the deposits: Conducting a gridded sampling campaign and field mapping would enable the miners to understand if targeted excavation is possible and minimize land disturbance by determining if there are trends of higher-grade material.

3. Fine sediment analysis: While the texture test was used to find that most of the fine sediment is silt, using a laser-based sedimentation column to understand the exact dimensions of the particles could reveal the properties of this finest portion of sediment which influences the fluid mechanics of the slurries and settling rates of gold (Veiga & Gunson, 2020).

4. Gold partitioning: Understanding whether the gold grains adhere to the mud and dust on the larger rocks could reveal better ways of screening and washing the ore to increase recovery. This could be done by dry sieving the cobbles and rocks, washing it, and then assaying the fines which were washed from the surface.

5. KPI's of current operation: Because the Mercury Free Mining team did not travel to Peru to collect samples, important KPI's like recovery, throughput, angle of inclination, and more could not be collected from CECOMIP and Cruz Pata. As mentioned in Appendix D, future projects should have the MFM team conduct ore sampling to also collect these important parameters that can inform more robust and holistic recommendations.

6. Conclusion

A novel system for mercury abatement within artisanal and small-scale gold mining was created and then piloted with two alluvial mining cooperatives in the Ananea District of Peru. The pilot was supported by market-side actors interested in responsible and sustainable supply chains. Ores concentrated in sluices and sluice tailings were randomly sampled by the miners and workers at the Alliance for Responsible Mining. These were shipped to 5 different processors: GOLDROP, Gold Cube, Flinder's Process, Cleangold, and ICON Centrifuge. These processors followed a standardized procedure designed to isolate the impacts of their mineral processor on the materials. The products of this processing were then shipped to be analyzed by Mercury Free Mining and key performance indicators for each processor was determined. A discussion of the hypotheses is in section 6.1, key findings are shown in section 6.2 and recommendations in section 6.3.

6.1 Discussion of Hypotheses

H1: *If the information discovered can increase miners' certainty about the efficacy of a mineral processor which increases their income, then the miners will be open to adopting the mercury free technologies.*

Even though mercury alternatives have not yet been implemented, there are still interesting observations related to H1. The miners at CECOMIP Ltda and Cruz Pata Chaquiminas are interested in finding more effective processors shown by their partnership and engagement throughout the sampling and shipping processes. Personal correspondence supports this claim. H1 remains plausible until phase 3 is completed but likely.

H2: *A scalable and repeatable system can be developed which enables miners to increase their confidence in mercury-free technology through objective scientific research.*

H2 also remains plausible but likely. This pilot project inherently does not test the repeatability of the system but the ability to use the system to two mines (when originally designed for one mine and one processor prior to minor revisions) shows that it is scalable. The ability to enable miners to have reliable information regarding the mineral processors was confirmed through the pilot project.

H3: *With supply chain integration, the proposed system can be sustained and repeated with other mining operations across the globe.*

Because this is a pilot project, H3 is plausible but likely and further projects will confirm the repeatability. Market-side supporters of Mercury Free Mining indicates that there is public support for implementing the proposed system. Ideally, the implementation of phase 3 of the project will enable Mercury Free Mining to better connect market demands to the two partnering cooperatives to provide additional benefits to the communities. This would be the success criterion needed to confirm H3.

6.2 Key Observations of the Ore and Mining Operations

- Cruz Pata Chaquiminas and CECOMIP Ltda mine alluvial-glacial ores composed of metamorphic rocks, minor igneous intrusives, and glacial flour. Their ores do not differ significantly in composition or physical characteristics.
    - Ores were deposited in an energetic environment with high heterogeneity, likely an alluvial fan, fluvial system, or due to syntectonic processes. Periglacial erosion has also created significant proportions of fine silts.
    - The ores have very little sulfides, ferric minerals, or diverse silicates which means that the tailings are likely to be environmentally safe and inert.
    - Cruz Pata and CECOMIP ores do not differ by type although there is local belief that the two vary drastically. There is little evidence to support these claims and instead it is likely the difference in appearance is due to the oxidation of ferric minerals in the basin where CECOMIP resides.
- The gold grains are typically completely liberated from the matrix and come in a large size range. They are flat, well-hammered, and reworked.
    - Cruz Pata grains are often pitted and have greater irregularity on their edges perhaps due to a difference in composition or less transport.
    - CECOMIP grains have a smooth surface and rounded edges.
- The operations are successfully concentrating the purest and most blade-like gold grains through using traditional sluices which have a high concentration ratio
    - The tailings contain smaller grains at a lower purity. These are less likely to be captured because of their lower density and smaller mass.

- Mercury amalgamation will not be very effective for capturing this gold because mercury amalgamation works best with gold that is of high purity.

- To date, the most effective gravimetric processors for capturing gold of this type are:
    - GOLDROP for processing concentrated Cruz Pata ores to create a smeltable concentrate
    - Gold Cube when processing Cruz Pata tailings to increase the grade slightly

6.3 Recommendations

Increase Gold Recovery by Classifying Ores:

Adding an additional screen for the large cobble-sized rocks before the slurry enters the sluices would provide the miners with greater control of the turbulent flow created in the sluices. Creating a two-screen system (current grizzly screen and finer screen for cobbles) would not lower throughput while increasing recovery. Alternatively, a second sluice could be added, and gravity separation could be used as shown in the diagram below, providing the benefit of also being able to employ two different inclinations and flow rates for sluicing.

- Thoroughly washing the ores is critical during classifying. The large, reworked grains can easily adhere to large boulders removed by the grizzlys if not washed well and hence be disposed as waste.

Capture More Gold with Two Sluice Sections:

Creating two sections of sluice, one with the current slope for capturing the purest and largest gold grains and a second sluice, at a lower slope, for the lower purity and smaller gold grains would increase the net recovery.

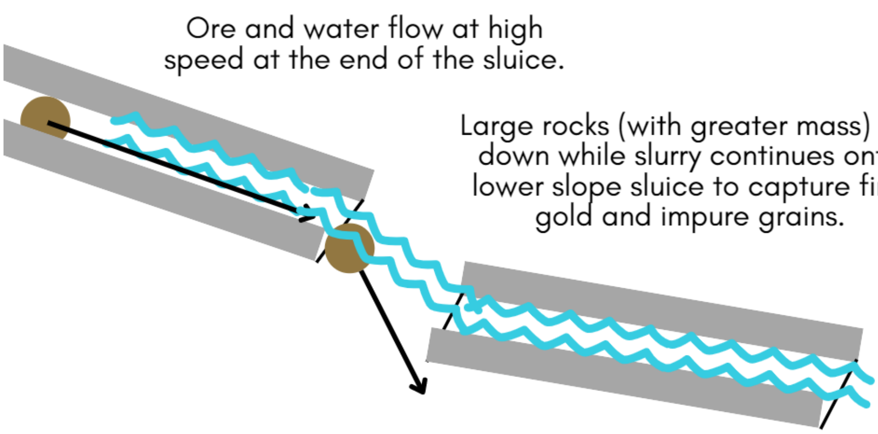


Figure 18: Potential method for further classifying the ores while also employing the two-sluice concept. The large cobbles have a larger mass which will mean that they will accelerate downwards faster and carried over the gap. The slurry (of lower density) will not accelerate downwards as fast and hence travel further horizontally, landing on the second sluice. This is recommended for further study and investigation.

Supplant Mercury with an Alternative:

This research shows that Cruz Pata can recover nearly 70% of gold from their concentrates utilizing a gravimetric process, like GOLDROP. This, coupled with the borax smelting procedure already in use at CECOMIP, would likely increase the amount of gold recovered given that mercury recovers less than half of the gold, on average, and processes ore at a rate of 240 kg/hr. This would increase gold recovery (profit), lower OPEX, and minimize health and safety risks. That said, it is recommended that more results are received before the implementation of any piece of equipment for maximizing the potential recovery.

Consider Leaching Ores to Increase Efficiency:

The general nature of the ores (particularly the more oxidized ores at CECOMIP) are theoretically amenable to leaching. Forthcoming evidence from the Flinder's Process will confirm viability of the process and whether it is worth considering if the more complex process is something that would be able to be completed at CECOMIP.

Add a Submersion Method in the Sluices:

It is well known that gold's hydrophobicity can cause it to float on the surface of water and that this is particularly likely with blade-like grains. Both operations should consider employing a concentration tool such as the submersion method used in Gold Cube to increase recovery.

Add the Upper Deck of Gold Cube on the End of the Sluices:

Adding a "slick plate" also known as the first mat of the Gold Cube could be an easy and cheap method for increasing the recovery of both of the mining operations. The capital cost of this is very small (less than $100USD) but would have immediate returns on investment. Furthermore, this would also improve the quality of the effluent because it would help capture mercury within the tailings.

CECOMIP Should Process Tailings with GoldCube:

The capital investment in Gold Cube is small (~US$1000) and at the recovery rate of 58% CECOMIP would need to process 21 tonnes of ore to recuperate the capital expenses. This does not factor in the operating costs which are assumed to be sunk costs because there is almost no maintenance and the cost for having miners clean the sluice mats has already been committed.

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Appendix:

A. Sampling Procedures

Below are the sampling procedures, unaltered from the pilot. This is followed by some photos from Fidel Cabana's report showing how each step occurred during the sampling process. The exact addresses used during the shipping of materials was omitted to ensure privacy.

On-site sampling instructions for miners:

NOTE: At MFM, our purpose is to support your commitment to ease, safety and profitability in your mining and we will help you in any way we can. Feel free to offer suggestions on ways we could improve our sampling and testing protocols and processes.

I.) Select material:

1.) Complete. Describe, in as much detail as possible, your sequential steps of gold ore processing and, if known, the amount processed per hour, the size of the ore particle (mesh), ore laws, and processing challenges you encounter. MFM would like to know which processing steps you would like to improve and be more efficient. MFM will try to find ways to improve these steps to maximize your profits.

2.) Based on your feedback, MFM will suggest material that we think may be better to test (concentrated ore and waste material). MFM intends to use the tests to understand if there is a more cost-effective method for processing the material that will allow you to earn more gold. MFM will determine the total amount of material and the number of sample collections needed to be accurate (17 kg of concentrates and 77 kg of tailings to be collected through 5 samples). Material samples that are consistent, ordinary, collected simultaneously, and average will make our tests as accurate as possible.

3. After discussing potential samples and before collection, miners and MFM representatives will discuss the potential value of the samples. Arrangements will be made to reimburse miners based on the value of the ore. This will be done through the use of legally binding electronic documents and shared with a third party, such as ARM, for ratification. Additionally, a legal representative of the mine will document the ore's origin and authorizes the samples to be exported for analysis.

a. MFM will be responsible for shipping costs and sample value after evaluating material quality.

II.) Sampling:

1.) Guidelines for all sample collection:

a. Samples must be collected at several different times (please collect 5 samples of approximately 3 kg of concentrates and approximately 15 kg of tailings) before sending all material to MFM or designated processors as agreed. We recommend taking small samples, at most, daily until the amount of material requested has been collected (a total of 17 kg of concentrates and 77 kg of tailings). These samples should be taken when conditions and the ore is most normal. Samples should not be taken when unique or special ore is being processed and occur at similar times to capture samples of the same feed in sequential steps, when possible.

b. At a minimum, three samples must be collected, and all collected material must be sent to MFM or the agreed processors for analysis. Each collection should be as consistent as possible with previous and future sample collections.

c. If possible, descriptions and photographs or videos of the sampling process that precedes the final packing of samples for submission are requested.

3.) Before sampling, label durable and appropriate containers to contain all samples from a source. One container should be created for concentrated ore and another for tailings.

4.) Create a plan about who will collect the material and identify where and when it will occur. Communicate this to MFM.

5.) When taking samples, it is essential to correctly label the material, be as consistent as possible with the amount of material being collected and the actions used when collecting a sample. Please record the sample name, collection site, date, weight, and origin of the ore.

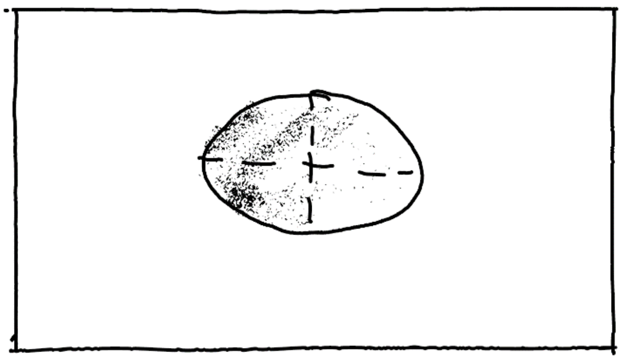
a. Potential "spoons" that would be good to collect include shovels, paddles, buckets, bags, or anything that allows you to collect all the material from a step.

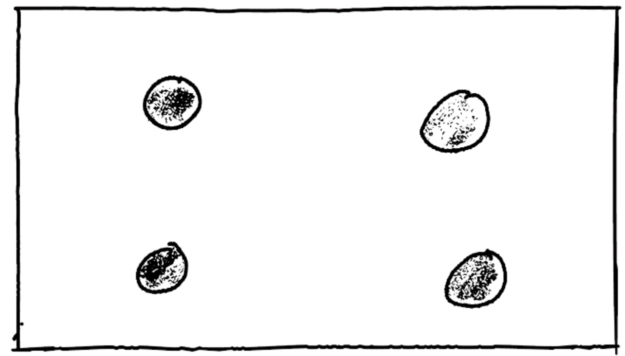
6.) MFM suggests using the following procedure to take any sample:

a. Collect a lot of material. More than will finally be placed into the container.

b. On a canvas, fabric, or table, place the collected material in a stack. Find a material that does not allow the material to mix with other dirt or rocks.

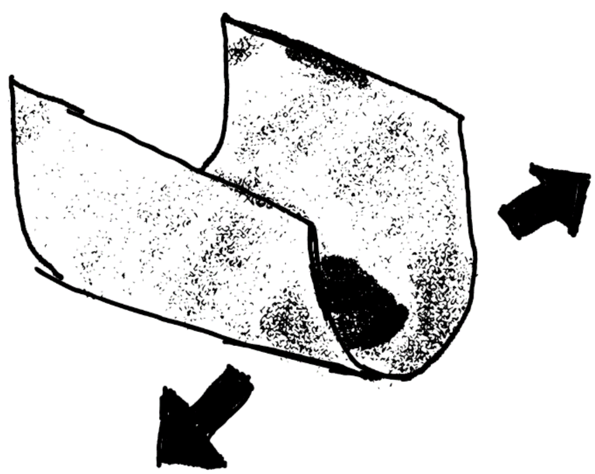
c. Divide the material into four parts as shown below.

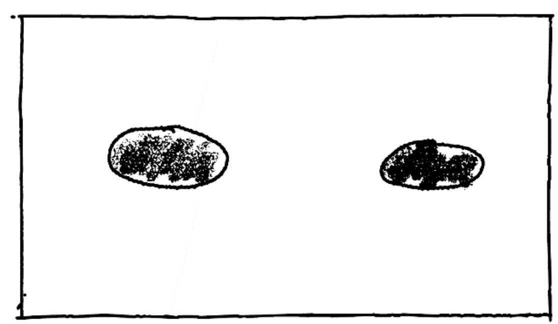




d. Mix each of these four parts separately and completely.

e. Create two larger stacks of material by combining two of the four smaller stacks. Then mix well (if you use a tarp, canvas, or cloth, this can be done by lifting two ends of the



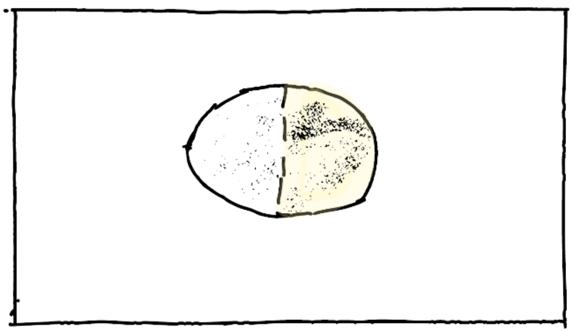


canvas and moving it from side to side or letting the material move, as shown)

f. Create a large final stack by combining these two halves. Mix well. (If you use a canvas/fabric, this can be done by lifting the four corners up and mixing the sample).

g. Select the desired quantity of this final stack to be collected and placed in the designated container for the sampled type of material. Return the other material to its place of origin. In the following image, this is represented by selecting the right half of this final stack, as highlighted.

H. This mixture should be made each time material is collected.



7.) After completing all the above steps and preparing the necessary equipment to take samples, it is time to start collecting material.

8.) To collect moving material:

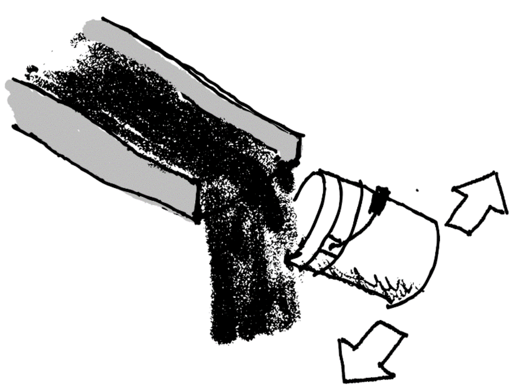
To. Hold a shovel near, but not within the moving material.

b. Move the spoon to the flowing material.

c. Move the spoon horizontally. Try capturing material from all areas of the flow, which are displayed with the arrows. Move the spoon left and right through the flow until the desired amount is collected.

d. Let the moving material fill the shovel. Avoid using up and down movements.

E. When moving the shovel, try to keep the movement even and smooth.



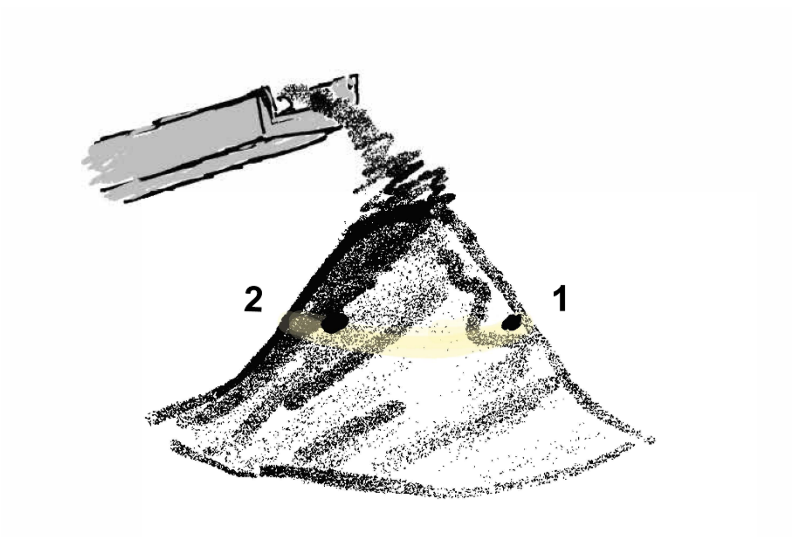
9.) To collect material from a pile that does not move.

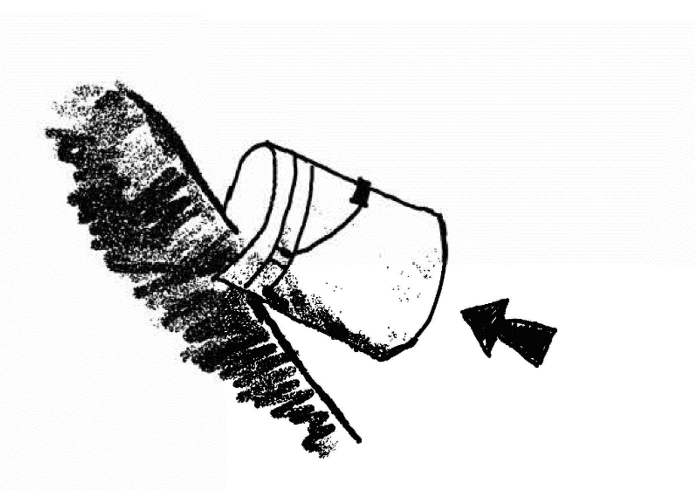
a. Find a safe place halfway to the top of the stack (at the base of the sluice for tailings). This is the best place to collect a sample. This is shown in the ring highlighted in the following image. We want the material not to be the large material that falls to the base of the stack or the small material at the top.

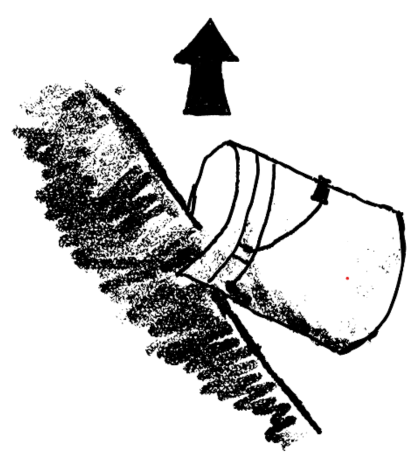
b. If material is continuously added to the stack and has not been degraded for extended periods, collect the sample by extracting the desired amount of material from the midpoint of the stack.

> i. If the material has degraded, remove the outer layer (about 10-20 centimeters) and remove the material deeper into the stack.

c. For each collection, try to sample different areas at the midpoint of the stack. This is shown below by collecting material in the band highlighted in points 1, 2, etc.







10.) After collecting and mixing the material, transfer it to the correct container designated to contain all such material. Samples should not be modified after picking them up. Be sure to place the sample in the correct container. After all the samples of each material are in the designated container, try to mix the material with a shovel or shaking vigorously.

11.) Separate the samples into the proper masses. Clearly label the materials before packing them safely for shipment. Please label samples with the sample name, collection site, date, weight, and origin of the ore.

12.) Send the collected samples to MFM or the designated processor. We will work to process the minerals and present our findings as quickly as possible. We hope our tests show that we can help you improve your profits.

Example: If MFM asks for 5 kg of raw feed, concentrates, and tailings to each be sent to processors "a", "b", and "c." After collecting many samples (15 kg) using the procedure above, all the collected raw feed would be mixed, and similarly the tailings and concentrates would be individually mixed within their designated container. Then 5 kg of raw feed would be collected, labelled, and prepared for shipment. A similar process would occur for 5 kg of concentrates, and 5 kg of tailings. These would all be shipped to processor "a." Then 5 kg of each material would be collected, labelled, and shipped to "b" and "c."

Sampling as Practiced in Pilot

Below are a series of photos which document how the sampling process, dictated above, was implemented within the pilot. While many photos only show one of the two partner operations, sampling occurred using the same procedures at both CECOMIP and Cruz Pata.

Phase I: The Alliance for Responsible Mining and Mercury Free Mining negotiated the payment of the samples and field reconnaissance identified the types of materials best for sampling. Payment was based on the amount of gold miners recovered by panning a sample of their concentrated ores. The miners gifted the project an unlimited quantity of tailings which are otherwise discarded as waste.

Phase II:

1. The photo shows miners sample tailings at CECOMIP Ltda. Fidel Cabana confirmed that the ore was average at the time of sampling meaning that it represented the general population of ore at the operation. To the best of our knowledge the miners were able to sample tailings at multiple times during the process to decrease the likelihood of sampling abnormal ore.

2. CECOMIP tailings from the various times of collection were decanted and then mixed on tarps. They dried on these tarps for several days before being quartered and shipped.

3. The photo shows Cruz Pata concentrates being quartered. The materials from the sluices were decanted, dried, and then placed onto a plastic sheet to be mixed and quartered. The remaining materials were panned for their gold content and Mercury Free Mining used this to dictate fair payment for the concentrated ores.


3. Samples were labelled and then transported to Lima to be shipped to each of the processors. Image on the left is Cruz Pata Chaquiminas and the right is CECOMIP. These were transported by Fidel Cabana.


B. Equipment Testing Procedures

1. All mineral processing equipment manufacturers first agree to a “mineral processing agreement” where they certified they would follow a common and standardized process along with provide basic information about the processor used.

Pre-Processing Agreement Form

Thank you for helping Mercury Free Mining identify effective mercury alternatives for artisanal and small-scale gold miners. We intend to objectively and scientifically verify your concentrator's effectiveness using a variety of gold ores and publish the results to facilitate demand for your product. In order for our testing to be legitimate we need you to follow the testing procedure as precisely as possible.

Please review and understand the preliminary questions and thoroughly read and understand the procedure BEFORE agreeing to follow it precisely. Any questions, concerns, or comments regarding the process can be directed to Toby Pomeroy, toby@mercuryfreemining.org, and Caelen Burand, caelen@mercuryfreemining.org of Mercury Free Mining.

* Required

1. Email *

2. Your Name and Processor Being Used *

Please indicate the following parameters regarding your concentrator

3. 1. Throughput (Ex: tons/hr, m^3/day, ft^3/hr, or other preferred units):

4. 2. Ideal feed size Ex: -50 mesh, 1-5 mm...

5. 3. Ideal feed type and grade range (if possible) Ex: concentrates (5-10 g/tons), tailings (1-3 g/tons)

6. 4. Operational Needs (water, electricity, infrastructure, training, etc.)

7. Other Relevant Factors Influencing Processors

8. Product Labelling: Please indicate what you intend to name the products of your processing. * Ex: "Sample/Trial 1 tailings"

Please Review and understand the following procedure. This is the procedure needed for our testing of your processor to be objective, accurate, and precise. Evidence of failure to follow the procedure will result in an inability for us to publish testing results and use your processor until legitimate testing has occurred.

9. Agreement Statement *
I have read and understand Mercury Free Mining's procedure for evaluating mercury-free processors and I will, to the best of my ability, follow this procedure. I understand that evidence of failure to follow the procedure will relinquish my ability to be a candidate for this project and Mercury Free Mining will be unable to use the results to stimulate demand for my product. Please respond "I agree" in the box below to certify the prior is correct and agreed to.

2. During processing, each equipment producer completed the following form. This is also the procedure that was referred to in the pre-processing agreement.

Processing Checklist

Thank you for helping Mercury Free Mining identify effective mercury alternatives for artisanal and small scale gold miners. We intend to objectively and scientifically verify your processor's effectiveness using a variety of ores and publish the results. This testing will help us understand how we can best implement your processor and eliminate mercury in gold mining! Although this form may seem to be a tedious process, it ensures we are conducting an accurate evaluation of key components of your mineral processing. The results of testing will be made available for you first and then to others second to encourage demand for your product.

* Required

1. Your Name and Processor Being Used *

2. Pre-Processing Checklist: *

Check all that apply.

- [ ] Durable bags for resulting material (waste and concentrates) have been prepared, completely labelled, and accessible (minimum 6 bags for three trials with waste and concentrates from each trial)
- [ ] The processor has been THOUROUGHLY cleaned and cleaning process documented
- [ ] Ore-Received and photographed upon reception

Processing Ore Samples

Please process the received ore using your preferred practices for maximizing efficiency.

3. Trial Separation

Please separate the received ore into three approximately even samples by weight. Each sample will be one trial. Label each trial with their respective number as previously indicated.

Check all that apply.

- [ ] I have completed the above statement.

Processing Checklist

4. Please Complete the Following and ONLY Check the Boxes Following Completion *

Check all that apply.

- [ ] 1.) Ore is separated into three trials.
- [ ] 2.) Processor is thoroughly cleaned PRIOR to testing
- [ ] 3.) The first sample of material has been processed.
- [ ] a. Photograph or video the processing showing the material feeding and gold concentration.
- [ ] 4.) Products of trial 1 placed into the pre-assigned bags (waste, concentrates)
- [ ] 5.) Processor has been lightly rinsed.
- [ ] 6.) Processed Trial #2. Products placed into separate pre-assigned bags
- [ ] 7.) Processor has been lightly cleaned
- [ ] 8.) Processed Trial #2. Products placed into separate pre-assigned bags

Shipping

Congratulations! You are almost complete with the testing process! We appreciate your diligence during this process and ensuring we are accurately evaluating your processor.

5. Please Complete the Following ONLY Checking the Boxes Following Completion *

Check all that apply.

- [ ] All samples have been sealed in their respective labelled bags.
- [ ] A photograph of all the samples has been taken.
- [ ] Materials have been packaged to ensure no leakage/mixing will occur during transport.
- [ ] Material has been shipped to Toby Pomeroy 4070 SW Fairhaven Dr Corvallis, OR USA 97333
- [ ] All photos, descriptions, and other information sent to Mercury Free Mining.

The only identified deviations from the above procedure was John Richmond's use of the Goldclaw pan.

C. Sample Drying and Mass Analysis

All samples, upon reception, were subjected to a mass balance to ensure that anomalous amounts of material did not disappear from any one sample. To understand the impact of water weight on each of the samples, the following procedure was used.

1. Upon reception, samples could be quite moist and were extensively dried in an open atmosphere (in the Tucson desert at over 100^{o}F) for many days before an ~100 gram random sample was taken.

2. This sample was spread onto a monolayer on a stainless steel baking tray and inserted into an open oven at 100^{o}C for 15 minutes.

3. The sample was once again massed and the change in weight was used to estimate the water content in the broader population.

4. The difference in mass was extrapolated to identify the total amount of mass in the samples which was only rock, not water.

D. Revising the system

The research objective is to create a novel catalog of mercury-free processors that have been tried and tested through this research. It will require several iterations of testing using similar methodologies to that which is dictated in the space below. The project will be complete when we are able to address the most common contexts of ASGM. Ideally, the ore types that are tested include, volcanic arc fluvial and lode, island arc alluvial and lode, disseminated/sulfide-rich, craton lode and alluvial, continental lode and alluvial, and eolian deposits. Infrastructure requirements that would be ideal include low water scenarios (like Sudan), ball mills vs. SAG or cone crushers, and high vs. low throughput.

The results of these experiments will need to be accompanied by extrapolation of data to “fill the gaps” for areas from which we are unable to gather data before deploying. At a minimum, 5 research programs should be conducted in order to have a skeleton-like understanding of the variety of potential situations encountered. At this point the MFM team can begin focusing more effort on advising based on the research and collecting information.

Below is a chart that shows the successes, failures, and recommended changes based on the lessons learned from the pilot program.

Phase	Successes	Failures	Recommendations/Improvements
Fundraising & Project Planning	- The pilot was funded by an engaged market-side stakeholder - It formally connected organizations across sectors and disciplines - Created large-scale commitment to the project of mercury elimination in ASGM - Developed a working relationship with two mining cooperatives	- Budgeting accuracy (net total is in check but allocation is not as stated) - Responsibility/project investigator delegation - **Inefficient negotiations/proposition process** - Unable to predict the ore types and associated processors - Uncertainty regarding the number of mines and scope of project	- See proposed methodology below for funding mechanisms. - Create the "project investigator" role -> this has been completed - Increase the interaction between the funder and the community -> pre-viability visits collecting specific information for research and story-telling -Experimenting with alternative funding models -> crowdfunding or shared funding (research is itemized and funded by individuals/groups) - Broaden search -> Ask on Facebook and within our networks for communities that are interested in participating and create a queue
Sampling, in-country transport, & shipping	- The sampling guidelines and resulting report of the sampling received only positive reviews -Samples were representative of the population, well labeled, and packaged well - Miners and MFM reached an agreement regarding payment	- **Shipping costs** and logistics - Entering the situation "blind" when receiving the ores - Customs and bank wire transfers caused delays and friction - Due diligence on local laws and regulations prevented Carlos Heneo from receiving ore samples	- Increase knowledge of samples, operations, and due diligence -> MFM representative (preferably PI) directly involved during this stage. They are responsible for producing and operations analysis, geological analysis, and understanding local laws/regulations for ore transport and shipping - Shipping costs & logistics-> Inquire with local ministry of mines about customs and potential legal issues. Use "known" shippers like Fedex or DHL exclusively.
Aligning Processors	- 5 of 6 processors received and processed ores - 4 of 6 completed the "pre-processing agreement" prior to receiving samples - Processors represent major "classes" of Hg-free gold concentration	- Unclear timelines for receiving & processing ore samples - Prior to processing, there was inadequate due diligence related to the processes being used and the various steps involved with each process - Continuous communications with the miners and our stakeholders	- Due diligence -> Conversing with each processor prior to the agreement to understand their processes and share this information with the miners. This can also be used to share findings from on-site analyses to help contextualize the scenario. - Timelines -> Centralization of the testing process will help us adhere to a project timeline developed during the fundraising phase

Processing Samples: Shipping, returning, and assaying	- 5 of 6 processed the ores according to the procedure - 2 videoed the process - Good communication prevented any large-scale mishaps from jeopardizing results	- **Labelling.** Processors found the initial labelling confusing and did not have a standard way of labelling return material. - Containers for the raw material and for the return materials varied and were inadequate. - Not having more information on the ores and operations prior to processing, which was a common request among the partnering processors	- Labelling/Packaging -> Create more clear labels that are printed and use both numbers and letters (ex: batch #1 – CE-T). Prepare the return packaging with the samples, pre-labelled. Inquire into the logistics of having return labels pre-printed for samples - Containers -> Understanding the ore character prior to reception will allow for better planning. - Experiment with in-country methods of analysis by using a community science model during further research endeavors
Results & Analysis	- There were not any large-scale mishaps jeopardizing results - Communication has been clear and disagreements in the data have yet to occur	- **Lack of communications with the miners and the public** detracted from the impact factor of the process - Time delays related to finding the laboratory equipment needed to complete analyses	- Communication -> Creating an updatable page on the website for current projects, integrating more social media posts, and sending monthly video updates to the miners explaining what has occurred. - Time delays -> Finding a partner laboratory whose facilities can be utilized for these projects regardless of time. This is bolstered by having staff more directly responsible for only research. -Helping with the sampling processes will help close the boundary between the miners and the analyses