Technical Report

Mercury-free techniques for the processing of gold ores in the Artisanal and Small-scale Gold Mining sector in Mauritania

This report and the study which it is based upon, has been produced with financial support of EPRM (70%) and Magma (30%, via Sahel Clean Gold). The Report represents an output for the EPRM Project led by Pact, titled the Business Pilot for Responsible ASM Gold in Mauritania. Findings of the study are intended for the benefit of Mauritanian stakeholders, particularly the Ministry of Mines, and Ministry of the Environment, in the hope that the study will assist the government with their evaluation and consideration of alternatives to the use of mercury for the extraction of gold. The report presents results from mineral processing study conducted by Pact and Magma, in partnership with ASGM stakeholders in Mauritania, during the period 2022-2023.

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Glossary of Abbreviations

EPRM	European Partnership for Responsible Minerals
ASGM	Artisanal and small-scale gold mining (sector)
HM	hammer mill
WOA	whole ore amalgamation
WPM	wet pan mill, also known as cone mill, or chilean mill
AAS	atomic absorption spectrometry

This is a technical report focusing on mineral processing, and the intent of this report is to present results of mineral processing test work undertaken by the project in Mauritania. The report does not rely heavily on literature review, references, or supporting literature. Footnotes are used to provide key references or definitions, where helpful.

1. Introduction

In Mauritania, ASGM activities account for a significant and growing portion of the country's gold production. Since 2021, the EPRM Project "Business Pilot for Responsible Mauritanian ASM Gold" has been working to demonstrate a business case for responsible artisanal and small-scale gold production and trade. Among other themes, the project has worked to introduce mercury-free mineral processing technologies in the Mauritanian context with the goal to reduce the harmful impacts of mercury. The use of mercury in the processing of gold represents a major environmental and human health risk as it can contaminate the air, water, and soil, as well as pose a serious threat to the health of miners and local communities.

The gold mining rush in Mauritania which began around 2015, and the methods employed by miners have been influenced to a large degree by influx of mining practices and processing methods from Sudan. It was the Sudanese who introduced wet-pan mills (WPM), aka cone mills, as the primary means for gold recovery from ore. In this method, mercury is added to each WPM while the ore rock is being crushed and milled. This process is referred to as whole-ore amalgamation (WOA) because all of the ore (the "whole ore") comes into contact with mercury. WOA is a widely known worst practice associated with gold mining, because it consumes and emits larger amounts of mercury than concentrate amalgamation, which only adds mercury AFTER a mineral concentrate is produced from the ore. The WOA method as used in Mauritania, Sudan, and in northern Mali consumes (and emits to the environment) approx. 5x's more mercury, compared to the concentrate amalgamation method, which is more common across other parts of West Africa.

In response to this important issue, and at the request of government counterparts in the EPRM Project (MAADEN and the Ministry of Environment), Pact and Magma focused EPRM project resources to support stakeholders in the development of mercury-free mineral processing technologies *adapted to the Mauritanian context.*

This technical report presents the outcomes of a mineral processing study - jointly funded by EPRM and Magma, with the aim to evaluate the effectiveness and feasibility of a mercury-free alternative method which uses existing mineral processing equipment in Mauritania that ASGM actors have invested in – in particular the wet pan mills, which are widespread in Mauritania.

Note: This is a technical report which assumes readers have comprehension of mineral processing systems for the recovery of gold. *Fundamentals* of mineral processing are not reviewed here, and definitions are not provided for common terms and principles (e.g. gold liberation, mineral concentration, gold assay by acid digest, etc.).

2. Objectives of the Mineral Processing Study

1. Design and determine feasibility of a *locally adapted* mineral processing system which does not use mercury, and which could realistically be implemented in the Mauritanian context.
2. Compare the mercury-free method, (i) against the standard mercury technique; and also against a "mercury-*reduced* method" that is the amalgamation of "mineral concentrate". Note that both of these "alternatives" would result in tailings that are not contaminated by mercury, which is an important priority since these tailings are subsequently treated using leaching techniques by "Category-F" companies, as authorized by MAADEN and the Ministry of Environment.
3. Conduct a feasibility study concerning the mercury-free method tested, on the basis of costs, technical requirements (i.e. process control, maintenance, etc.), and time, water, and energy requirements.

3. Methodology

3.1. Setting

Conducting reliable (repeatable, trustworthy) test work on mineral processing systems in ASM contexts is challenging for a variety of reasons including: (i) variability in ore streams, nugget affect in gold ores; (ii) mistrust between actors who "own" or control the ore; (iii) inability to control key variables of the testing environment (e.g. differences between mineral processing equipment in use; difficult or not possible to control or test for variables such as grind size, water pressure, flow rates, slurry density, etc.). To overcome these challenges, and building from Pact and Magma's experience, a mineral testing facility was constructed at Magma's laboratory facility in Nouakchott, where mineral processing circuits could be tested in a controlled environment. In addition to mineral test-work, Pact and Magma have used the facility to provide hands-on training for ASM miners and investors, as well as live demonstrations for decision-makers in the Mauritania administration, while fulfilling outcomes of the EPRM project design.

Figure 1. Magma's mineral testing facility in Nouakchott where mineral processing equipment has been setup with support of the EPRM project for mineral test work, and for training ASM miners. Note that no mercury is used here and the facility is designed and used as a testing facility only (non-production). At right, note the engineered water recycling system, which has demonstrated a simple solution for water re-use.

Figure 2. (left) The "wet-pan mill", also known as "cone mill" (abbreviated WPM, herein) is the most widespread gold recovery technology used in Mauritania. (right) At the Magma yard, the WPM has been outfit with a custom port which allows slurry to run directly from the WPM to mineral concentrators: which can be: the shaking table (as shown above); or into the iCon150 (centrifuge); or directly onto sluice boxes (a method which is commonly employed in Mongolia).

3.2.Study Design (Methodology)

3.2.1. Gravity Recoverable Gold (GRG) test

The first requirement of the mineral test work was to evaluate the viability of mechanical (gravimetric) methods for gold recovery from typical gold ores mined by artisanal miners in Mauritania: notably the quartzite ore. To accomplish this, gravity recoverable gold tests (GRG tests) were undertaken by the Magma team, with technical and scientific support of Professor Marcello Veiga of the University of British Columbia, Magma.

The GRG test is a standardized protocol utilized by mineral processing engineers for understanding the nature of « gravity recoverable » gold particles. The test consists of intermediate grinding to recover the gold, as it is liberated through successive grind sizes. The objectives for the GRG tests were to: (i) determine the effectiveness of mechanical (gravity) methods for gold recovery; and to (ii) determine optimal grind size for maximum gold recovery.

In 2022, Magma purchased a state-of-the-art lab-scale concentrator from Falcon Industries called the "Sepro L40" (lab-scale centrifuge) for the purpose of conducting GRG tests. The Sepro L40 takes advantage of variation in particle density to separate heavy (i.e. denser) particles from lighter (i.e. less dense) particles through centrifugal force. The team used the GRG test work to confirm *how much gold* could be recovered using gravity methods, and also *how fine* the ore should be milled to optimize gold recovery.

The L40 concentrator was used in combination with laboratory bench grinder, on a parent sample of 28 kg of quartzite ore from ASGM miners operating in Inchiri province. A standardized GRG test protocol was employed, using successive rounds of milling and concentration, as follows:

1. Sample of 28 kg of quartzite ore was purchased from ASGM miners in Chami. This ore had been crushed manually by miners to around <5 WPM;
2. The ore sample was milled at the Magma lab using grinder to 800 µms;
3. (Following GRG protocol) the 800 µm sample was then subjected to concentration using the L40 concentrator (slurry of 20-30% solids, fed to the Falcon L40 at approximately 3.2 L/min);
4. The L40 was carefully cleaned to recover mineral concentrate (70-100 grams). The concentrate was further panned (manually) to ~10 grams (separated into 2 parts). The parts were subjected to total gold determination by assay (acid digest, AAS);
5. Following this, the ***same parent material*** (i.e. tailings from the L40) were then dried and milled again to 200 µm. Following this, concentration and Au recovery steps were repeated.
6. Finally, the same material was milled again to 75 µm, followed by gold recovery once more.

The standard GRG protocol is shown in figure 3 bleow. Note that additional details are provided in the GRG test summary report, included as Annex 3.

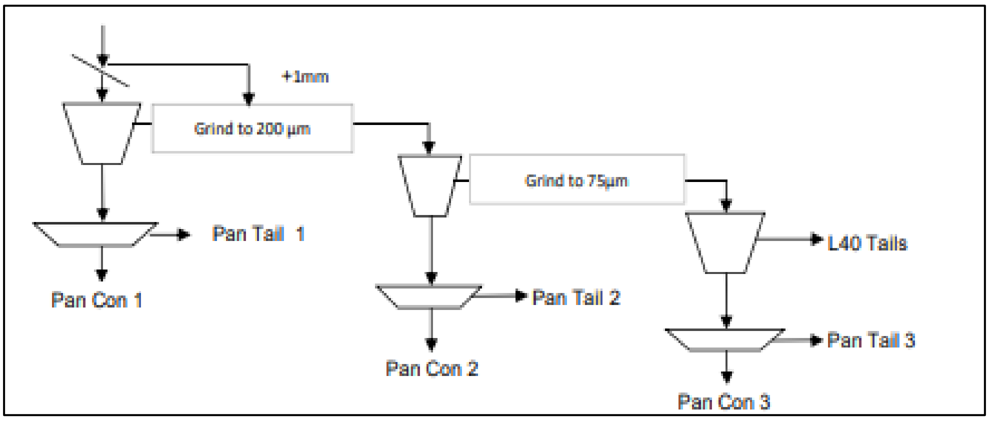


Figure 3. Gravity Recoverable Gold flowsheet (illustration of GRG test protocol)

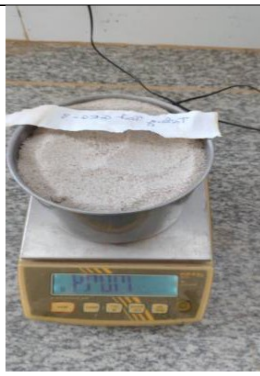
		
Sepro L40 concentrator installed at the Magma Laboratory. The L40 has a centrifugal force of up to 150g, and provdes an excellent method to test gravimetric gold recovery in a standardized (laboratory) setting and scale.	*Mineral concentrate is captured in grooves of the centrifuge bowl.*	*Above is a photo of the initial sample ground to 800 µms, before concentration.*

Figure 4. Photos from the GRG testing in Magma's lab, using the Falcon L40 centrifuge.

3.2.1. Mineral test for gold recovery

Following the lab-based GRG work, full-scale concentration and gold recovery tests were conducted by the team. One and a half tonnes (1,500 kg) of quartzite ore was purchased from miners in Inchiri province, near Chami. Three different mineral concentration techniques were evaluated by the team from low-cost low tech, to higher cost higher tech, as follows: (1) locally made sluice box using combination of miners moss and short hair carpet; (2) shaking table; (3) small-scale centrifuge (iCon).

During the study design phase, a decision was made to focus on the shaking table as the principal concentration technique for this study, due to factors which the team believes make the ST a good fit for artisanal mineral processing context, in Mauritania. These factors include the following: (i) easy for miners to see and understand what is happening on the shaking table (unlike the centrifuge); (ii) Shaking table could easily be adapted to government controlled mineral processing areas ("grillage"); and (iii) local manufacturing for the tables could quite easily be considered.

The shaking table used in the study (as seen in photos) was designed in the USA by Mount Baker Mining and Metals (MBMM). The size of the table is 1.5 m x 2.5 m, and it functions as a run-of-mill (ROM) processing table with capacity up to 1000 kg solids/hour (ideal slurry volume is 20-30% solids; slurry volume approx. 40-50 liters per minute). This differs from shaking tables which are designed to function exclusively as "clean-up" tables (e.g. of the "gemini" variety, which typically have lower capacity/through-put). As such this type of shaking table can be setup to receive material directly from milling equipment, if controls are in place to control the slurry flow. Slurry moves across the table and is separated into 4 ports: ports #1 and 2 are primary and secondary concentrates, while port #3 is "midlings" and port #4 is "tailings".

Importantly, the outcomes of this study are not limited to performance of the shaking table (method). Rather, a major focus (and contribution) of this study comes in the stage *after* mineral concentration: when the mineral concentrate (which can be developed via several different methods) is treated by "direct smelting" to recover the gold.

Full-scale concentration and gold recovery tests proceeded in 2 stages, as described here:

Stage 1: pre-milling and homogenizing the head ore, then separating into samples to prepare ore for running batch samples (sampling each of batches, tested for gold content by acid digest + AAS);

Stage 2: processing the batch samples through different processing "circuits for gold recovery", as described below. These stages are described in further detail, below.

Stage 1. Mill and homogenize the head ore, and test head ore for gold content (by laboratory).

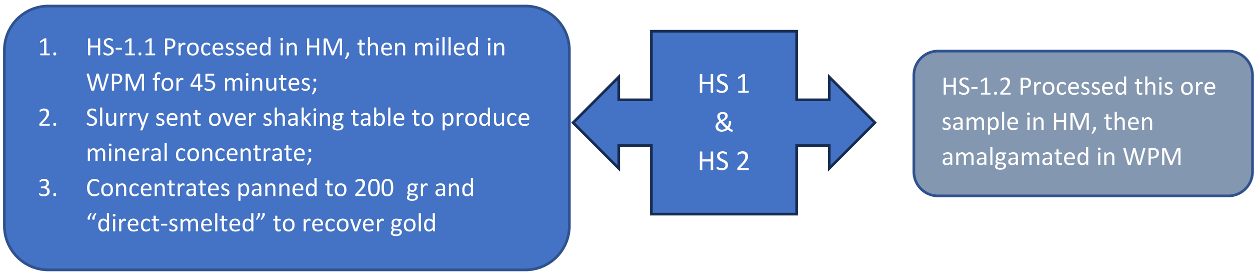
This was accomplished by:

1. Passing the ore (<10 WPM rock) through Jaw Crusher, reducing ore to <2.5 WPM;
2. Passing through Hammer Mill (screen size 1.2mm), reducing feed to < 1mm. Note that hammer milling was done "dry" so that milled material (ore sand) could easily be "split" afterwards. Dust protection was employed to prevent exposure to fine dust particles.
3. Milled ore (now reduced to sand) was thoroughly (dry) mixed, using spades, for period of 10 minutes, inside a cement basin. After mixing, compound sub-samples were collected and sent to the Amarpam laboratory for Au assay by AAS (in duplicate or triplicate).

Stage 2. Split the "head samples" into matching pairs (splits), and then process them through different processing "circuits" to allow for head-to-head comparison of the split samples.

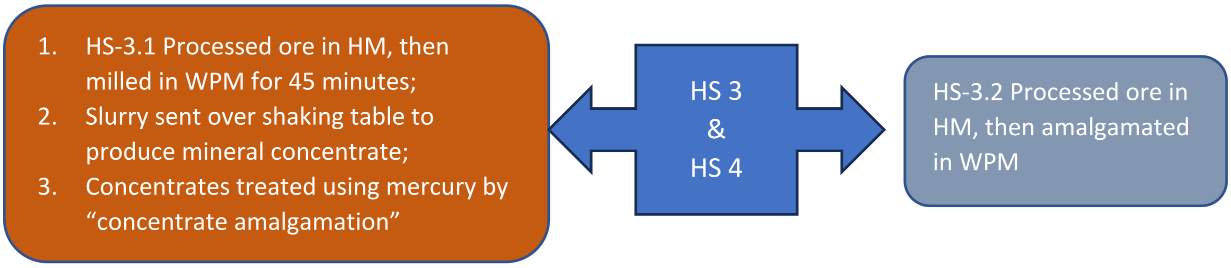
This was accomplished by:

- Head Sample #1 (HS-1) was "split" into 2 sub-samples: HS-1.1 & HS-1.2 (150 kg each)



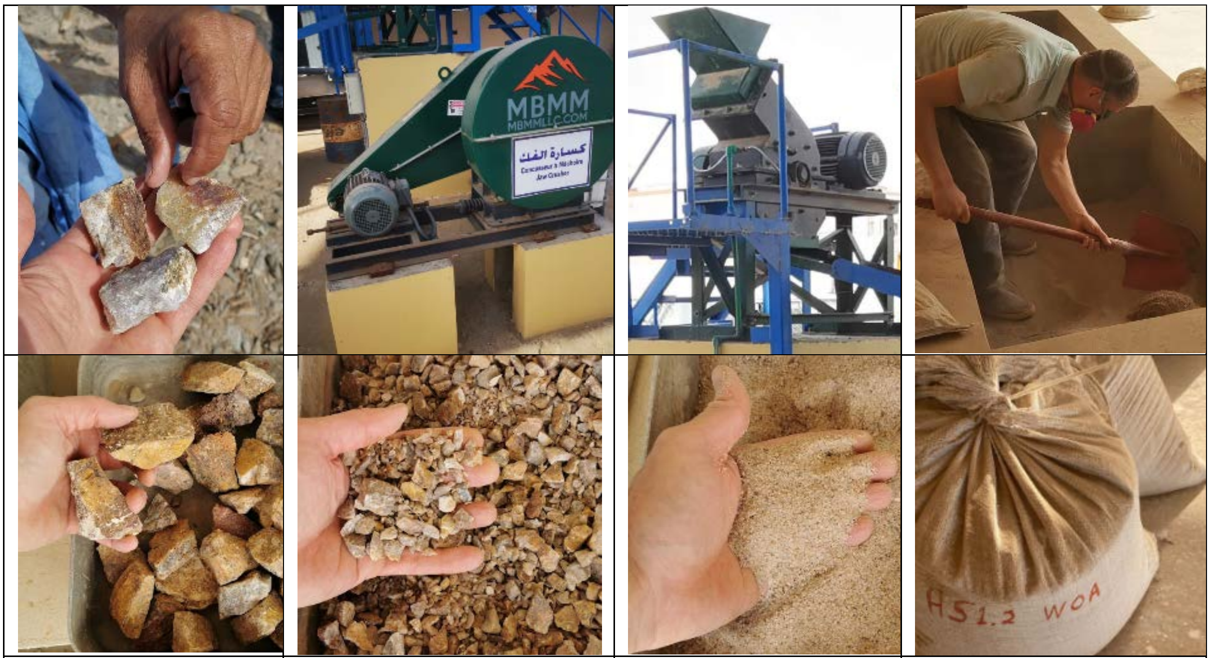
- Head Sample #2 (HS-2) is a duplicate of Head Sample 1. HS-2.1 & HS-2.2 (108 kg each). These samples were treated using the same protocol shown above for HS-1.

- Head Sample #3 (HS-3) was also "split" into 2: HS-3.1 & HS-3.2 (130 kg each)



- Head Sample #4 (HS-4) is a duplicate of Head Sample 3. HS-4.1 & HS-4.2 (147 kg each). These samples were treated using the same protocol shown for HS-3.

(In Photos) : Methods employed in Stage 1



(Start) Bagged ore from the gold mines is <10 WPM, on average.	*Ore passed through Jaw Crusher to reduce size to <2.5 WPM.*	*Ore is then passed through Hammer Mill (dry), to reduce to <1mm (sand).*	*Mix, then divide samples, sample for gold assay; then weigh, bag and label the samples.*

Figure 5. Methods employed in Stage 1

(In Photos) : Methods employed in Stage 2

*Test-work determined that after **45 minutes** in the WPM (with water), the sand-sized material from the HM is reduced to 80% passing 150 mesh (i.e. 80% is <100 µm). Most of the gravity recoverable gold has been liberated. The material is now ready for concentration stage.*	*Once the target grind is achieved, the port on the WPM is opened and slurry runs onto the ST. Mineral separation occurs on the ST: free gold can be seen separating in the furthest grooves, while grey-colored sulfides (containing gold) flow to port 3 as midlings; more than 70% of material passes to port 4 (tailings).*

Figure 6. Methods employed in Stage 2.

3.3. Direct Smelting (Methodology)

Production of "mercury-free" gold is only completed once the gold producer has a sellable gold product in-hand (ingot form, ready for sale). Readers should be aware that many products marketed as "mercury-free" are simply tools which help operators to produce mineral concentrates.

In order to extract gold from the mineral concentrate without the use of mercury, the mineral concentrate can be smelted at high temperature: a method which we refer to as ***direct smelting***. The specific direct smelting methods deployed in this study were pioneered by J. Gaber of MBMM[1], and the method is adaptable to ASGM regions around the globe. The method consists of 2 parts: (1) smelting of the mineral concentrate using a small gas-powered forge, which results in a metallic button containing the gold; and (2) cupellation of the metal button to purify the gold, using a small electric furnace and low-cost magnesia cupel. The method results in high purity (nearly 24K) gold bead or "prill", which can be readily sold by the mineral processor.

A small portable and durable gas-powered forge is used for smelting, with a large crucible (size 8, 9 or 10). 200-250 grams of mineral concentrate (containing gold) is smelted, along with several additional ingredients, which constitute the "flux". These are added to facilitate smelting. The following recipe was found to be effective for direct smelting tests undertaken on quartzite ore in Mauritania:

- 1 part mineral concentrate
- 2 parts borax (sodium tetraborate; helps dissolve oxides & impurities, produces liquid slag)
- 2 parts soda ash (sodium carbonate; basic ingredient in flux, helps ensure sulfides are reduced)
- 0.5 part silica sand (added to flux to ensure homogeneity and low viscosity of slag)
- A small amount of "collector metal" is also added, which helps to ensure that the gold will coalesce in the tip of the cone mold as a metal button (4-10 grams, bismuth or lead). Note that collector metal is not required if the concentrate contains a significant amount of gold (e.g. >5 grams).

Both lead as well as bismuth were tested as collector metals. Bismuth is preferred because it provides a non-toxic alternative to lead, however it is more expensive than lead. For reference 5 grams of lead (amount required for 1 smelt) has value of (approx. 12.5 cents euro, or 5 Ouguiya) while 5 grams of bismuth has value of (25 cents euro or 10 Ouguiya). Since bismuth is *not currently readily available* in Mauritanian, a local supply (solution) is warranted, in order for this method to be adopted and scaled in the country's ASGM sector. The tools used for direct smelting are shown below in Fig. 6.

		
Pictured above are the tools used for direct smelting. (A) small (lightweight, durable) forge, which is powered by torch, and lined with ceramic fabric; (B) butane gas with regulator, which powers the forge; (C) silica or graphite crucible; (D) tongs; (E) cone mold.	Lead and bismuth were both trialed as collector metals in the study.	A magnet is used to remove excess iron from the mineral concentrate. This helps ensure optimal gold recovery.

Figure 7. Direct Smelting methods (preparation)

[1] Jason Gaber from Mount Baker Mining and Metals (MBMM) supported the EPRM project as a consultant to Mauritania in Feb. 2023, assisting to optimize direct smelting techniques for the Mauritania context. Refer to MBMMLLC's YouTube channel for learning resources on this subject: https://www.youtube.com/@mbmmllc

The duration (time required) for direct smelting is dependent on the mass of concentrate that is being smelted, and the efficiency of the forge (including the burning temperature, insulation quality, and other factors). Using the method shown here, the average "smelt time" is 20-25 minutes, for a mineral concentrate sample of 200 grams (in this case the total charge will have mass around 1 kg). Smelt times are reduced when smelting a smaller mass of concentrate, or if starting from a pre-heated forge.

The charge is mixed in crucible, and placed into forge where it is subjected to temperatures over 1000 deg Celsius (melting temperature of gold is 1,064 deg C). An opening in the top of the small furnace enables the operator to look down and determine when the charge in the crucible is fully melted (liquid). At this point the gas supply is cut to power off the furnace, then the tongs are used to carefully remove the (very hot) crucible and pour the charge into a steel cone mold (min. 4 mm gage steel). While the charge remains liquid, the gold and other metal elements descend to the bottom of the cone. After 5 minutes the charge cools (forms solid), and a small amount of water is used to quench the mold. It is tipped over to recover the metal button, which contains the gold. Above the metal button, the hardened slag has the texture of glass. If there is a matte layer between the metal and the slag (glass layer), then it is likely that metals are being lost here, and the flux recipe should be adjusted to make it more basic (by adding more soda ash).

		
Setting the crucible into the gas powered forge. Note PPE usage.	Iron rebar is used to stir the charge to: ensure uniform melt and presence of iron to assist reduction of sulfides.	Once melted, the charge is poured into a steel cone mold, using tongs.

Figure 8. Direct Smelting Methods (smelting process)

		
After the charge cools in the mold, the melt is converted to "slag", with the metal button sinking to the bottom (the tip of the cone mold), due to greater density of metal.	The steel mold is overturned to remove the slag, and the metal button, which is removed using a hammer or set of pliers.	The metal button is primarily comprised of the collector metal, but now contains the gold as well, which can be separated by cupellation.

Figure 9. Direct Smelting Methods (end result)

3.4. Cupellation (Methodology)

Cupellation is an ancient technique used to purify precious metals by removing base metals, and this is done by taking advantage of base metals (e.g. lead, bismuth, iron, copper) propensity to form oxides when certain conditions are present (while precious metals gold and silver do not form oxides in the same conditions). The "cupel" is a small porous crucible made historically from bone ash, while most are now fabricated from magnesia. When the cupel reaches temperatures around 900 C, the base metals are absorbed into the cupel when oxides are formed with the magnesium, while the precious metals (gold and silver) remain.

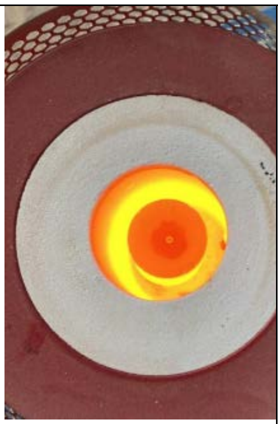
			
Small electric furnace (designed for jewelry workers) runs on 220V and is effective for cupellation.	Electric furnace at temp, during cupellation: base metals being absorbed into the cupel as oxides.	After, only precious metal (gold bead) remains; the discolored cupel is the lead or bismuth oxides, absorbed into cupel along with impurities such as copper.	Clean gold "prill" produced by cupellation, during the study (near to 24K).

Figure 10. Cupellation Methods

3.5. Mercury Amalgamation (Methodology)

As indicated in the study design section, split samples were bagged and labelled as duplicates, and transported for processing in Chami using mercury by whole ore amalgamation (WOA): the widely used technique in Mauritania. Ore samples were already milled into sand by the hammer mill, and weighed 100-150 kg, per sample. These samples were individually processed in the WPMs, each time with 300 grams of mercury added, for 4-5 hours of grinding, during which time amalgamation of the gold occurs. Afterwards, the WPM was drained, and the heavy sediments remaining in the mill were carefully collected using shovel and hand tools into a plastic tub. Using the amalgamation tub, per local tradition, an additional 300 grams mercury was then added, followed by mixing by hand, while rubbing and scraping the mineral concentrate and mercury with a smooth stone. After 5 minutes of this treatment, the material is panned to recover the mercury, which contains amalgamated gold. The mercury is then filtered through a cloth to separate the amalgam: a soft grey colored mixture of approx. 50% mercury and 50% gold. The residual liquid mercury which passes through the cloth is captured and will be re-used. The final step in the amalgamation process is the open burning of amalgam - which evaporates the mercury but leaves the gold behind.

			
Sample bags are loaded into WPM with 300 gr mercury and the wheels are turned steadily for 4 hours.	The pulverized ore containing mercury is carefully recovered from the WPM.	The “pregnant” Hg is collected by panning and is “washed” to separate from sediment.	The Hg is filtered through cloth, to produce amalgam (a 50/50 mixture of Au & Hg).

Figure 11. Mercury Amalgamation Method (mixing)

			
The amalgam is grey in color, and it contains the gold that has been extracted.	The amalgam is then heated in open air, to evaporate the mercury.	After the gold recovery process, the result is a shiny gold ingot.	The gold ingot is then weighed, tested for purity, and can be sold.

Figure 12. Mercury Amalgamation Methods (end result)

Recall that the study included “concentrate amalgamation” tests as well. These were also carried out by experienced mercury processors in Chami, under the supervision of Magma’s technicians. For this method, the heavy mineral concentrates from port 1 and port 2 of the shaking table were joined together to form a mineral concentrate sample weighing 5kg (per sample). These samples were processed using mercury in the same plastic tubs (and metal pans), used regularly in Chami for WOA. Three hundred grams of mercury was used. No additional crushing or grinding was done, save for the rubbing and washing using smooth stone, during the amalgamation process, lasting 15 minutes. The mercury was recovered by panning, after which the mercury was pressed through filter cloth to recover the gold-mercury amalgam.

4. Results and Analysis

4.1. Gravithy Recoverable Gold (i.e. feasibility of gravimetry)

The GRG test on quartzite ore from Inchiri determined gold recovery under optimized conditions, through grinding to 800 µm, 200 µm, and to 75 µm.

The measured head-grade of the parent sample (milled to 800 µm and homogenized) was 10.80 PPM, determined by aqua regia digest and AAS (average, n=2). Meanwhile, the “back-calculated” head grade of the parent material following the GRG test work, was 9.23 g/t Au. The discrepancy results from the *nugget effect’* which is common when analyzing gold ores. A decision was made to base the GRG recovery rates, on the "back-calculated” head grade from the GRG tests, to reflect the higher sampling undertaken during GRG testing, and thus to minimize variance in measurements. The GRG results have been summarized in the table below:

Table 1. GRG test results (refer to appendix 3 for a more detailed summary report)

Test Products	Calculated Au Distribution (% recovered)
Ore milled to P80 800 µm	16.1 %
Ore milled to P80 200 µm	31.0 %
Ore milled to P80 75 µm	28.1 %
Sum (total) gravity recovered gold	**75.2 %**
Not recovered by gravity	**24.8 %**

The GRG test achieved a gold recovery of 75.2% from a calculated head grade of 9.23 g/t Au leaving a tailings grade of 2.3 g/t Au. Accordingly, 75.2% of total gold was recovered using shaking table and direct smelting, following milling the quartzite ore to P80 of 75 µm. Meanwhile, however, when milled to only 200 µm, only 47% of total measured gold was recovered. This clearly indicates that a large portion of the recoverable gold exists in the "very fine" fraction, smaller than 200 µm. The results also indicate that approx. 25% of the gold was not able to be recovered using mechanical, gravimetric method, with grinding to 75 µm. Other methods should be considered to recover this fraction (e.g. leaching by cyanidation, or other chemical reagents).

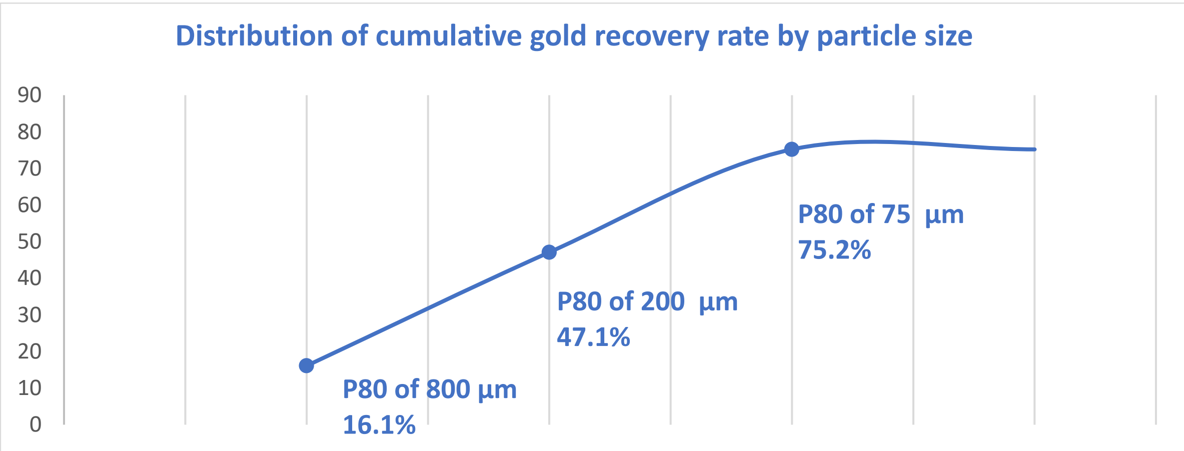


Figure 13. Distribution of the rate of recoverable gold by gravimetric concentration by particle size (with cummulative percent recovered on the Y axis).

4.2. Gold liberation

Additional studies were undertaken by Magma and Pact on gold liberation. For example, tests were done to evaluate how much gold would be liberated by the hammer mill (alone, which only reduces the material to <1mm). The results from these tests are presented in Annex 4, and align well with outcomes of the GRG tests; the findings can be summarized as follows:

1. A large portion of the gold present in the quartzite ore from Inchiri province can be classified as very fine. For optimal gold recovery, the hammer mill does not mill the ore sufficiently fine to recover this gold: to effectively liberate very fine gold, a finer grind is necessary.
2. To achieve the target grind size in the most efficient and cost effective manner possible, the hammer mill was setup *in series with the Wet Pan Mill*. Milled ore from the HM (<1mm) was passed to the WPM for secondary milling. Milling effectiveness was measured by collecting samples from the WPM after timed intervals, with the motivation to achieve the target grind size of 75-100 µms (determined from GRG tests). Compound grab samples were collected from the WPM after 15 min, after 30 min, and after 45 minutes.

3. After each interval, the mill was stopped and compound grab samples were taken, dried, and then dry-sieved in laboratory (while ensuring to avoid erroneous results caused by clumping of particles due to wet/dry process). The grain size analysis results are presented in Table 2, below.

Table 2. Particle size analysis (results) for WPM grinding intervals (percent mass in size class)

Wet Pan Mill (WPM) grind time (following HM)	<0.075 mm	0.075 - 0.106 mm	0.106 - 0.250 mm	0.250 - 0.425 mm	0.425 - 0.85 mm
15 min	31%	19%	42%	7%	1%
30 min	31%	18%	49%	2%	0%
45 min	56%	32%	13%	0%	0%

The findings illustrate that after only 45 minutes in the WPM, 88% of the sample has been reduced to smaller than 0.106 mm; and that (nearly) no particles remain larger than 0.25 mm. Based on this result, “45 min” was selected as the target WPM milling time for subsequent tests for gold recovery.

4.3. Gold Values of the head ore

From each of the (4) batches of head sample, compound sub-samples were collected (after thorough mixing of the entire parent sample) and sent to Anarpam (certified government laboratory) for gold assay by acid digest by aqua regia, and gold determination by AAS. Following this, gold recovery tests were made on the head samples, per the protocols explained in Section 3.2 above and results are summarized below in Table 3.

Table 3. Gold assay results (total gold by AAS)

Head Sample designation	N (number samples collected and assayed for gold content	Gold content of head sample (gold assay by acid digest, and AAS)[2] PPM (i.e. grams Au / tonne ore)
HS-1 (150 kg x2)	4	7.30
HS-2 (108 kg x2)	2	9.90
HS-3 (130 kg x2)	2	7.38
HS-4 (147 kg x2)	2	6.67
HS-J (225 kg)	2	8.67
Mean		7.98

Analysis and key takeaways:

For ASGM gold miners in Mauritania, this material constitutes *low grade* ore. In Chami, miners explain that the gold recovery process is only worthwhile if they recover (at minimum) 0.5 grams of gold per 70 kg sac. This amounts to a “*mercury-recovered gold grade*” of ~7 g/t (since [1000*0.5]/70 = 7.1). If we assume mercury is recovering on the order of 50% of the gold, then the total gold grade is 14 g/t. Accordingly, it follows that the *approximated* “cut-off grade” for ore being exploited by ASGMs in Mauritania is around 14 g/t.

In Mauritania and in many areas where miners rely principally on mercury for gold recovery, the majority of ASGM operations are essentially “high grading” ore bodies because miners are only interested in ore grading 10 grams per tonne or higher. The result is inefficient resource utilization (i.e. *ineffective beneficiation relative to the full potential of the ore body*). There is an urgent need (and

[2] Note that the Aqua Regia + AAS method for gold assay has known propensity to under-report gold values in sulfide rich ores (https://www.911metallurgist.com/laboratory/understated-gold-aas-assay/). This implies that gold recovery (calculations reported below), may be *slightly over-estimating* gold recovery.

also a business opportunity) for investments in (small-scale) hard rock gold mines which facilitate improved mine planning and also mechanization, specifically designed to enable miners to increase tonnage while lowering cut-off grades, while increasing throughput and performance of mineral processing systems.

4.4. Gold Recovery

For ASGM stakeholders, the test which means the most is "gold recovery" – and this is certainly true when miners participate in the test-work, and see the results with their own eyes.

Gold recovery was measured after the ore was processed to recover solid gold prills, which were weighed, following the respective gold extraction processes. Due to relatively small sample sizes, gold prill weights ranged from 0.16 grams through to 1.46 grams. Prill weights were then normalized to correct for gold purity, and calculations were made to determine gold recovery as percentage of the total gold (grade) in the head ore.

Table 4. Gold recovery in Percent, based on prill weight and assay results of head ore

Head Sample designation	Au Assay Result (ppm = g/t)	Direct Smelting Au Recovery Result (%)	Whole Ore Hg Amalgamation (%)	Concentrate Hg Amalgamation (%)
HS-1 (150 kg x2)	7.30	14%*	14%*	na
HS-2 (108 kg x2)	9.90	77%	69%	na
HS-3 (130 kg x2)	7.38	na	68%	14%
HS-4 (147 kg x2)	6.67	na	38%	17%
HS-J (225 kg x 1)	8.67	72%	na	na
Averaged Results (all)	7.98	54%	47%	16%
***Corrected Results (average but excluding outlier results of HS-1)**	**8.15**	**74%**	**58%**	**16%**

na = not available (*i.e. not analyzed)*

Analysis and key takeaways:

1. The results indicate that the mercury-free method recovered more gold than the WOA (mercury) method, by 16%, on average. Regardless of this modest improvement, the tailings from the process still contain gold, and remain of economic interest for further processing by leaching technology (i.e. by category F companies, in Mauritania). This aspect has important implications concerning various parties in Mauritania's gold mining sector.
2. *Anomalous results were attained in *both methods* (mercury and mercury-free) on the ore from the HS-1 sample bags. The reason for this is not 100% certain, however leading suspicion is that mistakes were made when performing the gold recovery being that this was the first sample processed. In the case of the direct smelting test, poor Au recovery was due to a thick slag (following which flux ingredients were adjusted to ensure increase soda ash and borax). Interestingly, the HS-1 sample subjected to Au recovery with mercury ALSO performed poorly in terms of gold recovery (relative to the others, cause unknown). Since the results in the case of both HS-1 samples resulted in clear outliers, these results have been excluded from the set of values used to calculate *averages* of (successful) gold recovery trials.
3. There is considerable variability in the results. This indicates that one must be cautious not to "over-analyze" small differences between individual test results. Rather, interpretation of the results should focus instead on *averages* and *trends*.
4. Gold recovery using the mercury method (WOA in WPMs) recovers about 58% (range 55-60%; average, n=3). This finding agrees with previous work by the EPRM team conducted in Chami in 2021 which also identified high recovery rates from WOA (documented in Annex 4). This finding *contradicts* the widely held myth that the mercury methods recover only ~30% of the gold.

5. The test trials on amalgamation of concentrates (from the shaking table) performed *very poorly* in terms of gold recovery (recovered only 16% of total gold, on average, n=3). This is because (in general) the local amalgamation methods have not been adapted for gold recovery from concentrates. Specifically, far too much mercury was used (300 grams) even though it was known that the sample contained only a very small quantity of gold. We can infer that poor Au recovery is due to a dilution effect of the large volume of mercury being used in an effort to recover a very small mass of gold. The results concerning "concentrate amalgamation" should thus be interpreted as an underestimate for this technique. Further study of this *reduced-mercury* option would be helpful given the inconclusive results obtained for this method, in the present study.
6. The mercury free-method (i.e. gold liberation in the WPM for 45 min, followed by shaking-table, and then direct smelting of the concentrate) yielded gold recovery of 74% (average, n=2). This is an impressive result and corresponds well with the results from the GRG tests, which further bolsters the teams confidence in this finding.
7. Given that the recovered gold smelted from ports 1 and 2 on the shaking table (74% of the total gold), it follows that the remaining (~26% of the gold) reported to ports 3 and port 4. Analysis of the tailings and the midlings from the shaking table included grain size analysis, followed by gold assay of all size fractions. Material reporting to port 3 (midlings) averaged approx. 2 PPM Au and constituted approx. 20% of the total gold, with approx. 25% of the total mass reporting to Port 3. Material reporting to port 4 (tailings) averaged slightly under than 1 PPM Au; and constituted approx. 10% of the total gold, with approx. 70% of the mass reporting to port 4.

5. Feasibility Analysis

A detailed comparison of additional economic and performance indicators (in addition to gold recovery) is necessary to examine the business case for mercury-free mineral processing in the context of Mauritania's local ASGM economy, and related constraints. The feasibility analysis takes account of equipment purchase cost; equipment running costs, including maintenance; technical requirements for adoption by the artisanal workforce; and performance efficiency in terms of: energy usage, water requirements, and time demands. The feasibility analysis is summarized below; for additional detail refer to the Table presented in Annex 1.

On the "cost" side of the feasibility equation:

- Equipment purchase cost is around 15K - 30K euros (depending on options selected, and depending on the country in which equipment is manufactured, etc.).
- Running costs and maintenance requirements are greater for the mercury-free mineral processing equipment. The cost has been estimated to be between 5.50 and 9.50 euros per tonne of ore (representing around 1% of the value of the gold recovered, on average). Ideally, replacement parts should be manufactured locally, and this also is most practical.
- The shaking table requires slightly more water, compared to using the cone mill. However, the water recycling prototype showed very promising results for water clarification, and recycling (a water pump is necessary and enables efficient closed-loop water reuse). If widely implemented, the net effect could even be an overall *reduction* in water consumption.

On the "profit" side of the feasibility equation:

- Cumulative results indicate successful demonstration of a locally adapted technique which meets the objective to find an alternate Hg-free process which achieves a higher gold recovery (10-15% greater recovery), while producing tailings (residues) *free of mercury contamination.*
- In terms of cost of reagents (mercury amalgamation, verses direct smelting) the mercury-free alternative is approximately 5 times less expensive (around €5/tonne instead of €30/tonne).
- Concerning "energy use" the Hg-free system operates with approx. 4.8 times less energy (*not including smelting*). The WOA system currently used in Chami consumes approximately 179 kWh per tonne (179 kWh costs approx. €22.38, at rate of € 0.125 /kWh). The Hg-free system consumes

37.4 kWh per tonne (37.4 kWh costs approx. €4.68, at rate of € 0.125 /kWh). The financial implications of this are significant, and this also represents a significant environmental benefit.

- Concerning the time requirements for mineral processing: the mercury-free alternative requires approx. 4 times less time than the WOA method. This represents significant savings in terms of personnel, and logistics.

Overall, the results of the preliminary feasibility analysis can be described as "very positive". Details of the economic feasibility analysis are provided in table format, in Appendix 1.

6. Conclusions

The central aim of the study was to evaluate the effectiveness of mercury-free mineral processing methods *adapted to the Mauritanian ASGM context i.e. especially making use of existing equipment*. The study included head-to-head comparison of gold recovery of the mercury-free process, verses the mercury-intensive process used in Mauritania and Sudan (i.e. WOA in wet pan mills). The design of the mercury-alternative method focused on *fundamentals* for gold recovery: ensuring effective gold liberation, followed by effective mineral *concentration*, and finally gold recovery using *direct smelting*.

Results of the study confirmed the effectiveness and feasibility of mercury-free processing using a circuit consisting of jaw crusher - for initial head ore size reduction, followed by hammer mill for primary milling, and wet pan mill for secondary milling, then proceeding to mineral concentration, and direct smelting. This process recovered 74% of the total gold, on average, while the trials using mercury amalgamation recovered 58% of total gold, on average (10-15% increase gold recovery was demonstrated). Regardless of this modest improvement, the tailings from the alternative method: (i) are mercury free; and (ii) still contain gold and thus remain of economic interest for secondary processing by leaching (i.e. by category F companies, in Mauritania). This aspect has important implications concerning the dynamics of present-day business arrangements in Mauritania's gold mining sector.

Two limitations of the study design and results must be highlighted: (1) the limited sample size (focused only on a single ore deposit, and with limited size, and relatively low-grade ore); and (2) variability in the results between test trials. It follows that interpretation of results should focus on trends and averages, with respect for the limited scope of the study. Additional test work - including on different ore bodies (e.g. different mine sites, from different regions and ore bodies in Mauritania) is warranted.

A preliminary feasibility analysis was undertaken comparing metrics such as capital cost, running costs, technical requirements, and performance criteria such as time, energy and water consumption. The analysis suggests strong potential for positive return on investment, and even repayment of initial investment costs (equipment costs) in just a few months, assuming investors have consistent access to ore. It appears obvious that the mineral processing circuit tested in the study will be well suited for small-scale mines in the country. However, there are also signs that the mercury-free alternative could be adopted as a "model processing system" in Mauritania's government-controlled treatment centers, which service the artisanal mining sector.

The study demonstrated that the wet pan mill does not need to be used with mercury to be effective. It is highly effective when used in series as the secondary milling device, and by directing slurry directly to a mineral concentrator, as demonstrated in this study with the shaking table. Pre-crushing and pre-milling the ore - prior to final milling with the WPM, can provide operators with remarkable improvements in milling efficiency, as evidenced by reduction of milling time, and energy usage.

Annex 1: Feasibility Analysis, Comparison of key indicators (refer appended)

Annex 2: Results of the particle size analysis (refer appended)

Annex 3: Gravity Recoverable Gold (GRG) Summary Report (refer appended)

Annex 4. Comparison of Gold Loss Report from Chami (refer appended)

Annex 1. Comparison of key metrics (between Mineral Processing methods), including performance, cost, and demands for energy, water, and time

Performance Metric for Comparison	"Local method" using mercury by WOA	"Mercury-free" method using shaking table, Direct Smelting + Cupellation
Gold Recovery	58%	74%
Time Required (per tonne of ore) *Note that 1 tonne of ore = 1000 kg = approx. 15 "sacs"*	24 hours cone mill time (3 separate machines, approx. 8 hrs each, each process 5 sacs (330 kg) 1 hr amalgamation Total = 25 hours	2 hours crushing and milling (inc. 1.5 hrs CM) 1.5 hour shaking table 1 hour direct smelting & cupellation Total = 4.5 hours
Equipment capital cost. (Crushing and milling machines required, & approx. cost in €)	Wet pan mill = €5,000 *Total = 5,000€*	Jaw crusher – JC (4,000-6,000) Hammer mill – HM (5,000-10,000) Cone mill – CM (5,000) Shaking Table – ST (5,000-10,000) Smelting kit (500) *Total (range) = 19,500 – 31,500 €*
Machine maintenance (€ per tonne of ore)	CM (negligible) Negligible cost	JC – replace jaw plates after 100 t (cost estimate = 1.50 - 2.50 € / t) HM – replace hammers after ~50 t (distributed cost estimate = 3 – 7 € / t) ST (negligible) CM (negligible) Total = 5.50 – 9.50 € per tonne of ore
Reagent costs (€ per tonne of ore)	Hg cost = 100€ /kg Hg consumption estimate = 300 grams per tonne* *note that 300-500 gr Hg is used *per CM.* However, most of this Hg is recovered/re-used. Mercury cost per tonne of ore = 15€	Direct smelting (DS) process assumptions: (a) "clean-up" on ST after 2 t ore; (b) smelt 200 gr conc. from ST; DS requirements (reagents): Borax (@2.5€/kg): each DS consumes 500gr (1.25€); Since DS done on conc. from 2 t: Cost per tonne = 0.65€. NaCO3 (@4€/kg): each DS consumes 500gr (2€); Since undertaken on con from 2 t, Cost per t = 1 €. Gas cost for forge: 2 €/t. Crucible and cupel costs: 1 €/t. Total cost (direct smelting + cupellation) per tonne of ore = 4.65 €
Energy Usage* (per tonne of ore)	CM (24 hrs) = 179 kWh [10*24 = 240 HP hours x's 0.7457 to get kWh] Total = 179 kWh par tonne de minerai (22.38€/tonne, @ € 0,125 par kWh]	JC (0.5 hr) @ 7.5 HP = 2.8 kWh HM (1 hr) @ 15 HP = 11.3 kWh ST (2 hrs) @ 0.5 HP = 0.75 kWh CM (2 hrs) @ 15 HP = 22.5 kWh Total = 37,4 kWh par tonne de minerai (4.68€/tonne, @ € 0,125 par kWh]
Water Usage (per tonne of ore)	Approx. 1,000 liters per CM (8hr for 330 kg ore); Therefore approx. 3,000 liters per tonne of ore Effective water recycling? *Generally, no.*	Shaking table uses 40 liters per min, 120 minutes. Therefore approx. 3,600 liters / tonne of ore Effective water recycling? *Yes.*

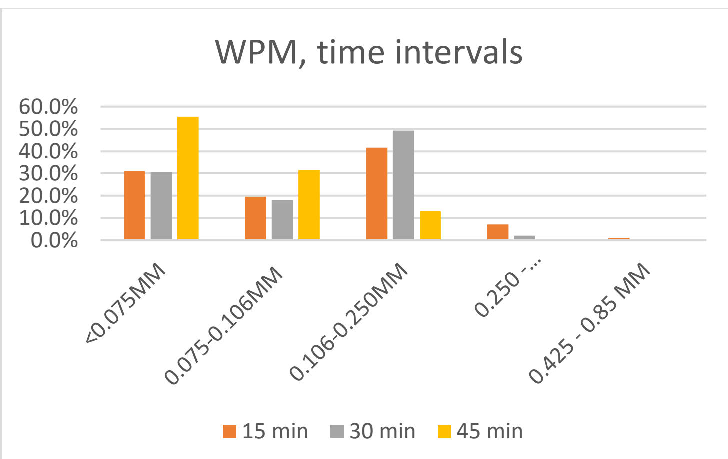
Annex 2: Results from Granulometry Analysis (i.e. regarding milling efficacy)

1. Nov. 2022 WPM grind time (interval test work)

Results presented below are averages from sample pairs. All samples were collected as compound grab samples.

Table 1. Results of Granulometry tests to determine mill size achieved from WPM, using feed stock from HM, and time intervals at 15 min steps.

	Percent	<0.075MM	0.075-0.106MM	0.106-0.250MM	0.250 – 0.425MM	0.425 – 0.85 MM	0.85 – 2.0 MM
Percentage in Class							
15 min	100.0%	30.9%	19.4%	41.5%	7.1%	1.0%	0.0%
30 min	100.0%	30.6%	18.1%	49.2%	2.0%	0.0%	0.0%
45 min	100.0%	55.5%	31.5%	13.1%	0.0%	0.0%	0.0%
Cumulative Passing Sieve (percentage)							
15 min	100.0%	30.9%	50.4%	91.9%	99.0%	100.0%	100.0%
30 min	100.0%	30.6%	48.7%	98.0%	100.0%	100.0%	100.0%
45 min	100.0%	55.5%	86.9%	100.0%	100.0%	100.0%	100.0%



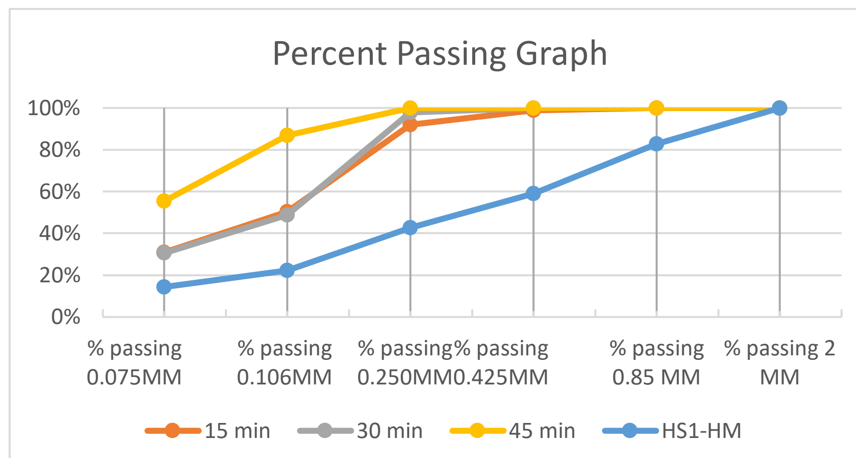


Figure 1. (left) Bar graph showing grain size results of WPM sediment grab sample tests, based on 15 minute interval testing (i.e. percent in class). (right) Percent passing chart, representing the same data.

2. Grainsize Analysis and gold values of Shaking Table Residues

Samples from Port #3 (Midlings) and to Port #4 (Tailings) were collected and analyzed for granulometry and for gold values. This was done for samples HS-1.1, HS-2.1, and HS-3.1. The results presented below are averages from the analyses.

Table 2. Results of Granulometry tests to determine discharge of the Hammer Mill, and of the shaking table residues (processed by WPM)

	Mass (gr)	Percent	<0.075MM	0.075-0.106MM	0.106-0.250MM	0.250 - 0.425MM	0.425 - 0.85 MM	0.85 - 2.0 MM
Percentage in Class								
HS1-HM	1917.3	100.0%	14.4%	7.8%	20.6%	16.3%	23.8%	17.12%
ST-Midlings	1009.00	100.0%	33.0%	31.2%	30.4%	4.5%	0.8%	0.0%
ST-Tailings	1818.95	100.0%	20.1%	27.5%	47.3%	5.0%	0.1%	

Table 3. Gold Assay results on Shaking Table residues

Au assay result in PPM (gr/tonne)				
	<0.075MM	0.075-0.106MM	0.106-0.250MM	0.250-0.425MM
Midlings	3.6	2.0	1.4	1.7
Tailings	2.7	1.4	0.7	0.7

Table 4. Gold content in Residues from shaking table, normalized (based on percentage in each size class)

	Gold content PPM (g/tonne)
Midlings (port 3)	2.26
Tailings (port 4)	1.17

Annexe 3: Summary Report from Gravity Recoverable Gold (GRG) Tests by Magma

Author : Mohamed Lamine Tarr (MSc.)
Technical support from : Daniel Stapper (MSc.) ; Dr. Marcello Veiga ; Dr. Abderahmene KHALIFA
Date of GRG test work : February - August, 2022

Contents

1. Introduction and Objectives

The gravity recoverable gold (GRG) test is a standardized lab test utilized widely used by mineral processing engineers for understanding the nature of « gravity recoverable » gold particles. The test incorporates intermediate grinding to recover the gold as it is liberated. This GRG is critical - especially for hard rock gold ore, as gold liberation is a critical aspect of mineral process engineering. Gold must be liberated in order to be concentrated (separated) using gravimetric methods.

The purpose of the GRG test protocol is to determine the optimal target grind size for a specific gold ore, in order to maximize gold recovery using gravimetric gold recovery methods. In 2022, Magma purchased state-of-the-art lab-scale centrifugal concentrator from Falcon Industries in Canada, called the Sepro L40 (lab scale centrifuge), for the purpose of conducting professional GRG tests on ore bodies in West Africa.

The Sepro L40 concentrates milled particles by centrigugal force, through applicaiton of centrifugar force up to 150 G. The concentrator takes advantage of variation in particle density to separate heavy (i.e. more dense) particles from lighter (i.e. less dense) particles.

The test work reported here was conducted by Magma, using a parent sample of quarzite ore, purchased from ASM miners in Chami, Mauritania. The size of the ore sample used for the testwork (parent) was 28 kg. The L40 was then used to undertake laboratory scale test work on a homogenized subset of this parent ore sample. A standardized GRG test protocol was employed, using successive rounds of milling and concentration. The GRG protocol employed developed with the support from Dr. Marcello Veiga, from the University of British Columbia (UBC) in Canada.

2. Methodology

The following protocol was followed, to undertake the GRG test work :

1. Parent ore was 28 kg of quartzite ore purchased from ASGM miners in Chami. This ore had been crushed manually by miners to around <5 cm.
2. The ore sample was milled at the Magma lab in Magma's lab crusher to 800 microns.
3. The 10 kg sample was homogenized and split into test charges by coning and quartering method.
4. A 1 kg sub-sample was submitted to certified laboratory for gold determination (by acid digest, AAS)
5. A size fraction analysis was conducted on the 800 micron sample to determine the distribution of gold by particle size, for the « parent sample ».
6. Then, following standard GRG protocol, the 800 micron sample was subjected to concentration using the Sepro L40 concentrator. The milled ore was mixed with water to produce a slurry of 20-30% solids, which was fed to the Falcon L40 at approximately 3.2 L/min (equivalent to 0.6-1.0 kg solids/min depending on pulp density).
7. The concentrator was then carefully cleaned out to recover mineral concentrate (70-100 grams). This concentrate was further panned (manualy) to approx. 10 grams. In this way the recovered concentrate was split into 2 fractions. These are referred to as « Pan Con # » , and « Pan Tail # » for each of the 3 grind size intervals.
8. The concentrates materials were subjected to total gold determination by acid digest, AAS.
9. Following this, the **same parent material** (i.e. tailings from the L40 concentrator) was then decanted, dried, and milled again. The stage 2 grind size was P80 of 200 micron.
10. According to the protocol, the concentration steps were repeated (using the L40 concentrator) on the 200 micron sample.
11. Finally, the **same material** was milled once again, this time to a P80 of 75 micron, followed by concentration steps once more.

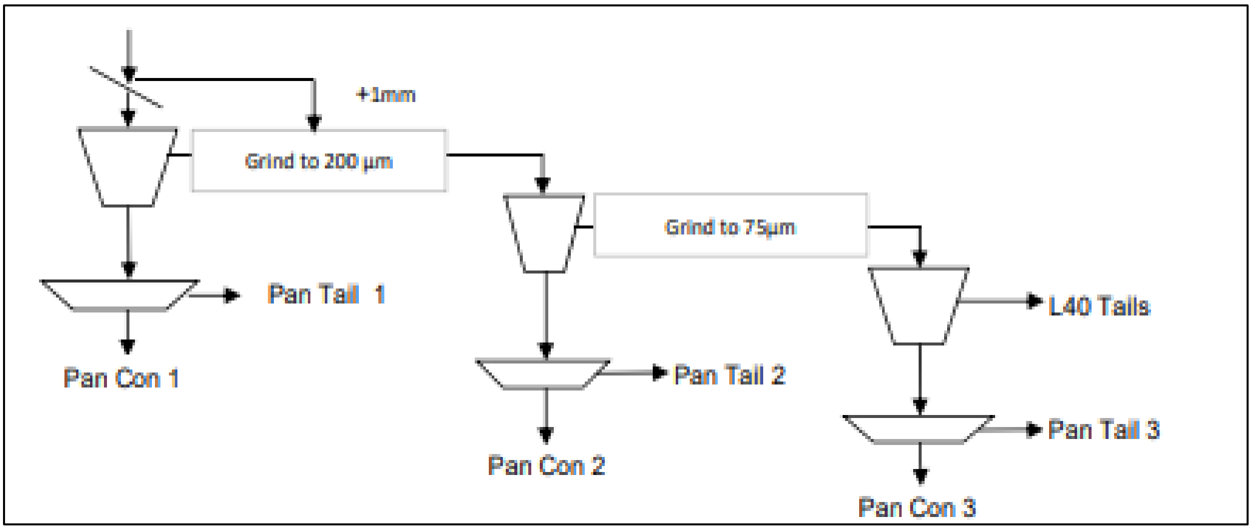


Figure 1. GRG Protocol (flowsheet illustration of GRG test protocol). The sample subjected to the test is grinded first into a P80 of 800 micron, then processed in the L40.To reduce the nugget effect in the assay the concentrate are split by panning to separate the free gold from the fines or unliberated gold both of the concentrates are assayed by AAS. The same process are repeated at a P80 of 200 micron and the then at a P80 of 75 micron.

Figure 2. Sepro L40 laboratory-scale concentrator purchased from Falcon, in Canada.

2.1. Challenges encountered

After first tests of running the L40 a common problem of sanding the bowl was encountered (compaction of the sand inside of the bowl blocking the tailings output). Test work was required to determine run-parameters to avoid this problem, for the ore sample in question. This was accomplished by determination of the optimal discharge time. The mass of concentrate in the L40 must be less than 10% of the sample processed. The idea is to time the process to see at what time we reach this maximum. Other parameters such the optimal fluidizing water pressure and the slurry density were determined by repeating the tests and analyzing the concentrate versus tailings, and amount of material lost as tailings. Based on optimizing for these conditions, the following parameters were selected and used for subsequent test work: a feed of 2kg of solids in a 30% slurry; discharge time 20min, 0.6kg solids/min and fluidizing water 4L/min.

Figure 3. Various photos of milled ore samples : before, inside and after concentration wiht the L40 concentrator.

3. Results

3.1. Gold assay of the Head Ore

Concerning the head grade of the parent sample : the averaged results of gold assay on the head samples (milled to 800 micron, homogenized) was 10.80 PPM (i.e. g/t Au) (n=2). Meanwhile, the « back-calculated » head grade of the parent, following the GRG test work, was 9.23 g/t Au. The discrepancy results from the ‘’nugget effect’’ which is common place when analyzing high-grade ores. A decision was made to base the GRG recovery rates, on the "back-calclated » head grade from the GRG tests, in order to minimize the nugget effect. This could result in the calculated gold recovery results being slightly higher, than the actual gold recovery rates realized.

3.2.GRG Test Results

Results from GRG tests are summarized in Table 2.

Table 2 : GRG Test Results

Test Products	Weight (g)	Weight (%)	Au Concentration (g/t) (measured by acid digest, AAS at certified lab)	Calculated Au Distribution (% recovery)
GRG Stage 1: 800 microns				
Pan concentrate 1	6.3	0.06	1345.1	9.2
Pan Tail 1	81.3	0.81	78.8	6.9
Sum @800 um	87.6	0.88	169.8	16.1
GRG Stage 2: 200 microns				
Pan Concentrate 2	12.4	0.12	1857.0	25
Pan Tail 2	65.2	0.65	85.3	6
Sum @200 um	77.6	0.78	368.4	31
GRG Stage 3: 75 microns				
Pan Concentrate 3	12.2	0.12	1731.2	22.9
Pan Tail 3	58.5	0.59	81.5	5.2
Sum @75 um	70.7	0.71	366.1	28.1
Total gold recovery (from all fractions)			-	75.2
Total gold that was NOT recovered by gravity (remaining in residue tailings from L40 concentrator)			2.4 (average)	24.8

The GRG test achieved a gold recovery of 75.2% from a calculated head grade of 9.23 g/t Au leaving a tailings grade of 2.35 g/t Au. The results indicate that a high-grade concentrates can be produced from this material.

4. Summary and Recommendations

In summary, the GRG test work demonstrated that gravity recoverable gold amounted to 75.2% of the total measured gold in the head sample (of 9.23 g/t Au), after grinding to P80 of 75 micron (very fine).

When ground (only) to 200 micron, only 47 % of the total gold was effectively liberated – illustrating that a large portion (i.e. more than 25%) of the gravity recoverable gold is very fine (i.e. smaller than 200 micron). Accordingly, milling circuits designed for gravity recovery need to be optimized to achieve a grind size (target) of P80 of 75 micron.

We can also observe that some of the gold is liberated at a grain size of 800 micron, which explains the presence of the nugget effect observed when the head sample was assayed. 25% of the gold cotent was not gravity recoverable.

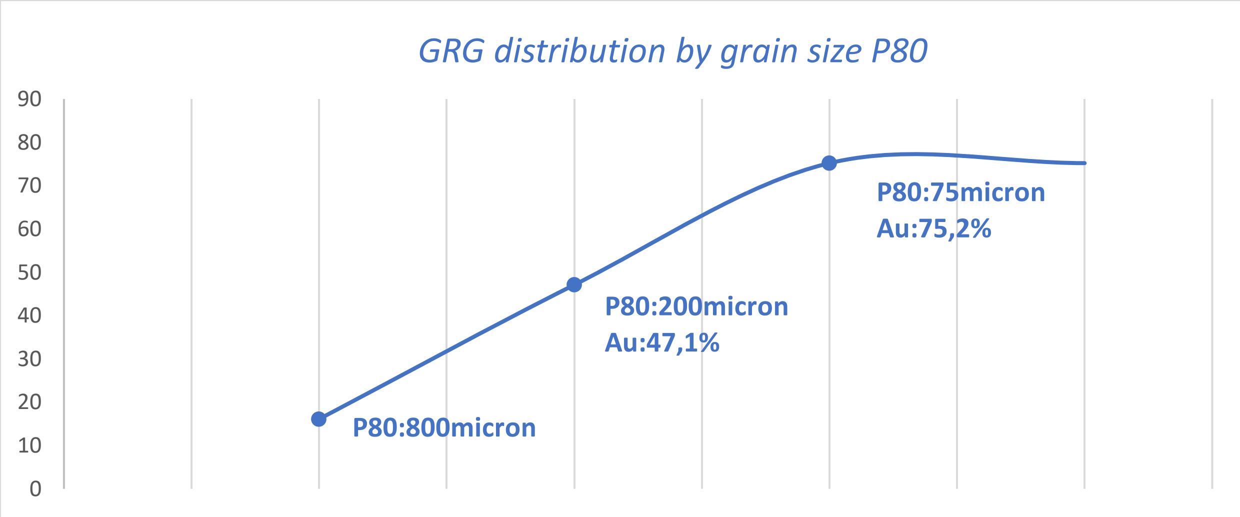


Figure 4. Gravity Recoverable Gold distribution curve, by grind size.

The test results indicate that fine grinding is required to liberate the majority of the GRG in the sample. Even after achieving a grind size of P80 75 microns, the GRG test results shows that approx 25% of the gold remains in the tailings. In the case of this ore, this amounted to gold values of approx. 2 PPM (grams per tonne). Flotation methods or leaching methods could be considered for recovering the remaining gold.

Finally, it must also be noted that concentration using the iCon150 concentrator (also purchased by Magma from Falcon and undergoing subsequent test work in the Mauritania context) is expected to produce higher grade concentrates, as compared to the lab-scale L40 concentrator. This is possible because the Icon150 model has greater concentrating forces and lower mass yield[1].

[1] https://labs.seprosystems.com/advances-in-centrifugal-gravity-concentration-beyond-low-mass-yield/

Les activités de MAGMA sont régies par le décret du Conseil des Ministres N°0105-2015 paru au Journal Officiel n° 1337 de la République Islamique de Mauritanie en date du 15/06/2015.

01	27/09/2021	TEMPORARY REPORT	A. KHATTRY	S. HOUSSEM	A. KHALIFA
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Rev.	**Date**	**Description**	**Prepared by**	**Verified by**	**Approved by**

MAITRE D'OUVRAGE		CLIENT
Sahel Clean Gold Mauritanie	magma Code : AD/PRS/04 TÜVRheinland CERTIFIED Management System ISO 9001:2015 www.tuv.com ID 9108637592	pact building local promise.

PROJECT

BUSINESS PILOT FOR RESPONSIBLE MAURITANIAN ASM GOLD

TITLE

COMPARISON OF GOLD LOSS USING MBMM'S HAMMER MILL AND SHAKER TABLE, ALONGSIDE THE TRADITIONAL CONE MILL'S USED IN CHAMI

DEVIS No.	DATE	DOCUMENT No.	REVISION	PAGE
	27/09/2021	DC2020/R01	1	25
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1. INTRODUCTION

Gold ore is predominantly processed in Chami, Mauritania using traditional pan mills (also known as cone mills) – to which mercury is added, in a process known as 'whole ore amalgamation', which consumes large amounts of mercury.

Magma is interested in exploring alternatives to this type of processing and to do this, Magma engaged with Sidi Maouloud who operates in Chami. Mr. Maouloud explained his frustration that the turnkey ore processor which he bought from Mt. Baker Mining and Metals (MBMM) in the USA, was not able to recover as much gold as the pan mill and mercury process. In this context the MAGMA and MBMM have been supporting Sidi Maouloud's team - on the basis of a test protocol whose objective is to compare the performance of methods.

Mr. Maouloud has two cone mills and also a turnkey ore processing system from MBMM including jaw crusher, hammer mill and shaking table. The hammer mill was shipped with screen size (options) of 1.2mm (slots) and a screen with 0.8mm slots. However, after it became clear that these produced too coarse of a grind, Sidi has instead been utilizing a modified screen which has 0.6mm slots.

The principal objective of the test work is to better understand gold recovery and gold loss between the 2 different systems. Daniel Stapper of Pact and Jason Haber of MBMM helped Magma to develop the testing protocols. The test protocol was designed to measure and to compare the gold which is being lost during processing. This was accomplished by analyzing and comparing the gold present in the tailings from each process.

Sidi explained that at present his team is processing ore only with the cone mill, pending a solution to the problem which is for him a problem of coarse grinding. Sidi's team is familiar with the MBMM's machinery, but still have been using mercury to amalgamate the mineral concentrates off of the shaking table. This test work explained in this report was conducted by Magma's team in Mauritania between 9th October 2020 and 11 October, 2020.

2. METHODS AND EQUIPMENT

Ore Testing Protocols

1 tonne (1000 Kg) of hammer-crushed head ore was used by Magma for the test-work. This ore arrives in 80-90kg sacs, by truck to Chami. The ore pile was mixed mixed well, and then divided into 4 piles, each weighing 250 Kg. The test protocol was designed to test 2 piles through the MBMM system, and the remaining 2 piles using cone mills. The result was 2 'tests' for the pan mill, and 2 'tests' for the MBMM system.

The focus for the protocol was to collect midlings and tailings, from each process in order to determine how much gold was being lost in the process, and where in the process the gold was being lost. To accomplish this, midling and tailing samples were collected from the MBMM shaking table from port #3 (midlings) and port #4 (tailings). For the cone mill tests, tailing samples were collected from the tailings output (refer to photo 11) and also from the amalgamation bin, after amalgamation with mercury had been completed. Effort was made to collect large and consistent samples from these locations, for each of the 4 tests. Three sets of measurements and analysis were then conducted on each of 'set' of samples, and these are explained below.

A. Mass measurements

Each of the samples was weighed, and this analysis allows us to mass balance the ore flow being processed (e.g. the proportion of the ore which ends up in the midlings verses the tailings pile, from the shaking table).

In the case of the shaking table tests, samples were also collected and weighed from the concentrates from port #1 and port#2. Gold was collected from these samples, but they were not included in grainsize and gold assay test work.

B. Grainsize Analysis

All samples were transported to Magma's laboratory in Nouakchott, where they were dried and weighed. Following this, 20kg sub-samples were passed through sieves (refer to Pictures14, 15 &16) and split into 4 grain size categories (or grain-size 'fractions'). The 4 size fractions used were:

1- › 0.315 MM
2- 0.315-0.150 MM
3- 0.150-0.075 MM
4- ‹ 0.075 MM

Analyzing each size fraction separately, enables us to determine which particles contain the gold, for each sample that is tested. Following sieving, each of the size fractions was weighed. This enables us to understand how much of the ore (for each process) ends up in each size fraction. This is a key piece of information which is necessary to determine the fate of the gold particles we are interested in.

Since there were 8 original samples (2 from each 'test'), and each of these were split into 4 size fractions, the grain-size analysis would resulted in 32 individual samples. However, none of the 4 cone mill test samples had sufficient coarse material (the largest size fraction, greater than 0.315 mm) to enable further testing. Thus, the total number of samples was 28.

C. Gold Measurements

As per local custom in Chami, Gold was recovered from each process using mercury amalgamation: 'whole ore amalgamation' in the case of the cone mills, and 'concentrate amalgamation' in the case of the shaking tables.

Each of the 28 individual samples from (B) was dried and sent to MSA LABS for gold detection by fire assay - to determine gold being lost by each of the processing systems in question. The fire assay was done on 100 gram samples ground to uniform pulp, by fusion and Atomic Absorption Spectroscopy (AAS; MSALABS method FAS-211). This gold assay is designed to detect gold grade in ore samples and is suitable for Au concentration range 0.01 – 100 PPM (PPM = parts per million, which is the same as 'grams per tonne').

Laboratory Equipment

The team took from MAGMA laboratory all the necessary equipment to realize the requested tests as in the list below:

- Scale
- 2 shovels.
- 3 sieves (75,150,315 Mic)
- 2 Buckets of 20L
- Sample bags.
- Geological hammer
- Markers
- 2 Small white board with erasable markers
- Bubble level
- Tape measure
- 2 pans

Picture 1: Laboratory Equipment used

Safety Equipment

During the mission, the security of people was a priority for Magma. It provides safety glasses, dust masks, gloves and personal protective equipment as in the picture number 2.

Picture 2: Safety equipment used

Operation of MBMM Hammer Mill

The costumer has 24'' X 16'' Mill and he received a screen that had 1.2mm slots and a screen with 0.8mm slots but he works actually with a modified screen has 0.6mm slots. The Hammer mill was running wet the quantity of water flowing into the mill is 6 gal/min (22 liters per minute). The feed-rate of ore is 1300 per hour lbs (590 kg per hour).

Operation of MBMM Shaking Table

The customer's table is 5 ft x 12 ft with ½ HP Electric motor, it is fixed on a flat concrete slab. Refer to photos 3, 4 and 5. Among the advantages of this shaking table, claimed by MBMM:

- High-grade gold concentrate; 95% of the free gold at >325 mesh with minimal contamination.
- Utilizes ramp and plateau system (old Deister patent) with specially designed table grooves for maximum recovery.
- Sulfide middlings with values and other dense material recovered with little contamination.
- Separate discharge for tailing (waste) product

The table has the capacity to treat up to 2 tons of ore per hour. The table has 4 'ports': number 1 and 2 ports for concentrates should contain most of the gold. Port 3 is for midlings, and port 4 is for tailings.

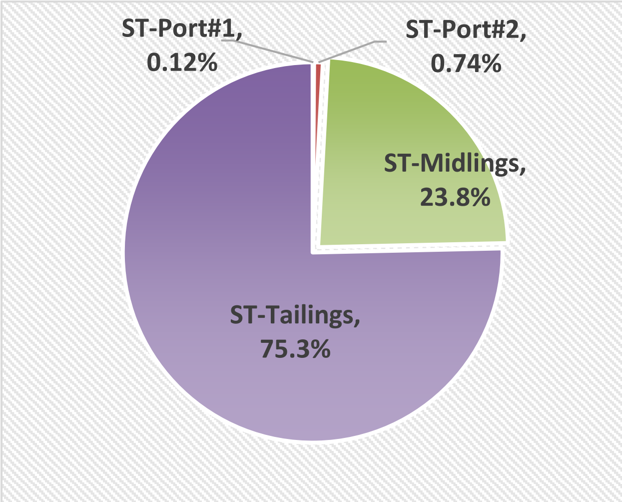
Sample Designations

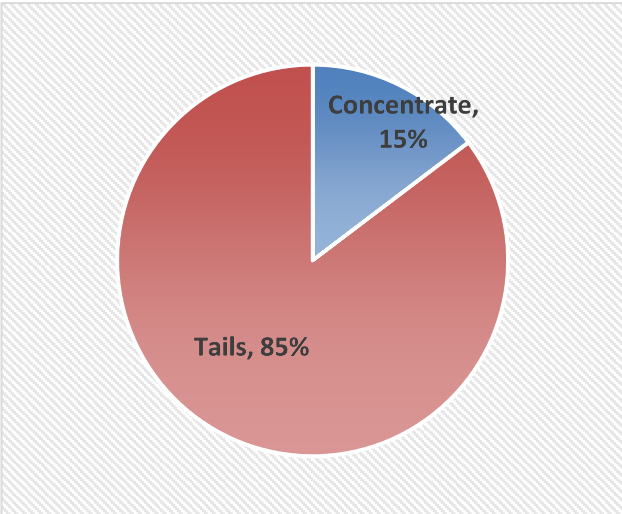
Sample ID	Sample Designation	Sample Description
ST-1	ST-midlings1	shaking table test 1, port#3 <0.075mm
ST-2	ST-midlings1	shaking table test 1, port#3 0.075-0.150mm
ST-3	ST-midlings1	shaking table test 1, port#3 0.150-0.315mm
ST-4	ST-midlings1	shaking table test 1, port#3 >0.315mm
ST-5	ST-tailings1	shaking table test 1, port#4 <0.075mm
ST-6	ST-tailings1	shaking table test 1, port#4 0.075-0.150mm
ST-7	ST-tailings1	shaking table test 1, port#4 0.150-0.315mm
ST-8	ST-tailings1	shaking table test 1, port#4 >0.315mm
ST-9	ST-midlings2	shaking table test 2, port#3 <0.075mm
ST-10	ST-midlings2	shaking table test 2, port#3 0.075-0.150mm
ST-11	ST-midlings2	shaking table test 2, port#3 0.150-0.315mm
ST-12	ST-midlings2	shaking table test 2, port#3 >0.315mm
ST-13	ST-tailings2	shaking table test 2, port#4 <0.075mm
ST-14	ST-tailings2	shaking table test 2, port#4 0.075-0.150mm
ST-15	ST-tailings2	shaking table test 2, port#4 0.150-0.315mm
ST-16	ST-tailings2	shaking table test 2, port#4 >0.315mm
CM-1	CM-outlet1	Cone mill 1, oullet sample <0.075mm
CM-2	CM-outlet1	Cone mill 1, oullet sample 0.075-0.150mm
CM-3	CM-outlet1	Cone mill 1, oullet sample 0.150-315mm
CM-4	CM-Hg-pan1	Cone mill 1, panning bin sample <0.075mm
CM-5	CM-Hg-pan1	Cone mill 1, panning bin sample 0.075-0.150mm
CM-6	CM-Hg-pan1	Cone mill 1, panning bin sample 0.150-315mm
CM-7	CM-outlet2	Cone mill 2, oullet sample <0.075mm
CM-8	CM-outlet2	Cone mill 2, oullet sample 0.075-0.150mm
CM-9	CM-outlet2	Cone mill 2, oullet sample 0.150-315mm
CM-10	CM-Hg-pan2	Cone mill 2, panning bin sample <0.075mm
CM-11	CM-Hg-pan2	Cone mill 2, panning bin sample 0.075-0.150mm
CM-12	CM-Hg-pan2	Cone mill 2, panning bin sample 0.150-315mm

3. RESULTS

3.1 Mass Measurements

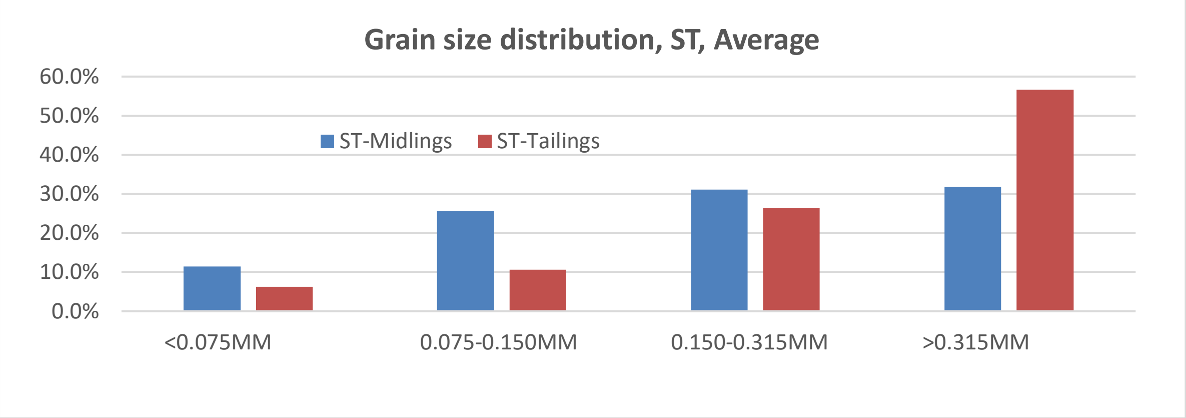
Sample designation	mass in kg	mass in %
Test 1 (shaking table)		
ST-conc#1	0.225	0.09%
ST-conc#2	1.425	0.57%
ST-midlings	51	20.4%
ST-tailings	119	47.6%
missing (remaining tails)	78.35	31%
sum	250	
Test 2 (shaking table)	**mass in kg**	**mass in %**
ST-conc#1	0.369	0.15%
ST-conc#2	2.270	0.91%
ST-midlings	68	27.20%
ST-tailings	136	54.40%
missing (remaining tails)	43.36	17%
sum	250	
Test 3 (Cone Mill)	**mass in kg**	**mass in %**
CM-outlet	54	22%
CM-Hg-pan	36.2	14%
missing (remaining tails)	159.8	64%
sum	250	
Test 4 (Cone Mill)	**mass in kg**	**mass in %**
CM-outlet	58	23%
CM-Hg-pan	36.8	15%
missing (remaining tails)	155.2	62%
sum	250	



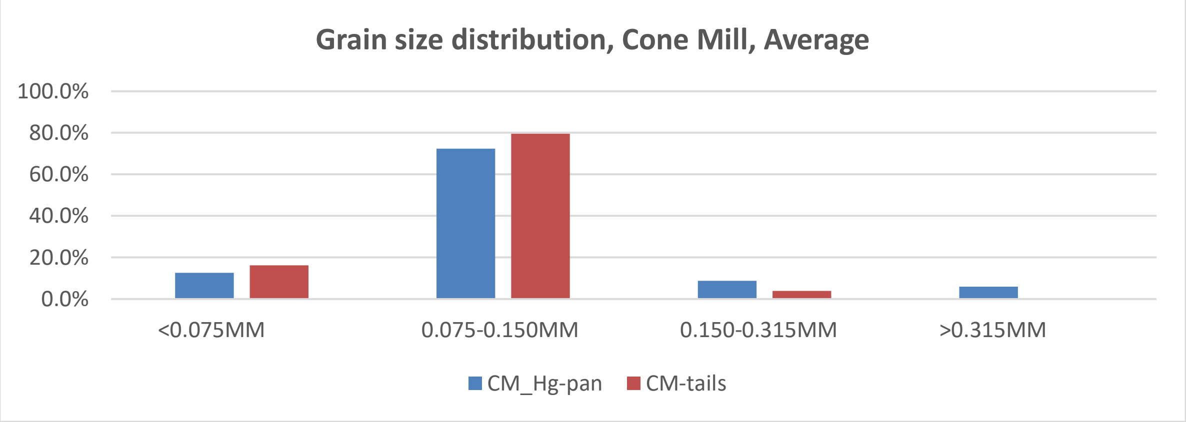


3.2 Grain Size Analysis

	Mass - Percentage			
Sample designation	<0.075MM	0.075-0.150MM	0.150-0.315MM	>0.315MM
Test 1 (shaking table)				
ST-midlings1	11.1%	25.8%	31.5%	31.5%
ST-tailings1	6.2%	10.7%	26.3%	56.8%
missing (tails)	6.2%	10.7%	26.3%	56.8%
Test 2 (shaking table)				
ST-midlings2	11.8%	25.5%	30.7%	32.0%
ST-tailings2	6.4%	10.6%	26.5%	56.6%
missing (tails)	6.4%	10.6%	26.5%	56.6%



Sample designation	<0.075MM	0.075-0.150MM	0.150-0.315MM	>0.315MM
Test 3 (Cone Mill)				
CM-outlet1	15.4%	80.9%	3.4%	0.2%
CM-Hg-pan1	12.2%	74.6%	8.1%	5.0%
missing (tails)	40.0%	60.0%	na	na
Test 4 (Cone Mill)				
CM-outlet2	16.3%	79.6%	3.8%	0.3%
CM-Hg-pan2	12.7%	72.4%	8.9%	6.0%
missing (tails)	40.0%	60.0%	na	na



3.3 Measurements of Captured Gold

3.3.1. MBMM Hammer mill, shaking table, followed by Concentrate-Amalgamation

250 kg of head ore is processed through the MBMM's machinery (from Jaw crusher to shaker table). The same test was repeated two times with the same head ore quantity (250kg), for the first test we have 2.58 g of gold as recovery extracted from ports #1&#2(Picture8) and for the second 3.4 g of gold extracted from ports #1&#2 of shaker table (Picture9).

Picture 8

Picture 9

3.3.2 Cone Mill -> Shaking Table

250 kg of head ore grinded with local cone mills without mercury and processed on shaker table, the gold recovery from material discharged in ports #1 & #2 it was 4.4g.

3.3.3 Cone Mill with Whole Ore Amalgamation (common process technique in Chami)

New 250 Kg of head ore processed through the local cone mills with mercury gave 6.16 g gold recovered from cone mill material (Pictures 10 and 11).

Picture 10

Picture 11

3.3.4 Reprocess ST tailings using Cone Mill

	Weight	Processed with	Gold recovery
Sample from ports #3 and #4	240 Kg	Cone mill	1.6 g

3.3.5 Reprocess Cone Mill tails on Shaking Table

	Weight	Processed with	Gold recovery
Sample from cone mill Barren	240 Kg	Shaker table	0.09 g

The implication (interpretation) of 1.4 and 1.5 test results is that more gold remained in the Shaking Table tails than the Cone mill tails, and that the Cone Mill + WOA method proved effective to recover this remaining gold.

3.3.6 Gold Captured During Test-Work on 1000 kg of Chami ore

ST Test 1, followed by concentrate amalgamation of Port 1 and 2	2.58
ST2 Test 1, followed by concentrate amalgamation of Port 1 and 2	3.40
CM3 Cone Mill then onto Shaking Table, then concentrate amalgamation	4.40
CM4 Cone Mill using Whole Ore Amalgamation	6.16
Total Au Recovered (from original 1000 kg ore pile)	18.23
We make assumption that this gold was 21K (87.5 %)	15.95

Re-Process of 240 kg ST tails with Cone Mill	1.60
Re-Process of 240 kg Cone Mill tails over Shaking Table	0.09
Total Au Recovered (from original 1000 kg ore pile)	

3.4 Measurements of Non-Captured Gold

3.4.1 Lab Results from certified laboratory, Gold Assay by AAS

As documented in the methods section, sub-samples of tailings from each of the 4 main tests were subjected to grain size analysis, followed by pulping at the ALS lab in Nouakchott, and were sent directly from ALS to the MSLAB in Cote D'Ivoire – where the pulps underwent fire assay test work. The results from the fire assay are shown in the table below. Note that the assay result in PPM is equivalent to saying grams per tonne (1 gram / 1000 kg = parts per million).

Table 1. Gold Assay Results from Certified Laboratory

Sample ID	Sample Designation	Sample Description	Gold Assay Result in PPM ppm (+/- 0.01)
ST-1	ST-midlings1	shaking table test 1, port#3 <0.075mm	1.85
ST-2	ST-midlings1	shaking table test 1, port#3 0.075-0.150mm	1.13
ST-3	ST-midlings1	shaking table test 1, port#3 0.150-0.315mm	1.53
ST-4	ST-midlings1	shaking table test 1, port#3 >0.315mm	1.29
ST-5	ST-tailings1	shaking table test 1, port#4 <0.075mm	2.28
ST-6	ST-tailings1	shaking table test 1, port#4 0.075-0.150mm	1.52
ST-7	ST-tailings1	shaking table test 1, port#4 0.150-0.315mm	1.79
ST-8	ST-tailings1	shaking table test 1, port#4 >0.315mm	1.08
ST-9	ST-midlings2	shaking table test 2, port#3 <0.075mm	1.96
ST-10	ST-midlings2	shaking table test 2, port#3 0.075-0.150mm	0.99
ST-11	ST-midlings2	shaking table test 2, port#3 0.150-0.315mm	1.12
ST-12	ST-midlings2	shaking table test 2, port#3 >0.315mm	0.85
ST-13	ST-tailings2	shaking table test 2, port#4 <0.075mm	1.27
ST-14	ST-tailings2	shaking table test 2, port#4 0.075-0.150mm	0.61
ST-15	ST-tailings2	shaking table test 2, port#4 0.150-0.315mm	0.78
ST-16	ST-tailings2	shaking table test 2, port#4 >0.315mm	1.5
CM-1	CM-outlet1	Cone mill 1, outlet sample <0.075mm	0.82
CM-2	CM-outlet1	Cone mill 1, outlet sample 0.075-0.150mm	0.32
CM-3	CM-outlet1	Cone mill 1, outlet sample 0.150-315mm	0.21
CM-4	CM-Hg-pan1	Cone mill 1, panning bin sample <0.075mm	5.28
CM-5	CM-Hg-pan1	Cone mill 1, panning bin sample 0.075-0.150mm	1.56
CM-6	CM-Hg-pan1	Cone mill 1, panning bin sample 0.150-315mm	2.29
CM-7	CM-outlet2	Cone mill 2, outlet sample <0.075mm	1.36
CM-8	CM-outlet2	Cone mill 2, outlet sample 0.075-0.150mm	0.35
CM-9	CM-outlet2	Cone mill 2, Outlet sample 0.150-315mm	0.28
CM-10	CM-Hg-pan2	Cone mill 2, panning bin sample <0.075mm	4.25
CM-11	CM-Hg-pan2	Cone mill 2, panning bin sample 0.075-0.150mm	1.7
CM-12	CM-Hg-pan2	Cone mill 2, panning bin sample 0.150-315mm	2.88

*these samples from the amalgamation bin tails, were expected to have higher gold concentrations, than this range.

3.4.1 Preliminary Analysis of Fire Assay Results

This fire assay result is much lower than expected. Recall that the cumulative total gold recovery from the 4 sets of ore test work (totaling 1000 kg original material), was 18.23 grams of gold , equalling 15.95 grams when we consider 21K purioty (Ie. gold recovery of 15.95 grams/tonne).

However, based on these fire assay derived gold concentrations, (when multiplied by the mass of each size fraction, for all four tests), the assay results suggest total gold lost to tailings of only 1.03 grams. Thus total (recovered using Hg, and total from lost gold) = 16.98.

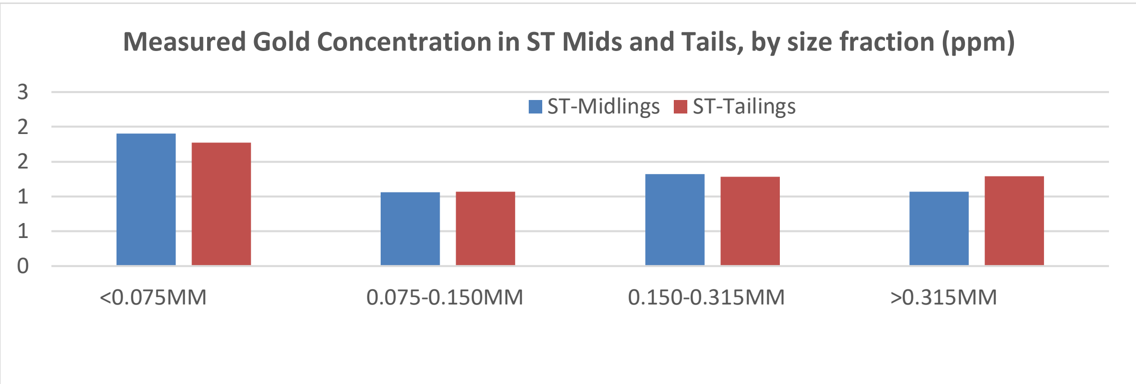
This indicates that Au remaining in Tails (across all tests) comprises only 6 % of the TOTAL gold (recovery + tails = 16.98 grams). This is the same as saying that the mercury methods used during the test work achieved a gold recovery of 94 % (of *total* gold – which seems too high). Similarly puzzling, the "Hg-Pan" Au levels (1.56 – 5.28 PPM) appear to be *lower* values than would be expected.

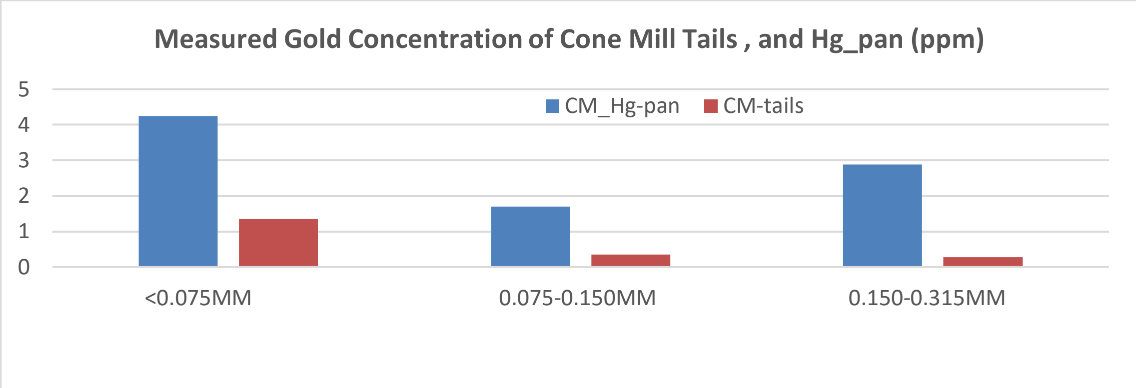
It is not clear what could have caused this result. The lab provided QAQC results including g standard reference materials in the same range as expected, and the estimated accuracy of the fire assay test is 0.01 ppm (~2 orders of magnitude lower than the standard deviation of our dataset in question). Further tests and laboratory analysis on additional sets of tailings are required to re-test this confusing result.

3.5 Gold Assay Results per tailing size fractions

Recall that grain size distribution analysis was made on all samples, before they were pulped and subjected to grain size analysis. This analysis is intended to show us which size fraction, from each type of milling equipment used, contains most of the "lost" gold. Two series of bar graphs below are used to present this result: (1) Average gold concentrations by fire assay, per size fraction - for each method; and (2) Mass of gold lost to tailings, per size fraction, for each method.

Average gold concentrations by fire assay, per size fraction - for each method

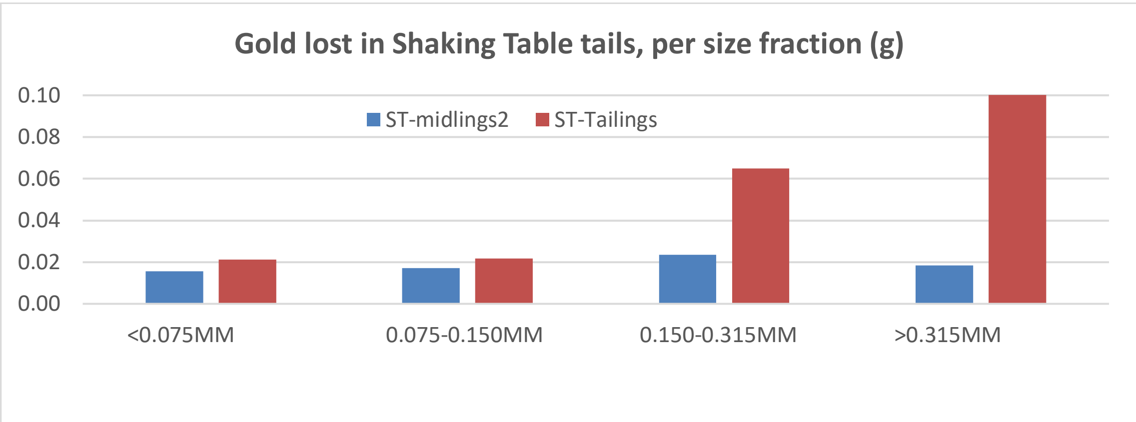


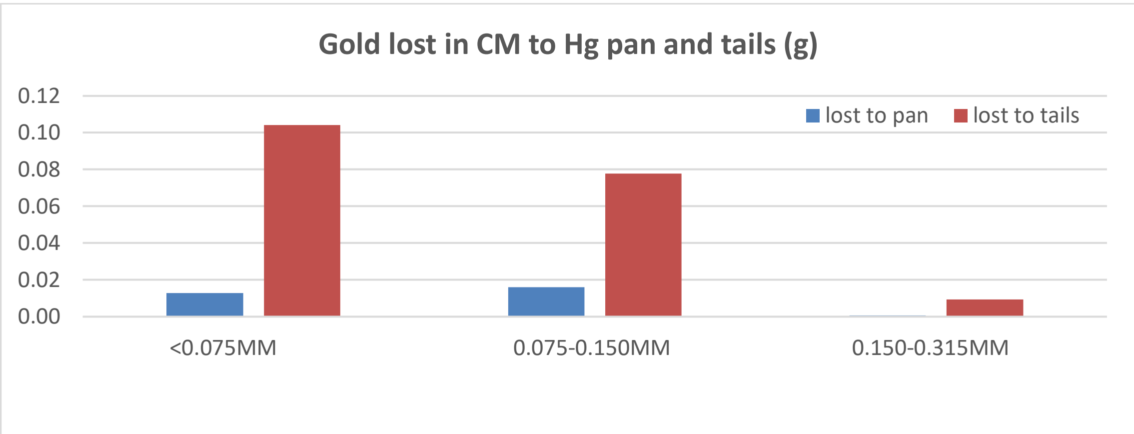


Preliminary Analysis

From the shaking table results it is evident that the shaking table has not concentrated gold in the midlings, compared to the tailings. This is a potentially concerning result which requires further investigation. The CM results indicate higher gold values in the amalgam tailings, and comparatively low gold values in the main cone mill tailings. While this is what would be expected, it would have been expected to measure significantly higher gold values in the amalgamation tails.

Mass of gold lost to tailings, per size fraction, for each method





Preliminary Analysis

From the shaking table results it is evident that the hammer mill -> shaking table method is losing a large amount of gold in the coarse size fraction. This indicates that the hammer mill is not milling the particles fine enough. The large mass of tailings (port 4) contributes to significant gold loss from particles >0.315mm , where the gold has not been adequately liberated.

The cone mill results shows that most of the gold being lost in this system is from the fine fraction of tailings which do not report to the amalgamation bowl, which is what we would expect. The cone mill operation seems to not be effective to capture this very fine gold fraction, which likely exists the mill in suspension, associated with very fine sediment fraction.

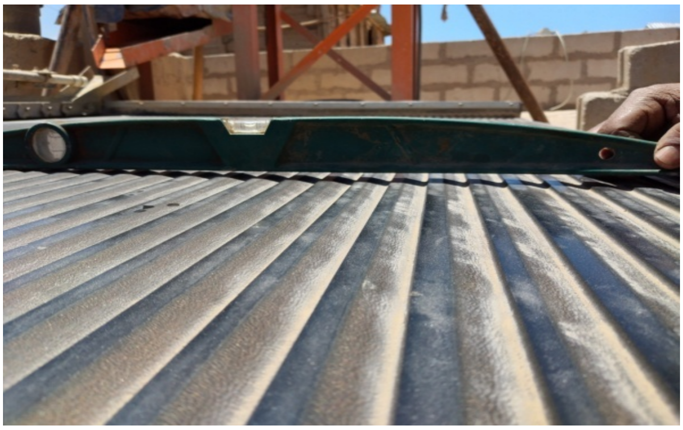
5. CONCLUSION AND NEXT STEPS

The test work and preliminary analysis is very interesting and informative. However, the gold assay results seem to indicate much lower gold content reporting to the tails, than expected. Further test work and analysis is required to resolve this question. It is recommended to collect additional tailings samples from Chami, to repeat the test. When collecting tailings samples care should be taken to ensure (i) they are fresh tailings (i.e. have not been reprocessed); (ii) the type of ore can be documented; (iii) and primary gold recovery (by mercury amalgamation) is known, associated with the tailings in question. This will enable us to compare the mercury recovered gold, to the amount of gold which remained in the tailings.

Note this report was started by Mohamed Abdellahi of Magma but completed by Daniel Stapper of Pact. This report should be treated as preliminary, and confidential.

6. PHOTO APPENDIX

Picture 3 MBMM Shaking table



Picture 4 and 5 MBMM Shaking table slope adjustment

Picture 6: MAGMA team mixing the test ore batch, with shovels to ensure homogeneity

Picture 7 and 8: dividing and weighing the ore into 4 piles

Picture 9 and 10: ore processed with Cone mill

Picture 11: preparing the samples for weighting (washing)

Picture 12: samples in the oven

Picture 13 and 14: weighting the samples

Picture 15 and 16: sieving of crushed ore samples

Picture 17 and 18: samples ready to be sent to laboratory for fire assay

Picture 19: Ore samples prepared and ready for cone mill test-work

Picture 20: Cone mill in operation at Chami

Picture 21: Loading the cone mill

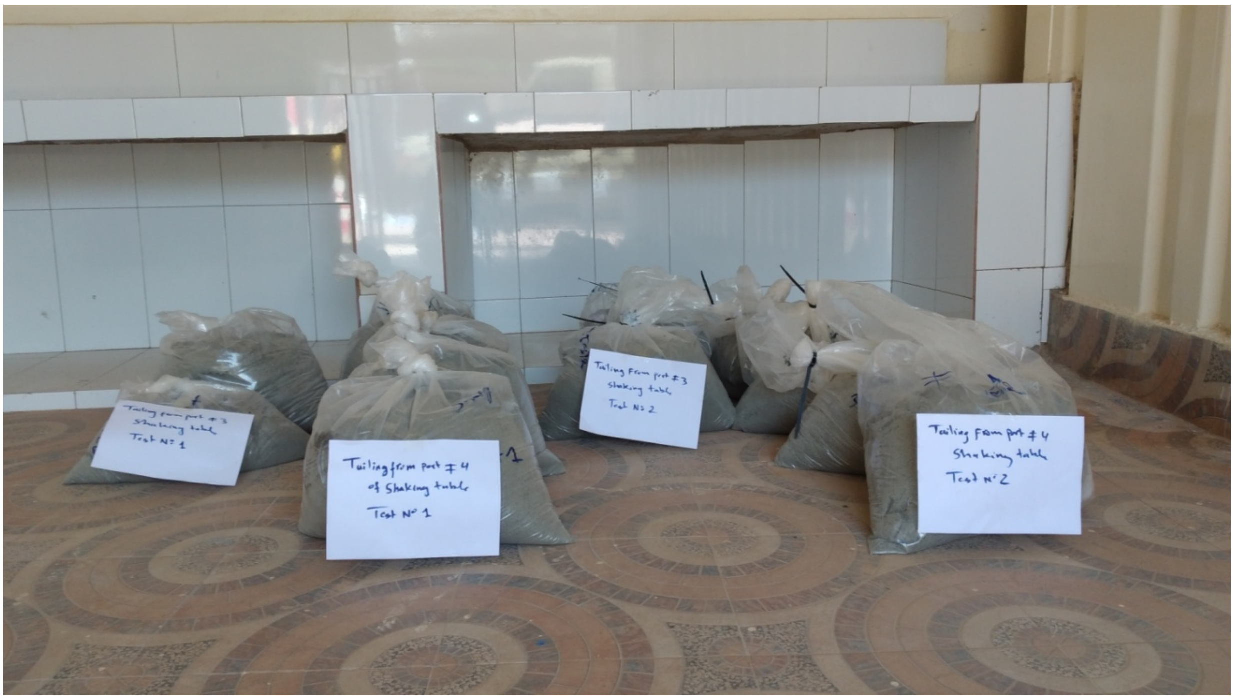
Picture 22: MAGMA team Washing and sampling

Picture 23: MBMM’s turnkey ore processing system

Picture 24: weighting ore samples before test work

Picture 25: mixing and weighting

Picture 26: samples of ore



Picture 27: Samples after sieve analysis

Picture 28: MBMM Jaw Crusher

Picture 29: MBMM shaking table during operation

Picture 30: MBMM Hammer mill in operation

Picture 31: MAGMA work to divide samples and load in cone mills

(End of report)