Reducing the Negative Environmental and Health Impacts from Artisanal and Small Scale Gold Mining in Peru: Strengthening Local Capacity for Community-Driven Remediation

In response to RFA#WHAP-WHAAQPPC-14-002 from
Department of State, Bureau of Western Hemisphere Affairs

Project carried carried out in 2016-17 by
AppelGlobal, Denmark
Elplatek A/S, Denmark

May 2018

Community-driven Artisanal and Small-Scale Gold Mining (ASGM) Remediation Planning in Peru

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Ollachea
test site

Abstract

Cleaning mercury polluted tailings from small-scale gold mining has successfully been carried out at two sites. Five out of ten tests yielded more than 10 percent recovery with peak value of 74 percent. Assays of the tailings showed that most tailings have three-digit high mercury contents with peak value of 480 grams per ton. Those figures are alarming from an environmentally point of view considering that mercury contents in common soil according to World Bank is not supposed to be more than 0.10 gram per ton! Peruvian allowed maximum mercury contents in soil in mining area is 24 grams per ton. Gold contents in tailings peak with more than 50 grams per ton. This shows that large amounts of gold are lost to the environment. Peter Plates indicate a road map towards a cleaner Peru with the extra benefit of gold as a by-product. Peter Plates can process about 100 kg per hour, which obviously is too low compared with the thousands of tons' tailings in the two test sites and presumably in other sites of Peru. However, a combination with Peter Plates and a recently invented large industrial processing plant processing 15 to 20 tons per hour, which has been tested in Nicaragua may pave the road for a cleaner Peru.

Introduction

Small-scale gold mining is the largest contributor to global mercury pollution (AMAP 2013). More than 10 million miners in South East Asia, Africa, Central- and South America use mercury to extract the yellow metal. Their activities provide livelihood for more than 100 million people, but contribute 37% of the global mercury pollution (AMAP 2013). In an attempt to reduce global mercury pollution, the Minamata convention was issued some years ago. More than 130 nations have so far signed the convention and many of those nations have also ratified it. The ratification indicate that the nations intend to take action towards reducing/stopping use of mercury. Small-scale gold miners use mercury to extract gold. During that process there is a direct release of mercury to the environment by evaporation. Even worse, however, is that the dumps (tailings) from small-scale gold mining contain high amount of mercury. That mercury gradually evaporates and give rise to drastic increase of mercury pollution on planet Earth.

Dual action has to be taken:

- Teach small-sale gold miners to use mercury-free gold extraction
- Develop methods to clean the hundreds of thousands of tailings from small-scale gold mining for mercury. These tailings provide a ticking bomb under the health of future generations on our planet.

First issue has been addressed and is currently being addressed in several Third World countries:(www.appelglobal.com). The present project addresses the second action. The project was carried out during two missions to Peru. The first one took place June 20th to 29th 2016 where two test sites were inspected and samples were collected for analytical work. The second mission took place November 14th and ended November 30th 2016 where mercury was extracted from tailings in two selected mining sites by using a gadget developed in Philippines named Peter Plates.

The Peter Plates were developed several years ago in Philippines (Appel et al, 2011). The target of the present project was to test whether the Peter Plates worked on the different types of gold ores occurring in Peru. And to test ways to improve the Peter Plate concept. Gold ores varies immensely from place to place. Commercial mining companies have to test which processing techniques gives the best recovery before they even consider mining the gold ore in question. Similarly, Peter Plate technology has to be tested on the gold ores in question Another aim of the present project was to test whether an organic compound can increase mercury recovery efficiency of the Peter Plates.

The present project is thus a research project aimed at finding avenues for cleaning tailings from small-scale gold mining for mercury in Peru. The present project show a way for reducing the massive mercury pollution in Peru caused by small-scale gold mining, but does not answer all questions yet.

Brief description of the use of mercury in gold extraction

Small-scale gold mining is low tech mining with very primitive tools. When a miner has dug up his gold ore, he crushes it to walnut sized bits either manually or using a crusher. Second step is milling. The ore is ground down to fine powder. This is in order to liberate the gold grains from other minerals in the ore. The small gold grains are difficult to capture for the miners, but if they add mercury to the milling, mercury will amalgamate (“dissolve”) the gold, which makes it easier to recover gold from the ore. The amalgam is then burned whereby mercury evaporates and gold is left behind. Unfortunately, this processing creates problems. During milling mercury is beaten up into mm-sized droplets which have lost the capability to coalesce. That mercury, which is called mercury flour (Fig. 1), ends in tailings (waste dumps) from where it cannot be recovered. Some of the mercury flour floats on water see below and ends in the draining system supplying drinking water (see further down in this text). The small droplets seem impossible to recover which is unfortunate from an environmental and health point of view, but also from a financial point of view. The droplets contain gold which is lost to the environment. This is not only a big problem for the individual miner, but also for the countries in loss of income. If means to extract mercury flour from tailings could be developed, then part of the cost of remediation could be covered by the recovered gold.

Fig. 1. Shiny dots of mercury flour in a spoonful of tailings

Cyanidation

Small-scale gold miners in Ollachea and presumably in many other places in Peru realise that they cannot extract all gold in their ore. They therefore sell their tailings to cyanide plants. In Ollachea truckloads of bags with tailings full of mercury flour were driven away from Ollachea and towards cyanidation planets.

At the plants cyanide dissolves mercury flour, whereby the plant owners can recover part of the gold. During that process a highly soluble mercury cyanide compound Mercury(II) cyanide $Hg(CN)_2$ is formed. This compound is very toxic. The compound also easily disintegrates leaving mercury in solution. That mercury will then over time be released to the environment mainly in aquatic system and from there directly into the food chain ending in the fish stock eaten by the local population.

Mercury flour

Mercury flour released from small-scale gold mining is a serious two sided problems. It creates heavy pollution of planet Earth, and large amounts of gold in the mercury droplets are lost to the environment. The mere fact that mercury droplets are dispersed in tons of tailings and that the mercury flour often floats on water has deterred many to try to recover the mercury flour thereby earning money and saving the environment. Work carried out in Philippines (Appel et al. 2011, reference listed at the end of this report) created a gadget called Peter Plates which could capture part of the mercury flour. Unfortunately, only a fraction could be captured. During the present project improvements of the Peter Plates were made.

Organic compound

One of the reasons that mercury flour is so difficult to extract from tailings is that the individual droplets are coated with a thin film of mercury oxide which prevents them to coalesce. This film was formed during milling of the mercury. If the film could be removed the mercury flour would be easier to capture. A Danish group consisting of Elplatek, Danish Technical University and Appelglobal carried out a research project a few years ago in order to find a way to break the oxide film. They succeeded in discovering a non-toxic organic compound which when mixed with mercury flour remove the oxide film. Tests made in Denmark proved that the method was efficient. When Elplatek and Appelglobal were rewarded the present project from DoS through Pure Earth they decided to use the organic compound on the tailings to be cleaned in Peru.

Source of mercury pollution in Madre Dios

The miners in Ollachea and reportedly also in other parts of Peru mill their gold ore in a very peculiar way. The authors have not seen that method elsewhere in the World. Mining is done in tunnels. The ore stems from systems of quartz veins with slightly different mineralogy. The ore is blasted free in the tunnels and transported to the surface where it is crushed down to walnut size. These steps are like seen in other parts of the World. Next step is to reduce the grainsize to powder so all gold grains are liberated. This is done in a unique way!

The system used is called a quimbalette. It consists of a stone weighing well over 100 kg which has been nicely shaped to fit into a cavity carved into the bedrock (Fig. 2). The cavity is filled with walnut sized bits of gold ore together with water and mercury. Then the stone is pushed into the cavity and a miner steps on the top of the stone. The stone is then rocked back and forth (Fig. 3). During the rocking the stone slowly grind the gold ore whereby gold grains are liberated and amalgates with mercury. Some of the mercury will be flushed out during grinding and ends in a tub next to quimbalette (Fig. 4). In the tub part of the milled material sinks to the bottom and can be scooped up. However, a large part floats out to the environment with its load of auriferous mercury flour. Miners informed us that about half of the mercury they add to the processing is lost to the environment. This rocking is a very time consuming process. It can take the greater part of a day to grind a small amount of ore with the rocking stone. When grinding is finished the rocking stone is pulled out of the cavity and the amalgam is scraped out of the cavity. This is a long and tedious process.

Quimbalettes are widespread throughout the Ollachea valley and presumably also in other small-scale gold mining sites in that part of Peru. There are few advantages and many disadvantages in using the Quimbalette. The only advantage we can think of is that the quimbalette last very long and needs no maintenance. Disadvantages are many:

- It is a time consuming job to produce the quimbalette out of local stone.
- Grinding takes a very long time compared to modern techniques
- A high percentage of gold is smeared out on the stones and cannot be recovered, and is thus lost for the miners
- A high percentage of the mercury in the processing is ground into mercury flour and is released to the environment
- The mercury flour contains appreciable amounts of gold which is lost to the environment

Fig. 2: Quimbalette
The loose stone is
about one-meter long

Fig. 3: Quimbalette being
rocked back and forth

Fig. 4: Drain tub from the quimbalette.
The water is covered with mercury flour

Fig. 5. Detail from the outflow showing
a 2.5 cm wide and two cm thick ridge
of mercury flour

Mercury flour floating on water in a tub similar to the one shown in Fig. 5 has been sampled and analysed for gold by Actlabs, Canada. The result was that the mercury flour floating away to the drainage system contained 75.1 gram of gold per tonne of mercury flour! Comparing this amount of gold with gold grades of 5 to 10 grams of gold per ton normally mined by small-scale miners it is obvious that very large amounts of gold escapes to the environment

The miner shown on Fig. 3 above explained that the amount of mercury flour released from his quimbalette is representative for the other quimbalettes in the area. This is of course of major concern from a health and from an economic point of view. When the grinding in the quimbalette is finished the mercury together with the amalgam is separated from the milled ore by panning. The mercury is separated from the amalgam. The amalgam is heated whereby the mercury evaporates and the gold is left behind. The tailings are sold to cyanide plants.

June 2016 mission

The scope of the first mission was to sample tailings from the sites where we at a later stage shall test whether we can extract part or all mercury flour from tailings. It was also important to get an idea how much mercury the tailings contain. During this phase of the project it was decided where the second phase of the project should take place and what material had to be bought and constructed prior to Phase two. This part of the project which was carried out June 2016, was carried out by the first author with help of Pedro Sifuentes Yepes (Pure Earth's project officer).

Paolita II

The target here is gold ore, which is dug up from the floor of the local river called placer gold. Therefore, no crushing or grinding used. Mercury is mixed with the ore and amalgam is extracted. Four 200 litre metal drums filled with tailings were available for the project. In order to test the efficiency of our mercury extraction process it is obviously vital to know how much mercury and gold there is in the tailings before we start our tests. To get reliable figures of mercury and gold contents in tailings a very thorough sampling programme is required. The principles and advantages of this sampling programme are described in Esbensen and Appel, 2017 (see reference list below).

Ollachea

Next location was in Ollachea, where gold is mined in hard rock out of tunnels. The ore stems from a system of quartz veins with varying mineralogy. The ore is transported to the surface where it is crushed down to walnut size and milled further down to millimetre size in quimbalettes.

Results of June 2016 mission

The samples were sent to Actlabs laboratories in Canada for assaying with the following results:

Analyte Symbol	Au	Hg	Location
Unit Symbol	ppm	ppm	
Detection Limit	0,03	10	
Analysis Method	FA-GRA	ICP-OES	
Peru-1	6,56	60	Laberinto
Peru-2a	12,1	30	Ollachea
Peru-3a	17,1	430	Ollachea
Peru-4a	16,5	100	Ollachea

Gold and mercury contents in tailings from the two sites

The results show that mercury contents in tailings range from 30 ppm up to 430 ppm. This proves that tailings in the investigated areas and similar areas elsewhere indeed provide a ticking bomb under the health of the population of Peru. The Peruvian standards state a maximum of 24 ppm mercury in soil from mining areas (Minam).

Of interest is also the gold contents. They are high. In general, a gold ore containing say 5 to 10 ppm (grams per tons) is high grade gold ore. Gold ores with two digits' ppm gold are really attractive. It shows that the small scale miners only recover a small fraction of the gold in their ore.

November 2016 mission

This part of the project which was carried out November 2016, was carried out by the two authors assisted by Pedro Sifuentes Yepes.

Peter Plates

Peter plates (Fig. 6) is a devise developed in Philippines based on an invention in Australia in the 1850'ies (Appel et al., 2011). A number of copper plates are coated with a thin film of copper amalgam. When tailings with mercury flour are flushed down over the plates mercury flour is captured by the copper amalgam (Fig.7) and can later be scraped off.

Paolita II

At Paolita II two experts from Lima joined the team and watched sampling and processing of tailings: Christian Diaz Alvarez (christian.diaz@qhse-ingenieros.com) and Jaime Lorenzo Costilla Aliaga from the Ministry of Environment in Peru (jcostilla@minam.gob.pe). All requested material was in place at Puerto Maldonado and we could assemble the Peter Plates at our working site near the village of Laberinto in Paolita II (Pedro Ynfante mining concession). One set of Peter Plates was assembled at the site of the samples (Fig. 2). Tailings were sampled and subsequently processed over the Peter Plates.

Fig. 6. Peter Plates at Laberinto

Ollachea

Two sets of Peter Plates were assembled and several groups of local miners were asked for tailings which we could use for our tests. The miners were promised to get whatever mercury and amalgam we collected on the plates. The miners were furthermore welcomed to watch the processing of their samples.

Each batch of tailings was carefully sampled and at the same time split into two equal sized batches. One batch was processed directly at the Peter Plates. Small amounts of organic compound were added to the second batch together with several litres of water. The tub containing the tailings being soaked in organic compound was left overnight. Next morning that batch was processed on the Peter Plates.

Tailings were gradually flushed down the Peter Plates. As soon as a droplet of mercury flour hit the Peter Plates the mercury flour was stuck on the plate (Fig. 7).

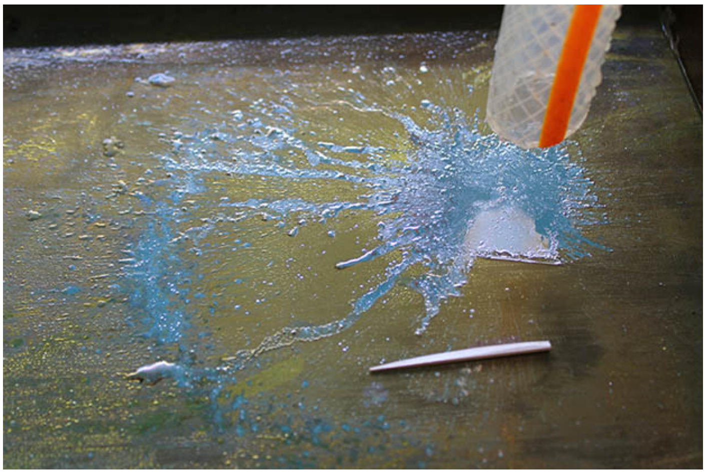


Fig. 7. Mercury flour captured on Peter Plate. 5 cm long toothpick for scale

Processing

All samples obtained for processing on the Peter Plates were split according to the procedure described by Esbensen & Appel 2017. Each sample was split into two halves (Fig. 8). One half to be processed straight away on the Peter Plates whereas the other half was soaked in water and stored until next day in tubs with small amounts of the organic compound. Each sample was allocated a two-digit number e.g. 18 A. The sample to be processed without organic compound would be denoted such as 18 AC whereas the sample treated with organic compound would be denoted 10 AO.

The samples were scooped from the tubs onto the feeder (Fig. 9) for the Peter Plates and from there flushed down the Peter Plates.

Fig. 8 Splitting sample to two tubs with and without organic

Fig. 9. Feeder

When a sample has been flushed over the Peter Plates the captured mercury flour has to be recovered. That can be done by a window scraper (Fig. 10). All four plates must be thoroughly cleaned and all tiny drops of mercury flour must be recovered.

Fig.10. Captured mercury flour is scraped off the plates with a window scraper

When all four plates were cleaned for mercury flour, the mercury was weighed and placed in a small plastic bag. Before the team left Ollachea Pedro Sifuentes Yepes returned the mercury to the rightful owners.

Results

The assay results of the collected samples gave an alarming picture of the situation in Ollachea and Paolita II. Mercury contents range from 60 to 480 grams per ton. These figures are likely to be representative for the tens of thousands tailings littering Peru. Normal levels in soils range from 0.05 to 0.08 gram per ton and should not exceed 0.1 gram per ton (World Bank, 1998). Peruvian maximum allowed mercury in soil from mining areas is 24 ppm (Minam). The mercury in tailings in Peru are thus many orders of magnitude above the Worldwide accepted maximum value for clean soils. The gold contents are likewise critical showing that Ollachea and Paolita II miners loose alarming high amounts of gold every day.

The table below shows the results of processing. Samples Peru 10 to 12 are from Laberinto. The remaining samples are from Ollachea.
First column shows sample numbers e.g. 18 A which is the full sample, which then has been split into two halves 18 AC and 18 AO. Sample 18 AC was processed as it is and whereas second split (18 AO) was treated with the organic compound.

	Au	Hg	Weight of processed	Mercury in processed	Recovered	Recovered
	g/tonne	g/tonne	tailings	tailings in	mercury in	mercury in
Detection Limit	0.03	10	Kilogram	grams	grams	percent
Peru 10 A C	6.54	60	40		Trace	
Peru 11 A O	8.71	60	40		Trace	
Peru 12 A C	8.17	220	35	7.7	6.5	84
Peru 12 A O	2.59	150	35	5.25	14.5	276
Peru 15 A	21	430	200			
Peru 15 A C	31.9	360	100	36	1.7	5
Peru 15 A O	31.3	310	100	31	2.7	9
Peru 16 A	31.6	460	200			
Peru 16 A C	36.1	450	100	45	1.88	4
Peru 16 A O	27	430	100	43	3.8	9
Peru 17 A	45	430	240			
Peru 17 A C	52.7	400	120	48	18.6	39
Peru 17 A O	< 0.03	480	120	57.6	15.1	26
Peru 18 A	20.9	150	200			
Peru 18 A C	25.9	190	100	19	1.5	8
Peru 18 A O	24.7	240	100	24	17.7	74
Peru 19 A	51.1	290	250			
Peru 19 A C	50.8	320	125	40	3.1	8
Peru 19 A O	43.2	260	125	32.5	1.2	4
Peru 20 A	17.6	180	180			
Peru 20 A O	15.2	140	90	12.6	1.9	15
Peru 21 A	11.6	110	60			
Peru 21 A C	25.8	230	30	6.9	1.5	22
Peru 22 A	10.1	140	140			
Peru 22 A C	11.9	120	70	8.4	2.4	29
Peru 22 A O	11.7	130	70	9.1	3.3	36
Peru 23 A	13.2	130	130			
Peru 23 A C	18.7	190	65	12.35	5.8	47
Peru 23 A O	14.4	160	65	10.4	2.3	22
Peru 24 A	27.7	340	166			
Peru 24 A C	26.8	400	80	32	2.7	8
Peru 24 A O	9.91	300	80	24	3.8	16

Column two and three shows the analytical results for gold and mercury grams per tons as analysed by Actlabs, Canada. Detection limit is an indication of the lowest amount of that element that Actlabs can detect with the analytical method they use on these samples. Column four shows the weight of the samples and the splits.

Column five shows how many grams of mercury there was in the samples calculated as follows. E.G. Sample 15 AC analysis showed that this sample contained 360 gram of mercury per ton. We used 100 kg. The content of mercury in those 100 kg is thus 36 grams.

Column six shows how much mercury containing an unknown amount of gold was captured by the Peter Plates.

Column seven shows how many percent mercury (less weight of gold) was recovered from the total amount present in each split. This is calculated as follows e.g.in sample 15 AC. Total mercury was 36 grams. We recovered 1.7 gram of mercury. 1.7 makes up 4.72 percent of 36 grams.

The very high apparent recovery of mercury in Sample Peru 12 A O is strange and the most obvious explanation is that a few drops of mercury was spilled into the sample during processing.

Sample numbering is as follows: e.g. Peru 24 A which is a sample given to us in Ollachea by a miner. We divided the sample into two samples 24 AC which was processed on Peter Plates without using organic compound and in sample 24 AO which was processed on Peter Plates after having been treated with organic compound.

Three samples from Laberinto were processed. Two of them (Peru 10 A and Peru 11 A) contained so little mercury that the Peter Plates did not recover more than a trace which was too little to weigh. Those two samples have been lying around for a very long time so most of the mercury has evaporated. It should, however, be noted that the samples contain appreciable amounts of gold. Sample Peru 12 AC and AO was processed and strangely enough more mercury was recovered than was in the sample. This may be because a little surplus mercury from the coating of the copperplates was not scraped off before processing the two samples. The placer samples processed in Laberinto did not give high recovery of mercury. This is mainly due to the low content of mercury in the samples. The reason for the low mercury content is that those samples have been stored for well over a year in open 200 litre fuel drums. Therefor has most of the mercury evaporated. Those results do thus not indicate that the mercury extraction with Peter Plates is less efficient from placer mining tailings than from tailings from hard rock mining.

Ten samples of tailings from the Ollachea mining site have been processed. The highest mercury recovery rate in processing without organic compound is 47 percent and with using organic compound 74 percent. The lowest recovery rate in processing without organic compound is 5 percent and by using organic compound 4 percent. In the table above it can be seen in which cases use of organic compound was advantageous and in which it was not. Out of ten samples five showed higher recovery of mercury from samples treated with the organic compound.

At the present time no explanation can be offered at to these differences. One avenue is to investigate the mineralogy of the different samples (see section below).

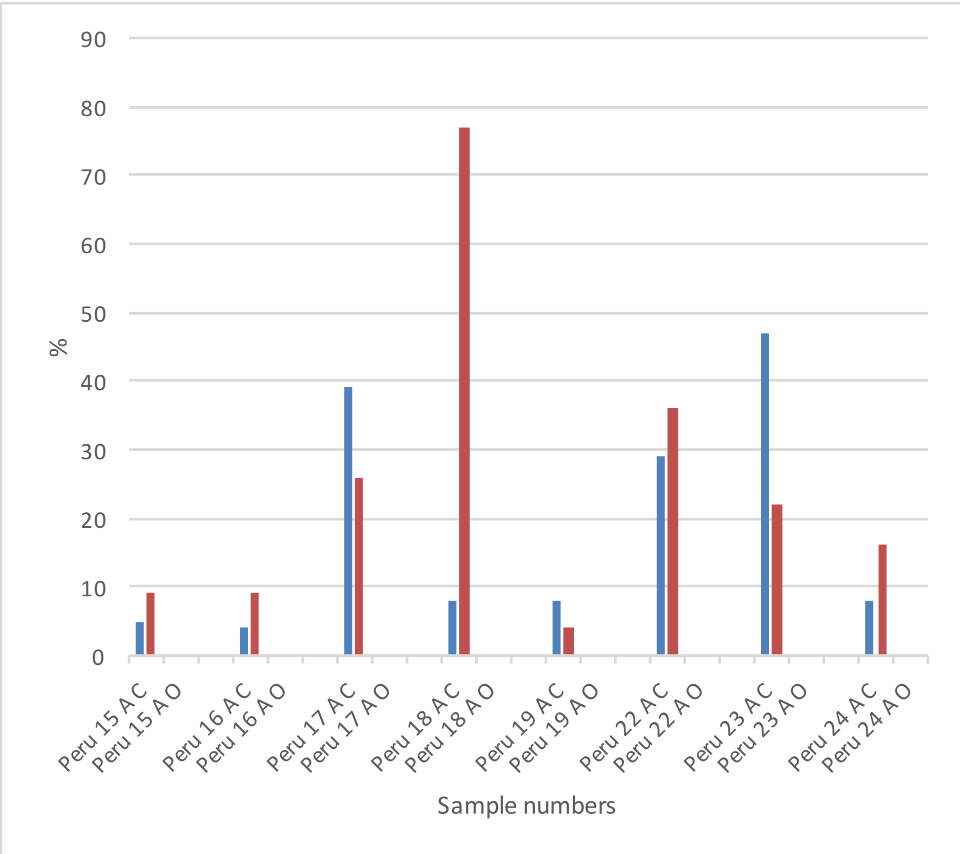


Fig. 11. Recovery of mercury with (red) and without (blue) organic compound

Figure 11 shows how many percent of the total mercury in the samples was recovered by the Peter Plates. The column in blue is tailings not processed with organic compound whereas the red columns show recovery in percent from tailings treated with organic compound. It is obvious that the organic compound improved recovery in most samples. However, working without the organic compound will also recover large amounts of mercury in three out of eight samples.

Mineralogy

Mineral composition

Prior to the mineralogical investigations the samples had to be dried. That is a time consuming job which has to be done under absolute thermal control. The samples were wet from water which is easy to dry, but they also contained mercury which requires higher temperatures for drying and safe exhaust systems. That drying requires tight control over temperature. If the drying temperature is too high some of the minerals present may react and transform. This would influence the mineralogical studies below. The drying procedure was carried out at Elplatek A/S

The mercury recovery rate of the tested tailings varies widely. One explanation could be that the mineralogical composition of the samples could influence the recovery. In order to test this hypothesis very exhaustive x-ray mineralogical investigations were carried out by Elplatek at Geological Institute, University of Copenhagen (see Appendix and table below). The aim of this investigation was to discover whether samples with low mercury recovery on the Peter Plates differ significantly in mineralogical composition from samples with high mercury recovery. There seems to be no significant difference between the two groups apart from a slight grouping of samples containing high amounts of the iron sulphide pyrrhotite yielding low recovery (samples 16 and 19) compared with samples with slightly lower contents of Pyrrhotite (samples 17, 18, 22 and 23). This difference is so low so it is not considered significant.

Samples 10, 11, 12, 13 and 14 have a mineralogical composition vastly different from the other samples. These sample are from river beds whereas the other samples are from hard rock gold ore.

It must be concluded that the mineralogical studies unfortunately not present clues to explain the differences of mercury recovery from one sample to the next. Another avenue is to study whether the degree of milling the gold ores can explain the different recoveries. Different ores react differently to milling and one miner may mill better than another. A study of degree of milling of the samples should be carried out in the future. Attached to this report are two zip files with results from the mineralogical investigations of the tailings used by the project.

sample	ilmenite	hematite	magnetite	quartz	zircon	riebeckite	feldspars	chlorite	mica
10A	49(3)	22(1)	6.6(4)	11.9(6)	7.6(4)	3.3(5)	0.3(2)	Tr.	Tr.
11A	51(2)	23(1)	6.2(4)	8.5(4)	6.7(3)	3.6(5)	0.3(2)	Tr.	Tr.
12A	45(2)	21(1)	7.3(5)	13.4(7)	8.5(4)	4.1(5)	0.3(2)	Tr.	Tr.
13A	46(2)	22.1(8)	7.0(4)	12.7(5)	8.2(3)	3.2(4)	0.2(2)	Tr.	Tr.
14A	50(2)	22(1)	7.2(4)	10.6(5)	7.2(4)	2.2(4)	0.2(2)	Tr.	Tr.
sample	Pyrrhotite	Pyrite	Arsenopyrite	Quartz	Mica	Chlorite	Jarosite	Sulphur	Rutile
15A	5.0(2)	0.4(1)	1.3(2)	67.0(5)	19.5(7)	5.5(3)		1.0(2)	0.3(1)
15AC	5.5(2)	0.4(1)	1.3(2)	68.5(5)	18.1(7)	4.9(3)		0.8(2)	0.5(1)
15AO	4.6(2)	0.5(1)	1.9(2)	70.5(6)	16.3(8)	4.4(4)		1.7(3)	0.2(1)
16A	7.2(2)	0.4(1)	2.6(2)	63.4(7)	19(1)	4.3(5)	1.7(3)	1.6(3)	0.3(1)
16AC	6.1(2)	0.5(1)	2.6(2)	65.5(7)	16.9(9)	4.6(5)	1.9(2)	1.5(2)	0.3(1)
16AO	9.0(3)	0.3(1)	2.7(3)	63.0(6)	16.6(7)	4.9(5)	1.0(2)	2.0(3)	0.4(2)
17A	4.4(2)	0.4(1)		62.7(5)	25.5(6)	4.4(3)	1.3(2)	0.8(2)	0.4(1)
17AC	5.8(2)	0.3(1)		68.2(6)	18.8(7)	4.1(4)	1.4(2)	1.0(2)	0.4(1)
17AO	6.3(2)	0.3(1)		65.4(6)	19.3(8)	5.3(5)	0.8(2)	2.3(3)	0.3(1)
18A	3.5(2)	0.5(1)	1.3(2)	66.1(5)	21.0(6)	4.8(3)	1.2(2)	1.1(3)	0.4(1)
18AC	4.6(2)	0.4(1)	1.7(2)	69.9(6)	16.1(7)	4.4(3)	1.7(2)	0.8(2)	0.4(1)
18AO	3.7(2)	0.4(1)	1.4(3)	67.7(6)	18.3(8)	5.1(4)	2.3(2)	0.8(2)	0.5(1)
19A	6.8(2)	1.6(1)		55.9(5)	26.6(7)	6.6(4)	0.6(2)	1.4(2)	0.5(1)
19ACa	8.3(2)	2.1(1)		57.4(6)	22.1(9)	6.5(4)	1.3(2)	1.9(3)	0.3(1)
19AO	7.5(2)	1.8(1)	1.9(3)	55.9(6)	22.7(9)	7.0(5)	1.3(2)	1.5(3)	0.4(1)
20A	4.4(2)	0.2(1)	1.9(2)	74.9(6)	11.7(7)	3.3(4)	1.5(2)	1.5(2)	0.4(2)
20AO	3.4(2)	0.3(1)	1.7(3)	74.6(8)	11(1)	5.1(6)	1.4(2)	2.5(2)	
21A	1.1(2)	0.3(1)	0.5(1)	58.4(4)	30.6(6)	7.3(3)	1.2(2)		0.6(1)
21AC	1.8(2)	0.5(1)	0.8(2)	63.6(6)	21.6(8)	6.6(4)	3.5(2)	1.0(2)	0.5(1)
22A	5.5(2)	0.3(1)	0.9(2)	65.7(5)	20.6(7)	5.4(3)	0.4(2)	0.8(2)	0.3(1)
22AC1	3.9(2)	0.5(1)	1.0(2)	69.4(6)	16.6(8)	5.4(4)	1.5(2)	1.5(2)	0.2(1)
22AO	4.3(2)	0.4(1)	1.2(2)	69.1(7)	16.1(9)	5.1(5)	1.4(2)	2.1(2)	0.4(1)
23A	3.4(2)	0.4(1)		69.2(5)	18.0(7)	6.5(3)	1.1(2)	1.1(2)	0.3(1)
23AO	3.2(2)	0.5(1)		72.7(7)	14.2(8)	6.1(4)	0.9(2)	2.1(3)	0.4(2)
24AC	4.7(2)	0.8(1)	1.1(2)	68.8(6)	15.5(8)	4.5(4)	1.7(2)	2.5(3)	0.4(2)
24AO	5.5(2)	1.2(1)	1.8(2)	68.4(7)	13.9(9)	4.6(5)	1.9(2)	2.3(3)	0.5(2)
31A	7.1(2)	1.0(1)		50.0(5)	28.8(7)	8.3(4)	0.9(2)	1.3(2)	0.5(1)

Refining the Peter Plate concept

Reducing the production costs of the copper plates

Copper is an expensive metal and in order to bring the cost down on the Peter Plates Elplatek A/S tested how to reduce the costs of the Peter Plates. The solution could be to use steel plates and coat them with copper. If the copper coating is too thin it may be worn off during mercury flour capturing. If it is very thick the financial bonus is gone. We have focused on the copper thickness to extend the lifetime of the positive effect from coppers affinity to capture mercury floor. We therefor considered whether steel plates coated with copper is a way to reduce the price of future manufacturing Peter Plates.

Testing of copper thickness has been made by plating copper on steel plates in our lab, in different thicknesses, to find which thickness which gives the best wear resistance. The copper bath used is based on an alkaline copper bath which is available from most suppliers of plating chemicals. Plating has been done at 1 Amp/Dm^2. See photo from laboratory below.

Table below shows the results.

Test of copper thickness

Copper	Time	Abrasion	Resistance to wear
5 microns	10 min	1	Poor
10 microns	20 min	1	Poor
20 microns	40 min	2	Good
40 microns	80 min	2	Good

Elplatek A/S Laboratory copper testing

It shows that thickness under 10 microns will be too thin to prevent wear, but a thickness around 20 microns seems to be useable for long time processing tailings.

The wear test has been done at by Elplatek A/S Danish Technical University where students have helped.

The tests show that copper plating of steel may be a feasible way to reduce costs of producing Peter Plates

Comparing recovery with and without DETOX

The organic compound (deoxidizer) is non-toxic and non-expensive. It is often used in daily cooking. It is important in which amounts it shall be added to the processing. Testing of the right DETOX concentration has been carried out in the laboratories at Elplatek A/S, where different concentrations have been tested against a fixed mercury concentration. The DETOX is dissolved in water, and it is easily to work with. DEOC removes the thin oxidation on the mercury, so it will be easier to capture.

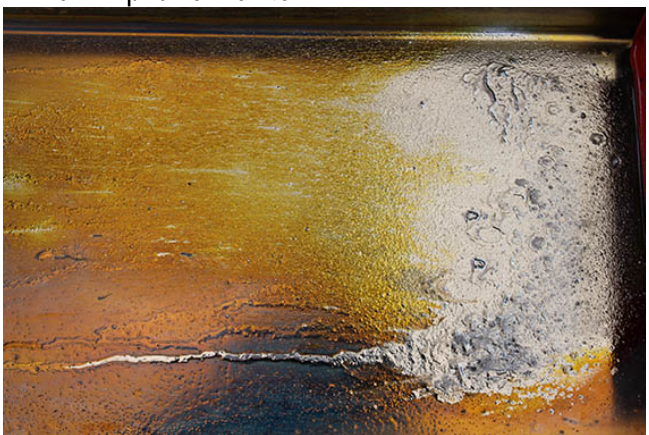
The Danish consortium Danish Technical University, Elplatek and Appelglobal found that the DETOX removed the oxide film on mercury flour. This consortium plans to seek patent on the method.

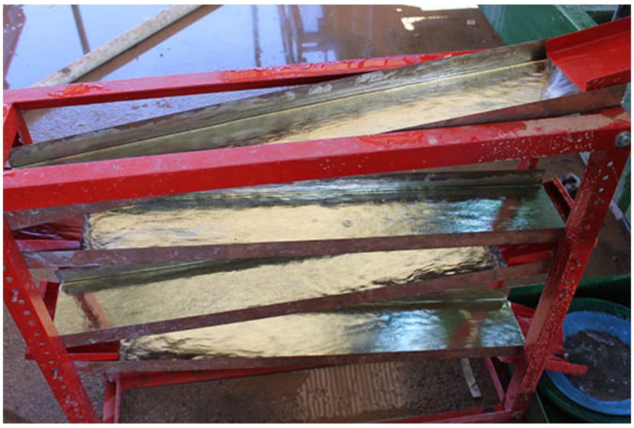
Table below shows the results.

Test with deoxidizer DEOC

DEOC g/L	Hg concentration before	Hg concentration after
0,5	2,5	1,9
1,0	2,5	1,5
1,5	2,5	1,1
3,0	2,5	1,1

It shows that a concentration of 1,5 g/l gives good results, and extending it only gives minor improvements.





Peters Plates capturing mercury flour

Conclusions

This project is a first test of the capability of Peter Plates to extract mercury flour from tailings in Peru. The tests were done at two sites: one placer gold ore (Laberinto) and one hard rock gold ore (Ollachea). Mercury was extracted from ten samples with varying success rate. In five samples addition of an organic compound proved to increase mercury recovery on the Peter Plates. An example is sample 18 where extraction without using organic compound yielded a recovery rate of 8 %. Adding the organic compound increased recovery of mercury to 74%. Highest recovery rate without using organic compound was 47%. Five out of ten samples yielded recovery percentage well over 10 percent. They worked best using the organic compound, but also without using this compound.

It is obvious that using Peter Plates to extract mercury and gold from tailings in Peru is a first step towards a cleaner country and at the same time it will increase earnings of the small-scale gold miners. The Peter Plates worked absolutely fine on Ollachea gold ore. The present results indicate that the method works fine on hard rock gold deposits and less efficient on placer deposits. A future research project may find out why placer gold deposits are less amenable to the mercury-free gold extraction with Peter Plates.

Next step

Brief description of large scale cleaning of tailings for mercury from small-scale gold mining

Peter Plates can extract mercury and auriferous mercury flour from tailings at a rate of about 50 to 100 kg per hour. This is fine, but on a country and global scale where heaps of mercury polluted tailings containing thousands of tons of tailing litter third World continents it is not efficient.

A Danish American group has with generous funding from Danish Ministry of Environment and Food in 2016 and 2017 carried out tests in Nicaragua of a set-up with a large industrial plant combined with the Peter Plates.

The Industrial plant MRP (Mercury Recovery Plant) is fed with 15 to 20 tons' tailings per hour. The MRP extract in the order of 50 kg of heavy minerals as well as mercury from the tailings. The 50 kg concentrate is fed to the Peter Plates where mercury and mercury flour is captured.

Fig. 1 Mercury recovery plant

Mercury Recovery Plant (MRP)

Separation takes place through a series of spirals where the concentrate from each spiral is directed to the next spiral. The tailings from the two first spirals rougher and cleaner is directed to the scavenger which is a centrifuge. The concentrate from the centrifuge is directed to the last spiral which is the finisher (see photo below). From 15 to 20 ton of tailings MRP produces in the order of 50 kg heavy minerals including mercury and gold.

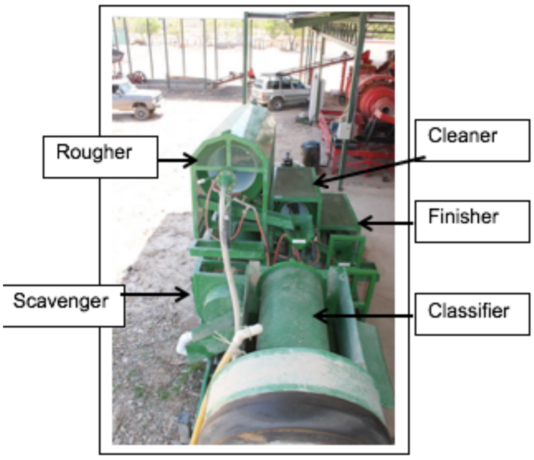


Fig. 2 Spirals in the MRP used for producing heavy mineral concentrates

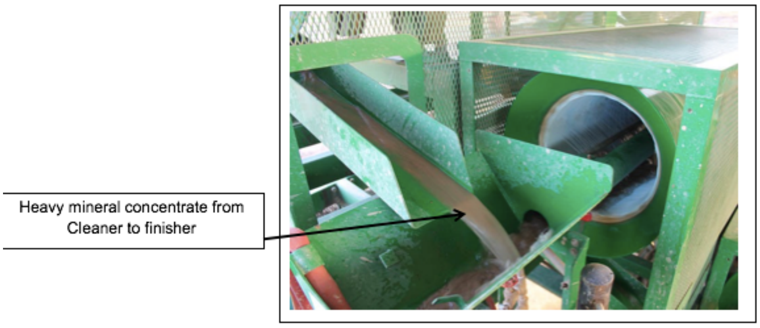


Fig. 3. Heavy mineral concentrate from Cleaner to Finisher

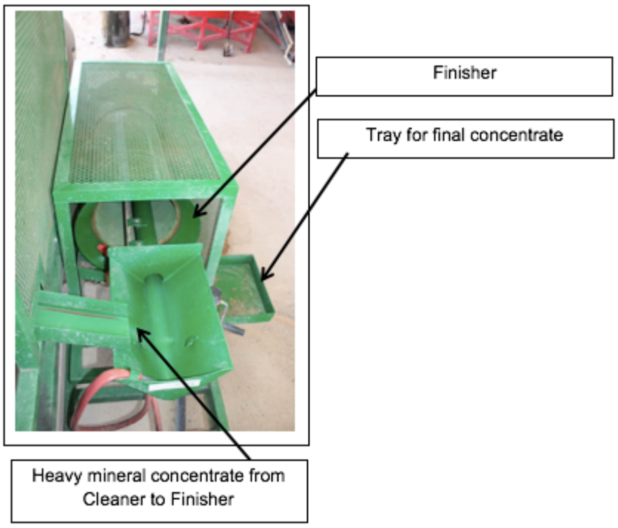


Fig. 4

Fig. 5. Peter Plates attached to the MRP outlet of heavy minerals including mercury

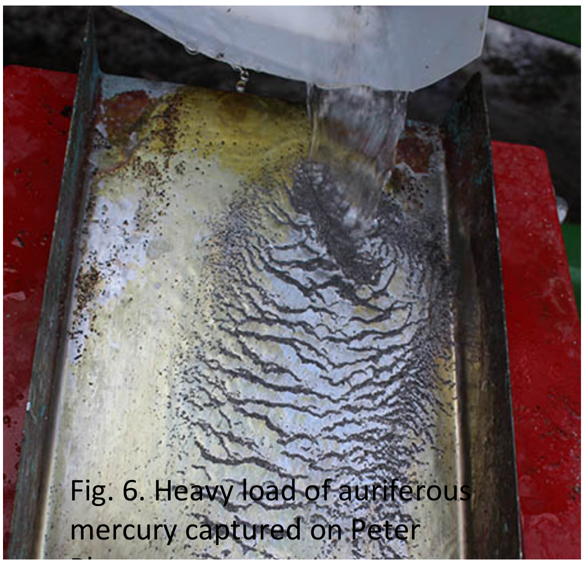


Fig. 6. Heavy load of auriferous mercury captured on Peter

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Appendix

Analysis report
25 Sept. 2017

Ordered by:
Peter Appel for
Jan Boye Rasmussen
Adm.Direktør / CEO
Elplatek A/S
Samples: 35 samples from Peru

Method:

Powder X-ray Diffraction with quantitative phase analysis of the bulk samples.

Table 1. Instrumental parameters

instrument	Bruker-AXS powder diffractometer D8 Advance
radiation	Cu X-ray tube
monochromator	Primary beam Ge111
wavelength	1.54059 Å
geometry	Bragg-Brentano
detector	LynxEye, linear PSD, 3.3^{o} opening
Divergence slit	Fixed, 0.45^{o}
Measuring range	5 – 90^{o} 2θ
step	0.02^{o}

Rietveld method (Program Topas 4.1, Bruker-AXS product) was used for the determination of crystalline mineral proportions.

Results:

The weight percentages of minerals are given in the Tables 1 and 2, which are the supplement to this report.

The samples can be divided in two major groups. Samples 10A to 14A are composed mainly of iron and iron-titanium oxides with additional quartz, zircon and minor other minerals. The other samples are dominated by quartz with minor chlorite, variable contents of mica and iron and iron-arsenic sulphides and other minerals.

Supplement: Tables
XRD diagrams (measured pattern in blue, calculated in red, with indication for positions of diffraction lines of minerals)
Full results of the Rietveld analysis

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Leader, XRD Laboratory