DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/127

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

G E U S

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MINISTRY OF CLIMATE AND ENERGY

GEUS

Contents

Summary

This report presents the results of experiments involving the revival of an old method for removal of mercury from tailings after gold extraction by small-scale miners

Numerous tailings from small-scale gold mining are found throughout the Philippines. The tailings have proved to contain large amounts of mercury (up to 250 gram per ton). Furthermore, the tailings contain large amounts of gold locked-up in the mercury - up to 16 gram per ton. The mercury occurs as mercury flour (globules less than a millimetre across). Mercury flour is produced through milling of gold ore, when the mercury is added to the milling drums (whole ore amalgamation). The globules “hidden” in the mercury flour cannot be recovered by small-scale gold miners in any environmentally benign ways.

No commercial methods are available for extracting mercury flour from tailings or polluted soils. Many years ago in Australia and Brazil gadgets were constructed to clean mercury from polluted soils. The gadgets soon went out of production.

A modified version of the Australian so-called State Battery was constructed in Benguet, Northern Philippines. The Filipino construction was named ‘Peter Plates’ by the Benguet Federation of small-scale miners, who were very active in testing the plates.

Successful tests of the ‘Peter Plates’ have been carried out in Benguet, Philippines. The first took place in September 2010 and the second in October 2011. The tests showed that up to 60 percent of the mercury flour can be recovered by a primitive pilot set up.

These results are satisfying but to make sure that the method can be applied in realistic and real conditions, it is necessary to take the next step to optimise the various parameters of the ‘Peter Plates’, and scale them up to industry size for commercial use.

When an industrial scale set of ‘Peter Plates’ has been constructed, it can start to clean the tailings from one end of the Philippines to the other. The cleaning process will apart from cleaning the country, also recover large amounts of gold. This will compensate for all cleaning up costs and properly handled could create a handsome profit.

Since the Peter Plates are a further development of the State Batteries used in Australia 150 years ago, it will not be possible to patent the Peter Plates. The concept can thus be used by everyone for free.

Background

Small-scale mining (ssm) is carried out by an estimated 100 million people in South America, Africa and Asia. A large proportion of the miners extract gold. The final step in gold production is extracting gold from a mineral concentrate produced by mining with primitive methods. This is mostly done using an amalgamation process relying on heavy use of mercury.

In different countries slightly different techniques for the extraction of gold with mercury are employed. In most African countries the small-scale miners use approximately one gram of mercury to extract one gram of gold. In the Philippines and Indonesia a ssm typically use 20 to 50 gram of mercury to extract one gram of gold.

The reason for this discrepancy is differences in working methods. In Africa, the small-scale miners grind their ore in ball or rod mills. Then they concentrate the heavy minerals including gold. Next step involves adding mercury to the concentrate in order to extract the gold. Mercury amalgamates with the gold. The amalgam is burned, whereby mercury evaporates and gold is left behind.

In the Philippines and Indonesia a different method is used. The ore is milled for a couple of hours in a rod or ball mill. Kilograms of mercury are added to the mill, which runs for one more hour. The thoughts behind this process are understandable. The miners argue that in this way the ore and mercury is thoroughly mixed and mercury thus has a better chance of capturing all the gold.

The process is actually quite different. Mercury does indeed capture gold, but a problem is created: When mercury is milled with hard metal rods or balls, the violent repeated pounding of the mercury causes this to form tiny droplets called mercury flour. The mercury particles are less than a millimetre across. This flour is so fine-grained that the mercury drops cannot sink to the bottom and coalesce. The ssm can therefore not recover it (Fig. 1). All mercury flour (and the gold associated with it) ends up in the tailings.

Figure 1. *Mercury flour in tailings. The shiny mercury drops are less than a millimetre across. Scale 1 cm.*

The ssm are aware of this and consequently the tailings are sold to a cyanide plant, where they expect to extract more gold. The problem is that cyanide cannot extract gold, which is amalgamated inside mercury flour. All the gold hosted in mercury flour is therefore lost to the final tailings (see the chapter on tailings dams).

Tailings dams with high amounts of mercury litter many parts of the Philippines. They are not properly secured, and there is a high risk that the dams collapse during earth quakes or typhoons and that the tailings slide downhill towards the coastal areas. Streams draining the tailings dams capture and distribute the mercury into the lower-lying drainage system, which among other functions, importantly supply rice paddies with water. Unfortunately, the rice plants uptake the mercury during their growth and becomes tainted food, often unsuspected by the people living on the rice.

The amount of mercury released to the environment by ssm in the Philippines is enormous:

In 2001 Mr. Samuel T. Ramel, Ambassador of the Philippines in Switzerland, submitted a short report from the Department of Health in Manila to United Nations Environmental Programme in Geneva. The report was entitled:

"Health and environmental impact of mercury in the Philippines"

The report documented that 140 tons of mercury were released annually to Butuan Bay and Davao Gulf on Mindanao. The mercury was released upstream by small-scale gold miners.

In 2007, a small World Bank financed project on gold extraction methods in small-scale gold mining was carried out in Zamboanga del Norte and in Camarines Norte (Perez *et al*., 2007). The report documents that in two small mining communities a total of 5 tons of mercury is released to the environment every year.

Extrapolating these figures to all ssm communities gives an estimated yearly release to the environment in the Philippines in the order of 200 to 500 tons of mercury.

The worst documented mercury disaster in the history of mankind is the Minamata disaster in Japan. Over a period of 34 years 623 tons of mercury was released to the environment, later seen to give rise to serious health problems. Thousands of people died, and many more children were born heavily mentally and/or physically disabled. Note that although it is an uncertain estimate, it seems that the release is orders of magnitude higher in the Philippines than the release estimated for Minamata Bay.

It is evident that unless immediate action is taken, the Philippines will experience a mercury disaster more severe than the Minamata disaster. Already in certain parts of Mindanao up to 40% of the population are polluted with mercury (Appleton *et al*., 2006) (Fig. 2).

Two actions must be taken:

- Small-scale miners must be taught to use a mercury free gold extraction method. Such a method is well established in Northern Philippines. A training program is presently being carried out, in which local and regional health providers and communities learn to identify symptoms of mercury poisoning and other relevant health issues in relation to mercury toxicity. Both projects started mid-2011 and will reach their conclusion mid-2014. The projects are carried out by Danish NGO Dialogos, Philippine NGO Bantoxics, GEUS and Benguet Federation of small-scale miners.
- The numerous existing tailings dams must be cleaned of mercury flour.

This report deals with a realistic way of achieving success with the second action.

Figure 2. *Twelve year old girl multi handicapped from mercury poisoning in pre-natal state, Mindanao.*

Tailings dams

As described, the process of gold extraction by milling with mercury, results in poor recovery of gold, because a large part of the gold ends up in mercury flour from which the gold cannot be extracted, not even by cyanide. This is clearly demonstrated by the analyses of samples of tailings before and after treatment in a cyanide plant (Table 1).

Table 1. Analysis of tailings for gold and mercury

GEUS sample no.	Type of tailings sample	Gold gram/ton	Mercury gram/t
494855	Before cyanide treatment	16.5	250
494856	After cyanide treatment	13.6	200
494857	Before cyanide treatment	14.0	120
494858	After cyanide treatment	13.1	73

Tailings dams therefore contain a foul mixture of mercury flour and cyanide. Fortunately, the cyanide reacts with the atmosphere and becomes harmless after a short time. It is a different matter with the mercury, which is initially in metallic form but then is transformed into methylated mercury by microbes, when metal mercury enters the drainage system. This mercury compound bio accumulates and thus is capable of ending up in plants, fish and humans.

Tailings dams are common in many parts of the Philippines. They vary in size from a few to several tens of metres across and can be up to 20 metres deep (Fig. 3). In order to prevent them from sliding downhill, they are often “secured” by plastic bags filled with tailings. As can be expected, these plastic bags do not last long. It is certain that over time all the dams will deteriorate and the tailings will flow downhill and downstream. Eventually the contaminated material will end in the ocean and the mangrove swamps hugging parts of the Philippine coastline. The mangrove swamps serve as hatching grounds for fish and shell fish.

It is not only this transport of the mercury flour that should be considered a hazard to the environment and human health. Rain water percolating the tailings produce soluble mercury compounds, which in dissolution travel downstream and end in drinking water, some of which will flood rice paddies, where the rice will uptake the mercury; the rice grains will be contaminated even before harvest. Silt from rice paddies has been found containing high amounts of mercury (Appleton et al., 2006).

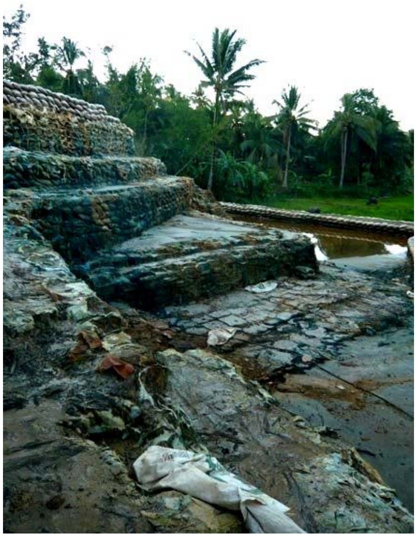


Figure 3. *Large heap of mine tailings ”secured” with deterioating plastic bags filled with tailings.*

Gold contents in tailings

The 300.000 small-scale miners in the Philippines produce yearly around 30 tons of gold. The associated yearly release of mercury caught in tailings is estimated to be in the order of 200 to 500 tons. A very conservative estimate of the gold content of the tailings based on the figures in Table 1 is in range of 5 to 12 tons. This is the amount of gold that is released, or lost, to the tailings every year. This has a market value of 275 to 700 million US$ (Gold price 1800 US$ per oz, mid-August 2011), lost every year for the Philippine economy.

This clearly demonstrates that there are at least two strong incentives for cleaning the tailings of the Philippines from mercury:

- Health of the Filipinos and environment of the Philippines will benefit
- The economy of Philippine will benefit

How to extract mercury flour from the tailings?

The crucial problem is how to extract mercury flour from the tailings. Presently, no commercial methods are available.

There are unfortunately some small-scale miners in the Philippines, who have realised that they lose substantial amounts of gold to their tailings. They have developed a very simple, inexpensive, but very unfortunate way to recover the gold hosted in the mercury flour. They spread rice hull over a metal plate and sprinkle it with kerosene. Then they place a layer of tailings on top of the rice hull and ignite the kerosene. The heating causes all the mercury flour to evaporate (and subsequently play havoc with the environment) while the gold is left behind (Figs. 4) to be recovered by simple methods. It is a very dangerous process, which will boost the mercury pollution of the Philippines, if it is allowed to spread and evolve.

Figure 4. *Rice hull spread over a metal plate. Kerosene is added. Tailings are spread over the rice hull and the kerosene is ignited. The mercury evaporates and gold can be recovered.*

Constructing plates for extracting mercury

Around 150 years ago the Australian government had problems with small-scale gold miners polluting Western Australia with mercury. The government constructed a gadget called State Battery, which reportedly could extract mercury from soil and tailings. In Brazil, many years ago, a company produced copper and silver coated copper plates, which were meant to clean soil for mercury spill. There was not a big market for the plates, so production soon stopped. The Australian and Brazilian systems used the same principle where the soil or tailings were flushed with water down a system of plates covered with a thin layer of amalgam. The amalgam supposedly captured the mercury.

It was decided to make a Filipino version of the Australian State Battery and the Brazilian copper plates. This was done in 2010 in Benguet, Northern Philippines. Benguet Federation of small-scale miners coined the name 'Peter Plates' instead of State Battery. The plates were arranged as seen on Fig. 5 in a position that allowed tailings to be flushed down one plate to the next. A container hosting the tailings was placed on top of the plates, and a hose flushed tailings down on the plates with a constant water flow. Very quickly mercury flour is being captured, building up mercury patches on each plate (Fig. 5). At intervals the process is stopped and the captured mercury is scraped off with a rubber scraper.

Two types of plates were tested.

- Copper plates coated with copper amalgam
- Copper plates electroplated with silver and coated with silver amalgam

Two ways of coating the plates with amalgam was tested:

- Coating using mercury nitrate
- Coating using activated mercury

Figure 5. *Peter Plates. Tailings being flushed down the plates and mercury is captured by copper amalgam on the plates. Scale 1 cm*

Coating with mercury nitrate

The coating was carried out in a village outside Baguio, Philippines using the following process: Metallic mercury was dissolved in concentrated nitric acid. The resulting strongly acid solution of mercury nitrate was applied over the rinsed copper plates. An immediate reaction between nitric acid, mercury nitrate and copper produced a thin layer of copper amalgam coating the copper plate, and a bluish green copper nitrate, which was easily washed away with water (Fig. 6)

Figure 6. *Mercury nitrate is added to the copper plate forming copper amalgam and blue green copper nitrate*

Investigations in scanning electron microscope (SEM)

The plates are almost completely covered by copper amalgam. The crystal size is mostly in the order of 10 to 30 µm and the crystals are densely packed. It is obvious that there is a very large surface area of amalgam which can capture mercury flour. The SEM investigation also showed that the amalgam coating varies in thickness from 5 µm to more than 30 µm.

A detailed description of these investigations is shown in Appendix 1.

Coating with activated mercury

Working with concentrated nitric acid is not very pleasant, nor safe. It was therefore decided to test another method of coating plates with amalgam. A set of copper plates and another set of copper plates, which were electroplated with silver, were used for laboratory testing. The reason for testing two types of plates, copper and silver was to test, which types of plates would obtain the most complete coating with amalgam and to test whether a coating of copper amalgam (Cu-amalgam) was more efficient to capture mercury flour than silver amalgam (Ag-amalgam).

The process chosen was coating with activated mercury. Metallic mercury normally has a very high surface tension and, when applied on a plate, will just lie as drops on the surface (Fig. 7). If, however, mercury is activated, the surface tension is reduced, allowing mercury to spread thinly over the metal plates (Fig. 8).

The mercury was activated as follows:

A small container was filled with salt water (NaCl). A few tens of grams of mercury were added. The mercury was set to be the cathode and a graphite stick was the anode. The electrodes were connected to a 12 volt car battery for 15 minutes.

The activated mercury was scooped onto the cleaned copper plate and immediately covered the whole plate in a thin layer, which rapidly reacted with the metal beneath. After some time surplus mercury was scraped off, leaving the copper coated with a thin sheet of copper amalgam.

The same procedure was followed with a copper plate electroplated with silver. On that plate, activated mercury similarly easily amalgamated with silver.

Investigations in scanning electron microscope

A plate coated with copper amalgam by activated mercury was investigated in SEM. The coating was perfect. The plate was completely covered with densely packed crystals of amalgam. The crystals were in the order of 30 µm big and showed well developed crystal faces. A detailed description is given in Appendix 2.

Next, a plate coated with silver amalgam by activated mercury was investigated in SEM. The result is perfect coverage with silver amalgam. The amalgam is very fine with crystals in the order of a few microns (Appendix 3).

The silver cover on the plates was almost completely altered to silver amalgam with a quite uniform thickness of about 10 µm. Locally the innermost one to two micron thick layer next to the copper plate was not amalgamated (see Appendix 3).

The main difference between coating copper and silver plates with amalgam by using activated mercury is that the copper amalgam forms crystals of around 30 µm, whereas the crystal size of silver amalgam is less than a few microns.

Presently it is not possible to determine which type of amalgam coating is best for extracting mercury flour. This must be tested in a large future test program briefly outlined at the end of this report.

Figure 7. *Mercury 'pearls' on a metal plate. Photo 15 cm across*

Figure 8. *Perfect coating of a copper plate with activated mercury*

Field tests in Benguet, Northern Philippines

September 2010 test

The tailings used were produced locally. Leoncio Na-Oy took some of his own tailings which did not contain any mercury. He ran mercury spiked tailings in his mill The tailings were then run three times over the 'Peter Plates'. Samples were collected after each run. The process was repeated twice (Table 2).

Samples were analysed by the Japan Atomic Energy Agency (Osawa et. al., 2011). The test was very successful. The best test showed a reduction of mercury content of the tailings from ~2700 ppm to 12 ppm Hg.

Two tests were carried out in Benguet, Northern Philippines V1-4 and V5-7 respectively, see Table 2 and Fig. 9.

It is obvious that the plates worked efficiently although the reason for the sudden increase in the values V4 is not clear.

Table 2. Mercury content of test run V1-V4 (red dots on Fig.9 below) and V5 - V7 (blue dots on Fig. 9 below)

Sample	Hg	
	ppm	error
V1	1461	15
V2	93	2
V3	35	2
V4	281	4
V5	2692	26
V6	43	2
V7	12	2

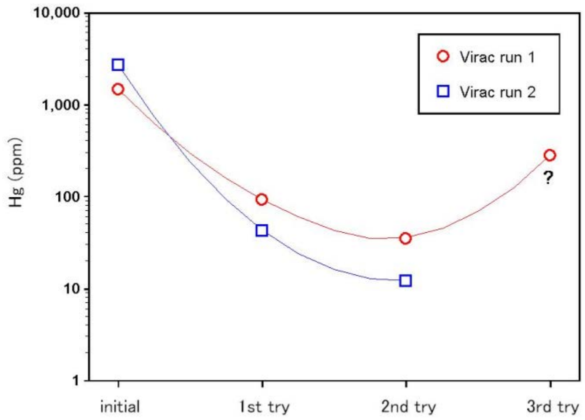


Figure 9. *Two sets of tailings were run over Peter Plates whereby most of the mercury flour was captured by the plates.*

October 2011 test

For this experiment 500 kg of tailings were bought from a small-scale miner who uses mercury for gold extraction. There was thus an unknown amount of mercury in his tailings. Each set of plates treated 500 kg of tailings spiked with 250 gram of mercury.

Test with plates covered with copper amalgam

Tailings spiked with 250 gram of mercury were run three times (Sample 525601)

After the first run the plates had captured 170 gram mercury (Sample 525602)

After second run the plates had captured 105 gram mercury (Sample 525603)

After the third run the plates had captured 25 gram of mercury (Sample 525604)

In total the plates captured 300 gram of mercury. See Fig. 10.

Test with plates covered with silver amalgam

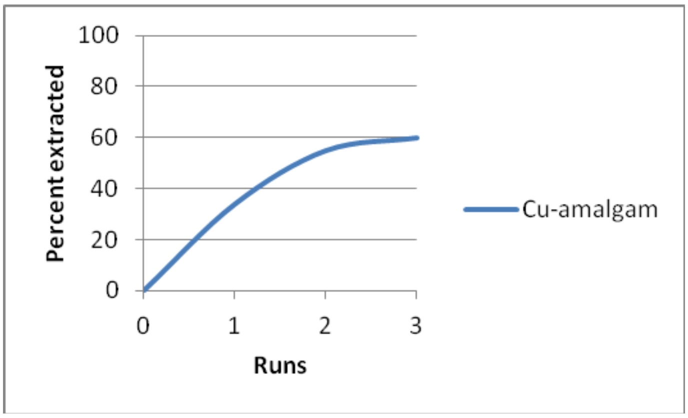
Tailings spiked with 250 gram of mercury were run three times (Sample 525605)

After the first run the plates had captured 50 gram mercury (Sample 525606)

After second run the plates had captured 25 gram mercury (Sample 525607)

After the third run the plates had captured 25 gram of mercury (Sample 525605)

In total the plates captured 100 gram of mercury. See Fig. 10.



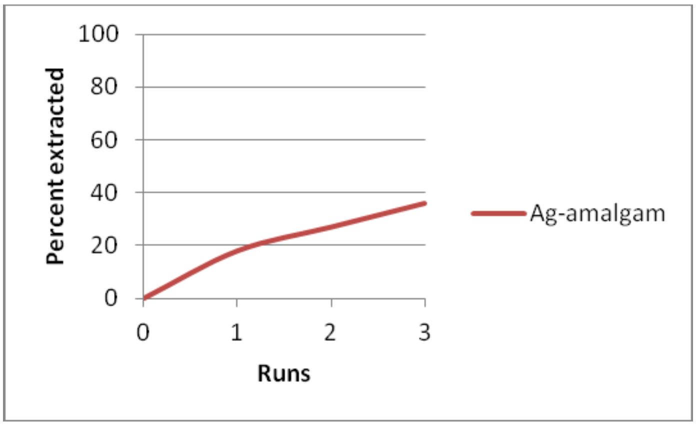


Figure 10 *The above diagrams show the efficiency of the plates coated with Cu –amalgam and Ag-amalgam respectively to extract mercury from the tailings. See Appendix 4 for calculations leading to the diagrams above.*

Conclusion

Amalgam coating done by using mercury nitrate or activated mercury seems to be equally good for capturing mercury flour. However, using nitric acid is rather unpleasant. Thus amalgam coating with activated mercury can be recommended.

The Cu-amalgam extracts 60 % and the Ag-amalgam 38 % of the mercury. Right away Cu-amalgam coating seems preferable. However, it must be borne in mind that the Ag-amalgamated treated tailings, which contained much less mercury than the Cu-amalgamated plates. The analytical data behind the diagrams are described in Appendix 4.

“Peter Plates” both the ones coated with Cu-amalgam and the ones coated with Ag-amalgam have proved to be able to capture significant amounts (60% and 38% respectively) of mercury flour. The plates seem to have indicated a possible road towards a cleaner Philippines, with a side prize of significant earnings of gold. A real win-win situation.

Recovering gold from mercury

To ensure a positive outcome of this method, it is necessary, when the mercury flour has been recovered, to further involve the next steps:

- Extract the gold from the mercury
- Find a proper storage place for the mercury

Extracting gold from mercury

This is an easy task. A simple type of distillation must be used, whereby the recovered mercury flour with gold is heated in a closed system. The mercury will evaporate and can be condensed. Environmentally, this can be done in an absolutely safe way.

Storage place for mercury

The Philippine NGO Bantoxics received August 2011 significant funding for finding principles of storage places for mercury in the Philippines.

Economic considerations

Naturally, the question arises: what are the environmental and financial implications of a country-wide clean up of all the tailings from small-scale gold mining? There is no doubt that it will be of huge benefit for the environment and health in the country. But will it be costly or will it be financially beneficial for the Philippine government?

A lose estimate of the value of the recovered gold will perhaps provide an answer to this question:

The small-scale miners of the Philippines release between 200 and 500 tons of mercury per year. The tailings contain in the order of at least 5 gram of gold per ton. This is a very conservative estimate (see the chapter on Background). For the sake of this estimate it is assumed that tailings containing 200 gram of mercury and 5 grams of gold per ton

Tailings containing a total of 200 tons of mercury will then contain 5 tons of gold with a market value of 275 million $US (Gold price 1800 $US per oz, mid August 2011). Taking the other extreme of the range, tailings containing a total of 500 tons of mercury will contain 12.5 tons of gold with a market value of 690 million $US (Gold price 1800 $US per oz, mid August 2011). Assuming that small-scale miners have released similar amounts of mercury and gold every year over a period of at least 10 years, would indicate that the miners have lost in the order of 2.7 to 7 billion $US worth of gold.

Cleaning the tailings from small-scale gold mining will thus generate a substantial amount of money. Since the idea of the Peter Plates was borne more than 150 years ago nobody can obtain a patent and thereby earn all the money from the gold recovered. It must therefore be up to the Philippine Government who shall have the financial benefit from the cleaning process.

Conclusions and recommendations

The tests have shown that ‘Peter Plates’ are indeed able to capture substantial amounts of mercury flour from tailings. It seems that the plates may be a solution to solve one of the major mercury problems in the Philippines.

The present tests were on a laboratory scale only and the system has to be scaled up to commercial industry scale. It must be designed to be carried by a truck and moved from one tailings dam to the next. It will also be necessary to optimise all the different parameters in the system such as:

- Velocity of flow of the tailings water mixture
- Ratio of tailings to water
- Inclination of the plates
- Size of the plates
- Thickness and durability of the amalgam coating
- Which type of amalgam copper or silver is strongest and will capture most mercury flour in the long run.

The present project was funded by the Sumitomo Foundation, Japan and by Geological Survey of Denmark and Greenland. Next step will require substantial funding a full time devotion to the project. It is suggested that the appropriate Department of the Philippines write a project proposal to World Bank and/or Asian Development Bank and ask for funding. The funding agency can then announce the project for Philippine industrial companies. The winner will have 8 to 12 months to produce an up-scaled fully operational version of the Peter Plates.

Acknowledgements

This work could not have been carried out without financial support from the Sumitomo Foundation in Japan. The authors are indebted to Dr. Graciano Jun Yumul, Dr. Victor Maglambayan and Miss. Emy Perez for their continuous support to the project. The support of the Benguet Federation of small-scale miners is gratefully acknowledged. Generous funding from the Sumitomo Foundation, Japan is gratefully acknowledged. Mr. Sumali Agrawal, Kalimantan, Indonesia guided the authors on how to activate mercury.

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Appendix 1

Amalgamation with mercury nitrate

The copper amalgam coating was formed by applying Hg2NO3 on the copper plate

A few square centimetres of a plate coated with Cu-amalgam and used in the test September 2010 was investigated in scanning electron microscope (SEM). See the spectre in Fig. 1.

The plate is almost completely covered by copper amalgam with a composition ranging from 72% Hg and 28% Cu to 67% Hg and 33% Cu The crystal size is mostly in the order of 10 to 30 µm and the crystals are densely packed see backscatter images below (Fig. 2-7).

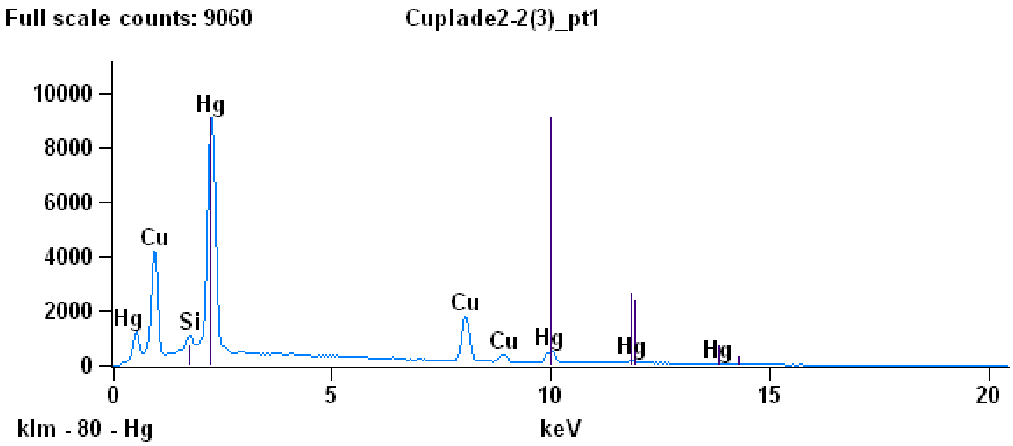

Figure 1. *Diagram showing the different peaks from copper amalgam from the measurements on scanning electron microscope on EDS.*

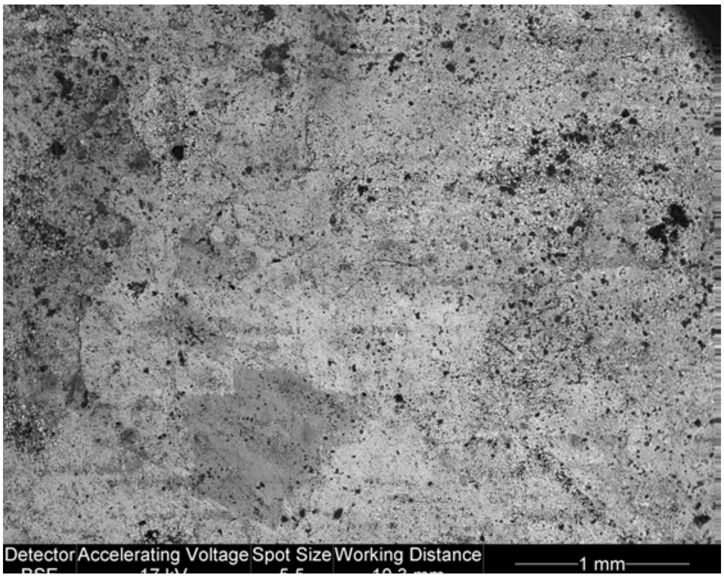

Figure 2. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

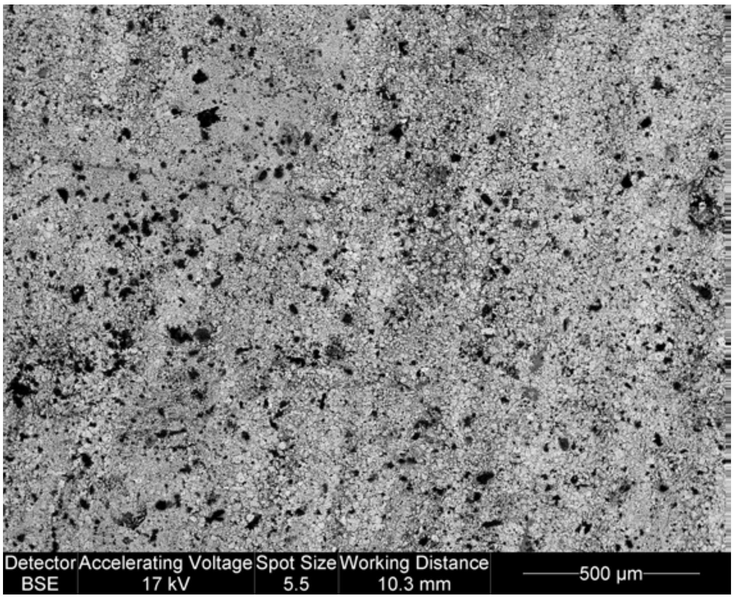

Figure 3. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

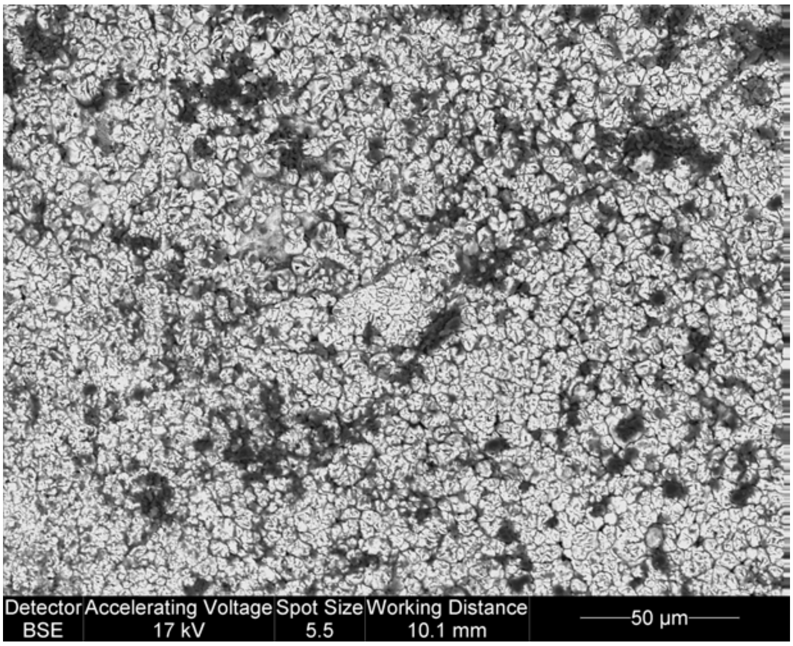

Figure 4. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

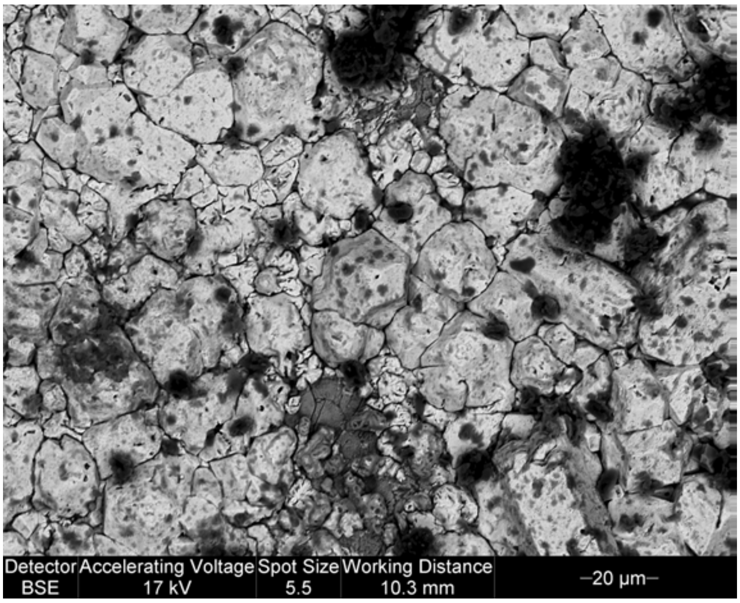

Figure 5. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

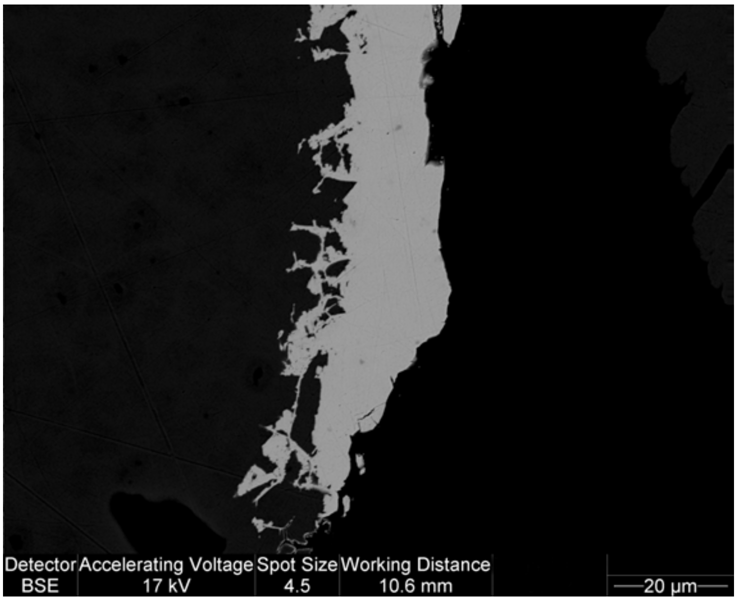

Figure 6. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Cross section. Cu-Plate on the left side.*

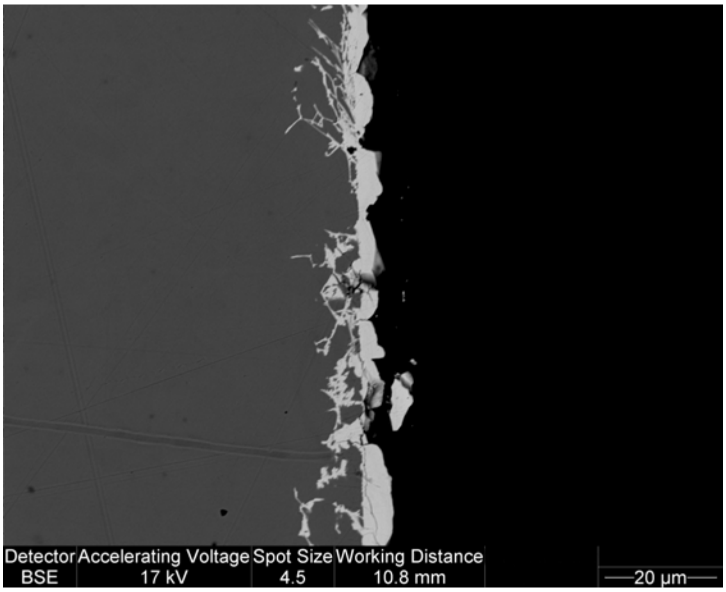

Figure 7. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Cross section. Cu-Plate on the left side.*

Appendix 2

Copper-amalgamation with activated mercury

A small copper plate was coated with copper amalgam by applying activated mercury on the cleaned surface of the plate.

The plate was investigated in scanning electron microscope (SEM) See the spectre in Fig. 1. Back scatter images are shown in Fig. 2 to 5.

The amalgam covered the whole copper plate with amalgam crystals with size ranging from 10 to 30 µm. There is virtually no empty space between the crystals. The composition of the copper amalgam is fairly uniform with 27% Cu and 73% Hg.

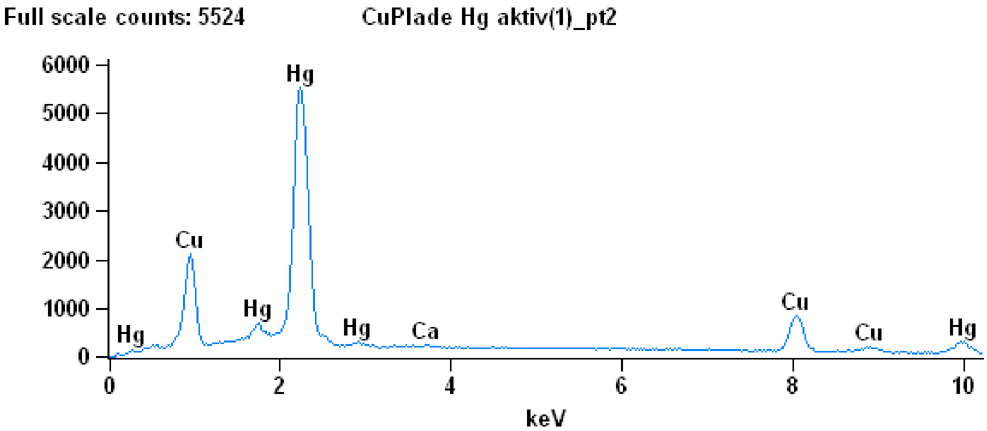

Figure 1. *Diagram showing different peaks from copper amalgam from the measurements on scanning electron microscope on EDS.*

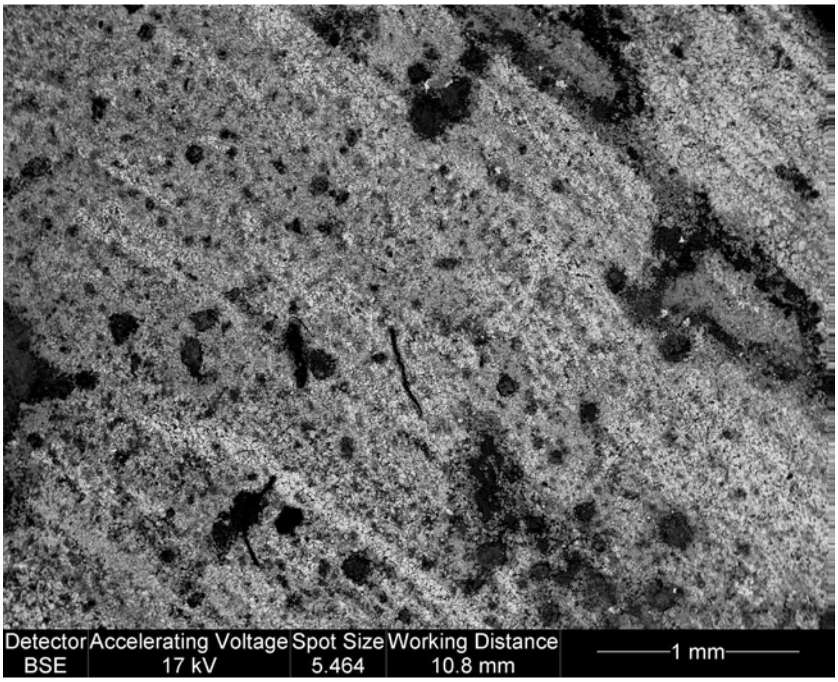

Figure 2. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

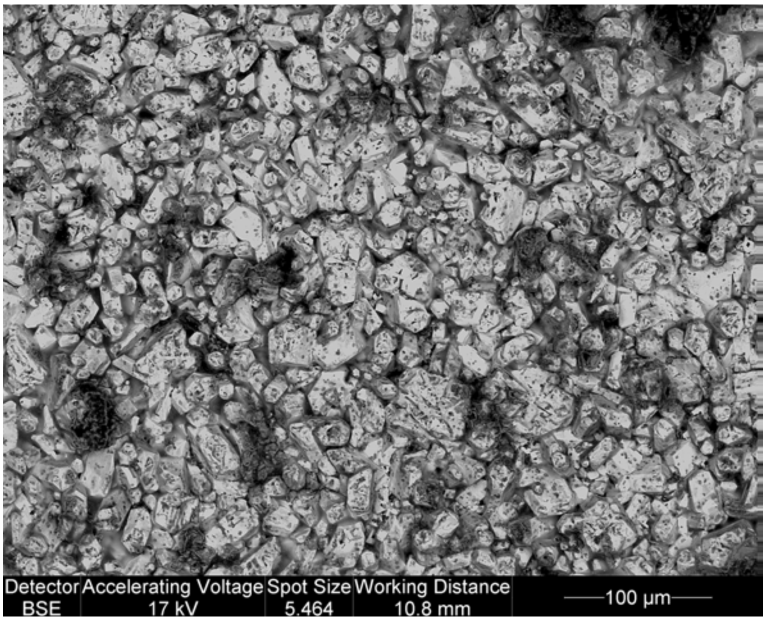

Figure 3. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section.*

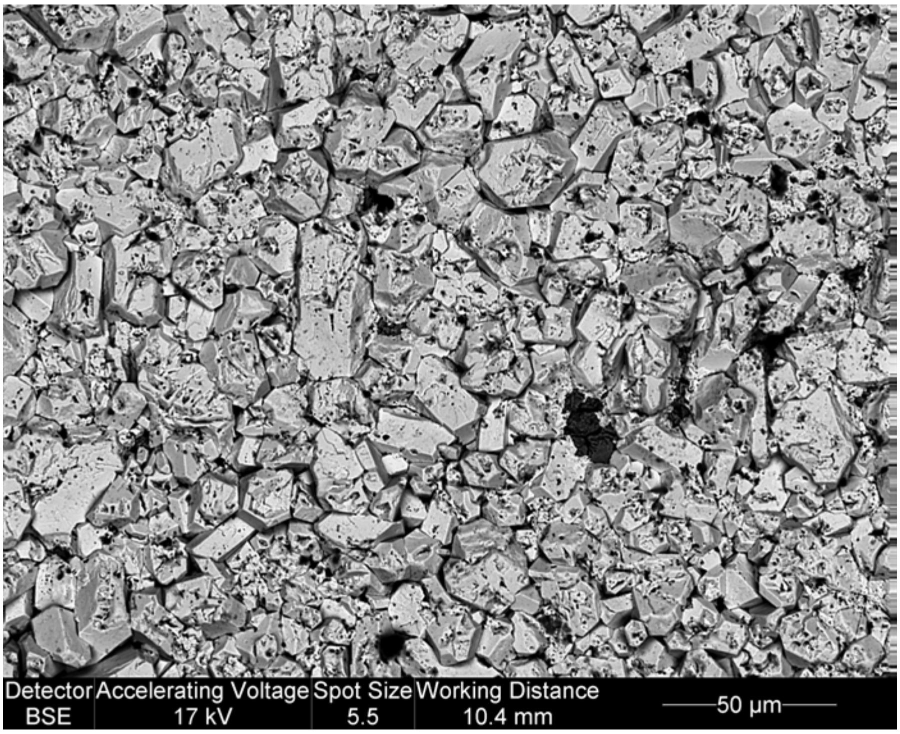

Figure 4. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section. Note the coarse crystals.*

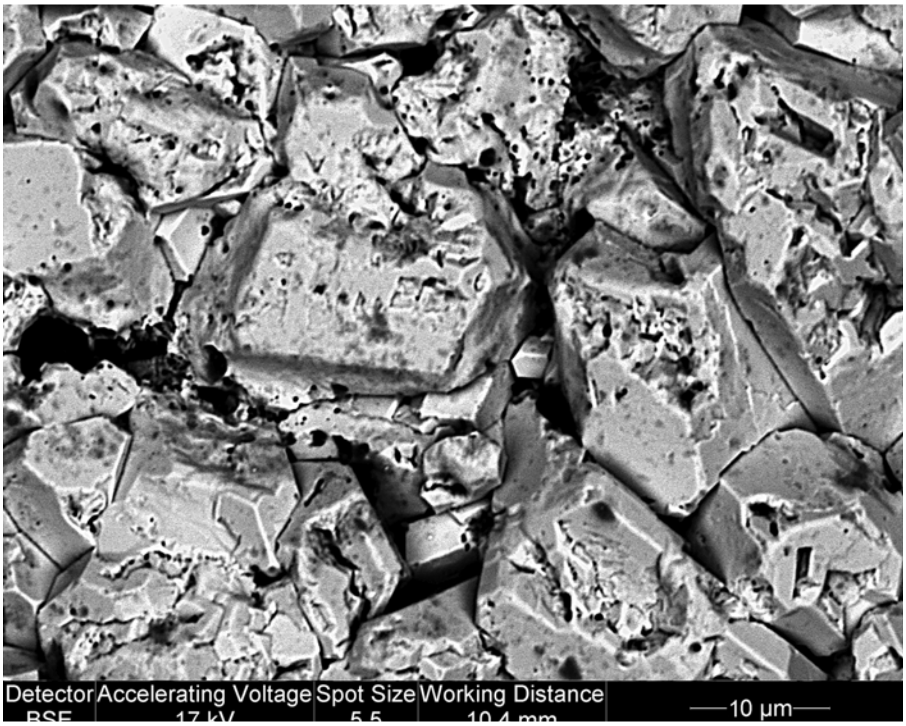

Figure 5. *Back scatter image of Cu-amalgam coating on copper plate. The coverage is near perfect. Note scale on the image. Plane section. Note the very coarse crystals.*

Appendix 3

Silver amalgam coating with activated mercury

A copper plate was electroplated with a thin layer of silver. Then activated mercury was applied to the surface of the silver coating.

The plate was investigated in scanning electron microscope (SEM) See the spectre in Fig. 1. Back scatter images are shown in Fig. 2 to 6.

The amalgam covered the whole plate and the individual silver amalgam crystals are generally around 1µm in size. Composition of silver amalgam 31%Ag and 69%Hg

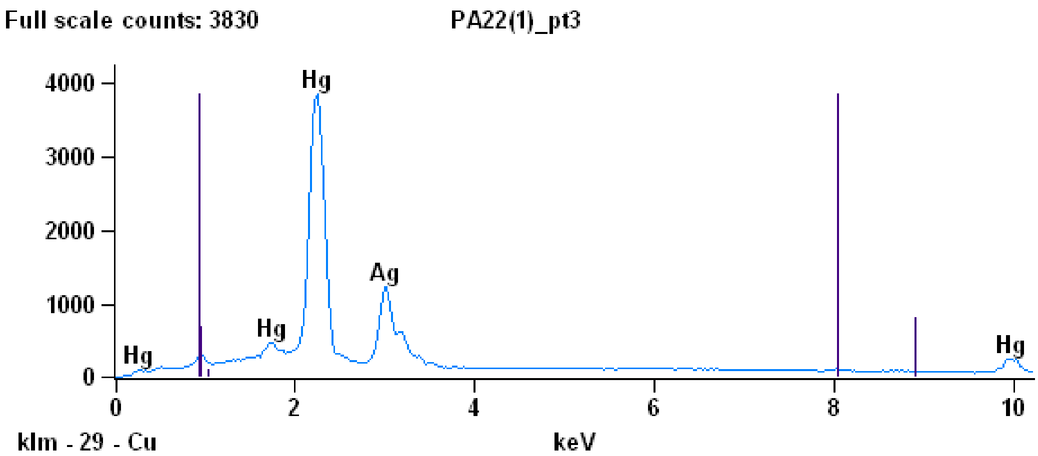

Figure 1. *Diagram showing the different peaks from copper amalgam from the measurements on scanning electron microscope on EDS.*

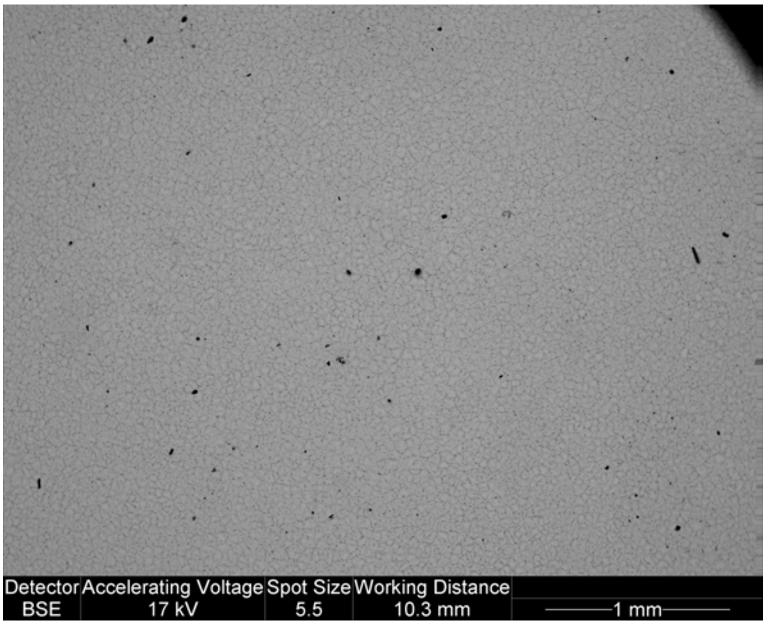

Figure 2. *Back scatter image of Ag-amalgam coating on copper plate. The coverage is absolutely perfect. Note scale on the image. Plane section.*

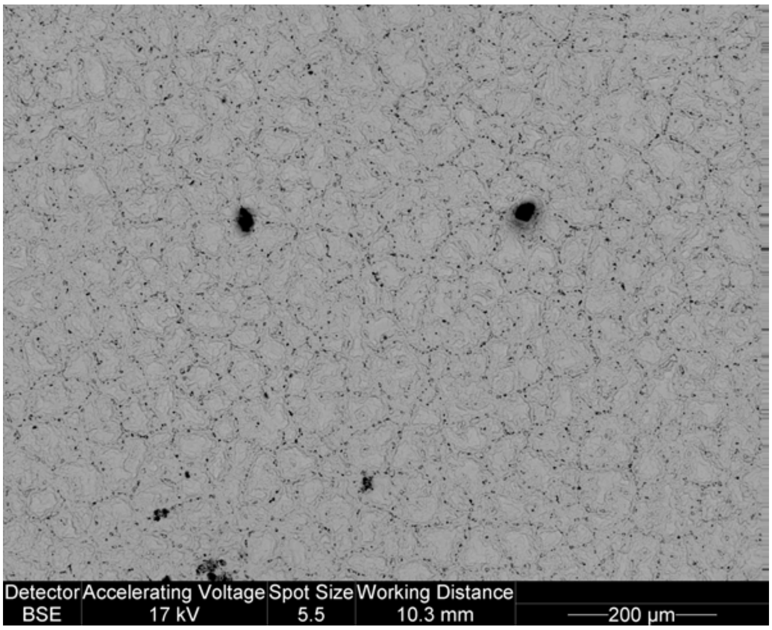

Figure 3. *Back scatter image of Ag-amalgam coating on copper plate. The coverage is absolutely perfect. Note scale on the image. Plane section.*

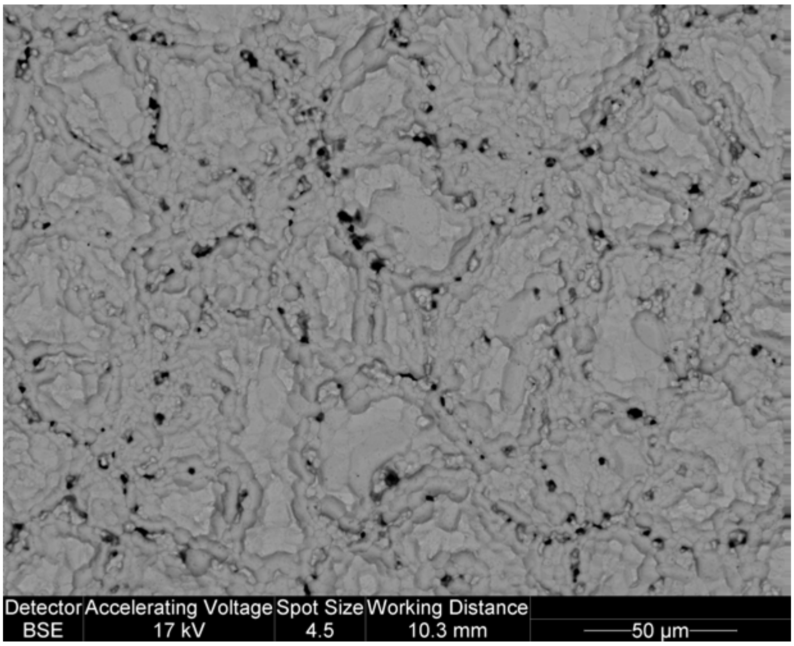

Figure 4. *Back scatter image of Ag-amalgam coating on copper plate. The coverage is absolutely perfect. Note scale on the image. Plane section.*

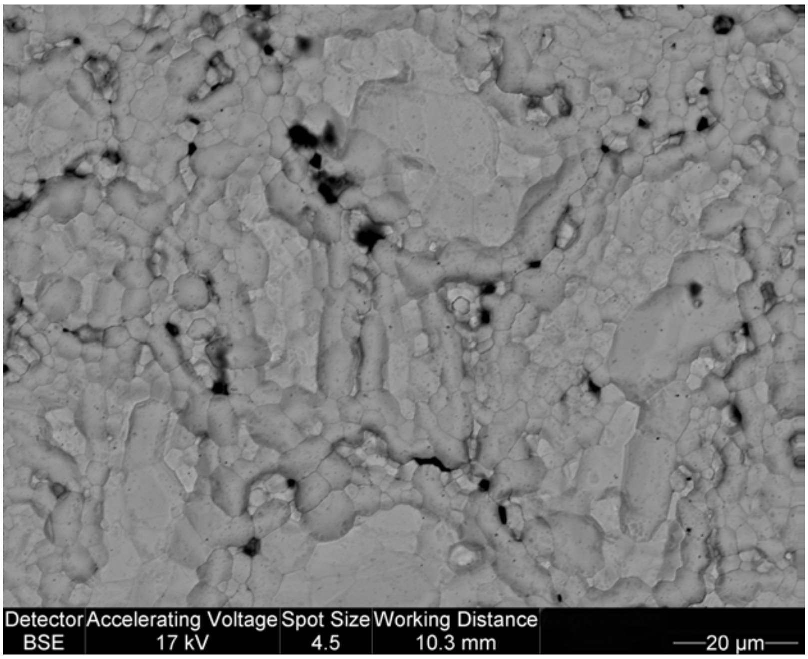

Figure 5. *Back scatter image of Ag-amalgam coating on copper plate. The coverage is absolutely perfect. Note scale on the image. Plane section.*

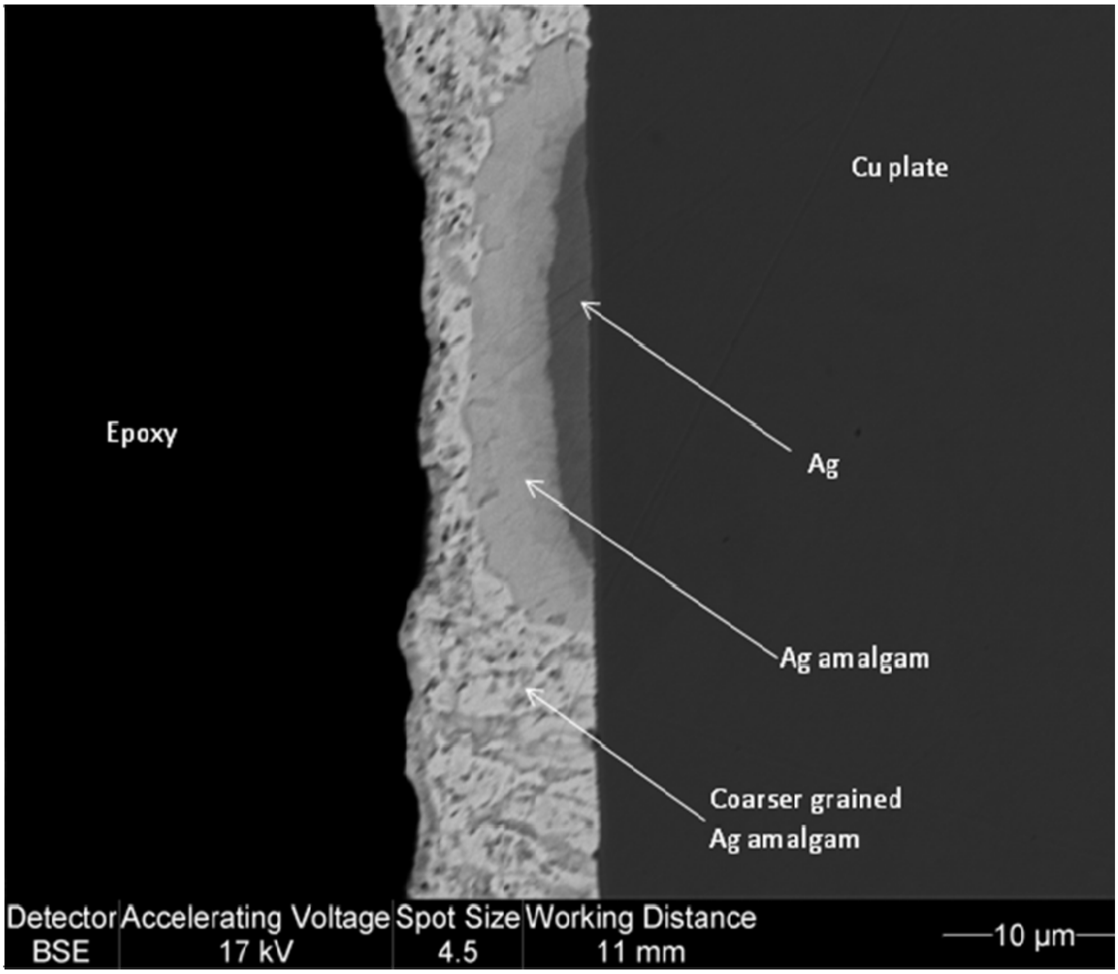

Figure 6. *Back scatter image of Ag-amalgam coating on copper plate. The coverage is absolutely perfect. Note scale on the image. Cross section of the plate described above showing how mercury has amalgamated by most of the silver coating leaving only few small patches of pure silver at the border of the copper plate. The silver amalgam partly coarser grained than the inner part of the amalgam close to the silver. The coating with silver and silver amalgam is fairly constant in thickness of about 10µm.*

Appendix 4

Field tests of plates coated with Cu-amalgam and Ag-amalgam respectively

Test of plates covered by copper amalgam

The tailings used for the experiments were obtained from a small-scale miner who uses mercury. There was thus an unknown amount of mercury in the tailings. The tailings were milled for one and a half hour after being spiked with 250 gram mercury. The total mercury content was then at least 250 gram. Before starting processing the tailings were visually inspected and numerous very small drops of mercury (mercury flour) were identified. The drops in the mercury flour are fractions of a millimetre in size.

The tailings were flushed down with water on the first plate and onwards to the second plate. From the second plate there was a drop of about 10 centimetres to the third plate. From the third plate the tailings flowed in a channel and finally dropped around ten centimetres onto the last plate. The tailings finally ended in a big tub. From the tub the tailings were bagged for the next run.

Five hundred kilograms of tailings were run over the plates three times and each step was sampled. Prior to processing sample 525601 was collected. Sample 525602 was tailings which had been processed once. Sample 525603 was from tailings which had been processed twice. Sample 525604 was from tailings which had been processed three times.

During each run numerous blebs of mercury up to centimetre size built up on the plates (Fig. 1) when the blebs reached a certain size they trickled down the plate and created trails of mercury. It was significant that most mercury flour was captured by plates where the tailings dropped on the plate. This meant that plates one and four were the ones which captured most mercury.

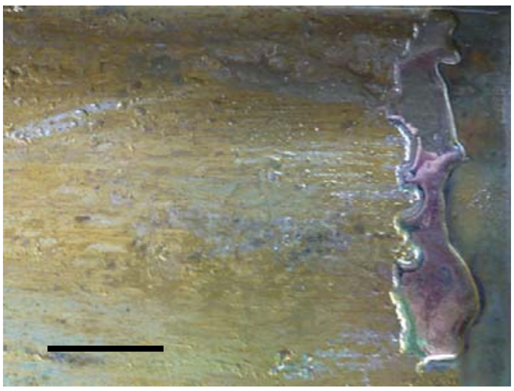

Figure 1. *Mercury flour captured on copper amalgam. Scale 1 cm.*

When the mercury blebs got so big that it was felt that they might start migrating from one plate to the next, the process was halted and the mercury was removed from the plates with a soft sponge. The recovered mercury was weighed after each of the three runs over the plates.

Results of plates with copper amalgam

Tailings spiked with 250 gram of mercury were run three times (Sample 525601)

After the first run the plates had captured 170 gram mercury (Sample 525602)

After second run the plates had captured 105 gram mercury (Sample 525603)

After the third run the plates had captured 25 gram of mercury (Sample 525604)

In total the plates captured 300 gram of mercury.

Test of plates covered by silver amalgam

The plates were arranged as in the previous experiment. The tailings used in this experiment was the tailings used during the previous experiment, but milled again for one and a half hours after being spiked with 250 gram mercury.

The silver amalgam coated plates did capture mercury flour, but as tiny droplets which quickly merged to a continuous thin layer of mercury on the silver amalgam, as opposed to the Cu-amalgam where the captured mercury flour accumulates to large drops. Here again the plates which received tailings at a splash captured most of the mercury flour.

Five hundred kilograms of tailings were run over the plates three times and each step was sampled. Prior to processing sample 525605 was collected. Sample 525606 was tailings which had been processed once. Sample 525607 was from tailings which had been processed twice. Sample 525608 was from tailings which had been processed three times.

Results of plates covered by silver amalgam

Tailings spiked with 250 gram of mercury were run three times (Sample 525605)

After the first run the plates had captured 50 gram mercury (Sample 525606)

After second run the plates had captured 25 gram mercury (Sample 525607)

After the third run the plates had captured 25 gram of mercury (Sample 525605)

In total the plates captured 100 gram of mercury.

Analytical results

The samples from the two sets of analysis were dried in the laboratory of GEUS in Copenhagen. Then each sample was split and one split was sent to Actlabs laboratories in Canada for instrumental neutron activation analysis.

The results are as follows:

Table 1. *Mercury content in the starting tailings and from each step after having passed over the plates. The right column show the cumulative percentage catchment of mercury flour after each passing over the Peter Plates. The results in the right column are shown in Figs. 2 and 3*

Analyte Symbol	Hg (mercury)	Hg gram	Recovered
Unit Symbol	ppm	in 500 kg	Hg in gram
Detection Limit	1	tailings	
Analysis Method	INAA		
525601	1040	520	0
525602	388	194	170
525603	550	275	105
525604	320	160	25
525605	553	277	0
525606	383	191	50
525607	626	313	25
525608	436	219	25

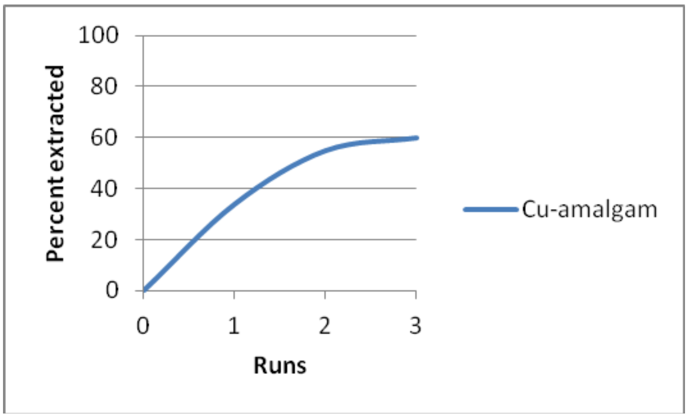

Figure 2. *Efficiency of the plates covered by Cu-amalgam to extract mercury flour.*

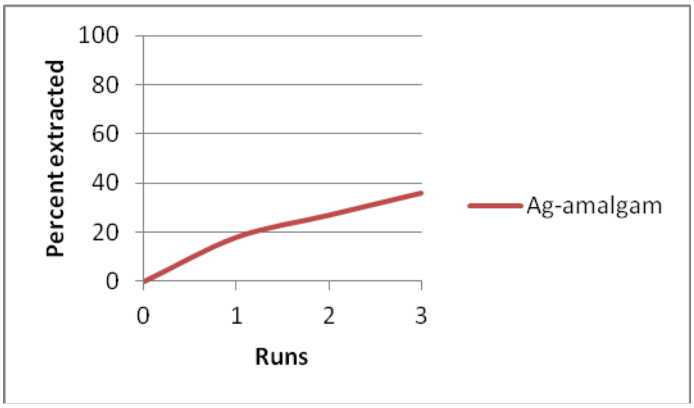

Figure 3. *Efficiency of the plates covered by Ag-amalgam to extract mercury flour*

The analytical results are slightly confusing in as much as the values from step to step varies in a not perfect systematic way. The reason being that out of 500 kg only two grams was analysed and the mercury content is not uniformly distributed throughout the 500 kg of tailings.

The following procedure was then used to make the graphs shown above.

The Peter Plates with Cu-amalgam. The analysis showed that the 500 kg of tailings spiked with 250 g of mercury had a mercury content of 1040 ppm which is equivalent of 520 grams in the 500 kg of tailings. The total amount of mercury recovered by the Cu-amalgam was 300 g which is equivalent of a 60 percent recovery after three runs over the Peter Plates.

The Peter Plates with Ag-amalgam. The analysis showed that the 500 kg of tailings spiked with 250 g of mercury had a mercury content of 553 ppm which is equivalent of 277 g of mercury in the 500 kg of tailings. The total amount of mercury recovered by the Ag-amalgam was 100 g which is equivalent of ca. 38 percent recovery.

Conclusion

Cu-amalgam recovers a good deal more mercury flour than Ag-amalgam. It should be borne in mind that the starting material for the test with Ag-amalgam contained much less mercury then the test with Cu-amalgam.

The fact that mercury flour on the Cu-amalgam accumulate as big drops and as a thin film on Ag-amalgam. The reason for this in unknown.