UPPSALA
UNIVERSITET

# An investigation of an environmentally benign method for small-scale gold mining in the Philippines

Jenny Öhlander

Arbetsgruppen för Tropisk Ekologi
Committee of Tropical Ecology
Uppsala University, Sweden

Minor Field Study 111

March 2005 Uppsala

UPPSALA
UNIVERSITET

# An investigation of an environmentally benign method for small-scale gold mining in the Philippines

Jenny Öhlander

Master degree thesis, Department of Limnology, Evolutionary Biology Centre, Uppsala University
Supervisors:
Lars Hylander (Department of Limnology, Uppsala, Sweden)
Ana Trinidad Francisco Rivera (Department of Health, Manila, the Philippines)

## Abstract

In the Philippines about 100 000 persons are working with small-scale mining. The methods that are used in gold extraction are the amalgamation method and the cyanide process. The use of mercury started in the 1980's, when the price of gold went up. In the Philippines, the workers live in the same place as they work, they do not use any kind of safety equipment and the tailings are left anywhere. The rivers in the areas are dead, all the fish is gone and the communities further downstream get bad crops due to the polluted water. The concentration of mercury in drinking water, soils, sediments, tailings and edible fish near gold mining operations in the Philippines exceeds in general national and international limits. Mercury is a hazardous heavy metal that does not seem to serve any biological function in living organisms. Cyanide is toxic to living organisms at very low concentrations. Fish and aquatic invertebrates are particularly sensitive.

The main aim of the study was to evaluate an environmental friendly method for small-scale gold extraction without the use of any chemicals. An additional aim was to interview the local miners about their situation regarding health and their interest in using a chemical- free method for gold recovery. The study was performed at five different sites in the Philippines: Diwalwal, Mainit, Acupan, Balatoc and Paracale. The gold separation method (US patent granted in July 1999, #5,927,508) that was evaluated is developed by David Plath, USA. The principle of the method is to use magnetism to create riffles in a simple sluice, for a physical separation of gold from grains with lower density, instead of using mercury or other chemicals for separation via chemical reactions. Samples collected were sent to Acme lab in Canada for gold analysis by fire assay.

The gold recovery from the different sites varies both between and within the sites. The highest recovery was obtained in Balatoc (73%) and the lowest in Acupan with a top value of 15%. The results from the samples taken in the magnetic sluice showed that gold had been concentrated at all tests.

The miners in the Philippines are very interested in a new method for gold extraction. With more investigations on adapting the sluices to the specific ore composition of the Philippines, magnetic sluices may reduce the use of mercury significantly. The miners are all aware of the risks with mercury, both for themselves and the environment. As long as the miners are using mercury, safety equipment should be handed out among them. A solution for where to put the tailings is required. Stricter control and better legislation of the use of mercury should be introduced. It should be harder for the miners to obtain mercury and the export of mercury to developing countries has to stop.

## Table of contents

## Introduction

In the 1980's, the price of gold went up which resulted in a gold rush in many places in the world, for example in Latin America, Central Africa, and South East Asia including the Philippines (Hylander and Meili, 2005). In the Philippines and in several other developing countries, the use of mercury in small-scale mining is widely spread. The Philippines are contributing with large mercury emissions to the global environment. Their discharge is 26-47 tons per year compared to the total global emissions of Hg from gold mining that is about 500-700 tons per year (Lacerda, 2002, Hylander and Plath, 2004). Globally, there are 10-15 million people working in small scale mining, of which about 100 000 persons in the Philippines (Lacerda, 2002, Hylander and Plath, 2004). In the Philippines, the workers live in the same place as they work, which means that they are affected by the mercury at all times, not only when they are working, and that their family members are affected even if they are not working as miners. It is usual that several members of the family work with gold extraction, even women and children. The people who work in the mountain tunnels with mining the ore are often the ones who process the ore, too. At many places, women are not allowed to work in the tunnels. Children start to work at the age of seven or eight. They do not work in the tunnels but they carry sacks with rocks, use the ball mills and hammer rocks to cross them into smaller pieces (Drasch, 2000). The workers do not use any kind of safety equipment and the tailings are left anywhere. The rivers in the areas are dead, all the fish is gone and the communities further downstream get bad crops due to the polluted water. The concentration of mercury in drinking water, soils, sediments, tailings and edible fish near gold mining operations in the Philippines exceeds in general national and international limits (Eisler, 2002). In addition to the amalgamation method, the cyanide process is also used when extracting gold in the Philippines.

Generally, the principle for the amalgamation method as practiced in the Philippines is as follows: the ore is grinded in a rod mill together with mercury to form amalgam (an alloy between mercury and another metal such as gold and silver). Then the mixture flows through a bucket, in which the amalgam and the surplus mercury sink to the bottom. The rest of the ore (the tailings) is transported to another place for leaching with cyanide. The mercury and amalgam are squeezed through a cloth and only the mercury that contains gold and silver amalgam will remain in the cloth. To get rid of the mercury, the amalgam is heated by a blow-torch in the open and most mercury will be steamed off, leaving a mixture of gold and silver (60/40). The remaining Hg (a few percent) will be driven off when founding ingots at the gold dealers.

This method is not used all over the Philippines. In some places they use a type of sluice box. The ore flows through the sluice and the gold grains, due to their density, get hampered by the cloth in the sluice. The material on the cloth is panned together with mercury to form amalgam. The amalgam is then heated with a blow-torch.

The principle of the cyanide leaching process is that a solution of cyanide is added (NaCN or KCN) at about 0.5 to 1.0 kg cyanide per ton ore. The cyanide will dissolve the gold in the ore according to the following formula: $4Au + 8NaCN + O_2 + H_2O$ _ $4NaAu(CN)_2$ 4NaOH. After this dissolution process, active carbon is added to adsorb the gold from the solution. To separate the active carbon, the pulp is screened with a 45-mesh screen (0.35 mm). The last refinement before the gold/silver can be extracted is to add general flux (borax) that lower the melting point and smelt the mixture to produce gold bullions.

The reason why both the amalgamation and the cyanide processes are used is that the different methods extract gold in different size ranges. The amalgamation method can extract gold in the particle range 70µm-1.5mm while the cyanide process will extract gold up to 200µm (Mcdonald, 1983). One reason for some miners to only use the amalgamation method, even if it is not as effective as the cyanide process, is that the cyanide process is more expensive and many of the miners can not afford to have a cyanide plant (Clemente *et al,* 2004). Even if the miners do not have a cyanide plant, they sell their tailings to one.

Mercury is a hazardous heavy metal that does not seem to serve any biological function in living organisms. Mercury has a boiling point of 357°C and is liquid at room temperature (Rydén *et al,* 2003). Elemental mercury (metallic mercury, Hg°) will evaporate already at room temperature into mercury vapour. The higher temperature the more vapour will be released. Mercury that is absorbed on particles and ionic mercury will deposit close to the source, at a local to regional distance, while elemental mercury vapour can be transported over long distances, which makes the vapour a global problem. Mercury vapour is quite dangerous since 80 % of the inhaled vapour is absorbed by the lung tissues. The vapour is a well documented neurotoxicant. The inhalation of the vapour can give neurological and behavioral disorders. The symptoms are for example tremors, emotional instability, insomnia, memory loss and headaches. The organic forms of mercury, especially methyl mercury, are of particular concern since they bioaccumulate and biomagnify in nature, especially in freshwater and saltwater fish and other marine animals to levels that are thousands of times greater than the levels in the surrounding water. Large predatory fish (for example mackerel, pike and large tuna) contain the highest concentration of mercury. Methyl mercury is a severe neurotoxicant (UNEP, 2002). Methyl mercury is fat soluble and can therefore penetrate the blood/brain barrier to the brain and the placental barrier of pregnant mammals and humans. Humans are mostly exposed to methyl mercury by eating seafood; fetus and small children are most sensitive. High consumption can lead to blindness, deafness and paralysis due to destroyed brain cells (Rydén *et al,* 2003). Before birth or in growing children even low exposure can cause physical and mental retardation (Wolpher *et al*, 2003), which is of concern in the Philippines, where seafood is a large part of the diet.

The gold diggers in the Philippines are exposed to mercury vapour since they are handling the elemental form of mercury. They also inhale mercury fumes when the amalgam is heated in the open by blow-torches or in their kitchen on the stoves. The

tailings after the amalgamation and cyanide process are disposed in the river or just dumped anywhere and are then transported by wind or water into the ecosystem (Drasch *et al*, 2000). The inhalation of metallic mercury vapour is the main route of exposure to the workers. In the Philippines, the concentration of mercury in ambient air at many workplaces exceed the general recommended exposure levels of 50_g Hg $m^{-3}$ and may be as high as 1664_g Hg $m^{-3}$ (Eisler, 2002).

Cyanide most commonly enters the body through breathing when the air contains hydrogen cyanide vapour. People that live close to the areas where there is a cyanide plant or a waste site will be affected in this way. Cyanide can also enter the body through food or drinking water. When the cyanide tailings are left anywhere, cyanide can reach the underground water and enter the drinking water. When a person is exposed to high levels of cyanide in a short period of time the central nervous system, respiratory system and cardiovascular system gets harmed. It can even lead to coma and death. Exposure to lower levels can result in rapid, deep breathing, shortness of breath, convulsions and loss of consciousness. Since cyanide does not stay in the body, compared to mercury, the short term effects will go away with time. (eco-usa.net) Cyanide is toxic to living organism at very low concentrations, fish and aquatic invertebrates are particularly sensitive. Effects on aquatic life can be reduced swimming performance, inhibit reproduction, disrupted respiration and osmoregulatory disturbances. High levels of cyanide in the water have acute toxic effects. For humans, the LC50 (concentration that is lethal to 50% of exposed population) for hydrogen cyanide vapour is 100-300 parts per million. Inhalation in this range will cause death within 10-60 minutes. (cyanidcode)

The cyanide plants in the Philippines are integrated with the houses people are living in, in the same way as the amalgamation establishments are. This means that people are affected by cyanide in there homes. The miners working at the plants are of course most affected, but since the vapour from cyanide can spread, others will also be influenced. The tailings after cyanidation are often left in the rivers which lead to negative effects on the aquatic life.

On the 26:th of August, 2004 me, Jenny Öhlander, and Sofie Lücke went to the Philippines to conduct a study. The main aim of the study was to evaluate an environmental friendly method for small-scale gold extraction without the use of any chemicals. An additional aim was to interview the local miners about their situation regarding health and their interest in using a chemical- free method for gold recovery. In the Philippines we cooperated with officials at the Department of Health (DOH), the Department of Environmental and Natural Resources (DENR) and the Mines and Geosciences Bureau (MGB).

## Materials and methods

### Site descriptions

The study was performed in five different sites in the Philippines (fig 1).


Fig. 1. Map over the Philippines with the testing site positions (A-E).

A: Diwalwal, Compostella valley, Mindanao.

People started to move to Diwalwal in 1982 when the area was classified as a “gold rush area”. In 1985 there were 80 000 people living there. Today there are 20 000 people living in the area. Diwalwal was classified as a mineral reservation (8100 ha) by the government in 2002. Globally, Diwalwal is a significant site for gold production (Appleton, 1998). The village is situated in the mountains with roads in a very bad condition and houses that stand close together near the mountain slope. The people live and work in the same place, every third house has a rod mill. Almost everyone that lives in the area is involved in the gold business in some way. The methods that are used for extracting gold are the amalgamation method and the cyanide process (Fig. 2). There are 600 establishments of workers that use the amalgamation method. The tailings are left everywhere, along the roads, in the river and they even build houses on sacks of tailings. (Orally, local miners)

The ore used for the test was clayey with grey color and had a high water content. According to the gold diggers, the ore contained 10 g Au/ton.

B: Mainit, Compostella valley, Mindanao.
Mainit is situated in the lowlands. It is a small village where the gold extraction is not as obvious as in Diwalwal. About 6000 people live in the village and 20 % of them are working with gold extraction. In 1970, they extracted gold by sluicing and panning in the river, in 1980 they started to use mercury. The methods they use today are the amalgamation method and the cyanide process; there are six plants in the area leaching with cyanide (Fig. 2). The tailings are put in "septic tanks"; the tanks are holes in the ground without clay to prevent leakage, so the cyanide will leak into the ground. (Orally, local miners)
The ore used for the test was brown-yellow and clayey with a quite high water content. The gold content in the ore was 20 g Au/ton according to the gold diggers

C: Acupan, Benguet, Luzon.
Acupan is also a mountain village like Diwalwal, but it is not as large as Diwalwal and the conditions are a little bit better here. In Acupan, 1500 people live. About 50 % of them are working with gold extraction. The method they are using is a "sluice box" with a cloth (Fig. 2). The gold settles in the cloth and then they pan the material that gets caught in the cloth. In the pan they add mercury. They have used mercury for 20 years. They also have cyanide plants in Acupan. The tailings are just left in the river. The Benguet cooperation used to buy the tailings and put it in dams, but due to shortage of money they stopped doing that about ten years ago. (Orally, local miners)
The ore used for the test was sandy and light grey in color with a low water content. The test was performed on the ore after it had run once through the sluice box. The gold content in the ore was 15 g Au/ton according to the workers.

D: Balatoc, Benguet, Luzon.
The area in Balatoc is run by the Benguet cooperation, a private company. The Benguet cooperation started in 1927 in Acupan and Balatoc as a large scale mining company, but due to financial problems it shut down in the late 1980s (Clemente *et al,* 2004). Now it is back in Balatoc but as a small scale mining company with 700 employees. A couple of years ago the area was a large scale mining area, but due to financial problems it has become a small scale mining area. The method used is the "sluice box", but the miners do not add mercury in the pan (Fig. 2). The tailings go to the cyanide plant where they use 1.5 kg cyanide/ton ore. They process 40 ton ore/day. The tailings from the cyanide plant are pumped to dams. (Orally, local miners)
The ore used for the test was sandy, dark grey in color and had low water content.

E: Paracale, Bicol, Camarines Norte
Paracale is a low land village similar to Mainit, with 10 000 inhabitants. About 50 % of the people work with gold extraction. 60 % of all the houses have a rod mill. The methods that are used are the amalgamation method and the cyanide process (Fig. 2). There are seven cyanide plants in the village. The tailings are left in the area where the cyanide plants are situated. (Orally, local miners)
The ore used for the test was sandy, dark grey with a low water content.

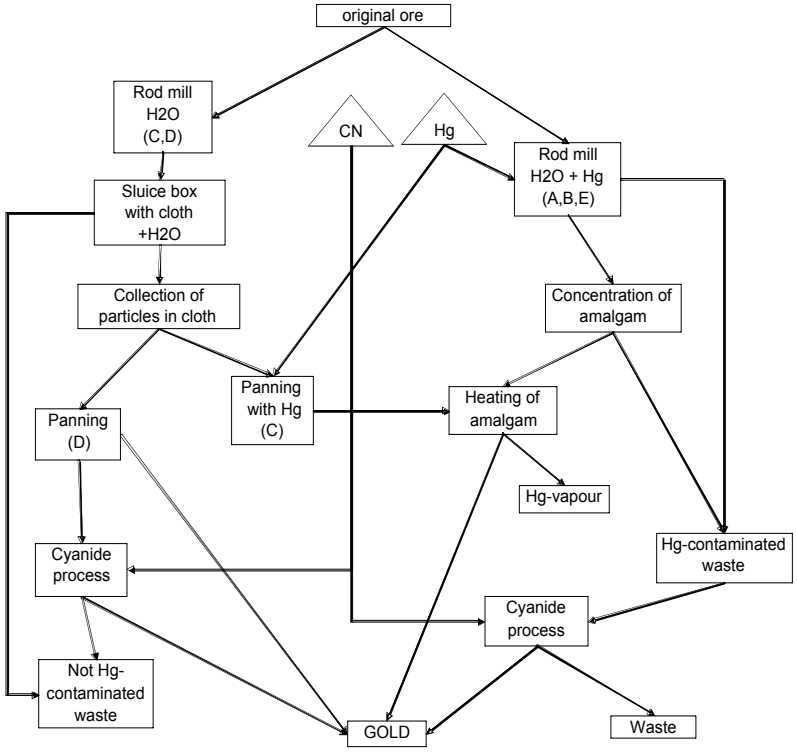


Fig. 2 Flow chart over methods used at the different test sites (A-E), the Philippines, 2004. A= Diwalwal; B= Mainit; C= Acupan; D= Balatoc and E= Paracale

**The magnetic sluice**

The gold separation method (US patent granted in July 1999, #5,927,508) that was evaluated is developed by David Plath, USA. The principle of the method is to use magnetism to create riffles for a physical separation of gold from grains with lower density, instead of using mercury or other chemicals for separation via chemical reactions. The only equipment needed is a simple sluice, which the gold containing ore and relatively small amount of water is passed through, by laminar flow. To extract the gold, the ore has to contain ferromagnetic components, or inexpensive recyclable magnetic material has to be added. The gold grains settle in the riffles and then the material attached to the sluice is scraped off into a pan (Hylander and Plath, 2004). The final extraction of gold from the gold concentrate in the sluice is done by traditional panning, which we got help with at each site by a gold digger. After the panning the gold in the pan is absorbed with a small plastic vial.

At every site, the test was performed five times (about 40 min each) with approximately 10 kg of ore each time (Fig. 3). The ore passed through the sluice twice each time. The following samples were taken:

- on the original ore (3 samples in Diwalwal and 5 on the other sites)
- after the ore had passed through the sluice two times (5 at each site + duplicates)
- in the sluice (5 at each site + duplicates)
- after the amalgamation process (5 at each site)
- after cyanide process (5 at each site except in Acupan)

Fig 3. Jenny Öhlander and Sofie Lücke working with the magnetic sluice in the Philippines, Diwalwal, 2004.

The samples were sent to Acme lab in Canada for analysis by fire assay. Fire assay is the most reliable method for determining the content of gold. The sample is melted in a clay crucible with a mixture of fluxes (silica and borax), lead oxide and reducing agent (frequently flour). The fluxes lower the melting point. The lead drops dissolve the gold and then combine and gradually sink through the sample to form a metallic layer at the bottom of the crucible. The lead is heated under oxidizing conditions to eliminate the lead. The metallic layer that is left is the precious metal. The metal is boiled in nitric acid to dissolve the silver and the gold that is left is weighed. (Britannica online, 2004)

**Interviews**

One or two gold miners were interviewed at each site. In total we interviewed eight people, two women and six men. The questions the interviews started out from were:

1. How long have you worked as a gold miner? Do you work in a cooperative or by yourself?
2. What kind of methods have you been using during this time?
3. Where do you by the mercury you use? What is the price?
4. Do you work with something else besides mining or is this your only income?
5. What about the working conditions? Is it anything that could be improved?
6. Do you have a family? If yes: do they work here as well?
7. How is your health? The health of your family or the other workers health?
8. How do you look at the future?
9. Are you interested in a new method without mercury?

## Results

### The magnetic sluice

The gold recovery from the different sites varies both between and within the sites. The highest recovery was obtained in Balatoc (73%) and the lowest in Acupan with a top value of 15% (Table 1 and Fig. 4). In three tests, the samples of processed ore contained more gold than the original ore (see appendix).

Table 1. Variation and mean value in gold recovery from the different sites in the Philippines, 2004.

| Test site | Gold recovery (%) | Gold recovery, mean value (%) |
|---|---|---|
| Diwalwal | 31-54 | 42 |
| Mainit | 0-24 | 3 |
| Acupan | -8-15 | -8 |
| Balatoc | 21-73 | 48 |
| Paracale | 34-59 | 48 |

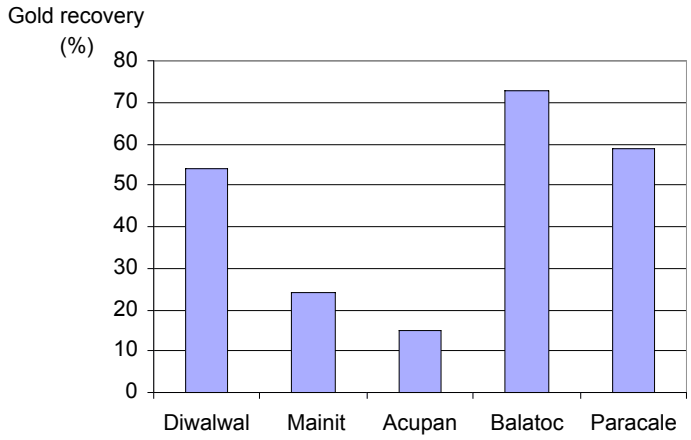


Fig 4. The highest recovery of gold in each test site in the Philippines, 2004.

The results from the samples taken in the magnetic sluice showed that gold had been concentrated at all tests (see appendix). The mean values of each site vary from 1.7 to 11.3 (Table 2).

Table 2. Mean value of the concentration factor at each test site, the Philippines, 2004.

| Test site | Mean value of the concentration coefficient |
|---|---|
| Diwalwal | 6.9 |
| Mainit | 1.7 |
| Acupan | 3.3 |
| Balatoc | 3.4 |
| Paracale | 11.3 |

The gold content in the samples after the amalgamation method and the cyanide process are presented in table 3. No samples were taken in Acupan. A comparison

between the samples from the magnetic sluice and the samples from the amalgamation method and the cyanide process is not possible to do since the process is not done on the same original ore.

Table 3. The mean gold content (g/t) after the amalgamation method and cyanide process at each site, the Philippines, 2004. In Balatoc the samples are taken after processing the ore with the sluice box without Hg. No samples were taken from Acupan because it was not possible to get samples after the amalgamation process at this site.

| Test site | Mean gold content after the amalgamation method (g/t) | Mean gold content after the cyanide process (g/t) |
|---|---|---|
| Diwalwal | 7.5 | 0.4 |
| Mainit | 65.6 | 1.2 |
| Balatoc | 5.6 | 21.8 |
| Paracale | 10.4 | 2.4 |

**Interviews**

We interviewed in total eight persons. Two in Diwalwal, one man and one woman, three men in Mainit, one woman in Acupan, one man in Balatoc and one man in Paracale.

*Question one*

All the miners we interviewed had worked as miners in about 20 years, except one man from Balatoc, who had been working for five years only. The miners that had worked for 20 years started to work when mercury started to be used for gold mining in the Philippines. Almost all of the miners are working individually and not in a cooperative. An exception is Balatoc, where the private company, Benguet cooperation, owns the mining site. Even if people work by themselves, there are other kinds of associations they are a part of. The two people we talked to in Diwalwal were members of the "ore mill operation association". All the members in the association own a ball mill each. There are 600 establishments in Diwalwal which have one mill each. In Acupan all the miners were a part of the "Acupan, an Upper Camps Livelihood Association" and they had a meeting while we were there and discussed problems in the community.

*Question two*

Almost everyone is using mercury in some way; the exception is again Balatoc, where they only use the sluice box and cyanide. The people in Diwalwal, Mainit and Paracale use the amalgamation method and add mercury in the ball mills. In Acupan they add mercury in the pan after the ore has passed through the sluice box.

*Question three*

No one was really sure about where the mercury comes from. Places that were mentioned were Malaysia, Belgium, China and Africa. Some of the miners just said that they buy the mercury in a store. They were all telling a similar price of mercury, about 1000P per kilogram mercury, which corresponds to approximately 20 US$ or

150 SEK. They use about three kilograms per month. Some of the miners recycle the mercury.

*Question four*
All miners had mining as their only income, except the man in Paracale. He was a versatile person, but gold extraction was his main work.

*Question five*
They all felt that their working conditions could be improved, but then more money is needed. They are aware of the health and environmental problems that come with the use of mercury and cyanide. The man in Balatoc said: *"Sometimes it's good, sometimes it's bad. I get happy when I find gold."*

*Question six*
The man in Diwalwal said that he has a family, but he does not want them to work with him. He said*: "No, I don't want my family to work here. I don't want them to have the same life, as I have had."* That was his way to protect them. The woman we talked to there was alone, she was thinking of moving soon because she is getting older and Diwalwal is not a good place to live in when you are old, because the roads are very bad and there are no doctor in the area. The man in Paracale said that his children will work with him when they get older. Some of the others had wives who worked in the mining activity and had children who were abroad. The man in Balatoc had his whole family abroad.

*Question seven*
To the health question, almost everybody answered that they did not have any health problems and they did not know anybody else who had it, but the man in Diwalwal had not seen a doctor for the last 18 years. The woman in Acupan said *"We have worked with mercury during the last 20 years, and we are still alive."* One man in Mainit had felt something last year; he had headaches and felt cold. He went to the doctor, who did not find anything wrong with him and after the control he has not felt unwell. It was only the man in Paracale who admitted that he had some health problems. He said that he was loosing weight and that his sight got worse. He also said that he knew other workers who felt the same thing.

*Question eight*
All miners thought they would continue with gold extraction for a long time. The mountains will provide them with gold for many years ahead. One said that as long as he felt strong he will continue. The man in Paracale said: *"I'm not sure how long I want to continue with this. Maybe I'll find another job or leave the country. I feel that my body is tired."* The man in Diwalwal said that they have been looking for another method for a long time because they do not want to use poison. He also said: *"Mercury is keeping us alive."*

*Question nine*
Everybody was interested in a new method so they would not have to use mercury anymore. As said before, all are much aware of the problems, but they need money to make a change. One man in Mainit said*: "If there is a mercury-free method that is at least as efficient as the amalgamation method, we would like to use it. And that would be good for the security, health and the surroundings."* The woman in Diwalwal said about our method*: "We hope that what you are doing now, using the magnetic sluice, could be efficient for here so we can adapt it here. Maybe we can make it bigger because it is very small and it takes time to get the gold."* The woman also said that they have asked the government *"to please, help us, unfortunately, until now nothing."* It seems like they are all waiting for a change.

## Discussion

The magnetic sluice is tested in other places in the world, for example in Venezuela and in Ghana. But there are no documented results from these studies. The inventor, David Plath, says that the sluice has a recovery of 90% of the gold, which is from his own studies from the beaches in Alaska (Hylander and Plath, 2004). The results from his own studies are not published. When the sluice was tested in Ghana they did not take any samples for analysis, they just saw that they could extract gold with the sluice. Apart from David Plath, there is another group from the University of British Columbia that has been testing the sluice in Canada and Venezuela but the results have not been published yet and are not official.

The results from our investigation show that it is possible to exchange the present amalgamation method with the magnetic sluice, even if the results vary between the sites and within the sites. In the Philippines, they extract about 30-50% of the gold in the ore with the amalgamation process (orally, MGB). According to McDonald (1983), the recovery by the amalgamation method is around 30%. In Balatoc, the mean gold recovery with the magnetic sluice was 48% which is approximately the same that they extract with the amalgamation method. The highest recovery with the magnetic sluice was 73%. If this result is possible to achieve every time with the sluice, then it is a very good replacement instead of using mercury. The recovery could be improved by mounting the sluices in stands with fixed angle in the position giving optimal recovery and by running the ore through the sluice several times, which could be done automatically with slurry pumps.

To get more reliable results for evaluating the efficiency of the sluices, I think we should have taken larger and more samples before and after processing with the sluice. The samples after processing were taken in a bucket by chance, two after each test, which means that the gold content is much dependent on where in the bucket the sample is taken, if the sample is not thoroughly homogenized. The original ore contained a low amount of gold so the samples may not be representative for the average gold content in the ore. In some places we even had more gold in the after-samples than in the before-samples, which is strange since the samples taken in the sluice show that in every test, gold had been concentrated in the sluice. This indicates that the problem is samples collected not always being representative for the bulk.

One possible problem to face when using the sluices in the Philippines is that the gold is very fine, as contrary to the beaches in Alaska, where the gold grains are quite large. The ore we did the testing on contained a lot of other minerals, for example pyrite. The pyrite grains have a high density and settled in the sluice. The gold grains are supposed to replace the pyrites, but if the gold is too fine and the pyrite grains are a little bit bigger, maybe the gold just flows through the sluice without settling. Another problem with the high content of pyrites is that the panning is difficult. Pyrite glows as gold and when the gold is very fine it is hard to pan until

there is only gold left in the pan, so it is very hard to absorb the gold with the plastic vial.

The miners were very skeptic about the final step with the plastic vial. They asked us several times what we were going to do next, how did we purify the gold in the bottle? When we told them that this is the final step and that after the water has evaporated they would have just gold left, they were not convinced. Both in Balatoc and Paracale, where the results were good, the gold grains were quite large and the ore did not seem to contain as much pyrites as in the other places. The larger the gold grains are, the better the magnetic sluice works. However, the amalgamation with Hg does not work on fine gold grains (< 0.07 mm; McDonald, 1983), while cyanidation needs fine grains (<0.2 mm). Therefore a combination of the sluices and cyanide may be the most pragmatic solution under present conditions.

The small magnetic sluice costs about 30 US$ (~ 200 SEK) and the larger sluice cost around 150 US$ (~ 1000 SEK). The miners in the Philippines use about 3 kg of mercury per month and each kilogram costs 1000P (20 US$ or 150 SEK), so it would be beneficial for the miners to use the magnetic sluice instead of buying mercury each month. I think that the problem for the miners if they want to buy the sluices is that they do not have all that amount of money at any time. To make it possible for the miners to buy the magnetic sluice, they need to be able to get a loan/micro credit.

It seems like most of the people do not want to acknowledge the fact that they are affected by the high mercury levels in the environment as well as in their own bodies. Out of all the eight people we interviewed, just one man (from Paracale) admitted that he was not feeling well. He felt that he was loosing weight and had problems with his eyes and he also told us that there were several others in the area who felt the same thing. There are still fish in the river in Paracale and the people eat it. This is a difference from all the other places we visited, where all the fish was dead. The fish in Paracale may still be alive because the river is connected by the sea so the pollution is diluted due to a large amount of water, but the fish can still be so contaminated that it affects people's health.

The DOH (the Department of Health) of and others have done a lot of health studies in different mine sites in the Philippines. In Diwalwal workers showed severe symptoms due to mercury. A few symptoms the miners experienced were fatigue, tremor, memory problems, loss of weight and restlessness. In the mining sites even children are working. It is hard work for them and they are exposed to a lot of mercury (Drasch *et al*, 2000). Since it is about 20 years ago the use of mercury started in the Philippines, no one can really tell what the health effects will be in the long run. Maybe all the adults will die before they turn 60 and the ones that are children now will be sick before they turn 30. Nobody knows, only time can tell. Even if the workers do not feel so much health effects now from the mercury, they might say something different in 10 years. Instead of continuing to do health studies, the DOH and others should educate and give the miners safety equipment. It would

be of great importance for the workers' health if they used masks and gloves instead of nothing while they are working. Everybody knows that the miners are intoxicated by mercury so there is no need for any more medical investigations.

It is possible to treat people, who are mercury intoxicated, with a substance called DMPS (2,3-Dimercapto-1-propane-sulfonic acid, Dimaval®). A study made in Diwalwal showed that many of the treated patients reported they felt their health had improved. Even if the treatment may be successful, the usage of mercury that people are affected by must be reduced for a lasting effect (Böse-O´Reilly *et al*, 2002). Alternatively, when a person is treated, he or she should move from the area to avoid further exposure. The miners in the area of Diwalwal are mostly exposed to metallic and inorganic mercury. The inhabitants of the community Monkayo, downstream from Diwalwal, are mostly affected by methyl mercury. The mercury is obviously methylated on the way down to Monkayo (Böse-O´Reilly *et al*, 2002). Consumption of fish under a long time is the primary source of methyl mercury in individuals (Hirokatso *et al*, 2000). In river water 14 km downstream from Diwalwal, the mercury content exceeds the WHO Drinking Water Guideline value and the USEPA Water Quality Criteria for the Protection of Aquatic Life (Appleton *et al*, 1998). The highest recommended level of mercury in blood is 10 µg/l. In the Philippines, a concentration as high as 108 µg/l was measured in workers at a ball mill and up to 57 µg/l in school children, who studied close to mining areas (Eisler, 2002). In a school in Tagum, on Mindanao, where there are small-scale mining activities, the DOH got complaints about the children's health. Fish is the main ingredient in the children's diet, but they are also affected by the mercury in the ambient air, which means that the children are exposed by both inorganic and methyl mercury at the same time (Hirokatso *et al*, 2000). This shows that people around the mining areas are affected, and not just the workers, by the use of mercury and that it is very important that something is done about it.

One environmental problem that can be seen in the areas is that the fish is dead in the rivers (except in Paracale). The problems do not only affect the area closest to the mining site, but also the communities further down stream. The communities downstream from Diwalwal have started to complain because their crops are getting contaminated due to the high discharge of pollutants. For every gram of gold recovered, two to five grams of mercury are released into the environment (UNIDO, 2004).

In contaminated rivers in general, there is a clear decrease in animal diversity, and sometimes there are no animals present at all (Tarras-Whalberg *et al*, 2000). In an investigation done by Tarras-Whalberg *et al*. (2000) in southern Ecuador, they could see some indications that rivers can recover biologically comparatively rapidly, if the discharge of contaminants is reduced or completely ended. Therefore, if the discharge of tailings in the rivers in the Philippines is diminished, it is possible that life will return. Even if the mining activity is so-called small-scale, its extension and the lack of resources to handle the waste properly from both the amalgamation

process and the cyanide leaching severely damages the environment, both in the area and many kilometers away from the source (Tarras-Whalberg *et al*, 2001).

People in the Philippines want a change, and they are aware of all the problems that are connected with the use of mercury, but they are not working to get a change. They are waiting for the government or somebody else to come with the solution to them. They have been very positive to the new method, the magnetic sluice, but also very skeptic. Since we did the testing on the smallest sluices, they thought it would take a very long time for them to process the amount of ore they process during one day. There are larger sluices to use and the inventor, David Plath, says that it is possible to process a lot of ore during a short period of time; about _ ton of ore can be processed during _ hour (cleangold, 2003). But it was kind of hard for us to convince the people of that, they would like to see it with their own eyes before they can believe it. In Diwalwal, where they use a lot of mercury, it would be a great improvement if they started to use the magnetic sluice and just added mercury in the pan for the final refinement of the ore, instead of what they are doing now, adding large quantities of mercury in the ball mill. Even if they at this point have the gold extraction as their only income, they should think one step further. They do not take any responsibility for their tailings and for the environment or the safety for their children. It is hard to change, but the gold extraction with mercury is not a sustainable way of living.

Also the government has to take responsibility to improve the conditions. In Diwalwal, the government has built a tailings dam, 5 km from the area where the gold diggers live and work. The gold diggers are against this dam because it will be too expensive for them to transport their tailings down hill on the extremely bad roads. It is also too expensive for them to move their establishments closer to the dam. The dam is ready to be used, but nobody is using it. The government says that they will build a pipeline from the gold area down to the dam which the tailings can be pumped through, but the money to build it does not exist yet (orally, MGB). It feels like the government is starting in the wrong end. It is a very good idea that the tailings will be left in a dam, but they have to work together with the miners. If the miners will not use the dam, then all the money the government has invested in this project will be in vain.

I think the government should try to help the miners to get a better life in all the mining areas. Try to help them find other methods to use; it is obvious that other methods exist. The government has started to make a survey of the miners in the Philippines. In Diwalwal, the miners pay taxes to the government. The tax is 15% of the ore. The payment is not in money but in ore, which the government then processes using mercury. We asked the female miner we interviewed in Diwalwal what she thought about the taxes. She said: “It’s good that people are sharing.” She thought it was right since the government is in a financial crisis. Maybe she also thinks that if they pay taxes to the government, then they will get some help regarding their situation. DENR/MGB (the Department of Environmental and Natural Resources and the Mines and Geosciences Bureau) told us that when they

have located the miners, they will also have to apply for a certificate to use mercury. But it does not work in real life. The miners use mercury with or without the certificate. It seems to me that the people from DENR/MGB do not have the use of mercury under control and do not know how much mercury the miners use. When we went to Acupan, the people from MGB told us that the miners did not use so much mercury. On our way there, we visited the mayor and he said that the fish in the rivers had deformed heads due to the pollution of mercury. At the site, the miners did use a lot of mercury and just threw the tailings everywhere, and they were not reluctant to tell us about it, although people from MGB and DOH accompanied us.

In 1998, UNIDO, United Nations Industrial Development Organization, was on Mindanao in the Philippines to introduce a method to recycle the mercury and prevent it from being released into the air instead of just use the blow torch in the open air (orally, MGB). The equipment, a retort, consisted of a glass or metal container in which the amalgam is put. To remove the mercury from the amalgam, the glass container is heated from underneath and the mercury vapour flows through a glass pipe with water to cool the vapour down. The mercury will then be in liquid form again and is collected in a glass container. The problem with this equipment was that the miners thought it took a long time to get the gold and they said that they could not really see the gold when they heated it. Time is money for the miners. They also thought that gold got absorbed in the glass so they got a loss of gold (orally, MGB). Another problem with the used retort model is that the miners can remove the cover from the container. If they do that when it is hot the mercury vapour will be released and the miner and the environment will be exposed to it (Veiga and Gunson, 2004). The people from DENR/MGB gave the miners the equipment for free and the miners said that they were going to use it, but when the DENR/MGB people went up to the miners the next time, they did as they always have done, using the blow torch in the open air. This can be a problem, for if the DENR/MGB/DOH would hand out safety equipment; the miners may not use it when they are alone. So even if the miners want to have a change and help from other people, they also are very comfortable and the new methods have to be as or even more efficient compared to what they are using now.

The last 15-20 years, the use of mercury in Europe has been reduced, but in many developing countries the use of mercury has been stable or increasing (Maxson, 2004). In the past, North America and Europe dominated the consumption of mercury, but that has changed to East Asia, especially China, and South Asia. The reason why the usage in Europe is declining is that mercury is being replaced by other materials in many products, but the supplies of mercury from Europe to the developing countries are still stable and the mercury prices are declining, except in 2004, which probably is a temporary increase (Hayes, 2004). EU member states imported about 400t of raw mercury in year 2000 and exported over 1400t. EU stands for 20-30% of the global mercury supply. The Netherlands shipped 245t of raw mercury to about 18 countries outside of the EU. Most of the mercury was low-priced and with low purity. This kind of mercury is used in small-scale mining. Spain exported low purity mercury to 20 countries outside of the EU, 774 t, and two-

thirds of this to the East Asia/Pacific region. The areas with the highest import of raw mercury in year 2000 were Latin America/Caribbean (1197t), East Asia (1100t) and South Asia (628t). The mercury came mostly from the EU, namely 50% of the mercury transported to East Asia and all of the mercury to South Asia. Spain, the Netherlands and the UK were the main suppliers in EU, especially for low-priced, low purity mercury. Globally, the three main countries that contribute with mercury to the markets are Spain, Kyrgyzstan and Algeria, which mainly mine mercury for export (Maxson, 2004). The mines in Spain have alone contributed with one third of the global mercury production (Hylander and Meili, 2005). During the past ten years, the price of mercury has been reduced and is now close to its lowest level ever. If mercury would be more expensive, the usage would decrease according to basic economic laws. Presently, small-scale miners are under no economic pressure to use less mercury (Maxson, 2004). Now the demand for mercury is mostly satisfied with mercury that has been recycled or mercury that is produced as a byproduct when other metals (gold, zinc, lead and copper) are refined (Hylander and Meili, 2005). The dominating mercury producer in the EU is the Spanish state company, MAYASA, which is running the mine in Amaldén. The mine had to close in 1990 because it was not profitable anymore. But with public contributions, the mine reopened in 1993, even though the price on mercury was low and the demand declining. Before a second closure in 2002, the company extracted tens of thousands of tonnes of mercury mineral, stored for melting as sales proceeds of metallic mercury (Ross-Thomas, 2005). Other mines, for example in Algeria, China and Kyrgyzstan, are also state owned, and are supposed to produce mercury even at economic losses. This leads to that virgin mercury is used instead of recycled mercury, which may lead to a larger environmental pressure (Hylander and Meili, 2005). To reach the problem with mercury, the mercury export needs to be stopped globally. A first step in this direction has been taken in the EU Community Strategy Concerning Mercury, proposing to phase out the export of mercury from the EU by 2011 (EU, 2005).

## Conclusions

With more investigations on adapting the sluices to the specific ore composition of the Philippines, magnetic sluices may reduce the use of mercury significantly. It is economically beneficial for the miners to start to use magnetic sluices instead of mercury. To buy magnetic sluices involves quite a large non-recurring amount of money, so the miners need to get a loan/micro credit for the investment. The habits of the miners need to change. The miners want to change their situation, and they are very positive about the new method, and open for others. It is important to continue to evaluate environmentally friendly methods for gold extraction.

It is possible to treat intoxicated miners, but then it is necessary to move them from the mining site after the treatment; otherwise the treatment will be in vain. As long as the miners use mercury, safety equipment should be handed out among them. It would also be a good thing to educate the miners about mercury and the effects on their health.

It is important to find solutions for where to store the tailings. It is good to build tailing dams, but the dams have to be close to the mining sites so that the miners will use them. The dams are the first step to get the biological life back into the rivers and to reduce the pollution effects to the farmers downstream.

Stricter control and better legislation of the use of mercury should be introduced. The government has started mapping the miners to get a better control, but it is not working in real life yet. Mercury is too accessible for the miners. The export of mercury from Europe has to stop, the sooner the better.

## Acknowledgement

First, I would like to thank our supervisors, **Lars Hylander** (Department of Limnology, Uppsala, Sweden) and **Ana Trinidad Francisco Rivera** (Department of Health, Manila, the Philippines) for all your support and for making this investigation and adventure possible. Thank you **David Plath** (cleangold) for information about the method.

Thank you **all gold miners** in Diwalwal, Mainit, Acupan, Balatoc and Paracale for being so interested in our work and for letting us get to know you, I will never forget you!

Thank you to the **Governors and Mayors** in the regions for your time and for allowing us to go out in the field and conduct our study.

Thank you **Dr. Annabelle P. Yumang** for taking care of us, helping us and being our friend. Thank you **Arlene J. T Maglana** for your help and hospitality and not at least for all the fruits! Thank you, **Nancy T Juntilla** for your help and for all the interesting discussions.

Thank you all the people who have helped us at the **Mines and Geosciences Bureau (Department of Environment and Natural Resources)** in Manila, Davao, Baguio and Legaspi. Thank you all, helpful employees at the **Department of Health** in Manila, Davao, Nabunturan, Monkayo, Baguio, Legaspi and Paracale.

Thank you **Sida and the Committee of Tropical Ecology** (ATE) at Uppsala University.

Thank you my **Emil** for all your support before, during and after the trip to the Philippines. And finally, thank you **Sofie** for this adventure and for being such a good travel companion.

## References

**Appleton J.D., T.M. Williams, N. Breward, A. Apostol, J. Miguel and C. Miranda, 1998.** Mercury contamination associated with artisanal gold mining on the island of Mindanao, the Philippines. The Science of the Total Environment 228 (1999) 95-109.

**Böse-O´Reilly S., G. Drasch, C. Beinhoff, S. Maydl, M.R. Vosko, G. Roider and D. Dzaja, 2002.** The Mt. Diwata study on the Philippines 2000-treatment of mercury intoxicated inhabitants of a gold mining area with DMPS (2,3-Dimercapto-1-propane-sulfonic acid, Dimaval®) The Science of the Total Environment 307 (2003) 71-82.

**Clemente E., K. Sera., S. Futatsugawa and S. Murao, 2004**. PIXE alanysis of hair samples from artisanal mining communities in the Acupan region, Benguet, Philippines. Nuclear Instruments and Methods in Physics Research B 219-220 (2004) 161-165.

**Drasch G., S. Böse-O´Reilly, C. Beinhoff, G. Roider and S. Maydl, 2000.** The Mt. Diwata study on the Philippines 1999 – assessing mercury intoxication of the population by small scale gold mining. The science of the Total Environment 267 (2001) 151-168.

**Eisler R., 2002**. Health risks of gold miners: a synoptic review. Environmental Geochemistry and Health 25 (2003) 325-345, 2003.

**EU. 2005**. Community Strategy Concerning Mercury. http://www.europa.eu.int/comm/environment/chemicals/mercury/pdf/com_2005_0020_en.pdf updated 2005-01-28, accessed 2005-02-09.

**Hayes, M. 2004.** Exotic mercury soars to high on tight supply. Reuters. http://www.reuters.com/newsArticle.jhtml?type=reutersEdge&storyID=6115119 updated 2004-08-31, accessed 2004-09-02.

**Hirokatsu, A., E. S. Castillo, N. Cortes-Maramba, A.T. Fransisco-Rivera and T.D. Timbang, 2000.** Health assessment for mercury exposure among schoolchildren near a gold processing and refining plant in Apokon, Tagum, Davao del Norte, Philippines.
The science of the Total Environment 259 (2000) 31-43.

**Hylander L. D. and M. Meili, 2005.** The rise and fall of mercury: converting a resource to refuse after 500 years of mining and pollution.
Critical Reviews in Environmental Science and Technology 34 (2005) 1–36.

**Hylander L. D. and D. Plath, 2004**. A simple method for the mercury-free recovery of fine gold and platinum. RMZ-materials and geoenvironment, periodical for mining, metallurgy and geology 51 (1) (2004) 625-628.

**Lacerda, L. D. 2002.** Updating global Hg emissions from small-scale mining and assessing its environmental impacts. Environmental Geology 43 (2003) 308-314.

**Macdonald, E. H. 1983**. Alluvial Mining. The geology, technology and economics of placers. Chapman and Hall, London, UK. 508 pp.

**Maxson, P. 2004**. Mercury flows in Europe and the world: The impact of decommissioned chlor-alkali plants. Prepared by Concorde East/West Sprl for the European Commission (Environment Directorate), final report dated February 2004, Brussels, Belgium.
http://europa.eu.int/comm/environment/chemicals/mercury/index.htm

**Ross-Thomas, E. 2005.** Spain's Almaden has no plans to restart mercury mine. Reuters.
http://www.alertnet.org/thenews/newsdesk/L14715311.htm updated 2005-01-14, accessed 2005-02-09

**Rydén L., P. Migula and M. Andersson, 2003.** Environmental science. A Baltic University Publication.

**Tarras-Whalberg, N. H., A. Flachier, G. Fredriksoon, S. Lane, B. Lundberg and O. Sangfors, 2000.** Environmental impact of small-scale and artisanal gold mining in southern Ecuador. Ambio 29 (2000) 484-491.

**Tarras-Whalberg, N. H., A. Flachier, S. N. Lane and O. Sangfors, 2001.** Environmental impacts and metal exposure of aquatic ecosystems in rivers contaminated by small scale gold mining: the Puyango River basin, southern Ecuador. The Science of the Total Environment 278 (2001) 239-261.

**Veiga, M. M. and A. J. Gunson, 2004.** Technical Aspects of Mercury Pollution Caused by Artisanal Gold Miners in Block B, El Callao, Bolivar State, Venezuela. UNIDO (United Nations Industrial Development Organization, Project XP/VEN/C04.

**Wolpher H., M. Tropp, E. C. Silva, L. D. Hylander, L. J. Oliviera and E. G. Neis, 2003.** Will the power plant at Rio Manso, Brazil, cause elevated mercury levels of fish and reduce fish populations? Revista Saúde e Ambiente, 6 (2003): 12-26.

**Internet sources**

**Britannica online**: http://www.search.eb.com/eb/article?tocId=81544
Accessed 2004-12-01, 11:10

**Cleangold:** www.cleangold.com
Accessed 2003-10-08

**cyanidecode**: http://www.cyanidecode.org/library/cn_facts_health.html
Accessed 2004-12-01, 16:00

**eco-usa.net**: http://www.eco-usa.net/toxics/cyanide.shtml
Accessed 2004-12-01, 15:50

**UNIDO**: http://www.unido.org/en/doc/4199. Accessed 2004-12-07, 12:00

**Personal contacts**

Local miners at all sites visited (Diwalwal, Mainit, Acupan, Balatoc and Paracale, the Philippines)

People working at MGB/DENR (Department of Environment & Natural Resources)/MGB (Mines and Geosciences Burau), Manila, Davao & Baguio, the Philippines.

Appendix. All samples and analyses from the investigation in the Philippines, 2004.

| Site and number of tests | Sample analyzed (g) | Gold content (g/t) | Gold recovery (%) | Conc. factor in the sluice | Gold content in the sluice (g/t) |
|---|---|---|---|---|---|
| **Diwalwal** | | | | | |
| 1 | 15 | 4.7 | 40 | | |
| 2 | 7.5 | 4.8 | 40 | | |
| 3 | 7.5 | 3.7 | 54 | | |
| 4 | 15 | 4.5 | 43 | | |
| 5 | 7.5 | 5.5 | 31 | | |
| Original ore | 15 | 8.9 | | | |
| " | 15 | 7.8 | | | |
| " | 15 | 7.2 | | | |
| Sluice sample 1 | | | | 4.5 | 36.1 |
| Sluice sample 2 | | | | 8.1 | 64.5 |
| Sluice sample 3 | | | | 9.5 | 75.0 |
| Sluice sample 4 | | | | 2.4 | 19.0 |
| Sluice sample 5 | | | | 10.2 | 80.6 |
| After amalgamation | 7.5 | 5.5 | | | |
| " | 15 | 8.8 | | | |
| " | 15 | 8.3 | | | |
| " | 15 | 6.4 | | | |
| " | 15 | 6.7 | | | |
| After cyanidation | 15 | 0.5 | | | |
| " | 15 | 0.3 | | | |
| " | 15 | 0.4 | | | |
| **Mainit** | | | | | |
| 1 | 15 | 7.1 | 24 | | |
| 2 | 15 | 11.2 | -19 | | |
| 3 | 15 | 7.2 | 24 | | |
| 4 | 15 | 8.7 | 8 | | |
| 5 | 15 | 11.5 | -22 | | |
| Original ore | 15 | 8.9 | | | |
| " | 15 | 8.7 | | | |
| " | 15 | 11.5 | | | |
| " | 15 | 8.1 | | | |
| " | 15 | 10.0 | | | |
| Sluice sample 1 | | | | 0.9 | 8.6 |
| Sluice sample 2 | | | | 1.2 | 11.3 |
| Sluice sample 3 | | | | 1.9 | 17.7 |
| Sluice sample 4 | | | | 1.2 | 11.7 |
| Sluice sample 5 | | | | 3.2 | 30.4 |
| After amalgamation | 7.5 | 66.5 | | | |
| " | 7.5 | 63.8 | | | |
| " | 15 | 69.60 | | | |
| " | 7.5 | 58.6 | | | |
| " | 7.5 | 69.5 | | | |
| After cyanidation | 7.5 | 1.4 | | | |
| " | 7.5 | 1.1 | | | |
| " | 7.5 | 0.98 | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Acupan** | | | | | |
| 1 | 7.5 | 10.5 | 1 | | |
| 2 | 7.5 | 10.6 | 0 | | |
| 3 | 7.5 | 9.4 | 11 | | |
| 4 | 7.5 | 9.0 | 15 | | |
| 5 | 7.5 | 16.1 | -52 | | |
| Original ore | 5 | 14.3 | | | |
| " | 7.5 | 9.6 | | | |
| " | 7.5 | 8.7 | | | |
| " | 7.5 | 9.0 | | | |
| " | 7.5 | 11.4 | | | |
| Sluice sample 1 | | | | 1.5 | 16.0 |
| Sluice sample 2 | | | | 3.0 | 32.3 |
| Sluice sample 3 | | | | 4.0 | 42.8 |
| Sluice sample 4 | | | | 3.3 | 34.6 |
| Sluice sample 5 | | | | 4.8 | 51.1 |
| **Balatoc** | | | | | |
| 1 | 7.5 | 31.2 | 73 | | |
| 2 | 7.5 | 53.4 | 54 | | |
| 3 | 7.5 | 38.2 | 67 | | |
| 4 | 7.5 | 85.4 | 26 | | |
| 5 | 7.5 | 91.6 | 21 | | |
| Original ore | 7.5 | 186.4 | | | |
| " | 7.5 | 158.4 | | | |
| " | 7.5 | 117.4 | | | |
| " | 7.5 | 102.6 | | | |
| " | 7.5 | 11.1 | | | |
| Sluice sample 1 | | | | 2.7 | 313.5 |
| Sluice sample 2 | | | | 3.8 | 437.2 |
| Sluice sample 3 | | | | 4.7 | 540.6 |
| Sluice sample 4 | | | | 2.7 | 307.8 |
| Sluice sample 5 | | | | 3.2 | 368.3 |
| After sluice box | 7.5 | 7.8 | | | |
| " | 7.5 | 3.0 | | | |
| " | 7.5 | 6.5 | | | |
| " | 7.5 | 5.0 | | | |
| " | 7.5 | 5.8 | | | |
| After cyanidation | 7.5 | 12.6 | | | |
| " | 7.5 | 30.9 | | | |
| " | 7.5 | 21.8 | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Paracale** | | | | | |
| 1 | 7.5 | 24.8 | 34 | | |
| 2 | 7.5 | 18.5 | 51 | | |
| 3 | 7.5 | 21.1 | 44 | | |
| 4 | 7.5 | 15.3 | 59 | | |
| 5 | 7.5 | 18.3 | 52 | | |
| Original ore | 7.5 | 21.3 | | | |
| " | 7.5 | 100.5 | | | |
| " | 7.5 | 28.5 | | | |
| " | 7.5 | 15.7 | | | |
| " | 7.5 | 22.3 | | | |
| Sluice sample 1 | | | | 10.6 | 399.6 |
| Sluice sample 2 | | | | 18.4 | 695.1 |
| Sluice sample 3 | | | | 14.2 | 534.9 |
| Sluice sample 4 | | | | 8.5 | 318.7 |
| Sluice sample 5 | | | | 4.9 | 185.2 |
| After amalgamation | 7.5 | 11.2 | | | |
| " | 7.5 | 11.0 | | | |
| " | 7.5 | 10 | | | |
| " | 7.5 | 9.3 | | | |
| " | 7.5 | 10.5 | | | |
| After cyanidation | 7.5 | 2.9 | | | |
| " | 7.5 | 2.2 | | | |
| " | 7.5 | 2.1 | | | |