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Abstract

Approximately 100 000 people are involved in small-scale gold mining activities in the Philippines. The methods that they mainly use are the amalgamation and/or cyanidation processes. These technologies, which have been used during the last 30 years, are easy, efficient and relatively cheap, but at the same time the toxic mercury and cyanide have brutal effects both on humans and environment. The miners themselves are the ones who are mostly affected by the poisons; no safety equipment is being used and toxification of mercury results in tunnel vision, cramps and paralysis. Waste problems are frequent, since tailings dams in most cases not are built. This results in dispersal of toxicants, which affects, or even kills, the fishes in the nearby running waters. Since the mercury also is easily transported, the problems related to gold mining could be classified as both local and global. The gold miners are in a difficult situation. They are dependent of the income from the gold and therefore they are using the cheap and simple methods. If an economic sustainable and environmentally benign method could be introduced to the gold miners in the world today, it would help to prevent environmental degradation.

The aim of this study was to evaluate a new method for gold recovery, suitable for small-scale miners and in which mercury, cyanide or other chemicals are not used. The study was performed at five different gold sites in the Philippines (Diwalwal, Mainit, Acupan, Balatoc and Paracale). In order to understand the complex situation from a miner's perspective and further determine the possible willingness and chances to improve the situation in the small-scale gold mining areas of the country, interviews with the local miners were also performed.

The results of the study show that use of mercury in small-scale gold mining in the Philippines, theoretically, could be replaced by use of magnetic sluices. The efficiency varies slightly, both within and between the sites, but according to the evaluation tests, the top value of the efficiency is estimated to 73%. In comparison, the recovery using the amalgamation method is estimated to between 40 and 50% and the recovery after cyanide treatment is estimated to approximately 90%. Though, it is possible that further studies could lead to development and/or adaptation of the method to local conditions, which could increase the recovery even more. If the magnetic sluices cannot completely replace the amalgamation method, the chances of at least reducing the use of mercury are large, for example by adding mercury in the final step only, while panning.

In conclusion: the miners want and need a change. The obstacles for development are lack of technology and knowledge, unstable economy, habits and the fact that mercury and cyanide are easily accessible on the market. With financial support, measures such as free distribution of safety equipment, education, medical treatment of intoxicated persons, and building of waste disposals could become reality. Further, for development and adaptation of environmentally benign methods, stricter control/legislation and accessible loans/micro credits to the miners are important. In summary: by having an intense dialogue with the gold miners and work from their perspective using the right measures, I believe that the use of mercury in small-scale gold mining has a high potential of being reduced in the future.

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Introduction

Background

The first documentation of gold mining activity is dated back to 4000 BC. Since then gold has been a symbol of power and wealth, as well as a metal of extra high density, workability, durability and chemical resistance (Müezzinoglu, 2003). It is estimated that the earth crust contains approximately 0.004 grams of gold per ton, which makes the metal one of the most rare in nature. The gold is, however, unequally spread over the globe, because of the enrichment processes, which have occurred on the surface of the earth. South Africa is the world's leading gold producer, producing 31.3% of the total gold produced during 1987-1990. Other important gold producing countries are Tanzania, Ghana, Brazil, China, United States and Peru (Nationalencyklopedin, 1992). The methods for extracting gold have varied during the years, starting with simple small hand operations like gravity panning, diverse sluicing techniques to the presently and frequently used amalgamation and cyanide leaching (Macdonald, 1983). However, use of mercury and cyanide is not exceptionally new technologies. Mercury has been used in gold recovery for about 500 years while cyanide treatment was introduced about 125 years ago (Hylander & Meili, 2005.). The earlier methods of extracting visible gold pieces without mercury or cyanide used to have less serious environmental impacts than the present methods. The 10-15 millions small scale gold miners of today are emitting approximately 500-700 tons of mercury every year, as they are extracting gold using the amalgamation method (Hylander & Plath, 2004). This is because two to five grams of mercury are used and released into the environment for every gram of gold recovered (UNIDO, 2004). The effluents of cyanide are also sometimes extensive. According to Korte and Coulston (1995), 125 tons of cyanide is added for extracting 750 kg of gold in a 250 000-tons ore processing plant containing 3 ppm gold. Problems related to the tailings are frequent since large amounts of cyanide are left in the waste, which in many cases is not taken care of. Sometimes the toxic compound also is spilled in the working area. Globally this results in large amounts of cyanide leaching to the surroundings. The environmental impacts of gold mining activities are severe (Tarras-Wahlberg et al., 2001).

The situation for the gold miners in the world is in many cases problematic and affected by actions made by, so called, industrialized countries. Environmentally benign alternatives to mercury in combination with strict legislation on use of mercury have reduced the use of mercury significantly in all industrialized countries. However, these reductions in use have had the effect of lowering demand relative to the supply of mercury, which has kept mercury prices low and encouraged ongoing use of mercury and outdated mercury technologies in less developed countries (UNEP, 2002). Rather than globally reducing the availability of mercury, the EU has indirectly supported mercury contamination in the world by large economic contributions to the Spanish government, owning and running the mercury mines and ore processing plants in Almadén, Spain (Hylander & Meili, 2003). The mine, which is operated by Minas de Almadén y Arrayanes S.A. (MAYASA), has unpredictably increased its production of mercury during the last decade, producing 236 tons of mercury during year 2000 and 745 tons during 2003 (Maxson, 2004). The direct emissions of mercury to air from this mine are extensive, for example approximately 4 tons of vapor mercury was let out during the year of 1995 (EU report, 2002).

The dream of a better life is in the mind of small-scale gold miners in developing countries such as the Philippines. Gold mining activities in the country date back to the 3rd century A.D., when Chinese traders referred to Luzon as the Isle of Gold (http://www.mgb.gov.ph/asomm/min_resources.htm, 041110). Presently, about 50% of the small-scale gold miners in the Philippines have, during the last 30 years, been using the amalgamation method for extracting gold (orally, MGB/DENR, Manila). In most of the cases the miners also are using cyanide to be able to recover nearly all the gold in the ore. The methods are easy, efficient and relatively cheap, but at the same time the toxic mercury and cyanide have brutal effects both on humans and environment. The miners themselves are the ones who are mostly affected by the poisons; no safety equipment is being used and toxification of mercury results in tunnel vision, cramps and paralysis. Problems regarding the waste are enormous, since tailings dams in most cases not are built. This results in dispersal of toxicants, which affects, or even kills, the fishes in the nearby running waters. Since the mercury also is easily transported, the problems could be classified as both local and global. The gold miners are in a difficult situation. They are dependent of the income from the gold and therefore they are using the cheap and simple methods. If an economic sustainable method, without using mercury and/or cyanide, could be introduced to the gold miners in the world today, it would help to prevent environmental degradation.

In this study an evaluation of a new environmentally benign method for gold recovery among small-scale gold miners in the Philippines was done. Interviews with local miners were also done in order to broaden the picture of working/health/environmental conditions. Further on, conclusions regarding the possibility in changing the situation among the small-scale gold miners were drawn.

Gold recovery in the Philippines

Artisanal small-scale gold mining has a long tradition in the Philippines, dated back to the 3rd century A.D. (http://www.mgb.gov.ph/asomm/min_resources.htm, 041112). The continued increase of gold prices in the later part of the 1970s (Figure 1), when the price more than doubled from 7.34 USD/gram in 1978 to 16.19 USD/gram in 1979 (http://goldinfo.net/yearly.html, 041123), in combination with the depressed socio-economic conditions in the country, made people search for alternative means of livelihood. Discovery of “gold pockets” in many parts of the country triggered a number of gold rushes and the number of small-scale gold miners increased dramatically during the 1980s (Clemente et al., 2004). Today the country inhabits approximately 100 000 small-scale gold miners, among most of them are rural people equipped with basic tools, such as picks, shovels and pans (UNIDO, 2004).

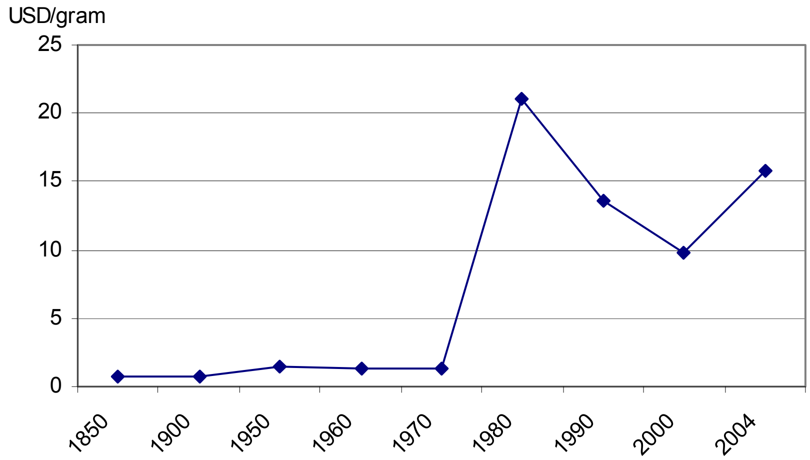

Figure 1. Gold prices in current USD/gram during 1850 to 2004 (http://goldinfo.net/yearly.html and www.goldprices.com, 041124).

Gold mining methods

The methods that have been used in the country, during the years, span from traditional panning in the river to combinations of sluice boxes, amalgamation and cyanide treatment. Gold panning refers to the recovery of free gold through gravity using a wooden or metal dishpan. This method is typically taking place where the ore contains free gold grains, for example in the river banks. Another method/equipment that has been frequently used in former days, and sometimes still today, is the sluice box. This method also uses gravitation by letting the ore pass through a sluice, made of wood or concrete. The sluice is covered with materials, such as jute/corduroy cloth, which captures the gold grains when the ore/water mixture passes the sluice. The cloth is subsequently washed in a basin to recover the gold and other grain particles collected, which afterwards are panned to separate the pure gold from other particles, such as quarts sand (MGB/DENR, 1997). Nowadays, panning is often used in combination with the use of mercury, which is added directly to the pan. The principle behind this is the same as when mercury is added directly in the ball mill, while milling the ore. The gold grains in the ore attract physically to the mercury, forming amalgam. Thereafter, the mercury is easily steamed off by using a simple gas burner. What remains is the gold. The normal procedure after the amalgamation method is to submit the waste for further treatment using cyanide. This is because the mercury normally only captures approximately 40-50% of all the gold in the ore. The cyanide, however, usually captures about 90% of the gold, including the small gold grains (orally, local miner). The cyanidation method is very efficient, which is the reason why it is used in 90% of the gold production in the world today (Akcil et al., 2003). In the process, metallic gold is oxidized and dissolved in an alkaline cyanide solution (Encyclopedia Britannica Online, 2001). The following chemical reaction takes place with sodium cyanide used as a lixiviant (Müezzinoglu, 2003):

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN^-)_2 + 4OH^-$$

The different methods have diverse advantages and disadvantages. The disadvantage for the miners, using the traditional pan, is that it is relatively time consuming compared to the more modern techniques. The advantage, though, is that it is a cheap method, which does not consume any chemicals, resulting in a clean environment, both locally and globally. But since time is money and efficiency sometimes is more important than environment and health, the miners often add mercury to the pan, making it easier to catch the gold grains. The effects of mercury as well as cyanide, regarding health and environment, are brutal (Drasch et al., 2000).

Mercury – use, properties and effects

Mercury (Hg) is one of the most dangerous toxic substances. As an element, it cannot be destroyed by chemical reactions or break down into harmless elements (www.environ.se, 041126). Mercury is found in three forms; elemental mercury, inorganic mercury salts and organic mercury (Erle et al. 1997). Micro organisms in soil and water can convert the toxic metal to its most toxic form, the organic methyl mercury (CH_3Hg). This compound is easily accumulated in the food chain, which may result in large damages to top consumers, for example sea eagles and humans (www.environ.se, 041126). Environmental mercury levels have increased dramatically since the beginning of the industrialization. The major releases of mercury contamination are emissions to air, mainly from coal combustion, but mercury is also released from a variety of sources directly to land and water. Once released, mercury persists in the environment where it circulates globally between air, water, sediment, soil and biota in various forms (UNEP, 2002). The residence time of particle-bound mercury in the atmosphere ranges from a couple of days to weeks. This means that the metal can be transported thousands of kilometers before it deposits. Elemental mercury has a residence time of up to two years (Rydén et al., 2003). Worldwide, a total production of almost one million tons of metallic mercury is reported throughout the history, from which one third originates from the mercury mine Almadén in Spain (Hylander & Meili, 2003). The lustrous liquid metal has, due to its extraordinary properties, been used and is still used in different types of industries – chlor-alkali plants, war industry, thermometers, barometers and other measuring devices, batteries and other electric applications including fluorescent lightning, fungicides, medicines and dentistry (Rydén et al., 2003) Even though legislation has been stricter and alternatives to mercury in many cases are available on today's market, the discharges of mercury continue. The small-scale gold mining is, besides the gold mining industries, a great source of mercury pollution, letting out approximately 500-700 tons of mercury in the environment every year (Hylander & Plath, 2004).

The toxic effects of mercury depend on its chemical form and route of exposure.
The mercury that affects the gold miners is generally elemental mercury in vapor form. The toxic vapor is inhaled and absorbed directly by the lungs of the worker while burning the amalgam, the mixture of gold and mercury. The gaseous form of the metal easily penetrates the blood-brain barrier and is a well-documented neurotoxicant (UNEP, 2002). Effects such as memory loss, headache, tremor, disturbance of speech, insomnia and

neuromuscular changes are frequent. Many mercury poisonings result in death or severe permanent neurological damage (Eto et al., 1997). The methylated forms of mercury are more fat soluble than metallic mercury. This is the reason why it easily accumulates in the food chain, resulting in high concentrations in top consumers (Rydén et al., 2003). Studies on fish have shown negative effects on for example growth, genetics, hormones and reproduction (www.pesticideinfo.org, 041129).

Cyanide – use, properties and effects

Cyanides are chemical compounds that contain the C≡N group. They are found in nature, produced by certain bacteria, fungi, algae and in numerous of foods and plants. But due to its properties they are also widely produced for use in industries, such as electro plating, metallurgy, production of chemicals, photographic development, and mining processes (http://www.masterliness.com/a/Cyanide.htm, 041201). Therefore, they are sometimes found in water and food consumed by humans (Herbert, 1993). In the gold extracting carbon-in-leach and carbon-in-pulp processes, sodium cyanide (NaCN) is frequently used. The processes enable commercial recovery of gold at very low concentrations (down to 0.85 gram/ton). Between 300 and 500 tons of sodium cyanide is required for each ton of gold produced (http://www.chemlink.com.au/cyanide.htm, 041125). The manufacturing of sodium cyanide has increased dramatically since the gold prices went up during the 1970s. During 1987, for example, the United States produced 56 699 tons of the chemical (http://www.kemi.se/kemamne/cyanider.htm, 041126). In January 2000, the accidental discharge of large amounts of cyanide solutions and tailings from the Aurul mine in Romania resulted in significant pollution of the nearby river system. This incident radically increased the consciousness of governments, international organizations, industry and the public of the environmental risks connected to the use of cyanide in the gold mining industry (International Cyanide Management Code, 041201), but still large amounts of cyanide are used globally in gold industries, both in small-scale mining, but also in large industries such as the Swedish mining company Boliden. The company produces tons of gold every year, using different methods, where cyanidation is one. Approximately 600 tons of cyanide was used for production of 450 kilograms of gold, during 2004 (personal contact, Boliden 041207).

The poisonous effects of sodium cyanide if inhaled are for example dizziness, nausea, vomiting and unconsciousness. Skin contact may also result in corrosion, deep ulcers, severe irritation, pain and second degree burns (www.pesticideinfo.org, 041129). Once in the blood stream cyanide forms a stable complex with the enzyme cytochrome oxidase, an enzyme that promotes the transfer of electrons in the mitochondria of cells during the synthesis of ATP. This finally results in a shift from aerobic to anaerobic metabolism, leading to cytotoxic hypoxia or cellular asphyxiation and an accumulation of lactate in the blood. In conclusion, this results in depression of the central nervous system that can result in respiratory arrest and death (www.cyanidecode.org, 041129). Though there is a little chance of bioaccumulation in organisms, the acute toxic effects of cyanide are severe. Sodium cyanide is moderately to very highly toxic to fish, in which effects on behavior, enzymes, growth, histology and physiology have been shown (www.pesticideinfo.org, 041129). A common measure of acute toxicity is the lethal dose (LD50) or concentration (LC50) that causes death in 50% of treated animals (Walker et al., 2002). The mean LC50 value (96 hours) for the zooplankton Cyclopoid copepod (*Cyclops viridis*) has been estimated to 147.0 μg/l. Further, the mean LC50 value for gold fish (*Carassius auratus*) exposed for sodium cyanide during 24 hours has been estimated to 330.0 μg/l (www.pesticideinfo.org, 041129).

Objectives

The objective of this study is to evaluate a new method for gold recovery among small-scale miners, without using mercury, cyanide or other chemicals. The study has been performed at five different gold fields of the Philippines. Interviews with the local miners concerning their situation, health and their interest in using a mercury-free method for gold extraction have also been done. This was done in order to understand the complex situation from a miner's perspective and further determine the possible willingness and chances to improve the situation in the small-scale gold mining areas of the country.

In this report, I have tried to answer the following questions in view of the above objectives:

1) Is the mercury-free method as efficient as the other methods used today in small-scale gold mining?

2) What are the costs and benefits using the different methods? What are the perspectives - environment, health, food on the table?

3) What are the local miners' opinion regarding their situation and interest in using a mercury-free technology?

4) What are the obstacles for implementing new technology in the gold mining areas in the Philippines?

5) What could be done on a local/global scale?

Figure 2. Gold mining areas A-D visited during the study.

A - Diwalwal, Compostella valley, Mindanao

B - Mainit, Compostella valley, Mindanao

C - Acupan, Benguet, Luzon

D - Balatoc, Benguet, Luzon

E - Paracale, Bicol, Camarines Norte

Material and methods

Area description

A) Diwalwal, Compostella valley, Mindanao

The mountain village Diwalwal was, due to a gold rush, formed in 1983, when an epithermal system with a total gold reserve of several million grams was discovered by artisanal prospectors (Appleton et al., 1998). This made thousands of people move to the area at that time, set up houses and mills without any sign of planning and started to dig for gold in the mountains. In 1985, the population reached 100 000 people (Miranda et al., 1997), subsequently decreasing to the 20 000 inhabitants of today. About every third house has a mill and almost everybody is somehow connected to the small-scale gold mining industry – operate mills, work in the tunnels, buy or sell gold. The methods that are being used are a combination of amalgamation and crude bath cyanidation plant (Carbon in Pulp leaching). The waste from the mining activities is left at the site of processing, or dumped into the nearby surroundings, ending up in the Agusan River. A tailings dam has been built, but is not yet in use. The cost of time and money prevents the miners to transport the waste on the five kilometers extremely ruff and steep road. The government has refused to help the miners economically, but the plan is to make the transportation possible by building a pipeline from the village to the dam. The problem is lack of money (orally, local miner). The gold concentration of the ore that is being processed is estimated to 10g/ton (orally, local miner). The ore that was used for the magnetic sluice testing was grey in color and had a high content of water, in comparison with ores from the other sites visited.

B) Mainit, Compostella valley, Mindanao

The small gold mining village Mainit is situated in the low land of Compostella valley. About 6 000 inhabitants live in the village and approximately 20% are working with gold extraction. The gold mining has a long tradition in the area and until the 1970s the methods used were sluicing and panning in the river. During the 1980s mercury and cyanide were introduced, and these methods are still in use. The waste from the mining industry is dumped into septic tanks/holes in the ground. The tanks do not have any protective clay layer, but according to the miners, the poisons are completely encapsulated in the tanks. According to the miners, the ore contains about 20g Au/ton. The ore that was used during the magnetic sluice testing was yellow-brown in color and contained less water than the ore in Diwalwal.

C) Acupan, Benguet, Luzon

Approximately 1500 people live in the small mountain village Acupan on north Luzon, and more than 50% of these people are involved in the small-scale gold mining activities. The method used is a combination of the traditional sluice box (cloth), amalgamation and CIP. Mercury has been used during the last 20 years in the area, but in contrast to the other sites visited, the mercury is only added in the pan, after the ore has passed the sluice. This results in a markedly smaller amount of mercury used than at the other sites visited. The ore is said to contain about 15 g Au/ton and by using the present method (amalgamation) they can extract approximately 50% of the total gold content in the ore.

The waste that is produced is dumped into the environment leaving tracks from years of mining activities (orally, local miner). The ore, used in the testing of the magnetic sluice was already processed once, using their traditional sluice box. It was quite dry and had a grey-white color.

D) Balatoc, Benguet, Luzon

The mining in Balatoc, with its approximately 700 employees, is driven by the private company "Benguet Corporation", dating to 1903 (www.benguetcorp.com, 041115). Even though the industry is quite large, the methods used are more of a small-scale character. The ore passes a sluice box, which is covered with cloth, and the pure gold grains are finally extracted by traditional panning. No mercury is used. The waste from the sluice box is run in a CIP plant. Approximately 1.5 kilogram cyanide is used per ton ore. Since about 40 tons of ore is processed in the CIP every day, this results in a total cyanide consumption of about 60 kilograms per day. The waste is transported through a pipeline to a tank (orally, local miner). The ore that was used during the field test contained very little water. The color of the ore was dark grey.

E) Paracale, Bicol, Camarines Norte

The total population of the small coastal village of Paracale, Camarines Norte, is about 10 000. About 50% of these people are involved in the gold mining, while the other 50% are fishermen (orally, local miner). The ore is mined in tunnels in the mountains, but the so called "compressor mining" is also applied in the area. This is a crude method of alluvial gold ore mining, wherein miners descend in a deep, narrow and inundated hole. The mining is done manually with the use of iron bar, pick and shovel. The miners breathe underground with the use of a plastic hose that is stuck to their mouth and connected to a gasoline-powered compressor at the surface. The miners lack visibility underground because of the muddy water and the absence of light equipment. The miners normally stay under water at an average of six hours at the time (MGB/DENR, orally). The methods used are, since the 1980s, amalgamation and CIP. The waste is dumped into the environment and spread into the ocean, since no septic tanks are available (orally, local miner). The ore that was used for the magnetic sluice testing was quite sandy, dry and dark grey in color.

Methods

Testing of the magnetic sluice

The testing was done by using the "prospector sluice" (Picture 2), constructed and patented by the American inventor David Plath (US patent granted in July 1999, # 5,927,508). The sluice was initially covered with magnetite sand, creating magnetic riffles on the surface of the sluice. A handful of ore was placed in the centre of the sluice, where after it was dipped into shallow water and shaken a little bit to even out the ore on the sluice. More ore was subsequently added to the sluice and thereafter the process continued by dipping one end of the sluice into water, lifting it up, and letting the water and ore pass from one side to the other. By the laminar flow of the water, and the forces of gravitation, most of the heavy gold grains settled in the riffles created by the magnetite sand or got trapped within the sand. About ten kilograms of milled ore was run through the sluice during each period of testing, which took about 40 minutes. Each set of ore was run twice to be able to catch as much gold as possible. After processing the sample of ore through the sluice twice, the ore/sand that covered the sluice was scraped into a pan by using a plastic scraper (it is important to use a scraper made of plastic, to ensure that the surface of the sluice will stay intact). To be able to separate the pure gold from the magnetite, the ore was panned by one of the local miners. The gold grains that were recovered were sucked up in a snuffing bottle together with some water from the pan. The process was done five times at each site, in total using about 50 kilograms of milled ore per site.

Figure 3. The prospector sluice, US patent granted in July 1999, # 5,927,508.

Sampling for analyses

Ore samples were taken during the test to be able to measure the efficiency of the method. Initially, samples were taken from the original ore to determine the quality of the ore. Five samples of the original ore were taken at each site, except at Diwalwal where only three samples were taken. Representative samples were also taken of the ore that had passed the sluice to be able to determine how much gold that was captured in the process. Ten such samples were taken at each site (duplicate samples from five sluicing events). In order to further control the efficiency of the method, five samples (+ duplicate) straight from the sluice were also taken at each site visited.

In order to be able to compare the efficiency of the different methods (magnetic sluice, amalgamation and cyanidation), ore samples, from the tailings of the local methods used, were also taken. Five samples of ore that had passed amalgamation and cyanide treatment were taken at all sites, with the exception of Acupan. This was due to the lack of saved tailings from the panning in combination with difficulties reaching the CIP plant in the area.

Laboratory analyses

The samples were dried at 105°C over night, crushed in the lab at the Department of Limnology, Uppsala University and thereafter sent to Acme Analytical Laboratories Ltd, Vancouver, Canada, for analysis of gold. The method used was fire assay, which is considered the most reliable method for accurately determining content of gold in ores or other concentrates (Encyclopedia Britannica Online, 2001). The sample aliquot is custom blended with fire assay fluxes such as silica and borax, lead oxide litharge and a reducing Ag inquart. The lead oxide is reduced to lead, at 1050°C, which dissolves the gold (Acme Analytical Laboratories Ltd., 2004). When the mixture is cooled, the lead remains at the bottom, while a glass-like slag remains at the top. The gold is separated from the lead in a secondary procedure called cupellation (www.alschemex.com, 041125). The final analysis is done on Elan 6000 ICP-MS (Acme Analytical Laboratories Ltd., 2004).

Interviews

At each site, interviews with one ore two local miners were done (8 miners in total). To get a broader picture of their experiences, view of life, health, willingness to change their situation etc, the following questions were asked:

I) How long have you worked as a gold miner? Are you working alone or in a cooperative?
II) Do you work with anything else than gold mining or is this your only source of income?
III) Which type of methods have you been using during your time as a small-scale gold miner? Which method is the most efficient?
IV) Where do you buy the mercury that you are using? What is the price? Do you know from which countries the Philippines import mercury used in small-scale gold mining?
V) What do you think about your working conditions? Is there anything that could be improved?
VI) Do you have a family? If yes, - what are they working with?
VII) How is your, your family’s and your co-workers’ health?
VIII) What about your personal future, the future of this gold mining village etc?
IX) Are you interested in a mercury free method for gold extraction? Do you think it is possible to start using another method if it turns out to be at least as efficient as the methods you are using today?

Results

Testing of the magnetic sluice

The results from the analyses of the samples, taken during the study, show a recovery of gold during 21 of the 25 tests. The recovery is determined by calculation, using the amount of gold in the original ore before processing and the amount of gold in the processed ore. The rate of recovery varies, both within (Figure 4, Table 1) and between the sites (Figure 5, Table 1). For example; in Diwalwal, the first place visited, the recovery spans from 31-54% and in Paracale, the last place visited, the variation range between 34-59%. The highest recovery was reached in Balatoc (top value 73%), while the test in Acupan showed poor results (top value 15%). During four tests (in Mainit and Acupan) the ore surprisingly contained more gold after being processed in the sluice. In Mainit, for example, the result from the analyses showed an increase of gold during two cases, with 19% and 22%, respectively.

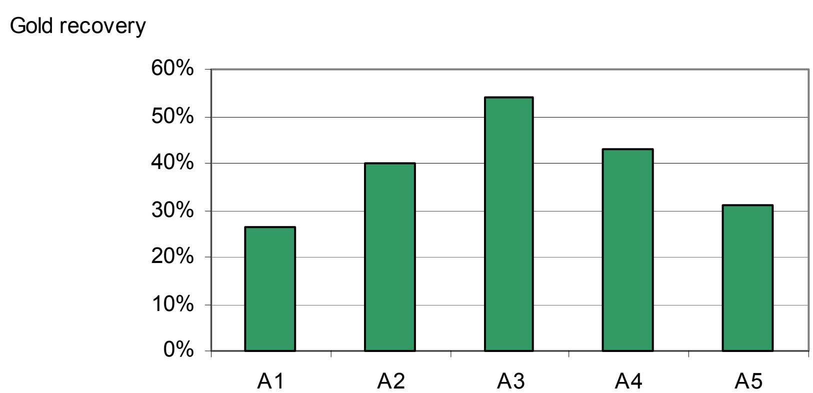

Figure 4. Variation in gold recovery during the five tests in Diwalwal, the Philippines, 2004.

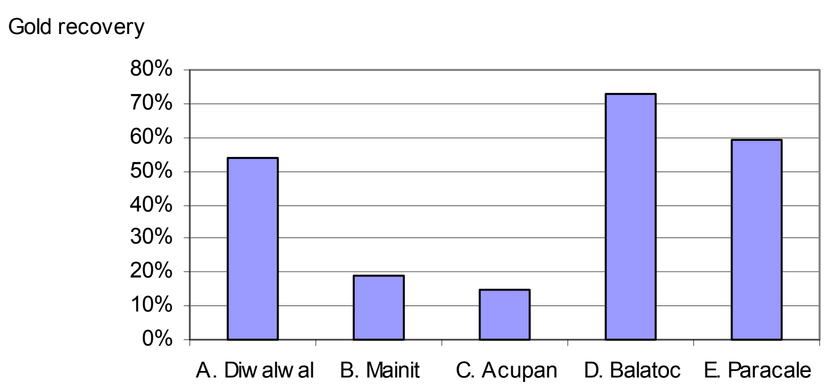

Figure 5. The highest recovery of gold during the tests in Diwalwal, Mainit, Acupan, Balatoc and Paracale, the Philippines, 2004.

Table 1. Gold recovery - mean value and range – from the test in Diwalwal, Mainit, Acupan, Balatoc and Paracale, the Philippines, 2004. $n = 5$ at each site.

Site	Gold recovery, mean value (%)	Gold recovery, range (%)
A. Diwalwal	42	31-54
B. Mainit	3	0-24
C. Acupan	-8	-8-15
D. Balatoc	48	21-73
E. Paracale	48	34-59

The analyses of the samples taken directly from the magnetic sluice show an increased concentration of gold in the sluice at all sites visited. This so called "efficiency coefficient" ranges from 1.7 to 11.3 times (Table 2) and proves the capability of the sluice to catch the gold grains. The maximum amount of gold was caught in Paracale, concentrated to 426.7 g/t in the sluice.

Table 2. The efficiency coefficients and mean value of gold concentration on the sluice from the tests in Diwalwal, Mainit, Acupan, Balatoc and Paracale, the Philippines, 2004.

Site	Efficiency coefficient	Au concentration (g/t)
A. Diwalwal	6.9	55.0
B. Mainit	1.7	15.9
C. Acupan	3.3	35.4
D. Balatoc	3.4	393.5
E. Paracale	11.3	426.7

Samples from amalgamation and cyanidation processes

According to the results from the test, the waste from the amalgamation and cyanidation methods contained gold in all cases (Table 3). In Diwalwal, for example, the ore from the amalgamation process contained 7.1 g/ton gold, while the waste from the ore treated with cyanide contained 0.4 g/ton gold. The actual efficiency of the methods was not possible to calculate, since the waste from the amalgamation and cyanidation processes did not have the same original quality. As a consequence, no comparison between the efficiency of the different methods (magnetic sluice, amalgamation and cyanidation) was possible to do.

Table 3. Mean value of gold from samples taken of the waste at the amalgamation and cyanidation plants in Diwalwal, Mainit, Balatoc and Paracale, the Philippines, 2004.

Site	Amalgamation (Au, g/ton)	Cyanidation (Au, g/ton)
A. Diwalwal	7.1	0.4
B. Mainit	65.6	1.2
C. Acupan	no samples taken	no samples taken
D. Balatoc	5.6	21.8
E. Paracale	9.0	2.4

Interviews

Seven of the eight miners we talked to have worked as small-scale gold miners for the last 20 years. Some work alone at the mill, while others work in cooperatives or are employed by the private mining company Benguet Corporation. All the miners use the amalgamation- and/or cyanidation methods, sometimes in combination with traditional panning depending on their economic situation. One person mentions that he would like to use the CIP plant since it is the most efficient method, but he is missing the money for doing it. At all mining sites, the modern methods were introduced during the early 1980s.

Most of the miners have gold mining as their only source of income. A few have other jobs, as for example driver and electrician. A female miner, that owns a tunnel in the mountains, also breeds and sells canaries for earning some extra money. The miners that have a family normally do not want them to work as small-scale gold miners. One says for example; *"No, I don't want my family to work here. I don't want them to have the same life as I have."* It seems like they want to protect their close ones. Every one gives the impression of being aware of the problems regarding the toxicants. They know that the mercury vapor is not good for their health and the environment, that the fishes in the river are dead due to the pollutants, that there is a problem with large amounts of waste and they all find it urgent to find other possible technologies. But even though they are aware of the toxic mercury and cyanide, they are denying bad health. One miner defends her use of mercury by saying *"We have used mercury during the last 20 years, and we're still alive."* Another miner says that he doesn't feel anything from the use of mercury, but in the same sentence he declares that he has not been able to see a doctor during the 18 years he has worked with gold mining. In total, there is only one miner out of eight, which confesses that he has been sick due to the use of mercury. He lost weight, got headaches and deteriorated eyesight. He further declares; *"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."* Another miner says that he is planning to continue with gold mining in his village for many years. He says: *"There are lots of gold left in the mountains… and the mercury is keeping us alive."*

The quantity of mercury used varies from miner to miner, depending on the size of the plant they operate. One miner, which has quite a small production, says for example that he uses about 3 kilograms of mercury every month. Since the current price (Sep. 2004) for mercury to the miners is about 20 USD/kg, this results in a monthly cost of approximately 60 USD. Another miner says that he uses about 15 kilograms a month, which of course results in a larger cost. At one of the places visited, the mercury is being reused. The consumption of cyanide is, at one of the CIP plants visited, approximately 1.5 kg per ton ore. Since about 40 tons of ore is processed in the CIP every day, this results in a total cyanide consumption of about 60 kilograms per day. The chemicals "circulate" among the people and are therefore easy to find and buy. The prices are fairly low. Concerning the question *"From which countries do the Philippines import mercury?"* most of the miners answer that they do not know. One man says that he is not sure, but he has heard that it is being bought from Africa or Malaysia. Another man suggests China or Belgium.

The life as a gold miner in the Philippines appears to be hard. The days are long, sometimes from 4 am to 10 pm, 7 days a week, and the work is tough. Safety equipment is absent in all cases except one, where gloves and masks are used for handling the cyanide. The tools are simple, such as picks, shovels and pans. The safety in the tunnels is frequently discussed, where problems such as falling stones and accidents during the dynamite explosions occur. One miner says about his work: *"Sometimes it's good, sometimes it's bad. I get happy when I find gold"*.

All the miners we talked to seem to be longing for a change. But at the same time they are incapable of improving the situation by themselves. The lack of money and new technology is the most frequent answer to the question why nothing has happened yet. They are waiting for help from others, such as the government, the Bureau of Mines, the Department of Health, UNIDO or other researchers, like us. One of the women says: *"We have asked the government to, please, help us, but until now, nothing…"* The people are aware of the problems related to small-scale gold mining. They know that both mercury and cyanide have toxic effects, but at the same time they are strongly dependant on their source of income. It is difficult to change habits, especially since the mercury and cyanide are very easy to find, the present methods are simple and no reasonable alternatives are available. All the miners were very interested and optimistic concerning our study. If the results show that the magnetic sluice is at least as efficient as the present methods used, they are interested in changing their habits in order to get rid of the chemicals. Some of them were concerned that the magnetic sluice is very small and that it maybe cannot compete with the present methods in terms of efficiency. One woman says *"We hope that what you are doing now, using the magnetic sluice could be efficient here, so that we can adopt it here. Maybe we can make it bigger, because it is very small and it takes time to get the gold"*. Another man says *"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."*

Discussion

The small-scale gold miners in the Philippines are waiting for help. The need for a mercury- and/or cyanide-free method is enormous. Development of new technology is, of course, not the single key to improvement in the gold rush areas, but together with other measures, e.g. economic support in forms of for example micro credits, it may be possible to change habits in the future. A reduction in the use of mercury and/or cyanide will in the long run result in a healthier and cleaner environment, locally but also globally.

The results of this study show that the use of mercury, in small-scale gold mining in the Philippines, theoretically could be replaced by the use of magnetic sluices. Recovery of gold is shown in 21 of the 25 tests and the top value of the efficiency is determined to 73%, even though the efficiency varies both within and between the sites. During 4 of the tests the results surprisingly show a larger amount of gold after the sluicing process. These sources of error will be discussed later on. Though, the increased concentration of gold in the sluice is determined to 1.7 to 11.3 times in all the tests, which shows that the sluice has the ability to catch gold grains.

The best recovery was, according to the results, reached in Balatoc and Paracale (mean value 48% for both sites) while the tests in Mainit and Acupan showed poor results (mean value 3% and -8%, respectively). The variation in recovery between (and within) the sites might be explained by the difference in ore quality where the original ore both in Balatoc and Paracale contained between 4 and 115 times more gold than the original ore in Mainit and Acupan. The variation in presence of other minerals such as sulphide minerals (e.g. pyrite) could also affect the results, since these particles, like the gold grains, have the ability to attach to the magnetic sluice because of their relatively high density. Grain size is also a central factor that could have an effect on the results. The larger the gold grains are, the easier they are to catch during the sluicing process. In general the gold particles in the Philippines seemed to be very fine, but varied slightly between the sites. The variation was not measured in a scientific way, but ocular inspection of the gold grains revealed that the ones in Balatoc were the largest ones. This is in agreement with that the recovery in Balatoc was highest.

What also could influence the results is the amount of ore samples analyzed and the problems in getting representative samples. The samples analyzed ranged from 7 to 15 grams and the gold content in the original ore was approximately 10 grams/ton (e.g. Mainit and Acupan). This means that the content of gold in our samples was very small and the chances of “catching” them while taking the samples were relatively small. This problem was clearly shown during 4 of 25 tests (16%) run in Mainit and Acupan where the ore surprisingly contained more gold after being processed in the magnetic sluice. In future studies, I therefore recommend larger samples, both in volume and number.

In comparison, the recovery using the amalgamation method is estimated to between 40 and 50% and the efficiency after the cyanide treatment is estimated to approximately 90% (orally, local miners). The comparison between the magnetic sluicing method and the presently used methods has been done from the information given by the local miners and not from our testing. This because, in most cases it was not possible to distinguish if the ore, used in our study, had the same quality (gold content) as the ore used in the amalgamation and cyanidation processes.

Other similar studies accomplished in the United States, Ghana and Venezuela have, according to the inventor David Plath, shown efficiency of approximately 90%. But since these results and their different methods are not well documented it is impossible to compare the studies and their results. However, it is hard to tell why our study shows much less recovery than former studies. Maybe the ore tested at the various sites differed in grain size and quality, maybe the losses of gold grains, while processing, tended to be smaller during the earlier tests or maybe the inventor himself was more used to his equipment than we were, though, I assert that it is important that several independent objective studies are done in order to get the most reliable result. Anyway, this far the results from the magnetic sluice testing have shown about the same recovery as the amalgamation method. However, it is difficult to reach the same recovery levels as during the processes in the CIP plants. It is possible, though, that further studies could lead to development and/or adaptation of the method to the local conditions, which would help to increase the recovery even more, maybe replacing also the cyanide in the future. I furthermore believe that one possible way to go is to convince the miners to stop adding mercury while milling the ore, to start use the sluices and to add mercury only in the final step while panning. This would reduce the amount of mercury used tremendously. The miners themselves are positive to the magnetic sluices, but at the same time they feel that using them would feel like taking a "step back" in terms of technology. The use of traditional pans is according to many miners' related to old techniques and instead of starting using their bare hands again, during the sluicing and panning, they all are interested in developing the equipment into bigger automated sluices. This despite the fact that mechanization of the magnetic sluicing technology, as well as any other technology, results in fewer workers needed for a static production.

The situation for the small-scale gold miners in the Philippines is complex. The miners seem to have a desire to improve their situation, even though they are incapable of doing it by themselves. They are dependent of their source of income and no equivalent environmentally benign methods have, this far, been available. The perspective is short and the blame is put on the government. Instability in the country, corruption and inadequate legislation and control contribute to the situation of today. The perspective varies depending on the situation. The miners naturally think more of their needs to support themselves and their family than of the environmental and health effects. They deny the risks of using mercury and cyanide and are not concerned about that their food provisions cannot be produced locally due to the polluted soils and waters. The lack of present alternative methods further contributes to an absent awareness and concerns about the future. It is easy for the Western world to get upset over the situation, but who is responsible - the poor miners, the local Bureau of Mines, the Philippine government, the countries that are exporting the toxic mercury or the public in rich countries, wearing jewelry with gold recovered without paying for environmental degradation? It is impossible to implement western environmental legislation and control in a country like the Philippines. There is a need of strong forces in order to change the situation.

There are several obstacles for implementing new technology in the gold mining areas in the Philippines, but since the miners give the impression of wanting/needing improvement I do not consider it impossible, although there is a long way to go. Loans/micro credits need to be available, in order to make it possible for the miners to buy the new technology. The price for the smaller "prospector sluice" for example is 40 USD, while the bigger "economy sluice" costs 150 USD. This is a one time cost for the miner that could be difficult to pay, but in the long run the magnetic sluice would be cheaper than the monthly purchase of mercury (compare approximately 60 USD/month). Therefore economic support needs to be offered, so that the miner can start using the new technology. Other measures that need to be taken are education in how to use the equipment efficiently, this in order to change daily habits. On a wider scale, the almost uncontrolled use of mercury needs to be restricted. The import and export rules have to be examined and the companies that manage to escape from responsibility need to be controlled. It is also important to inform the public, in media as well as in jewelry shops, of the environmental cost while producing gold. Many consumers are not aware of their actual contribution to environmental degradation, as they are buying their jewelry. Certification of “clean gold”, produced without use of mercury, cyanide or other chemicals, could hopefully be available on the market in the future, this according to the Swedish gold selling company Guldfynd. The environmentally benign produced gold could be certified and thus obtain a higher market price. In order to control whether the gold is produced using environmentally friendly methods or by using mercury, cyanide or melting techniques David Plath has invented a method based on inspection of gold grain surfaces with a light microscope. The certification idea is linked to the “polluters pay principle”, where it should be economically more advantageous to use “clean” methods while extracting gold by adding an extra fee to gold producers that harm the environment. This fee should correspond to the estimated environmental cost while using chemicals such as mercury and cyanide. The fees should be used for remediation of contaminated sites and construction of tailings dams (Hylander & Plath, 2004).

Numerous studies have been done in the Philippine gold mining areas in order to monitor health and environmental effects of the gold mining activities. Mercury poisoning resulting from unregulated use of mercury in the gold fields, was brought to the attention of the Department of Environment and Natural Resources (DENR) as early as 1986 (Tiglao & Tempongko, 1997). Since then the Mines and Geosciences Bureau/DENR, together with the national Department of health (DOH) and the UNIDO program have been and are still active in many districts. Several studies with health perspectives have been conducted among the miners in the country. What normally is studied is the concentration of mercury in blood, urine and hair. One such investigation was accomplished in the Acupan region, Benguet and the results showed hair samples containing 0-27 ppm of mercury, with only 7 of the 70 respondents showing no traces of mercury (Clemente et al., 2004). A large number of environmental studies on mercury contamination in water, sediments, soil and biota have also been conducted in different parts of the country. In one study accomplished in Diwalwal, mercury contamination was extended to about 10 km from the gold mining area and the concentration of Hg in the main stream within and near the mining area reached a maximum of 1539 μg/l (Miranda et al., 1997). Another study made in the same area showed extremely high levels of mercury both in solution maximum 2906 μg/l, and in bottom sediments, >20 mg/kg (Appleton et al., 1998).

I believe that what needs to be done in the future is not only mapping of environmental and health problems. It is most important that constructive measures are taken in order to reduce the toxic effects among the workers and their environment. Introduction of prevention measures, such as free distribution of safety equipment, e.g. masks and gloves is essential. Another action that could be made is to give the miners concrete information about how their work affects themselves, their families and the environment. In one study about knowledge, attitude and practices among gold miners in the country only 22.5% of the involved miners knew that mercury pollutes rivers and seas (Tiglao & Tempongko, 1997). It is therefore important, for everybody, to become aware of the problems and to obtain a longer perspective of the use of mercury and cyanide.

It is also important to be able to treat patients that suffer from mercury poisoning. Studies have shown that there are effective ways of treating mercury-intoxicated inhabitants by using the chelating therapy with DMPS (Böse-O'Reilly et al. 2003). Of course economic support is needed so that such treatments can be initiated. Financial support is also important in order to be able to take care of tailings and prohibit that mine wastes are dumped into rivers etc. The example from Diwalwal, Compostella valley, is striking. A tailings dam has been built, but is not yet in use. The cost of time and money prevents the miners to transport the waste on the rough road. The project has stopped since money is deficient. There is a strong need for realistic projects that do not stop half-way.
Another measure that needs to be taken is to remind the gold diggers that other techniques could be used, if they only accept them. Though, there might be many obstacles and skeptical miners along the way. For example, in 1998 UNIDO introduced retorts, equipment that is used while steaming off the mercury. It is a closed system, which makes it possible to reuse the mercury twice or three times (then it gets too diluted with sulphur compounds etc to work properly). Despite all the positive effects such system would bring, the miners were against it. They argued that the process was time consuming and that they could not really see what happened inside the instrument, thinking that the gold was trapped in the system. Therefore, the new, environmentally and health benign method was not accepted (orally, MGB/DENR, Manila). It is though, despite this example, very important to continue the development of new "friendly" technology. By having an intense dialogue with the gold miners and work from their perspective using the right measures, I believe that the situation can change in the future.

Conclusions

1) The miners want and need a change!

2) Obstacles for development are and have been:
    a. Lack of technology and knowledge.
    b. Bad economy.
    c. Habits.
    d. Easily accessible mercury and cyanide.

3) Measures that need to be taken and financially supported:
    a. Free distribution of safety equipment and treatment of intoxicated patients as long as the present methods are used.
    b. Information and education to the gold miners.
    c. Building of waste disposals that could be used in reality.
    d. Loans/micro credits to the miners.
    e. Stricter control and legislation, both for miners and exporters of mercury.
    f. Further development and adaptation on environmentally benign methods.

4) The use of mercury in small-scale gold mining has a high potential of being reduced.

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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.

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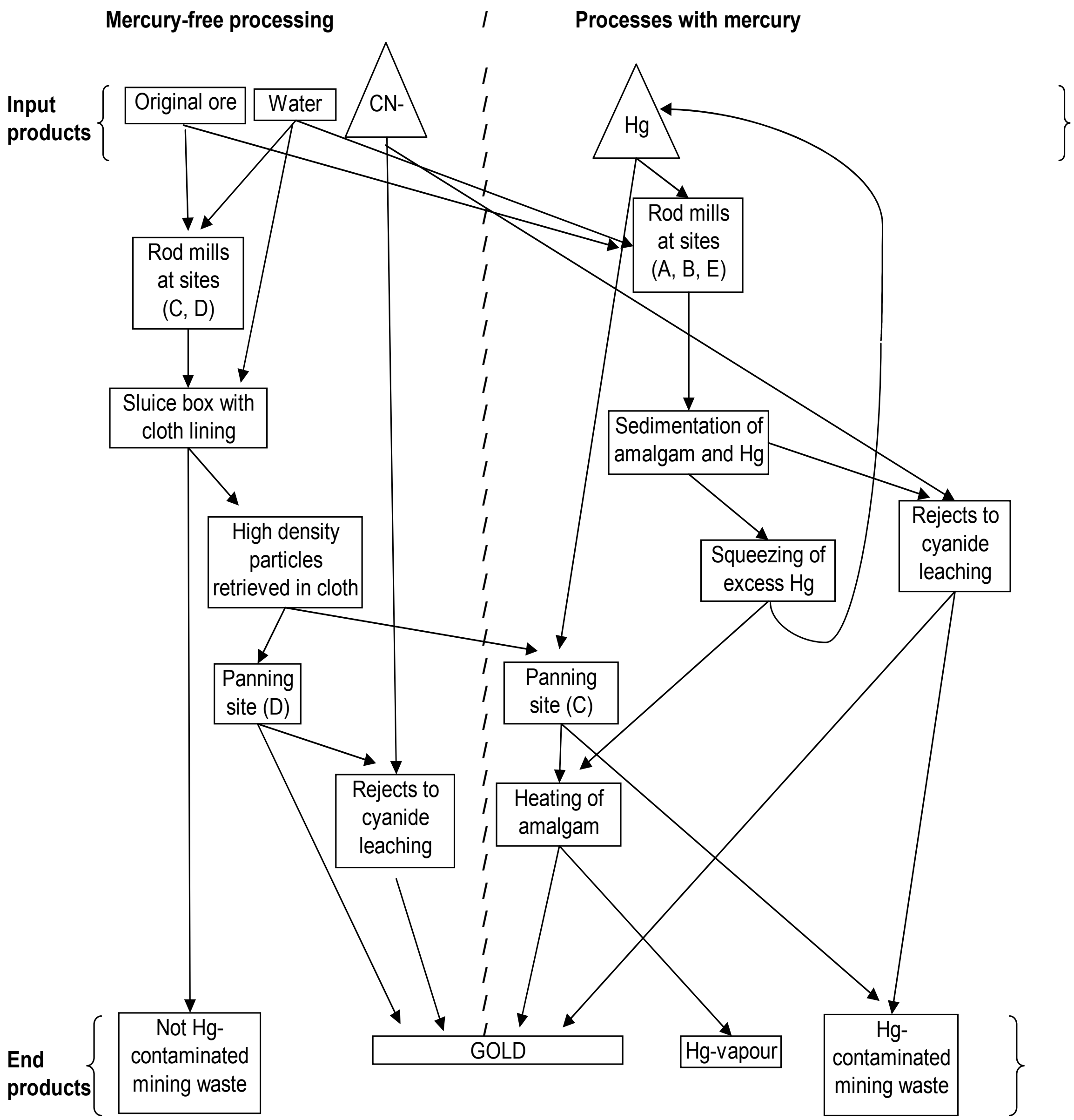
Manfred Lindvall, General Manager, Boliden, Sweden

Appendix

Processes for gold extraction at visited sites in the Philippines;
A – Diwalwal
B – Mainit
C – Acupan
D – Balatoc
D - Paracale



Results from ACME ANALYTICAL LABORATORIES LTD. 852 E. HASTINGS ST. VANCOUVER BC V6A 1R6 PHONE(604)253-3158 FAX(604)253-1716 D.TOYE, C.LEONG, J.WANG; CERTIFIED B.C. ASSAYERS @ CSV TEXT FORMAT

A - Original ore (x-fore), samples from ore that had passed the magnetic sluice (x-P), amalgamation method (x-A) and cyanidation method (x-C).

Sample name	Weight (gm)	Au content (ppb)
Diwalwal		
AP fore 1	15.0	8861
AP fore 2	15.0	7714
AP fore 3	15.0	7239
AP 1		N.S.
AP 2	15.0	4736
AP 3	7.5	4752
AP 4	7.5	3688
AP 5	15.0	4492
AP 5 2	7.5	5478
AA 1	7.5	5517
AA 2	15.0	8845
AA 3	15.0	8313
AA 4	15.0	6356
AA 5	15.0	6706
AC 1	15.0	531
AC 2	15.0	281
AC 3	15.0	389
Mainit		
B fore 1	15.0	8874
B fore 2	15.0	8708
B fore 3	15.0	11505
B fore 4	15.0	8088
B fore 5	15.0	10039
BP 1	15.0	7132
BP 2	15.0	11232
BP 3	15.0	7186
BP 4	15.0	8663
BP 5	15.0	15220
BP 5 2	15.0	7774
BA 1	7.5	66485
BA 2	7.5	63810
BA 3	15.0	69610
BA 4	7.5	58645
BA 5	7.5	69485
BC 1	7.5	1377
STANDARD AU-R2	15.0	613
BC 2	7.5	1118
BC 3	7.5	983

Sample name	Weight (gm)	Au content (ppb)
Acupan		
C fore 1	5.0	14327
C fore 2	7.5	9570
C fore 3	7.5	8695
C fore 4	7.5	8972
C fore 5	7.5	11384
CP 1	7.5	10470
CP 2	7.5	10563
CP 3	7.5	9401
CP 4	7.5	9000
CP 5	7.5	20085
RE CP 5	7.5	21240
CP 5 2	7.5	12073
Balatoc		
D fore 1	7.5	186445
D fore 2	7.5	158445
D fore 3	7.5	117360
D fore 4	7.5	102610
D fore 5	7.5	11125
DP 1	7.5	31165
DP 2	7.5	53365
DP 3	7.5	38210
DP 4	7.5	85405
DP 5	7.5	122245
DP 5 2	7.5	60880
DA 1	7.5	7818
DA 2	7.5	2968
DA 3	7.5	6470
DA 4	7.5	4950
DA 5	7.5	5757
DC 1	7.5	12615
DC 2	7.5	30920
DC 3	7.5	21765
Paracale		
E fore 1	7.5	21320
E fore 2	7.5	100525
STANDARD AU-R2	7.5	621
E fore 3	7.5	28485
E fore 4	7.5	15735
E fore 5	7.5	22320
EP 1	7.5	24765
EP 2	7.5	18485
EP 3	7.5	21080
EP 4	7.5	15275
EP 5	7.5	15938

Sample name	Weight (gm)	Au content (ppb)
EP 5 2	7.5	20565
EA 1	7.5	11320
RE EA 1	7.5	11130
EA 2	7.5	11011
EA 3	7.5	9967
EA 4	7.5	9302
EA 5	7.5	10448
EC 1	7.5	2879
EC 2	7.5	2218
EC 3	7.5	2144
STANDARD AU-R2	7.5	605

B – samples taken from the magnetic sluices (x-R)

Sample name	Weight (gm)	Au content (gm/mt)
AR-1	3,5	36,11
AR-2	1,12	64,47
AR-3	1,08	75,05
AR 4	1,09	18,99
AR 5	0,65	80,63
BR 1	7,81	8,64
BR 2	8,11	11,28
BR 3	12,6	17,68
BR 4	6,74	11,65
BR 5	4,31	30,36
CR 1	1,71	16
CR 2	5,95	32,28
CR 3	4,25	42,83
CR 4	5,05	34,61
CR 5	4,48	51,13
DR 1	17,1	313,47
DR 2	7,58	437,22
DR 3	9,19	540,56
DR 4	14,67	307,84
DR 5	9,71	368,34
ER 1	6,11	399,64
ER 2	5,89	695,14
ER 3	8,8	534,69
ER 4	3,05	318,71
ER 5	5,27	185,15