

Testing Local Conditions for the Introduction of a Mercury-free Gold Extraction Method using Borax in Zimbabwe

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Introduction

Mercury is extensively used in artisanal small-scale gold mining (ASGM) in more than 70 countries worldwide.¹ The international community has identified and specified mercury as an extremely hazardous chemical with harmful effects to human health and the biophysical environment. Thus, the

Background. Mercury is extensively used in artisanal small-scale gold mining in many parts of the world, including Zimbabwe. Mercury-free mining technologies are urgently needed to protect the biophysical environment and human health.

Objective. The testing of local conditions for the introduction of a mercury-free gold mining technology entailing the use of borax in a field project in Kadoma/Zimbabwe.

Materials and Methods. A one-day theoretical workshop and a two-day practical demonstration were conducted in Kadoma/Zimbabwe in December 2013. The willingness of the miners to change to another gold extraction technology other than mercury amalgamation, the local availability of appropriate materials and equipment, and the suitability of the ore for applying the borax technology for gold smelting were used as variables to test local conditions for introducing the borax method. Simple methods like trial and error and the collection of indices during discussions and observations were applied.

Results. 1.11 grams of gold from half a ton of ore was the result of the demonstration. A number of potential improvements to the process were identified. A total of 50 invited local stakeholders took part in the theoretical workshop, and 30 to 40 decided immediately to also participate in field demonstrations. The project team noticed that the local miners were interested and impressed by catching very fine gold particles with the borax method.

Conclusions. The project confirmed that the local conditions in Kadoma are appropriate for mining mercury-free gold. The optimization and comprehensive introduction of the borax method in the Kadoma gold mining region is recommended to eliminate the use of mercury.

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“Minamata Convention on Mercury” prepared by the UNEP (United Nations Environment Programme) was finalized in October 2013 in Kumamoto, Japan. The convention will be a global, legally binding instrument as soon as it is ratified by a majority of UNEP member countries. In Article 7 and Annex C of the convention, specific tasks are mentioned in connection with ASGM: “Each Party that has” ASGM “and processing subject to this Article within its territory shall take steps to reduce, and where feasible eliminate, the use of mercury and mercury compounds in, and the emissions and releases to the environment of mercury from, such mining and processing”²

The implementation of mercury-free or at least mercury-restricted gold mining technologies is urgently needed to protect the biophysical environment and human health.³⁻⁶ Nevertheless, a new technology needs to be very convincing for miners to quit their traditional, easy, and effective amalgamation technology.⁷⁻⁹ A currently promising, but not fully developed technique is the use of borax.¹⁰ Borax is applied as a flux to reduce the melting point of gold dust contained in grinded ore; thus, after a direct smelting process, very pure and mercury-free gold is the result.^{11,12}

Borax is a naturally occurring mineral and can be mined. It is used in many

products like soap or in industry, e.g. as a flux in metallurgy.¹³ Borax is not considered to be an acutely toxic substance. Although borax exposure in air, which is the pathway of interest in the gold mining process, can be associated with mild irritation of the eye, throat, and nose, it is not thought to cause cancer. Animal studies have suggested that high exposure to boron is related to reproductive toxicity, but there is no evidence for humans.^{13,14} However, the ingestion of large amounts of boron (e.g. 30 grams of boric acid) may be fatal.¹³ In summary, the borax method can be a safer alternative to mercury in gold extraction.¹⁴

In the Benguet area of the Philippines, borax is traditionally used in ASGM.¹⁵ The method was tested and introduced in Tanzania,^{12,15,16} Ghana,⁷ Mongolia,¹⁷ and Sumbawa in Indonesia¹⁸ with good results. In Kalimantan (Indonesia), the method failed because of the peculiar ore mineralogical composition.^{9,19}

Current gold mining and processing practice in Kadoma

In the Kadoma area, mercury amalgamation is the technology of choice in ASGM.²⁰⁻²³ The fourteen steps typical of the current gold mining and processing practice in Kadoma are depicted in Figure 1. Currently, ASGM in Kadoma begins with digging for the ore (*step 1, Figure 1*). The ore is collected from underground gold mines (Web Figure 1 in the Supplemental Material). Dynamite is commonly used to blast the rocks. The miners performing these functions are referred to as diggers and blasters. The ore is manually carried to the surface.

The ore is transported to a custom milling centre, which is normally a central point where the miners from surrounding mines bring their ore for milling (*step 2, Figure 1*). In some

Abbreviations			
ASGM	Artisanal small-scale gold mining	DIN EN ISO 10628	Norm for graphical symbols for process plants (issued by the German Institute for Standardization, DIN; the European Committee for Standardization, EN (European Standard); the International Organization for Standardization, ISO)
Au	Gold		
BMUB	German Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety		
Cu	Copper	GMP	Global Mercury Project
		H ₂ O	Water
		Hg	Mercury
		UNEP	United Nations Environment Programme

cases, hammers are used to crush big boulders before bringing the ore in wheelbarrows to the mill (*step 3, Figure 1*). The ore is crushed by the stamp mill (*step 4, Figure 1*) (Web Figure 2) which may be powered by an electric generator or connected to grid power. Water is added to the milled ore (*step 5, Figure 1*) and the resulting pulp is then flushed over a sieve grid in order to catch residual oversized ore particles (Web Figure 3).

The pulp is further flushed down over a mercury covered copper plate (*step 6, Figure 1*). The gold contained in the pulp binds onto the mercury on the copper plate. At the end of the flushing procedure, the worker scrapes the copper plate with a rubber scrubber to collect the gold-mercury amalgam which is later further concentrated through panning (*step 8a, Figure 1*) and squeezed in a special cotton silky cloth to remove excess mercury from the amalgam before smelting (*step 9a, Figure 1*). The overflow pulp may

collect in a centrifuge through a pipe starting at the end of the copper plate. Residual gold contained in the pulp is concentrated by the rotating centrifuge (*step 7, Figure 1*) (Web Figure 4); before further panning (*step 8a, Figure 1*) and squeezing in a cloth (*step 9a, Figure 1*) to produce a final solid piece of amalgam which is then transported to the smelting place (*step 10a, Figure 1*). Over a piece of burning charcoal or firewood (*step 11a, Figure 1*), the amalgam piece is smelted (*step 12a, Figure 1*) (Web Figure 5). The mercury in the amalgam vaporizes (*step 13a, Figure 1*) and the gold (with residual mercury) is the result (*step 14a, Figure 1*).

Beyond the copper plate and centrifuge, the tailings, containing residual gold as well as mercury or other added components, are piped into a tailings dam. However, the tailings are further processed through a cyanidation process by the miller (*step 8b to 10b, Figure 1*)

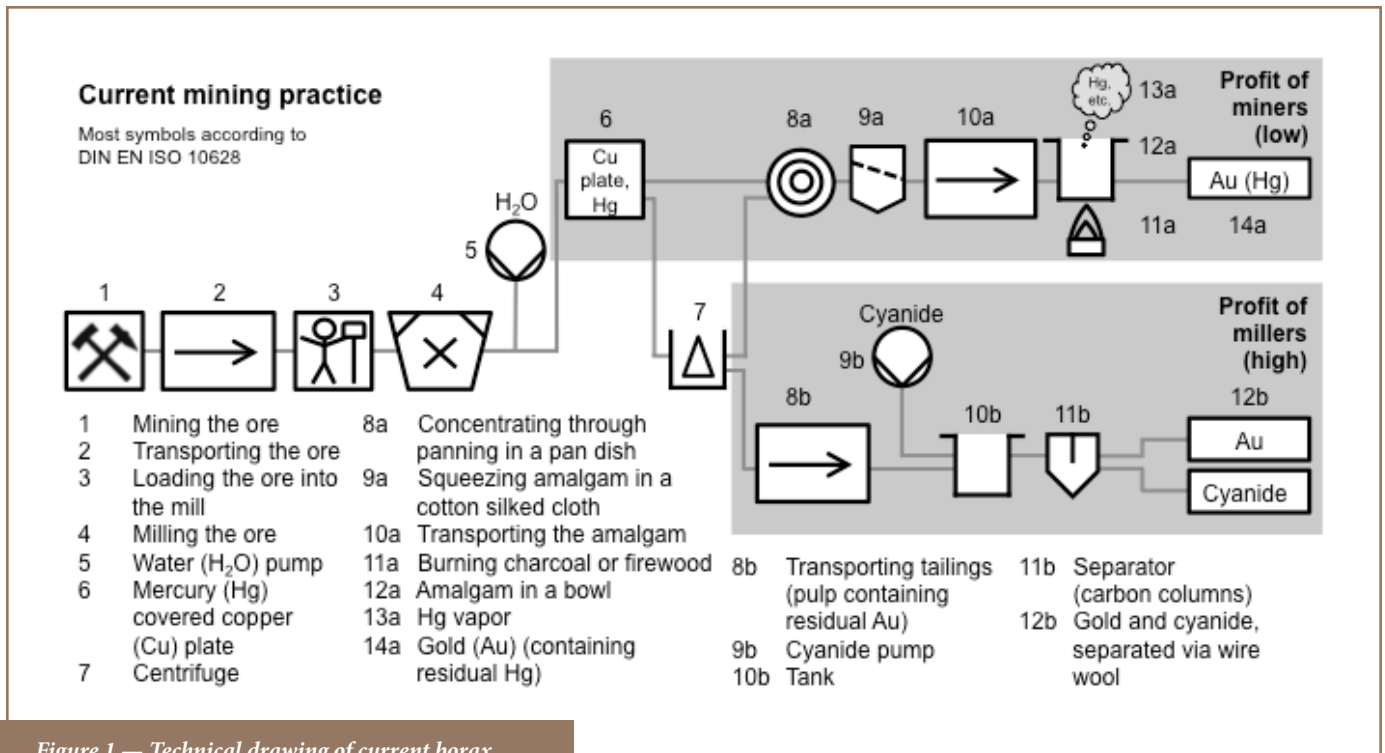


Figure 1 — Technical drawing of current borax gold processing method

and 2). Within an 8-24 hour cycle, the residual gold is dissolved by the cyanide to form a pregnant solution. The pregnant solution is exposed to active carbon columns which adsorb the gold (step 11b, Figure 1). The gold loaded carbon columns eventually release the adsorbed gold onto wire wool which is ultimately burned to obtain the pure gold (step 12b, figure 1).

An important aspect of this methodology is that mercury is added to the ore pulp before concentration rather than to a concentrate. This is what is referred to in the literature as ‘whole ore amalgamation’ and is believed to result in the loss of a lot of mercury to the environment.⁸

In the Kadoma area, the use of whole ore amalgamation is very common.²⁰ Mercury is therefore a serious environmental and health

hazard in the area,²¹ especially for children,²⁴ as results from the Global Mercury Project (GMP) showed.²⁰ It is therefore imperative and urgent to introduce mercury-free gold extraction techniques in Kadoma and other gold mining areas in Zimbabwe and globally.

Objectives

A successful introduction of the borax method depends on the local conditions and has been shown in previous studies.^{7,11,12,15,16,19} Therefore, the objective of the project was to test if gold extraction using borax is possible in Kadoma. Is the ore suitable for extracting gold using borax? Are the equipment and materials necessary for the borax method available in Kadoma? Are the miners interested in embracing the borax method instead of amalgamation? A field project in Kadoma/Zimbabwe was done to

demonstrate the mercury-free gold extraction technology using borax.

Materials and Methods

Zimbabwe was selected as a project country because of the high mercury release due to ASGM, with an estimated 25 tons of mercury used in the sector annually.^{25,26} Thus, Zimbabwe belongs to the top 10 mercury emitters due to ASGM worldwide.¹ It is estimated that 10% of the gold produced by ASGM in Zimbabwe is produced in Kadoma,²⁶ which underscores the choice of the region. Additionally, Kadoma is known to the authors due to their participation in the GMP.²⁵ The contact between the partners from Zimbabwe and Germany has never been broken since 2002, when the GMP started. The call for a mercury-free mining technology came from the local partner in Zimbabwe.

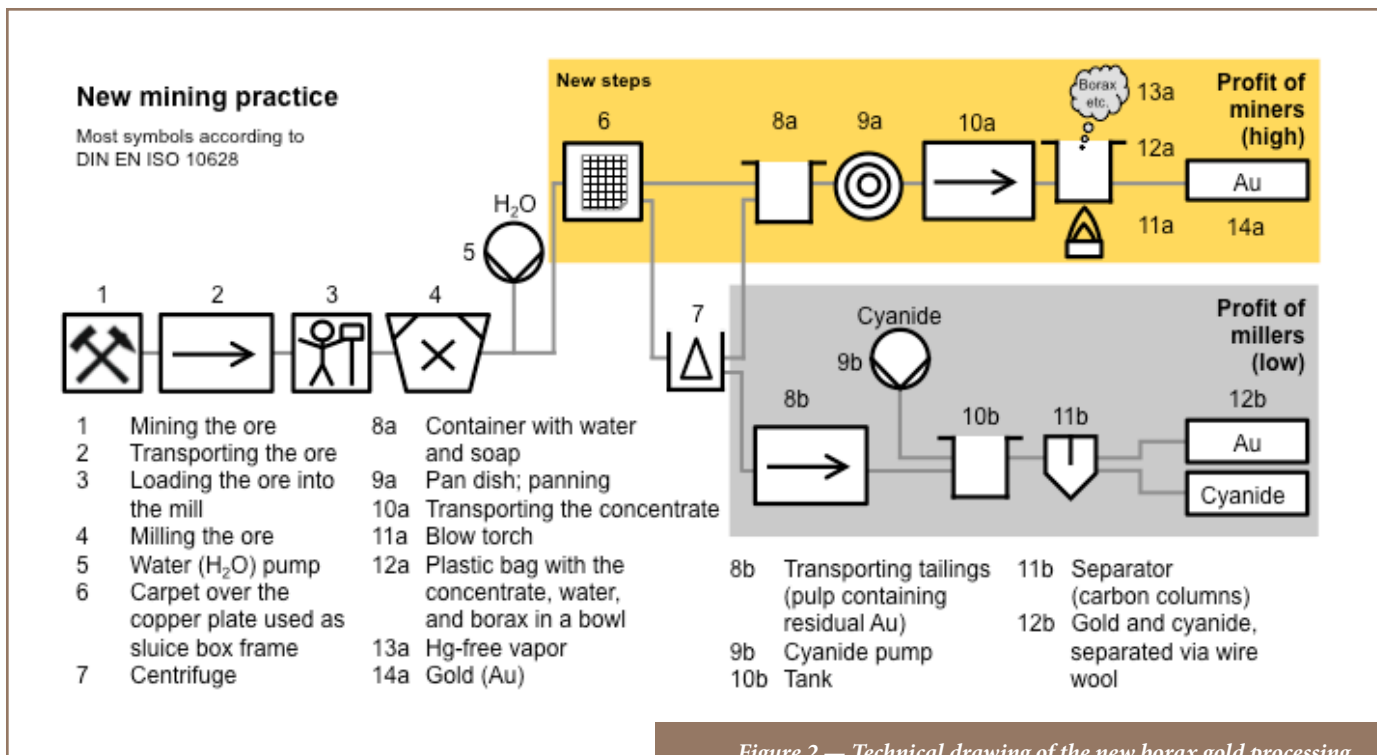


Figure 2 — Technical drawing of the new borax gold processing method demonstrated in the field project in Kadoma, Zimbabwe

The local conditions for the introduction of a mercury-free gold extraction method in Kadoma were tested in terms of (a) acceptance by the locals, (b) availability of equipment and materials, and (c) suitability of the ore. The results, based on discussions and observations as well as by trial and error, were documented on the spot in the form of notes, pictures, and videos.

The project consisted of a preparation phase (September until early December 2013) and a field phase, including a one-day theoretical workshop and a two-day practical field-based demonstration, conducted on the 4th to the 6th of December 2013 in Kadoma. The project team consisted of German scientists from the University Hospital Munich (Nadine Steckling, Stephan Bose-O'Reilly, Rudolf Schierl), who organized the overall project preparation, coordination, and

implementation, a German engineer (Stefan Muschack) was responsible for technical support and documentation by photographs and videos, while the partner in Zimbabwe (Dennis Shoko) organized the field phase. International experts in the borax method were invited to join the field phase, but the limited time frame hindered their participation. However, they promoted project success by providing written and audio-visual information used in addition to the existing published material.^{8,11,15,16,27,28}

The theoretical workshop took place at Kadoma Sports Club and was organized to inform and theoretically educate the local miners and stakeholders about the project, proving the need for mercury-free methods, to introduce the borax method, and to get feedback from the miners about the acceptability of a new technology. Every point of the agenda, listed in

Web Table 1, included enough time for discussion, questions, and answers.

All equipment and material was sourced in and around Kadoma town. The demonstration was conducted at the Tix and Venture mills, while smelting was done in Kadoma town.

The project did not compare the borax and amalgamation methods. Conclusions regarding recovery rates, costs, ease of use, or time required for the borax (and/or amalgamation) method(s) are beyond the paper's scope. Consequently, a comprehensive demonstration of the new method, including verifiably convincing the miners to change to the method would be a next well-prepared step after the successful testing. During the December 2013 short demonstration project, there was neither the time nor the financial resources to conduct a survey or to collect health and/or



Figure 3 — Sluice box

biomonitoring data. The scope of the project was limited to a short field-based demonstration of the borax method, which was realized by the use of simple methods (observations, discussions, and trial and error).

Results

Fifty invited locals (miners and officials of ministries and agencies) listened carefully to the lectures and videos at the theoretical workshop, asked questions, and reported experiences (Web Figure 6). They were especially interested in the differences between amalgamation and the borax method, the applicability of borax by use of available equipment (e.g. mills), the availability, price, and required quantity of borax, as well as possible health effects due to mercury compared to borax. During the workshop they asked for demonstrations of the borax method and 30 to 40 of them spontaneously decided to take part in the subsequent practical demonstration (Web Figure 7). They invested two further days and organized transport to the testing sites

on their own. These positive indices convinced the project team that the miners were interested and that they were willing to change to a mercury-free technology.

The practical demonstration started with purchasing the necessary material and equipment. While borax, plastic bags, and soap were easily obtainable, the availability of carpets and blow torches was very limited (Web Table 2). Finally, an artificial turf was used as a carpet substitute and a blow torch was rented in Kadoma town, several kilometers away from the mills.

The main steps of the new method are depicted in Figure 2.

The mined ore was milled and mixed with water (*steps 1 to 5, Figure 2*) before entering the provisional sluice box (*step 6, Figure 2*). The artificial turf (carpet substitute) was cut and sized to fit onto the copper plate to create a sluice box (*Figure 3*). Adjustments to the length and inclination angle of the sluice box would improve the processing conditions (Web Table 2).

The next step involved the regular washing of the artificial turf in a container full of water to wash the ore concentrate out of the turf (*Figure 3, right, step 8a, Figure 2*). A second string of ore concentrate was collected in the centrifuge beyond the sluice box (*step 7, Figure 2*) and also collected in the water container (*step 8a, Figure 2*). The water-ore mixture was taken out of the water container and repeatedly panned in a washing plate to rid the concentrate of light waste minerals (*step 9a, Figure 2*). The heavier gold and other heavy mineral particles were mechanically concentrated. To improve the separation of gold and other minerals, soap was added to reduce the surface tension (Web Figure 8). The resultant concentrate contained a visible high percentage of gold dust.

The panning process took a lot of time, resulting in time pressure. The efficiency of the panning process was called into question when one of the gold miners panned a part of the residual ore once again resulting in another visible amount of gold dust. The second recovery of fine gold showed that the panning process needed refining to make it more efficient. Further panning was not possible within the limited project timeframe. Consequently, the tailings were discarded after the second run concentrate was recovered.

In the next step, a magnet was used to remove a large amount of iron from the concentrate (probably wear and tear from the stamp mill) (Web Figure 9). Nitric acid was added to eliminate the remaining impurities. The final concentrate was stored under water in a plastic bag (Web Figure 10), which was taken back to Kadoma town (*step 10a, Figure 2*) where blow torch services were available (*step 11a, Figure 2*). This stage involved the mixing of the concentrate with an equal amount of borax and some water (Web Figure

11). This mixture was smelted with a blow torch in a ceramic bowl (*steps 11a to 13a, Figure 2*) (Web Figure 12). Salt was added to the smelted mixture to produce a well-shaped 1.11 gram gold button (*step 14a, Figure 2*) (Web Figure 12).

On the first demonstration day at Tix mill, a local gold miner provided a part of his ore for the demonstration. After concentrating the ore by use of the artificial turf and a washing plate (*until step 9a, Figure 2*), the local miner noticed more fine grained gold particles than were captured by the traditional amalgamation process. The trial was stopped by the ore owner after observing the fine gold particles in the concentrate. He decided to proceed rapidly to amalgamate rather than wait for the borax method which was going to require blow torch services back in Kadoma town, about twenty kilometers away. Subsequently, the project team decided to buy half a ton of ore from a local miner at Venture mill. This enabled the entire process, starting with ore and resulting in gold, without any interference.

Conclusion

The demonstration project proved that a mercury-free gold winning method using borax and a carpet-covered sluice box is feasible in Kadoma, Zimbabwe resulting in 1.11 grams of gold from 500 kg of ore. The project team noticed a huge interest from the miners in the borax method. The borax pilot project was very successful and encouraging and should hopefully pave the way to the phasing out of the use of mercury in gold mining and processing in Zimbabwe.

Although the once-off primary pilot project had a very experimental character, largely mercury-free gold was the result. The miners noticed small mercury particles in the

concentrate during the panning stage. This was due to the fact that although the mills were cleaned before the borax demonstrations, the environment and the existing equipment remained contaminated. Nevertheless, the mercury was not needed to obtain the gold in this project.

Currently, the millers make their money by applying cyanidation to the tailings, obtaining a significant part of residual gold (*see steps 8b to 12b in Figures 1 and 2*). Improving the milling process and implementing carpet sluice boxes to concentrate the ore mechanically and more efficiently might result in more gold for the miners and less gold for the millers. This could be a source of conflict between miners and millers. It is therefore necessary to design the project demonstrations in such a way that conflicts are avoided in order to ensure success and wider acceptance of the new technology. It is also likely that the new technology may require some technology change in milling as well.

Recommendations

Following this successful pilot project, there remains a need for follow-up implementation activities in support of the borax method in Zimbabwe.

1. Optimization: The borax method needs to be optimized in the field (*see Web Table 2*). The optimal material and equipment (e.g. effective mills, more suitable carpets, longer sluice boxes) available or acceptable in the region needs to be determined.

2. Comparison: A direct comparison of the optimized borax method and the common amalgamation procedure regarding costs, gold recovery, practicability, and time efficiency is necessary. A higher output by the borax method in comparison to amalgamation can be

expected, but needs to be verified by multiple testing.⁹

3. Demonstration: The effectiveness of the borax method needs to be demonstrated for the miners, either by comparing both methods or by applying the borax method to tailings of the amalgamation process. Consequently, the gold lost due to their highly polluting traditional technology would be visualized. A mobile demonstration unit is recommended to reach as many miners as possible.

4. Convincing and winning over the miners: Although the demonstration was of a very experimental nature and short duration, the results appeared to have convinced the miners that the borax method works, as perceived by the project team. Nevertheless, the perception of the project team needs to be statistically verified. The conviction and acceptance of the new methodology by the miners will have to be tested thoroughly after an optimization of the borax method.

5. Assessment: There is a risk that the miners may not change from mercury amalgamation to the borax method entirely, but that they may apply both techniques side by side. It will therefore be necessary to monitor the success of the “phasing out” of mercury amalgamation by testing the mercury exposure of miners in human biomonitors and to survey the health situation of the miners as well as their knowledge, attitudes, and practice (KAP).

The above interventions are essential for future projects to ensure a successful and sustainable introduction of the borax method in ASGM in Zimbabwe. Follow-up work coupled with the expected restriction of mercury availability following the expected ratification of the Minamata

Convention may eventually provide the sway in favour of mercury-free technologies. A very valuable addition for future studies would be the consideration of other health risks in mining other than mercury, e.g. toxic cyanide.^{29,30}

This project demonstrates that mercury-free technologies are available and that miners are able and willing to use them. This is in accordance with the “Minamata Convention”, in which Article 7 calls for: “Use of existing information exchange mechanisms to promote knowledge, best environmental practices and alternative technologies that are environmentally, technically, socially and economically viable.”²

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