Operation and Cost Analysis of a Partly Mechanized Small Scale Gold Mine in Ghana

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ABSTRACT

The economically successful operation of partly mechanized small scale mines in Ghana could fill the gap between large scale, industrial and foreign controlled mining operations and the artisanal (or "galamsey") small scale operations which use only manual labour and simple tools and are mainly confined to alluvial gold deposits and on limited scale to hard rock occurrences. The need to initiate and operate partly mechanized small scale mines stems from the existence of many small orebodies spread all over Ghana which are in their extent and amount of available ore reserves too small to be of interest to medium or large scale mining companies.

In this presentation one of these small auriferous orebodies is described and the operation of a small mine is outlined. The employed mining methods during start up and throughout production phases are described. Special attention is given to safety aspects of such operations.

A mechanised plant for crushing and grinding the ore in preparation for gravity separation (sluicing) was set up by using locally obtainable or manufactured crushing, seeving and milling equipment. The extraction results over 6 month operation are presented and discussed.

The total investment for the small mine and the production costs are presented giving an overview on the economics for such operation.

Factors to be observed to safeguard a small mine from causing adverse environmental effects are discussed.

Finally, an outlook in respect of multiplication of such operations in Ghana is presented.

1. INTRODUCTION

After a long decline of gold production in Ghana since 1986 the gold mining sector is recovering and mainly foreign investment led to substantial exploration efforts as well as to the opening up of new mines and/or rehabilitation and expansion of the existing mines after their divestiture (privatization). Foreign junior exploration and mining companies and established international mining houses are currently exploring the country in search of large, therefore commonly low-grade gold deposits which are amenable to highly mechanized open pit mining and low grade ore extraction technologies.

Beside such orebodies of the disseminated type or in granites, Ghana is endowed with many occurrences of gold quartz veins and banket reefs, which vary in width from a few centimetres to several metres and have striking length from a few 10 meter to several kilometer. Whilst such larger orebodies with ore reserves of above 1 Mio. tons are a target for industrial mining operations, the smaller "stringer"-occurrences are not of interest, if not only as indicators in prospection for possible adjacent disseminated mineralization.

Such restricted orebodies could offer investment and employment opportunities for Ghanaian owned mining groups and companies and should therefore contribute also to economic development of the hinterland. Some of these orebodies as well as the ubiquitous gold bearing alluvials are currently mined by artisanal small scale miners, commonly called "galamsey", which use manual labour only and employ simple handtools in their operations. A visit to such operations will convince any observer that in almost all cases the operations are either inefficient, including the skimming of orebodies, or dangerous, or environmentally unsound or a combination of these. This is due to the long oppression of small scale mining activities first by the Colonial Government from about 1920 ongoing, later by the Ghanaian authorities after Independence. Only in 1986 under the Minerals and Mining Law, PNDC-Law 153 was the small miner legally recognized and a basis laid for his operations.

Vast experience in narrow vein mining, which was available among African small scale miners before and around the advent of this century has been lost.

To prove this point, mention should be made of the African engineer T.B.F. Sam, who managed and operated singlehandedly the Adja Bippo Mine near Tarkwa before 1900, the only mine of all the mines in operation since 1880 which was profitable and declared dividends (Rosenblum, 1974).

Today it can still be assumed that there will be no re-juvenation of skilfull vein mining by African small scale miners as long as it has not been proved to Ghanaian investors that such operations could be viable. The proof can be presented best by a few reference operations applying durable, locally available machinery, simple and sound mining and extraction methods, basic safety standards and bearable working conditions as well as in their effect on the environment controlled operations. Such reference mines could also provide the necessary information in respect of day-to-day running problems, required amounts of investment, minimum working capital, maintenance and repair needs and problems with unskilled labour drawn from the surroundings of such small mines, to mention only a few areas of missing experience.

2. THE TETREM SMALL MINE

The Tetrem Small Scale Mining Group (TSSMG) was formed in early 1990 and obtained a Small Scale Gold Mining Licence on 15th July 1991 over an area of 25 acres (about 100.000 m^2) adjacent to the Village of Tetrem, Ahanta West District, Western region of Ghana. Tetrem is situated about 2 km after the Axim-Elubo Junction on the road between Agona Nkwanta and Tarkwa. The licence area was choosen on the basis of a favourable geological report by the then Gold Coast Geological Survey Geologist Tom Hirst, written in 1932, and after inspection of the overgrown workings, which included at that time one old, fallen in shaft.

2.1 History

Hirst reported in 1932 as follows: "This prospect lies in flat ground in an open valley at the head of the Fankoba river." ... "It is exposed in three recent trenches over a length of 80 feet (24.38 m), and was seen 93 feet (28.35 m) to the south-west in another trench. The reef strikes 37° magn. and dips vertically. It is 2 feet (0.61 m) thick at the extreme N.E. end, 1' 6" (0.46 m) in the two trenches southwest of the above, and only 6" (0.15m)in the last trench 93 feet (28.35 m)to the south-west. The total length as seen is therefore 173 feet (52,73 m). The quartz, which lies in granite (with little ferromagnesian material) is dense, greyish and somewhat greasy in appearance, and in places rich in pyrite mostly altered to cubes of limonite. It is smoky in places due to indeterminate inclusions. it is, however, everywhere rich in visible gold, associated with pyrite, or limonitic material. One large block on the surface, almost a yard square, gave coarse visible gold almost every time it was broken with the hammer, whilst very rich tails of gold were obtained by dollying over the whole extent of the reef. It was extremely difficult to obtain samples free from visible gold. A sample from the extreme N.E. end gave 25.6 dwt. per ton (39.8 g/t) whilst another taken 80 feet (24.38 m) to the south-west gave 17.6 dwt. (27.4 g/t) (Ariston assays)." (Metric measurements in brackets inserted by the author).

Hirst's report showed that the vein had been discovered and worked to a little extent by African miners. Later on, the Ahanta Mining Company sunk two shafts and dug several trenches in the area but their findings are not known today and they resolved not to start a mining operation. The area was sporadically mined by Galamsey-miners over the years, which resulted in various rock-heaps scattered around the main trench on the vein and broken rock scattered at the water-pools of the Fankoba river.

2.2 Geology and Description of the Ore

The orebody is a vertical dipping quartz vein which filled a shear zone related fracture at the contact between the undifferentiated greenstone and tholeitic basalt in the West and the belt granitoid of quartz dioritic composition in the East (Loh et al., 1995). Several volcanic-intrusive events had consecutively opened the fracture and the quartz shows clear laminations which also contain the greater part of the gold and the associated sulphides. The quartz consists of the bluish smokey, grey-white-greasy and the pure-white, hungry looking types. The latter is mostly barren but contains sporadically isolated specks of gold visible to the naked eye. The vein is distinctly frozen to the hanging wall in the west and at the footwall to the east a thin black-brown leader defines the contact. Samples taken of the hanging and footwall showed values below 0.2 g/t, i.e. no mineralization.

2.3 Initial Exploration, Ore Reserves

The Tetrem Small Scale Mining Group undertook an exploration and sampling exercise before first operations were started in 1992. On the basis of 30 samples taken along the reef in the open trench near the surface an average grade of 11.48 g/t with an average width of the ore of 1.015 m over 122 m striking length was established. The reclamation of the old shaft to a depth of 11 m and subsequent sampling allowed the ore reserves to this depth be pegged at 3500 t with a gold inventory of at least 1200 oz. Further reserves were to be expected in the extension into depth and at both ends of the vein being assumed to be open ended (Barko, 1992).

2.4 Previous Operations

A group of Small Scale Miners from Tarkwa was engaged in mining the locality for about 18 months in 1992 and 1993. They employed the usual galamsey methods of operation by digging the trench to depths of about four metres, digging short shafts and extracting ore through chiselling and breaking with crowbars. The ore was then handpicked and sorted and mainly the oxidized rock, clearly distinguishable through its reddish appearance, and other high grade material was broken with hammers, crushed in mortars and sluiced with the usual sluice-boards equipped with cocoa-bags for gold dust recovery. The operations of this group were quite unsystematic, caused erratic holes and pits as well as dumps of broken rock mixed with soil all over the area. Due to the fact that this group of miners resolved to hide the gold produced for their own purposes and failed to account for gold production as well as supplied tools and inputs the leaders of the TSSMG dissolved this group and stopped their operations. The area was lying idle up to the time of the present operation described in the following.

2.5 Start Phase of the Partly Mechanized Operation at Tetrem

2.5.1 Mobilization

The new operations at Tetrem were started in early September 1995. The mobilization phase included clearing of the site from overgrowth, re-cutting of the borders of the licenced area, felling of trees near the open trench for safety reasons and enlarging an existing pond in the valley for process-water supply. The erection of a fenced shed for tools and materials, the building of a latrine, acquisition of accomodation from a farmer for outside workers and having the access road with rock fillings made passable was part of the mobilization. Because the area was quite unsafe due to the rock and soil heaps placed nearby the trench causing falls of the sidewall of the trench a major exercise of clearing and sorting those heaps was begun. At the same time the trench was also excavated to remove all loose material fallen or pushed in and to expose the vein.

From the mixed up materials the rock boulders and pebbles were first sorted out by hand and the remaining soil was sieved through a grizzly with 2 cm openings. This grizzly had been produced locally from round 1.3 cm building steel welded on a frame of 1 by 1.5 m dimension. About 120 t of rock of the size between 50 cm and 2 cm size was recovered in this way representing the rejected rock of all previous galamsey operations.

After panning tests had shown some gold in the soil a test run was carried out with the water-powered Prospector II equipment, supplied by the Small Scale Mining Project of the Minerals Commission.. Several m³ of the soil were washed but gave a total return of 0.3 g of gold only. The supplied Honda-pump to power the Prospector II turned out to be unsuitable and got damaged beyond repairs (broken connecting rod with subsequent damage of the crank-housing). The only gain from such an operation would have been the broken rock of size below 2 cm washed out with the sieve of the Prospector II with sieve-openings of 6 mm. This material assayed 2.13 g/t, being therefore very marginal.

The total cost of the mobilization phase up to end of the year 1995 amounted to 4.71 Mio. Cedis (or 3,150.- US$).

2.5.2 First ore treatment tests

Because no experience with quartz vein ore of the type found at Tetrem was available, the extraction of the ore was first tested with a pilot-plant consisting of a laboratory type jaw-crusher, a hammermill and a pulverizer (Make Brown, USA) with 20 cm diameter carbon-steel grinding plates. Rocks sorted out from the heaps were reduced with hammers to a size less than 5 cm and then milled in the pilot plant to 100% of the fines below 1mm. The fines were then sluiced over a sluice box of 7.3 m length (two times 12 feet) equipped with corduroy for gold recovery. From the concentrates obtained, an average gold content of 10.5 g/t of sluicable product was won with tailings assaying 1.26 g/t, resulting in a recovery of 89 %.

The tests proved an extreme hardness of the ore together with a considerable abrasiveness, resulting in heavy wear of all steel parts. The results clearly showed the cause why this deposit had not extensively been mined by galamsey miners in the past. The hardness and abrasiveness of the ore simply prevented treatment with the conventional comminution methods available to galamsey miners.

3. MINING OPERATIONS AND RESULTS

During the initial clearing of the heaps near the main trench and during excavation of the loose material out of the trench care was taken to deposit the resulting sieved soil material as far away as practical from the trench to prevent the material from running back during rains. The main trench, the north end and the southern tail of the reef were completely dug out to the extent of the previous galamsey operations. In the course of this work, the second old shaft of the Ahanta Mining Co. was re-discovered, which had completely fallen in over the first 5.5 m (18 feet) from surface and had to be re-timbered because of the loose sapprolite in the shaft walls. The remaining of the shaft was found closely timbered to a depth of 12 m and the timbering still in very good condition after about 60 years under water.

The south end of the reef was opened up by an open trench started at the bottom of the valley along reef strike to ascertain the reef width in depth and to allow later gravity dewatering of the main workings. The reef was found to be uneconomically low in grade and in thickness, below 2 g/t and thickness not exceeding 20 cm (8") over the first 25 m striking length from the South end, average thickness being less than 10 cm.

Also further north, in the main trench and at the north end of the vein, the ore-widths found at a depth of about 4 m were considerably lower than previously established near surface during the exploration. At the north end the vein thinned out to below 15 cm and dives downwards. For the remaining workable area of 75 m striking length with reef widths of above 25 cm an average weighted width of 38.4 cm has been determined, which probably will be reduced further due to the fact that in the rediscovered South shaft at 12 m depth the vein was found only 16 cm wide. The available ore reserves from the previously mined out level down to the 10 m level was recalculated to be 360 tons only, together with the rocks won from the heaps and rubble therefore less than 20 % of the originally assumed ore reserve to this depth.

The mining was carried out in a kind of underhand stoping with slicing first a portion of the hanging or footwall - whichever was found softer to be excavated with pickaxe and shovel. In a second step, after removing the waste, the ore was separately broken in with chisels and crow bars, when necessary reduced in size with sledgehammers and then hoisted with buckets to the surface. Ore transport to the treatment plant was effected in half oil drums and by a trolley on car-tires as in common use in Ghana's markets for transportation.

In eight months of operation, about 240 tons of ore have been won and about 200 m³ of waste materials have been moved, resulting in a total output per man and shift of about 0.38 t including all accessory works like timber cutting, timbering, transport of ore to mill etc.. The overall mining production rate in respect of ore is 0.125 t per man and shift.

3.1 Dewatering of mine workings

Water is the enemy of any miner and this was experienced to the extreme at the operations at Tetrem. During the dry season, when operations were started, not much difficulties by occasional rains were experienced. The two shafts acted as dewatering sumps and by pumping them out with an electric pump, driven by a generator-set, the workings were kept dry.

Conditions changed dramatically with the advent of the rainy season in May 1996. The area became flooded during torrential rains and the workings filled up to the brim with water, which caused the sapprolitic material in the walls, which in the dry season was only to be mined by heavy breaking with pickaxe, to become soft, greasy and muddy with the result of the collapse of a part of the workings. The amount of water in the ground became so excessive, that even day long pumping did not lower the water table in the main trench. Only the south end was kept somehow dry due to the gravity dewatering of these workings through the existing tunnel towards the valley. Within the tunnel, heavy re-timbering was necessary to prevent the caving in of the tunnel due to excessive pressure from the sapprolite in the walls. In fact, every stull of the previously set timber support had to be supported by posts with bracings mounted at the top and foot.

3.2 Safety aspects in mining operation

Every worker was personally protected by a helmet, safety boots, leather-gloves and, where necessary, with safety goggles to prevent eye damages during chisseling of rock or breaking of boulders with the sledge hammer.

It had been found that constant reminders were necessary to enforce the wearing of these safety items. Virtually every day some workers were found to flout these rules due to comfort, negligence or because they had taken the helmet or boots home and left them there. The helmet and boots became rather a status symbol in the adjacent village than an accepted protection equipment during work.

During shaft reclamation or in the trench at unknown areas with the possibility of underlying old stopes it was made obligatory that workers were secured by belts and ropes kept as short as possible and tightened to firm posts outside the workings. This safety measure was also constantly flouted by the workers due to the restrictions imposed by the ropes during shovelling.

Work in shafts or deep trenches necessarily needs a permanent observer at surface to enable instant alarming of the foremen or other workers in case of a danger or an incident.

It was made a rule that during heavy rains and one day after heavy rains no work was permitted in unsupported trenches or pits with depth of more than 1.8 m (6 ft.). Likewise, every morning an inspection of the workings had to be carried out first before the workers were allowed to start. The inspection has to concentrate on rock-falls overnight, visible cracks or fissures in the benches or trench walls and any timber work damaged.

3.3 Maintenance of tools and machinery for safe and efficient operations

Handtools like pickaxes, shovels, spades, chisels, crowbars, hammers, sledge hammers need continuous servicing in respect of their wooden parts and handles to avoid accidents from flying off hammer-heads. Access to a blacksmith for sharpening and hardening of the picks, crowbars and chisels is indispensable. At Tetrim, one worker with carpentry background was given responsibility to carry out hand tool service daily.

All the above proves the need for a small workshop at the mining site comprising of a electric welding machine, two hand angle grinder for cutting steel, electric handdrill and standing drill, vice, thread grinding equipment for threads from 4 mm to 12 mm diameter and for pipes from 3/8 to 1.5 inches (9.5 mm to 38.1 mm).

Beside the usual tool sets with spanners, screwdrivers, files, hacksaw etc., universal pulleys, a set of crowbars, a chain pulley with 3 t lifting capacity and at least two big pliers for pipes up to 3 inches are indispensable.

3.4 Discussion of mining operation

Whilst the restriction of Small Scale Mining to a depth of 10 m is beneficial for alluvial operations to prevent collapse of pits with instant burial of workers, in hard rock, especially vein mining this restriction is inappropriate because it leads necessarily to bad mining practice. For a vein like that found at Tetrem from the surface to a depth of at least 8 m a safety pillar should have been left to prevent inrush of surface waters and the collapse of sidewalls made up of unconsolidated materials like the sapprolite. This would render the deposit for small scale mining useless, because only some two or three meters of ore would be left for mining within the given limit. Consequently, the mining started right at the outcrop and with advance into depth all difficulties with wall instabilities, surface waters etc. are met with.

4. ORE TREATMENT AT TETREM

The treatment plant was installed in Nov./Dec. 1995 and was fully operational at the beginning of 1996 being therefore in the Western Region the first plant of this kind in small scale mining. The plant consisted of a locally obtained crusher, locally produced hammer mills, sieves, and sluice boxes. The crusher, a Parker 14 x 7 inches (35 x 18 cm) jaw crusher made in 1956 was reconditioned locally and powered by a 5.9 kW (8 hp) slow speed, one cylinder diesel engine of Indian make commonly used for powering cornmills. Despite some doubts at the beginning the engine turned out to be sufficiently strong to drive the crusher even when fully loaded with rock.

To obtain a maximum amount of fines from the ore, the crusher was installed on a flat concrete platform to allow crushed material to build up under the crusher in order to retain the ore as long as possible between the crushing plates. This mode of operation produced an average of more than 30% of fines below 1mm size per crushed ton of rock. The material obtained from the crusher was loaded by shovel on a double deck sieve of local production, which was vibrated by a rope connected to the moving crusher stock. The sieve with 6 mm square opening separated the oversize from the fines, which were further separated by a sieve of 1 mm square opening in mill entry product (- 6mm to + 1mm) and fines of -1mm, which were sent without further comminution to sluicing. The oversize of +6mm was recirculated into the crusher and for each batch of rock at least three recirculation cycles were performed.

The mill entry product of - 6mm and + 1mm was milled in a hammer mill to 80% below 1mm fines, which were send to sluicing. The mill was built from a locally obtained palm kernel crusher through lining the inside of the mill housing with spring steel and fabrication of a rotor, which was holding three pairs of hammers manufactured also from flat spring steel. The fines from the mill were caught in small drums.

The sluice consisted of two wooden sluices of 45 and 50 cm width and 3.65 m length each, used in series and equipped with corduroy. The water supply of 50 l/min was obtained from a 1 m³ watertank, put on a timber crib of round timber. Water supply was effected from the pond in the valley with a 5-hp-Hondapump.

The sluice-fines of < 1 mm were suspended in a hopper with the water fed by a waterhose and then run through both sluiceboxes. The tailings discharged into a tailing pond from where they were regularly backed onto a tailing heap for eventual further treatment in the future. Depending on the type of fines treated the corduroy was washed according to a set-out schedule regularily and the concentrates collected in plastic buckets for further extraction.

The collected concentrates were always transferred to Tarkwa to avoid amalgamation on the site due to safety and environmental reasons. The concentrates were amalgamated and the amalgam separated from the concentrate through washing. The amalgam was pressed to remove free mercury, then retorted, providing the sponge gold for smelting to arrive at the final product.

The operational experiences with this plant, the findings about the recoveries in the separate stages and the maintenance and safety aspects are presented in a separate publication „Gold Ore Treatment at Tetrem Small Scale Mine“

4.1 Results of ore treatment at Tetrem

During six months of operation, a total amount of 140 t of ore was treated and 120 t of sluice fines extracted.

The average recovered grade, i.e. final, smelted product, was 6.14 g/t, ranging for single ore batches from 1.4 g/t to 10.5 g/t. The average head grade of the ore was calculated to be nearly 10 g/t (9.94 g/t) which was 1.5g/t lower than the average grade found during initial exploration. The "picking of the eyes" by the initial "galamsey"-operation could account for this. Anyway, the grade of the ore is, as usual with such quartz veins, erratic and patchy and at Tetrem with clearly lower grades at the northern and southern end of the exposed vein. Ore batches with grades below cut-off-grade were milled because preliminary pounding and panning with sample-tyre had shown them to be carrying gold but the sampling obviously did not represent the whole batch of ore. In the opposite, ore that was assessed very marginal through pounding and panning of samples turned later out to be even above average in grade. The ore-grade control in a small scale operation like Tetrem is one of the major problems discussed further below in the chapter "Profitability".

The average recovery at the treatment plant was found to be 74% with single recoveries from nearly 90% to as low as 50% in heavy sulphidic ores. The recovery in gold amalgam extraction also varied between 98% and 51 % giving an average recovery of 84%. Therefore the overall recovery of the operation was 62%.

4.2 Plant capacity and utilization

The plant utilization, here defined as time of plant worked to available working time in a one-shift per day operation was around 40%, this mainly due to non-operation of the plant when the engineer was not present. The average output of the crushing and milling plant was just above 2t/day with single outputs ranging from 0.5 to 3.3 t/day. The actual long term capacity of the plant per month in one shift/day operation can be estimated at 50 t.

At the sluice, depending on the frequency of washing of the corduroy and depending on the availability of water in the pond for pumping, at an average 2.2 tons of fines per day have been treated, with peak outputs of nearly 4.5 tons per day.

5. COST ANALYSIS OF TETREM SMALL MINE

5.1 Investment costs

The primary exploration, mobilization and acquisition of equipment demanded a total investment of 22.769.000 Mio. Cedis (at average of 1500 Cedis to 1 US$) which is broken down in Table 1:

Table 1: Break down of investment for Tetrem Small Mine

Item	Costs (Cedis)
Acquisition of Licence, payments to local authorities etc	900.000
Cost for 55 Samples	1.204.000
Machinery and accessories (Crusher, mills, 3 diesel engines, pumps, Prospector II, generator-set)	12.470.000
Handtools (shovels, pickaxes, pans etc)	330.000
Workshop equipment (welding, grinding etc.)	1.285.000
Shed, roofs over plant, foundations	910.000
Safety equipment (helmets, boots, etc)	970.000
Mobilization (3 months)	4.700.000
TOTAL	22.769.000

With an average work force of 18 workers (engineer, two foremen, one mechanic/welder, 12 workers and two security/watchmen) the average investment per working place amounts to 1.265 Mio. Cedis.

5.2 Operation costs

During six months of operation average working costs per month of 2.041 Mio. Cedis have been experienced, which are broken down in Table 2.

Table 2: Operation costs at Tetrem according to cost items and cost centres

Cost items	%
Labour Cost	71
Energy	7
Consumables, spares	21
Cost centres	
Mining	45
Milling, Extraction	36
Overhead (Security, Admin.)	19

5.3 Profitability of the operation, discussion

After nine month of operation and six month of production it was found that the Tetrem Small Mine was not profitable. The gold returns just covered the operation cost, but did not contribute to investment repayment including payment of interest on investment. Several reasons account for it:

- Ore grade was lower than expected
- Recovery was far lower than expected
- Ore width was less than expected, therefore higher mining costs
- Low utilization of the treatment plant
- Ore batches below cut-off grade were processed in the treatment plant

As was already mentioned earlier, the average ore grade was found to be around 10 g/t instead of 11.5 g/t. The recovery was estimated during pilot plant tests to be at 80 %, but turned out in the actual plant to be 62%. The originally calculated cut-off grade of 6 g/t was therefore set too low and should have been rather set at 8 g/t given the experienced recovery and the actual cash returns for gold with about 18 to 19 carat. This cut-off grade would have definitely restricted the available ore reserves further.

At Tetrem it came as a complete surprise to have run into ore with fresh sulphides and galena as associated mineral at a level only 4 to 5 m below surface. It was originally assumed that the free milling properties of the ore met with at surface will continue at least to a depth of 10 to 15 m.

An increase of the overall gold recovery through better recovery of sulphides and better extraction of gold from sulphides should have enhanced the economics of the operation but this was outside the capabilities of the existing gravity extraction plant.

The considerably reduced ore width of 0.384 m compared with 1.014 m has caused higher mining costs, because more waste rock had to be handled to excavate the minimum necessary mining width of 1.2 m in presently mined areas where the hanging and footwall had to be supported by timbering. With increased mining depth it was to be expected that the hanging- and footwall had become more stable allowing operation with a reduced mining width of about 1m.

The treatment of ore batches below cut-off was caused due to the in-availability of reliable assaying facilities. But carrying out reliable assays at the mining site is beyond the capabilities of a small mining operation. The estimation through pounding and panning turned out to be unreliable, as described earlier. Because of the patchiness of the ore, every batch of 3 to 5 tons should have been assayed. Sending assays outside to available laboratories turned out to be prohibitive expensive, one assay costing 17 US$ plus batch fee of 20 US$ for the four or five samples to be sent. The services of the Small Scale Mining Centre in Tarkwa could only be used, when stockpiling larger amounts of ore to be able to send the by them required minimum number of 10 samples, which will still attract 100.000 Cedis assay-charge.

Considering an operation far away in the hinterland, the ore might have been milled already when the assay results become available at the mine. Further research and trials are necessary to find a lasting solution for this ore grade control problem.

On the basis of the investment and cost records at Tetrem, which can not be reproduced here in detail, the following was arrived at: With an initial investment of 22.77 Mio Cedis, an interest rate of 50 % per annum by quarterly annuity and an investment repayment period of three years expected the operation will break even at a head grade of the ore processed of about 14g/ton. This under the condition that all other parameters of the operation remain constant, i.e. recovery rate of 62 % for an operation with similar ore (hardness, abrasiveness), one shift operation and ore to waste ratio of 1:1. The gold returns were entered with 15.000 Cedis per g of gold of 18 carat. The minimum required proven ore reserves for three years operation are between 720 t for 20t per month and 1800 t for 50 t per month plant capacity.

From the operations was learned that at Tetrem only enhanced recovery to about 80 to 85% and full utilization of the plant would have secured profitability if the average ore grade remained around 10 g/t. For further operation additional ore reserves were necessary, but were only available in depth with then even higher sulfide contents of the ore. Therefore it had to be decided to close the operations after a running out phase of another 4 months.

As a general observation for similar quartz mining operations it can be stated, that at least an average grade of 12 to 15 g/t for the initially proven reserves is desirable to secure the success of the small mine. It is of interest to note that over 60 years nothing much has changed because in the 1930th quartz veins with less than 10 dwts. (15.5 g/t) were considered marginal or uneconomical as various progress reports of geologists of the Gold Coast Geological Survey had stated.

6. ENVIRONMENTAL CONSIDERATIONS

Any mining operation should be planned and carried out in a way to minimize its effect on the environment. Mining is using the restricted land ressources only for a comparative short time to take out minerals contained in the land. This short term use should not spoil the future use of the land for agriculture, forestry, recreational or residential purposes. Same applies to water ressources.

At Tetrem Small Mine the following factors were especially observed to safeguard the environment:

1.

No use of mercury or other chemicals at the site, which is near the headwaters of the Fankoba river. The extraction of concentrates through amalgamation was carried out in Tarkwa under controlled conditions in a laboratory-like environment.

2.

In respect of tailings disposal and water disposal from the sluices a series of ponds was created to allow settlement of slimes before the water seeped into the natural drainage. An additional advantage of settling ponds is that tailings can be recovered and stacked for future re-treatment. The initial planning of the tailing site will finally allow the deposition of the tailings in terraces as infilling of a small valley. The-run off of the tailings after final deposition will still pass the settling ponds for de-sliming.

3.

After abandonment, pits, trenches and shafts can pose hazards to animals and human beings when left open. Therefore, at Tetrem measures were taken to place waste material in a way that easy backfilling could be effected. This heaped material was acting in the meantime as a small protective dam and prevented water run-off into the workings from the slightly eastward sloping adjacent farmland. In addition, with advance into depth the chosen mining process involved the covering of the trenches, levelling the areas on surface and replanting. This provides the immediate advantage for the ongoing mining operation that rainwaters will not run into the workings but rather be led away, erosion is minimized and the workers used the levelled areas for planting foodstuff. Shafts should be planned in a way that they can be later easily covered or converted into water wells. This will require a concrete cover on surface to avoid contamination of the well with run-off or through fallen in animals. The water has to be chemically analyzed before handing such wells over to the public.

4.

All machine sites have been concreted to prevent oil or diesel spillage to seep into the ground. In case of leakages, immediate repair is enforced.

5.

As laid down in the mining regulations, a latrine has been built to prevent contamination of the surrounding with faeces and especially to prevent the possible contamination of the ponds at the headwater of the Fankoba with bilharzia. These ponds are used as watersource by the villages nearby.

7. MULTIPLICATION OF PARTLY MECHANIZED SMALL MINES

Given sufficient ore reserves of at least 3000 t of proven ore at an average grade of around 15g/t for a gold occurrence the multiplication of partly mechanised small mines in Ghana should be possible if the following factors are observed and assistance will be provided.

From the experience gathered at Tetrem Small Mine the initial exploration is of prime importance to such quartz vein mining operations. Whilst in most cases no money will be available for extensive exploration, the exploration has to prove at least the minimum amount of ore reserves to enable repayment of the investment. For further continuation of the operation out of the ore development can take place. The near-surface properties of the vein can be assessed by digging trenches and sampling but the extension into depth will be only assessed properly by drilling.

Assistance for Small Mines should therefore provide cost-free or pre-financed core-drilling facilities to prove ore-grades and -thicknesses to a depth of 15 to 20 m. This could be effected by employment of Cobra-drills (Petrol-driven, portable handdrill with core-barrel).

Depending on the extent of the orebody, at least some 50 to 100 samples will have to be analyzed and costs of 2000 US$ have to be reckoned with. The samples should not be analyzed for gold only but also for elements like silver, copper, lead, zinc, arsen and iron to allow an immediate assessment in respect of sulfides and/or refractory nature of the ore.

Tetrem's operations have shown that local equipment, which has been extensively tested under actual working conditions, can be used for similar operations. But the availability and the distribution of the machines alone will not promote the multiplication. Assistance with spare-part depots, workshop- and servicing facilities would be of prime importance. Crediting and selling of suitable equipment without securing the after sales services and a continuous engineering assistance is inappropriate.

Not all investors can afford the investment solely from equity. The necessity of loan-facilities for the small scale mining sector in Ghana through opening of mining windows at banking institutions had been postulated at every conference or meeting in respect of Small Scale Mining but until today such facilities are missing. Credit systems for imported mining equipment were abrogated because the supplied, untested equipment failed after a short time and the small miners did not repay the loans for already obsolete equipment which did not contribute to income from their operations.

With short-term financing opportunities available, operations like Tetrem could resolve seasonal problems like water deficiencies during dry season and too much water during rainy season through seasonal mining schedules, which demand higher working capital outlay. During the dry season only ore winning would be performed and all ore stockpiled for treatment in the rainy season, when sufficient water is available for high utilization of the sluice boxes. Such schedule will require working capital for at least 5 to 6 months of operation without any tangible returns.

As long as no specialized experience about the particularities of mining operations is available in the banking sector the multiplication of small mines like Tetrem and mining ventures of Ghanaian companies in general will be seriously hampered and only foreign investment will promote but also control all gold mining activities in Ghana.

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