CASM-AGM – 11- 15 November 2006
Antsirabe, Madagascar

ENGINEERING FOR SMALL SCALE MINING AND SUSTAINABLE LIVELIHOODS IN AFRICA

Dr. Daniel Limpitlaw, Pr. Eng.
Principal: Limpitlaw Consulting

ABSTRACT

Artisanal and small scale mining is often characterised by lack of technical skill on the part of the miners. This results in serious health and safety hazards, frequently reduces the efficiency of mineral extraction and leaves behind highly degraded landscapes. When these impacts are coupled with the low or survivalist income captured by many small scale miners, the position of the miners becomes increasingly unsustainable. To promote sustainability, many theorists argue that natural capital (i.e. mineral and renewable resources such as water) must be efficiently converted into various forms of anthropogenic capital. The latter includes financial, social, human and physical capital. Where miners are injured or become ill through poor workplace conditions, human capital is lost and strain is placed on societies. Limited extraction of ore bodies destroys the natural capital base without a commensurate increase in the financial and social capital. At the end of the life of the mine, a devastated environment prevents a post mining land use, such as agriculture, and often forces miners to migrate to new deposits and so repeat the cycle.

Using examples from Nigeria and Zambia, this paper illustrates the potential of appropriate mining engineering interventions for the promotion of sustainable livelihoods in African settings.

INTRODUCTION

Substantial numbers of people in Africa earn their living directly from artisanal and small-scale mining (ASM), or depend on the sector (Hoadley & Limpitlaw, 2004). In 1998 the International Labour Organization (ILO) estimated that 13 million people were directly employed in ASM globally, and up to 100 million depend on it. No recent estimates are available, and given the growing levels of poverty in sub-Saharan Africa, it is reasonable to assume that these numbers have increased significantly, and will continue to do so.

The ASM sector in many countries lacks financial support, equipment and appropriate technology for expansion. ASM activities often cause extreme environmental and social impacts and seldom contribute to government revenues. In this form, they cannot be regarded as promoting sustainable livelihoods, although they provide emergency poverty relief and daily sustenance. The use of inadequate mining and mineral processing techniques leads to low productivity and mineral recovery. The resultant low revenues and the inability to accumulate funds for investment mean that productivity cannot be improved and this traps the miner in an unending poverty cycle.

ASM AND SUSTAINABILITY

In sustainability theory, the resources available to a community can be divided into natural capital (minerals, soils, water, etc.) on the one hand, and anthropogenic capital on the other. Anthropogenic capital is further divided into several classes: financial, social, human and physical capital. Financial and physical capital are generally well understood – the western economic system is based on the accumulation of wealth as measured by the growth of these two capital classes. Social and human capital are less easily measured and have been ignored in the past. Social capital is made up of the networks and organisations with a community that provide mutual support and work for the welfare of the community (Hoadley, pers. comm., 2006). Human capital is made up of the accumulation of skills, knowledge and wisdom of individuals.

In a developing country context, relevant to most of Africa, a sustainability paradigm that allows some form of conversion of natural capital into one or more of the anthropogenic forms of capital is useful[1]. This means that a non-renewable natural resource, such as an ore body, can be depleted in a sustainable way if the gains made in the anthropogenic capital classes outweigh the loss in the natural capital class. In many instances small scale mining is conducted in a way that reduces the efficiency of conversion of natural capital into anthropogenic capital.

Critics of ASM may argue that the sector affects the various classes of capital in the following ways:

1. Natural capital

- Ore bodies may be sterilised by *picking the eyes out of the deposit*. This refers to selectively mining accessible, high-grade areas, thereby lowering the average grade of the deposit below the pay limit and rendering the bulk of the mineralised ground unminable.
- Mining of the ore often destroys the topsoil by mixing it in with waste rock and overburden or destabilising the ground surface to such an extent that the surface collapses. When the ore is depleted, the ground is effectively useless and is removed

[1] This type of sustainability paradigm is often referred to as *weak* or *moderate* sustainability as conversion of capital classes is possible. *Moderate* sustainability requires that thresholds of natural capital depletion are not exceeded and *strong* sustainability does not allow net conversion of natural and other forms of capital (all conversions must be fully offset by other gains in natural capital).

from the resource base of the community. Rivers may be polluted with acid drainage, reagents (such as mercury) or silt, rendering them unfit for agricultural purposes.

2. Social capital

- Especially under *gold rush* conditions[2], the chance to get rich quick sets people against one another and fractures social structures. The influx of cash-rich outsiders promotes various vices including substance abuse, prostitution and crime. Unsafe working conditions may result in high rates of injury and fatalities. Poor working conditions also result in high incidence of occupational diseases, such as pneumoconiosis.

3. Human capital

- Children may be removed from school by their parents to work a claim or may be indentured into a form of slave labour for a third party. This inhibits the creation of human capital. Illness and injury also impact on this form of capital.

4. Financial capital

- Much of the wealth generated by small scale miners is captured by middlemen traders who operate outside the law. Small scale miners commonly consume all of their income to survive.

5. Physical capital

- Houses and roads may be undermined and destroyed by uncontrolled, explosive *gold rushes*. Even where this does not occur, little or no re-investment in physical infrastructure takes place. Most of the wealth generated is spirited out of the country and not invested locally.

A number of interventions are required to avoid the impacts listed above. These include the often discussed social and environmental impact mitigations that are prevalent in literature on ASM. Small scale miners themselves are often focused on access to markets and appropriate technology. This paper provides some examples of the sustainable development (SD) dividend that can be extracted by applying appropriate mining engineering approaches to ASM operations. This paper only considers the process up to the pit head and does not discuss transport, mineral processing or marketing.

---

[2] These conditions apply to a broad range of commodities but were typified by the sudden scramble for claims that followed the announcement of South African gold discoveries in the 19th Century.

To optimise the ASM contribution to sustainability, mining methods must be carefully selected. Work done by Mintek (2005) identified criteria for the selection of a mining method. These include:

- improving the organisation, productivity and production of operations,
- ensuring quality and constancy of production and supply to consumers,
- encouraging value-adding sorting, washing and/or processing, as appropriate and feasible,
- improved working conditions – the promotion of healthy and safe mining conditions with avoidance of mine site collapses, and
- improving environmental management practices at mine sites – rehabilitation to remove environmental degradation caused by the mining and the danger old mine openings present to livestock and people.

CASE STUDY 1: SHALLOW UNDERGROUND MINING IN NAFADA – NIGERIA[3]

Artisanal Mining of Gypsum

Gypsum is produced by artisanal miners at Nafada in Nigeria's Gombe State. The mining method used is known as the Loto System, and is a modified version of the mining that takes place in Nigeria's alluvial tin mines (Mintek, 2005). In this mining method underground extraction of ore is conducted by sinking shafts through the overburden. When the relatively rich zone of gypsiferous shale is intersected, generally at depths around 5 m below the surface, tunnels are driven out to intersect the shaft bottom of the neighbouring shaft (20 to 30 m away). A typical mine consists of five workers at each shaft (two miners working underground, a miner hoisting material to surface using a rope and bucket, and two sorters). Women and children transport the sorted ore some 50 to 100 m to a central stockpile for further sorting and loading into 5 t trucks. The gypsum is then transported to roadside collection points for sale to agents and transport to the end users in 30 t trucks (Mintek, 2005). Approximately 14,000 people are involved in the production of 45,000 t of gypsum annually from these mines.

This mining method is hazardous with poor resource utilisation. It is estimated that less than 25% of the *in situ* resource is recovered due to the need to leave supporting pillars (Mintek, 2005). The Loto System also results in significant environmental degradation as the shafts and

[3] The author is grateful to the Ministry of Solid Minerals Development of the Federal Republic of Nigeria and Mintek for permission to use this case study.

underground galleries are not rehabilitated once they are worked out. This presents an immediate hazard for people and animals and a potential future subsidence risk.

A More Sustainable Approach

Underground mining is not a suitable method by which to efficiently and safely extract this shallow, horizontal ore body overlain by unconsolidated sediments and decomposed shales. Supporting a weak roof under such conditions is very onerous and roof integrity cannot be guaranteed, even when the bulk of the reserve is sterilised by leaving large numbers of closely spaced pillars *in situ*. For these reasons, a surface mining method would be more appropriate.

To effectively access the ore horizon, a mechanised pre-strip and overburden stripping operation was proposed using mobile, diesel-powered earth moving plant. Top soil must be stockpiled separately and the stripped overburden placed into spoil piles adjacent to the cut. Topsoil stripping is effected using a small excavator. Once the ore horizon is exposed, it is excavated manually and hand sorted to improve gypsum grades before leaving the pit. After the gypsum ore material has been removed from the pit, it is sorted again to maximise grade before being loaded onto trucks for transportation to the market.

The ore horizon is 4 m thick and therefore hand excavation of a mini-high wall, advancing along the axis of the strip, is not feasible. Once exposed, delineated sections of the ore body can be loosened with picks and then excavated layer by layer until the pit floor is reached. Hauling of ore out of the pit can use either the existing hoisting system or a highwall ramp and wheelbarrows. Demarcation and management of the sections is effected using the existing structure in place for the Loto shafts: each owner assigns a team to a specific section within the pit with several owners cooperating in one open cut (pit) to cover the cost of the overburden stripping operation. Assuming that each lasher moves at least 0.5 t/hour and works for the full 750 potential hours in the season, he or she will be able to excavate ore over an area of 58.6 m^2 and will advance approximately 15 m along the open cut over the season. If two lashers work each block, then a reasonable section length will be 30 m.

Spoil piles need to be re-contoured to re-establish pre-mining surface drainage patterns and to facilitate post-mining land use. As the volume of spoils material is relatively small and the strips are confined, the levelling can be achieved by using a small machine, such as a small bulldozer or a digger-loader. Both the overburden material and the waste from the sorted ore consist of weathered shale, so blending the two wastes poses no additional environmental liability. Once spoils have been recontoured, stockpiled topsoil is spread over the spoils and hand-seeded to re-establish vegetation.

This type of strip mining can also be applied in areas where underground mining has previously taken place. One of the major considerations to this would be to assess the stability of the excavator on the highwall with the underlying pillars offering sufficient support. This modified strip mining method has the potential to minimise the risks associated with the current Loto System where the threat of unwanted collapse of the underground workings is significant and potentially catastrophic. With strip mining all the ore can potentially be removed, requiring selective sorting outside of the mining area which will maximise the extraction of the gypsum ore.

The gypsum is contained within shale/weathered shale which has an anticipated *in situ* density of about 2.1 t/m^3. This would mean that approximately 356 m^3 of ore would have to be removed per hour to satisfy production requirements. Based on 4 m average ore thickness, an area of 88.9 m^2 is required to be mined per hour. The average overburden thickness is 5 m, and therefore the required rate of removal is approximately 444.6 m^3/hour or 934 tonnes/hour. The production target requires 3 excavators with 5.5 m^3 buckets. Three strips will have to be mined at any one time. The overburden stripping process can be in advance of the ore extraction process by a significant distance. The stripping operation is within the operability range of a medium-sized hydraulic excavator (such as a Caterpillar 416C back-hoe) which has a maximum digging depth of 6 m. As it would only be required for 4 months of the year, it can be contracted in for that period, together with any other smaller earth movers for post-mining recontouring of spoil piles and subsequent rehabilitation. Mobile plant should be sourced, with operators, from a mining contractor for the period of mining, as skilled operators and maintenance personnel are not available on site.

The modified strip method will require hand lashers for ore mining, manual winch operators to remove ore from the pit and sorters.

- **Sorters**: the sorters will not be affected by the change in mining method. If the same tonnage per sorter achieved in the Loto System is assumed, i.e. 56 t (ROM) per sorter per season), the proposed strip method requires 10,000 sorters.

- **Hand lashers**: can be expected to load at least 0.5 t of material per hour. The total number of lashers required is 1,500. The ore will require breaking up with picks and one person per lasher will be required for this purpose. 3,000 miners are required.
- **Winch operators**: a manual winch operator in Loto System hoists 200 t (ROM) per season (Mintek, 2005). This can be increased to 250 t or 280 t per season in a pit with few obstructions and good access ramps. 2,000 manual winch operators are required.

The total labour complement for the modified strip mining method, to achieve a saleable production of 80,000 t of ore, is conservatively estimated at 15,000 people (see Table 1). More people will need to be employed to undertake revegetation activities on the recontoured spoils, but these numbers are excluded here to ensure comparability with the current mining system, where no rehabilitation is undertaken.

Table 1 Comparison between the Loto System and the proposed modified strip mining method.

	Loto System (current production)	*Loto System (proposed production)*	*Modified Strip Mining*
Production target	45,000t	80,000 t	80,000 t
No. of Loto shafts required	2,800	5,000	-
Mining area disturbed per mining season	2.25 km^2	4.5 km^2	0.066 km^2
Mining workforce	14,000	25,000	15,000
Nature of post mining surface	Dangerous shafts, potential for future subsidence	Dangerous shafts, potential for future subsidence	Recontoured, revegetated and stabilised. Potential for future agricultural use
Potential ore extraction	25%	25%	Up to 100%

The proposed mining method not only allows a substantial increase in the rate of production, thereby reducing the country's dependence on foreign imports, but it maintains the previous levels of employment, thus preserving livelihoods. Because the production rate has nearly doubled, from 45,000 t to 80,000 t, each miner is more productive and has the potential to earn more for his or her labour. The mining footprint at any given time is smaller (although more acutely disturbed), but most importantly, this footprint can be recontoured and rehabilitated to facilitate post-mining return of the land to agriculture.

CASE STUDY 2: THE NDOLA EMERALD AREA – ZAMBIA

Introduction

Small-scale mining operations are conducted for emeralds in the Ndola Rural District, situated approximately 70 km south of the Zambian town of Kalulushi in the Copperbelt. The emerald mineralized area covers an area of approximately 1,200 km^2 (GRZ, 2004). In 2004, there were between 600 and 1,000 licensed small-scale miners. A minority is unlicensed, but the numbers are increasing and this has the potential to be a significant problem. The environmental impact of the emerald mining in the Ndola Rural District is severe. Impacts mainly take the form of land degradation, deforestation and open pits which are simply abandoned at the end of their operational life. Currently, environmental issues are the least of the government's concerns, as bread and butter issues are foregrounded.

Current Situation

There are both medium scale, small scale and artisanal operations in the Ndola Emerald Area. The medium and small operations are often characterised by a lack of planning. Pits, generally less than 30 m in depth, are started in a haphazard way without understanding the geology of the orebody[4]. When mineralised ground is discovered, the small scale miners set about accessing the ore and dumping waste material immediately adjacent to the pit in an effort to minimise the physical labour input required. This unplanned approach often results in sterilisation of the parts the ore body covered by this waste material. Even when the cost of rehandling the waste is not prohibitive, this approach is wasteful and reduces the financial capital formation resulting from the mine as the operating costs are higher than the optimum.

Pits are often created simply to chase the mineralised ground, resulting in steep highwalls without benches. Such pits are intrinsically unstable and liable to collapse, presenting a safety hazard. There is often a noticeable lack of optimisation of these pits: they have uneven benches (or none at all), uneven pit floors and sometimes require the rehandling of pre-stripped materials. Pre-stripped materials are stored in haphazard heaps around the pit periphery and are not always sorted into topsoil stockpiles and overburden heaps. The consequence of this poor pit management is that, on closure, the miner is faced with a large void with steep slopes and little topsoil or overburden material for rehabilitation. During the life of the mine, the mining footprint

[4] The emeralds are hosted in pegmatites.

remains large as little concurrent rehabilitation is possible without careful pre-mining planning. This means that impacts on hydrology and the generation of dust is maximised. Failure to carry regularly spaced benches in a pit highwall increases the likelihood of failure and represents a safety hazard. The processing of ore consists of crushing, followed by drum washing. Tailings deposits are often disturbed by ASMs invading old mined areas and reprocessing the wastes. This reprocessing is conducted by washing wastes in local rivers resulting in sedimentation.

The larger operations employ up to 200 people during periods of peak production. Lack of geological knowledge results in unexpected and unplanned mine closure. The consequence of this is large scale loss of livelihoods for the miners and substantial environmental legacies.

Mine Planning

Mine planning deals with the selection and coordination of sub-systems in a mine. This includes production capacity, workforce numbers, equipment selection, budgeting, scheduling and rehabilitation. Mine design involves the engineering design of sub-systems in the mine – loading, haulage, transportation, power, water, dust control, ground support and excavation geometry (DME, undated). Small scale miners seldom have any technical background or mining training, resulting in the problems experienced in the Ndola emerald fields.

A mine plan should be drawn up before excavation commences and should be regularly updated. A formal planning process should include the production of plans, cross-sections and longitudinal projections of the ore resource and a written description of the proposed mining work to be done. The objectives of the mine plan should be two-fold:

1. optimal exploitation of the ore reserve and
2. concurrent rehabilitation of disturbed sites with mining to ensure progress towards a defined, low maintenance future land use.

To establish an optimised pit layout, thorough geological proving of deposit is required. This requires adequate geological mapping and a drilling programme to confirm the extent of the deposit at depth. Such a programme enables the deposit to be classified into economically extractable material (reserves) and potentially extractable material in the future (resources). The optimal pit configuration to access these reserves can then be determined.

Topsoil[5] and overburden stockpiles can be sited with final pit extents in mind so that re-handling of material is avoided. Overburden stockpiles can be minimised by making use of concurrent backfilling and recontouring so that old areas of the pit are rehabilitated while new areas are being excavated. This reduces:

- the size of the mining window,
- dust pollution,
- hydrological and aesthetic impacts, and
- safety risks to people and livestock.

Concurrent recontouring and rehabilitation reduce closure impacts and promote early re-establishment of ecological function. Initial earthworks on site have the greatest potential for negative impact (DPIWE, 1999). Poorly located initial pits and access tracks become constraints for future pit layouts and must be avoided. Rehabilitation planning should commence before the site is opened. All planning should focus on a clearly defined end land use as this will reduce the cost of closure and reduce project risk. Early decisions to be made include determining the site of topsoil stockpiles, working areas and progressive rehabilitation (DPIWE, 1999). The location of existing vegetation and topography for screening to reduce noise, dust and visual impacts is important in site selection for surface infrastructure.

Ground Control

To prevent unexpected slope failures, the design methodology for pit slope angles must be appropriate for the geological, groundwater and geotechnical conditions under which the pit operates. Where operators have inherited pre-existing pits, pit walls should be re-profiled to ensure that slope angles are within acceptable limits. Designs should be reviewed on regular basis (DME, undated). Geological structures, such as faults and dykes, as well as general stratigraphy, should be described. Any hazardous conditions should be indicated on a map showing major geological features in relation to mining outlines.

Ground control entails the design and management of excavation walls to achieve the required levels of safety, serviceability, productivity and design life of the mine. Issues that need to be addressed in a ground control programme include:

- depth and life of the pit,

[5] Where such material exists.

- expected ground conditions in the pit wall,
- size, shape and orientation of the excavations,
- location of working faces and transport routes,
- potential for surface and ground water problems,
- equipment to be used, excavation methods and handling of ore,
- presence of nearby surface structures,
- potential for the public to inadvertently gain access during and post-mining and
- time dependent characteristics of the ground mass,

(DME, undated).

Safety should be engineered into mining and processing environments. This is achieved by careful design of pit highwalls and haulage routes, appropriate equipment selection and maintenance and rigorous operating procedures and training. A slope management programme should be established to prevent the failure of benches and overall slopes. This should detail strategies for ongoing stability monitoring and geotechnical mapping as well as the development of a mine hazard plan (DME, undated). The integrity of accesses and exits (such as ramps) from the pit should be protected to ensure safe access and egress in emergencies.

Physical stability hazards may be significant in both small scale and artisanal pits. These include steep slopes, unstable faces and erosion. These hazards may result in hydrological impacts and compromised safety conditions. As all pit walls have the potential for failure, an appropriate factor of safety must be built into the design. This provides a margin of conservatism in the design of the pit wall proportional to the degree of risk of failure. Minimisation of pit hazards may be achieved through re-contouring, establishment of vegetation concurrently with mining where possible, maintenance of fences and warning signs, bunding and adequate pit drainage (Sassoon, 2002). Abandonment of pits can result in significant failure of the pit walls and therefore a designated safety zone should be left around abandoned pits (UNEP, 1991).

CONCLUSION

Enhancing the contribution to sustainability of any economic activity requires a multi-disciplinary approach in which technical, economic and social factors are considered alongside biophysical factors. This type of approach is especially critical when considering activities, such as mining, which deplete non-renewable natural resources.

Historically, the mining sector has attempted to solve environmental and social problems by employing an exclusively technical approach. The resultant failure to promote sustainability has led to a general de-emphasis of such approaches, especially in NGO initiatives in the ASM sector – a sector in which social and environmental challenges are particularly acute.

In the two examples provided in this paper, it can be seen that mining engineering is a discipline that can contribute to improving the sustainability dividend generated by ASM operations. There is a need to restore the technological approach to the group of disciplines that are currently employed to improve ASM.

REFERENCES

DME (Department of Minerals and Energy) (undated) *Guideline for the Compilation of a Mandatory Code of Practice for Combat Rock Fall and Slope Instability Related Accidents in Surface Mines*, Mine Health and Safety Inspectorate, DME/7/4/118 AB4.

DPIWE (Department of Primary Industries, Water and the Environment, Tasmania) (1999) *Quarry Code of Practice, Environmental Protection*, Planning and Analytical Services Division, Hobart, Tasmania, Australia, 48 pp.

Hoadley, E.M. (2005), pers. comm., independent researcher, mariehoadley@iafrica.com

Hoadley, E.M. & D. Limpitlaw, (2004) The artisanal and small scale mining sector & sustainable livelihoods, *Small Scale Mining Conference 2004* – Book of Proceedings, Mintek Small Scale Mining Conference 2004, 9 September, Nasrec, Johannesburg, pp1-9

Mintek (2005) *Artisanal and Small-Scale Gypsum Mining Pilot Project, Report on the Initial Field Visit: Gombe State and Yobe State*, Nigeria, for the Ministry of Solid Minerals Development of the Federal Republic of Nigeria, 51 pp.

GRZ (Government of the Republic of Zambia) (2004)
http://www.mines.gov.zm/smallsca.html accessed May, 2004.

Sassoon, M. (2002) Environmental aspects of mine closure, appendix 3h, *Berlin II Guidelines for Mining and Sustainable Development*, United Nations, 52 pp & appendices.

UNEP (1991) *Environmental Aspects of Selected Non-Ferrous Metals Ore Mining – A Technical Guide*, United Nations Environment Programme: Industry and Environment Programme Activity Centre, Technical Report Series No. 5, 116 pp.