Woman resting at Azara barite operation Nazarawa State

Boy organising his game on mining site

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ning site

5. How to organise and develop an ASM site

The organisation and development of an ASM site following the discovery of a mineral deposit and the acquisition of a small scale mining lease (SSML) entails satisfying all requirements of the Nigerian Minerals and Mining Act, 2007, before the commencement of development activities needed to exploit the mineral deposit.

5.1. Satisfying statutory requirements

The statutory requirements that need to be satisfied before the commencement of development works are:

i. Submission of application and securing approval of water-use permit needed to legalise the use of water for all mining operations during the life span of the SSML
ii. Submission of environmental impact assessment studies and mitigation plans needed to minimise the negative impact of the operations on the environment to the Mines Environmental Compliance Department (MECD) and securing approval of same. These mitigation plans shall spell out how the mined-out area shall be reclaimed / restored to its initial condition or better as well as how effluents and wastes would be treated before discharge to the environment
iii. Preparing and submitting a detailed work programme to be undertaken in the SSML area to Mines Inspectorate Department (MID) for approval. This programme shall contain the production schedules of the operations, stripping ratio, pit limit, mine plan and design, mining and processing methods to be used amongst others. Copies of this report shall also be submitted to the Mining Cadastre Office (MCO) and MECD
iv. Submission of Community Development Agreement to the MECD and securing approval of same.
v. Payment of compensation to the land owners for the revocation of their rights to use the land as well as notify them and other land occupiers as to the commencement date of mining operations.
vi. Submission of copies of this notification and record of compensation payments to the MID, MCO and MECD. Submission of the environmental impact assessment statement (EIAS) to the Federal Ministry of Environment in respect of mining operations to be conducted over the SSML and securing approval of same. An approved EIAS must be submitted to MECD
vii. Arrange that a mandatory periodical operations report is prepared for submission to the MID, MCO and MECD

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viii. Organise an effective management system for tailings and other waste disposal by ensuring that all discharges to the environment are within the threshold limits as specified by Federal Environmental Protection Agency (FEPA) Act.

5.2. Mine planning and design

Mine planning refers to the process of establishing a mine and mining sequence that will result in the extraction of mineral values from the said mine in a safe and economic manner. The factors that are usually considered while planning a mine as provided by Atkinson (1983) and Hartman and Mutmansky (2002) include:

a. *Natural and geological factors:* These comprise geological conditions, ore types and grades, hydrological conditions, topography, metallurgical characteristics, climate and environmental variables of the site.
b. *Economic factors:* These comprise ore grade, ore tonnage, stripping ratio, cut-off grade, operating cost, investment cost, desired profit margin, production rate, processing and / or smelting costs, and market conditions.
c. *Technological factors:* These comprise equipment, pit slope, bench height, road grade, property lines, transportation options and pit limits.

The objective in mine planning is always to get the mineral to be produced as soon as possible without disrupting production or cash flow. In line with this thinking, Mathieson (1982) and Hartmann and Murmansky (2002) listed the following objectives:

a. Mine the best ore to generate income as early as possible
b. Maintain proper operating parameters (adequate bench width and haul roads)
c. Maintain sufficient exposure of ore to overcome miscalculations or delays in- drilling and blasting
d. Defer stripping as long as possible without constraining equipment, manpower, or the production schedule
e. Follow a logical and achievable start-up schedule (for training, equipment procurement and development etc.) that minimises the risk of delays in the initial cash flow
f. Maximise pit slopes, while maintaining reasonably low likelihood of slope failure
g. Examine the economic merits of various production rates and cut-off grades
h. Subject the favoured choice of method, equipment and pit sequence to exhaustive contingency planning before proceeding with development.

To accomplish these goals the overall economics of the deposit and its extraction are analysed using several different alternatives, namely long-range mine plan-

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ning, short-range mine planning and production scheduling.
Long-range mine planning refers to the general extraction plan for a mine with emphasis on the entire life of the mine or a major portion thereof. To accomplish this task, the mine is normally evaluated by dividing the deposit into relatively large geometric blocks and assigning values to each block based on the estimated ore grade within it. The possible extraction sequences are then analysed to provide an estimate of the overall pit limits and the gross sequence of exploitation.

Some of the technological factors that are used in pit design / optimisation are:

5.2.1. *Bench height*

This is the vertical distance between each horizontal level of the pit as shown in Fig. 5-1 below. Unless geological conditions dictate otherwise, all bench height should be of the same height which will depend on the physical characteristics of the mineral deposit; the degree of selectivity required in separating the ore and the waste with the loading equipment; the rate of production; the size and type of equipments; and the climatic conditions.

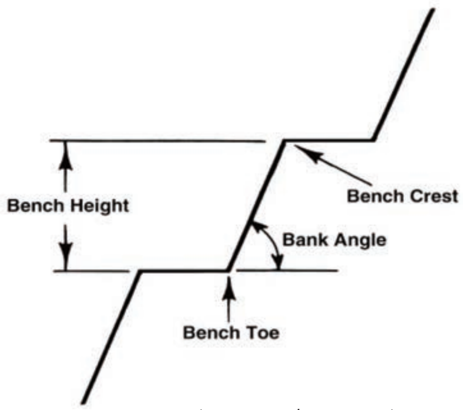

Fig. 5-1. Bench cross section (Source: Atkinson, SME, 1983)

The bench should not be too high as to present safety problems of towering banks of blasted or unblasted material. The bench height in open pit mines ranges from 1 m to as high as 15 m.

5.2.2. *Pit slopes*

The pit slope is expressed in degrees from the horizontal plane and helps in determining the amount of waste that must be moved to mine the ore. It is one of the factors that affects the size and shape of the mine pit. Rock strength, presence of water, faults, joints etc. are key factors used in evaluating the proper slope angle as they tend to change the pit slope as their conditions vary from one location to the other.

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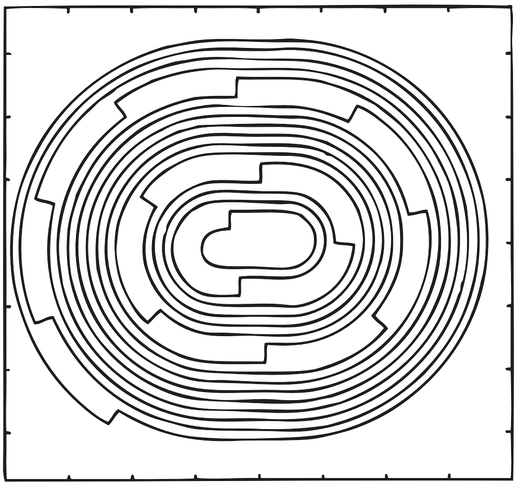

Fig. 5-2. Pit with 45 degree inter-ramp slope and a road system (Source: Atkinson, SME, 1983)

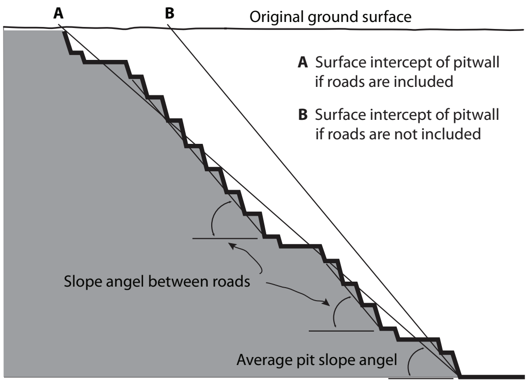

Fig. 5-3. Vertical section through a pit wall (Source: Atkinson, SME, 1983)

A pit wall needs to remain stable as long as mining activity is in that area which can only be obtained by proper slope evaluation. The pit slopes should be set as steep as possible to minimise the stripping ratio. The overall pit slope used for the construction must be flatter to allow for the road system in the ultimate pit. This will depend on the width, grade, and anticipated placement of the road.

Figure 5-2 shows a pit with 45° inter-ramp slope and a road system while Fig. 5-3 shows its vertical section. The inter-ramp angle is projected from the bottom of the pit upward to the original ground surface at point **B**. The overall pit slope angle is the angle from the toe of the bottom bench to the crest of the top bench. Point **A** shows the intercept of the overall pit slope angle with original ground surface.

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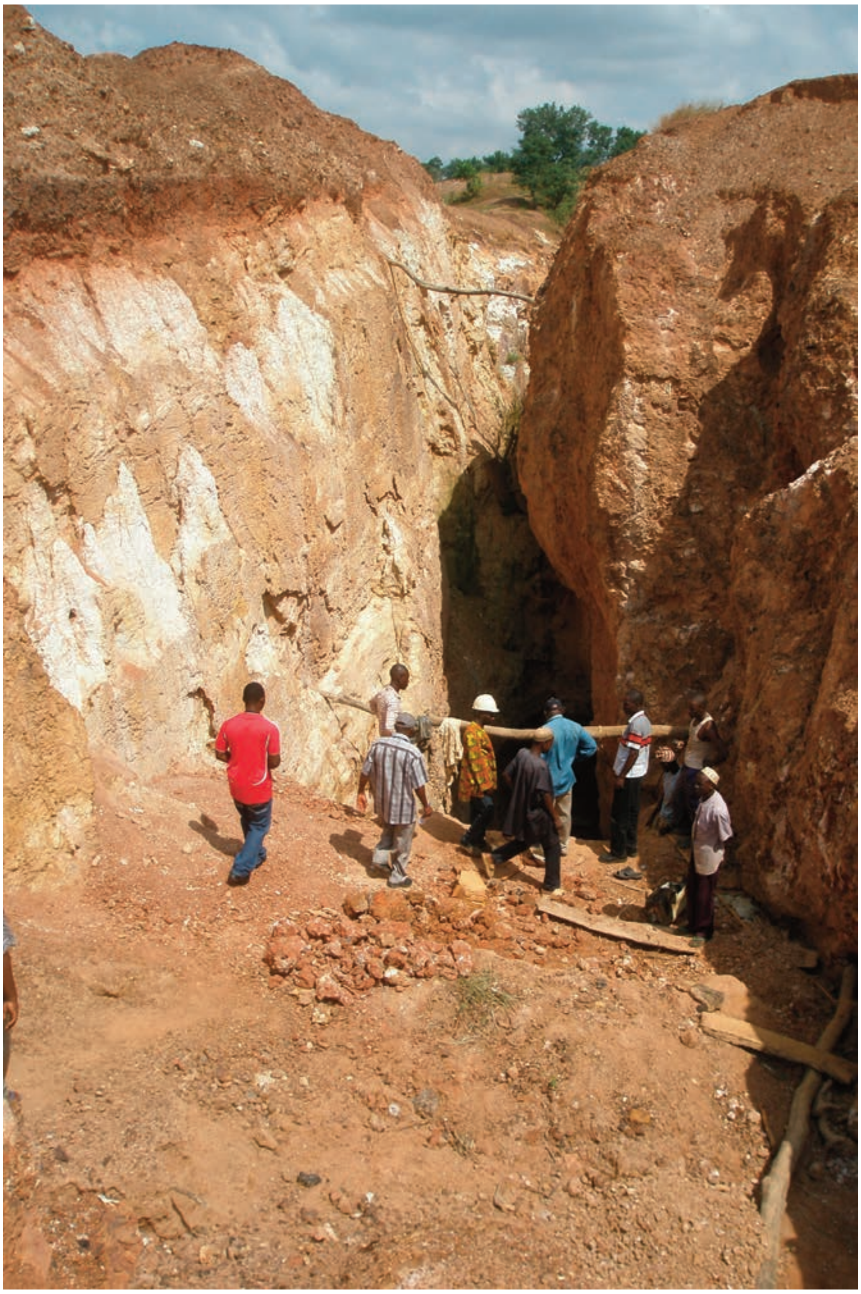

Fig. 5-4. Open pit barite mining in Azara, Nasarawa State.

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5.2.3. Cut-off grade

Cut-off grade refers to the grade of mineral ore above which it can be exploited at a profit at the prevailing conditions and below which its exploitation is not viable. For any block to be mined, it must pay for the cost of mining, processing and marketing. The grade of ore that can pay for this but not for stripping is the break-even mining cut-off grade.

In the planning stage, all direct costs of mining, milling and marketing should be taken into account. In the mining stage, the drilling, blasting, loading and hauling cost should be used. In the processing stage costs should include crushing, conveying, grinding and concentration.

5.2.4. Strip ratio

This is the ratio of the number of tonnes of waste that must be removed for one tonne of ore to be mined. The pit design will determine the tonnage of waste and ore that the pit contains. The ratio of waste and ore will give the average strip ratio for the pit, which must be higher than the break-even strip ratio. The maximum allowable stripping ratio (SRmax) used in determining the pit limits is as follows:

$$SR_{max} = \frac{\text{value of ore} - \text{production cost}}{\text{stripping cost}}$$

5.2.5. Mine ventilation

Mine ventilation refers to the provision of air into the mine in order to:

a. Provide sufficient oxygen for workers to breath
b. Ensure that the working conditions allow for work to be carried out at maximum efficiency
c. To dilute and displace gases and dusts that would otherwise contaminate the mine atmosphere.

These objectives are achieved by passing a sufficient volume of clean, fresh air into the workings via the main shaft to displace foul air caused by the presence of carbon monoxide, carbon dioxide, nitrogen oxides, methane, hydrogen sulphide and dusts that are exhausted through the ventilation shaft. The fresh air also cools the working areas and provides adequate humidity.

To cause a flow, a pressure difference must be established to overcome the mine resistance to air flow. In small mines, such ASM underground mines, this is achieved by natural ventilation pressure due to the difference in the weight of the air columns in both shafts. Larger mines mostly require an exhaust fan installed over the collar of the ventilation shaft, reinforced by booster fans placed strategically in the main mine ventilation circuit to secure adequate pressure difference.

5.2.6. Equipment selection

Mine, process and auxiliary equipment are selected based on the following factors:

a. Scheduled production rate and type of method to be used in carrying out the activity
b. Depositional characteristics of drilling equipment and mineral processing equipment
c. Initial cost of equipment
d. Operational cost as well as availability of spare parts.

The equipment that will produce the required scheduled production rate at least cost is mostly selected.

5.3. Mine development

Mine development generally refers to the work needed to be carried out in order to bring a mine to full, scheduled production. It is carried out in order to provide access to the mineral deposit, permitting entry of miners, equipment, supplies, power, water, ventilation air, as well as exits for the mineral being mined and the waste produced.

Development for surface mines entails removal of overburden (stripping) to expose the mineral value. The overburden is then placed in disposal areas for later reclamation.

Development for underground mines is generally more demanding and expensive. The principal openings may be shafts or adits to allow for the passage of workers, machines, ore, waste, air, etc. Metal mines are mostly located along steeply dipping mineralisation resulting in the need to open up the mineral from shafts, with drifts, winzes, and raises serving as production areas.

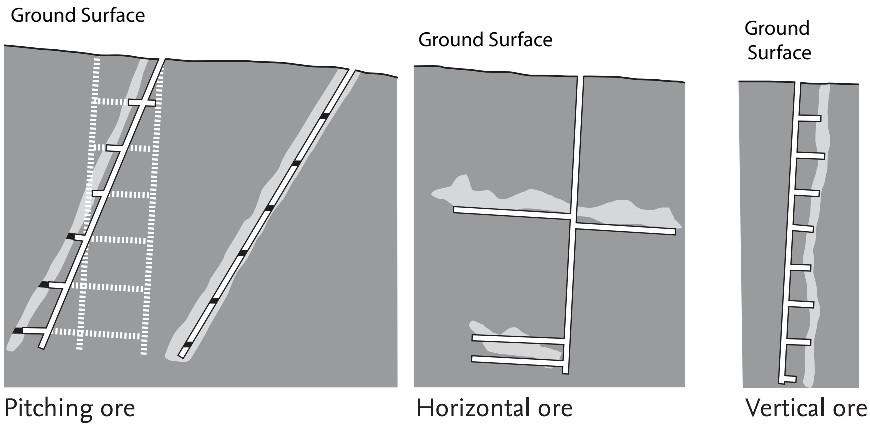

Fig. 5-5. Modes of entry (Source: Peele 1948).

Modes of entry for pitching veins, shown in Fig. 5-5, could be either a vertical shaft (**CD**) started in the hanging wall, a footwall vertical shaft (**AE**), a footwall inclined shaft (**AB**) or an inclined shaft (**GH**) in the vein. Except in the last case, crosscuts will be needed at intervals to reach the vein. A vertical shaft is the right entry for flat or vertical deposits.

Factors usually considered in mine development include the following:

a. *Locational factors*
Mineral deposits are rarely found in ideal locations resulting in geography affecting the mineral operations significantly. The following are some of the factors that are affected by location:
- Ease of transporting mineral products and supplies
- Availability of labour and support carriers
- Operational impacts of climate and weather.

b. *Natural and geological factors*
The natural setting of the mineral deposit and the geological environment govern many key aspects of mine development especially access openings and surface plant location. The most important factors in this category include:
- Topography
- Spatial relation of the mineral deposit (size, shape, depth, etc.)
- Geologic consideration (mineralogy, structure of ore, etc.
- Rock mechanics properties
- Chemical and metallurgical properties of the mineral deposit.

Fig. 5-6. ASM operators using a winch to raise material from a deep-shaft operation.

c. *Social – economic – political – environmental factors*

These factors exercise a disproportionate influence on both the development and operations of the mine. They mostly comprise:

- Demographic and occupational skills of the local population which will decide on whether to bring in workers from outside host community or not
- Means of financing or marketing which determine the scale and continuity of the operations
- Political situation and level of security in and around the mineral deposit area
- Environmental legislation.

5.3.1. Sequence of mine development

The steps usually carried out during mine development for both surface and underground mines after the acquisition of land and mineral rights are as follows:

- Adoption of the feasibility report as a planning document subject to modification as the project is developed and mined
- Confirmation of mining methods and general sequence of mining including

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the initial choice of equipment types and size of workforce
- Arrangement of financing based on confirmation of ore reserves and cost estimates by independent assessors
- Erection of mineral processing plant, if required and mineral handling and shipment facilities as well as preparation of stockpiling and waste disposal facilities. These items should be located in areas that would not in any way disrupt mineral extraction activities
- Acquisition of mining equipment for development and exploitation
- Construction of main opening to the mineral body in underground mining or advanced stripping in surface mining to provide direct access to the ore zone.

5.3.2. Mine exploitation

Mine exploitation is a stage of mining that is associated with the actual recovery of mineral ores from their natural habitat. The methods used in mineral extraction fall into two broad categories, namely surface and underground mining methods. Surface mining includes mechanical excavation methods such as open pit and open cast (strip mining), and aqueous methods such as placer and solution mining. Underground mining is the type of excavation that is carried out underground and is usually classified into three categories: unsupported, supported and caving. A detailed breakdown of the various types of mining methods is given below.

Classification of mining methods used by ASM

CATEGORY	CLASS	SUBCLASS	METHOD	COMMODITY
Surface	Mechanical	-	1. Open pit mining*	Metallic
			2. Quarrying	Non-metallic
			3. Open cast (strip) mining*	Coal, non-metallic
			4. Auger mining	Coal
	Aqueous	Placer	Hydraulicking	Metallic, non-metallic
			Dredging	Metallic, non-metallic
		Solution	Borehole mining	Non-metallic
			Leaching*	Metallic
Underground	Unsupported	-	Room and pillar mining*	Metallic, non-metallic

*Asterisks indicate the most important and commonly used methods

5.3.3. *Guidelines and procedure for selecting mining methods*

Factors that are used or considered in reviewing the mining methods for suitability in ASM exploitation of a given ore deposit are listed below:

- Spatial characteristic of the deposit such as depth from the surface, size, shape, dip, etc.
- Geological and hydrological conditions such as mineralogy, petrography and chemical composition
- Geotechnical properties such as ore and surrounding rock strength, etc.
- Health and safety aspects associated with the mining methods.

The procedure of selecting a suitable mining method involves eliminating methods that are not suitable for the deposit at hand using the factors listed above.

Findings by Nilsson (1992) arising from works carried out are also used as guides in selecting suitable mining methods. The said findings are:

- That in a buried horizontal deposit, mining of the deposit will be optimised by using either surface method or underground method but not using both
- That for a steeply dipping vein or massive deposit that outcrops on the surface and extends to depth, the optimum strategy would be to mine first using surface methods, then switch to underground method
- The point at which surface mining should be switched to the underground mining method is normally reached when the surface mining cost reaches the underground mining cost, if ore production rates do not change at that point.

The decision to use either the surface method or the underground method for buried horizontal deposit will normally be made by a simple cost comparison between the surface method and the underground method. However, for steeply dipping deposit that extend to depth, the analysis of the strategy would involve both surface and underground mining costs as well as a thorough analysis of the optimum point of switching from surface to underground. Social and environmental considerations also play a great role in the final decision.

5.4. Reclamation

The desire to carry out mineral development and exploitation in a sustainable manner leads mine planners into planning for mine closure before the first tonne of ore is mined. Planning for reclamation mostly entails designing a mine that is

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safe in all ramifications, i.e. to say all threats to life and the environment are completely taken care of by ensuring that safe mining methods are used with waste and effluents adequately monitored and treated before discharge or stockpiling. Adequate plans for mine closure are also made to reclaim the mine site restoring it to what is was before the commencement of mining operations or put to other more useful use.

The above considerations form an integrated part of Mining Operation Plan, which has to be submitted to MMSD, see the following page.

FEDERAL REPUBLIC OF NIGERIA
MINISTRY OF MINES AND STEEL DEVELOPMENT
The Nigerian Mineral and Mining Act 2007
REGULATION 108 (6) (c)

MINING OPERATION PLAN

1. Name of mineral title holder
2. Number of mineral title
3. Location of title
4. Address of mineral title holder
5. Name and qualification(s) of technical manager
6. Establishment of acceptable stripping ratio and definition of shape of the excavation and limits of surface mining
7. Development and maintenance of access for equipment
8. Opening up working faces to ensure quality deposits that can furnish required grades at all times
9. Determination of sidewall slope angle
10. Location and gradient of access roads
11. Height of working faces
12. Surface and groundwater control
13. Mine design
14. Mine development plan
15. Mineral production plan
16. Mineral beneficiation plan
17. Mine restoration, reclamation and rehabilitation plan
18. Mine health and safety scheme
19. Mine tailings and waste disposal plan
20. Mine closure plan

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Photo shows use of sluice, *see figure on page 71*

6. Mineral processing

Mineral processing by ASM operators is mostly carried out on a low technological level. At rush mining sites the incentive for ASM operators to invest money in better extraction equipment is often limited. At more permanent mining sites some of the miners are interested in obtaining higher recovery and they invest in better equipment. These miners will often copy extraction equipment which they have seen in other mining sites.

New methods spread slowly, even sometimes very slowly from site to site. There is often a tendency to conservatism among ASM operators. When they have used a certain method for decades they are reluctant to change to new methods. One convincing argument in support of adopting a new method is the prospect of increased earnings. A detailed description of advanced technical equipment for mineral processing is given in Appendix A.

The major metallic and non-metallic minerals (industrial) that are currently exploited in Nigeria by the ASM are listed below with details of processing methods:

Metals/metallic minerals

1. Gold
2. Tantalum ore (Tantalite)
3. Lead, zinc and copper ores
4. Cassiterite (tin ore)

Industrial Minerals

1. Barite
2. Bentonite
3. Gypsum
4. Diatomite
5. Kaolin
6. Calcium carbonate
7. Dimension stone

Gemstones

6.1. Metals/metallic minerals

6.1.1. Gold

Gold is used in jewellery, for coins, dentistry etc.

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Flowchart 1. Gold extraction using mercury.

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ASM operators mostly extract gold from auriferous quartz veins. Gold grades vary from a few grams up to several hundred grams of gold per tonne. It is thus necessary to mine and treat large amounts of ore in order to extract just a little gold.

The most commonly used gold extraction process is outlined in Flowchart 1.

When the quartz-gold ore has been mined and hoisted to the surface it is crushed down to pebble size. This is often done manually with a hammer (see flowchart). However, in some small-scale mining communities some miners have invested in a jaw crusher, which can do the job in minutes instead of hours. The advantage with a jaw crusher is not only that it is works faster, but it also reduces accidents.

The next step is grinding or milling. This is done in ball or rod mills and can be wet or dry grinding (Flowchart 1). Wet grinding is preferable since it reduces dust emission and makes less noise.

After this come sluicing (Flowchart 1). There are probably as many types of sluices as there are miners and they are not all very efficient (Fig. 6-1-A). If the sluice is not built properly it does not work properly. Fortunately, it does not require very sophisticated materials to improve the sluices, but several pitfalls may result in a reduction of gold recovery, such as using the wrong construction or wrong material.

There are a few parameters which are crucial for obtaining a high recovery:

1. **A constant water flow:** Many ASM operators are not aware that the water flow in a sluice shall be constant. They throw a bucket of water in the sluice, let that drain and then the next bucket is thrown into the sluice. To separate heavy minerals from light minerals in the best possible way, it is vital that the water flow is constant. This can be done easily with a half 200 l drum placed immediately above the sluice as shown in Fig. 6-1-B. The velocity of the water flow is also important and trial and error will show the best speed for that particular sluice and type of ore.

2. **Textile material suitable for catching heavy minerals:** The sluice is covered by a piece of cloth which will catch the heavy minerals. Often ASM operators use old sacks, but this type of cloth is not the best. It is possible to increase gold recovery several times by using other types of cloth, e.g. felt has proved to be a very efficient gold catcher in sluices.

Fig. 6-1-A. A very primitive sluice where buckets of water are thrown on the upper part of the sluice. The result is that many of the heavy mineral grains (gold or tantalite) will be washed out of the sluice and get lost at Tongakura, Kogi State.

3. **The inclination of the sluice:** The inclination of the sluice must be adjustable to be able to find the inclination which yields the best gold recovery with this particular ore. The sluices are mostly in the order of a couple of metres long.

4. **A uniform grain size:** The grain size shall be as uniform as possible. The less uniform the poorer the recovery of gold. This is a question of milling. The longer the milling the more uniform the milled ore is. However, too much milling may cause the gold particles to be smeared on the inner wall of the drum preventing its recovery.

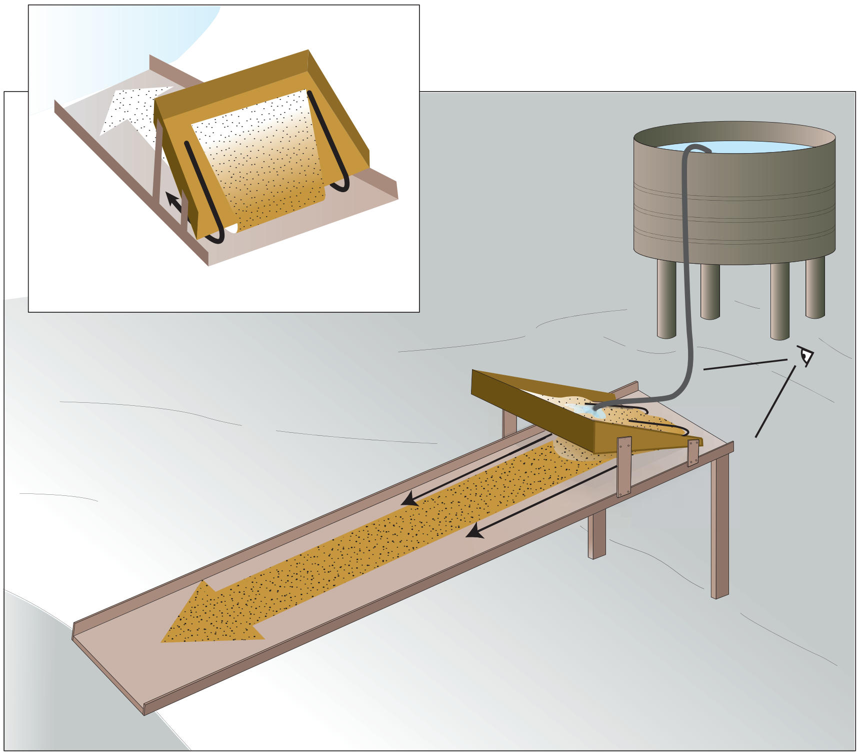

Fig. 6-1-B. The ideal sluice. The tailings are gradually flushed down the sluice with a constant water flow. This simple construction will increase recovery of heavy minerals several times compared with a sluice where the water is flushed down from buckets of water.

The first steps in gold extraction work as follows (Flowchart 1). After milling, the finely milled ore is placed in the box on top of the sluice. With the hose water is gently flushed down on the upper part of the sluice and the ore runs down the sluice. The heavy particles including gold are caught by the cloth on the upper part of the sluice. The lighter particles are flushed further down. Some are captured by the cloth further down and the rest ends in a small dam at the foot of the sluice. The water flow and the inclination must be properly adjuster so only the heavy particles are captured in the uppermost part of the cloth.

When all the milled ore has been flushed down the sluice then the cloth is washed in a large bucket of water (Flowchart 1). The heavy particles then rest at the bottom of the bucket. They are then scooped into a gold diggers pan (Flowchart 1). In the pan the heavy minerals are further concentrated. A skilled ASM operator can make an almost pure gold concentrate with that pan, as the ASM operators in Igila in the Osun state proved. Unfortunately, very few ASM operators worldwide have the skill or patience to make a good gold concentrate with a gold digger's pan. Most use mercury to extract gold from the heavy mineral concentrate. It is not known how widespread the use of mercury is among ASM operators in Nigeria, but there is no doubt that the use of mercury will increase rapidly as seen in many other countries in Africa. It is therefore appropriate to present a fairly detailed description of how to extract gold with mercury below, and how to reduce the health and environmental problems.

6.1.1.1. Amalgamation

Amalgam is gold 'dissolved' in mercury. Amalgamation is a gold extraction technique that has been used by ASM operators for thousands of years. Today, millions of ASM operators use amalgamation every day and the number is swiftly increasing resulting in serious damage to the environment and to mankind.

Amalgamation is a very easy to learn and inexpensive gold extraction method for ASM operators. The method is not used by large-scale mining companies. In its simplest form, mercury is added to a heavy mineral concentrate. The mercury is thoroughly mixed by hand with the heavy mineral concentrate (Flowchart 1). The result is that all gold grains and flakes 'dissolve' in the mercury as an amalgam. The mercury with the amalgam, recovered from the heavy mineral concentrate, is squeezed through a small piece of cloth. This process leaves the amalgam, which has a pasty texture, in the cloth, whereas the clean mercury sprinkles through the cloth and can be recovered for later use. The amalgam is then put into an iron cup which is placed in a fire (Flowchart 1). The mercury evaporates and leaves the gold behind. It is not all mercury that evaporates. Some of the mer-

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Fig. 6-2. Two retorts made of a few pieces of plumbing tubes. The scale is 10 cm.

Fig. 6-3. The amalgam is placed in the cup of the retort on some ash to get the cup airtight.

Fig. 6-4. The retort with amalgam in the cup is heated in a charcoal burner.

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Fig. 6-5. Most of the mercury has evaporated and the gold is left behind.

cury is still trapped, giving the gold a pale yellow colour. This pale gold is sold to gold buyers who melt the gold with borax (see below) and thereby drive off the remaining mercury, leaving a nice warm yellow-coloured gold.

The amalgamation method has its serious drawbacks. It is highly toxic to most forms of life (see Chapter 7). Fortunately methods to reduce the amount of mercury released into the environment do exist. One method is to use a so-called retort, which is a simple device constructed to distil mercury. The retort is fairly widespread in South America.

In its simplest form, the retort consists of a few pieces of plumbing tube which can be manufactured by most local black smiths (Fig. 6-2). The procedure is as follows. The amalgam is placed in the small cup which is then tightly screwed on to the rest of the retort (Fig. 6-3). The 'head' of the retort is then placed in a charcoal burner (Fig. 6-4). Air is blown on the charcoal in order to increase the temperature. The end of the tube is placed in a small bowl with water. After some time air starts to bubble out of the end of the tube. After prolonged heating and gentle tapping on the tube, small drops of mercury run out of the tube into the water bowl. After 15 to 20 minutes of heating, the retort is removed from the charcoal burner and is allowed to cool slowly. When the retort has cooled, the cup can be opened and the gold be removed (Fig. 6-5).

Advantage of using the retort: The use of retorts reduces the release of mercury by more than 90%.

Disadvantage of using the retort: It takes 10 to 15 minutes longer than direct evaporation of mercury. This may not seem important, but it is an argument many

ASM operators put forward. It has also been argued that ASM operators fear that they loose gold because they cannot see what happens inside the retort. This prompted UNIDO and other donors to produce retorts of fire proof glass. The problem with the glass retorts is that they cost about US$ 500 and they are very fragile. However, experience tells us that if the ASM operators get a proper explanation they will no longer believe that gold disappears in the retort.

6.1.1.2. Borax

An alternative to using mercury is the so-called borax method. The idea of using borax by ASM operators was born more than thirty years ago in the Philippines, where it presently is used by around fifteen thousand ASM operators. The borax method was recently tested in Ghana through an EU-financed project with good results. The method is simple, easy to learn and does not require purchasing expensive equipment. Borax is a chemical with the formula $Na_2[B_4O_5(OH)_4] \cdot 8H_2O$, which occurs in nature as evaporite deposits. It is environmentally benign, and it is cheaper than mercury. Borax is used by gold dealers to purify the gold they buy from ASM operators.

The method is outlined in Flowchart 2. The first four steps in this method are the same as on Flowchart 1. The ASM operators use a gold digger's pan to produce a very good gold concentrate (Flowchart 2). The concentrate is mixed with borax and a few drops of water in a small plastic bag or piece of plastic. The plastic bag is placed in a pre-heated, borax-cleaned clay bowl together with burning pieces of charcoal. Vigorous blowing increases the temperature and after some time the borax melts and so do all the heavy minerals including the gold. The small droplets of molten gold sink to the bottom and unite to a larger drop of gold (Flowchart 2) which is recovered by the tip of a knife.

6.1.1.3. How can a small-scale gold miner be convinced to use borax instead of mercury?

There are obviously the environmental and health arguments. However, not all miners are willing to embark on new methods in order to save the environment and their health. Arguments put forward saying that they save money because borax is cheaper than mercury will not convince them. The prices of both commodities are negligible compared to the value of the gold they recover. Gold recovered by the borax method does not contain mercury and will thus fetch a higher price than gold recovered by amalgamation. The price difference is probably not enough to motivate the miners to swap extraction methods.

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Flowchart 2. Gold extraction using borax.

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The most convincing argument is gold recovery. It can be demonstrated that gold extraction using amalgamation result in significant loss of mercury. The explanation is as follows: Most ASM run the tailings through the gold extraction process again and again. Some of them run the tailings through the mill up to ten times in order to extract all the gold. The problem is that a good deal of the mercury is not recovered and will thus be milled. In the mill, mercury will repeatedly be pounded by the hard metal balls and therefore be transformed into what is called mercury flour. Mercury flour is extremely fine mercury particles which have lost the capability to coalesce. Mercury flour cannot be recovered by the ASM and neither can the gold hosted in the mercury flour. It is thus a substantial amount of gold which is lost in mercury flour. Analyses of gold in tailings in Tanzania, which have been through the milling many times, show gold values of more than 50 gram per tonne.

By using borax the ASM may increase their gold recovery significantly as well as reducing the negative impact on the environment and their health. This is what is called a win-win situation.

6.1.1.4. Cyanide gold extraction

Cyanide gold extraction is normally done by large-scale mining companies. There are however, ASM operators who successfully carry out cyanide gold extraction mainly as a second step where tailings are treated in order to recover gold which has not been recovered by other processes. Two types are carried out by ASM operators in order to extract gold from their tailings.

It must be emphasised that cyanide is a very toxic chemical which kills fast. However, a cyanide spill is neutralised fast when exposed to the atmosphere and the sun.

Heap leaching. A heavy-duty rubber or plastic tarpaulin is placed on the ground. A layer of tailings is placed on the tarpaulin. The tailings are slowly sprinkled with a cyanide solution. The set-up is covered by a tarpaulin in order to reduce evaporation (Fig. 6-6). The solution gradually penetrates the heap of tailings and underway it dissolves the gold. The so-called pregnant brines are tapped from the bottom. The brine is placed in a container and mixed with active carbon. Gold is precipitated on the active carbon. The carbon is burned. The ash is mixed with borax in a 30% or more ratio (the higher percentage of borax the easier it is to melt) and is cooked in a blower.

Fig. 6-6. Heap leaching a pile of tailings with cyanide. The plant is sheltered by a blue tarpaulin to reduce evaporation of the cyanide.

Active leaching of tailings. The tailings are mixed with water in the ratio 40% tailings to 60% water. Lime is added to keep the solution alkaline. Cyanide is added and the solution is kept for up to 100 hours depending on the type of ore. Then active carbon is added and the mixture is stirred for a couple of days (Fig. 6-7). The carbon is recovered by filtering. The loaded carbon is placed in a pressurised burner and boiled with cyanide and caustic soda for several hours. It is treated in an electro-winning process using steel wool. The gold will plate the steel wool which will then be digested in nitric acid. The resulting gold dust will then be cooked with borax.

6.1.1.5. The Igoli mercury-free gold extraction process

The Igoli process (Flowchart 3), developed by MINTEK, uses chlorine, which is present in chemicals such as bleach (NaOCl) and hydrochloric acid (HCl), to extract gold from concentrates. It has already been successfully used by small-scale miners in Tanzania. Instead of poisonous products such as mercury being discharged into the environment, the chlorine is converted to a harmless salt. The process entails producing a pre-concentrate using a screen mesh (to remove

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Fig. 6-7. Active leaching of tailings by cyanide. A tank containing a cyanide tailings mixture which is slowly stirred.

boulders) and strake (sluice) which is then leached using bleach and hydrochloric acid. The leached gold is precipitated using sodium meta-bisulphate to produce gold in powdered form that is pressed to produce a gold disc.

The Igoli process has an advantage in the treatment of refractory ores. It is an environmentally friendly and efficient method to extract gold even from these ores. The income of the miner is increased in this way, and his health and the environment protected.

The strake (sluice) is a flat channel with walls on each side. The bottom of the channel has a rubber mat glued to it. The mat has grooves which are in the shape of the teeth on a wood saw. The teeth must have the perpendicular side facing

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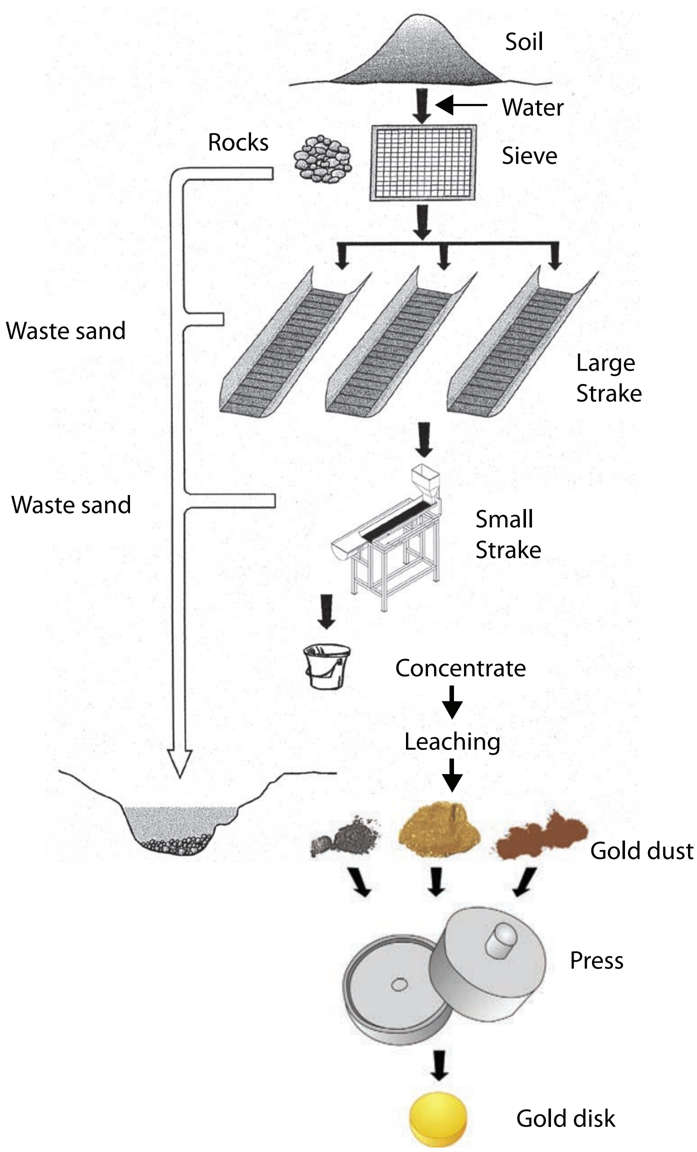

Flowchart 3. The Igoli Mercury–free gold extraction method. (Modified from Mintek, April 2006).

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downstream. The strake is set at an angle so that a stream of pulp containing the fine gold ore or sand will flow downwards. The walls prevent the mixture from spilling. The strake has hinges on one side so that it can be tilted to wash the concentrate into the gutter on its side. This in turn directs the concentrate into a drum or bucket.

The gold concentrate is subsequently boiled in a solution of hydrochloric acid, sodium hypochlorite and sodium metabisulphate.

6.1.1.6. Advantages and disadvantages of the described gold extraction methods

The amalgamation process

Advantages are:
- It is easy to learn and to carry out
- It does not require investment in equipment
- Mercury is easy to handle

Disadvantages are:
- Long term toxicity
- Low recovery of gold

The borax process

Advantages are:
- It is easy to learn and to carry out
- It does not require investment in equipment
- High gold recovery
- Borax as a powder is easy to transport
- Borax is environmentally benign

Disadvantages are:
- Borax is not readily available in villages

The cyanide process

Advantages are:
- Can recover gold from tailings
- As heap leaching it is not labour intensive
- Toxicity is very short lived

Disadvantages are:
- It is highly toxic and requires utmost care

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- Requires substantial investment
- Cyanide is difficult to transport and to get hold of in villages

The Igoli process
Advantages are:
- Can recover gold from complex ore
- No long-term toxicity

Disadvantages are:
- The chemical ingredients are not readily available in local communities
- The chemical ingredients bleach and hydrochloric acids are strongly etching
- Requires substantial investment in technical equipment

6.1.2. Tantalum

Tantalum is a heavy metal occurring in the mineral tantalite. It is used in electronics components such as mobile phones, as alloys in plates and pins for orthopedic surgery.

Tantalite is presently only extracted by ASM operators from soil overlying hard rock tantalum occurrences and from river sand and gravel. Sluicing is an efficient method to concentrate tantalite. The recovery rate of the sluices used today is, however, very poor. Sluices along the same lines as described above should be constructed. When a proper concentrate has been made, there will be many black minerals in the concentrate, mostly magnetite. A simple way to get rid of the magnetite and to produce a cleaner tantalite concentrate is to use a small hand magnet, which removes the magnetite.

6.1.3. Lead, zinc and copper

The lead, zinc and copper minerals are the sources from which these metals are extracted. They are often intergrown, which makes it impossible for ASM operators to separate them. It is thus in general very difficult for the miners to process the minerals apart from handpicking the best samples and knock off the non-paying minerals such as quartz.

The sluice can be used after crushing / grinding to produce a high grade composite concentrate of lead, zinc and copper sulphides. The ASM operators can further separate this composite concentrate into various fractions of lead, zinc and copper sulphide concentrates using froth flotation. Froth separation, however,

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requires substantial financial investment and much technical knowledge.

Lead is used in the manufacture of batteries, corrosion resistant pipes and linings, alloys, pigments and in radiation shielding.

Zinc is used as:
a. Corrosion protective coatings on iron and steel ('galvanising')
b. An important alloying metal in brass and zinc die-castings
c. A raw material for producing corrosion-resistant paints, pigments and fillers.

Copper is used where high electrical or thermal conductivity is important. It is also used in a variety of alloys, brass, bronze and aluminium bronze.

6.1.4. Tin

Tin is mainly used as tin-plate in e.g. cans. It is also used to produce various alloys such as solders, bearing-metals, bronze, type-metal and pewter.

It is exclusively extracted from tin ore (cassiterite) predominantly mined from placer deposits. The mineral which is weathered out of granite is concentrated in rivers at placers where the river is slow running. The lighter minerals from the granite is washed further down the river leaving the heavy cassiterite mineral in the river bed along with other heavy minerals such as magnetite, ilmenite, tantalite and columbite.

The heavy mineral assemblage made of cassiterite and its associated minerals need to be processed before the ASM operators can obtain a concentrate which they can sell. The cassiterite- rich sand is screened. The next step involves sluicing. Jigs can also be used.

6.2. Industrial minerals

The main industrial minerals exploited in Nigeria by artisanal miners and ASM operators are barite, bentonite, gypsum, diatomite, kaolin, calcium carbonate and dimension stone. There are only a few things that ASM operators can do to process these minerals, and thereby add value to their commodities. Processing and adding value to industrial minerals are mainly done on commercial plants. Current processing practices applied to some industrial minerals are outlined below.

6.2.1. Barite

Barite is a heavy mineral composed of barium sulphate that is mostly used as a weighting agent in oil and gas drilling. It is also used in the manufacture of chemicals and glass and as a pigment, filler, etc. It has a theoretical s.g. (specific gravity) of 4.5, but the presence of impurities or inclusions usually lower this to about 4.2–4.35. It is relatively soft with mohs hardness of 3 to 3.5.

It is inert, non-toxic with quartz, iron minerals and calcium carbonate, as its major impurities.

The processing method adopted usually depends on the type of product to be produced. The specifications for the various barite products are listed in Table 6-1.

Barite processing usually starts with sorting in the field to produce high grade barite or jigging after crushing to produce a concentrate containing predominantly barite with the gangue removed as tailings.

Run-of-mine (ROM) material is generally stockpiled according to specific gravity (s.g.) ranges of 4.00–4.09; 4.10–4.14; 4.15–4.19; 4.20–4.24; 4.25–4.29; 4.30 and above. The various ranges are crushed separately to 100% passing 10 mm and are then jigged or stockpiled. The products produced are then blended to specific gravity requirement before grinding.

Usage	Form (size)	$BaSO_4$	Specific gravity (s.g.)	Fe_2O_3
Weighting agent in oil and gas drilling	-75 µm with an allowance of 3% max.	90%	4.20 (API) but can vary depending on user.	NA
Glass making	100% passing 1.19 mm with 5 – 40% -149 µm fraction	97%	NA	0.15%
Filler for rubber, paint and urethanes	100% passing 44 µm			
Pigment	100% passing 44 µm	94% min.	NA	0.05% max .
Barium Chemicals	840 –16000 µm	95% min.	NA	1% (combined Fe)

Table 6-1: Specification of barite products. Source: Carr 1994.

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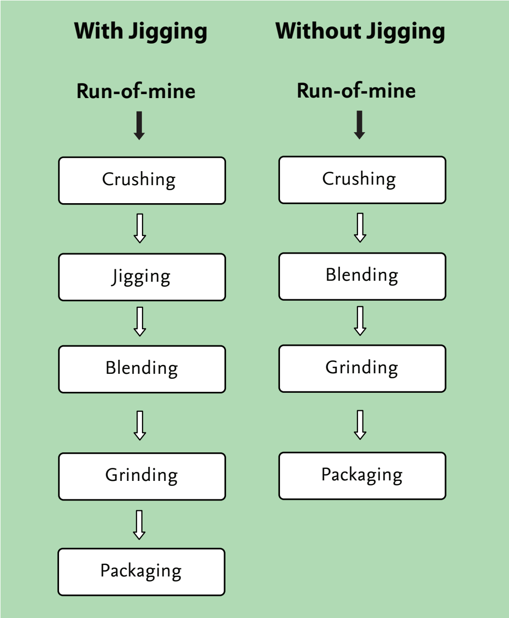
The specific gravity of barite is usually determined by the Le Chatelier flask method as prescribed by the American Petroleum Institute (API), by the density bottle method or the air pycnometer method.

Barite milling entails dry grinding of blended crushed barite to minus 75 μm sieve size with samples of milled barite taken periodically for s.g. determination and sieve analysis to ensure that the product meets the required specifications. Simplified barite processing is shown in Flowchart 4.



Flowchart 4. Barite processing.

Blending usually entails mixing various proportions of low and high s.g. fractions to obtain a required s.g. mix. The right quantities to be mixed are determined using the expression:

required s.g.= $(Q_L{*}s.g_L + Q_H{*}s.g_H)/(Q_L+Q_H)$

where: Q_L is the quantity of the low s.g. fraction used
Q_H is the quantity of the high s.g. fraction used
$s.g_L$ is the s.g. of low s.g. fraction used
$s.g_H$ is the s.g. of the high s.g. fraction used.

The product obtained after mixing is then sampled and tested to confirm the s.g. before grinding.

6.2.2. Bentonite

Bentonite is a hydrous aluminium silicate composed of the clay mineral, smectite (montmorillonite).

It is used to control the viscosity of drilling fluids. It is also used as binder in foundry sand bond and for iron-ore pelletising. There are two types, Na and Ca

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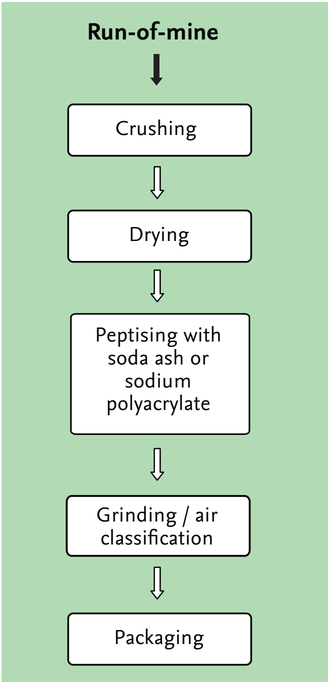

Flowchart 5. Bentonite processing.

bentonite with the sodium bentonite being the most preferred because it swells more and provides better viscosity.

The Nigerian bentonite is mostly the Ca-type with gypsum, quartz and mica as its major contaminants.

Ca-bentonite is mostly peptised using sodium carbonate or sodium polyacrylate and then milled to achieve the proper mixing.

The quality of the product produced is controlled by periodic sampling and testing for fineness of grind as well as the viscosity.

Simplified bentonite processing is shown in Flowchart 5.

6.2.3. Gypsum

Gypsum is the dihydrate form of calcium sulphate ($CaSO_4.2H_2O$). It is found in association with anhydrite, the anhydrous form of calcium sulphate and shale, etc. While gypsum has a s.g. of about 2.3 and a hardness of 2.0 (Mohs Scale), the anhydrite has a s.g. of about 2.85 and a hardness of about 3.25.

Calcium sulphate is one of the principal constituents of evaporite deposits. When pure, gypsum has 32.6% CaO with 20.9% combined water while the anhydrite has 41.2% CaO with 0% combined water. Gypsum is used in:

i. Calcined form to produce plaster of Paris (POP), which when mixed with water, can be made into many varieties of plasters, wallboard and moulds.
ii. Raw form to produce Portland cement, condition soil for agricultural purposes, and to produce mineral filler.

Gypsum processing as practiced by ASM operators comprises the following (Figs 6-8 to 6-11):

i. Sorting (manually) /forking to lower the shale content to about 30% in line with cement company specs for local gypsum;

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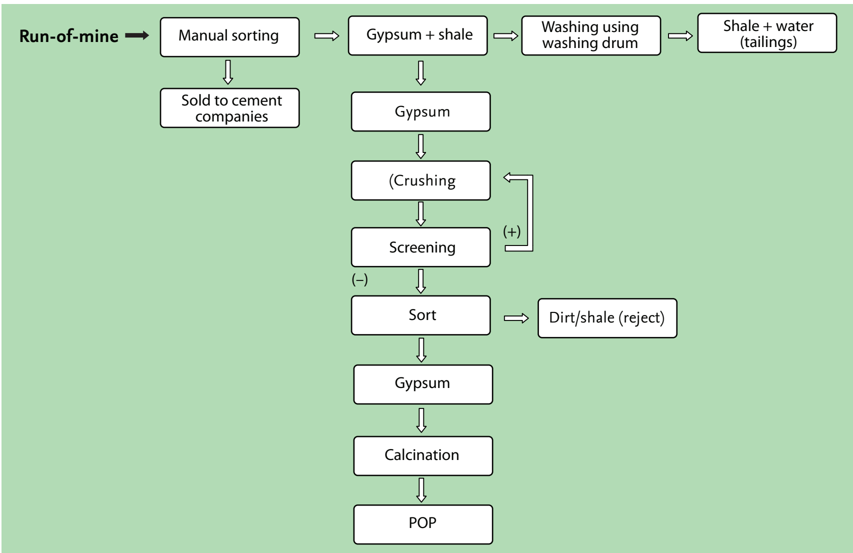
Figs 6-8 to 6-11. Gypsum pit with shale, washing and calcination by ASM operators, Yobe State.



Flowchart 6. Gypsum Processing.

ii. Washing and screening in ponds to produce clean gypsum needed for POP production.

POP production is carried out by crushing washed gypsum, screening, sorting, and calcining in open frying pans (Flowchart 6).

The current practice results in:

a. Inadequate removal of shale content
b. Use of intensive manual labour for sorting, forking and washing in ponds
c. Production of low grade POP due to lack of temperature control resulting in the production of some dead burnt gypsum or insoluble anhydrite that do not take water at any appreciable rate
d. Improper handling of wastes.

The way to optimise this process is:

a. To use a washing drum to scrub and separate slurrified shale from the gypsum thereby lowering the shale content with ease
b. To provide a sump for collecting shale + water (slurry) which would be allowed to settle with the clarified water reused for washing
c. Use a temperature-regulated kettle or rotating kiln with the temperature set at the appropriate calcination temperature of about 150°C.

6.2.4. Diatomite

Diatomite is a very light rock with a density of about 320 to 545 kg/m^3. It is soft with a chalky appearance.

Its colour varies from snow-white in a pure, well-bleached and dry deposit, to olive-green or darker where substantial organic remains are still present and where the moisture content is high. It exhibits stratification, caused by either, or both, sedimentation of particularly flat beds or a large number of disc-shaped diatoms, or by seasonal, rhythmic deposition of clay and other impurities.

Diatomite is used in filler and filter applications where the diatomaceous silica remains inert. The fine particulate structure of the diatom skeleton imparts low density, high surface area to milled powders resulting in the provision of high porosity, permeability and clarifying ability required in fil- tration applications. It also imparts absorption capability as well as low thermal conductivity.

Diatomite is processed either by direct milling of the run-of-mine followed by classification or calcination of the run-of-mine (with or without flux addition) followed by milling and classification to produce coarse and fine fractions sold as, respectively, filter aids and filler grades.

Calcination without flux addition is carried out between 870-1100°C with flux cal-

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Type	Colour	Density, pcf* Dry	Wet	Screen analysis % retained, 106 µm	pH	Median pore size, µm	Permeability, d'Arcy	Typical applications filtration
Natural	Gray	7.0	16	2.0	7.0	1.5	0.057	Vegetable oil
Calcined	Pink	8.0	18	4	7.0	3.5	0.28	Beer and wine
Flux calcined	White	9.5	18	9	10.0	10.0	2.0	Industrial and portable water

* pounds per cubic foot

Table 6-2.Typical physical properties of processed diatomite products used as filter aids. (Modified from: Carr 1994)

Physical properties	Paper	Paint (semi-gloss)	Conditioning agent (toxicant carrier)
Loose wet, pcf*	8.0	8.5	8.0
Wet density, pcf*	20	22	24
Moisture content % max.	6.0	0.5	6.0
Retained on 106 µm, wt%	0.5	Trace	Trace
Retained on 75 µm, wt%	8.0	Trace	0.5
Colour	Light grey	White	Buff
pH max.	7.0	10	7.0
Refractive index	1.40	1.46	1.43
Oil absorption	210	105	175
Surface area, m/g	10–20	0.7–3.5	10–20

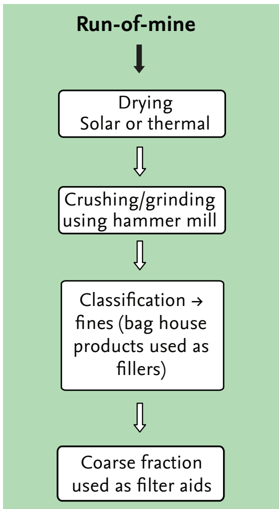
* pounds per cubic foot

Table 6-3.Typical physical properties of processed diatomite products used as fillers. (Modified from: Carr 1994)

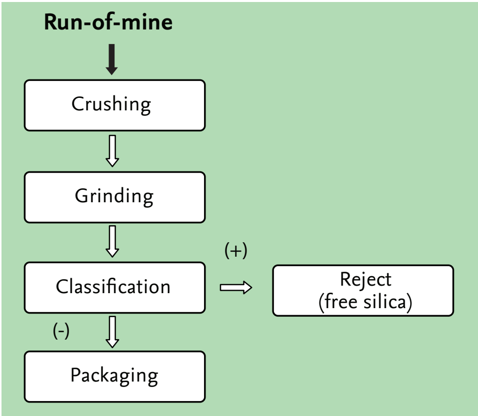
cination (using about 3–7 wt% of feed as flux) carried out at 1200°C. Calcination generally adjusts particle structure and particle size distribution and results in the increase of the refractive index (brightness) of the diatomite especially when flux calcination is carried out with soda ash or sodium chloride. Typical properties of some commercial filter aids and fillers are tabulated below (Tables 6-2, 6-3, Flowchart 7).

6.2.5 Kaolin

Kaolin is a hydrous aluminium silicate clay consisting of substantially pure kaolinite ($Al_4Si_4O_{10}(OH)_8$ with a theoretical chemical composition of SiO_2, 46.54%; Al_2O_3, 39.50%; and H_2O, 13.96%. It is soft with a hardness of 2 to 2.5 and is naturally white or



Flowchart 7. Diatomite Processing.



Flowchart 8. Dry kaolin processing.

can be beneficiated to be white or nearly white. Kaolin fires white or nearly white, and is amenable to beneficiation by known methods to make it suitable for use in ceramics, porcelain, coated paper, rubber and paint.

Kaolin is mostly formed by the alteration of aluminium silicate minerals in a warm and humid environment with feldspar being the most common source mineral.

Two types of kaolin occurrences are known, namely:

i. Primary kaolin occurrence, formed insitu and thus retains the texture form of the parent rock
ii. Secondary kaolin occurrence formed as a result of weathering and deposition of kaolin by sedimentation in fresh or somewhat salty water environments.

Common impurities in kaolins are quartz, mica, illite, smectite, feldspar, goethite and hematite.

Kaolin processing entails the removal of free quartz along with other impurities to produce marketable products using either wet or dry methods. The wet methods are generally used to treat the primary deposits that tend to contain high content of free quartz.

The wet processing method comprises blunging, using hydraulic monitors or blungers, which ensures liberation of the kaolin grains from those of free quartz and other associated minerals thus making it possible for the kaolin grains to be separated from the associated impurities using a combination

	Brazil fine (secondary)	Cornwall, UK, coarse (primary)
SiO_2	46.0	47.2
Al_2O_3	37.0	37.6
TiO_2	0.98	0.04
Fe_2O_3	1.8	0.68
MgO	0.07	0.20
CaO	0.02	0.08
Na_2O	0.08	0.08
K_2O	0.0	1.37
H_2O	14.3	12.7

Table 6-4: Chemical composition of paper-coating clays of similar brightness. (Modified from: Carr 1994)

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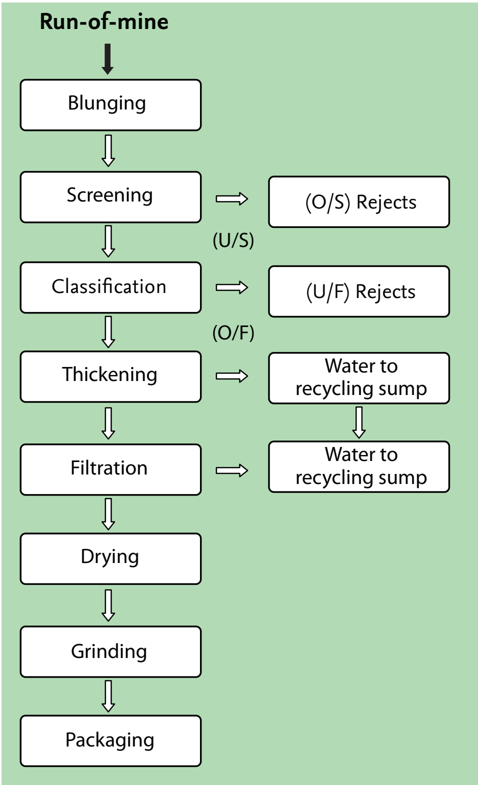
of wet-jet sieves and hydrocyclones.

The clay fraction from the hydrocyclones, removed through the over flow, is then thickened, filtered, dried and ground to specification, usually 100% passing 44 µm, if pure enough. Otherwise, it is subjected to further concentration using magnetic separation, flotation, flocculation in combination with bleaching, before filtration, drying and grinding.

Bleaching could be incorporated if the clay needs to be made brighter by using a combination of alum, sulphuric acid and sodium hydrosulphite.

In the drying process, the properties of the kaolin product are almost entirely dependent on the crude clay quality as delivered from the mine. For this reason, deposits must be selected to have the brightness, grit percentage, and particle size distribution that can be dry processed to make a particular product.



Flowchart 9. Wet kaolin processing.

The best practice is to stockpile run-of-mine according to their physical and chemical characteristics and treated separately or blended to the required specs before dry processing.
The upper limit of grit percentage that can be handled in the dry process is usually about 7%.

Dry processing is used to treat kaolin that is essentially pure like the Alkaleri deposit in Bauchi State requiring only crushing, grinding and air classification to produce a market grade.

Typical kaolin product specifications of similar brightness is given in Table 6-4, Flowcharts 8, 9.

6.2.6. Calcium carbonate

Calcium carbonate is generally sourced from carbonate rocks comprising limestone, dolomite and marble. These rocks and their derived products are used as aggregates, fluxes, glass raw material, refractories, fillers, soil conditioners, etc.

Limestone is a sedimentary rock composed principally of the mineral calcite ($CaCO_3$) with dolomite being a sedimentary rock composed mostly of the mineral dolomite ($CaCo_3.MgCO_3$). Other carbonate minerals found in minor quantities in association with limestone and dolomite are siderite ($FeCO_3$), ankerite ($Ca_2 MgFe(CO_3)_4$ and magnesite ($Mg CO_3$).

Typical sieve analysis - glass grade

Size (mm)	% retained cumulative	% passing cumulative
1.68	0.00	100.00
1.19	0.17	99.83
0.84	5.20	94.80
0.30	62.25	37.75
0.15	88.90	11.10
0.07	98.40	1.60
Pan	100.00	0.00

Typical chemical analysis - glass grade

Reported as:	%
$CaCO_3$	97.8
$MgCO_3$	1.25
Fe_2O_3	0.095
SiO_2	0.56
Al_2O_3	0.23
Ni	<0.002
Cr_2O_3	<0.001
SrO	0.03
MnO	<0.01

Table 6-5.Typical physical and chemical analyses of limestone glass grades (sieve and chemical analyses). (Source: Carr 1994).

Carbonate minerals have very similar physical properties making it very difficult for one mineral to be distinguished from the other. The rate of solubility of the different minerals in dilute hydrochloric acid is a most useful technique for identifying carbonate minerals in the field where calcite is found to be much more soluble than dolomite. Hence, if a fresh rock surface is etched, the amount of dolomite left standing in relief can be estimated using a hand lens. X-ray diffractometer is also used to determine the mineralogical composition of a carbonate rock bulk sample.

Carbonate rock processing entails crushing and grinding to size specification such as 100% passing 1.68 mm sieve size for glass-grade limestone.

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Typical specifications for various calcium carbonate products are found below:

6.2.7. Dimension Stone

Dimension stone refers to stone that is finished to specific dimensions and shapes and used for their aesthetic appeal, durability and ease of maintenance. Generally, dimension stones are quarried in large rectangular blocks, sawed into slabs for further finishing.

They are used in buildings, monuments, furniture, etc. Other stones (aggregates) are used in natural or broken sizes and shapes which are sorted in size ranges but not finished or dressed to specific dimensions. They are used for e.g. building and paving.

Rocks that are processed and sold as dimension stone include granite, marble and limestone. The suitability of a given stone to be used as dimension stone depends on its physical properties (strength, absence of structural defects, uniform grade) and aesthetic appeal (Table 6-6).

COLOUR	Classic colours	Marble Granites	White, black, pink, green Black, red
	Ordinary colours	Marble Granites	Beige Grey, pink
	Special colours	Marble Granites	Yellow, red, blue Yellow, purple, blue, green
TEXTURE	Homogenous Oriented	(even drawing) (uneven drawing)	
GRAIN SIZE	Fine Medium Large		

Table 6-6. Factors that determine the aesthetic value of dimension stone. (Source: Ragone 2010).

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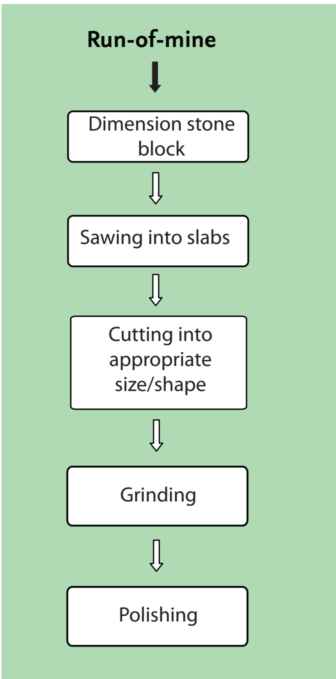
MARBLE TILE		GRANITE TILE	
THICKNESS (mm)	DIMENSIONS (mm)	THICKNESS (mm)	DIMENSIONS (mm)
7	150 × 300	7	150 × 300
10	300× 300	6.5	305 × 305
10	305 × 305	10	300× 300
10	400× 400	10	300× 600
13	400× 400	12	400× 400
15	457 × 457	12	457 × 457
15	600× 300	12	600× 600

Table 6-7. Typical tile dimensions. (Source: Ragone 2010).



Flowchart 10. Dimension stone production.

Dimension stone quarry operations generally involve:

i. Cutting the stone using diamond wire saws, automated jet burner or drilling a series of long parallel holes using pneumatic or hydraulic powered percussion drills
ii. Breaking the stone using wedges and feathers or very light explosive
iii. Removing the stone from its broken position.

ASM operators involved in dimension stone production in Nigeria usually sell their products in block form. The most ideal thing to do is to produce a finished product where the blocks should be sawn into slabs and then cut into suitable sizes and shapes, ground and then polished.

Equipment usually used in producing finished dimension stone include:

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i. Gang saw, wire saw or circular saw for primary cut

ii. Circular saws (bridge saws) for secondary cut

iii. Hand-held pneumatic tools, wire saw, carborandom or diamond wheels for shaping

iv. Surfacing machines using impregnated diamonds for grinding

v. Grinding/polishing machine that moves the spindle over the stone for polishing.

Typical tile dimensions for marble and granite finishing are as given in Table 6-7. A typical dimension stone production is as shown in Flowchart 10.

6.3. Gemstones

The gemstones exploited by ASM operators in Nigeria are mainly tourmaline in various colours. The attractive, coloured tourmalines are named rubelites. The mining is underground or in pits, and mining is carried out by blasting. When a face has been handpicked for gemstone quality stones, then drilling and blasting are carried out. In the blasted material, the rubelites are highly fractured, and thus fetch a very low price only. On the surface behind the blasted material non-fractured gemstones occur.

There are types of explosives which do not shatter the rocks very much. If such blasting material is used, then less rubelite would be destroyed. Another way to prevent the fracturing of so many gemstones could be to have experts in blasting to set up patterns for drilling and optimising loading of the drill holes.

Children in Russo, Kaduna State

7. Health and safety issues in ASM

ASM is a dangerous occupation. The number of casualties and health problems among miners is enormous. Two of the reasons that the miners jeopardize their lives and health are lack of knowledge and lack of money. If ASM operators knew how lethal finely ground quartz is to their lungs, they would probably use dust masks, which provide an efficient and inexpensive protection against stone lungs. If the miners had a better economy they could spend money on timbering shafts, walls and roofs in their tunnels in order to prevent collapse of their tunnels.

7.1. Health problems

Numerous health problems trouble the ASM operators ranging from inhaling quartz dust over hearing loss to mercury poisoning.

Occupational health hazards comprise:

1. Stone lungs/silicosis (dust)
2. Lead poisoning (dust)
3. Mercury poisoning
4. Cyanide
5. Radiation
6. Noise

7.1.1. Stone lungs/silicosis

Quartz is the main mineral in most of the gold ores mined by small-scale miners. To liberate the fine gold grains it is necessary to crush and grind the quartz. Grinding is mostly carried out in ball or rod mills. Depending on availability of water the grinding can be done dry or wet. If the grinding is dry there is a major risk of inhaling the fine-grained quartz dust (Fig.7-1a). The dust will over time accumulate in the lungs and eventually cause silicosis also called stone lungs. Breathing is very difficult with stone lungs and if the miner goes on inhaling quartz dust the final result will be death.

There are two ways out of this problem. The easiest is to use dust masks (Fig. 7-2). They are easy to use and inexpensive. They may be difficult to get hold of in ASM communities, but should be available in larger towns.

Another way to reduce the risk of silicosis is to use wet grinding instead of dry grinding. Wet grinding of gold ore is widely distributed in the Philippines (Fig. 7-1b). This will prevent the immediate risk of silicosis. However, precaution must

Fig. 7-1a. Dry grinding of quartz-gold ore in a ball mill produces large amounts of dust.

Fig. 7-1b. Wet grinding of quartz-gold ore in a rod mill produces no dust and no noise.

be taken with the tailings from the grinding as the fine quartz dust will be blown around and cause stone lungs in the mining communities, when the tailings dry out. To prevent the tailings from drying out, they should be properly sealed with a layer of mud.

7.1.2. Lead poisoning

In 2010 a major health disaster occurred in Northern Nigeria where a large num-

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Fig. 7-2. Dust masks reduce the risk of getting silicosis/stone lungs.

ber of children died. After proper investigation it turned out that they died from lead poisoning and the lead came from small-scale gold mining. The grounding produced not only quartz dust but also lead-rich dust. The grounding took place in the ASM communities and often even inside their houses. Utensils which are used for preparing food were used during processing the ore. During milling of the ore a fine-grained, lead-rich dust was inhaled by many of the inhabitants, especially children. The fine-grained, lead-rich tailings were disposed in or near the communities as dry powder. When windy, the powder was blown around and was not only directly inhaled but also polluted the food. The result was severe lead poisoning of the population leading to around 200 deaths.

This could have been avoided by extracting the gold outside the villages and by securing the lead-rich tailings by covering them with a layer of clay. This would effectively seal off the toxic tailings.

7.1.3. Mercury poisoning

During gold extraction (Chapter 6) with mercury (amalgamation) the metallic mercury is burned off. Some of it will be inhaled by people doing the amalgamation and by the villagers. Mercury vapour which is not inhaled will precipitate with rainfall and gradually be washed into the local drainage system. In the aqueous environment metallic mercury is transformed by bacteria to methylated mercury which is even more toxic than metallic mercury. The methylated mercury (also called organic mercury) enters the food chain and eventually ends up in fish which are eaten by people. In this way the population may get high concentrations of mercury in their bodies (Fig. 7-3).

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Fig. 7-3. Paths of mercury in the environment and the food chain. ***Hg*** *is the chemical symbol for mercury. The 'story' starts in the lower left corner and moves forward clockwise. An ASM operator burns amalgam and thereby releases metallic mercury. He inhales some of the mercury. The rest of the mercury falls down on the soil with the rain. Then the metallic mercury is converted by bacteria to methylated mercury and enters the food chain through the drainage system and ends up in cows, hens, fish and rice. When eating the food the population is poisoned by mercury.*

7.1.3.1. Health hazards caused by mercury

Metallic mercury is dangerous to the health and must be handed with outmost care. When heated the fumes get into the atmosphere. These fumes cannot be seen or smelled. In the lungs the metal fumes are easily absorbed in the bloodstream, carried around in the body and taken up by various organs.

Classic symptoms of mercury poisoning are tremors. In the beginning the tremors are intentional, that is, only visible when the patient is asked to approach a glass of water to his/her mouth, to move a finger towards his/her nose or to write a signature. Later, the tremors become static, and may spread to the whole body. Erethism is a mental disturbance characterised by acute irritability, abnor-

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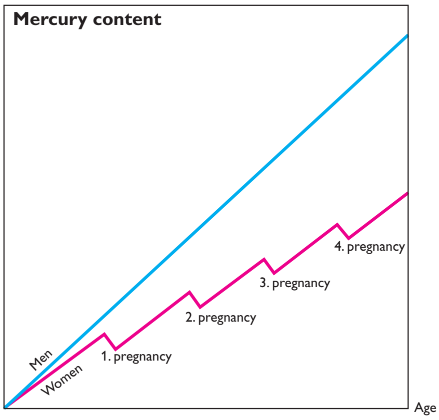
Fig. 7-4. The build-up of mercury content of men and women from birth to old age. The woman exemplified here has had four pregnancies. In each case the foetus has extracted much of the mercury from the mother.



mal shyness, indecision and overreaction to criticism. Inflammation of gingiva and metallic taste are other symptoms.

When mercury is present in the blood stream of a pregnant woman, it will pass the placental barrier to be concentrated in the foetus. As the foetal period is the most sensitive to environmentally dangerous chemicals such as mercury, pregnant women should never be exposed to mercury. If a pregnant woman is exposed to mercury she may give birth to a mentally and/or physically disabled child (Fig. 7-4).

Methylated mercury can pass the placental barrier and cause development deficiencies in children such as loss of intelligence, decreased language skills, memory and attention. Methylated mercury in adults has also been linked to increased risk of cardiovascular disease including heart attack. It can also cause neurological symptoms such as loss of physical coordination, difficulty of speech, narrowing of the visual field (tunnel vision), hearing impairment, blindness and death.

A simple field test is to ask a person to draw a circle. If the person is poisoned by mercury he/she cannot draw a proper circle due to tremors (Fig. 7-5).

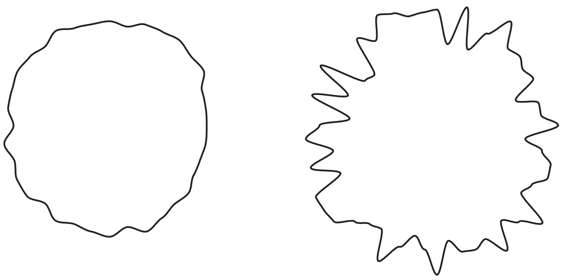


Fig. 7-5. Circles drawn by a person without mercury poisoning (left) and by a person with mercury poisoning (right).

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In chapter 3 different gold extraction methods are described several of which will reduce/eliminate use of mercury in ASM.

7.1.4. Cyanide

Cyanide is used for extraction of gold; it is a very toxic agent which kills almost instantaneously. Inhaling or ingestion can be lethal. One of the effects of cyanide in the human body is that it inhibits the uptake of oxygen in the blood. Great care has thus to be taken during storage and use. It is especially important to alert the surrounding community in case of a cyanide spill. If the cyanide finds its way to streams and rivers the water must under no circumstances be used for consumption. However, cyanide disintegrates very fast by interaction with the atmosphere to harmless ingredients. If cyanide was spilled in water used for drinking purposes then it is ok for drinking after a short time.

7.1.5. Radiation

Tantalite/columbite is mined by ASM operators in several places in Nigeria. Today the mineral is extracted from soil overlying hard rock tantalite deposits. The mining itself is not dangerous since it does not involve deep diggings. However, the storage of the ore concentrate may create problems. The mineral columbite/tantalite frequently contains small amounts of uranium. Uranium is radioactive and its radiation produces the radioactive gas radon. Radon produces a number of radioactive daughter products some of which are metals. Radon and its daughter products are inhaled and may damage lung tissue.

As long as the columbite/tantalite is stored outside there is no risk of radiation damage. However, if the tantalite/columbite is stored indoors in houses where people sleep, the radon accumulates and can seriously harm them. It is thus of importance to store the mineral outside or in rooms where nobody lives.

7.1.6. Noise

Noise can be a major problem for small-scale miners, but can be mitigated easily. If the miners use dry grinding in ball or rod mills it not only produces a lot of dust, but also an unbearable noise. Many of the miners doing dry grinding have advanced stages of tinnitus or are almost deaf. If the miners switch to wet grinding there are no noise problems whatsoever. An argument put forward by many miners is that it requires lots of water. It does consume water, but the water can be recycled.

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7.2. Safety problems

One of the main problems in underground mining is that most miners support neither roofs nor walls. This is essential to do in order to avoid collapse with risk of severe bruises or casualties and lack of oxygen in tunnels and shafts (Fig. 7-6).

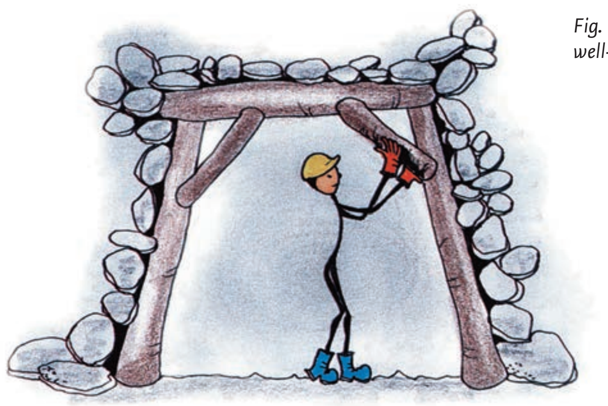
Extracting stones from hard rock deposits is done by hammer and chisel. A major problem is that splinters from the rock may hit the eye and cause blindness if safety goggles are not used. It is therefore important to instruct workers to use safety goggles. (Fig. 7-7).

Pits and tunnels are dangerous working places, but simple inexpensive means, e.g. safety boots, safety helmets and protective gloves, will protect miners against many accidents (Fig. 7-8).

Safety measures should be taken against falling stones and collapsing walls in deep pits. (Figs 7-9 and 7-10).

If accidents do happen it is important to have a first-aid kit near the mining site and someone who has been taught the basics of first aid (Fig. 7-11).

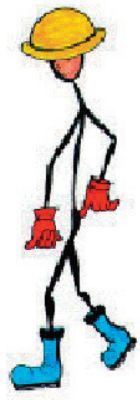
Lack of oxygen is a frequent problem which many ASM operators face. A deep shaft extended by tens of metres long tunnels is a real death trap. If miners do not make shafts at each end of tunnels in order to create ventilation then they are due to suffocate. If miners use compressors or water pumps in the mine then all oxygen may be used by the engines and replaced by carbon dioxide and diesel fumes. If miners work at the bottom of the shaft or in tunnels when the machines are running they have a big risk of suffocating.



Source: Walle & Jennings 2001

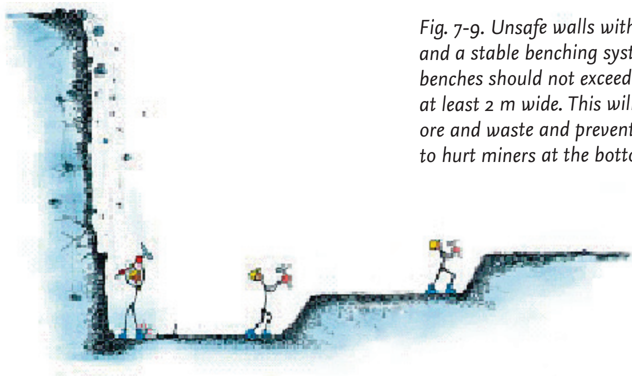
Fig. 7-6. Entrance to a tunnel with well-supported walls and roof.

Fig. 7-7. Always use safety goggles



Source: Walle & Jennings 2001

Fig. 7-8. Always use safety helmet, boots and glows.



Source: Walle & Jennings 2001

Fig. 7-9. Unsafe walls with rock fall on the left and a stable benching system on the right. The benches should not exceed 1.5 m in height and be at least 2 m wide. This will facilitate carrying up ore and waste and prevent material falling down to hurt miners at the bottom of the pit.

In shorter tunnels a man powered air pump may be sufficient to supply oxygen to the miners. The pump can be engine powered but for lack of funding for such an engine a bicycle powered pump can be used as shown on Fig. 7-12. This type of pump is well known in Nigeria.

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Fig. 7-10. Very deep pit with near vertical walls with a high risk of accidents caused by falling stones.

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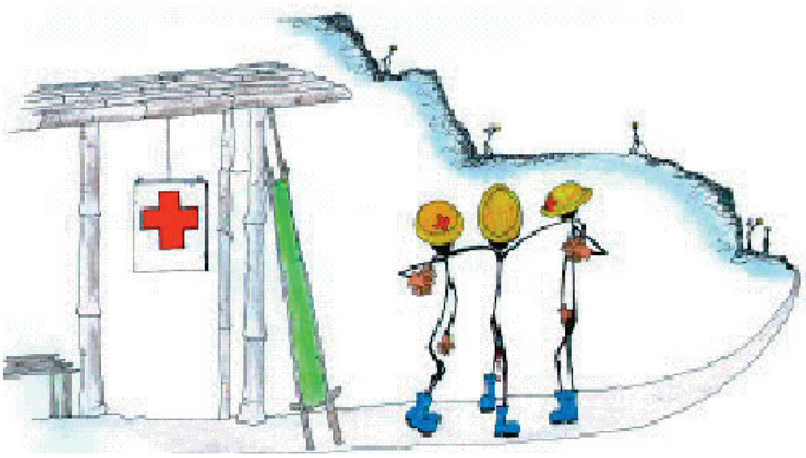

Source: Walle & Jennings 2001

Fig. 7-11. If accidents do happen it is important to have a first-aid kit near the mining site and someone who has been taught the basics of first aid.

Fig. 7-12. Bicycle-powered pump for providing oxygen to tunnels.

Nahuta lead/zinc mining site in Gombe State

Female workers in the barite mine in Azara, Nazarawa State