# Technologies for Small Scale Mining

## Examples of traditional and alternative mining and processing methods

***Part 2***

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# Concentration and Separation

# Alternatives for the amalgamation of gold bearing concentrates (examples)

a) direct smelting
b) cyanide leaching
c) leaching with other reagents (chrorine, bromine, thiourea, etc.)
d) gold/oil aglomeration

**These processes are difficult to implement in small scale mining**, due to their

- need for highly enriched concentrates (a, d)
- technical comlexity (c, d, e)
- high costs (c, d)
- health, safety and environmental problems (b, c, d)
- slow processes (b, c)

**In some cases, simple methods can replace amalgamation of concentrates:**

- panning (especially for coarse gold)

- combination of magnetic separation and panning (if magnetic minerals are presen

- blowing (for small quantities)

- friction-separation on inclined rough surface (for small quantities of flaky gold)

For alluvial gold in more sophisticated operations, a combination of magnetic separation (low-intensity, followed by high intensity) to separate magnetic minerals and dry electrostatic separation to separate the Zircon can be useful

The use of mercury/amalgamation will be in the next future the preferred method in small scale gold mining for the separation of gold from concentrates, due to its

- easy handling

- relative high recovery

- use with no or cheap machinery

- relative low costs

If it is not possible to eliminate the amalgamation in small scale mining, it has to be

- **controlled**
- **optimized** and
- **restricted to the amalgamation of concentrates**

# Possibilities to minimize mercury emissions in small scale minin

1. Improve general handling (transport, storage, etc.)

2. Eliminate totally the use for raw ore

3. Optimize amalgamation of concentrates

4. Recover mercury from amalgam

5. Cleaning and appropriate deposition of amalgamation tailings

If the main mercury emissions are occurring either

- through its use in open concentration circuits or
- through burning of amalgam

these are the main fields of intervention

The most effective way to reduce mercury emissions in open concentration circuits is the improvement of gravity concentration

# Reducing mercury emissions through efficient gravity concentration

Gravity concentration is the most appropriate method for small scale gold mining because of

- no reagents are needed
- simple operation (exception: jigs and centrifuges)
- low investment costs (exception: centrifuges, spirals, shaking tables)
- other valuable minerals can be recovered (sulfides, cassiterite, diamonds)
- great variety of types and size of machines available
- process water can be recycled easily after solids removal

# Gravity concentration processes and equipment

The most important and appropriate gravity concentration devices for small scale gold mining are

- improved sluice boxes and strakes
- spirals (spiral concentrators)
- shaking tables
- jigs
- centrifugal concentrators (under certain restrictions)

# Sluice box (alluvial), Strake or Blanket Table (primary)

**Advantages:**

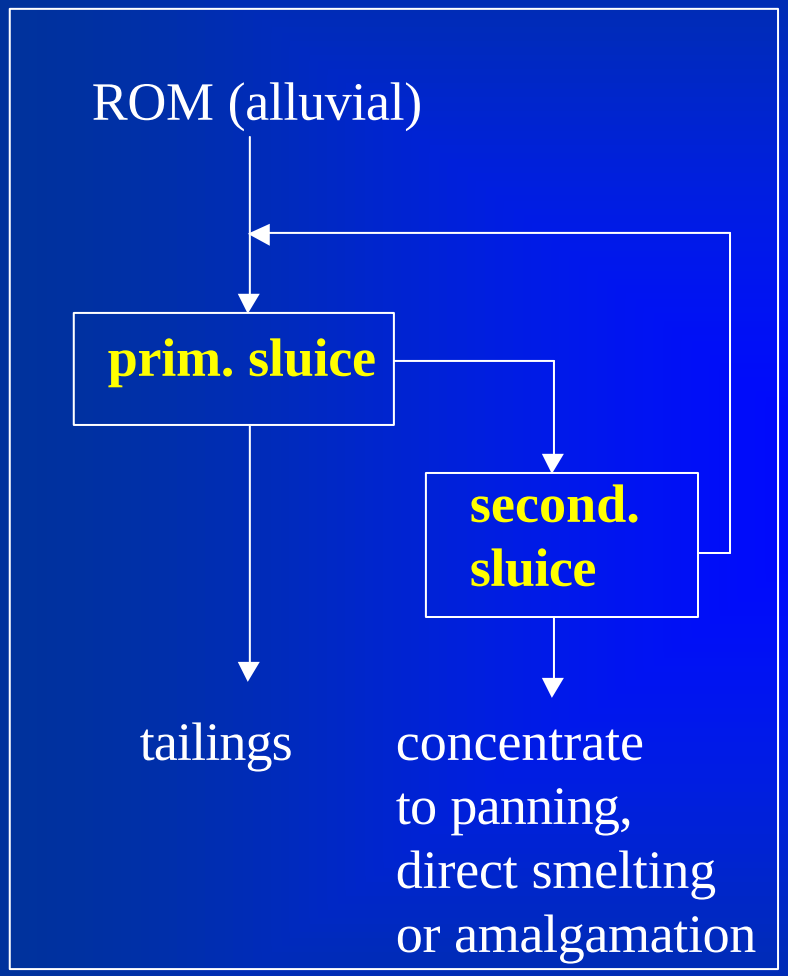
- very low cost
- high capacity (alluvial mining)
- local production
- no motor no moving parts
- easy operation
- good recovery even for fine gold (if properly built and operated)
- high enrichment ratio
- good for cleaning of amalgamation tailings

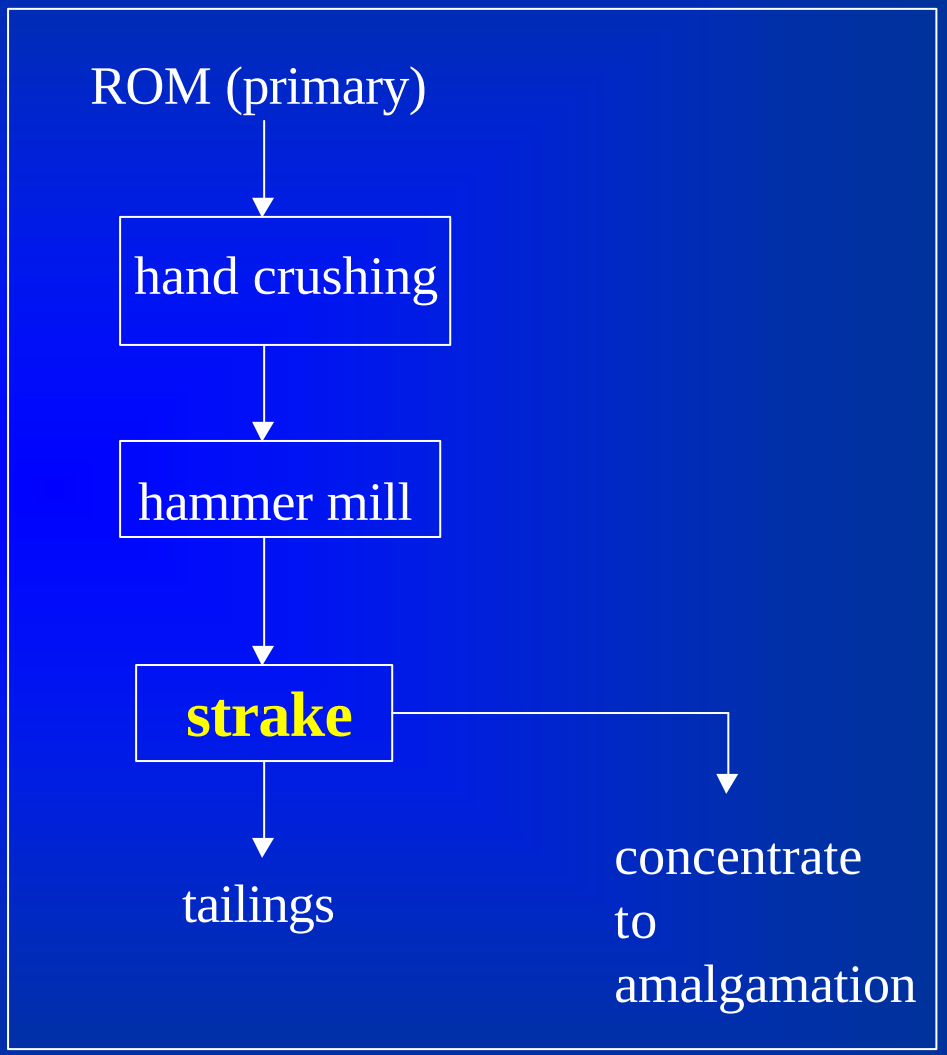
**Disadvantages:**

- needs much manual work, security problem
- does not completely recover sulfides in primary mining
- discontinuous process

Test Sluice Box (left: turbulent, right: laminar)

# Examples for the use of sluice boxes/strakes (1)



# Examples for the use of sluice boxes/strakes (2)

ROM (primary)

use: scavenger

jaw crusher

mill

spiral

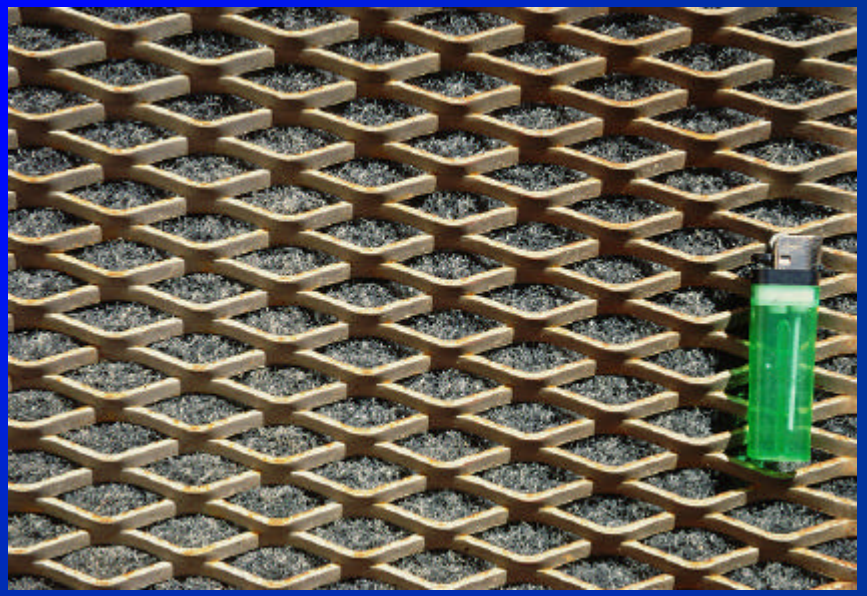
shaking table

**strake**

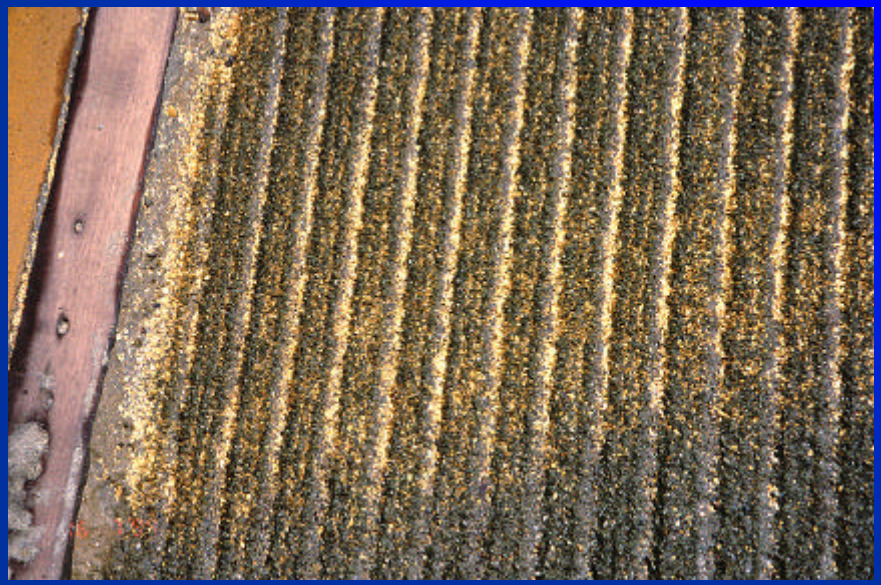
concentrate to direct smelting or amalgamation

tailings

# Riffeled sluice box (for coarse gold)



Various carpets for sluice boxes



## “carpet only” -sluice boxes:

- little amount of preconcentrate
- high enrichment
- fast amalgamation
- little amount of amalgamation tailings

„carpet-only“ sluicebox for fine alluvial gold (see re-cleaning sluice left)

Sluicebox for cleaning alluvial pre-concentrate

„carpet-only“ sluicebox for fine alluvial gold

„carpet-only“ sluicebox of a dredge

# Typical mass balance for the use of sluiceboxes

Feed: alluvial gold ore: 100m$^3$ or 180t (one day) = 100%

Rougher sluicebox pre-concentrate: 180kg = 0,1%

Cleaner sluicebox concentrate: 18kg = 0,01%

Only the cleaner concentrate or 0,01% of the material is amalgamated!

99,99% of the material is discharged completely free of mercury contamination

Cleaner sluicebox tailings are recycled to feed

Note: similar mass-balances can be achieved using other gravity concentratio equipment

# Jig (mechanic)

**Advantages:**

- can be produced locally
- high capacity (in alluvial mining), low cost
- good recovery of heavy minerals, such as gold bearing sulfides in primary mining and diamonds in alluvial mining
- recovers flattened gold after ball mills
- wide size range of feed and products

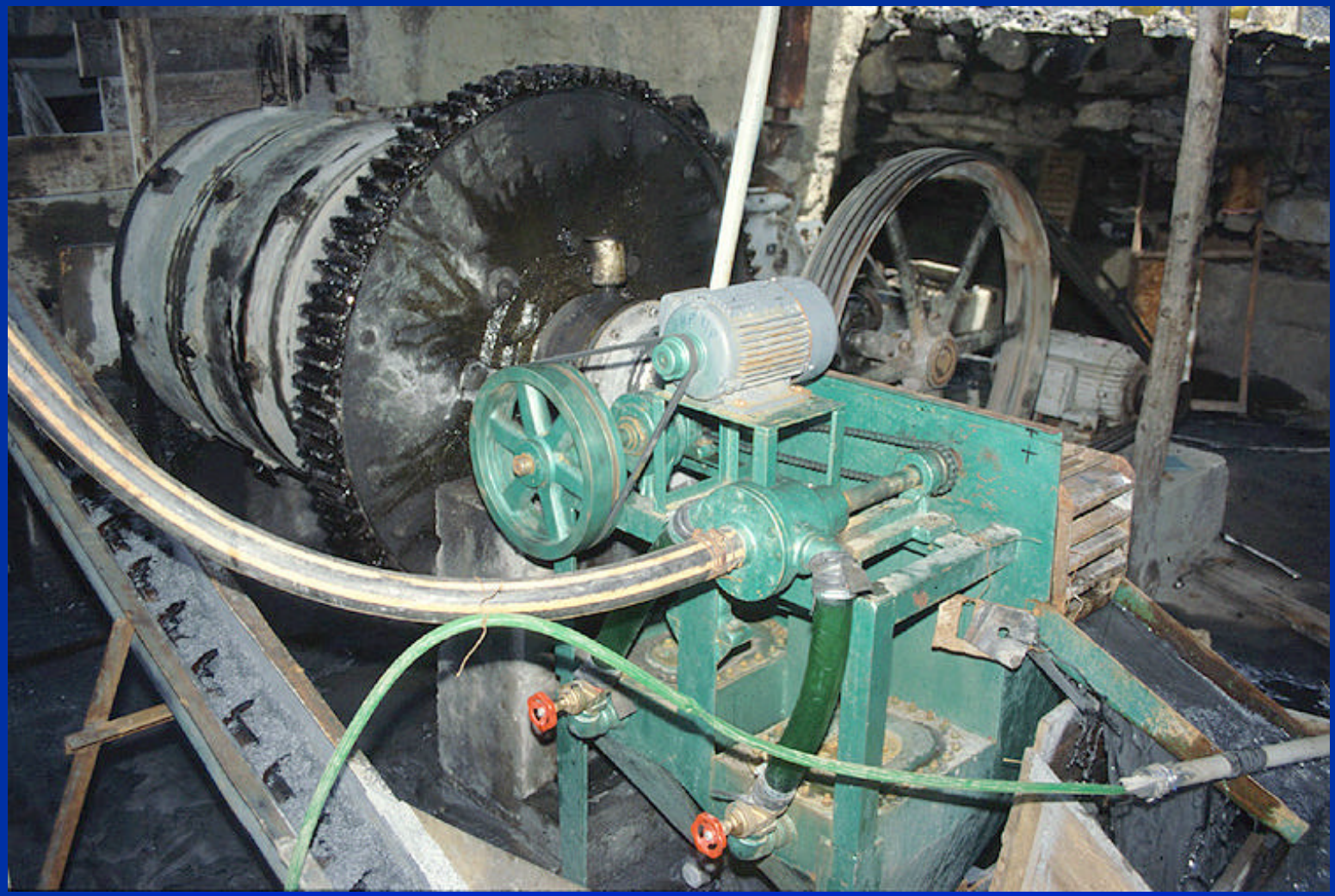
**Disadvantages:**

- relatively difficult set-up and operation
- needs motor (not the hydraulic type “Pulsator Jig”)
- needs hutch water

Jig (Type Panamerican) in alluvial diamonds processing

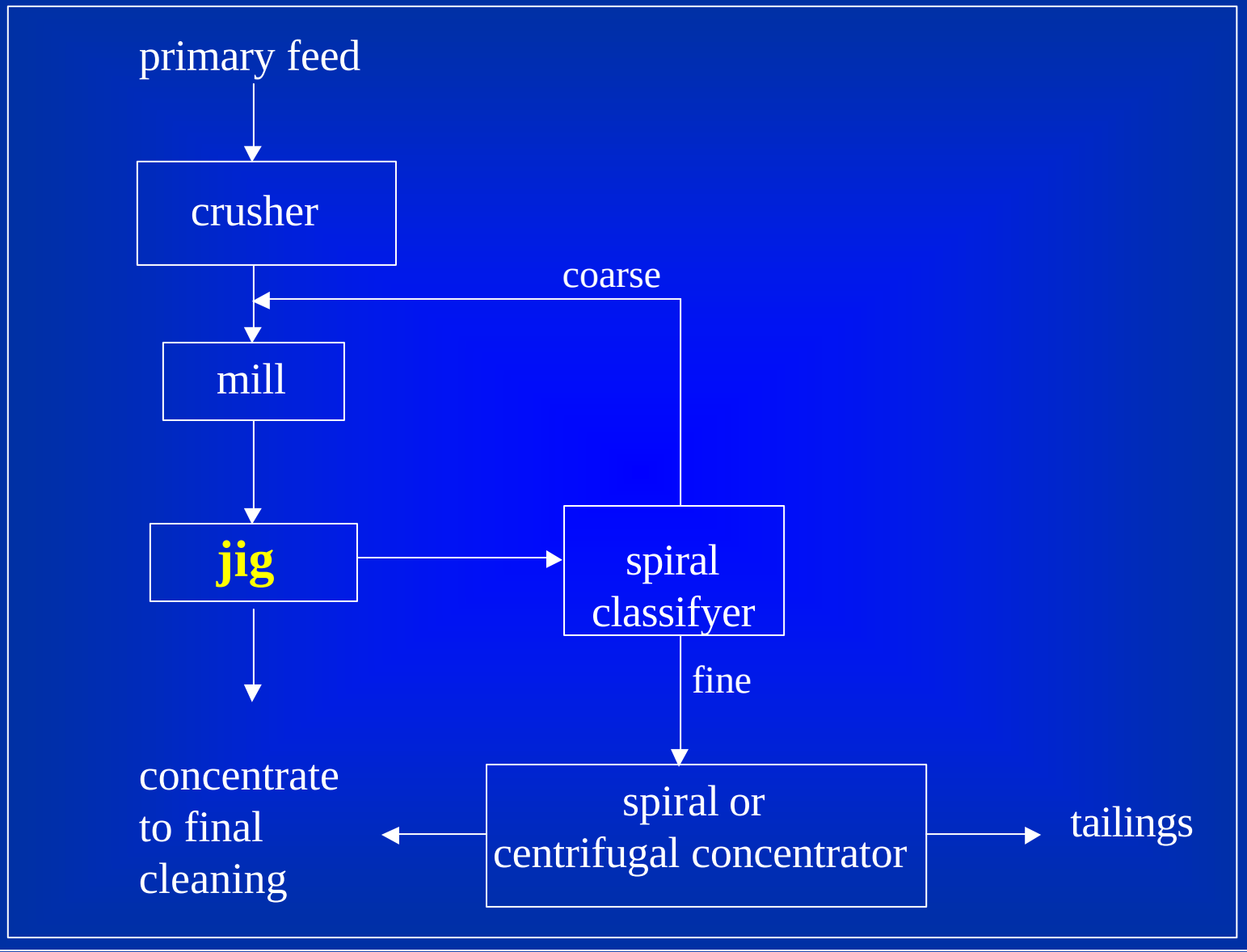
Jig (cassiterite and tantalite mining)

Jig (Ruby mining), combined with scrubber/trommel screen

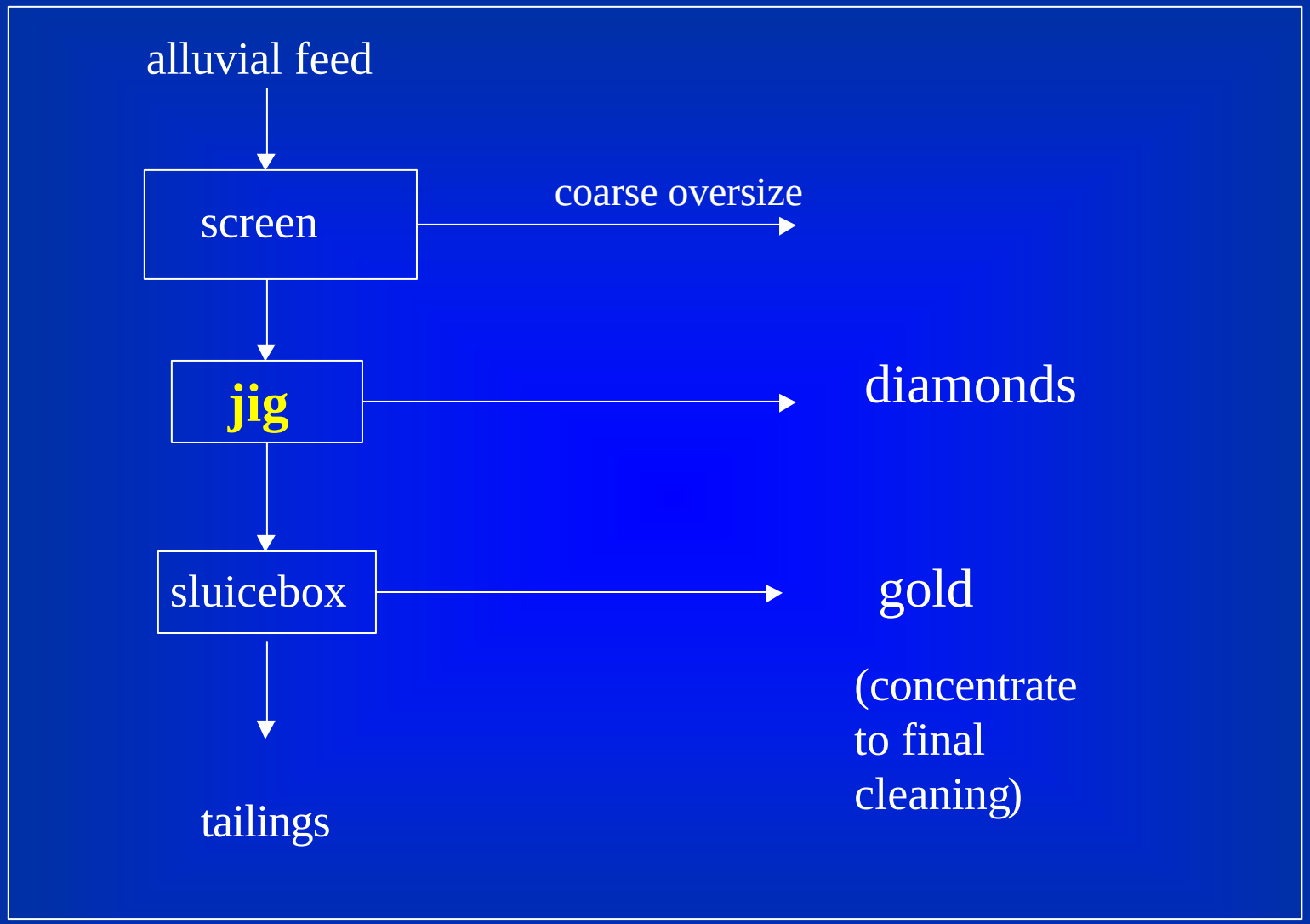


Jig (Type Denver Mineral Jig) in closed milling circuit (gold)

# Examples for the use of Jigs (1)



# Examples for the use of Jigs (2)



# Shaking table

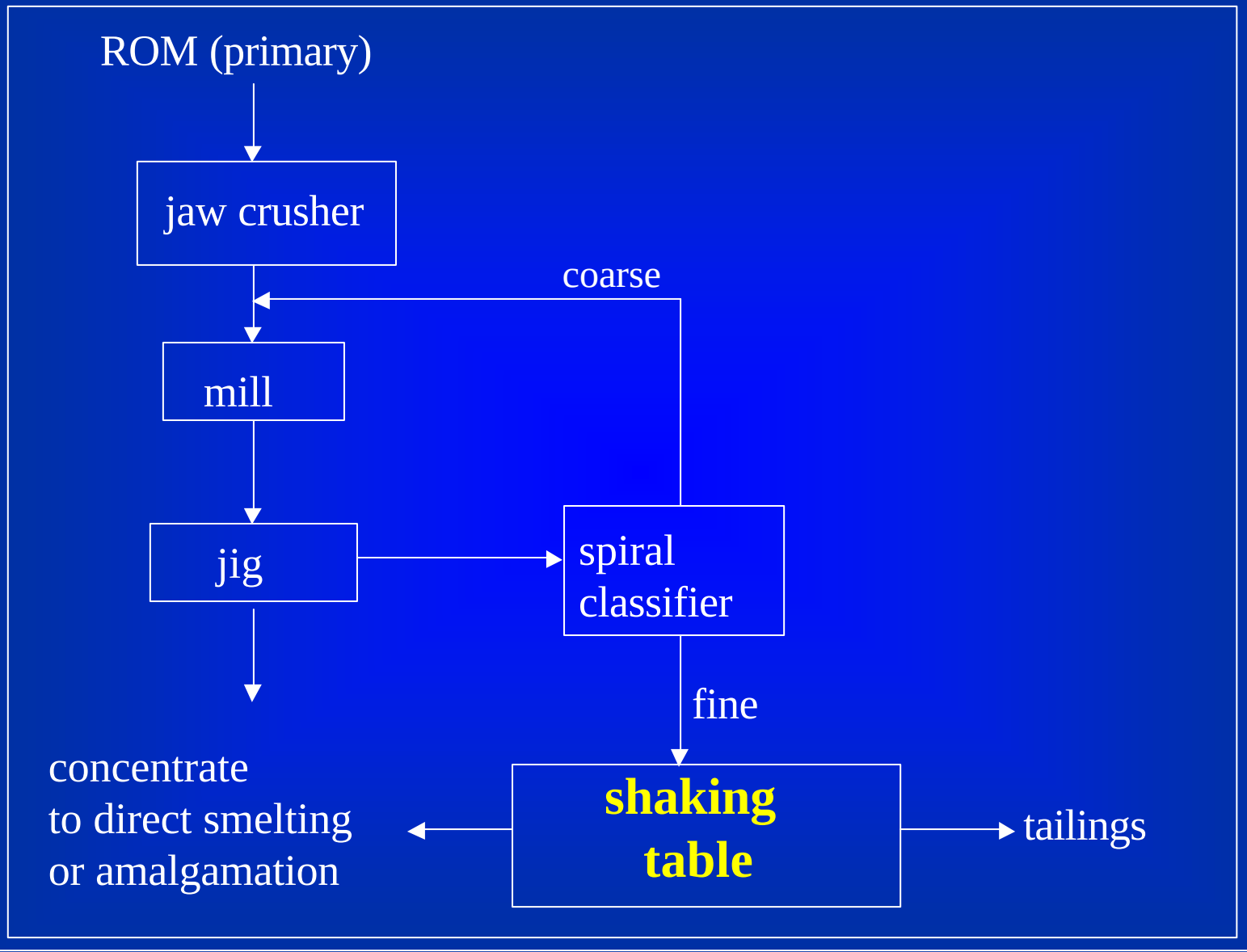
**Advantages:**

- recovery of various products
  (concentrate, middlings, tailings)
- visible process, good control
- flexibility
- good gold and sulfide recovery
- relative easy operation
- high enrichment factor
- for cleaning amalgamation tailings
- continuous process
- local production posssible

**Disadvantages:**

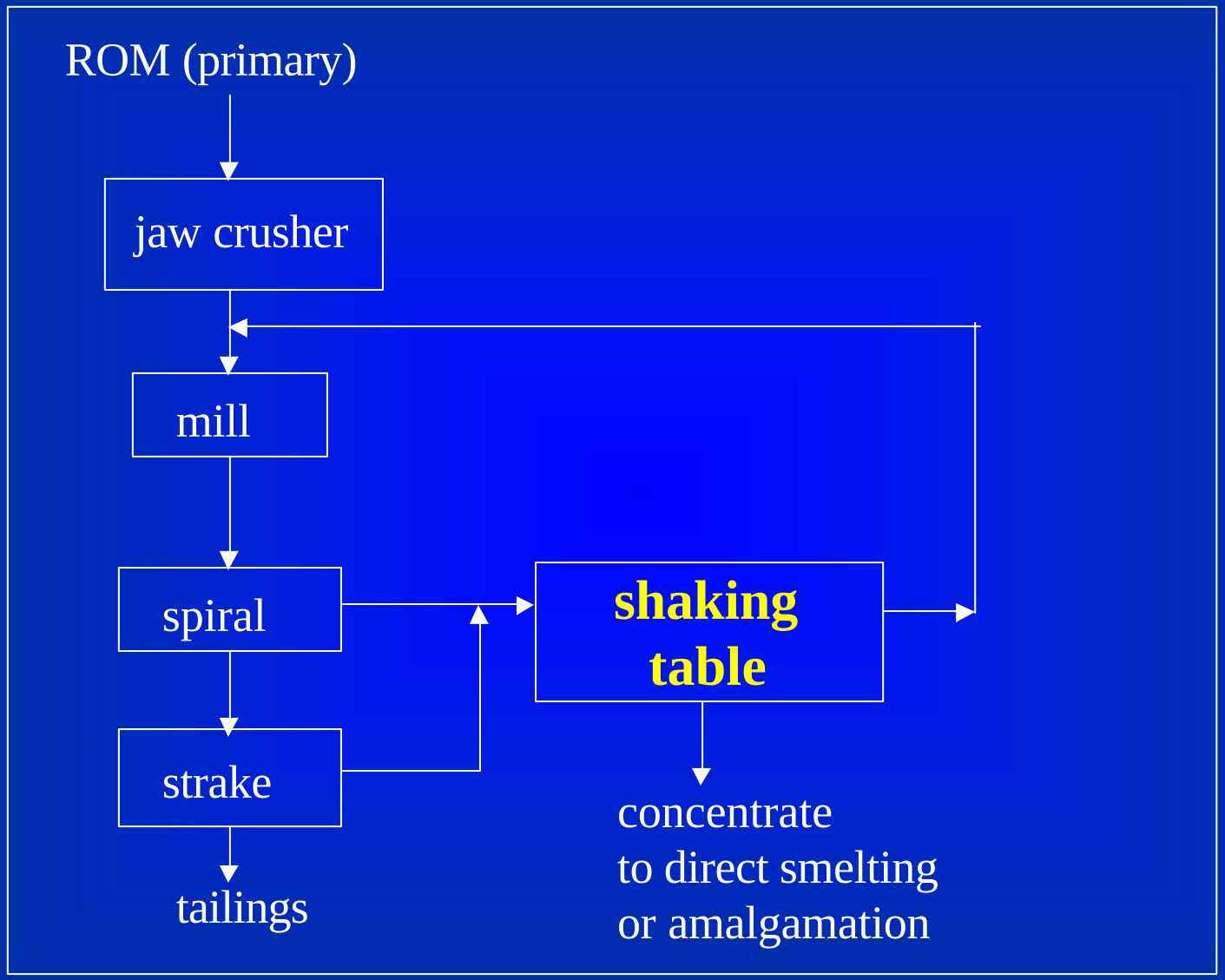
- high cost regarding its limited capacity
  (principal use as secondary enrichment/cleaner step)
- needs very steady feed and constant supervision
- needs motor

# Examples for the use of shaking tables (1)



Gold, heavy minerals and quartz on shaking table (operation stopped)

# Examples for the use of shaking tables (2)



## Shaking table type „Gemeni“

- produces very clean gold concentrate for direct smelting

- low recovery with fine or very flaky gold

- low throughput, high price

# Spiral concentrators (spirals)

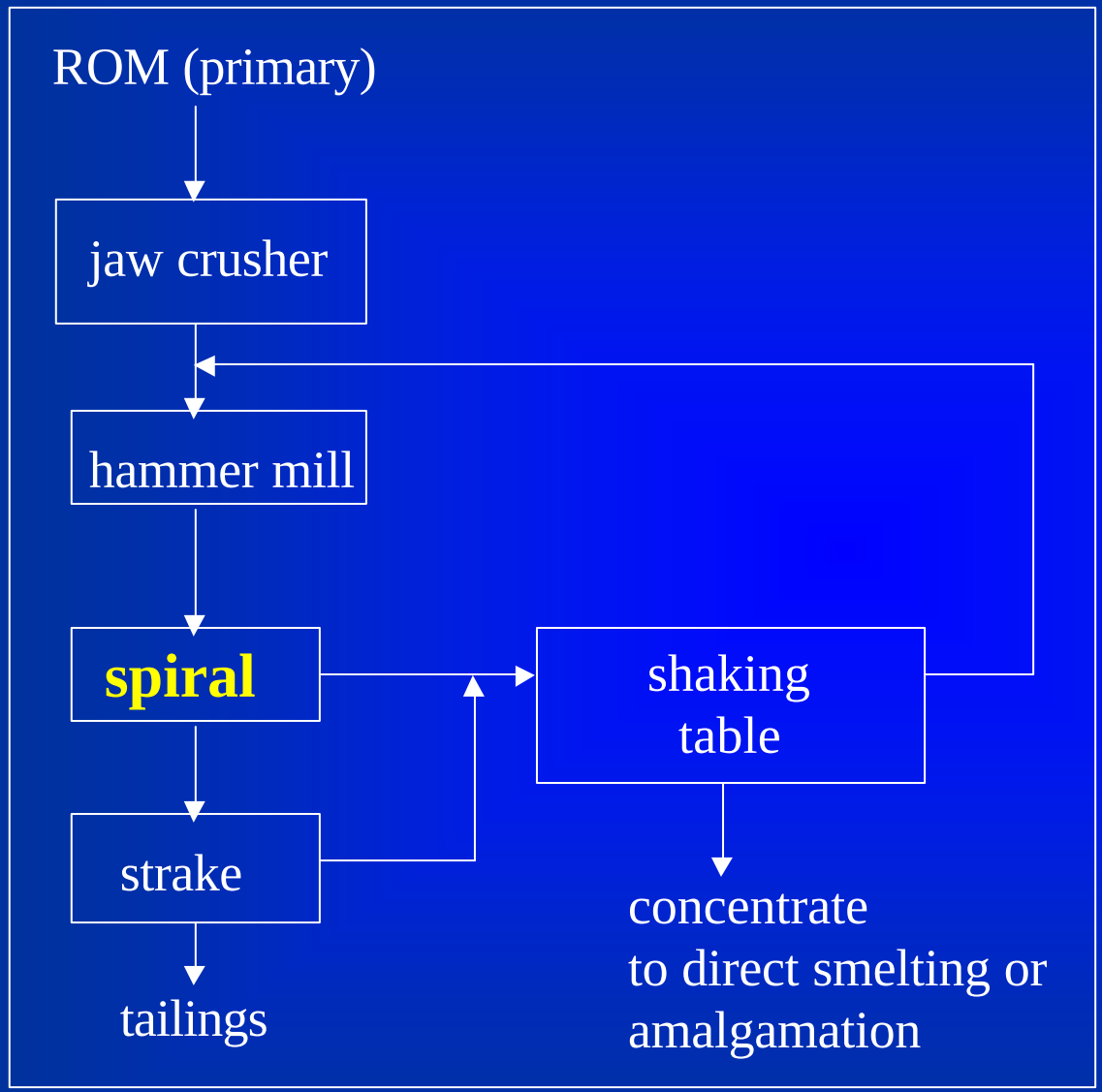
**Advantages:**

- recovery of various products (concentrate, middlings, tailings)
- material visible during the process
- good recovery of gold and sulfides
- easy operation
- continuos process
- high capacity for small primary gold mining (50t/d for a single start spiral)
- no motor no moving parts

**Disadvantages:**

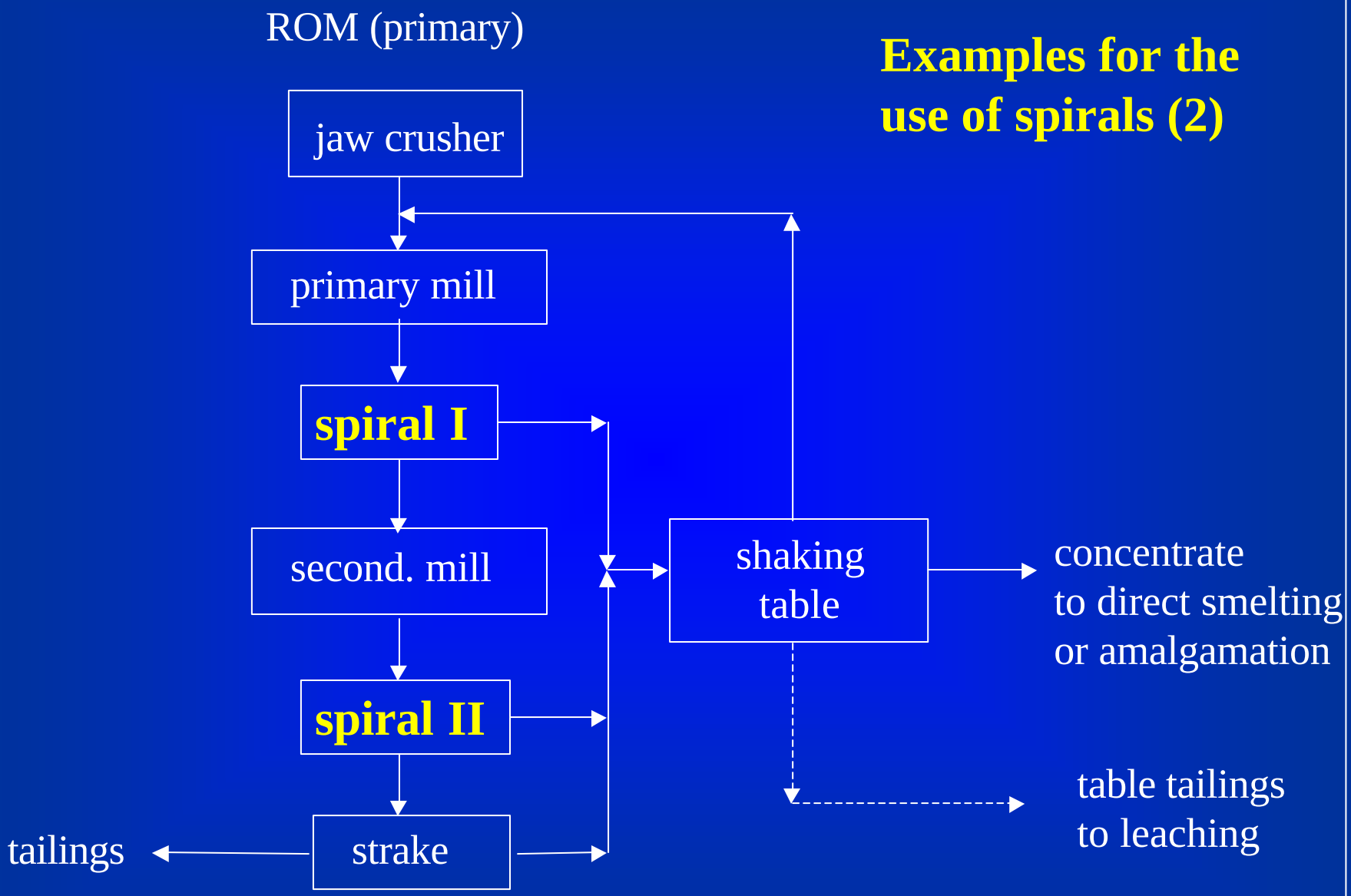
- needs material screened to minus 2mm
- low enrichment factor (typical pre-concentration device)
- needs ca. 4 m altitude from feed to discharge (with pump or natural)
- not suitable for local production

# Examples for the use of spirals (1)




Spiral splitter setting (oxidised primary gold ore)

# Examples for the use of spirals (2)



# Centrifugal Concentrators (Falcon, Knelson), batch type

**dvantages:**

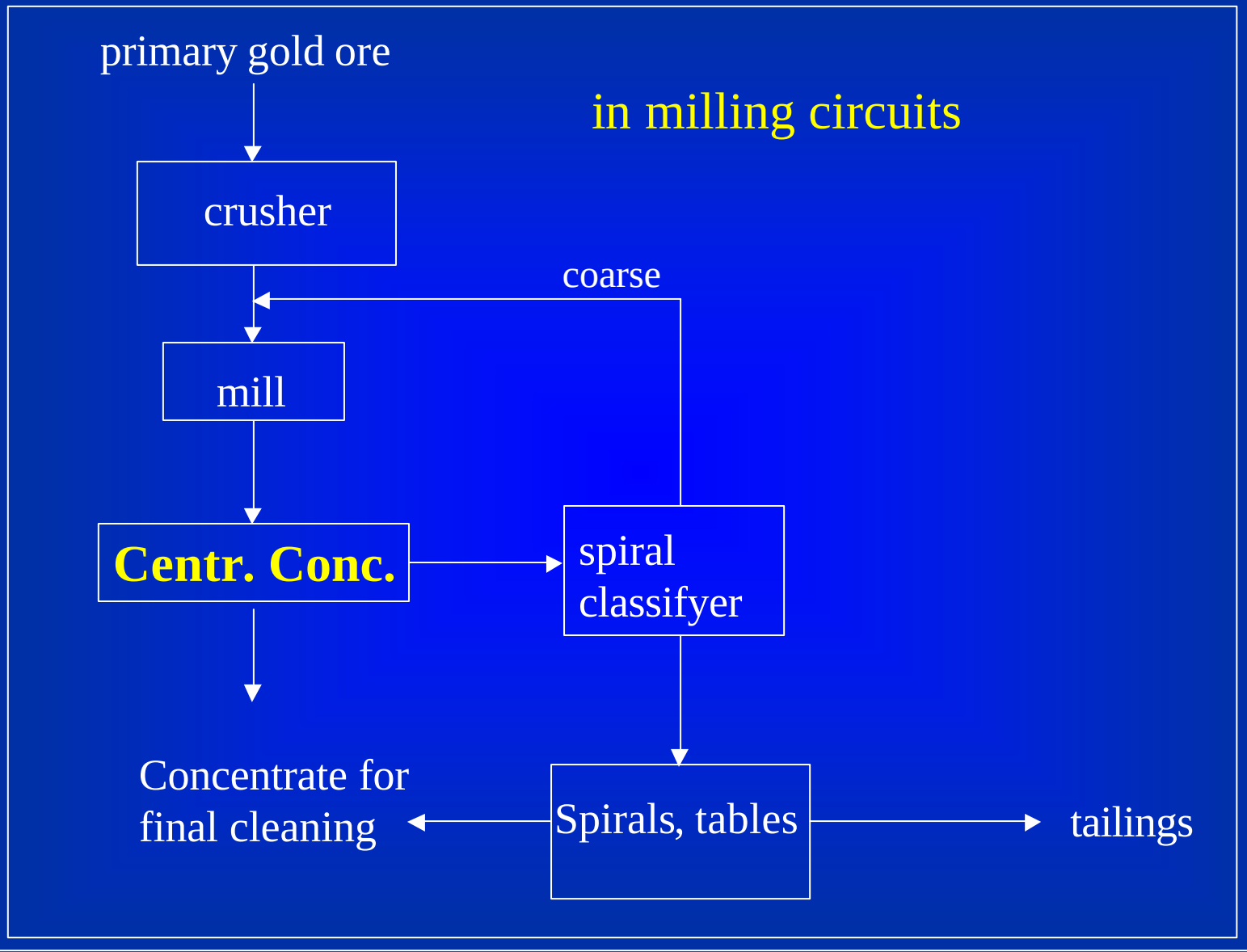
- size/capacity from small to large
- good recovery (for example, for fine gold < 30µm, better than any other equipment)
- very high enrichment factor (can work without secondary upgrading)
- good for cleaning amalgamation tailings
- high security against theft


**isadvantages:**

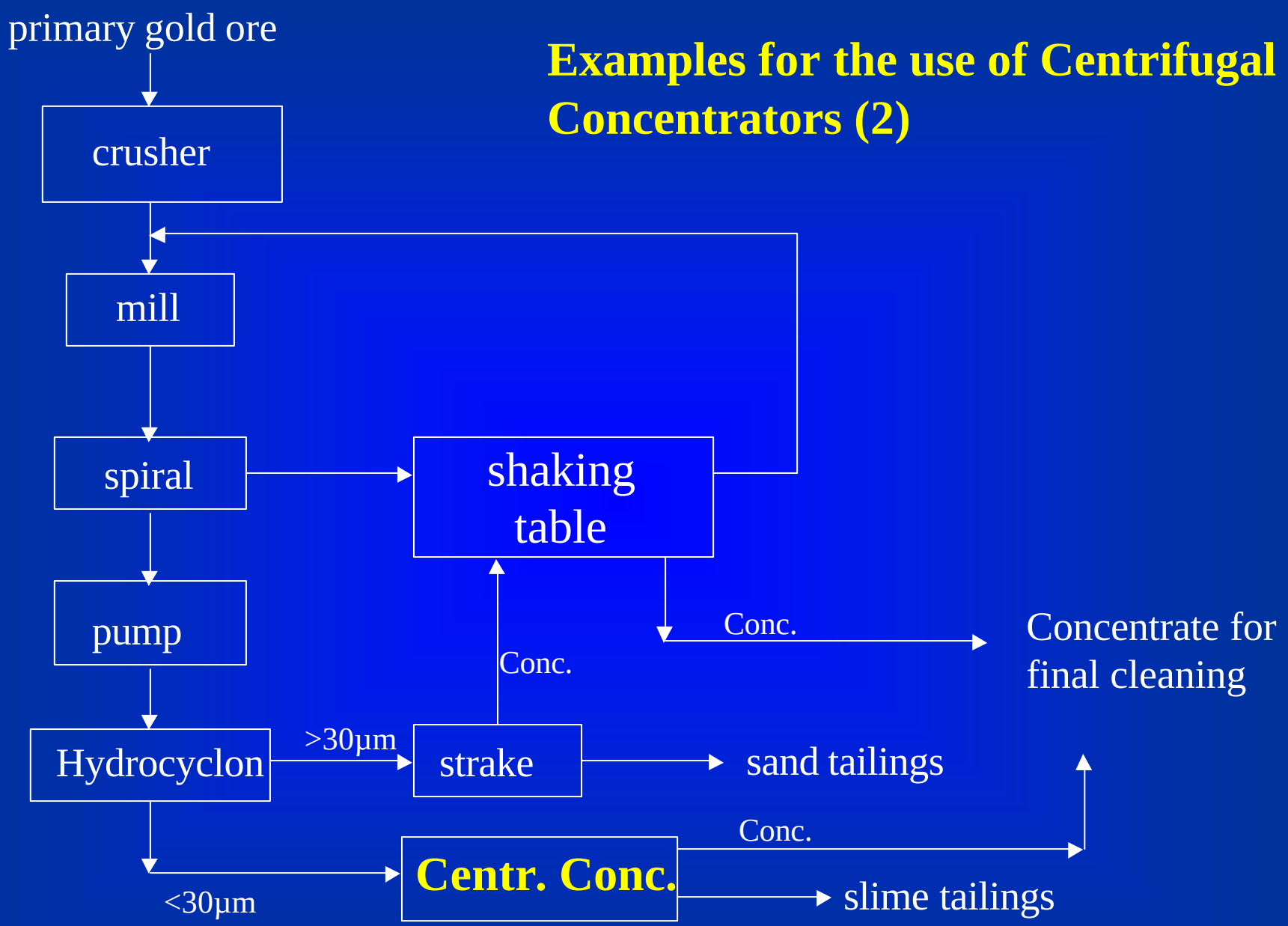
- needs clean and pressure water
- limited recovery of sulfides
- difficult handling
- needs electrical motor
- needs narrow classified feed
- local production not possible
- spare-parts and maintenance problem
- high investment costs

**highly effective, but not really a “small scale miners proof “ piece of equipment!**

# Examples for the use of centrifugal concentrators (1)



# Examples for the use of Centrifugal Concentrators (2)



# Optimization of the amalgamation of concentrates

**objective:**

- high recovery
- low production of floured mercury
- low content of gold and mercury in amalgamation tailings

**realized through:**

- use of appropriate equipment (barrels, cones, mixers)
- appropriate amalgamation time
- use of reagents to improve amalgamation process
- process control

# Mechanized Amalgamation

Amalgamation Drum

Amalgamation Mixer

# Methods for the separation of gold from amalgam recovering the mercury

- small mobile retorts

- stationary retorts

(- nitric acid followed by cementation of the mercury by metallic copper)
not recommendable

# Small Retorts (mobile retorts)

**Advantages:**

- high mercury recovery (98%) in liquid form

- light and mobile equipment

- relatively easy handling

- local production possible

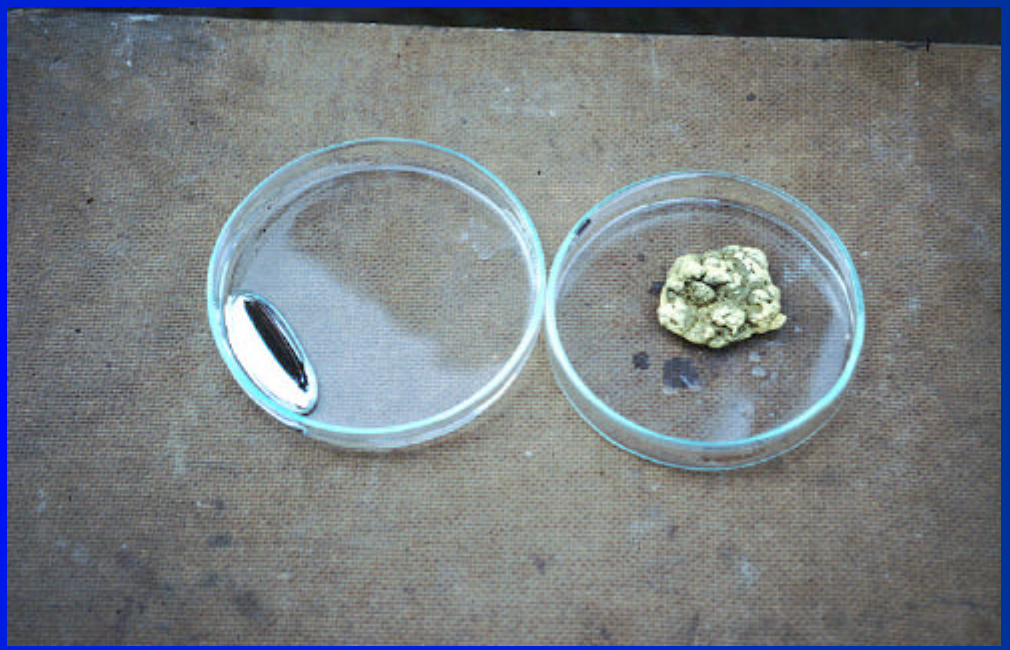
- old mercury can be cleaned

-low cost (from local production)

## Disadvantages small mobile retorts:

- gold is not visible during the process (with exception of glass retorts which break easily in normal operations, but serve as demonstration device)

- needs more time and energy than burning on open air



- gold comes out gray and dull (gold buyers pay less)

- often, no appropriate heat sources available

- poisoning through unsealed retorts occurs

- not very suitable for very small amounts of amalgam

# Large retorts (stationary)

Large stationary retorts have a air suction system driven by a ventilator. The burning of the amalgam takes place using torches, the gold is visible during the process

**Advantages:**

- amalgam and gold visible during the process

- gold comes out clean and shiny

- short process time

- mercury recovered in liquid form

- amount of amalgam does not matter

## Disadvantages large stationary retorts:

- heavy, large stationary equipment
- needs electric or gasoline motor for the ventilator
- recovery considerably lower than in small closed retorts (85%)
- relative high investment costs
- maintenance (mainly motor)

# Flotation

**Advantages:**

- for nearly every (fine) mineral
- good for fine gold and sulfides
- can produce a variety of different products

**Disadvantages**:

- needs very fine grinding
- needs reagents which are partially dangerous in handling and for the environment
- relatively high costs for reagents
- complicated process, needs very well trained operators
- reagents in non mining countries difficult to obtain
- water recycling dificult
- marketing of concentrates difficult (especially small amounts)

Only in special cases good for small scale mining!

Flotation cell floating gold bearing sulfide concentrate

# Cyanide leaching

**The use of cyanide is an alternative to mercury in small scale gold mining.**

- it makes absolutely no sense to combine amalgamation and cyanidation

- cyanide leaching of amalgamated material is producing dissolved mercu

- cyanide is a highly toxic, deadly reagent. Maximum attention has to be given to proper handling and environmental protection

Cyanide leaching is in a process of auto-diffusion
in many small gold mining areas. It is most important to start now
with education of the miners to guide them from the beginning

Percolation leaching of gold bearing gravity concentration tailings

# Cyanide leaching methods used in small scale mining

In small scale mining, mainly two methods are used

- percolation leaching (vat leaching) of sands
- agitation leaching of fines

**Advantages:**

- good recovery of gold and silver
- usable for gravity concentration tailings
- reltively simple process

**Disadvantages:**

- mercury and heavy metals in the material are partially dissolved and emitted in water and tailings
- emissions of cyanide and its components
- safety problems
- in small scale mining, rarely correct residue water treatment and tailings deposition are found

Agitation leaching

zinc swarf fresh

zinc swarf loaded with gold

# Water and Tailings Management

It is necessary to recover plant tailings to

- avoid siltation and/or contamination of rivers
- avoid problems with neighbours (farmers, fishermen)
- save the material to re-process it in future with better technology
- sell the tailings to leaching plants (primary gold mining)
- clarify and recycle process water
- work according the environmental laws and rules

Residues which require a special sealed deposit are

- amalgamation tailings (contaminated with mercury)

- tailings with sulfide content (can produce acid water)

The deposits for this materials need to have a sealed base (best with plastic and/or clay layer), and finally a sealed surface against rain and wind. Sulfide tailings should be mixed with lime/limestone to buffer acid generation.

## Methods to separate solids from tailings streams (pulps)

- sedimentaton ponds or vats (in serie)

- tailings dams (upstream raised, downstream raised)

- dry deposition using e.g. a spiral cassifyer or hydrocyclon to separate the sand from the water. The dewatered sand can be stored dry, the water with the fines has to be cleaned preferably using a thickener with flocculants.

# Methods to clarify water

**Cleaning process water is necessary to**

- recycle it and use it again
- discharge it (e.g. into a river)

**Techniques to clarify process water**

- sedimentation ponds and tanks (in line)

- thickeners (best for small scale mining: lamella type) using flocculants

To improve the environmental situation in small scale mining, by introducing alternative technologies, and /or to improve productivity

individual and adapted
solutions for each mine/deposit/operation have to be found

**„one size fits all“ - solutions do not exist !**

# General Aspects of the Implementation of Technical and Environmental Measures in Small Scale Mining or "Lessons learned" (1)

- the technical and environmental measures have to be adapted and tested together with the miners and approved by them. The proposed techniques have o be simple, low-cost, easy to operate and maintain

- simple and low-cost processes have much more potential to be used and spread out than complicated and/or expensive processes, therefore:
  - it is usually more efficient to make a massive campaign of a simple technology, which does not solve the problem completely, but is then widespre used, than to try to introduce high-tech processes, which have low probability of diffusion

- technical measures have to be accompanied by education and training of the miners, completed by long-term follow -up

- it is easier and more efficient, to optimize existing traditional processes than to import and introduce new processes

## Lessons learned (2)

- it is very important, to understand the organization of the miners, as well as the socio-economic relations and dependencies between miners, mine owners, equipmen owners, mill owners, mineral buyers, equipment and consumables suppliers, local communities, as well as religion, superstitions, habits and traditions of the miners. Generally, these factors are strong obstacles to changes and are much more difficult to change than technical aspects

- one successful introduced measure- no matter how big- builds confidence and opens doors for more substancial changes.

- it is necessary to think and act in integrated solutions (environmental protection, production health, energy, etc.)

# Lessons learned (3)

- Small scale miners are usually very open for co-operation, but will usually not accept to be patronized. Any solution has to be found together with them, not over them

- Working groups should incorporate not only technical staff, but also social experts and small miners, who serve as a link and translators

- It is very difficult to co-operate with an unorganized mass of miners or individuals. First step of a co-operation has to be helping to formalize the organization of the miners (e.g. founding of co-operatives or small enterprises). A clear structure within the miners groups is needed to establish key-persons and responsibilities. Desirable democratic structures within the miners (e.g. co-operatives) can slow down decision processes very much; small enterprises are generally more easy to handle.

- If it is expected from the small miners to install environmental measures or to implement environmentally sound mining and processing processes, there are two options: either the project pays for it or, better, win-win solutions with economical benefit **and** reduced environmental damage are identified, which can be used by the miners

# Lessons learned (4)

- A co-operation does not mean to make the small miners dependant, especially financially, on the project. It must be the aim of the co-operation, that the small miners operate their workings in a social, environmental and financial (self)-responsible manner.

- If the small miners are not the only locals in the area, the other groups have to be included in the project or have to have the chance to be included in other special projects (with indigenous people, etc.). If not, confrontations between the preferred miners and the other groups are unavoidable and affect the relation to the project, too.

- In cases of confrontation and/or deep disagreement between project and small miners, it turned out to be positive to make use of external consultants as mediators, which do not belong to either of the groups

- Any decision concerning the project have to be openly discussed in regular meetings with the representatives of the small miners, major issues have to be treated in general assemblies, where all miners take part

# Lessons learned (5)

- Responsibilities on both sides (project-miners) have to be assigned clearly. All essential decisions and agreements have to be done in a written form (contract)

- Small miners are not used to accept reports, data and studies. They need to see, touch and try out the new to technologies they are expected to use. Finally, small miners are learning by doing. Approach to more complex technology has to be done stepwise

- Mistakes cannot be avoided completely and are necessary in order to learn. Every learning process takes time!

- Small miners tend to over-estimate their capabilities in handling complex equipment, but: see point above!

- Be aware that the opinion of the leaders does not necessary reflect the opinion of the majority, many small miners are not used to express their thoughts in general assemblies!

## Lessons learned (6)

- it is absolutely necessary to guarantee a long-term follow-up of the introduced measures. Short-term engagements do usually not lead to sustainable results

- the proposed measures have to be within the economic range of the average miner in the area

- it is important to leave the level of “pilot operations” and start with massive campaigns to dpread out the proven and successfull measures. Only one or few pilot mines does not usually mean taht they spread out “automatically”

- There are no “one size fits all” solutions!

## Conclusions (I) :

It is possible to introduce “cleaner” technologies to small scale miners

Each case is different, there are many possible solutions

Principal factor for acceptance, apart from cultural problems, is the need to combine ecology and economy in the proposed solution

## Conclusions (II):

The proposed technologies have to be low-cost, easy to handle and highly effective, they must fit into the social/cultural background

These technologies exist, there is not much need for investigations and/or studies

Massive campaigns to spread out the knowledge and to introduce and implement the cleaner technologies are needed now

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