SPECIAL REPORT

Technology and problems of small-scale mining in South America

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Tin and tungsten mining in Bolivia, coal- and gold-mining in Colombia are discussed as examples of the current situation and the technical problems that face small-scale mining in South America.

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SMALL SCALE MINING (SSM) IN SOUTH AMERICA

Introduction

For the last two years, Projekt-Consult GmbH has been working for the *German Agency for Technical Cooperation* (GTZ) on the "Tools for Mining" project, the aim of which is to propose technical alternatives to the people involved in small-scale mining. The purpose of these technical innovations is multifarious assistance in helping to solve the problems of small-scale mining, namely by:

- improving operating results by increasing the recuperation of metal content
- securing jobs with low specific labour costs
- raising production through partial mechanization using regenerative sources of energy
- improving work safety
- avoiding pollution

A handbook has been produced containing not only the techniques required in the field of ore/mineral processing, but also analytical studies on underground and open-cast mining and on the supply of energy. Technical proposals for solving problems, as well as suggestions on improving the organisation of working practices are also included. Here the study examines traditional mining machines, modern small-scale mining equipment and traditional techniques. Concerning all small-scale mining activities in the Andean region, additional measures are necessary for protecting the source areas from deforestation and the burning off of vegetation.

Importance and problems

The Andean zone of the South American subcontinent has a 400 year old mining tradition. Apart from the internationally known large scale and medium-sized mining operations, eg the gigantic copper open cut in Chuquicamata, there are numerous small-scale mines. According to Nötstaller, the following raw materials in South America are mainly mined in small-scale operations (Table 1).

With regard to the size of the operations and their production, the limits for small-scale mining do vary somewhat from country to country, however, small-scale mining can generally be characterized by the following:

- large share of manual work due to low mechanization level,
- lack of qualified technicians employed by the mine and therefore a great demand for advisory services,
- ignorance of the reserve situation because of unsatisfactory geological and ore- body surveys and as a result,
- limited access to credit,
- bad safety conditions,
- relatively unplanned mining, mostly in the form of irregular face workings and
- a marginal revenue situation.

Small-scale mining is therefore in a vicious circle (Fig 1).

By using two examples, the technical level of small-scale mining in South America will be demonstrated and the specific problems will be described. Small-scale mining of tin and tungsten in Bolivia shall open up the examples.

SSM of tin and tungsten in Bolivia

Apart from the unofficial sector, a kind description of cocain trafficing, around 95% of Bolivia's foreign currency at the beginning of the 80's was earned by exporting mining products. Metals mining in Bolivia is grouped as follows

- The state-owned COMIBOL,
- Minería Mediana, large, private consortiums,
- Minería chica, the private small-scale mining and
- Cooperative mining.

Small-scale mining and the cooperative sector, which best survived the economic crisis in the 80's, face large mining and processing problems. Unlike the state-owned and medium sized mining sector, which uses modern, mechanized techniques of a near industrialized country standard, the small-scale mining and cooperative sectors still work with traditional procedures.

It involves simple, labour-intensive processes with home-made machines. Nevertheless, these two sub-sectors contribute 30 % of the value of domestic production.

Small-scale tin and tungsten mining operations in Bolivia are carried out by more than 4 000 mines. As a rule, these are based on vein-type ore bodies with simple paragenesis and medium to coarse intergrowth of the minerals.

Mining methods

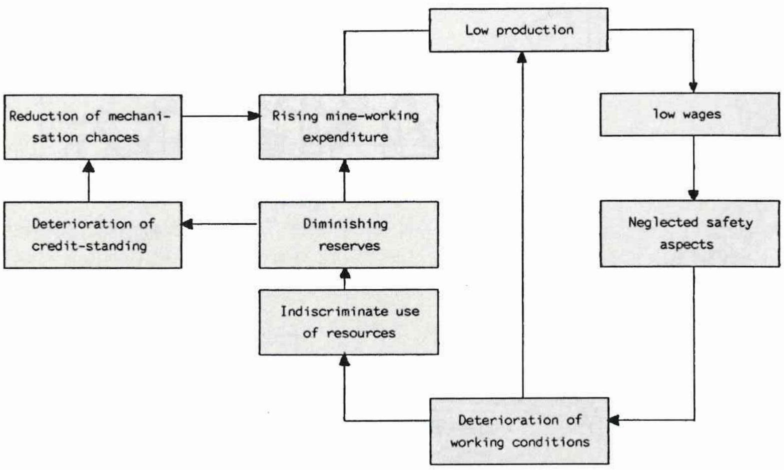
Underground mining is characterized by small-scale stall working in a mainly manual procedure. The dimensions of the workings are kept as small as possible and frequently only the richest veins are mined in a coyoting fashion. Artificial ventilation of the pit or other mine locations is unusual. Due to high investment costs, there is frequently a lack of compressors and compressed air systems, and drilling is therefore done mainly by hand. Advance per round lengths of 30 cm and less can be seen. Loading is also done by hand, leather sacks and hand winches are used for conveying. Hand-pushed wagons are used in the tunnels. If required, drainage is carried out using leather sacks. Walling is a great problem in the highlands with its lack of vegetation. Occasionally artistically set connection stone arches are used.

The situation in cooperative mining is particularly difficult. Although the large number of personnel there would favour delegation and diversification of the actual mining work, the high level of distrust has led to a form of organisation named Cuadrilla. In a Cuadrilla, four workers form a mining cooperative. Each cuadrilla is allocated a section of the stretch to be mined eg 15 m, from which the mineralized structure can be mined upwards or downwards. Frequently, the lack of oxygen in the unventilated pits interrupt the mining prematurely. Each Cuadrilla is responsible for the mining, transport and even the processing of its own raw ore. There is naturally no exploration strategy in this kind of "mining".

Table 1
Most important mineral commodities extracted by small scale mining in South America

Argentina	Antimony, asbestos, beryl, bismuth, columbite, lithium, mercury, tantalite, tungsten, vermiculite
Bolivia	Antimony, copper, gold, mercury, silver, sulphur, tin, tungsten, zinc, lead
Brazil	Beryllium, chromite, columbium, gold, precious stones, tin, titanium
Chile	Barite, carbon, copper, gold, lead, manganese, mercury, sulphur
Colombia	Antimony, carbon, chromite, emeralds, gold, iron ore, lead, mercury, precious stones zinc
Peru	Antimony, bismuth, copper, diatomite, gold, lead, manganese, molybdenite, silver, tin, zinc
Venezuela	Asbestos, diamonds, gold

Figure 1
Vicious circle of small scale mining



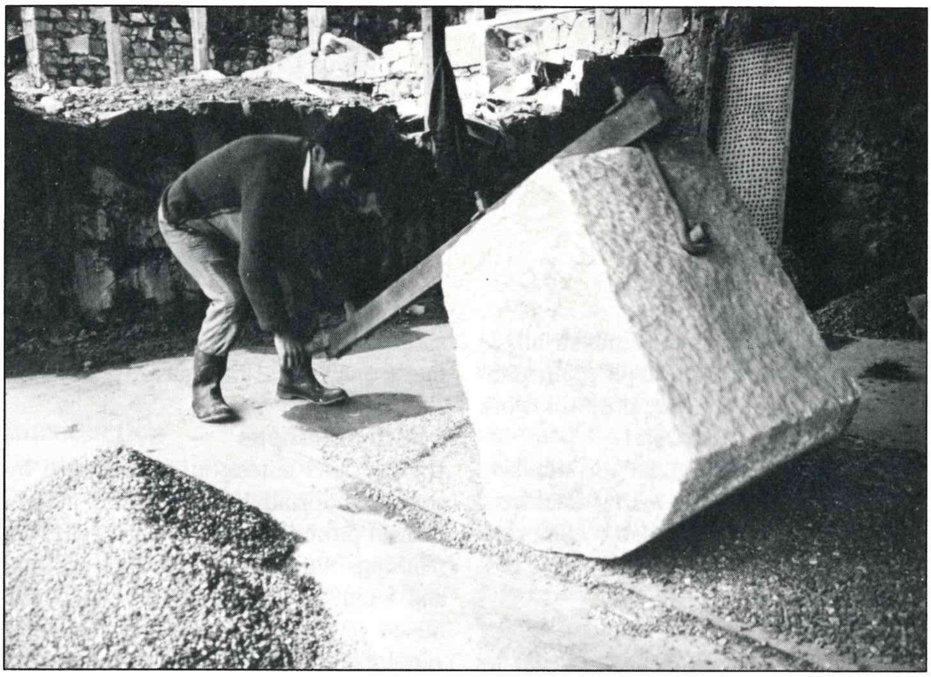
Processing techniques.

To produce marketable products, the traditional processor uses large, hand-operated rocker stones for crushing the so-called Quimbaletes (see photo p 42).

Classification is carried out by using sieves, classifying drums and classification in sieve jiggers (photo page 42).

Sorting is done by using hydromechanical density separation. The coarse particles are sorted using simple hand jigs, so called Maritates. Medium sized granules are sorted in sluices. Fine products are concentrated in various forms of buddles, as shown in Figures 2 and 3.

Final gravimetric cleaning treatment can be done using the refining barrel in accordance with the dolly tub or Tina de levante.



Quimbalete, hand operated rocker stone to crush primary tin ores in the processing plant of Kalauyo mine, La Paz, Bolivia. (right).

Flotation in cells, sluices or buddles is restricted to the separation of pyritiferrous impurements from oxidic concentrates.

Sorting by hand plays an important role in grading up ores and cleaning concentrates. Drying is carried out in the sun.

The processing procedures are almost never continuous. Particularly in the fine granule sector, the ore is re-processed up to 5 times in order to achieve marketable concentrates. Middlings are also recrushed and resorted as shown in the flowsheet (Figure 3).

The traditional mining operations in their simplest form completely avoid mechanisation. The specific energy demands involved in crushing led to partially mechanized transitional forms of rustical processing procedures.

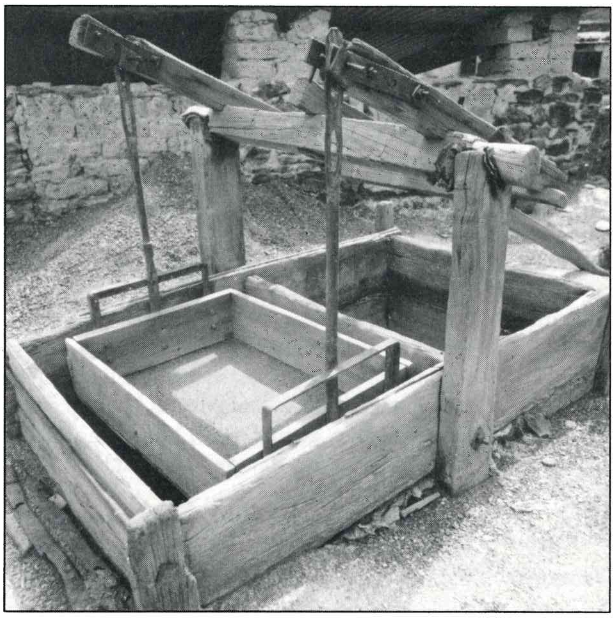
Each processing machine was examined in respect of the recovery of masses and values. The focal point was the buddle and Tina de levante, because an important role is attached to the sorting of fine granules in the processing of intergrown ores. In the case of tungsten processing the dressing recovered a mean of values in the concentrates with handjigs of around 30% with buddles of approximately 50% with tinas and sluices of around 60%.

As previously discussed, this individual procedures are linked to processes in which concentrates, middlings and tailings are retreated.

In this way it is possible for the traditional processor to maintain the total recovery rate of values around 50%. As a comparison some details regarding modern gravity separation will be given.

According to unofficial figures, state-owned COMIBOL calculates a recovery of between 36 and 48% (1989) for its operations; processing in Potosi done in hired plants reach a recovery of around 50% (incl. expenditure for rent).

A main advantage of the traditional ore processing technique is the low investment and operating costs. The installation of mechanised plants requires investment of at least 20 000 USD. Customs duties,



Maritate, simple hand jig for the gravity separation of wolfram ores, Kami, Bolivia (right).

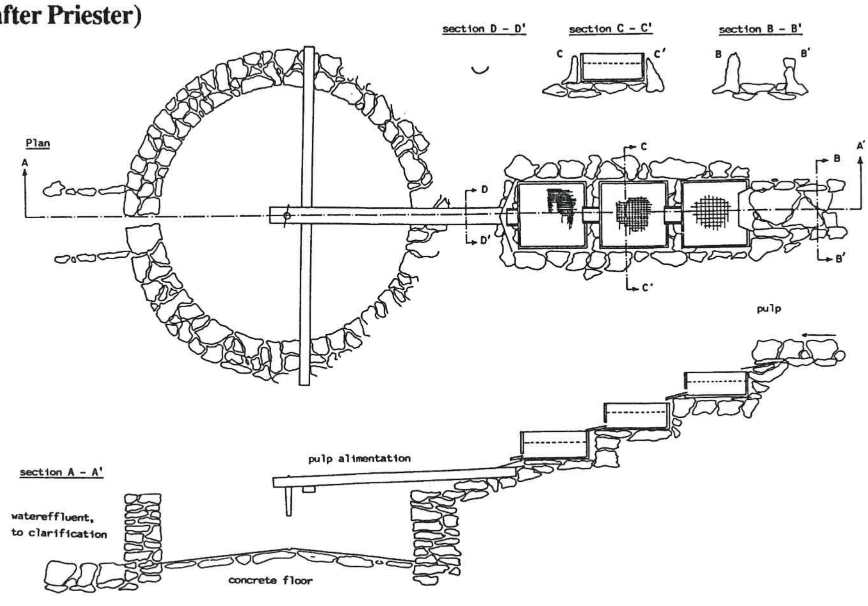
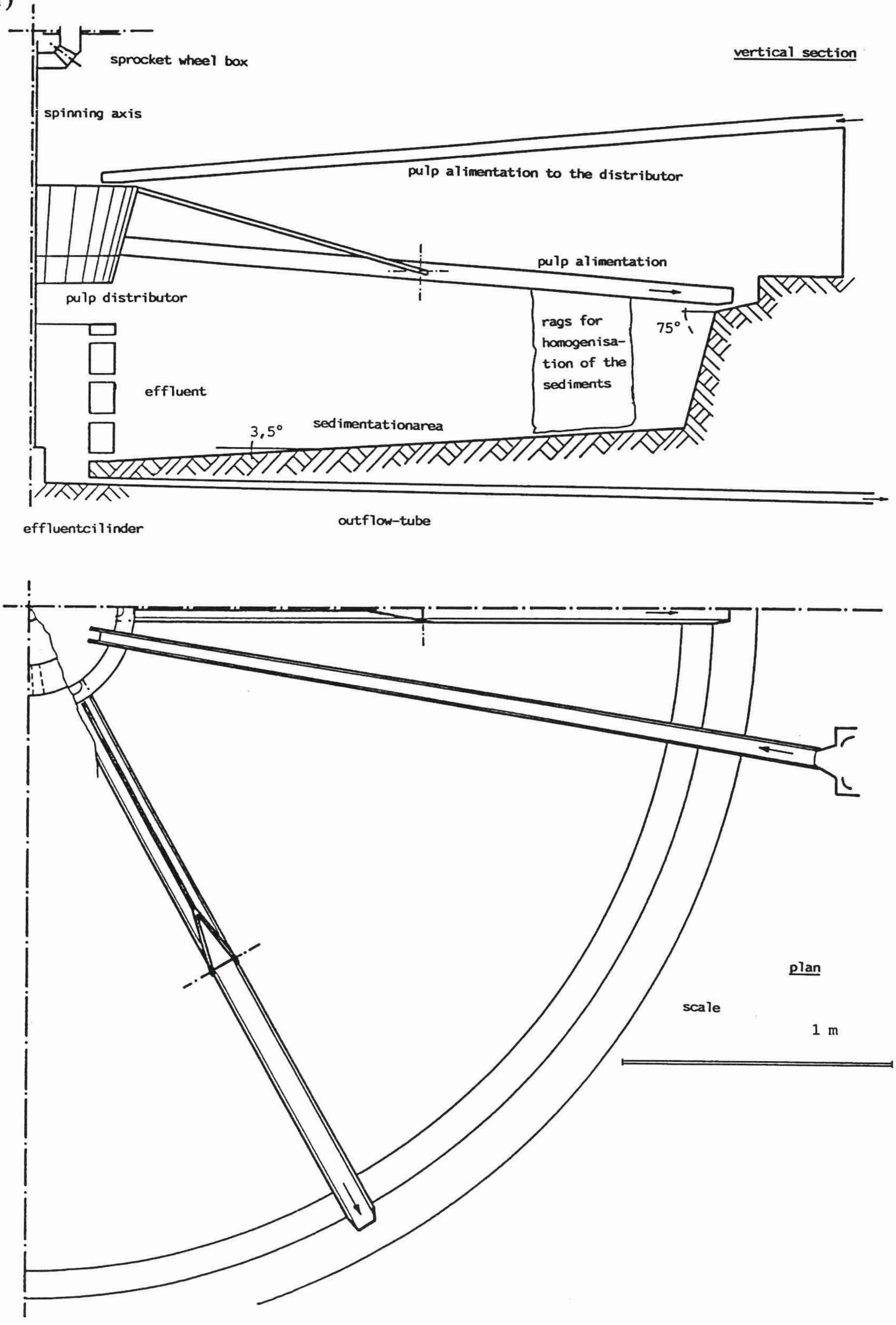


Fig 2
Bolivian round buddle with screens for classification of the mineral (after Priester)

Figure 3
Construction of a mechanized circular buddle in vertical section and plan (after Priester)



transport and assembly will double this amount. Investment of this magnitude cannot be undertaken by the small-scale mining industry because of its chronic lack of capital. Traditional plants, which cost around 10 % of the previously mentioned figure, are therefore the only choice.

The capacity of traditional processing plants is, however, very low. The manual method of work, the low throughput of the individual machines and the frequent recirculation of the products lead to a processing capacity of under 1 t/ms.

Comparing the sub-sectors the small-scale mining is at the bottom of the scale. Productivity in the cooperatives is approximately twice as high, and in the mechanized Minería Mediana, it is around seven times as high (Table 2).

Considering the high subordinates costs, such as transport, insurance, storage, production, leasing and the penalties and smelting costs, the revenue situation for miners is marginal.

Energy supply to small-scale gold mining in the Andean region of Nariño, Colombia

The energy supply of small-scale gold mining in southern Colombia will serve as a last example for the description of small-scale mining from the technological viewpoint. In the Andean region of the Southern province of Nariño small scale mining operations produce around 250 kg of gold yearly.

The driving and mining is completely unmechanized and drilling and loading of the blasted ore is done manually. Transportation of the raw ore from the pithead to the process plant is carried out using towing gear or mules.

Simple gravitational cableways are sometimes used for transportation. They consist of a pair of main cables and a brake cable running over a pulley. The haulage containers are attached to the latter with a hinged bottom. After the container is filled, gravity pulls it down and

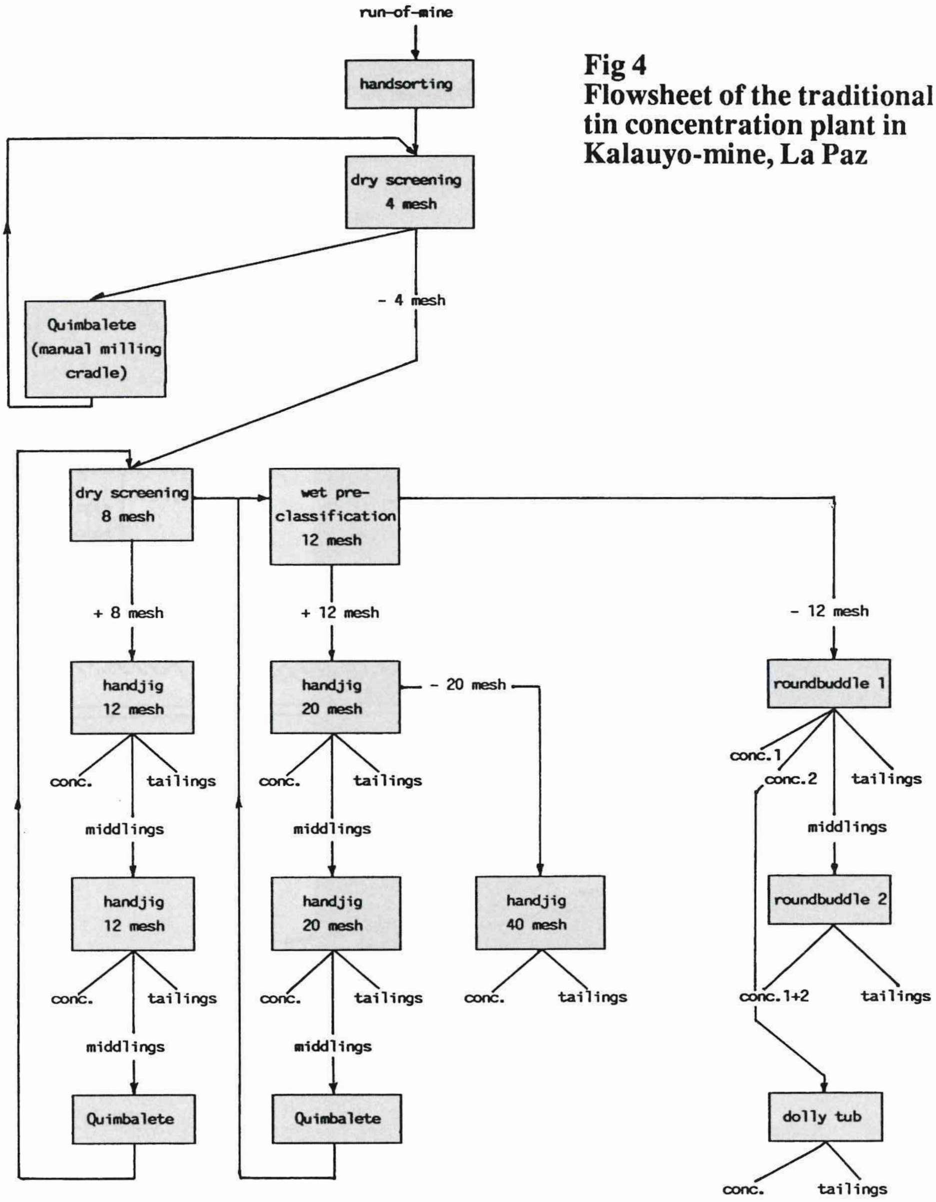


Fig 4
Flowsheet of the traditional tin concentration plant in Kalauyo-mine, La Paz

Table 2
Productivity of the different mining subsectors of Bolivia (after Stolz)

Mining subsector	Specific productivity in tin-metal--content (kg/man/year)
Privately owned, medium sized mining	4.281
COMIBOL, government owned large and medium scale mining	2.785
Cooperative mining	1.271
Private small scale mining	.626

In Colombia a locally fabricated concussion table is driven by a small improved overshot waterwheel (below).

sends its counterpart up. At the lower end, the container opens and empties itself.

The processing of the raw ore mainly takes place in plants driven by micro hydro power at the bottom of valleys. The water serves not only as energy for the waterwheel, but also as process water for gravimetric processes. In the valleys, the small plants are frequently laid out like a string of pearls for the purpose of manifold utilisation of the head of the water along the course of the water (Photo 3).

Upstream overshot water wheels constructed of wood and with a diameter of 5-6 m are used. In some cases a water system with canals from neighbouring catchment areas is constructed. In the dry season, variable precipitation can lead to temporary shortages in the water supply. A tendency deterioration in the supply of water, must, among other things, be traced back to the fact that senseless burning-off of vegetation alters the hydrological relationship in the area of the source.

Hydraulic energy utilisation is not restricted to waterwheels. Locally, there is direct drive of work machines through simple Pelton turbines, which are also used to produce electricity for lighting.

Waterwheels are in need of improvement in many respects. The shortcomings are caused by

- bad cell forms and construction (acute angled cells without overlapping)
- leaky cells and
- badly designed water chutes.

This leads to a large amount of water loss in the case of the distribution onto the waterwheel and from the cells before the water reaches the bottom dead centre. In the dry season in particular, the low level of efficiency leads to reduced performance levels. It appears to be sensible to promote the traditional hydropower utilisation and not to replace it with conventional driving. Further dissemination of hydropower through small turbines would be sensible and suited to local production eg the direct drive of compressors.

The situation described above implies that:

- Improvements must be achieved with a minimum of investment expenditure.
- A necessity for improving the qualitative utilisation of resources.
- The traditional – sometimes still completely manual – working practices can be simplified through partial mechanization with more widespread utilisation of domestic, regenerative energy resources.
- New machines have to be adapted to the socio-cultural context of the miners.

There is a need for machines, which are simple, require little maintenance, are easy to use and repair, durable, environment-friendly and which can mainly be built by the miners themselves or local craftsmen.

As a result of the project "Tools for Mining" a manual on around 125 different techniques and machines for small scale mining in developing countries is now available. The datasheets for each technique consist of a collection of technical and economical data, photos and drawings of local manufacture.

The target group of this manual are technical assistants, consultants for small scale mining, mining commissioneers, technicans and engineers in the ministry of mines, the local supply industry and engineers in small scale mining.

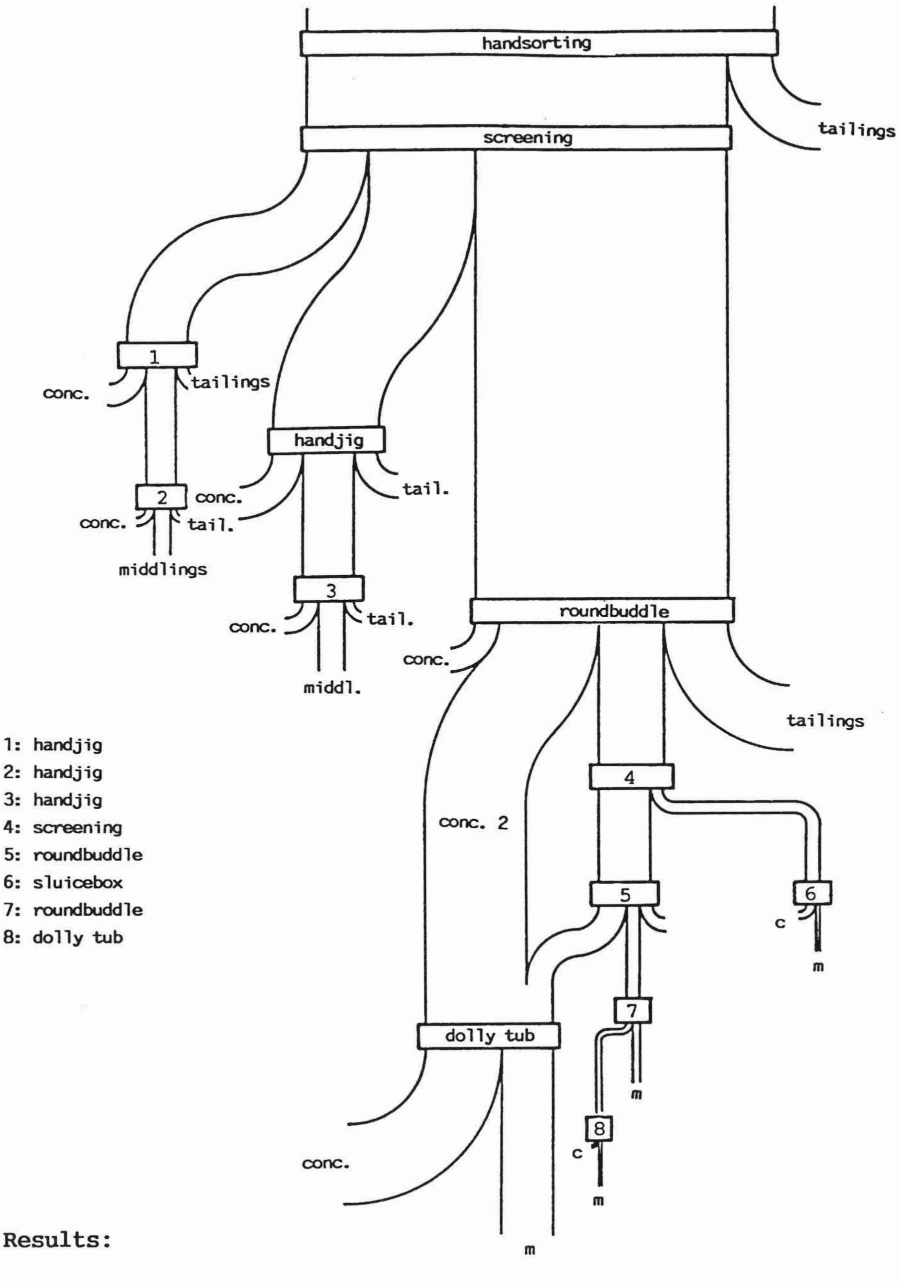
SSM-Promotion by technical innovations

In the framework of a pilot project, based on the suggestions made in the handbook, a practical implementation of small-scale mining promotion using appropriate technology, was evaluated. The project was carried out in the previously mentioned Andean region of Nariño and should be regarded as a successful example of technology transfer for small-scale mining.

PROBLEMS

The raw ore in this region is characterized by an extremely fine intergrowth of native gold (94 % with a fineness level of between 790 and 850 o/oo) with quartz and a high grade of sulphides. The sulphides involve pyrite, arsenopyrite, chalcopyrite, pyrrhotite, marcasite, molybdenite, galenite and sphalerite. The orebody parameters indicate that a fine grinding of

Figure 5
Flowsheet of values in a traditional tin concentration plant

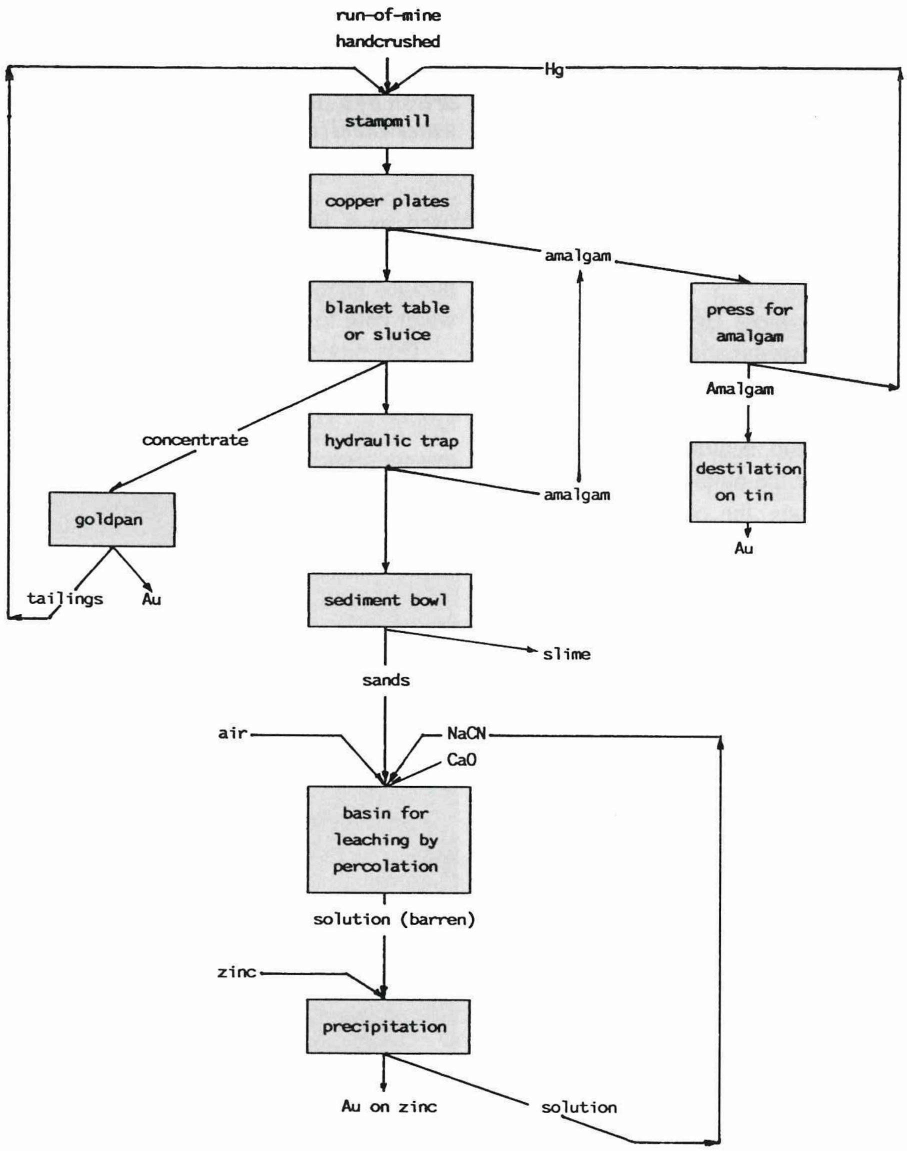


Results:

values in concentrate:	40,23 %
values in tailings:	37,00 %
values in middlings to be retreated:	22,77 %

recovery of values: 52,1 %, if the retreatment shows the same recovery as the whole rom
47,1 %, if you calculate on 30 % recovery of values for the middlings during retreatment

Figure 6
Flowsheet of the gold plant of Los Guavos-mine, Sotomayor, Colombia



the raw ore is necessary (distinctly under 100 m). Processing of the ore is done by hydromechanical gravitational processing, amalgamation and cyanadi leaching as specified in the process flowsheet (Figure 6).

Due to a comparatively low recovery and low throughput of the processing systems, it was decided to implement improvements particularly concerning the processing procedure. The environmental damage caused by the intensive use of amalgamation forced immediate measures to be taken. An evaluation test of the throughput made it clear that a plant examined released around 5 kg of mercury per month. The technique for preventing environmental damage from mining activities was the most important part of the study.

Implementation

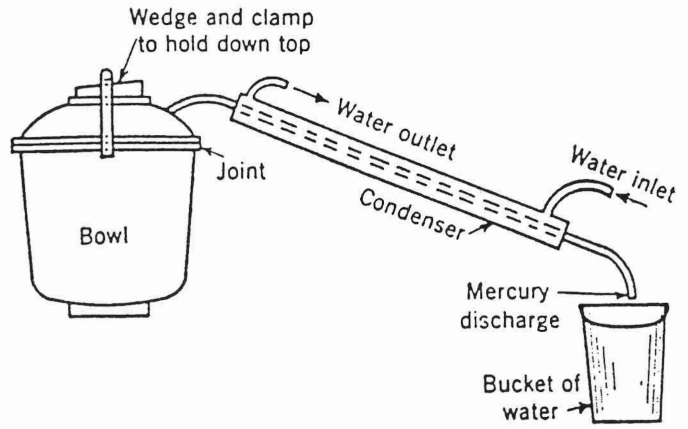
A local workshop in Pasto, the provincial capital, constructed:

• a concussion table for the improvement of gravimetric processing and

• a set composing an amalgam press, a hydraulic trap and a mercury retort, to prevent the release of mercury in the course of the amalgamation process.

The equipment was installed in the field during the second phase of the project, tested and improved.

Figure 7
Construction of a retort for the destilation of amalgam (after Bernewitz)



The practical project results

The retorts, which were manufactured in two different forms, revealed a mercury recovery of around 90% in the initial tests. After small construction adjustments, which improved the thermal conductivity and minimized the loss of condensated mercury on the retort walls, a dissemination-ripe model was produced in a small series of seven (Figure 7). The amalgam press field tests showed a greater selectiveness in separating amalgam and mercury. To improve the prototype an anti-corrosive surface coating was necessary, and this was achieved by nickel-plating the press (Photo 4).

In the practical tests, the hydraulic trap revealed a recovery of around 85 %, even though it lacked the adjustment experience for counter flow water feeding. Improvements were made regarding the

In Colombia locally fabricated nickel plated amalgam press to separate free mercury from amalgam (top).

Locally fabricated concussion table driven by a small improved overshot waterwheel (bottom).

angle of taper, the kind of taps and the geometry of the underwater distribution (Figure 8).

The three-piece Hg set can thus be regarded as dissemination ripe. Acceptance seems to be high because the sensitivity towards the danger of mercury for the environment and health had distinctly increased after the duration of the project.

In test runs, the concussion table revealed very great selectivity, where even fine gold of distinctly under 20 m was recovered in the concentrate. In this way, the recovery of rest gold particles took place in tailings which had already been sorted several times. With more experience, it will be possible to adjust the device for greater sensitivity (Photo 5)

In comparison to the price situation for imported goods, locally fabricated equipment has been quite cheap. This is shown in Table 3 listing prices for mineral dressing equipment fabricated in Colombia.

Appropriate development

The retorts will be used as a brief example to show how appropriate development of prototypes is derived. The problems, such as incrustation of the gold destillate and mercury loss through condensation in the retorts, were tackled as follows:

1. The further reduction of the strength of the material and the turning off of roughness, as well as leaving stand a cone lifter ring to catch the falling Hg pearls near the lowest point of the crucible.

2. The installation of a bellows with a clack valve in a second pipe for exchanging the mercury atmosphere at the end of the destillation process. This change was abandoned at a later stage because more tests showed that mercury condensed in the blow pipe. The amounts were the equivalent to the mercury which was driven out.

3. The construction of a pipe retort in which the pressure of the blow lamp was used as a heating source to drive the destillation fumes and gases through a buckled pipe, which sometimes lay in the water bath to condense the Hg.

This pipe retort was open at the back and the front and had a diameter of around 2". This construction was not continued after field trials, because the mercury recovery rate was far below that of conventional retorts and due to the large condensation surfaces, large amounts of Hg attached themselves to the interior of the pipe surface in the form of finely distributed films of

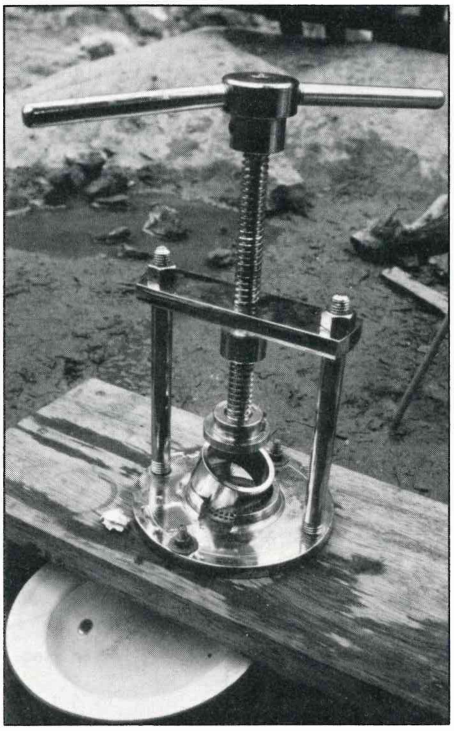
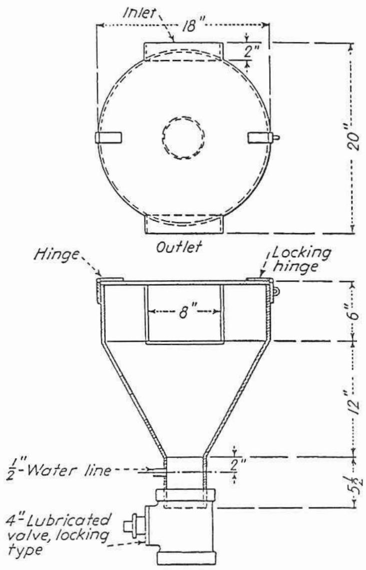
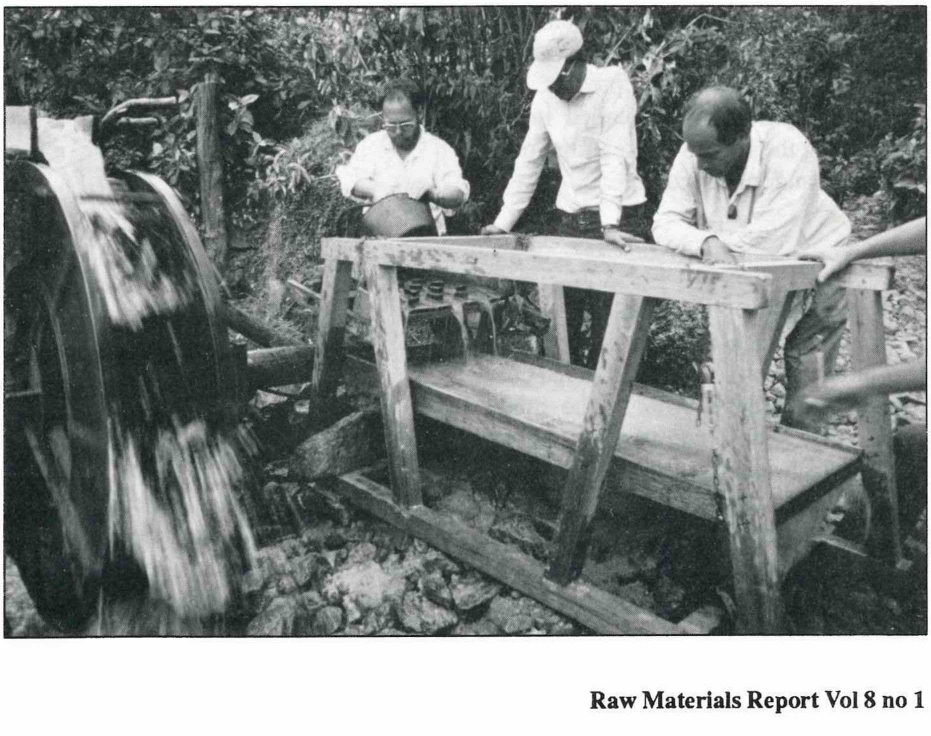


Fig 8
Hydraulic trap to recover gold, amalgam and mercury (after Bernewitz)





pearls, which even water and tensides could not wash out and cleanse.

Confidence building measures

In Quito, a technical glassblower was commissioned to construct a fireproof glass retort for the destillation of amalgam. This retort was used for demonstration purposes and is intended to improve the acceptance of such retorts among the miners.

The miners from the area were repeatedly involved in carrying out the examination of the recovery of values and of contents in the tailing by panning the products.

Outlook

These examples of supplying the SSM with locally fabricated low cost tools may prove the viability of small scale mining promotion by appropriate technology. This seems to be the only solution of breaking up the above mentioned vicious circle by the SSM itself.

The practical phase of implementation could include the following important components:

- Local manufacture of appropriate mining and ore/mineral processing machines in national crafts firms and/or small-scale industries. This meets the demand in the country itself and can lead to an intensification of South-South cooperation.
- Advice for small-scale mining firms accompanied by the installation of appropriate equipment and support for the development thereof etc.
- Training measures, schooling of small-scale mining personnel, planners, advisors in suitable training centres, in eg subjects such as analysis, economic geology of mineral deposits, organisation of work, mining and ore/mineral processing techniques, work safety, marketing and economics.
- Devising and implementing environmental protection measures in small-scale mining (preventing mercury emission in gold-mining caused by amalgamation, avoiding the problems of cyanide leaching of gold ore, the excessive strain on draining caused by the too high a quantity of reagents used in floation processes).

SUMMARY

Selected examples describe the current situation and technical problems of small-scale mining in South America. The tin- and tungsten-mining situation in Bolivia, and energy problems in primary gold mining from Nariño, South Colombia are discussed.

The GTZ project "Tools for Mining" is to be seen as the answer to typical small-scale-mining technology problems. The aim of this project is to devise a technical and work-organisation handbook for small-scale mining in development countries.

The last part of the publication presents the results of pilot studies in connection with the small-scale mining project "Tools for Mining". The basic challenge were the technical problems of processing extremely fine-grained gold ore from Nariño and severe environmental problems caused by mercury emission from the amalgamation process. Possible solutions using reasonably priced locally manufactured mining equipment are demonstrated.

Table 3
Pricelist for equipment for mineral concentration fabricated locally in Colombia

Retort for distillation of amalgam	70. -- USD
Retort for demonstration, made of pyrex	120. -- USD
Hydraulic tramp	60 – 100. -- USD
Press for amalgam	75. -- USD
Concussion table	150. -- USD

Sources:

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