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An Environmental Study of Artisanal, Small, and Medium Mining in Bolivia, Chile, and Peru



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Foreword

Throughout much of Latin America and the Caribbean there has been a revitalization of the mining sector in recent years. While in the 1980s Chile led the way, the 1990s have seen a spurt of activity across the region. In six countries of the region—Bolivia, Chile, Guyana, Jamaica, Peru, and Surinam—mining accounts for between 5 and 50 percent of GDP and over 25 percent of export revenues. Exploration investment in the region has increased 130 percent in the last five years, a figure which increases to 500 percent if Chile is excluded.

Governments have revamped legislation, especially mining codes, to create an enabling environment for private investment while becoming more sensitive to the environment. These two trends are not contradictory as the importation of state-of-the-art foreign technology is seen as one of the main methods of improving the environmental performance of the sector.

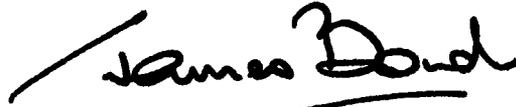
While in “day-to-day” operations the recently developed or rehabilitated medium and large mines have tremendously improved their environmental performance, the same cannot be said for artisanal, small or older medium and large mines. Paradoxically public concern generally continues to be aimed at large companies and not at artisanal, small, and older medium mines, even though a growing body of evidence suggests that the latter three are clearly a major problem.

This report examines the environmental effects of artisanal, small, and medium mines in three Latin American countries—Bolivia, Chile, and Peru. The researchers, who were all based in the respective countries, undertook three main tasks. First, they evaluated the environmental performance of artisanal, small, and medium mines to assess their environmental impact. A question of particular importance was whether or not artisanal and small mines were economically viable when environmental costs were taken into account. Second, they analyzed the policy framework in which the mines operated and recommended policy actions to improve environmental performance in the future. Third, given that indigenous groups, with their historic and close ties to the land, are often an important stakeholder when discussing mining and the environment, emphasis was placed on the relationship between mining, the environment, and indigenous groups. As part of the project, a study of the historical development of the relationship between the mining sector and indigenous populations in Canada was included in order to disseminate lessons for the three Latin American countries from Canada's experience.

The studies were undertaken and this report has been prepared to provide input to the mining sector, local communities, government policy makers, academics, and international institutions. Four of the most important elements to be considered are the age of the mine, which is often more important than its size, management of tailings

dams, the heterogeneity of the artisanal and small mine sectors, and the increasing need to take cultural considerations into account in the decision-making process.

Finally, I would like to mention that this work could not have been undertaken without the support and funding of the Canadian Foundation for the Americas (FOCAL), the International Development Research Centre (IDRC), the Canadian International Development Agency (CIDA), the Government of Switzerland, and the Government of Austria.

A handwritten signature in black ink that reads "James Bond". The signature is written in a cursive style with a long horizontal stroke extending to the left.

James Bond

Director

Energy, Mining and Telecommunications Department

Abstract

The paper synthesizes a study examining the environmental performance of artisanal, small, and medium mining in Bolivia, Chile, and Peru. Summaries of each of the three country studies are also included. Significant emphasis is placed on the viability of artisanal, small, and medium mines if environmental costs are taken into account as well as policy actions to improve the environmental performance of viable mines. Given that indigenous groups, with their historic and close ties to the land, are often an important stakeholder when discussing mining and the environment, particular concern is also placed on the relationship between mining, the environment, and indigenous groups. As part of the project, a study of the historical development of the relationship between the mining sector and indigenous populations in Canada was included in order to disseminate lessons to the three Latin American countries from the rich Canadian experience.

The most important conclusions and recommendations are: (a) The distinction of mines by size is not as important as age, at least with respect to medium and large mines. (b) The management of tailings could be opened up to market mechanisms. (c) Artisanal and small mines form a very heterogeneous group. Those which are economically viable, including environmental costs, should be encouraged. Those which are not economically viable should not be encouraged or subsidized as such actions would only prolong uneconomic and polluting activities. Mining policy should not substitute for social policy. (d) Cultural and social considerations are increasingly important in the decision making process of the mining sector, from the perspectives of both business and government.

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Abbreviations and Acronyms

ARD	acid rock drainage
ASM	artisanal and small mines
COCHILCO	La Comisión Chilena del Cobre
CODELCO	La Corporación Nacional del Cobre (Chile)
COMIBOL	La Corporación Minera de Bolivia
COMSUR	Compañía Minera del Sur (Bolivia)
CONAMA	La Comisión Nacional del Medio Ambiente (Chile)
ENAMI	Empresa Nacional de Minería (Chile)
IENIM	Industry and Mining Division of Industry and Energy Department, World Bank
ILO	International Labour Organization
LAC	Latin America and Caribbean Region
LAMS	Latin American and Caribbean Mining Strategy paper by World Bank staff
MMS	medium mining sector
PAMA	El Plan de Adecuación Medio Ambiental (Peru)
RTZ	Rio Tinto Zinc (recently renamed to Rio Tinto)
SERNAGEOMIN	El Servicio Nacional de Geología y Minería
SONAMI	Sociedad Nacional de Minería (Chile)
UK	United Kingdom

1

Introduction

Throughout much of Latin America and the Caribbean (LAC) there has been a revitalization of the mining sector in recent years. Whereas in the 1980s Chile led the way, the 1990s have seen a spurt of activity—political, exploration, and excavation—across the region. In six countries of the LAC region—Bolivia, Chile, Guyana, Jamaica, Peru, and Surinam—mining accounts for between 5 and 50 percent of GDP and over 25 percent of export revenues. It is also a significant, albeit relatively smaller activity, in Brazil, Colombia, and Mexico. Exploration investment in the region has increased 130 percent in the last five years, a figure which increases to 500 percent if Chile is excluded.¹

The political side of the story has been centered on revamping legislation, especially mining codes, to make the sector more attractive for private and foreign investment and more sensitive to the environment. These two trends are not contradictory as the importation of state-of-the-art foreign technology is seen as one of the main methods of improving the environmental performance of the sector.

Due to its inherent nature (creative destruction) and the above developments, mining is one of the sectors attracting most attention from the viewpoint of sustainable development and the environment. Mining² is generally seen as an important polluter despite the great improvements that have been made over the years. This may be due to lack of knowledge or due to focus on a number of isolated environmental/cultural incidents. Significantly, it is also the sector where the greatest transfer of “clean” technology has taken place in recent years. Given the opening up of most countries of the Americas to joint ventures and foreign investment, this transfer is likely to increase significantly in the near future provided the right policies are in place. Noteworthy is the fact that new investment in large and medium sized mines often follow standards more strenuous than those of their host country, given that their technology is based on the

1. See IENIM (1996).

2. In this paper the generic term “mining” includes prospecting, construction of mines, extraction, concentration, and smelting of non-oil and gas minerals.

2

The Medium Mining Sector and the Environment

Traditionally the mining sector is divided into large, medium, small, and artisanal mines according to the tons of rock treated each day and/or the amount of sales. For example, the Latin American and Caribbean Mining Strategy paper (LAMS) defines a medium mine as one with daily operations of 1,000 to 5,000 tons and annual sales of \$10 million to \$100 million.^{3,4} Small miners have operations of up to 1,000 tons/day and annual sales under \$10 million. Artisanal miners are very small miners with little or no mechanization. While the Chilean and Peruvian studies in this paper more or less fit these guidelines, the situation was more complicated for Bolivia. Until recently the large mine sector was synonymous with the state owned COMIBOL whereas all private mines above a certain size were considered medium mines. With the breaking up of COMIBOL, including the capitalization of some mines, the formal definitions no longer make much sense. Therefore, the medium mine sector is considered any operation above 500 tons per day. The Bolivian paper discusses separately two new joint ventures, Inti Raymi (Battle Mountain) and COMSUR (RTZ), the former of which is a large mine by the LAMS definition (since 1994) while the latter is a medium-sized company.

One of the most important results of the present study was that with respect to environmental performance the distinction between medium and large mines is not near as important as the distinction between old and new mines. One of the main hypotheses of this study was that large mining operations had mostly cleaned up their environmental performance but that artisanal, small and medium mines had advanced very little. In fact, it was assumed that the next major environmental improvements should be targeted at the medium mining sector as, unlike the artisanal and small miners, they were relatively easy to monitor and had access to capital. However, the studies show that, similar to new large mines, new medium sized operations are usually foreign-owned or joint ventures and use state of the art technology. The perception that medium is dirty and large is clean

3. See IENIM (1996), page 48.

4. All monetary amounts in this document are in US dollars.

An indirect solution to environmental problems associated with tailings is resort to the courts by affected citizens. This has already occurred in both Chile and Peru. Of course, the success of such actions depends on well-defined and workable legislation, as well as the ability of companies to pay damages or compensation. While this seems to be the situation in Chile and Peru, it will likely be some time before the same can be said in Bolivia, given the long, difficult period that its mining industry has come through and the recent nature of the mining code and environmental legislation in general.

The complexity of the environmental problems associated with tailings is readily seen in the case of the breaking of the tailings dam at the Porco mine in Bolivia. The mine is part of a joint venture between RTZ of the United Kingdom and COMSUR of Bolivia, with the former operating the mine. The tailings dam was of a recent vintage but it collapsed due to improper management. Nevertheless, the company moved quickly and the ultimate damage was much less than expected. In sum, we have a case of a well-intentioned company using new hardware but the software (management) was of a different vintage. At the same time, the company had sufficient capital (and reputation) to mitigate the damage significantly.

Competition for scarce water resources is a significant problem facing the MMS in all three countries as most medium mines are located in dry to very arid climates. The problem is exacerbated, of course, if the mines are polluting part of the existing limited water supplies, a particularly serious problem in Bolivia and Peru. The Peruvian and Bolivian studies report that the most serious social conflicts between the MMS (as well as small mines) and local communities is due to pollution of the limited water supplies. Many legal actions have been taken against mining companies by the mayors of small towns in Peru. Even when water pollution is not a serious problem, mining is a thirsty industry which can put significant demands on existing water supplies. Bolivia's most important mining region, the Altiplano, covers 13 percent of the country but has only 0.5 percent of the water. In some regions of Chile 50 percent to 60 percent of water rights belong to the mining industry. Water rights are allocated without cost in Chile, although they can later be traded. In addition, the groundwater rights are included with the mineral concession.

While solutions to the tailings problems will resolve many of the problems associated with scarce water resources, recycling of water in mines and the move to processes which use less water will also be important. Paradoxically, some of the most important innovations to reduce water use pose new threats to water supplies. In particular, concentration processes using leaching, which are becoming common in the copper industry in Chile, use much less water than traditional methods based on flotation, but they can also require more hazardous reactive agents such as cyanide and sulfuric acid. When these processes are being used, it is essential that the ground is covered with impermeable materials.

Finally, the creation of fully functioning markets for water is an essential step in its conservation. Water rights should not be awarded at zero cost but sold or auctioned.

age of the mines, processing plants, and smelters. More creative solutions are only likely to be necessary in the case of active mines which do not have enough reserves to justify large environmental investments, although it was noted that the cost of properly storing tailings could be considerably reduced through building joint facilities or creating a market to provide such a service. Moreover, the reprocessing of tailings could offset a significant part of the investment cost. In general, the problem of proper mine closure needs to be given more study and thought for a segment of the industry which generally proceeds on the basis of four years of proven reserves, generally an inadequate period of time to amortize environmental investments. It is also clear that there is a need for environmental investments in people as well as technology. Finally, in the case of abandoned mine sites near populated areas, the burden of responsibility for clean-up is on the government unless the former owners can be identified.

3

Artisanal and Small Mines and the Environment

The outstanding characteristics of the artisanal and small mine sectors (ASM) is its informality and heterogeneous nature. A common perception is that it is very dirty—barely feasible even if environmental costs are not included and not at all when they are. Moreover, its problems are commonly perceived as of a social nature, rather than strictly economic or environmental. While the results of our studies indicate that on average ASM is significantly dirtier per unit of output than other types of mining, this is not always the case. Moreover, ASM is often economically viable, even when environmental costs are taken into consideration, suggesting that many of the solutions lie in the areas of environmental and economic policy. In general, the results show that the environmental effects of ASM can be quite small under specific circumstances and the serious dangers which exist could be remedied without jeopardizing the profitability of the enterprises. This is partially due to the relatively ecologically insensitive nature of much of the mining area in Bolivia, Chile and Peru (i.e., dry sierras and deserts).

If one compares the situation of hard rock gold miners in the Ica-Arequipa region of Peru with the cooperative miners in the Altiplano area of Bolivia, the heterogeneity of the sector is dramatically displayed. In Ica-Arequipa the ASM usually work veins which are not economically viable for large firms as they are too small. Nevertheless, the average income of the miners is about \$3,000 per year, well above most other income alternatives. The study shows that these are often economically viable even if environmental costs are included. In fact, the environmental costs of the extraction process could be significantly higher with medium and large mines due to the amount of rock they would excavate. On the other hand, much of the ASM sector in the Altiplano of Bolivia is involved in reworking old tailings or closed mines. In addition to the hazardous working conditions, the environmental damages are severe as old tailings are often exposed, increasing the problems of acid rock drainage. Moreover, new tailings are

other members (often one and the same) are more tolerant. A similar situation was found in a study in Ecuador where conflict between indigenous communities and miners caused by environmental damage is at least partially dependent on who the miners are.¹²

It is clear that the ASM is unlikely to disappear unless there are substantial other economic opportunities. In all three countries entry into the small mining sector was largely the result of a lack of other economic opportunities coupled with low start-up costs. While ASM is a substantial source of employment, miners seem highly mobile both within the sector and to employment outside of the sector. In Chile and to a much smaller extent in Bolivia there is evidence that the number of artisanal and small miners is falling as other economic opportunities increase. It is also important to note that more efficient large and medium mines leave less profitable tailings and waste rock for ASM to work over, implying a smaller ASM sector in the future, all things equal. Workings of old tailings is particularly important in Bolivia; the reduced productivity of these tailings may be as important for the migration out of the sector as the growth of other alternatives.

The most important environmental problems in the ASM sector are mercury disposal, direct dumping of tailings and effluents into rivers, improperly constructed tailings dams, acid rock drainage arising from the tailings dams or open galleries and the related problem of improper closure, river damage in alluvial areas, and erosion damage at the edge of highland areas. Sitting on top of all these problems is the great difficulty in monitoring and enforcing environmental violations due to a lack of resources and the widely scattered and inaccessible nature of the sector.

In many cases ASM is often a short-run phenomenon of a gold rush nature; for example, the "easy pickings" in the Madre de Dios region are already near exhaustion. In such cases, most of the attention should be paid to pollution problems with long-run effects. In our study, these "stock" pollution problems, which would exist long after the mines are closed and the miners leave, include mercury stocks, ARD from depositing tailings in poorly constructed tailings dams, and river bed and landscape destruction in Amazonian areas.¹³

Occupational health and safety concerns are often as or more important than environmental externalities. These were found to be severe in all three countries. It has already been noted that the average lifespan in the town of Huanuni in Bolivia is just 40 years.

The most important externalities of ASM may not be the long-run environmental damage but the irreversible nature of cultural damage due to entry or invasion of sensitive tribal lands. While this problem is also associated with medium and large scale mining, the problem can be particularly severe if there is a large scale invasion of small miners. They can quickly substantially outnumber the local population and form a dominant sub-

12. See Carvajal and Wray (1996).

13. For a discussion of the mercury flow and stock problem in Brazil, see Biller (1994).

where effective interventions can be made. The emphasis needs to be on incentives or ways of internalizing the environmental costs rather than traditional monitoring and enforcement. There is also a need to work together with medium and large mines, especially with respect to the construction or use of shared tailing dams and processing facilities. In the mechanized small mine sector it may be possible to use presumptive charges or deposits to formalize the sector and help protect the environment. The Peruvian study recommends a presumptive tax on the use of barges and deposits on the entry of front-end loaders into the Amazonian region. The latter would be returned when inspection revealed a proper closure of the activities. Education programs have an important role to play in all three countries; in Chile the authors recommend that environmental education and other programs become a new focus of ENAMI, the state company which processes and sells the output of small and medium mines.

On the other hand, where ASM is not economically feasible and environmentally destructive, it should not be encouraged to continue. In the Chilean and Bolivian studies the authors argue that mining policy should not be social policy. That is, there are much better ways of dealing with poverty than using subsidies to encourage the propagation of a non-viable and dirty sector. As stated in IENIM (1996: 74): "Solving the environmental and social problems associated with informal mining should focus on alleviating the worst aspects of the situation without subsidizing or otherwise prolonging uneconomic operations."

4

A Strategy for Artisanal, Small, and Medium Mining in Bolivia, Chile and Peru

The goal of this strategy is to improve the environmental performance of artisanal, small and medium mining in the three countries of the study as well as other countries in Latin America confronting similar problems and situations. The strategy is centered on four of the most important characteristics of the situation as revealed in the study: (a) The distinction of mines by size is not as important as age, at least with respect to medium and large mines. (b) The management of tailings should be opened up to market mechanisms. (c) Artisanal and small mines form a very heterogeneous group. Those which are economically viable, including environmental costs, should be encouraged. Those which are not economically viable should not be encouraged or subsidized as such actions would only prolong uneconomic and polluting activities. (d) Cultural considerations are increasingly important in the decision making process of the mining sector, from the perspectives of both business and government.

In the context of each of these four points, we recommend a number of policy actions.

A. For medium and large mines, the age of the mine is more important than the size.

Medium-sized mines (including smelters linked to the sector) should be subject to the same environmental laws, regulations and treatment as large mines. They are relatively easy to monitor and exhibit similar behavior. Particular emphasis needs to be placed on legislation and enforcement with respect to mine closure.

With respect to medium and large mines, creative solutions must be sought for older mines, where the greatest environmental problems often reside. It should be recognized that very large investments will often be necessary to improve their performance to acceptable standards. Often the sharing of facilities, as discussed in B below, or the reworking of tailings can help offset some of the costs of environmental investments.

When old state-owned mines are capitalized or privatized, special attention must be paid to the environmental condition of the mine and the past and future liabilities.

Water should not be a free good. Water rights and use should be allocated based on competitive bidding.

B. The management of tailings should be opened up to market mechanisms.

In both the small and medium mine sectors, companies should join together to make and share environmental investments whenever practical, especially with respect to tailings dams and water treatment plants.

Similarly, governments should encourage the development of a market for the construction and operation of tailing ponds. Construction companies, in particular, may have a strong interest in entering such a market. The role of the government may be just to remove any existing impediments to the creation of such markets.

C. Artisanal and small mines form a very heterogeneous group.

Governments could provide technical assistance to artisanal and small mines, especially with respect to the use of more productive and environmentally benevolent technologies. However, this assistance should only be provided if: (i) the mines are economically viable, including environmental costs; and (ii) the resources cannot be profitably exploited at a larger scale. When the mine is not viable, the focus should be on poverty alleviation, not mining.

Clear property rights should be established for artisanal and small miners. Inefficient and environmentally unsound techniques are often directly the result of inadequate property rights.

Under specific circumstances the environmental effects of artisanal and small mines could be remedied without jeopardizing the profitability of the enterprises. Innovation and adaptation should be encouraged in such cases. Research programs (which could be partially funded by donors) have a critical role to play in the development and dissemination of economically profitable and environmentally sound mining practices.

Artisanal and small mining is often a short-run phenomenon of a gold rush nature. In such cases most attention should be paid to pollution problems with long-run effects, such as mercury stocks and ARD from depositing tailings in poorly constructed tailings ponds.

In artisanal and small mines occupational health and safety concerns are often as or more important than environmental externalities but they do not receive similar

attention. Domestic governments should pay particular attention to unsafe working conditions, including the funding of research on the development of safer practices.

D. Cultural considerations are increasingly important.

One of the most important externalities of mining may not be the long-run environmental damage but the irreversible nature of cultural damage due to entry/invasion of sensitive tribal lands. Although this problem exists with all types of mines, it is particularly serious in the case of informal mining where negotiated settlements are difficult if not impossible and lawlessness is often the rule. In such cases government must provide both legal title to the land and proper protection for the indigenous groups. In some cases, it may be necessary to completely prohibit the mining activity.

At the same time indigenous groups often benefit from mining activities. Solutions should be sought which maximize the benefits of mining to indigenous groups while minimizing the damage to their environment and cultures. Opposition to much more efficient and cleaner mining operations by indigenous communities are rarely irrational but arise from the realization that they will benefit less in such cases than from the existing inefficient and environmentally damaging mining practices. Solutions to the problem often may be particularly sensitive if one indigenous group is benefiting from the mining activity while another indigenous group is suffering the costs. In Latin America there is often potential for conflict between indigenous miners from the highlands and lowland indigenous groups.

Given the long history of relations between mining and indigenous groups in countries such as Canada and Australia, stakeholders in countries with significant indigenous populations could learn a great deal from studying the evolution of this relationship in Canada and Australia.

5

Environmental Impact of the Small and Medium Mining Sectors in Bolivia

Recent Developments

After the tin crisis of the 1980s, the Bolivian mining sector is regaining an important role in the country's development. Its significance for the foreign accounts and fiscal revenues is increasing and expected to rise importantly in the near future. According to the New Economic Policy that began in 1985, the growth of the mining sector is a task of the private sector. Consequently, the government has tried to attract private investment to mining activities. The restrictions on large areas of the country to development by state-owned mining companies have been lifted, the trading of the minerals has been liberalized, and the mining code has been updated. Furthermore, the state mining company (COMIBOL) is abandoning the direct exploitation of minerals and currently has only three operations. It is also foreseen that the company will only participate in joint ventures with the private sector, with management delegated to the private partner. The private sector has answered positively, substantially increasing its investment in mining.

"New" and Medium Mining

Although efforts were being made to diversify mineral production, at the time of the fall of tin prices in 1985, the private mining sector was still heavily concentrated in tin. It reacted to the crisis by reducing its tin production and increasing the production of other minerals such as zinc, silver, lead, and (later) gold. This was the outcome of the closure and downsizing of many private operations, and the growth of others that were able to adapt themselves to the new market conditions. The latter are referred to now as

Note: This section was written by José Luis Evia, senior researcher, IISEC, Universidad Católica, La Paz, Bolivia, and Ramiro Molina Barrios, Professor, Universidad Católica. It summarizes Evia and Molina (1997).

the New Mining Sector. They presently comprise just two companies: Inti Raymi and COMSUR.

New Mining is concentrated in gold and zinc. It is associated with foreign capital and the introduction of new technology. This new capital-intensive technology reduces the demand for labor, especially unskilled. It thus dilutes an important link with the local community. New mining has a good environmental record; the firms make a detailed assessment of their environmental impact and comply with environmental standards that in many cases are stricter than the national ones. Despite the equipment and standards of the new mining, an environmental disaster recently took place, which has put in question the safety of these operations and points to the difficulties of technology transfers. The performance of a technology depends not only on the physical technology but also on the human factor. In the case of the Porco mine in the Potosí region, a recent vintage tailings dam broke owing to poor operation of the dam, exacerbated by heavy rains. It should be noted that if the dam had been operated properly, the rains would not have caused it to break. The company, however, moved speedily and efficiently to clean up the spill, quickly reducing the environmental damage to levels well below what was expected at the time of the disaster.

The medium mining sector, in which we group COMIBOL and medium mines that do not belong to the new mining sector, was also very concentrated in tin production at the time of the crisis. This sector absorbed the shock by downsizing its operations and closing some of them. In recent years, the significance of this sector has decreased importantly. Many operations need substantial investment just to keep functioning at present levels. The medium mining sector did not take the environment into consideration in their operations. Nevertheless, due to technical requirements, they frequently had water recycling systems and tailing dams in operation. Today, a lot of those systems have deteriorated, allowing spills of effluents into the environment.

With the help of foreign assistance, COMIBOL has begun recently to pay attention to its environmental problems. The plans for the re-engineering of COMIBOL includes the transfer of its operations to the private capital through joint ventures. To establish the environmental responsibilities of the new management, COMIBOL has undertaken environmental audits. Flow pollution will be responsibility of the new operator, but the stock of pollution (the environmental liabilities) will remain the responsibility of COMIBOL or the Bolivian government.

Small and Artisanal Mining

The small mining sector consists of cooperatives and small miners. This sector was strongly affected by the crisis at the beginning of the 1980s, but in contrast to the others, it increased its production of all minerals, especially of tin. What is noteworthy is that this increase was made with very primitive technologies and dependent on increased manpower. More recently, the sector is increasing its production of gold, zinc, and silver.

The so-called traditional cooperatives (the ones that produce tin, zinc, lead, etc.) have always co-existed with small state and medium mining, working its tailings and abandoned operations. The cooperatives have also been important producers of gold in the Tipuani area. As important as the output of this sector has been its job creation. Between 1971 and 1980, the sector employed almost 20,000 workers. Employment began to increase in 1982, accelerating in 1986. This is explained by the economic crisis of the 1980s and by the closure of many COMIBOL operations. In many cases, to offset the unemployment caused by the downsizing of its operations, COMIBOL fostered the creation of cooperatives and then transferred the mines to them. Nevertheless, since 1994 the growth of the employment in the small mining sector has stopped. This can be explained by the growth, albeit modest, of the economy as a whole and the depletion of their reserves, especially old tailings.

The traditional cooperatives consist mainly of old COMIBOL workers, their families, and seasonal migrants, mostly indigenous peasants of the nearby communities. The number of workers in each cooperative is large and variable; there are cooperatives of hundreds or thousands of workers. Sometimes many cooperatives work the same deposit. It should be noted that the term cooperative is not technically accurate. A cooperative is really an organization that gathers together many teams (*cuadrillas*) of workers and represents them. The *cuadrillas* are groups of one to ten workers, which work on part of the deposit as allocated by the cooperative. The *cuadrilla* is independent of the cooperative in its production, processing, and trading. The cooperative usually gives them some services (compressed air, technical assistance, trading) in exchange for some percentage of the net value of their sales.

The exploitation methods of the cooperatives have had severe environmental impacts, destroying not only the deposits, but also the tailings dams and the water recycling systems. Furthermore, the cooperatives work without any respect for the security of the worker or the environment. They do not have systems for disposal of tailings or water treatment.

The gold cooperative sector is a very heterogeneous one, ranging from cooperatives with important resources and levels of production to individual miners or small groups that work in very primitive conditions. Most of the operations have their own, typically rustic mill and use mercury for the processing of the mineral. They have no skilled labor, industrial security, or technical assistance.

The organization of gold cooperatives is very complex. By law, these operations have to be worked by the partners. In many cases, they leave in their place a so-called representative who performs their work in exchange for a wage or some percentage of the production. There are also so-called volunteers who receive in exchange for their labor the right to work the deposit for their own benefit for some time. In addition, many cooperatives contract workers. Associated with the gold cooperatives are the *barranquilleros*, informal miners who reprocess the tailings of the cooperatives.

In alluvial mining, large quantities of material are removed, which are dumped into rivers after the treatment process. This pollutes the rivers, changes their course, and destroys the fertile beaches. Vibrating screens and sluice boxes are used in the concentration process, producing a preconcentrate, which is later refined in gold pans. The gold grains are recovered directly in the gold pans, and the fine gold is amalgamated with mercury. The amalgam is burned into the air, and all the volatilized mercury is lost.

The cooperatives that work in primary deposits dig galleries to extract the ore. Most of them are small, extracting only a few tons a day. Some cooperatives do remove large quantities of land, using open pit systems. The environmental impact of the extraction is low (with the exception of the open pit operations). The ore is crushed and amalgamated in humid or dry systems, and the amalgam is later separated in gold pans. In mechanized processes crushers, ball mills, or Chilean mills are used to crush the ore, and concentration takes place in sluice boxes, jigs, shaking tables, or amalgamating plates. The use of mercury in the concentration process is common and is the most serious environmental impact of this type of mining.

An estimation of the profits of cooperatives shows that the semi-mechanized operations are the most profitable (by unit produced), for both traditional and gold mining. Generally, mechanized operations are more profitable than manual operations (tin, primary gold). The latter provide more employment than any other kind of operation, however.

Environmental Regulations

Bolivia has an environmental law (1992), which is regulated by five bylaws in five areas: (1) environmental management, (2) environmental control and prevention, (3) atmospheric pollution, (4) water pollution, and (5) activities with hazardous substances. At the national level, the environmental authority is the Ministry of Sustainable Development and the Environment, while at the departmental level, it is the Departmental Secretariat of Sustainable Development and the Environment.

The environmental legislation established a number of procedures. New projects must undertake an Environmental Impact Assessment and produce an environmental report (Ficha Ambiental). If approved, these give way to the Declaration of Environmental Impact. The latter must include a prevention and mitigation plan. Existing operations must present an Environmental Manifesto (Manifiesto Ambiental), which must include a remediation plan. If approved, the Environmental Manifesto gives way to the Declaration of Environmental Remediation. The law also establishes an Environmental Audit, which detects the deficiencies of an operation and establishes a remediation plan. There are also regulations for the use of water. In the case of water, the bylaw on water pollution calls for the classification of the aquatic resources of the country. It fixes the maximum parameters for any discharge into a given body of water, depending upon its classification.

Tax System

The tax system for the mining sector is based on a profit tax of 25 percent and a complementary (or minimum) tax, which is a type of presumptuous tax. The latter is applied to the gross selling value of the mineral, with a rate that varies according to the mineral and its price. For gold, the rate varies between four percent and seven percent, while for silver the range is between three percent and six percent. This tax is actually levied only if the amount paid as profit tax is less than the complementary tax, in which case the company has to pay the difference. When the mineral is exported, an amount equal to the complementary tax rate is withheld. The amounts withheld are distributed to the regional governments (*prefecturas*). At the end of the fiscal year, the profit tax is calculated. If the amount to be paid as profit tax is bigger than the accumulated advance payments, the company has to pay the difference. If the accumulated advance payments are bigger than the calculated profit tax, the complementary tax becomes effective.¹⁵

Decentralization

An important process of decentralization has been implemented in Bolivia. This process transfers resources and responsibilities to the departmental and municipal levels. In the environmental area, the departmental governments have wide-ranging responsibilities. They are in charge of controlling the use of the natural and environmental resources; managing the national plans and environmental standards in the department; reviewing the Environmental Reports, defining the category of the Environment Impact Assessment Reports; and issuing, denying, or cancelling the Declaration of Environmental Impact and the Declaration of Environmental Remediation. They also control the limits of any discharge and issue discharge permits.

Mining and the Community

In the highlands and valleys, the deterioration of the productive conditions and the fragmentation of the land have resulted in an impoverished landed property. In the lowlands, commercial farming and peasant farming coexist. The peasant community provides seasonal labor; a great deal of the urban and rural labor markets have a seasonal character. The mining sector (medium, small mining, and the artisanal) has relied traditionally on that kind of labor. This is especially the case of the cooperative mining. This fact is reflected in (1) the temporal nature of the operations and employment in mining; (2) the existence of secondary activities for the miners (in which agriculture is the most important); and (3) the migration statistics of the mining population.

15. There is also an additional 25 percent tax on "extraordinary profits." The amount of profits considered to be extraordinary depends on their level relative to sales and investment.

Most gold cooperatives are temporary, and only a few of them have permanent workers. Most of the workers in cooperative operations and *barranquilleros* have a secondary activity, especially agriculture. The population has diversified its economic activity, combining agriculture with mining activities. This complementarity between agriculture and mining explains the limited polarization and conflict between these two sectors. The use of natural resources (including the related pollution) are part of negotiations and agreements between the community and the miners, a large number of which are also peasants.

Even if the migration figures show that the populations of mining regions are highly mobile, it is not so high if we take into account the contingency of the mining work and the deficient work conditions. The mobility is concentrated in the cooperatives, while the *barranquilleros* present a lower spatial mobility. This relatively low spatial mobility shows again that mining activity is not the only source of income.

Mining and Indigenous Communities

A key feature of Bolivia is that the majority of its population is indigenous. In the rural area, this majority lives and is organized in the indigenous farmer community. The basis of the relationship between mining and the community is the benefit that the community receives from the exploitation of the resources that they consider to be their own. Up to now these benefits have taken the form of employment of local labor, and the benefits that would emerge from the negotiation with the mining industry. In the cases of conflict, its origin seems to be in the perception of the community that the mining activities are invading its "societal space" (lands, resources, and so forth) without leaving any benefit to the community.

The relationship between community and mining is changing because of the reduction in direct benefits to the local community from mining, the appearance of a structured ethnic movement, and the acknowledgement of the rights of the indigenous population in the laws. The constitution establishes that the mining resources are the property of the state, which can concede the right to exploit them. Therefore, there is no legal disposition on which the indigenous communities could base any demands to benefit from the exploitation of the non-renewable natural resources found in their lands or territories. Nevertheless, Article 171 of the new constitution establishes that "the economic and cultural rights of the indigenous people that live in the national territory are respected and protected, especially those related to their community lands, warranting them the use of the natural resources, their identity, their values, languages, customs and institutions." This article has given rise to a series of claims of the indigenous people, including rights over the natural resources. This position is reflected clearly in the project of law for the indigenous people of the Lowlands, (the Chaco and the Amazon), presented by indigenous institutions to the national congress. This project considers the non-strategic minerals as exclusive property of the indigenous people, and claims preferential

rights for strategic minerals, with respect to their use, royalty payments, and co-management in all phases of exploitation.

Toward Sustainable Mining

An efficient excavation is one that covers its operational costs, environmental costs, and resources costs. Governments have established standards or charges on pollution, and taxes or royalties on the resource, in order to force the producer to internalize these costs. A sustainable operation is then one that operates covering its costs and complies with the tax and environmental regulations. An existing operation that complies with the tax and environmental regulations must be considered as viable.

The New Mining Sector operates in compliance with the laws and is clearly viable. The sustainability of medium, cooperative, and artisanal mining is much less clear. Nevertheless, from our cost estimations, it seems that at least the gold cooperatives are sustainable. They are able to cover the costs of the resources and the environmental cost. This is much less clear in the case of the traditional cooperatives that work manually, especially the ones that exploit antimonium and complex ores. The operations that are not viable impose a net cost on society, which would benefit if they were closed. This needs a qualification. It is possible that the cost of the resource that is exploited by the cooperative is zero. Then the operation must comply only with the environmental standards and cover its operating and investment costs to be viable.

There have been some arguments claiming that even if it is true that mining has a negative externality (pollution), it also has a positive externality (employment). Therefore, unviable mining should be tolerated to provide employment. It is not efficient, however, to accept greater pollution by unviable operations in the mining sector in order to create more employment. It is possible that other sectors could generate more employment if they are not forced to comply with environmental regulations. Furthermore, the alleviation of poverty and unemployment is a task of social policy. The goals of the social policy should not be addressed through mining or environmental policy.

In principle, all mining operations should comply with tax and environmental regulations. Many problems are likely to arise, however, if the informal sector is forced to comply with the law. This sector is highly mobile and disperse. Moreover, it has a combativeness that would make it very difficult for the government to enforce the law. In such a case, it is preferable to think of policies to discourage the growth of the sector. To some extent, the increase in the efficiency of the medium mines, as the result of the process of privatization of the COMIBOL mines, would reduce the incentive to cooperative mining. This would occur because owing to efficiency gains the tailings of these operations contain less mineral, making their reprocessing less profitable. The same would happen if, at the time of the closing of the operations, the new and medium

mines have a closure plan that makes the old operation inaccessible to the artisanal miners.

Alternatively, one can think of reconversion plans, although the experience of these kinds of programs is not encouraging. Usually, these programs work only while the financing last. It is more practical to think of a natural reconversion, in which artisanal miners who are marginal will exit the mining activity as the deposits that they exploit are depleted, and/or as the growth rate of the of the economy offers them better alternative sources of income.

The relationship between the mining operation and the community is complex. In principle, the resource belongs to the state, which gives it in concession and charges for its use. But because of the rise of an organized indigenous movement and the acknowledgement of indigenous rights, the indigenous people are beginning to claim a share of the benefits of the exploitation of natural resources. Up to now, the benefits of mining that accrued to the indigenous people were in the form of employment and compensation granted by mining companies (especially the "new mining"). The first kind of benefits will disappear if the new mining becomes the dominant mining in Bolivia, although it should remain important in the relationship between the cooperatives and the community. Besides, as the rights of the indigenous people are increasingly acknowledged, the benefits that are negotiated with the new mining will be seen not as a concession but as an obligation. Therefore, there is the danger that the company ends up paying for the resource twice. To avoid this danger, the tax system must ensure that the resource costs are paid to their owner; that is, to those who have rights over them (indigenous community, government). To this end, the decentralization of the tax system is important, ensuring that part of the benefits of the taxation accrues to the communities.

6

Environmental Impact of Small and Medium Mining Sectors in Chile

Introduction

The Chilean mining sector is composed mainly of copper, gold, and silver producers. Although it has long been an important activity in the domestic economy, it is in the past decade that mining has become one of the most dynamic sectors. Between 1974 and 1995, the mining sector received investments of more than \$8,700 million and in 1995 provided 49 percent of total Chilean exports. Mining activity can be found throughout the country, but the majority of copper and gold reserves are located in northern Chile. The most important activity is copper mining, which also generates a significant part of the production of gold and silver as subproducts. In 1995, production reached 2.49 million metric tons of fine copper, 43,600 kilograms of fine gold, and 1,042,000 kilograms of fine silver. Also, the production of copper, gold and silver grew with respect to the prior year 11.7 percent, 11.8 percent and 6 percent, respectively. Direct production of silver is relatively small, because 80 percent is obtained as a subproduct from other metals.

After the nationalization process of the copper industry in the 1970s, the state assumed a direct role in the production and sale of Chilean copper. During the past years, and in the wake of an intensive foreign investment process, private sector participation has increased constantly. In 1995 private mining surpassed government mining production indices for the first time, producing 53.7 percent of copper, 93.6 percent of gold, and 71.4 percent of silver. Furthermore, it is estimated that it will continue increasing as several new private mining projects, currently in different stages of development, begin their operations.

Note: This section was written by José Miguel Sánchez C., associate professor, and Sara María Enríquez B., research assistant, Department of Economics, Universidad de Chile. It summarizes Sánchez et al (1997).

The Chilean mining sector is organized in an institutional framework that embodies various organizations and institutions: The Comisión Nacional del Medio Ambiente (CONAMA) is the maximum authority in charge of environmental policy in Chile. It operates in a decentralized way through its regional environment commissions. The role of the Empresa Nacional de Minería (ENAMI) is to improve and promote mining activities and to contribute to the sustainability of small-and medium-scale mining. The Ministry of Mining is responsible for designing and carrying out the government policy for the mining sector. El Servicio Nacional de Geología y Minería (SERNAGEOMIN) is a public entity reporting to the Ministry of Mining. Its functions include supervision in relation to mining properties, exploration, and geology. It is also in charge of safety in mining operations, including supervision and approval of tailing dams. The role of the Comisión Chilena del Cobre (COCHILCO) is to protect the interests of the state in the public enterprises that operate in the mining sector. Finally, Sociedad Nacional de Minería (SONAMI) is an association that represents the interest of more than five thousand members, including small, medium, and large mining producers.

In recent years, Chile has been developing its environmental legislation, whose general coordination is the responsibility of CONAMA. Even though there are no specific regulations for small and medium mining, several organizations and public services have authority over mining in environmental matters. Among them are SERNAGEOMIN, regional CONAMA commissions, various public work agencies and services and the agriculture and health ministries. In general, the legislation envisages regulations for different types of potential environmental impacts of small and medium mining, even though it does not make any specification for these cases. It regulates the operation of sources of sulfur dioxide, particulate matter, and arsenic, the allocation of water rights in all the national territory, and the disposal of effluents. It also prohibits the disposal of harmful liquids and solid residuals.

The mining sector has three readily distinguishable sectors—small-, medium-, and large-scale mining. Public sector mining activities are carried out in the large-scale facilities of CODELCO (Corporación Nacional del Cobre) and ENAMI. The private sector contains all three types of mines. Even though neither the small nor the medium scale mines have smelting infrastructure, these are the main suppliers to ENAMI.

Large mining includes all those undertakings that annually produce more than 75,000 tons of metallic copper or its equivalent. It also includes those firms that, even though they might not reach this level of production, share the following characteristics: they are subsidiaries of large multinational mining companies, operate with recent technology, have access to international financial markets, have the necessary capability and infrastructure to sell their product in domestic and international markets, and are highly competitive. With respect to the environment, even though this subsector is responsible for the majority of the pollution generated by the mining sector, it has reached a high level of pollution control and mitigation.

The medium mining sector includes all mining operations whose production level is more than 200 tons of mineral a day. It currently includes eighteen firms. They sell mainly concentrates or precipitates of copper or gold and had a production level of \$293 million in 1995. These mines are important direct employment generators. Furthermore, this sector permits the associated development of the small mining sector, which supplies the mineral for the medium-size concentration plants. The existence of ENAMI and its participation in the productive process has resulted in a strong relation with the medium mining sector. This sector does not sell their product through traders. Instead, the firms operate on the basis of a contract system with ENAMI, which guarantees the purchase of all their production.

The small mining sector is defined as operations that own or rent facilities with an extraction capacity of less than 200 tons of mineral per day either for its direct sale as ore or for processing by small processing facilities. This sector consists of a large number of miners that largely sell their production to ENAMI, using a predetermined tariff system. It has been a very dynamic sector. Their annual deliveries to ENAMI have grown in past years. Moreover, an important mobility toward larger scale operations has been observed, either by mergers with larger firms or by expansion of their own operations. This group is rather heterogeneous. Some firms have a modern structure (technological and managerial) while some other companies exhibit difficulties with their environmental management. There are also firms for whom it would be difficult to increase production or their productivity, fundamentally due to the effects of scale economies and the lack of exploration and long-time planning resources.

The degree of atomization and socioeconomic conditions of small mining anticipate that environmental considerations are absent or play a minor role in the production decisions of the miners. In this sector and even more so in the artisanal segment, environmental management is particularly complicated, given that this group has been traditionally considered to be important, especially at the level of local economies in the northern regions where there are not many other working opportunities.

When we assess the environmental impact of mining, it will be necessary to distinguish between mines and plants, since their impacts are very different. In 1994 a total of 1,626 small mines and 281 small plants were identified. They produce about 1.72 million tons of minerals a year (5,743 tons a day), while small plants have an annual treatment capacity of 2.96 million tons (8,640 tons a day).

To characterize the environmental impacts of mining for each of the sectors studied, an impact path analysis has been performed. (See Figure 1.) It analyzes the impacts produced during different phases of the mining process, from the primary extraction phases until closure or abandonment. In both plants and mines, the main elements that can be affected are water, soil, air, landscape and humans. The impact will depend on the process, the location of the operation, its proximity to populated centers, its proximity to water resources and the management of the different phases of the process.

Role of ENAMI

ENAMI's supply structure brings together the different segments in the analysis. ENAMI's plants and medium-scale mining firms deliver concentrates and precipitates, and the small mining firms deliver minerals, concentrates, and precipitates. ENAMI classifies its clients and gives them a differentiated treatment. By law, it must give preference to small and medium mining deliveries to fulfill its smelting capacity. ENAMI's promotional activities include a number of technical and credit assistance programs. ENAMI has to purchase all the production of the small mining firms on the basis of a tariff system and offers a direct subsidy to ease the fluctuations in copper prices. With medium mines, ENAMI uses a contract system and operates under market conditions.

ENAMI's strategic plan, in terms of the promotion of the sector, focuses its efforts on small and medium "viable" mining. In 1994 ENAMI reformed its commercial policy. Currently, ENAMI operates under a *maquila* system in which it obtains concentrate from miners and pays them the international price of copper minus the smelting and refining costs, which is subsidized for small miners. However, this subsidy is being phased out and is expected to disappear by the year 2001.

In 1995 ENAMI's production reached 65,354 tons of concentrates and 12,139 tons of precipitates. Lack of uniformity in the mineral ore received and highly seasonal behavior of deliveries increase costs relative to those that a modern mine and plant complex can obtain.

Deliveries from the medium mining sector are of vital importance for ENAMI's productive system and a mutual dependency relation exists. ENAMI's productive structure in the smelting phase is supported mainly by the medium mining sector. Nevertheless, ENAMI adds value to the product supplied by the miners, allowing them to sell without a trader copper of degree A instead of concentrates.

In its smelting stage, ENAMI is supplied by 18 medium firms. In 1995 the deliveries increased 24.3 percent for copper concentrates, 42.8 percent for gold concentrates, and 75 percent for copper precipitates. They operate with annual contracts of sale and *maquila*, in which a preset supply quantity (delivery quotas) is established although a wide variance is allowed.

An important part of the supply of minerals for ENAMI comes from the small mining sector. These deliveries correspond approximately to 20 percent of the total of fine copper produced by ENAMI and about 2 percent of the national copper production. The marketing structure is particularly complex in the case of artisanal gold mining. Those miners that do not deliver to ENAMI sell their gold to other registered producers and private plants. Therefore, their identification and regulation is even more complex.

Small Mining Sector

In the small mining sector, most of the producers are concentrated in the lowest sections of the size distribution, producing between 0 and 200 tons a month of minerals and between 0 and 10 tons a month of precipitates and concentrates. According to ENAMI, between 1992 and 1995 the number of producers of minerals, concentrates, and precipitates was decreasing, especially in the low end of the production range where most of the producers are situated.

With regard to production costs in the small mining sector, the available information, although partial, suggests that there is a high percentage of marginal miners among those miners with whom ENAMI operated during 1995. Small processing plants have greater access to financing than those that only produce mineral because of the added value that allows them to obtain relatively higher profits than primary miners, especially when the plant is associated with a small mine. In any case, the income of the small miners that supply ENAMI has been linked to the existing subsidy. However, as noted, the subsidy has been decreasing and is expected to disappear by the year 2001. It can be anticipated that the local and regional impacts of the subsidy removal will be important, given that the small miners are high-cost producers operating with narrow margins.

Small mining is a way of life in northern Chile, and it is an activity with an important social impact. There is not a unique rationale behind the behavior of small miners. They have different incentives, and to a large extent, depend on the promotion policy of ENAMI. As a first approximation, there are two types of small miners: those whose active presence in the sector depends on the copper price and therefore produce sporadically and those for whom mining is their main activity and therefore remain active even under adverse price conditions. The first group is formed, in general, of young workers that take advantage of the periods of high prices with very short-term lease contracts for mines. The other group is formed by older miners, whose permanence is explained by a series of cultural aspects, the lack of subsistence alternatives, and a very low risk aversion.

No exact data is available with respect to the number of people employed by the small mining sector. However, we can obtain an indirect estimation given that the sector sells its mineral to ENAMI or to private plants that have commercial relations with ENAMI. According to 1995 estimates, 630 operations made monthly deliveries of up to 200 tons of minerals. Assuming the average family group is composed of 5 members, it is estimated that about 80,000 persons depend on small mining.

With regards to small miners that operate in plants with a greater degree of formality, they can be characterized as being small companies with high cost technologies—that is, they have high sunk costs that hinder entry and exit to the industry in response to fluctuations in the price of copper. Considerable interdependence exists

between groups. Medium-size firms make contracts with the small miners for supply. Small miners and *pirquineros* (artisanal miners) sell to ENAMI.

The small mining sector faces several limitations, which are even more severe at the artisanal level. There is a high percentage of leaseholders who operate with short-term contracts, a very rudimentary knowledge of the exploitable reserves, and very limited or no access to financing. They use antiquated and artisanal technologies that involve high costs even though the copper grade of the ore might be quite high. As a whole, the sector is highly unstable with a large number of seasonal miners, who also tend to be the smallest ones. The most formal part of this sector is found in the processing facilities. In this part of the production process, for a large number of owners, switching to a different activity would be quite costly.

It is important to note that in Regions III and IV there are a large number of mineral deposits—both gold and copper—that because of their geological characteristics can only be exploited by the selective labor of small-scale mining. Hence, these deposits are unattractive for larger mines. In addition, the large mining projects tend to be located far from populated centers in very arid zones where competition for water makes it unattractive for small mining operations.

Chilean small-scale mining exploits underground mines, open pits, buddling (washing) tanks, and tailings. The underground mines represent 92 percent of total operations and 95 percent of production. Of these mines, 76 percent extract copper; this accounts for a similar percentage of their production. The gold mines are in general of smaller size and represent 11 percent of output. There are just a few polymetallic mines. The mines are located in Regions I through VI, although most are in Regions III and IV. Water scarcity in the north of the country makes alluvial gold mining a rare operation. The few existing operations are distributed from Copiapó to the southern extreme.

Of the installed capacity of the plants, 42 percent is for the processing of gold. A minimal amount is devoted to silver. A total of 27 percent of the plants operate solely with flotation and an additional 28 percent combines this process with gold amalgamation. Flotation processes permit the miners to obtain copper and gold as product and byproduct. Plants in the range processing from 0 to 50 tons a day are by far the most common. Amalgamation of gold with mercury is a widespread process. Approximately 26 percent of the operations work with this technique, especially in the artisanal segment, mostly in small facilities with less than 25 tons per day. Only 22 plants, corresponding to 30 percent of the installed capacity, produce at higher levels (between 75 and 150 tons). As is the case with mines, the plants are concentrated in the Regions III and IV.

Special conditions characterize the artisanal segment of small-scale mining. By definition, an artisanal miner is an informal worker with little or no patrimony who operates with rudimentary techniques. They tend to work in groups of one to eight people, and their average daily per capita production is less than one ton of mineral.

Given the aggregation of the available information, it is not possible to separate this group clearly. However, it is estimated that there are about 2,800 pirquineros operating. Most of these informal workers are located in Regions III, IV, and V. Miners in Region V are particularly relevant because they have a direct relationship with poverty levels in certain districts. They are a marginal group whose activity is very sensitive to fluctuations in prices or costs. Most informal miners have a low degree of ownership of mining property, and their activity is basically a subsistence one. The mines are mostly located in zones where there are no alternatives besides mining. Most artisanal plants produce amalgamated gold, although they also process copper mineral on a small-scale.

Small mining undertakes exploration in very rudimentary and low-cost ways. Nevertheless, they have been able to identify mining resources. Underground mines constitute the most widespread method of extraction. To process the minerals, small plants use either flotation, leaching, or amalgamation. These processes are performed with old inefficient methods without any environmental consideration.

The disposal of the tailings of the flotation processes is the greatest problem encountered in small mining. Tailings dams are usually not properly built or operated. In addition, abandoned dams constitute an environmental hazard when located near or above water resources. Of particular concern is the gold concentration process that uses amalgamation with mercury. It is very widely used by artisanal miners because it is adaptable to small-scale operations while producing a high value end product. The concern is twofold. On the one hand, miners manipulate the mercury without any protection mechanism and are exposed not only to the vapors but also to direct skin contact at different stages of the amalgamation process. On the other hand, during the amalgamation process, a part of the mercury will inevitably end up in the effluents, causing a potential environmental problem when the tailings are not properly managed.

In general, the impacts of the small mining sector are: environmental risk due to plant location in an urban zone or near rivers or natural water courses; soil and river bank pollution because of liquid effluents; filtration and overflows from tailings dams; and soil pollution by domestic solid waste. Even though the use of mercury is not massive, there are identified effects over those who participate directly in the process.

On the basis of the analysis of the existing information, it can be concluded that the small mining sector—given its low levels of production, wide geographical dispersion, and very arid climatic conditions in the areas where the production takes place—does not constitute an important factor for environmental pollution in Chile. It may, however, pose some local hazards associated with the operation of processing plants and tailings disposal. There are also direct risks for the miners that operate directly in contact with mercury. In Figure 2, the environmental effects from the small mining sector over the different components are described using an impact path approach.

Medium Mining Sector

In most cases, medium firms have their plants close to the mine. Those that do not have mines are supplied totally or partially by small mining operations of the nearby districts. Medium mining produces copper concentrate using traditional processes of flotation of sulfurized mineral, copper precipitates from leaching oxides, and gold concentrates from either flotation or cyanization. Of all the mining processes, it is in the concentration process that most of the water is consumed. The other stages consume only about 7 to 15 percent of total water use.

Technology is also changing in this sector. The hydrometallurgical processes, which have already been incorporated by larger firms to replace the traditional concentration and fusion process, are beginning to be used in medium mining projects. These processes are an improvement with respect to traditional leaching in terms of environmental performance.

The medium mining sector has shown sustained growth in past years. In general, the companies have been incorporating cleaner technologies in the concentration process and have been introducing better environmental control of their operations. The environmental performance of medium-size companies is more closely associated with their age rather than size. Critical points of the operation of plants are tailings management and disposal, the location of the plant, and use of water resources. There are two fundamental aspects associated with water management: (1) scarcity, particularly in the north; and (2) pollution, associated with the operation of tailing dams. The identified effects in the medium mining sector gives rise to the impact path that is described in the attached Figure 3.

Conclusions and Strategy

The main conclusion of the study is that the environmental impact of medium and small mining in Chile is not very serious. In fact, the most important environmental problem related to these mining sectors is caused by the gaseous emissions from the smelters. Nevertheless, a strategy for each sector is proposed in relation to (1) the identified environmental impacts, (2) the promotion policy of the state, and (3) the legal and institutional framework of the sector.

The medium mining sector is formed by eighteen well-established formal companies that are relatively easy to monitor. In terms of environmental regulation, the same restrictions levied on large-scale mining should apply to them. In fact, many of these firms have been incorporating cleaner technologies in their processing facilities and generally operating with adequate environmental safeguards. The only things that need to be done in this sector are to standardize the control procedures and extend it to all firms, consolidate the enforcement task in SERNAGEOMIN, and ensure that firms whose environmental management is not appropriate do not escape from the environmental control that is applied to larger firms.

Special attention needs to be placed on the effects caused by the amalgamation processes, especially on the miners themselves whom, in most cases, ignore the adverse health effects of doing what they do and how they do it. In this regard, there is an important role for the specific projects of the Ministry of Mining for small and artisanal mining, especially in terms of dissemination of information.

ENAMI has centered its relation with the mines and plants on commercial aspects, totally ignoring the environmental aspects. Given the importance that ENAMI has had on small and medium mining, the future evolution of its promotion policy will be fundamental in the performance of these sectors. It is important to consider the following:

- The small and medium sectors are important suppliers of the smelting process, and hence any regulation of the smelting activity will also affect these sectors. International environmental restrictions are moving in the direction of imposing much stricter requirements to processes. Therefore, it is expected that there will be strong incentives for constant improvements of environmental management throughout the process.
- The rationale behind the state promotion policy carried out by ENAMI should be to promote sustainable small mining based on the exploitation of mining resources that cannot be exploited at a larger scale, mainly minerals found in small veins. The promotion policy should not prolong the life of an otherwise unviable operation. Mining policy is not social policy. There are better ways of dealing with poverty than subsidizing marginal mining operations. The promotional action of ENAMI should be centered on training, development, technology transfer, and environmental management diffusion.
- Given the large number of marginal miners, it is expected that the removal of the subsidy will produce the disappearance of many artisanal and unsustainable small mines. It is very important to separate the promotion role of mining from the assistance role to poor population groups. For those miners that are unsustainable, other alternatives should be considered, focusing on poverty as the problem and not mining. Policies to be considered include reconversion, retraining, and education for other jobs as well as direct financial assistance.
- It is also advisable to use existing programs of the Ministry of Mining to address the issue of improper mercury use. The main task would be to educate the miners about the risks involved in the inadequate disposal of mercury residuals as well as the risks of inhaling the vapors in the process of recovering the gold from the amalgam.

The Chilean environmental legislation has a number of instruments for the enforcement of environmental regulations, but these have limited applicability in the small and artisanal mining sectors. In these cases, the role of the environmental public

policy has to focus more on prevention rather than on monitoring and punishing improper actions.

In the short run, it is important to use existing institutions to manage the environmental problems of the small and medium mining. With regard to the plants and tailing dams operation, SERNAGEOMIN has the necessary structure and the technical personnel to perform the job. Hence, it is the natural agent to take responsibility for these processes.

Peru: Informal Mining and the Environment

This document studies informal gold mining in Peru by analyzing two cases: alluvial gold exploitation in Madre de Dios and underground exploitation in the highlands of Ica and Arequipa. These areas account for about 75 percent of Peru's informal gold production. Informal production accounted for 40 percent of total gold production in Peru in both 1995 and 1996, in spite of the increasing production of new formal firms like Yanacocha.

The author defines informal mining as an activity performed by persons who illegally exploit and concentrate minerals—that is, they do not have the legal right to a mining concession (or a contract with a party that does). Different reasons can explain the explosion that informal mining has shown during the past years: the dramatic increase of international gold prices since the early 1970s, the easy access to gold in the aforementioned areas, the low amount of investment required, the existence of simple technologies that do not require high technical knowledge, the proximity of the ores to very poor areas or those affected by terrorism, the lack of government's institutional capacity to enforce previous concession rights, the economic crisis and unemployment (especially in the agricultural sector), and finally, the potentially high profit margin of the activity.

In summary, the informal mining phenomenon can be explained by the combination of socioeconomic factors that affect the country as a whole, as well as certain technical and geological characteristics of the ore body and the mining process itself. Usually informal mining is associated with a migratory process. As the economy recovers and employment increases, informality should diminish. Meanwhile, the government can do little to eliminate this phenomenon. It is wiser to attempt to formalize this activity than to think that it could be eradicated in the near future.

Note: This section was written by Alberto Pascó-Font, a senior researcher of GRADE, Lima, Peru. It summarizes Pascó-Font (1997).

Alluvial Gold: The Case of Madre de Dios

Mining exploitation in Madre de Dios takes place in two different areas: on the alluvial plains, including the beaches of various rivers and their adjoining areas (the piedmont), and on the "hanging terraces" of the Amazon foothills. The piedmont is exploited during the dry season, when river flows are reduced substantially, while the Amazon foothills are mainly exploited during the rainy season, from December to March.

Technical Aspects

Exploration in the area is by trial and error. Miners do not know or use any geological or technical parameters. If they find a rich ore, they proceed to exploit it immediately without concern for the mineral distribution in the area.

Mining operations can be divided into artisanal, semi-mechanized and mechanized. Artisanal operations have decreased dramatically in the area due to the reduction of the grade in the gravels after years of continuous exploitation. Semi-mechanized operations currently account for 80 percent of the total gold production in the area.

There are five types of artisanal operations: *ingenio*, pushcarts, high pressure hoses, *chupaderas*, and small dredges. The simplest is called *ingenio*.¹⁶ In this operation, one or two persons divert a water stream to build a small ditch whereby the water flow will be used to wash the gravel. A rug is placed at the end of the ditch where coarse gold particulates are deposited. The lack of knowledge about the distribution of mineral deposits causes miners to wander from "discovery to discovery," obtaining from 0.25 to 1.5 grams of gold each day.

A more complex operation, which is used on beaches during the dry season, involves groups of four to six persons with small washing platforms fed by pushcarts. Water is pumped by using buckets or five horsepower pumps.

The use of high pressure hoses is a common method of mining in the foothills. Miners shoot high pressure water to wash the material from the terraces and use the slope to eliminate the waste. The mineral is conducted to sluice ditches where the gold is deposited.

The *chupaderas* work on beaches and in the piedmont. This method extracts gold by suctioning the mineral located underneath the water table with pumps and hoses four to six inches in diameter. The material thus extracted is conducted to platforms where the concentrate is deposited by use of gravimetric methods. Finally, dredges operate on rivers using suction ducts with a six-inch diameter and thirty-five horsepower pumps. Divers manipulate the ducts underwater. The equipment and the sluice boxes are located on the dredge.

16. The nomenclature is *ingenio* as the method used is considered quite ingenious.

Semi-mechanized operations use front-end loaders and dredges that operate similar to those with six-inch diameter ducts but use ducts of eight-, ten- and twelve-inch diameter and pumps with 35 to 90 horsepower. The dredges use iron ducts whose movements are directed by mechanical or hydraulic mechanisms. The concentrate (black gravel) is recovered by gravimetric methods.

Operations that use front-end loaders (also called shutes) are located in the Caychive and Huaypetue creeks in the foothills. Usually, these operations work during the rainy season and exploit the higher part of the terraces where most of the gold is located. Although of recent introduction, this is the predominant operation in the area. The number of front-end loaders has doubled from 200 to 400 since the middle of 1994.

This operation consists in extracting gold gravels using front-end loaders that scrape off the open vertical face of the earth and carry the mineral to the washing platforms. Front-end loaders are also used to clean the waste accumulated around platforms. Water is pumped to washing platforms to clean material that slides over an iron grid. The grid allows particles smaller than one third of an inch to fall into the sluice boxes. These operations are limited by a lack of water or when vertical faces are not easily accessible.

In general, all of these extraction methods are technically inefficient and carried out without much knowledge about basic technical parameters such as ore grades, reserves, or equipment efficiency. However, as operations are still profitable despite this poor management, the miner's only objective is to extract the gold as quickly as possible. They do not try to adopt more sophisticated techniques to increase productivity. Legal instability can help to explain this behavior. The miners do not have the ability to legally defend the property that they are working on. They usually want to extract the greatest amount of mineral in the least amount of time—before the concession is taken away from them.

Once the mineral is extracted, it is washed in a sluice box that consists of a wooden canal of variable dimension and inclination. The canal is covered with plastic, on top of which is placed a coarse cloth or a special chemical, depending on the type of operation. This cover retains the heavy gold particulate while the lime rolls with the water flow. After one shift (of usually 8 hours), the cloth or rugs are dusted to obtain the concentrate to be amalgamated. In all operations, ducts are designed by trial and error, and there is no systematic attempt to find the most efficient method. This reduces operational efficiency to between 50 and 80 percent. Pushcarts have higher recovery rates (80 percent) because the mineral is washed slowly with a controlled flow of (usually) clear water from rivers and creeks.

Mercury is added to the concentrate—usually in huge amounts to speed up the process—to capture the gold particulate. Then, the mix is shaken vigorously to obtain the mercury and gold amalgam. After the black gravel is separated from the amalgam, the excess mercury is removed by compressing the amalgam, which then is burned in a tuna

fish can, usually in the miner's kitchen. The mercury vaporizes at relatively low temperatures leaving "burned" gold.

The investment required increases with the degree of mechanization. It starts at \$100 for an ingenio up to \$250,000 for the larger dredges. Pushcarts also require pumps and an electric generator, which cost from \$3,000 to \$5,000 depending on the power of the pump. Although the total investment required to start a front-end loader operation is about \$250,000, the equipment can be bought on credit, substantially reducing the cash requirements for start-up.

Basic artisanal operations have experienced low profitability during the past years, and consequently, they are disappearing. On the contrary, front-end loader operations have increased substantially. It seems that there are some economies of scale. Profit margins, which have been analyzed for operations using one front-end loader, probably increase when more than one front-end loader feeds one washing platform.

In the case of dredges, six-inch dredges report monthly profits of \$2,500 and eight-inch dredges, \$5,000. Given that the investment required by the latter are not double the former, eight-inch dredges are obviously the most profitable operations in the alluvial plains.

Based on the income of miners by type of operations and the total number of operations in the area, in 1994 the Ministry of Energy and Mines estimated that total production is about 9 to 10 metric tons of gold a year. About 80 percent of this production comes from the foothills operations and the rest from the alluvial plains. These figures are consistent with data reported from gold traders. Because the number of front-end loaders has increased substantially since 1994, the present level of production in the area is not certain, although the amount of gold being traded in Madre de Dios and Cuzco does not seem to have changed substantially.

Environmental Aspects

The environmental effects of informal mining depend on the type and area of operation. Artisanal operations like ingenio and pushcarts have little environmental impact given that they produce small amounts of gold and remove little material, so the jungle can recuperate easily. The exploitation of beaches or riverbeds are quickly reverted when rivers swell during the rainy season. Piedmont operations (*chupaderas*) have larger impacts because they remove more material and use oil and lubricants. However, because they work in flat areas, erosion after the operation is abandoned is limited, allowing the jungle to quickly recover.

The operations of front-end loaders in the Amazon foothills have by far the greatest environmental impact. This result is due to the type of operation and because, as the largest producers of gold in the area, they account for most of the mercury contamination. A typical operation using a front-end loader starts by cutting trees and burning the thicket. Then material and rocks are removed using front-end loaders, which compacts the soil and makes the recovery of the jungle quite difficult. Land removal and

the separation of gravel according to its size affects the water streams and pollutes them with the fine particulate (lime). This affects aquatic life in the region. Finally, the excavation of terraces as well as waste disposal promotes erosion even after the operation is finished. As a consequence, the ability of the jungle to recover once the operation ceases is very limited. Moreover, these operations have important additional environmental effects due to the incorrect use of mercury, petroleum, and lubricants.

Legal Aspects

Most informal miners in the area live near the exploitation site and often have small agricultural plots for self-consumption. Most of them have been residing in the area for more than four years, and are referred to as resident informal miners. This group constitutes 95 percent of informal miners in the area.

Most of these miners were not able to ask for a mining concession as the areas where they were working were already granted to others, most of whom never worked the area. However, under the new Mining Code, those who own mining concessions have to pay an annual fee for using them. If they fail to do so for two consecutive years, they lose their concession. Subsequently, a large number of phantom concessions have been cleared, reducing the past monopolization of concessions by a small number of persons.

As concessions have reverted to the State, the government has had the opportunity to reorganize property in the area and grant informal miners some form of preferential access to the areas where they have been working to formalize their situation. After a census at the end of 1996, the government granted 1,300 mining concessions to previously informal miners in the Department of Madre de Dios.

Finally, although Peru has developed an advanced legal framework for mining, there are several aspects that are addressed in the recommendations below that need to be taken into account for alluvial small-scale mining.

Social Aspects

Mining is an important source of direct and indirect employment in Madre de Dios. Work relations depend on the type of operation. In the case of *ingenio*, operations are family run. As the degree of mechanization increases, so does the number of paid workers. Hiring conditions are generally verbal agreements, which often generates problems in the future.

High rotation and seasonality are two essential characteristics of working relations in the area. More than 80 percent of workers are from Cuzco, Puno, or Apurimac, in that order of importance. Although wages are much higher in Madre de Dios than in neighboring vicinities, work conditions are quite hard. Front-end loaders, high pressure hoses, and sometimes pushcarts operations have permanent camps where up to twelve workers live in crowded and deficient conditions. Work shifts vary from eight to twelve hours. If weather conditions are taken into account in this hot, humid tropical forest, it is

not surprising that productivity is lower than for similar workers. Miners are exposed to tropical illness and are not compensated when sick.

There are forty-one native communities in Madre de Dios, of which only twenty-four are legally recognized. Sixteen of these have a formal title to their territory. There are serious conflicts between these communities and informal or formal miners over land because the Ministry of Agriculture grants lands to native communities while the Ministry of Energy and Mines grants mining concessions in the area. There is no coordination procedure to avoid overlapping claims.

There are three types of legal problems that affect native communities: (1) a lack of procedures that would allow them to defend themselves from the ecological disequilibriums generated by mining operations, (2) a lack of priority to obtain concession over their territory, and (3) a dearth of authorities in the area capable of enforcing their legal rights against informal miners. This situation prevails even though Peru has signed ILO Convention 169, which grants special treatment to native communities in their territory.

Recommendations

Regarding legal aspects the following is recommended:

- A new category should be created for artisanal alluvial miners aside from the existing small miner category.
- Dredges should be classified adequately given that they both extract and process mineral. The new Mining Code classifies dredges as mobile metallurgical plants. As such, the code demands high payments without taking into account that they process a high volume of material with low gold content. The volume processed by dredges should be measured in cubic meters (not tons) and the Ministry of Energy and Mines (not the Navy) should be the only governmental office allowed to authorize their operation.
- A quick and effective inspection system is needed to resolve conflicts among neighboring concessions. There must be some type of protection and a way to stop operations if there is an alleged invasion of neighbors or informal miners. Otherwise, in a short period of time, a substantial amount of gold can be excavated. The corresponding authority should give priority to these situations.
- Contracts should be allowed for only parts of the concessions between the owner of the mining concession and other informal miners (called "invitados") that are not confused with service contracts which are subject to 18 percent IGV (value added) tax.
- All gold traders should be registered and provide some document for every transaction they make.

- Government presence in the area should increase to expedite conflict resolution and give some technical and legal support to miners in the area.

The suggested strategy to implement these recommendations is to create a committee that proposes the legal modifications in such a way that alluvial mining is appropriately considered in the Mining Law.

Regarding property rights, although the Mining Office has made substantial improvements, coordination must be developed among different sectors. In this way, the Ministry of Agriculture would not sell land previously granted to a miner. In the long term, a territorial management plan is required for the whole department such that all concessions (either from agriculture or the mining ministries) use the same universal transversal mercator coordinates. This plan should include a special treatment of the territories of native communities to ensure an ecological equilibrium consistent with their subsistence lifestyles.

For technical purposes, if implemented, an assistance program for exploration, extraction, and mineral processing would increase the productivity of miners and improve their environmental record. Along these lines, a program is recommended to educate miners about the toxic effects of mercury and the use of retorts. The government has distributed retorts in the area but has not checked their use or efficiency. It will be better to develop a mercury monitoring plan that will include educational campaigns regarding mercury poisoning.

Although there are several problems in the area, it is recommended that the work start in the Caychive and Huaypetue area where most front-end loaders operate. By means of a refundable deposit system, it is feasible to force front-end loader operators to register and abide by some technical and environmental procedures to regain their deposit. A non-governmental organization selected by public bidding could be in charge of implementing such a system and coordinating the relevant public offices. There is a great deal of duplication among government offices in the area. This program could be financed using international cooperation funds.

Underground Informal Mining in the Ica-Arequipa Region

Informal mining in the departments of Ica and Arequipa exploits thin veins with relatively high grade ores that are disseminated across the region. Recent estimates are that they extract about 9 metric tons a year. The geological characteristics give an advantage to informal miners over more traditional operations. By selective extraction of the seam, the artisanal miners can essentially omit the concentration operation that follows, substantially reducing the cost required to obtain metallic gold. Thus, it is geology that makes the work of artisanal miners profitable where traditional miners would lose money. This is a central premise in the work.

Technical Aspects

Although several informal mining operations are located in abandoned formal operations, informal miners have discovered new ores in the area that would have been extremely costly to detect using conventional methods. Exploration is undertaken by groups of 200 to 300 persons, each one covering a different area, giving a high probability of success at a low investment.

After a successful exploration, miners remove mineral and then sort the mineral by hand and transport it to the processing plants. This process is commonly referred to by the Quechua word "pallaqueo." The mineral is removed using the Circado method (selective mining) which has three phases: (1) drilling, blasting, and waste rock removal, (2) cracking and extraction of the seam, and (3) drilling and removal of the box rock above the vein in order to continue the operation. Waste disposal is done either outside the mine when it is not very deep or inside when the mine is deep or used to support a gallery.

Under the conventional alternative, this process is not advisable because it is slow and requires a huge number of workers. Traditional mining totally removes the vein and the box. However, this dilutes the mineral grade, in some cases rendering the operation unprofitable because of the high cost of mining and the treatment of the waste material involved.

Artisanal exploitation of gold veins is based on hand drilling, using augers or chisels and sledgehammers. Of the total, 70 percent of miners use manual drilling, 9 percent use electric drills, and 20 percent use conventional compressors. Only manual drilling can be performed individually. Given that it does not require equipment or oil, it is most suitable for very remote places. It does not require technical knowledge for operation or machinery maintenance, and production is not stopped by malfunctioning equipment. Work progresses very slowly, at a speed less than ten percent of electric drilling and one percent of pneumatic drilling. Likewise, the investment required is also very low, one percent of electric drilling and 1/10 of one percent of pneumatic drilling.

It has been estimated that more than half of the miners in the area work mines less than 50 meters deep. Only 20 percent of miners exploit mines more than 150 meters below the surface, much shallower than typical traditional mines. Artisanal miners are not capable of going any deeper because of deficient ventilation and the large effort involved in removing the waste.

Pallaqueo, or hand sorting of mineral, is an ancient technique used to increase the grade of the mineral and hence reduce the cost of processing, transportation, and trading. The processing of the mineral is done in the so-called *quimbaletes*. A quimbalete is a type of huge mortar in which the mineral is milled, using water, to a fine sand that then is mixed with mercury in order to recover the gold. The amalgam at the bottom of the quimbalete is then separated from the tailing. Excess mercury is removed by filtering, and the amalgam is burned to recover the gold. The transport of the mineral to the

quimbaletes is usually paid for by the owner of the quimbalete in exchange for the tailings.

Leaching of the mineral using cyanide is not common in the area as a result of previous failures caused by technical deficiencies when implementing the system. However, in some areas, miners sell their mineral directly without milling it in the quimbaletes. This greatly reduces mercury use and avoids its toxic effects.

On the contrary, leaching of tailings is quite common. It has been practiced for years in the southern region of the country, especially in Nasca where at one point up to 20 plants operated simultaneously. These were small, hand-fed artisanal plants, capable of processing between three and ten tons of tailings each day. The plants use the carbon in pulp method, and their final product is coal filled with gold (3 to 10 grams per kilo) that need additional processing in a desortion and refinery plant. Most of these operations collapsed when the demand for tailings from larger plants (such as Laitaruma and Belen) increased their price from \$15 to \$120 per metric ton.

Minimum investment for an informal miner is about \$50 but increases exponentially with the use of pneumatic drilling that also requires leaching plants for minerals. Operating costs for the different alternatives (hand drilling, electric drilling, and pneumatic drillings) fluctuate between \$142 and \$186 per ounce of gold, the lowest being for pneumatic drilling, a process that also allows for the exploitation of the lowest grades. These costs are well below international prices; thus, miners should reap high profits. However, a substantial part of these potential earnings is reaped by gold and supplies traders. Mineral processing in their own plants, as well as direct trading of their gold, would substantially increase the profits of miners.

Quimbaletes centers and leaching plants also have significant profit margins (over 30 percent). Accordingly, they should be able to include environmental costs that are not properly taken into account now.

Environmental Aspects

As the area of exploitation is a desert, water is scarce, and there is little flora or fauna. In this context, mining has little environmental impact. Moreover, artisanal mining has much less impact than traditional mining, which uses more explosives, demands more water, and removes much more material.

The main environmental problem associated with this activity is related to mineral processing in the quimbaletes with the corresponding use of mercury and burning of amalgam. Leaching plants also have some environmental impacts, especially those that process quimbaletes tailings containing mercury. Mixed with cyanide, this process can render very toxic compounds. However, these plants are easier to monitor and environmental controls can be easily enforced.

It has been estimated that 12.6 metric tons of mercury contained in the amalgam volatilizes every year and that another 200 metric tons of mercury per year are contained in

quimbalete's tailings treated by leaching plants. The high content of mercury compounds is quite dangerous given plant locations. Most quimbalete centers are close to water streams or agricultural areas.

Another potential source of pollution is tailings dust. When tailings dry, mercury contained in them quickly evaporates. The dryness of the area together with strong winds spreads mercury across vast areas. Tailings dropped along roads between quimbalete centers and leaching plants are also a source of pollution. Winds spread them quickly, and they eventually contaminate water sources.

Finally, the most important source of environmental damage occurs when burning the amalgam, allowing mercury to evaporate into the atmosphere. Most miners burn the amalgam in traders' places in the area; only 10 percent within their own houses. Although 40 percent of miners are aware of retorts, very few use them. The chemical method of dissolving and recovering mercury from the amalgam using nitric acid is a short-term technical alternative to alleviate the environmental impact of mercury evaporation. This method generates a much better quality of gold because iron, copper and silver impurities are also eliminated with the acid. It also offers a quick, complete and observable recovery of mercury. These impurities are not eliminated by using retorts and higher quality gold is a factor the miners greatly appreciate. However, before full-scale implementation of this method in the area, it is necessary to do some extra trials to improve the method, train miners to do it by themselves, and control the emission of toxic nitric gases.

With time, adequate training and professional supervision, this method could render refined gold (24 carat gold) in the same laboratory where mercury is recovered. This is not only an environmental improvement but also an economic one that will allow miners to trade their gold at better prices. After this stage, it will be easier for the government to control the trading of gold and to obtain tax revenues.

In the long term, however, a more comprehensive environmental solution would be to eradicate the use of mercury and encourage direct mineral processing in leaching plants, where environmental control is much easier, and the existing law could be more easily enforced. However, in doing so, leaching plants will have to be reconstructed to avoid the use of obsolete and dirty practices. To achieve this objective, a crucial element will be the training of miners to be able to determine the mineral grade and to obtain a fair price for their gold.

Legal Aspects

Artisanal mining in the area operates on granted concessions because this activity started on abandoned formal mines. In Madre de Dios, concessions were not open to the general public until the situation of informal miners was resolved. Conversely, in Ica and Arequipa, Mining Registry reform and the opening of the area to new concessions since January 12, 1995 has complicated the process of formalization of artisanal miners in the area. Very few miners were capable of starting private companies to be able to bid for

concessions in the area. As a result, all the area has been granted, and informal miners are still working on concessions that do not belong to them. However, a huge proportion of the bidders that obtained concessions in the area are either speculators who expect to negotiate with foreign investors or leaching plants that enjoy a privileged negotiating position with informal miners by owning the concession. As mentioned above, the geological characteristics of the ores precludes formal mining from operating in the area. However, formal operations have the capital and technology for operating leaching plants. These plants need informal miners to supply the mineral and tailings. Accordingly, they do not want to get rid of them because of this complementary relationship. The plant owners take advantage of the informal situation of miners, however, to pay them low prices.

In this case, the formalization process should provide a mechanism to encourage and regulate fair contracts between miners and plant owners (who legally own the concessions).

Social Aspects

Most informal miners have migrated from poor areas and different type of activities. Because of the economic crisis, they work as miners even though they have limited previous knowledge of the activity. Thirty percent of miners were peasant farmers, but there are also industrial workers (20 percent) and students (15 percent). An important proportion of miners immigrated to the area within the past few years, an indicator of the fast growing rate of this activity.

There are very few illiterate miners. Many are young and relatively well-educated people (with high school diplomas and even some university studies), which could be useful for future training in technical and environmental programs. The number of family members of a typical miner is 3.5; thus, about 45,000 persons depend on this activity aside from the approximately 13,000 miners.

Miners work alone or in small groups. Mining associations are rare and, to some extent, conditioned by the geology of the ore. Rich grade ores are usually synonymous with individual operations, while poor grade ores usually encourage team work and more social organization. There are few paid laborers in the area, and these are limited to providers of secondary inputs like food. Miners live in very poor conditions. Due to water scarcity, they confront serious sanitary and health problems.

Recommendations

Artisanal mining is a profitable activity and an important source of employment for the inhabitants of Ica and Arequipa. This activity can easily coexist with traditional mining operations because the geological characteristics of the ores give the informal miners an advantage over traditional mining alternatives.

In this context, it is recommended that a technical assistance program for artisanal miners is provided. The program would allow miners to deepen their work and improve

gold recovery in a more environmentally sound way. The development of a domestic technology suited to local problems is needed. To do so, applied research in situ should be promoted.

Regarding environmental aspects, short-term technical support should focus on ways of substituting the burning of the amalgam as a way to recover the gold. Nitric acid is one solution. In the long term, however, it will be advisable that miners process all mineral directly in leaching plants where environmental control is easy. To reach this point, it will be necessary to train miners to determine mineral grades in order that buyers will not cheat them.

Regarding legal aspects, the formation of a committee that will suggest ways to accommodate the existing legislation to the characteristics of artisanal mining is recommended. This committee should also check the legal status of mining concessions in the area. This would help to organize their current situation. Special attention should be paid to: (1) the classification of artisanal miners in a category that comprise smaller producers than that of small miners; (2) the adjustment of the yearly payments on concessions and minimum yearly production requirements; and (3) the legalization of contractual relations and the regulation of payments between plants, which usually also own the mining concessions, and groups of informal miners.

Additionally, an institution should be created to support and give legal, accounting, and tax advice to miners associations. This would serve to develop them into artisanal mining enterprises that would operate as private corporations that could legally buy their inputs, undertake contracts, and bid for concessions.

8

Economic and Environmental Viability of Small and Medium Mines in Peru

Mining is an important source of foreign exchange in Peru. During the past five years, the country has experienced an investment boom in this sector. At the same time, Peru has built up a legal body aimed at preventing any negative environmental effects resulting from mining activity. This legislation is also intended to provide foreign investors with a clear and stable set of rules.

Using the command-and-control approach, the mining authorities have set the standards that firms will have to comply with within the next five years in order to avoid paying fines. Firms have had to present and follow an Environmental Improvement Plan (PAMA is the Spanish acronym). The law also requires firms to make an annual investment in environmental improvements of a minimum of one percent of total annual sales. They will help to reach the intermediate goals of their PAMAs.

Medium and small mining operations in Peru are quite old. They are run by domestic entrepreneurs that do not always have access to the appropriate technology or the financial resources needed to convert their operations into cleaner ones. In this new framework, there is uncertainty whether some medium and small scale operations will be able to simultaneously achieve profitability and behave in an environmentally sound manner. In such cases, it could be socially beneficial to shut them down. This paper aims to propose strategies so that most small- and medium-scale mining operations can be both profitable and environmentally sound.

Environmental Problems

The basin of the Mantaro River in the central highlands of Peru hosts a large number of small- and medium-size underground mines that exploit polymetallic ores with a high sulfur content. Most of the enterprises have flotation plants whose tailings are

Note: This section was written by Alberto Pascó-Font, a senior researcher of GRADE, Lima, Peru. It summarizes Pascó-Font and Villachica (1997).

accumulated in inappropriately designed tailings dams. Very few mines use tailings to refill underground galleries. On the contrary, they prefer to use the coarser tailings fractions to build the dams.

Given the huge amount of tailings that have accumulated over time, tailings dams are the most important environmental problem in the area. The steep topography of the area, as well as the existence of frequent seismic movements, seriously jeopardizes the physical stability of the dams. The lack of space in the area has forced mining firms to locate dams in narrow valleys. Their most important consideration is to minimize space, not to maximize safety considerations.

Mines in this area have been worked for decades. As a consequence, there are numerous underground open galleries, chimneys, and tunnels where acid rock drainage (ARD) is common. Acid water also leaches metals contained in the rock. These mine waters end by polluting streams in the region. As a consequence, ARD is an important environmental problem in the area.

Most tailings dams in the Mantaro area have been built using the old upstream method rather than the environmentally preferable downstream method. In the former case, once the dam is filled in, it is augmented by building a new embankment over the fine tailing deposits. In the downstream method, the new embankments are built over the previous ones. The risk that an upstream dam will collapse is high due to the low consistency of tailings on which they are built and the steep incline of the embankment, which in turn is explained by the desire to save space. This is specially dangerous in a seismic area. Moreover, rain can be very heavy in the area, and most tailing dams do not have appropriate drainage systems and cannot prevent water infiltration. Tailings are not stratified or treated before being thrown into the dam. As a consequence, dams hold dangerous volumes of water even though they have not been in use for years. A correctly designed downstream dam requires twice the space, so it is much more expensive. Accordingly, miners believe that complying with environmental regulations is costly.

In sum, tailings management and ARD are the main environmental problems resulting from mining activity in the Mantaro basin. Both have a very negative impact on water quality in the area.

Potential Solutions

Small operations are only required by law to invest about \$100,000 a year. This amount is clearly insufficient to overcome their environmental problems, that is, a properly designed tailings disposal system as well as a water treatment plant. For some operations, the amount of proven reserves are not enough to justify the environmental investment; thus, it is likely that such investment will not occur.

One way to solve this problem, even for mines with low reserves, is to search for economies of scale and common solutions for a group of neighboring firms. For

example, the construction of a large tailings dam, where all firms in the Morococha-Yauli area could accumulate their tailings, would be much cheaper than each firm building its own tailings dam.

One firm could be the leader in this process. For example, Volcan, a medium-size operation located in the lower part of the Yauli River basin, could probably find the resources to finance such dam. The financial costs involved probably preclude smaller operations from financing their own dam. Instead, nearby firms could jointly build a tailings pipeline that would convey tailings to the above dam. The cost of this pipeline would be less than \$1 per ton of tailings, which could be easily absorbed by small operations that exploit high-value minerals. Moreover, small mines could even pay the above company for the disposal of their tailings and be better off than building their own tailings dam. Given the proximity of operations, a tailings market in the area could be developed. This option could even foster the development of small mining in the Pomatarea and Pomacocha area.

The building and financing of tailing dams as well as their management could be undertaken by private firms that need not to be related to other mining operations. Engineering and consulting firms specialized in building dams should be able to undertake such an enterprise and to charge a fee to use their facilities. Miners would be released from the need to build and manage tailings dams and focus on extracting and processing minerals. Water treatment plants could be dealt with in a similar fashion (see below) as an integral part of tailings management.

Joint Solutions for ARD and Tailings Disposal

Instead of confronting the problems of ARD and tailings disposal separately, they should be addressed simultaneously. A sensible way to reduce the investment required to build a tailings dam is to reduce the amount of tailings to be disposed of by using as much as possible to refill old underground galleries. By filling the galleries, the amount of ARD is reduced, as is the need for a water treatment plant.

Typical small and medium mining operations in this area only use from 9 to 20 percent of their tailings as refill. However, they could easily increase that amount to 50 percent. Tailings are underutilized as fill because mining operations were designed without taking environmental considerations in mind. Solving environmental problems after the fact is more expensive than reorganizing operations to prevent environmental problems at the beginning. The proposed solution involves a new engineering system designed to deal simultaneously with mineral processing, tailings disposal, and mine refilling. With an appropriate design, up to 70 percent of tailings can be used as fill, reducing ARD substantially.

In essence, the case under study presents a solution that was designed for a specific mine in the Mantaro region. The mine under study is a medium-size underground operation that has serious ARD and tailings disposal problems and pollutes

the Yauli River. The concentration plant treats an ore containing zinc, silver, lead, and copper, which is extracted from a pyritic-limestone host rock. Mining is performed by a conventional undercut fill method whereby waste rock fill is mainly used. Room and pillar and, to a lesser extent, hydraulic backfilling are also used. Only 9 percent of the tailings are used to refill the mine. The rest is deposited in tailing dams that were built using the coarser fraction of the tailings. The tailings dams have upstream embankments with steep slopes (more than 45 degrees), jeopardizing their physical stability. Old dams have started to generate ARD as the permeability of the coarse tailings stored in the dam facilitates their contact with oxygen. As the tailings dams are located quite close to the Yauli River, the ARD pollutes the river, especially during the rainy season. Under the above circumstances, it was not advisable to build a dam using the tailings. Instead, earth should be used so that all the tailings can be submerged to avoid sulfur oxidization.

The study evaluates five options to solve the mine's environmental problems. The first option was to build a dam of earth to store future tailings. The other options, however, tried to minimize the amount of tailings stored in dams by maximizing their use as refill. The tailings that cannot be used as refill are stored in smaller dams. Dehydrating and compacting the tailings also reduces the required size of any tailings dams. The investment required to store tailings depends crucially on the size of the dam. When using dehydrated and compacted tailings, the cost depends on the equipment required for these processes.

Two options for refilling were considered: Optimized hydraulic filling, using small cyclones to achieve a higher proportion of underflow to use as filling (options 4 and 5); and paste filling, which requires densification using thickeners and dehydration in disc filters of the whole tailings (options 2 and 3). When compacting tailings before storage, the paste filling plant dehydrates all of the tailings, avoiding the need for additional filters or thickeners.

ARD of this mine is 33,300 cubic meters per day, and its treatment has also been included into the simulations. Obviously, a substantial amount of this drainage will be reduced if the tailings dam is reduced in size and galleries are refilled. This fact has been taken into account when designing the water treatment and neutralization plant. Other factors taken into account in the simulations are: (1) management cost of the dams are estimated for the next ten years, and (2) financial costs of the required investment are those associated with repayment in five years.

Hydraulic backfill replaces waste rock backfill. This could involve additional costs. Each alternative cost considers the use of a slurry pump and pipeline to transport and place the tailings into mine stopes. They also consider a difference in levels of 100 meters and a pipeline length of 1,200 meters. The pipe diameter considered is 6 inches, although a smaller diameter would likely be satisfactory. Cement with a dosage of 5 percent is added to the tailings when using the paste backfill method, in order to improve fill strength.

Table 8.1 summarizes the different costs involved in each option. Option 1, the traditional option of building a downstream tailings dam, is very costly and can significantly reduce mine profitability. However, option 5, compacting fine material and hydraulic backfilling, costs only one tenth of the traditional option, and the operational cost involved is a fifth of managing a traditional tailings dam. The amount of investment required does not affect mine profits, and it is quite manageable. In addition, the proposed technology is available and known by Peruvian miners.

Table 8.1 Joint Management of Tailings Disposal and ARD: Costs of Alternative Options

(US\$/metric tonnes mineral; in million US\$)

<i>Option</i>	<i>Direct</i>	<i>Indirect</i>	<i>Operational</i>	<i>Financial</i>	<i>Environmental</i>	<i>Investment</i>
Option 1: Current, all tailings to the dam	7.02	1.40	8.42	3.04	11.47	10.22
Option 2: Paste backfilling and dam	5.31	1.06	6.37	2.37	8.74	7.98
Option 3: Paste backfilling and compact tailings	4.51	0.90	5.42	0.82	6.24	2.77
Option 4: Hydraulic backfilling and dam for fine tailings	2.28	0.46	2.73	1.70	4.43	5.71
Option 5: Hydraulic backfilling and compacting fine tailings	1.89	0.38	2.27	0.34	2.61	1.16

Source: Constructed by Alberto Pascó-Font

An Implementation Strategy

The objective of the strategy described below is to identify the least expensive way to convert old dirty mines into profitable and cleaner operations and to provide access to the technologies to achieve such a conversion. The proposed program will help develop the required technical studies required by mining enterprises.

The Ministry of Energy and Mines would screen suitable consulting firms specialized in designing and building clean mining operations. Mining firms could negotiate with these firms (or any that are suitable for this task) in order to find integrated solutions that will help solve their environmental problems—and those of the mines in a given district—while remaining financially viable. Most likely this will imply the revision of the PAMA programs for most small size operations since a more thorough review may affect the entire operation as well as that of neighboring mines. It is worth recalling that PAMAs have been conceived as a solution to alleviate existing problems

rather than as a complete review of the whole mining operation which aims at minimizing environmental problems.

The program would help coordinate mining firms to contract qualified consulting companies to undertake the necessary studies. All participating firms would pay their share of the cost. Since many mining enterprises in the Mantaro basin have realized that they contribute to the same environmental problems, they appear willing to coordinate solutions. This could be a good starting point to initiate a joint program to revamp the old operations in a cleaner way. The program will encourage the search for joint solutions in a specific area.

Given that mining pollution imposes a cost on the entire society, it could be economically efficient to subsidize a solution if the environmental cost involved is higher than the support required and there is a coordination or free rider problem associated with the technical research; that is, all the companies can use any results developed, so for each individual company it is profit-maximizing to let other companies spend the resources. Accordingly, the program could offer resources at convenient terms and interest rates depending on political considerations and resource availability. If one assumes that the average cost of the studies required is \$100,000 and that less than 50 medium and small size mines are operating in the country, then the studies will require a maximum of \$2.5 million—and substantially less if there are many joint proposals—in order to meet potential demands. Hence, the amount of the (once-and-for-all) assistance would be relatively small, given that it would be a fraction of this figure.

Once the best technical solutions have been identified, the government would promote and disseminate the results. They would also provide the mining companies with contacts to access the most appropriate technologies and contractors.

Given the relatively recent changes in environmental legislation in Peru, the question of financial assistance for mine reconversion is likely to be considered as an instrument to reduce the possibility of bankruptcy. Even if there is confidence that the usual political economy problems associated with such a support scheme can be avoided, financial assistance would only be justified in the following circumstances: (1) there are coordination problems associated with the investment, especially if it is necessary to build facilities which service a number of mines or plants; or (2) a once-and-for-all subsidy to correct an existing environmental problem in a firm with inadequate access to credit would result in an expected long-run flow of revenues sufficient to cover all costs.¹⁷ In such a situation the preferred mechanism could be a long-term loan at market interest

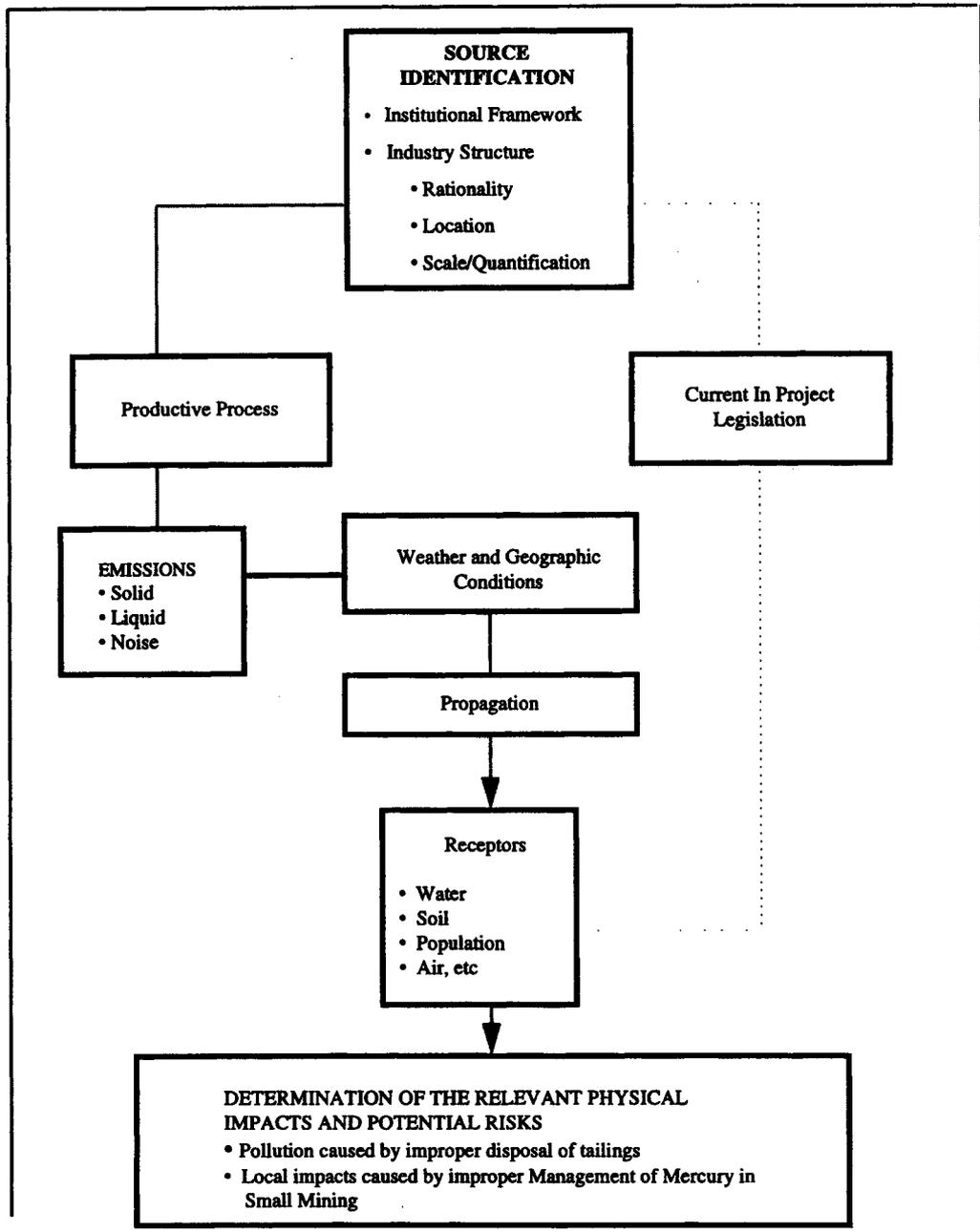
17. Of course, if the subsidy comes from general government revenues, the social rate of return must be higher than in alternative investments.

rates, guaranteed by a government agency.¹⁸ In the current situation in Peru it is likely that only a small number of mechanized small and medium mines need and could benefit from such assistance. Any mine that needed financial assistance year after year to mitigate environmental damage should be allowed to close.

18. An alternative would be to set up a "mining reconversion fund," which would lend funds for environmental upgrading based on the decisions of a board of mining and financial experts. However, the same principles would apply as in the simpler case.

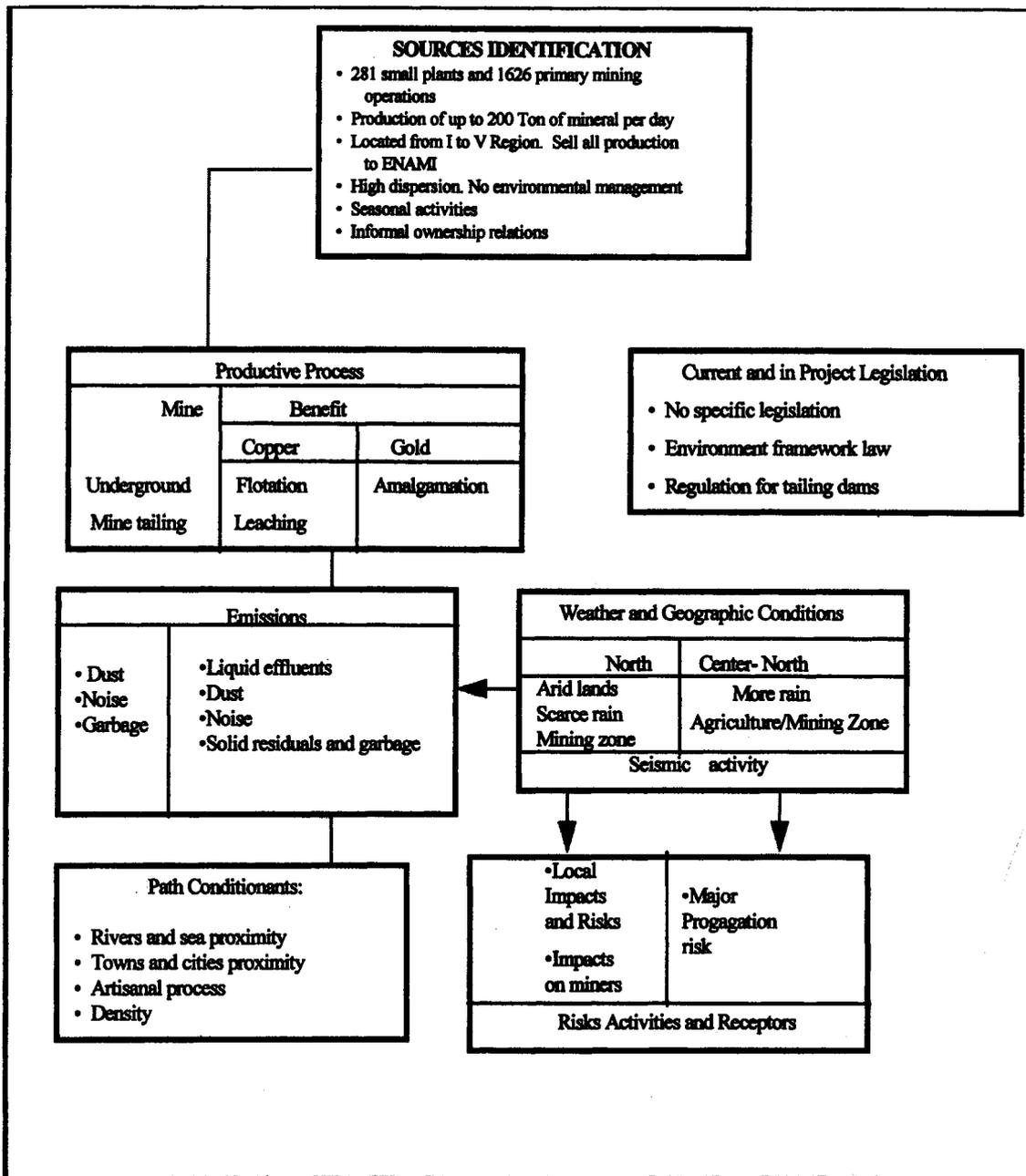
Annex 1

Figure A.1 Impact path



* - See text for explanation.
Source : Own elaboration

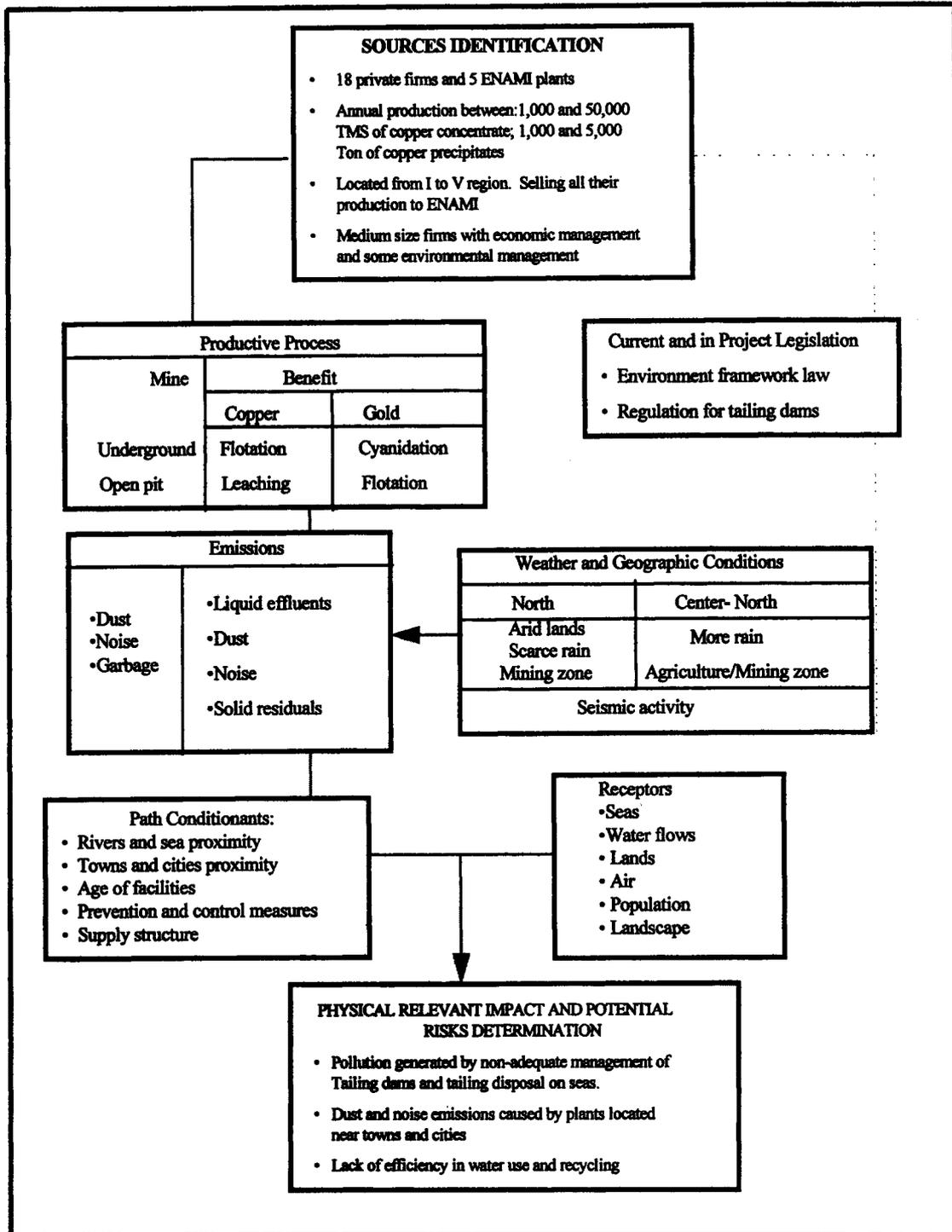
Figure A.2 Small-Scale Mining Impact Path



* - See text for explanation.

Source: Own elaboration

Figure A.3 Medium-Scale Mining Impact Path



* - See text for explanation.
Source: Own elaboration

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