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UNITED NATIONS INDUSTRIAL
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UNIVERSIDAD NACIONAL
EXPERIMENTAL DE GUAYANA

UNIDO PROJECT SI/VEN/94/801
ADVISORY ASSISTANCE ON INTRODUCTION OF ALTERNATIVE GOLD MINING AND EXTRACTION TECHNIQUES AVOIDING MERCURY POLLUTION

Ciudad Guayana, October 1995

UNIDO PROJECT SI/VEN/94/881
ADVISORY ASSISTANCE ON INTRODUCTION OF ALTERNATIVE GOLD MINING AND EXTRACTION TECHNIQUES AVOIDING MERCURY POLLUTION

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ABSTRACT

Mercury pollution in the Guayana region, in special the Bolivar State, represents a serious environmental issue in this locality. The main problem arises from the procedures used by miners for mercury handling and as a consequence most of the mercury is disposed with tailings which are dumped into rivers or onto land surfaces during hydraulic mining and excavations. The remaining part of mercury is left in the atmosphere during amalgam roasting done for gold recovery.

This work shows some of the main environmental and health problems in two traditional places where gold exploitation has been performed for decades : the lower section of Caroni River and Las Claritas area. Hot spots were identified in both places by using a heuristic system for environmental risk assessment of mercury from gold mining operations.

A survey of mercury levels in river water, sediments and fish is presented for two sectors located at the lower section of Caroni River where extraction of alluvial gold by using barges and dredges have become a significant activity. Total mercury concentration in water appears below 1.0 µg/L which is the maximum allowable level in Venezuela Environmental Laws. The mercury concentrations in sediments ranged from 0.09 to 0.8 mg/Kg over all the sampling points. The values of total mercury in fish, edible part and, gut and gill, fluctuated from 0.092 to 0.62 µg/g and from 0.17 to 1.00 µg/g, respectively.

This work also stress the importance of the Gold Recovery Centers as an alternative for recovering most of the mercury used in amalgamation and the necessity of using a technique like the Goldtech plates (or any other technique) to recover mercury and gold from tailings.

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1. INTRODUCTION

Few years before the discovery of South Africa's Witwatersrand deposits in the Eastern Transvaal in 1886, Venezuelan Guayana was one of the world's major gold producers. The majority of Venezuelan's gold was concentrated in Bolivar State, with El Callao area as the main source. Historical records show El Callao, Mocupia and other mines located in the green-stone belts of La Pastora province contained ores with grades surpassing often 50 g/mt and production reported in the area was 49 mt. during last century (Sarmentero, 1992).

GOLDFIELDS OF VENEZUELA acquired most of the concessions in 1898, but production stalled due to political pressures. In 1924, production revived thanks to the introduction of cyanide and flotation processes, and in 1928 NEW GOLDFIELDS OF VENEZUELA was formed. Subsequently, the Venezuelan government formed MINAS DE ORO DE EL CALLAO, which operated the mines from 1953 to 1966. The new history of gold mining in Venezuela is starting right now with the rediscovery of several world class deposits as Km 88 at Las Claritas area (Sarmentero, 1992).

The lower section of Caroni River (Bajo Caroni), has been a known producer of gold and diamonds for over thirty years. Production has been irregular and was handled by small and medium sized companies. In most cases, the technology and/or operating procedures used, have not been adequate for effective mining and high recoveries. The government agencies have had little control over these operations and consequently, the taxation revenues from this industry have been meager (MINPROC CANADA Inc.,1991).

The main environmental concern related to mining activities in the lower section of Caroni River is that the processes executed with barges and divers, as well as mechanical dredges, remove bottom sediments from river bed. Heavy metals like mercury which may be present in the sediments can be re-suspended (Bermudez, et. al.,1994).

There are two government agencies that carry out gold exploration in Venezuela: the Ministry of Energy and Mines (M.E.M.) and the Guayana Development Corporation (C.V.G.) - a regional development agency. On the other hand, only a few private exploration companies have been active in the Venezuelan gold mining scene.

Exploration and mining activities in Venezuela are done according to the existing "Mining Act and Regulations"- which came into effect on January 18th, 1945 - and to a series of subsequent administrative decrees and resolutions. The only government agency that have been created in order to deal with the mining law enforcement is the M.E.M.

It is being now considered the approval of a new mining law named "Mining Fomentation and Development Law", which will become into a real legal response to meet the needs of Venezuela's organized mining development.

About 30,000 people are involved with gold and diamond mining in Southeastern Venezuela, using panning and other rudimentary process, with recovery levels below 40%. According to local estimates, up to 15 mt/y of gold are produced in Venezuela. Of this amount, some 10 mt/y are sold illegally (Sarmentero, 1992).

The distribution of Venezuelan Guayana's informal miners, has been estimated as 50% Venezuelan, 29% Brazilian, 12% Colombian, 9% Dominican, 3% Guyana, and 2% of other nationalities. This situation is changing quickly, however. (Sarmentero, 1992).

The informal miners work alluvial deposits and use large amounts of mercury to extract the gold by amalgamation process, which is highly dangerous, since the mercury severely pollutes the miners and their environment as well.

2. STATEMENT OF THE PROBLEM

For several decades, gold mining activities in Venezuela's Guayana Shield region have resulted in severe mercury contamination of the mining areas. The amalgamation process involves relatively simple techniques, making it accessible to even the smallest mining operations.

Unfortunately, many miners who use amalgamation fail to keep proper procedures for mercury handling, and mercury that is left to the environment is estimated in 1.5 times the amount of gold recovered. About 40% of this mercury is disposed with the tailings. The remaining is left in the atmosphere during amalgam roasting done for gold recovery. The tailings are released back into the rivers during dredging operations. Moreover, tailings may be dumped into pools or onto land surfaces during hydraulic mining and excavations (USFS, 1993).

Two different behaviors are expected as mercury is released into the environment through amalgamation tailings and amalgam burning. With amalgamation tailings, the formation of hot spots is typical, and with mercury release, surface contamination may be followed by high levels of mercury in soil. Furthermore, the presence of hot spots in aquatic systems increases the possibility of mercury complexation and bioaccumulation.

3. OBJECTIVES

The following are the purposes of this study:

a) Identify highly mercury contaminated sites (hot spots).

b) Determine bioaccumulation risks of hot spots by applying "A Heuristic System for Environmental Risk Assessment of Mercury from Gold Mining Operations" (HgEx).

c) Assess the health condition of workers exposed to mercury.

d) Summarize sociological investigations undertaken previously by several institutions and evaluate the present situation at mining settings.

e) Collect and evaluate the data on toxic waste production and disposal, and analysis of effluents and river sediments in mercury polluted areas.

4. AREA UNDER STUDY

Two different mining areas were selected to carry out this project.

4.1 Lower Section of Caroni River

This is located in eastern Venezuela's Bolivar State. It is a 70 Km portion of the Caroni River, between the Guri Dam and the Caroni-Orinoco junction. This area was once a site of extensive mercury usage during gold dredging (Fig. 1).

There are small villages and mining camps along the north shore of the river. Two Gold Recovery Centers, located in the villages of Carhuachi and Playa Blanca, are described further on.

4.2 Las Claritas Area

This village is located southeast of Bolivar State, Km 85 on Venezuelan Highway 10, south of El Dorado town (Km 0). Access can be done by a dirt road from paved Highway 10 (Fig. 2).

5. METHODOLOGY

Two surveys were carried out in two sectors of the lower section of Caroni River. Samples of water, sediments and fishes were collected in this sectors for analyses of total mercury. The mercury concentrations were determined by Atomic Absorption Spectrophotometry using a Perkin Elmer 2380 equipment provided with a cold-vapor generator Perkin Elmer MHS-10. In addition, temperature, conductivity, pH, redox potential and dissolved oxygen were carried out using portable equipments.

A Goldtech plate was used to recovery free mercury and amalgam from the tailings coming from the Recovery Gold Centers and mills. This technology was developed in Brazil were a thin coating of Hg is electrolytically deposited onto a metallic plate. Gold is captured and firmly fixed on the plate surface and no Hg loss has been observed. When the plates are fully loaded, amalgam is removed for washing with a plastic scraper.

Figure 1. Relative location of the lower section of Caroni River

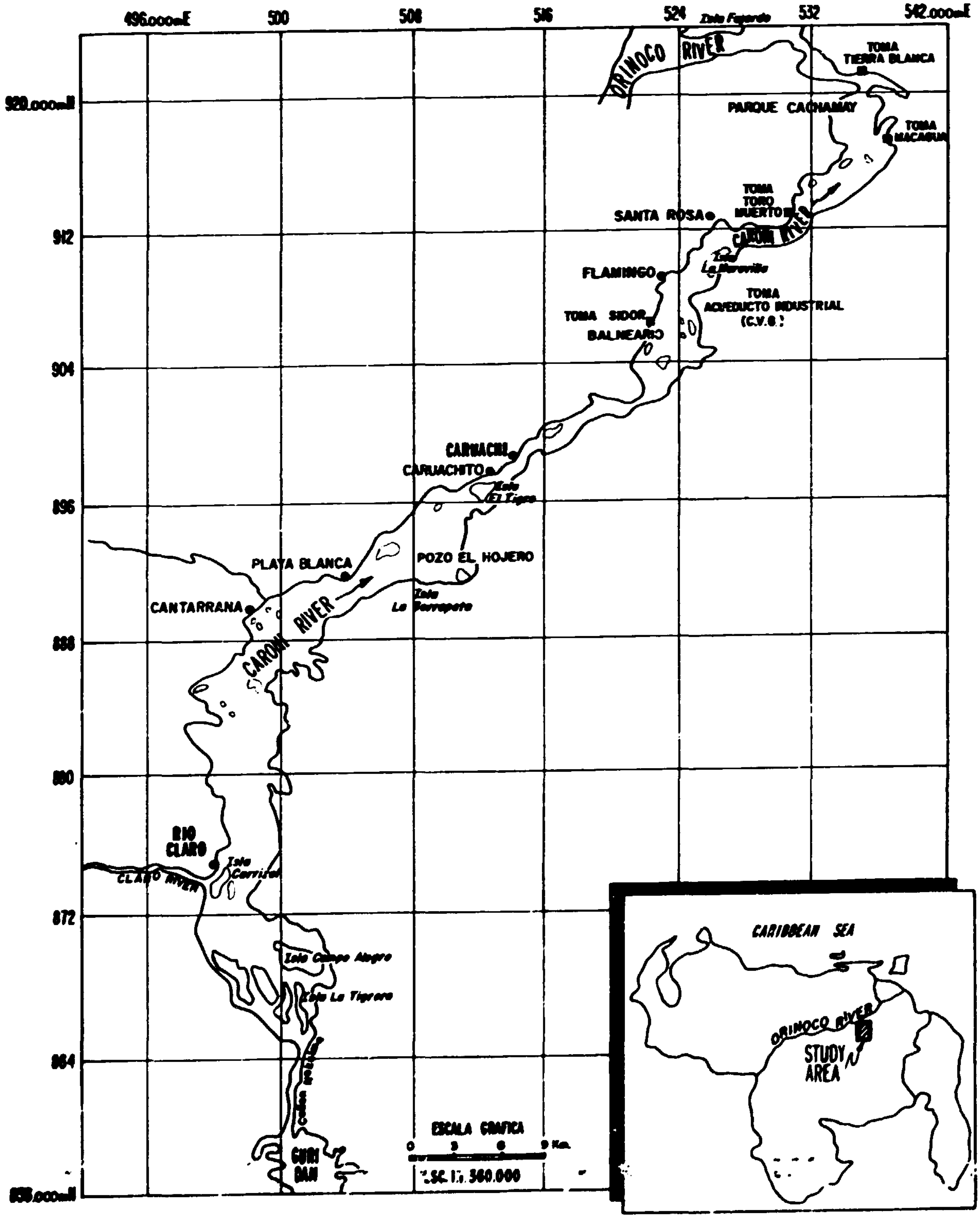
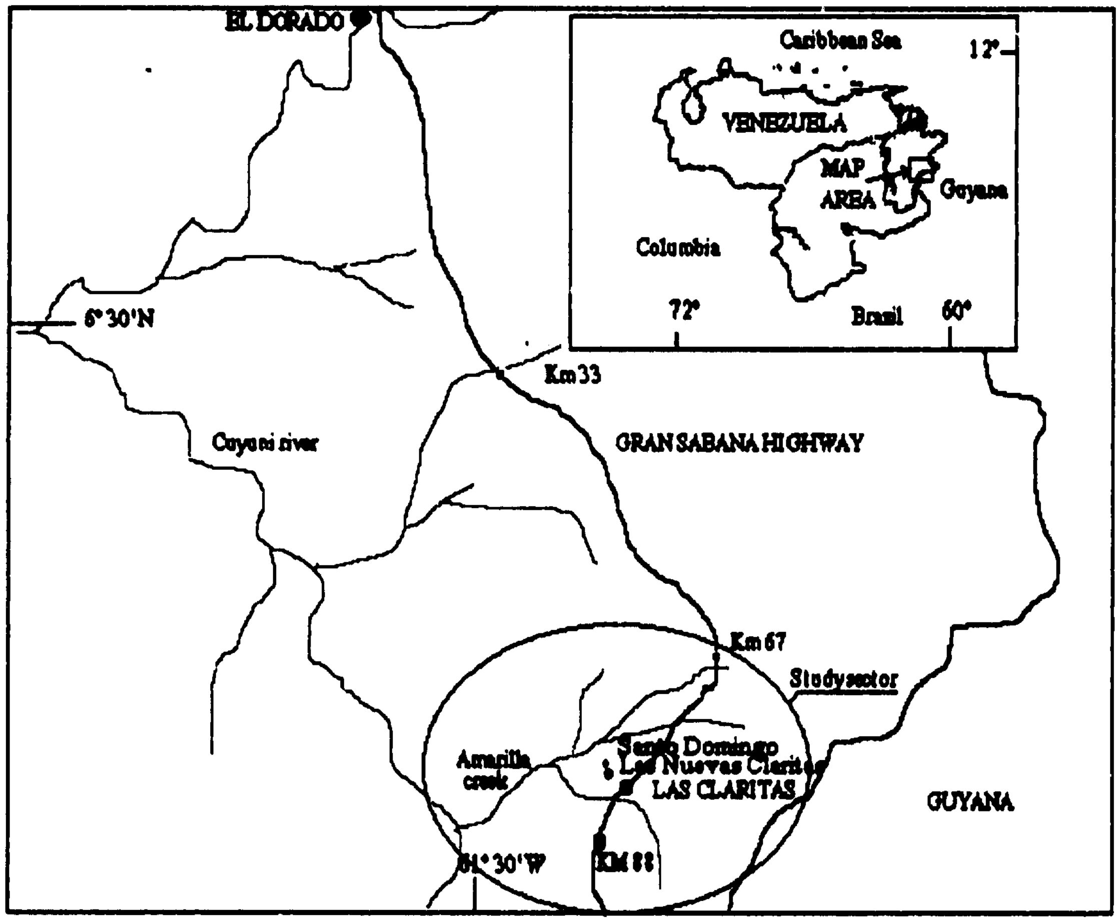


Figure 2. Relative Location of Las Claritas Area



A heuristic system for environmental risk assessment of mercury from gold mining operations (Hg-Ex) was used for determination of bioaccumulation risk of the hot spots as a preliminary diagnosis.

Assessment of health condition of informal miners exposed to mercury was carry out by interview, clinic evaluation and revision of the clinic history at the medical centers.

The most recent information about the social-economical status of the informal miners in the selected areas was collected.

6. RESULTS AND DISCUSSION

6.1 Identification of Hot Spots

6.1.1 Lower Section of Caroni River

Until 1989, about 200 dredges were operating to extract gold and diamond from sediments of Caroni River. The dredges have used 8 to 14 in. suction lines and can operate down to 40-45 m. in depth (20 in water and 20 in placer). Some dredges use suction nozzles operated by divers to pump the sediment up to the sluice boxes. However, most dredges have cutter-head systems which hit a hard layer of sediment (crust of cemented gravel in a sandy matrix of hydrous ferric oxides) in which gold is immediately below. The dredge material is concentrated on board usually by using sluices with rugs or mats. In some cases jig and centrifuge are used. Amalgamation was practiced on board using copper plates and contaminated tailing was returned to the river. Miners have estimated that from 2 to 4 tons of mercury were discharged before 1991. On July 26, 1991 was promulgated the Decree 1740 which banned the use of mercury into the river while realizing mining activities. In practice, usually 20 % of mercury introduced in the process is lost when retort is not used. Operations with mercury losses around 50 % are not frequent, but can occur when whole ore is amalgamated, i.e. when mercury is placed in riffled sluices. The major mercury loss is related to amalgam burning in open systems (pans or shovels) to evaporate mercury in amalgam. The second source of loss is attributed to amalgamation tailing, i.e. mercury droplets are dragged with solid waste. The third source of emission occurs when residual mercury is released when gold is melted. All mercury emissions can reach watercourses (Veiga, 1995).

6.1.1.1 Mercury Concentration in Dredged Sediments

This research was done in the Carhuachi area and it was originally based in the reports of Mr. Carlos Carlesi, who is a MEM concessionaire.

For the past three years (1991-1994) the average mercury recovery from the river bed was 0.56 g/Kg of concentrate. Considering that an exploitation unit (dredge) can remove up to 35 t/h of material from the river bed and the concentrate obtained after a 40-hour working day is 40 Kg, we can calculate that the amount of mercury recovered from the sediments is 0.02 g Hg/t of dredged material.

Considering as well that the total material removed by all the exploitation units that are working at this moment in the Carhuachi area remove 70 t/h, and the effective time of activity is 80%, we are able to perform the following calculations:

360 days X 24 hours X 0.8 = 6,912 hours

6,912 hours X 70 t/h = 483,840 t/year

Therefore, the amount of mercury recovered per year from the river bed in that area would be:

483.840 t/year X 0.02 g Hg/t ≅ 10 Kg Hg/year.

6.1.2 Las Claritas Area

Up to 1991, informal miners in this area mostly used hydraulic monitors for gold exploitation activities both in zones of mining concessions and free mining zones. Material was taken to a sluice matting and mercury was used both in trays and water boxes.

As the use of hydraulic monitors was restricted and informal miners were displaced by the concessionaires themselves in order to avoid sanctions prescribed in the Environment Penal Law - which is in operation since 1992 - these miners went to areas previously exploited because they could not mine virgin areas. The simplest technology was to dig holes in the areas previously mined, extract vein material and process it in mills. This led to a wide spreading of mills in this area.

Hot spots in the milling areas of gold-bearing material coming from veins were reported. The process of gold recovery in this area differs largely from the one used in the lower section of the Caroni River. The use of mercury without discrimination and the lack of control of its emissions throughout the various steps of gold recovery, contrasts with that we saw in the lower section of the Caroni river with regard to mercurial contamination.

The metallic mercury for gold recovery is used in specific areas of milling where there are groups of millers with installations of 2 or 4 hammer mill units powered by 25-30 HP electric motors. Gold-bearing material from rocks - that informal miners bring from exploitation zones - is crushed by each of these units. During the milling process, metallic mercury is added in order to amalgamate the primary tailing that is attained at the mill outlet. The operator performs this addition by mixing it manually.

6.2 Bioaccumulation Risk of Hot Spots

6.2.1 Lower Section of Caroni River

6.2.1.1 Elements that Promote Bioaccumulation

a) Use of amalgamation as one of the methods for gold recovering from concentrates.

b) Amalgam burning and melting with direct exposure to mercury vapors.

c) Lack of technical and sanitary measures for personal and work ambient protection, e.g. absence of mercury vapor filters on respiratory masks, non appropriate vestment, wrong handling of contaminated clothes, lack of captivation systems for mercury vapors, and lack of information about the effects of mercury in the human body.

d) Critical moments of high mercury emission at Gold Recovery Centers, i.e. burning and melting during retort opening and casting of melt material, respectively.

e) Lack of official supervision of vigilance and control of activities, and non fulfillment of maximum permissible levels of mercury both in environmental and biological samples.

f) Lack of official supervision of occupational risk education that must be given to the employee due to mercury exposure.

6.2.1.2 HgEx Diagnosis

The HgEx (Veiga, 1994) was used as a preliminary diagnosis to determine the bioaccumulation risk of the hot spots.

At present the size of mining activity at the lower section of Caroni River is medium and for the gold melting operation these are small number of gold shops (4) working with a special filter for mercury abatement.

Even though we did not have analytical result for establishing the sediment background through the HgEx we got a figure of 0.108 ppm with low quantity of organic matter, sediment is rich in sand. The following table shows the values of some of the parameters that were analyzed and introduced to the model:

Parameter	Value
Conductivity	20 µS cm
Average Hg in sediments	0.24 ppm
Hg in hot spots	0.56 ppm
Eh	100 mV
pH	7
Average Hg in fish	0.19 ppm

The report on mercury pollution showed the following:

a) Bioaccumulation evidence: although the biological samples show low Hg concentration level, these is a high risk of bioaccumulation It is necessary to collect more fish samples (carnivorous fish). monitoring programs are strongly recommended to follow up the situation.

b) Remedial procedures: hot spots were identified and remedial procedures must deal with dredging and covering. Sucking dredges with cut edges reduces sediment dispersion during removed operation. Covering can be applied when dredging is not recommended. The principle of covering must be stable at the bottom of the aquatic system and eventual Hg oxidation can be controlled by adsorption which hinders the action of methylation agents.

c) Bioaccumulation risk: bioaccumulation risk is high (84 %); currently mercury emission level is low (19%); dangerous environmental conditions (65 %) and the possibility of Hg adsorption by sediments (0 %) due to low concentrations of suspended solids). The numbers between parenthesis represent the degree of belief.

d) Mining and amalgamation: mercury emission is low.

e) Natural variables: dark water systems have particular characteristics which favor methylation. Although hot spots were identified, the Hg concentration is low; additional samples should be collected to characterize the presence of a dangerous hot spots. Metallic mercury should be stable at these Eh and pH conditions, with low solubility. Suspend solids from the mining activities is not an important characteristic.

f) Biota samples: medium-low Hg concentration, the fish are likely not polluted.

6.2.2 Las Claritas Area

6.2.2.1 Elements that Promote Bioaccumulation

a) Processing of tailing material coming from mining sites where mercury has been used.

b) Practice of informal mining without official control.

c) Vein gold processing - indistinctly or together with tailings coming from alluvial material - at milling centers where amalgamation is used as the only way for gold recovery.

d) Mercury handling without any skin, respiratory or sanitary protection when mercury is added to whole or concentrate material, both are mixed at mill outlets, and gold is recovered by panning.

e) Environmental exposure to mercury vapors at milling centers due to the large amount of metallic mercury used in this process (up to 2 Kg of mercury per day), long stays in this centers (8-hour working day), and climatic conditions of the region, i.e. high temperatures and high relative humidity.

f) Exposure to high concentrations of mercury vapors when burning and melting the recovered product at gold purchase sites or, in more severe cases, direct burning in the open air using blowpipes. Due to these factors, not only miners get contaminated at but so do gold buyers and surrounding population, where there is an important number of children and women, which - the latter - are in reproductive stage, because gold exchange takes place at the miners' dwelling areas.

g) Absolute ignorance about mercury effects on health on the part of miners, mill owners, gold buyers and population in general.

h) Ordinary practice of eating, smoking, drinking and even sleeping in milling centers during the amalgamation process and the corresponding burning of material.

i) Important exposures in frequency and intensity to mercury vapors at the hot spots. Such exposures, for the Las Claritas' case, are represented by the places where the mills are - miners go to these centers between 3 and 5 times a week - and some stores in town where amalgam burning is done.

6.2.2.2 HgEx Diagnosis

At present the size of mining activity at Las Claritas area is small and these people amalgamated the whole ore. For the gold melting operation there are only a small number of gold shops working with a special filter for mercury abatement.

The Hg background getting from the model was 0.108 ppm and the sediments have low quantity of Fe-oxide. The following table shows the values of some parameters that were analyzed and introduced to the model:

Parameter	Value
Conductivity	10 µS/cm
Hg in hot spots	3.0 ppm
Eh	200 mV
pH	6.5

The report on mercury showed the following:

a) Bioaccumulation evidence: biological samples are not available to provide evidence of bioaccumulation (hard to fish!).

b) Remedial procedures: mercury is being discharged into the watercourses forming sites with high Hg concentration. Mercury dispersion is likely as well. Remedial procedures must deal primarily with the source of Hg dispersed (when Hg pollution occurs from atmospheric sources, Hg dispersion occurs over a large area, usually measured in Km2). The model suggest retorts and air filters.

c) Bioaccumulation risk: bioaccumulation risk is high (100 %); high Hg emission level (72 %); dangerous environmental conditions (70 %) and possibility of Hg absorption by sediments (36 %). Figures between parenthesis represent the degree of belief.

d) Mining and amalgamation: it is possible to reduce Hg emission with some measures. However mining activities are emitting high mercury levels into aquatic environmental which in natural conditions are relatively dangerous for methylation and bioaccumulation.

6.2.2.3 Health Condition Assessment of Miners Exposed to Mercury

Health general conditions are contradictory because although they have a deficient nutrition mainly based on carbohydrates and canned food, poor sanitary, feeding, mental and social conditions, plus large physical waste after each working day, there is a predominance of malaria-related cases at the local rural hospital, as it was seen on its book of diseases, which coincides with the malaria outbreak declared at present.

Secondly, an important number of medical consultations on sexual transmission diseases was reported and, in third place, on muscular pain.

No case of clinical hydrargirism was reported, nor were remarkable the medical consultations on gastrointestinal disorders in adults.

During the clinical assessment performed to 20 people including several miners at the rural hospital, and through the questionnaire done to people in general and to personnel of the milling centers, the following can be remarked:

a) Bad buccal health - which is connected to chronic mercurial poisoning symptoms, even though we cannot forget that the low educational level of most of the people and lack of adequate personal hygiene can be important elements for dental caries and loss of healthy teeth because of diseases on support tissues as gingivitis and pyorrhea.

b) Skin diseases, dermatomycosis, unicomycosis on hands and feet , lacerations and cutting wounds, and actinic dermatitis.

c) The habit of smoking is predominant, with an average consumption of half a package of cigarettes a day per capita.

d) Most of them have had more than three occurrences of malaria.

e) Most of them have caught sexual transmission diseases.

f) Most of them have reported tendon and muscle pains in upper and lower limbs as well as lumbago.

g) No one reported distal shivering of upper limbs.

h) Only one of the people questioned stated a sensation of metallic taste in his mouth.

i) No one reported alterations in the hand-writing.

j) Three of them stated character alteration, which they relate to the emotional tensions they are submitted to, and the physical waste for the defense of their properties and family as well.

k) One of them stated that his mate had aborted three months ago.

l) Three reported sexual dysfunction and one reported secondary sterility.

6.3 Social-Economical Status

6.3.1 Lower Section of Caroni River

The following information was taken from Environmental Consulting (1993), and AMCONGUAYANA (1992, 1994, 1995)

6.3.1.1 Demographic Profile

The total population of this area is about 1,140 inhabitants; the most important towns are Río Claro (52%), Santa Rosa (10%), Carhuachi (18%), and Playa Blanca (18%) (Percentage of people). There are no native communities in this area. There is an 85% of male people, which is not characteristic of a mining town and perhaps due to this low percentage, delinquency is low, compared to other mining centers.

6.3.1.2 Labor Power

The economical activity of the area mostly concentrates in mining (40%). Sixty two percent (62%) of the population is economically active.

In general, there is only one kind of miner, which is the one that works inside the exploitation units in the river (rafts and dredges). Perhaps 1% performs traditional mining activities by means of pans.

The average income per capita is Bs 29,500/month (US$ 173.5/month or US$ 43.4/week).

There are 368 economically active women who do not work directly in mining but in an indirect manner: cooks, traders, housework people, and prostitutes.

6.3.1.3 Commercial Activity

The most important commercial activities are food sale, liquor sale and prostitution.

The most important service lines of business are restaurants, bars and equipment and machinery repair shops.

6.3.1.4 Physical-Social Structure

Regarding to health, there are 3 small first-aid clinics with a permanent nurse and periodic medical visits, and a Type I shifting clinic or ambulatory with a permanent physician.

Regarding to education, there are usually elementary schools. Twenty six percent (26%) of the school-age population doesn't receive any teaching because they are into mining or service activities.

There are approximately 250 barracks; the rest of the housing units are buildings made of blocks and zinc plates, which are the small clinics, the gold recovery centers and Playa Blanca's C.V.G. camp.

Regarding to public services, electricity goes only to Santa Rosa and Carhuachi; There is service for picking garbage up and water closets in all the areas. Water is obtained directly from the river; many people use potable water which they bring from the nearest towns. Communication is done by means of radios and cellular telephones.

6.3.2 Las Claritas Area

The following information was taken from C.A. "MINCA" and C.V.G. (1994)

6.3.2.1 Demographic Profile

The total population of the area between Km 74 and Km 88 of the El Dorado-Santa Elena de Uairén road is approximately 3,658 people. The most important towns are Nuevas Claritas (37.3%), Km 88 (18.7%) and Santo Domingo (12%). The two native communities of this area are only 8% (296 people) of the total population.

In the area under study, the population represents only 0.24% of the Guayana Region, mostly distributed in Nuevas Claritas, Km 88 and Santo Domingo. The percentage indicator of male people is high (113%) and most of the couples live in concubinage.

6.3.2.2 Labor Power

The economical activity of the area mostly concentrates in mining (47%). Sixty-two per cent (62%) of the population is economically active (between 15 and 65 years old). There are three kinds of small miners in the area: The ones who use the traditional trays (39.5%), those who use hydraulic monitors (27.9%) and those who work transporting gold-bearing material in sacks to the milling areas (32.6%).

The average income level of the small miners is approximately Bs. 5,700/week (US $ 33.5/week). A high percentage of this labor crowd states their willing to work for the international mining companies, looking for work stability.

It is important to mention that the women's participation in the mining activity is meaningful, not only in the production frame but also in the commercial area as well. They participate in domestic and any service-related jobs that are characteristic of any mining settlement.

6.3.2.3 Commercial Activity

Commercial activity is mostly around the sale of supplies for the small mining, such as hardware, construction, liquor, and tobacco.

The service areas are also a result of the economic dynamical of the mining activity. Such areas are: recreation (restaurants, eating places, bars, billiards, boarding-houses and hotels), auto repair shops, and public electricity and water services. Among these, the eating places are the most numerous, and they are spread in the Nuevas Claritas and Las Claritas area.

6.3.2.4 Physical-Social Structure

The existing health-related structure is deficient; it does not count with adequate hospital installations, neither with necessary medical equipment in good condition and enough supply of surgery material nor with an adequate number of physicians and paramedic personnel, needed for the existing population. All this is aggravated by the fact that this is a malarial zone.

The education related structure is also deficient: it lacks the basic operational conditions, and there is a low children's school attendance - they are involved in the mining activities or in any other domestic task. Hence the percentage of homes with children in school ages that do not go to school (25%) is much higher than the national or Bolivar state percentage.

In the area under study, the majority of the houses (66%) are in bad condition (they are made of zinc plates and clay), which have a number of occupants (5.4) per house, and an indicator of heaping (16.7%) similar to the national indicator.

The public services such as water and electricity are limited and expensive; most of the houses have water closets connected to septic wells (52%), and a large percentage of them (27%) does not even have water closets. There is no telephone service in the area.

Regarding to the socio-psico-cultural profile , the native, Creole and foreign immigrants communities are in a transformation process towards modernization. Fortunately, this process shows that local people do not reject the new "actors" who come in the area; they rather consider the fact of the installation of international companies (mining companies) as an opportunity to improve their condition as well as their communities.

6.4 Collection of Data And Evaluation of Toxicity of Mercury Contaminated Tailings

It is known that Hg-organic complexes are formed from reaction of mercuric compound solutions with organic (Lövgren and Sjöberg, 1989; Ramamoorthy and Rust, 1976). However, no information is found in the literature to predict the complex formation when metallic mercury is brought into contact with organic-rich solutions, as occurs when Hg is condensed from vapor or amalgamation tailing is dumped into Amazon creeks that bear sediments with high organic levels. Since natural organic acids have extremely variable chemical composition, thermodynamic data on metallic-complexes are difficult to estimate (Veiga, 1994).

In spite of stopping Hg emissions in rivers like Caroni River, the most important tributary of Orinoco River, mercury content in sediments is subjected to complexation and further methylation due to medium level of organic matter in sediments, as well as in solution. Caroni River is a black-water river and humic substances (humic and fulvic acids) are responsible for the low pH of these water and they reach the water streams during the rainy season by leaching of litter on top of sandy soils (Veiga, 1995).

In order to estimate the toxicity of gold-bearing material coming from several places of the Guayana region, it is necessary to describe the sites where both the concentrate material that comes from the bed of Caroni River, and the gold-bearing material from the primary tailings handled around the area - where metallic mercury is added to them for gold recovery -, are traditionally processed i.e. the Gold Recovery Centers.

These centers are designated, basically, for processing of fine gold-bearing material and are distinguished because they have equipment and personnel for handling and control of metallic mercury in the gold recovery process from the primary concentrate, and proper disposition of tailings, in order to recover the free mercury. They also control the fume produced during burning of retorts and gold melting, properly said.

Using these centers as an alternative, a high percentage of recovery of the mercury used in the amalgamation process is guaranteed.

6.4.1 Lower Section of Caroni River

Until 1991, only 30 % of the miners from the lower section of Caroni River had the evidence that amalgamation was more effective to be applied to concentrates and they conducted their amalgamation on shore. The Decree 1740 of July 25, 1991 prohibited all amalgamation activities on board or on shore. The same Decree establishes that the Ministry of Environment (MARNR) may provide an authorization to one who wants to use mercury, based on a description of the equipment to be used. A consequence of above Decree was the creation by CVG of the Gold Recovery Centers to receive gravity concentrates and to amalgamate them under controlled conditions. At present the situation related to mercury contamination in the lower section of Caroni River is better than before the promulgation of the Decree 1740. Before July 25, 1991 the two most common sources of mercury contamination in the environment were: spills from barges using copper plates covered with mercury and during the recovery of gold from the amalgam. Even when the amalgamation was made on the dredging barges miners dumped the amalgamation tailings into the rivers forming high mercury concentration spots. These spots are more easily identified close to the margins which were old amalgamation pools.

The local practice for recovering gold from amalgam in the best of the cases consisted in heating the amalgam to its fusion point and evaporating Hg. Mercury vapor was then condensed in a very rudimentary form in the open atmosphere using cold surfaces or even wet blankets and carpets as the condenser chiller and the liquid mercury was collected and recycled to the amalgamation table, while a gold button was left behind. The contamination of the people carrying out this operation and those living close to that places is obvious and losses of mercury vapor to the air must have been very common (MINPROC CANADA Inc., 1991).

After July 25, 1991 the situation was totally different. The miners start applying mercury only to gravity concentrates under controlled conditions at the Gold Recovery Centers located at land and managed by specialized personnel, tailing are disposed in safety places before selling them to a company that recoveries gold by cyanide process Excess of mercury from amalgam is removed by centrifugation in some cases and heating steps (retorting and melting) are accomplished in special places.

There are some Gold Recovery Centers on the lower section of the Caroni River and, because of its importance, two of them were selected to be described in this project. One is located in Playa Blanca Village and the other in Carhuachi Village.

6.4.1.1 Playa Blanca Gold Recovery Center

The separation processes of gold in this center -which belongs to C.V.G.- is done as follows (Fig. 3):

a) The concentrates are submitted to a separation process on a Geminis vibrator table, where it is attained the gold that is taken directly to melting. Occasionally, the miner can skip the Gemini table operation to do amalgamation of the concentrates directly in rolling cylinders using the ratio 1:100 = Hg: concentrate.

b) The middling that come from the Gemini table are amalgamated by using cylinders in close circuit in order to attain fine gold.

c) Mechanical panning separation to remove heavy mineral.

d) The separation of free mercury from amalgam is done by squeezing the amalgamated material with a piece of cloth.

e) The amalgam is taken to a hermetic distiller where mercury is evaporated and recovered by means of a water-cooled serpentine condenser.

f) The gold, with some impurities, remains in the distiller; hence, a primary melting by using borax is performed to separate physically such impurities.

6.4.1.2 Carhuachi Gold Recovery Center

The separation processes in this Gold Recovery Center - which belongs to Mr. Carlos Carlesi - is done as follows (Fig. 4) (Photos 1 - 4, Annex 1):

a) The concentrates coming from the exploitation units in the river are submitted to an agitation process where liquid mercury is added to them in a 100.1 ratio (20 Kg concentrate: 200 gr. Hg).

b) After amalgamation, the material is taken to a regulator hopper which feeds an elutriator, where by specific gravity pressure of an ascending water current, the heavier elements and amalgam are separated from the rest of material

Figure 3. Separation Processes at Playa Blanca's Gold recovery Center

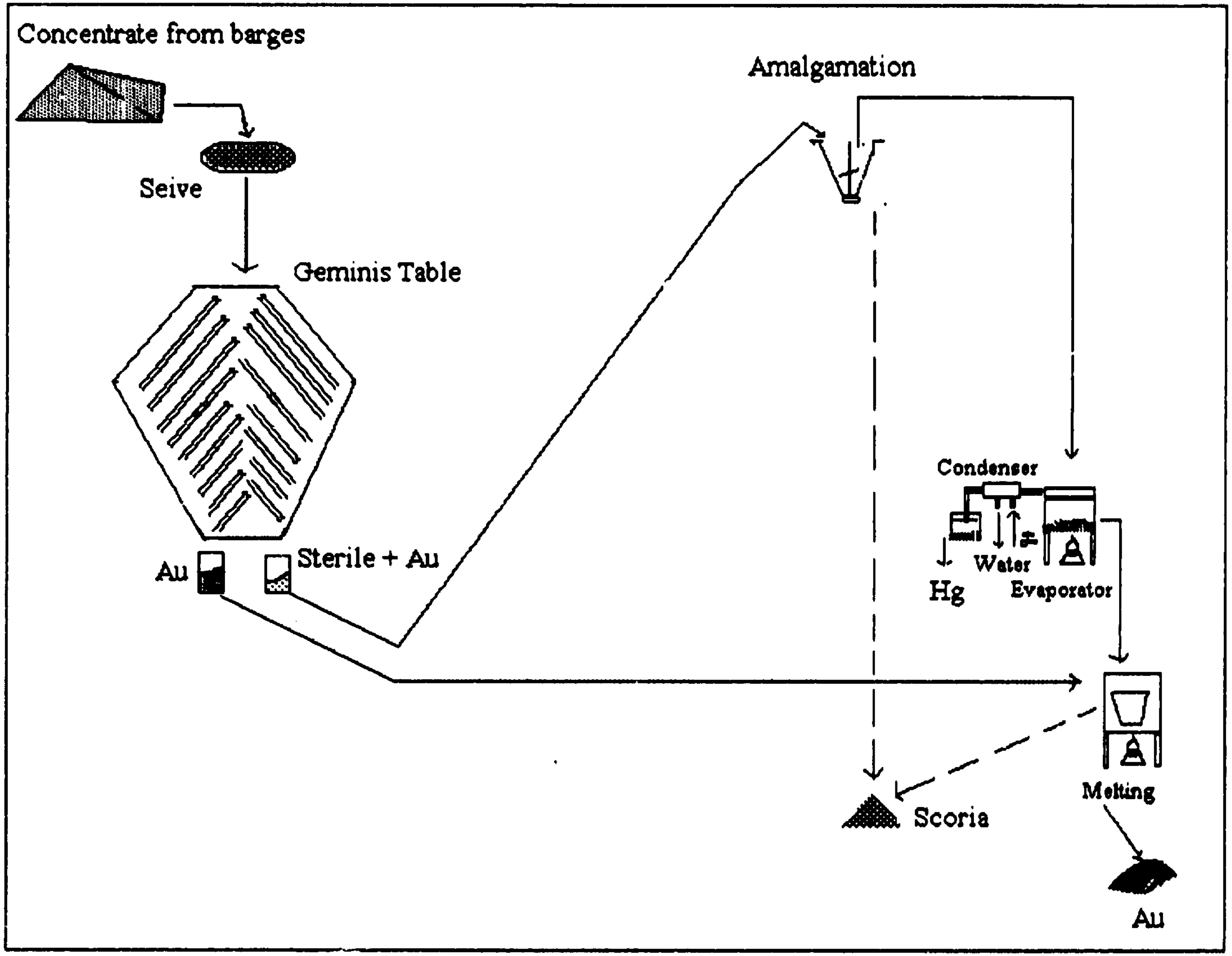
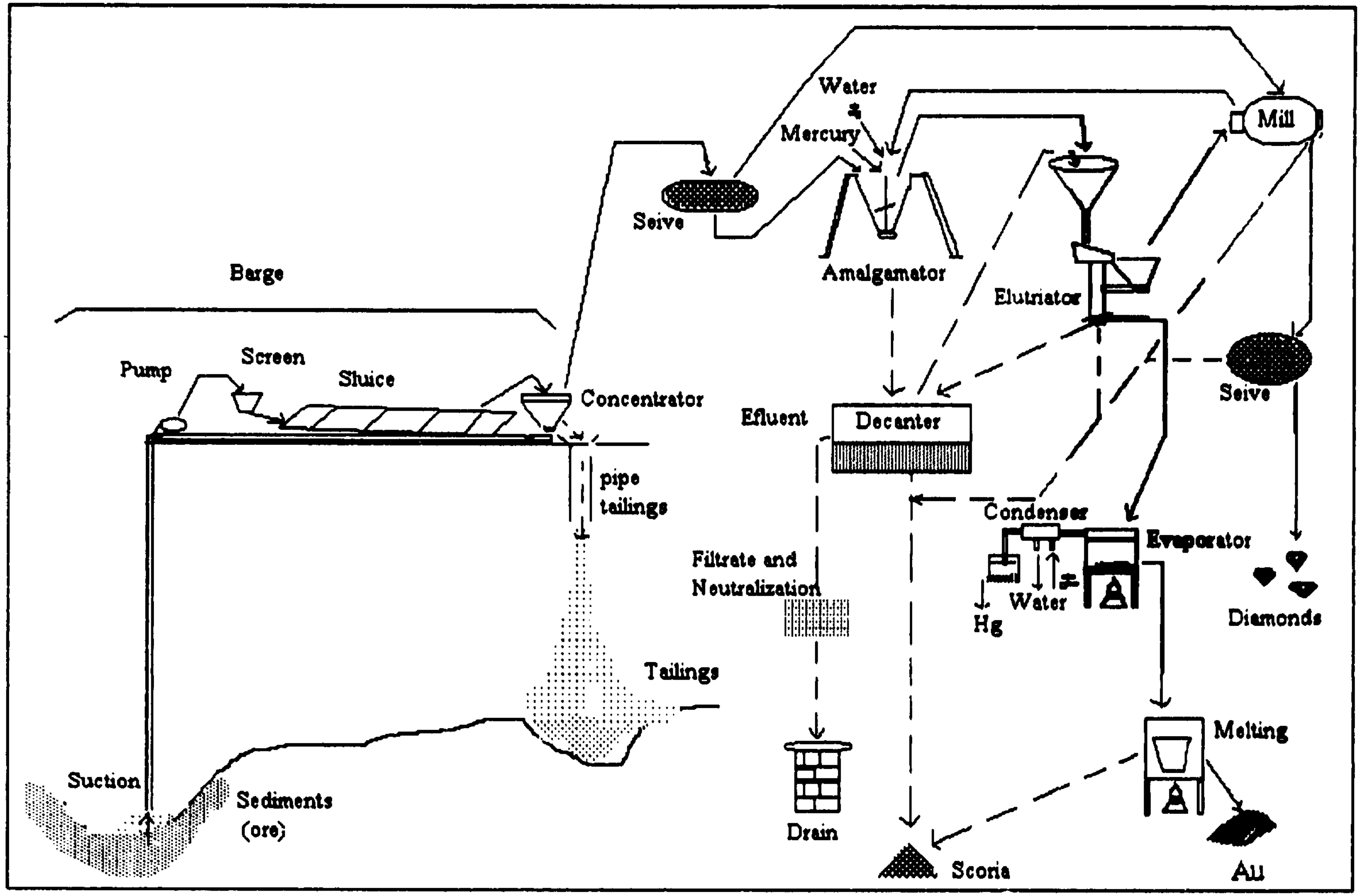


Figure 4. Separation Processes at Carhuachi's Gold Recovery Center



c) The amalgam is washed out in order to make the finer and heavier materials precipitate.

d) The material is taken to a centrifugal machine in order to recover the mercury that could have remained free during the amalgamation process. The amalgam separation is performed automatically in a closed ambient, based on the centrifugal force principle.

e) The amalgam is taken to a hermetic distiller where it is heated up to 800 °C for 150 min. with a gas burner. The mercury contained in the amalgam is evaporated and recovered in its liquid state in a container annexed to the distiller, through a water-cooled serpentine condenser. This procedure is performed in a closed room using a gas control equipment and a high extraction power mantel. Approximately 97% of the mercury added is recovered in this stage.

f) The gold with some impurities remains in the distiller, hence a primary melting is performed by using borax. The material is submitted to temperatures of 1200 °C for 2 hours. The melt mass is poured into ingot molds where impurities are physically separated.

g) The tailings from this process are recycled by submitting them to a milling process in a low capacity ball mill, where a pulp is attained. This pulp is taken to a copper plate which separates the amalgam remainders (< 3%) from the sterile material.

6.4.1.2.1 Use of Goldtech Plate

The Goldtech plate was used to recover free mercury and amalgamated gold of tailings coming from Carhuachi's Gold Recovery Center. Two samples were tested with the Goldtech plate in order to determine the amount of free mercury and amalgamated gold that could be retained on the plate.

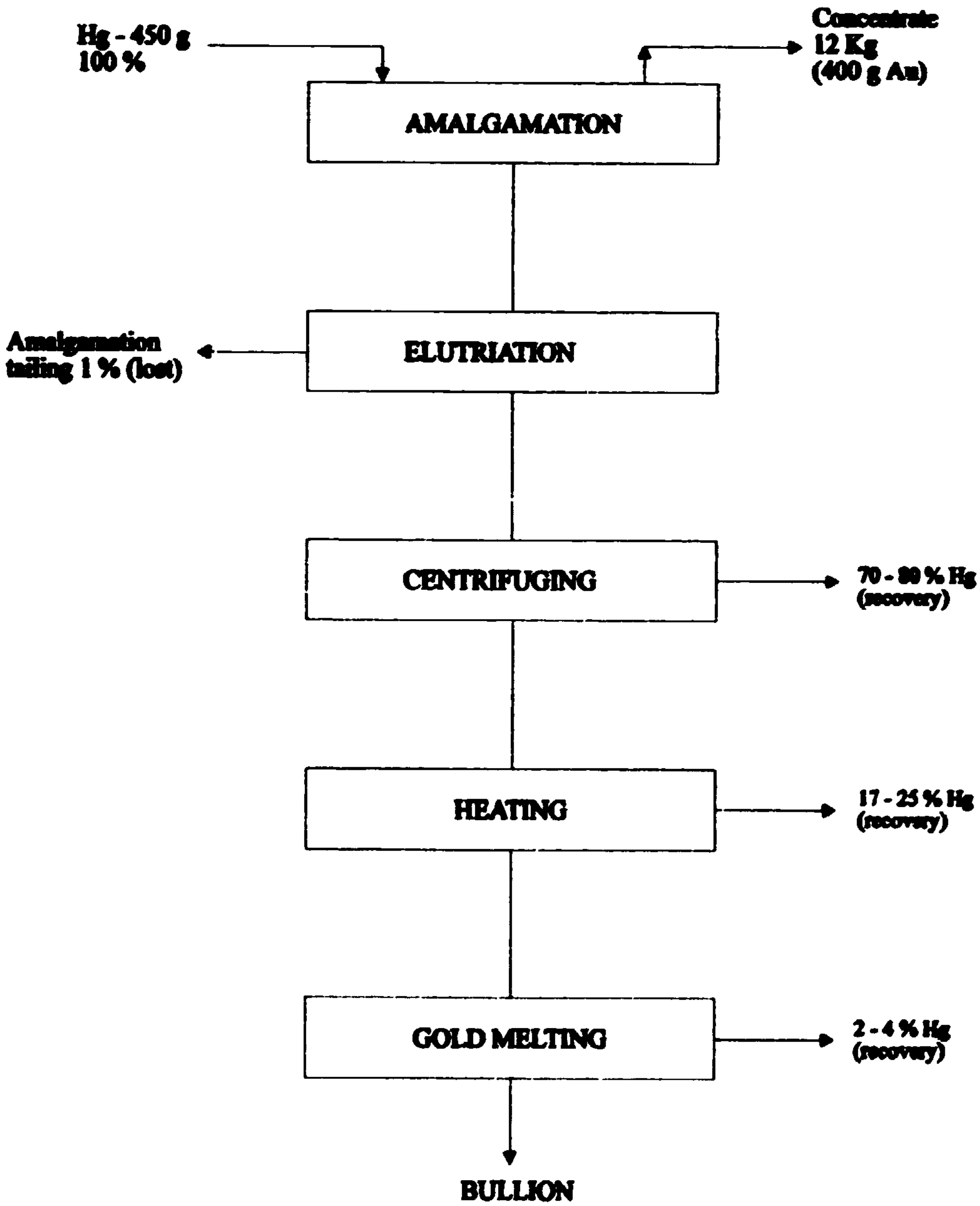
a) A 14.5 Kg sample of the tailing from the elutriator was passed on the plate. It was retained and recovered a total of 5.0 g of material: 0.8 g corresponded to free mercury and 4.2 g to amalgam. After the amalgam burning, it was obtained 3.1 g of gold and 1.1 g of mercury, hence the total recovery of mercury was of 1.9 g or 131 g Hg/tn of tailing material.

b) A 7.0 Kg sample of the tailing with a tenor of 466 mg Hg/Kg, stored in this Center's yard, was passed on the plate. It was obtained a total of 0.8 g of free mercury, which corresponds to a recovery of 114 g Hg/tn. This results in an equivalent recovery of 25% (114/466).

6.4.1.2.2 Balance of Mercury in the Amalgamation Steps

This research was done towards finding out the balance of mercury in the different steps of the process of gold recovery.

Figure 5. Balance of mercury in the amalgamation steps at Carhuachi's Gold Recovery Center.



Two volumes of concentrate, 12 and 14 Kg each, were processed through the different steps used at Carhuachi's Gold Recovery Center which were previously added 450 and 300 g of metallic mercury, respectively (this difference is due to the fact that the criteria for adding mercury to the concentrates is giving by miners). We can see in Figure 5 the percentage of mercury lost in the amalgamation tailing (1%), as well as the recovering ranges in the centrifuging steps (70-80%), heating (17-25%) and gold-melting (2-4%). Volatilized mercury during heating and gold-melting is recovered in two ways: using water-cooled serpentine condensers and a mantel to take the vapors towards a nebulizer which contains an iodine solution. Mercury entering the atmosphere can represent as much as 50 % of that introduced into the amalgamation process when retorts are not used (Veiga, 1.994).

6.4.1.3 Mercury Levels in Urine of Workers from the Gold Recovery Centers

A research was carried out by Karen Schultz (1995) Graduated Student from the "Universidad Nacional Expimental de Guayana" (UNEG) related to Hg levels in urine of the operators of some of the Gold Recovery Centers located at the lower section of Caroni River. These results are shown in the following table:

	Number of workers with Hg in urine	
Place	< 50 µg/L	> 50 µg/L
Playa Blanca's GRC	7	3
Carhuachi's GRC	0	3
Total	7	6

It can be seen that there were workers with a mercury concentration in urine higher than 50 µg/L which is the maximum allowable limit according to the World Health Organization (1978). Workers with values of mercury above 50 µg/L in urine showed gastrointestinal and nervous system symptoms. The main source of exposures occurs when retorts are opened. While the work research was carried out at Carhuachi's Gold Recovery Center emissions of mercury vapors were detected. It was found high mercury levels (up to 2000 µg/m3) when retorts were opened, but decreasing to background levels after thirty seconds. This motivated improvements at the center and a mighty ventilation system was introduced. The fumes were conducted to a series of scrubbers with iodine solution which guarantee that no Hg is emitted to the atmosphere.

6.4.1.4 Water Quality Research

A survey of mercury levels in water, sediments and fish was carried out in two sectors at the lower section of Caroni River (Fig. 6). There should be appointed that is hard to fish in that section because of the low biomass.

6.4.1.4.1 Santa Rosa Sector

The sampling points at Santa Rosa sector are shown in figure 7. The concentrations of total mercury in water, sediments and fish are in tables 1, 2 and 3, respectively. Mercury levels in unfiltered water fluctuated from 0.15 to 0.48 µg/L (Table 1). These values are considerably much lower than those found in Madeira River watershed (up to 5.1 µg/L) southwest Amazonia, Brazil (Pfeiffer et al., 1991) where the extraction of alluvial gold is similar to that in the lower section of Caroni River. The mercury concentrations in sediments ranged from 0.06 to 0.27 mg/Kg (Table 2). Mercury levels much higher were found in Madeira River's sediments (up to 2.62 mg/Kg) (Pfeiffer, et al., 1991). The results of total mercury analysis in fish's edible part fluctuated from 0.092 to 0.62 µg/g (ppm), while in guts and gills ranged from 0.17 to 1.0 ppm (Table 3). There is a tolerance limit level of Hg in fish which is variable value adopted by many countries to control Hg content in edible parts: 0.5 ppm (µg/g wet weight) is used by USA, Canada, Brazil; 0.7 ppm by Italy; 1 ppm by Finland, Sweden and Japan (Johansson et. al., 1991; Suckcharoen et. al., 1978).

The redox potential was 80 mV, with average pH of 6.97 and conductivity of 17.67 µS/cm.

6.4.1.4.2 Carhuachi Sector

The sampling points at Carhuachi sector are shown in figure 8. The concentrations of total mercury in water and sediments, and fish are in tables 4 and 5, respectively. Mercury levels in water fluctuated from 0.01 to 0.06 µg/L (Table 4). These values are considerably much lower than those found in Madeira River watershed (up to 5.1 µg/L) southwest Amazonia, Brazil (Pfeiffer et al., 1991) where the extraction of alluvial gold is similar to that in the lower section of Caroni River. The mercury concentration in sediments ranged from 0.58 to 0.78 mg/Kg (Table 4). Mercury levels much higher were found in Madeira River's sediments (up to 2.62 mg/Kg) (Pfeiffer, et al., 1991). The results of total mercury analysis in fish's edible part fluctuated from 0.18 to 0.26 µg/g (ppm) (Table 5).

The average redox potential was 49 mV, with average pH of 6.59 and conductivity of 19 µS/cm.

6.4.2 Las Claritas Area

The amalgamated material that comes from the mills is treated in two different ways:

a) One process uses a copper plate covered with mercury to retain both the amalgamated gold and free gold. The final concentrate is placed in 5-gallon plastic containers where metallic mercury is again added to it to finally recover the amalgam, using trays and water boxes. The mercury in excess is extracted by squeezing the amalgamated material with a piece of cloth. The amalgam burning is done in the open ceiling at the milling sites.

Figure 6. Relative Location of Santa Rosa and Carhuachi Sector

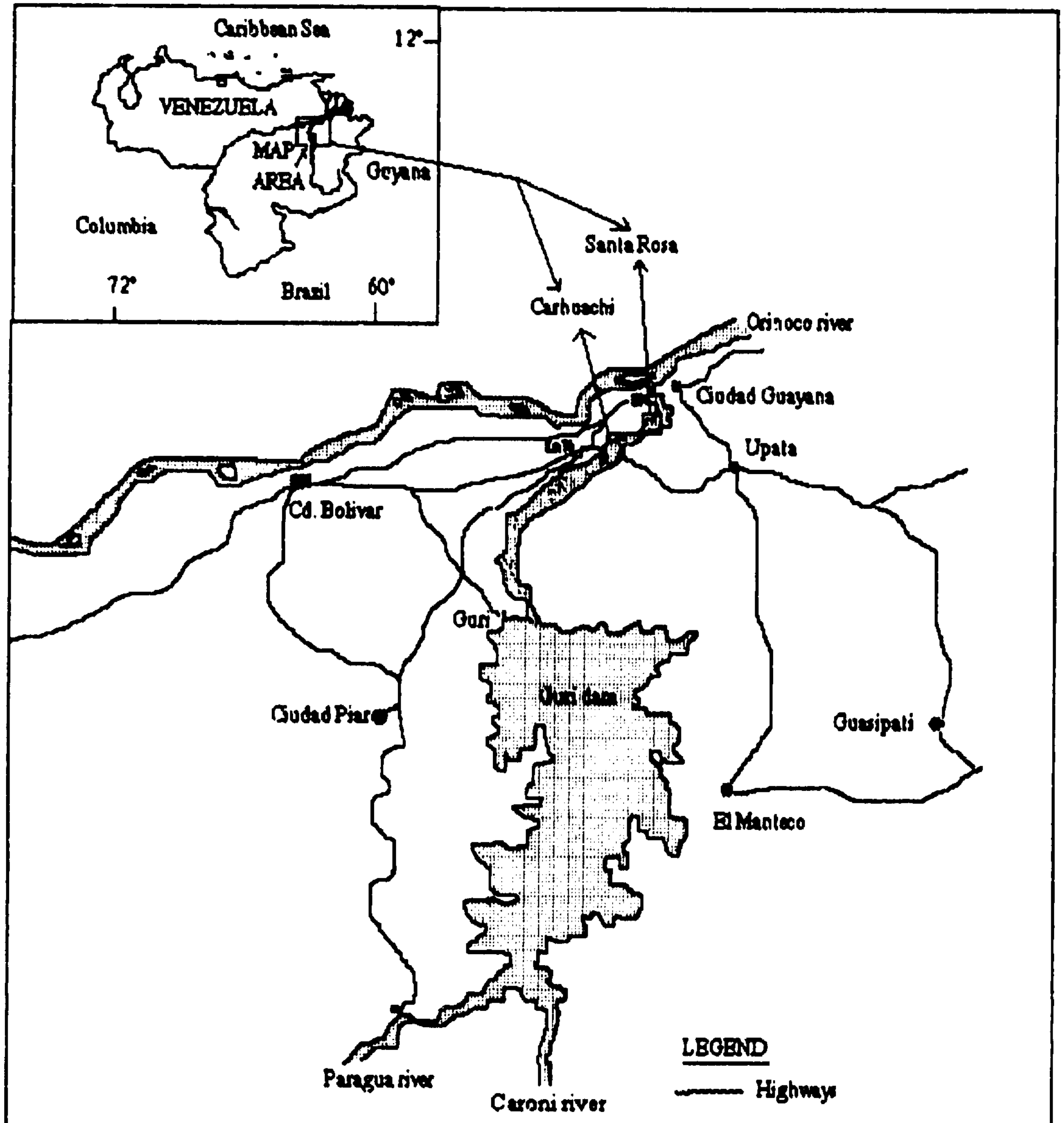


Figure 7. SANTA ROSA SECTOR: Sampling Points, August 1995

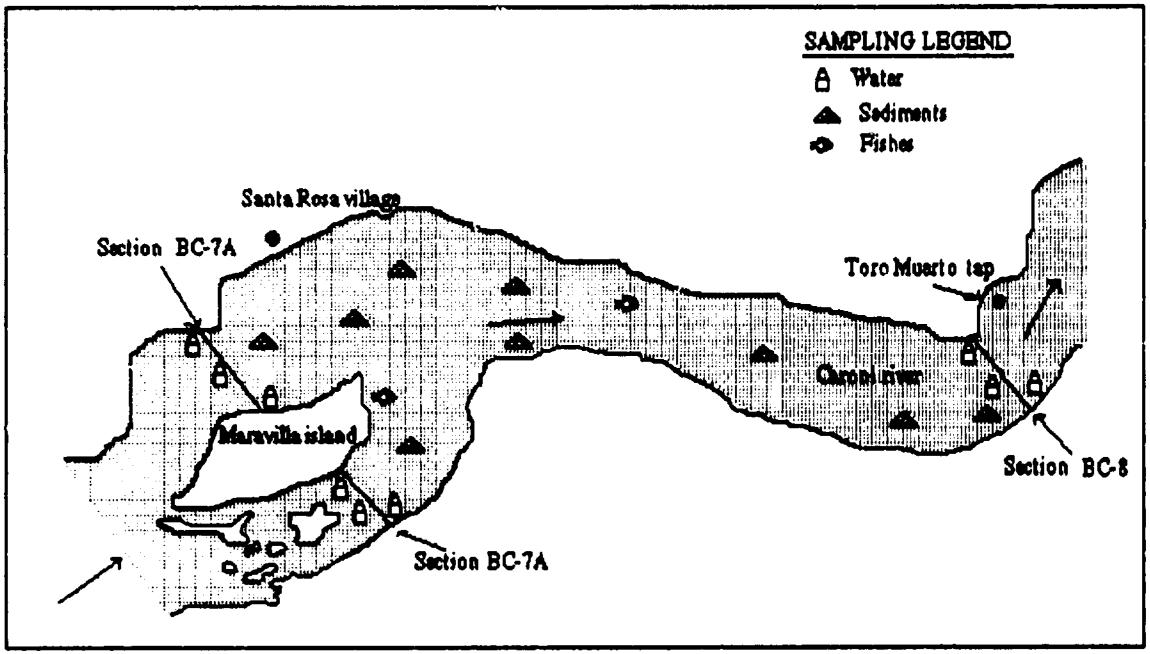


TABLE 1. SANTA ROSA SECTOR : Physical and Chemical Analyses in water, August 1995.

Cross Section	Coordinates UTM	T (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (μS/cm)	Eh (mV)	Total mercury (μg/L)
LC-7A	525.768 E 910.033 N	22.8	6.6	9.02	15	80	0.15
BC-7B	526.724 E 909.807 N	23.0	7.0	8.76	20	70	0.15
BC-8	531.008 E 911.858 N	23.2	7.3	9.02	18	90	0.48

TABLE 2. SANTA ROSA SECTOR: Total Mercury Concentration in Sediments, August 1995.

Place	Coordinates UTM	Total Mercury (mg/Kg)
1	910.232 N - 527.271 E	0.09
2	909.958 N - 525.073 E	0.10
3	910.537 N - 526.399 E	0.06
4	911.013 N - 526.227 E	0.27
5	909.062 N - 524.683 E	0.16
6	911.087 N - 528.341 E	0.12
7	911.116 N - 527.500 E	0.27
8	911.428 N - 528.462 E	0.16
9	911.222 N - 528.902 E	0.12

Note: Sediment's samples were collected between 1 and 5 m. below the river bed through a diver.

TABLE 3. SANTA ROSA SECTOR: Total Mercury Concentrations in Fish, August 1995

Place	Scientific Name	Common Name	Fish Number	Total Length (cm)	Weight (g)	Total Mercury (μg/g)	
						Guts and Gills	Muscle
La Maravilla Island (east extreme)	*Hydrolycus scomberoides*	Payara	1	64.4	2.000	0.17	0.620
	Cichla Orinocensis	Pavón	1	62.0	2.000	0.39	0.330
Right margin of the river (in front of La Maravilla Island)	*Hydrolycus macrophtalmus*	Aymara	1	48.0	1.000	1.00	0.092

Note: All these fishes are carnivorous

b) The other process uses a matting to retain both amalgamated gold and fine gold. The tailing material that comes out of the matting is taken to a centrifugal concentrator (hydrojet). The concentrate is placed in plastic containers and mercury in excess is eliminated the same way - as in the former process - but the amalgam burning is performed in retorts located in places authorized by M.E.M.

The resulting final tailing of both processes is taken to a storage area in the open ceiling, in a place next to an intermittent-current stream.

It can be seen that both processes are wholly performed inside the towns, which makes the milling and the amalgam sites real hot spots (Fig. 9 and 10)

6.4.2.1 Use of Goldtech Plate

The Goldtech plate was used to recover free mercury and amalgamated gold of tailings coming from the mills located at Las Claritas area.

There are at least 10 places where hammer mills are used for crushing of rock material towards obtaining the gold in it by using metallic mercury in Las Claritas. The auriferous material comes from the surroundings of Las Claritas. Each mill processes 12 tons per working day. In addition, material of fine-size particles coming from tailings of old camps - which contains mercury - is put in the mills with the rock material, and metallic mercury is added as tailings come out from them. According to estimates of the miners, they can get to use up to 1 Kg of mercury a day.

a) A 5.0 Kg sample of the tailing from Mr. Omar Navarrete's mill was put on the plate. It was retained and recovered 3.0 g of material on the plate: 1.2 g was mercury, so the metal recovery for each ton of tailing material was of 240 g.

b) A 20 Kg sample of the tailing from a mill located in the area known as Santo Domingo was put on the plate. There was a total of 0.95 g of free mercury retained and recovered in the plate, so the metal recovery for each ton of tailing material was of 43 g.

The Redox potential found in the sediments of the Las Claritas river - close to the area under study - was 200 mv, 6.5 pH and conductivity of 10 µS/cm.

6.4.2.2 Revegetation Works

To carry out the restoration plans of the areas affected by mechanical equipment (e.g. hydraulic monitor) and the areas that show mercurial contamination (hot spots), we present a work scheme that is based on eight basic principles. These principles have been designed for fomentation and improving of the natural succession of vegetation in the perturbed areas. Its total fulfillment is necessary to ensure success of the restoration process.

Figure 8. CARHUACHI SECTOR: Sampling Points

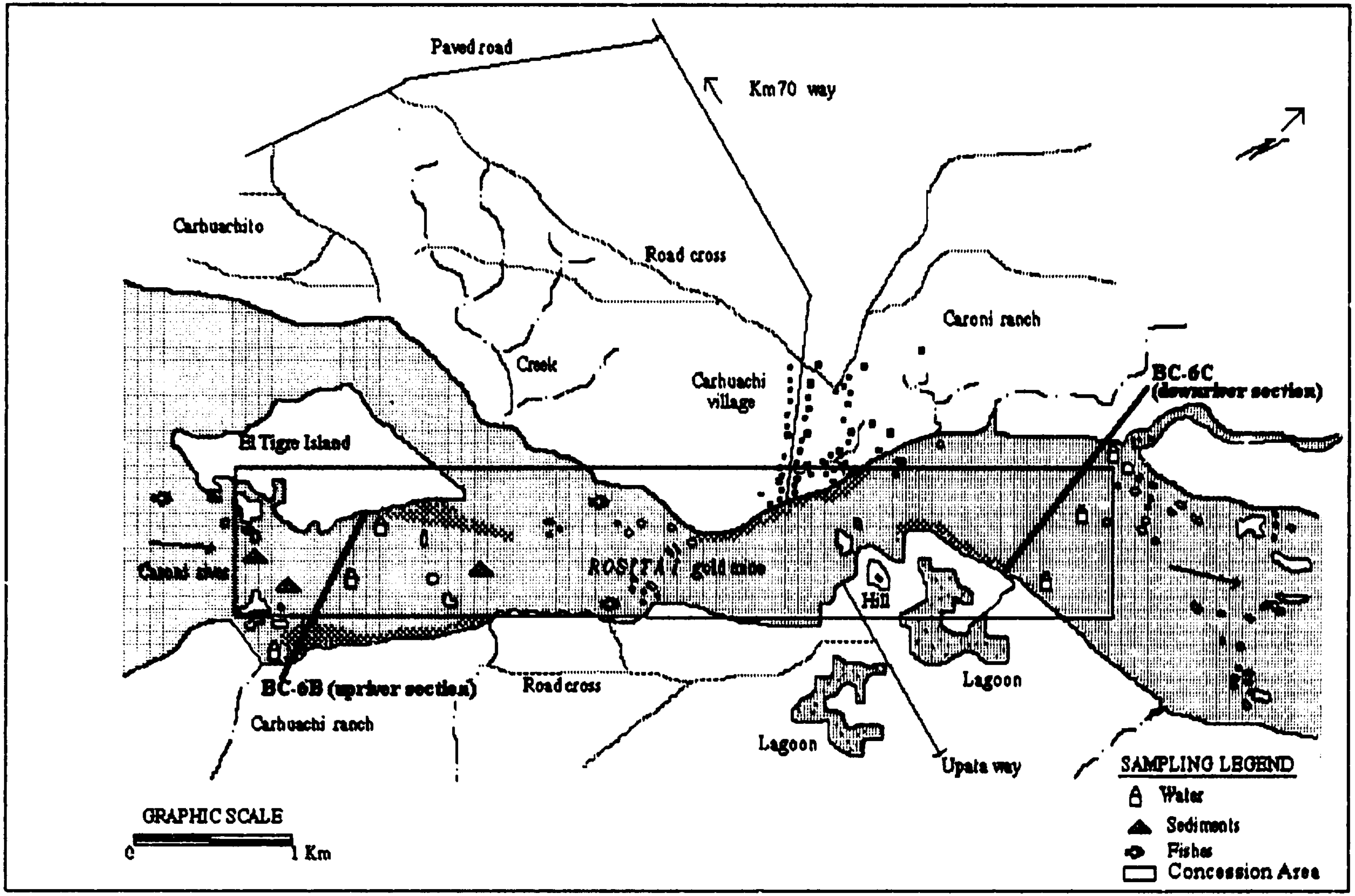


TABLE 4. CARHUACHI SECTOR : Physical and Chemical Analyses in water and sediments, August 1995.

Cross Section	Coordinates UTM	T (°C)	pH	Conductivity (µS/cm)	Eh (mV)	Total Mercury in water (µg/L)	Total mercury in sediments (mg/Kg)
BC-6BI*	511.820 E	27.1	6.48			0.01	0.71
BC-6BC*	896.130 N	27.2	6.54	20	50	0.01	-
BC-6BD*		27.2	6.49			0.04	0.78
BC-6CI	515.356 E	27.3	6.6			0.06	-
BC-6CC	899.666 N	27.4	6.7	18	48	0.06	0.58
BC-6CD		27.4	6.7			0.06	-

Note: Sediment samples were collected between 1 and 5 m. below the river bed through a diver.
*I = Left margin
C = Centro
D = Right margin

TABLE 5. CARHUACHI SECTOR: Total Mercury Concentrations in Fish, August 1995

Place	Scientific Name	Common Name	Fish Number	Total Lenght	Weight (g)	Total Mercury in Muscle (µg/g)
Upriver the concession area	*Cichla ocellaris*	Pavón	1	47.0	1.700	0.24
			2	48.0	1.700	0.18
	Mylisinus Schomburgkii	Surapire	1	47.5	1.950	0.26

Figure 9. LAS CLARITAS AREA: Mills at Santo Domingo Sector

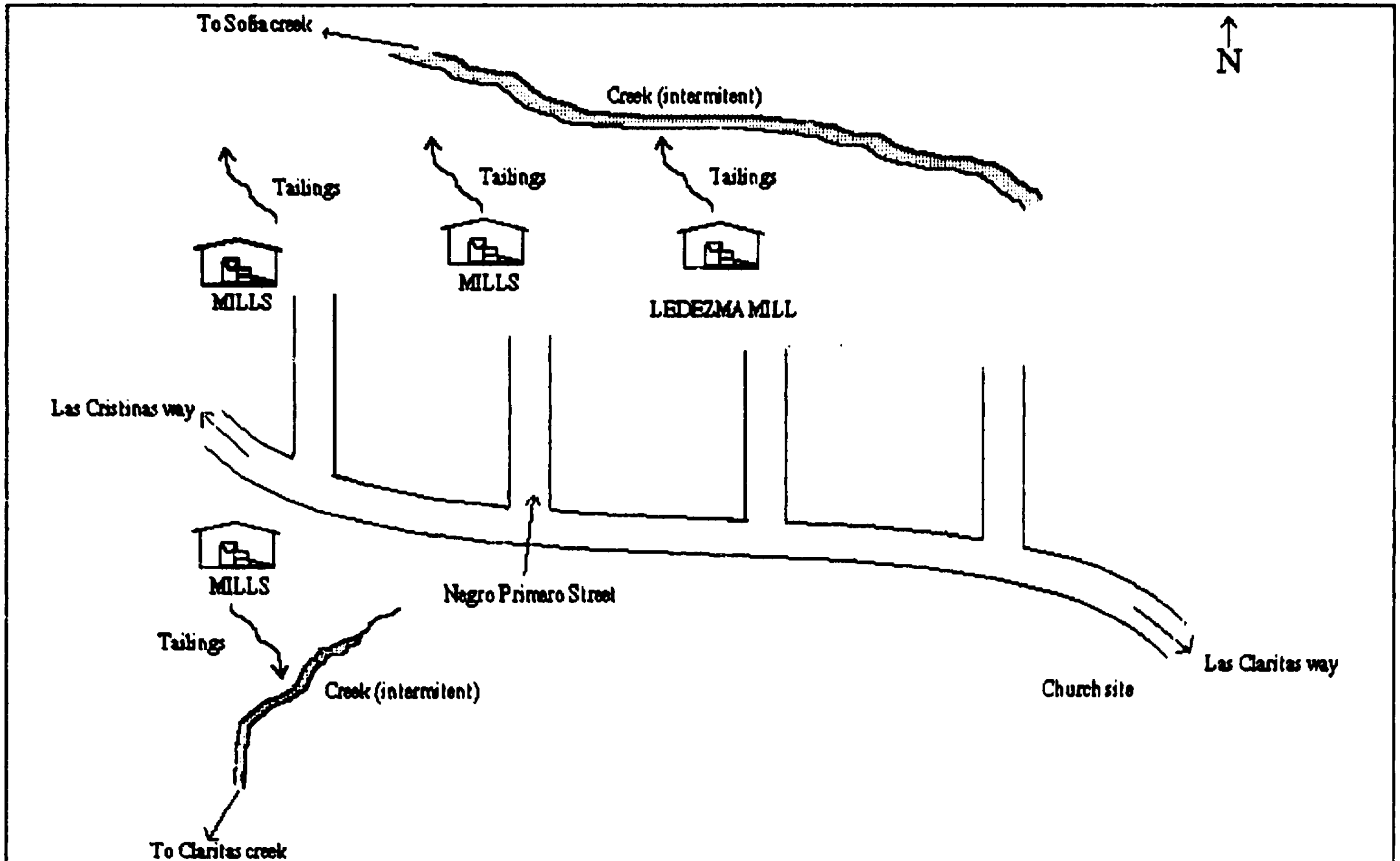
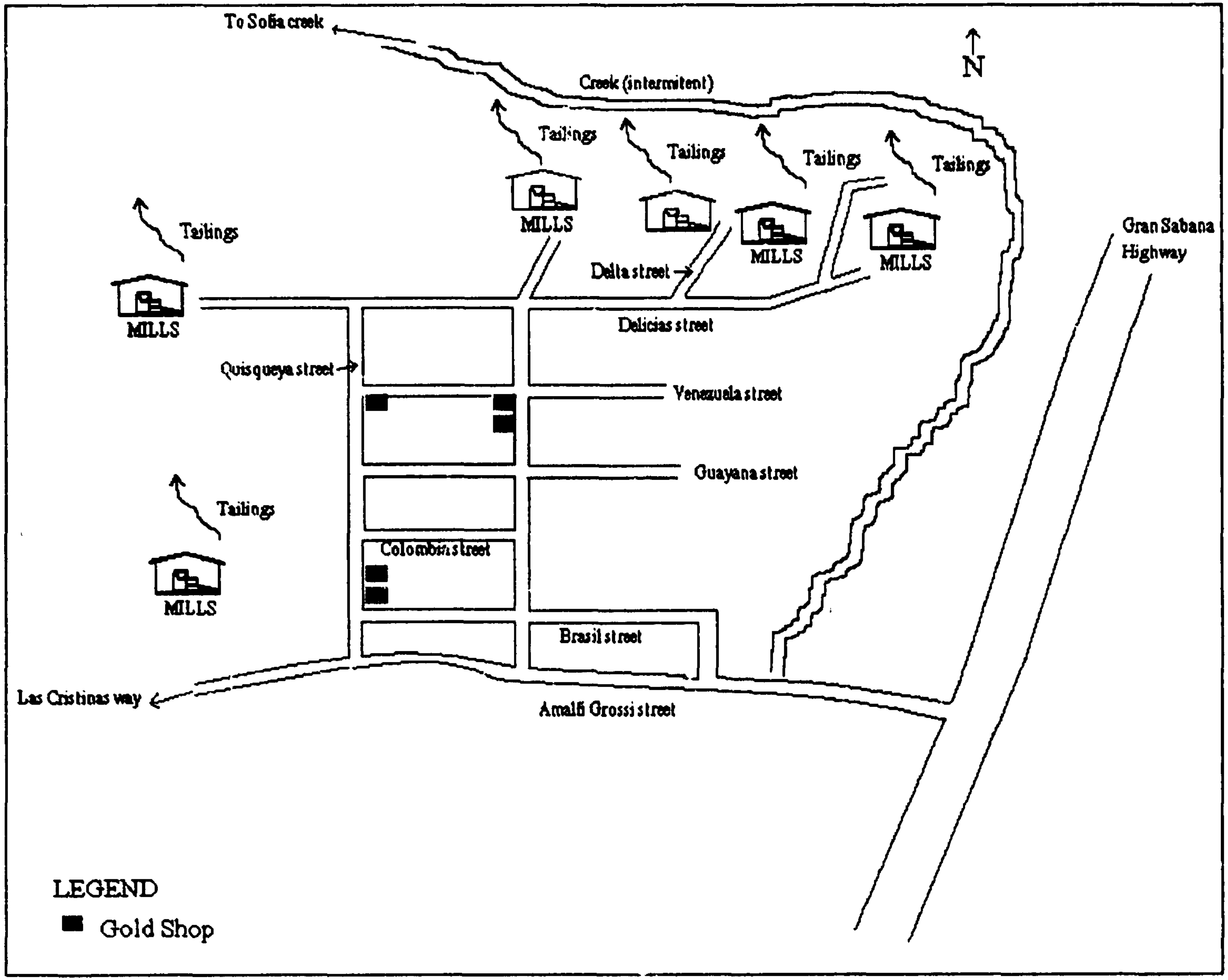


Figure 10. LAS CLARITAS AREA: Mills and Gold Shops at Las Nuevas Claritas Sector



a) Land conformation

It consists in the replacement of the land horizons in the area to be recovered, together with the vegetal layer, in order to harmonize - from a hydrologic and esthetic point of view - the final look with the original topographic characteristics, or at least to make them similar to what they were before the mining intervention. This intends to minimize the erosion process due to the current's way deviation as well as to define the drainage channels of surface waters.

b) Soil characterization

This activity will be performed by means of soil sampling and analysis - before the re-vegetation process is starting - which will give accurate information about the variability of the soil, sub-soil and any nutritional elements existing in it. This is essential to identify the limiting physical-chemical conditions, as well as the bio-availability of essential elements and those that are toxic for the soil - which might affect the re-vegetation works.

c) Spread of organic remains.

After the land is conformed and characterized, side slopes are minimized, and sedimentation filters are put in the existing gullies, organic remains will be spread. Its importance obeys to the fact that the humic content (micro-flora) these remains have, and the bioavailability of nitrogen, phosphorus and potassium in them, accelerate the recovery process, since the vegetation that is to be used - gramineae and cyperaceae in one first stage and ligneae species in a second one - will have, at first, the availability of the necessary nutriments to a better adaptation to the medium.

In the case of the hot spots, a land conformation by spreading a layer of clay will have to be done in order to isolate the mercury-polluted material from the organic remains that will help grow the vegetation to be sown.

d) Spread, and application of fertilizers and amends.

This activity will be done to improve the soil's nutritional conditions as well as its physical-chemical properties. The amends are considered as nutritional elements that, as they are incorporated to the soil, improve its physical-chemical characteristics, help the plants grow, and accelerate the edaphic stabilization processes. These amends include organic remains - to improve the plants' oxygenation, water retention capability, and level of nutriments - and agricultural lime - to adjust the pH. Fertilizers, on their part, allow to increase the phyto-availability of essential nutriments.

e) Selection of plants species to be sown

Once the land is conformed and leveled, we'll proceed to select and sow the aboriginal or insert tree and herbaceae species that exist in the area.

f) Best season to initiate the restoration processes.

The best time of the year to commence the re-vegetation and restoration processes will be based on the climatic variables (rainy season), phenological development of the vegetation to be used, and availability of other propagative vegetation around the area to be recovered.

g) Sowing methods.

The sowing methods will be combinations of seed spread and vegetative material transplantation in the surroundings of the area to be recovered.

h) Post-restoration handling.

This activity will have to be performed by the mining community itself. The time elapsed isn't an adequate indicator of success. Success is rather a condition based on the vegetation's settling and the characteristics of the area.

7. CONCLUSIONS

1. Before 1991, high losses of mercury occurred at the lower section of Caroni River. Miners have amalgamated the whole dredge in copper plates, discharging contaminated tailing into the river. Nowadays, this situation is changed and only concentrates are amalgamated at the river shore.

2. Even if retorts would not be in use, losses of 25 % of mercury originally introduced are likely expected when amalgamation is performed only on concentrates. Amalgamation of concentrates was clearly an evolution in the artisanal mining activities, as well as the introduction of Gold Recovery Centers in which amalgamation is conducted by qualified operators.

3. The amalgamation of concentrates at the Gold Recovery Centers represents a maximum lost of 5 % (4 % in gold melting plus 1 % in elutriator tailing) when retorts are used and there have no condenser and/or hood to reduce mercury vapors during gold melting.

4. At the Carhuachi's Gold Recovery Center where does have condenser in the oven melting the mercury losses are around 1 % which is associated with elutriator tailings. Nevertheless, this mercury does not go to the environment because these tailings are sold to some enterprises located at the towns El Callao and Tumeremo to be processed by cyanide process. In this process the efficiency should be around 70 % inasmuch as the cyanide kinetic dose not favor the mercury but gold.

5. The relatively dangerous conditions for bioaccumulation at the lower section of Caroni River are indicated by natural variables such as slightly low Eh, slightly acidic pH, low conductivity, dark water color and low biomass productivity.

6. Hot spots were identified in both the lower section of Caroni River (tailings from the Gold Recovery Centers) and Las Claritas area (tailings from the mills).

7. No case of clinical hydrargirism was found however, there are several people with suggestive syndrome of mercury contamination that should be evaluated, mainly at Las Claritas area.

8. Informal miners from Las Claritas not only have the mercury as an occupational risk but also have to face aggressions from tropical diseases (malaria, yellow fever, dengue, leishmaniasis), waterborne diseases (diarrhea, amoebiasis), sexual transmission diseases (AIDS, gonorrhea), psycho-social disturbs (alcoholism, prostitution, drug addiction, crime and violence) and inadequate sanitary conditions.

9. Total mercury concentrations in water samples were below 1.0 µg/L which is the maximum allowable level in Venezuela Environmental Laws.

10. Mercury is not dispersed in the bottom sediments as indicated by low mercury levels analyzed. The mercury distribution in the sediments of the lower Caroni section is still unknown but clearly there is a high possibility for preferential accumulation of mercury in specific sites, forming hot spots. Location of these hot spots will favor mitigation procedures, including dredging operations in the future.

11. Total mercury in fish (edible part) was below 0.5 µg/g except in a sample of *Hydrolycus scomberoides* whose value was 0.62 µg/g.

8. RECOMMENDATIONS

1. The kinetics of cyanide process of tailings with mercury must be investigated in different enterprises located at the towns El Callao and Tumeremo to find out the mercury dispersion in the final tailings.

2. The use of retorts in the informal mining must be encouraged by governmental institutions.

3. It is necessary to use the Goldtech plates or any other alternative technique to remove mercury from tailings. Inasmuch as removal operations are costly, the gold extracted from the hot spots can reduce these costs.

4. The Gold Recovery Center approach must be encouraged by governmental institutions because of the fact that using these centers as an alternative, a high percentage or recovery of the mercury used in the amalgamation process is guaranteed.

5. It is necessary to establish an Epidemiological Vigilance Program to follow up hydrargirism at Las Claritas area.

6. Even though is hard to fish in the lower section of Caroni River it is necessary to use fishes as indicators of mercurial contamination.

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ANEXO

Photo 1. AMALGAMATOR

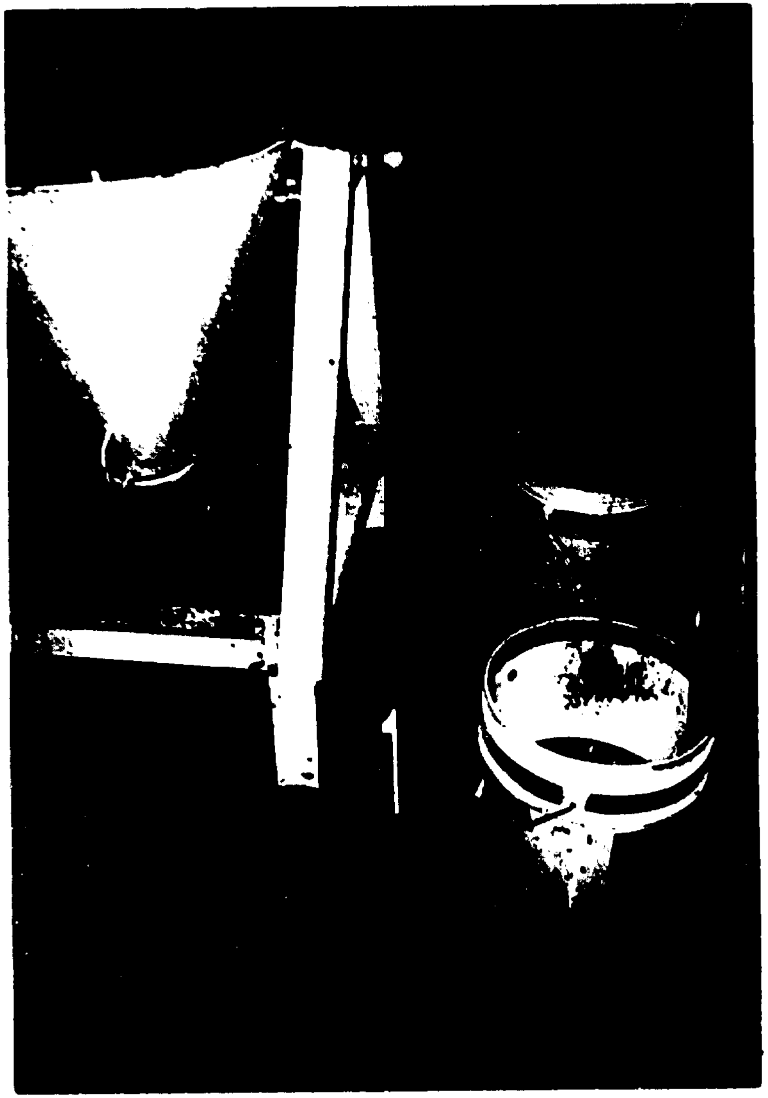

Photo 2. ELUTRIATOR

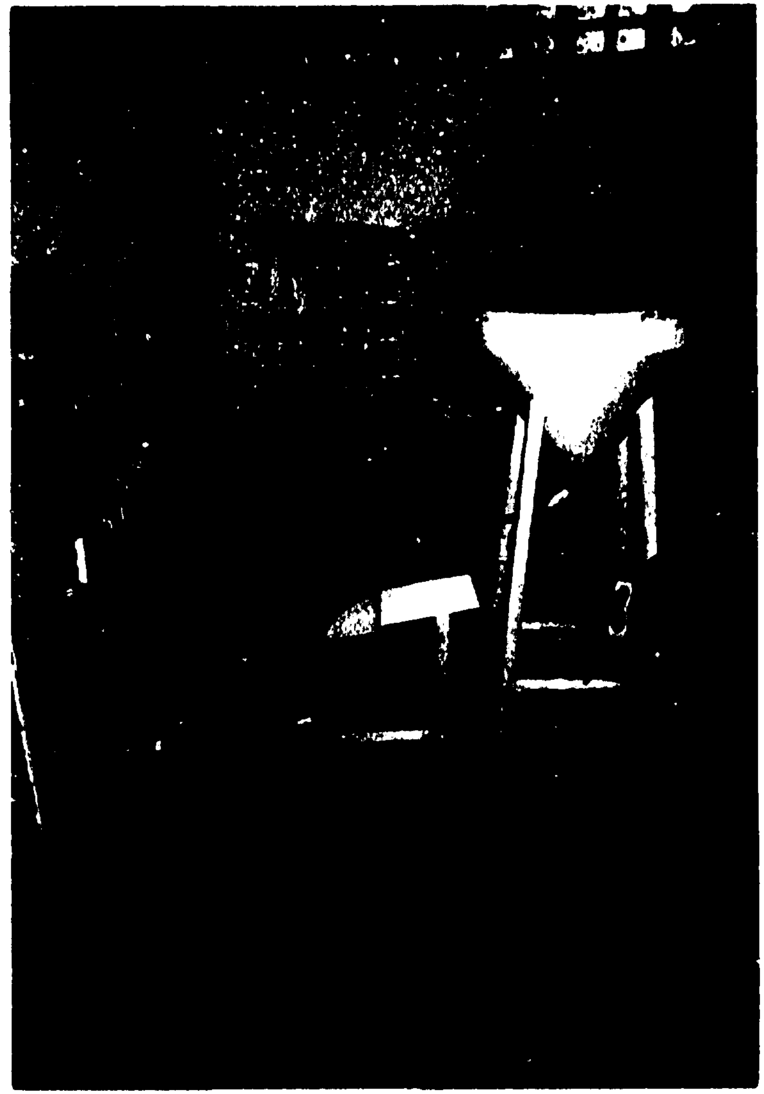

Photo 3. CENTRIFUGUE

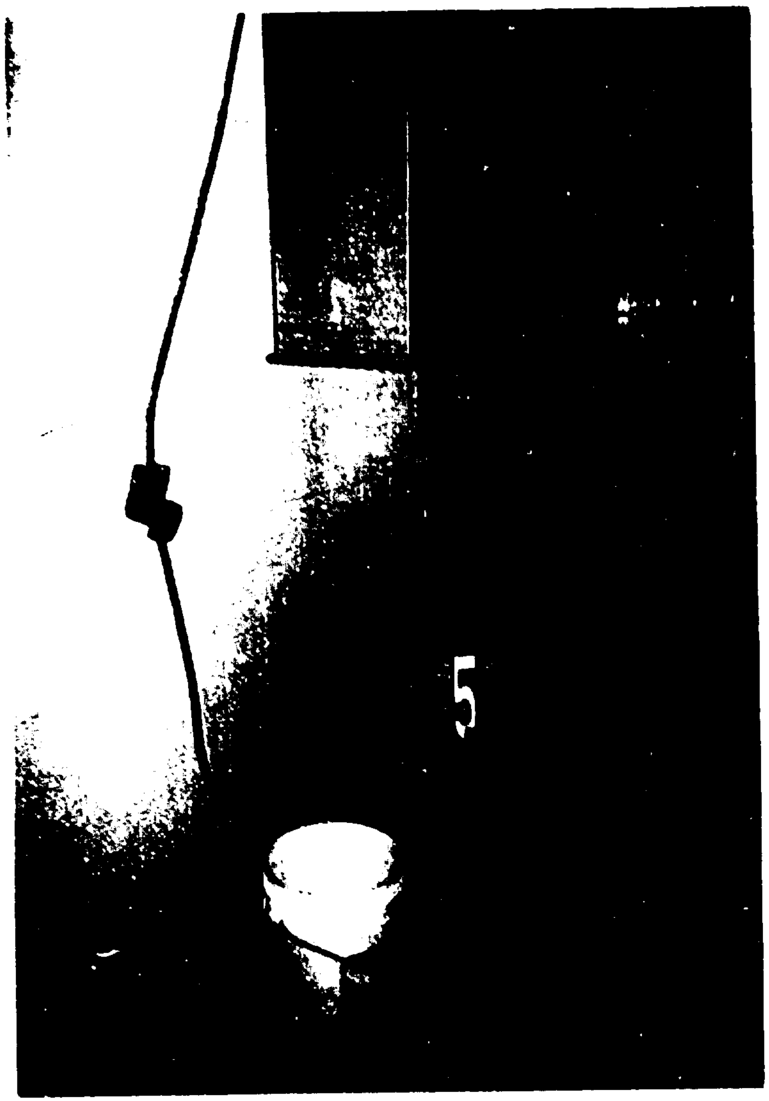

Photo 4. MELTING OVEN