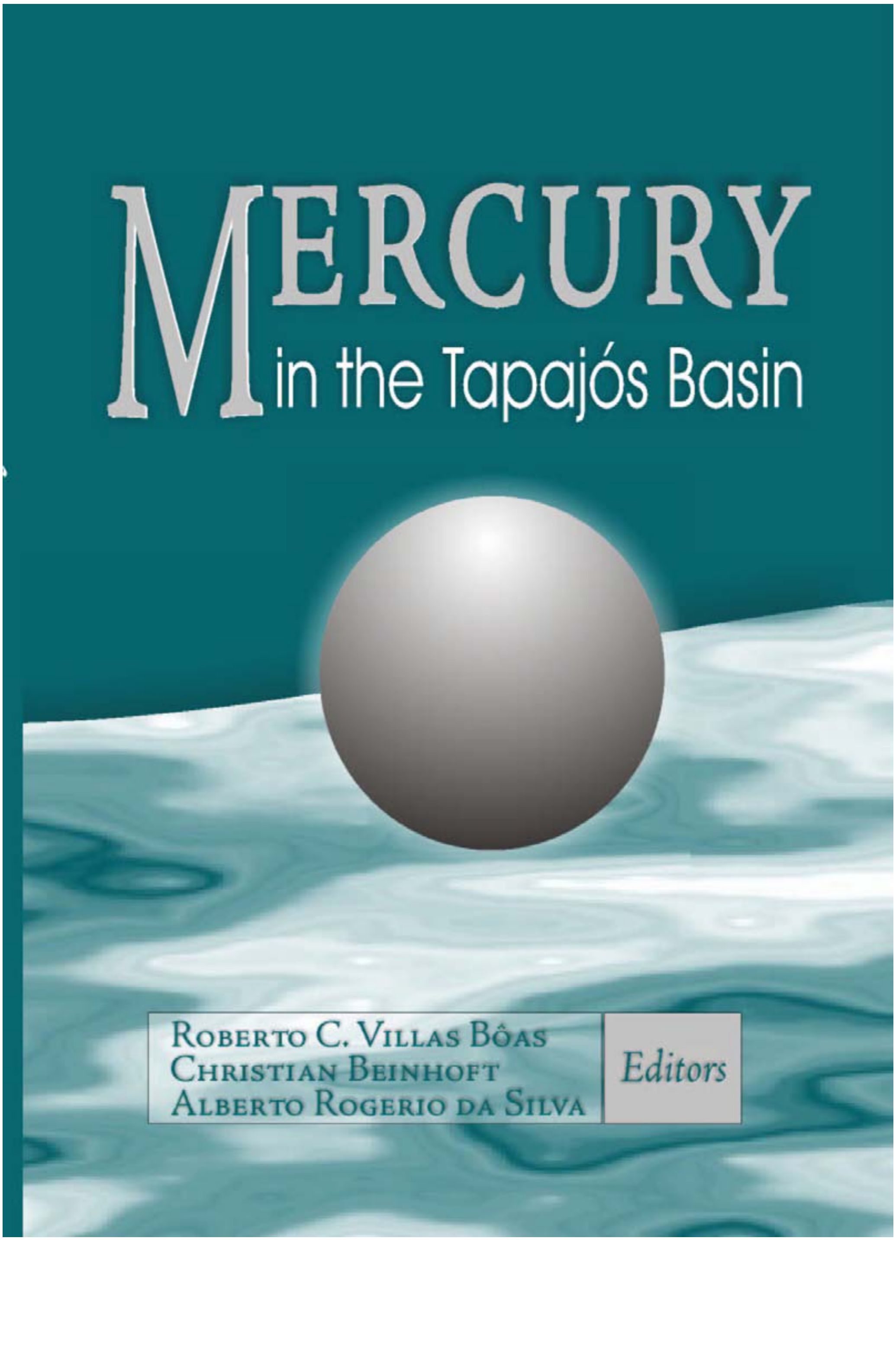
MERCURY
in the Tapajós Basin
Roberto C. Villas Bôas
Christian Beinhoft
Alberto Rogerio da Silva
Editors

Mercury in the

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MERCURY IN THE TAPAJOS BASIN

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Preface

This book summarizes the discussions and analysis held during the UNIDO Workshop in Belém, Pará, Brazil, on Project EG/GLO/97/G43 referring to the removal of barriers to the introduction of clean artisanal gold mining and extraction technologies.

The Workshop was the first one in a series of planned meetings with stakeholders attended by a vast range of participants, from Federal, State, Municipal Government and agencies, universities, research institutions, garimpeiros and press. Brazil, amongst the several nations that participate in the overall Project, was chosen as participating country in the starting phase, due to the enormous efforts already made in this country on how to handle mercury and alternative process routes of garimpos, as well as having available information gathered since the beginning of the 90's on the effects of mercury on biota and human health.

The book brings texts in English and Portuguese! Some of them just in English and some others in Portuguese.

It was decided to print it as such in order to shorten the time gap between the generation of ideas and the respective text publication, as well as maintaining as close as possible the original views and expressions of the stakeholders!

We hope that the reader will enjoy the chapters !

Belém do Pará, 13th of December, 2001

Roberto C. Villas-Bôas, CETEM

Christian Beinhoff, UNIDO

Alberto Rogério da Silva, Consultant Pará

Prefácio

Este livro resume as discussões e análises realizadas no seminário promovido pelo GEF-UNDP, em Belém do Pará, Brasil, tendo como objeto o Projeto EG/GLO/97/G43 apresentado à area focal do GEF "Águas Internacionais ", o qual se propõe à remoção das barreiras à introdução de tecnologias limpas de mineração e extração de ouro, para operações de garimpos.

Também foi este o primeiro dos vários seminários previstos no projeto como um todo, tendo contado com expressiva presença de interessados, quer dos governos Federal, Estadual e Municipal, bem como suas agências, universidades, centros de pesquisas, garimpeiros e imprensa. O Brasil, dentre todas as nações que participam do projeto, foi o local escolhido como fase inicial, tendo em vista os grandes esforços já realizados por este país na temática da utilização e manuseio do mercúrio e outras rotas alternativas de processamento nos garimpos, bem como pela disponibilidade de informações coletadas desde o início da década de 90 sobre os efeitos do mercúrio sobre a biota e saúde humana.

O livro traz textos em Inglês e Português! Alguns em Português e outros em Inglês!

Foi decidido imprimir dessa forma a fim de minorar o tempo gasto entre a geração de idéias e sua apresentação de forma impressa, ao mesmo tempo em que se mantiveram as integridades das visões expressas pelos participantes.

Esperamos que o leitor se satisfaça com o texto apresentado!

Belém do Pará, 13 de Dezembro de 2001

Roberto C. Villas Bôas, CETEM

Christian Beinhoff, UNIDO

Alberto Rogério da Silva, Consultor Pará

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Presentation

The Pará State is the second Brazilian mineral producer and, according to the World Bank's concept, it is considered a "mineral based economy", because more than 10 per cent of its GDP and 50 percent of its mineral exportation come from industry and vertical integration mining. However, the Pará mineral sector has important mining companies, specially the holding Companhia Vale do Rio Doce (CVRD).

Another mining sector is represented by the gold garimpagem, which has been also important in the Pará history since the XVII century. However, only in the last five decades, it was included in the Pará mineral production. For example, in 1983, the gold garimpos consisted in 70 per cent of the Pará mineral production value. In the same year, the Serra Pelada gold production reached 14 tons.

A peculiar scenario in the garimpos area is the high number of people. In the peak of the garimpagem in the end of the 80's and beginning of the nineties of the last century, in the whole Pará, there were about 200,000 people working in the garimpos. That performance occurred mainly because of the strong trade in diesel oil, food, specially small potency engine, and carpets used to recover the gold in the suction pump. The gold exploitation involves the large movement of small aircrafts, mainly mono engine. In Itaituba landings and take-offs per day were about 300 to 350.

The Tapajós Region is the largest garimpeira area in the Pará State and has accumulated a historical real gold production around 600 tons. Nowadays its population is 35,000-40,000 people organized in unions or associations. The great environmental impacts caused by garimpeira activity and many researches imposed to the federal state and municipality governments challenges to transform the garimpo models in joint venture with garimpeira communities, because the gold garimpos involved many complex problems.

In fact, the Global Environment Fund (GEF-UNDP), through the "Removal of barriers to the abatement of global mercury pollution from artisanal gold mining project" will develop researches to introduce the sustainable gold garimpos with clean technologies in the Tapajós Region that is very important to the Pará Government. As a UN priority for this century, the project will be developed inside of a great ecosystem, particularly in the Amazon River.

The Tapajós Region characteristics and its importance were decisive for the selected area whose final goal will be reducing mercury use, and introducing clean technologies. However, the current garimpo phase will be also included like alternatives for the exploitation gold quartz veins. The researches will be developed in the economical, social and environmental contexts with sustainable standard to attend GEF-UNDP and garimpeira communities interests.

Belém, Pará, Dezembro 2001

Hidelgardo Nunes
Vice Governor
State of Pará

Apresentação

O Estado Pará é o segundo produtor de bens minerais do Brasil e é considerado pelo Banco Mundial como economia mineira, haja vista que mais de 10% de seu PIB vem da mineração ou de seus produtos de transformação. Entretanto, a indústria mineral paraense é fortemente marcada pela presença de empresas de mineração, destacando-se a Companhia Vale do Rio Doce (CVRD) e suas empresas coligadas e controladas.

Por outro lado, a garimpagem de ouro tem papel histórico relevante, uma vez que remonta ao século XVII. Entretanto, foi só nas últimas cinco décadas que, realmente, teve presença marcante no peso da produção mineral paraense. Em 1983, por exemplo, quando o garimpo de Serra Pelada produziu 14 toneladas de ouro, esta substância contribuiu com 70% do valor da produção mineral paraense.

Uma situação peculiar nas frentes de garimpagem é o elevado contingente humano. No auge da garimpagem no final da década de 80 e início dos anos 90 do século passado, em todo o Pará, estimava-se cerca de 200 mil pessoas trabalhando diretamente naquela atividade. Isso arrastou uma potente massa comercial de óleo diesel, de gêneros alimentícios e, principalmente de motores de pequena potência e carpetes utilizados para reter o ouro nas moto-bombas de sucção, além de ter provocado elevado movimento de pequenas aeronaves. Em Itaituba chegou-se a registrar uma média de 300-350 pousos e decolagens diárias.

A região do Tapajós, como maior área garimpeira do Estado, historicamente acumula uma produção da ordem de 600 toneladas e atualmente agrega população em torno de 35-40 mil pessoas, com elevado caráter de organização. Os grandes impactos ambientais causados pela atividade garimpeira, aliado ao bom nível de pesquisas ali realizadas impõem ao poder público grandes desafios que devem ser tomados em conjunto com a sociedade civil organizada, tendo em vista a alta complexidade que os garimpos de ouro envolvem.

Nesse sentido, a iniciativa do Global Environment Fund das Nações Unidas, através do projeto Removal of barriers to the abatement of global mercury pollution from artisanal gold mining, que desenvolverá estudos visando a criar um modelo de garimpo sustentável para a região merece todo o apoio governamental. Dentro das prioridades da ONU para o século XXI, a iniciativa será desenvolvida dentro de um grande ecossistema – a bacia hidrográfica do Rio Amazonas.

As peculiaridades e a importância que o Tapajós representa balizaram a escolha, cujo produto final deverá ser o de reduzir o lançamento do mercúrio, utilizando tecnologias limpas, entretanto, a atual realidade dos garimpos será contemplada, estudando-se alternativas para o aproveitamento dos filões de quartzo produtores de ouro. O conjunto de ações pesquisará os segmentos econômicos, sociais e ambientais, dentro de padrões sustentáveis que estejam intrinsecamente ligados, atendendo de um lado os interesses da Unido e de outro os das comunidades envolvidas.

Belém, Pará, Dezembro 2001

Hidelgardo Nunes
Vice Governador
do Estado do Pará

Opening Speech

given at the Brazilian Workshop on the GEF Global Mercury Project
"Removal of Barriers to the Abatement of Global Mercury Pollution from Artisanal Gold Mining",

Ladies and Gentlemen,

We all realize that Governments, national and international institutions, industry, and society in general become more and more conscious of the problems posed to our planet by the release of toxic chemicals. Mercury is one of numerous pollutants causing growing concern because of the long-term impact on the ecosystem and human health. This concern has been reflected in over 500 publications presented at the last International Conference on Mercury as Global Pollutant in Rio de Janeiro held in Rio de Janeiro 1999.

Only part of the mercury emissions to the environment is man-made. Because of its high vapor pressure and due to degassing from the earth's surface, natural mercury emissions greatly exceed the man-made pollution. Besides coal and natural gas combustion and the electrolytic production of chlorine and caustic soda, the mining sector remains, however, an important anthropogenic source of mercury emissions.

The official consumption figures of mercury show a downward trend since the early 1980s owing in part to regulations regarding mercury discharges and emissions, and to concern to the ultimate fate of mercury-bearing products. In industrialized countries the concern is so serious that regulations have virtually eliminated the use of mercury in electrical batteries. In these countries people have even had their amalgam fillings removed knowing that mercury exposure from dental fillings is toxicologically significant and unnecessary.

In contrast to the chemical and electrical industry, where innovations led to a substantial decrease in mercury emissions, artisanal and small-scale mining remains a dangerous source of mercury pollution. This problem affects all developing countries in Latin America, Africa and Asia, where gold is produced on artisanal basis. According to a conservative estimate, 1.5 million people are directly involved in this subsector, whereas several million people are economically dependent on these activities.

Since 1980, small-scale gold mining activities have increased steadily. Now, small-scale mining might account for one-quarter of the world gold output. Despite the current low gold price, the gold rush in the artisanal sector does continue. A high percentage of these small-scale miners use the mercury-based amalgamation process with potentially catastrophic results for the environment and their own health. Some hundred tons of mercury vapors are released every year into the atmosphere. Since they quickly return to the river ecosystem with rain, they add up to the mercury spillage occurring during the amalgamation process. Participants of the Workshop know very well the seriousness of mercury pollution in Brazil.

But not only Latin America is affected. Diagnostic missions of UNIDO revealed the same practice of excessive use of mercury in other parts of the world. It is well known that this amalgamation process is devastating to health, not only to users but also to those indirectly involved, including the unborn, through peripheral contamination and introduction into the food chain. Within the last years, life-threatening mercury pollution has been identified in most developing countries where artisanal gold production is taking place.

UNIDO INTERVENTION PROGRAMME OBJECTIVE

Since many years, continuous efforts have been made by the Organization to provide assistance to the small-scale mining sector, in particular to the artisanal gold mining sector. The requests for assistance in reducing mercury emissions were forwarded to UNIDO especially by those governments, which had become increasingly aware and concerned about the dangers involved in these activities. Since the issue of impact on health and environment is multifaceted and complex, Governments requested support, especially in education, training and technology transfer for improving the situation.

In this respect, UNIDO had to offer cross-disciplinary programmes, comprising measures for environmental protection, introduction of new technologies and manufacturing of equipment and training in these fields, especially training for women. In these programmes, UNIDO is undertaking special efforts to ensure that women participate and benefit equally from the introduction of new equipment and processing techniques.

More than 10 countries have requested UNIDO's assistance in different projects related to artisanal gold mining. In general, these governments have inadequate resources, lacking capacity and insufficient institutional framework to control informal gold mining activities and the resulting mercury pollution. UNIDO's approach in addressing this problem is to replace low recovery, high mercury consuming and discharging processes with environmentally safe and high-yield gold extraction alternatives that will sharply reduce or eliminate the use and discharge of mercury. Thanks to the financial assistance of the Global Environment Facility (GEF), UNIDO can focus now on selected areas, which are subject to transboundary mercury contamination problems in shared river basins or enclosed water bodies.

During the initial phase of the GEF Project, diagnostic missions to countries with active artisanal gold mining activities have been undertaken, especially to areas where waterbodies and basins with global ecological significance are shared. In collaboration with host governments, barriers limiting the adoption of cleaner artisanal gold mining and extraction technologies have then been identified in the following countries: Brazil (Amazon), Sudan (Nile), Tanzania (Lake Victoria), Zimbabwe (Zambezi), Lao PDR (Mekong), Indonesia (marine environment, Java Sea). In this phase, UNIDO was especially identifying hot spots with the potential for affecting international waters in Africa, Asia and Latin America.

IMPLEMENTATION STRATEGIES

The large-scale (follow-up) Project aims at establishing the extent of mercury pollution through studying the general health conditions of those living in selected areas, conducting geochemical sampling and analysis in order to identify "hot spot" areas, collecting and analyzing human specimens and other biological samples, studying mercury migratory patterns in the area and assessing the impact and extent of mercury pollution in waterbodies. In collaboration with respective Governments, local laboratories will be identified and their resource capacities enhanced in order to enable them to develop and conduct continuous monitoring of mercury pollution of waterbodies in artisanal gold mining areas. The Project will also formulate and carry out measures for remediation of the identified "hot spots".

Since training and awareness raising are important tools for developing the small-scale mining sector, UNIDO focuses also on

- On-the job training in cleaner technology;
- Training of women and women entrepreneurs, who have a big share in the sector;
- Enhancing awareness through workshops on local, regional and international level
- Raising the interest of the medias. Inter alia BBC and CNN have already reported on mercury-related activities of UNIDO.

In order to introduce efficient and affordable technologies, the project will analyze the existing processes and propose modifications for technology and equipment. The aim of these activities are

- To familiarize local manufacturers with the design of non-high-tech but efficient gold recovery equipment;
- To demonstrate alternatives to amalgamation;
- To prove the cost effectiveness of the new techniques;
- To develop micro financing programmes in cooperation with the private sector.

On request of the participating governments, UNIDO will

- Review current policies and advise on legislation;
- Establish sustainable gold extraction indicators;
- Convene workshops to discuss recommendations on the legal framework;
- Assist Governments to develop enforcement programmes and set enforceable standards;

CONCLUSION

The involvement of the Global Environment Facility can be considered as a breakthrough in reducing mercury emissions to international waters. It has to be noted that the GEF will cover only the difference, i.e. the increment, between the costs of the project with the global environmental objective in mind, and the costs of an alternative project that the country would have implemented in the absence of a global environmental concern regarding mercury.

The cooperation of UNEP, UNIDO, and the GEF in programs related to reducing mercury emissions has resulted in an increased awareness about this problem in developing countries. This is reflected by the increasing number of requests for technical assistance and an obvious interest of governments and donor agencies in supporting these activities. Funds made available so far do, however, not suffice to cover the demand for assistance. Therefore, donor efforts need to be encouraged and coordinated in order to improve the effectiveness of assistance to the small-scale mining sector.

Coordination can be achieved by sharing information on success and failure, by identifying areas where joint efforts may create synergistic benefits, by meeting regularly to plan for future activities, by collaborating in project implementation and creating opportunities for formal cooperative agreements and joint project implementation.

Belém, 5 October 2001

Christian Beinhoff
Dr.-Ing.
Project Manager
United Nations
Industrial Development Organization
(UNIDO),
Vienna/Austria

MERCURY IN BRAZIL AS RESULT OF GARIMPO OPERATIONS

Prof. Dr. *Roberto C. Villas Bôas*

CETEM/CNPq

ABSTRACT

The formidable impacts caused by mercury usage in industrial activities, be it in chemical factories or energy production, as it is inherent in coals used in thermal power plants, and in agriculture as part of herbicides compounds are all well documented in the literature. As well teeth amalgams are an old concern, recently revived in the scientific literature.

From the end of the 80's onwards the extraction of gold in rain forest areas and wetlands, in the form of **garimpo** operations, are receiving increased attention from scientists and public planners.

The purposes of this paper is to situate the problems caused by **garimpo** extractions which utilize mercury in Brazil advancing some interaction effects of such utilization within the ecosystems and population health, as well as present some solutions to date to deal with such a problem and, last but not least pointing out some of the still pending problems.

INTRODUCTION

Etymologically, **garimpo** is a Brazilian word quite utilized during colonial times, meaning the working of gold, diamonds and emeralds mines, by a **garimpeiro**, that is a person with practical skills but without the formal licensing of the legal authority, thus illegally performing such extractions. Or, as stated in the Royal Decree dated of march, 26, 1731" *o nome com se apelida neste país aos que mineram furtivamente as terras diamantinas e que assim são chamados por viverem escondidos pelas grimpas das serras"* or, translating," the name given in this country to those outlaws miners that mines the lands of Diamantina, being thus called due to the fact that they live in" grimpas" on the hills" .

Throughout times it became synonim of small, artisan type, operations, as contrasted to industrial mining.

By the end of the 80's however, due to the paramount extraction of gold in the amazon region, the word also means informal mining, in the sense that the size of the operations might be small or large, but always semi-outlawed or totally outlawed, since the legal authorities did not produced a legal framework on time to accommodate all the several particularities of the said operations. For details on the terms being utilized to describe gold extraction activities, the reader has to refer to VEIGA(1997).

Notwithstanding, **garimpo** is the best terms for such activity worldwide, whenever the following facts are present:

- Gold is extracted as free gold or alluvial gold;
- Such extractions are in rainforest areas and tropical wetlands;
- The exploitation is performed under no legal framework, either mining or environmentally;
- Normally no formal working links exist between the players in the **garimpo.**

GOLD GARIMPO IN BRAZIL

The map (MARCONDES, 1996) that follows illustrates in unquestionable manner the scattering of **garimpos** throughout the Brazilian territory, the reason being purely geological, since in tropical precambrian areas the presence of secondary compounds is favored, gold not being an exemption, except for the case of not occurring as a compound, but rather as the metal itself !

Garimpo in primary sources, as those of massive sulfides are unknown for gold in the country, and those occurring as quartz veins,in modern times, are quite rare, although sometimes seen.

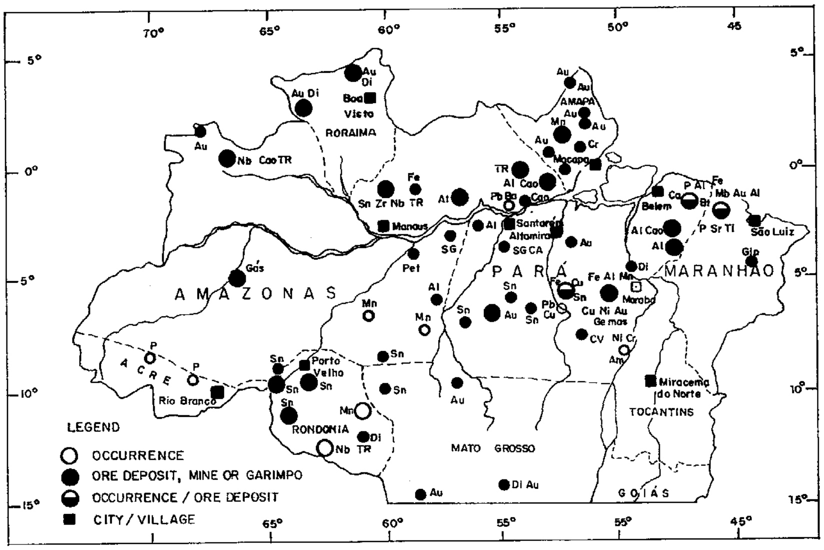


Figure 1 – Mineral Resources of the Brazilian Amazon

One of the typical characteristics of the **garimpos**, in the golden ages of the 80's and 90's, due the very favorable selling price of gold ingots, was their mobility, in such a way that the authorities always issued some kind of legal bill, after the site of operation has being occupied, overnight, by thousands of **garimpeiros**, arriving from all places.

Thus, the following table brings the areas, so called, reserved areas to the **garimpagem** and the substance that was allowed to be **garimpada**, as published by DNPM in 1994, and still pretty much the same.

AREA	ORE	STATE	COUNTY
Carnaíba	Emerald	Bahia	Pindobaçu
Rio Madeira I	Gold	Rondonia	Porto Velho
Alto Coité	Diamond	Mato Grosso	Poxoreu
Rio Madeira II	Gold	Rondonia	Porto Velho
São Tomé	Pegmatites	R. G. Norte	Lages
J. do Serido	Pegmatites	R. G. Norte & Paraíba	Juazeirinho
Zé Vermelho	Gold	Mato Grosso	Alta Floresta
Cabeças	Gold	Mato Grosso	Alta Floresta
P. de Azevedo	Gold	Mato Grosso	Peixoto Azevedo
Tapajós	Gold	Pará	Itaituba
Cumaru	Gold	Pará	S. Felix Xingú
Tepequem	Diamond&Gold	Roraima	Boa Vista
S. Terezinha	Emerald	Goiás	Sta. Terezinha
S. Pelada	Gold	Pará	Curianópolis
Rio Jurema	Gold	Mato Grosso	Alta Floresta
Minas	Several	Minas Gerais	Vários

Of these the largest areas are Tapajós, in the Itaituba county, with 2.874.500 ha; Minas Gerais, in the counties of Diamantina/Monjolos/ Gouveia/Dantas/Bocaiuva, with 1.178.375 ha;Peixoto de Azevedo, with 657.550 ha ; Alta Floresta, totaling 171.000 ha ; Cumarú, in the county of São Felix do Xingú, with 95.145 ha , etc... just to give an account of the sizes we are mentioning.

Therefore, due to the given reality of the **garimpo** existence, bills were passed in the house of representatives in order to provide a legal structure for the activity, these being Bill of Law 7805/89, dated 20/06/1989, followed by Federal Decree 9812, dated 04/01/1990.

As for gold, the Brazilian **garimpos** may be grouped in five main classes:

1.- Manual: quite rudimentary;

2.- Semi-mechanized: where the rocks at the river bottom are sucked via hoses manually driven by divers and powered by Diesel motors up to 32 HP;

3.- Drags: the same as above except that the hoses are thus conducted by mechanical hoisting and no divers exist;

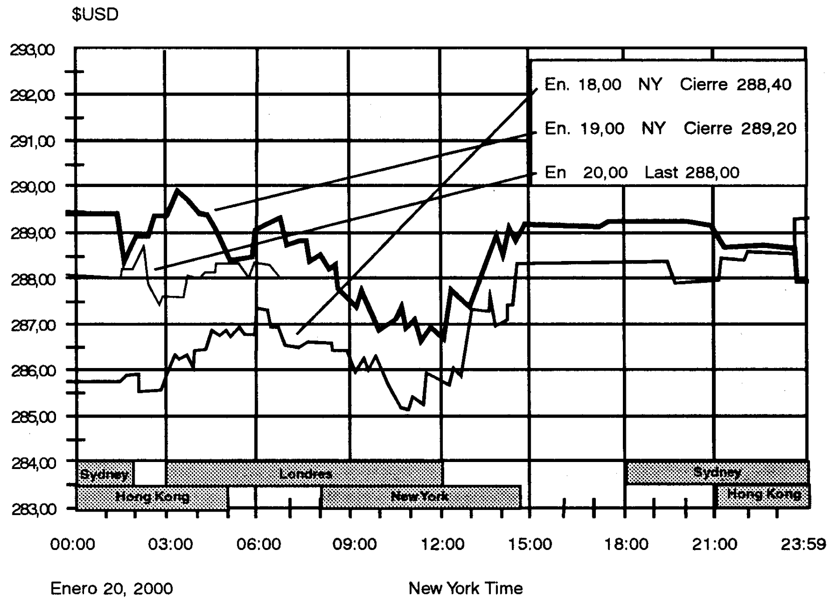
4.- Hydraulic: hydraulic loosening of the waste rock; as well caterpillars and trucks might be seen, instead of the hydraulic monitors;

5.- Primary Ore: in quartz veins.

The National Department of Mineral Production, herein denominated DNPM, yearly issues the publication SUMÁRIO MINERAL BRASILEIRO, and quite regularly the most complete ANUÁRIO MINERAL BRASILEIRO, both bringing all of the most important statistics in the mineral arena in the country. They shows the extraordinary decrease in **garimpo** gold production from the nineties onwards, due to the very low selling price of the troy once. Some analysts affirm that only at a US$ 400.00 per once troy will bring back **garimpo** production in larger scale, besides the fact that, according to MARON (1999), after the Kandir Bill in 1996, that allowed less taxation of primary and semi-manufactured Brazilian products, the largest part of the Brazilian gold is being exported as such, since that part of gold that goes into the domestic market is quite taxed!!

For an overview of some of the legal, economical and social problems of **garimpos** the reader is invited to consult MIRANDA et al. (1997)(SED 38); for an overall account of the mineral economic facts related to gold, please seek http://www.dnpm.gov.br.

An interesting feature of gold price fluctuations , however , is given by this graph , recently published by PANORAMA MINERO (January 2000) shown the variations of gold prices within a 24 hours period, in Sydney, Hong Kong , London and New York , accordingly to NY Time.



THE MERCURY PROBLEM

In rainforest areas and tropical wetlands, whenever a situation as the one aforementioned arises, mercury originates from gold extraction, **garimpo**, operation, both in the form of elemental mercury, used to amalgam gold, and mercury vapor, either elemental or oxidized, originated from the burning of the amalgam, thus liberating gold and mercury, as well. Such mercury compounds will then be released to the environment, carelessly, due to the very fragile legal framework in which such operations are carried out, not to mention the law enforcement alone, into rivers, into soils or just into the atmosphere.

For a complete account of the several unit operations carried out at gold **garimpos** sites in Brazil, please see FERNANDES et al. (1991), FARID et al.(1992), RODRIGUES et al.(1994), RODRIGUES FILHO (1995,1996), DA SILVA et al. (1996), BRAGA and ARAÚJO (1995), ARAÚJO and SANTOS,(1995) and VILLAS BOAS (1997).

The environmental problems associated to the presence of mercury in the environment, being it in a liquid, ionic, or vapor form are all well documented in the literature, for instance D'ITRI (1990), CÂMARA (1993), PECORA (1970), amongst others (5th I.C. on Hg, 1999). However, no alternative route to Hg amalgamation is in effect, and processes as cyanidization, a problem in itself, oil or wax agglomeration, halide extraction, etc. neither compete economically nor are suitable for **garimpagem**, see CRAMER(1990)!

FERGUSSON(1990) lists some of the alkyl derivatives of the heavy metals relevant to the mercury environmental geochemistry and chemistry, the interests being in the toxicity of such compounds and the fact that methylation does occur for many of the heavy metal elements.

Methylation represents the transfer of a methyl group from one compound to another, the process occurring biologically or abiotically. Bacteria and fungi so far reported to methylate Hg, As, Se,Te,Pb,Cd,Tl and In, are usually aerobic, exception being clotridium sp and methanobacterium which are anaerobic.

There is good evidence for biomethylation of mercury, arsenic, selenium and tellurium; however there are doubts regarding that of the other heavy metals.

In 1964 the cobalt complex ion (CH3Co(CN)5)3-, which is the model for vitamin B12 was show to methylate mercury. WOOD(1968) suggested that the methylating agent associated with methane-producing bacteria was methylcobalamin, i.e. the methyl derivative of vitamin B12, where the CN- group is replaced by CH3-.

On the other hand, methylation by non-enzymatic MeCoB12 may be treated as abiotic, except that the reagent itself is produced biotically and may be re-methylated biotically. The two main abiotic methylation processes are transmethylation, and to a lesser degree photochemical.

Several features of the chemistry of mercury facilitate its existence in organo-species and is quite important to consider when dealing with the mercury problem in tropical estuaries, not to mention the aforementioned role of the vitamin B12 as a methylating agent, sometimes not taken into account even by scientists visiting **garimpo** areas !!

One of these features is that both Hg2+ and CH3Hg+ are soft acids and bond pretty well to soft bases such as S2- and SH-, the cation being large and polarizable, and because of the positive charge, in itself a good polarizing cation with tendency to constitutes covalent bonds. The Hg-C bond, though not that thermodinamically strong (60 to 120 kJ/mole) is stronger that Hg-O bonds, therefore persisting in the environment.

Bacteria that might be associated with mercury methylation are located in the bottom of sediment rivers, estuaries and the oceans, besides the intestines and feces, soils and yeast, the factors that influences their methylating action being temperature, Hg and bacteria concentrations, redox conditions, pH, type of soil, type of sediment, sulphide concentrations.

Methylmercury accounts for circa 0.1 to 1.5 % of the total mercury in sediments, and around 2% of the total in sea water, but in fish it accounts for over 80% of the total. It is not clear, however, if the CH3Hg+ is taken in by the fish from the water or formed within the fish, or both.

The changing chemistry of mercury was already pointed out by RENUKA(1993) and it is always a point of concern among those who are devoted to the study of mercury and mercury compounds.

In Brazil, remediation procedures for exhausted gold ores, however carrying mercury were tried, and an electroxidation method was introduced in **garimpo** sites in order to reclaim mercury from tailings as described by SANTOS E SOBRAL (1998). A discussion will be given in a later section of this paper to this process.

The rationale behind the several research project conducted throughout the major **garimpo** areas in Brazil was to seek answer for the following questions:

What is the fate of mercury into the environment ?

Is there any alternative reagent to mercury that is competitive with it?

How to avoid environmental damage from these operations and from mercury ?

At the beginning of the 90's, the Brazilian House of Representatives decided to seriously look upon the mercury problem in garimpos and commissioned CETEM – Center for Minerals Technology – of the Brazilian Research Council – to perform a four year program for that matter, utilizing all available resources in the country or outside the country.

Several links were thus established between CETEM all of the other institutions that were interested in mercury, from several viewpoints, namely, mining, reclamation, health, environment, ecology, legislation, social structure, economy, etc...

All major research organizations in the field participate in such a program, plus government institutions dealing with the mining and environmental issues, plus the **garimpeiros** unions, these institutions being:

- Research: CETEM, UFRJ, UFPa, UFF, FIOCRUZ, EVANDRO CHAGAS, UFMT.
- Federal government: MME, MMA, DNPM, IBAMA.
- State government: METAMAT, SEICOM/Pa.
- County government: Prefeitura de Poconé, Prefeitura de Alta Floresta, Prefeitura de Itaituba.
- Unions: Sindicato Nacional dos **Garimpeiros** da Amazonia, Sindicato dos **Garimpeiros** de Itaituba.

And the task was to answer the aforementioned questions plus some others that throughout the research path were discovered to be of significance to the final goal.

THE PARTICULATE MATTER

Besides mercury, the release of particulate matter coming from earth-moving also contributes to the deleterious effects on the biota and health. Physical impacts on the environment coming from mining activities are related to the release of particulate into rivers, lakes oceans and the air.

These,as known, interact with the environment and may substantially alter the biota. Little is known of such effect when associated with heavy metals cations, mercury included; later, we shall discuss in more detail some satellite photos taken of particulate carrying mercury in the upper atmosphere.

If one utilizes the partition coefficients (Kd's) as proposed by DUURSMA(1994),the partitioning of the contaminants may thus be determined, between the several compartments of interest, i.e. water, sediment, particulate and biota, hence furnishing useful empirical data in determining the percent distribution between dissolved and particulate matter, accumulation in organisms, etc.. and a very intriguing fact is that a newly contaminated tropical estuary might be a sink for a long period, afterwards becoming a source as equilibrium is attained faster that in temperate climates.

A very extensive program, named CAMGA-TAPAJOS, monitoring the **garimpos** at the Rio Tapajos area was conducted by SEICOM/Pa(1992) and the following table may be inferred.

Environmental impacts derived from extraction and concentration techniques for gold recovery in Rio Tapajós, as related to particulate matter

Causes		Physical and/or Chemical	Biological	Antropic
EXTRACTION	CONCENTRATION	erosion/increasing suspended load	changes in ecological habitats	damaging fishing activities
		changes in color, turbidity and other organoleptic water properties		increase in water treatment costs
		silting-out and changes in river courses	changes in ecological habitats	losses of natural resources
		water pollution (soaps and oils)		endemic diseases
				losses of natural resources

SOME DATA COLLECTION OF INTEREST

Some relevant physical chemical data collected, are herein summarized, in order to present the kind of problems that are found in **garimpos**. We tried not to be exhaustive, for that matter see Proceedings of the 5th I.C. on Hg as a Global Pollutant, but just present data that are quite representative of the overall posed problem and that we were directly involved.

a) Background and sediment mercury concentrations, measurements in local air, gold shops and urban areas were made, as well as Au/Hg ratio, and the content of mercury in processed tailings determined.

These measurements and determinations were reported in the literature, see VILLAS BÔAS (1997), VEIGA et al. (1991), RODRIGUES FILHO and MADDOCK (1997), FARID (1992), BRAGA and ARAÚJO (1995), and ARAUJO and SANTOS (1995), all from CETEM. Tables 1 and 2 summarize these findings.

Table 1 - Mercury concentrations in sediments, air, gold shops and tailings

Area	**Mercury[a]**					
	Background (ppm)	Sediments Cn/Bn[b]	Air ($\mu g/m^3$)	Gold Shops ($\mu g/m^3$)	Au/Hg	Tailings (ppm)
Poconé	~ 0.10	1.5 to 24	0.14-1.68	~ 100	1:1.5	1 - 25
Alta Floresta	~ 0.07	1.5 to 48	up to 5.8	up to 41	1:1.5	5 - 134
Itaituba	~ 0.15	1.5 to 24	up to 6.6	> 9.9	N.A.	47

[a] concentration from several field samples.

[b] Cn/Bn accounts for the ratio between the concentration of Hg in the -74μm fraction and the background value of Hg in the same fraction.

Table 2 - Field results for Peixoto de Azevedo [c].

Source	Hg input kg/month	Recovery kg/month	Total Losses kg/month	Losses to Air kg/month	Losses to Water kg/month
Garimpo do Melado	16	3.20	12.8	7.7	5.1

[c] BRAGA and ARAÚJO, 1995.

Several other important data on soil, sediments and water were collected, analyzed and presented elsewhere (LACERDA, 1992, 1994, 1996, 1997; RODRIGUES FILHO,1994; FARID, 1992; TUMPLING et al, 1995; MUELLER, 1996), among others.

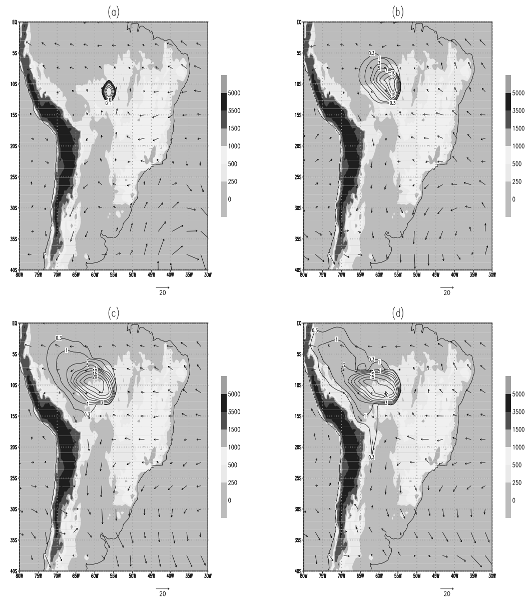
Also data on the health status of the living community were collected an reported elsewhere (CAMARA,1993; TOBAR, 1996; HACON, 1996), among others trying to establish correlation between mercury poisoning among the local population, including the **garimpeiros**, and eating habits, concurrence of diseases, and inhalation of mercury vapor. These subjects are also present still today in several papers of this 5th I.C.

b) Mercury dispersion in Alta Floresta: later in 1996, another grant, via PADCT enabled CETEM to coordinate an effort involving several other institutions, some of the already mentioned and some new ones, as INPE, the National Institute of Space Research, and USP through the Institute of Physic, dealing with mercury measurements in the atmosphere in the region of Alta Floresta. The findings of such a project were published elsewhere, see COELHO (1997).

Some interesting features emerged from the data shown in the figures (Apud NOBRE et al. 1996) regarding the atmospheric dispersion of contaminants, after 7 days from the emission, at the level 925 hPa, from a source with constant intensity, active for 5 days, beginning in 20/08/95 and located in Alta Floresta. At the seventh day, it can be observed that the dispersion was directed to the west as well as to the north and south directions, certainly due to the effect produced by the Andes, as a geographical barrier. Thus, in a few days, contaminants such as mercury, emitted from the Alta Floresta region, may deposit in relatively distant hydrological basins. A look at the satellite photos due show the extraordinary, predicted, mobility of air parcels carrying mercury aerosols throughout the atmosphere, with pre andine, caribean and even at the La Plata estuary consequences ! SILVA FILHO et al., (1999), discusse the mercury distribution in surface soils in central amazon.

c)Accredited analytical procedures, for total mercury, were used for soils, and water, see WILKEN,(1991); PADBERG, (1991), and air emissions in Alta Floresta, via denuders, as discussed by MARINS (1996), or via CVAAS and PIXE for the particulate, see HACON et al(1995); ARTAXO (1996) and GERAB (1996). The results for sampling of the gold shops ambient showed that the major part of the mercury associate to the particulate, coming from the hoods is in the gross fraction of the aerosol; however, an important fraction of mercury is within the fine particulate, thus facilitating its transport together with the ”queimada” aerosol; about half of the mercury associate to the particulate is non-volatile, being strongly attached to the particles, see FERNANDES et al (1996).

Also, a biomonitor, i.e. *Tillandsia usneoides*, a bromeliad for atmospheric mercury was tested (MALM et al., 1996) showing promising results at a comparatively low cost, although some advocates that, FONSECA et al (1999), its use is indicated only to areas where Hg concentration are higher that 5ug/m3 of air; also interesting other discussions are available such as SCHWUGER et al.(1999); KVIETKUS et al (1999); GUIMARAES et al.,(1999); CECILIO et al.(1999); PINTO et al.(1999); MAURO et al. (1999) amongst others; methylmercury determinations, were conducted at the Instituto de Biofísica of UFRJ, as shown by PFEIFER et al. (1991) and much later on, via the guidance of AKAGI (1996), and HORVAT (1997), CETEM was able to perform them MELAMED (1999).



Mercury dispersion in Alta Floresta, considering a constant source of emission of 3.5 units initiated at 20/08/95. (a) first day; (b) second day; (c) seventh day; (d) ninth day after the beginning of the emission.(APUD NOBRE et al, 1996)

SOLUTIONS FOUND

Problems with mercury release in **garimpo** are well widespread in the Pacific Rim, Latin America and Africa requiring the conception, design and implementation of adequate methods for mercury utilization, monitoring and mitigation.

The solutions to the problem of mercury usage were divided into two classes:

- in those areas where the problem already exists
- future avoidance of the problem

In order to tackle both, the local involvement of the community is a must (in Brazil it is quite common to find, besides labor and employee unions, Rotary's and Lion's Clubs that act as facilitators). Nobel Prize HOFFMAN (1995), presented the methodological approach that we utilized in those already mentioned areas. Such methodology takes into account the fact that the samples we were collecting involved people living in communities; therefore a historical context of that particular community, a social profile of that community, a description of the political power underlying that community. And the legal aspects of the extraction activities and the environmental concerns of that community were established and analyzed by social researchers, see BARRETO (1991); BARRETO et al.(1996); PORTELA(1991); BARBOSA and LOBATO (1992) and MENEZES (1996).

Results were then discussed in several meetings with local community involvement, utilizing in this communication procedure all the available social entities that were stakeholders for that problem, i.e., the Lyons and Rotary Clubs, the Unions, both worker'' and bosses'' and societal commitments were reached in other to mitigate the problems associated with Hg releases.

These commitments involved:

- the understanding of the problem
- the will to commit community efforts in dealing with it
- to gather all the stakeholders involved in the discussions and to reach a consensus approach (those that favored the procedures and those that didn't)
- once the consensus was reached the following solutions to mitigate the problems were established a)closed circuit utilization of mercury in the concentration/amalgamation steps; b) burning of the amalgam in retorts in the field, and use of fume hoods in gold dealers' shops; and c) confinement of processed material in specially build settling ponds.
- these measures were taken both for the present operations and proposed to avoid future problems.
- for the present operations, after sampling the levels of mercury, risk areas were assessed, isolated and remediation measures

were performed, regarding mercury fixation and/or recovery as below.

Immobilization of hg

Mercury can be fixed by sulphur in polysulphides. This method, however, which can be utilized for the inactivation of Hg in solid masses, has been criticized on the grounds of the equilibrium constants for the several Hg-S bonds. No field tests were conducted, but a quite interesting paper on the subject is that of BENOIT et al. (1999).

However, laboratory testing was performed utilizing polysulphide solutions, obtained from a mixture of sulphur flowers and soda ash, i.e., commercial grade sulphur and sodium hydroxide. The results, although looking promising could not be numerically assessed, in terms of the actual degree of fixation, (we are talking of sites containing below 10 ppm of total mercury) due to the still difficulty in analyzing HgS below 1 ppm, as shown by WILKEN and ALLEGRA (1991).

Recovery of Hg

Whenever possible, mercury has to be recovered. One method tested by CETEM is that of electrooxidation (SOUSA, 1991;VEIGA et al., 1991; SOBRAL and SANTOS, 1995). Its main feature is generation of hypochlorite ions by oxidation of chloride ions to elemental chlorine that in a aqueous media results in hypochlorite. Such a process may be viewed as an electrolytic segregation process, because small amounts of NaCl are intermixed with the resulting residue (“ ore”) in an aqueous pulp that is electrolyzed. The general reactions may be written as:

$$Hg + 2ClO^- + 4Cl^- + 2H_2O \Leftrightarrow Cl_2 + HgCl_4^{2-} + 4OH^- \qquad (1)$$

and

$$2Au + 7NaCl + NaClO_3 + 3H_2O \Leftrightarrow 2NaAuCl_4 + 6NaOH \qquad (2)$$

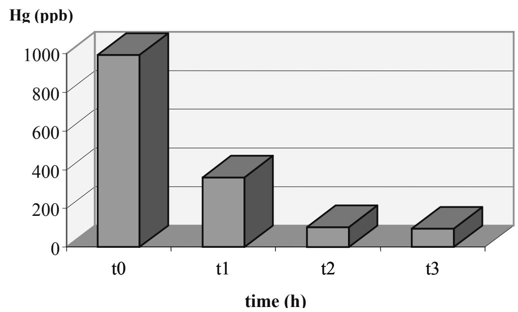
the dissolved gold being electrowon jointly with mercury.

Mercury recovery from tailings was conducted by installing and electro oxidation pilot demonstration unit in which up to 92% Hg recovery was achieved for a 6 h electrolysis time, in a 100 g/L NaCl solution, with an average energy consumption of 177 kWh/t, at pH 6-7, from tailings containing 6.8 mg/kg of Hg, producing a final solid material with 0.5 mg/kg of Hg. The dissolution of mercury may be viewed as:

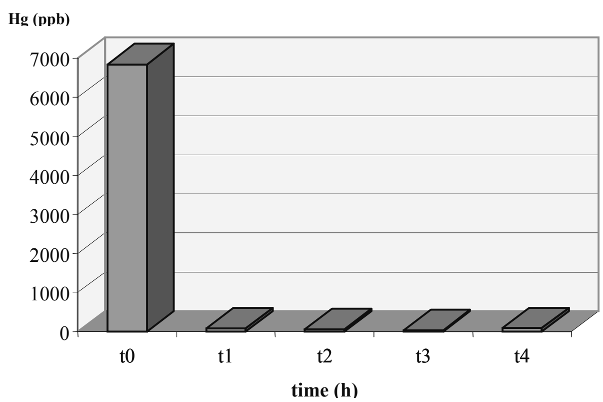
$$2NaOCl + Hg^0 + 4HCl \rightarrow 2Na^+ + HgCl_4^{2-} + 2H_2O + Cl_2 \qquad (3)$$

and mercury being deposited as elemental mercury.

A series of pilot plant runs were conducted in the location of Rio do Rato, Itaituba. The results of this field campaign are given below (SANTOS & SOBRAL, 1995).



Mercury concentration in the residue during electroleaching, i_a = 0.8 A/dm^2; 49.1 g NaCl/dm^3; 17 mL HCl; time 4 h; 1550 rpm.



Mercury concentration in the residue during electroleaching, i_a = 0.8 A/dm^2; 49.1 g NaCl/dm^3; 25 mL HCl; time 4h; 1550 rpm

Others

Other more obvious, and common senses solutions and measures were found and implemented, such as:

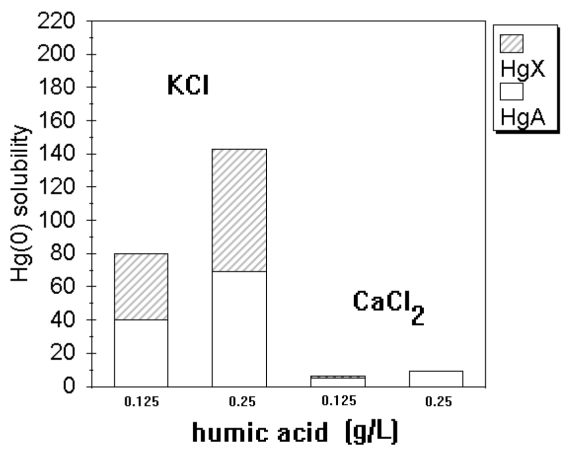
- no spilling of mercury during the amalgam phase, being a matter of mercury management throughout the process
- use of amalgamation vessels
- processing of the ore in close-circuit
- use of retorts in order to collect the mercury vapors
- use of fume hoods at the gold shops

Also an overall manual on how to process alluvial gold ores and manipulate mercury safely was issued (CETEM, 1994;1995; DNPM, 1996). Also, an overall account of part of this experiences are available,see SADEK et al. (1999).

MERCURY IN PRESENCE OF HUMIC ACIDS

The importance of the study of the mechanisms through which humic acids interacts/reacts with mercury compounds were stressed by MELAMED et al. (1997); VILLAS BÔAS et al. (1997) and, among others, VARSHAL (1999).

Tests utilizing Ca to revert the effect of humic acid on the enhancement of Hg^0 solubility, MELAMED and VILLAS BÔAS (1998), show that the increased solubility of Hg^0 due to the *Aldrich* humic acid was reverted in the presence of Ca. The need to verify such an amendment, and the possible development of this technology in the presence of natural organic acids MELAMED et al. (1999) is a must. Interestingly, the data shown in indicate that Ca prevents the dissolution of Hg^0 rather than a competitive complexation mechanism.



PENDING PROBLEMS

Pollution Limits: in order to assess if a substance, or compound, is effectively deleterious to animal health and or to the environment its past usage records are reviewed and reassessed. It also may be tested in simulation experiments on living organisms. Analytical and instrumental methodologies are to be available for lower detection limits, otherwise temporary lower detection limits are fixed.

Tests driven under simulation conditions have to be standardized or via consensus. These are very important to inform on individual risks and the lowest observed adverse effect level., as well, but how to conduct this in the amazon ?

Compartments: the interactions between pollutants, environment and compartments are to be carefully assessed and speciation techniques are becoming a must in order to define the toxicity of the substance or compound, see for this matter, COQUERY et al. (1999).

Responsabilities: in fixing the lower and upper limits of pollution; they are not JUST a technical responsability; they are a POLYTICAL responsability that will include, besides technical evaluation, an economical evaluation and their social consequences (health, education, employment). Here lies a very intriguing problem since in the majority of rain forest areas, **garimpo** activities are considered to be illegal, what difficult quite a bit its willingness to collaborate in environmental and health matters, or, as in the case o Brazil its legalization procedures are so cumbersome that, in fact, the great majority just remains illegal. At the 5th. IC. several papers dealed with the threats to public health and, eventual, responsabilities (PIVETTA et al., 1999; PASOOS et al., 1999; HACON et al, 1999; SANTOS et al., 1999;VASCONCELLOS et al. 1999;GRADJEAN et al., 1999;JESUS et al., 1999; MATTOS et al. 1999; SANTA ROSA et al., 1999;TAVARES et al., 1999; MIEKELEY et al. 1999;MERGLER et al. 1999; GUAN et al., 1999; DESCHAMPS et al. 1999;OLIVERO et al. 1999; TUCEK et al. 1999). Also, several papers presents views on educational programs and, eventual, responsabilities (KLIGERMAN et al., 1999; CAMARA et al., 1999;DESCHAMPS et al., 1999; DAVIDSON and VEIGA, 1999;GUERRIER et al., 1999;VEIGA et al. 1999; WHEATLEY, 1999; SHAMLAYE, 1999;); at the industry level(KINDBOM and MUNTHE, 1999 ; GUSTAFSSON, 1999)

Fish Species: once methyl mercury is formed it goes via the food chain reaching higher concentrations in fish species that are located at the top of the aquatic food chain, due to biomagnification effect through throfic levels. The amazon area is the richest worldwide in fish species; what is the threshold figure for every fish specie regarding mercury level concentrations in order to assess if such a fish is" intoxicated" with it ?And,then, what about RfD for methyl mercury ? See, for instance, quite interesting discussions on RfD for methyl mercury (SCHOENY et al., 1999; CASTILHOS and BIDONE, 1999); several reported measurements in the brazilian amazon (KEHRING and MALM, 1999;BRABO et al., 1999;MORAIS et al.,1999);NAKAZONO et al., 1999; SANTOS et al., 1999; LIMA et al., 1999: REOULET et al., 1999), in the wetlands (PINTO et al., 1999), the role of selenium (BARBOSA et al., 1999). The need of differential guidelines for permissible mercury levels in water, depending upon the fact that such a water, and fish species,is in a tropical or non-tropical area (RIBEIRO et al., 1999).

Sinergisms: in Nature quite rarely 2 + 2 is equal 4 ! Therefore, a better understanding of the several interplays between the many physical, chemical and bio variables that affect a given speciation mechanism within a given compartment is still lacking Not to mention in health, for instance, when trying to detect if a given symptom derives from mercuarialism or, on the other hand, say, malaria (TOBAR, 1996); Some papers are important in this regard (SILBERGELD;et al.,1999.; STRICKLAND et al., 1999). Also of interest is" a holistic approach to mercury liberation and its toxicity" (GHOMSHEI et al., 1999).

Mathematical Models: well always a problem, this we all know since. they intend to represent/simulate a complex system through certain number of compartments that interact with each other; here again, synergisms !Therefore, mathematical models, before utilized, have to be thoroughly understood.Some discussions on the use of models are clarifying (ROULEAU and PELLETIER, 1999; BENOIT et al., 1999).

Geo and Biogeochemistry of Hg: the geo and biogeochemistry of heavy metals in general is still a very much open question and that of mercury is not an exemption. Very intriguing questions as the role of the presence of other metal species as regard mercury accumulation in soils are still to be answered As for tropical soils the always present iron (VEIGA, 1993; RODRIGUES FILHO, 1995; LACERDA, 1996) needs more research (see ZEIDEMANN et al., 1999; FOSTIER et al. 1999,; RIBEIRO Jr. Et al. 1999 at this 5th. I.C.). Quite useful papers are,on this matter, on the role of total Hg, methyl Hg and Hg(II) (BAILEY et al., 1999; HINES et al., 1999).; on the origin of mercury in amazon soils, anthropogenic or natural ?,(MILLER et al., 1999)

Decomissioning: borrowed from the nuclear industry this term means what to do after mine closure, as regard the mine site itself, the environment surrounding the mine site, the living community etc. This subject, as taken for the **garimpo** areas spread out through Latin

America, the Pacific Rim and Africa is, again, a completely open question; no valid decommissioning methodology and procedure has been established as yet. Several papers dealing, in one or another form, with such subject are , (VEIZAGA and BOURGOIN, 1999;MACHADO, 1999; PESTANA and LECHLER, 1999; SOUZA et al., 1999;ARAUJO NET, 1999;BERMUDEZ and VEIGA, 1999) on gold extraction; others on mercury extraction (RYTUBA, 1999; KIM et al., 1999; COVELLI et al., 1999) and, yet some quite relevant for guideline establishments (LAPERDINA, 1999; ASHLEY, 1999; QU, 1999; WHYTE and KIRCHNER, 1999).

Sustainable Development: well this is a very interesting issue, since we are discussing, at this talk, mercury and sustainability; but, again, such.an issue requires some framework to start with, not to mention the, unbelievable, war striking in Europe. Well, this apart, sustainability of some dangerous pollutant has to be brought either by banning it or managing its use. At our findings, throughout these campaign experiences that we reported in this talk, we found mercury sustainable IF some measures were taken; these measures were already exposed earlier in this talk, and all of them needed a strong commitment of the communities involved as well as local authorities. However this is not a solution overall accepted. At this 5th IC. Some very interesting papers on this are available (GUSTAFSSON and REIN, 1999); REIN and FIN, 1999; REIN, 1999; ANDREWS and SWAIN, 1999; PONCE et al. 1999; PILGRIM et al. 1999); a paper on appropriate treatments for surplus and waste mercury" (ANSCOMBE, 1999) that is very appropriate since the US Stockpile was responsible some years ago for the release (selling) of large quantity of mercury flasks ! A paper proposing a network to look at the impacts of global warming and the cycling of mercury (REUTHER, 1999) And, last but not least, an intriguing paper (REYES and GALVAN, 1999) on the economics of mercury pollution and its negative externality !!

TAPAJOS GOLD GARIMPOS

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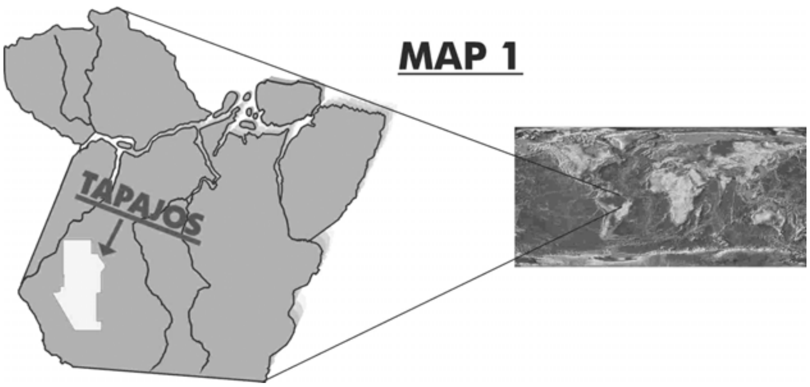
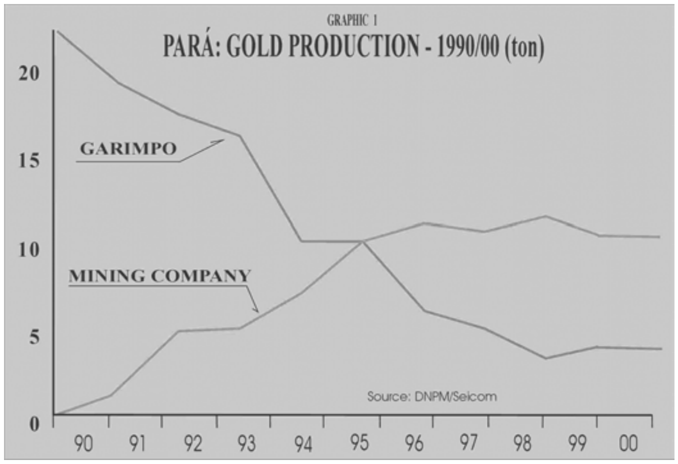
1. GENERAL ASPECTS

The Tapajos Region is situated in the Southwest of the Para State, 1,300 km straight line from Belem. The principal access is from Itaituba through commercial and private flight mainly monoengining (small air taxi) and through Tapajos River and Transamazonica and Santarem-Cuiaba road (map 1)



The Para gold garimpagem is very important to the regional economy. Its was considered the biggest mining gold production until 1995 (graphic 1).



In the Amazon Region, the garimpagem (map 2) has an area of 236,000 km^2 (4,34 per cent of the total area). In the Para State, these areas reach 150,000 km^2 being Tapajos the largest garimpeira area in the world – 100,000 km^2 – and the most important garimpeira gold producer in Brazil (map 3). From 1979 to 1984, the federal government delimited a series of "Official Garimpeira Reserves" that correspond to 31,500 km^2 (13,3 per cent of the total area – table 1).

Concerning to the heavy mineral history, we can observe that the main gold discoveries belong to individual works. The biggest world gold rush such as the Urais Mountain (Russia - 1744), the California (USA - 1849), the Australia (1851), the Klondike (Canada - 1896), the Witewatersrand (South Africa - 1896), the Tapajos (1958) and Serra Pelada (1980 both in Brazil). All lot them were characterized for a great number of people whom, empirically, looked for their economical independence, by individual work.

The gold is present in the Brazil’s chronological history, since 1500, when the Letter of Pero Vaz de Caminha mentioned Brazil as a gold producer. The Magna Letter of 1603, which instituted the tax called gold fifth (quinto do ouro), already mentioned Para as a gold producer. In 1747, it was discovered, for the first time, gold in the Tapajos Region, and, in 1853, the same occurred in the Amapa State.

In 1958, the great first gold rush began in the Tapajos Region, transforming that area in the principal gold producer in Brazil. It was supplanted only by Serra Pelada’s garimpo that was discovered in 1980 and whose the gold production decreased year by year from 1983.

Another important step to the Brazilian gold market occurred in 1986, when the Sao Paulo Stock Market (BMF) started up the organization of the Gold Brazilian Secondary Market, an idea of the Brazil Central Bank. The Federal Constitution of 1988 according to Law nº. 7.766, of 1989, considered gold as a financial asset. The last progress occurred in August, 1994, when the Para State Government, through the Camga-Tapajos Program, tried to implant the Gold Regional Secondary Market, in Itaituba. The task force had the collaboration of many institutions, but the Brazil Central Bank leaded the operation. The Gold Regional Secondary Market did not obtain success, however, it began the garimpos model transformation, including the official areas legalized in the Tapajos Region.

Table 1 – Garimpeira Official Area

Place	DNPM number	Date	Area (ha)
Rondônia	1,345	10/07/79	18,935
Rondônia	1,034	21/07/80	26,642
Roraima	143	03/02/84	12,000
Itaituba – Pará	882	28/07/83	2,874,500
Serra Pelada – Pará	Law number 7,194	11/06/84	100
Cumaru do Norte – Pará	25	10/01/84	95,145
Peixoto de Azevedo – Mato Grosso	550	10/05/83	121,000

Source: DNPM

The gold has been present in humanity's history for 20,000 years, since Paleolithic period in Egypt, where had begun the gold metallurgy and techniques. The gold metal attracts many people from all the world, because of its beauty, rarity, durability and considerable valorizations. Among centuries, investors and countries have considered the gold as the most efficient and secure way to maintain reserves and value. The General Charles De Gaulle, the France President, in the peak of the discussion of the gold standard in the international monetary system, in the 60's of the last century, indicated the gold as instrument that will be eternal and universally accepted as the only form of unalterable and constant reserve. For this reason, when occur international crises like strikes, wars or financial and inflationary instabilities, the investor falls back upon the gold as a refuge to assure your profitability.

The Amazon Region gold garimpos, the Tapajos Region particularly, has different periods of evolution. Until 1978, the activity was followed by Mining DNPM's Code, which characterized the garimpagem as a mining rudimentary research and individual work. Garimpeiros, when seeking the ore, followed the smaller creek and, when they found, for empiric processes, the auriferous anomalies, they exploited the baixões (gold alluvial flat). After that, garimpeiros isolated the strip for recovering the gold area in 10 meters by 10 meters, called "cata", or an area of 5 meters by 5 meters called "banda". For gold exploitation, at first, it is necessary to remove the overburden and the gravel to recover the gold. If the access was difficult, the next step would be built an airstrip. The airstrip would allow people, goods, equipments for gold exploitation to come in and out, all controlled by garimpo's owners.

The rose of gold prices in the international market, surpassing US$ 800 per ounce, in London Metal Exchange (LME), reflected in the Brazilian and regional market. One of them was the new gold rush in the Amazon Region.

In addition, in the garimpos area, the exhaustion of gold alluvial flats, the logistics in garimpos (airstrip, shopping, etc.), and the gold's discovery in the active bed of the rivers, without or with reduced overburden, allowed garimpeiros to look for more investments in the mineralized areas providing garimpo gold production mechanization. And through suctions pump that exploited the active bed of the drainages, the garimpos mechanization started. The following steps were: the introduction of chupadeiras (two suctions pump, the first one, to remove the overburden and the other one, to make the suction of the gravel or mineralized level) in elluvial and colluvial deposits; and, in the primary gold, garimpeiros used scrappers and hammer mills.

For this reason, there was a contradiction: meanwhile, garimpeiros removed large ore volumes, in function of potent equipment utilization, the final concentration continued in the traditional cobra-fumando (sluice for recover the gold). Then, the garimpeiros exploitation exhausted the secondary deposits, accumulating great tailing dams volume. After that, they began to detect primary gold mineralization, whose exploitation technology is not well dominated by them. In fact, there were great environmental impacts and the discovery of a series primary gold mineralizations occurrence. Nowadays, primary gold mineralizations show the transformation of the garimpagem model, such as in South Africa, Canada, United States, Australia, etc.

In international level, the artisanal mining has been discussed in a series of events:

- United Nations Seminar – Zimbabwe (1993) – called orientations for the development of the small and medium scale-mining. It involved the following themes: financial, legal, and fiscal aspects; technical, environmental and social aspects; and investments aspects; marketing and government support. The main final decisions were: definition of alternatives for the small scale-mining; maximization of benefits of the small-scale mining; creation of conditions to legalize the small-scale mining and to improve small-scale mine performance, through government support; use of clean technologies, involving all small-scale mining; and offered equipments for the small and medium scale-mining.
- World Bank Conference to the artisanal mining (garimpo) – Washington (1995) – discussed the following points: support to the garimpo as an economical and sustainable activity for people without resources in underdeveloped and developing countries; evaluation of the economical potential associated to the activity; and, recovery of degraded areas. The principal conclusions were: the garimpo has many facets and it imposes a series of complex and controversial subjects; the garimpo is a associated to poverty, but also to opportunities; reforms in the garimpo request an unified strategy; and, the principal objective is to transform the garimpo in small-scale mines.
- Second Conference of African Ministers responsible for the development and utilization of mineral and energy resources – Durban, South Africa (1997) – in this event the panel included: Small-scale mining, contribution for the poverty reduction and perspectives for technical cooperation in Africa.

- Conference on Shifting Sands: changing investment climate for the International Mining Industry - Toronto, Ontario (1999) – a forum of the event was the Commitment to social responsibility: easer, and probability cheaper than you think.

The United Nations Organization (UN) maintains a department of economic and affairs, with a special consultant for small-scale mining.

The research Excavating, loading and haulage equipment, accomplished by Parker Bay Company, in February, 1999, indicates that the small-scale mining involves 13,742 equipments, with a value of US$ 30.4 billion, operated in 760 places and 63 countries

2. GARIMPO'S MODELS

In the Amazon Region there are different gold garimpos model:

- Madeira River – this exploration occurs in the active riverbed, with the use of potent pumps, whose infrastructure is above the one that it is used in the other areas. The rafts remove a big volume of material, whose suction caliber is around 10 inches. The level mineralized recovered are layers of gravels or latheritics concretion, with local called as "mocororo". The ore recovered can be made inside or in the margins of the Madeira River, causing a great environmental impact, since the overburden or the mineralized level is removed, or yet for the effluents released and for the own metallic mercury.
- Tapajos – garimpos activity consisted in selected the strip selection, demarcating barrancos (garimpos site) and removing overburden, followed by gold recovered. Until 1978, the mechanization improved and use of dredges or rafts was started. Later, with the gold discovery out of flat alluvial, it was started also the gold exploitation in sequeiros (elluvial and colluvial ores), through chupadeiras (two suctions pump, the first one, to remove the overburden and the other one, to make the suction of the gravel or mineralized level). After 1990, it was discovered in the garimpos the primary gold mineralization in the rocks or quartz lode. Nowadays, there is a great amount of occurrences primary

gold that attracts mining companies to make joint ventures with the garimpo owners. This model is also applied to the North of Mato Grosso Region.

- Southeast of Para – this area contains young drainages, mainly because of the high erosion degree. The predominant gold exploitation is by chupadeiras and hammers mills. This model is also applied to the area of the Yanomamis, in Roraima State.
- Serra Pelada – this garimpo is different from the others, in the Amazon Region. Although the garimpagem began in a creek - Grota Rica –, the gold exploitation was dislocated quickly to the small hill drained by Grota Rica, called “Babilonia”, where, the gold was found in semi-altered sandstones breccias rocks and grew manganesiferous siltstone. The Serra Pelada’s garimpo presented a high gold and garimpeiros concentration. For this reason, the “catas” (gold exploitation site in the garimpo) dimension were 3 meters by 2 meters. The total Serra Pelada area is 30,000 m^2 and its form is like an ellipse, more similar to a bean grain. Another important Serra Pelada’s characteristic was the high number of “bamburros” (discovery of high gold concentration in reduced area), which provided, also, great “reques” or “recos” (donation of small amounts of ore, with high auriferous concentration), reaching sometimes gold’s kilograms. In addition, the federal government applied investments to remove the overburden in more than 1,500,000 m^3 to maintain the pit for garimpagem and to the correction of the pit’s border. There are more 4,000 “catas” in Serra Pelada. The excavation in the pit reached the water table, so it was necessary to use bigger water bombs to drain all the water of the pit bottom to allow the garimpeiros will be able to work in the area.
- The nineties – several Federal Government economical plans**,** the evolution of the price of the petroleum higher than the price of the gold, the declination of the prices gold ounce in the international gold market, reflecting in the Brazilian gold market; the end of the conflict between garimpeiros and mining companies, the reducing of the secondary gold deposits, followed by discovery of primary gold in rock, demanding cleaner technologies unknown by garimpeiros; the environmental pressures of the organized civil society; the legislation exigencies, as well as, the garimpeiros

organization in union and association, created the new conscience in the garimpo owners.

Today, there is a harmonic and democratic coexistence between garimpo owners and the mining companies. The first one, consider the joint venture the only alternative to advance in the garimpos evolution. And the second one are conscious that the work of the garimpeiros is very important to eliminate the research's initial risk, because when garimpeiros discovered the primary gold mineralization, the mining company's research will be facilitated.

Nowadays it is very common in the Para State, mainly in Tapajos Region, joint ventures between mining companies and garimpeiros. State Government promotes these partners.

3. RESEARCHES

The garimpagem in the Tapajos Region has been usually researched for government institutions. The first research was executed by Assistance Garimpeiros Foundation (FAG), in the 60's of the last century. The National Department for Mineral Promotion (DNPM), Federal Government, has made some research in the Tapajos Region. The Para's State Secretary for Industry, Commerce and Mining (Seicom) has also made important research looking for organizing and transforming the actual garimpos model.

In the beginning of 80's, ecologists and communities accused garimpeiros of a great environmental degradation. Meanwhile, the mercury was identified in the garimpos and it caused big reflexes in the national and international media.

Researches Studies:

- DNPM – it is responsible for the first collection of samples dosed for total mercury, including qualitative evaluations, environmental impacts studies, garimpeiros statistics, and environmental education, this one included in the Camga-Tapajos Program.
- Commission of the European Union (CUE), Sol 3 – Center for Studies and Researches of Europe, London's Imperial College, Seicom and Group for Studies and Defense of the Ecosystems of the Lower and Medium Amazonas (Gedebam) - the goal was to

study the Tapajos Valley, however it just realized the first project phase for Mercury contamination on the Brazilian Amazon. It was collected samples in four areas, two considered as critics, both inside of the garimpos area (Crepori and Cuiu-Cuiu), and two outside of the garimpos area (Jacareacanga and Itaituba).

- Commission of the European Union (CUE), Imperial College Consultancy (Icon), Seicom, DNPM, Evandro Chagas Institute (IEC) and Tapajos Gold Association (Amot) – this project was considered as second phase of the first project financed by the Commission of the European Union. It had four goals: technical alternatives (improvement in the evaluation of the garimpeira sites, with introduction of preliminary evaluation whose purpose was to reduce the risk for garimpeiros, mercurial studies impacts, but targeting to the occupational health; laboratories to assist people affected by possible mercurial contamination; and environmental information, compatible with garimpeiros culture.
- Cetem, Seicom, Evandro Chagas Institute (IEC) and DNPM – this project was applied in the Rato Creek. The researches involved mercurial contamination and impacts evaluations.
- Tropical Medicine Center of the Para Federal University (UFPa) and Japan International Cooperation Agency (Jica) – represented by doctor's team that has studied mercury risk groups, located in the Tapajos River. The merit of this research is the clinical accompaniment of possible mercurial intoxication.
- Evandro Chagas Institute (IEC), DNPM, Seicom and Japan International Cooperation Agency (Jica) – responsible for occupational health and the mercurial contamination evaluation. The Evandro Chagas Institute keeps the largest mercury database in the Amazon Region, with about 16,000 samples, most of them already treated. It reaches about 6,000 in the Tapajos Region.
- Promin – it was elaborated still in the Camga-Tapajos Program. The Company for Researches Mineral Resources – Brazilian Geologic Survey (CPRM) executed studies in the second half of the 90's of the last century. The Tapajos Mineral Province Project (Promin) whose principal intent were to make the regional geological mapping, however it also executed a series of the primary gold evaluation occurrences, as well as mercurial

contamination studies in some garimpo areas in the Tapajos Region.

- Camga-Tapajos Program – includes Tapajos Region it was executed since 1991, through the Para State Government, by Seicom. The Tapajos Region was chosen because the garimpeira activity is very important for the regional economy. For this reason, the Para State Government decided to study this area and created the Program for Garimpagem Controls (Camga-Tapajos Program), whose as final goal, in the medium/long-terms, was to minimize the great impacts in the garimpeira area as well as to transform the actual garimpo models. From that moment, the gold could be explored inside of the mineral, environmental and social legislation, with benefits to the communities involved in the garimpos exploitation and with focus to the sustainable development.

The reasons to develop the Tapajos Region program consisted in: being the largest Para and Brazil garimpeira area, involving the largest activity population, producing more of the half of the Para gold production, suffering the largest environmental impacts, and involving the largest number of garimpeiros leaderships.

The most important points to the Camga-Tapajos Program: being target to the Region, involving previous actions discussion, capitalizing positive effects from the other projects, partnership involving the public government and communities, responsibilities participation, promoting the activity organization (Amot), democracy in the actions.

The Camga-Tapajos Program concerned in six subprograms: social and economy, impacts studies, solid tailing dams contention, technological alternatives, environmental information as well as establishment for agriculture-extractivism, with garimpagem model's change.

The Camga-Tapajos Program research involved:

- Social and economy context – extractivist structures, including soil and subsoil occupation; garimpeiras shopping, the social relationships study in the gold garimpos sites; agriculture and "garimpeiros" workers – the relationship between the mineral extractive activity and the agriculture; women of the gold, the force of the feminine work in the garimpos; gold production unit study; and the urban nuclei studies

- Impact studies context – monitoration for mercurial contamination in the water and fish in the Tapajos River, study for the current environmental impacts of the mineral extrativism and mercurial pollution and mercury in Itaituba, coordinatinated by Cetem
- Environmental information context – informative campaigns and courses highlighting the main garimpeiras communities
- Establishment and transformation of the garimpagem model – increment to the gold production. The objective was to attract investments, through joint ventures between mining companies and garimpos owner. It is, in the specific case, necessary the promotion for Para State Government and all areas must be in mineral and environmental legalization. The first one by DNPM (Small-Scale Mining Permission) and the second one by Sectam (Environmental Licenses)

4. TAPAJÓS GOLD OFFICIAL PRODUCTION

The Tapajos area garimpeira corresponds to 100,000 km^2 (60 per cent of the Amazon garimpeiras area) and it is considered the largest gold garimpeira area in the world. Its area is larger than Portugal, also bigger than Switzerland and Netherlands, together. The official Garimpeira Reserves area is 28,000 km^2. Since 1958, it has a real production, on average, about 10-12 tons per year, has about 500 airstrips that support around 2.200 garimpos site. Its gold production is primary gold (rock and quartz lode) and secondary gold (alluvium, colluvium and elluviam). The Tapajos Region is the most researched in the whole Amazon garimpeiras areas and has the largest number of total and organic mercury samples collected (around 6,000 samples). Other important point is garimpeiros organization such as Tapajos Gold Association (Amot) that involves the principal garimpeiro owners and the experiences on joint venture with mining companies (about 26 joint venture for gold evaluation executed in the second half of the 90's last century).

The progressive gold exploration in the Tapajos Region permitted garimpeiros to discover around 500 occurrences for primary gold, including about 200-quartz lode, of which 50 are in activity. The new reality imposes to the Tapajos auriferous province a new profile and the production is mostly from veins and quartz lodes that corresponds to 60 per cent of the Tapajos gold production.

5. TAPAJOS GOLD PRODUCTION

The Tapajos official gold production (table 2), between 1991 and 2000, represented 36 per cent of the Para gold production, three times more than the Cumaru-Redeção-Tucumã Region and ten times more than any other Para gold production area. It is very important that Para gold performance influenced by Igarape Bahia gold mine in the Carajas mineral province (Companhia Vale do Rio Doce) which produces around 10 tons per year.

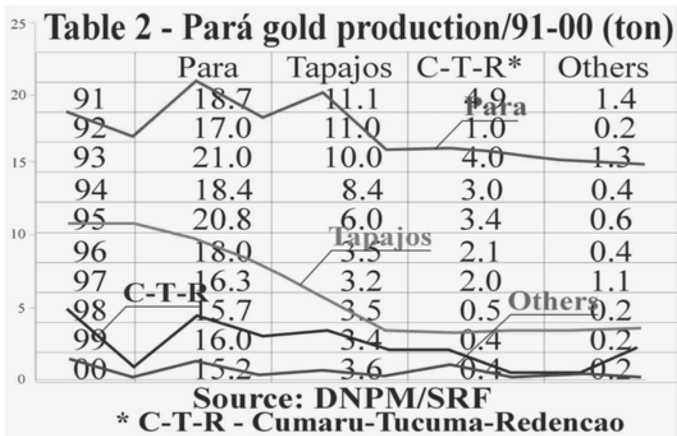


Table 2 - Pará gold production/91-00 (ton)

	Para	Tapajos	C-T-R*	Others
91	18.7	11.1	4.9	1.4
92	17.0	11.0	1.0	0.2
93	21.0	10.0	4.0	1.3
94	18.4	8.4	3.0	0.4
95	20.8	6.0	3.4	0.6
96	18.0	3.5	2.1	0.4
97	16.3	3.2	2.0	1.1
98	15.7	3.5	0.5	0.2
99	16.0	3.4	0.4	0.2
00	15.2	3.6	0.4	0.2

Source: DNPM/SRF

* C-T-R - Cumaru-Tucuma-Redencao

6. ENVIRONMENTAL IMPACTS

In the last fifty years, the environmental impacts in the Amazon Region mineral industry projects were divided in three phases:

- No environmental impact conscience – the best example is the Icomi project in the Serra do Navio, in the Amapa State. It was responsible for a big environmental impact, including topography alteration, aggression to the forest and a considerable tailing dam volume.

- Minimum environmental impacts conscience – the best example is Mineracao Rio do Norte project, in the Trombetas Region that polluted the Batata Lake and invested US$ 80 million to recover it and change the bauxite mine exploitation.
- Maximum environmental impacts conscience – this is the current phase and the best example is Carajas (iron, manganese and gold) project.

However, the garimpeira activity, mainly because of its semi-artisanal exploration, has caused serious damages to the environment, some almost irreparable, for instance: the antrophic activity, physical chemistry and biological degradation, reflecting in drainages.

- Antrophic activity – the garimpagem does not differ from the other mining activities regarding to the forest degradation. The deforestations are limited to the garimpos sites, reaching the ciliary's forests (vegetation along drainages) and the areas where they build their villages or currutelas (communities population nuclei). When the access is difficult, it is necessary to construct airstrips, the main logistic support to the garimpeiros (personal goods and equipments movement). In fact, there are not many garimpeiras areas with agricultural activities and cattle, this last one has caused intensive antrophic degradation though.

The currutelas were formed without any previous planning causing the population increase and a chaotic dispersion. Therefore, sanitation and public health is not usually a concern to these communities and it reflects in forest alteration.

- Physical degradation – the garimpos gold exploitation occurs inside or next to the drainages causing great environmental impacts to the water, and reflections in the alteration of the drainages, provided by overburden removal in the unconsolidated deposits (alluvium, elluvium and colluvium) and levels mineralized recovered. The physical degradation occurs in any exploitation mining, manual or semi-mechanized ("chupadeiras", dredges or rafts) provoking a considerable solid effluents in the river and resulting in a great visual environmental impact observed hundreds of kilometers downstream.

The environmental impacts in the drainage alters the waters coloration, reducing visibility and expelling life from their natural habitats and, it imposes the elimination and removal of the original phlore and phaune in the ecosystems.

The physical impact effects are well characterized in the drainages worked by garimpeiros. They cause the appearance of small lakes dammed by the gold recovered in the garimpeiros propriety, that are truly endemic focuses.

Another environmental impact, even more reduced, but equally serious, is trash left by garimpeiros in the area, such as recipients and food packages (canned and plastic, mainly). They are thrown near home and carried for the drainages or dammed in depressions.

- **Mercury**

- Chemical degradation – considering that the drainage receives all the impacts, the chemical degradation includes gold exploitation phases from the removed overburden to the gold recovered.

In the garimpos area, the petroleum derivates are the most important for gold exploitation. Nowadays, gold exploitation is mechanized and the diesel and oil lost is not controlled.

The mineralized column, mainly in the overburden, has abundance in fine sediments (clay predominance) and in the pre-concentration in “cobra-fumando” (sluice for recover the gold) of which the fine fraction is a barrier for the gold recovery, because it creates a superficial tension in the water. Since then, the garimpeiros add excessive detergents and break this tension, contributing again to the chemical aggression in the ecosystem

The metallic mercury or Hg (chemical symbol) is a silver liquid metal whose density is 13,5 times more than the water. It is also highly volatile, has cumulative character, forms amalgam with the gold and is used, frequently, in the gold recovery in the Amazon and Tapajos Region garimpagem area. From the mercury used in the gold recovered, a small part form the amalgam (mercury and gold league) and the other one goes to the main drainage. The incorporate fraction in the drains is divided in two segments: one is buried in the metallic form, and the other one goes to the hydrographic basin in the metallic form. When the mercury is transformed from metallic to inorganic and to the organic form using reaction with bacteria in the limnologhicus habitats, it can cause great damages for all ecosystems, including the human life.

There is no trade between mercury amalgam and the gold so it is necessary to separate the mercury before the commercialization. In most of the garimpos area, this separation is made improperly and causes the mercurial vapor release that is extremely harmful for the environment, polluting the area and contaminating the garimpeiros.

- Biological degradation – the most affected is the human being, mainly in the garimpos area. The mercury reaches the throphic chain and becomes very dangerous to the ecosystem, mainly if there is the transformation to organic mercury, which is the most toxical derivative.

The organic mercury contaminates the algae, then the fish that eats these algae will be contaminated and, subsequently, the human being that will eat this fish. Mostly, the victims are riverside habitants whose fish from the river is their main food. This is mercurial contamination through trophyc chain.

Another kind of mercurial contamination is the vapor of the amalgam burn. The average absorption of the human body is 70 per cent of this vapor. In some cases, it can reach until 100 per cent. The mercury vapor is the most common mercurial contamination in the garimpos area.

Other biological degradation comes from the antrophic activity, because of the absence of sanitation and public health in the garimpos area. The biological degradation reflects in and out of the garimpos area, for example, through the destruction of ecological niches and biomass loss as economical resource.

The alteration of original habitats, mainly the phaune and phlore in the aquatic habitat, as well as the biota contamination are considered the main negative aspect for artisanal gold exploitation.

The Pan-American Organization of the Health web site shows the main use of the mercury, such as: grains, seeds, several cultures, ink, leather, naval shipyards, batteries, photographic cameras and industrial parks, including the use in dental amalgam. The mining presents a small portion, around 1 per cent, in which it is not contemplated the garimpos gold consumption. Therefore, the mercury is out of the official statistics.

Nowadays, the mercurial contamination can be also caused by soil erosion, forests burn and lakes formed by hydroelectric. Moreover, it is observed the decline of garimpos gold production and the mercury release in the ecosystem. According to current researches, the environmental and human health is important; however the first priority should be the communities education for accomplishing it.

To solve the mercurial contamination in the gold garimpos area, it is necessary clean technology, based on environmental and human health aspects. The first consists in looking for healthy and sustainable technologies, with technical alternatives and regularization garimpagem sites by DNPM and Sectam. The second involves the environmental education through appropriate campaigns according to the reality of the garimpos area, in order to change the current garimpeira culture. The result would be creating a sustainable standard to the gold garimpos.

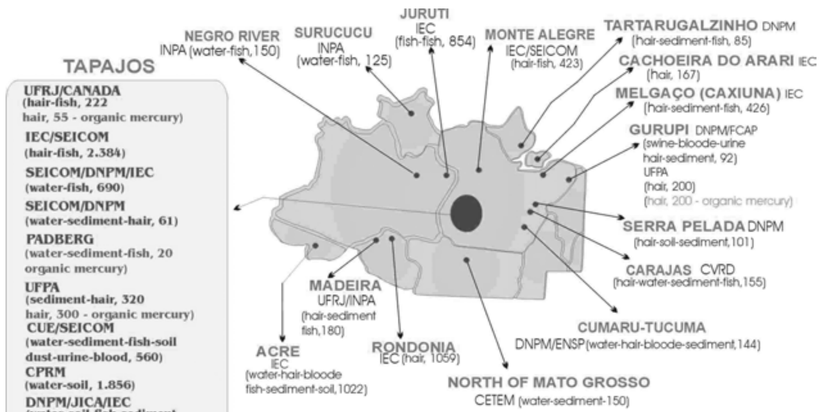
In regards to the human health, case studies, involving risks groups, are important as well. For instance, there is the one made by Tropical Medicine Center with clinical and therapeutic studies.

If both – clean technology and human health – are taken in consideration in the gold garimpos area, there will be an appropriate and modern gold garimpos exploration benefiting the regional communities.

If the Tapajos Region mercurial contamination is compared to the Minamata contamination in Japan, there are big differences between them. In the first one, the environment is tropical, the area is infinitely larger, the mercury used in the gold garimpos area is metallic form, the residence of the mercury in the air is unknown in the tropical atmosphere as well as the regional background in the gold garimpos area.

In addition, while the Tapajos Region has only 43 years of gold garimpagem activity, the Minamata contamination has 68 years (1907

– 1975) which affected the time needed for mercury methilation. In fact, maybe it is unlikely to have the Minamata disease in the Tapajos Region.



Map 4 - MERCURY IN THE AMAZON REGION
Database: december/2000

7. SAMPLES

In the Amazon Region, there are 11,284 samples of mercury (table 3 and 4, and map 4), almost all already analyzed. Most of those samples come from the Tapajos Region (53 per cent) with some exceptions such as those from Monte Alegre and Juruti Municipalities, a small part from Tapajos Region collected for regional background and samples from Acre State. According to the researches, 575 samples were analyzed for organic mercury, and the Tapajos Region represents 375 (table 4).

Table 3 – Total mercury samples

Place	Sample	Total Samples
Tapajós-Pará	Hair, water, blood, sediment, sool, dust, urine, plant, vapour	5,951
Rio Negro-Amazonas	Water-fish	150
Surucucu-Roraima	Water-fish	125
Juruti-Para	Fish	300
Monte Alegre-Pará	Hair, fish	423
Tartarugalzinho-Amapá	Hair, sediment, fish	85
Gurupi-Pará	Swin, blood, urine, hair, sediment	292
Serra Pelada-Pará	Hair, soil, sediment	101
Carajás-Pará	Hair, water, sediment, fish	155
Cumaru/Tucuma-Pará	Water, hair, blood, sediment	144
Norte do Mato Grosso-Mato Grosso	Water, sediment	150
Rondônia	Hair	1,059
Rio Madeira – Rondônia	Water, sediment, fish	180
Acre	Water, hair, blood, sediment, soil	1,022
Melgaço (Caxiuana) – Pará	Hair, sediment, fish	426
Cachoeira do Arari-Pará	Fish	167
TOTAL		**11,284**

Source: DNPM/IEC/CPRM/ESICOM/CETEM/NMT-UFBa/INPA/ PADBERG/SOL 3/GEDEBAM

Table 4 – Organic mercury samples

Place	Sample	Total Sample
Tapajós – Pará	Hair	355
Tapajós – Pará	Water, sediment, fish	20
Gurupi – Pará	Hair	200
TOTAL		575

Source: DNPM/SEICOM/CETEM/NMT-UFPa/Quebe's University/ PADBERG/SOL 3/GEDEBAM

8. BIBLIOGRAPHY

Cetem. Estudo dos Impactos Ambientais decorrentes do Extrativismo Mineral e Poluição Mercurial no Tapajós – pre-diagnosis . Mineral Technology Serie. Rio de Janeiro-RJ. Cetem/Seicom, 1994.

Nunes, Hildegardo de Figueiredo. O Estado do Pará e a Democratização do Subsolo. Delta Gráfica e Editora. Belém-Pa, 2000.

Para State Government. Mulheres do Ouro – o trabalho feminino nos garimpos do Tapajós. Belém-PA, Seicom, 1994

Para State Government. Estrutura Fundiária e a Ocupação do Solo e Subsolo – caracterização geral do município de Itaituba . Belém-PA, Seicom, 1994

Para State Government. Cantinas Garimpeiras – um estudo das relações sociais nos garimpos de ouro do Tapajós. Belém-PA, Seicom, 1994

Para State Government. Trabalhadores Rurais e Garimpeiros do Vale do Tapajós. Belém, Seicom-PA, 1994

Para State Government. Unidade Básica de Produção do Garimpo – a equipe. Belém-PA, Seicom, 1996.

Para State Government. Monitoramento de Águas e Peixes na Bacia do Tapajós. Belém-PA, Seicom, 1996.

Ramos, Carlos Romano & Silva, Alberto Rogério Bendito da. Uma visão da Macroeconomia Paraense: perspectiva da economia mineral. Development Para Magazine. Belém-PA,Idesp, 1990.

Silva, Alberto Rogerio Bendito da Evolução e Tendência da Atividade Garimpeira de Ouro. Lecture presented on Gold Garimpos Seminar: evolution and tendencies. Cuiabá-MT, 1994.

Silva, Alberto Rogério Bendito da. Carajas como fator de Desenvolvimento Regional. Para business – Para Trade Association. Belém-PA, 2000.

Hg GEOCHEMICAL DYNAMICS AS A REFERENCE FOR ENVIRONMENTAL CONTROL IN GOLD MINING SITES

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ABSTRACT

This paper proposes a geochemical assessment methodology applied to the receiving environment under a historical perspective which takes into account sources and fate of mercury. It is thought to constitute a valuable tool in choosing alternatives for site rehabilitation and hazards prevention, since it reconstructs the Hg geochemical dinamics on the mine site before and after mining operations.

The elemental mercury used for amalgamating the gold particles, which is the final stage of the mineral processing, has caused abnormal Hg concentrations in waterways. This occurs principally in the amazon region, where the gold occurrences are mostly associated with alluvial deposits. The close association of these deposits with drainage waters means that the mercury lost during open-circuit amalgamation process reachs the waterways becoming prone to interactions with water and biota.

INTRODUCTION

The increasing societal demand for actions and strategies towards sustainability of small-scale gold mining in developing countries has led experts to face the challenge of managing the harzards associated with mercury pollution from active and abandoned mine sites. Mercury pollution in drainage systems and its health effects are the most frequent subjects on environmental researchs dealing with small-scale gold mining worldwide. Also, filling of river beds with mineral matter originated from runoff of abandoned mining waste piles and tailings generally causes both silting of waterways and elevation of Hg concentrations in the environment.

For a better understanding of current environmental changes, namely those caused by mining operations, it is required to investigate the existing geochemical patterns prior to the establishment of a mining activity. The environmental history of a drainage system is commonly achieved via analyses of sediment cores taken in low-energy deposits, such as overbank and lake sediments.

The use of common geochemical and mineralogical records as indicators of Hg pollution might introduce, however, some uncertainties with regard to the partitioning of anthropogenic and lithogenic Hg, once lithogenic Hg concentrations in sediments may range from 0.05 to 0.30 µg/g according to the mineralogy found within catchment soils (Rodrigues-Filho and Müller, 1999).

Based on observations from temperate regions, several authors pointed out that definitive evidence for soil erosion may be difficult to obtain from sediment chemistry because changes in soil mineralogy are too subtle to detect (Engstron and Wright Jr., 1984; Chesworth, 1972). However, this seems not to be the case in tropical regions, where chemical weathering causes marked mineral transformations and the relative accumulation of less mobile metals in surface horizons under neutral or oxidizing conditions, such as Al, Ti, Fe, Mn, Be, Ti, Cr and Ni. Thus, geochemical contrasts among soil horizons favor the reconnaissance of source imprints in sediments (Wasserman, Silva-Filho and Villas Bôas, 1998).

Mineralogy of tropical soils also helps a great deal in identifying sediment provenance, since contrasting accumulation of quartz and secondary minerals within weathering profiles is a well documented fact (Lucas et al., 1993; Kopp, 1986; Irion, 1984; Curi and Franzmeier, 1984). Goethite and gibbsite generally occur in the uppermost soil horizon as a result of hydration of hematite and leaching of silica from kaolinite, respectively (Nahon, 1986).

SOURCES OF Hg IN THE BRAZILIAN AMAZON

Estimates of total gold production from small-scale gold mining (*garimpos*) in the Amazon account 60-70 t/a from 1980 to 1990, while almost 50% of that were due to the production from the Tapajós region, state of Pará (SEICOM, 1992). During the 90's, garimpo gold fields experienced a decline period mainly due to lowering of the ratio gold price/production cost.

A ratio produced-Au/released-Hg of 1.4 has been calculated for the gold fields in Alta Floresta, state of Mato Grosso, where processing technology usually consists of concentration through sluice and amalgamation as a separate process (CETEM, 1992). This Au/Hg ratio, however, is much higher in those sites where concentration and amalgamation are carried out together using copper plates into the sluice. This practice has been reported in many garimpos of the Tapajós region (SEICOM, 1992). Thus, a reasonable estimate of the Hg load released to the Brazilian Amazon due to gold mining for the last 20 years accounts more than 1000 tonnes.

Another source of Hg in the Amazon is the atmospheric Hg released from deforestation, evapo-transpiration of leaves, vegetation decay and global volcanic activity. Among these sources deforestation is likely to contribute with a significant load, which has been estimated from the biomass distribution in the Amazon as 710 tonnes for the last 20 years (Veiga et al., 1994).

The following three major Hg sources are pointed out for the Brazilian Amazon, while four different types of gold fields are classified according to the technology employed, proximity to waterways and awareness of miners, which are indicative of distinct polluting potentials (Table 1) :

1. Small-Scale Gold Mining (g*arimpos de ouro*)
   - Gold fields of active alluvial deposits – explored by rafts (*garimpo de balsa*) ;
   - Gold fields of inactive alluvial deposits – explored by hydraulic jet (*garimpo de baixão*);
   - Gold fields of lateritic deposits – explored through open pit (*garimpo de sequeiro*);
   - Gold fields of primary deposits – explored through open pit or shaft *(garimpo de filão*);
2. Deforestation and vegetation decay;
3. Naturally Hg-enriched soils through long-term atmosferic precipitation.

Table 1 – Polluting potential of different gold fields in the Brazilian Amazon

Type of Gold Field	Hg-containing waste	Atmosferic emission	Silting of drainage	Nomadic character
Raft - alluvial	High	High	High	High
Hydraulic jet - alluvial	High	High	High	High
Lateritic Au	Moderate	Moderate	Moderate	Low
Primary Au	Moderate	Moderate	Low	Low

Naturally Hg-enriched soils are simultaneously source of Hg to drainage systems and fate of long-term atmospheric Hg precipitation. A previous study assessing mercury pollution in two gold mining regions of the Brazilian Amazon has shown that Fe-rich soils and sediments play a major role in retaining/transporting Hg (Rodrigues-Filho and Maddock, 1997). There, a possible association between Hg and Al hydroxide was not taken into consideration.

Similarly, Roulet et al. (1996) have observed a marked accumulation of Hg in surface horizons of different Amazonian soils, averaging 0.20 µg/g. The authors pointed out that these Hg levels are one order of magnitude higher than those reported for temperate soils. Furthermore, Hg accumulation appeared to be entirely controlled by Fe and Al hydroxides. The closely associated contents of Fe and Al oxyhydroxides did not allow the authors to evaluate whether Hg is enriched on Fe or Al oxyhydroxides, or both.

A study on Hg dynamics from soils and lake sediments was carried in Lake Silvana, state of Minas Gerais (Rodrigues-Filho and Müller, 1999). There, a widespread Hg accumulation in surface horizons of lateritic soils is likely to be mainly controlled by adsorption onto gibbsite (Al $(OH)_3$). Hg concentrations in B horizons reach up to 0.28 µg/g and represent an increase to values 10 times higher than those observed in the lowermost horizons. Hg in surface soils is likely to be adsorbed onto gibbsite, since a positive correlation (r = 0.83) exists between Hg and *aqua-regia* soluble Al within soil profiles (Fig. 1).

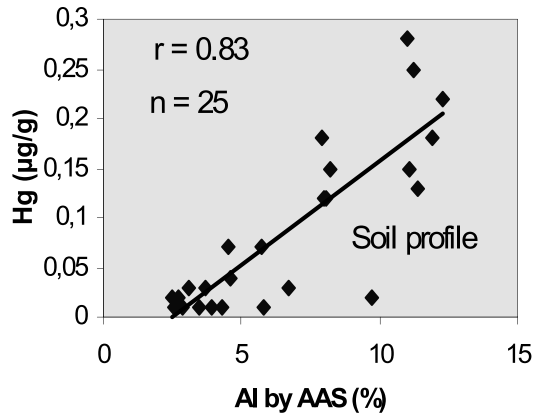

Figure 1. Correlation between Hg and *aqua-regia* soluble Al in soil profiles – Lake Silvana catchment.

It is noteworthy that a presumable Hg immobility during weathering, as indicated by its accumulation in surface soil horizons, is not in accordance with its ionic potential which points to its high mobility. Metalic Hg (Hg^0) seems to be easily oxidized to inorganic salts, notably halides and sulfates, as a result of natural leaching or weathering cycles (Jonasson and Boyle, 1979). Based on data from Canadian soils, these authors have demonstrated that Hg concentrations tend to be enriched in surficial humic soils, presumably due to vegetation decay, but with enrichment factors relative to the saprolite not greater than 2. There, concentrations in the B horizon exhibit no enrichment relative to the saprolite horizon.

As tropical ferralitic soils are thought to be as old as ~ 5 Ma. (Nahon, 1986; McFarlane, 1983), the long-term deposition of atmospheric Hg in soils rich in Fe and Al hydroxides is likely to explain the widespread Hg accumulation in surficial ferralitic soils rather than a weathering-driven accumulation process from the parent rock. Therefore, most of the Hg found in surficial tropical soils is likely to be derived from natural rather than anthropogenic sources, as sediments with elevated Hg concentrations have been deposited in Lake Silvana since 9000 yr ago, according to radiocarbon age determinations (Fig. 2) (Rodrigues-Filho and Müller, 1999).

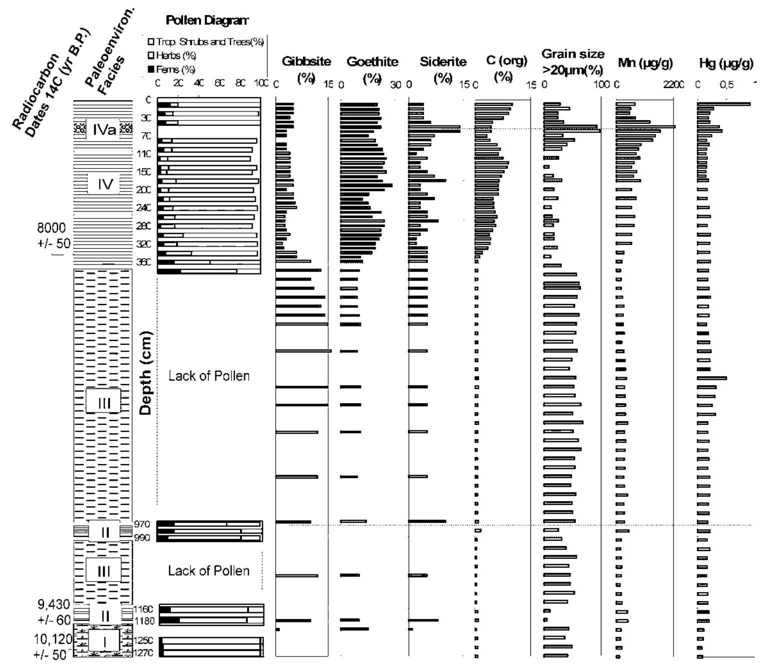

Figure 2. Sumary diagram of sedimentary data - pollen, mineral and metal - Lake Silvana

FATE OF HG IN TWO GOLD MINING AREAS OF THE BRAZILIAN AMAZON

The municipality of Pocone is located at the northern edge of the Pantanal wetland, state of Mato Grosso, an important ecological unit for conservation, where savannah-like vegetation covers yellow-red latosols. Most of the gold occurs as nuggets associated with lateritic soils.

The municipality of Alta Floresta is located at the northern part of the state of Mato Grosso, where the terrains are covered by typical Amazon rain forest. Most of the gold occurrences are associated with alluvial deposits, although more recently primary Au occurrences have been prospected. Also in the region of the Tapajos river, prospection of primary Au occurrences has been observed.

Sampling campaign was designed to cover areas where different variables could affect Hg concentration in sediments and soils – namely rocky substrate, characteristics of drainage waters, vegetation, pedological horizons (soils) and proximity to the gold fields (Rodrigues-Filho and Maddock, 1997). "Geoaccumulation indexes" (Igeo) of Hg in sediments were used to assess pollution levels in the aquatic environment (Müller, 1979). The "Igeo" is defined as follows:

$$\mathbf{Igeo = log_2.C_n/1.5.B_n}$$

where, C_n is the measured Hg concentration in the fraction < 2 µm (clay), and B_n is the background value of Hg found in sub-recent clayey sediments.

Hence the "Igeo" in class 0 indicates absence of contamination, and the "Igeo" in class 6 represents the upper limit of maximum contamination. The Igeo can also be applied to the grain size fraction < 74 µm used in this study provided there is definition of background values in this fraction.

An average Hg concentration of 0.10 µg/g was found based on stations with no impacts of gold mining. This Hg background in the < 74 µm fraction of fluviatile sediments was higher than that in lacustrine sediments in remote areas of the Pantanal wetlands, with 0.02 µg/g (Lacerda et al., 1991). This lower value in lacustrine sediments is probably due to the distance from the lithogenic sources of Hg and to the extremely low sediment transportation energy of the waters throughout the Pantanal lowlands.

The Bento Gomes River is the depository of sediments transported by tributary drainage waters and was the main focus of study in the Pocone area.. At the sampling point where the river forms a large lake, high concentrations of Hg (class 3) and other trace metals were observed in sediments, denoting this lake as a sink for metals. Downstream of the lake, Hg concentrations in sediments were considerably reduced and come close to background levels.

In the Alta Floresta region, the close association of alluvial Au deposits with the waterways has caused higher Hg concentrations in sediments than those observed in the Pocone region. There was a clear predominance of Hg associated with the grain size fraction < 74 µm downstream of the main Hg sources in the Teles Pires River. Near the main sources there was a predominance of Hg in coarser grain size fractions > 74 µm, indicating that the Hg is found principally in the elemental form and is not prone to interactive processes with sediment particles. Nevertheless, Hg concentrations detected in sediments of the Tele Pires River close to the *garimpos* were the highest of the area studied, reaching an Igeo class 5 or "highly polluted".

Sampling at Alta Floresta was also meant to assess the dispersion of Hg released during amalgam burning by the gold-buying shops in the urban area. A total of 130 surface soil samples were collected from a regular sampling grid of approximately 100 x 300 m, covering an area of about 3.4 km^2.

Mercury concentrations in the surface soils were clearly predominated by abnormal values related to Hg emission from gold-buying shops. Superficial contamination of the soils occurs primarily in the vicinity of the sources which indicates that some of the vaporized Hg is quickly deposited. High anomalies (> 1.0 µg/g) were observed at up to 600 m distant from the sources while less pronounced anomalies (0.2 – 0.3 µg/g) were found up to 1000 m away. Dispersion of Hg in the soils follows two directions: east and southwest. These directions coincide with those for winds in the rainy season and confirms that rain is principaly responsible for the short-term deposition of vaporized Hg.

One sediment core was also taken in a lake located in the vicinity of Alta Floresta, which formed after the construction of a road in 1978. The sediment core was composed of red clayey sediments and organic matter in the first 10 cm, and a white gley between 10 and 40 cm. Mercury concentrations show background values of 50 to 70 µg/g in the lowest 30 cm section and a significant increase in the first 10 cm, reaching up to 210 µg/g. It has been assumed that the marked change of the sediment composition at 10 cm of depth was caused by the formation of the lake itself in 1978. Hence, the Hg flux into the lake was calculated by subtracting the obtained background concentration from the measured concentration for each core section, according to the following expression (Cundy and Croudace, 1995):

$$\mathbf{f(Hg) = þ.\,(C_{\mathit{i}} - C_{\mathit{0}}).\,s.\,10^4}$$

where,

f(Hg) = Hg flux ($\mu g.m^{-2}.yr^{-1}$)

þ = sediment density ($g.cm^{-3}$)

C_i = Hg concentration at a *i* depth ($\mu g.kg^{-1}$)

C_0 = background concentration($\mu g.kg^{-1}$)

s = sedimentation rate ($cm.yr^{-1}$)

The distribution of Hg flux into this lacustrine environment from 1976 to 1996 has been calculated and compared with the gold production from the Alta Floresta region, whose data have been reported by Hacon (1996). Both gold production and Hg flux are positively correlated, indicating that amalgam burning contributes to increase Hg concentrations in lacustrine sediments (Fig. 3). This indication constitutes a major environmental concern, since lakes play an important role in the biogeochemical cycle of Hg. Rather than sinks, lakes are like reactors capable of changing inorganic Hg into ready bioavailable organic chemical forms.

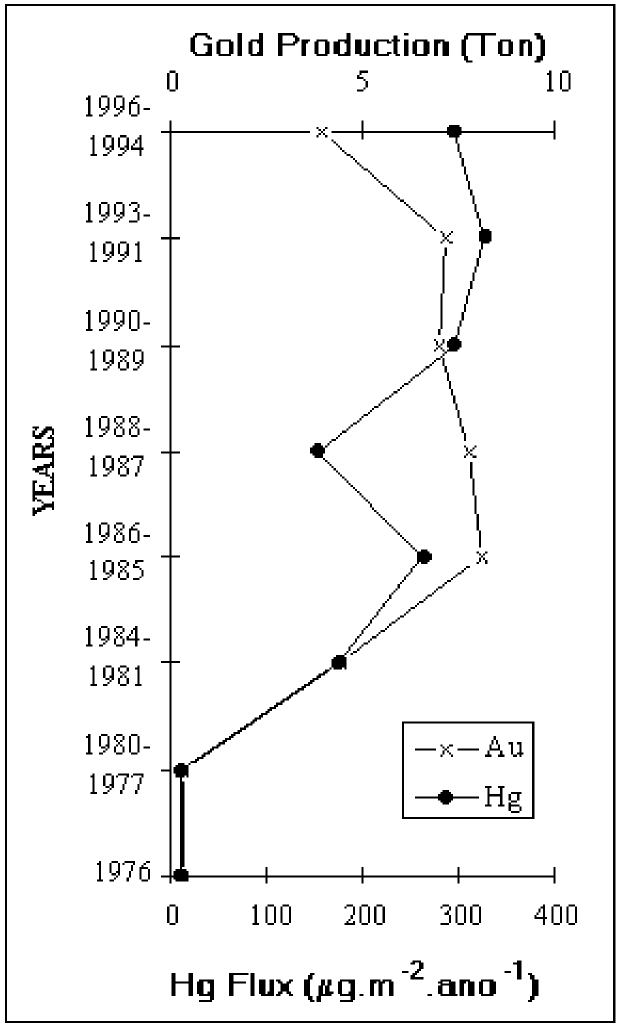

Figure 3. Gold production from Alta Floresta and mercury flux into the lake studied.

RECOMENDATIONS FOR DESIGNING A WORKING PLAN TOWARDS ENVIRONMENTAL CONTROL IN GOLD MINING SITES

1. Mercury geochemical dynamics:

- Assessment of local Hg sources and their effects upon the aquatic environment;
- Risk analysis using fishes as bioindicators;
- Indication of hot spots of Hg pollution in waterways and tracing of Hg pathways through the food chain to human populations.

2. Mineral processing:

- Development of new technologies and adaptation of existing ones towards prevention and abatement of Hg pollution derived from small-scale gold mining;
- *In situ* demonstration to local miners and stakeholders of the economic and environmental benefits derived from the technological improvements.

REFERENCES

CETEM (1992). Preliminary diagnosis of the environmental impacts caused by gold prospecting in Alta Floresta(MT). Farid, L.H. (ed). Centro de Tecnologia Mineral, Rio de Janeiro. 185 pp.

Chesworth, W. (1992). Weathering systems. *In*: Martini, I.P. and W. Chesworth (eds), Weathering, Soils and Paleosols. Elsevier, Amsterdan. Developments in Earth Surface Processes, vol. 2, pp. 19-40.

Cundy, A.B. and Croudace, I.W. (1995). Sedimentary and geochemical variations in a salt marsh: mud flat environment from the mesotidal Hamble estuary, southern England. *Marine Chemistry*, 51: 115:132.

Curi, N. and Franzmeier, D.P. (1984). Toposequence of oxisols from the Central Plateau of Brazil. *Soil Science Society of America Journal*, 48: 341-346.

Engstrom DR and Wright Jr. HE. Chemical stratigraphy of lake sediments as a record of environmental change. In: Haworth EY, Lund JWG, editors. Lake Sediments and Environmental History. University of Minnesota Press, 1984, pp. 11-67.

Hacon, S. (1996). Exposição ao mercúrio da população de Alta Floresta, Mato Grosso. PhD thesis, Universidade federal Fluminense, Niterói-RJ, 134 pp.

Irion, G. (1984). Sedimentation and sediments of Amazonian rivers and evolution of the Amazonian landscape since Pleistocene times. *In*: Sioli, H. (ed.), The Amazon: Limnology and Landscape Ecology of a Mighty Tropical River and its Basin. Dr. W. Junk Publishers, Dordrecht, pp. 537-579.

Kopp, D. (1986). Mineralogische, geochemische und geophysikalische Untersuchungen von Verwitterungsprofilen in Minas Gerais, Brasilien. Ph.D. Dissertation, Universität Freiburg, 213 pp.

Lacerda, L.D.; Salomons, W.; Pfeiffer, W.C. & Bastos, W.R. (1991). Mercury distribution in sediment profiles of remote high Pantanal lakes, Central Brazil. *Biogeochemistry*, 14: 72-79.

Lucas, Y., Luizão, A., Chauvel, A., Rouiller, J. and Nahon, D. (1993). The relation between biological activity of the rain forest and mineral composition of soils. *Science*, 260: 521-523.

Nahon, D.B. (1986) Evolution of iron crusts in tropical landscapes. In: Colman SM, Dethier DP, editors. Rates of Chemical Weathering of Rocks and Minerals. Academic Press, London, pp. 169-191.

Rodrigues-Filho, S. and Maddock, J.E.L. (1997). Mercury pollution in two gold mining areas of the Brazilian Amazon. *Journal of Geochemical Exploration*, 58: 231-240.

Rodrigues-Filho, S. and Müller, G. (1999). A Holocene Sedimentary Record from Lake Silvana, SE Brazil: Evidence for Paleoclimatic Changes from Mineral, Trace-Metal and Pollen Data. Lecture Notes in Earth Sciences, Vol. 88. Springer-Verlag. Heidelberg, New York, Tokyo. 96 pp.

Wasserman, J., Silva-Filho, E.V. and Villas Bôas, R.C. (1998). Environmental Geochemistry in the Tropics. Lecture Notes in Earth Sciences, Vol.72. Springer-Verlag, Heidelberg, New York, Tokyo. 305 pp.

INTERACTIONS AT THE SOLID-LIQUID INTERFACE AFFECTING THE MERCURY GEOCHEMICAL CYCLE

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ABSTRACT

The indiscriminate and unsustainable use of elemental mercury in garimpos has contributed for the dispersion of Hg through out the environment. Once released to the environment, complex chemical reactions at the inorganic and organic levels, might lead to the formation of methyl-mercury, the most toxic form of the metal, which is a high threat to humans. Speciation and complex formation are key processes in the reactivity and transport of Hg in surface, interstitial and ground waters. In this regard, parameters such as pH, Eh, concentration of inorganic ligands such as chloride and sulfide, as well as concentration of organic acids play an important role. The effect of organic acids in Hg chemistry is of particular interest due to its presence in dark river waters of tropical forests, where most of the garimpo activity take place. This paper highlights some physico-chemical reactions that affect the fate and cycling of Hg

INTRODUCTION

The unsustainable use of elemental mercury (Hg^o) for gold amalgamation, carried out by informal gold miners (garimpeiros), has contributed to the dispersion of mercury through out the environment. Once discharged to the atmospheric, aquatic and terrestrial compartments, Hg^o may undergo a series of transformations to methyl-mercury (CH_3Hg), the most toxic form of the metal, which is incorporated in living organisms and accumulates in the food chain. Methyl-mercury causes irreversible damage to the central nervous system of man [Cleary et al., 1994; Wood et al., 1978].

The complexity of mercury chemistry and biochemistry is related to its various possible species with different physico-chemical properties. In this respect, the speciation of mercury depends on biotic and abiotic processes which are linked to the types of organisms and concentration of ligands in a particular system. Mercury interactions in the environment that affect its chemical behavior and bio-availability, include sorption at mineral surfaces and formation of complexes with organic materials.

With respect to interactions at the solid-liquid interface, it has been considered that, mercury dissolved in surface water, interstitial water and ground water, as well as adsorbed at the water soluble and exchangeable phases of minerals, are more mobile and more bio-available, while mercury adsorbed on Fe and Al oxides and at the residual phases are less mobile and less bio-available [Gambrel et al., 1980]. Thus, mercury speciation and the physical-chemistry of the system play important roles in its transport, fate and bio-availability.

Organic acids are important components of dark river waters in the tropics. Although the role of organic acids in mercury bio-availability is not very clear, it has been shown that the solubility of elemental mercury is enhanced in the presence of humic acid through a solubilization-complexation mechanism, and that the organo-mercury complex formed is relatively more mobile [Melamed et al., 1997].

This paper describes the importance of physico-chemical interactions in soils and natural water systems in the geochemical cycling of Hg.

UTILIZATION, DISCHARGE AND FATE OF MERCURY

Elemental mercury has been extensively used in rain forest areas, including the Brazilian garimpos. Calculations indicate that, in 1989, at least 160 tones of Hg^0 were used in Brazil only. The efficiency of Hg^0 to recover gold (Au) is related to the greate affinity of these two metals to amalgamate, forming complexes such as: $AuHg_2$, Au_2Hg and Au_3Hg.

Elemental mercury is sometimes introduced during the ore processing phase, or later, at the amalgamation step. In garimpos where gold occurs in alluvial deposits, Hg^o is introduced in sluice boxes, mounted on dredging barges or at the river borders. In this case, the fate of Hg^o is the water column and the river sediments. In garimpos, in which the gold is relatively free, occurring in quartz veins,

Hg^0 accumulates, at the end of the ore processing, in the tailings that are disposed at the soil surface, susceptible to leaching, erosion and volatilization or degassing.

In general, the processing phase is carried out in open circuit, without the use of an amalgamation drum for instance, and without any care to separate the tailings from the hydro-system. Approximately 20-25% of the mercury emitted to the environment comes from the amalgamation tailings.

At the last stage of gold recovery, the burning of the Au-Hg amalgam, usually in open circuit, without the use of retorts, promotes the emission of the Hg^o vapor to the atmosphere of approximately 75-80% of the total mercury input [Lacerda and Salomons, 1992]. The "bullion" (a porous mass of gold), taken by the garimpeiros to the dealer shops downtown, still contains 5% of Hg^o which are also transferred to the atmosphere due to an additional burning in open circuit. Elemental mercury has substantial vapor pressure ($2{,}46 \times 10^{-1}$ Pa at 25 ^oC) and Henry's constant (0,32 at 25 ^oC) which explain its high volatility [Iverfeldt and Lindqvist, 1986]. The relatively high first ionization potential of Hg^o (241 kcal mol^{-1}) justifies its presence in the atmosphere, mainly in the reduced form (Hg^0), despite the oxidizing potential of the atmospheric system.

Once in the atmosphere, the Hg^o vapor is oxidized to Hg(II) by reactions mediated by ozone (O_3), ultraviolet radiation and water vapor [Iverfeldt and Lindqvist, 1986], with formation of different forms of Hg(II) such as Hg^{2+} and Hg_2^{2+}, and $HgCl_2$.

During the raining season, Hg(II) is deposited in the aquatic environment and in soils. The Hg(II) in these compartments may be transformed, through either biotic or abiotic processes [Garvis and Ferguson, 1972; Rogers, 1977], to methyl-mercury (CH_3Hg^+). This species is considered the most harmful form of Hg, being very stable in acid pH and highly soluble in fats. Methyl-mercury can be highly incorporated by the aquatic biota and, consequently, accumulate in the food chain. At the top of the food chain, it is estimated that 90 % of incorporated mercury is in the methyl form [Huckabee et al., 1979].

Many pathways lead to Hg contamination, reflecting the complexity of Hg chemistry in the environment. Figure 1 shows the main pathways of concern of the mercury cycle and fate in soils, atmosphere and river waters. These pathways are:

- Direct input of Hg^0 into river waters
- Volatilization of Hg^0 following burning of Au-Hg amalgam
- Binding of volatilized Hg^0 to aerosol and transport
- Deposition of Hg^0 in soils and waters
- Oxidation of Hg^0 by ozone or radiation and deposition of Hg(II) in soils and waters
- Methylation of Hg(II) to methyl mercury
- Adsorption of Hg(II) to water suspended particulate matter and sedimentation
- Immobilization of Hg by anoxic layer sulfide
- Reduction of Hg(II) to Hg^0 mediated by radiation mediated by organic acids and volatilization at the water air interface.
- Solubilization of Hg^0 through organic acid induced dissolution-complexation
- Leaching and transport of Hg(II) through the soil matrix leading to groundwater contamination
- • Dimethylation of methyl mercury and volatilization at the water air interface

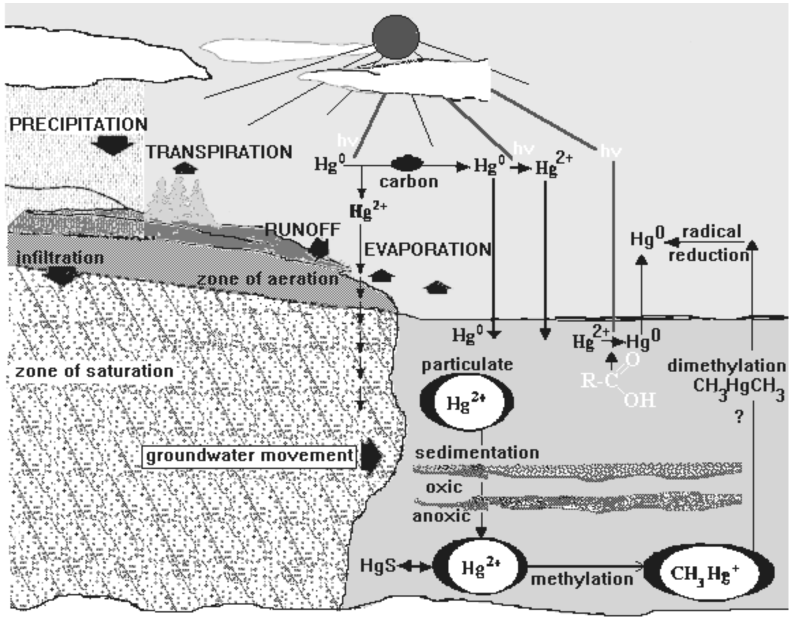


Figure 1 - Pathways of the mercury geochemical cycle

EFFECT OF PHYSICO-CHEMICAL INTERACTIONS ON Hg SOLUBILITY, ADSORPTION AND METHYLATION

The complexity of Hg chemistry in the environment is related to the fact that the metal forms many soluble ionic complexes with various degrees of stability and the possibility of many oxidation states. Depending on the redox conditions of the system, the forms Hg^0 and Hg(II) may be present. Hg(II) is the stable form at redox potentials above 0.4 V.

The system pH also play a key role in different aspects of the chemistry and physical-chemistry of Hg. Due to its strong ability to form complexes, the ion Hg^{2+} is rarely found free under natural conditions. In acid solutions, $HgCl_2^0$ is the complex that usually occurs in soils

[MacNaughton and James, 1974]. Above pH 7, the complex $Hg(OH)_2^0$ is the stable form of Hg(II). One straight forward implication of system pH on Hg speciation is that this parameter affects the transport of Hg in soils. The effect of pH on mercury adsorption indicates that the metal behaves as other metals that form hydrolyzable cations. The increase in Hg(II) adsorption in an Oxisol is relatively high for a relatively small increase in pH [Melamed and Villas Bôas, 1998], producing a sigmoidal function usually referred as *adsorption edge* [Sposito, 1984], that reflects the competition of the cationic species with H^+ for the surface site.

The phenomenon of adsorption in soils is important in the geochemical cycle because it has a direct influence in mercury mobility and bio-availability. While specific adsorption may hinder metal bio-availability, the non-specific adsorption, corresponding to the exchangeable phase allows biotic and abiotic transformations. Ramamoorthy and Rust (1976) concluded that the retardation coefficient of Hg(II) decreases in the order: level of organic matter > CEC > surface area, reflecting a character of non-specific adsorption. On the other hand, Melamed et al. (2000) showed the specific adsorption character of Hg(II) in an Oxisol, for its high affinity with Fe oxides.

In addition to the redox potential and pH, the concentration of ions such as sulfide and chloride are parameters of importance in the chemical speciation of Hg in solution.

The concentration of Cl^- ions in solution has a great impact in the mobility of Hg(II) because the Cl^- ligand forms anionic complexes. These complexes have a much lower interaction at the soil/solution interface, and thus, are relatively more mobile. Adsorption and retention of Hg(II) in an Oxisol were shown to be enhanced in a $KClO_4$ system as compared to a KCl system [Melamed and Villas Bôas, 1998]. These findings are mainly relevant in estuarine environments, where the concentration of chloride ions are relatively high.

Another important property of Hg is to form strong complexes with the sulfide ion. In reduced conditions, the ionic form of Hg is stable in the presence of H_2S and HS^-. However, at higher redox potentials, HgS precipitates, or in systems of high alkalinity, the ion HgS_2^{2-} is formed. In redox conditions normally found in surface soils, mercury is present as Hg(II). The presence of sulfide may cause a decrease in the conversion of Hg(II) to CH_3HgCl, as demonstrated with synthetic solutions of $HgCl_2$, Na_2S and methylcobalamin, a methylating agent. However, the presence of sulfide enhances the solubility of Hg^0, with the production of polysulfides in solution [Melamed and Villas Bôas, 2000].

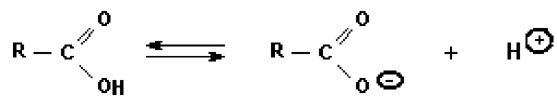
Based on stability fields of Hg [Hem, 1970], one can estimate, for values of Eh and pH found in river waters, a maximum dissolved concentration of 25 **ppb**, even in spots saturated with Hg^0. However, the presence of organic acids, dissolved in soils and river waters of the tropics, may oxidize Hg^0, enhancing its solubility above the values forecasted for inorganic systems, by means of a dissolution-complexation mechanism [Veiga, 1994; Melamed et al., 1997].

The solubility of Hg^o in humic acid increases considerably with time. Experiments demonstrated that after 30 days of reaction the concentration of dissolved total Hg is, approximately, six times higher than its concentration after 1 day.

Organic acids are composed of a mix of substances resulted from the chemical and biological degradation of plants and animals mediated by the activity of microorganisms. They are predominantly aromatic, hydrophilic, chemically complex, and having a molecular weight that varies from hundreds to millions [Stevenson, 1982]. These substances since they vary in composition do not show specific physico-chemical characteristics such as defined boiling point, refraction index or elementary composition. They may be divided into three major fractions: humic acid, fulvic acid and humine. These three fractions are structurally very similar, differing in molecular weight and quantity of functional groups [Barros et al., 1994]. Humic acid is the main humic substance that can be found in rivers, soils and sediments. One major characteristic of humic substances in general is their high capacity of interaction with metallic ions, giving rise to stable complexes. This ability is due to the high percentage of functional groups having the oxygen element in their formula, as carboxyl, phenolic hydroxyl and carbonyl groups [Jordão et al., 1993; Varshal et al., 1999].

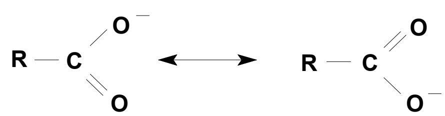
At the acidic range of the pH scale, the excess of H^+ ions competes with Hg(II) ions for active sites on the humic acid molecule. Another factor that may contribute to decrease the formation of organo-mercury is the precipitation of humic acids at low pH values [Jordão et al., 1993; Varshal et al., 1999]. As the pH rises, and the proton concentration diminishes, this competition decreases, and the formation of Hg(II) complexes with humic acid increases.

Considering the active sites present in the humic acid macromolecule, the carboxyl group is considered the most reactive, because it is able to dissociate, releasing H^+ ions into aqueous solution, as shown in the reaction:

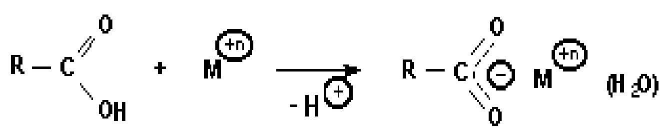


where R represents the organic chain.

The carboxylate ion, which resulted from carboxyl ionization, is stabilized by two resonant forms, identical and having the same energy, turning the equilibrium reaction to the direction of the dissociation of the acid:



The high dissociation capacity of the -COOH group increases the chances of the formation of organo-mercury complexes to occur on this site, since a higher quantity of $-COO^-$ ions are available for the formation of complexes with a metal, as compared to the other acid sites of the humic acid molecule. The formation of the organo-mercury complex at the carboxylate site can be represented as follows:



where $M^{n+} = Hg^{2+}$, $HgCl_4^{2-}$, $HgCl_3^-$

The role of organic acids in mercury bio-availability is not very clear. However, in addition of enhancing the solubility of elemental mercury, the organo-mercury complex formed is relatively more mobile, which was attributed to the size of the molecule having a much lower interaction at the solid-liquid interface [Melamed et al., 1997]. The possibility of donation of methyl groups from the organic acid chain to promote mercury methylation is uncertain.

Although the sediment compartment is the most important mercury methylation site, studies conducted by Mauro et al. (1999) demonstrated the relevance of the roots of floating aquatic macrophytes, where high production of methyl-mercury occurs. The mechanism is attributed to the suitable environment, promoted by the large macrophyte stands and high temperatures, for optimum growth of sulfate reducing bacteria, which is considered the main Hg methylators [Compeau and Bartha, 1984]. These microorganisms are usually found where redox potentials are low, although they can also be found in oxic environments [Jorgensen and Bak, 1991].

Methylation by macrophytes increases from 10 to 35 ^{o}C. At pH values of 6 and 7, methylation was stimulated and a significant decrease was verified at pH 8. Increasing $KClO_4$ concentrations led to a significant decrease of the methylation rates, while for KCl and $CaCl_2$ solutions, only a slight decrease was observed.

Mercury adsorption kinetic studies [Melamed et al., 1997] demonstrated that the rate of adsorption of Hg(II) is much faster than the rate of adsorption of methyl-mercury and that methyl-mercury has a lower affinity for mineral surfaces as compared to Hg(II). Thus, the impact caused by methylation is two fold: it produces a compound that accumulates in living organisms, and because methyl-mercury has relatively lower affinity for mineral surfaces, it enhances the mobility and the dispersion of Hg throughout the environment.

CONCLUSIONS

The processing of gold in open circuit, widely practiced by garimpeiros, has been responsible for large quantities of elemental mercury discharged to the different environmental compartments. Many pathways lead to the formation of methyl-mercury, which accumulates and bio-magnifies in the food chain.

Adsorption in soils is important in the geochemical cycle because it has a direct influence in mercury mobility and bio-availability. In this regard, various physico-chemical parameters may interfere. In the absence of chloride, specific adsorption of Hg, in soils rich in Fe oxides, occurs and as such retention increases as the system pH is increased.

The presence of sulfide hinders the methylation process, however it enhances the solubility of elemental mercury.

The presence of organic acids dissolved in soils and dark river waters increases the solubility of Hg^o, resulting in the formation of a organo-mercury complex that has a relatively lower interaction with mineral surfaces.

Mercury methylation produces a compound that accumulates in living organisms and contributes for the dispersion of Hg throughout the environment, because methyl-mercury has a lower affinity for mineral surfaces.

BIBLIOGRAPHY

Barros, M.C P., Paula J. R and Rezende M. O. 1994. In: *Química Nova*, vol. 17, p. 376.

Broekaert, J.A.C., Gücer, S. and Adams, F. eds. 1990. Metal Speciation in the Environment, NATO ASI Series, vol. G 23:339-359.

Cleary, D. et al. 1994. Mercury in Brazil. *Nature*. 369, 613-614.

Compeau, G. and Bartha, R. 1984. *Applied Environ. Microbiol*. **48** (6): 1203-1207.

Driscoll, C.T. et al. 1994. The chemistry and bioavailability of mercury in remote Adirondack lakes. In: III International Conference on Mercury as a Global Pollutant, Whistler, British Columbia, Canada, July 10-14.

Fagerström, T. and Jernelöv, A. 1971. Formation of methyl mercury from pure mercuric sulfide in aerobic organic sediment. *Water Research*, Pergamon press, v.5:121-122.

Farid, L. H. et al. 1992. Diagnóstico Preliminar dos Impactos Ambientais Gerados por Garimpos de Ouro em Alta Floresta/MT: Estudo de Caso. In: Série Tecnologia Ambiental - *CETEM*, v. 2.

Gambrel R.P., Khalid, R.A. and Patrick, W.Jr. 1980. Chemical availability of mercury, lead and zinc in mobile bay sediment suspensions as affected by pH and oxidation-reduction conditions. Environ Sci. Technology 14:431-436

Garvis, J. and Ferguson, J.F. 1972. The cycling of mercury through the environment. *Water Research*. 6, 989-1008.

Hem, J. D. 1970 *U.S.Geological Survey*, Professional Paper, n.713, Washington D.C.

Huckabee, J.W., Elwood, J.W. and Hildebrand, S.G. 1979. Accumulation of mercury in freshwater biota. In: J.O. Nriagu. (Editor), The Biogeochemistry of Mercury in the Environment, pp. 277-302. Elsevier/North Holland Biomedical Press, Amsterdam.

Iverfeldt, A. and Lindqvist, O. 1986. Atmospheric oxidation of elemental mercury by ozone in the aqueous phase. *Atm. Environ.*, 20 (8): 1567-1573.

Jordão C. P; Costa E. D; Brune W; Goulart A.T. 1993. Adsorção de Cátions Metálicos em Ácidos Húmicos de Latossolo. In: *Química Nova*, v. 16, n. 6, p. 517 - 520.

Jorgensen, B.B. and Bak, F. 1991. *Appl. Environ. Microbiol.* **57** (3): 847-856.

Lacerda, L. D. and Salomons, W. 1992. Mercúrio na Amazônia: Uma Bomba Relógio Química? In: *Série Tecnologia Ambiental*, CETEM, v. 3, 78 p.

MacNaughton, M.G. and James, R.O. 1974. Adsorption of aqueous mercury (II) complexes at the oxide/water interface. *J. Colloid Interf. Sci*. 47, 431-440.

Mauro, J.B., Guimarães J.R.D. and Melamed, R. 1999. Mercury methylation in a tropical macrophyte: Influence of abiotic parameters. *Applied Organometallic chemistry* 13:631-636

Melamed, R, Villas Bôas, R.C., Gonçalves, G.O. and Paiva, E.C. 1997. Mechanisms of Physico-Chemical Interaction of Mercury with River Sediments from a Gold Mining Region in Brazil: Relative Mobility of Mercury Species, *Journal of Geochemical Exploration*, vol. 88, p. 119-174.

Melamed, R. and Villas Bôas, R.C. 1998. Phosphate-background electrolyte interaction affecting the transport of mercury through a

Brazilian Oxisol soil. *The Science of the Total Environment*. 213: 151-156

Melamed, R. and Villas Bôas, R.C. 2000. Application of physico-chemical amendments for the counteraction of mercury pollution. *The Science of the Total Environment*. 261: 203-209.

Pfeiffer, W.C. and Lacerda, L.D. 1988. Mercury inputs into the Amazon region, Brazil. *Environm. Technol. Letters*. 9, 325-330.

Ramamoorthy, S. and Rust, B.R. 1976. Mercury sorption and desorption characteristics of some Ottawa river sediments. Can. J. Earth Sci. v. 13: 530-536

Robertson, D.E., Sklarew, D.S., Olsen, K.B., Bloom, N.S., Crecelius, E.A., Apts, C.W., 1987. Measurement of bioavailable mercury species in fresh water and sediments. Research Project 2020-3, Final Report, Batelle PNW Laboratories.

Rogers, R.D. 1977. Abiological methylation of mercury in soil. J. Environmental Quality 6(4): 463-467.

Schnitzer, M. and Kahn S.U. 1972. *Humic Substances in the Environment*, Marcel Dekker, New York.

Sposito, G. 1984. The chemistry of soils. New York. John Wiley & Son

Stevenson, F. J. 1982. *Humus Chemistry*, New York, John Wiley & Son.

Varshal G. M; Koshcheeva I. Ya; Khushvakhtova S. D; Danilova V. N; Kholin V, Tatsy Yu. G; Krigman L. V and Tyutyunnik O. A. 1999. In: V *IInternational Conference Mercury as a Global Pollutant*, May 23-28, Rio de Janeiro, Brazil, p. 345.

Veiga, M.M. and Meech, J.A. 1993. Remedial Procedures for mercury pollution from gold mining activities in the Amazon: I. A review of clean-up techniques. Randol at Acapulco "Latin American Opportunities" Acapulco, Mexico. October 25-27.

Wilken R. D and Hintelmann, H. 1990. Metal Specification in the Environment, *NATO ASI Series*, v. G23, p. 339.

Wilken, R-D. 1991. Heavy Metals Program, Analytical Support. Task Force Joint Meeting. GKSS-CETEM, 31 pp.

Wood, J.M. et al. 1978. Mechanisms for the biomethylation of metals and metalloids, *Federation Proc*. 37 16-21.

MERCURY AS AN ENVIRONMENTAL PROBLEM: HUMAN HEALTH RISK AND AQUATIC ECOSYSTEMS CONTAMINATION ASSESSMENT

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INTRODUCTION

Once released to an aquatic system, Hg may continue to cycle between sediments, water and biota for tens or even, hundreds of years before finally being flushed from the system, or permanently buried in sediments. The impact of mercury pollution, initially recognized as an acute and local problem, is now also understood to be global, diffuse, and chronic (Mahaffey, 2001). Environmental methylmercury (MeHg) arise largely, if not solely, from the methylation of inorganic mercury (Hg^{2+}). MeHg is listed by the International Program of Chemical Safety (ICPS) as one of the six most dangerous chemicals in the world's environment. The general population is primarily exposed to MeHg through fish consumption (WHO, 1990; Clarkson, 1994; US EPA, 2001).

In the Brazilian Amazon gold mining ("garimpos"), Hg is used to amalgamate fine gold particles from placer deposits. Hg loss from gold mining to local ecosystems was estimated to reach 1,300 t in the amazon, between 1980 and 1993 (Cid de Souza and Bidone, 1994). More than 50% of this Hg were used in "garimpos" locate in Tapajós river, in Pará State, mainly by garimpos of "Reserva garimpeira de ouro do Tapajós" as large as 28.000km^2. It was the most important gold mining area in Northern Brazilian Amazon in the 80's when the peak in Amazon "gold rush" occured. Nowadays, the gold production is close 6 tons/year and the gold mining population are around 6.000 people in this region. Generally, the released Hg0 by "garimpos" is incorporate into the river sediments. Amazonian environmental conditions might favor methylation processes (Lacerda and Salomons, 1998).

The common dominator to managing human exposures is control of the use and release of inorganic mercury (Mahaffey, 2001). Currently there is a lack of consensus in the literature as to the importance and magnitude of several potential sources of Hg in Amazon. It is difficult to assess the major Hg source to Amazon aquatic ecosystems, since they integrate basin sources and direct and indirect atmospheric deposition. Atmospheric deposition can affect remote sites from sources, then affecting areas far from direct emission, which can be considered background. Major sources of Hg in the Amazon include biomass burning (Veiga et al., 1994), natural degassing (Roulet and Lucotte 1996) and gold mining (Lacerda, 1997), but we have gold mining as the principal one. Our works have been demonstrated significant differences considering Hg levels in fish from a direct influenced gold mining area (contaminated area) and a non influenced area (non contaminated area) (Castilhos et al., 2000; Castilhos et al., 2001), as well as the human health risks associated with Hg contaminated fish consumption (Bidone et al., 1997; Castilhos et al., 1998).

Socio-economic costs derived from the toxicological risks associated to this contamination should be taken into consideration, including its impact on the economic perspectives of a given region. In the case of the Amazon region, on major potential impact is on fish farming (Castilhos et al., 1998).

HUMAN HEALTH RISKS: MERCURY EXPOSURE DUE TO FISH CONSUMPTION BY AMAZON POPULATION FROM TAPAJÓS RIVER REGION

Different chemical forms of mercury have quite different metabolism and toxic effects. Thus when evaluating risks to human health, each of the various chemical forms must be considered separately. The potency to produce irreversible brain damage and teratogenic effects makes MeHg the specie of mercury of greatest public health concern (Clarkson, 1994). There are many scientific publications about this subject, so a briefly description is shown below and emphasis is done in MeHg toxicity and human health risks assessment.

Most of the mercury encountered in the atmosphere is elemental mercury vapor and it is readily absorbed through the lungs, goes directly to the Central Nervous System and may be distributed throughout the body. Occupational exposure in humans indicates that neurotoxicity is the adverse effect most likely to occur at lowest exposure level (LOEL) and usually it is reversible. Elemental mercury is categorized as Group D, unable to be classified as to human carcinogen, according to USEPA Guideline for Carcinogen Risk Assessment (USEPA, 1986).

Inorganic mercury is generally absorbed by gastrointestinal tract. Its sentinel toxic end point is kidney damage mediated through an autoimune effect. (Schoeny, 1996). There are no data on the carcinogenic effects of inorganic mercury in humans, but it has been classified as Group C, possible human carcinogen, according to USEPA Guideline for Carcinogen Risk Assessment (USEPA, 1986), because there are some evidences from animal studies.

Methylmercury (MeHg) is rapidly and extensively absorbed through the gastrointestinal tract; once absorbed it is widely distributed in the body and across blood-brain and placental barriers. There are ample data from human and animals to consider MeHg to be a development toxicant. The most important toxic effect is on the nervous system. Neurological abnormalities have been observed in humans exposed as adults or “in utero”. The developing fetus is at greater risk from MeHg exposure than are adults. In addition, children are considered to be at increased risk of MeHg exposure by virtue of their greater food consumption as a percentage of body weight (mg food/kg body weight) compare to adults exposures. Additional risk from higher mercury ingestion rates may also result from the apparent decreased ability of children’s bodies to eliminate mercury. MeHg appears to be clastogenic but not to be a point mutagen; that is, mercury causes chromosome damage but not small heritage changes in DNA. EPA has classified MeHg as being of high concern for potential human germ cell mutagenicity; but the data are not sufficient to permit estimation of the amount of MeHg that would cause a measurable mutagenic effect in the human population. EPA has found MeHg to have inadequate data in humans and limited evidence in animals and has classified it as a possible human carcinogen, Group C, and has not calculated quantitative carcinogenic risk values for MeHg. Given the levels of exposure most likely to occur in the U.S. population, even among consumers of large amounts of fish, MeHg is not likely to present a carcinogenic risk (Schoeny, 1996).

It has been demonstrated that Hg usually accumulates in fish tissues as MeHg, from inorganic Hg sources (Huckabee et al., 1979). The absence of a consistent relationship between Hg concentrations in water, sediment and various fish species illustrates the complexity and site-specific nature of mercury bioaccumulation. Thus, direct Hg determinations in the local biota appear to be crucial to adequately evaluating Hg sources, and, ultimately, the risk of the Hg exposure to human health (Peterson et al., 1996).

In a previous study, we reported on the Hg concentrations in the fish fauna and on the corresponding potential human exposure to Hg due to fish consumption, in a contaminated and non contaminated section of the Tapajós river basin. The contaminated site is located in the Tapajós river between the cities of Jacareacanga and Itaituba, into which the gold mining sites are distributed alongside the tributaries of the Tapajós river. The background site is located in a fluvial lacustrine system near Santarém, 250 Km downstream the contaminated site, which does not receive contamination from the site, but has the same basic characteristics. We sampled and analyzed 541 specimens from 22 fish species: 238 from contaminated area and 303 from noncontaminated area. They include representatives of about 85% of the species caught and commercialized in the study areas (Isaac and Ruffino, 1995). The catch and market show a relationship 1:1 between carnivorous and noncarnivorous species in this region. The same relationship is thus assumed for human consumption.

Mercury was analyzed in the fish muscle through Atomic Absorption Spectrophotometer (A-G/VARIAN MODEL) using a Vapor Generation Acessory-VGA (CVAAS). The samples were diggested in sulfuric-nitric acid solution in the presence of vanadium pentoxido 0.1%; the oxidation completed by adding potassium permanganate 6% until the fixation of the violet color. Immediately before the determination, the excess of permanganate was reduced with hydroxylamine 50% (Campos 1990). Reference standard IAEA-fish muscle tissue with a certified Hg concentration of $0.74 \pm 0.13\ \mu g.g^{-1}$ were also analyzed, giving a value of $0.73 \pm 0.08\ \mu g.g^{-1}$ (n=4).

The "fish enrichment factors" for Hg were calculated by equation $FEF = (Hg_{contaminated\ site} - Hg_{background}) / Hg_{background}$, showed that the contaminated site is enriched *vis-a-vis* the background location for total fishes, noncarnivorous fish and carnivorous fish from 0.5, 0.6 to 0.8 (or plus 50%, 60% and 80%), respectively and the differences between means are statistically significant (Student's t-test; $p<0.001$). The results are shown in Table 1.

Table 1. Fish Hg mean concentration (μg.Kg^{-1}) in carnivorous species and non carnivorous species from the background location and from the contaminated site and the "fish enrichment factor", FEF values for the study area; (n) = number of samples.

Food Habit	Hg mean concentration (μg.Kg^{-1})		FEF
	Background site (n)	Contaminated site (n)	
Carnivorous	228±171 (159)	420±230 (98)	0.8
Non carnivorous	39±47 (144)	62± 53 (140)	0.6
Total	138±159 (303)	210± 240 (238)	0.5

We used a screening approach to compare the potential human health hazard between areas (US EPA, 1989). Although this assessment may be simplistic, in particular for MeHg, it allows easy comparison between populations under different levels of exposure to a given pollutant. This method permits that the differences between contaminated and background area must be applied so that the toxicological - rather than simply the statistical - significance of the contamination can be ascertained. The knowledge of background (i.e., pre-impact or "natural") environmental conditions permits the establishing of physical standard reference of the environmental quality.

Risk assessments recommended by US EPA follow the paradigm established by the National Academy of Sciences. This entails a series of interconnected steps including hazard identification, dose-response assessment, exposure assessment, and risk characterization, which are briefly described in this paper. Hazard identification uses available data on biological end points related to a material to determine if that material is likely pose a hazard to human health; these data are also used to define the type of potential hazard. In the dose-response assessment, data from human and animal studies are used to estimate the amount of material that is expected to produce a given effect in humans. In this step it is generally necessary to apply mathematical models to the data to calculate a quantitative risk estimate usable for low-dose response, resulting in reference doses (RfD) and slope factors (SF) for noncarcinogenic and carcinogenic effects respectively. The exposure assessment seeks to determine the extent to which a population is exposed to the material and uses available data relevant to population exposure. Fate and transport of the material in the environment, routes of exposure, and pharmacokinetics of material once in the body may be considered in the exposure assessment. Risk characterization is the last step of the risk assessment process. This step evaluates assessments of human health and ecological effects and delineates areas of uncertainty, limitations and assumptions made in the risk assessment.

At a screening level, a Hazard Quotient (HQ) approach, assumes that there is a level of exposure (i.e., RfD = Reference of Dose) for non-carcinogenic substances below which it is unlikely for even sensitive populations to experience adverse health effects. HQ is defined as the ratio of a single substance exposure level (*E*) to a reference of dose (E/RfD). When HQ exceeds unity, there may be concern for potential health effects. The estimated exposure level was obtained by multiplication of 95^{th} percentil upperbound estimate of mean Hg concentration considering all fish samples (156.0 $\mu g.kg^{-1}$ for background location and 240.0 $\mu g.kg^{-1}$ for contaminated site) – as suggested by US EPA (1989) – by the adult human ingestion rate for riverside populations (0.2 $Kg.d^{-1}$) that consume more fish and therefore, the most harmful situation, and divided by 70 kg, considering the weight average human adult. The MeHg RfD value is 1 E-04 $mg.Kg^{-1}.d^{-1}$ (IRIS, 1995) and its uncertainty factor is 10 and its confidence level is high. The resultant MeHg HQ is 4 and 7 for the background and for contaminated sites, respectively. These results suggest the need for further research on the potential health hazard from MeHg exposure in local population, even for what is considered here as background exposure. The results are shown in Table 2.

Hair concentrations of Hg are proportional to blood concentrations at the time of the formation of the hair strand. The estimates of Hg concentration in blood and in hair in contaminated and in noncontaminated sites were done by using the single-compartment model (WHO, 1990), through which the steady-state Hg concentration in blood (C) in $\mu g.L^{-1}$ is related to the average daily dietary intake (d) in µg of Hg, as follows: C = 0.95 * d. The estimated hair Hg concentration (11.4 $\mu g.g^{-1}$) agree with the observed 16.6±10.5 $\mu g.g^{-1}$ total Hg concentration and the observed 15.2±10.5 $\mu g.g^{-1}$ MeHg concentration reported by Akagi et al. (1994) in hair samples from 48 individuals from contaminated site of the Tapajós river. The chemical Hg speciation in hair samples indicated that ~ 88% of the total Hg concentrations were MeHg. The total Hg in hair reported by Akagi et al. (1994) could be related to ~ 65 $\mu g.L^{-1}$ in blood, using the single-compartment model. This value agree with the data reported by Cleary (1994) in blood from 12 residents of a fishing village of Jacareacanga (74.8 ± 61.0 $\mu g.L^{-1}$). The results are shown in Table 2.

Table 2. Hg concentration in fish ($\mu g.g^{-1}$); estimated intake (D; $\mu g.kg^{-1}.d^{-1}$); Reference Dose (RfD); Hazard Quotient (HQ); estimated average Hg daily intake (d; $\mu g.d^{-1}$); estimated blood Hg concentration (b; $\mu g.L^{-1}$) and estimated hair Hg concentration (h; $\mu g.g^{-1}$).

Location	Hg in fish* ($\mu g.g^{-1}$)	D ($\mu g.kg^{-1}.d^{-1}$)	RfD ($\mu g.kg^{-1}.d^{-1}$)	HQ	D ($\mu g.d^{-1}$)	B ($\mu g.L^{-1}$)	H ($\mu g.g^{-1}$)
Background	0.16	0.4	0.1	4	31	29.5	7.3
Contaminated site	0.24	0.7	0.1	7	48	45.6	11.4

* 95 percent upper confidence limit on the arithmetic mean

This report is of screening level, and uncertainty remains as to the health effects of eating large quantities of contaminated fish in the area studied, however our results agree with WHO recommendation: “measure to reduce methylmercury exposure via consumption of fish will need to consider the impact of these measures on the overall dietary requirements of these individuals”, in view of the importance of fish consumption for the local population, particularly significant in the absence of any other abundant food resource. As a general rule, it is advisable to start the assessment with the “worst case” study; for any given environmental risk, we must assume the worst and then attempt to prove that a better situation exists (Wilson, 1991).

Also, uncertainties of the RfD statistics have been reported, suggesting an under-estimation of RfD for Hg presented in IRIS, 1995 (Smith and Farris, 1996). However, currently neurodevelopment problems in children secondary to maternal MeHg consumption during pregnancy are considered to be the most sensitive indicators of adverse effects of MeHg exposures. The oral RfD (1 E-04 $mg.Kg^{-1}.d^{-1}$) is associated with a maternal whole blood mercury concentration of 5.8 $\mu g.L^{-1}$. Although more protective than some other recommendation, this RfD has been found to be based on credible science by the United

States National Academy of Sciences Committee on the Toxicology of Methylmercury. Most recently additional findings describing adverse cardiovascular and immunological effects of low-dose MeHg exposure suggest that these organ systems are at least as sensitive, and possibly more sensitive, than the developing nervous system.

Table 3 shows the toxicity values derived by US EPA (2001) for elemental, inorganic and organic mercury, mainly MeHg, concerning to human exposure and critical adverse health effects. The toxicity values, presented here, are Reference Concentration (RfC) and Reference Dose (RfD) for elemental, inorganic and organic mercury, respectively. The modified factors (MF) and uncertainty factors (UF) for each toxicity value express the confidence level in them and are estimated depending on the quality of data base available.

Table 3. Toxicity values (RfD and RfC) for mercury species concerning to human exposure and critical adverse health effects.

Species	Critical effects	UF	MF	BMDL (NRC)	RfD ($\mu g.kg^{-1}.d^{-1}$)	RfC ($\mu g/m^3$)
Elemental	Neurological effects* (adults)	30	1			0.3
Inorganic	Autoimmune effects	1000	1		0.3	
Organic (MeHg)	Neurological effects (child)	10	1	58 ppb	0.1	

UF= uncertainty factor; MF= modifying factor; NRC- National Resource Council; BMDL Benchmark lower limit dose related to MeHg in cord blood; *The critical effects related to human exposure to elemental mercury: hands tremor; increases in memory disturbances; slight subjective and objective evidence of autonomic dysfunction.

Recent studies have examined populations that are exposed to lower levels of MeHg due to fish consumption, including studies of populations around the Great Lakes, the Amazon basin (Câmara and Corey, 1992; Câmara et al.,1993; OPAS/OMS, 1996), the Seychelles Island and the Faroe Island (USEPA, 1997). The last two studies are of large populations of children presumably exposed in utero. The results from the Seychelles study of fetal MeHg exposure and child development, involving a main results of 779 infant-mother pairs highlights the difficulties in interpreting epidemiologic studies of this type (Mayers et al. 1995; Mayers et al., 2001). Maternal total hair mercury values during pregnancy ranged from 0.5 to 26.7ppm with a median of 5.9 ppm. This value is close with those estimated for hair from the local populations in the background site.

Significant uncertainties remain, however, because of issues related to exposure, neurobehavioral endpoints, confounders and statistics, and study design. Additional data are needed on the exposure levels at which humans experience subtle, but persistent, adverse neurological effects. Data on immunologic and reproductive effects are not sufficient for evaluating of low-dose MeHg toxicity for these end-points (US EPA, 1999).

In addition, one should take in account that epidemiological control, which may represent a useful "feed-back" for the adjustment of preventive measures in the case of slight and reversible pathologies due to environmental impacts, has no preventive value in the case of irreversible damages (Zapponi, 1988). It has been expanded recognition of the range of adverse effects of MeHg on human and animal health, and the results have been a marked change in interpretation of what degree of mercury exposure is considered excessive. This parallels broad changes in approach by public and environmental health authorities: emphasis on primary prevention rather than only treatment of disease (Mahaffey, 2001).

MERCURY IN FISH: SPATIAL AND TEMPORAL ENVIRONMENTAL CONTAMINATION ASSESSMENT FOR DECISION-MAKING AND PROPOSED METHODOLOGY

Aquatic organisms accumulate MeHg from water, food and sediment. Both dissolved, inorganic Hg and MeHg accumulate in phytoplankton. However, in contrast to MeHg, inorganic Hg is not biomagnified as the trophic transfer from phytoplankton to zooplankton. At the base of the food chain MeHg typically constitutes a smaller percentage of Hg pool, but within the fish community, virtually all the Hg is MeHg. In addition, MeHg attains its highest concentration in the tissues of fish at the top of aquatic food chain, the carnivorous fish. Elimination of MeHg by fish is very slow relative to the rates of uptake and the accumulation. The direct bioaccumulation factor (BAF) or bioconcentration factor (BCF) of Hg is defined as the ratio of Hg concentration in fish tissue to the Hg concentration in water. The indirect bioaccumulation or biomagnification is the accumulation of a chemical in a given species according to its trophic levels in the food chain (Bruggeman, 1982).

Castilhos & Bidone (2000) have characterized the Hg biomagnification in the amazon ichthyofauna from the Tapajós River Region, suggesting a general trophic sequence as: herbivorous = or < detritivorous < omnivorous < planktivorous < carnivorous omnivorous = carnivorous ichthyophagous.

Bioaccumulation and/or biomagnification are the most direct study of mercury reaction at the environmental interface of the aquatic organisms. In environmental hazard analysis, the ecological effect of a specific substance on an organism or group of organisms in an aquatic system can be described as a function of the dose during a defined period of time. Although the bioaccumulation/biomagnification processes have not been traditionally interpreted as a pharmacological/toxicological "effect", one could suggest that as higher the internal dose (bioaccumulation), the higher is the potential aquatic risk. Moreover, several effects show a positive correlation with exposure but a causal-effect relationship is a difficult task to access, but bioaccumulation/biomagnification processes, which have to have, at least, exposure conditions for a determinant chemical agent. In this particular context, the ecological effect is defined as Hg-content in fish. In addition, the US EPA concluded that it is more appropriate, at this time, to derive a fish tissue (including shellfish) residue water quality criterion for MeHg rather than a water column-based water quality criterion. This new criterion is based directly on the dominant human exposure route to MeHg, and the resulting Fish Residue Criterion (TRC) is 0.3 mg MeHg/kg fish. This is the concentration in fish tissue that should not be exceed based on a total fish and shellfish consumption-weighted rate of 0.0175 kg fish.d-1 (US EPA, 2001).

In general, the Hg levels in fish muscles show large inter-individual variability, resulting in very high values for relative standard deviation (US EPA, 1999). Many factors have been considered as important in the bioaccumulation and/or biomagnification of Hg in fish. Among them, the Hg load-dependent factors in the aquatic environment, specially those related to Hg in sediments and environmental conditions, like bio-production (Häkanson, 1980; 1991);

as well as local biota's physiological-dependent factors, like size, length, age and metabolic rate (Phillips, 1980; WHO, 1990); and, in addition, the food-chain characteristics (Cabana et al, 1994). So, Hg levels in fish for spatial and/or temporal comparisons have been normalized by the average Hg content in 1 Kg of fish (as pike) (Johnels et al., 1967; Häkanson, 1991), by using only fish of one year old (Post et al, 1996), or a specific length (Scruton, et al., 1994), or a specific weight (Watras et al., 1998).

Castilhos et al (2001) suggested a field dose-response approach as a tool for assessing the environmental Hg contamination, through the mercury analysis in fish. Dose-response approach is usually used for analysis of data from laboratory or epidemiologic studies. However, we have proposed its use for assessment of Hg contamination in fish sampled from field. This methodology was used to assess the Hg contamination in fish from Tapajós River Region. The Tucunaré (*Cichla* spp) specie was chosen for many reasons. At the moment, there are few toxicokinetics studies from field or laboratory-controlled conditions about Hg in *Cichla* spp., but this specie may be considered good bioindicator of Hg accumulation in the Amazonian ecosystem, specially because of its time-integration capacity. According to the reproductive strategies, carnivorous icthyophagous *Cichla* spp could be classified as "in equilibrium" (Winemiller, 1989 cited in Ruffino & Isaac, 1995). The fish considered "in equilibrium" are the most sedentary and present a territorial behavior. Their density does not change strongly during the year. Spawning season is long and it is not necessarily at the beginning of the flood time. Their preferred habitat is lentic (slow moving) water. The influence of amazonian seasonality (well characterized by two hydrological periods: a low waterlevel and a high waterlevel period) on Hg accumulation in fish was studied and the results showed that carnivorous fish, including *Cichla* spp, were not affected by seasonality (Castilhos, 1999). Their fine taste and abundance in native habitat have made it an important commercial specie (Ruffino and Isaac, 1995). Also, Tucunaré was reported as most frequently consumed fish by indigenous community in Pará State (Brabo et al., 2000).

The results showed different daily uptake doses by Tucunaré (*Cichla* spp.) between non-contaminated and contaminated areas (~4.0 times), and such differences could be attributed to different Hg loading rates between the studied areas, and also, could be a consequence of a potential pollution source, the gold mining activity.

We have also tested the applicability of the proposed methodology (DRAC) by using the literature data (Castilhos and Lima, 2001). Seven species of fishes from 8 different aquatic ecosystems, including lentic and lotic freshwater, estuarine and marine ecosystems, that were chosen from scientific publications, in which Hg levels in muscles and estimated age or measured length for individual specimens, were available.

The “DRAC” methodology was described in a previous work (Castilhos et al., 2001), and a brief description is presented as follows. The dose-response relationship has the competence to absorb inter-individual variability. The responses are of two kinds: quantal and quantitative. The quantal test are designed to estimate the concentration of a test material that affects 50% of the test organisms, the mean effective dose (ED 50% or ED50). One must choose the effect to be observed. Thus, this is a quantal rather than a graded response, since the specific effect is either present or absent. The ED50, for accumulation of Hg by fish, indicate the exposure time necessary to attain those tissue concentration levels by half of the exposed individuals. Some methods are used to calculate ED50, and, among them, there is the “probit” method (American Public Health Association, 1985; Ross and Gilman, 1985).

The D50 for accumulation of Hg by fish (accumulation dose 50 or AD50) indicates the exposure time necessary to attain those tissue concentration levels by half of the exposed individuals. This resulting time can be related to response, as follows: $t_{exposure} * C = constant$ (adapted from Dämgen and Grünhage, 1998); in which a certain response (K, constant) can be achieved from a exposure time ($t_{exposure}$) and the concentration in the aquatic environment C; such concentration will result as a potential dose or daily uptake rate (DUR), expressed in $\mu g.Kg^{-1}.d^{-1}$. From these results one could estimate the exposure time to reach either 300 $\mu g.Kg^{-1}$ or 500 $\mu g.Kg^{-1}$ and compare the contamination magnitude (or bioavailability) among different aquatic ecosystems.

The objectives were: (i) to establish and compare the dose-response relationship for Hg accumulation by different fish species, from several ecosystem and collection time (ii) to estimate and compare the daily Hg uptake rate by those different fishes; (iii) to estimate and compare the potential exposure time necessary for Hg accumulation to reach 500μg.Kg^{-1}, the limit concentration for human consumption, adopted in many countries, and, (iv) to present this approach, in addition to that expressed by U.S. EPA, for water quality criteria for methyl-mercury.

The results are presented in Table 4, which displays the popular name of the fish, the local and time of sampling, food habit, number of collected specimens, observed effect (OE), daily uptake rate estimate (DUR), estimate of time of exposition to reach 300μg.Kg^{-1} and 500 μg.Kg^{-1}, respectively, and references. Comparing the OE values (mean Hg concentration in μg.kg^{-1}) in the population sampled, for piscivorous and zooplanktivorous fishes, one could suggest the following crescent order of contamination or crescent contamination magnitude/bioavailability: Sepetiba Bay (corvina) < Ilha Grande Bay (corvina) = Guanabara Bay (corvina) = lagoons-Santarém (tucunaré) < Conceição Lagoon (corvina) < Tongue River- reservoir (white crappie) < Tongue River-reservoir (walleye) = Tongue River-reservoir (pike) = Tapajós River (tucunaré) < Tongue River- reservior (sauger) < Gulf of Trieste (conger-conger) < Tucuruí River- reservoir (tucunaré). However, considering the daily uptake rate estimates and/or the time necessary for half of the specimens to reach 500μg.Kg^{-1}, the order of contamination is altered to: Tongue River-reservoir (white crappie) < Conceição Lagoon (corvina) < Ilha Grande Bay < Guanabara Bay < Sepetiba Bay < Tongue River-reservoir (pike = sauguer= walleye) = lagoons-Santarém (tucunaré) < Tapajós River (tucunaré) < Gulf of Trieste (conger-conger) < Tucuruí River-reservoir (tucunaré).

Considering TRC, sauger (Tongue River), tucunaré (Tucuruí Reservoir) and conger-conger (Gulf of Trieste) showed Hg levels above the limit. However, looking at the estimated daily uptake rates, northern pike, sauger and walleye (Tongue River) and tucunaré (lagoons=Santarém) showed the same value: 0.2μg.kg^{-1}d^{-1}. The estimated daily uptake rates for conger-conger (Gulf of Trieste), tucunaré from Tapajós River and tucunaré from Tucuruí Reservoir resulted in 2 times, 4 times and 8 times higher than 0.2μg.kg^{-1}d^{-1}, respectively. The zooplanktivorous fish from Tongue River reservoir became, as expected, the less contaminated specie compared to carnivorous and piscivorous fish. For the Tucuruí system the possible differences in the tucunaré growth rate should be investigated, since the literature data indicate the existence of dwarf species in reservoirs (Doyon et al., 1998).

The objective was to test the applicability of the dose-response approach as a tool for environmental assessment mercury contamination by using the literature data. Indeed, the results might not represent, actually, the magnitude of mercury contamination/availability among those sites, because there are significant differences in temporal sampling as well as in analytical procedures.

We suggest that, in addition to TRC (0.3 mg methylmercury / kg fish) for specific fish specie, one could estimate the daily uptake rate, which may express the bioavailability of mercury in a defined aquatic ecosystem, and compare the time necessary to attain the TRC value. The dose-response approach might permit an integrate comparison among different aquatic ecosystems using the same or different fish species. The DRAC is a simple and fast methodology and can be applied to any data bank including spatial and temporal contamination assessment for environmental contaminants that show bioaccumulation.

Table 4. Popular and scientific names, food habit, locality, date and number of fish collected (N), observed effect (OE;µg.Kg^{-1}), estimated daily uptake rate (DUR; µg.Kg^{-1}.d^{-1}), estimated time of exposure to attain either 300µg.Kg^{-1} (T300, years) or 500µg.Kg^{-1} (T500, years) and references.

Popular name	Scientific name	FH[*]	Locality	Date	N	OE (µg.Kg^{-1})	DUR (µg.Kg^{-1}.d^{-1})	T300 (years)	T500 (years)
Northern Pike	*Esox lucius*	P	Tongue River- Reservoir (EUA)[1]	1978	56	300	0.2	4.1	6.8 [5]
Sauger	*Stizostedion canadense*	P	Tongue River- Reservoir (EUA)[1]	1978	31	350	0.2	4.1	6.8 [5]
Walleye	*Stizostedion vitreum*	P	Tongue River- Reservoir (EUA)[1]	1978	26	300	0.2	4.1	6.8 [5]
White crapie	*Pomoxis annularis*	Z	Tongue River- Reservoir (EUA)[1]	1978	36	200	0.05	16.4	27.0 [5]
Corvina	*Micropogonias fumieri*	C	Guanabara Bay (RJ, BR)[2]	1992	56	100	0.15	5.5	9.1 [6]
Corvina	*Micropogonias fumieri*	C	Ilha Grande Bay (RJ, BR)[2]	1990-1991	57	100	0.13	6.3	10.5 [6]
Corvina	*Micropogonias fumieri*	C	Sepetiba Bay (RJ, BR)[2]	1990-1991	60	80	0.10	8.2	13.7 [6]
Corvina	*Micropogonias fumieri*	C	Conceição Lagoon (SC, BR)[2]	1990-1991	42	130	0.08	10.3	17.0[6]
Tucunaré	*Cichla spp*	P	Lagoons –Santarém (PA, BR)[3]	1992	28	100	0.2	4.1	6.8
Tucunaré	*Cichla spp*	P	Tapajós River (PA, BR)[3]	1992	41	300	0.8	1.0	2.0
Tucunaré	*Cichla spp*	P	Tucuruí River- Reservoir (PA, BR)[4]	1995	61	1000	1.65	0.5	0.8 [5]
	Conger conger	P	Gulf of Trieste (Slovenia)[7]	1995-1996	25	610	0.4	2.1	3.4

REFERENCES

Akagi H, Kinjo Y, Branches F, Malm O, Harada M Pfeiffer WC, Kato H (1994) Methilmercury pollution in Tapajos river basin, Amazon Environ Sci 3: 25-32.

American Public Health Association (1985) Part 800 Toxicity test methods for aquatic organisms, In: 16th Edition, Greenberg AE, Trussell RE, Clesceri, L. and Frason MAH (ed) Standard Methods for Examination of Water and Wastewater. Baltimore, Maryland, USA, p. 689-819.

Bidone ED, Castilhos ZC , Cid de Souza TM, Lacerda LD (1997) Fish contamination and human exposure to mercury in the Tapajós River basin, Pará State: a screening approach. Bull Environ Contam Toxicol 59: 194-201.

Brabo E, Santos E, de Jesus I, Mascarenhas AFS, Faial KF(2000) Mercury contamination of fish and exposures of an indigenous community in Pará State, Brazil. Environmental Research Section A 84, 197-203

Bruggeman WA (1982) Hidrophobic interactions in the aquatic environment. In: Hutzinger O (ed) The Handbook of environmental chemistry, vol 2. Spring-Verlag, Germany, p 205.

Cabana G, Tremblay A, Kaff J, Rasmussen JB (1994) Pelagic food chain Structure in Ontario Lakes: A determinant of mercury levels in lake trout (Salvelinus namaycush). Canadian J Fish Aquat Sci 51:381-389.

Câmara VM (1993) Mercúrio em áreas de garimpo de ouro. Série Vigilância 12.

Câmara, VM & Corey, G (1992) O caso dos garimpos de ouro no Brasil. Epidemiologia e meio ambiente.

Castilhos ZC, Bidone ED, Lacerda, LD (1998) Increase of the background human exposure to mercury though fish consunption due to gold mining at the Tapajós river region, Amazon. Bull Environ Contam Toxicol 61: 202-209

Castilhos ZC (1999) Estimativa da taxa de captação diária de Hg por Micropogonias furnieri a partir da interrelação dose-resposta em quatro estuários brasileiros. "Workshop" Efeitos de Poluentes em Organismos Marinhos, UFF/FAPERJ; 08 a 10 de novembro de 1999, p.22.

Castilhos ZC & Bidone ED (2000) Mercury biomagnification in the icthyofauna of the Tapajós River Region, Brazil. Bull Environ Contam Toxicol 64:5, 693-700.

Castilhos ZC, Bidone ED, Hartz, S (2001) Bioaccumulation of Hg by Tucunaré (Cichla ocellaris.) from Tapajós River Region, Brazilian Amazon. A Field Dose-Response Approach. Bull Environ Contam Toxicol 66:631-637.

Castilhos ZC and Lima C (2001) Interrelação dose-resposta para a avaliação da magnitude da contaminação mercurial em peixes. VI Congresso de Geoquímica dos Países de Língua Portuguesa- Faro, Portugal, 9 a 12 de abril de 2001.

Clarkson TW (1994) The toxicology of mercury and its compounds. In: Watras CJ, Huckabee JW (ed) Mercury pollution: Integration and synthesis. Lewis Publishers, Boca Raton, Florida, USA, p. 631-640.

Cleary D (1994) Mercury contamination in the Brazilian Amazon: Na overview of epidemiological issues. In: Proceedings of the international workshop on "Environmental mercury pollution and its health effects in Amazon river basin", Rio de Janeiro, Brazil, p. 61-72.

Dämgen U and Grünhage L (1998) Response of a grassland ecosystem to air pollutans. V. A toxicological model for the assessment of dose-response relationship for air pollutants and ecosystems. Environ Pollut 101:375-380.

Driscoll CT, Schofield CL, Munson R K, Yan C, Kolsapple JG (1994)The mercury cycle and fish in the Adirondack lakes. Environ Sci Technol 28:136-143.

Doyon J-F; Bernatchez L, Gendron M, Verdon R, Fortin R (1998) Comparison of normal and dwarf populations of lake whitefish (...) with reference to hydroelectric reservoirs in northern Quebec. Arch Hydrobiol Spec Issues Advanc Limnol 50:97-108.

Håkanson, L (1980) An ecological risk index aquatic pollution control. A sedimentological approach. Water Res:975-1001.

Håkanson, L (1991) Mercury in fish-geographical and temporal perspectives. Wat Air Soil Pollut 55:159-177.

Horvat, M et al (1999) Mercury in contaminated coastal environments; a case study: the Gulf of Trieste. Sci Tot Environ 237/238:43-56.

Huckabee JW, Elwood JW, Hildebrand SG (1979) Accumulation of mercury in freshwater biota. In: Nriagu JO (ed). The biogeochemistry of mercury in the environment, Elsevier, North Holland, Amsterdam, p. 277-302.

IRIS - Integrate Risk Information System (1995) EPA, Office of research and Development, Washington, DC.

Johnels AGT, Westemark T, Berg W, Persson PI and Sjonstrand (1967) Pike (Esox lucius L) and some other aquatic organisms in Sweden as indicators of mercury contamination in the environment. Oikos 18:232-33.

Kherig, H. (1992) Estudo comparativo dos níveis de concentração de mercúrio total em corvinas (Micropogonias furnieri) de quatro estuários brasileiros. Dissertação de mestrado - Rio de Janeiro - PUC.

Lacerda, LD; Solomons, W (1991) Duch ministry of housing, physical planing and environment. Chemical Time Bomb Project.

Lacerda, LD (1997) Evolution of mercury contamination in Brazil. Wat Air Soil Pollut 97:247-255.

Mahaffey, K. (2001) Mercury as an environmental problem: perspectives on health effects and strategies for risk management . 6th ICMGP 2001 - Minamata, Japan.

Mayers GP; Marsh DO; Davidson PW (1995) Main neurodevelopmental study of Seychellois childrenfollowing in utero exposure to methylmercury from a maternal fish diet: outcome at six mouths. Neurotoxicol 16:65333-664.

Mayers GJ (2001) The Seychelles child development study: testing and results at 107 months of age. ICMGP, Japão, 15 a 19/11; Keynote Lectures, p.12

OPAS/OMS - Organização Pan-Americana da Saúde / Organização Mundial da Saúde (1996) Projeto de avaliação de risco à saúde na região amazônica relacionados com a contaminação ambiental por mercúrio

Peterson MJ; Southworth GR; Crumby WD (1996) Monitoring mercury in fish in a stream system receiving multiple industrial inputs. Environ Monit Assess 40: 91-105.

Phillips DJH (1980) The effects of age (size, weight) on trace metals in aquatic biota. In: Mellanby K (ed) Quantitative aquatic biological indicators. Applied Science Publishers, Essex, England.

Phillips GR, Lenhart TE, Gregory RW (1980) Relation between trophic position and mercury accumulation among fishes from the Tongue river reservior, Montana. Environ Res 22:73-80.

Porvari P (1995) Mercury levels of fish in Tucuruí hydroeletric reservior and in river Mojú in Amazonia, in the state of Pará, Brazil. Sci Total Environ 175:109-117.

Post JR, Vandenbos R and Mcqueen J (1996) Uptake rates of food-chain and waterborne mercury by fish: field measurements, a mechanistic model, and an assessment of uncertainties. Canadian J Fish Aquat Sci 53:395-407.

Ross EM & Gilman AG (1985) Pharmacodynamics: Mechanisms of drug action and the relationship between drug concentration and effec. In: Goodman A, Gilman A, Goodman LS, Rall TW, Murad F (ed) 17th Goodman and Gilman's The Pharmacological Basis of Therapeutics MacMillan Publishing Company, New York, NY, p.35-48.

Ruffino ML, Isaac VJ (1995) Life cycle na a biological parameters of several Brazilian Amazon fish species. NAGA, The ICLARM Quartely 18: 41-45.

Schneider, C (2000) GIF Coordinates - software developed at The University of Utah.

Schoeny, R (1996) Use of genetic toxicology data in U S EPA risk assessment: The mercury study report as an example. Environ Health Perspect 104:663-673.

Scruton DA, Petticrew EL, Ledrew LJ, Anderson MR, Williams UP, Bennet BA, Hill, EL (1994) Methylmercury levels in fish tissue from three reservoir systems in Insular Newfoundland, Canadá. In: Watras CJ, Huckabee JW Mercury Pollution: Integration and Synthesis. Lewis Publishers, USA, 727p.

Smith JC; Farris FF (1996) Methilmercury pharmacokinetics in man: a reevaluation. Toxicol Appl Pharmacol 137:245-252.

U.S. EPA – Environmental Protection Agency (1989) Risk Assessment Guidence for Superfound vol 1. Chapt 6, pp. 1-54.

U.S. EPA (1999) The national survey of mercury concentrations in fish data base summary 1990-1995, Washington DC, 210p.

U.S. EPA (2001) Water Quality Criteria- Methylmercury. www.epa.gov.

Veiga MM; Meech JA; Onate M (1994) Mercury pollution from deforestation. Nature 168:816-817.

Watras CJ, Back RC, Halvorsen S, Hudson RJM, Morrison KA, and Wente SP (1998) - "Bioaccumulation of mercury in pelagic freshwater food webs". Sci Tot Environ 19:183-208.

Wilson AR (1991) Environmental risk: Identification and mangement. Lewis Publishers Inc. Chelsea, MI, USA, 431p.

WHO (1990) Environmental Health Criteria 101: Methylmercury. Geneva, World Health Organization.

ELECTROLEACHING PROCESS FOR REMEDIATION OF MERCURY CONTAMINATED SOILS

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ABSTRACT

This paper presents some results for the treatment of mercury bearing residues, from the gold prospecting activities in the Tapajos basin region that uses elemental mercury to amalgamate gold in gravity concentrates, so as to recover and recycling the remaining elemental mercury. The utilized technique was the electroleaching which deals with the electrolysis of a residue suspension in a sodium chloride solution by using graphite electrodes. Additionally, some results of mercury recovery were presented infering that, as the reaction goes on, gold particles present in the residue, in the ppm range, were also leached and codeposited on the cathode surface forming a gold amalgam. It was also shown the necessity of recycling the sodium chloride solution, after finishing the treatment of such residues, as it is a question of a high salinity effluent.

Key Words - electroleaching, amalgamation, graphite, salinity.

1. INTRODUCTION

The growth in industry and the changes in manufacturing processes have resulted in an increase in the volume and complexity of waste water discharges to the environment. Many traditional and new treatment processes are being modified and developed to try to eliminate the release to surface waters of the diverse chemical substances found in waste water discharges.

Biological methods are now being applied to an ever increasing range of effluent types[1/2] However, sometimes these processes are impractical and are unable to be employed in the treatment of effluents containing biologically resistant substances.

Physical treatment processes, such as adsorption onto granular activated carbons, are effective at removing pollutants from water and such processes are quite adaptable over a wide range of process conditions[3,4].

Physical-chemical treatment processes incorporate the addition of secondary chemicals to precipitate or react with the primary pollutants in the effluent. The use of high chemical doses to clean up an effluent often results in a discharge that itself remains unacceptable. Combined treatment processes are almost always required to treat a discharge in order to make it acceptable to Local Authorities. Such combined processes can be effective at eliminating pollution but usually require long contact times and larger areas to make them practical.

The interest in the use of electrochemical processes for treating waste waters is continuing to grow. The implementation of electrochemical processes in the treatment of such effluents can result in the destruction of the organic contaminant and lead to a total reduction in the COD (chemical oxygen demand) and BOD (biochemical oxygen demand) of the effluent[5,7]. The method is simple and the process operating requirements and areas are significantly less than conventional treatment processes.

A major source of mercury-containing effluents has traditionally been the chlor-alkali industry. Although other sources such as mercury bearing residues, from the gold mine industry that uses elemental mercury to amalgamate gold in gravity concentrates, may also present significant environmental hazards. Conventional mercury recovery routes involve chemical precipitation, as sulphide[10,11] or thiosulphate[12], ion-exchange[13], or cementation, using a copper-coated nickel[14] or “base metal” fluidized bed[15]. Other routes involve the use of hypochlorite[13,16,17] to produce soluble Hg(II), either from insoluble mercury species or from elemental mercury, which can be reduced at the surface of different cathodes. Hypochlorite can be used, in the mercury dissolution process, as a chemical or being electrolytically generated in the reaction system.

This work presents a contribution to the extraction and recovery of mercury from mercury bearing materials. One of the object of the present work is to provide an improved and economical process for the hydrometallurgical extraction and recovery of mercury that can be applied to low as well as high mercury content residues.

2. THEORETICAL CONSIDERATIONS

The disorderly use of mercury, during the gold recovery by treating gravity concentrates, has been generating high mercury content residues. Some experiments have been carried out so as to treat such residues by a pirometallurgical process. During this process the mercury is volatilized, by increasing the temperature, and immediately condensed. The use of this route brings about some drawbacks, such as: the need of using big capacity equipment for treating great amount of residues, and the difficult task of dealing with mercury vapours, which requires sophisticated condensation systems to assure no leak to the environment.

The electrochemical process to recover mercury from residues takes place by the action of hypochlorite ions, generated during the electrolysis of a suspension made up of residue in an aqueous sodium chloride solution. The generation of hypochlorite ions is the result of the oxidation of chloride ions to elemental chlorine, which in contact with the aqueous solution produces such ions in charge of the elemental mercury dissolution.

This process for treating residues with high mercury content, promotes the dissolution of mercury as $HgCl_4^{2-}$ that is, immediately, deposited on the surface of graphite cathodes. The success of this process will depend, to some extent, on how effective is the chlorine reaction with the aqueous solution, generating the oxidising agent (ClO^-), which promotes the mercury dissolution according to the following reaction:

$$Hg + 2ClO^- + 4Cl^- + 2H_2O \Leftrightarrow Cl_2 + HgCl_4^{2-} + 4OH^- \quad (1)$$

Mercury compounds are highly soluble in aqueous chloride solutions because of the complexation of mercuric ions. The following equilibrium reactions must be considered:[18]

$$Hg^{2+} + Cl^- \Leftrightarrow HgCl^+ \qquad K_1 = 5{,}6x10^6 \quad (2)$$

$$Hg^{2+} + 2Cl^- \Leftrightarrow HgCl_{2(aq)} \qquad K_2 = 1{,}7x10^{13} \quad (3)$$

$$Hg^{2+} + 3Cl^{-} \Leftrightarrow HgCl_3^{-} \qquad K_3 = 1{,}2x10^{14} \qquad (4)$$

$$Hg^{2+} + 4Cl^{-} \Leftrightarrow HgCl_4^{2-} \qquad K_4 = 1{,}2x10^{15} \qquad (5)$$

The total mercury concentration in the solution is given by:

$$C = [Hg^{2+}] + [HgCl^{+}] + [HgCl_{2(aq)}] + [HgCl_3^{-}] + [HgCl_4^{2-}] \qquad (6)$$

By substituting into Equation 6 the concentrations of $HgCl^{+}$, $HgCl_2$, $HgCl_3^{-}$ and Hg^{2+} ions from the equilibrium expressions (2)-(5) respectively and rearranging, the relationship between the concentration of the $HgCl_4^{2-}$ species and the total mercury concentration can be obtained:

$$\frac{[HgCl_4^{2-}]}{C} = \frac{K_4[Cl^{-}]^4}{1 + K_1[Cl^{-}] + K_2[Cl^{-}]^2 + K_3[Cl^{-}]^3 + K_4[Cl^{-}]^4} \qquad (7)$$

According to Equation 7, when the chloride concentration is 0.86 mol dm^{-3} approximately 90% of the total mercuric ions will conform to the $HgCl_4^{2-}$ species. The calculation procedure, based on the above equations, is only an approximate one as the activity coefficients were not taken into account. However, it is useful as it allows us to propose the following reaction

$$HgCl_4^{2-} + 2e \Leftrightarrow Hg^{o} + 4Cl^{-} \qquad (8)$$

as the predominant reaction during the deposition of mercury from a solution containing chloride ions in high concentration. Reaction 8 has a reversible electrode potential, under standard conditions, of 0.4033 V(SHE). This potential was calculated from standard Gibbs energy data[19].

In the situation where sodium chloride is used as the electrolyte the reaction occurring at the anode is

$$2HClO + ClO^{-} \Leftrightarrow ClO_3^{-} + 2Cl^{-} + 2H^{+} \qquad (9)$$

and the reaction taking place at the cathode is

$$2H_2O + 2e \Leftrightarrow 2OH^{-} + H_2 \qquad (10)$$

In a cell in which the anode and cathode products are not separated there is a measuring process which can be expressed by the following reaction:

$$2OH^- + Cl_2 \rightarrow Cl^- + ClO^- + H_2O \qquad (11)$$

Both the hypochlorite and the free chlorine can act as oxidising agents and are also chemically reactive in their own.

As the electrolysis goes on, the oxidising power of the reaction system increases due to the generation of chlorate ions (ClO_3^-) by two different ways, either by purely chemical reaction of the hypochlorite ion with hypochlorous acid in the bulk solution (chemical chlorate formation), according to the following reaction:

$$2HClO + ClO^- \Leftrightarrow ClO_3^- + 2Cl^- + 2H^+ \qquad (12)$$

or by electrochemical oxidation of the hypochlorite at the anode under simultaneous oxygen evolution (anodic chlorate formation):

$$6Cl^- + 3H_2O \Leftrightarrow 2ClO_3^- + 4Cl^- + 6H^+ + 3/2O_2 + 6e \qquad (13)$$

This reaction seems, in general, quite convenient regarding the treatment of mercury containing residues from the amalgamation process. Such residues contain, normally, low gold contents (### 1 ppm) which can be dissolved by chlorate ions, according to the following reaction:

$$Au + 7NaCl + NaClO_3 \Leftrightarrow 2NaAuCl_4 + 6NaOH \qquad (14)$$

The dissolved gold is codeposited with mercury generating an amalgam. The phase diagram of the system Au-Hg[20] indicates that at ambient temperature, alloys with more than 5% of gold are solid and single phase. On the other hand, the mercury deposition from chloride solutions, at electrode surfaces where no reaction occurs among the elemental mercury and the electrode material, mercury droplets lost from the electrode cause calomel precipitation on the bottom of the cell by the following reaction:

$$Hg^o + Hg^{2+} + 2Cl^- \Leftrightarrow Hg_2Cl_{2(s)} \qquad (15)$$

As can be seen, in the reaction (15), a very insoluble mercurous compound (Hg_2Cl_2) is formed which will remain in the residue after the electroleaching process. Thus, is imperative to use some device able to collect those mercury drops, falling down from the cathode surface, extracting them from the reaction system.

In the early stage of the electroleaching process, hydrogen evolution occurs according to the reaction (10). This reaction is in charge of a pH rise. Subsequently, this pH rise occurs through the mercury and gold dissolution reactions , reaction (1) and (2) respectively.

During the electroleaching process, the solution pH has to be controlled in a safe range, between 4 and 9. When the solution pH goes down below 4, mercurous chloride (Hg_2Cl_2) is formed, which is very insoluble in chloride solution. On the other hand, if the solution pH goes up above 9 causes precipitation of a large amount of mercury oxide (HgO), as insoluble as mercurous chloride and will remain in the residue as such.

3. EXPERIMENTAL

All solutions used for voltametric studies contained 0.83 mol dm^{-3} NaCl (AnalaR) as supporting electrolyte and a mercury concentration of 5×10^{-4} mol dm^{-3} as mercuric chloride ($HgCl_2$). Solutions were made up using deionized distilled water and were de-aerated with oxygen-free nitrogen before steady state polarisation curves were recorded. A nitrogen flow was maintained over the solution, during the experiments, so as to avoid the oxygen to get into the cell.

The voltametric study was carried out by using a glassy carbon rotating disk electrode (area = 3.7×10^{-5} m^2) embedded in a PTFE holder and attached to a rotating disc assembly (Oxford Electrodes - England). A conventional Pyrex cell assembly (Figure 1) was used, incorporating a saturated calomel reference electrode separated from the bulk solution by a Luggin capillary; a large platinum foil (0.04 m x 0.04 m) in a separate compartment served as a counter electrode.

Linear potential scans were generated using a potentiostat (EG7G - Princeton Applied Research, model 363) in conjunction with a waveform generator (EG7G - Princeton Applied Research, Universal Programmer, model 175). The applied potential and the resulting current were stored in a PC computer through data acquisition software (Labtech Notebook) using a high-resolution data acquisition board (Mini-16-Strawberry Tree - Computer Instrumentation & Controls) and subsequently analysed.

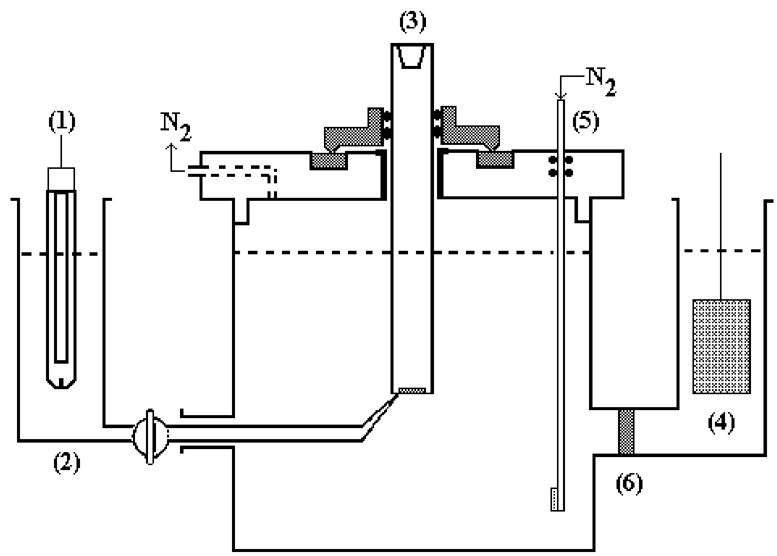

Figure 1 - Experimental cell design for experiments with rotating disc electrodes. (1) reference electrode, (2) Luggin capillary, (3) rotating disc electrode (working electrode), (4) platinum foil electrode (counter electrode), (5) nitrogen bubbler, (6) porous glass sinter.

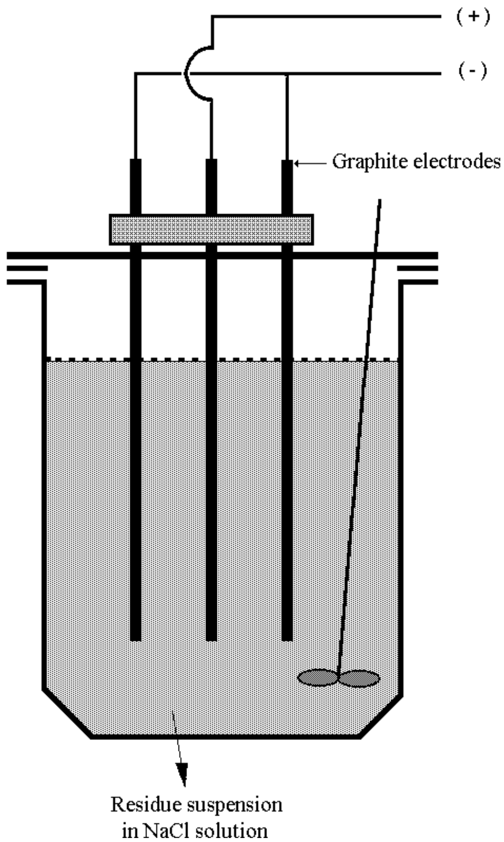

Figure 2 - Reaction system for electroleaching tests.

The reaction system shown in Figure 2, consists of one litre capacity Pyrex reactor. In each test 0.20 kg of residue was used, suspended in one litre of 0.86 mol dm^{-3} sodium chloride solution.

The residue used in this study is derived from Poconé region (Mato Grosso) which was generated during the amalgamation of gold from gravity concentrates. The average mercury and gold concentrations were 2.3×10^{-4} mol kg^{-1} (45.7 ppm) and 5.1×10^{-6} mol kg^{-1} (1 ppm) respectively.

4. RESULTS AND DISCUSSION

a- Kinetics of the mercury-chloride complex ion ($HgCl_4^{2-}$) reduction.

The reduction of $HgCl_4^{2-}$ species (reaction 8) was studied with a rotating disk electrode by using the experimental conditions described before. Figure 3 shows some typical curves of current density as a function of the potential at different angular velocities, *i.e.* curves (a), (b), (c) and (d). Curve (e) corresponds to the hydrogen evolution on a mercury-coated vitreous carbon electrode and was obtained at 1000 rpm in the supporting electrolyte.

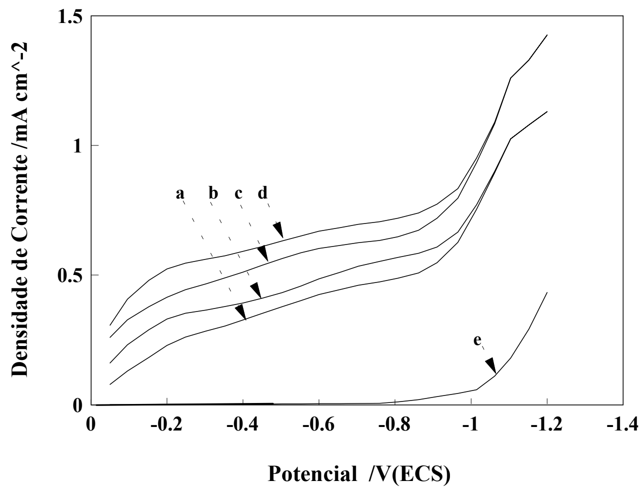

Figure 3 - Current density as a function of the electrode potential at different angular velocity. (a) 500 rpm, (b) 750 rpm, (c) 1000 rpm, and (d) 1250 rpm. Hydrogen evolution from a 50 g dm^{-3} NaCl solution at 1000 rpm.

Although the current is not really constant, the figure reveals that mercury reduction is mass-transfer controlled over a wide range of potentials; namely from about -0.3 V to -1.0 V(SCE), where hydrogen evolution begins to increase considerably.

Likewise because of the low value of the limiting current density for the mercury reduction and in order to increase the space time yield of the reactor, it is necessary to increase the surface area where the reaction takes place. Therefore, several configurations of electrochemical reactors have been proposed. Williams and Olson[21] showed the technical feasibility of removing traces of mercury by using extended surface electrolysis. Robertson *et al*[22] reduced the level of mercury to below the accepted concentration of 0.01 ppm in wastes by employing the swiss-roll cell with a cadmium coated stainless steel cathode. An industrial cell with a fluidized bed electrode was reported by van der Heiden *et al.*[23], and Kreysa[24] reported on experimental results obtained with a packed bed electrode. The use of graphite felt as an efficient porous electrode for the removal of traces of mercury ions from aqueous electrolyte solutions was investigated by Oren and Soffer[25]. Matlosz and Newman[26] investigated a flow-through porous electrode, made of reticulated vitreous carbon, for removal of mercury from contaminated brine.

Figure 4 shows a Levich-plot for mercury concentration of 5 x 10^{-4} mol dm^{-3}, where the limiting current density were measured at a potential of 0.90 V(SCE). From the slope of the Levich-plot and using the literature value for the kinematic viscosity of 8.0 x 10^{-7} m^2 s^{-1}[27] the resultant diffusion coefficient is 2.21 x 10^{-9} m^2 s^{-1}. This result is in close agreement with the reported value[26.

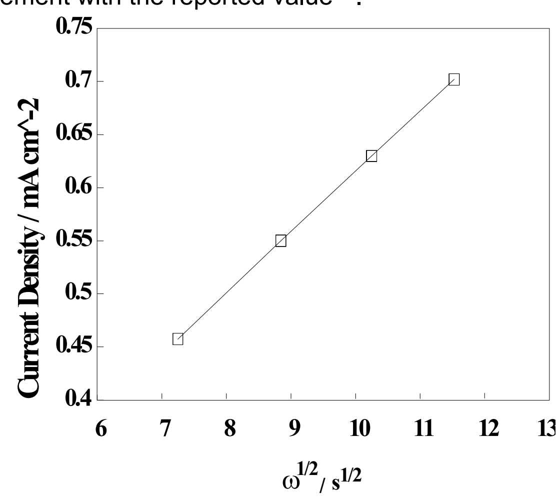

Figure 4. Limiting current density against square root of the electrode angular velocity. $[Hg^{2+}] = 5 \times 10^{-4}$ mol dm^{-3}.

b- Mercury Electroleaching

Figure 5 shows some experimental results obtained with the reactor outlined in Figure 2. Analysing this figure, it can be seen that the mercury dissolution process occurs with high efficiency; after 3 hours of operation, under the conditions of the experiment, the mercury concentration was reduced from 45.7 ppm to 0.1 ppm which means an extraction over 99%. In addition, after finishing each test, the suspension was filtered and the residue did not suffer any washing process but dried before going to be analysed. This means that part of the mercury present in the electroleaching residue should coming from the remaining solution after filtering process. The mercury concentration in the solution, after the leaching process, was, on average, of 0.09 ppm. Neither the mercury concentration in the solution nor in the residue were low enough to be considered as suitable for discharging, which indicates the necessity of extending the electrolysis time.

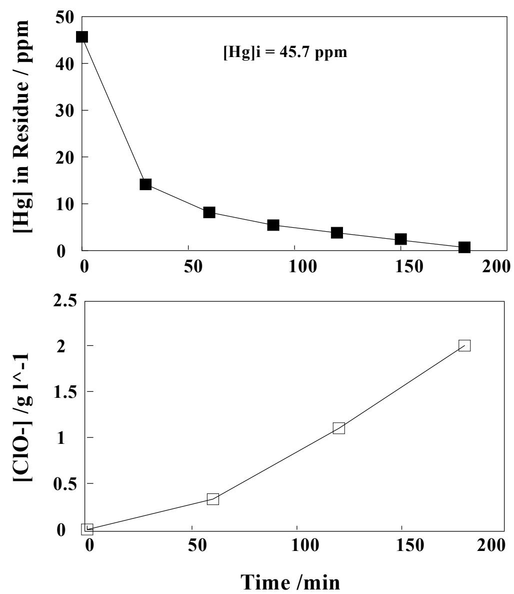

Figure 5 - Mercury concentration in the residue and hypochlorite concentration profiles, during the electroleaching test. $[Hg]_{res.}$ = 45.7 ppm, $[NaCl]_{sol.}$ = 0.86 mol dm^{-3}, i_a = 0.6 A dm^{-2} and i_c = 0.83 A dm^{-2}.

Figure 6 shows the effect of the ever increasing hypochlorite concentration on chlorate generation during the electrolysis.

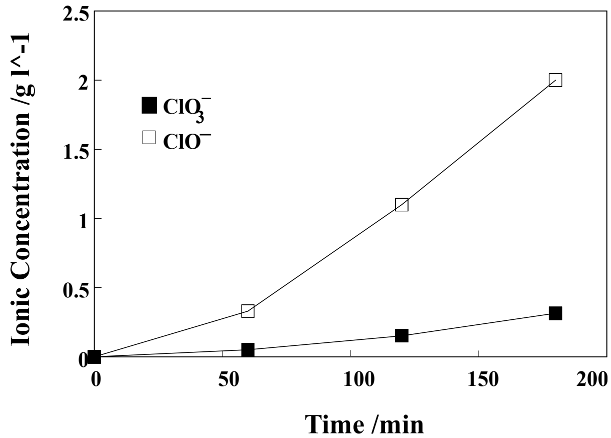

Figure 6 - Variation of hypochlorite and chlorate ions concentration. $[Hg]_{res.}$ = 45.7 ppm, $[NaCl]_{sol.}$ = 0.86 mol dm^{-3}, i_a = 0.6 A dm^{-2} and i_c = 0.83 A dm^{-2}.

As mentioned previously (item 2), during the electroleaching process there are two different ways to produce chlorate ions (Reactions 12 and 13) as the hypochlorite ion concentration builds up (Reaction 11). As the chlorate ion concentration builds up the oxidising power of the reaction system increases permitting not only the gold dissolution, present in the residue, but also to enhance the mercury dissolution process. The gold dissolution as well as its deposition were evidenced as long as the cathode surface was scraped, the shavings dissolved with aqua regia and the solution analysed for gold.

Figure 7 shows how the solution pH changes with the reaction time. The pH variation can be interpreted as a result of a continuous hydroxyl ions generation by the mercury and gold dissolution, as shown by reactions 1 and 14 respectively. This pH rise occurs very slowly, as shown in Figure 7, since the chlorate ion generation reactions

(Reactions 12 and 13), which occur in a less intensive way, tend to decrease the pH by the H^+ ions generation. During the performed tests, the leaching solution pH did not exceed the upper limit of the safe pH range (from 4 to 9).

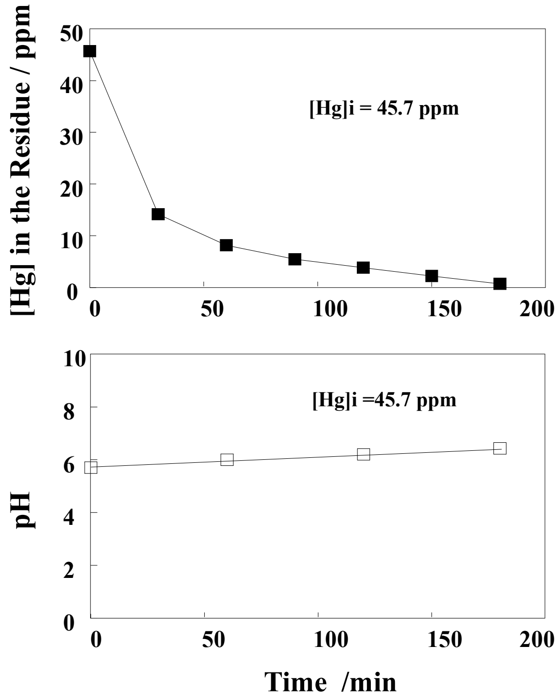

Figure 7 - Variation of pH with reaction time. $[Hg]_{res.}$ = 45.7 ppm, $[NaCl]_{sol.}$ = 0.86 mol dm^{-3}, i_a = 0.6 A dm^{-2} and i_c = 0.83 A dm^{-2}.

5. CONCLUSIONS

The experimental results permit to conclude that, by choosing the suitable operational conditions, it was possible to reduce the mercury concentration to low values with high extraction efficiency (>99%), considering the utilised residue. The final mercury concentration was of 0.1 ppm, which is not low enough to be considered as suitable for discharging, indicating the necessity of extending the electrolysis time.

The final leaching solution should not be discharged since it contains not only high salinity but also mercury concentration not suitable for discharging. It is recommended the recycling of this solution to the residue treatment process.

According to the low current densities obtained from the voltametric study, it is recommended the use of high surface area cathodes and provides good mass transfer conditions so as to enhance the reactor performance.

In case of dealing with higher mercury content residues (### 50 ppm), it is imperative to use special devices to extract the elemental mercury from the reaction system, accumulated on the cathode surface during the electroleaching process, so as to avoid the reaction between elemental mercury droplets and Hg^{2+} ions producing the quite insoluble mercurous chloride (Hg_2Cl_2) which remains in the residue.

It was evidenced the gold dissolution and its deposition, during the electroleaching process, by analysing the shavings scraped from the cathode surface.

REFERENCES

1. Moo-Young, M., *Int. Conf. Environ. Biotechnol. Waste Treatment and Recycling*, Hong Kong, 1992, p. 11.

2. Yu, P. H. F., *Int. Conf. Environ. Biotechnol. Waste Treatment and Recycling*, Hong Kong, 1992, p. 13.

3. Allen, S. J., McKay, G. & Khader, K. Y. H., *J. Coll. Int. Sci.*, **126** (1988), 517-24.

4. Allen, S. J., McKay, G. & Khader, K. Y. H., *J. Chem. Tech. Biotechnol.*, **45** (1989), 261-302.

5. Kaba, L., Hitchens, G. D. & Bockris, J. O###M., *J. Electrochem. Soc.*, **137** (1990) 1341-5.

6. Comninellis, C. & Plattner, E., *CHIMIA*, **42** (1988), 250-2.

7. Pletcher, D., Walsh, F. C., & White, I., *I. Chem. E. Symp. Ser.*, **116** (1990), 195-218.

8. B. Commoner, *Chem. Br.*, **8** (1972), 52.

9. R. Caban and T. W. Chapman, *AIChE J.*, **18** (1972), 892.

10. For example, *Chem. Abs.*, **81**, 82126e.

11. *ibid.*, 81, 111188j.

12. Sumitomo Chemical Co. Ltd., German Patent 2 321 196 (1973).

13. W. C. Gardiner and F. Munoz, *Chem. Eng.*, **78** (1971), 57.

14. D. J. Flood and C. J. Kraynik, *Chem. Abs.*, **83** (1973), 65287g.

15. P. E. Waltrich, US Patent 3 704 875 (1972).

16. E. Wygasch and G. Weiss, US Patent 3 755110 (1973).

17. BP Chemicals Ltd., British Patent 1 336 084 (1973).

18. Latimer, W. M., The Oxidation States of the Elements and Their Potentials in *Aqueous Solution*, 2nd edn., Prentice-Hall, Inc., Englewood Cliffs, NJ, 1952, 181 pp.

19. Balej, J., Mercury. *Standard Potentials in Aqueous Solutions*, eds A. J. Bard, R. Parsons & J. Jordan. Marcel Dekker, New York, 1985, pp. 265-85.

20. M. Hansen, Constitution of Binary Alloys, McGraw-Hill, London (1958).

21. Williams, J. M. & Olson, M. C., *AIChE Symp. Ser.*, **73** (1976), 119-31.

22. Robertson, P. M.,Scholder, B., Theis, G. & Ibl. N., *Chem. Ind.* (London), **1 July** (1978), 459-65.

23. van der Heiden, G., Raats, C. M. S. & Boon, H. F., Eine, *Chem-Ing-Tech.*, **51** (1979)651-3.

24. Kreysa, G., *Metalloberfläche*, **34** (1980), 494-501.

25. Oren, Y. & Soffer, A., *Electrochim. Acta*, **28** (1983), 1649-54.

26. Matlosz, M. & Newman, J., *J. Electrochem. Soc.*, **133** (1986), 1850-9.

27. Washburn, E. W. (ed), International Critical Tables of Numerical Data, Physics, Chemistry and Technology. McGraw-Hill, New York, 1929, Vol. III, 79 pp e Vol. V, 15 pp.

LEGAL ISSUES RELATED TO GARIMPOS IN BRAZIL

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1. INTRODUCTION

Due to its geological fate the rainforest areas of the world are a rich compartment for secondary to primary gold ore deposits. Thus, colluvial, alluvial and near-surface ore bodies are all scattered in these regions, promoting a nice business environment for the "*garimpeiros*".

For this reason, mercury is widely utilized in gold extraction, since it readily amalgamates, and the resulting amalgam is easily broken by fire. With amalgamation and firing operations, mercury is released to the environment because when mercury is introduce to amalgamate gold particles, it is seldom handled in a close-circuit; the same being true when it is released from the amalgam through burning, which is generally carried out at open air.

The problems regarding elemental and other forms of mercury in the environment and local population are all well discussed and documented in the literature. For the brazilian case, see for instance, LACERDA and SALOMONS (1992), BARRETO (1993), SILVA (1995), AKAGI et al. (1996), and VILLAS BÔAS (1997).

2. LEGAL ASPECTS

The Brazilian Mining Law, approved in 1967, defines the profile of the "garimpeiro" as a professional who works the outcropping deposits (typically alluvium, eluvium and colluvial deposits) manually (with the help of tools). Ideally, he should be a professional individual, without economic and technical resources, who would make "garimpo" mining his means of subsistence. Because of this technical and economic limitation, the damage to the mineral reserves, even in the case of ambitious mining practice (predatory mining), would be negligible.

The most recent Brazilian Constitution (1988), favors the "garimpeiro" - even in detriment to the constituted mining activity - according to many - and gives the Federal Government the power to establish areas and conditions for the "garimpo" activity (Art. 21, XXV and Art. 174, paragraphs 3 and 4). The aim is to encourage the "garimpeiros" to associate in cooperatives, and doing so, gives them priority for prospecting and mining the deposits that could be exploited by the "garimpo"- in areas where they are already working at, and in other areas that may be legally determined.

Until 1988, there was no reference made whatsoever in any legal document, to the "garimpo", as a mining activity with rights and responsibilities, rather than a mining activity always subordinate to the prospecting and mining systems. The Constitution raised the "garimpo" activity to mining system "status", recognizing it as an economically profitable and socially desirable activity.

The "Regime de Permissão de Lavra Garimpeira" ("Garimpo" Mining Permit System) was instituted as a result of these constitutional provisions, and can basically be defined as the system to be applied to the alluvium, eluvium, colluvial or other deposits, as defined by the DNPM ("Bureau of Mines"), that may be mined without the need for previous prospecting work. This law can only be applied inside well-defined areas.

The "Garimpo" Mining Permit introduced a new mining system, with rights and responsibilities, defining the difference between the Concession and the Permit systems as: the type of deposits that may be worked by the "garimpo", the individual work, and the absence of mineral prospecting studies. The cooperative was chosen as the type of organization because in the constitutional legislator's evaluation, this would hasten the social and economic development of the "garimpeiros" and make environmental preservation feasible.

These distinctions between the systems are, in fact, strictly partial, which means, for example, alluvium, eluvium and colluvial mineral deposits can be the subject of concessions under the mining concession system. On the other hand, the "Garimpo" mining permit, although a simplified mining system, may require mineral prospecting studies. The difficulty of distinguishing between the two systems has led inevitably to persistent conflicts between the two main economic agents: mining companies and “garimpeiros”.

Law No. 7805/89, which instituted the “Garimpo” Mining Permit, mainly aims to discipline “garimpo” activity. However, the concept of a simplified system was affected by the difficulty of establishing a homogeneous picture of the role of the “garimpo” activity in the mineral and even in the national scenario. The result of this situation was the regulation of dissimilar and even contradictory conceptions of the “garimpo” activity, which in practice brought about an overload of technical and bureaucratic requirements, in an attempt to regulate the Permit System, according to corporate reasoning, and ignoring that of the “garimpo”.

All these incongruities and evident contradictions denote the difficulty of legally differentiating between the various mining systems. This deadlock has been adversely affecting the mining sector because of the increasing importance of the “garimpo” activity in recent years.

The priority given to the cooperative over other systems led the legislator to exclude the small and medium-size mining companies, meaning that a large part of the “garimpo” activity has evaded legal control. Such a rationale is much more business-oriented than cooperative or individual, since “garimpo owners” are commonly known as “garimpo entrepreneurs”. It seems necessary that the small and even medium-sized companies be recognized in the Brazilian mining scenario, not only because of the “garimpo”, but principally for their own sake.

Reference to the small and medium-sized mining companies, means different rights and responsibilities from those of the so-called mining companies. This means a company with simplified legalization processes, taxed according to its size, although without losing its identity as a mining enterprise.

Equating the cooperative to the mining company is much more an enigma than a solution because, for logical and legal reasons, a cooperative is, and will always be, a cooperative and a company will always be a company. There are several types of companies, but they can never be mistaken for a cooperative.

Two points stand out in the current regulations: the priviledge of not having to carry out previous prospecting studies and doubts about the size of the area for the "garimpo".

Regarding the first point, both in the 1968 legislation and the current Law, one of the basic differences between the "garimpo" activity and mining companies was, and still is, precisely the non-existence or demand for mineral prospecting studies. This is not incidental, nor does this mean that the "garimpo" activity is being favored. The legislator's reasoning was to recognize the special nature of the "garimpo" activity due, essentially, to the type of deposit that can be mined. These are defined by law and are the alluvium, eluvium and colluvial deposits.

Regarding the second point, the size of the "garimpo" area, prevailling legislation determines that the "garimpeiros" are not allowed an area larger than 50 ha, and in spite of this restriction, this area is considered large, apparently without any plausible justification.

In short, this is a good reason, without knowing whether an area is larger than 50, 100 or 200 ha, for having large areas. "Garimpo" is an activity where prospecting studies are not required for the reasons mentioned above; therefore it does not have previously delimited mines or deposits: the limits and ore contents are uncertain and are defined as the work progresses.

It would make no sense, for example, if a cooperative requested a mining permit, which is presently a very complex process, and after one month's work has to abandon the area because the deposit is not in the requested area, or because it is not economically feasible.

Obviously, in large areas this may also occur but on a smaller scale, and as part of the risk involved in the mining activity in general. It seems that an exaggerated limitation (e.g. 50 to 100 ha) in the case of the "garimpo" and specially in the Amazon region, will make it an extremely high risk activity, making it impractical or leading to illegal practice, as currently occurs.

In the case of "garimpo", some concepts and beliefs must be clarified. One of them refers to "garimpo" phenomenon itself. What is the reason for the existence of "garimpo" in Brazil? Generally, there is only one answer, whether from the progressive or conservative sectors: the reasons are exclusively social. The serious economic crisis in Brazil has brought to the “garimpo” a large number of unemployed people with no schooling or professional qualifications, who dedicate themselves to this activity as a last choice. Hence, if the social problem is solved, the “garimpo” problem would be solved.

Looking at the problem from another angle, there are geolocial reasons which motivated the appearance and increase of “garimpo” activity in Brazil. As long as these reasons persist, there will be “garimpo” activity in Brazil, regardless of the social reasons. These social reasons may aggravate the situation, but in themselves will never be determinant. This has to be proved not only empirically, but also technically and this means that if this is true, the solution is not outside the mineral sector and that the solution to the existing conflict between miners and “garimpeiros” must come from the mineral sector itself.

The attitude taken by current legislation shares the same idea: the creation of a new mining system is a clear example, although, as explained above, this is still contradictory and incipient.

An aspect of the utmost importance in the solution to the “garimpo” problem is to know if: Is it possible to reconcile “garimpo” activity with environmental preservation? The answer to this question is crucial, since there is a progressive and inexorable movement in the direction of eliminating activities which are potentially and inevitably polluting. Certain activities can be considered as causes of greater environmental impacts than others and would be the “naturally polluting”. To eliminate such impacts requires the development of technology and investment in the production processes so that these activities would become economically impractical.

In activities that are essential to mankind , the economic cost/environmental improvement ratio may be counter-balanced by subsidies, exemptions and other forms of economic and non-economic incentives. However, the tendency in the activities defined here as naturally polluting is their transformation, when possible, from a technological and economic point of view, or their elimination.

In this aspect, is “garimpo” a naturally polluting activity? The answer to this question is complex, because it involves a complete analysis of the work methods and relations, the technology used, the environmental impacts, among other relevant aspects of the “garimpo” activity in itself, meaning that the answer at this moment must come from reflections based on discussions of the matter, rather than from results of studies on it.

Politically speaking, the matter is addressed in another way, considering that the “garimpo” activity intrinsic nature could be described as disorganized, and consequently detrimental to the mineral sector (the ore would not be suitably mined), to the environment and to society. Nevertheless, in innumerable “garimpo” sites throughout the Brazilian territory, including the States of Amazonas, Roraima, Pará, Goiás, Amapá, Acre, Tocantis and Mato Grosso, to mention only the most important, there are people working according to determined methods; the objectives and the social and professional status of each worker being clearly defined and structured. At a “garimpo”, it is immediately apparent who is in command, and it is easy to discover which task each “garimpeiro” is responsible for. This is also the case for the methods and instruments which are used for extracting the ore, or even how and by whom a certain deposit was found, what classes of “garimpeiros” exist (much more will be revealed to those who are interested and ask properly).

It is often assumed that mining companies are characteristically organized, while the “garimpo” activity is characteristically disorganized. There are disorganized companies as well as organized “garimpos” and, of course, the opposite is also true.

If there is a disorganized characteristic in the “garimpos” this is due to the fact that the cooperative’s legal nature, does not fit in with the “garimpo’s” reality, nor that of the “garimpo” workers, because they are neither partners, nor individual workers, but someone else’s employees. Any effort at regulating the “garimpo” must keep in mind the question of adapting the law to the “garimpo” reality. When the distortion of the work is mentioned, this refers to a “garimpo” system that has not existed since the sixties, although this is the concept of the “Código de Mineração” (Mining Code) and also, in part, of the recent law. This concept is perhaps mostly responsible for the current conflicts between “garimpeiros” and miners, which have led mining to become impractical in several regions of the country.

Disorganization is therefore not an intrinsic characteristic of the “garimpo”. What are then the characteristics of the “garimpo”? What is referred to when talking about the “garimpo”? What are the differences between a mining company's activity and the "garimpo" activity? The answers to all these questions are found in the law; but are they satisfactory? These questions and answers could help understand the complex reality of the "garimpo" and the regulation of this activity.

If disorganization is not a "garimpo" attribute, and a conciliation of the "garimpo" activity with environmental preservation is possible, it remains to briefly present the environmental regulations that apply to "garimpo" activities. In the first place, it should be noted that there are no substantial differences between the regulations applied to the Permit System and those applied to the other Mining Laws.

The previous Constitution (1967) on which the Mining Code was based, did not foresee environmental rules that would cover the activity of the different economic agents; hence, the Mining Code deals with this matter in a sporadic way, and only regarding one point or other. The eighties are particularly important for Brazilian environmental legislation. A set of rules and new concepts, like that of environmental preservation, were introduced in the 1988 Constitution, as well as in subsequent common law. The 1988 Constitution puts a great emphasis on the environment and requires that States and Municipalities legislate and supervise environmental matters, and that class action may void any act harmful to the environment. The Amazon Forest, the Mata Atlântica, the Serra do Mar, the Mato Grosso wetlands (Pantanal) and the Coastal Zone were declared Protected National Properties.

This legislation applies to all economic activities, including mining, although some constitutional principles had been established for the mining activity (these were demands that were previously established by law). Among them are: all activities that may cause any environmental degradation must, before being established, be preceded by an environmental impact study; responsibility for recovering the degraded environment is required from the miners; and physical or corporate agents responsible for conduct and activities considered to be harmful to the environment are subject to penal and administrative sanctions, regardless of the obligation to repair the damage caused.

On one side, the 1988 Constitution defines the exclusive competence of the Federal Government to legislate on mineral deposits, mines and other natural resources, on the other, it establishes the competence of the Federal Government, of the States and of the Federal District (DC) to legislate on the preservation of nature, protection of the soil and mineral resources and protection of the environment and pollution control. Accordingly, federal control of prospecting and mining of mineral resources, must observe the federal environmental legislation and the “Normas Suplementares Estaduais Específicas” (Specific State Supplementary Rules).

The “garimpeiro”, as is the case of the miner, must request Environmental Licensing from the “Órgão Estadual Ambiental” (State Environmental Department) or from the “Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis” - IBAMA - (Brazilian Environment Institute) (Hermann, H.; Fornasari Filho, N.; Loschl Filho, C., Universidade Estadual de Campinas, unpublished data).

Environmental licensing depends on an Environmental Impact Study - EIA. The Environmental Impact Report (RIMA) must reflect the conclusions of the Environmental Impact Study. The Environment Department holds a public hearing for presenting details about the project and its environmental impact as well as to discuss the RIMA.

3. CONCLUSIONS

This paper leads to the following conclusions:

1. Legal issues are still pending of solution for the “garimpo” to be developed as a sustainable activity.
2. This is not an easy task , since the legal instruments which regulate the activity are to be reviewed , proposed and finally approved by the Brazilian Congress House , after some lenghty consultations and negotiations .
3. Also, discussions and definitions , in legal terms, of sustainability are to be encouraged !

6. REFERENCES

LACERDA, L.D. and SALOMONS, W. (1992) Mercúrio na Amazônia: Uma Bomba Relógio Química? STA/CETEM/CNPq, Rio de Janeiro.

BARRETO, M.L (1993) Uma Abordagem Crítica da Legislação Garimpeira - SED/CETEM/CNPq, Rio de Janeiro.

SILVA, A.P.; ALBUQUERQUE, G.S. and BARRETO, M.L. (1995) The "Garimpo" Problem in the Amazon Region, Chap. 21, p. 281 in Chemistry of the Amazon, ACS Symposium Series 588, edited by SEIDL, P.R; GOTTLIEB, O.R. and KAPLAN, M.A., Washington, DC.

AKAGI, H.; MALM, O. and BRANCHES, F.J.P (1996) Human Exposure to Mercury Due to Gold Mining the Amazon, Brazil - A Review, Environmental Sciences, 4, 3, p. 199-211, Tokyo.

VILLAS BÔAS, R.C. (1997) The Mercury Problem in the Amazon Due to Gold Extraction, Journal of Geochemical Exploration, 58, p. 217-222, Elsevier, Netherlands.

VEIGA, M.M. et al. (1991) Poconé: Um Campo de Estudo do Impacto Ambiental do Garimpo. STA/CETEM/CNPq, n. 1, 113 pp., Rio de Janeiro.

COMUNIDADES RIBEIRINHAS DO TAPAJÓS: CONDIÇÕES DE VIDA E SAÚDE

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RESUMO

O estudo tem por objetivo identificar e descrever fatores clínico epidemiológicos relacionados às condições de vida e saúde de comunidades ribeirinhas do Tapajós visando a contribuir com outros estudos destinados para promover condições sustentáveis à essas populações. A partir de formulário específico foram obtidos dados demográficos, consumo de alguns nutrientes, ocorrência de doenças endêmicas; realizados exames clínico-neurológicos com tomada da pressão arterial, além de registro dos sintomas e sinais clínicos. As comunidades estudadas representam populações adultas, concentrando-se na faixa etária de 30 a 45 anos, com predomínio do sexo feminino. O tempo médio de residência local variou entre 21 e 28 anos. Serviços domésticos e lavoura representaram as atividades ocupacionais predominantes entre os ribeirinhos. História de trabalho anterior em garimpo teve a seguinte distribuição: Rainha (55,55%), São Luiz do Tapajós (22,85%) e Barreiras (26,56%). Água de consumo oriunda de poço artesanal e/ou do rio constituíram as fontes mais comuns. O consumo diário de peixes em Barreiras, São Luiz Tapajós e Rainha representa 67,0%, 82,9% e 38,9%, respectivamente. Índices de hipertensão arterial variando de 11,1% a 22,2% foram registrados na população com idade superior a 45 anos. Malária foi a doença infecciosa relatada com maior freqüência, entretanto, contraída em trabalhos de garimpagem no passado. Concluiu-se que as comunidades ribeirinhas estudadas apresentaram características semelhantes entre si, quanto aos aspectos demográficos, de saúde, saneamento e hábitos culturais. Esses fatores, associados à exposição ao mercúrio, podem torná-las vulneráveis ao desenvolvimento de intoxicação por metilmercúrio. A freqüência relativa de manifestações neurosensoriais observadas em todas as comunidades investigadas, adverte para a necessidade de estudos controlados, com o objetivo de identificar a relação direta entre a presença do metilmercúrio no organismo e essas manifestações clínicas.

Palavras chaves: Saúde e ribeirinhos. Endemias. Hipertensão arterial. Saúde e saneamento. Epidemiologia.

INTRODUÇÃO

No Brasil, como em outros países em desenvolvimento, observa-se a coexistência perniciosa das doenças infecciosas com outros problemas de saúde em crescimento: doenças crônico-degenerativas, efeitos da violência, além de doenças de origem ambiental e ocupacional (Barreto, 1998).

Particularmente na Amazônia, a prevalência das doenças infecciosas mais antigas estão relacionadas às insuficiências na estrutura de saneamento, baixas condições de vida e precariedades na distribuição dos serviços de saúde individual e coletiva, acrescida da migração descontrolada. Assim, malária, leishmaniose, tuberculose, hanseníase, têm se mantido com características endêmicas nesta Região.

Além das doenças infecciosas, a Amazônia tem contribuído com importantes índices de morbidade e mortalidade por doenças crônico-degenerativas. Um exemplo marcante são os índices elevados de câncer do colo de útero do país, registrado no Estado do Pará.

Os efeitos da poluição ambiental decorrente da atividade garimpeira de ouro na região têm contribuído para a exposição ocupacional (Grandjean *et al.,* 1993) e ambiental ao mercúrio (Pinheiro, *et al.* 2000), com risco previsto para ocorrência de novas formas de doenças na Amazônia (Nakanishi *et al.,* 2000).

A Região do Tapajós compreende muitos povoados típicos da Amazônia, na forma de vilas e aglomerados rurais, localizados às margens do Rio Tapajós. Essa distribuição dificulta, por vezes, a realização de estudos sistematizados que permitam melhor avaliação da condições de saúde regional.

Nas últimas décadas, com o crescimento da atividade garimpeira de ouro, que exige a utilização de quantidades expressivas de mercúrio, alguns estudos têm sido desenvolvidos em grupamentos que habitam a região, no sentido de investigar a saúde das populações, principalmente daquelas expostas ao mercúrio. Santos, *et al.*, 1995, apresentaram dados sobre a saúde e as condições de vida e trabalho de garimpeiros da região, em estudo realizado em 1992. Outros trabalhos avaliaram o impacto da poluição ambiental sobre a exposição humana ao metilmercúrio em ribeirinhos (Pinheiro *et al.,* 2000, Santos *et al.*, 2000, Harada *et al.,* 2000).

Embora sejam conhecidas as interações de determinados fatores na gênese de processos patológicos, os dados epidemiológicos existentes para as áreas ribeirinhas da Amazônia, são ainda pouco precisos e dispersos. Neste sentido, este trabalho propõe uma avaliação descritiva, baseada em observações de dados clínicos epidemiológicos das condições de vida e saúde de povoados não indígenas situados à margem do Tapajós.

OBJETIVOS

Geral

Contribuir para a realização de novos estudos destinados a melhoria de condições de vida, saúde e saneamento direcionados às populações tradicionais Amazônicas, que visem àa prevenção e o controle dos agravos à saúde dessas populações.

Específicos

1- Identificar fatores clínico-epidemiológicos relacionados às condições de vida e saúde da população ribeirinha adulta do Tapajós;

2- Descrever as condições de saúde e saneamento nas comunidades ribeirinhas expostas ao Hg.

METODOLOGIA

O estudo consiste de uma avaliação observacional descritiva, ocorrida por ocasião de duas visitas realizadas em julho/200 e janeiro/2001 a três comunidades ribeirinhas do Tapajós: Rainha, São Luiz do Tapajós e Barreiras, cujos índices de exposição ao mercúrio são elevados e vêm sendo monitorados desde 1994.

Essas comunidades pertencem à microrregião geográfica de Itaituba, situada na mesorregião do Sudoeste paraense.

Características das comunidades estudadas:

- ***Rainha:*** povoado de aproximadamente 150 habitantes, situado à montante do centro de comercialização aurífera de Itaituba, na margem direita do Rio Tapajós. O universo pesquisado envolveu 18 adultos (9 homens e 9 mulheres).
- ***São Luiz do Tapajós (SLT):*** povoado localizado à margem direita do Rio Tapajós, à montante de Itaituba. Possui uma população estimada em 1000 habitantes (PRIMAZ, 1996) e uma população observada, em jan/2001, de 490 habitantes. O universo pesquisado envolveu 35 adultos, sendo 25,7% homens e 74,3% mulheres.
- ***Barreiras (BRR):*** povoado localizado à margem esquerda do Rio Tapajós, cerca de 80 Km à jusante de Itaituba. A população estimada em 1996 (PRIMAZ) foi de 1000 habitantes. Em jan/2001 tinha uma população real de 745 habitantes (observação local). O universo pesquisado envolveu 64 adultos sendo 39,1% homens e 61,94% mulheres.

Critérios de inclusão:

- residente por período igual ou maior a 1 ano;
- ser adulto (idade maior ou igual a 14 anos);
- independente de índice de HgT conhecido em amostras de cabelo.

Os dados para análise foram extraídos do formulário clínico-epidemiológico específico para o registro de dados de interesse do *Programa de Investigação à Saúde de Ribeirinhos*, desenvolvido pelo NMT/UFPA desde 1994.

Assim sendo, foram obtidos:

1) dados demográficos (idade, sexo, tempo de residência, ocupação anterior, ocupação atual);
2) informações sobre consumo de alguns nutrientes: água e proteína. Estabeleceu-se a freqüência de consumo em: **diário** (1 a 3 refeições diárias – durante 5 a 7 dias da semana); **semanal** (1 a 3 refeições durante 1 a 4 dias da semana); **mensal** 1 a 3 refeições/dia com intervalos de no mínimo duas semanas; **não consome**, ausência de peixe na alimentação;
3) ocorrência de doenças infecciosas endêmicas;
4) registro de hipertensão arterial (índices igual ou maior que 140x90);
5) dados sobre manifestações clínicas, de acordo com sinais e sintomas relacionados com órgãos e sistemas, conforme discriminado abaixo:

- manifestações gastrointestinais: náuseas e/ou vômitos, diarréia, cólicas intestinais, epigastralgia, pirose;
- manifestações respiratórias: tosse, dispnéia, coriza
- cardiovasculares: hipertensão arterial, precordialgia, edema de membros inferiores generalizados.
- neurosensoriais: distúrbios visuais, parestesias, distúrbios auditivos, de memória, tumores.
- osteoarticulares: artralgias, lombalgia, cervicalgia;
- genito urinário: disuria, amenorréia, cólica nefrítica, poliúria;
- dermatológicas: manchas, nódulos, feridas, etc.

Critérios de exclusão:

- indivíduos em trânsito na comunidade
- pessoas que não concordou em ser investigado

Aspectos éticos

O estudo faz parte do Projeto **Toxicidade do Metilmercúrio (MeHg) em Áreas sob a Influência da Garimpagem de Ouro na**

Amazônia que está sendo desenvolvido de acordo com a Resolução 196/96 e foi submetido a apreciação ética e aprovado pelo Comitê de Ética do NMT/UFPA em 20/12/2000.

Resultados e Discussão

Essas comunidades são constituídas por pessoas jovens em plena força de trabalho. Concentram uma população feminina jovem em idade de procriação e, em sua maioria, são residentes nativos vivendo no local desde o nascimento (t*abelas 1* e *3*).

Tabela 1 - Distribuição da população por faixa etária e sexo segundo localidade - janeiro/2001

	Rainha			São Luiz do Tapajós			Barreiras		
Faixa etária	**Masculino**	**Feminino**	**Total**	**Masculino**	**Feminino**	**Total**	**Masculino**	**Feminino**	**Total**
14-29	0	4	4	3	16	19	7	18	25
30-45	7	2	9	3	6	9	7	11	18
46-61	2	3	6	3	3	6	7	7	14
62-73	-	-	-	-	1	1	4	3	7
Total	**9**	**9**	**18**	**9**	**26**	**35**	**25**	**39**	**64**

Dados obtidos em trabalho de campo em janeiro/2001

Os índices de exposição ao mercúrio entre as comunidades variaram de 9,2%±2,9 à 20,5±12,1 µg/g, conforme estudos realizados pelos autores no período de 1994 à 1998, *tabela 2.* Outros estudos realizados na região mostraram também índices de exposição humana ao mercúrio (Akagi *et al*., 1996, Santos *et al*., 2000).

Tabela 2 - Índices de Mercúrio em Amostras de Cabelo de Comunidades Ribeirinhas do Tapajós. 1994-1998.

Localidade	Mês/Ano	Nº de amostras	Hg total cabelo ($\mu g/g^{-1}$)	MeHg	% de MeHg	Hg Total Min-Max
Barreiras	Mar/94	26	20,5 ± 12,1	18,5 ± 11,0	90,2 ± 5,3	7,2 – 62,9
	Mar/95	52	17,7 ± 12,1	15,8 ± 11,1	87,8 ± 6,6	0,6 – 50,6
	Out/96	46	16,3 ± 12,5		–	2,2 – 56,3
	Ago/96	33	18,5 ± 12,5		–	4,1 – 71,5
	Nov/98	76	16,4 ± 10,6		–	1,8 – 53,8
Rainha	Mar/94	16	19,3 ± 9,7	18,3 ± 8,5	96,0 ± 4,6	5,5 – 39,0
	Mar/95	13	15,9 ± 6,2	14,3 ± 6,1	89,1 ± 3,8	7,1 – 26,5
	Nov/98	12	14,2 ± 9,3		–	3,1 – 34,5
São Luiz do Tapajós	Ago/96	30	25,3 ± 12,5		–	3,0 – 48,3
	Nov/98	44	20,6 ± 10,5		–	5,1 – 42,2
Paraná Mirim	Ago/96	21	9,2 ± 2,9		–	2,9 – 14,9

Dados obtidos em trabalho de campo realizados no período de março/1994 a novembro/1998

As comunidades estudadas foram representadas por população adulta, concentrando-se na faixa etária de 30 a 45 anos, com predomínio no sexo feminino e tempo médio de residência local entre 21 e 28 anos. Serviços domésticos e na lavoura representaram as atividades ocupacionais atuais predominantes entre os ribeirinhos. História de trabalho anterior em garimpo foi relatada em 55,5% (Rainha), 22,8% (São Luiz do Tapajós) e 26,5% (Barreiras), *tabelas 1 e 3*.

Tabela 3 - Características demográficas da população adulta - Itaituba/2001

Localidades / Dados demográficos	Rainha (18)	São Luiz do Tapajós (35)	Barreiras (64)
Idade			
m(min-max)	39,7(23-59)	31,9(14-66)	38,6(14-73)
Sexo M:F	9:9	9:26	25:39
Tempo de residência- anos m(min-max)	21(12-55)	24,3(2-49)	28,3(3-73)
ocupação anterior garimpeiro	10(55,5)	8(22,8)	17(26,5)
ocupação atual			
doméstica	8(44,4)	19(54,2)	37(57,8)
lavrador	4(22,2)	5(14,2)	10(15,6)
estudante	-	4(11,4)	5(7,8)
serviços gerais	-	1(2,8)	5(7,8)
pescador	3(16,6)	3(8,5)	4(6,2)
outros	3(16,6)	3(8,5)	3(4,6)

Dados obtidos em trabalho de campo em janeiro/2001

Considerando-se as fontes de consumo dos principais nutrientes (água e proteína) entre as comunidades estudadas, Rainha distinguiu-se das demais, quanto ao número de opções de fonte de água para consumo (rio, poço e gruta) e quanto à menor freqüência de consumo diário do pescado (38,9%). Alguns fatores justificam esse índice: acesso mais fácil à zona urbana de Itaituba, disponibilidade de outras fontes de proteínas local, face à existência na comunidade de pequena fazenda de pecuária diversificada, propriedade das famílias.

De várias maneiras a água pode afetar a saúde do homem, como: ingestão direta, preparação de alimentos, higiene pessoal, agricultura, indústria ou lazer.

Os riscos para a saúde relacionados à água podem ser distribuídos nas seguintes categorias principais: riscos relacionados com a ingestão de água contaminada por agentes biológicos (vírus, bactérias e parasitas), contato direto, por meio de insetos vetores que necessitam de água para o seu ciclo biológico; riscos derivados de poluentes químicos e radioativos, geralmente de esgotos industriais.

Considerando as informações obtidas, a exposição a agentes infecciosos através da água de consumo entre os ribeirinhos, pode ocorrer por qualquer uma das fontes citadas (*tabela 4*), tendo em vista que, o tratamento dessa água não constitui um hábito comum entre os ribeirinhos estudados. O uso de hipoclorito de sódio (NaOCl) foi relatado por uma minoria de pessoas da comunidade de Barreiras. Além da carência no sistema de abastecimento de água, inexiste um sistema de saneamento básico.

Tabela 4- Principais fontes nutricionais e freqüência de consumo nas comunidades ribeirinhas - Itaituba/2001

Localidades	**Rainha (18)**	**São Luiz do Tapajós (35)**	**Barreiras (64)**
		N(%)	
poço	6(33.3)	33(94.3)	61(95.3)
rio	6(33.3)	2(5.7)	3(4.7)
gruta	6(33.3)	-	-
Consumo de peixes (%)			
diário	7(38.9)	29(82.9)	43(67)
semanal	11(61.1)	5(14.3)	20(31.3)
mensal	-	-	1(1.6)
não consome	-	-	-
sem informação	-	1(2.9)	-

Dados obtidos em trabalho de campo em janeiro/2001

Também tem sido observada a ocorrência de exposição a agentes químicos, a exemplo do mercúrio. Estudos realizados por Pinheiro *et al.,* 2000, Akagi *et al.,* 1996, Santos *et al.,* 2000, demonstraram a exposição de ribeirinhos do Tapajós ao mercúrio. A freqüência relativa de consumo diário de peixes observada entre as comunidades estudadas, sugerem que essa exposição está relacionada com o consumo diário de peixes da região (*tabela 4*).

Apesar de Rainha, ter freqüência de consumo diário de pescado menor que os demais povoados, a freqüência relativa de consumo semanal de 61,1% parece ter também importância para a exposição, considerando que essa mesma comunidade apresentou índices de exposição ao mercúrio ao longo do período de 1994 à 1998 (*tabelas 2 e 4*).

Sobre a freqüência do consumo do pescado, estudos revelam um efeito protetor para doenças cardiovasculares associado a quantidade de gorduras insaturadas e ácidos graxos Ω3 em grupos de pessoas que consomem regularmente peixe. Outros estudos indicam que uma dieta rica em peixes contém ácidos graxos potencialmente oxidáveis com uma relação antioxidante/pró-oxidante menos favorável que uma dieta com baixa quantidade de peixe (Anttolainen *et al.,* 1996).

Em recente estudo prospectivo, o mercúrio derivado de peixe tem sido associado com um risco maior de doenças cardíacas coronarianas, doença cardiovascular e morte súbita (Saloneen *et al.,* 1995). O mecanismo de ação do MeHg foi sugerido pelos autores ser através da peroxidação lipídica *in vivo*.

A hipertensão arterial é uma condição clínica associada ao aumento de riscos para doenças cardiovasculares, a elevação da morbidade e mortalidade na população adulta, principalmente nos grandes centros urbanos. As formas mais simples de hipertensão que podem ser analisadas geneticamente são as chamadas formas mendelianas, ou seja, aquelas nas quais a mutação em um único gene é suficiente para produzir aumento da pressão arterial. Apesar dessas síndromes serem raras, o seu estudo poderá fornecer informações para a compreensão da interação entre genes e destes com fatores ambientais que podem participar da gênese da hipertensão arterial essencial (Krieger, 1999). Índices de hipertensão arterial variando de 11,1 a 22,2% foram registrados na população com idade superior a 45 anos (*tabela 5*). Assim sendo, é importante considerar a hipótese de que a hipertensão em ribeirinhos, associada ao consumo de peixes contaminados por mercúrio, pode representar um risco maior para doenças cardiovasculares nessa população.

Tabela 5 - Ocorrência de hipertensão arterial em ribeirinhos - Itaituba/2001

Localidades	Rainha (18)	São Luiz do Tapajós (18)	Barreiras (47)
número de casos	2	4	6
(%)	11,1	22,2	12,8

Dados obtidos em trabalho de campo em janeiro/2001

Com relação à ocorrência de doenças infecciosas endêmicas, a malária foi registrada com uma freqüência relativa maior do que as demais doenças, sendo que, dentre as três comunidades estudadas, o povoado de Rainha apresentou maior registro de casos (*tabela 6)*. Entretanto é importante ressaltar que os casos registrados foram adquiridos em anos passados, ocasião em que exerciam atividades em áreas de garimpo. A observação desse fato chama atenção para a necessidade de esclarecimento sobre o risco de transmissão da malária dentro da comunidade, para que medidas de prevenção possam ser adotadas.

Tabela 6 - Ocorrência de doenças infecciosas (endemias) em ribeirinhos - Itaituba/2001

Localidades	Rainha (18)	SLT (35)	Barreiras (64)
		N(%)	
malária	14(77.8)	13(37.1)	14(21.9)
Leishmaniose cutânea(LTA)	-	1(2.9)	2(3.1)
hepatite	3(16.7)	1(2.9)	3(4.7)
hanseníase	-	1(2.9)	1(1.6)
tuberculose	-	-	2(3.1)

Dados obtidos em trabalho de campo em janeiro/2001

A freqüência do uso de substâncias tóxicas foi observada entre os habitantes dos três povoados. O consumo de cigarro foi registrado em freqüência superior ao consumo de bebidas alcoólicas. Não houve registro do uso de droga ilícita em nenhuma das comunidades estudadas (*tabela 7)*.

Tabela 7 - Freqüência de uso de substâncias tóxicas – Itaituba/2001

Localidade	Rainha (18)	São Luiz do Tapajós (35)	Barreiras (64)
		N(%)	
fumo	2(11,11)	9(25,71)	12(18,75)
álcool	1(5,55%)	5(14,28)	4(6,25)
drogas ilícitas	-	-	-
medicamentos (uso prolongado)	-	-	3(4,68)

Dados obtidos em trabalho de campo em janeiro/2001

O consumo regular de álcool entre os ribeirinhos mostrou um freqüência relativamente maior na comunidade de São Luiz do Tapajós (25,71%). O álcool está implicado na gênese de doenças hepática, pancreática, cardíaca, neurológica e outras.

Sabe-se que o fumo e o álcool constituem elementos tóxicos envolvidos na patogênese de vários processos mórbidos. Assim, o hábito de fumar é um importante fator de risco independente para o infarto do miocárdio e outras doenças cardiovasculares, atuando sinergicamente com outros fatores de risco, tais como a hipertensão arterial e níveis elevados de colesterol sangüíneo. O fumo é também um importante fator na indução de câncer de pulmão, de doenças pulmonares crônicas e exerce efeito maléfico sobre a gravidez e o feto.

Um trabalho sobre a educação e saúde para as comunidades do estudo deve ser recomendado informando-as sobre o risco associado a esses hábitos.

A freqüência de pessoas apresentando sinal ou sintoma de doença foi 77,7% em Rainha, 74,28% em São Luiz do Tapajós e 54,68% em Barreiras (*tabela 8*). As manifestações osteoarticulares (cervicalgia, lombalgia, artralgia) e neurosensoriais (alterações visuais, auditivas, distúrbio de memória, parestesias) apresentaram as maiores freqüências relativas.

As manifestações neurológicas, associadas ao alcoolismo, estão geralmente combinadas com deficiências nutricionais, a exemplo da encefalopatia de Wernicke, causada pela deficiência de tiamina (vitamina B1) caracterizada clinicamente por confusão mental, ataxia, motilidade ocular anormal e polineuropatia (Rubin *et al.,* 1990). Essas manifestações podem ser observadas também em indivíduos expostos ao metilmercúrio (Fugino, 1994).

Embora o estudo tenha sido realizado em ribeirinhos expostos a índices altos de mercúrio e, os índices de manifestações neurosensoriais entre os indivíduos estudados tenha sido elevado nas três comunidades (*tabela 8)* não se pode, ainda, inferir a relação direta desse metal na gênese dessas manifestações. É importante ressaltar que doenças osteoarticulares que também foram observadas entre os ribeirinhos podem ainda ser responsáveis pelas manifestações neurosensoriais encontradas.

Tabela 8 - Freqüência de manifestações clínicas em adultos - Itaituba/2001

Localidade	**Rainha**	**SLT**	**Barreiras**
total de sujeitos pesquisados	18	35	64
sem sintomas	4(22,22)	9(25,71)	29(45,31)
com sintomas	14(77,77)	26(74,28)	35(54,68)
gastrointestinais	2(11,11)	6(17,14)	7(10,93)
respiratórios	3(16,66)	1(2,85)	2(3,12)
cardiovasculares	2(11,11)	5(14,28)	6(17,1))
osteoarticulares	4(22,22)	4(11,42)	9(14,06)
genitourinários	3(16,66)	-	
neurosensoriais	8(44,44)	12(34,28)	18(28,12)
dermatológicos	-	3(8,57)	2(3,12)
outros (cefaléia)	3(16,66)	10(28,57)	17(26,56)

Dados obtidos em trabalho de campo em janeiro/2001

CONCLUSÃO

Conclui-se que as comunidades ribeirinhas estudadas apresentam algumas características semelhantes entre si, quanto aos aspectos demográficos, de saúde, saneamento e hábitos culturais. Esses fatores, associados à exposição ao mercúrio, podem torná-las vulneráveis ao desenvolvimento de intoxicação por metilmercúrio em suas diferentes formas.

A freqüência relativa de manifestações neurosensoriais observadas em todas as comunidades investigadas adverte para a necessidade de estudos controlados, com o objetivo de identificar a relação direta entre a presença do metilmercúrio no organismo e essas manifestações clínicas.

Diante do exposto, observa-se a necessidade de uma melhor atenção às condições de vida e saúde das populações ribeirinhas do Tapajós.

REFERÊNCIAS BIBLIOGRÁFICAS

1 Barreto, M. L. (jul/ago, 1998): Emergência e Permanência das Doenças infecciosas Médicos HC-FMUSP. ***1***(3):18-23

2 Pinheiro, M. C. N., Guimarães, G. A, Nakanishi, J., Oikawa, T., Vieira, J. L., Quaresma, M., Cardoso, B., Amoras, W. (2000): Avaliação da Contaminação Mercurial Mediante Análise do Teor de Hg Total em Amostras de Cabelo em Comunidades Ribeirinhas do Tapajós, Pará, Brasil. *Revista da Sociedade Brasileira de Medicina Tropical.* ***33***(2):181-184.

3 Pinheiro, M. C. N., Nakanishi, J., Oikawa, T., Guimarães, G. A., Quaresma, M., Cardoso, B., Amoras, W., Harada, M., Magno, C., Vieira, J. L. F., *et al.* (2000): Exposição Humana ao Metilmercúrio em Comunidades Ribeirinhas do Tapajós, Pará, Brasil. *Rev. Soc. Bras. Med. Trop.* ***33***(3):265-269.

4 Grandjean, P., Cardoso, B., Guimarães, G. (1993): Mercury Poisoning. *The Lancet. 342:991*.

5 Nakanishi, J., Konuma, S. Oikawa, T., Pinheiro, M. C. N. (1997): Risk – Based Evaluation of Countermeasures Against Mercury Pollution in the Amazon and Minamata. In: *International*

Conference Human Health Effects of Mercury Exposure. Tórshaun, Faroe Islands, June 22-26.

6 Santos, E. C. O., Loureiro, E. C. B., Jesus, I. M., *et al.* (abr/jun,1995): Diagnóstico da Condições de Saúde de uma Comunidade Garimpeira na Região do Rio Tapajós, Itaituba, Pará, Brasil, 1992. *Caderno de Saúde Pública, RJ.* ***11***(2):212-225.

7 Santos, E. C. O., Jesus, I. M., Brabo, E. S., Loureiro, E. C. B., Mascarenhas, A. F. S., Weirich, J., Câmara, V. M. (2000): Mercury Exposures in Riverside Amazon Communities in Para, Brazil. *Environmental Research* ***84***:100-107.

8 Harada, M. Nakanishi, J., Yasoda, E. Pinheiro, M. C. N., Oikawa, T., Guimarães, G. A., Cardoso, B. S., (2000): Mercury Pollution in the Amazon Basin, Brazil. In: *International Conference on Heavy Metals in the Environmental* August. 6-10. Ann Arbor, MI.

9 Ministério de Minas e Energia. Governo do Estado do Pará. Prefeitura Municipal de Itaituba. Programa de Integração Mineral no Município de Itaituba (PRIMAZ) Desenvolvimento Municipal; 1996:9-10

10 Akagi, H., Malm, O., Branches, F. J. P. (1996): Human Exposure to Mercury Due to Gold Mining in the Amazon, Brazil. *A Review. Environmental Science* ***4***(30):199 – 211.

11 Anttolainen, M., Valsta, L. M., Alflham, G., *et al.* (1996): Effect of Extreme Fish Consumption on Dietary and Plasma Antioxidant Levels and Fatty Acid Composition. *European Journal of Clinical Nutrition.* ***50***:741-746.

12 Saloneen, J. *et al.* (1995): Intake of mercury from fish, lipidy peroxidation, and the risk of myocardial infarction and coronary, cardiovascular, and any death in eastern Finnish men. *Circulation.* ***91***:645-655.

13 Krieger, J. E. (1999): Mapeamento dos Genes Responsáveis pela Hipertensão Arterial. Médicos HC-FMUSP. ***6***:59-61.

14 Rubin, E., Farber, J. L. (1990): Patologia Ambiental e da Nutrição. *Patologia.* Tio de Janeiro: Interlivros. 248-269.

15 Fugino, T. (1994): Clinical and Epidemiological Studies on Chronic Minamata Disease, Part 1: Study on Katsurajima Island. *Kumamoto Med. J.* ***44***(4):139-155.

POLUIÇÃO POR MERCÚRIO E SAÚDE HUMANA NO VALE DO TAPAJÓS

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INTRODUÇÃO

O trabalho se propõe a registrar, de forma superficial, as circunstâncias que nos últimos trinta anos vem condicionando a saúde humana na região, na medida em que as mesmas se refletem em alterações do meio ambiente e na capacidade do homem regional para defender sua vida e integridade.

A distribuição populacional característica da região, assim como a composição das populações Amazônicas, têm sido grandemente afetadas pela política de desenvolvimento adotada pelo Estado. Com o propósito de integrar a Amazônia ao esforço de modernização do país, o governo brasileiro promoveu, a partir da segunda metade dos anos 60, diversas estratégias que consistiram principalmente na abertura de estradas ligando a Amazônia ao resto do país; na implantação de usinas hidrelétricas que estimulariam o desenvolvimento industrial da região; na transformação de órgãos oficiais em agentes de distribuição de incentivos fiscais a empresas privadas; implantação de um sistema de comunicações difundido por satélite; na ampliação do regime de incentivos fiscais e financeiros; na concentração de recursos nos chamados "pólos de desenvolvimento agropecuário e agrominerais" e na tentativa de implantação de programas de exploração integrada (Santos *et al*., 1992).

Essas estratégias estimularam a vinda de imigrantes oriundos de outras regiões, resultando em acelerada e desordenada ocupação dos espaços amazônicos, alterando o equilíbrio natural do ambiente, agravando e dispersando as endemias locais, introduzindo outras anteriormente inexistentes e degradando o meio ambiente regional, promovendo risco à saúde em decorrência do aumento da concentração de poluentes. Entre estes poluentes destaca-se o mercúrio utilizado no processo de produção de ouro (Câmara & Corey, 1992; Santos, 1993, Santos *et al*., 1995).

Consequentemente a isso houve uma sensível desatualização da infra-estrutura de atendimento no campo da saúde e do saneamento, da alfabetização e da educação fundamental, do abastecimento alimentar e de consumo em geral, de criação e recomposição do emprego, treinamento de mão-de-obra, transporte da produção e de passageiros, hierarquização equilibrada das cidades surgentes e dos centros urbanos tradicionais.

No campo, a ocupação da floresta pelos projetos agropecuários, madeireiros, por estradas, construções de hidrelétricas, exploração mineral e demais recursos naturais, tem expulsado sistematicamente as populações pré-existentes para fronteiras mais longínquas, e causado graves desequilíbrios ambientais (Santos *et al*., 1992).

A saúde das populações regionais, autóctones ou imigrantes, não poderia ficar indiferente a tão numerosas e expressivas mudanças a interferirem com intermitência quotidiana no meio ambiente, no regime de trocas sociais, no movimento geográfico das populações, nos contactos humanos, na expansão ou estimulação de agentes etiológicos das enfermidades.

A garimpagem de ouro, cujos primeiros registros na Amazônia remontam ao século XVIII, começou a proliferar significativamente na região na década de 70, com o Plano de Integração Nacional e a construção das rodovias Transamazônica e Cuiabá-Santarém (Santos *et al*., 1992).

Até a segunda metade da década dos 70, a lavra garimpeira na Amazônia era exclusivamente manual e se localizava tradicionalmente nas planícies de inundação dos cursos d'água, nos paleo-aluviões e, mais raramente, em aluviões ativos, apoiada em equipamentos rudimentares como pás, picaretas, etc, e o mercúrio só era usado na concentração final do minério. A partir daí, o trabalho passa a ser desenvolvido com o auxílio de maquinário que retira o capeamento do solo através de desmonte hidráulico utilizando um conjunto de moto-bomba. Agora, o mercúrio (azougue), além de ser usado na caixa concentradora, é lançado diretamente nos barrancos. Em alguns locais como nos rios Madeira e Tapajós, a garimpagem é igualmente feita no próprio leito ativo das drenagens com a utilização de balsas e dragas, quando então a agressão ao ecossistema aquático é mais grave e o assoreamento do rio mais rápido (Governo do Estado do Pará, 1992).

Paralelamente à instalação do processo garimpeiro, outras atividades capazes de liberar o metal que pode residir na composição normal da floresta, foram tendo gradual aumento, tais como o desmatamento, as queimadas, as barragens e a construção de hidrelétricas, também responsáveis pela emissão de quantidades significativas do metal para a atmosfera e sistemas aquáticos. Essas diferentes formas de emissão do mercúrio para o ambiente contribuem para a incorporação do metal nas drenagens e na poluição da biota aquática, que serve de veículo para levar o mercúrio na sua forma metilada, até o homem, como ápice da cadeia alimentar (Santos, 1993; Veiga *et al*., 1994; Santos *et al*.,1995; 2001; Akagi *et al*, 1995; 1996, Brabo *et al*., 1999a; Fostier *et al*., 1999; Zeidemann *et al*., 1999).

O Instituto Evandro Chagas – IEC, que integra a estrutura organizacional da Fundação Nacional de Saúde/FUNASA//Ministério da Saúde/MS, vem realizando pesquisas nas áreas biomédica e ambiental e fazendo parte do Sistema Nacional de Vigilância Epidemiológica e Ambiental. Também possui atribuição de referência nacional para ações de laboratório de saúde pública e de vigilância epidemiológica e ambiental das doenças e agravos com importância epidemiológica na Amazônia Legal, atuando ainda como centro formador de recursos humanos e de apoio e supervisão técnica às unidades estaduais localizadas nesta região.

Neste sentido, foi criada em 1992 a Coordenação de Ecologia Humana e Meio Ambiente - COEHMA, hoje Seção de Meio Ambiente - SAMAM, com o objetivo de desenvolver estudos dos impactos ambientais na região amazônica e seus efeitos sobre a saúde da população e sobre o ambiente.

SAÚDE E MEIO AMBIENTE NA AMAZÔNIA

A saúde humana é parte de um conjunto alternativo cujo outro extremo é a doença, e na concepção de Dubos esse processo saúde/doença pode ser medido pela avaliação do maior ou menor sucesso do homem em suas diferentes interações com o meio ambiente (Dubos, 1989). A compreensão do conjunto exige informações, as mais variadas, sobre o universo da sociedade humana, no qual fatores de natureza físico-química, biológica, sócio-econômica e cultural interferem, facilitando ou impedindo as oportunidades de sucesso e instalação da doença.

As condições de vida e o meio ambiente peculiares à região amazônica influenciam cotidianamente o desempenho das populações residentes, que coexistem com a falta de saneamento básico e seu cortejo de agravos, com as endemias locais incluindo as hepatites e a malária, com as doenças em decorrência das circunstâncias penosas do trabalho na roça, no garimpo ou na floresta, e com a precariedade de procedimentos preventivos, tudo agravado pela falta de atendimento médico. A exposição ao mercúrio é a ameaça mais recente (Santos *et al*., 1995).

PROGRAMA DE TRABALHO

Como primeiro Programa de trabalho a SAMAM/IEC vem pesquisando o perfil de saúde, inclusive a exposição ao mercúrio, de populações humanas residentes em ambientes epidemiológicos diversos, situados na bacia hidrográfica do rio Tapajós, área de poluição ambiental por mercúrio, assim como comunidades fora da área de risco do mercúrio oriundo da garimpagem, que tenham em comum o mesmo hábito alimentar, como forma de estabelecer controle para as demais pesquisas, e construir parâmetros de “normalidade” para a região. Esses estudos foram iniciados em 1992 e vêm sendo desenvolvido através de diferentes projetos.

O objetivo do Programa é conhecer a situação e identificar os riscos presentes que possam atingir a integridade da saúde humana regional e degradar a qualidade de vida das comunidades.

A área geográfica da pesquisa foi definida inicialmente como a Bacia do rio Tapajós entre Santarém e Jacareacanga, no Estado do

Pará, envolvendo os diferentes municípios localizados nesse percurso (Santos *et al*., 1999a; 1999b; 2000). Posteriormente o Estado do Acre foi incluído nas investigações.

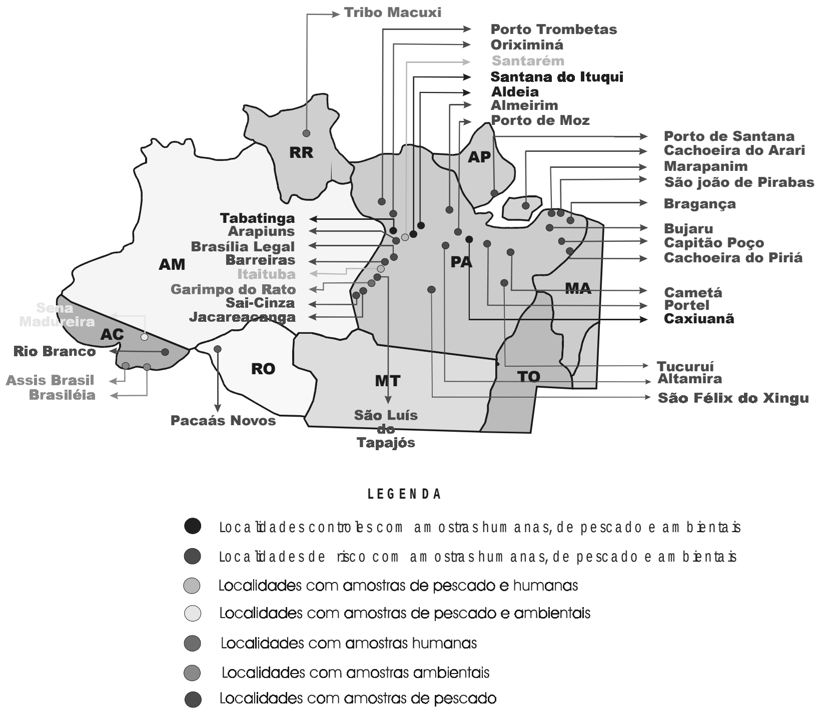
Em relação à Bacia do Tapajós, esta região foi responsável em 1980 por cerca de 50% do ouro produzido no Brasil, sendo que a maior concentração de garimpos localiza-se nos municípios de Itaituba e Jacareacanga, onde ficam as principais fontes de emissão do metal proveniente da garimpagem, nessa região (Silva *et al*., 1989; Ramos, 1992; Santos *et al*., 1992). De acordo com dados oficiais sobre a produção de ouro o Brasil produziu 98,2 toneladas de ouro em 1990, enquanto em 1998 esta produção foi de 49 toneladas. No mesmo período os garimpos foram responsáveis por uma produção de ouro que variou de 63,6 a 11,8 toneladas (DNPM - SEICOM 1999).

As primeiras linhas de investigação definidas pelo programa de trabalho foram as seguintes:

1) Investigação das populações de risco de intoxicação por mercúrio através da via respiratória. Esse grupo é composto pelos garimpeiros, sobretudo os queimadores do amálgama (ouro/mercúrio), pelas pessoas que trabalham nas casas de compra e venda de ouro e em joalherias, e pelos residentes de casas situadas nas proximidades dos locais em que o ouro é queimado, e que venham a inalar os vapores do metal dispersados pelo vento.
2) Investigação das populações de risco de intoxicação por mercúrio através da via alimentar. Envolve as populações ribeirinhas inclusive as indígenas, cuja principal, e as vezes única, fonte de proteínas é o pescado.
3) Investigação em comunidades ribeirinhas fora da área de risco de contaminação pelo mercúrio da garimpagem, com os mesmos hábitos alimentares, como forma de construir parâmetros de normalidade regional que possam servir de base para análises comparativas posteriores.
4) Investigação dos níveis de mercúrio da biota característica da bacia do rio Tapajós, sobretudo o pescado, já que o mesmo é a principal fonte de proteínas das populações ribeirinhas.

5) Investigação em solos e sedimentos de diferentes pontos em cada localidade estudada.

6) Investigação ambiental no Estado do Acre, onde não existe registro de atividade garimpeira, envolvendo solos, sedimentos, a biota aquática e populações humanas.



METODOLOGIA DO PROGRAMA

O método de trabalho utilizado em todas as investigações de saúde humana, no campo, foi de natureza epidemiológica, estruturado sobre a clínica, a estatística e os resultados laboratoriais.

As atividades de campo abrangeram os seguintes aspectos:

a) Realização do censo da comunidade, com aplicação de ficha e visita em todas as residências, trinta dias antes da pesquisa.

b) Apresentação de um documento de consentimento e aplicação individual de um questionário epidemiológico, incluindo informações sobre identificação, condições de vida, história ocupacional, hábitos alimentares e morbidade.

c) Montagem de um laboratório de campo para coleta, identificação, separação e conservação de espécimes biológicos e ambientais, e para algumas análises clínicas e hamatológicas.

d) Atendimento médico com a observação de sinais e sintomas gerais e exame físico especial com atenção para disfunções da fala e da visão, disfunções do equilíbrio estático e do equilíbrio dinâmico, da coordenação motora, da sensibilidade tátil e dolorosa, do tônus muscular e da posição segmentar.

e) Coleta de espécimes biológicos na população geral, com ou sem queixa clínica no momento.

f) Coleta de pescado.

Entre todos os entrevistados são coletados os espécimes abaixo relacionados, segundo as respectivas finalidades:

(a) Urina - quando houve indicação clínica ou quando era indicada para análise de mercúrio.

(b) Cabelo - quantificação de mercúrio total.

(c) Sangue/soro - estudos de prevalência, diagnóstico de malária, hemograma, algumas dosagens hematológicas e bioquímicas, e determinação de mercúrio.

a) Fezes - parasitoscopia direta.

Todos os dados obtidos são armazenados em microcomputador utilizando o banco de dados dBase, e analisados através de programas estatísticos.

PESQUISAS DESENVOLVIDAS

Sobre as pesquisas que já desenvolvemos ou estamos desenvolvendo, e que visam a esclarecer os impactos que a presença desequilibrada do mercúrio possa estar causando à saúde humana, oferecemos a seguir algumas informações.

Quanto aos efeitos precoces da intoxicação por mercúrio em populações humanas expostas e métodos diagnósticos apropriados para a região, já foram estudadas seis populações ribeirinhas, das quais duas indígenas, uma população garimpeira, e dois grupos de queimadores de ouro.

Sobre o conhecimento dos valores de referência (background) regional, já investigamos quatro populações ribeirinhas.

Para conhecer os teores de mercúrio em peixes de todas as bacias hidrográficas da região, analisando estes resultados à luz dos conhecimentos gerados pela sua ictiologia, projeto em andamento há 3 anos, já coletamos cerca de 16.000 amostras em diferentes bacias em 3 Estados da Amazônia.

Investigar a importância dos hábitos, inclusive os alimentares, que possam justificar a ausência de formas clínicas em indivíduos que apresentam indicadores biológicos de exposição acima dos recomendados pela OMS, é um projeto ainda com poucos dados.

Com a proposta de mapear as diferentes formas de liberação do Hg para o ambiente (queimadas, desmatamentos, hidrelétricas, barragens e garimpagem), iniciamos recentemente um estudo utilizando técnicas de georeferenciamento.

Para avaliar os teores de mercúrio nos diferentes compartimentos ambientais e o seu potencial de acumulação e mobilização e introdução nos ecossistemas aquáticos, nas áreas trabalhadas são estudados os teores de Hg das diferentes matrizes (solos, sedimentos, água).

Para conhecer os mecanismos de absorção, eliminação e metilação do mercúrio em organismos vegetais e animais terrestres, estamos em fase de preparação de um Projeto juntamente com o Museu Paraense Emílio Goeldi (MPEG).

Outro projeto de estudo que está sendo desenhado junto com o Museu Paraense Emílio Goeldi (MPEG), é a investigação de outros elementos presentes nos alimentos da região que possam interferir na eliminação do mercúrio, como é o caso do Selênio.

Avaliar o potencial das condições meteorológicas na dispersão do mercúrio na Amazônia, e conhecer as emissões de mercúrio para o meio ambiente amazônico em relação ao balanço global, são estudos que ainda não iniciamos.

POPULAÇÕES DE RISCO DE INTOXICAÇÃO POR MERCÚRIO

As populações garimpeiras são compostas predominantemente por adultos jovens. Há uma concentração muita alta de imigrantes da região nordeste do país entre esses trabalhadores, assim como um percentual significativo de analfabetos (Couto *et al.*, 1988). A alimentação é composta sobretudo por feijão, arroz, farinha, milharina e, às vezes, carne de boi ou galinha. A constituição física desses trabalhadores permite supor um estado nutricional que se aproxima do normal (Santos *et al.*, 1995).

As casas de compra e venda de ouro, entretanto, estão situadas em cidades, levando o risco de contaminação pelo metal até os moradores urbanos.

Entre os trabalhadores urbanos, os valores mais elevados de Hg foram observados em Santarém, onde os estabelecimentos apresentaram pior situação quanto a equipamentos de proteção e de processamento do ouro, quando comparado a Itaituba. Em ambos os lugares, a exposição de indivíduos que praticavam a queima do amálgama e apresentavam os níveis mais altos foi considerada mais intensa em relação àquela observada entre os garimpeiros, cujos teores médios de mercúrio foram 11,7 vezes menores que os encontrados entre os queimadores de Santarém e 5,2 vezes menores em relação aos apresentados pelos queimadores de Itaituba (Jesus *et al*, 2001).

Apesar da maior produção de ouro no momento deste estudo ter sido observada na lojas de Itaituba, lá também verificaram-se as melhores condições de proteção individual para o trabalho, bem como equipamentos e instalações.

A via respiratória na grande maioria das vezes é menos grave, mais susceptível de ser tratada, e, quase sempre basta afastar o paciente da área de risco e o problema regride. Os casos graves e irreversíveis de hidrargirismo por essa via são encontrados entre pessoas que estiveram submetidas ao risco durante muito tempo e nas quais já aconteceram danos irreparáveis em órgãos importantes, inclusive no sistema nervoso. É um problemas de medicina do trabalho. Equipamentos de proteção já existentes, quando usados, previnem ou diminuem o risco.

A via alimentar é a segunda via através da qual o mercúrio, já agora em sua forma orgânica, ingressa no organismo humano, através do consumo de peixe. É uma via de alcance mais amplo, envolve as populações ribeirinhas inclusive as indígenas, cuja principal, e as vezes única, fonte de proteínas é o pescado, cujo consumo constitui hábito cultural antigo (Santos *et al*, 1999b; Brabo *et al*, 1999 a; 1999b; 1999c; Santos *et al*,2000).

A exposição ao mercúrio por essa via é uma ameaça de consciência recente e a mais alarmante, na medida em que se propaga contaminando o meio ambiente, não pode ser controlado apenas por recomendações de saúde individual ou coletiva, e cuja solução envolve os interesses econômicos de uma atividade produtiva de fiscalização difícil como é o processo garimpeiro.

O risco à saúde em decorrência da concentração de mercúrio nos rios da região ainda não é objeto de monitoramento regular pelos serviços de saúde, cujos profissionais não estão preparados para fazer o diagnóstico diferencial ou associativo dessa nova patologia com as principais endemias prevalentes na região.

O aumento da concentração de mercúrio metálico na calha do Tapajós, iniciado há quase 40 anos atrás, hoje pode ser medido na biota aquática. O pescado, por ser a principal fonte de proteínas das comunidades ribeirinhas, se transformou no veículo potencial para o aumento do risco da exposição ao metilmercúrio nestas populações humanas.

Foram estudadas quatro comunidades ribeirinhas, Brasília Legal, São Luís do Tapajós, Barreiras e uma aldeia indígena

Mundurucu denominada Sai Cinza, nas quais a dieta alimentar - pouco variada e muito pobre em verduras - tinha como principal fonte protéica o pescado. Em todas elas o consumo de peixes, medido pelo número de ingestões, é alto, variando em média de 11 a 14 vezes por semana.

A pesquisa laboratorial de mercúrio nos cabelos das quatro populações residentes em área de risco de poluição, distribuídas por faixa etária, mostra uma média elevada e um gradiente de níveis de acumulação do mercúrio nos organismos individuais, que tende a crescer na primeira parte da curva, a medida em que a idade aumenta, e diminui na segunda metade da série. Pode-se indagar a hipótese de que o segmento da população com 30/40 anos, ou mais, nasceu de mães cujo organismo ainda não possuía teores alterados de mercúrio, acumulando a partir daí o metal, na medida em que o tempo passa e o mesmo aumenta na biota aquática (peixes), enquanto que os nascidos nos últimos vinte e cinco anos já nascem com teores de mercúrio alterados, herança do acúmulo do metal proveniente do organismo materno. A exceção dessa regra é a comunidade de Barreiras, que ainda está sendo estudada, e que parece possuir uma relação de exposição ao metal, mais antiga (Gráfico 1).

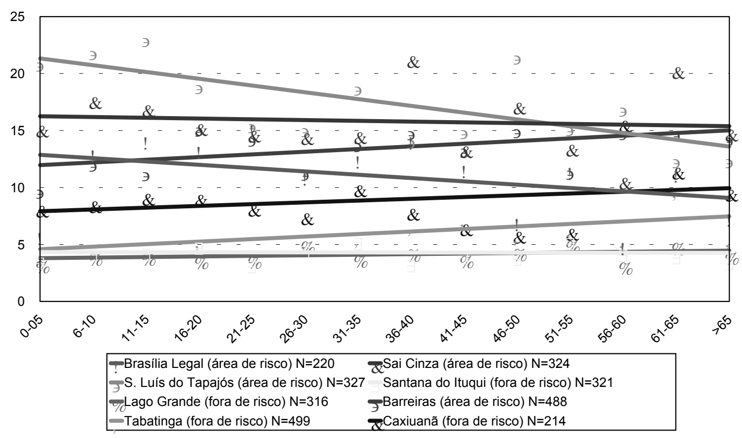


Gráfico 1 – Concentrações de mercúrio em tecido capilar segundo faixa etária, em cinco populações ribeirinhas da Amazônia, dentro e fora da área de risco, Pará, Brasil, 1994-2000.

A investigação dos aspectos clínicos, que não encontrou nos indivíduos examinados a forma aguda da doença, ou sinais e sintomas que pudessem ser associados à intoxicação por mercúrio, recomenda a necessidade de testes clínicos capazes de detectar as formas sub-clínicas da intoxicação, sem esquecer o diagnóstico diferencial com outros agravos presentes.

É necessário conhecer melhor as variáveis que influem nos mecanismos de absorção do mercúrio orgânico pelo organismo humano, a possível influência dos hábitos alimentares sobre esses mecanismos, e até saber se o poli-parasitismo intestinal freqüente nessas comunidades exerce alguma influência no processo todo.

COMUNIDADES RIBEIRINHAS FORA DA ÁREA DE RISCO DE CONTAMINAÇÃO PELO MERCÚRIO DA GARIMPAGEM.

A política de ocupação da Amazônia iniciada nos anos 70, facilitou a instalação de diversas atividades capazes de liberar o mercúrio para o meio ambiente, inclusive a garimpagem do ouro, o que resultou no aumento significativo das emissões desse metal para a atmosfera e sistemas aquáticos, e na incorporação lenta e progressiva do mesmo em diferentes compartimentos ambientais.

A medida em que a academia criava a consciência sobre o risco da contaminação da região, pelo mercúrio, particularmente o da garimpagem, inúmeros projetos de pesquisa foram sendo desenvolvidos, muitos dos quais pontuais, outros mais abrangentes. Entretanto, a busca pelos níveis de contaminação excluiu a procura dos parâmetros de normalidade pré-existentes, que, em algumas áreas já se perdeu completamente.

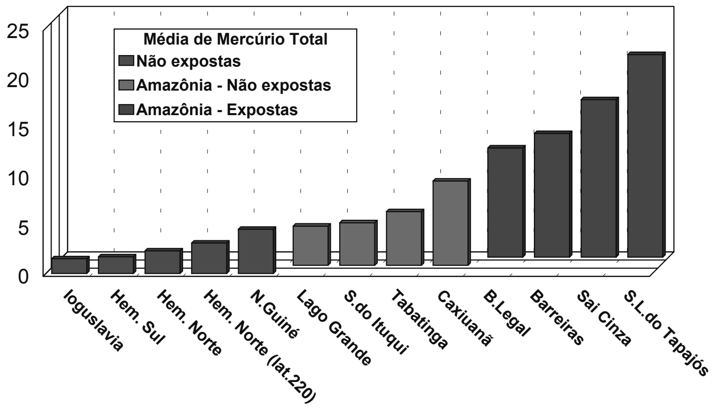
A Seção de Meio Ambiente do IEC vem investigando comunidades fora da área de risco do mercúrio oriundo da garimpagem, que tenham em comum o mesmo hábito alimentar, como forma de estabelecer controle para as demais pesquisas, e construir parâmetros de “normalidade” para a região. O trabalho que se segue faz parte dessa linha de investigação.

Entretanto, para a construção desses parâmetros, muitas outras variáveis precisam ser levadas em conta, entre elas as diferenças físico-químicas que caracterizam as diversas bacias hidrogáficas da região, e o conhecimento da localização das várias fontes de liberação do mercúrio para o meio ambiente. Esses levantamentos já começaram a ser realizados.

As quatro populações estudadas, Santana de Ituqui, Aldeia do Lago Grande, Tabatinga de Juruti e Caxiuanã, apresentavam um padrão semelhante que serve como critério para comparação com aquelas descritas nos estudos realizados em áreas sob influência do mercúrio, isto é, são populações ribeirinhas, apresentam um padrão social e econômico razoavelmente semelhante e seus hábitos alimentarem são caracterizados por um elevado consumo semanal de pescado.

As médias dos teores de mercúrio total nos peixes foram menores que aquelas encontradas em estudos em áreas impactadas por mercúrio, com exceção da comunidade de Caxiuanã, que embora tivesse uma média semelhante às outras 3 áreas estudadas, apresentava amostras de peixes com teores de até 2.529 μg/g, fato observado, e para o qual ainda não se tem uma explicação plausível.

Quanto aos teores de mercúrio no cabelo, com exceção de Caxiuanã, as outras comunidades apresentaram médias cerca de 3 vezes abaixo das encontradas em Brasília Legal e Barreiras, 4 vezes menor do que em Sai Cinza e 4.5 vezes menor do que em São Luís do Tapajós, que são populações sob influência da garimpagem de ouro. Entretanto, em alguns indivíduos foram observados valores que parecem mostrar que os mesmos estão submetidos a algum grau de exposição, sem haver a possibilidade neste momento de se esclarecer se existe um foco de exposição ou esta distribuição é característica da região. Novos estudos devem ser desenvolvidos para compreensão dos teores de mercúrio nas amostras ambientais e biológicas encontradas em Caxiuanã (Gráfico 2).



Fonte: Horvat et al.; Ayrey; Suzuki et al.; Santos et al.

Gráfico 2 – Teores de mercúrio total em cabelos de populações expostas e não expostas ao mercúrio

As discussões sobre valores de referência para estes indicadores de “normalidade” incluem várias outras questões além da definição dos limites de referência. É possível que, após investigações em um número maior de comunidades, se conclua que a “normalidade” na Amazônia, quando se refere a limites, seja superior aos preconizados pela Organização Mundial da Saúde (OMS). A população da Amazônia, notadamente os ribeirinhos, possui um padrão de alimentação que em muito difere das populações a que os limites da OMS se referem, além de outras características como peso, altura, etc que são de elevada importância para definição de valores de referência (Santos *et al*, 2001).

Tabela 1 - Banco de Amostras Humanas da Seção De Meio Ambiente/Iec/Fns/Ms e Teores Médios de Hg - 1992 A 2001.

LOCAL DA INVESTIG.	TIPO DE POPULAÇÃO	SEXO MASC.	SEXO FEM.	TOT.	MÉDIA DE Hg
Igarapé do Rato – Itaituba	Garimpeira	149	74	223	6,51μg/l
Cidade de Santarém	Queimadores de ouro	42	8	50	57,52μg/l
Cidade de Santarém	Controle dos queimadores	20	18	38	4,82μg/l
Brasília Legal - Aveiro	Ribeirinha	93	153	246	11,75μg/g
Cidade de Itaituba	Queimadores de ouro	72	10	82	27,85μg/l
Aldeia Munduruku de Sai Cinza – Itaituba	Ribeirinha Indígena	137	193	330	16,0 μg/g
São Luís do Tapajós – Itaituba	Ribeirinha	139	194	333	19,91μg/g
Santana do Ituqui-Santarém	Ribeirinha(controle)	155	171	326	4,33μg/g
Comunidade de Aldeia - Monte Alegre	Lacustre (controle)	182	145	327	3,98μg/g
Pacas Novos – Rondônia	Ribeirinha Indígena	477	581	1.058	8,37μg/g
Rio Branco - Acre	População Urbana	962	1.480	2.442	2,4 μg/g

Tabela 1 - Banco de Amostras Humanas da Seção De Meio Ambiente/Iec/Fns/Ms e Teores Médios de Hg - 1992 A 2001 (cont.)

LOCAL DA INVESTIG.	TIPO DE POPULAÇÃO	SEXO MASC.	SEXO FEM.	TOT.	MÉDIA DE Hg
Nova visita a São Luís do Tapajós –Itaituba	Ribeirinha	163	213	376	19,81μg/g
Tabatinga - Jurutí	Ribeirinha (controle)	234	329	563	5,37μg/g
Caxiuanã	Ribeirinha (controle)	117	105	222	8,56μg/g
Barreiras - Itaituba	Ribeirinha	222	269	491	12,58μg/g
Tribo Macuxi – Roraima	Ribeirinhos Indígena	27	23	50	1,65μg/g
Cachoeira do Piriá	Urbana Ex - Área Garimpeira	433	482	915	Em andamento
Vila do Elesbão	Ribeirinhos	881	1.167	2.048	Em andamento
TOTAL		4.505	5.615	10.120	

INVESTIGAÇÃO DOS NÍVEIS DE MERCÚRIO NA BIOTA DE DIFERENTES BACIAS NO ESTADO DO PARÁ

A medida em que o Programa acumulava informações, ficou claro que - em se tratando da avaliação da saúde humana em áreas ribeirinhas de risco de poluição por mercúrio – o indicador da situação seria o pescado. Nesse momento o Programa incorporou a investigação de peixes nos principais rios do Estado do Pará: Amazonas, Trombetas, Xingu, Guamá, Tapajós, Araguaia, Caxiuanã (reserva), Arapiuns e Tocantins, assim como amostras de pescado da área do salgado (Oceano Atlântico). O mapa acima contém informações sobre sobre os pontos de coleta de pescado.

Este trabalho vem sendo realizado não só para conhecer a extensão do problema no que diz respeito ao meio ambiente, mas também como forma de avaliar riscos para as populações humanas. O trabalho de coleta já foi concluído no Estado do Pará, e está na fase de análise. Os dados preliminares estão parcialmente apresentados em diferentes tabelas, e sem comentários (Tabelas 2-5).

Tabela 2. Amostras de peixes procedentes de 14 bacias de drenagem do Estado do Pará, Amazônia Brasileira

BACIA DE DRENAGEM	NÚMERO DE AMOSTRAS	PERÍODO DE COLETA
Rio Tapajós	5.912	1995-1999
Bacia doTapajós - Rio Arapiuns	418	1999
Rio Amazonas	792	1998-1999
Bacia do Amazonas - Rio Trombetas	941	1999
Rio Caxiuanã	408	1998-1999
Rio Xingu	1.072	1999
Rio Araguaia	486	1999
Rio Tocantins	754	1999
Rio Marapanim	272	1999
Rio Pirabas	298	1999
Rio Caeté	304	1999
Rio Guamá	536	1999
Rio Pará	522	1999
Rio Marajó	650	1999
TOTAL	**13.129**	**1995 - 1999**

OBS. Dados incompletos.

Tabela 3. Níveis de mercúrio em peixes carnívoros procedentes de localidades ribeirinhas do rio Tapajós, Estado do Pará, Amazônia Brasileira (média Hg μg/g), 1995 -1999

LOCALIDADE	PIRARARA n = 7	TRAÍRA n = 61	CURVINA* n = 50	TUCUNARÉ n = 667	SURUBIM n = 149
Sai Cinza	-	0,322	-	0,267	0,385
Jacareacanga	0,407	0,400	0,128	0,475	0,777
São Luís do Tapajós	-	0,259	0,170	0,599	0,488
Itaituba	-	-	-	0,597	0,644
Barreiras	0,365	-	0,113	0,502	0,820
Brasília Legal	-	0,537	0,109	0,583	0,694
Aveiro	0,510	0,515	-	0,446	0,283
Santarém	-	0,244	-	0,250	0,227
Média Geral	**0,460**	**0,368**	**0,122**	**0,464**	**0,539**

OBS : * Peixe carnívoro com hábitos especiais

Tabela 4. Níveis de mercúrio em peixes carnívoros procedentes de localidades ribeirinhas do rio Tapajós, Estado do Pará, Amazônia Brasileira (média hg μg/g), 1995 - 1999

LOCALIDADE	ARUMARÃ n = 18	PIRARUCU n = 15	MAPARÁ n = 12	PACU-BRANCO n = 10	CUJUBA n = 29
Sai Cinza	-	-	-	-	-
Jacareacanga	0,835	-	-	0,241	0,143
São Luís do Tapajós	1,116	-	0,047	-	-
Itaituba	-	-	-	-	-
Barreiras	-	0,256	0,751	-	-
Brasília Legal	-	0,750	0,255	-	0,102
Aveiro	-	0,099	0,328	-	0,076
Santarém	-	-	0,215	-	-
Média Geral	**0,851**	**0,312**	**0,254**	**0,241**	**0,083**

Tabela 5. Níveis de mercúrio em peixes carnívoros procedentes de localidades ribeirinhas do rio Tapajós, Estado do Pará, Amazônia Brasileira (média hg μg/g), 1995 - 1999

LOCALIDADE	SARDA n = 127	ARUANÃ n = 64	JACUNDÁ n = 25	PIRANHA n = 340	PESCADA n = 106	PESCA DINHA n = 16
Sai Cinza	-	0,174	-	0,219	-	-
Jacareacanga	1,751	0,426	0,360	0,502	1,429	-
São Luís do Tapajós	0,484	-	-	0,560	0,478	0,132
Itaituba	0,647	-	-	0,599	0,660	-
Barreiras	0,614	-	-	0,932	-	-
Brasília Legal	0,644	0,595	-	0,823	0,455	-
Aveiro	0,464	0,180	-	0,308	0,450	-
Santarém	0,297	0,137	-	0,182	-	-
Média Geral	0,466	0,346	0,360	0,503	0,526	0,132

BIBLIOGRAFIA

AIREY, D. 1983. Total Mercury concentrations in human hair from 13 countries in relation to fish consuption and location. Sci. total Environ*.,* 31: 157-180.

AKAGI, H.; MALM, O.; BRANCHES, F.J.P.; KINJO, Y.; KASHIMA, Y.; GUIMARÃES, J.R.D.; OLIVEIRA, R.B.; HARAGUCHI, K.; PFEIFFER, W.C.; TAKIZAWA, Y. & KATO, H. 1995. Human exposure to mercury due to goldmine in the Tapajós River Basin, Amazon, Brazil: speciation of mercury in human hair, blood and urine. *Water, Air, and Soil Pollution*. 80**:** 85-94.

AKAGI, H., MALM, O. & BRANCHES, F.J.P. 1996. Human exposure to mercury due to mining in the Amazon, Brazil - A Review. *Environmental Sciences*, **3**: 199-211.

BRABO, E.S.; SANTOS, E.O; JESUS, I.M.; MASCARENHAS, A.F. & FAIAL, K.F. 1999a. Níveis de mercúrio em peixes consumidos pela Comunidade Indígena de Sai Cinza, Município de Jacareacanga, Estado do Pará – Brasil. *Cadernos de Saúde Pública*.15(2):325-331.

BRABO, E.S.; SANTOS, E.C.O; JESUS, I.M; FAIAL, K.R.F.; & MASCARENHAS, A.F.S.1999b. Mercury in fish of areas without gold mining in Amazon Region - Amazon Basin. Anais da 5ª International Conference Mercury As a Global Polluant - Biota, Food Chain, Bioaccumulation, Biomonitoring. Rio de Janeiro, Brasil.

BRABO, E.S.; SANTOS, E.C.O; JESUS, I.M; Faial, K.R.F.; & MASCARENHAS, A.F.S.1999c. Exposure to mercury of an Indian Commuinity in Amazon due Fish Consumption. Munduruku Reservation, State of Pará (5ª International Conference on Mercury as a Global Pollutant - Human Health: Exposure Issues). Rio de Janeiro - Brasil.

CÂMARA, V.M. & COREY, G., 1992. Epidemiologia e Meio Ambiente. O Caso dos Garimpos de Ouro no Brasil. Metepec, México: Centro Panamericano de Ecologia Humana e Saúde/ECO/OPS.

COUTO, R. C. S. et al. 1988. Intoxicação Mercurial : Resultados preliminares em duas áreas garimpeiras no Estado do Pará. Pará Desenvolvimento. IDESP, N° 23, 63 - 67.

Departamento Nacional de Produção Mineral - DNPM.Pará. Secretaria Executiva de Indústria, Comércio e Mineração - SEICOM 1999. Sumário Mineral: Belém, 21 p. ilust.

DUBOS, René. 1989. El Hombre em Adaptacion. México, Fondo del Cultura Económica. 2ª edición aumentada.

FOSTIER,OLIVEIRA, S.M.B.; GUIMARÃES, J.R.D.; FORTI, M.C.; MELFI, A.J.; BOULET, R.; FAVARO, D.I.T.; KRUG, F.J. 1999. Mercury accumulation in natural forested Amazonian soils.. Mercury as a Global Pollutant –5th International Conference, Rio de Janeiro, Brazil, p 522.

GOVERNO DO ESTADO DO PARÁ.1992. Secretária de Indústria, Comércio e Mineração-SEICOM. Programa de Controle Ambiental da Garimpagem no Rio Tapajós (Canga-Tapajós). Estudo dos Impactos Ambientais Decorrentes do Extrativismo Mineral e Poluição Mercurial do Tapajós. 185p.

HORVART, M.; MAY, M.; STOEPPLER, A. & BYRNE, R. 1988. Comparative studies of methylmercury in biological and environmental samples. *Applied Organometalic Chemistry*. 2:515-524.

JESUS, I.M., SANTOS, E.C.O., BRABO, E.S., LOUREIRO, E.C.B., CÂMARA, V.M., MASCARENHAS, A.F.S., SILVA, D.F.L., CLEARY, D.2001. Exposure to elemental mercury in urban workers and golg miners from the Tapajós Region, Pará, Brazil. Bull.Environ. Contam. Toxicol. (2001) 67:317-323.

RAMOS, J.F.F. 1992. Garimpagem: poluição química e física. Apresentado no Seminário Internacional sobre Meio Ambiente, Pobreza e Desenvolvimento - SINDAMAZÔNIA. Belém - PA, 16-19fev.

SANTOS, E.C.O.; TRAVASSOS DA ROSA, J.F.; JESUS, I.M.; LOUREIRO, E.C.B., 1992. A saúde das populações da Amazônia Brasileira *in Enfoque integral de la salud humana en la Amazonia* L. Yarzabal, C. Espinal y L.E. Aragon (Eds.) UNAMAZ: p.95-156.

SANTOS, E.O., 1993. Garimpagem e Saúde. In: Consequências da Garimpagem no Âmbito Social e Ambiental da Amazônia (Armin Mathis & Regine Rehaag orgs.) pp.36-37, Belém:Ed. CEJUP.

SANTOS, E.O., LOUREIRO, E.C.B., JESUS, I.M., BRABO, E.S., SILVA, R.S.U., SOARES, M.C.P., CÂMARA, V.M., SOUZA, M.R. AND BRANCHES, F. 1995. Diagnóstico das condições de saúde de uma comunidade garimpeira na Região do Tapajós, Itaituba, Pará-Brasil (1992). *Cadernos de Saúde Pública.* **11**(2):212-225.

SANTOS, E.C.O; JESUS, I.M.; BRABO, E.S.; CÂMARA, V.M.; LOUREIRO, E.C.B.; SILVA, D.F.L; SOUZA, M.R.S; BRANCHES, F. & CLEARY. D. 2000. Mercury exposure in riverside Amazon communities in Pará-Brazil. Environmental Research. V.84 (2):100-107.

SANTOS, E.C.O.; JESUS, I.M; BRABO, E.S.; LOUREIRO, E.C.B.; WERICH, J. & MASCARENHAS, A.F.S.1999a. Hair as indicator of exposure to the mercury through the ingestion of fish in two areas which do not suffer impact from mining activity. State of Pará - Brazil. (5[a] International Conference on Mercury as a Global Pollutant - Human Health: Exposure Issues). Rio de Janeiro - Brasil.

SANTOS, E.C.O.; JESUS, I.M; BRABO, E.S.; LOUREIRO, E.C.B.; WERICH, J. & MASCARENHAS, A.F.S.1999b. Descriptive study of the levels of exposure to the mercury among two riverside communities of Amazônia. (5ª International Conference on Mercury as a Global Pollutant - Human Health: Exposure Issues). Rio de Janeiro - Brasil.

SANTOS, E.C.O.; JESUS, I.M.; BRABO, E.B.; CÂMARA, V.M.; LOUREIRO, E.C.B.; MASCARENHAS, A.F.S; FAIAL, K.F.; SILVA, A.P.; LUIZ, R.R.; HIGUCHI, H. 2001. Exposure to mercury in the urban population of Rio Branco city, State of Acre, Brazil, Bull. Environ. Contam. Toxicol. (no prelo).

SANTOS, E.O.; CÂMARA, V.M; JESUS, I.M.; BRABO, E.S.; LOUREIRO, E.C.B.; MASCARENHAS, A.F; FAIAL, A.F.S.; SÁ FILHO, G.C.; SAGICA, F.E.S.; LIMA, M.º; HIGUCHI, H., 2001. A contribution for the establisment of reference values for total mercury levels in hair and fishes in Amazonia. Environmental Research (no prelo).

SILVA, A.R.B. et al. 1989. O mercúrio no garimpo e suas implicações ambientais, Apresentado no I Encontro das Organizações não Governamentais Conservacionistas. Altamira-PA, 20 a 25 de fevereiro.

SUZUKI, T.; WATANABE,S.; HONGO, T.; KAWABE, T.; INAOKA, T.; OHTSUKA, R. & AKIMICHI, T. 1988. Mercury in scalp hair of Papuans in the Fey Estuary, Pupua new Guinea. Asia-Pacific Journal Public Health. 2:39-47.

VEIGA, M.M., MEECH, J. A. & ONATE, N. 1994. Deforestation: a major source of mercury pollution in the Amazon. *Nature*. 368: 816-817.

ZEIDEMANN, V.K., FORSBERG, B.R., ROULET, M., LUCOTTE, M.; JARDIM, W.F. 1999. The geochemistry of mercury in soils of the Negro River Basin (Brasilian Amazon) and its role in the regional mercury cicle. Mercury as a Global Pollutant –5th International Conference, Rio de Janeiro, Brazil, p 561 .

ROMPENDO BARREIRAS. POSSIBILIDADES E LIMITES DA INTERVENÇÃO NO GARIMPAGEM DE OURO NO TAPAJÓS.

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Quadro décadas após o seu início, a mineração não-indústrial de ouro na Amazônia ainda não conseguiu se organizar de uma maneira socialmente aceitável. Na última década sobretudo, os impactos ambientais dessa atividade influenciaram chamaram a atenção do público. Evidentemente, esse novo enfoque não significa que os outros problemas, até então associados à garimpagem, foram todos superados. Dando continuidade ao olhar ambientalista, o projeto proposto por UNIDO/UNDP/GEF, visa remover as barreiras que impedem a introdução de tecnologias limpas nos garimpos de ouro. Sem entrar na avaliação dos méritos desse projeto, o presente trabalho é entendido como uma reflexão necessária antes de iniciar as atividades de execução do projeto. Essa reflexão se faz necessária pelo fato de que uma intervenção que vise para uma determinada atividade econômica, uma modificação da relação sociedade – natureza, precisa ter clareza das suas possibilidades e dos limites da sua atuação, a fim de poder concentrar os esforços naquilo que é viável.

As tendências atuais no cenário de intervenção - seja no nível de interação (famílias, grupos), organização (consultoria para empresas) ou de regiões (política de desenvolvimento regional) - mostram que os simples modelos de input (intervenção) – output (mudança de atuação) não representam os acontecimentos reais. Seguindo a nova teoria de sistemas sociais, partimos do seguinte entendimento sobre a intervenção nestes sistemas sociais.

- Ela é uma oferta a um definido sistema social ou individual;
- A maneira como o sistema social ou o indivíduo reage (ou não) a essa oferta, depende das experiências históricas e das estruturas existentes dentro do sistema social que é alvo da intervenção;

- A percepção e a receptividade da intervenção depende da importância que o sistema alvo atribui ao problema que desencadeou a intervenção;
- O objeto da intervenção são os processos e estruturas que caracterizam o sistema alvo;
- O sucesso da intervenção depende do conhecimento desses processos e estruturas pelo interventor.

Quais os desafios que essa visão lança para o projeto proposto?

- Identificar os sistemas sociais que serão alvo da intervenção;
- Conhecer as estruturas e os processos que definem as visões do mundo desses sistemas;
- Conhecer o funcionamento do sistema social que assume a função de interventor.

O ALVO DA INTERVENÇÃO

Diferentemente da mineração industrial, que é exercida por organizações formais (empresas), a garimpagem se caracteriza por uma variedade de formas organizacionais do processo produtivo. Embora não constituído como organização formal, o processo extrativo tem, historicamente, formado uma série de costumes que fornecem para todos os participantes uma certa segurança para sua participação. A base desses procedimentos é a interpretação da organização social do processo extrativo como associação temporária entre capital e trabalho. Assim, o início e fim da associação estão diretamente ligados à fatores naturais (forma do depósito) e à tecnologia empregada na extração. Em geral, um ciclo de trabalho se fecha com a apuração do ouro e a distribuição em natura das porcentagens no resultado.

A ausência de uma organização formal gera uma variedade nas formas como o grupo dos trabalhadores se relacionam com o capital. No tempo inicial do garimpo, a diferenciação entre capital e trabalho, no que diz respeito à origem social, estilo de vida e visões do mundo, era quase inexistente. Transições sociais - ascensão de trabalho para capital e declínio de trabalho para capital – eram comuns, e a sua possibilidade um fator constituinte do funcionamento do sistema. No final dos anos 70, o surgimento da mecanização na garimpagem, em conjunto com a entrada do atores sociais com uma percepção do mundo formado em outras regiões, mudou esse quadro. Esses empreendedores de garimpo entraram no garimpo com capital e somente nessa qualidade percebem os trabalhadores, em geral falta-lhe a convivência direta com os trabalhadores. O elo entre capital e trabalho é estabelecido através do papel do gerente, pessoa da confiança do dono dos meios de produção para organizar o processo de extração.

Em uma visão geral, podemos enumerar os seguintes papeis envolvidos diretamente na garimpagem.

- Do proprietário da terra onde está sendo feita a extração. A posse da terra pode se basear em um título legal de propriedade ou, no caso de terra devoluta, em um direito informal derivado do fato da descoberta da área aurífera ou da compra informal da terra.
- Do proprietário dos meios de produção. Ele organiza – em geral através da intermediação de um gerente - o processo de extração.
- Do comerciante – seja fora ou dentro do garimpo – que investe através de um *joint venture* no financiamento dos custos de exploração.
- Dos trabalhadores que estão diretamente empregados no processo de extração. No final da década de 90 traçamos o seguinte perfil dessa mão-de-obra[1]. A maioria é solteiro ou separado, tem idade média de 32 anos. O grau de instrução é muito baixo, sendo que pelo menos um quarto se compõe de analfabetos e na sua grande maioria não chegou a concluir o primeiro grau. A maior parte (73%) da força de trabalho dos garimpos do Pará provém do Nordeste. A origem rural da mão-de-obra garimpeira é muito mais acentuada (Pará 55%). No Tapajós para 25% dos entrevistados, o garimpo é o primeiro lugar de trabalho e que somente um terço pretende voltar para a atividade exercida antes da garimpagem.
- Os prestadores de serviços que dão suporte ao processo de extração. Esse grupo é muito heterogêneo, envolvendo tanto as

1 Mathis / Brito / Brüseke (1997).

atividades meio (preparo de alimentação, manutenção do equipamento) quanto outras atividades que vivem do excedente gerado no garimpo (prostituição, comércio etc).

Dentro de uma intervenção que visa modificar a relação da garimpagem com a natureza, os grupos que se destacam como alvo dentro desse conjunto são os trabalhadores que devem usar as novas tecnologias, e os proprietários de meio de produção que precisam adquiri-las. Somente quando ambas as alterações acontecem em conjunto, a intervenção pode ser considerada como realizada.

OS PROCESSOS A SEREM MUDADOS

Mudanças nas técnicas de extração não são estranhas à história da garimpagem. Na segunda metade da década de 70, ficou evidente que só uma mudança da base tecnológica do processo de extração do ouro poderia prolongar a vida da garimpagem na região. As inovações surgiram quase ao mesmo tempo em vários lugares da Amazônia. A mecanização da garimpagem tornou possível o trabalho em jazidas que antigamente não estavam ao alcance dos garimpeiros (aluviões nos leitos ativos dos rios e aluviões mais profundos).

A alta do preço do ouro nos mercados internacionais, em 1979/80, foi responsável pela rapidez com que a nova técnica se estabeleceu como padrão na exploração de ouro aluvial nos garimpos da Amazônia. Devido à riqueza das novas jazidas, não alcançáveis, até então, pelos garimpeiros, e a elevação do preço de ouro, a mecanização se tornou possível para a maioria dos donos de meios de produção somente com os lucros da garimpagem, sem necessidade de recorrer ao capital externo.

Uns quinze anos após a mecanização dos garimpos, os indícios de escassez dos depósitos aluvionais obrigaram os garimpeiros novamente a recorrer a uma nova tecnologia para poderem alcançar os depósitos primários subterrâneos. Diferente da mecanização, essa inovação demorou em se tornou hegemônico na região. Isso se explica, em parte, pela existência de depósitos aluvionais ainda rentáveis, mas por outro lado, é conseqüência da necessidade de investimento que essa nova tecnologia exige do proprietário dos meios de produção. Um investimento cujo retorno não está assegurado da maneira como isso aconteceu na transição para a mecanização.

A terceira, e mais recente, onda de inovação que podemos observar no Tapajós é o uso de trados, caracterizando assim uma modernização da tecnologia de prospecção, contribuindo para a redução da insegurança do retorno dos recursos investidos na extração. A introdução do trado como instrumento simples de prospecção, foi resultado de um projeto de intervenção financiado pela Comunidade Européia.

COMO MUDAR?

Quais as lições que podemos tirar dessa história da evolução tecnológica da garimpagem para o projeto proposto?

Primeiro, as mudanças das técnicas de extração ou exploração aconteceram em momentos em que os próprios garimpeiros tiveram uma forte noção das limitações impostas pela natureza dos métodos até então usados. Através da modernização, novos tipos de depósitos se tornaram acessíveis. Ao mesmo tempo, o ouro que no início da garimpagem manual aflorava na terra, se torna cada vez mais invisível, exigindo, finalmente, novas formas de prospecção para o tornar visível.

Segundo, a aceitação das novas técnicas – tanto pelo capital quanto pelo trabalho – foi inicialmente facilitada pelo fato de que elas conseguiram aumentar significativamente o ganho de ambos os lados. Isso mostra a sensibilidade dos garimpeiros ao retorno financeiro.

Terceiro, existe uma tendência entre donos de meio de produção de transferir parte do aumento dos custos de produção gerados pelas novas tecnologias para os trabalhadores. Essa mudança unilateral nas regras dos costumes da sociedade entre capital e trabalho foi aceita inicialmente pelo aumento do ganho que o aumento da produtividade gerou. No momento em que a renúncia não está sendo compensada, a aceitação social da nova tecnologia está em jogo. Precisam-se então de outros mecanismos que convençam o garimpeiro trabalhador a usar essa tecnologia[2]. Isso se torna uma

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[2] O fato que a modernização da base tecnológica da garimpagem exige cada vez mais uma 'especialização' maior do trabalhador evidenciando assim a divisão de trabalho, merecia também uma discussão. Sobretudo,

tarefa crucial para a introdução de tecnologias limpas, que visam um "ganho" para a natureza. Um direito cuja atribuição é estranho para um sujeito que percebe a natureza primeiramente como algo que esconde – e cada vez melhor - as suas riquezas da possível exploração.

Experiências com modernizações ecológicas entendidas aqui como substituição de processos produtivos poluentes por processos menos danosos em países industrializados mostram que elas são resultado de um processo de negociação que envolve diretrizes do poder público, iniciativas voluntárias e participação da sociedade civil, seja como consumidor ou na forma de representantes de interesses particulares. Transferido para a nossa tarefa no Tapajós, ficam patentes alguns obstáculos a serem enfrentados, onde percebe-se que o grau de organização formal do público alvo da intervenção é muito pequeno.

Os incentivos para promover a institucionalização de organizações representativas partiram, em geral, dos proprietários, e não dos trabalhadores. A falta de reconhecimento da contradição entre capital e trabalho, que está na raiz do regime de trabalho nos garimpos dificulta, há muito tempo, a criação de organizações coerentes. A Constituição de 1988 escolheu, partindo de uma visão distorcida do garimpeiro, o cooperativismo como forma ideal de fomentar a atividade garimpeira. Em conseqüência disso, nota-se, a partir de 1989, uma onda de criação de cooperativas de garimpeiros como forma de legalizar a atividade extrativista. Até então, a única forma legalmente reconhecida de organização de garimpeiros era o sindicato patronal. Ambas as formas tentam, dentro da lógica do regime de trabalho nos garimpos, negar a identidade do garimpeiro trabalhador. Elas, em conseqüência disso, restringem-se às atividades de assistência social ou foram transformadas em simples órgãos dos donos para defender seus interesses particulares. Mas esse quadro começou a mudar no início dos anos noventa. O esgotamento das jazidas secundárias, junto com a queda do preço interno do ouro e as restrições impostas pela conscientização ecológica, redimensionaram o futuro dessa atividade. Durante essa pressão, parte dos donos dos garimpos do Tapajós organizou-se dentro de uma associação, tentando criar um instrumento de diálogo com os órgãos governamentais e de fomento.

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quando se vislumbra as tendências ao longo prazo. A garimpagem deixará de ser uma oportunidade de trabalho para pessoas sem formação.

Assim, buscaram influenciar o processo de legalização de suas atividades numa fase de transformação da garimpagem de jazidas secundárias para depósitos primários.

Enquanto o capital tem a sua representação – embora a sua existência se dê mais em função de demandas externas[3] – os trabalhadores diretos não possuem organizações representativas. Uma intervenção que quer atingir esse grupo, ou procura o acesso indireto, via capital (donos de garimpo, donos dos meios de produção), ou vai ter que achar formas de acesso que superaram essa lacuna. Levando em consideração o caráter do projeto, considero fundamental o esforço de estabelecer formas de acesso direto aos trabalhadores dos garimpos. Evidentemente essa entrada não será possível através de um apelo à consciência ecológica deles, mas sim através de temas que se constituem como problemas individuais, e que oferecem uma abertura para intervenções externas[4]. Em uma região onde o poder público está pouco presente deve-se esperar uma demanda reprimida muito grande para serviços públicos de qualquer natureza (segurança, educação, saúde, lazer etc.).

ROMPENDO AS BARREIRAS COM CIDADANIA

O grupo que constituirá o sistema social responsável pela intervenção, tem que saber como lidar com as demandas ou as expectativas ligados ao projeto, tendo clareza de que não podem ser atendidas na medida em que ultrapassam o âmbito deste projeto. Por um lado, necessita-se de capacidade de direcionamento dessas demandas para os devidos destinatários. Isso será facilitado na medida em que representantes do poder público com poder de decisão, fizeram parte do grupo de intervenção. Por outro lado, é necessário desenvolver mecanismos capazes de mostrar as possibilidades e limites do projeto, e de manter os vínculos

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3 A AMOT provavelmente não existia até agora, sem a demanda dos diversos projetos de intervenção que foram lançados na região de incorporar uma organização 'representativa' dos garimpeiros.

4 Descobrir essas demandas ou aberturas para intervenção será sem dúvida uma das primeiras tarefas do projeto.

estabelecidos pela demanda mesmo após frustração de não tê-la atendida.

O ganho social aspirado - a modernização ecológica da atividade garimpeira – tem que ser traduzido em ganhos perceptível no nível do indivíduo. Enquanto esse ganho se mede para o capital em uma maior rentabilidade do seu investimento, o envolvimento dos trabalhadores somente se dará caso eles tenham participação nesse ganho ou se eles conseguirem 'capitalizar' a colaboração no projeto de outra forma. Como a intervenção não se dispõe a intervir diretamente na relação capital –trabalho, não há como garantir para os trabalhadores a participação no ganho.

O que está dentro do alcance do projeto é a tentativa de aumentar a capacidade do público alvo de se tornar mais autônomo e capaz na formulação e no direcionamento das suas demandas – seja frente ao poder público, seja frente ao capital. O instrumento que se dispõe para fazer isso é a comunicação nas suas mais diversas formas. O quadro 01 mostra de forma ilustrativa como esse desafio pode ser enfrentado através de um programa de educação não-formal.

Traduzida para a filosofia do projeto proposto podemos partir do pressuposto de que uma das principais barreiras que impedem a introdução de tecnologias limpas na garimpagem é a falta de cidadania no seu sentido amplo, dos atores sociais nela envolvidos. Formar cidadãos que tenham noção dos seus direitos e das suas responsabilidades frente aos outros e a natureza é uma das formas de contribuir para uma modernização da garimpagem. Conseguir isso será por um lado, uma grande contribuição para a sustentabilidade das mudanças após o fim da intervenção e, por outro lado, algo que vai introduzir uma dinâmica no projeto que tornará a dinâmica da sua execução em parte não-previsível. Isso, sobretudo no que diz respeito às formas de colaboração de poder público local, que não tem interesse em mudanças das estruturas políticas enraizadas, e dos representantes do capital, que poderão perder o seu monopólio de representação única dos garimpeiros.

Quadro 1: Proposta de conteúdo programático para um Programa de Educação Ambiental para garimpeiros-trabalhadores

Módulo Cidadania

⇒ Noções básicas da *legislação trabalhista*:

→ principais direitos trabalhistas (horário de trabalho, remuneração para trabalho nos fins-de-semana, demissão, demissão por justa causa, aviso prévio, contribuições para previdência, carteira trabalhista, salário mínimo, etc.),

→ justiça do trabalho (enquadramento da atividade garimpeira, funcionamento da justiça de trabalho).

⇒ Noções básicas da *legislação mineral:*

→ a garimpagem dentro do conceito da constituição (art. 21 XXV, art. 174 § 3, art. 174 § 4),

→ as leis, que regulam a garimpagem: lei 7.805 (permissão de lavra garimpeira), d. lei 98.812 (regula a permissão de lavra garimpeira),

→ novas propostas de legislação sobre a garimpagem: estatuto do garimpeiro, etc.

→ as leis que regulam a mineração: o código de mineração, processo administrativo para conseguir um alvará, etc.

→ a mineração em áreas especiais: reservas garimpeiras, reservas indígenas, áreas de fronteira.

⇒ *Sindicato e Cooperativa*:

→ características básicas do sindicato (classista, financiamento, história do sindicalismo, reúne trabalhadores, organização interna, exemplo de sindicatos, etc.)

→ características básicas da cooperativa (sistema de quotas, igualdade dos membros, organização interna, tipos de cooperativas ("consumo e produção"), exemplo de cooperativas, etc.)

→ as principais diferenças entre sindicato e cooperativa

→ sindicato e cooperativa como forma de auto-organização dos garimpeiros

⇒ *Viver na cidade*:

→ a infra-estrutura urbana, como conhecer e usá-la (oferta de escolas, postos de saúde, centros comunitários, etc.),

→ noções básicas sobre as responsabilidades de uma prefeitura,

→ formas de auto-organização na cidade (organização de bairro, organização de moradores, etc.)

⇒ *Ocupação alternativa para o*s garimpeiros:

→ cursos profissionalizantes (SEBRAE, SESI, FIEPA)

→ estudos no ensino formal (primeiro e segundo grau)

Módulo Saúde

⇒ *Higiene pessoal e sanitária* como forma de prevenção:

→ tratamento de lixo,

→ tratamento de água,

⇒ Noções básicas sobre o *sistema da saúde pública* no Brasil e especificamente em Roraima:

→ as diversificações no sistema médico;

→ FNS / SUCAM e INSS: funcionamento, quem tem direito a atendimento?

→ setor municipal: Postos de Saúde, funcionamento, quem tem direito a atendimento?

→ formas alternativas de atendimento médico: sistema SESI para membros do sindicato, ONG's atuando na região.

⇒ *Vacinação* como forma de se proteger:

→ as principais vacinas para adultos e crianças;

→ quem vacina?

→ as campanhas nacionais de vacinação.

⇒ Noções básicas sobre as *doenças endêmicas* mais comuns no ambiente tropical ou nos garimpos: malária, leishmaniose, hepatite

→ sintomas,

→ forma de transmissão e contaminação,

→ formas e lugares de tratamento, risco da automedicação

⇒ *Primeiros socorros* no caso de acidente de trabalho no garimpo

→ cortes

→ quedas

→ picadas e mordidas de animais

Módulo Garimpagem e Meio Ambiente

⇒ Noções básicas sobre as *características toxicológicas do mercúrio*:

→ ciclo do mercúrio,

→ formas de contaminação,

→ sintomas e exemplos de contaminação mercurial.

⇒ Formas de evitar ou diminuir o *lançamento de mercúrio nos garimpos*:

→ retorta (canudinho),

princípio de funcionamento, modo de usar, os preconceitos mais comuns contra o uso;

→ concentração final em um recipiente fechado (circuito fechado de mercúrio),

uso de tambor de óleo diesel, caixa de madeira ou tanque de concreto, vantagens desse método, i.e. perdas na apuração (ouro e mercúrio) são recuperáveis dentro do recipientes fechados, integráveis dentro do processo existente;

→ evitar usar mercúrio direto na caixa concentradora ou no baixão

argumentos contra essa prática: fluxo de água leva o Hg, Hg e Au precisam de um tempo para poder formar o amalgama, custo elevado do Hg,

⇒ Formas de evitar ou diminuir a *poluição* e o *assoreamento dos rios*:

→ principais conseqüências do assoreamento dos rios:

água deixa de ser apropriada para o consumo humano dentro do garimpo ou para as comunidades ribeirinhas (lavagem de roupa, água para consumo), transformações na flora e fauna devido o aumento das partículas pequenas, mudanças no leito do rio (arrotos) dificultam sua navegabilidade, água barrenta não é adequada para os processos da separação gravimétrica do ouro;

→ bacias de decantação,

princípio de funcionamento de uma bacia de decantação, formas de trabalhar com o princípio da decantação dentro do garimpo usando barrancos já trabalhados como depósito do estéril;

→ barragens,

construção de barragens como forma de evitar o assoreamento do rio abaixo, construção de barragens como forma de administrar a disponibilidade de água dentro do garimpo, construção de uma barragem como forma de desvio do curso d'água (material usado, medidas de segurança);

→ plano de lavra antes de começar,

características de um plano de lavra, vantagens de uma lavra previamente planejada (administração de água, não destruição da jazida, evitando trabalho duplo de remanejamento de material, etc.);

→ problema do detergente na água,

função do detergente na água, principais problemas causados pelos detergentes na água (mudanças da flora e fauna devido o excesso de fosfato), maneiras de evitar o uso do detergente na água.

⇒ Contaminação do meio ambiente por falta de atenção no *manuseio das máquinas*:

→ como cuidar de um motor,

manutenção necessária de um motor e de uma bomba de sucção, frequência da troca das peças,

→ perigo do óleo derramado,

contaminação do solo, perigo para a água caso o lençol freático seja atingido, pequenos descuidos que se somam a perdas econômicas significativas.

⇒ *Saneamento dentro do garimpo*:

→ conceitos básicos sobre tratamento de água, porque a necessidade de tratar água, maneiras de tratamento de água (filtragem, desinfecção química), uso de Qboa como substituto do cloro.

→ construção de poços e fossas,

locais apropriados, distanciamento entre poço e fossa, uso de materiais disponíveis no garimpo, vantagens de poço e fossa em vez de usar a água do rio e a mata,

→ sistemas simples de abastecimento de água,

poço artesiano, sistema de encanamento, limpeza do sistema de abastecimento

BIBLIOGRAFIA

Mathis / Brito / Brüseke (1997). *Riqueza volátil: a mineração de ouro na Amazônia*. Belém (CEJUP).

CONTROLE E MONITORAMENTO DE MERCÚRIO NA AMAZÔNIA LEGAL E NO PANTANAL PROGRAMA MERCÚRIO (*PROMER)*

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EXPOSIÇÃO DE MOTIVOS

Os problemas associados à contaminação por metais pesados têm recebido um destaque especial em vários países, independentemente do seu grau de desenvolvimento. O controle do mercúrio ressurge como uma preocupação atual devido à sua grande toxicidade e acumulação em sitemas aquáticos e biota, estando incluído no rol das Substâncias Tóxicas Persistentes (STP), sob monitoramento global pelo GEF/PNUMA. Tendo em vista a alta mobilidade e dispersão atmosférica deste metal nos reservatórios do nosso planeta, com um tempo de residência que pode chegar até 2 anos na atmosfera, vários países já implementaram programas de monitoramento. A Agência de Proteção Ambiental dos EUA (USEPA), através do relatório *Mercury study report to Congress* enfatizou a necessidade de se regular emissões de mercúrio frente aos riscos que o mesmo apresenta. O programa similar canadense, *Long range atmospheric transport of heavy metals*, avalia o transporte de mercúrio a longa distância e suas possíveis implicações na qualidade de vida. A comunidade cientifica internacional reconheceu que o metilmercurio na cadeia alimentar aquatica é um potencial de risco para o meio ambiente e saúde humana, gerando um programa de controle do mercúrio nos países que compõem o NAFTA: Estados Unidos, Canada e Mexico.[1]

No Brasil, o controle ambiental ficou sob a responsabilidade dos governos estaduais, mas falta uniformidade de objetivos e ações, sem articulação com a esfera federal e com os institutos de pesquisa. Como consequência, o país não dispõe de nenhum programa nacional de monitoramento de poluentes. O PROMER tem como meta preencher essa lacuna, criando um programa pioneiro de monitoramento de mercúrio, um metal de toxicidade comprovada, em duas regiões de importância estratégica para o futuro do Brasil, Amazônia e Pantanal Matogrossense.

A Amazônia Legal, com uma área de 5,8 milhões de km^2 e com a menor densidade demográfica do país, juntamente com o Pantanal, constituem reservas estratégicas para o Brasil. Para gerenciar adequadamente essa riqueza, é de extrema importância que se conheçam todos os agentes agressores, naturais ou antrópicos, presentes nos dois ecossistemas.

Dentre os agentes que poderiam ameaçar este estoque estratégico o mercúrio é o que merece maior atenção. Contaminações de fontes naturais[(2,3)] associadas àquelas de origem antrópica, como o garimpo[(4-6)], têm mostrado que os teores de metilmercúrio nos peixes da Amazônia é elevado[(7-9)], causando sua biomagnificação na biota aquática e nas populações ribeirinhas[(10-21)]. Os efeitos deste acúmulo a longo prazo não podem ser previstos com exatidão, sendo o conhecimento da sua ecotoxicologia peça fundamental para o manejo sustentável desta riqueza.

OBJETIVOS

O Programa pretende montar uma Rede Nacional e Permanente de Monitoramento dos níveis do mercúrio na Amazônia Legal e no Pantanal, em várias matrizes, que permita elucidar o ciclo biogeoquímico do mercúrio em ambientes aquáticos nestes biomas, identificando fontes de emissão regionais e globais, transporte, ciclagem e acúmulo na cadeia trófica, de tal modo que se tenha um diagnóstico preciso sobre o ciclo e, por conseguinte, a ecotoxicologia do mercúrio.

Como objetivos específicos podem ser citados:

- Diagnosticar o atual estágio de contaminação por mercúrio, identificando as fontes de emissão e o destino do metal nestes ecossistemas;

- Determinar as bacias e reservatorios de maior risco a serem monitoradas;
- Normatizar procedimentos de coleta, amostragem e metodologia analítica;
- Treinar e capacitar o pessoal técnico local;
- Propor acompanhamento da população ribeirinha;
- Elaborar cartilha com recomendações úteis específicas para educação ambiental
- Propor medidas de recuperação de áreas degradadas pela atividade garimpeira;
- Sugerir medidas de prevenção e mitigação de danos, acionando os órgãos responsáveis
- Criar um banco de dados, com áreas pesquisadas, resultados e publicações, centralizado e acessível à comunidade científica e geral.
- Propor diretrizes e prioridades para pesquisas futuras.
- Fornecer subsídios para a implementação de políticas de controle e gestão.

IMPLEMENTAÇÃO DO PROGRAMA

No primeiro ano do programa, pretende-se identificar as potencialidades e necessidades dos laboratórios locais com experiência na determinaçao de mercúrio, bem como os grupos qualificados que atuem no monitoramento ambiental. Sera feito um diagnóstico dos laboratórios, quanto à disponibilidade e adequaçao dos equipamentos, a possibilidade de contar com um técnico exclusivo, as metodologias analíticas disponíveis para as diversas matrizes a serem monitoradas e a experiência anterior com exercícios de intercablibraçao. À partir deste diagnóstico, que será feito por meio de visitas técnicas de especialistas, o IBAMA pretende, com apoio dos parceiros interessados no Programa, como CNPq, OPAS, FNMA, ANA, ELETROBRAS, ELETRONORTE, Universidades e Centros de Pesquisa, etc, suprir as lacunas detetadas, promovendo treinamento dos técnicos e cuidando da implantação do Controle de Qualidade Analitica, coordenando exercícios de intercalibração, de forma que todos os laboratórios da rede estejam aptos a iniciar os trabalhos de monitoramento.

O segundo ano será dedicado ao monitoramento propriamente dito, começando com as matrizes mais fáceis de serem analisadas por todos os laboratórios, como amostras de peixe, cabelo, solo e sedimento. Para um segundo momento ficarão as amostras de água e ar, que por conterem normalmente, concentrações muito baixas de mercúrio, exigem cuidados especiais, tanto na coleta quanto no tratamento analítico. As áreas prioritarias de monitoramento serão as bacias dos rios Tapajós, Madeira, Xingú e Negro, incluindo os reservatórios próximos, tais como Curuá-Una, Samuel, Tucuruí e Balbina.

LABORATÓRIOS COMPONENTES DA REDE DE CONTROLE E MONITORAMENTO

A principal componente e a célula unitária deste programa são as Unidades Geradoras de Dados de Monitoramento ou simplesmente os Laboratórios Locais (LC), que compõem a Rede de Monitoramento. Para melhor funcionamento dos LC, estão previstos três laboratórios de suporte, chamados Laboratórios de Referência (LR). Esta classificação está baseada na capacitação técnica dos laboratórios participantes, sendo que o papel de cada um deles, respeitando-se suas vocaçoes especificas, está definido dentro das atribuições previstas no Programa.

Laboratórios Locais: são laboratórios localizados na Amazônia e no Pantanal que já dispõem de um histórico de atuação na determinação de mercúrio. Os LC são laboratórios que necessitam de recursos para aprimorar seu parque instrumental para que possam analisar todas as matrizes de interesse identificadas na primeira fase do projeto, bem como para treinar pessoal apto a desenvolver trabalhos de rotina e de pesquisa. Estes laboratórios desempenham um papel importante pois já se encontram inseridos nas respectivas bacias. Foram detetadas as seguintes unidades que poderiam atuar como LC:

1. *Instituto Nacional de Pesquisas da Amazônia (INPA),* Manaus, Depto. de Ecologia Aquática, – Prof. Dr. Bruce R. Forsberg.
2. *Universidade Federal do Pará, Posto Avançado,* Santarém - Prof. Aldo Queiróz e Profa. Maria das Graças Pires.
3. *Universidade Federal do Pará, Núcleo de Medicina Tropical,* Belém - Dra. Maria Conceição Pinheiro.
4. *Instituto Evandro Chagas* - Belém – Sra. Elisabeth Santos
5. *Departamento Nacional de Produção Mineral* – DNPM – Sra.Terezinha Cid.
6. *Universidade Federal de Rondônia*, Porto Velho - Prof. Dr. Ene Glória da Silveira e Wanderley Bastos.
7. *Universidade Federal de Mato Grosso,* Porto Velho - Prof. Dr. Ednaldo Castro e Silva

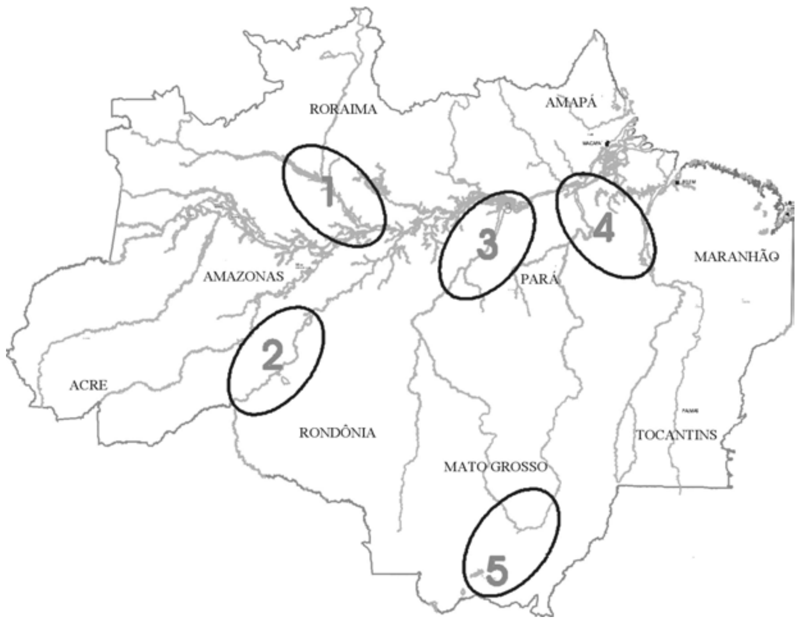
Laboratórios de Referência: Os LR se caracterizam por possuir larga experiência na determinação de mercúrio em matrizes diversas. São laboratórios com um parque instrumental sofisticado, pessoal qualificado e bem treinado, com projeção internacional no tema mercúrio. Dentro do programa de monitoramento, os LR tem a função de Centros de Referência dentro do país, produzindo os protocolos necessários para as atividades previstas, cuidando do treinamento de pessoal necessitado, auditando a qualidade dos dados gerados experimentalmente, por meio de programas de intercalibração e de outras atividades que garantam a confiabilidade e rastreabilidade destes dados. Dentre os laboratórios existentes no Brasil que se enquadram nesta classficaçao, destacamos os três, indicados abaixo, mas outros podem ser posteriormente incluidos:

- Universidade de Brasília (UnB), Instituto de Química, Laboratório de Química Analítica - Prof. Dr. Jurandir R. de Sousa.
- Universidade Estadual de Campinas (UNICAMP), Instituto de Química, Laboratório de Química Ambiental - Prof. Dr. Wilson de F. Jardim.
- Universidade Federal do Rio de janeiro (UFRJ), Instituto de Biofísica, Laboratório de Radioisótopos -Prof. Dr. Olaf Malm.

RESULTADOS ESPERADOS

Identificação e aprimoramento analítico de laboratórios locais, treinamento de técnicos na determinação de mercúrio, normatização de protocolos de amostragem, coleta e metodologia analítica e estabelecimento de exercício de intercalibração laboratorial. Após a montagem de uma estrutura adequada de laboratórios locais, com garantia de controle de qualidade analítica, realização do monitoramento de mercúrio na Amazônia e no Pantanal.

LOCALIZAÇÃO DA REDE DE MONITORAMENTO



EQUIPE

Executores: Antonio Carneiro Barbosa - IBAMA – Diretoria de Licenciamento e Qualidade Ambiental, Wilson de Figueiredo Jardim - UNICAMP - Instituto de Química, Olaf Malm - UFRJ - Laboratório de Biofísica.

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Aquática, Ene Glória da Silveira/Wanderley Bastos - UNIR, Porto Velho - Departamento de Quimica, Aldo Queiróz/ Maria das Graças Pires, UFPA - Posto Avançado da UFPA, Santarém, Maria Conceição Pinheiro - UFPA, Belém, Núcleo de Medicina Tropical, Terezinha Cid DNPM, Belém, Elisabeth Santos - Instituto de Medicina Tropical, Belém, Ednaldo Castro e Silva - UFMT, Cuiabá, Departamento de Química.

Colaboradores: CNPq, OPAS, DNPM, ELETRONORTE, ELETROBRÁS, ANA - Agência Nacional de Águas, MMA/FNMA e PQA/SQA, UnB: Departamentos de Genética e de Nutrição, UFF, UFCe e PUC-RJ, FIOCRUZ – ENSP, GEOS- Recuperação de mercúrio, IBAMA – Representações de: Campo Grande – MS, Cuiabá – MT, Belém-PA, Porto Velho-RO, - Santarém-PA (CENAQUA), Manaus – AM.

REFERÊNCIAS BIBLIOGRÁFICAS

1. Pilgrim, W., Schroeder, W. et al, *Developing consensus: mercury science and policy in the NAFTA countries (Canada, the United Stades and Mexico*, The science of the Total Environment 261: 185-193, 2000

2. Fadini, P. and Jardim, W., *Is the Negro River Basin (Amazon) impacted by naturally occuring mercury,* The Science of the Total Environment, 275:71-82, 2001

3. Roulet, M, Lucotte, et al, D, Amorim, M. *Spatio-temporal geochemistry of mercury in waters of the Tapajos and Amazon rivers, Brazil*, Limnol. Oceanogr.46: 1141-1157. 2001

4. MALM, O., CASTRO, M.B., BASTOS, W.R., et al, *An assessment of Mercury pollution in different goldmining areas, Amazon Brazil*, Science of Total Environment. 175(2): 127-140, 1995

5. Malm, O. *Gold mining as a source of mercury exposure in the Brazilian Amazon,* Environ.Res. 77:73-78, 1998

6. Roulet, M, Lucotte, et al, D, Amorim, M. *Spatio-temporal geochemistry of mercury in waters of the Tapajos and Amazon rivers, Brazil*. Limnol. Oceanogr. 46:1141-1157, 2001

7. Malm, O.; Guimarães, JRD; et al, *Follow-up of mercury levels in fish, human hair and urine in the Madeira and Tapajós basin, Amazon, Brazil*. Water, Air and Soil Pollution, 97:45-51, 1997

8. Barbosa, A.C., et al, *Mercury Contamination in the Brazilian Amazon. Environmental and Occupational Aspects*, Water, Air and Soil Pollution, 80: 109-121, 1995

9. Lodenius M and Malm O. *Mercury in the Amazon, Rev Environ Contam Toxicol Review* 157:25-52, 1998

10. Santos EC, Jesus IM, Brabo ES et al, *Mercury exposures in riverside Amazon communities in Para, Brazil*, Environ Res. 84(2):100-7. 2000

11. Barbosa, A.C., Jardim, W., Dórea, J.G., Fosberg, B., Souza, J.R., *Hair Mercury Speciation as a Function of Gender, Age and Body Mass Index in Inhabitants of the Negro River Basin, Amazon, Brazil*, Arch. Environ. Contam. Toxicol. 40, 439-444, 2001.

12. Barbosa, A.C., Silva, S.R.L., Dórea, J.G., *Concentration of mercury in hair of indigenous mothers and infants from the Amazon Basin*, Archives of Environ.Contamin. and Toxicol. 34, 100-105, 1998.

13. Grandjean, P.; White, R.F.; Nielsen, A.; Cleary, D. and Oliveira Santos, E., *Methylmercury neurotoxicity in Amazonian chilcren downstream from gold mining*, Environ. Health Perspect. 107:587-591, 1999.

14. Silva-Fosberg, MC; Fosberg BR; Zeidemann, VK. *Mercury contamination in humans linked to river chemistry in the Amazon Basin*, Ambio, 28:519-521, 1999.

15. Bidone ED, Castilhos ZC, Cid de Souza TM, Lacerda LD., *Fish contamination and human exposure to mercury in the Tapajos River Basin, Para State, Amazon, Brazil: a screening approach*, Bull Environ Contam Toxicol. 59(2):194-201, 1997

16. Malm, O, Branches, FJP, Akagi, H, et al, H. *Mercury and methylmercury in fish and human hair from the Tapajos river basin, Brazil*, Sci. Total Environ. 175:141-150. 1995

17. Hacon, S.S; Yoko E; Valente, J; *Exposure to mercury inpregnant women from Alta Floresta - Amazon Basin, Brazil.* Environmental Research, 84:204-210, 2000

18. Hacon, S. S., Rochedo, E., Campos, R. C., Lacerda, L. D. *Mercury exposure through fish consumption in the urban area of Alta Floresta in the Amazon Basin*, Journal of Geochemical Exploration. Netherlands, 58: 209-216, 1997

19. Guimarães, JRD. *Origins and effects of mercury on riparian populations of the Brazilian Amazon,* International Journal of Occupational and Environmental Health, 7(2, suppl):23-25, 2001

20. Kehrig, H., Malm, O., Akagi, H., Guimarães, J.R.D. & Torres, J.P.M. *Methylmercury in fish and hair samples from the Balbina Reservoir*, *Brazilian Amazon.* Environmental Research, Section A 77:84-90, 1998.

21. Akagi, H; Malm, O; et al, *Human exposure to mercury due to goldmining in the Tapajós river basin, Amazon, Brazil: speciation of mercury in human hair, blood and urine,* Water, Air & Soil Poll, 80: 85-94, 1995.

EM BUSCA DO OURO LIMPO

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RESUMO

A garimpagem desordenada de ouro na Amazônia, persistente há muitas décadas, configura o uso insustentável de recursos minerais importantes em âmbito mundial. Com o declínio da atividade, muitas áreas aluvionares têm sido abandonadas com graves consequências sociais, econômicas e ambientais. Acredita-se que a remoção eficaz de ouro e de mercúrio contidos em minérios remanescentes e rejeitos pode ser a melhor via, senão a única, para viabilizar o ordenamento social dos garimpos de ouro da região, com reabilitação das várzeas e o uso sustentável de recursos hídricos e florestais presentes, até aqui devastados pela *febre do ouro*. Isso requer o desenvolvimento de um novo modelo de produção, amparado em metodologias e tecnologias adequadas, viabilizável apenas sob uma ampla transformação cultural. Delineia-se um projeto cooperativo para implantação de *centros de mineração experimental* nas áreas degradadas pela garimpagem de ouro na Amazônia, propondo-se iniciá-lo na região do Tapajós.

O OURO INSUSTENTÁVEL

A garimpagem de ouro na Amazônia tem sido praticada de modo desordenado, sob condições ambientais adversas, à distância do poder público. A atividade migratória, predatória e usualmente ilegal, exercida anonimamente, não trouxe benefícios duradouros para os locais de extração, ao contrário do ocorrido em outras regiões do país no século 18. Após 20 anos de intensa produção mecanizada, experimenta irreversível declínio, deixando graves problemas sociais, econômicos e ambientais para as comunidades envolvidas (Veiga *et al*., 1999).

A província do Tapajós, no Pará, é a mais tradicional e importante região de garimpagem de ouro da América Latina, talvez do mundo. Estende-se por 100.000km². Está em atividade contínua desde

1958, somando mais de 600t de ouro artesanalmente produzidas em 430 áreas – cerca de 2.000 frentes de garimpagem, muitas delas abandonadas (D. S. Frederico, com. pes.). Poucos foram beneficiados. Como em outras regiões da Amazônia, as operações rudimentares nos aluviões resultaram em graves danos ambientais, com comprometimento de recursos hídricos e bióticos ainda pouco conhecidos. A amalgamação ineficiente, combinada ao lançamento descontrolado de rejeitos contaminados com mercúrio, implicou em ampla exposição ocupacional e poluição ambiental (Veiga e Veiga, 2000).

Com o fim do ouro fácil, a extração voltou-se para as fontes primárias (sobretudo veios de quartzo), prenunciando o fim da garimpagem. A falta de conhecimento técnico, de informações geológicas e de capital, necessários à lavra subterrânea, tem conduzido ao insucesso e conseqüente abandono de áreas degradadas (Veiga *et al*., 1999). A produção declinou continuamente durante os anos 1990. Os registros do Departamento Nacional de Produção Mineral demonstram decréscimo da ordem de 75% na produção declarada – cerca de 15t anuais no início do período, para menos de 4t em 2000 (www.dnpm.gov.br). A produção real em 2000, estimada pela Prefeitura de Itaituba, situou-se em torno de 7t de ouro, incluindo os municípios vizinhos (D. S. Frederico, com. pes.).

A população garimpeira diminuiu na mesma medida, passando de aproximadamente 90.000 pessoas diretamente envolvidas na atividade produtiva em 1990 (DNPM, 1993), para 25.000 estimadas em 2000 (A. R. B. Silva, com. pes.). Milhares de garimpeiros migraram para países vizinhos – Suriname, Guiana, Bolívia, Venezuela – onde reproduzem o famigerado modelo de produção desordenada (Veiga *et al*., 1999). Todavia, a atividade no Tapajós ainda mantém alguma expressão, favorecida pela abundância de filões ricos aflorantes e pela disponibilidade de um persistente contingente de refugiados econômicos.

Naturalmente, a produção tornou-se mais cara, mais difícil e mais predatória. Cerca de 60% provém hoje da explotação de veios de quartzo (J. Antunes, com. pes.), sabidamente inexpressiva enquanto houve ouro secundário abundante. Os processos rudimentares de moagem e amalgamação limitam a recuperação rentável à porção superficial (oxidada) dos filões. Por serem pouco eficazes, acarretam consumo exagerado de mercúrio. Abaixo de 50m de profundidade, o ouro permanece agregado a sulfetos em rocha dura e a operação deixa de ser rentável, implicando no abandono da lavra e, eventualmente, na busca de outro filão.

Na segunda metade dos anos 1990, abriu-se espaço à atuação de empresas de mineração organizadas. Cerca de 30 companhias investiram expressivos recursos técnicos e financeiros na exploração de ouro primário no Tapajós, mas nenhuma logrou encontrar reservas da ordem de 30t de ouro (1 milhão de onças), consideradas necessárias à viabilização de operações mineiras. Frustrava-se assim a expectativa de implantação da mineração organizada na região, inviável ante a pequena dimensão dos corpos primários conhecidos.

O PASSIVO AMBIENTAL

Não se sabe a quantidade real de mercúrio consumida na garimpagem de ouro na Amazônia. Contudo, considera-se que as estimativas usuais (entre 1.000 e 3.000t) estão aquém da realidade, pois baseiam-se majoritariamente nas perdas estimadas ao final do processo (queima do amálgama ao ar livre). Ignoram perdas ocorridas no descarte de rejeitos contaminados (na amalgamação e na apuração), usualmente maiores porém de mais difícil aferição. Tampouco se conhecem as consequências ambientais desse descarte descontrolado. Pesquisas recentes assinalam elevadas concentrações naturais de mercúrio no contexto amazônico, junto a evidências preocupantes de contaminação a grande distância dos locais garimpados. Essas questões aguardam estudos mais aprofundados e um melhor entendimento do ciclo biogeoquímico do mercúrio na região (Veiga e Veiga, 2000).

Todavia, considera-se necessário intervir, de imediato, nos principais focos de contaminação conhecidos, através de ações para reabilitação ambiental de áreas garimpadas. Sabe-se que há ouro remanescente e um vasto potencial ainda inexplorado, porém dificilmente aproveitável pelas vias convencionais – tanto garimpeiras quanto empresariais – em vista da desordem praticada e das dificuldades naturais de trabalho na região. São rejeitos diversos contaminados com mercúrio, em meio a trechos virgens descontínuos, bem como depósitos primários por vezes muito ricos, porém de pequeno porte. Seu aproveitamento pode ser a oportunidade desejada para a reabilitação das várzeas e o uso sustentável dos outros recursos presentes, até aqui devastados pela *febre do ouro*.

A idéia não é nova: há muito se discute a necessidade de transformar a garimpagem numa atividade rural estável e ambientalmente sustentável, depurada de suas persistentes mazelas (Salomão, 1984; Barros, 1994, dentre outros). De qualquer forma, considera-se que a decadência da garimpagem diminui a resistência ao seu ordenamento, favorecendo a mudança pretendida (Veiga e Veiga, 2000).

A ATUAÇÃO PROFISSIONAL NA AMAZÔNIA

A GEOS é uma empresa brasileira de consultoria e serviços, fundada em 1974. Desde 1979, teve ampla atuação na região do Tapajós e em outras províncias auríferas amazônicas (histórico disponível em www.geos.com.br). Entre 1984 e 1986, seu corpo técnico integrou-se ao Grupo Paranapanema, que operava minas aluvionares de ouro no Mato Grosso e no Amapá. A figura 1 ilustra as principais áreas de atuação durante o ciclo do ouro na Amazônia.

Esse período foi marcado por uma vertiginosa expansão da atividade garimpeira, sob o aporte de capitais exógenos e intensa mecanização das operações de desmonte, porém ainda atreladas a sistemas de tratamento rudimentares, ineficazes e poluentes. A legislação tampouco evoluiu, distanciando-se da realidade e tornando-se inócua ante os interesses em conflito (DNPM, 1994). Ainda assim, o conhecimento técnico ampliou-se consideravelmente. A busca de um melhor aproveitamento dos recursos auríferos envolvia a caracterização criteriosa das jazidas e a racionalização da lavra e do beneficiamento. Por outro lado, requeria especial atenção aos aspectos sociais e culturais da garimpagem (Salomão, 1984; Barros, 1994; Veiga, 1999, dentre outros).

A atuação técnica em minas e garimpos de ouro, abrangendo variados tipos de jazimentos secundários e primários, resultou em algumas realizações:

1. Proposição de um modelo genético-exploratório e de procedimentos de pesquisa adequados aos aluviões amazônicos, consolidados em uma dissertação de mestrado e divulgados em publicações, palestras e cursos diversos: Salomão e Veiga (1984); Salomão e Falleiros (1986); Veiga, Dardenne e Salomão (1988); Salomão e Veiga (1989); Veiga (1990); Veiga e Barros (1991), dentre outros;
2. Aplicação experimental de processos inovadores para amalgamação controlada e remoção de ouro e de mercúrio contidos em minérios e rejeitos: pesquisa e desenvolvimento de processos de amalgamação controlada, com uso de placas especiais produzidas pela Goldtech – empresa brasileira detentora de tecnologia pioneira para mercurização de superfícies metálicas por eletrodeposição (Veiga *et al*., 1995).

OPÇÕES TECNOLÓGICAS

As opções tecnológicas oferecidas aos garimpos nunca foram utilizadas em escala significativa, por serem caras, complexas, pouco práticas ou pouco eficientes. Algumas se resumiam a ligeiras melhorias no velho sistema do mercúrio na bateia. Por outro lado, as retortas e capelas existentes no mercado podem oferecer proteção adequada durante a destilação (*queima*) de amálgama, nos garimpos e casas compradoras de ouro. Embora sejam equipamentos de uso obrigatório, a sua utilização e manutenção têm sido negligenciadas, ante a falta de mecanismos efetivos de orientação e controle (DNPM, 1993).

Quanto às etapas anteriores do processo produtivo, onde se encontram arraigadas as práticas mais danosas ao ambiente, concebeu-se uma opção efetiva, capaz de viabilizar ambientalmente as operações em curso, bem como propiciar a reabilitação de áreas degradadas. De fato, as aplicações experimentais coordenadas pela GEOS atestaram a aplicabilidade e versatilidade da tecnologia Goldtech, que permite a fabricação de equipamentos simples para substituição das tradicionais calhas (*bicas*), bateias e placas de cobre, evitando-se as perdas a elas inerentes, com importantes vantagens em relação a outras opções tecnológicas.

As placas mercurizadas foram utilizadas em diferentes situações e circuitos de beneficiamento, representativos da realidade dos garimpos, propiciando eficiente captação, em condições ambientalmente seguras, de ouro livre (ainda que ultrafino) e de mercúrio metálico, contidos em minérios e rejeitos. São utilizáveis em recipientes modulares, para processamento de polpas minerais em circuito fechado, tanto em escala contínua (mecanizada), quanto descontínua (manual). Os principais resultados foram sumarizados por Veiga *et al*. (1995):

Caso 1: em 1992 foi montada em Cavalcante – GO uma operação-piloto para processamento de rejeitos variados, precariamente empilhados na zona urbana (mina Buraco do Ouro). Foram tratadas cerca de 2.800t de rejeitos, com recuperação de aproximadamente 4kg de ouro bruto e 2kg de mercúrio, em prazo equivalente a 50 dias de operação plena (5t/h).

Caso 2: em 1994 foram tratados rejeitos de amalgamação provenientes de concentrados de balsas, estocados pelo Sindicato dos Garimpeiros de Minas Gerais em uma central de apuração instalada em Porto Firme – MG. A garimpagem fora interditada judicialmente, tendo sido liberada após o ordenamento da atividade pelos próprios garimpeiros. Foram tratadas cerca de 90t de rejeitos, resultantes do trabalho de 35 balsas durante 4 meses. Cerca de 42kg de ouro haviam sido extraídos por amalgamação convencional. O tratamento dos rejeitos permitiu recuperar mais 0,9kg de ouro e 145kg de mercúrio, que teriam sido lançados ao rio pelo sistema usual.

Resultados semelhantes foram obtidos em diversos garimpos na Amazônia – no Pará, Tocantins e Mato Grosso – atestando as vantagens dessa técnica, capaz de oferecer opções práticas, baratas, seguras e facilmente assimiláveis para extração de ouro livre e de mercúrio metálico em minérios e rejeitos. Porém, a exemplo das retortas e capelas, sabia-se que a problemática dos garimpos não se resumia à disponibilidade de equipamentos potencialmente benéficos, porém prendia-se à persistência de métodos inadequados e à desordem praticada.

A dinâmica da produção desordenada, amparada em inúmeros interesses, dificultava a difusão do equipamento. Sua aplicação conseqüente requeria a organização da lavra e do beneficiamento, de modo a prevenir danos desnecessários e assegurar seu uso em circuito fechado, com deposição segura dos efluentes. Não era uma tarefa fácil, na desordem característica daquela corrida do ouro. O projeto permaneceu em ritmo lento, enquanto a garimpagem declinava em todo o Brasil. Todavia, continuou em pauta, à espera de ações articuladas para ordenamento e melhoria do desempenho da atividade.

Atualmente, o CETEC de Minas Gerais desenvolve um projeto-piloto para recuperação de áreas garimpadas em Paracatu – MG, com recursos do FNMA e do CNPq. Após diagnóstico da área, prevêem-se ensaios tecnológicos em escala piloto e no campo, para definição do circuito de tratamento a ser aplicado na descontaminação do aluvião do córrego Rico. O desempenho das placas mercurizadas será aferido em diferentes circuitos de tratamento, para comparação com outras possibilidades tecnológicas. Os resultados antes obtidos sustentam perspectivas animadoras, sem prejuízo de outras opções porventura mais vantajosas. Ensaios semelhantes poderão ser realizados pelo CETEM, em escala piloto e em áreas selecionadas no Tapajós, para desenvolvimento do processo e adequação às condições amazônicas.

AÇÕES PROPOSTAS

A partir de 1993, a GEOS e a Goldtech empenharam-se em instalar centrais de amalgamação controlada na região do Tapajós. A importância dessa província requeria ações inovadoras de longo alcance, estimulando a busca de parcerias para implantação de unidades demonstrativas. Infelizmente, as articulações então realizadas, com o Governo do Pará (SEICOM e Paraminérios) e com a AMOT – Associação dos Mineradores de Ouro do Tapajós, esbarraram em obstáculos diversos e não alcançaram êxito.

Posteriormente, consolidava-se o conceito de *garimpagem limpa*, alicerçado em experiências desenvolvidas em outros países. As centrais de amalgamação controlada passaram a ser recomendadas pela UNIDO, conforme fluxograma ilustrado na figura 2 (Veiga, 1997a; Veiga e Beinhoff, 1997). No Brasil, receberam a chancela do Ministério do Meio Ambiente, dentre as diretrizes propostas para a solução de problemas críticos do setor mineral (MMA, 1997). Isso estimulou a retomada do Projeto Tapajós, propondo a *garimpagem limpa* em operações demonstrativas na região (Veiga *et al*., 1999).

O projeto foi novamente apresentado em um recente encontro ibero-americano promovido pelo CYTED, onde se discutiu a sustentabilidade da extração mineral na América Latina. Propôs-se o desenvolvimento de um modelo novo de produção no Tapajós (Veiga e Veiga, 2000, disponível em www.cetem.gov.br/imaac/proceedings.html – Module IV.doc, páginas IV-22 a IV-30). O programa proposto visa a seleção de áreas-piloto e a implementação de medidas necessárias ao ordenamento e regularização da garimpagem, para posterior difusão na província.

Pressupõe a cooperação entre organismos governamentais (federais, estaduais e municipais), entidades internacionais, instituições de pesquisa e o setor privado, tal qual a articulação ora iniciada pela UNIDO e instituições associadas (www.unido.org/doc/371455.htmls). Acredita-se que essa cooperação poderá firmar-se institucionalmente como uma organização civil voltada à mineração experimental, similar à fundação concebida no Suriname para disciplinamento da garimpagem e difusão de técnicas ambientalmente adequadas à realidade local (Veiga, 1997b).

A criação de *centros de mineração experimental* permitirá aos garimpeiros desenvolver seu talento prospector e aprender procedimentos simples de pesquisa, lavra e processamento de minérios, enquanto produzem ouro. Essas *operações-modelo,* legalmente amparadas em concessões minerais específicas, visam, a um só tempo (Veiga e Veiga, 2000):

- prover opções tecnológicas adequadas e métodos de trabalho eficazes, simples, seguros, rentáveis, compatíveis com as peculiaridades do ouro amazônico e com a proteção ambiental;
- desenvolver critérios e parâmetros para recuperação das áreas já degradadas;
- estabelecer bases para o assentamento rural de famílias dedicadas ao aproveitamento consorciado ou complementar de outros recursos naturais, incluindo o ouro primário e os recursos renováveis existentes.

Nesse programa, os garimpeiros serão responsáveis pela lavra e pré-concentração do minério, naturalmente conformados a normas técnicas e operacionais adequadas, estabelecidas em comum acordo. A condução da lavra e a deposição dos rejeitos finais deverão obedecer a planejamento criterioso, para racionalização dos custos e preparação das várzeas para posterior reabilitação. Os concentrados serão processados de modo organizado em centrais de tratamento construídas nos moldes recomendados pela UNIDO, operadas e mantidas pelos próprios garimpeiros, após treinamento e sob acompanhamento técnico. O ouro a ser recuperado deverá ressarcir parte dos dispêndios, estimulando o investimento em novas áreas.

A experimentação propiciará o desenvolvimento de equipamentos e processos, em busca de maior economicidade e segurança na lavra e tratamento de minérios e rejeitos auríferos. A proposta avança no aspecto educacional: sob uma organização civil de interesse público, os garimpeiros e a comunidade em geral podem receber apoio e orientação em temas relacionados à legalização e organização da atividade mineira, seguridade social, saúde e segurança ocupacional, assuntos familiares, contabilidade e controle dos impactos ambientais.

Os prazos e custos inicialmente estimados (US$250.000,00 para implantação da primeira central, em prazo de 6 meses), deverão ser detalhados após a seleção dos locais para implantação. O planejamento e o acompanhamento dessa transição serão feitos em conjunto, de modo a ajustar as diferentes necessidades e interesses envolvidos, com vistas a conquistas duradouras. Na regulamentação específica que deverá balizar as atividades, reserva-se um papel decisivo à SECTAM, órgão ambiental do Pará (Veiga e Veiga, 2000).

A UTOPIA DO GARIMPO LIMPO

Os centros de mineração experimental são instrumentos poderosos para a descontaminação de áreas degradadas e a conscientização das comunidades garimpeiras – quer sobre os malefícios inerentes ao sistema tradicional, quer sobre o uso sustentável de outras possibilidades econômicas, com vistas à melhoria da qualidade de vida (Veiga, 1997a; Veiga e Beinhoff, 1997; Veiga *et al*., 2000). As projeções efetuadas asseguram vantagens econômicas importantes, capazes de estimular e consolidar o novo modelo de produção, que poderá ser estendido a outras regiões afetadas por problemas similares, no Brasil e em outros países.

Como visto, a criação de centros de processamento controlado pressupõe transformar operações artesanais desorganizadas em pequenos empreendimentos mineiros, tecnicamente compatíveis com a proteção ambiental e o uso de outros recursos presentes (Veiga e Veiga, 2000). Trata-se de uma ampla transformação cultural. A promoção do trabalho em condições dignas e tecnicamente evoluídas não se esgota na disponibilidade de equipamentos apropriados. Sabe-se que a questão é complexa e não pode ser resolvida através de iniciativas empresariais isoladas, como foi o caso das placas mercurizadas, até aqui desenvolvidas apenas com recursos privados.

De fato, a compatibilização da garimpagem com a proteção ambiental demanda o esforço articulado de produtores locais, empresas privadas, instituições de pesquisa, organismos governamentais e não-governamentais, suportado por políticas e determinações legais consistentes. Recorda-se que a legislação brasileira ainda trata a garimpagem de forma simplista, incapaz de distinguir responsabilidades entre trabalhadores e empresários, estabelecer deveres e, consequentemente, induzir as mudanças necessárias ao controle dos danos e à ampliação dos benefícios gerados por essa tradicional atividade (DNPM, 1994).

A construção do novo modelo produtivo requer ações coordenadas, em todos os níveis, visando os seguintes objetivos (Barros, 1994):

- definição adequada e enquadramento legal da garimpagem e dos garimpeiros (empresários e trabalhadores);
- simplificação dos procedimentos para regularização dos empreendimentos, como pequenas empresas ou como cooperativas autênticas;
- ações efetivas de monitoramento, fiscalização e eventual punição;
- divulgação de experiências pioneiras positivas.

Ademais, considera-se que o assentamento organizado de garimpeiros e familiares, em pequenas comunidades *agromineiras*, é fundamental à transformação pretendida. Sua fixação à terra é que garantirá o bom uso dos recursos existentes. Outras possibilidade econômicas deverão complementar sua renda e assegurar a permanência na área, após o esgotamento do ouro. Dentre elas, citam-se: diferentes modalidades de extrativismo, atividades agropastoris, artesanato mineral e joalheira (Veiga e Veiga 2000).

CONSIDERAÇÕES FINAIS

Já se disse que o primeiro ciclo do ouro ocorrido no Brasil nos legou o barroco; o segundo, apenas barracos e buracos. Especialmente na Amazônia, a escalada garimpeira resultou, ao final do século 20, em um perverso passivo ambiental sem responsáveis legais definidos. Com o declínio da produção, a questão tem recebido menos atenção da mídia, porém a ameaça do mercúrio permanece latente. Por seu lado, as comunidades envolvidas na faina do ouro continuam desassistidas, agora sem horizontes.

A remoção eficaz de ouro e de mercúrio contidos em minérios remanescentes e rejeitos pode ser a melhor via, senão a única, para viabilizar a reabilitação das várzeas e o ordenamento social dos garimpos na região. Isso naturalmente demanda ações articuladas de longo curso, recomendando a formulação de um amplo programa de educação e extensão ambiental, com participação de garimpeiros, técnicos, empresários e da comunidade em geral. Reitera-se a proposição de implantar centros de mineração experimental para reabilitação de áreas garimpadas e melhor aproveitamento de outras possibilidades econômicas presentes, a começar pelo Tapajós (Veiga e Veiga, 2000).

O ordenamento da garimpagem e sua compatibilização com a proteção ambiental implicam em uma grande transformação cultural. Requerem o desenvolvimento de um novo modo de produção, possível apenas em um projeto cooperativo de grande alcance. A exemplo da UNIDO, o engajamento de outras entidades internacionais será decisivo na busca da sustentabilidade do uso dos recursos minerais da Amazônia – tanto nas etapas de planejamento, diagnóstico e experimentação, quanto na produção regular e futura reabilitação das áreas degradadas.

Certamente há um longo caminho a percorrer. De todo modo, a conjuntura atual parece favorecer um esforço cooperativo para a construção de novos paradigmas, ao contrário dos conflitos e da resistência vigentes no auge da produção aurífera. Constata-se hoje uma salutar convergência de propósitos, com vistas ao bom uso dos recursos e à melhoria das condições de trabalho e de vida na região, em benefício dos seus habitantes e do país como um todo. Resta-nos avançar nessa utopia – aqui entendida como idealização motivadora, jamais como um sonho impossível.

REFERÊNCIAS BIBLIOGRÁFICAS

BARROS, J.G.C. (1994). Diretrizes para o gerenciamento ambiental da garimpagem no Brasil. Ministério do Meio Ambiente, Recursos Hídricos e Amazônia Legal – MMA e Programa das Nações Unidas para o Desenvolvimento – PNUD, Brasília, 141 p. il.

DNPM – Departamento Nacional da Produção Mineral (1993). Levantamento Nacional dos Garimpeiros – relatório analítico. DNPM, Série Tecnologia Mineral 45, Brasília, 90 p.

DNPM – Departamento Nacional da Produção Mineral (1994). Plano plurianual para o desenvolvimento do setor mineral. DNPM, Brasília.

MMA – Ministério do Meio Ambiente, Recursos Hídricos e Amazônia Legal (1997). Diretrizes ambientais para o setor mineral. MMA e PNUD – Programa das Nações Unidas para o Desenvolvimento, Brasília, 56 p. il.

SALOMÃO, E.P. (1984). O ofício e a condição de garimpar. *In*: Rocha, G. A. (org.) Em busca do ouro – garimpos e garimpeiros no Brasil. Ed. Marco Zero, São Paulo, p. 35-86.

SALOMÃO, E.P. e FALLEIROS, W.G. (1986). O controle das variáveis operacionais de sondagem (CVOS): uma nova e consistente metodologia para determinação de teores na sondagem banka. *In*: Simp. Intern. do Ouro, 2, Rio de Janeiro, anais.

SALOMÃO, E.P. e VEIGA, A.T.C. (1984 e 1989). Prospecção e pesquisa de depósitos aluvionares. Publ. Av. IBRAM – Curso "Pesquisa e lavra de aluviões", Belo Horizonte.

VEIGA, A.T.C. (1990). Significado paleo-ambiental e econômico dos aluviões auríferos e estaníferos da Amazônia, UnB – Instituto de Geociências, Brasília, 111p. il., dissertação de mestrado, inédita.

VEIGA, A.T.C. (1999). A geodiversidade e o uso dos recursos minerais da Amazônia. Terra das Águas, 1: 88-102, NEAz/UnB, Brasília.

VEIGA, A.T.C. e BARROS, J.G.C. (1991). A genetic - exploratory model for the alluvial gold placers of the Brazilian Amazon. Proc. Intern. Symp. on Alluvial Gold Placers. ORSTOM/UNDP, La Paz.

VEIGA, A.T.C. e VEIGA, M. M. (2000). Uma proposta para reabilitação de áreas garimpadas na Amazônia. *In:* Villas Boas, R. C. e Barreto, M. L. (ed.). Cierre de Minas – experiencias en iberoamerica. CYTED / IMAAC / UNIDO, Rio de Janeiro, p. 287-301.

VEIGA, A.T.C.; DARDENNE, M.A.; SALOMÃO, E.P. (1989). Geologia dos aluviões auríferos e estaníferos da Amazônia. SBG – Congr. Bras. Geologia, 35, Anais; Belém.

VEIGA, A.T.C.; SALOMÃO, E.P.; VEIGA, M.M. e BARROS, J.G.C. (1999). Tapajós Project – A Proposal for a Clean "Garimpagem" in the Brazilian Amazon. *In:* Proc. 5th Intern. Conf. on Mercury as a Global Pollutant, p.291, Rio de Janeiro (abstract e poster).

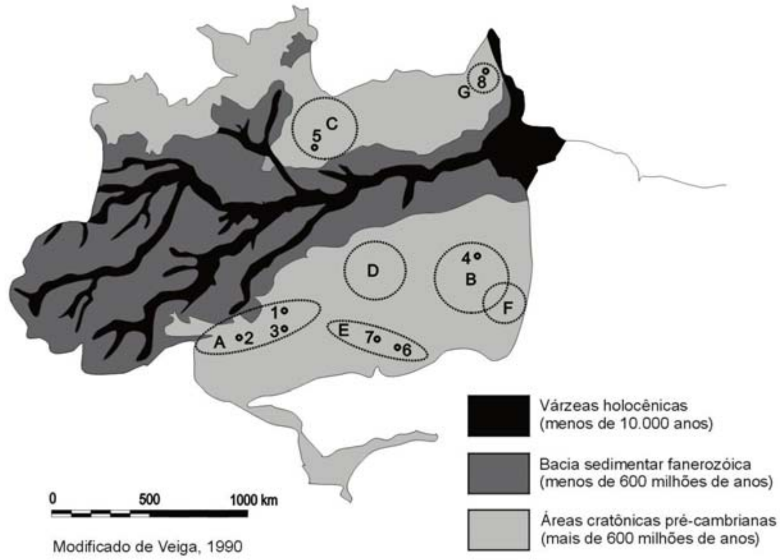
VEIGA, M. M. e BEINHOFF, C. (1997) UNECA Centers, a way to reduce mercury emissions from artisanal gold mining and provide badly needed training. UNEP – Industry and Environment, Oct-Dec. 1997, v. 20, n.4, p. 49-51.

VEIGA, M.M. (1997a). Introducing new technologies for abatement of global mercury pollution in Latin America. UNIDO / UBC / CETEM, Rio de Janeiro, 94 p.

VEIGA, M.M. (1997b). Artisanal Gold Mining Activities in Suriname. Report to UNIDO – United Nations Industrial Development Organization. 32p.

VEIGA, M.M.; McALLISTER, M.L.; SCOBLE, M. (2000). Mining with Communities. Proc. PDAC/CIM Conference, Toronto, March 5-10, 2000 (abstract).

VEIGA, M.M.; VEIGA, A. T. C.; FRANCO, L. L.; BONAGAMBA, M.; MEECH, J. A . (1995) An integrated approach to mercury-contaminated sites. Proc. Eco Urbs' 95, p.51-53. Rio de Janeiro.



PRINCIPAIS ÁREAS ESTUDADAS

PROVÍNCIAS ESTANÍFERAS
- A - Rondônia
- B - Xingu
- C - Pitinga - Mapuera

PROVÍNCIAS AURÍFERAS
- D - Médio Tapajós
- E - Teles Pires - Juruena
- F - Sudeste do Pará
- G - Cassiporé

MINAS

ESTANHO
- 1 - Igarapé Preto (AM)
- 2 - Massangana (RO)
- 3 - São Francisco (MT)
- 4 - São Raimundo (PA)
- 5 - Pitinga (AM)

OURO
- 6 - Jau (MT)
- 7 - Novo Planeta (MT)
- 8 - Cassiporé (AP)

Figura 1 – Esboço geológico da Amazônia Brasileira

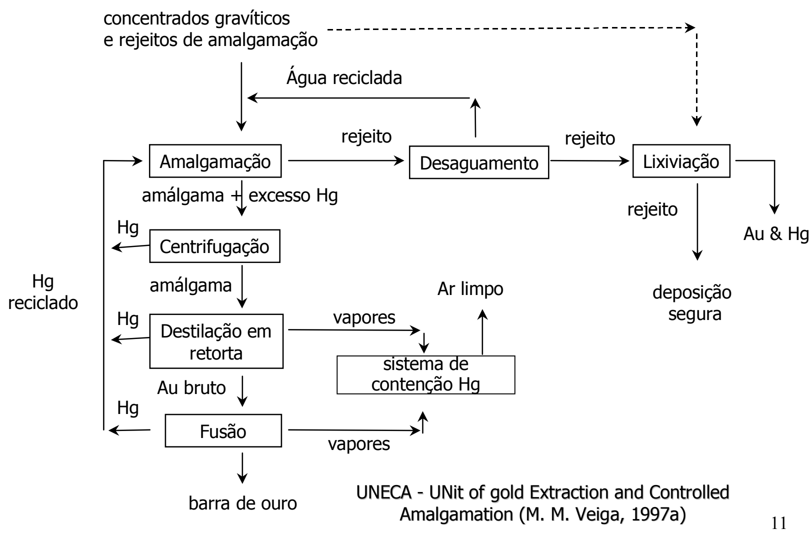


Figura 2 – Fluxograma de uma central de processamento UNECA

Global Environment Facility http://www.gefweb.org

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