

MERCURY AND
ARTISANAL AND SMALL-SCALE GOLD MINERS
IN CHINA

by

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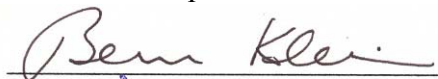
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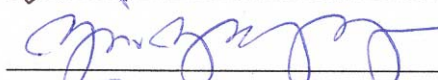
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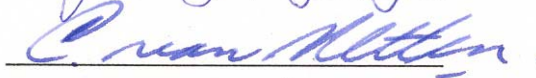
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Abstract

This thesis determines that over four hundred thousand artisanal and small-scale gold miners all over China systematically use amalgamation and release approximately 240 tonnes of mercury per annum. Artisanal and small-scale gold mining (ASGM) is one of the largest sources of mercury pollution in China. This thesis outlines an approach to investigating ASGM in China based on a series of three studies. The main findings of the thesis were that ASGM and amalgamation are widespread in China, and that mercury releases from ASGM have serious health and environmental impacts on the miners themselves and on their surrounding communities and environment. The use of whole ore amalgamation was demonstrated to be the primary source of these releases, and Muller mill amalgamation was pinpointed as being responsible for over 70% of the ASGM mercury releases. In addition, the practice of following amalgamation with cyanidation was indicated to increase the solubility of mercury and perhaps further increase its risks. The test work completed on an ore sample from the community of “Gold Mountain” demonstrated that alternative technology could largely replace whole ore amalgamation (although not cyanidation) with gravity methods and thus greatly mitigate the health and environmental impacts of ASGM.

Table of Contents

ABSTRACT	II
TABLE OF CONTENTS	III
LIST OF TABLES	VIII
LIST OF FIGURES	IX
LIST OF ABBREVIATIONS	X
ACKNOWLEDGEMENTS	XII
1 Introduction.....	1
1.1 STATEMENT OF PROBLEM.....	1
1.2 BACKGROUND	2
1.2.1 <i>Artisanal and Small-scale Mining</i>	2
1.2.1.1 Definition.....	2
1.2.1.2 Extent and Impact	2
1.2.1.3 Health, Safety and Environment	3
1.2.1.4 Gender and Social Issues.....	4
1.2.1.5 Sustainable Livelihoods & Communities.....	4
1.2.2 <i>Mercury as a Global Pollutant</i>	5
1.2.3 <i>Mercury as a Local Health Concern for ASGM</i>	8
1.2.3.1 Mercury Vapour.....	8
1.2.3.2 Methylmercury.....	10
1.3 OUTLINE OF THESIS	12
2 Study One: Artisanal & Small-scale Gold Mining in China.....	14
2.1 INTRODUCTION	14
2.1.1 <i>Literature Review</i>	14
2.2 METHODOLOGY	18
2.2.1 <i>Site Visits</i>	18
2.2.2 <i>Interviews</i>	19
2.2.3 <i>HgEX Expert System</i>	20
2.3 RESULTS.....	22
2.3.1 <i>Site Visits – Gold Processing Equipment and Methods in China</i>	22
2.3.1.1 Muller Mills	22

2.3.1.2	Ball Mill / Sluice	24
2.3.1.3	Gold Dredges and Placer Mining.....	25
2.3.1.4	Retorts	27
2.3.1.5	Cyanidation & Zinc Strip Smelting	28
2.3.1.6	Gold Shops	29
2.3.2	<i>Interviews</i>	30
2.3.3	<i>HgEX Expert System</i>	31
2.3.3.1	Alpha Factor Determination for China.....	31
2.3.3.2	Bayuan Site Contamination.....	38
2.4	DISCUSSION - ASGM IN CHINA.....	40
2.4.1	<i>Significance of ASM in China</i>	40
2.4.2	<i>Scale of ASGM in China</i>	41
2.4.2.1	Definition.....	41
2.4.2.2	Scale of ASGM in China.....	44
2.4.3	<i>Economic Impact of ASGM</i>	47
2.4.3.1	National Impact.....	47
2.4.3.2	Local Impact	48
2.4.3.3	Impact on Formal Mining Companies	48
2.4.4	<i>Legal Framework</i>	50
2.4.4.1	Government Framework.....	50
2.4.4.2	Government Policy.....	50
2.4.4.3	Laws and Enforcement.....	51
2.4.4.4	Tax.....	53
2.4.4.5	Illegal ASGM.....	53
2.4.5	<i>Social Context: ASGM in the Community</i>	54
2.4.5.1	ASGM Labourers.....	54
2.4.5.2	ASGM Income	55
2.4.5.3	Women	55
2.4.5.4	Children	56
2.4.5.5	Labour Unions	56
2.4.6	<i>Health, Safety, and Environmental Impact</i>	56
2.4.7	<i>Technical Assistance Programs</i>	58
2.4.7.1	Technical Assistance	58

2.4.7.2	Research Cooperation	58
2.4.7.3	Domestic Financial Institutions	59
2.4.7.4	Non-Governmental Organizations	59
2.4.7.5	Multilateral Organizations	59
2.5	CONCLUSION	60
3	Study Two: Artisanal and Small-scale Gold Miners in “Gold Mountain”	61
3.1	INTRODUCTION	61
3.2	“GOLD MOUNTAIN” - CASE STUDY METHODOLOGY	61
3.3	“GOLD MOUNTAIN” CASE STUDY- RESULTS	62
3.3.1	<i>“Gold Mountain” Mining and Processing Practice.....</i>	<i>62</i>
3.3.1.1	Mining Practice.....	63
3.3.1.2	Comminution and Amalgamation.....	63
3.3.1.3	Retorts	65
3.3.1.4	Cyanidation and Zinc Smelting	67
3.3.1.5	Gold Purification.....	68
3.3.1.6	“Gold Mountain” ASGM Cost Structure	68
3.3.2	<i>“Gold Mountain” Mercury Releases and Sample Collection.....</i>	<i>70</i>
3.3.2.1	Mill Operator Estimates on Mercury Lost.....	70
3.3.2.2	Mill Data on Mercury Lost.....	70
3.3.2.3	Sample Collection Data on Mercury Lost.....	71
3.3.2.4	ASGM Mercury Release Estimates	71
3.3.3	<i>ASGM Health and Environmental Impact.....</i>	<i>72</i>
3.3.3.1	Health Impact.....	72
3.3.3.2	“Gold Mountain” Aquaculture.....	73
3.4	DISCUSSION.....	74
3.4.1	<i>“Gold Mountain’s” Processing Practice.....</i>	<i>74</i>
3.4.2	<i>Health and Environmental Impact of Mercury Releases in “Gold Mountain” ...</i>	<i>74</i>
3.4.2.1	Health Impact of Mercury Vapour.....	74
3.4.2.2	Bioaccumulation	75
3.5	CONCLUSION	76
4	Study Three: “Gold Mountain” Alternative Technology Test Program.....	77
4.1	INTRODUCTION	77

4.1.1	<i>Sample GM1 – “Gold Mountain” Feed Ore</i>	77
4.1.2	<i>Sample GM2 – “Gold Mountain” Muller Mill Tails</i>	77
4.1.3	<i>Sample GM3 – “Gold Mountain” Cyanidation Tails</i>	77
4.2	METHODOLOGY.....	78
4.2.1	<i>Sample GM1 – “Gold Mountain” Feed</i>	78
4.2.1.1	Sample Preparation and Characterization.....	79
4.2.1.2	Gravity Recovery Test.....	79
4.2.1.3	Gravity / Cyanidation Tests.....	80
4.2.2	<i>Sample GM2 – “Gold Mountain” Muller Mill Tails</i>	82
4.2.2.1	Sample Characterization.....	82
4.2.2.2	Gravity Recovery Test.....	83
4.2.2.3	Mercury Solubility Test.....	83
4.2.3	<i>Sample GM3 – “Gold Mountain” Cyanidation Tails</i>	84
4.2.3.1	Sample Characterization.....	84
4.2.3.2	Gravity Recovery Test.....	84
4.2.3.3	Mercury Solubility Test.....	85
4.3	RESULTS.....	85
4.3.1	<i>Sample GM1 – “Gold Mountain” Feed</i>	85
4.3.1.1	Sample Characterization.....	85
4.3.1.2	Gravity Recovery Test.....	85
4.3.1.3	Gravity / Cyanidation Tests.....	86
4.3.2	<i>Sample GM2 – “Gold Mountain” Muller Mill Tails</i>	89
4.3.2.1	Sample Characterization.....	89
4.3.2.2	Gravity Recovery Test.....	90
4.3.2.3	Mercury Solubility Test.....	91
4.3.3	<i>Sample GM3 – “Gold Mountain” Cyanidation Tails</i>	91
4.3.3.1	Sample Characterization.....	91
4.3.3.2	Gravity Recovery Test.....	92
4.3.3.3	Mercury Solubility Test.....	93
4.4	DISCUSSION.....	93
4.4.1	<i>“Gold Mountain” Samples</i>	93
4.4.1.1	GM1.....	94
4.4.1.2	GM2.....	95

4.4.1.3	GM3	95
4.4.2	<i>Mercury Solubility</i>	96
4.5	CONCLUSION	97
5	Mercury Releases, Alternatives, and Implementation	98
5.1	CHINA’S MERCURY RELEASES	98
5.1.1	<i>Estimating China’s ASGM Mercury Releases</i>	98
5.1.2	<i>Other Sources of Mercury</i>	101
5.1.3	<i>Comparing Mercury Releases in China</i>	103
5.2	ALTERNATIVE TECHNOLOGY	104
5.2.1	<i>Sustainable Alternative ASGM Technology</i>	107
5.3	TECHNOLOGY TRANSFER	112
5.3.1	<i>ASGM Processing Centres</i>	113
5.4	ASGM AND POLICY	116
6	Limitations and Bias	117
7	Areas for Additional Research	120
8	Conclusion	122
	Bibliography	124
Appendix	I	134

List of Tables

Table 1.1	ASM Production of Various Minerals and Metals	3
Table 2.1	Site Visits, 2000-2002	18
Table 2.2	Chinese Productions of Several Major Minerals	41
Table 2.3	Major health, safety, and environmental impacts of ASM in China	57
Table 3.1	Typical Miner’s Revenue and Profits Per Tonne of Ore.....	69
Table 3.2	“Gold Mountain” Processing Centre Data	70
Table 3.3	Muller Mill Mercury Loss Estimates	71
Table 4.1	GM1 Sample Characterization	85
Table 4.2	GM1-A Gravity Recoverable Gold Test	85
Table 4.3	GM1-B Test Results.....	86
Table 4.4	GM1-C Test Results.....	86
Table 4.5	GM1-D Test Results	87
Table 4.6	GM1-B and GM1-C Cyanidation Tailings Analysis	88
Table 4.7	GM2 Sample Characterization	90
Table 4.8	GM2 Gravity Test Results.....	90
Table 4.9	GM3 Sample Characterization	92
Table 4.10	GM3 Gravity Test Results.....	92
Table 4.11	Mercury Solubility	93
Table 4.12	Grade Differences Between Test Samples	93
Table 5.1	Mercury to Gold Loss Ratio for China	100
Table 5.2	Chinese Annual Mercury Releases attributable to ASGM.....	100
Table 5.3	Low Estimate of ASGM Gold Production and Mercury Releases (2001).....	101
Table 5.4	Chinese Sources of Mercury Releases Due to Mining (2001)	103

List of Figures

Figure 1.1	Number of Artisanal & Small-scale Miners Around the World by Country	7
Figure 1.2	Eh (redox potential) versus pH for the Main Inorganic Mercury Species	11
Figure 2.1	Alpha Factor for HgEX.....	21
Figure 2.2	“Gold Mountain” Muller Mill	23
Figure 2.3	Jiangxi Ball-Mill Mercury Sluice Circuit.....	25
Figure 2.4	Guangxi Gravel/Gold Dredge Operation	26
Figure 2.5	“Gold Mountain” Gravel/Gold Operation.....	27
Figure 2.6	Jiangxi Province Retort Cooling Tube	28
Figure 2.7	“Gold Mountain” Zinc Strip Boxes	29
Figure 2.8	Burning <i>Doré</i> in Longsheng.....	30
Figure 2.9	Alpha Factor Comparison	37
Figure 2.10	ASGM Areas Across China.....	44
Figure 2.11	ASGM Tunnels, Boka, China.....	49
Figure 3.1	Cleaning the Concentrate From the Muller Mill	64
Figure 3.2	“Gold Mountain” Retort Diagram	66
Figure 3.3	“Gold Mountain” Retort Photo.....	66
Figure 3.4	Mercury Droplets from “Gold Mountain” Retort.....	67
Figure 4.1	GM1 Test Program	78
Figure 4.2	GM2 Test Program	82
Figure 4.3	GM3 Test Program	84
Figure 4.4	GM1-D Leach Time.....	87
Figure 4.5	GM1-B and GM1-C Cyanidation Tailings Analysis	88
Figure 4.6	GM2 Size, Gold, and Mercury Distributions	89
Figure 4.7	GM3 Size, Gold, and Mercury Distributions	91
Figure 5.1	China’s Mercury Releases Due to Mining	103
Figure 5.2	Gold Particle Size Recovery Range	108
Figure 5.3	Muller Mill / Centrifugal Concentrator, Chile.....	111

List of Abbreviations

ASGM	Artisanal and Small-scale Gold Miners
ASGM _{Au}	China's annual gold production due to ASGM
ASM	Artisanal and Small-scale Mining
AT	Appropriate Technology
BBC	British Broadcasting Corporation
BC-MEMPR	British Columbia - Ministry of Energy, Mines and Petroleum Resources
BS _{Au} %	The percentage of gold produced by ASGM ball mill/slucio operations
BSR	The ratio of mercury lost to gold recovered for ball mill/slucio operations
CF	Certainty Factor
CASM	Communities and Small-Scale Mining
CASM-China	Communities and Small-Scale Mining Regional Network in China
CCC	Criterion Continuous Concentration
CIA	Central Intelligence Agency
CIDA	Canadian International Development Agency
CMC	Criteria Maximum Concentration
DFAIT	Department for Foreign Affairs and International Trade
DFID	Department for International Development (United Kingdom)
DoBDEF	Degree of Belief - Dangerous Environmental Factor
DoBHEF	Degree of Belief - High Emission Factor
DoBMAF	Degree of Belief - Mercury Adsorption Factor
ESAT	Environmentally Sound and Appropriate Technology
GM1	Gold Mountain Feed Ore Sample
GM2	Gold Mountain Muller Mill Tails Sample
GM3	Gold Mountain Cyanidation Tails Sample
GMP	Global Mercury Project
GRG	Gravity Recoverable Gold
Hg _{Au}	The amount of mercury released per annum due to ASGM activities
HgEX	Expert System for Risk Assessment for Mercury Discharge from Gold Mining Operations
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
IIED	International Institute of Environment and Development

ILO	International Labour Organization
ITDG	Intermediate Technology Development Group
KC-MD3	Knelson Concentrators lab-scale MD3 centrifugal concentrator
MMAu%	The percentage of gold produced by ASGM operations using muller mills
MMR	The ratio of mercury lost to gold recovered for muller mills
MMSD	Mining, Minerals, and Sustainable Development
NGO	Non-Governmental Organization
NIMD	National Institute for Minamata Disease
NMAZ	National Miners' Association of Zimbabwe
NSERC	National Science and Engineering Research Council
NRCAN	Natural Resources Canada
PBC	People's Bank of China
PMAu%	The percentage of gold produced by ASGM placer operations
PMR	The ratio of mercury lost to gold recovered from placer deposits
PRC	People's Republic of China
RMB	Renminbi (Chinese Dollar or Yuan)
SCOPE	Scientific Committee on Problems of the Environment
SWG	Southwestern Resources
TDU	Transportable Demonstration Units
TOC	Total Organic Carbon
TVE	Township and Village Enterprises
UBC	The University of British Columbia
UNECA	Unit of Gold Extraction and Controlled Amalgamation
UNIDO	United Nations Industrial Development Organization
UNDESA	United Nations Department of Economic and Social Affairs
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
YPNI	Yunnan Province Nuclear Industry Team 209

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1 Introduction

This thesis determines that artisanal and small-scale gold mining (ASGM) in the People's Republic of China (PRC) employs at least 400,000 miners extracting about 60 tonnes of gold per annum and releases around 240 tonnes per annum of mercury into China's environment. This thesis focuses on describing China's artisanal and small-scale gold miners, estimating their mercury releases, and exploring technological alternatives to reduce these releases.

Mercury is one of the most toxic heavy metals, and mercury pollution has led to many tragic incidents around the world. ASGM is a major source of global mercury releases; the health impact of this mercury is of significant concern, both locally and globally. This thesis grew out of an interest to understand China's role in these releases and to learn how ASGM in China differed from ASGM in other regions of the world.

1.1 Statement of Problem

An exploratory literature review found only one article regarding ASGM in China; that article stated that most ASGM has been strictly prohibited since 1996 (Lin *et al*, 1997). However, a handful of global reviews of ASGM prepared by multilateral agencies such as the International Labour Organization (ILO), indicated that China was home to millions of artisanal and small-scale miners. This thesis grows out of an initial research trip to China, conducted in 2000, undertaken to examine the situation regarding ASGM in China.

Specifically, this thesis aimed to address the two following questions:

- 1) Does ASGM still occur in China, and if so, at what scale and in what socio-economic context?
- 2) Does ASGM in China use mercury, and if so how much? How does ASGM in China use mercury, and are there methods of dealing with the resulting environmental and health problems applicable to other parts of the world, or can techniques used in other nations be applicable to China?

1.2 Background

Artisanal and small-scale gold mining is closely linked with the global emission of mercury. This link is of importance on a number of levels. Locally, ASGM mercury use is a serious health risk faced by millions of artisanal and small-scale miners and their communities around the world. Non-mining communities located downstream from mercury-using ASGM operations are also placed at risk. On a global level, ASGM contributes to mercury releases that may be linked to the atmospheric deposition of mercury around the world. This section reviews artisanal and small-scale gold mining and mercury use in a global context.

1.2.1 Artisanal and Small-scale Mining

1.2.1.1 Definition

Artisanal or small-scale mining (ASM) is the use of rudimentary processes to extract valuable minerals from primary and secondary ore bodies, and is characterized by the lack of long-term mine planning/control (Hinton *et al*, 2003a). ASM can be illegal or legal, formal or informal and can encompass everything from individual gold-panners to large-scale operations employing thousands of people.

1.2.1.2 Extent and Impact

Artisanal and small-scale mining operations form the backbone of hundreds of developing rural communities around the world and supplement the income of thousands of agricultural communities. In an authoritative ILO study on ASM, Jennings (1999) estimates that there are 11 to 13 million artisanal miners worldwide, with 80 to 100 million people directly or indirectly dependent on artisanal miners for their livelihood. ASM extracts a wide range of metals, precious stones, and industrial minerals, and accounts for a significant portion of world production, as can be seen in Table 1.1.

Table 1.1 ASM Production of Various Minerals and Metals
(Noetstaller, 1995)

Metals	Mined by ASM (%)	Industrial Minerals	Mined by ASM (%)
Beryllium	100	Fluorite	90
Mercury	90	Graphite	90
Tungsten	80	Talc	90
Chromium	50	Vermiculite	90
Antimony	45	Pumice	90
Manganese	18	Feldspar	80
Tin	15	Clay	75
Iron	12	Gypsum	70
Lead	11	Barite	60
Zinc	11	Sand and gravel	30
Cobalt	10	Dimension stones	30
Gold	10	Salt	20
Silver	10	Coal	20
Copper	8	Phosphate	10

1.2.1.3 Health, Safety and Environment

The employment, income and production generated from ASM often come with significant costs to miners' and nearby communities' health, safety, and environment. ASM hazards are many and varied.

In ASM mines, hazards include: poor ground conditions leading to underground failure, methane or coal dust explosions from coal mines, flooding, machinery accidents, poor lighting and ventilation, explosives accidents, and electrocution (Priester *et al*, 1993). Hydraulic monitoring of secondary deposits can also be extremely unsafe, as a potential exists to undercut hill slopes and generate landslides (Hinton *et al*, 2003a).

Mercury, cyanide and other hazardous chemicals are used as reagents for recovering and purifying gold and other precious metals. Fine dust from mineral processing, leading to silicosis, and noise pollution are endemic problems. ASM accidents are often underreported, due to the illegal or semi-legal status of most ASM operations; Jennings

(1999) estimates that non-fatal accidents in ASM are still 6-7 times greater than in the formal mining sector.

ASM operations can also lead to the destruction of arable and grazing land through excavation, the accelerated erosion of top soils, landslides, the collapse of old workings, unsafe tailings disposal, the lowering of water tables, soil contamination due to dust from mines and tailings, and increased levels of sediment load and flooding in nearby rivers.

1.2.1.4 Gender and Social Issues

Perhaps 30% of the ASM miners around the world are women, involved at all stages of mining from ore extraction to processing to market (Hinton *et al*, 2003b). Women also frequently work part-time as cooks and service providers, or in transporting and processing, and thus the actual number of women involved in artisanal mining could be significantly higher than generally estimated. Processing activities are often conducted in homes by women of childbearing age who are especially susceptible to mercury poisoning (Hinton *et al*, 2003a).

In addition, ASM, especially in the boomtowns that arise from big mineral finds in remote locations, may come with major social challenges such as prostitution, substance abuse, and gambling. Women are often disproportionately harmed by these factors. The roles of women in ASM are significantly different from those of men and thus deserve, but generally do not receive, special attention with regard to policy, development, and research (Hinton *et al*, 2003b).

1.2.1.5 Sustainable Livelihoods & Communities

With the range of ill effects that arise from ASM, governments often see closing these often-illegal mines as a desirable end. However, ASM frequently provides impoverished remote communities with a rare opportunity to alleviate poverty and contribute to community development (Dahlberg, 1997). All ore deposits are finite, thus by definition no single mining operation can be sustainable. Nevertheless, ASM can contribute to the sustainable development of communities by providing opportunities for economic diversification through auxiliary enterprises, such as jewellery production and agricultural

development, and by providing enough economic impetus to allow impoverished communities to move toward sustainability. International organizations, such as Communities and Small-scale Mining (CASM) and the United Nations Department of Economic and Social Affairs (DESA) are focusing on promoting a sustainable communities approach to ASM. An underlying premise of this thesis is that ASM must be looked at in the context of sustainable livelihoods and communities in order to most effectively mitigate the impact of ASM activities while maximizing its benefits to current and future generations.

1.2.2 Mercury as a Global Pollutant

Mercury is a global pollutant due to both its impact through actions such as the disposition of atmospheric mercury in the Arctic, and its local impact in communities worldwide. Present concern about the health impact of mercury can be traced back to the methylmercury poisoning disaster in Minamata, Japan, in the 1950s (NIMD, 2001). The Minamata outbreak, followed by another incident in Niigata, Japan, both occurred due to the consumption of large quantities of seafood polluted by mercury-contaminated industrial effluent. Both culminated in several hundred deaths and claimed hundreds of more victims with severe mercury induced symptoms (Harada, 1978). These cases created widespread awareness about the ill effects of mercury and prompted much research on the topic (Horvat, 2002).

The global importance of mercury became increasingly evident due to a number of further issues. Mercury-based fungicides and seed disinfectants were found to have caused severe reductions of bird populations (Jernelöv *et al*, 1975). In 1971-2, a large epidemic that killed over 450 people and may have disabled over 100,000 people occurred in Iraq when farmers consumed foreign aid supplied wheat, intended for seed, treated with alkyl mercury fungicide (Förstner and Wittman, 1997). Unsafe levels of mercury accumulation were found in fish and wildlife in Canada, the northern United States, and Scandinavia during the 1960s (Williamson, 1986). Fish in reservoirs in Quebec and Manitoba were found to have elevated levels of mercury, perhaps due to forest fires or organic material in newly flooded areas (Williamson, 1986; Stokes and Wren, 1987). Mercury vapour poisoning killed 15 miners, with 205 more miners admitted

to hospital, in a mercury mine in Keniya, Turkey (Trakhtenberg, 1974). A report from 1992 estimated that in the previous 40 years, over 20,000 people were afflicted by mercury poisoning, including 1,400 deaths (Larcerda, 1997).

This rising concern led to increasing efforts to understand global mercury releases and to create regulations to control its trade and use. First implemented in the 1970s, these regulations have steadily reduced global releases of mercury, primarily through banning mercury-based fungicides and mercury-cell chlor-alkali plants and through the recycling of mercury from solid wastes (Larcerda, 1997). The sale of fish containing mercury levels above 0.5 mg/kg was banned in the 1970s.

In the mid to late 1990s, atmospheric deposition of mercury in the Arctic due to both natural and anthropogenic sources became an issue of increased concern (Lu *et al.*, 2001). Anthropogenic releases of mercury originate primarily from: coal and oil combustion, refuse incineration, solid and urban waste disposal, and agriculture and forestry practices. Anthropogenic releases are four times higher than natural mercury releases (Larcerda, 1997). Pacyna and Pacyna (2002) estimate that the 1995 anthropogenic global mercury emission was about 1900 tonnes, with three quarters of the total emission coming from combustion of fuels, particularly coal combustion in China, India, and South and North Korea. A European Commission Report estimates the current annual market supply of mercury at 3800 tonnes (Maxson, 2004). In the past, mercury mining has been the major source of mercury; Hylander and Meili (2003) estimate around 1 million tonnes of mercury have been mined globally since 1500.

A major source of mercury releases has been ASGM. Maxson (2004) estimates total global mercury releases due to ASGM in 2000 to be 650 tonnes, 20% of the total global anthropogenic amount of 3386 tonnes. Mercury has been used to amalgamate precious metals since as early as 2,700 BC, when the Almaden mines in Spain were opened (Lacerda, 1997). Amalgamation is a simple and inexpensive method of recovering gold. The wetting of gold by mercury is not alloying, but a phenomenon of moderately deep sorption, involving some interpenetration of the two elements (Pryor, 1965). As the

surface tension of mercury is greater than that of water, but less than that of gold, mercury adsorbs onto the surface of gold particles. In addition, mercury acts as a dense medium; gold sinks into the mercury while the lighter gangue material floats overtop. The solubility of gold in mercury is only 0.06% at 20°C. When the resulting amalgam is heated, the mercury vaporises, leaving gold *doré*.

The practice of using mercury to extract gold had largely faded in the early twentieth century, until the gold rushes in Latin America began during the 1970s and 1980s (Veiga, 1997). Millions of miners flocked to sites such as Serra Pelada, where 80,000 miners produced 90 tonnes of gold from a single pit. Veiga (1997) estimated that around 5,000 tonnes of mercury was released into forest and urban areas in Latin America over this time. In addition to Latin America, small-scale mining spread through areas of Africa and the Asia Pacific. Mercury, due to its simple effectiveness and practicality, is virtually ubiquitous with small-scale gold processing. These gold miners have been both a major source of mercury releases and have been one of the groups, along with nearby communities, most seriously harmed by mercury pollution.

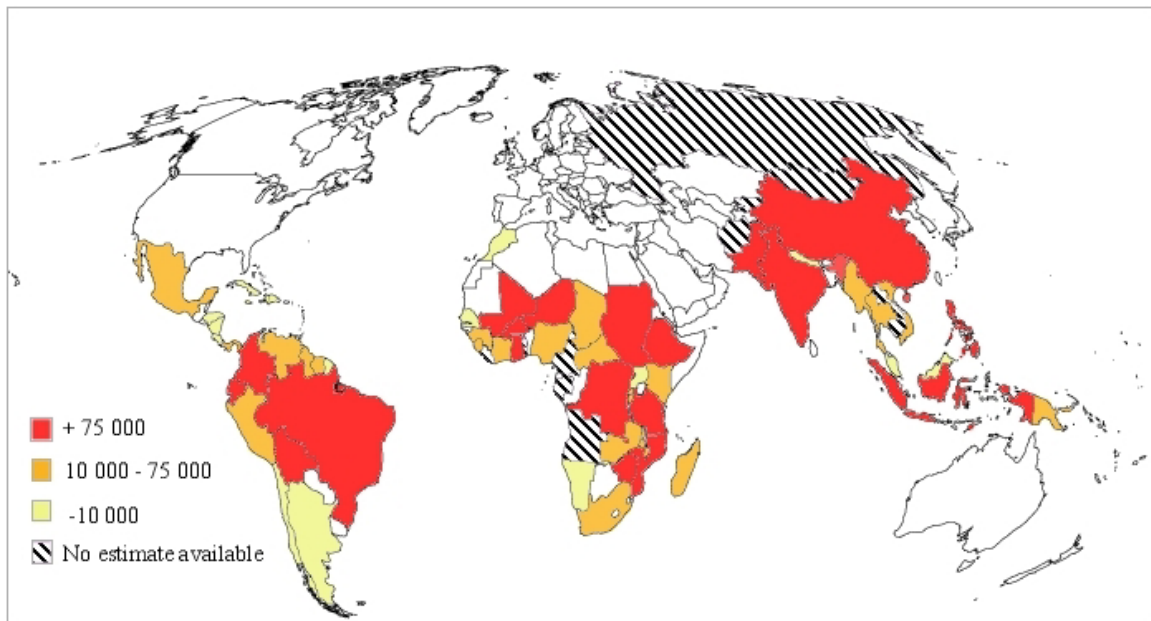


Figure 1.1 Number of Artisanal & Small-scale Miners Around the World by Country

Using the ILO data from Jennings (1999), Mining, Minerals, and Sustainable Development (MMSD) (Hentschel *et al*, 2002), CASM (Davidson, 2003) and the United Nations Industrial Development Organization's (UNIDO) Global Mercury Project (GMP) (Veiga, 2004c), Figure 1.1 was compiled. Countries where estimates have not been made, but ASM is known to occur, are listed as "no estimate available." National ASM numbers were calculated as the mean of the high and low estimate compiled from the reports. This figure does not include any countries with a GDP/capita over \$US 15,000, with a population under 150,000, or with an area less than 4,000 square miles, in order to exclude tiny countries and recreational gold panners in affluent countries.

1.2.3 Mercury as a Local Health Concern for ASGM

The mercury used in ASGM has wide effects on the miners, the local environment, and the people living downstream from ASGM operations. Exposure to mercury mainly occurs through inhalation of mercury vapour or through the consumption of methylmercury. Repeated exposure to mercury eventually leads to progressively more serious health problems.

1.2.3.1 Mercury Vapour

Elemental mercury vapour is rapidly absorbed through the lungs (Keating *et al*, 1997). The people most affected by mercury vapour are the artisanal miners who practice amalgamation, and the gold shop workers, where the gold *doré* is bought and purified. Amalgam typically consists of about 60% gold and 40% mercury, with varying amounts of silver. Miners often purify their amalgam into *doré* by either directly evaporating mercury on a stovetop or by open flame. This method can lead to serious mercury vapour poisoning. An alternative is to use a retort to distil the amalgam into *doré* while safely collecting and condensing the mercury vapour. Artisanal gold miners frequently purify their *doré* at gold shops, or at home. This process releases the 2 – 5 % mercury remaining in the *doré* into the gold shop and thus into the town environment. People living near the mining operations or the gold shops are also affected; the majority of mercury emitted by gold smelters is deposited near the emission source (i.e. within 1 km), contaminating the local areas (Veiga, 1997).

Malm (1991) measured up to 60,000 $\mu\text{g}/\text{m}^3$ of mercury in the air when amalgam was burnt in pans; the recommended limit for public exposure is 1.0 $\mu\text{g}/\text{m}^3$ (Malm *et al*, 1990) and the recommended health-based exposure limit for metallic mercury is 25 $\mu\text{g}/\text{m}^3$ for long-term exposure and 500 $\mu\text{g}/\text{m}^3$ for short-term exposure (WHO, 1991). When retorts are used, mercury vapor concentration drops to as low as 10 $\mu\text{g}/\text{m}^3$ (Veiga and Baker, 2004), much lower than the 50 $\mu\text{g}/\text{m}^3$ limit for industrial exposure outlined in the Health, Safety and Reclamation Code for Mines in British Columbia (BC-MEMPR, 1992).

Mercury vapour is oxidized in the lungs and forms mercury complexes that are soluble in many body fluids (Veiga and Baker, 2004). While around 90% of the inhaled mercury is excreted through urine and feces in a few days (Hacon, 1990; WHO, 1991), some of the mercury accumulates in the central nervous system (Mitra, 1986). Mercury can permanently damage the nervous system – the kidneys are most affected in the medium-term, while the brain is the dominant receptor in long-term exposure (Suzuki, 1979). Total mercury elimination through urine can take several years (Veiga and Baker, 2004).

High, short-term exposure (1000 to 44,000 $\mu\text{g}/\text{m}^3$) to mercury vapour is typically associated with symptoms including chest pains, dyspnoea, cough, haemoptysis, impairment of pulmonary function, and interstitial pneumonitis. Chronic exposure symptoms include a metallic taste in the mouth, gum diseases such as gingivitis, ulcers and the formation of a blue line at gum margins (Stopford, 1979). Long-term, low-level mercury vapour exposure has resulted in less pronounced symptoms of fatigue, irritability, loss of memory, vivid dreams, and depression. Long-term exposure to high levels of mercury vapour can lead to delirium, hallucinations and suicidal tendency as well as erethism (abnormal irritability), excessive shyness, insomnia, and in some cases muscular tremors. In milder cases, erethism and tremors regress slowly over a period of years following removal from exposure pathways (WHO, 1991).

A person with a mild case of mercury poisoning can be unaware of the symptoms because they are mainly psycho-pathological. The symptoms can also be confused with fever, alcoholism, or malaria and other tropical diseases.

1.2.3.2 Methylmercury

Methylmercury exposure is a primary source of mercury uptake for humans and wildlife; methylmercury is easily bioaccumulated and becomes concentrated in fish, particularly in carnivorous fish. Carnivorous species are usually the preferred species of consumption by most people and represent the main exposure pathway of methylmercury to humans (Veiga and Baker, 2004). Methylmercury (CH_3Hg^+), an organic compound, is the most dangerous form of mercury, as it is easily absorbed through the gastrointestinal tract (Keating *et al*, 1997). When mercury from artisanal mining (or any other source) is released into water systems, it may react with organic acids and thus be oxidized into methylmercury (Hinton, 2002). This methylmercury is bioavailable, which means it can quickly find its way into the food chain. It can also easily bioaccumulate, or build up over time in an organism's body, and thus methylmercury concentrates at the top of the food chain, in fish and then in humans (Horvat *et al*, 2000). Around 70 to 90% of the mercury in fish is already in the form of methylmercury, which rapidly reaches levels where excessive consumption by humans can be dangerous. Carnivorous fish are most susceptible to bioaccumulation as they eat a large amount of omnivorous or herbivorous fish, and retain most of the mercury that those fish have accumulated. In fish, methylmercury can impair reproduction, growth and development, lead to behavioural abnormalities, and lead to death. Mercury can also harm plants, birds, and mammals, with reproduction also being effected (Keating *et al*, 1997).

Mercury-laden mine tailings have been linked with higher levels of methylmercury (Baker, 2002). While not of the magnitude of Minamata, fishing communities near ASGM operations have been found to exhibit symptoms of methylmercury poisoning, especially along the Tapajós River in Brazil (Grandjean *et al*, 1999; Harada *et al*, 2001; Mergler, 2002).

However, the actual mechanisms that convert metallic mercury to methylmercury are complex and not fully understood. Variables such as sediment Eh (standard hydrogen electrode potential), pH, conductivity ($\mu\text{S}/\text{cm}$), total organic carbon (TOC), and sulphate, all contribute to this transformation (Veiga and Baker, 2004). The other variables

identified which contribute to methylation include the supply of Hg(II), composition of micro-organisms, temperature, biomass, and iron (Hinton, 2002). Variables able to reduce mercury availability include the presence of hydrous ferric oxides, the presence of clay sediments, and suspended solids (Veiga and Meech, 1995). Figure 1.2 shows an Eh-pH diagram for the main inorganic mercury species.

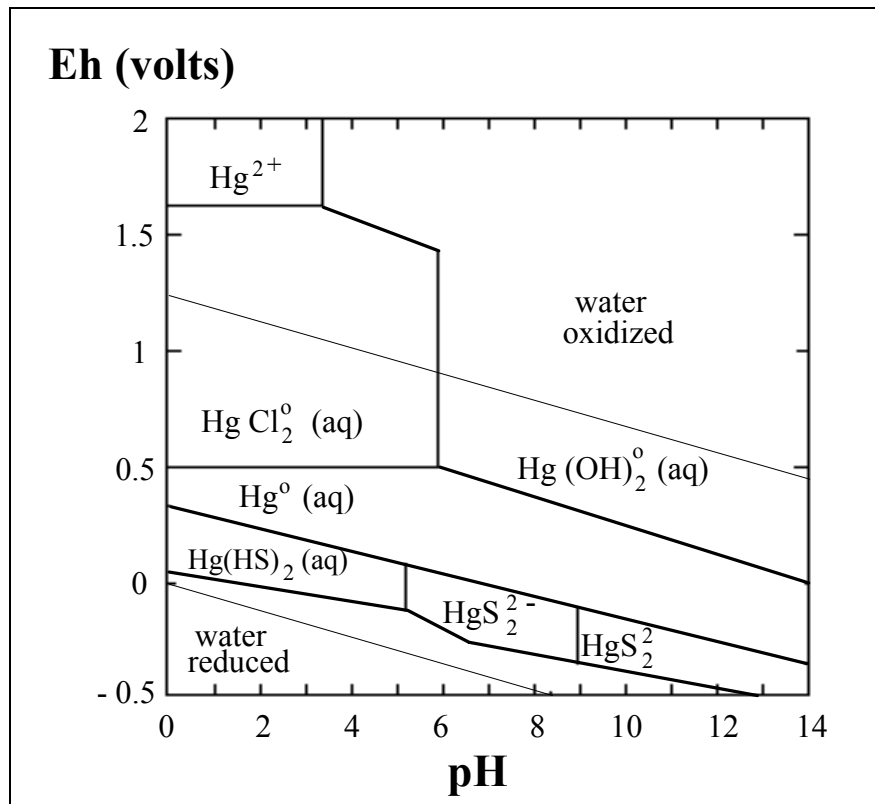


Figure 1.2 Eh (redox potential) versus pH for the Main Inorganic Mercury Species (Meech *et al*, 1998)

It is important to note that there is a wide variety of possible sources of mercury other than ASGM, including geologic weathering and erosion, evaporation from waters and soils, run-off waters, ancient gold and silver mining, plant transpiration and decomposition, waste incineration, and forest fires (Veiga and Baker, 2004). Camourze *et al* (2001) highlighted the importance of erosion in carrying natural mercury bound to intensively weathered soils to Amazonian aquatic systems. The authors stressed that this is a much more important source of mercury for the entire Amazonian environment than any other source, although ASGM activities are more relevant locally.

People with severe methylmercury poisoning, or “Minamata Disease” exhibit all of the following five symptoms: visual constriction, numbness of the extremities, impairment of hearing, impairment of speech, and impairment of gait. Muscular atrophy and mental disturbance are prominent in acute intoxication (Veiga and Baker, 2004). Unborn children are especially susceptible to methylmercury poisoning. Methylmercury can penetrate into the placental barrier, transferring mercury to the foetus. When the intake of mercury is large enough, sterility can occur in both women and men. When the dosage is smaller in women, pregnancy can take place but the foetus can miscarry spontaneously. Even when the pregnancy goes to term, the baby can have severe neurological symptoms, including psychomotor retardation and other developmental delays (Harada, 1978).

1.3 Outline of Thesis

Chapter one has provided a background review of artisanal and small-scale gold mining and mercury pollution, in order to underlie the following examination of China’s ASGM sector. The chapter introduced mercury as a global health threat, summarized the toxic nature of mercury vapour poisoning and methylmercury accumulation, and defined and summarized ASGM globally and its link to mercury pollution. In addition, it here outlines the structure of this thesis and its overall objective.

Chapter Two describes the objective, methodology and results of a general study of China’s ASGM industry and communities. At the time this research was undertaken, little research had been done to understand the nature of China’s ASGM and its relationship to mercury since the early 1990s, and none had been done since mercury was made illegal in 1996. The objective of this stage of the research was to examine several ASGM sites throughout China to evaluate whether ASGM still took place and under what conditions and if mercury use persisted and represented a potential health threat. A discussion explores the ASGM sector in China in detail, including estimates of the number of gold miners and production figures, basic laws and structures, and socio-economic situations.

Chapter Three is devoted to a case study of “Gold Mountain”, a small ASGM community in northern China. This study was undertaken to elaborate and verify the findings of the

general study described in Chapter Two. It describes the community, surveys its gold processing facilities, describes in detail its gold processing methods, estimates mercury losses, and describes a novel mercury retort used locally.

Chapter Four describes the objective, methodology and results of test work undertaken on three “Gold Mountain” samples. These samples include a feed ore, an intermediate tailing sample from amalgamation process, and a final tailings sample following amalgamation and cyanidation. The objectives of the test work are the following: to verify the mercury losses reported in Chapter Three; to evaluate the potential of centrifugal concentrators, in conjunction with cyanidation, to replace the current amalgamation/cyanidation techniques; and to explore the effect of cyanidation of mercury tailings on mercury solubility.

Chapter Five brings together the results of the previous chapters to estimate the extent of mercury released by ASGM in China. In addition, potential technology alternatives to amalgamation that could reduce those releases are discussed and issues surrounding alternative technology and technology transfer are examined.

Chapter Six discusses the limitations and bias of the thesis.

Chapter Seven identifies areas that would benefit from additional study.

Chapter Eight concludes the thesis by highlighting the key results and by discussing recommendations for how the impact of mercury releases from ASGM can be mitigated.

The Appendix contains a report of the inaugural meeting of CASM-China, an organization formed in part to address the issues raised in this thesis.

2 Study One: Artisanal & Small-scale Gold Mining in China

2.1 Introduction

As stated in Chapter One, the objective of the research described in this chapter is to examine several ASGM sites throughout China to evaluate whether ASGM was still taking place and under what conditions, and if mercury use persisted and represented a potential health threat. The basis of this research was a field study undertaken during the summer of 2000. The research focused on understanding the use of mercury by ASGM miners and seeing if their methods of dealing with these environmental and health problems could be applicable to other parts of the world, or if techniques developed outside of the PRC could be used by the Chinese.

The summer 2000 field study resulted in site visits to six regions, investigating seven mineral processing operations, three underground mines, one gold shop, one dredge operation, and one mine prospect. This survey resulted in a number of small case studies, future contacts, and a sense of how the ASGM industry operated in China, and provided the basis for further research. The trip demonstrated that ASGM and mercury use were common and widespread throughout China.

Interviews were also conducted with a variety of experts involved with ASGM in China in different capacities. These interviews, combined with the literature review and site visits, form the basis of the discussion section of this Chapter, an exploration of the place of ASGM in China.

2.1.1 Literature Review

The sum total of the literature available before the summer 2000 field study was one article: Lin, Guo, and Gan's *Mercury Pollution From Small Gold Mines in China* (1997). This article gave a brief overview of China's ASGM industry and a case study description of ASGM in Dexing County, Jiangxi Province. In 1993-4, Dexing had 200

“roll mills”, probably muller¹ mills, which each used around 8 kg of mercury per day, of which 10-20% was lost to the environment. Extensive use of mercury was recorded, with losses in Dexing reaching 160-320 kg of mercury per day. If it is assumed that the mines ran for 300 days per annum, 48 to 96 tonnes of mercury were released annually from Dexing County alone. Of four articles in the bibliography, two refer to American mercury guidelines and the other two refer to a difficult-to-find Chinese journal (*Environment & Exploitation*). The article also makes reference to a SCOPE China/CAST study in 1993-1994. This study is perhaps altogether lost, but is certainly unattainable. Lin *et al* conclude their article with the following statement:

“Since September 1996, most of the small scale gold mining activities were strictly prohibited by China's national environmental legislation. Recent investigation in late 1996 indicated all those small mines [researched] were shut off (Lin et al, 1997).”

Interestingly, the site visit in 2000 found a larger operation than described by Lin *et al* (1997) and amalgamation was still clearly integrated into their processes. The most valuable item from literature review, however, was Lin *et al*'s (1997) simple sketch of China that indicated areas with small-scale gold mining. This map formed the basis for the field study.

Some visiting Chinese professors to the UBC mining department declared there to be no artisanal mining in China and certainly no ASGM mercury use (Veiga, 2000). Thus, when the field study was undertaken, there was no indication that ASGM operations existed in China or continued to use mercury.

Other works include Golas's excellent history of mining in China (1999), which provided a great background, but provided little help for a study on contemporary China. Lacerda (1997) includes some erroneous information on China's ASGM in an article on global mercury releases. For example, he reports, “after granting permission to form individual

¹ The muller in muller mills is not capitalized – *muller* comes from an alteration of the Middle English term *molour* and means “a stone or piece of wood, metal, or glass used as a pestle for pounding or grinding (Merriam-Webster, 2004).”

enterprises in China, over 200 small mines were opened in Dixing Province since 1992, increasing gold production by 10% per year.” Larcerda was presumably reporting on the 200 ASGM operations in Dexing County, Jiangxi Province, recorded in Lin *et al*, 1997 (China does not have a Dixing Province). Larcerda also reports, “Major [mercury] impacts are from the Brazilian Amazon, followed by China, where over 200 small gold mining operations were settled and 120 t/yr of Hg are being released into the environment.” Again, these were the releases from one county among thousands in China, and are hardly a national figure. These errors demonstrate the importance of field research to aid in understanding a large and complex country.

Since the first field study, a handful of other articles relating to ASGM in China have appeared. These include “Mercury consumption and contamination of environment in gold mining in China” by He, Lin, and Li (2000). He *et al* (2000) estimated China’s mercury consumption to be only 80 tonnes per annum, but did so from estimates of 33 smaller state-owned mines, not by visiting ASGM operations. He *et al* estimated that 13% of gold production was from amalgamation, with 33 mines losing 14.6 g mercury/tonne, with 75% recovered and recycled, leaving 20 tonnes/a discharged. This can be taken as a reasonable estimate of the amount of mercury released by China’s formal mining sector, but not its ASGM industry.

Dai *et al*’s (2003) article on mercury releases from small gold mines in Tongguan County, Shanxi Province notes how gold has been mined for over 900 years in Tongguan, and that most families in the County are involved in gold mining. An unpublished 1997 report from Lin Yuhuan is cited, stating that around 120 tonnes of mercury are released in the county annually; 38% into the atmosphere, 62% into the tailings, and less than 1% into the local rivers. Dai *et al* (2003) report their findings of water sample mercury concentrations, with dissolved mercury ranging from 0.11 to 3.10µg/l (average of 0.74µg/l) and particulate mercury levels ranging from 0.10 to 258.62 µg/l. In filtered water, reactive mercury ranged from 7.76 to 62.28% of total mercury. Dai *et al* (2003) do not report on the amalgamation processes used.

An unpublished paper given by Zhong (1999) at the Small-and Medium-Scale Mining Workshop of the 3rd Environmental Cooperation Workshop on Sustainable Development of Mining Activities in 1999 detailed the small-scale mining industry in China. Zhong provided an overview of ASM in China and explained the importance of ASM to local development and environmental and safety issues arising from ASM activities. While the paper mainly focused on coal, it did provide some excellent information on new policies affecting ASGM. Zhong made no reference to mercury releases.

A 2001 report by Canada's Department for Foreign Affairs and International Trade (DFAIT), provides some useful statistics on ASM (although incorrectly sourced), but little else.

An extensive review undertaken for the MMSD ASM country report for China (Gunson and Yue, 2001) found a broader review of artisanal and small-scale mining in China yielded applicable laws, journal articles, books, statistical yearbooks, and newspaper reports. There was one book and twelve articles on ASM coalmines, primarily on safety and closure. With respect to mercury, there were three articles on coal combustion and mercury, and three short general articles on mercury in China (primarily coal and industrial sources of emission). There were twelve news articles on small-scale coal disasters (these were a sample – there are many more such small news reports, generally reporting the location and the number of dead miners), nine on a Guangxi ASM tin mine disaster, and one article on a labour protest. Eight laws and regulation guidelines were found to be relevant to ASM, and three general reports on China's mining industry included small sections on ASM. For an industry that directly employs 3 to 15 million people in China and has a major economic and environmental impact on the world's most populous nation, this is a shockingly understudied area.

Since 2000, a handful of additional articles on ASM coal policy have been written by Andrews-Speed in cooperation with Chinese academics (2002, 2003a, 2003b, 2003c). These articles, while specific to coal, have implications for the ASGM sector, discussed in later sections.

2.2 Methodology

In order to achieve the field study objectives, several ASGM sites and the amalgamation practices utilized at the sites were examined throughout China. Three main techniques were used:

- Site visits;
- Personal interviews with people associated with ASGM; and
- The HgEX Expert system.

2.2.1 Site Visits

Table 2.1 Site Visits, 2000-2002

Area	Year	County	Sites Visited
North-Central China	2000	“Gold Mountain” ²	One gold mine, one mine prospect, and three processing plants
Guangxi Province, South China	2000	Longsheng County	One Gold Dredge, One Gold Shop
Jiangxi Province, South Central China	2000	Leping County	One Gold Processing Plant
Jiangxi Province, South Central China	2000	Dexing County	One Gold Mine & Processing Plant
Anhui Province, Central China	2000	Tongling County	One Canadian Junior Joint Venture copper-gold-silver processing plant.
Shaanxi Province, West Central China	2000	Bayuan, Qingling Mountains	Two Gold Processing Plants.
North-Central China	2001	“Gold Mountain”	One gold mine, two gold processing plants, one zinc/Au smelting operation, two iron processing plants, two fishing reservoirs
Inner Mongolia	2001	Baotou Municipality	Mid-sized State Owned Gold Mine with centrifuges.
North-Central China	2002	“Gold Mountain”	Processing Plant, Placer Gold Operation, Sand and Gravel ASM operation.

Site visits were undertaken to research institutes in Beijing and ASGM areas in Hebei, Guangxi, Jiangxi, Anhui, and Inner Mongolia provinces, covering northern, southern,

²Gold Mountain is a pseudonym. While the miners have local government permits to operate, they are concerned about receiving publicity for fear that higher levels of government will shut them down.

south-central, and western China. Table 2.1 describes the site visits made, including visits to six counties, in these five provinces. Sites were chosen from the map included in Lin *et al* (1997), a small note found in Atiyah *et al* (1997) and discussions with a wide variety of people. Once in an area known to have ASGM, locals were queried as to exact locations of mines and processing operations. Upon arriving at a mine, processing site, or gold shop, a manager or operator would be asked for an interview and a tour.

2.2.2 Interviews

Over 25 interviews were conducted at ASGM mines, mills, and villages with labourers, operators, managers, financiers, retired miners, woman miners or wives of miners, fishermen, and local government officials. Interpreters were used when appropriate, or necessary, and were available at all times except for the first site visit to “Gold Mountain” and the site visits to Guangxi and Inner Mongolia. Over the course of the site visits, and especially during interviews, miners were observed for any signs of mercury-related illnesses, such as muscular tremors or gingivitis.

At ASGM mine and process sites, people interviewed were generally asked the following questions:

- How long has the mine been operating?
- How did the operation get started? What permits are required to operate?
- Is the operation legal?
- How many employees are there?
- What is the mine ownership structure?
- How many other gold mines/processing plants are in the area?
- What tonnage is usually processed per hour?
- What are the average gold grades and your general gold recovery?
- What is the mine or process operation?
- Is mercury used in the operation? How? Is the mercury use legal?
- Are they aware that mercury can be dangerous to their health and environment?
- Where did they get their mining equipment and how much did it cost?
- Where did they learn their techniques?

- What is their relationship with the government and how do they pay tax?
- What is their relationship with local environmental agencies?

In addition, over 15 people from research institutes, government offices and embassies, formal and international mining companies, and multilateral agencies were interviewed. These interviews were conducted in ASGM areas, Beijing and other major centres in China, and internationally. Questions were asked about:

- The political, social and environmental situation of artisanal miners in China, including their legal status;
- The land-use conflicts and coexistence between artisanal miners and the largely agriculture-based communities of rural China;
- The traditional mining concept and the current public perception of mining in China; and
- The relationship between artisanal miners and international mining companies.

These last interviews were necessary to develop a broad understanding of ASGM in China.

2.2.3 *HgEX Expert System*

During the initial field research, Veiga and Meech's "Expert System for Risk Assessment for Mercury Discharge from Gold Mining Operations", or HgEX (1996), was extensively used. Conventional approaches that attempt to correlate natural variables with mercury biota levels have relied on empirical regression models that often yield poor bioaccumulation predictions (Håkanson *et al*, 1988). Predictions are fraught with uncertainties and unknowns such as internal correlations between variables and site-specific aspects of biota contamination. HgEX uses a heuristic approach in which mining and amalgamation methods, along with natural variables, are dealt with using inference equations to give varying degrees of belief about the risk of bioaccumulation. The system can handle uncertain or vague data using fuzzy logic and neural network techniques. These procedures were intended to reduce the need for extensive monitoring programs and provide a preliminary diagnosis about bioaccumulation risk (Veiga and Meech, 1992). Despite sparse data and uncertainty, a diagnosis can still be made about the likelihood of a critical situation. HgEX was developed to make risk assessments of

mercury discharge from small-scale gold mining operations, primarily in the Amazon region by integrating information on biology, chemistry, geochemistry, and medical, social and political issues in order to evaluate mercury contamination for a single site or region (Veiga and Meech, 1996).

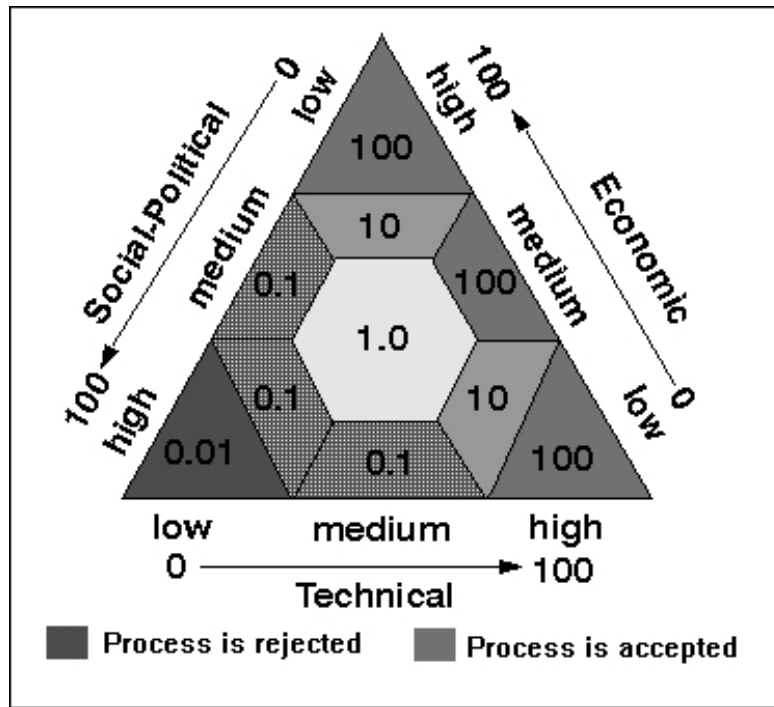


Figure 2.1 Alpha Factor for HgEX
(Veiga and Meech, 1996)

As the behaviour of workers depends on societal incentives and reactions, the definition of the level of acceptable mercury releases will differ with the values of the society. To map these differences, an alpha factor is calculated based on socio-political, technical and economic aspects of a society which relate to the acceptance or rejection of mercury use in gold mining operations. A high alpha factor indicates acceptance of amalgamation practice and low control of mercury releases enforced by a society, which may be a country, a region or a city. For many regions in Africa, Latin America and Asia, $\alpha = 1$; however, for Canada, where mercury is practically banned and well monitored by authorities, the alpha factor is much lower (0.1 or 0.01). For Canada 150 years ago, when the hazardous effects of mercury were unknown and thousand of miners were colonizing the West, the alpha factor would have been much higher (about 10 or 100). Thus the

alpha factor can adapt HgEX's conclusions on high emission levels to different countries' or regions' conditions (See Figure 2.1).

HgEX integrates common-sense knowledge with observations and field samples of variables that usually correlate positively with mercury pollution. By accepting vague data and by estimating the importance of variables, HgEX enables the evaluation and recording of mercury use and its potential effects in situations where a lack of funds and equipment would otherwise prohibit study.

2.3 Results

2.3.1 Site Visits – Gold Processing Equipment and Methods in China

This section describes the gold processing methods observed during the site visits. The primary methods observed include muller mills, ball mill/sluices, and dredges. Secondary processes observed include cyanidation, retorts, and *doré* purification.

2.3.1.1 Muller Mills

Muller mills were found at sites in “Gold Mountain” and Shaanxi. Muller mills, also known as edge mills or Chilean mills, simultaneously grind and amalgamate ore, kneading fine gold into the mercury. The mills usually consist of two or three large cast iron or stone wheels rotating on a central axis around a circular metal trough (see Figure 2.2). The wheels were approximately one metre in diameter. All muller mills observed were powered using electric motors, although it would be feasible to drive them with combustion engines or even animal power. All but the most remote areas of China are electrified, so electrical power is usually not a problem. Priester *et al* (1993) state that the mills require five to seven kilowatts of power to run, although a stronger motor is sometime required to start the wheels rolling.

Ore is crushed to roughly minus one inch and then shovelled into the mill. At least one kilogram of mercury is added per tonne of ore and ground together between the wheels and the trough. Lime is added to reduce mercury flouring and to raise the pH for cyanidation. Liberated gold contacts the mercury and forms amalgam, which can easily be collected by stopping the mill and cleaning the trough at least once a day. The

overflow fines are collected and leached with cyanide to further recover gold. The mills can process around one tonne of ore per hour, grinding the ore to approximately 80% mass passing 200 μm .



Figure 2.2 “Gold Mountain” Muller Mill

Locally manufactured muller mills are inexpensive, costing approximately US\$1200. The muller wheels need to be replaced periodically and chips of iron continuously fall off and need to be removed from the mercury, during cleaning, usually with magnets. As the muller wheels each weigh at least a tonne, having local sources of production is practical to minimize transportation costs.

In the “Gold Mountain” region a muller mill manufacturer claimed to have sold over 500 mills locally. “Gold Mountain” miners stated that they had taken the technology to areas in Inner Mongolia and to have exported the technology to areas as far as Myanmar, and that the technology was apparently introduced from Russia. In Shaanxi, a woman who used to mine explained that the muller mill technology was common in the area and had

been imported into the region by miners from Henan Province. Muller mills seem to be the technology of choice for ASGM in northern China.

The ratio of mercury lost to gold recovered ($Hg_{\text{lost}}:Au_{\text{produced}}$) is a common method for evaluating mercury losses from small-scale mining (Veiga, 1997; Hinton *et al*, 2003a). The ratio for muller mills varies greatly, as miners change the amount of mercury added based on their estimate of the gold grade and size distribution in their ore. Estimates of the $Hg_{\text{lost}}:Au_{\text{produced}}$ ratio run from about 10:1 to 50:1. This is explored in greater detail in Chapter 3.

2.3.1.2 Ball Mill / Sluice

Two operations in Jiangxi Province, two in “Gold Mountain”, and one in Shaanxi Province were observed using a ball mill / sluice box method. The ore is crushed by a jaw crusher and then passes to a hopper feeding the ball mill. The electric-powered ball mills observed were around 1.5 to 2 metres in diameter and about three metres long. Oversized “pebbles” are collected from the ball mill discharge screen and returned to the feed. The ball mill discharges onto a sluice box with a mercury-coated plastic carpet or copper amalgamation plate before flowing to a spiral classifier that returns the coarse material to the ball mill (Figure 2.3). The fines from the classifier continue on to flotation and/or cyanidation processes. The carpet or plate is cleaned at least daily to collect the amalgam. These plants process in the range of 30 to 100 tonnes of ore per day. As night shifts were uncommon, this likely meant 10-hour days processing 3 to 10 tonnes per hour. Ball mills typically use around 12 kW per tonne of ore, varying greatly with the ore’s hardness (Priester *et al*, 1993).

Miners in Jiangxi stated that they bought their mills from equipment manufacturers in Shandong Province and that other operations in the area used the same technology. Two larger mills in “Gold Mountain” were observed using similar unit operations, but did not use mercury at the time of the visit. A larger mill temporarily closed in Shaanxi Province, which appeared to use this technology and this type of operation, is identical to the 72 operations described in He *et al* (2000). Thus, this method seems common for slightly

larger ASGM operations. These types of mills are built as a package by equipment manufacturers and installed with some technical instructions.



Figure 2.3 Jiangxi Ball-Mill Mercury Sluice Circuit

Jiangxi miners claimed to process 30 tonnes of ore per day and to lose one kilogram of mercury per day. Getting accurate gold grades from miners was difficult, but assuming a generous amalgamation recovery of 10 grams/tonne, this would lead to a $Hg_{lost}:Au_{produced}$ ratio of 3.3:1.

2.3.1.3 Gold Dredges and Placer Mining

Over 10% of China's gold reserves are in placer deposits (Zhou and Goldfarb, 2002). One gold dredge visited in Guangxi Province shared its section of river with at least four other gold dredges. The dredge consisted of a line of heavy iron buckets attached to a digging arm inclined between two pontoons, with a small superstructure holding everything together (Figure 2.4).



Figure 2.4 Guangxi Gravel/Gold Dredge Operation

Each bucket could hold about two cubic feet of material, and the dredge probably moved less than 30 cubic yards per hour. The buckets discharged the river gravel onto a screen, separating the coarse stones from fine gravel. The fines passed over a simple sluice box with a plastic carpet to catch the gold. Both the fine and coarse material was deposited into small barges and then transported to shore. The sluice box was cleaned every day or two, and they usually recovered around one or two grams of gold with each cleaning, although they could recover up to six or seven grams in some richer areas of the river. However, these dredges were primarily recovering gravel for China's huge aggregates industry. The Guangxi dredge operation amalgamated and panned their sluice concentrates on the side of the river. From international experience, amalgamation of concentrates without retorts have $Hg_{\text{lost}}:Au_{\text{produced}}$ ratios of around 1:1 (Veiga, 1997).

In 2002 a return trip to "Gold Mountain" found a new gravel operation, using a front-end loader, screens, and a carpet sluice (Figure 2.5). The sluice was cleaned at least once a day and all of the heavies retained were passed over a shaking table. They claimed not to

use mercury to recover gold from the concentrates; however, they did use mercury at their muller mill operation.



Figure 2.5 “Gold Mountain” Gravel/Gold Operation

Over the course of this research, dozens of similar dredges and gravel operations have been observed all over China. It would be logical to assume that many of these also attempt to recover gold.

2.3.1.4 Retorts

Retorts were observed in Dexing and Leping in Jiangxi Province, and “Gold Mountain”. The Dexing and Leping retorts consisted of two parts: a cast iron pot and a lid device. A metal tube, approximately three feet long, was attached to the top of the removable lid. Around a foot away from the lid, a water coolant tube encircled the lid tube. Amalgam is placed in the pot and the lid is sealed. Heat is applied to the pot and the mercury in the amalgam evaporates, and escapes the chamber through the tube. As the mercury gas passes through the water-cooled section of the tube, the vapour condenses and drips out the end of the tube, to be collected and recycled (Figure 2.6). In “Gold Mountain”, miners used an innovative retorting method, heating amalgam in a bowl covered by a bucket sealed with water. This retort will be discussed in detail in Chapter 3.



Figure 2.6 Jiangxi Province Retort Cooling Tube

2.3.1.5 Cyanidation & Zinc Strip Smelting

ASGM leaching operations were observed in four processing centres in “Gold Mountain”, in Inner Mongolia, and in Leping and Dexing in Jiangxi Province. In Bayuan in Shaanxi, miners sell their tailings to larger mills for cyanidation. Gold ore, often after amalgamation and/or flotation, is placed in vats in the range of 200 cubic feet. The tank is saturated with a leach solution, and the pregnant solution is drained out the bottom of the tank. The leaching time depends primarily on the type of gold ore; refractory gold ores could be leached for as long as a week. Cyanide concentrations vary widely with the type of ore.

The unfiltered pregnant solution drains out the bottom of the tank and flows through locked metal boxes filled with fine zinc strips (Figure 2.7). Gold replaces the zinc through the Merrill-Crowe Process; periodically, the boxes are cleaned out, the zinc strips collected, and smelted to recover the gold. The solution is not aerated before cyanidation or de-aerated afterwards, leading to lower gold dissolution and recoveries.



Figure 2.7 “Gold Mountain” Zinc Strip Boxes

Slightly larger state-owned gold mines use activated charcoal in leach methods with stirred tanks to recover gold. These operations frequently cannot compete with the ASGM private processing operations.

2.3.1.6 Gold Shops

Gold shops were only visited in Guangxi and “Gold Mountain”, but can be found all over China. Inquartation, or ‘quartering,’ is undertaken to purify the gold. Silver is first added to ensure a gold-to-silver ratio of roughly 1:4. Then the silver and any remaining mercury are dissolved with nitric acid over a hot plate at low temperatures, usually out-of-doors with no fume hood, close to the miners’ home. Nitric acid will not dissolve the silver if the silver ratio is too low. Gold is left as a brownish powder.

To further purify the gold a cupellation process is used. Miners melt lead into the gold and place the gold-lead solid inside a concrete ball, which is then baked on a coal barbeque. The lead and other impurities are absorbed into the concrete leaving behind a relatively pure gold bead. Usually cupels are made of magnesite or bone ash; the use of

concrete for cupellation is uncommon. The gold is sold to local consumers or the government, usually at world market prices.



Figure 2.8 Burning *Doré* in Longsheng

2.3.2 Interviews

The results of the site visit interviews are integrated with the results of the site visit observations, in Section 2.3.1. In general, people interviewed were friendly and informative. More than a few of the site visits were followed up with a shared meal and a few drinks. These informal events often provided an excellent opportunity to gain the trust of the miners and to learn from them in a less threatening environment.

During the initial site visits and interviews, no overt signs of mercury related illnesses were observed, such as gingivitis and muscular tremors, often used as potential indicators of advanced mercury poisoning. Less pronounced symptoms such as fatigue, irritability, loss of memory, and depression would have been impossible to detect by an observer

with no medical training during short site visits and interviews. However, in the subsequent case study in “Gold Mountain”, one miner with severe mercury-related illness was interviewed, as described in Section 3.3.3.1.

The results of the interviews with people from research institutes, government offices and embassies, formal and international mining companies, and multilateral agencies are integrated into Sections 2.3.3 and 2.4. Where possible, the interview results are corroborated with references.

2.3.3 HgEX Expert System

HgEX was an invaluable tool during the initial research, as it provided detailed explanations of the primary factors of mercury releases from ASGM and of mercury bioaccumulation. It also provided an excellent set of questions and areas to investigate, which made the preliminary research far more effective than it would have been otherwise. In this section a determination of China’s national alpha factor is presented, along with an evaluation of mercury contamination for the site of Bayuan, Shaanxi Province.

2.3.3.1 Alpha Factor Determination for China

The national or regional alpha factor is one of the primary determinants of HgEX. The result of an alpha factor determination for China is shown below. HgEX questions are in italics and the certainty factor (CF) is noted in brackets at the end of the responses. “Yes” equals 100% CF and “no” equals 0%CF.

Is it easy to evade laws that control Hg usage?

Mercury laws were in place in China (Lin *et al*, 1997) and miners indicated they were aware of them in interviews. In Jiangxi Province and “Gold Mountain” it seemed relatively easy to get a locally issued permit to use mercury, although higher levels of government did not recognize these permits. Mercury regulations were sometimes enforced. In Bayuan a month before the site visit in July 2000, the Shaanxi Provincial Environmental Agency fined and shut down all operations using mercury. Everywhere visited was cautious about provincial environmental agencies. (50% CF)

Is there any incentive provided by the government for informal mining operations?

Interviews indicated there were not currently any incentives. In the 1980s to early 1990s the government did encourage ASGM (Andrews-Speed *et al*, 2003c), but since 1995-97 the government has cracked down heavily. However, local governments do encourage/work-with/own-a-stake-in some of the mines, as ASGM is frequently vital to providing employment and taxes to local economies. (10% CF)

Frequently Hg pollution affects other social groups, such as fishermen, natives, urban people, etc. not directly involved with mining activities. Do the groups, which may be affected by Hg pollution, have political power?

Downstream urban communities wield significant power in China, and are generally the driving force behind environmental concern. No areas visited had significant wild fish stocks, but aquaculture was common and fishermen would have some power. “Natives,” or minority groups in China, usually had some “autonomous” power over the counties they resided in, which would give them a significant amount of power. However, this would also mean they were probably a major force in local mining, although this does not seem to be the case in Tibet (World Tibet Network News, 1995) However, in poor regions local government would give precedence to ASGM. (90% CF)

Many societies hold a mystique that gold mines are an easy way to get rich. Is this an important point in this society?

Perhaps, however with so many sectors of the economy booming in China, this is only one of many options, and this is probably less of a factor than in other ASGM areas of the world. Miners interviewed considered mining more profitable than farming, but starting a business or moving to an urban area would be considered more profitable than mining. (50% CF)

Is mining a traditional occupation in this society?

Mining probably has a longer continuous history in China than anywhere else in the world, and is certainly is a traditional occupation. Historically mining, as with other

commercial activities, was looked down upon by Chinese society (Golas, 1999). Regardless, mining is new to some communities, and was new to the Bayuan site. (100% CF)

Is the level of education high in this society?

In the cities, the education level is high. In the areas where the mines are, the mine operators usually have about the equivalent of high school education, but much of this might have been received during the Cultural Revolution, when the education system was in turmoil. Virtually everybody would have been in school for between six and nine years. However, functional illiteracy is a big problem in rural China, mainly due to the difficulty of mastering Chinese writing. Officially the overall literacy rate in China is 86% (CIA, 2003); however, 90% of the illiterate 14% of the population is located in rural areas (People's Daily, 2002c). (80% CF)

Is the interaction between miners and other educated people (university level) frequent?

In the 1980s to early 1990s such interaction was more common (Zhang, 2002). In the early 2000s, much of the mining and process techniques came from equipment manufacturers, who presumably have access to university-educated people. The caution exhibited by ASGM operators toward environmental agencies indicates there was some interaction, and the environmental agencies presumably had some access to university-educated personnel. While some operations would interact, the vast majority would not interact frequently. (30% CF)

Is the dominant media reliable and well informed?

While the Chinese media is censored politically, it increasingly comments on environmental problems (People's Daily, 2000, 2002a, 2002b). The press tries to report on ASM disasters, but local operators and officials are often uncooperative. (40% CF)

Are ecological groups active?

There are many international groups with local cooperation on issues such as soil erosion in northern China, and urban environmental health issues. There are not any domestic

environmental NGOs with significant power (United States Embassy in Beijing, 2001). (20% CF)

Is amalgamation the first option considered by miners to extract gold?

Yes, all of the ASGM mines visited used amalgamation. Cyanidation is another common option, in addition to gravity and flotation. (100% CF)

Is mercury readily available to miners?

Yes, mercury was readily commercially available and inexpensive (US\$ 6 – 8.50/kg). China has had a large mercury mining industry, which probably supplied most of the mercury. China also had ASM mercury mines, which may have been in the mercury supply chain. In addition, mercury is imported into China both directly and through Hong Kong (Maxson, 2004). (100% CF)

Gold placers, colluvium, laterite deposits and abandoned tailings are usually neglected by companies due to low grade. Are miners currently working these types of deposits?

Most ASGM operations visited were working small, high-grade quartz veins. No miners were observed reprocessing tailings. Some gold dredges were observed, but only as part of aggregate operations. Reports from Canadian junior exploration companies (Southwestern Resources, 2004) indicate that ASGM miners often mine on potentially large deposits. (20% CF)

Do miners make frequent improvements in the amalgamation process to increase gold recovery and reduce mercury emission?

All operations would greatly vary the amount of mercury used depending on the quality of ore they were using. While miners visited tinkered significantly with their reagents, they tended to hold with the equipment available. (50% CF)

Is it easy to introduce new gold extraction technologies? (Miners can assimilate easily?)

The small-scale state owned mines did not seem very flexible, and in interviews managers stated they could not compete with the ASGM private operations, which were

generally run like small businesses. If a product could be shown to increase the revenue or reduce their costs, the private miners would be extremely interested. (50% CF)

Are miners aware of the side effects of mercury?

All of the miners and people interviewed were aware mercury is dangerous. However, the specifics of mercury contamination were not necessarily well understood. (70% CF)

Do the miners have access to any specialized technical support?

The miners in Dexing were in contact with a company in Shandong Province that made mining equipment and provided some specialized technical training; in addition, they used government exploration teams to find their mines. Experienced miners from Henan Province trained the miners in Bayuan. However, these sorts of contacts were erratic and not available to all operations. (60% CF)

Have the government or other research institutions come out with alternatives or solutions for mercury use?

In the 1980s and 1990s, there was some assistance and research. The prevalence of retorts suggests some involvement. However, since the ASGM crackdown, it doesn't appear like there has been much interaction. (60% CF)

Are miners currently working ores in which gold recovery from concentrate is low when amalgamation is used?

ASM operators were extremely discreet with gold recovery figures. Most operations visited used multi-stage recovery, following amalgamation with flotation and/or leaching. Miners claimed to recover 30-70% of their gold with mercury methods. (20% CF)

Is it easy to set up a monitoring programme to survey mercury pollution extent?

To set up an effective, nationwide monitoring program would be prohibitively difficult and expensive due to the size of China. However, local or regional surveys are possible, in close cooperation with Chinese agencies or organizations (Lin *et al*, 1997; Dai *et al*, 2003). (30% CF)

Are there any examples of spectacular gold discoveries (or rushes)?

Around 2001, gold was found in the Boka area in Yunnan Province. In the period of a couple of years over 50 tunnels were put into operation. Similar discoveries are probably made regularly, but are not significant in a country the size of China. In the early 1990s there was a gold rush in western China (Tse, 1996), and up to 10,000 miners rushed to the Nagqu area in Tibet in 1994 (World Tibet Network News, 1995). However, all the site visit mines were operated by local Chinese, and these gold rushes do not appear to have been on the scale of the gold rushes in Latin America (40% CF).

Is mining activity important for the region's economy?

In most of the areas visited, mining was clearly the dominant industry. In China as a whole, it is quite important, but is superseded by agriculture, manufacturing and commerce (China State Statistical Bureau, 2000). (80% CF)

Agriculture represents the main activity in some regions, but the quest for land leads individuals to see mining as an alternative. Is this the case for this society?

ASGM is certainly seen as an alternative to the poor returns of agriculture in rugged, remote areas. However, better alternatives exist in China's booming coastal economy. Mine owners/managers are largely local business people, seeking a high return on their capital. Labourers often seek to supplement their agricultural income. (80% CF)

Is the mercury price high compared with the international market (US\$ 4/kg)?

The price was as low as US\$ 5.50/kg in 2001. (0% CF)

Does mercury represent a high cost in the mining operation?

Since the cost of mercury was so low and the ore was usually high-grade quartz veins, mercury was a minor cost (See section 3.3.1.6). (0% CF)

Do the mining operations require expensive equipment? (High investment?)

Most of the mines had a significant investment in equipment (crushers, ball mills, muller mills, or dredges). However, these items are usually made locally for little cost, and some operations were low tech (Bayuan in particular). (30% CF)

Is the region experiencing difficult economic times and is mining seen as a feasible economic alternative?

China has boomed for the last 20 years; however, most of the development has occurred in the eastern coastal areas. ASGM areas are often far from the coast or large cities, and have had significantly less economic growth. Mining, along with migration to the cities, or small-scale rural industries is among the feasible alternatives. (50% CF)

Is the minimum wage low?

In some of these areas, US\$ 300 or 400 would be an average annual wage. (100% CF)

Is inflation low?

In the early-to-mid 1990s, there was significant inflation, up to around 20%/year. However, since 1997, inflation has not been significant and some prices have even dropped. (100% CF)

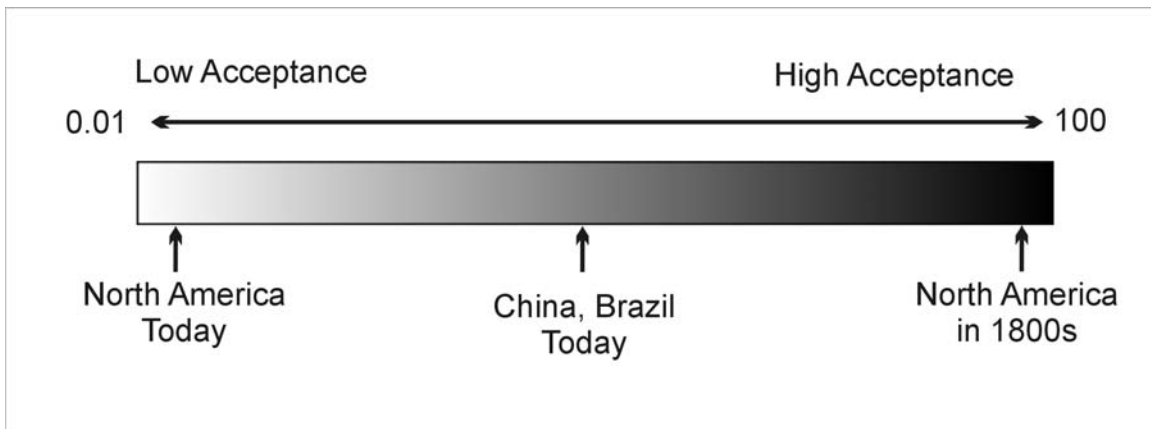


Figure 2.9 Alpha Factor Comparison

These answers led to an Alpha Factor for China of 1.00, indicating that China has a moderate acceptance of amalgamation practices. As shown in Figure 2.9, this factor is

similar to that of Brazil in 1994 (Veiga and Meech, 1996). This Alpha Factor was used as input for the site evaluate for Bayuan described below.

2.3.3.2 Bayuan Site Contamination

Bayuan, Shaanxi Province, is presented as a case study for a local diagnosis (Gunson *et al*, 2001). Southeast of Xi'an, a major interior city and ancient capital of imperial China, lie the Qingling Mountains, home to hundreds of ASGM operations. A local Bayuan woman, who had once owned and managed an ASGM processing centre, provided most of the information about the area. One month before the Bayuan field study, the Xi'an government environmental agency had shut down and fined a number of mines in the area due to non-compliance with environmental laws. It was assumed that the mines would soon reopen, as is frequently the case in China.

This valley had four state owned mines and over ten privately owned mines. The private mines mainly used locally manufactured muller mills to amalgamate whole ore and used a sluice box to recover amalgam. A past ASGM operator stated that amalgam was frequently burned openly without retorts, and the mill tailings drained into pits. These tailings were sometimes sold to the state mines for reprocessing, but otherwise they were piled nearby, which allowed the runoff to drain into the local stream. The Qingling Mountains are full of other small valleys similar to Bayuan.

HgEX accumulated data input through its heuristic method, accepting uncertain or vague information. Using fuzzy logic and neural network techniques, HgEX output the following bioaccumulation assessment:

This is a small site in which milling is the predominant extraction method. The amalgamation process is typically applied to whole ores, using muller pans. Amalgam is separated from heavy minerals in excavated pools or simply panned at creek margins. Amalgamation tailings are either discharged into the watercourse, left in pools or sold for reprocessing. Retorts are not used as the amalgam is burned directly in a pan. The sediment has a background level

inferred by HgEX at 0.042 ppm mercury.³ The water colour of the main drainage is clear and the biomass is low. Hot spots were visually identified, indicating a high mercury level. The contaminated sediment is rich in gravel and grey in colour. Near the mining activity, the watercourses are clear.

Based on the above information, using a weighted inference equation, HgEX calculated a diagnosis by determining the following factors:

- The local mercury releases were estimated to be very high, with a Degree of Belief - High Emission Factor (DoBHEF) of 90%. This factor is based on evidence about whether high releases of mercury are occurring locally, such as the use of muller mills;
- The natural conditions were estimated to be slightly dangerous, with a Degree of Belief - Dangerous Environmental Factor (DoBDEF) of 39%. This factor was based on indicators such as water colour and the presence of local hotspots;
- The adsorption process was slightly possible, with a Degree of Belief - Mercury Adsorption Factor (DoBMAF) of 20%, based on indicators such as suspended solids and sediment colour; and
- The overall risk of bioaccumulation was determined to be high, with a Degree of Belief - Potential Bioaccumulation Risk of 100%, based on the equation $\text{DoBHEF} + \text{DoBDEF} - \text{DoBMAF}$.

The summary generated by the input data was as follows:

Mining activities are emitting very high mercury levels into the aquatic environment in which natural conditions are slightly dangerous for methylation and bioaccumulation. Mercury adsorption by sediments is slightly possible to control bioavailability. This situation leads us to believe that the risk of increasing mercury levels in the biota is high.

³ Please note that HgEX has not been validated for China. These results are estimates only.

Finally, the HgEX output stated that retorts should be introduced at local mine sites.

2.4 Discussion - ASGM in China

The site visits and interviews, in conjunction with the HgEX expert program, conclusively determined that ASGM still took place in China in the early 2000s, and that mercury use was widespread and represented a significant health threat.

The following discussion integrates the results of the interviews about the general state of ASGM in China with the information gathered from site visits and interviews, HgEX, and the findings of the literature review. This broad overview highlights important differences between ASGM in China and other nations and is necessary in order to understand the present state of ASGM in China and how the sector can become less damaging and more sustainable in the future.

2.4.1 Significance of ASM in China

Unlike most developing countries, gold extraction is not the main ASM activity in China. China has the largest mining industry in the world, by number of mines, production, or employees. China's ASM miners make up the vast majorities of China's mines, approximately half of the employees, two fifths of the production, and around a quarter of the value of production (DFAIT, 2001). Mining is a significant economic activity in all of China's provinces, municipalities, and territories, with the exception of Shanghai. It has been an important driver of China's booming economy and is one of the largest sources of pollution in China.

China's ASM industry employs at least six million artisanal miners (Gunson and Veiga, 2004), composing about half of the artisanal miners in the world (Jennings, 1999) and constituting one of the largest sectors of the mining industry worldwide. They produce at least 11 per cent of the world's coal output, easily out-producing the entire coal industry of major producers like Australia or India. As shown in Table 2.2, China is one of the largest producers of metals and minerals in the world, topping the world in antimony, coal, iron, lead, manganese, tin, tungsten and zinc (Billiton, 1999); artisanal miners produce at least 30 per cent of each of these minerals (DFAIT, 2001). Table 2.2 does not

provide a complete accounting Chinese ASM, but highlights selected minerals. The chief economist of Rio Tinto, one of the largest mining companies in the world, states it “is difficult to overstate the importance of China to the future of the world mining and metals industries” (Humphreys, 2002). China is unique in the scale and diversity of its artisanal mining industry.

Table 2.2 Chinese Productions of Several Major Minerals
(after Billiton, 1999 and DFAIT, 2001)

Mineral Product	China's Production in 1997 ('000 tonnes)	China's World Ranking by Production	% Produced by Chinese ASM	Number of ASM workers
Aluminium	8,000	10	75.63	23,625
Antimony	101	1	46.44	54,599
Coal	1,360,000	1	42.58	2,696,056
Copper, mined	440	8	9.08	54,865
Gold ⁴	0.185	5	33.3	463,000
Iron Ore	249,000	1	32.13	259,704
Lead, mined	650	1	31.13	83,827
Manganese	2,300	1	65.77	74,170
Mercury	0.614	3	8.52	738
Molybdenum	30	2	15.46	11,364
Phosphate Rock	30,400	2	51.03	45,145
Salt	29,300	2	10.36	3,188
Tin, mined	56	1	44.48	31,906
Tungsten, mined	24	1	35.31	25,599
Zinc, mine	1,210	1	31.13	83,827

2.4.2 Scale of ASGM in China

2.4.2.1 Definition

China has few completely illegal or unregistered miners, primarily because it is relatively easy to get some sort of permit from the local government. Zhong (1999) estimates that only 10% of ASM had no legal status in 1999. However, reliable statistics estimating the number of illegal miners are simply not available, given the nature of illegal mines and

⁴ The gold figures are based on the discussion in section 2.4.2.2.

the scale of ASGM over a vast area. Undoubtedly the number of illegal mines varies widely from region to region.

Most artisanal and small-scale mining in China today can be categorized as Township and Village Enterprises (TVE). The concept of the TVE is a flexible organizational model that was developed to handle the dismantling of the commune system as China began to implement economic reforms in the late 1970s. TVEs were intended to “promote economic growth and to absorb the surplus rural labour force and discourage excessive urban migration” (ILO, 1998). TVEs have since come to dominate China’s rural economy, employing up to 120 million workers, and producing billions of dollars of goods including everything from toys to coal. They are also covered extensively in China’s statistics, and thus present an easy target to use to define small mining.

TVEs are hybrid institutions, commonly an ambiguous alliance between private entrepreneurs and local government officials acting as “owners”. The entrepreneurs, or managers, negotiate contracts containing both implicit and explicit conditions for them to conduct their business with the relevant public officials. Managers can gain a great deal of flexibility in such contracts and the local officials secure revenue for their local government (or for themselves). Officials often also provide special access to inputs, public resources, tax breaks, or any number of other incentives to help their local TVEs. The local Peoples’ Congress elects these officials, so many TVEs are inherently political institutions.

The term TVE officially means an organization owned or financed by a township or village government. For the purpose of collecting statistics, the term has been expanded to include collectively and individually owned enterprises, including self-employed people, if they are officially registered and are run by people from rural areas, defined as farmers, or peasants. As TVEs are by definition in rural areas, TVEs once fell under the responsibility of the Ministry of Agriculture, but are now under the Ministry of Land and Resources. The distribution of TVE ownership varies widely between regions. In

practice, local governments interpret what constitutes a TVE based on local conditions (ILO, 1998).

While the TVE category covers most ASM mines in China, there are exceptions. Some TVE mines are large enough, and perhaps sophisticated enough, to raise the question of whether they are actually artisanal or small-scale mines. There are privately owned small mines that may not be registered as TVEs, as well as an indeterminable number of outright illegal mines. Furthermore, a few of the state-owned mines, which are considered large-scale, are actually quite small and/or primitive. Mines owned by the federal, provincial, or prefecture (municipal) governments are often considered to be state-owned, or formal mines, whereas mines at a county, township or village level are generally TVEs. In addition, a range of state companies and agencies own ASM operations, including the army, the prison service and large-scale mining companies (Andrews-Speed *et al*, 2003b).

Private mines, while financed by private individuals, often have at least some connections to local government. These mines are usually licensed, but only with locally issued licenses that are often just a formality. Anywhere from one to several businessmen will often create a small formal company with ownership divided into shares based on the initial contributions. Profits are then split accordingly. These partnerships are sometimes referred to as collectives, but the labourers usually do not have a share in the partnership. The company will use local prospectors or hire a professional geological team to find a deposit, or will already have a deposit in mind. One or two of the businessmen will manage the mine. In practice, these managers have considerable control of the mine finances and may often be seen as not splitting profits fairly.

In the late 1990s, the central government turned over control of most of its artisanal mines to provincial and prefecture governments, in an effort to concentrate on larger mines. These state-owned small mines tend to follow the law much more closely than the other small mines, and often have a better safety and environmental record than others.

Worker cooperatives do not seem common. Equally absent are producer associations; individual small mines rarely formally cooperate with each other in associations, although the owners are often on good terms with the other mines in the area and occasionally discuss technical issues.

2.4.2.2 Scale of ASGM in China

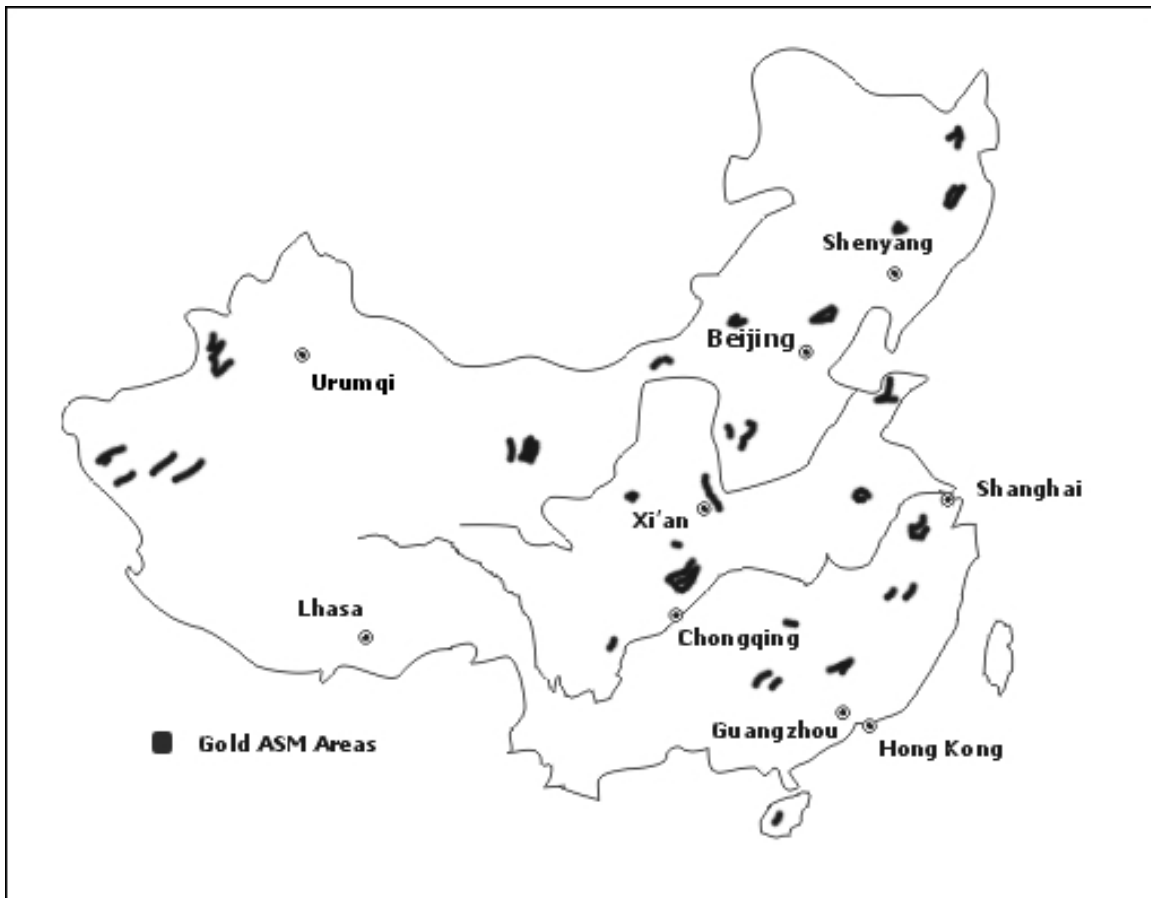


Figure 2.10 ASGM Areas Across China
(after Lin *et al*, 1997)

There are no published national figures estimating the numbers of small-scale gold miners in China or the amount of gold they produce. Estimates can only be inferred from other data. According to a DFAIT report (2001), in 1997, an estimated 3,000 ASM gold mines employed well over 150,000. In comparison, in 1994 the Chinese government estimated that 300,000 illegal entities were involved in ASGM (Tse, 1995). In another almost certain underestimate, Tse (2001) reports that in 2000, “about 1,000 gold mines were in China, most of which were small and processed ores with obsolete technology

that damaged the environment and wasted resources.” Zhou *et al* (2002) clarify this number, stating that in addition to the 1,000 small gold mines, there are “numerous very small local mines (treating <25 t rock per day) that are not accounted for in government statistics.” For context, in the North China Craton, with approximately 20% of China’s gold reserves, around 900 gold deposits and occurrences are known (Hart *et al*, 2002). Site visits in the area would indicate that the vast majority of these would have at least one, and probably several, ASGM operations in production. As seen in Figure 2.10, ASGM activities occur throughout China. Clearly, it is difficult to get accurate statistics on the number of ASGM operations or on the number of people who work at them.

The problem relates back to the difficulty of estimating China’s gold production. Until 2001, China required that all gold produced be sold to the People’s Bank of China (PBC), the central bank, at a fixed rate, usually around 10% below the international price. The price of gold was changed to roughly match international prices in 1999 (Tse, 2000), and a free gold market was established in 2001. Until 2001, China’s gold production was listed as the amount of gold purchased by the People’s Bank of China (Tse, 1997). However, most of the gold mined by illegal miners is not sold to the People’s Bank, so the total gold production was significantly underestimated.

Gold was sold illegally for several reasons:

- Higher prices could be received (if only by smuggling);
- Much of the gold was consumed locally for jewellery; and,
- Chinese individuals could not legally own gold as an investment until 2002. As a hedge against China’s currency, wealthy people would purchase gold.

An indication of the extent of this illegal trade was seen in 1997, when for a short time China’s official gold price was held above international prices, due to the plummeting of the international gold price. As much as 300 tonnes of gold was smuggled into China from Hong Kong alone during this period (Tse, 1998).

From 1990 to 2001, China’s gold production has increased from roughly 100 tonnes/year to 185 tonnes/year (Tse, 1996, 2002). There is a discrepancy between Chinese official

gold production numbers and outside experts' numbers, although it has been shrinking in the past five years. In 1994, Chinese official figures state that 90.2 tonnes of gold were mined, and that 82 tonnes were purchased by the PBC. Independent experts estimate that around 132 tonnes of gold were produced (Tse, 1995). By the government's own figures, around 10% of China's gold production was being sold illegally. However, extrapolated from the experts' estimate, around 40% of gold was being sold illegally. From figures available for 1994 and 1996 this adds up to 50 tonnes and 65 tonnes sold illegally respectively.

ASGM gold production estimates rest on two main factors; how much of the gold sold legally in China is from ASGM and how much additional illegal production occurs. Lin *et al* (1997) estimate ASGM produced one-third of China's gold production of 105 tonnes for 1995; however, Tse (2000) reports that the 1995 gold production was 140 tonnes. Lin *et al*'s (1997) assumption is probably an underestimate. Zhou *et al* (2002) state that "local governments and rural Chinese companies now play a more important role and are responsible for 45 and 38% of China's annual gold production, respectively." Probably none of these operations, accounting for a total of 83%, could reasonably be considered formal large-scale mines as understood in North America. The largest gold mine in China produces about 3 tonnes of gold per annum, far less than major international gold mines. China's gold production for 2001 was approximately 185 tonnes (Tse, 2002). Using a conservative estimate of one-third of production, this would lead to over 61 tonnes of gold produced by ASGM.

Veiga (1997) noted a correlation between gold production and the number of gold miners in South America. He found that the number of miners per kilogram of gold mined ranged from 2 to 8. The more gold a country produced, the higher the ratio of miners required, perhaps because a higher number of gold miners were lured by gold rushes. In rural China, the cost of labour is very low, with mine labourers in the wealthier coastal provinces being paid from US\$ 70 to 100 per month, and in poorer regions far less. Thus, the ratio of miners per kilogram of gold mined is unlikely to be at the lower end. If Brazil's ratio of 7.5 is used, the number of artisanal and small-scale gold miners in China

would be as high as 463,000. This is not unreasonable, given the extremely high numbers of rural unemployment and underemployment in China. Generating rural employment is arguably the highest priority of the Chinese government (The Economist, 2002).

This estimate can be verified using a simple model extrapolated from “Gold Mountain’s” experience. There, one miller mill/cyanidation operation processes around 10 tonnes of ore, recovering around 90% of the 20 g/t feed ore, and employs around 10 people for at least 150 days a year. About 10 small mines feed the operation, each employing around 20 people. The 210 employees at the process centre and the mines thus produce approximately 27 kg of gold per annum. In other words, 7.8 miners are required to produce one kg of gold. This ratio leads to a national total of 474,000 ASGM miners, quite close to the estimate indicated above. While this model is grossly simplified, similar numbers were observed in other areas during the site visits throughout China.

2.4.3 Economic Impact of ASGM

2.4.3.1 National Impact

Chinese ASM as a whole had an immense short-term positive impact on China’s economy. The annual production of China’s entire ASM industry’s value is in the range of US\$ 26 billion to \$180 billion (Ministry of Agriculture, 2000), significantly more than Canada’s entire mining and mineral processing industry’s output of USD\$ 12.5 billion in 2001 (NRCAN, 2002).⁵ It has employed millions of surplus rural labourers, people who may otherwise have added further pressure to the tens of millions of workers migrating from rural China to its booming coastal cities.

ASGM operations often mine small deposits that would not be economical for the large-scale mining sector to develop. However, ASGM can waste deposits that could be viable for more efficient large-scale mining. In addition, small-scale miners can encroach on the formal large-scale mines, and can cause great harm to the workings, by inadvertently flooding them. ASGM often high-grades a deposit, only taking the easy-to-reach, most

⁵ Canada’s output excludes oil and natural gas, but includes coal, and is calculated at an exchange rate of 1.55 Canadian dollars to one US dollar, the Bank of Canada’s exchange rate average for 2001.

valuable parts of the ore body. For example, in 1995 an estimated 30,000 “peasant prospectors” in the Hol Xil area of Qinghai Autonomous Region caused the government to close all gold mines in the area in an attempt to protect gold reserves (Reuters, 1995).

2.4.3.2 Local Impact

Locally, ASGM mines often supply the bulk of tax revenue and employment for poor and remote counties. This revenue is largely used to pay for infrastructure, health and education, and reduces or eliminates the need for higher levels of government to provide support. The economic impact of ASGM is most felt in poverty-stricken, remote, agriculturally poor provinces like Guizhou. In contrast, in a booming coastal province such as Shandong, the importance of ASGM is more localized and relatively minor.

2.4.3.3 Impact on Formal Mining Companies

Most foreign and state-owned mining company officials met in the process of this research could give examples of problems with artisanal miners. It is a sensitive issue; few people want to go on record on the topic and there is very little documentation. An indication of the animosity that exists between ASGM and larger mines can be seen from the complaints that arise. Chinese officials and state-owned companies, and Canadian junior exploration companies, frequently complain that ASGM destroys otherwise valuable deposits. ASGM often takes only 20-30% of the deposit, leaving the remaining ore less attractive to formal mining operations (United States Embassy in Beijing, 1996).

In general, artisanal miners, despite warnings and evictions, often repeatedly illegally mine on property licensed to larger companies, usually high-grading deposits. This can make conventional mining more dangerous, less profitable and, in extreme cases, not viable. On the other hand, larger companies often become interested in a site because of the presence of the artisanal miners. Larger companies bring in police to force the small-scale miners off the property. Occasionally these removal operations can be quite volatile. Often the artisanal miners are migrant workers, and are forced to return to their home areas. Local miners might be given compensation if a larger company decides to develop their property, and sometimes the larger company finds alternative areas for these miners

to work. These other areas may or may not be economically viable for the artisanal miners (Gunson and Yue, 2001).

Southwestern Resources (SWG), a Canadian junior, has an especially interesting relationship with small-scale miners. In 2002 SWG formed a joint venture company with China Yunnan Province Nuclear Industry Team 209 (YPNI) to develop the Boka property (Southwestern Resources, 2004). YPNI's name is a holdover from the planned economy days when exploration companies had mandates to explore for specific minerals to the exclusion of all others.

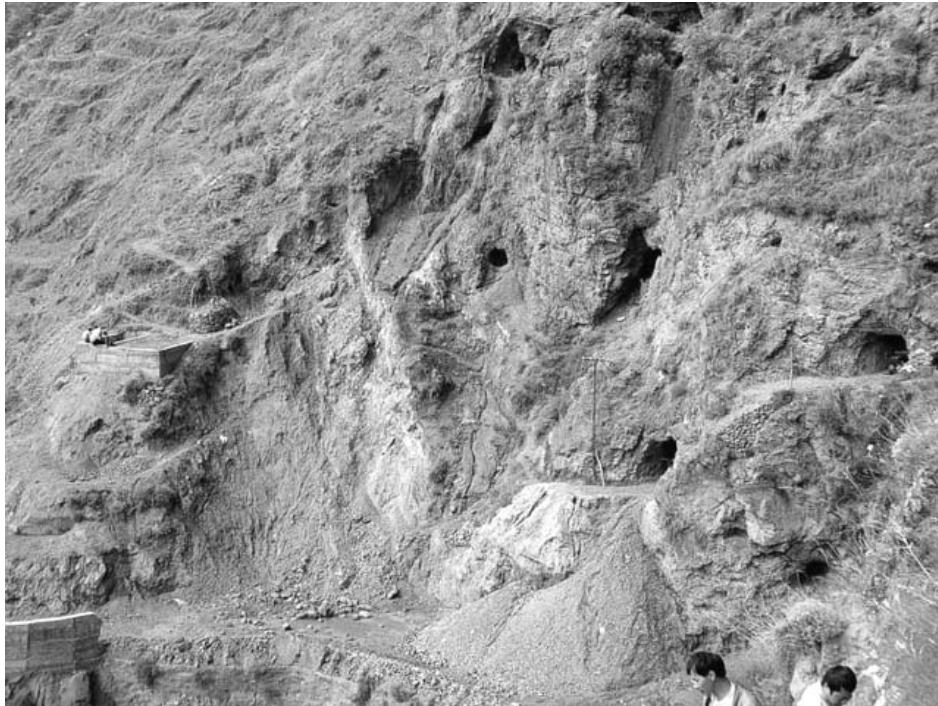


Figure 2.11 ASGM Tunnels, Boka, China
(Southwestern Resources, 2004)

YPNI had acquired a property called Boka, on the banks of the upper reaches of the Yangtze River, that the provincial exploration teams had indicated had gold, and started small-scale mining in early 2001. In 1999 or 1998, “illegal” small-scale miners had already heard of this assessment and started to mine the area heavily, building more than 200 tunnels into the mineralized zone, as shown in Figure 2.11 (Southwestern Resources, 2004). With the signing of the joint venture, YPNI had the “illegal” miners evicted,

probably by local police forces. The “illegal” miners had permits from local governments, but the local government did not have the authority to issue such permits (Paterson, 2003). Following the removal of the ASGM miners, the joint venture conducted extensive geological surveys of ASGM adits, or tunnels. Based on assays from samples collected from the tunnels, the joint venture announced the discovery of a massive gold deposit and SWG stock rose almost 12 times above its value at the start of the year. The joint venture undertook a large geological drilling program to delineate the deposit in 2003 (Southwestern Resources, 2004). No compensation was offered to the small-scale miners, although several were hired to be on the local exploration team (Paterson, 2003). YPNI did not stop small-scale mining operations until January 2004 (Southwestern Resources, 2004).

2.4.4 Legal Framework

2.4.4.1 Government Framework

China’s hierarchical government structure consists of 5 to 6 basic levels: National, Provincial, Municipal or Prefecture, County, Township, and Villages. While this may seem excessive, it is worth recognizing that many of the provinces are of similar population and size to major European nations. China is not a federal system – lower levels are directly subordinate to higher levels. In practice, however, these different levels of government often have conflicting interests and goals.

Over the past few years China has also undergone massive government institutional changes (Gunson and Yue, 2001). After being shuffled from the Ministry of Agriculture, ASGM now falls under the auspices of the Ministry of Land and Resources.

2.4.4.2 Government Policy

From the late 1970s to the mid-1990s, essentially all levels of government supported the rapid growth of artisanal and small-scale mining (Andrews-Speed *et al.*, 2003b). For example, ASM coal mines were given various subsidies and tax allowances. While there was consensus on the need to increase production, there was no such consensus on anything else, such as health, safety and the environment. Production grew at a prodigious rate but legal, technical, environmental, and safety requirements seemed to be

ignored in most mining areas. Short-lived and half-hearted rectification campaigns failed to make any significant impact on the behaviour of miners or local governments (Andrews-Speed *et al*, 2003a).

Since the late 1990s there has been little in the way of support for artisanal miners in China. Lin *et al* (1997) reported a crackdown on ASGM in 1996. Zhong (1999) outlined a series of government orders to curb small-scale mining that included:

- The No. 6 Order of the Minister of the State Commission of Economy and Trade on the Catalog of the Existing Lagged Production, Techniques and Products that must be Banned; and,
- Catalog of Curbing Unnecessary Repetition of Capital Construction Investment in the Industrial and Commercial Circles.

The “Catalog of Curbing Unnecessary Repetition of Capital Construction Investment in the Industrial and Commercial Circles” banned approval of or investment in cyanide operations treating less than 10 tonnes per day of gold concentrate, pyrometallurgical projects treating less than 50 tonnes of gold concentrates per day, heap leaching projects treating less than 5000 tonnes per day, hard rock gold mining projects treating less than 25 tonnes per day and placer operations treating less than 200,000 cubic metres per day. As it is difficult for many ASGM operations to achieve these tonnages, many are forced to become illegal.

2.4.4.3 Laws and Enforcement

ASM in China is subject to a large and continuously growing and changing body of legal documents drawn up by various government agencies at all levels of government. This regulatory framework is characterized by “duplication, inconsistency and omission” and ASM operations would be hard-pressed to comply with them all (Andrews-Speed, 2003b). Furthermore, much of the framework is unsuited to ASM.

A few examples of laws and regulations that apply to Chinese ASM include:

- Regulations for Registering to Explore For Mineral Resources Using the Block System, 1998
- Regulations for Registering to Mine Mineral Resources, 1998
- Regulations for Transferring Exploration Rights and Mining Rights, 1998
- Construction Law of the People's Republic of China, 1997
- Law of the People's Republic of China on Safety in Mines, 1992
- Regulations on Prohibition of Child Labour, 1991
- Regulations on Reporting and Handling Fatal Accidents of Workers and Employees in Enterprises, 1991
- Mineral Resources Law of the People's Republic of China, 1986.

Enforcement can be both erratic and harsh. Government agencies wield significant power over mines and other small industrial operations and are often regarded as corrupt and insensitive to local needs. In August 1994, Shandong Province, China's largest gold producing province, reportedly closed down 641 illegal gold mines and 50 retailing and processing shops (Tse, 1995). On the border of Henan and Shanxi Provinces, 430 illegal gold mines were closed, employing 13,000 ASGM miners, and 9,000 pieces of equipment were confiscated. In Tongguan County, Shaanxi, 87 ore processing mills were shut down (Tse, 1997). Judging from China's record with ASM coal shutdowns, many of these operations probably restarted.

China's environmental control agencies can occasionally be effective. In Beijing municipality, miners apparently use only gravity concentration for gold production. Over the 1990s, the spread of knowledge about mercury pollution and retorts may be due to these institutions.

In spite of the array of laws effecting ASGM, operators are often not particularly concerned about legal consequences; they can usually bribe their way out of trouble at the local level. Managers interviewed in Jiangxi Province stated that it is easy to get all of the necessary local permits by hosting banquets for local government officials. In contrast, going through official routes is time consuming and costly. Enforcement of safety

regulations is lax, and in the event of casualties, management is only expected to pay the family around US\$2,415 (Fong, 2001). In any case, the concept of a legal society and regulatory framework as understood in North America is rather new to the People's Republic of China; most of the laws are only a decade or so old and they often mean less and less the further one gets from Beijing.

2.4.4.4 Tax

As ASGM mines are essentially regulated by hundreds of small, local governments, which often own mines themselves, tax collection is anything but uniform. Rural tax collection is a contentious issue in China, characterized by violence and tax revolts, and unofficial taxes imposed by local governments (Pomfret, 2001). In theory, all mines are subjected to taxes, royalties, and other, often arbitrary, fees. Taxes include a 1.18% Resource Compensation Tax, a Resource Tax, and a Normal Business (or income) Tax. Royalties are collected locally for the central government, and about half of this money is redistributed at the county level. The received royalties are used for promoting exploration and technical/safety support to the mines as well as for local government administration. Counties may not receive disbursements in proportion to the royalties they collect; thus, there is not much incentive to collect these royalties, especially as the local governments often own the mines. Overall, the tax burden in rural China is relatively low, but ad-hoc fees imposed by local governments can be high, often reaching 20% of post-tax profits (The Economist, 2002). However, the overall tax burden of ASGM, including ad-hoc fees, is unknown and almost certainly varies significantly with location.

2.4.4.5 Illegal ASGM

According to Tse (1996), most of the illegal ASGM operations are found in western China, in Gansu, Guizhou, Ningxia, Shaanxi, Sichuan, Qinghai, Xinjiang, Xizang, Yunnan. Lin *et al* (1997) reported that most of the alluvial gold deposits are mainly exploited by individuals and that around half of the hard rock gold operations are mined by individuals or collective units. Tse (1996) describes the illegal operations as such:

Scrambling to get rich, hundreds or perhaps thousands of gold hunters rushed to the west. Widespread illegal exploration and unregulated gold mining seriously damaged the environment in the region. Government authorities were concerned that the country's already degraded base of natural resources was also being depleted. Most of the mined gold was traded illegally.

To keep things in perspective, most “illegal” ASGM operations researched had local permits, paid local taxes, and boosted remote rural economies. They were known and, at some level, permitted to operate by at least county level government officials. The miners were primarily small entrepreneurs trying to escape the extreme poverty of farming a small plot of marginal land. They were illegal primarily because of the lack of effective laws and regulations suitable for ASGM.

2.4.5 Social Context: ASGM in the Community

ASGM has a host of impacts on communities in China. Foremost is the employment and income ASGM brings to rural areas. The China State Statistical Bureau (2000) states that the average number of dependants per rural labourer is 1.54. Based on the estimate of 463,000 miners, this would lead to over 700,000 dependants. However, the ILO estimates that the number of people who depend on ASM, including a small multiplier effect, is approximately 7.5 dependants per miner (Jennings, 1999). Using this factor, the number of people dependant on ASGM in China would rise to 3,470,000 people.

2.4.5.1 ASGM Labourers

Artisanal mine labourers in China are categorized as farmers (peasants), but usually spend most of their time and derive most of their income from mining. All rural workers, in theory, have some farmland available. The mines visited shut down for periods of approximately ten days around planting and harvest time. One problem that arises from these workers' status as farmers is that when the government or companies shut down artisanal mining operations, they do not concern themselves with the labourers, as they can “just return to their farms.” However, many of these farms do not provide enough income to support a family, which is why many of the farmers begin mining in the first place.

Artisanal miners are occasionally migrants from poorer areas of China and bring all the problems usually associated with migrant workers, including prostitution and violence. This may be a particular problem with miners moving into ethnically distinct regions like Yunnan and Tibet (World Tibet Network News, 1995).

2.4.5.2 ASGM Income

The typical salary for mine labourers in eastern China in 2001 was between six and eight hundred Renminbi (RMB) per month (1 US\$ = 8.28 RMB), or about 8400 RMB per annum (US\$ 1014). Miners stated that this was roughly similar to other labour jobs, but that mines had paid much better even a few years previously. In comparison, the average Chinese mining engineer at a visited state-owned mine makes 27,000 RMB per annum (US\$ 3260), and the average annual income per capita in rural China is 2210 RMB per annum (US\$ 267), although this varies widely from region to region (China State Statistical Bureau, 2000). Mine owners are often quite wealthy, and are capable of investing hundreds of thousands of RMB in a new project. The owners are usually businessmen who may be involved in several types of industry. Their private businesses are often incredibly flexible, and demand quick payback of their investments. Arguably, the business skills learned by these ASGM mine managers and owners offer the best chance for sustainable development for these communities, as mines are closed down or run out of ore.

2.4.5.3 Women

According to the “Regulations on Labour Protection for Female Workers and Employees” (State Council, 1988), *“It is forbidden to assign female workers and employees to work in underground mines.”* Women are usually not directly involved with the ore extraction or mineral processing in Chinese ASGM, but they are often on mine sites assisting with cooking and other aspects of daily life. In “Gold Mountain”, some of the wives of ASGM owners were active in business affairs. The woman interviewed in Bayuan, Shaanxi, had been directly involved with processing gold ore, but she had insisted that her husband sell their processing centre and she bought a small store with the proceeds. She claimed she did not want to raise her children while operating a

mine. There may be hundreds of other such cases but women do not seem to be a significant source of labour. Dr. Peter Golas, from the University of Denver, spent considerable time traveling to various ASGM sites, while writing the “Science and Civilisation in China” history of mining. Golas (2003) concurred that women and children did not seem to be a large part of the labour force. In contrast, at a larger state-owned mine visited in Inner Mongolia about a third of the employees, including engineers, were women.

2.4.5.4 Children

In all but the most impoverished and remote areas of China, children usually attend school. Legally, children are prohibited from working until age sixteen (State Council, 1991). Miners interviewed in “Gold Mountain” believed that some underage boys worked in coal mines in the next municipality. One report indicates that 10% of the artisanal gold miners in Nagqu, Tibet, were under the age of 14 (World Tibet Network News, 1995). However, in part because of the one-child policy, there are perhaps fewer children involved than in other countries. It is uncommon for rural families to have more than two or three children. Since such labour is illegal, there are no official statistics on its extent. Regardless, child labour does not seem to be prevalent in China’s ASGM industry.

2.4.5.5 Labour Unions

China has only one union; the state controlled and sanctioned All China Federation of Trade Unions and its branches. Any unofficial unions, informal worker groups and attempts to form labour groups are illegal. The state union has little power to bring employers to account, and “given its status as a government sanctioned body in many cases, union leadership corresponds to factory management (China Labour Bulletin, 2003).” This was confirmed during site visits. Private ASGM operations visited did not have organized labour.

2.4.6 Health, Safety, and Environmental Impact

The negative impacts of artisanal mining in China on health, safety, and the environment are huge and difficult to quantify. Many villages have found themselves enriched at the expense of their health and environment. ASGM is far less deadly than China’s ASM coal industry, which kills 4,000-6,000 miners every year (State Bureau of Coal Industry,

2000). Regardless, ASGM certainly has accidents. In June 2002, an electrical fire ignited explosives in a Shanxi Province gold mine, killing 37 miners (People’s Daily, 2002b). Miners had been ordered by management to continue working after a fire had broken out underground. The owners then tried to cover up the blast by secretly removing the bodies at night (People’s Daily, 2002a). Table 2.3 lists a variety of health, safety, and environmental impacts arising from ASGM in China, in addition to mercury use.

Table 2.3 Major health, safety, and environmental impacts of ASM in China

Item	Impacts
Death and accident toll	While underreported, fatalities and serious injuries occur regularly.
Solid Waste	ASM tailings and waste rock are arguably the largest source of industrial waste in rural China (Andrew-Speed <i>et al</i> , 2003b)
Water	While most gold dredges and placer operations are prohibited, many still existed as of 2002. Dredging for aggregates is widespread, and causes significant sedimentation problems.
Cyanide	Gold producers’ cyanidation practices are often questionable and visibly cause significant problems downstream, where fish populations have sometimes disappeared. Cyanide spills have occurred.
Hazardous Chemicals	A wide variety of chemicals other than cyanide and mercury are often used by ASGM, including acids, flotation reagents, and pH modifiers. These chemicals are rarely closely accounted for or handled safely in a systematic method.
Air pollution	Blasts, heavy equipment, and comminution account for significant amounts of dust and gas emissions. Silicosis and other lung infections appear to be widespread, exacerbated by heavy smoking. In a Jiangxi Province mine, silicosis led to the death of 100 miners, a quarter of the mine’s workforce (Becker, 2004).
Loss of vegetation	Frequently nearby trees are cut for underground support (timbering), and vegetation is often cleared from around mine sites. This loss of vegetation can lead to erosion and loss of animal habitat.
Water table	Dewatering underground mines can lead to a drop in local water table, affecting agriculture.
Subsidence	Shallow, poorly or un-supported underground mining openings can subside, causing damage to surficial buildings or creating dangerous ‘glory holes’. China has a special problem with the formation of sinkholes in karst areas due to mining (Zhou, 1997).
Sound	Like all mining, ASGM operations can be extremely noisy, due to blasts, heavy equipment, and crushing and grinding. Not only do these cause permanent hearing damage to employees, who rarely wear aural protection, but can affect nearby communities and homes.

The harsh conditions of ASGM can also lead to illness. The World Tibet Network News (1995) reported that artisanal gold miners in Tibet working 14 hour days and subsisting on steamed corn were falling ill due to diseases such as emphysema.

There have been at least three major cyanide spills in the past 10 years in China. In late 2001, in Henan Province, 11 tonnes of sodium cyanide leaked into the Luohe River due to a road accident involving a truck transporting cyanide to a local gold mine. Thousands of police, soldiers, and civilians were mobilized to contain the spill (BBC, 2001). In September 2000, a transportation truck released 5.2 tonnes of liquid sodium cyanide into the Wuguan River in Shaanxi Province (People's Daily, 2000). Both accidents resulted in fish deaths, but no human casualties. However, a number of cyanide deaths resulted in an accident south of Kuanchung, Hebei Province, in 1995 (Mortensen, 2003).

2.4.7 Technical Assistance Programs

2.4.7.1 Technical Assistance

From the late 1970s to the mid 1990s, plenty of government assistance was provided to ASM. To use coal as an example, state-owned coal companies and coal bureaus provided substantial technical assistance to small-scale coal miners in the late 1970s and early 1980s (Andrews-Speed *et al*, 2003b), in an effort to increase national production. The state gold bureaus and companies may have been asked to give ASGM similar assistance at some point. In the 1980s and early 1990s some universities and research institutions provided technical assistance to ASGM (Zhang, 2003). However, since the mid-1990s, there has been little technical assistance available. Equipment manufacturers will often help with equipment installation and provide some initial instructions, after which the miners are left to their own devices. Some governmental agencies, such as the China Mining Association, have small-scale mining departments, but these are too small to offer much direct assistance.

2.4.7.2 Research Cooperation

There are a few cases of research programs or cooperation with ASM in China. In 1993, the Scientific Committee on Problems of the Environment (SCOPE) initiated a program that studied mercury and ASGM. The Slovenian Institute Jozef Stefan cooperates with

the Institute of Geochemistry, at the Chinese Academy of Sciences, in Guiyang, Guizhou Province on mercury-related issues, but ASM is only incidental to their research. Dr. Andrews-Speed, of the University of Dundee, Scotland, researches coal ASM and energy policy in China. Dr. Peter Golas, of the University of Denver, Colorado, undertook substantial ASM research in the 1990s while working on his history of mining in China.

2.4.7.3 Domestic Financial Institutions

Bank financing is theoretically available to ASGM, but none of the miners interviewed thought it was a serious possibility, mainly because too much collateral is required. The state-owned mines and TVEs have some access to government finance and would have better access to banks. The private miners studied were entirely financed with private money. In general, China's banking system is in crisis and is not in a position to lend money to small private operations (The Economist, 2002).

2.4.7.4 Non-Governmental Organizations

Non-Governmental Organizations are restricted in China, and the regulatory procedures necessary to officially register are often insurmountable. Many of China's NGOs are actually set up by the government with the intention of gaining international funding and have little or no institutional freedom (United States Embassy in Beijing, 2000). In fact, in order to avoid bureaucratic difficulties, a few genuine NGOs have actually registered as businesses (United States Embassy in Beijing, 2000). At its root the Chinese government is suspicious of any non-profit organization that does not owe allegiance to the Communist Party. Existing NGOs tend to focus on educational issues and do not interact with artisanal miners. No international NGOs are known to be involved with ASM issues in China.

2.4.7.5 Multilateral Organizations

Virtually none of the major multilateral organizations like the United Nations, the World Bank, or government development agencies like the Canadian International Development Agency (CIDA) have programs to work with Chinese ASM. The only exception seems to be the ILO in cooperation with the Gesellschaft für Technische Zusammenarbeit (German

Development Agency), which helped the Changsha Safety Training Centre for Small & Medium-sized Coal Mines in Hunan province.

2.5 Conclusion

The interviews, field studies, and use of the HgEX expert system undertaken in this study clearly indicate that ASGM is widespread in China, that mercury use is common and represents a potentially serious health threat. The literature review indicated that this was a woefully understudied area, with few articles of any variety on the topic. Every site and region visited showed indications of mercury use from ASGM, be it from muller mills, mercury sluices, or the amalgamation of concentrates. Many operations followed amalgamation of whole ore with cyanidation.

HgEX provided a valuable tool to assist with the evaluation of mercury contamination from ASGM in China. The national alpha factor for China was determined to be 1.0, roughly similar to Brazil, indicating that China is moderately accepting of amalgamation practices.

In the discussion, what constitutes ASGM in China is defined and it is determined that roughly 463,000 ASGM miners produced around 61 tonnes of gold in 2001, in regions all over China. The number of these miners' dependants could total almost 3.5 million people. The discussion outlines the complex relationship that ASGM has with the formal and international mining industry and highlights the lack of formal or informal support enjoyed by ASGM. ASGM is tightly bound with Chinese society through a wide range of ties and stakeholders, often with conflicting interests.

3 Study Two: Artisanal and Small-scale Gold Miners in “Gold Mountain”

3.1 Introduction

The purpose of this chapter is to develop a case study of the community of “Gold Mountain”, in order to elaborate upon and verify the findings of Chapter Two. “Gold Mountain” is a pseudonym for a northern Chinese gold mining village located in the rugged terrain between the Gobi desert and the Yellow River Plains. Geologically, “Gold Mountain” is located on the northern margin of the North China (or Sino-Korean) Craton, which underlies much of north-eastern China and contains hundreds of gold deposits, most containing less than 1 tonne of gold (Hart *et al.*, 2002). The gold in these deposits occurs primarily as veins associated with Mesozoic intrusions into mainly Precambrian host rocks (Poulsen and Mortensen, 1993). These veins chiefly contain pyrite, gold, electrum, chalcopyrite, galena, pyrrhotite, magnetite, molybdenite, and trace amounts of telluride minerals (Zhou *et al.*, 2002). “Gold Mountain” has hosted ASGM operations for over 70 years and is home to roughly 10,000 people. In addition to gold mining, iron mines and stone and gravel quarries operate in the valley. Agriculture consists primarily of corn and chestnuts in addition to some tree farms. In the nearby reservoirs, fish farms raise carp.

3.2 “Gold Mountain” - Case Study Methodology

This study describes the community of “Gold Mountain”, details its gold mining processes, describes a novel mercury retort used locally, and estimates mercury losses and the health and environmental impact due to ASGM. In order to build this case study, several site visits were made between 2000 and 2004.

The following steps were taken:

- **Site visits** were undertaken in order to understand in detail every step of their process and to determine the extent of ASGM in the community. Sites visited are noted in Table 2.1, Chapter Two;

- **Interviews** were conducted in order to gain a more in-depth understanding of community, the structure of ASGM in the village, and the health impact of amalgamation. People interviewed include mine and plant owners and managers, mine operators and labourers, retired miners, government officials, and local fishermen. During interviews, miners were observed for any signs of mercury-related illnesses, such as muscular tremors or gingivitis.
- **Representative samples** of approximately 200 grams were taken from intermediate and final tailings and assayed for gold and mercury back in Vancouver. Shovels full of tailings were taken from a number of locations in each tailings pile and then, using the cone and quarter method, the samples were reduced to approximately 200 grams. The samples were returned to Canada and sent for gold and mercury assay using ICP-MS; and,
- An **estimation** of the total mercury releases from ASGM in the community was calculated on the basis of the interviews and samples collected.

3.3 “Gold Mountain” Case Study- Results

3.3.1 “Gold Mountain” Mining and Processing Practice

In May 2001, there were six muller mills located in three different processing centres in and around “Gold Mountain”. These privately operated centres process ore from local gold mines at a set fee. There is a slightly larger state-owned gold processing operation in the valley, which only uses cyanidation. There are also several small, unlicensed and independent gold processing operations, which exclusively cyanide heap-leach low-grade ores. The ore is supplied to the centres by 40 to 50 small underground mines, mining gold-bearing veins in the area.

Artisanal gold mining operations decreased significantly between 2000 and 2001. In 2000, there were 12 muller mills, another larger gold processing centre, which used leaching technology, and between 70 and 80 mines. Low gold prices and the increasing difficulty of processing the ores are the main reasons for the shutdowns. The twisted iron remnants of discarded muller mills can be found on the outskirts of the village. However,

higher gold prices in 2002 have revitalized local interest in gold. This section details step-by-step the ASGM operations in “Gold Mountain”.

3.3.1.1 Mining Practice

Two gold mines were examined in “Gold Mountain”. The mines consisted of tunnels about five to six feet tall. Stopes were drilled using pneumatic jacklegs and blasted with dynamite. Miners usually cut into the mountain on one level, then angle down steeply to a gold vein level. Once a vein is found, the miners follow it, blasting out larger openings if the vein expands. The veins are typically one metre thick, slightly dipping, two or three metres wide, and extending several hundred metres. Gold grades usually range from 10-40 g/tonne. Ore is manually mucked, using handcarts, which are moved between levels by motor-driven winches. Waste rock is usually dumped a short distance from the mine’s mouth. From the mine, the ore is taken several kilometres to the mill, usually by locally constructed two-cycle 10 tonne ore trucks. Miners often, but not always, wear safety helmets; accidents do occasionally occur. One mine visited employed about 20 people, and the other about 30. Labourers were paid US\$ 72 – 97 per month. Managers received a share of the profits.

3.3.1.2 Comminution and Amalgamation

Two gold processing centres, operating a total of four muller mills, were studied. The first centre, operating one muller mill, employed about 10 people, including a cook, labourers, managers, and security guards. Labourers were paid around US\$ 72 per month. The second mill employed closer to 30 or 40 people.

Miners would bring their ore to a milling centre and pay a set fee per tonne of ore processed, in addition to paying for any reagents used. Miners would choose the quantity of reagents used in consultation with the millers. As all of the fees were fixed, the millers had little financial interest in the grade of the ore and were not responsible if little gold was recovered. A representative of the mine would observe all of the processing procedures.

At the processing centre, ore would be stored, segregated according to ownership. In turn, each miner's ore is crushed using a jaw crusher. The ore is then shovel fed to a muller mill along with several kilograms of mercury. A steady stream of water flows into the mill, and lime is added to reduce mercury flouring. The ore is ground and put in contact with the mercury by three large iron wheels turning around a circular ironclad track. The fines overflow into a chute and are collected as the slurry passes into several settling tanks, before draining into a small tailings pond. The settled fines are later shovelled out for cyanidation. Random objects (like a hammer from a hammer mill) are placed on the chute to be used as somewhat dubious obstacles to retain mercury. Most overflow material stopped by these objects tends to be washed into the settling tanks during the mill cleaning stage. The millers do not use riffles in the sluice box to catch fine gold or mercury, claiming they pose a security risk. Most of the particles seem to settle in the first few boxes. The final box, considered the mill's property, takes days to fill. About 10 to 15 tonnes of ore can be processed per day, or around one tonne per hour.

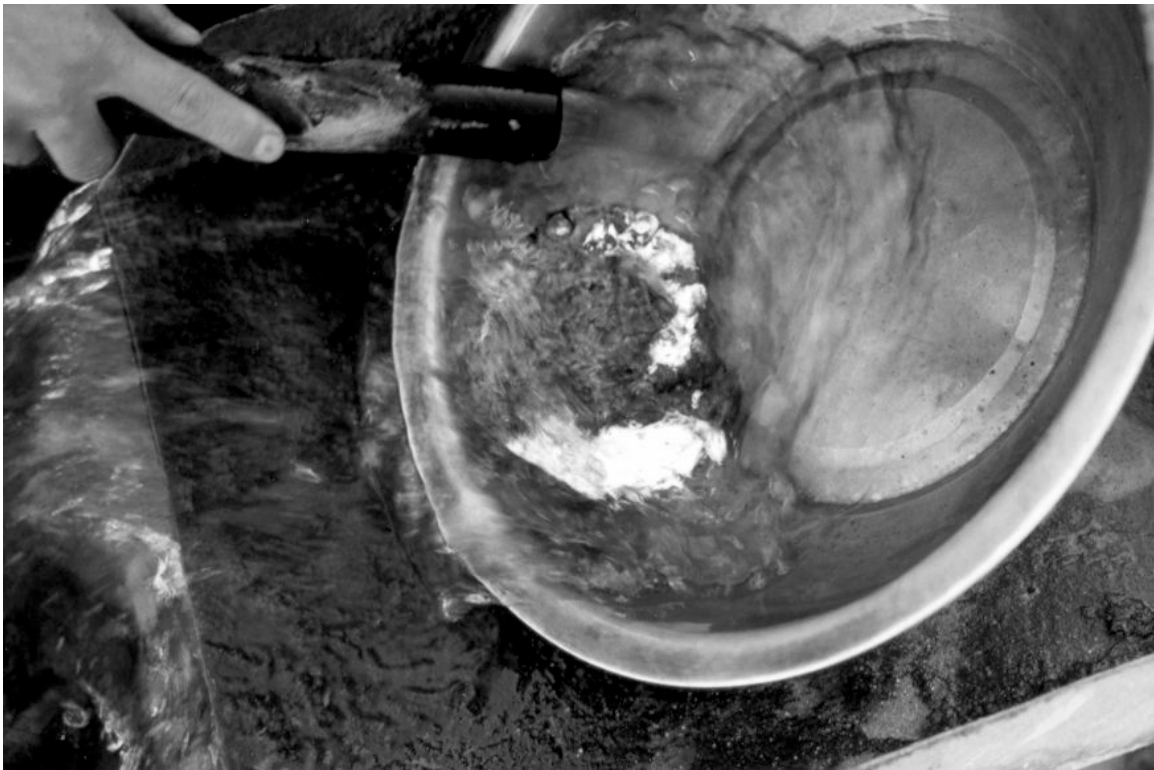


Figure 3.1 Cleaning the Concentrate From the Muller Mill

At least once per day, the muller mills are stopped and cleaned out. The ground ore and amalgam are shovelled into a hand basin, where the amalgam is liberated from coarse particles with a water hose (see Figure 3.1). Free iron from the mill is collected with a hand magnet. The excess ground material flows into the tanks with the fines. The amalgam is collected and placed in a thick cloth and manually squeezed, getting rid of the excess mercury. The amount of gold recovered by the mill varies with the ore, but miners claim it is frequently around 60% to 70%. The mills would operate around 10 to 12 hours per day.

The muller mills are manufactured in a nearby town, and a visit to the manufacturer found a busy and relatively sophisticated operation. In addition to the muller mills, machine tools are used to manufacture jaw crushers and magnetic separators. The iron for the muller wheels is cast on site. The plant has been in operation for between 15 and 20 years and has sold about 500 gold muller mills to the surrounding region, selling mills for about 10,000 RMB or roughly US\$1,200. There was also a smaller muller mill manufacturer in town.

3.3.1.3 Retorts

“Gold Mountain” processing centres use an uncommon and simple retort. The ball of amalgam from the muller mill cleaning is placed in a small pan on top of an electric hotplate, seated in a water-filled bowl, and then covered with a metal bucket (Figure 3.2; Figure 3.3).

The bucket and the water form an air seal, creating a crude but effective retort. When heated, the mercury evaporates and the mercury vapours condense on the cover-bucket walls and drip into the water-filled bowl. After approximately an hour, the cover is removed and the owner of the *doré* takes it home for further purification. As the temperature reached in the bucket is likely high, the mercury recovery is probably about 95% (Veiga, 2004b). The condensed mercury appears to coalesce (see Figure 3.4) and is periodically collected and recycled. This simple and cheap retort seems unique to “Gold Mountain”.

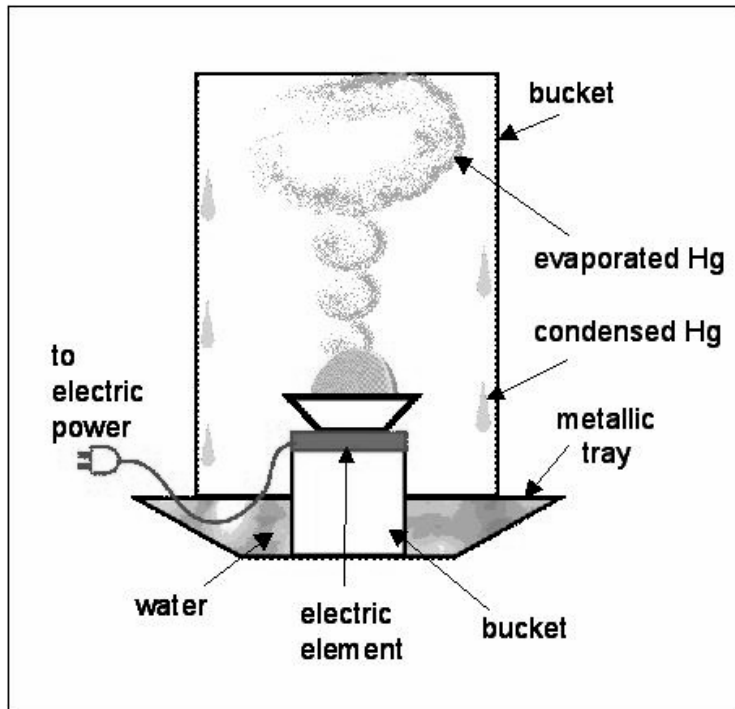


Figure 3.2 “Gold Mountain” Retort Diagram

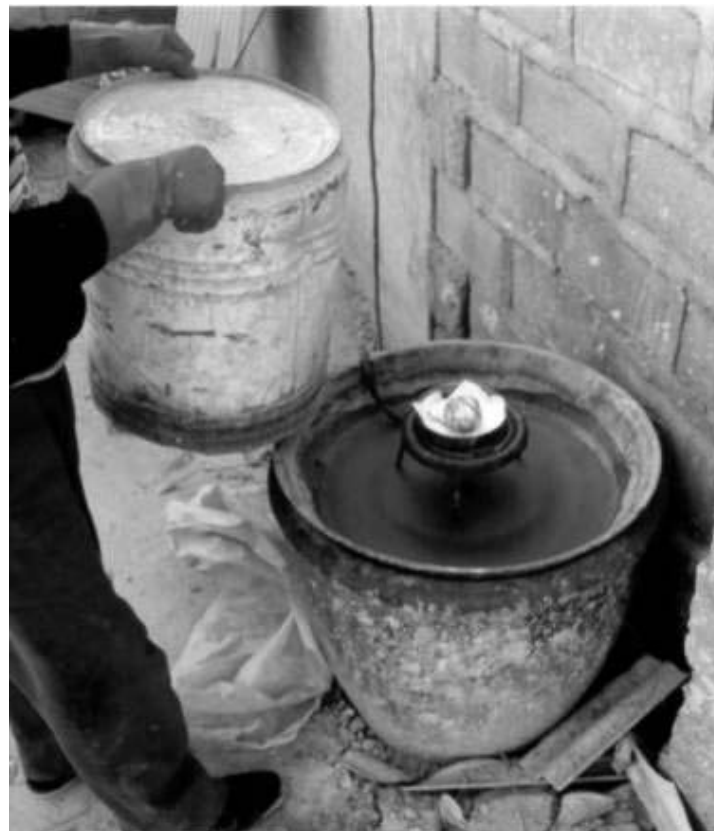


Figure 3.3 “Gold Mountain” Retort Photo

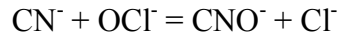


Figure 3.4 Mercury Droplets from “Gold Mountain” Retort

3.3.1.4 Cyanidation and Zinc Smelting

The fines from the settling tanks are shovelled out when the tanks are full and the sludge is placed in piles until the cyanidation tanks are available. Then the ore is shovelled into 10 tonne leach tanks, for vat leaching. About 5 kg of lime per tonne of ore are mixed with water or barren leach solution from the previous leach. Then, depending on whether the ore contains oxides or sulphides, 2.5 or 5 kg of sodium cyanide respectively are added to the solution. This solution percolates through the ore and then drains from the tank to a locked box full of zinc strips, which collect the gold (Merrill-Crowe Process). No de-aeration takes place, and cyanide is only added once at the start of the operation. The barren leachate is then re-circulated to the leach tank, with a retention time of usually seven days. If the ore grade is less than 3 or 4 g/t gold, determined visually from experience or simple panning, then the ore is ground using a hammer mill, then added directly to the leach tanks without amalgamation. The operators did not have any method of determining the cyanide or gold concentration in solution.

The final discharge is treated with powdered bleach ($\text{Ca}(\text{OCl})_2$) to remove the cyanide ions from solution. The primary reaction is:



It is not clear if the amalgamation tailing discharge is treated.

After the ore is leached, the zinc strips are scooped into a bag and the barren solution is drained off. The loaded strips are taken home, where a furnace will already have been started. The furnace is basically a sturdy iron barrel filled first with wood and then topped off with 200 kg of coking coal (at \$US60 per tonne). The wood is ignited first, and with the aid of a fan, the coke catches fire. Then the zinc strips are put in crucibles and placed in the furnace. After 30 to 60 minutes, several scoops of borax (at \$US0.12 per kilogram) are added to the crucibles. After 15 minutes or so, the flux is poured into other crucibles and allowed to cool, with the precious metals settling to the bottom. After being quenched, the crucibles are emptied onto an iron plate and the gold and silver are knocked off the bottom of the slag. Overall, the miners claim a recovery rate of about 90%.

No effort is made to protect against fumes generated during the smelting of the zinc strips. While the leaching kinetics of mercury are slower than gold (Flynn, 1995), mercury would both move into the solution and plate on the zinc strips along with the gold. This mercury recovered on the strips would then be volatilized in the smelting operation.

3.3.1.5 Gold Purification

Miners typically need to purify their *doré*, as described in Section 2.3.1.6.

3.3.1.6 “Gold Mountain” ASGM Cost Structure

It is important to understand the economic reality of the miners in order to understand the dynamics of their mercury use and in order to offer realistic alternatives to amalgamation. The following is a breakdown of the costs and revenue of one typical miner. He claimed it cost him roughly US\$12 to mine a tonne of ore and another US\$5/t to transport the ore

to the processing centre. He paid the centre roughly US\$17/t for processing and reagent fees, leaving him with a profit of US\$42/t at a recovery rate of 90% with a grade of 10g/t. His cut-off grade is roughly 4 g/t, not including silver. These figures do not include taxes or local corruption (“rent seeking”).

Since only six muller mills, each processing 10-15 tonnes of ore per day, serviced the 40 to 50 mines, the tonnages mined must be less than 3 tonnes of ore per day, excluding waste rock. At a 90% recovery of 10g/t, this would mean a daily production of about 27g/day per mine, or 90g/day per mill. As the grade can exceed 40 g/t, and the muller mills can process up to 15 tonnes per day, these estimates are conservative.

Table 3.1 Typical Miner’s Revenue and Profits Per Tonne of Ore

Ore Grade: 10 grams Au/ tonne Local Gold Price, Summer 2001: \$8.45/gram		
Item	\$US/tonne of ore	Percentage of cost
Total Revenue (90% recovery) (\$US/tonne of ore)	\$76.09	
Mining Costs	\$12.08	35.7
Plant Fee	\$9.66	28.6
Mercury	\$0.96	2.8
Other Reagents	\$5.56	16.4
Cyanidation	\$0.72	2.1
Transportation	\$4.83	14.3
Total Costs (\$US/ton of ore)	\$33.82	100.0
Profit (Total Revenue – Total Costs) (\$US/tonne)	\$42.27	

Mercury is included in the reagent fee, in addition to lime and any further reagents. Miners are charged for the amount of mercury not recovered after cleaning the muller mill. The mercury the miner is charged is for is thus the amount of mercury in the recovered amalgam (about 6 grams in this example) and the amount mercury reporting to the tailings (approximately 200 to 2500 ppm). Table 3.1 shows that mercury thus represents less than three percent of the processing costs. In Venezuela, where mercury costs close to five times as much (US\$ 20-25), mercury represents around 4% of the processing cost, not including cyanidation (Veiga and Gunson, 2004).

3.3.2 “Gold Mountain” Mercury Releases and Sample Collection

Through the site visits and interviews, several estimates of the amount of mercury lost by the muller mill amalgamation process were determined. These included verbal estimates, records from the processing plants, and assaying tailing samples.

3.3.2.1 Mill Operator Estimates on Mercury Lost

Mill operators at one processing site in “Gold Mountain” estimated that they used 10 kg of mercury per tonne of ore and lost around 0.5 kg/t. As the muller mills processed between 10 and 15 tonnes of ore per day, this would lead to mercury releases of 5 to 7.5 kg of mercury released daily for each of “Gold Mountain’s” six mills.

3.3.2.2 Mill Data on Mercury Lost

The muller mill operators kept records for all of the ore processed and the amount of reagents, including mercury, used at their plants; however, this data was a closely kept secret. Table 3.2 shows sample data on mercury losses, recorded and shared by one “Gold Mountain” processing centre. The “Mercury used in muller mill” column is the recorded mass of mercury added to the muller mill per tonne of ore. The “Mercury recovered from mill” column records the mass of the excess mercury recovered after squeezing the amalgam with cheesecloth. The “Mercury Lost” column is the difference between these two columns. As can be seen, the mercury recovered by the retort is only a small fraction of the total mercury used.

Table 3.2 “Gold Mountain” Processing Centre Data

Ore Sample	Mercury used in muller mill (kg/tonne)	Mercury recovered from mill (kg/tonne)	Mercury recovered from retort (kg/tonne)⁶	Total mercury lost (kg/tonne)
Miner 1	1.77	1.60	0.01	0.16
Miner 2	2.38	2.18	0.01	0.19

⁶ Assuming that amalgamation achieving 50% recovery of the gold in an ore grading 20g/t ore, that the *doré* consisted of 40% mercury and that the retort recovered 95% of the mercury.

3.3.2.3 Sample Collection Data on Mercury Lost

In order to assist with mercury emission estimates, a representative sample was collected from both muller mill tails and the cyanidation final tails at the centre. The muller mill tails had a mercury grade of 237 ppm, and the cyanidation tails had a grade of 108 ppm. The muller mill tails would indicate a loss of 0.237 kg/tonne of ore processed. These numbers are also in line with Lin *et al* (1997), who reported ASGM tailings in Dexing County averaged 100-300 ppm mercury.

3.3.2.4 ASGM Mercury Release Estimates

Table 3.3 compares the mercury estimates from sections 3.3.2.1-3.3.2.3, and estimates how much mercury is lost per muller mill per day, as well as the total for all six mills in the valley, processing from 10 to 15 tonne/day.

Table 3.3 Muller Mill Mercury Loss Estimates

	For One Muller Mill		
	Hg Loss (kg/tonne)	10 tonne/d ore kg of Hg/day	15 tonne/d ore kg of Hg/day
Miner 1	0.167	1.7	2.5
Miner 2	0.2	2.0	3
Tails Grade	0.237	2.4	3.6
Miller Estimate	0.5	5	7.5

As can be seen, the mill operator's estimate is far higher than the other two sources; it is also the least verifiable of the sources and is thus discounted as inaccurate. Based on the remaining two estimates, the total amount of mercury discharged per muller mill would range from 1.7 kg to 3.6 kg/day. While the muller mills may be able to process up to 15 tonnes/day, the average is probably closer to 10. The primary reason for this is that ore is not processed continuously; miners bring in lots often smaller than 10 tonnes and it takes time to switch from one miner's ore to the next. The best mercury loss estimate is from approximately 1.7 to 2.4 kg per mill/day.

Estimating the average gold grade as 20 g/t, and a muller mill gold recovery rate of 60%, the average ratio of mercury lost per gold recovered would be 14:1 to 20:1. This estimate is conservative, as the recovery rate is probably significantly lower than 60%.

The lost mercury would report primarily to the tails where it would be subjected to cyanidation. As can be seen from the final tailing mercury levels, much of the mercury is recovered during cyanidation and cemented on the zinc strips; however, this mercury is later lost during the smelting process. In addition, a significant portion of the mercury remains in the tailings, as seen in section 3.3.2.3. One processing centre, hosting a single muller mill, had an area of approximately 3000 metres squared. The amalgamation and cyanidation tailings were spread over an area of approximately 0.1 kilometres squared.

Assuming that six mills operate for at least 150 days per annum, the total mercury discharged in the community would range from 1.5 to 2.2 tonnes of mercury per annum. Furthermore, for many years, the amounts may have been twice as much, since there used to be at least 12 muller mills.

3.3.3 ASGM Health and Environmental Impact

“Gold Mountain’s” people and environment have endured artisanal gold mining operations for over 70 years. Gold mining, however, is far from being the only local source of pollution. Farming, with its extensive use of fertilizers on the hillsides, creates large erosion and runoff problems, and the widespread use of coal not only effects air quality but also contributes to acid rain. The two-cycle local haul trucks are also a major source of air and noise pollution. Iron mines and sand and gravel quarries and dimension stone quarries all lead to an assortment of health and environment problems. However, mercury and cyanide probably create the most serious local problems, and since there are relatively few sources, their effects could be mitigated.

3.3.3.1 Health Impact

As in the initial study on ASGM in China (Section 2.2.2), during site visits and interviews, miners were observed for overt indications of mercury related illnesses.

Unlike the initial study, one miller interviewed at a processing centre stated that he had been diagnosed with health problems due to mercury exposure.

The miller frequently handled mercury during his workday, through the cleaning of the miller mill, the retorting of the amalgam, and the smelting of the cyanidation zinc strips. His illness had reached a point where he was having difficulties with muscle tremors, a symptom of serious mercury vapour poisoning. He travelled to Beijing to receive more sophisticated medical treatment than was available in “Gold Mountain”, where his hospital urine test showed high levels of mercury. He was treated, possibly with a chelating agent, and recovered enough to return to work.

Miners interviewed reported that retorts were introduced around 1990, and that the use of retorts had dramatically reduced the number of acute mercury vapour poisonings in “Gold Mountain”.

3.3.3.2 “Gold Mountain” Aquaculture

The significant mercury losses in the valley raise the possibility of bioaccumulation of mercury in fish in the two local reservoirs. Both reservoirs were visited in order to evaluate this risk.

The reservoirs were constructed primarily to create a stable source of water for downstream agriculture. The larger reservoir had several floating fish pens located in deeper areas of the water. The smaller reservoir was stocked, without using pens. Three varieties of carp were farmed. The carp were fed pellets made from flour, bone, and fishmeal, processed elsewhere. No hatcheries were observed locally – fish farmers probably bought fingerlings from nearby regions.

Indigenous fish were virtually extinct. There was one local variety of carp, but it was carnivorous and local fishermen attempted to wipe out the species to protect their own stock. Anecdotally, the locals have stated that they frequently find deformed fish in the area.

The lack of indigenous fish may have been assisted by the ASGM operations. Around 1985 cyanide use became widespread in the area, and the poor treatment of cyanidation releases may explain the death of fish species in the streams and reservoirs. Much of China is heavily polluted due to a wide array of industrial activities; various other explanations are possible.

3.4 Discussion

Clearly “Gold Mountain” has significant mercury releases due to gold amalgamation, raising two key questions. First, what are the impacts of these releases and second, if these releases are dangerous, how can they be reduced?

3.4.1 “Gold Mountain’s” Processing Practice

There are two main issues of concern with regard to “Gold Mountain’s” amalgamation process. First is the use of muller mills to amalgamate all of the gold ore processed (whole ore amalgamation), not just a concentrate. The second concern is the use of cyanidation following whole ore amalgamation.

Whole ore amalgamation by definition puts all of the ore in contact with mercury, vastly increasing the amount of material contaminated. The key to reducing mercury releases is to encourage the amalgamation of only gravity concentrates, as then only a small portion of the ore is brought into contact with mercury. The high levels of mercury releases demonstrate a need to determine if alternate technologies can be introduced into ASGM processing centres in China, further discussed in Chapters Four and Five.

The practice of following amalgamation with cyanidation raised the question of whether cyanidation increases the mobility of mercury in the amalgamation tailings, further discussed in Chapter Four.

3.4.2 Health and Environmental Impact of Mercury Releases in “Gold Mountain”

3.4.2.1 Health Impact of Mercury Vapour

Mercury vapour pollution continues to be a concern, as demonstrated by the mercury illness described in Section 3.3.3.1. It is not clear that miners always use retorts, or if

miners using the “Gold Mountain” Retort wait until it cools before removing the lid. The impact of mercury vapour arising from the smelting of the gold-bearing zinc strips, or during purification of gold *doré* may be a significant factor.

While it was not possible to conduct mercury analysis of locals in “Gold Mountain”, Lin *et al* (1997) undertook such studies in Jiangxi Province. They found urine samples from miners in Dexing averaged 64.73 µg/L and ranged from 3.6 to 539.6 µg/L, with 91% of the 185 men, women, and children surveyed reporting above 20 µg/L. These numbers are far above the 4 µg/L that the World Health Organization (1991) considers normal. However, there is no indication that the urine samples were collected over a 24-hour period, as is standard for urine analysis, or that urine creatinine levels were sampled (Wilhelm *et al*, 1996). Ideally for urine tests, urine should be collected over a 24-hour period in order to minimize the effect of dilution from drinking fluids. In order to mitigate the awkwardness of 24-hour urine collection, creatinine levels can be analyzed in addition to mercury. Emissions of creatinine, a breakdown product of creatine, fluctuate little over a 24-hour period, thus creatinine can be used to normalize the concentration of mercury emissions.

Other non-intrusive procedures have been suggested as possible indicators of mercury poisoning. These include questionnaires, observing physical behaviours such as touching their finger to their nose, memory tests, or reproducing simple line drawings (Veiga and Baker, 2004). Care needs to be taken to avoid cultural bias with these sorts of tests. Tests such as these were not undertaken during this study, but are recommended for future work.

3.4.2.2 Bioaccumulation

With at least 1.5 tonnes of mercury being released annually from “Gold Mountain”, mercury bioaccumulation in fish in the local reservoirs is a real potential. This potential effect appears to be minimized, as the fish farmed in the local reservoirs are fed food pellets made outside of the “Gold Mountain” area. Fish are a luxury food item, hardly a staple, even for wealthier people. In addition, due to the “impoundment effect,” bioaccumulation of mercury occurs widely in reservoirs with no obvious source of

mercury (Stokes and Wren, 1987). Thus, even if bioaccumulation was demonstrated by testing fish samples from fish farms, it might not be attributable to ASGM, and fish consumption might be low enough not to lead to significant health problems due to methylmercury. Regardless, given the amount of mercury being released into the environment, it is likely that conditions favourable to bioaccumulation would occur somewhere downstream.

3.5 Conclusion

The “Gold Mountain” case study clearly verified that artisanal and small-scale gold mining in China releases significant amounts of mercury. All stages of the gold mining process were detailed, including a retort design that seems to be unique to “Gold Mountain”. A review of the cost structure for gold mining in “Gold Mountain” found mercury to be only 2.8 % of the overall cost.

Mill operator interviews, records, and assays of mill tailings led to the conclusion that the ratio of mercury lost per unit of gold recovered for muller mills is from 14:1 to 20:1. A sample of mill tailings was found to have a mercury concentration of 237 ppm, and a sample of cyanidation tailings had a concentration of 108 ppm. The small community of “Gold Mountain” alone was estimated to release at least one and a half tonnes of mercury per annum.

Mercury vapour was found to have caused at least one miner to become ill, although the impact of methylmercury was less clear. It was recommended that non-intrusive procedures be used to highlight possible indicators of mercury poisoning. The case study demonstrated that key areas of concern are amalgamation of whole ore using the muller mill and the smelting of cyanidation zinc strip concentrates without fume hoods.

4 Study Three: “Gold Mountain” Alternative Technology Test Program

4.1 Introduction

The high levels of mercury releases found in the “Gold Mountain” case study, and the associated health and environmental risks due to those releases, demonstrated a need to evaluate technology alternatives to amalgamation. In cooperation with a “Gold Mountain” processing centre, three samples were sent to UBC to undertake mineral processing test work. These three samples were not from the same ore body and are not uniform, thus provide insight into the variability of ore that the milling centre must process. This test program also provided an opportunity to verify the results of the initial research on ASGM in China and the “Gold Mountain” case study, and to examine the impact of cyanidation following amalgamation. This chapter describes the objective, methodology and results of test work undertaken on three “Gold Mountain” samples.

4.1.1 Sample GM1 – “Gold Mountain” Feed Ore

The first sample consisted of 14.6 kg of feed ore crushed to roughly minus one inch. The feed sample was to come from one of the several mines that bring ore to be processed at the centre. The feed sample was oxidized (reddish in colour), and contained some organic material and bits of plastic, probably from the shipping sack.

4.1.2 Sample GM2 – “Gold Mountain” Muller Mill Tails

The intermediate sample of 11.6 kg was taken from the muller mill overflow, before cyanidation; thus the ore had been ground with mercury and lime. The sample was grey in colour and slightly damp with some coarse material. It also contained some organic material and bits of plastic.

4.1.3 Sample GM3 – “Gold Mountain” Cyanidation Tails

The final sample (13.9 kg) was the tails from the cyanidation of the muller mill overflow. The sample was light grey in colour and slightly damp with some coarse material, in addition to some organic material and bits of plastic.

4.2 Methodology

The objectives of the test work were the following:

- To verify the mercury losses reported in Chapter Three;
- To evaluate the potential alternative technology to replace the current amalgamation/cyanidation techniques. A Knelson Concentrators lab-scale MD3 centrifugal concentrator (KC-MD3), in conjunction with cyanidation, was studied as the alternative technology; and,
- To explore the effect of cyanidation of mercury tailings on mercury solubility.

4.2.1 Sample GM1 – “Gold Mountain” Feed

The four main tests undertaken on the GM1 sample are outlined in Figure 4.1.

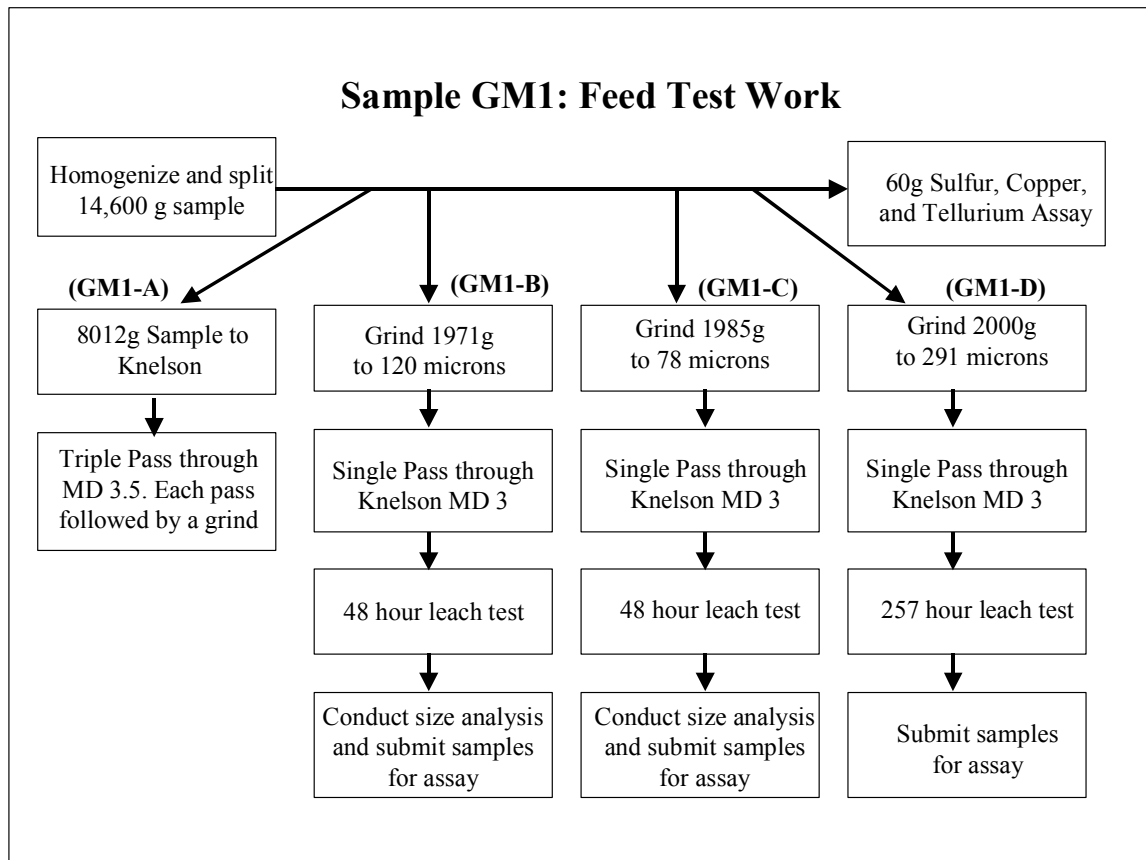


Figure 4.1 GM1 Test Program

4.2.1.1 Sample Preparation and Characterization

Once received in Vancouver, the GM1 sample was cleaned of plastic and organic debris. The entire sample was crushed to -10 mesh (-1 mm) using a cone crusher. Using riffles, two representative 30-gram samples were taken for assay. One sample was sent to ACME Analytical Laboratories to assay for copper, nickel, cobalt, iron, arsenic, antimony, mercury, and tellurium, using ICP-MS. The sample was assayed to determine the background level of mercury in the feed ore. The other substances were assayed to determine potential problems with gold recovery during cyanidation. The second sample was sent for a total sulphur level assay, in order to determine the sulphides content of the ore.

4.2.1.2 Gravity Recovery Test

The first test is called a Gravity Recoverable Gold (GRG) test. It was conducted with a centrifugal concentrator and provides an indication of how much gold could be recovered using only gravity methods.

The methodology for the first test (GM1-A) was as follows:

- 1) An 8 kg sample was processed through a 3” Laboratory Knelson Concentrator (KC-MD3) at a fluidization water flow rate of approximately 3.5 litres/minute and a rotation rate of 60 times the force of gravity;
- 2) During the test, sub-samples of the tailings stream were collected for assays;
- 3) At the end of the concentration stage, the concentrate was washed from the inner cone of the KC;
- 4) The KC concentrate was panned to produce a pan concentrate and pan tailings (middlings) sample;
- 5) The tailings were then ground in a lab-scale rod mill and steps 2 to 4 were repeated, followed by another grind and a final third pass through the KC-MD3;
- 6) The concentrate and tailings samples were labelled, dried, weighed and sent to an independent local lab for fire assay to extinction.

This methodology is based on the concept that progressive size reduction allows the determination of gold liberated at finer grinds, without over-grinding or smearing any coarse gold.

4.2.1.3 Gravity / Cyanidation Tests

In order to evaluate using gravity concentration in conjunction with cyanidation to replace amalgamation followed by cyanidation, the following three tests were undertaken.

The second and third tests (GM1-B and GM1-C) were run side-by-side to compare the effects of different grind sizes on recovery.

- 1) The first 2 kg sample was ground 18 minutes to 80% of the material passing 120 μm , and the second 2 kg sample was ground 50 minutes to 80% passing 78 μm , using a lab-scale rod mill;
- 2) Each sample was run through a KC-MD3 at a fluidization water flow rate of approximately 3.5 litres/minute and a rotation rate of 60 times the force of gravity;
- 3) At the end of the concentration stage, the concentrate was washed from the inner cone of the KC;
- 4) The KC concentrate was panned to produce a pan concentrate and pan tailings (middlings) sample;
- 5) The concentrates were labelled, dried, weighed and sent to an independent local lab for fire assay to extinction; and,
- 6) The tailings were dried and weighed, and then proceeded to cyanidation.

Samples GM1-B and GM1-C were subjected to cyanidation in bottle roll tests, run as follows:

- 1) The KC-MD3 tailings were slurried in a bottle to approximately 40% solids;
- 2) Lime was added to the slurry and the pH was adjusted to 10.5;
- 3) When the pH was stabilized, cyanide was added to give a concentration of 1 g/L sodium cyanide;
- 4) Small aliquots of slurry were removed at 24-hour intervals and the pH and cyanide concentrations determined;

- 5) Cyanide and lime were added as needed to maintain the initial pH and cyanide levels, and the aliquots were collected for gold analysis; and,
- 6) After 48 hours, the slurry was filtered, washed, and dried. The cyanidation residue was riffled and representative samples of approximately 500 grams were analyzed for size distribution and submitted for gold assay.

The fourth test (GM1-D) was run as follows:

- 1) A 2 kg sample was ground at 65% solids for 3 minutes in a stainless steel rod mill;
- 2) The sample was run through a KC-MD3 at a fluidization water flow rate of approximately 0.8 litres/minute and a rotation rate of 60 times the force of gravity;
- 3) At the end of the concentration stage, the concentrate was washed from the inner cone of the KC;
- 4) The KC concentrate was panned to produce a pan concentrate and pan tailings (middlings) sample;
- 5) The concentrates were labelled, dried, weighed and fire assayed to extinction; and,
- 6) The tailings were dried and weighed, and then proceeded to cyanidation.

Cyanidation proceeded using the bottle roll method, as follows:

- 1) A representative 480g sample of the KC-MD3 tailings was slurried in a bottle to approximately 35% solids;
- 2) Lime was added to the slurry and the pH was adjusted to 10.5;
- 3) When the pH was stabilized, cyanide was added to give a concentration of 0.5 g/L sodium cyanide;
- 4) Small aliquots of slurry were removed at several intervals and the pH and cyanide concentrations determined;
- 5) Cyanide and lime were added as needed to maintain the initial pH and cyanide levels, and the aliquots were collected for gold analysis; and,
- 6) After 257 hours, the slurry was filtered, washed, and dried. The cyanidation residue was riffled and representative samples of approximately 500 grams were analyzed for size distribution and submitted for gold assay.

4.2.2 Sample GM2 – “Gold Mountain” Muller Mill Tails

The test work undertaken on the GM2 sample is outlined in Figure 4.2.

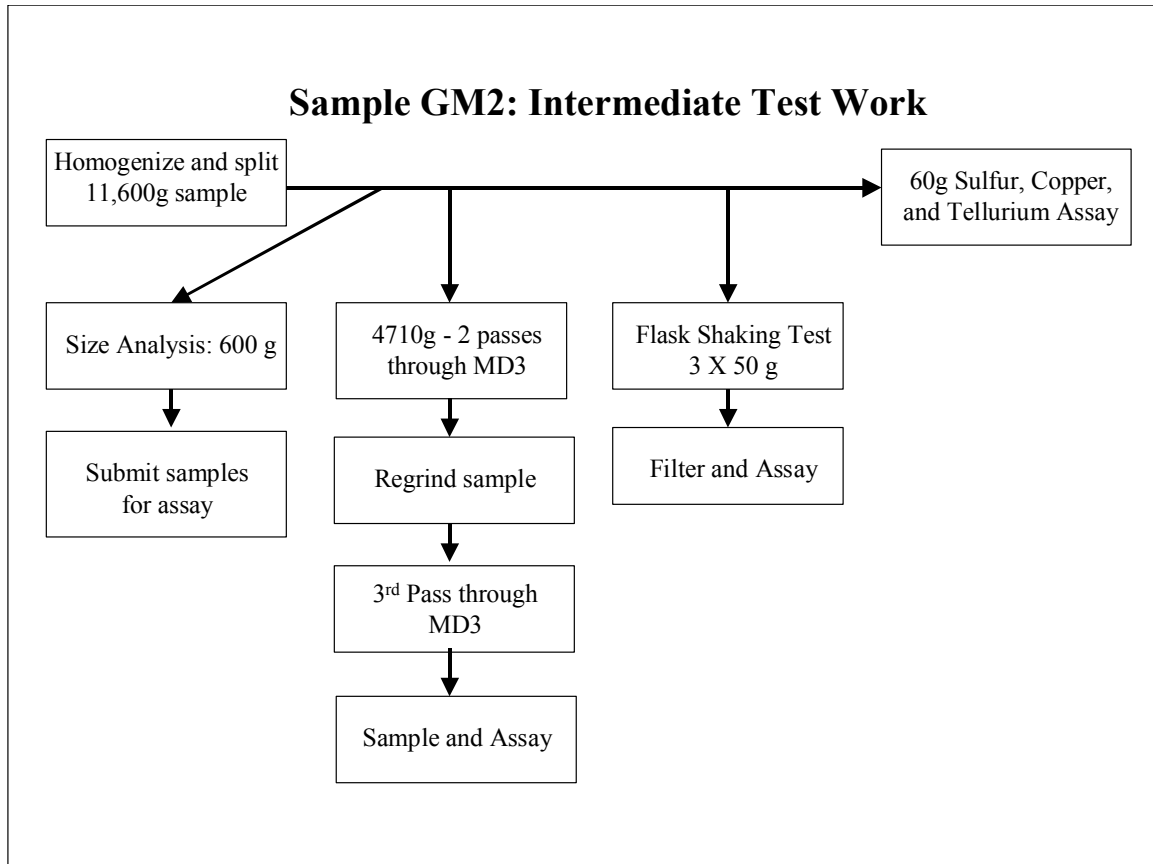


Figure 4.2 GM2 Test Program

4.2.2.1 Sample Characterization

The GM2 sample was cleaned of plastic and organic debris, then screened at 1 mm, dried and weighed. The plus 1 mm material was assayed for gold and mercury. The sample was homogenized with a riffle, and then a dry 650g representative sample was screened with a Roto-Tap for 15 minutes to determine the size distribution. Representative 15-30g samples were pulverized, sealed, and sent for gold and mercury assays to ACME Laboratories in Vancouver.

Two additional representative 30-gram samples were taken for assay. One sample was sent to ACME Analytical Laboratories to assay for copper, nickel, cobalt, iron, arsenic,

antimony, mercury, and tellurium, using ICP-MS, and the second sample was assayed for total sulphur.

4.2.2.2 Gravity Recovery Test

Sample GM2 was tested using a KC-MD3 as follows:

- 1) A 5 kg sample was processed through a KC-MD3 at a fluidization water flow rate of approximately 3.5 litres/minute and a rotation rate of 60 times the force of gravity;
- 2) At the end of the concentration stage, the concentrate was washed from the inner cone of the KC and the KC concentrate was panned to produce a pan concentrate and pan tailings (middlings) sample;
- 3) The tailings were passed through the Knelson a second time, and during the test, sub-samples of the tailings stream were collected for assay;
- 4) Step 2 was repeated;
- 5) The tailings were ground for two minutes in a lab-scale rod mill;
- 6) The tailings were passed a third time, and during the test, sub-samples of the tailings stream were collected for assay;
- 7) Step 2 was repeated;
- 8) The concentrate and tailings samples were labelled, dried, weighed and sent to an independent local lab for fire assay to extinction.

4.2.2.3 Mercury Solubility Test

The combination of mercury use followed by cyanidation gives rise to concern, as residual mercury may be oxidized during the cyanidation process, allowing the mercury to be more easily methylated by bacterial processes. In order to compare the solubility of mercury in the tailings before and after cyanidation, a shake flask test was undertaken.

This was completed as follows:

- 1) Two representative 50g samples of GM2 were placed in a 250 mL Erlenmeyer flask with 125 mL of distilled water;
- 2) The flask was shaken at medium intensity on a shake table for 24 hours; and

- 3) The solution was then suction filtered through glass fibre filter paper and submitted for mercury assay using a P S Analytical Millennium Merlin System.

This method was adapted from Hinton (2002).

4.2.3 Sample GM3 – “Gold Mountain” Cyanidation Tails

The test work undertaken on the GM3 sample is outlined in figure 4.3.

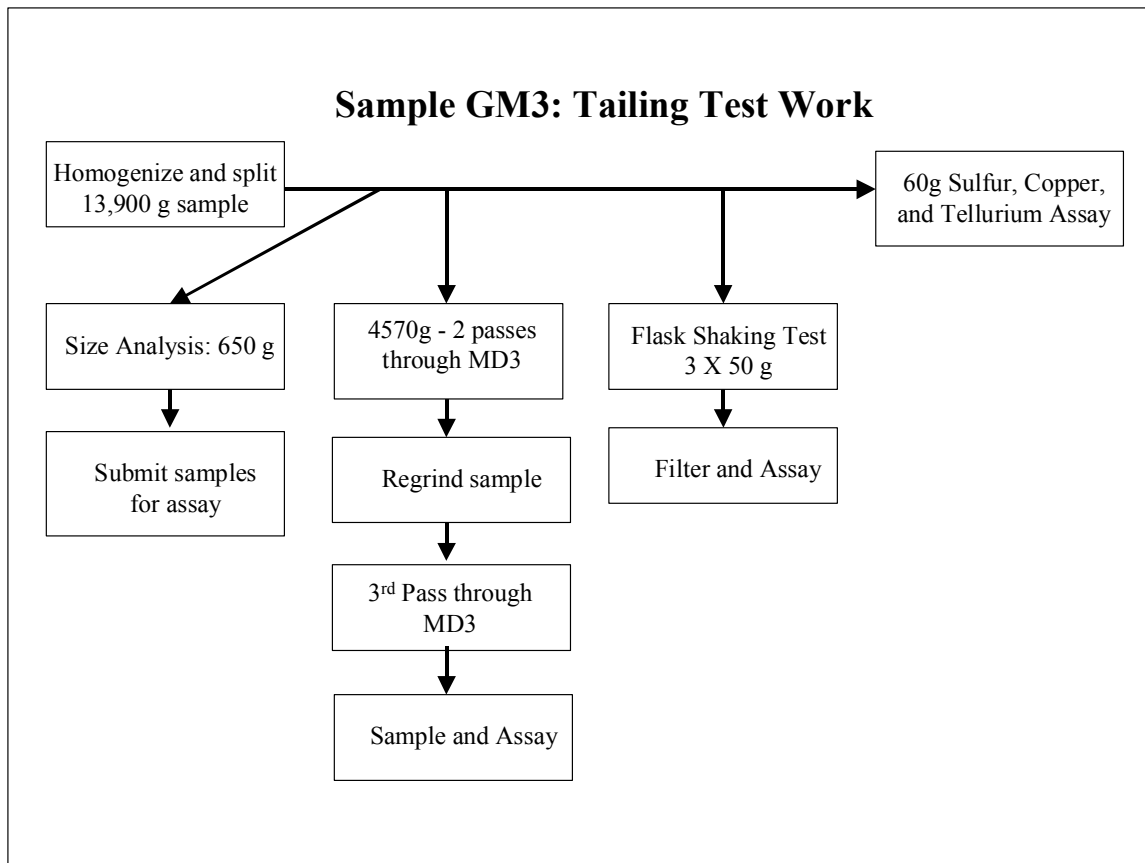


Figure 4.3 GM3 Test Program

4.2.3.1 Sample Characterization

The GM3 sample was characterized in an identical manner to GM2, except the initial screen sample was approximately 650 grams, not 600 grams.

4.2.3.2 Gravity Recovery Test

The GM3 sample was tested in an identical manner to GM2.

4.2.3.3 Mercury Solubility Test

The GM3 sample was tested alongside the GM2 sample, in an identical manner.

4.3 Results

4.3.1 *Sample GM1 – “Gold Mountain” Feed*

4.3.1.1 Sample Characterization

The assay results of the initial sample characterization for GM1 are displayed in Table 4.1. The high copper and sulphur levels, and the presence of tellurium, indicate the presence of copper sulphides and gold tellurides, which would inhibit cyanidation. The mercury level of 788 ppb can be taken as an indication of the background level of mercury in the gold ores. As this is far less than the mercury concentration in the muller mill or cyanidation tails, the background mercury levels are considered negligible.

Table 4.1 GM1 Sample Characterization

Cu (ppm)	Ni (ppm)	Co (ppm)	Fe (%)	As (ppm)	Sb (ppm)	Hg (ppm)	Te (ppm)	Sulphur (%)
4418.2	205.8	37.2	12.1	10.5	1.4	0.788	13.7	6.08

4.3.1.2 Gravity Recovery Test

Table 4.2 GM1-A Gravity Recoverable Gold Test

Size Dist'n (µm)	Product	Mass		Assay	Dist'n
		(g)	(%)	Au (g/t)	(%)
P80 = 475	Pan Conc.	8.7	0.11	2817	7.0
	Middlings	84.1	1.05	70.40	1.7
	Sample Tails	169.3	2.11	40.80	2.0
P80 = 236	Pan Conc.	17.8	0.22	2520	12.8
	Middlings	67.7	0.84	95.60	1.8
	Sample Tails	122.0	1.52	33.30	1.2
P80 = 117	Pan Conc.	27.1	0.34	1882	14.5
	Middlings	69.8	0.87	127.00	2.5
	Final Tails	7445.5	92.93	26.60	56.5
	Totals (Head)	8012	100.0	43.76	100.0
	Knelson Conc.	275.2	3.43	514.6	40.4

As can be seen in Table 4.2, the grade of the ore sample is calculated to be 43.76 g/t gold in test GM1-A. The test indicated that around 40% of the gold could be recovered by gravity methods. The 80% passing particle size for the initial pass was 475 µm, 236 µm for the second pass, and 117 µm for the third. The gold recovered increased with each grind, suggesting that most of the gold is quite fine. The gold recovered would be relatively easy to upgrade, as most of the recovered gold reported to the pan concentrate.

4.3.1.3 Gravity / Cyanidation Tests

The three gravity / cyanidation tests results can be seen in Tables 4.3, 4.4, and 4.5.

While not reflected in the gravity recovery stage, the increased grind time seems to have improved GM1-C's cyanidation recovery over GM1-B. As can be seen, the GM1-B and GM1-C tests' total recoveries are significantly less than GM1-D, primarily due to the significantly shorter leach time. The long leach times used by the miners in "Gold Mountain" thus seems justified.

Table 4.3 GM1-B Test Results

GM1-B	120 µm			
Product	Mass (g)	Mass (%)	Au (g/t)	Au Dist'n (%)
Pan Con	7.09	0.36	701.30	23.0
Pan Middlings	3.38	0.17	46.30	0.3
CN Solution (48 hr)	n/a	n/a	n/a	25.5
Tails	1974.63	99.47	22.57	51.2
Total	1985.10	100.00	43.33	100.0
Total Recovery		0.53		48.8

Table 4.4 GM1-C Test Results

GM1-C	78 µm			
Product	Mass (g)	Mass (%)	Au (g/t)	Au Dist'n (%)
Pan Con	28.06	0.36	2959.90	22.9
Pan Middlings	5.14	0.17	229.70	0.9
CN Solution (48 hr)	n/a	n/a	n/a	30.3
Tails	1937.60	99.47	21.26	45.9
Total	1971	100.00	46.09	100.0
Total Recovery		0.53		54.1

Table 4.5 GM1-D Test Results

GM1-D	291 μm			
Product	Mass (g)	Mass (%)	Au (g/t)	Au Dist'n (%)
Knelson Con	112	5.60	321.50	36.28
CN Solution (257 hr)	n/a	n/a	N/a	52.18
Tails	1888	94.40	21.26	11.54
Total	2000	100.00	49.63	100.00
Total Recovery		5.60		88.46

The mass of the gravity concentrate for samples GM1-B and GM1-C are unusually low, as the KC-MD3 concentrates are usually around 100 to 120 g. The GM1-B and GM1-C tests were conducted on an older KC-MD3, which sometimes rejected lighter material in the concentrate bowl during the process of shutting down the machine for cleaning. While the gold recoveries do not seem to have been significantly affected, a higher mass pull would likely have made the overall recovery higher, although the grade would be correspondingly lower.

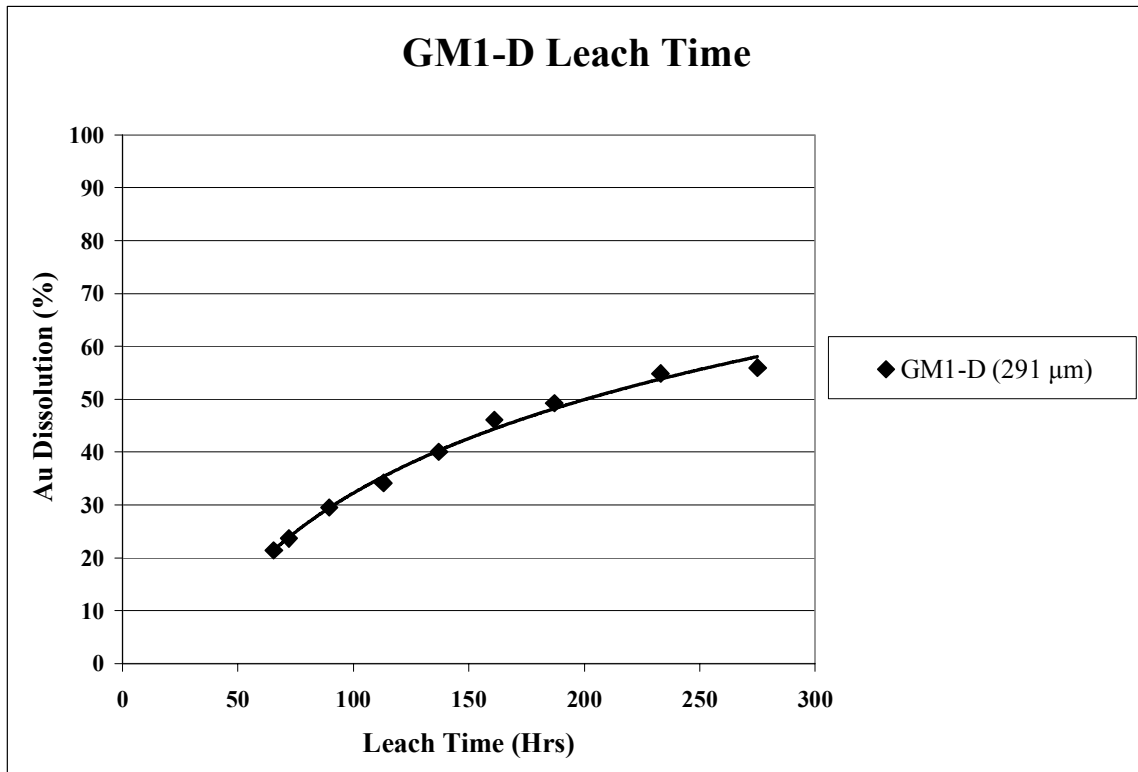


Figure 4.4 GM1-D Leach Time

The ore has an extremely slow leaching rate, as shown in Figure 4.4. Figure 4.4 does not include the gold recovered in the aliquots for GM1-D, which boosts the overall cyanidation recovery of the KC-MD3 tailings by 25.9%.

Table 4.6 GM1-B and GM1-C Cyanidation Tailings Analysis

Size (μm)	(GM1-B) P80 120 μm		(GM1-C) P80 78 μm	
	Au (ppm)	Au Dist'n (%)	Au (ppm)	Au Dist'n (%)
+150	28.50	4.5	5.01	1.2
+63	28.45	51.8	17.05	15.2
+45	21.41	17.0	25.13	31.0
+38	18.25	8.7	26.34	27.4
-38	15.24	18.0	19.50	25.2
Total	22.57	100.0	21.26	100.0

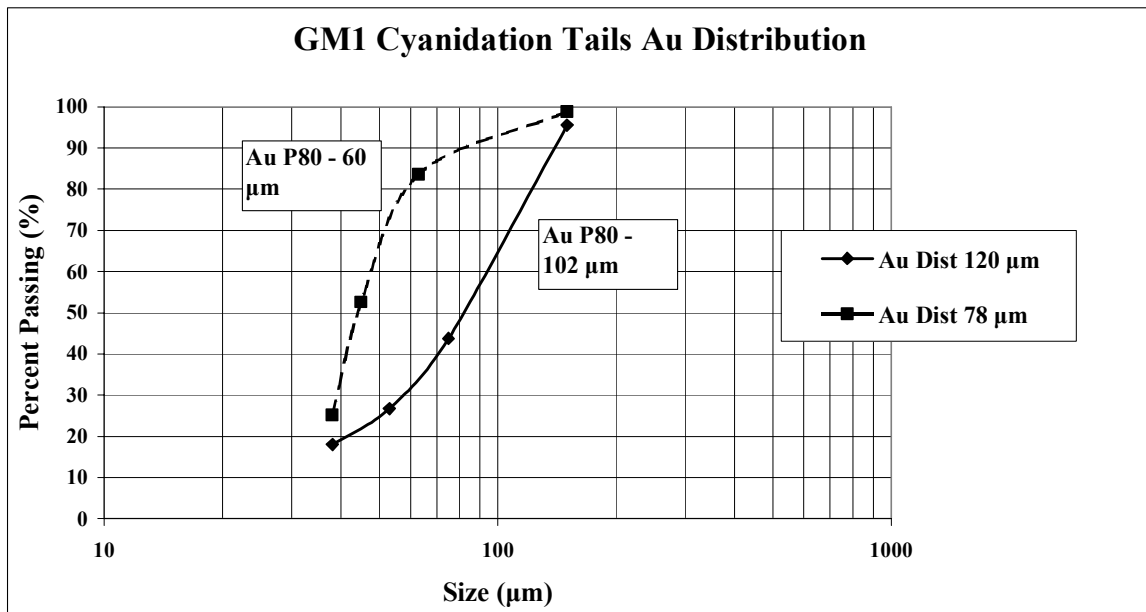


Figure 4.5 GM1-B and GM1-C Cyanidation Tailings Analysis

The effects of additional grinding on the ore are shown in Table 4.6 and Figure 4.5. Grinding sample GM1-C down to 78 μm significantly increased the gold recovery in the +45 μm range. The cyanidation tailings from the GM1-B sample, with the coarser grind, show that the ore retained 52% of its gold in the -150 μm to +63 μm size fraction, where sample GM1-C retained only 15% of its gold in the same fraction. The overall recovery

of GM1-C was 54.1% versus 48.8% for GM1-B, primarily due to the improved cyanidation recovery as a result of increased grinding.

4.3.2 Sample GM2 – “Gold Mountain” Muller Mill Tails

4.3.2.1 Sample Characterization

After picking out the obviously alien material, the +1mm oversize was 204 g, with 46.7 g/t gold and 1231 ppm mercury. This oversize material was assayed for gold and mercury and included in the size and grade distribution data. However, it was not included in any further test work, as it was a relatively small amount, at 1.75% of the total mass, and it would have needed to be crushed before it could be passed through the centrifugal concentrator.

The P80 for sample GM2 was found to be 180 μm . The back calculated assay for gold was 41.42 g/t. For mercury, the back calculated assay was 2350 ppm. The size analysis for GM2 showed that 52% of the gold and 53% of the mercury were found in the $-53 \mu\text{m}$ size fraction, representing 26% of the total mass.

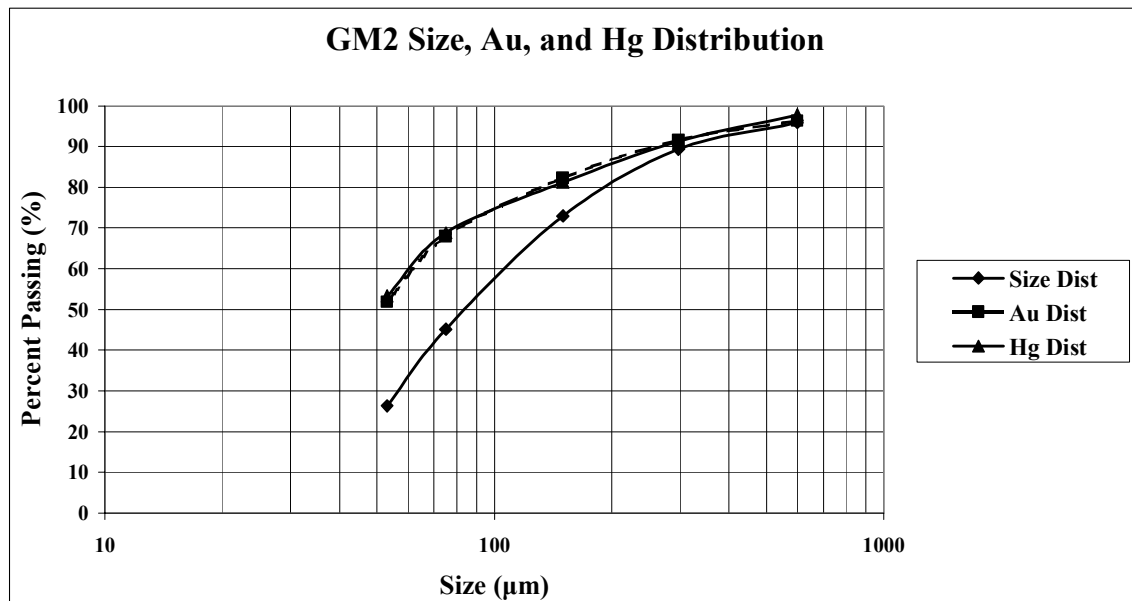


Figure 4.6 GM2 Size, Gold, and Mercury Distributions

As shown in Figure 4.6, the gold distribution closely matched the mercury distribution.

Table 4.7 GM2 Sample Characterization

Cu (ppm)	Ni (ppm)	Co (ppm)	Fe (%)	As (ppm)	Sb (ppm)	Hg (ppm)	Te (ppm)	Sulphur (%)
41065	117	32	7.09	7.7	43.6	2350	5.3	6.34

Table 4.7 shows that GM2 has a high copper content, at 4.1%, demonstrating that samples GM1, GM2, and GM3 are not from uniform ore bodies. The tellurium in the GM2 sample is significantly lower than that in the GM1 sample, which indicates that either amalgamation is recovering some tellurium with the gold, or that the sample simply has less tellurium than GM1. The high copper and high sulphur content may indicate that the copper is in the form of sulphides, such as chalcopyrite.

4.3.2.2 Gravity Recovery Test

As can be seen in Table 4.8, the GM2 test results calculate the grade of the sample to be 38.1 g/t gold, lower than the sample characterization assay results. The test indicated that around 43% of the gold could be recovered by gravity methods, which is surprising considering this sample had already been amalgamated.

Table 4.8 GM2 Gravity Test Results

Size Dist'n	Product	Mass		Assay	Units	Dist'n
		(g)	(%)	Au (g/t)	Au	(%)
P80= 144 µm	Pan Conc.	30.9	0.66	1447	948.7	24.9
	Middlings	62.0	1.32	157	206.7	5.4
	Pan Conc.	13.3	0.28	537	151.6	4.0
	Middlings	68.8	1.46	75.2	109.8	2.9
	Sample Tails	305.7	6.49	23.4	151.9	4.0
P80= 100 µm	Pan Conc.	24.7	0.52	336	176.2	4.6
	Middlings	58.7	1.25	49.8	62.1	1.6
	Final Tails	4145.9	88.02	22.8	2006.9	52.6
	Totals (Head)	4710	100.0	38.1	3813.9	100.0
	KC-MD3 Conc.	258.4	5.49	302		43.4

The size distribution for the initial pass was 80% passing 144 µm, lower than the initial size distribution, as the plus 1 mm material was not included. After the two minute grind the P80 was 100 µm. Over 30% of the gold was recovered in the first stage, suggesting

that additional grinding may not be economical. In addition, the gold recovered in the first pass would be relatively easy to upgrade, as most of the recovered gold reported to the pan concentrate.

4.3.2.3 Mercury Solubility Test

As this test was primarily undertaken to compare GM2 and GM3's mercury solubility, these results are examined together in section 4.3.3.3.

4.3.3 *Sample GM3 – “Gold Mountain” Cyanidation Tails*

4.3.3.1 Sample Characterization

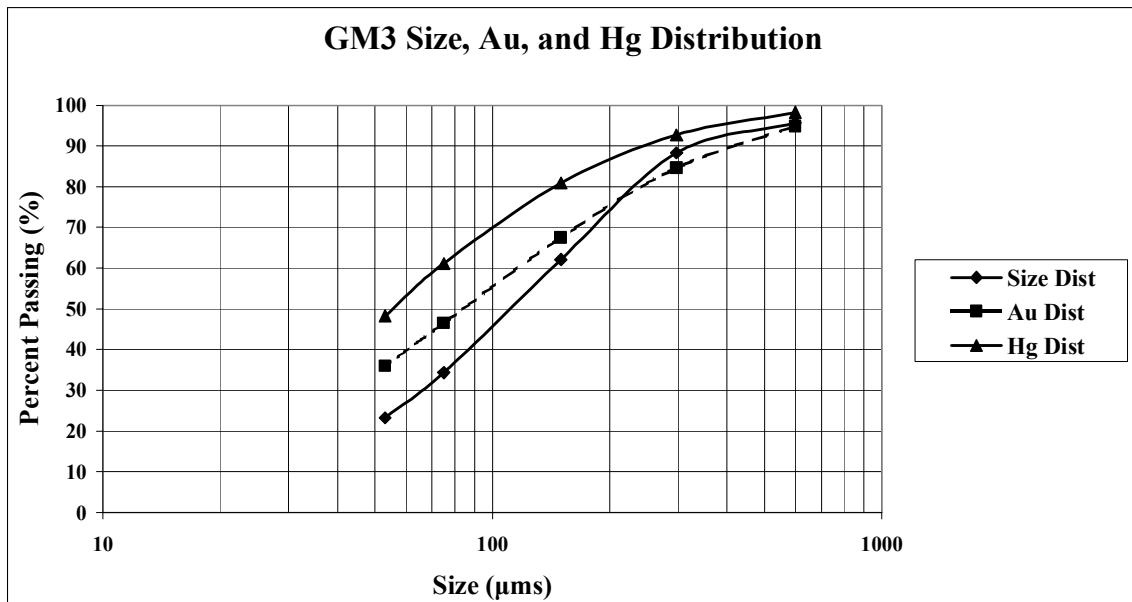


Figure 4.7 GM3 Size, Gold, and Mercury Distributions

After picking out the obviously alien material, the +1mm oversize was 305 g, with 1.31 g/t gold and 82 ppm mercury. This oversize material was assayed for gold and mercury and included in the size and grade distribution data. It was also not included in any further test work, as it was a relatively small amount at 2.18% of the total mass, and it would have needed to be crushed as well.

The P80 for sample GM3 was found to be 215 µm. The back calculated assay for gold was 1.58 g/t. For mercury, the back calculated assay was 283 ppm. The size analysis for

GM2 showed that 36% of the gold and 48% of the mercury were found in the –53 µm size fraction, representing 23% of the total mass. As can be seen in Figure 4.7, the gold distribution was not closely tied to the mercury distribution. Clearly cyanidation successfully recovers gold in preference over mercury.

Table 4.9 GM3 Sample Characterization

Cu (ppm)	Ni (ppm)	Co (ppm)	Fe (%)	As (ppm)	Sb (ppm)	Hg (ppm)	Te (ppm)	Sulphur (%)
9356	87.7	17	4.48	13.8	63.04	283	4.02	3.24

Table 4.9 indicates that copper grade is still relatively high, at almost 1%. Except for the arsenic and antimony content, the other metal contents were significantly lower than in GM2, suggesting that the leaching process removes a lot of the other metals, slowing the extraction of gold.

4.3.3.2 Gravity Recovery Test

Table 4.10 GM3 Gravity Test Results

Size Dist'n	Product	Mass		Assay	Units	Dist'n
		(g)	(%)	Au (g/t)	Au	(%)
	Pan Conc.	25.1	0.51	10.8	5.5	5.5
	Middlings	59.3	1.21	2.03	2.4	2.4
	Pan Conc.	37.6	0.76	5.19	4.0	3.9
	Middlings	48.4	0.98	2.28	2.2	2.2
	Sample Tails	90.1	1.83	1.33	2.4	2.4
P80= 121 µm	Pan Conc.	42.1	0.86	10.7	9.2	9.1
	Middlings	44.9	0.91	2.46	2.2	2.2
	Final Tails	4570.5	92.93	0.78	72.5	72.1
	Totals (Head)	4918	100.0	1.01	100.5	100.0
	KC-MD3 Conc.	257.4	5.23	4.89		25.4

As can be seen in Table 4.10, the GM3 test results calculate the grade of the sample to be 1.01 g/t, lower than the sample characterization assay results. The test indicated that around 25.4% of the gold could be recovered by gravity methods, which would perhaps be uneconomical considering the low grade. The size distribution for the initial pass was not recorded, but after the two-minute grind the P80 was 121 µm. The recovered gold

was widely distributed between the pan concentrates and middlings, and the concentrate grades low, suggesting that the gold may not be easy to upgrade.

4.3.3.3 Mercury Solubility Test

The intermediate mercury tails from the muller mill (GM2, 2224 ppm Hg) were compared to final tails following amalgamation and cyanidation (GM3, 285 ppm Hg), using two duplicate samples (A and B). The mean value of GM2's solution had a concentration of 15.34 µg/L mercury and GM3's solution mean had a concentration of 3.78 µg/L mercury. However, since GM2's overall mercury levels are an order of magnitude higher than GM3's, the ratio of mercury dissolved to the mercury present in the sample was compared. As seen in Table 4.11, approximately twice the ratio of mercury was dissolved from the cyanidation tails sample GM3, compared to the intermediate sample: 17.2×10^{-6} for GM2 and 31.1×10^{-6} for GM3.

Table 4.11 Mercury Solubility

Product	GM2 (2224ppm Hg)		GM3 (285ppm Hg)	
	(µg/L Hg)	Ratio of Hg (µg) in solution to Hg in tailings (µg)	(µg/L Hg)	Ratio of Hg (µg) in solution to Hg in tailings (µg)
Sample A	14.30	16.1×10^{-6}	5.14	45.1×10^{-6}
Sample B	16.37	18.4×10^{-6}	2.41	21.1×10^{-6}
Mean	15.34	17.2×10^{-6}	3.78	31.1×10^{-6}

4.4 Discussion

4.4.1 “Gold Mountain” Samples

Table 4.12 Grade Differences Between Test Samples

SAMPLES	Cu (%)	Fe (%)	Te (ppm)	Hg (ppm)
GM 1 - Feed Sample	0.44	12.11	13.71	0.78
GM 2 – After Muller, Pre Cyanide	4.11	7.09	5.30	2224
GM 3 - Final Tails	0.94	4.48	4.02	285

The three “Gold Mountain” samples are clearly not from the same ore deposit, as is demonstrated in Table 4.12. While this presents difficulties comparing the test work, it shows the diversity of ores that a mineral processing centre in “Gold Mountain” receives.

It also demonstrates that any alternative technology introduced needs to be robust enough to handle a diversity of ores.

The mercury levels in the samples are significantly higher than the initial samples collected during the case study research; 2350 ppm vs. 237 ppm for the miller mill intermediate samples (GM2), and 283 ppm versus 108 ppm for the final cyanidation tails (GM3). This verifies that the estimates of mercury releases made in section 3.3.2.4 are certainly conservative.

Detailed studies of the mineralogy of samples GM1-GM3 was not undertaken. While this may have provided further information on how to optimize the recovery of gold in these samples, the variability of the samples suggest that such an optimization might not be useful for the range of ores brought into a processing centre. The miners need inexpensive, simple, and robust technology capable of achieving good gold recoveries from a range of ores.

4.4.1.1 GM1

The GM1 test work verified that a significant portion of the ore is amenable to gravity separation, with a GRG value of 40%. The test work also showed that the long leach times used are indeed necessary, and that increased grinding would improve both gravity and cyanidation recoveries. The miners had indicated that some of the gold ores were especially refractory, and that they were interested in new technologies to improve recovery. It is quite possible that the GM1 sample was one of these ores, due to the high tellurium grade and the high percentage of gold finer than 63 µm. That after almost 11 days of cyanidation in a bottle roll, the tailings grade was still 5.6 g/t gold, indicates that the miners may have had significant difficulties achieving high recoveries. This slow leach time may be due to the copper and tellurium in the ore.

Miners may improve recovery by adding cyanide in stages. As mentioned in section 3.3.1.4, miners only add cyanide and lime at the beginning of cyanidation. The miners could float and/or roast the ore to improve recoveries, but this would likely be beyond the miners' technical skills or financial capability.

4.4.1.2 GM2

The high gold grade of GM2 (38.1 g/t), and the exceptionally high mercury levels (2224 ppm) suggests the amalgamation process was not especially effective in this case. Usual whole ore amalgamation tails have mercury levels in the range of 200 to 500 ppm (Section 3.3.2.3; Veiga, 1997). Perhaps the feed ore had a particularly high grade (over 60 g/t gold), and the miners had some inkling of this, thus added significant amounts of mercury in an attempt to increase recovery. The tight correlation between the mercury and gold size distribution (Section 4.3.2.1) indicates that amalgamation in the muller mills may be extremely effective; potentially all of the gold is essentially amalgamated. However, this sample is from the muller mill tailings; clearly the amalgam is not being effectively recovered from the mill. While “Gold Mountain” miners stated that amount of gold was in the range of 40-60%, it seems unlikely in this case. While the muller mill may be an efficient and inexpensive comminution and amalgamation device, it may not excel at gold recovery. This is corroborated by the high percentage of gold recovered by the KC-MD3 in the first pass. One of the prime causes for this may be that muller mills can flour the mercury, grinding it fine enough that it becomes largely inactive due to impurities and its inherent surface tension. Another reason may be that cleaning the muller mills by only removing the material found at the bottom of the muller mill trough is ineffective. Perhaps special amalgamation plates (Veiga and Gunson, 2004) would effectively remove much of the amalgam in the overflow. Presumably much of this excess mercury would be recovered using cyanidation and volatilized during the zinc strip smelting, to the hazard of the miners.

4.4.1.3 GM3

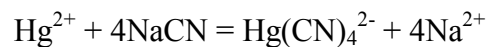
Sample GM3 demonstrates that on some ores, the “Gold Mountain” processing centres can be quite efficient at gold recovery. The low gold grades (~1g/t) and the poor results on the gravity tests (25.4% after three passes) indicate that their process (or at least their cyanidation) was effective, even with a high copper grade to inhibit cyanidation, unless the initial grade of this ore was quite low. Reprocessing tailings may not be an attractive option in “Gold Mountain”. The lower grade of mercury in the cyanidation tails compared to the amalgamation tails (283 ppm versus 2224 ppm), suggests that much of

the mercury from the amalgamation process is recovered during cyanidation. This recovered mercury is subsequently volatilized during the smelting of zinc strips, described in section 3.3.1.4. Obviously, uncapped tailings dumps often located beside streambeds, with mercury concentrations 283 ppm, are a significant risk to the local watershed.

4.4.2 Mercury Solubility

The United States Environmental Protection Agency's (USEPA, 2002) guidelines state two figures for freshwater mercury contamination. Its Criteria Maximum Concentration (CMC) is an "estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect." Its Criterion Continuous Concentration (CCC) is an "estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect." The CMC and CCC for mercury in freshwater is 1.4 µg/L and 0.77µg/L respectively (USEPA, 2002). Metallic mercury is a relatively stable substance, so significant dissolution shows the presence of soluble species. Thus the GM2 and GM3's dissolution concentrations of 15.34 and 3.78 µg/L mercury give rise to concern.

The leaching kinetics of mercury during cyanidation are fast, but slower than those of gold. As a result, only part of the mercury is leached, the rest remaining with the tailings. In gold leaching conditions, mercury forms $[\text{Hg}(\text{CN})_4]^{2-}$, through the following equation:



$[\text{Hg}(\text{CN})_4]^{2-}$ can easily form complexes with other substances (Flynn, 1995).

As the tailings are disposed of beside the local stream and no effort is made to safely manage the tailings, rainwater could easily mobilize this mercury. Hinton *et al* (2003a) suggest a number of options for remedial solutions for mercury-contaminated sites. The difficulty is that funding probably would not be available for clean up. Foremost efforts should be put toward helping existing operations use less damaging methods.

4.5 Conclusion

The test work completed verified that high levels of mercury were being released from “Gold Mountain’s” processing centres. The muller mill tailings’ mercury concentration was 2224 ppm, and the cyanidation tailings’ concentration was 285 ppm mercury, from a background mercury concentration, as indicated by the feed ore, of only 0.78 ppm. The three samples were from different deposits and show the diversity of ores that milling centres must process.

Test work completed on the feed sample, grading about 43 g/t gold, indicated that around 40% of the gold was recoverable by gravity methods. An eleven-day cyanidation bottle test showed that the leaching rate of the ore is extremely slow, perhaps due to the high levels of copper (0.44%) and tellurium (13.71 ppm) in the ore. Gravity methods could be introduced to replace whole ore amalgamation, although amalgamation of gravity concentrates may still be necessary to produce a saleable product for the miners. Increased comminution would help the miners achieve higher recoveries and potentially reduce cyanidation times.

The muller mill tailings sample, with a gold grade of 38.1 g/t, indicated that amalgamation had not effectively recovered gold from the initial ore, especially as 43% of the gold in the tailings was recovered, 30% in the first pass without additional grinding.

The cyanidation tailings sample, with a gold grade of 1.0 g/t, indicates that for this ore at least, the processing centre effectively recovered most of the gold. The mercury concentration indicates that much of the mercury from the muller mill is removed by cyanidation, to be volatilized during the zinc strip smelting process. The remaining mercury in the tailings also represents a significant risk to the local watershed. In addition, the mercury solubility tests indicate that cyanidation, following amalgamation, may increase the solubility of the mercury in the tailings. The miners should be encouraged to abandon their practice of whole ore amalgamation, although amalgamation of gravity concentrations may continue to be necessary.

5 Mercury Releases, Alternatives, and Implementation

As demonstrated in the previous three chapters, China's artisanal and small-scale gold mining industry releases significant amounts of mercury. This chapter brings together the results of the previous chapters to estimate the extent of mercury released by ASGM, discusses potential technology alternatives to amalgamation which could reduce those releases and examines some issues surrounding alternative technology and technology transfer.

5.1 China's Mercury Releases

ASGM represents one of the main sources of mercury releases in China, but is by no means the only source. First, the releases due to ASGM are estimated, followed by a brief discussion of other sources of mercury.

5.1.1 Estimating China's ASGM Mercury Releases

The following mercury emission estimate for ASGM is based on:

- The estimate of China's annual gold production due to ASGM (ASGMAu);
- Estimates of the methods of ASGM gold production; muller mills, ball mill/mercury sluice combinations, and placer methods; and,
- Estimates of the ratio of mercury lost to gold recovered by these different methods.

Thus, the annual mercury emission from Chinese ASGM production is estimated from the following equation:

$$\text{HgAu} = \text{ASGMAu} * (\text{MMAu}\% * \text{MMR} + \text{BSAu}\% * \text{BSR} + \text{PMAu}\% * \text{PMR})$$

Where:

HgAu is the amount of mercury released per annum due to ASGM activities;

ASGMAu is the amount of gold produced per annum by ASGM;

MMAu% is the percentage of gold produced by ASGM operations using muller mills (Section 2.3.1.1);

MMR is the ratio of mercury lost to gold recovered for muller mills;

BSAu% is the percentage of gold produced by ASGM operations the ball mill/sluice combination (Section 2.3.1.2);

BSR is the ratio of mercury lost to gold recovered for ball mill/slucice operations;
PMAu% is the percentage of gold produced by ASGM operations exploiting placer deposits (Section 2.3.1.3); and
PMR is the ratio of mercury lost to gold recovered from placer deposits.

The annual ASGM gold production estimate (ASGMAu) is 61 tonnes per annum, based on the calculation in section 2.4.2.2.

The estimates of the percentages of different ASGM gold production methods are the least certain of these estimates. Ball mill / sluice operations were found widely around China, as discussed in Chapter Two, and have the capacity to mill large amounts of ore. He *et al* (2000) demonstrated that this is the main amalgamation method for the smaller state-owned gold operations using amalgamation. There appeared to be large numbers of muller mills, but they were more localized, and thus are given a smaller share of total production. Placer gold makes up around 13% of China's total gold production and often producers are small-scale operations (Zhou *et al*, 2002).

Estimates of the ratio of mercury lost to gold recovered by method are detailed in Table 5.1. The muller mill estimate ratio (MMR) $Hg_{lost}:Au_{produced}$ ranges from is 14:1 to 20:1, as demonstrated in section 3.3.2.4. The ball mill / sluice ratio (BSR) range was determined as follows. He *et al* (2000) provide data for 33 ball mill / sluice operations, and claim that they consumed mercury at a $Hg_{lost}:Au_{produced}$ ratio of 6.35:1. On average, 75% of the mercury consumed was later recovered using retorts and active carbon filters, leaving a ratio of 1.59:1. While this is probably representative of the state-owned amalgamation mills, it may be an underestimate in the case of the smaller ASGM operations. Section 2.3.1.4 estimated the ratio as 3.33:1, based on interviews. However, mercury losses from a similar copper plate amalgamation process described by Veiga and Gunson (2004) revealed a $Hg_{lost}:Au_{produced}$ ratio of 1.5:1-2:1. As He *et al* (2000), and Veiga and Gunson (2004) produced more verifiable results than the interviews could have done, the BSR used for the low range is He *et al's* average of 1.59:1 and the high range is 2:1. The ratio used for the placer operations (POR) is 1. As no whole ore amalgamation placer

operations were observed in China, it was assumed that they only amalgamate concentrates. For all of these methods, the actual ratios vary widely with equipment quality, human ability and ore variation.

Table 5.1 Mercury to Gold Loss Ratio for China

Unit	Abbreviation	Mercury Lost: Gold Produced	Source
Muller Mills, China	MMR	14 – 20 : 1	Section 3.3.2.4
Ball mill – Sluice, China	BSR	3.33 : 1	Section 2.3.1.4
Ball mill – Sluice, China	BSR	1.59 : 1	He <i>et al</i> , 2000
Amalgamation Plate	~BSR	1.5 – 2 : 1	Veiga and Gunson, 2004
Only Concentrate	PMR	1 : 1	Veiga, 1997

Estimates of the total amount of mercury released due to ASGM in 1997 and 2001 are outlined in Table 5.2. For 2001, the low estimate is 237.6 tonnes of mercury per annum and the high estimate is 652.1 tonnes.

Table 5.2 Chinese Annual Mercury Releases attributable to ASGM

Factor	1997		2001	
	Low	High	Low	High
ASGM Au	58	87.5	61	92.5
MMAu%	20	30	20	30
MMR	14	20	14	20
BSAu%	50	45	50	45
BSR	1.59	2	1.59	2
PMAu%	30	15	30	15
PMR	1	1	1	1
HgAu	225.9	616.9	237.6	652.1

The ratio of mercury lost to gold recovered seems to be the standard method used for accounting for mercury losses (Veiga, 1997). However, it is an imperfect standard for two main reasons; it does not account for mercury lost when no gold is recovered, and it assumes that miners will accurately report the amount of gold they are recovering. It is easier to learn how much mercury is being lost per day per tonne of ore processed than it is to discover its ratio to gold recovered, as the former does not require miners to be

honest in reporting their gold recovery and can be verified by assaying tailings. Ideally the amount of mercury that miners buy each month could be recorded.

Table 5.3 Low Estimate of ASGM Gold Production and Mercury Releases (2001)

Method	Au Production (tonnes/a)	Au Production (%)	Hg Releases (tonnes/a)	Hg Releases (%)
Muller mill	12.2	20	170.8	71.9
Ball mill / sluice	30.5	50	48.5	20.4
Placer methods	18.3	30	18.3	7.7
Total	61	100	237.6	100

As can be seen in Table 5.3, by far the largest contributors to mercury releases are muller mills, with 20% of ASGM production and 72% of the mercury releases, even using the low end of the range of $Hg_{\text{lost}}:Au_{\text{produced}}$ ratios. Muller mills are clearly the area where efforts at reducing mercury releases should be concentrated.

5.1.2 Other Sources of Mercury

In addition to ASGM, China has several other sources of mercury releases.

He *et al* (2000) described how China's gold mines release around 20 tonnes of mercury per annum. The mines covered in the article are most likely the state-owned mines that still use amalgamation, and generally would not overlap with the mercury releases described above.

China's massive coal mining industry emitted around 303 tonnes of mercury from coal combustion in 1995 alone (Wang *et al*, 2000). Artisanal and small-scale coal mines contributed around 127 tonnes of mercury in 1997 (Gunson and Veiga, 2004). Feng and Hong (1999) determined that most of this mercury was associated with sulphides in the coal and could be removed by basic coal cleaning, at least in Guizhou Province. In 2001, China produced roughly 1089 million tonnes of coal, but due to the central government's policy of shutting down ASM coal mines, their share of production has dropped from 47% in 1996 to 23% in 2001 (Andrews-Speed *et al*, 2003b). Assuming an average

mercury content of 0.22 mg/kg in China's coal, ASM coal mines contributed around 56 tonnes of mercury and formal coal mines contributed 240 tonnes of mercury in 2001.

As detailed in Gunson and Veiga (2004), some 50 ASM mercury operations lose around 28 tonnes of mercury per annum (in addition to their mercury production). The formal mercury-mining sector would also contribute to mercury releases; however, apparently most of the state-owned mercury mines have now been shut down (Maxson, 2004). In 2001, China's state-owned mercury mining sector produced approximately 190 tonnes of mercury, down from 830 tonnes in 1997 (Tse, 2002). Assuming a 90% recovery rate of mercury, the state-owned mercury mines released around 19 tonnes of mercury in 2001. The mines' production should not be considered releases, since much of that mercury may make it to ASGM operations or mercury polluters and would thus lead to double counting.

There is a wide variety of other sources of mercury pollution including:

- Chlor-alkali plants (1400-2700 tonnes from 1952-2000, Qi *et al*, 2000);
- Batteries
- Oil product combustion;
- Cement production;
- Lead production;
- Zinc production;
- Pig iron and steel production;
- Caustic soda production;
- Waste disposal; and,
- Deforestation (Pacyna and Pacyna, 2002).

Maxson (2004) estimates that the total amount of mercury consumed in East Asia in 2000 was 1100 tonnes, including ASGM, not including combustion of fossil fuels. This figure almost certainly underestimates consumption from ASGM, especially in Indonesia (Veiga and Baker, 2004) and China. Regardless, much of the 1100 tonnes of mercury was probably consumed in China, and thus the number may provide an indication of mercury

releases from other sources. Furthermore, the wide array of additional sources for mercury makes it difficult to determine the exact source of ambient mercury in China.

5.1.3 Comparing Mercury Releases in China

The magnitude of mercury sources from mining in China for 2001 is compared in Table 5.4 and Figure 5.1.

Table 5.4 Chinese Sources of Mercury Releases Due to Mining (2001)

Source	Mercury Releases (tonnes)
ASGM	238
State-owned Coal Mines	176
ASM Coal Mines	127
ASM Mercury Mines	28
State-owned Gold Mines	20
State-owned Mercury Mines	19
Total	601

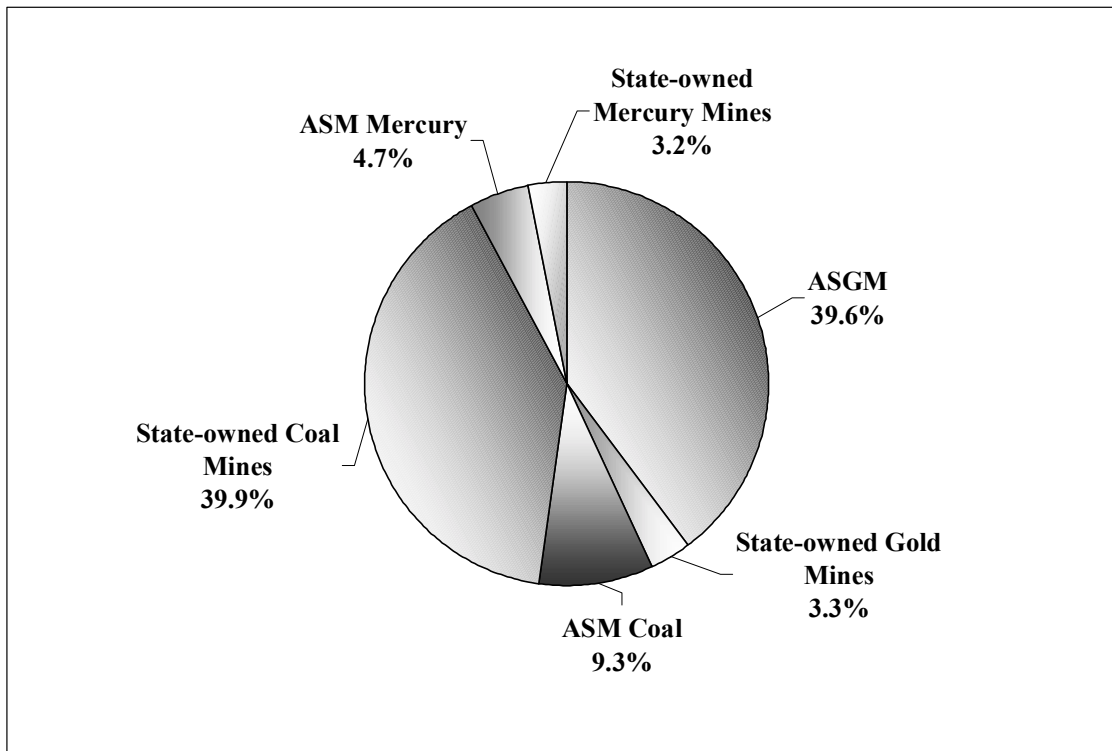


Figure 5.1 China's Mercury Releases Due to Mining

ASGM is the largest source of mercury in China, along with the state-owned coal mining sector. The rejection of whole ore amalgamation through the adoption of alternative technology could dramatically reduce mercury releases. However, the effective introduction of alternative technology is not a trivial matter.

5.2 Alternative Technology

Introducing alternative technologies to economically marginal activities in developing countries is hardly a new concept. Governments, NGOs, aid organizations and others have been doing this work for decades, especially in agriculture.

Past efforts have often failed unless they met the following criteria:

- Economically beneficial – The technology must be inexpensive to operate and it must generate obvious financial benefits;
- Simple – The technology must be easy to use and would ideally utilize readily available resources; and,
- Expedient – The economic mineral must be efficiently recovered.

More directly, any new technology must be “fast, easy, and cheap” (Hinton *et al*, 2003a).

The first efforts to address these issues were termed “Appropriate Technology.” Appropriate Technology is a curious term, with an ideological background and a politicized history. This section defines and explains “appropriate technology” and explains why “alternative technology” is used as a substitute in this thesis.

Appropriate Technology refers to a philosophy of life as much as to technology. It has its ideological basis in the Gandhian Movement and Edward Schumacher’s writings, such as “Small is Beautiful” (Schumacher, 1973). The term suggests that there are different technological options for solving problems and that some technologies may be more appropriate in some situations than others. The counterpart to this is that there is technology that is not “appropriate”.

In the 1970s and early 1980s Appropriate Technology was in vogue, and a number of books and articles were published on the topic, each with their own definition of what exactly Appropriate Technology (AT) referred to. The list of AT criteria in the “Appropriate Technology Sourcebook” by Darrow and Pam (1981), as listed below, is representative.

Appropriate Technology Criteria:

- 1) Low in capital costs;
- 2) Use local materials whenever possible;
- 3) Create jobs, employing local skills and labour;
- 4) Are small enough in scale to be affordable by a small group of farmers;
- 5) Can be understood, controlled and maintained by villagers wherever possible, without a high level of Western-style education;
- 6) Can be produced out of a small metal-working shop, if not in a village itself;
- 7) Suppose that people can and will work together to collectively bring improvements to their communities, recognizing that in most of the world important decisions are made by groups rather than by individuals;
- 8) Involve decentralized renewable energy sources, such as wind power, solar energy, water power, methane gas, animal power, and pedal-power (such as in that highly efficient machine, the bicycle);
- 9) Make technology understandable to the people who are using it and thus suggest ideas that could be used in further innovations;
- 10) Are flexible so that they can continue to be used or adapted to fit changing circumstances;
- 11) Do not involve patents, royalties, consultant fees, import duties, shipping charges, or financial wizards; practical plans can be obtained free or at low cost and no further payments are involved.

As can be seen from the seventh to the eleventh criteria, appropriate technology involved far more than simply using a technology that is most appropriate for the given situation. A more succinct definition, from the U.S. Congress’s Office of Technology Assessment,

defines AT as “being small scale, energy efficient, environmentally sound, labour-intensive, and controlled by the local community” (Hazeltine and Bull, 1999).

AT’s popularity arose from the belief that in order to alleviate poverty, groups concerned with development should focus on providing simple technology rather than expensive modern factories, dams, highways, and airports. AT could provide “goods, services, and jobs that will not be provided any other way. No company or organization will be able to invest enough in high-technology factories in developing countries to provide sufficient jobs” (Hazeltine and Bull, 1999). In addition, AT was attractive to people in wealthy nations trying to simplify and lessen the environmental impact of their lifestyle.

This apparently sensible approach to development was not without enemies. Leaders from developing nations resented the idea of trying to modernize using technologies and equipment often perceived as outdated and primitive. Did AT actually work toward national development, or did it in fact discourage industrialization? While the ideology of AT became widely accepted in the 1970s and 1980s, it was often used as a way to justify exporting cheap and low technology goods from developed nations. The term quickly became overused, creating a dichotomy between “real appropriate technology”, and “old fashioned/obsolete technology.” Developing nations became increasingly frustrated with the term and the poor quality equipment they were receiving under the guise of AT from various development programs. Often knowledge transfer was eschewed in favour of simply sending cheap equipment, without building the capacity to maintain the equipment or supply spare parts. In effect, AT came to be associated with obsolete equipment. By the early 1990s the term was badly enough regarded that the UNIDO eliminated the term in favour of terms like “sustainable technologies” (Veiga, 2003). In this thesis the term ‘alternative technology’ is used as a substitute, with the aim of capturing the flexibility and utility of appropriate technology without its stigma.

“Alternative technology” is hardly a new term either. Jequier and Blanc (1983) defined it as follows: *“the term used to describe new types of equipment or new organisational forms which represent a viable alternative to the existing ‘main-stream’ technologies of*

today.” Other terms with similar meanings include “environmentally sound and appropriate technology (ESAT)” for appropriate technology using renewable resources, and “intermediate technology,” for a technology that stood halfway between traditional and modern technology.

For the purposes of this work, “alternative technology” is:

- 1) Environmentally and/or socially beneficial – it must provide concrete improvements over the existing technology;
- 2) Economic – it must match the capital availability of those who will own and work with it and provide a reasonable return on investment;
- 3) Safe, with no major health risks;
- 4) Simple – the technology can be understood, and is attainable by the users;
- 5) Easy to maintain – users need to be able to afford spare parts or be able to repair the machine on their own;
- 6) Flexible enough to be able to handle changing circumstances;

“Sustainability” in ASGM is contradictory, as an ore deposit is inherently finite, and thus not sustainable. However, communities that host ASGM activities are potentially sustainable, and small-scale miner organizations (companies, cooperatives, or whatever form they take) are potentially sustainable sources of employment, materials, and income, if they act responsibly enough to gain social licence to operate and are flexible enough to adjust to changing circumstances (Veiga *et al*, 2001).

Any technical alternative must be thoroughly examined, pre-tested, and appropriately modified if it is to be successfully transferred to miners and lead to more environmentally sound and socio-economically sustainable ASGM activity.

5.2.1 Sustainable Alternative ASGM Technology

The test work above demonstrates that it is possible to get similar gold recoveries from a Knelson Concentrator / cyanidation circuit as from a mercury muller mill / cyanidation circuit, with far less mercury releases. A centrifugal concentrator was initially chosen for the alternative technology, as the miners were interested and the technology is relatively

efficient, and thus would provide a good indication of the optimal recoveries possible using gravity. The miners were familiar with traditional gravity technologies such as sluice boxes, but were not interested in using them, as they felt their mercury methods were more advanced.

Regardless, Knelson Concentrators may not necessarily be the most ‘sustainable’ alternate solution for ASGM miners using muller mill technology. A simpler gravity solution, such as a sluice box, jig, or the Cleangold™ magnetic sluice, in combination with cyanidation, may work almost as well. As demonstrated in Figure 5.2, both mercury and gravity circuits fulfill a similar role: removing coarser, more liberated gold as cheaply and easily as possible before the more costly and time-consuming process of cyanidation.

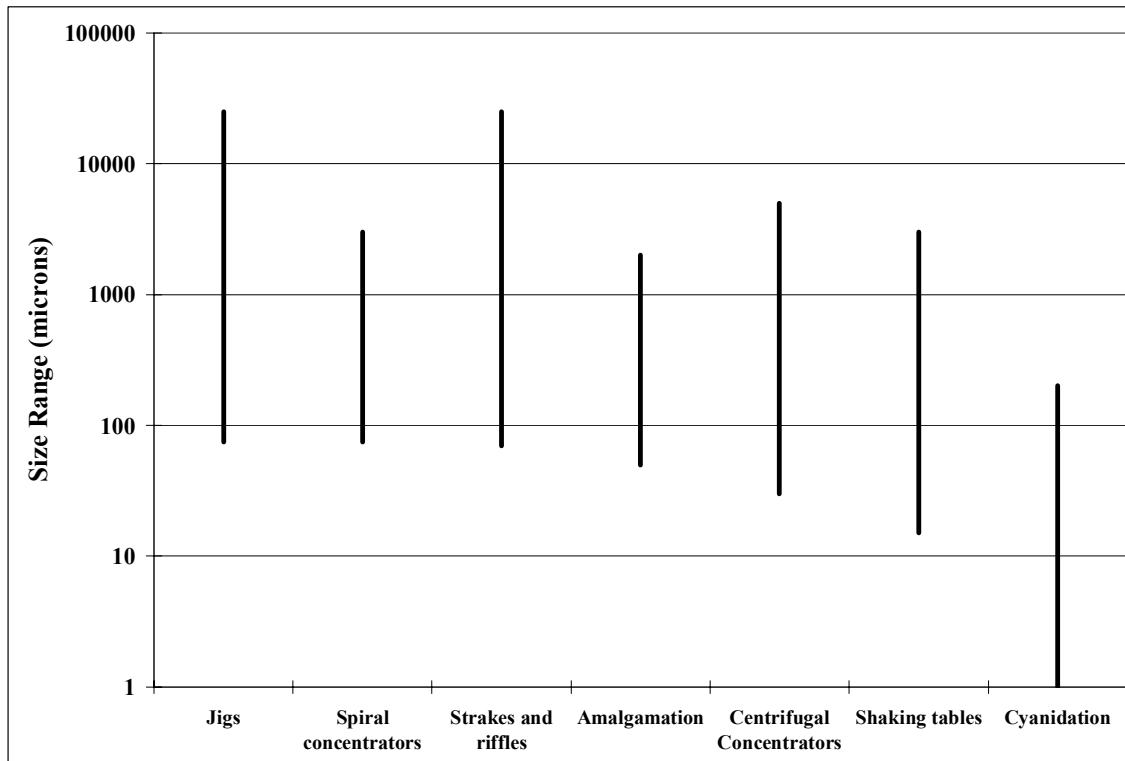


Figure 5.2 Gold Particle Size Recovery Range (after Yannopoulos, 1991 and Priester *et al*, 1993)

A centrifugal concentrator is likely to achieve higher recoveries than an alternative gravity method, as the centrifugal concentrators are more effective at recovering fine gold. However, the cyanidation process would likely pick up this fine gold in the next

step. Since the ASGM cyanidation processes are not especially efficient, recovering the fine gold in a gravity step would probably increase the overall recovery. For ASGM operations, as opposed to formal operations, this would probably be a small increase in revenues and might not have a fast enough payback to justify the added cost of a centrifugal concentrator.

One of the prime problems with centrifugal concentrators as alternative technology is that they are relatively complex to manufacture well. The main manufactures are located in Canada and thus concentrators are subject to import duties, and finding spare parts can be expensive and time-consuming. However, centrifugal concentrators tend to be robust, and many of the wear parts, like drive belts, could easily be replaced locally. In comparison, muller mills are simple, inexpensive and manufactured locally. As mentioned in section 2.3.1.1, a muller mill with a capacity of 0.5 - 1.0 tonnes per hour costs around US\$1,200, versus at least \$US10,000, not including duty or taxes, for a centrifugal concentrator with a similar capacity. At least one Chinese company produces centrifuges; however, they are not widely accepted, are poorly manufactured, and are not as efficient as the main Canadian suppliers. Inexpensive, simpler centrifugal concentrators are also manufactured in Brazil and Zimbabwe.

One of the main reasons that centrifugal concentrators might be appropriate is perception. Chinese ASGM operators/owners are well aware of the alternate gravity methods mentioned above, but disdain them and consciously choose mercury methods instead. Sluices/jigs/spirals are seen as too simple and susceptible to theft, as the high-grade gold concentrate may not be secure. Centrifugal concentrators can be easily locked during operation and may be less susceptible to theft. In addition, centrifugal centrifuges represent a new technology, and thus have the potential to renew interest in gravity methods. In other words, even if centrifugal concentrators did not offer significantly better results than simpler gravity technologies, ASGM miners might be willing to accept switching from mercury to gravity methods due the perception that centrifugal concentrators were a more modern, efficient technology, as well as reducing the need for mercury use.

Regardless, even operations that installed centrifugal concentrators would likely continue using mercury to some extent. The gravity concentrate is unlikely to be a high enough grade to proceed to direct smelting. The most efficient method of further concentration is to mix the gravity concentrate with mercury through barrel amalgamation. While this still involves mercury, using amalgamation on only the concentrates reduces by several orders of magnitude the amount of mercury released. Veiga (2004b) reports that barrel amalgamation can achieve recoveries of about 90%.

A key part of making the centrifugal concentrator / cyanidation method more appropriate for Chinese ASGM is to try to integrate the muller mills as the primary comminution stage of the circuit, without whole ore amalgamation, instead of introducing ball mills. The miners are comfortable with the muller mill technology, and its inexpensiveness, local manufacture, and efficiency make it more sustainable than getting new ball mills manufactured in other areas of China. A key point in favour of muller mills is that the entire process is visible; unlike ball or hammer mills, at no point is the ore hidden. This has proven a key concern in implementing new technologies in Zimbabwe (Veiga, 2004b). It also reduces the capital costs of installing a new gravity circuit.

A Belgian development assistance project in Chile implemented an identical flow sheet, replacing a Chilean muller mill amalgamation centre with a Knelson / cyanidation circuit, while keeping the muller mill for comminution, but not amalgamation (see figure 5.3) (Dandois, 2000). Stamp mills may be another alternative; however, they are not manufactured in China, and are not an accepted technology.

The Cleangold magnetic sluice, which uses polymeric magnetic sheets, with the magnetic poles aligned normal to the direction of the flow, inserted into an aluminium sluice box, offers another potential alternative technology. Magnetite or iron fillings, forms a corduroy-like bed on the sluice floor, which appears effective at recovering fine gold. Preliminary studies indicate recoveries similar to centrifugal concentrators for some ores (Gunson, 2003), with concentrate grades reaching 2854 g/t (Veiga and Gunson, 2004).

While the sluices are not manufactured locally, they are inexpensive, simple, and easy to maintain. Equipment to process 0.5-1.0 tonnes per hour would cost around \$US500.



Figure 5.3 Muller Mill / Centrifugal Concentrator, Chile
(Davidson, 2001)

Alternatives to reduce mercury releases are plenty, including gravity, flotation and cyanidation methods. However, any attempt to replace mercury use must understand that amalgamation is often an extremely effective method and can be difficult to improve on. One key understanding that seems to have arisen is the need not to focus on eliminating mercury use, but on eliminating the amalgamation of whole ore and to promote the use of retorts. Attempts to ban amalgamation may reduce releases significantly, but would force other operators underground and eliminate the possibility of introducing more sustainable approaches. A better alternative is to target practices that lead to the most releases, such as whole ore amalgamation in muller mills in particular, and share practical alternatives with artisanal and small-scale miners.

5.3 Technology Transfer

Transferring technology, even if it is alternative technology, is a hugely complex task. Comparatively little resources have gone into ASGM technology transfer compared to agricultural or industrial technology transfer, as ASGM activities have often been marginalized, and involve fewer people with far less political clout. However, the issues that arise are quite similar.

The basic tenet of technology transfer is that technology does exist, or technology can be readily developed, that is superior to the existing technologies being used by the people in the field. The challenge is how best to inform the end users that this technology exists, or can be developed, and to get them to accept the new technology and successfully implement it in their operations. Technology transfer immediately runs into a significant hurdle with its basic tenet; existing technologies have been honed for years (sometimes centuries) to local physical, economic and social conditions, and it can be difficult to prove or convince the users that the new technology is in fact better.

One example is the quimbalete, a traditional Andean amalgamation gold-processing technology that can metallurgically outperform newer gravity and cyanidation techniques. The quimbalete, while simple and cheap, also loses significant amounts of mercury, and is extremely labour intensive. Any attempts to replace quimbaletes must convince the users that the expense of new equipment and the potential loss of employment and tradition are outweighed by the improvements in their local health and environment and by increased productivity (CASM, 2002). All technologies have different costs and benefits and it is rare that the benefits of a new technology are so overwhelmingly positive that it will be universally accepted. New technologies often come with hidden or delayed costs, such as social disruption, overuse of land, or long-term health effects.

Any truly effective alternative technologies have to be developed in close cooperation with artisanal and small-scale miners and researchers. Working in isolation and bringing packaged solutions to the miners is unlikely to be successful, regardless of how clever the research. It is well demonstrated that bottom-up measures, or programmes developed by

the people participating in them, tend to be most effective and enduring (Hinton *et al*, 2003a).

ASGM encompasses an enormous diversity of operations and communities. A sustainable alternative technology solution for one area might be entirely inappropriate for another, even nearby, area. For example, a solution for a primarily agricultural community with part-time miners may be significantly different than one for a migrant gold rush community. Careful consideration of the local socio-economic conditions, as well as the technical problem, is paramount to a successful technology transfer. Technical assistance for ASGM should not simply be a downscale of formal mining technology. A truly sustainable alternative technology, if it is effectively transferred, should be self-maintaining, and should encourage further innovation. Other ASGM operations should be able to see its effectiveness and work toward their own sustainable solutions. An example of the difficulties involved with technology transfer can be seen from the international experience with ASGM processing centres.

5.3.1 ASGM Processing Centres

Several previous models and projects, described in brief below, have aimed to reduce ASGM mercury releases through the creation of clean (or cleaner) processing centres. The thrust of the concept was that individual, very small-scale processing operations are extremely difficult to effectively monitor, implement safety or environmental controls, or upgrade technologically. Building one central ore-processing centre in an area, in theory, allowed the creation of a larger-scale, cleaner operation, although still small in comparison to the formal mining industry. A central plant could be monitored to ensure health, safety, and environmental concerns are addressed, and could take advantage of more expensive and complicated technologies, leading to higher recoveries. Miners would bring a concentrate or high-grade ore to the centre and either pay a fee for milling or simply sell their ore to the centre. The more organized nature of processing centres could make them more attractive to investment, regulators, the legal system, and society, in essence allowing ASGM to become part of the formal economy (Hinton *et al*, 2003a). In addition, the centres can act as distribution points for technical and safety information for ASGM.

Several processing centres or models have been conceived, including:

- UNIDO's Unit of Gold Extraction and Controlled Amalgamation (UNECA) model, based on the Carhuachi Center in Venezuela. The UNECA Center concept was to be implemented in approximately six months, use special amalgamation plates and/or a sodium chloride electrolytic leaching process, and be built for approximately US\$250,000. Miners would be charged approximately US\$1 per kilo of concentrate processed. However, centres were expected to run at a loss (Veiga and Beinhoff, 1997) and no UNECA centres have been built.
- Intermediate Technology Development Group (ITDG), in cooperation with the National Miners' Association of Zimbabwe (NMAZ), built the Shamva Mining Center in Zimbabwe, in 1989. Acting as a central mill for approximately 200 miners, the centre process used a jaw crusher followed by a ball mill and a centrifugal concentrator. The concentrate was rolled in an amalgamation barrel and then retorted. The tails of both the centrifuge and amalgamation barrel were subjected to cyanidation and the pregnant leach solution was precipitated with zinc shavings. In addition, the Center provided drilling and blasting services, ore transportation, technical support, and information on legal issues, geology and metallurgy and the selection and purchase of equipment. Local miners were responsible for their own ore throughout the milling process, supervised by a plant manager. Miners paid ~US\$6 per hour (~US\$4/t) to use the plant and take away the gold recovered (on average ~5g/t). Tailings were reprocessed with cyanide by the plant to generate revenue (Hinton *et al*, 2003b; Simpson, 2004). Friction between NMAZ and ITDG caused the subsequent breakdown of project (Simpson, 2004).
- The Agence de Coopération au Développement par les Sciences Et les Techniques, a Belgian development agency, set up an assistance project in Chile that replaced a Chilean muller mill operation with a centrifugal concentrator / flotation circuit, using the muller mills as grinding mills in the late 1990s. The project cost US\$182,557 (Dandois, 2000), and has since closed.

Several issues can commonly arise from central processing centres. While locally effective in reducing mercury releases, these models were never cheap enough to become generally accepted among small-scale gold miners. Many of these centres still used mercury in the process, albeit losing far less mercury than the operations they replaced. Since these centres were static, they could only impact a small number of miners. They also competed against local processing operations, and they were often not profitable. For processing centres to genuinely appeal to small-scale miners, they need to have incentives to change their existing methods. Without maintaining at least the existing profits, it would be hard to convince miners of the utility in switching. Perhaps most importantly, all of the above examples required significant capital investment and expert inputs from outside organizations. That all three were not imitated and are all closed is the best indication of the limits of this model.

The Global Mercury Project (GMP), which has projects in Brazil, Indonesia, Laos, Sudan, Tanzania, and Zimbabwe is exploring a different model. Instead of static centres, the GMP would build Transportable Demonstration Units, or TDU (Veiga, 2004b). These units would demonstrate a variety of technical options for gold concentration, amalgamation and retorting to miners; the miners themselves would be able to select what is affordable, appropriate and durable for their own operations. Being transportable, the TDU would be able to visit several areas and educate a far wider range of miners than was possible with the static processing centres. Local processing centres would feel less threatened, as the TDU would not be a competing processing operation. Problems of land tenure, services, mineral rights, etc., involved with processing centres would be avoided and the TDU would be able to easily change and adapt new pieces of equipment used for demonstration. While the TDU would be dependant on aid money, it avoids many of the short falls of central processing centres and may be a more successful model for technology transfer to ASGM. However, for a large country such as China, for an idea like the TDU to be widely implemented would require the close cooperation of government at all levels.

5.4 ASGM and Policy

Despite the serious negative impacts of amalgamation and the presence of real technical alternatives, few governments have implemented effective ASGM policies with any measure of sustained success. Andrews-Speed *et al* (2003c) identifies three main barriers to the effective management and regulation of ASM:

The first is a combination of political opposition, vested interests and ineffective government. A policy for small-scale mining can only be implemented effectively if the interests of most or all relevant parties are adequately addressed. The second impediment is the inadequate or inappropriate nature of national regulatory regimes for small-scale mines, which includes both the system of laws and regulations and the institutional structure. The third obstacle is a lack of financial resources to implement policies.

This reflects the situation in China. Politically, many figures in higher levels of government simply see ASGM as a problem, and want to shut it down rather than create a viable framework within which it can exist. On the other hand, local governments, who often depend on ASGM tax revenue and employment, are cautious about cooperating with any efforts that may potentially disrupt their income. Concerning regulations, the effort to simply ban mercury led to mines either continuing amalgamation illegally or convincing local governments to ignore the mercury ban and issue local permits. The policy and regulatory regime simply do not encourage honesty or the responsible use of mercury. The lack of financial resources to successfully implement policies is a combination of the sheer scale of China and the lack of political will to use tax dollars to address the issue. Any effort to address the problems of amalgamation in ASGM must recognize these barriers and work toward overcoming them.

6 Limitations and Bias

The results of this thesis were restricted by several limitations. These include:

- **Language and Culture:** The author, while generally functional in Chinese, is hardly fluent. The interviews from the first trip to “Gold Mountain” and the trips to Guangxi and Inner Mongolia were somewhat limited due to the lack of an interpreter. However, the miners seemed more at ease without the presence of interpreters, as an interpreter indicates wealth and/or government connections. This ease can be demonstrated by the fact that the closest and most fruitful relationship developed over the course of this research was with the “Gold Mountain” miners, where the initial relationship and trust was built without the presence of an interpreter. Interviews, by necessity, were often informal and incomplete.
- **Access to Government Information:** The Chinese government probably has various reports on ASGM and mercury that would not be available to the author.
- **Government:** This research was not undertaken through official government or academic channels, primarily since such approval, if available, would have been costly and time consuming. Since amalgamation is largely illegal, miners were often cautious about discussing their practices, and site visit locations and interviewees often were obscured.
- **Medical Training:** A lack of medical expertise available restricted the ability to effectively judge the health impact of mercury use by ASGM miners.
- **Equipment:** The financial and geographical logistics of the site studies were such that it was impossible to take equipment for onsite mercury or gold analyses, or to keep biological samples for later testing.
- **HgEX:** HgEX was validated for the Amazon and for northern Canada. It may not be relevant in the sites examined in China.
- **Test Samples:** The samples sent for test work were clearly from different ore bodies, which greatly restricted the ability to compare between results. In addition, the “Gold Mountain” miners collected the samples, making it difficult to verify that the samples were representative.

A simple method of categorizing systematic research errors is to classify them in two general classes: selection and observation bias (Hennekens and Buring, 1987). Due in part to the above limitations the following bias are noted:

- Selection Bias
 - Site Visit Regions: Site visits were chosen to represent several different regions of China, however, a limitation was that all of the sites had to be reasonably accessible by public transportation. All sites visited were less than one day's travel from an urban center, a necessity as many rural village hotels are barred from accepting foreigners. This excluded ASGM sites in the most remote areas or in government restricted areas. It may be reasonable to assume that the more remote areas practice less safe processing methods than in areas relatively accessible to urban commercial and educational centers.
 - Site Visits and Interviews: Mines and processing centers could only be studied if the miners were willing to cooperate with the research. Outright illegal miners had little incentive to agree to site visits or interviews, and these miners' operations may have been less safe than operations willing to cooperate with the author.
 - Test Work Samples: The test work indicates that the samples may not have been representative. The high gold grade and slow leaching nature of the feed sample, and the high gold grade and mercury content of the muller mill tailing sample, indicate that they may have come from ores the miners were having difficulty processing. These samples may have exaggerated both the gold grades and the difficulty of processing of ores in "Gold Mountain".
- Observation Bias
 - Interviewer Bias (A), Observing for Indications of Mercury Poisoning: While the thesis indicates a low number of mercury poisonings, this could be due more to a lack of medical knowledge than an actual absence of illness. Systematic testing by skilled personnel could reveal far more

extensive mercury related health impacts. Only the most extreme cases could be observed.

- Interviewer Bias (B), Observing for Mercury Bioaccumulation: The lack of mercury analysis equipment meant it was impossible to demonstrate bioaccumulation in local aquaculture. Without verification, the bias was that bioaccumulation was not a serious factor.
- Interviewer Bias (C), Research Cooperation with Miners: Working with ASGM miners directly, instead of working through official channels, tended to bias the author in favour of the miners and local communities. Much of the research depended entirely on the good will of local government officials and miners. Many interview questions dealt with sensitive issues for the miners and the answers were not necessarily honest, but were still valuable.
- Recall Bias, Miner Estimates: The lack of assay equipment (or even scales) meant that miners often needed to be taken at their word for their estimates of grades and recoveries. Based on some discrepancies outlined in Chapters Three and Four, it is assumed that miners exaggerate their recovery rates and mislead with regard to their gold grades and mercury use.
- Misclassification Bias, Mercury Source: As mentioned in Chapter Five, China hosts many industries that emit or release mercury into the environment. Any ill effects due to mercury may not necessarily be due to ASGM.

These biases would have been difficult to overcome during the course of this research, primarily due to the lack of initial study on the topic and due to limited funds. However, additional research could easily overcome these limitations.

7 Areas for Additional Research

Several gaps in knowledge or practice were identified, including:

- Great uncertainty about the actual gold production of, income generated by, and number of people employed in ASGM in China.
- A lack of understanding regarding many details about the legal status and tax structure of ASGM in China.
- An incomplete picture of the role of women and children in ASGM in China.
- Uncertainty regarding the risk of mercury vapour poisoning due to the smelting of zinc strips following amalgamation and cyanidation.
- Uncertainty about the effect of cyanidation on amalgamation tailings. This preliminary work will be followed up by further research at the University of British Columbia under the direction of Dr. Marcello Veiga.
- Uncertainty about the amount of mercury that reports to the zinc strips versus the final tailings following the cyanidation of amalgamation tailings.
- A need for case studies to verify the feasibility of replacing whole ore amalgamation of hard rock ores with gravity concentration.
- A poor understanding of the effectiveness of muller mills for comminution versus more standard methods of hammer, ball, or rod mills.
- A gap in the understanding of mercury releases from industrial sources in China.

Toward the end of addressing many of these gaps, the following recommendations are suggested:

- A thorough socio-economic baseline study of at least one ASGM community should be undertaken, using a method such as the Department for International Development's (DFID) Sustainable Livelihoods approach (DFID, 2001).
- A proper environmental impact study of the behaviour of mercury in the environment due to ASGM should be undertaken in at least one area.
- A comprehensive epidemiological study regarding exposure to mercury and the resulting health impacts on the ASGM population should be completed in at least one community.

- Following the three studies listed above, the data obtained should be used to validate HgEX for China.
- An organization should be built to coordinate these and more studies and to share the information learned with miners, researchers, policy makers, and the international community.

To this end, the author has been instrumental in assisting in the creation of an organization called the Communities and Small-Scale Mining Regional Network in China (CASM-China). CASM-China aims to bring together a wide range of people involved in artisanal and small-scale mining in China, within the context of poverty alleviation and sustainable communities (See Appendix I for further details).

In addition, one of the initial aims of this research was to discover if Chinese methods of dealing with these environmental and health problems could be applicable to other parts of the world, or if techniques developed outside of the PRC could be used by the Chinese. The “Gold Mountain” retort has already been successfully introduced into Colombia (Sandoval, 2003), Venezuela (Veiga and Gunson, 2004), and Laos (Veiga, 2004a), and has been shared with the international community through two papers (Hinton et al, 2003; Gunson and Veiga, 2004). Centrifugal concentrators were introduced to the ASGM community of “Gold Mountain” in 2002. China also provides numerous examples of integrating ASM with a diversified rural economy; “Gold Mountain” meshes specialty agricultural crops, grain crops, tree farming, small-scale manufacturing, gold mining, iron mining, sand and gravel operations, and dimension stone quarries. CASM-China can help to further facilitate the exchange of best practices around the world.

8 Conclusion

The interviews, field studies, and test work undertaken for this thesis lead to the following main results and conclusions:

- ASGM in China employs 463,000 ASGM miners producing around 61 tonnes of gold, in regions all over China, with almost 3.5 million dependants. ASGM released 237 to 652 tonnes of mercury in 2001 and is easily one of the top sources of mercury releases in China. At the low range of the estimate, ASGM contributes about 40% of the mercury releases due to mining, and whole ore amalgamation in muller mills may be responsible for up to 70% of these mercury releases. At every site and region visited, ASGM operations used mercury, often followed by cyanidation. The HgEX expert system tool was used to demonstrate the potential impact of mercury contamination from ASGM and to indicate that China has a moderate acceptance of amalgamation practices.
- The “Gold Mountain” case study verified that ASGM in China could release significant amounts of mercury, with “Gold Mountain” alone releasing at least one and a half tonnes of mercury per annum. Mercury use represented only 2.8 % of the overall gold production cost, and the ratio of mercury lost per unit of gold recovered for muller mills is from 14:1 to 20:1. The “Gold Mountain” retort was described, representing a simple and inexpensive technology that has the potential to reduce mercury exposure to miners around the world.
- The “Gold Mountain test program further verified the high levels of mercury being released from “Gold Mountain’s” processing centres, with the muller mill tailings mercury concentration reaching 2224 ppm, and the cyanidation tailings reaching 285 ppm mercury, from a background mercury concentration, as indicated by the feed ore, of only 0.78 ppm. Test work completed on the feed sample, grading about 43 g/t gold, indicated that around 40% of the gold was recoverable by gravity methods and that the leaching rate of the ore is extremely slow, perhaps due to the high levels of copper (0.44%) and tellurium (13.71ppm). The test work demonstrated that gravity methods could be introduced to replace whole ore amalgamation, and that increased comminution would help the miners achieve higher recoveries, although amalgamation of gravity concentrates may still be necessary to produce a saleable product for the miners. The muller mill

tailings sample, with a gold grade of 38.1 g/t, indicated that amalgamation had not effectively recovered gold from the initial ore, especially as 43% of the gold in the tailings was recovered, 30% in the first pass without additional grinding.

- The health impacts of mercury releases are of key concern. Mercury vapour pollution, despite the use of retorts, is of primary concern, as demonstrated by a miller who stated that he had been diagnosed with health problems due to mercury exposure. The lower mercury concentration in the cyanidation tailings indicated that much of the mercury from the miller mill is removed by cyanidation, to be volatilized during the zinc strip smelting process. The potential for mercury bioaccumulation exists and should be further investigated; the mercury solubility tests indicate that cyanidation, following whole ore amalgamation, may increase the solubility of the mercury in the tailings.
- Any attempt to address mercury pollution from ASGM must come to terms with the complex socio-economic and political framework in which ASGM in China operates. ASGM operations provide desperately needed employment and tax revenue in remote areas with few alternative economic activities but essentially lacks any formal or informal support from domestic or international organizations.
- Effective policies must be implemented in China to encourage multi-stakeholder cooperation, and laws and regulations with which ASGM is reasonably able to comply must also be implemented. Building an effective policy toward minimizing mercury releases from ASGM would require significant political support at high levels, effective cooperation with local governments, and genuine dialogue between artisanal and small-scale miners, local communities and governments, and experts. An effective policy would require a multi-pronged approach to the issue, involving regulatory initiatives, organization, education and training, and financial support.

Ultimately this thesis found ASGM and the use of amalgamation to recover gold widespread throughout China and that it was the cause of significant environmental and health problems. Existing alternative technology could dramatically reduce the impact of ASGM and significantly reduce mercury releases. Furthermore, the practices of whole ore amalgamation and of following amalgamation with cyanidation should be eliminated.

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Appendix I

CASM-China Inaugural Meeting Report

Inaugural Meeting Report

To the Communities and Small-Scale Mining (CASM) Secretariat regarding the
Communities and Small-Scale Mining Regional Network in China (CASM-China)
Inaugural Meeting



Shen Lei
AJ Gunson
Philip Andrews-Speed

January 2004

Forward

The Communities and Small-Scale Mining Regional Network in China (CASM-China) held its inaugural meeting in Beijing from January 5-7, 2004. CASM-China aimed to bring together a wide range of people involved in artisanal and small-scale mining (ASM) in China, within the context of poverty alleviation and sustainable communities. Opinion within the country is sharply divided between those who see ASM activity as harmful and unnecessary and those who see it as essential for local development. This meeting broke new ground by including discussions that encompassed a full range of ASM issues.

During the course of the meeting 43 participants from 24 agencies met together and discussed how an effective network will be organized and what goals can be achieved in China's complex and often sensitive ASM sector. These agencies included:

- Seven departments in the Ministry of Land and Mineral Resources (China Mining Association, Department of Mineral Exploitation, Senior Consultancy Center, Information Center, Center of Land and Mineral Legal Affairs, Academy of China Geological Environmental Monitoring, and the Academy of Land Resources Economics);
- The State Safety Production Supervisory Bureau;
- Two institutes in the Chinese Academy of Sciences (the Institute of Geographic Sciences and Natural Resources Research and the Center for Eco-Environment),
- One institute in the Chinese Academy of Social Sciences (the Institute of Quantitative Economy and Technical Economy);
- Four universities (China Renmin University, Shanxi University of Finance and Economy, Chongqing University, Liaoning University of Technology at Fuxin);
- Three provincial agencies (Bureaus of Land and Mineral Administration of Yunnan, Chongqing, Shanxi), and;
- Two local agencies (Shahe City in Hebei province and Shanghang county in Fujian province).

Representatives from the Canadian Embassy, Rio Tinto, and BHPBilliton attended the second reception dinner, as well as Dr. Philip Andrews-Speed, from the University of Dundee and AJ Gunson, from the University of British Columbia.

In addition to summarizing the meeting, this report details CASM-China's organization, budget, goals and work plan for 2004. The total expense for hosting the meeting was under budget at USD \$7,786.29. The meeting marks a promising start for the network, and was well received by the participants, who were eager for the opportunity to discuss the role of ASM in China.

CASM-China Background

Following CASM's September 2003 Annual Meeting in Elmina, Ghana, Shen Lei, AJ Gunson, and Philip Andrews-Speed submitted a proposal to create CASM-China. In November 2003 CASM accepted the proposal and in December 2003 provided CASM-China with the terms of reference and the initial payments. Formal planning for the inaugural meeting began in November 2003 under direction of the organizing committee, composed of the initial proponents.

Meeting Agenda

There were three main goals for CASM-China's inaugural meeting:

- To bring together and form a network of a wide range of ASM researchers, experts and government officials;
- To design a practical organizational structure for CASM-China; and
- To build an initial work plan for CASM-China.

The agenda was set by the organizing committee and was intended to provide plenty of time for the participants to meet each other and discuss informally the issues raised during the meeting.

Table 1: Program of Events

CASM-China Inaugural Meeting Program of Events	
5th January 2004	
14:00	Registration
16:00	Introductions
18:30	Welcome Dinner
6th January 2004	
08:30	An overview of ASM in China (SL)
09:30	An overview of ASM and the international experience (PAS)
10.30	An introduction to CASM and the concept of sustainable ASM communities (AJG)
11:30	Questions and discussion
12:00	Lunch
14:00	Inaugural Business Meeting for CASM-China
18.30	Dinner with international stakeholders
7th January 2004	
8:30	Final wrap-up session
11:30	Closing

Meeting Summary

Monday, January 5, 2004

The meeting began at 4:00PM at the Beijing Foreign Experts Building, in northern Beijing. After a brief introduction by Shen Lei, all of the participants introduced themselves in turn, explained their experience with ASM, and described what they expected to get out of the meeting. As many of the participants were not familiar with each other, it was important to provide adequate time to get to know one another. This format is unusual for China, where often only the highest-ranking people present are given time to speak.

Following introductions, the participants met informally over dinner. After dinner, the organizers met with participants with three Chinese ASM officials with some authority to discuss the potential roles of CASM-China

Tuesday, January 6, 2004

At 8:30 AM the meeting reconvened for three presentations.

Shen Lei presented on the overall state of ASM in China. He reviewed the diversity and scale of Chinese ASM, the recent history and government policies toward ASM, and the positive and negative impacts of ASM in China.

Philip Andrews-Speed discussed the overall state of ASM around the world. He reviewed changes in the international community's approach toward ASM and key current questions facing policy makers and development agencies with regard to ASM. He touched on characteristics distinguishing ASM from formal mining, the costs and benefits of ASM, ASM government policy internationally and the difficulties of effective ASM policies, and methods by which ASM policies could be improved.

AJ Gunson presented on CASM's structure, vision, role, and activities. He stressed the importance of using ASM as a tool for poverty alleviation on the road toward more sustainable communities. He then discussed the potential for CASM to cooperate with CASM-China and a possible structure and role for CASM-China.

Following an informal lunch, the meeting resumed with a discussion of the costs and benefits of ASM in China. Participants noted that the ASM debate in China encompassed a wide range of topics including safety and health, environmental protection, industrial distribution, and rural poverty reduction. They also commented that the Chinese media and government usually only focused on the negative aspects of ASM in China. With a view to the broader issues, participants discussed current ASM policies in China and the potential for change. One main issue discussed was the legal definition of small-scale mining in China and its legal implications regarding mineral resource law. In particular, participants were concerned about creating a clear boundary between formal large-scale mining and ASM. Participants recognized that a new national policy toward ASM is vitally necessary. Some participants argued that in the future the central government cannot continue to close small-scale mines without providing any compensation for the

miners. In addition, the relationship of poverty reduction with ASM and health, safety and environment training were discussed.

After the discussion the participants reconvened for a more formal dinner with representatives from the Canadian Embassy, BHPBilliton, and Rio Tinto. The international participants expressed great interest in the situation of ASM in China and looked forward to cooperating more with CASM-China in the future.

Following the meal, the organizers met with four ASM officials from rural communities to discuss the role and structure of CASM-China and potential for future CASM-China activities and projects.

Wednesday, January 7, 2004

At 8:30AM the meeting continued with a discussion of the future structure and role of CASM-China. Participants fully recognized the importance and necessity of creating a multidisciplinary network approach to ASM in China. The importance of formalizing CASM-China and registering officially was stressed. Registering CASM-China independently was perceived as time-consuming and difficult. Not registering in some capacity is illegal. It was decided that the best option was to give CASM-China a home within the China Mining Association, which has a ASM department. The importance was stressed of using CASM-China's webpage for sharing both Chinese and international reports and papers on ASM. An online discussion forum was also deemed important. Participants recommended that CASM-China cooperate with the China Mining Association and a county level government to host a local meeting with a wide range of stakeholders to discuss the role of ASM and the potential for using ASM as a vehicle toward poverty reduction and more sustainable communities. Participants also decided to both widen the CASM-China network's membership nationally and deepen CASM-China locally. Shen Lei thanked the participants for their involvement and hard work. Philip Andrews-Speed thanked Shen Lei and his assistance for organizing the meeting and making it a success before closing the meeting.

Key Meeting Achievements

Over the course of the CASM-China Inaugural Meeting the following main results were achieved:

- The participants acknowledge as timely and of key importance the establishment of the CASM-China Regional Network. All participants fully recognized the necessity of further study on the issues of small-scale mining in China; while China's small-scale mining faces great challenges, it holds huge potential.
- Participants recommend that CASM-China become a legal organization under the China Mining Association (CMA). The CMA has broad and direct links with local small-scale miners and is closely involved with the administration and research on ASM in China. Further discussions with the CMA are required to formalize the details.
- Fu Mingke, previous Director General of Department of Ministry Exploitation in Ministry of Geology and Mineral Resources (now renamed the Ministry of Land and Resources), recommended that Shen Lei be appointed as the Director of the Small Scale Mines Committee in the China Mining Association (CMA) after CASM-China is linked with the CMA.
- The Senior Consultancy Center and the Center of Land and Mineral Legal Affairs, both in the Department of Land and Resources, also expressed interest in hosting CASM-China.
- While it was recognized that Chinese government officials and experts had made many great efforts to study and resolve ASM issues and done lots of studies on China's small-scale mines, there is still much work to be done. Participants recognized the importance of cooperating with international organizations such as the World Bank, UNIDO, and the ILO, both in order to share China's experience with other nations and to learn from the international experience.
- Participants recognized that of the many issues challenging Chinese ASM, the issues of regularization, environmental protection, health and safety and poverty alleviation should be given priority in future action plans.

CASM-China Work Plan 2004

Based on the outcome of the Inaugural Meeting, a work plan and budget for the rest of 2004 is shown in Table 2 on the next page. This work plan includes; formalizing CASM-China, developing the Chinese-language web-based knowledge center, hosting local stakeholder meetings, and formalizing a national policy paper. In early February 2004, CASM-China will initiate the work plan, starting with the formalization of CASM-China under the China Mining Association.

Table 2: CASM-China Work Plan and Budget 2004

Activity	Details	Budget	
		Projected (USD)	Actual (USD)
Inaugural Meeting	Held January 5-7, 2004		7,786.29
CASM-China Formalization	Set up CASM-China as a department under the China Mining Association (CMA)	In-kind contribution from the CMA	
Webpage Development	• Translate and make available key Chinese and international ASM legal and policy documents	1000.00	
	• Setup a discussion forum to share ideas and link agencies and individuals together	500.00	
Local CASM-China Meeting	• Co-host two pilot multi-stakeholder meetings in ASM counties with the CMA	3,000.00 + local county and CMA	
	• Report meeting results back to CASM-China		
Expand Network Nationally	Meeting participants are to reach out to their counterparts in ASM areas unrepresented at the meeting	In-kind contribution from participants	
Expand Network Locally	Rural meeting participants are to reach out in their communities to inform and involve other ASM stake-holders	In-kind contribution from participants	
CASM Annual Meeting	Send at least one CASM-China representative to the 2004 CASM Annual Meeting to report on CASM-China's activities	1,500.00	
National Policy Paper	Write a policy paper on ASM, poverty reduction, and sustainable communities to be presented to the Chinese State Council	500.00	
Projects	• Approach the China Science Foundation for cooperation studying the impact on communities of ASM coal mine closure and the potential for alternative sources of income	100.00	
	• Approach the ILO and the State Safety Production Supervising Bureau for cooperation on a pilot mine safety project	100.00	
	• Approach UNIDO and the Chinese Academy of Science for cooperation on a pilot mercury reduction project	100.00	
CASM-China 2005 Meeting	Begin planning and fund raising for the second annual meeting of CASM-China	300.00	
Transaction Costs	International money transfer fees, photocopying costs, and phone fees.	213.71	
Total		7,213.71	7,786.29

Figure 1: CASM-China Inaugural Meeting



Summary

CASM-China's Inaugural Meeting marks a promising start for the organization. Participants from around China were successfully brought together to discuss ASM in the context of poverty reduction and sustainability. A plan to formalize CASM-China under the China Mining Association was developed. As detailed in the work plan, much work remains to be done, including registering the organization, developing the webpage, holding a pilot local ASM stakeholder meeting, expanding and deepening the network and investigating potential projects.