THE IMPACT OF TECHNOLOGY ON THE WORLD MARKET SHARE OF U.S. GOLD PRODUCTION

by

Michael C. Nettesheim

T-3549

A thesis submitted to the Faculty and the Board ~~of~~ Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Mineral Economics).

Golden, Colorado
Date 4/12/88

Signed:
Michael C. Nettesheim

Approved:
Roderick G. Eggert
Thesis Advisor

Golden, Colorado
Date 4/12/88

John E. Tilton
Professor and Head,
Department of Mineral
Economics

ABSTRACT

The United States has experienced a dramatic growth in its market share of world gold production since 1979. The possible determinants for this growth are technological advancements, gold price increases, exploration and discovery of bulk-mineable gold deposits, government policies, changes in foreign exchange rates, and other costs of production. Market share growth also has occurred in Canada and Australia, the third- and fourth-largest producers among noncentralized economies. In contrast, the Republic of South Africa, the largest producer in the world, has declined appreciably in market share since the mid-1970s.

The U.S. growth has been motivated by technology developed since the late 1960s. For example, heap leaching has been responsible for a significant portion of its production in the 1980s. This technology has been facilitated by appropriate and necessary geologic endowment. In addition to technical development, Canada and Australia have benefited from the implementation of public policies and currency devaluations.

The United States, Australia, and Canada have experienced benefits provided by the increases in gold price. The portion of responsibility due to price is determined by the price elasticity of each country's bulk-mineable gold supply curve. The United States has a relatively flat, elastic curve, representing the ability to expand output quickly in response to price increases.

This thesis concludes that technological development, in particular heap leaching, in interaction with the effects of gold price, has led the United States to advantageously develop its bulk-mineable gold deposits. This interaction has permitted it to gain comparative advantage in gold production in the 1980s.

TABLE OF CONTENTS

Page

ABSTRACT iii

LIST OF FIGURES. vii

LIST OF TABLES viii

ACKNOWLEDGMENTS. ix

Chapter 1. INTRODUCTION 1

1.1 Overview and Purpose. 1
1.2 Technological Advances. 3
1.3 Scope 5
1.4 Methodology and Outline 7

Chapter 2. ECONOMIC FRAMEWORK 9

2.1 Comparative Costs and Factor Endowment 10
2.2 Impacts of Technology 11
2.3 Impacts of Gold Price 14
2.4 Impacts of Exchange Rates 15
2.5 Impacts of Exploration and Discovery 17
2.6 Impacts of Public Policy. 20
2.7 Impacts of Labor and Other Costs. . 22

Chapter 3. HISTORY OF THE U.S. GOLD INDUSTRY. . . . 25

3.1 The Nineteenth Century. 25
3.2 The Twentieth Century 26
3.3 The Rising Price of Gold. 29
3.4 The "New" Gold. 30
3.5 The New Technology. 34

Chapter 4. THE IMPACTS OF TECHNOLOGY. 35

4.1 Exploration 35
4.2 Mine Development and Extraction . . 36
4.3 Processing. 38

4.3.1 Non-Cyanide Leaching 39
4.3.2 Pressure-Oxidation Process . 42
4.3.3 Heap Leaching. 45

4.4 Recovery. 53

Chapter 5. THE IMPACTS OF OTHER DETERMINANTS. . . . 59

5.1 The Gold Price Motive 59
5.2 Changes in Exchange Rate. 61
5.3 Exploration and Discovery 64
5.4 Public Policy 66
5.5 Labor and Other Costs 68

Chapter 6. CONCLUSIONS. 70

6.1 Technology. 71
6.2 Gold Price. 73
6.3 Exchange Rates and Public Policies. 74
6.4 Exploration and Discovery 75
6.5 Labor and Other Costs 75
6.6 Summary 77

REFERENCES CITED 79

Appendix A: WORLD GOLD PRODUCTION: THE TOP 5 PRODUCERS 83

Appendix B: AVERAGE ANNUAL GOLD PRICES. 86

LIST OF FIGURES

FIGURE Page

2.1 Effect of Exclusive U.S. Technology. 13

2.2 Effect of Gold Price Increase. 16

2.3 Effect of Increase in Value of U.S. Dollar . . . 18

2.4 Effect of Increased U.S. Exploration and Discovery. 19

2.5 Effect of U.S. Public Policy Encouraging Domestic Gold Mining 21

2.6 Effect of Increased Foreign Labor Costs. 23

3.1 U.S. Gold Production by Ore Source 27

3.2 Price-Making Influences for Gold 31

3.3 Bulk-Mineable Gold Deposits in Nevada. 33

4.1 In-Situ Leaching System. 40

4.2 Pressure-Oxidation Circuit at Homestake's McLaughlin Mine. 44

4.3 Heap Leaching System 46

4.4 Dump Leaching System 47

4.5 Treating Heap Leach Solution 55

4.6 Carbon-in-Pulp Process 56

4.7 Merrill-Crowe Process. 56

LIST OF TABLES

TABLE Page

5.1 Foreign Exchange Rates: Major Gold Producers . . 63

A.1 World Gold Production: The Top 5 Producers (Market share in %). 84

A.2 World Gold Production: The Top 5 Producers (MM troy ounces) 85

B.1 Average Annual Gold Prices 87

ACKNOWLEDGMENTS

I wish to thank my thesis committee members, Dr. Rod Eggert, who ably advised, guided, and edited this work; Dr. John Tilton, who planted the topical seed; and Dr. Robert Drury, who supplied some interesting variations on a theme. Richard Kunter of Homestake Mining Company graciously provided me with invaluable technical process information.

I am grateful to John Cuthill of American Copper and Nickel Company, who first suggested that I apply to this department.

My friends in the Mineral Economics Department who helped me formulate ideas and gave me moral support shall be remembered always.

Finally, I thank Lita Dunham for her editorial assistance and Ellen Ewart who inspired me to find the right words.

Chapter 1

INTRODUCTION

1.1 Overview and Purpose

From 1979 through 1986, the U.S. share of world gold production grew from 2.5% to 7.3% (Table A.1). Similar changes occurred in Australia and Canada, all at a time when worldwide gold production increased by 30% (Lucas, 1986). The world's dominant gold producer, the Republic of South Africa, lost a large share of its market during that time. This thesis will examine the reasons why the United States, among other countries, gained such an advantage. Hence, it will not be concerned directly with production increases, but with the increase in market share.

In the 1960s, many U.S. gold mining firms initiated exploration programs which concentrated on locating gold deposits quite different from those prospects targeted previously. A large-tonnage gold find was made in 1961-1962 in northeastern Nevada by the Carlin Gold Mining Company, a wholly-owned subsidiary of Newmont Mining Corporation (Gries, 1979). This deposit was not a typical lode or vein deposit with normally occurring, intercalated zones of various grades of ore. Instead, it contained micron-sized and submicron-sized gold particles disseminated fairly evenly throughout a carbonaceous host rock. This kind of ore became known as "Carlin-type" ore. It is low-grade compared to most gold ores mined in the past. Nevertheless, the amount of gold-bearing rock, or reserve, was large by previous standards. The technical problems associated with Carlin-type ores vary and usually are metallurgical in nature. Prior to the 1960s, no company had processed successfully these hard-to-process, or refractory, ores, and the technology of the times was not completely satisfactory. Because of this situation, Newmont initiated a research and development program in cooperation with the U.S Bureau of Mines (USBM), an agency of the U.S. Department of the Interior, to find a way to efficiently process these new orebodies. Consequently, new technology led to the advancement and expansion of the entire nation's gold industry.

Obviously, there are more reasons for the increase in U.S. market share than merely those of a technical nature. Price, increased exploration, favorable government policies, and exchange rates are all potentially responsible. Nevertheless, since gold mining is such a technically oriented industry, one must look to technological change as a natural remedy to its problems. Thus, the central question of this thesis follows: Are technological advances largely responsible for the gains in U.S. market share in the 1980s? In addition to analyzing these advances, it is necessary also to evaluate the impacts that other factors have had on the market share increase. Have gold prices, exploration and discovery, exchange rates, or governmental policies provided the incentives necessary to elevate the U.S. market share over the shares of other countries? Furthermore, are there other costs which may have influenced market share? The purpose of this thesis is to examine these motives in an effort to determine the quality of responsibility for each in improving market share of the United States in gold production.

1.2 Technological Advances

Each stage of mining has had its share of technological advances. The exploration stage has benefited from improvements in remote sensing, for one. This area of technology ranges from aerial photography to ground geophysics. The advantages and impacts of remote sensing on the U.S. market share will be assessed.

Although technological improvements have been made in the development and extraction stages of mining, they were not changes which provided unusually exclusive or long-lasting economic benefits to the United States. Developments in exploratory drilling, mine tunnelling and engineering, ore deposit location methods, and mine reclamation have been made. Though many of them were developed by the USBM, many have evolved through private and foreign R&D efforts. Consequently, they have diffused quickly from point of origin, virtually giving every nation equal access.

Concerning the processing stage, cyanidation of ores was developed first in the late 1800s in an effort to improve on the gold recovery methods of gravity separation and mercury amalgamation. Though gravity separation is still used infrequently, mercury amalgamation has been eliminated primarily because of its toxicity. Consequently, cyanidation became the primary method of gold processing in the mid-1900s, and heap and dump leaching using cyanide now recover a significant portion of U.S. gold.

Carbon adsorption and zinc precipitation techniques are the primary commercial methods of recovering gold from cyanide heap leach solutions (Hiskey, 1985). With the discovery of gold ores different from those mined in the earlier part of the century, technologies have been developed which economically process a larger amount of ore per recovered ounce of gold metal than formerly had been feasible. Although the technique of heap leaching has been used in the processing of copper and uranium ores for many years, it never has been commercially viable for gold extraction because the economic incentive to process low grade gold ores was not present. Therefore, heap leaching techniques were developed further to economically recover the micron-sized, disseminated gold.

Other types of leaching also have provided benefits. They include bacterial and pressure-oxidation leaching techniques as well as those which utilize reagents other than cyanide. Furthermore, research is ongoing concerning in-situ recovery. As the engineering obstacles of this process are overcome, certain ore deposits will become economical.

1.3 Scope

As alluded to previously, the main area of examination will be the increase in U.S. market share of gold production. The technologies which have contributed critically to the increase, as well as the other factors mentioned will be analyzed and evaluated to determine the quality of their contributions. The Australian and Canadian market increases will be studied insofar as they are related to or similar to those advancements experienced by the United States. The market shares of the centrally governed economies, due partly to the lack of accurate data, as well as those of the Republic of South Africa, will not be evaluated, although their data will be listed for purposes of comparison.

Gold production, market share data, and prices from 1960 to 1986 are presented in the appendices. They were collected and estimated by the U.S. Bureau of Mines, the major source of numerical data for this paper. Data assembled by such entities as Consolidated Goldfields PLC, the South African Geological Survey, and mining industry periodicals are used as general references or cited specifically, but are not considered to have the reliability or continuity of the USBM data. The bulk of qualitative information not gained by the author's practical experience was gleaned from those sources mentioned, as well as government documents, professional journals, and gold texts. No single reference was located that integrated and examined thoroughly the economic and technical aspects.

The period of greatest interest is 1979 to the present. In 1979 and 1980, U.S. market share was less than 2.5% of world gold production. This changed dramatically in 1981 as U.S. share rose beyond three percent, continuing to increase through 1986 when it soared to beyond seven percent. The concurrent increases in Australia and Canada were caused by the same stimuli as those present in the United States. Thus, data from the 1980s are the most pertinent. However, data from 1960 to 1986 are presented in order to provide a quantitative framework in which to analyze the current trends. This database also will be useful when analyzing the potential other determinants of increasing market share, particularly gold price.

1.4 Methodology and Outline

This thesis examines the proposed areas of interest in a qualitative fashion, although employing the use of the databases in the appendices. Table A.1 provides market share data; Table A.2 lists production quantities. Additionally, Table B.1 provides gold prices, real and nominal, for the time period of interest. Chapter 2 establishes an economic framework around which the stated hypotheses can be evaluated. Additionally, graphs indicating the effects of technological development, changes in gold price, exchange rate changes, exploration and discovery, government policies, and labor costs on U.S. market share (and to a lesser extent, on the market share of other major producers)are presented in Chapter 2. Chapter 3 presents an historical look at the U.S. gold industry as well as at the major economic policy changes that have impacted it. Chapter 4 describes and evaluates, in detail, the physical and economic impacts of the major technologies used worldwide throughout the gold industry. Chapter 5 analyzes other possible determinants of the aforementioned increases in market share, based partly on the graphs presented in Chapter 2. In conclusion, Chapter 6 qualitatively summarizes the responsibility of each determinant.

CHAPTER 2

ECONOMIC FRAMEWORK

The central hypothesis of this thesis is that technology has had an appreciable impact on the share of the U.S. gold industry in the world market, particularly since the late 1970s. Nevertheless, other determinants do exist and the relative importance of each must be evaluated if the analysis is to be complete. This chapter provides an economic framework in which to analyze these impacts. The underlying equation governing the concepts to be examined is

$$MS = f(Qs) = f(P, T, E\&D, G, XR, C).$$

The market share (MS) of any producing country is a function of the quantities supplied (Qs) by it and other producing countries, which in turn, is a function of the gold prices (P), technology (T), exploration and discovery of gold (E&D), government policies (G), changes in exchange rates (XR), and other production costs (such as labor, and the costs associated with climate and location) (C). Except for prices and exchange rates, all these variables are <u>directly</u> related to costs. Furthermore, in the case of the United States and, to a lesser extent, Australia and Canada, the particular geologic endowment is important. Bulk-mineable deposits, also referred to as disseminated, Carlin-type, and microscopic gold deposits, have played a major part in the advances in market share, particularly in the way they influence the variables in the equation. The United States has developed a greater comparative advantage than Australia or Canada, and as the primary subject of this thesis, generally will be represented in the graphs in this chapter. Nevertheless, in some cases as noted, Australia or Canada provide better examples for the specific effects examined.

2.1 Comparative Costs and Factor Endowment

A vital component of international trade theory is the doctrine of comparative costs, developed in the early 1800s by David Ricardo. It says that states will produce and export those goods whose domestic costs of production are low relative to other products when compared to production costs in other states (Tilton, 1983). This doctrine and other concepts developed by the neoclassical and modern economists try to explain why some countries enjoy comparative cost advantages. The Factor Endowment Theory, developed by Hechscher and Ohlin in the early 1900s, applies well to gold mining due to the nature of the industry. Production of primary gold reflects the availability of natural resources, or the physical endowment of a country. Thus, endowment is the basis upon which all factors interact to create a comparative cost advantage.

2.2 Impacts of Technology

Technology is not an independent factor, but interacts with all the aforementioned determinants. Although technology is an initial cost for the gold mining industry, the benefits gained in the medium- to long-run often exceed the costs of R&D. The developers of technical improvements are usually the leaders in the industry who have accrued profits from previous, successful operations. Nevertheless, many small operators have developed techniques which have been adapted later for larger endeavors. The concept to be understood is that technology is a fulcrum upon which all the other motivating factors to be examined must rely, and its benefits are often timeless and without restriction. This implies a basic fundamental concept that technology has a tendency to diffuse unless the applications are limited.

As gold prices rose dramatically in the late 1960s and again in the 1980s, profits were earned by mining companies that subsequently reinvested them in new and existing properties. Those with foresight also invested in the R&D of gold processing technologies in an effort ultimately to recover previously unrecoverable or economically infeasible deposits. In this manner, technical methods such as heap leaching and carbon adsorption evolved or were improved, taking advantage of the newly discovered disseminated and Carlin-type deposits.

Technology has a predictable impact on production quantities. Generally, as its application diffuses throughout the world, no advantage to individual countries is maintained. This assumes ceteris parabis, including the conditions that deposits are similar across countries and lag effects are unimportant. The cases of the United States, Australia, and Canada differ from this rigid scenario insofar as their endowments and technical developments are respectively unique. In particular, the United States has disseminated gold deposits amenable to cyanide heap-leaching techniques. Thus, it has exhibited dramatic gains in gold production primarily because it has developed technologies which successfully process and recover those unique resources. Figure 2.1 illustrates this U.S. market share increase, showing how an exclusive

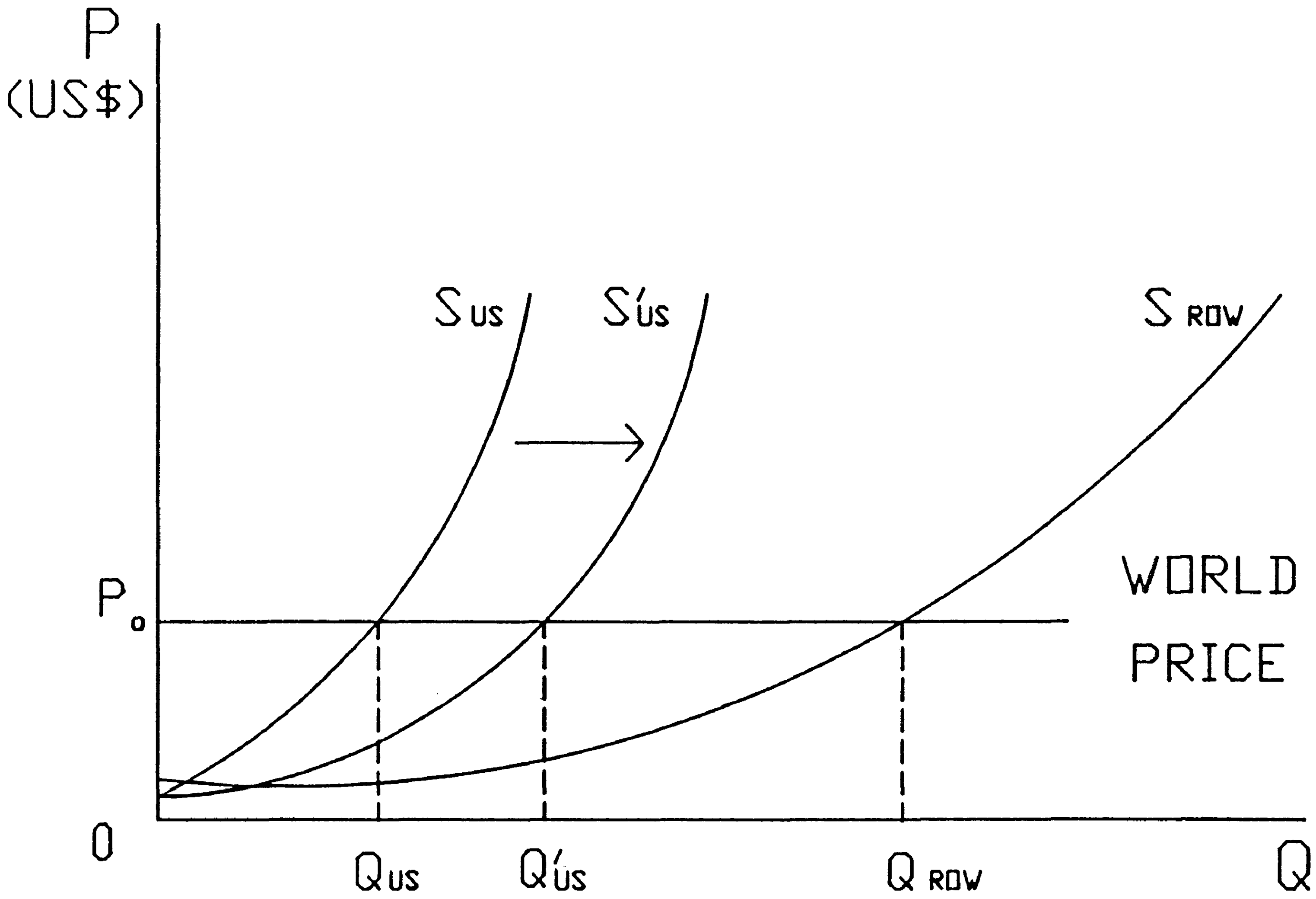


Figure 2.1: Effect of Exclusive U.S. Technology
(U.S. and Rest of World)

technology, such as heap leaching, reduces the total costs of production, shifting the supply curve (Sus) downward and to the right, and permitting larger quantities of gold to be processed at a lower cost. Meanwhile, the curve of those producers (Srow) who do not have the technical expertise to develop potential reserves remains stationary. This static condition not only illustrates the lack of technical expertise, but also reflects the necessity of a country to have access to the appropriate endowment upon which to implement the technological development.

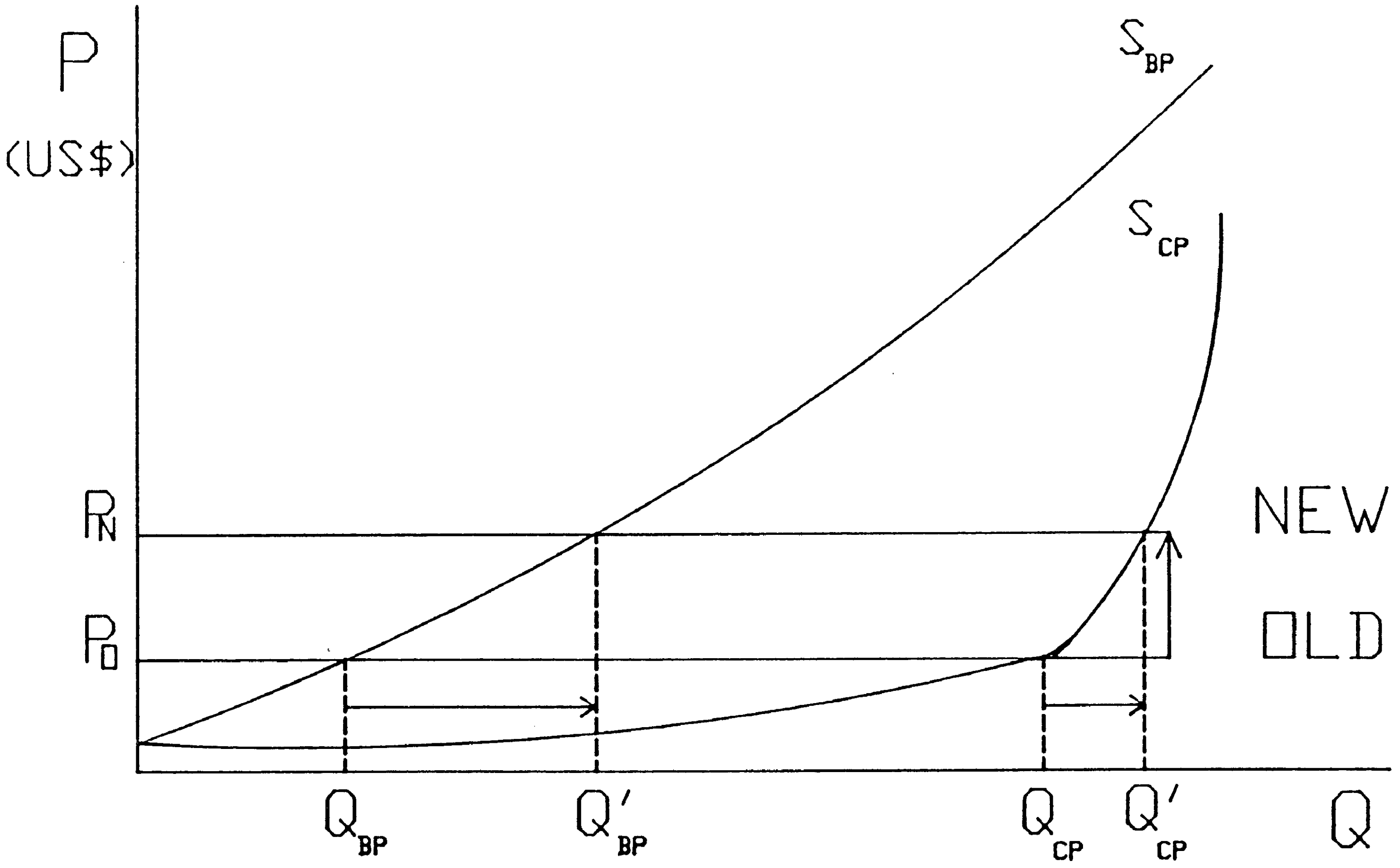
2.3 Impacts of Gold Price

Price is a dynamic and often noticeable driving factor behind the production of any good. But gold mining is an industry coping with appreciable lag times which inhibit normal production plans. Producers generally do not react to gold price fluctuations immediately. Thus, market share changes usually require several years in which to evolve.

Because gold price is uniform worldwide, all producers tend to supply more as the price rises, providing no long-term advantage to individual producers. This theory assumes equivalent endowments and capacities, as well as unfulfilled demand. In reality, each country has a unique capacity to develop and process its ores, having a different price elasticity of supply. Figure 2.2 illustrates how a producer that has a limited base of typically low-cost, bulk-mineable reserves lacks the capability to expand operations in response to rising gold prices. This conventional producer (CP) is nearly at its capacity constraint at the old price, thereby receiving little additional benefit at the new price. The country with a relatively large bulk-mineable reserve base and the technical capacity to develop it (BP represents the United States and, to some extent, Australia and Canada) finds significant incentive in increasing gold prices. Thus, Figure 2.2 shows how a given price increase results in a greater percentage increase in production for bulk-mineable producers than for those lacking that capability.

2.4 Impacts of Exchange Rates

Exchange rates do not affect directly the market share of the U.S. producers, but do influence the market share and production of other producers. This phenomenon exists primarily because gold is valued worldwide in U.S. dollars. Therefore, production costs (when valued in U.S. dollars) for foreign producers move with changes in the exchange rate, with the U.S. share increasing or declining



BP: producers with large reserves of bulk-mineables
CP: producers with small reserves of bulk-mineables;

Figure 2.2: Effect of Gold Price Increase

relative to the foreign producer's share. Figure 2.3 illustrates how U.S. gains in market share can result from a falling dollar, or rising foreign exchange rate. (A reminder: a rising foreign exchange rate means that more dollars are necessary to buy a unit of foreign currency.) As the dollar falls, foreign costs rise, motivating a left, upward shift of the foreign supply (marginal cost) curve. Thus, the relative position of the U.S. cost curve improves, giving it a larger portion of world production.

2.5 Impacts of Exploration and Discovery

Assuming no imminent limit to gold demand, exploration and discovery can provide a market share increase to a producer who can bring a mine on line in a relatively short amount of time.

Exploration and discovery of disseminated gold deposits in the United States, Canada, and Australia have expanded reserve bases, thus new sources of production, for those countries. Because this type of gold deposit often is amenable to inexpensive solution recovery techniques and generally not endemic to South Africa, the world's largest producer, it is a motivating factor behind increased market shares. Figure 2.4 illustrates this simple effect, graphically identical to the effects of implementation of

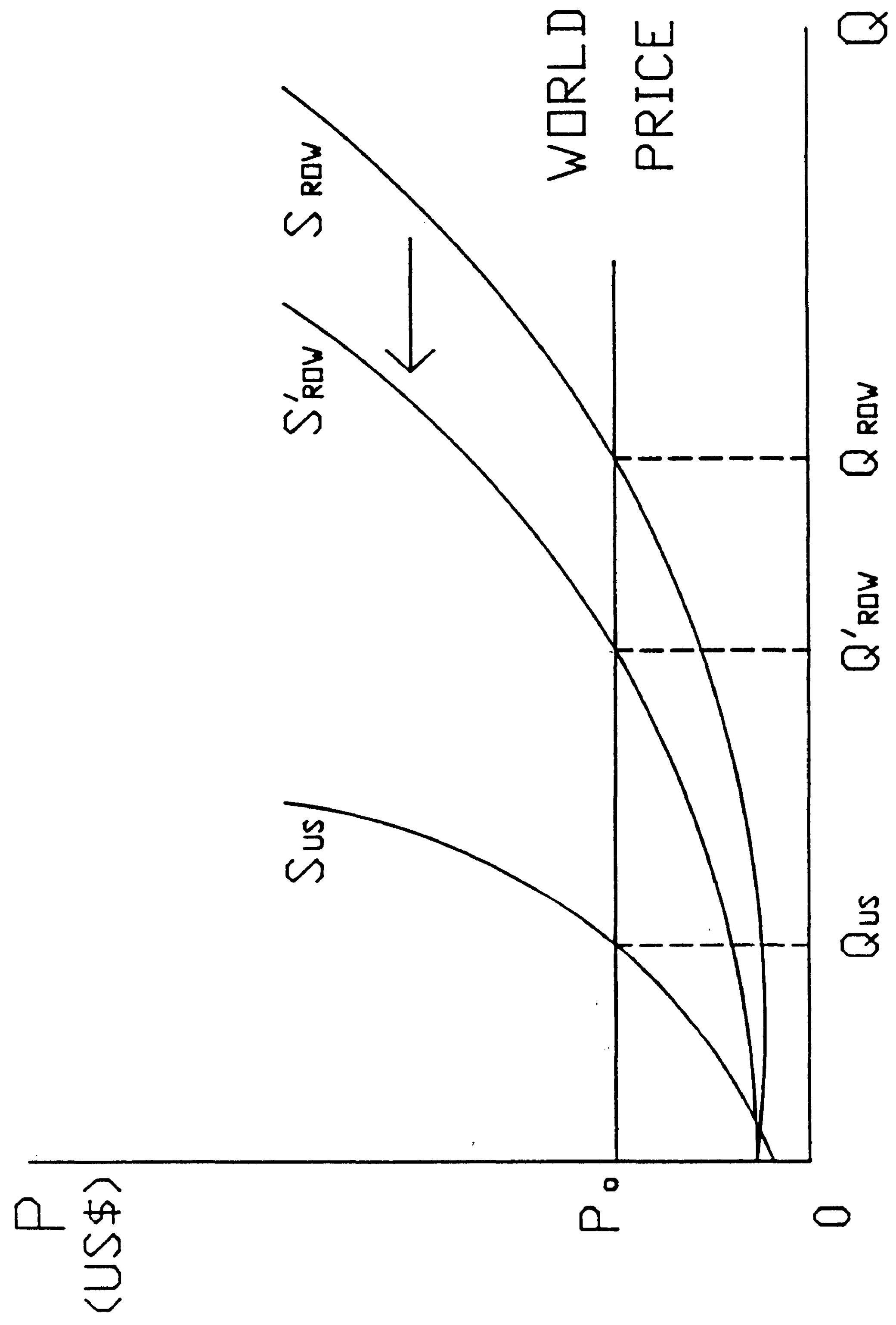


Figure 2.3: Effect of Increase in Value of U.S. Dollar (U.S. and Rest of World)

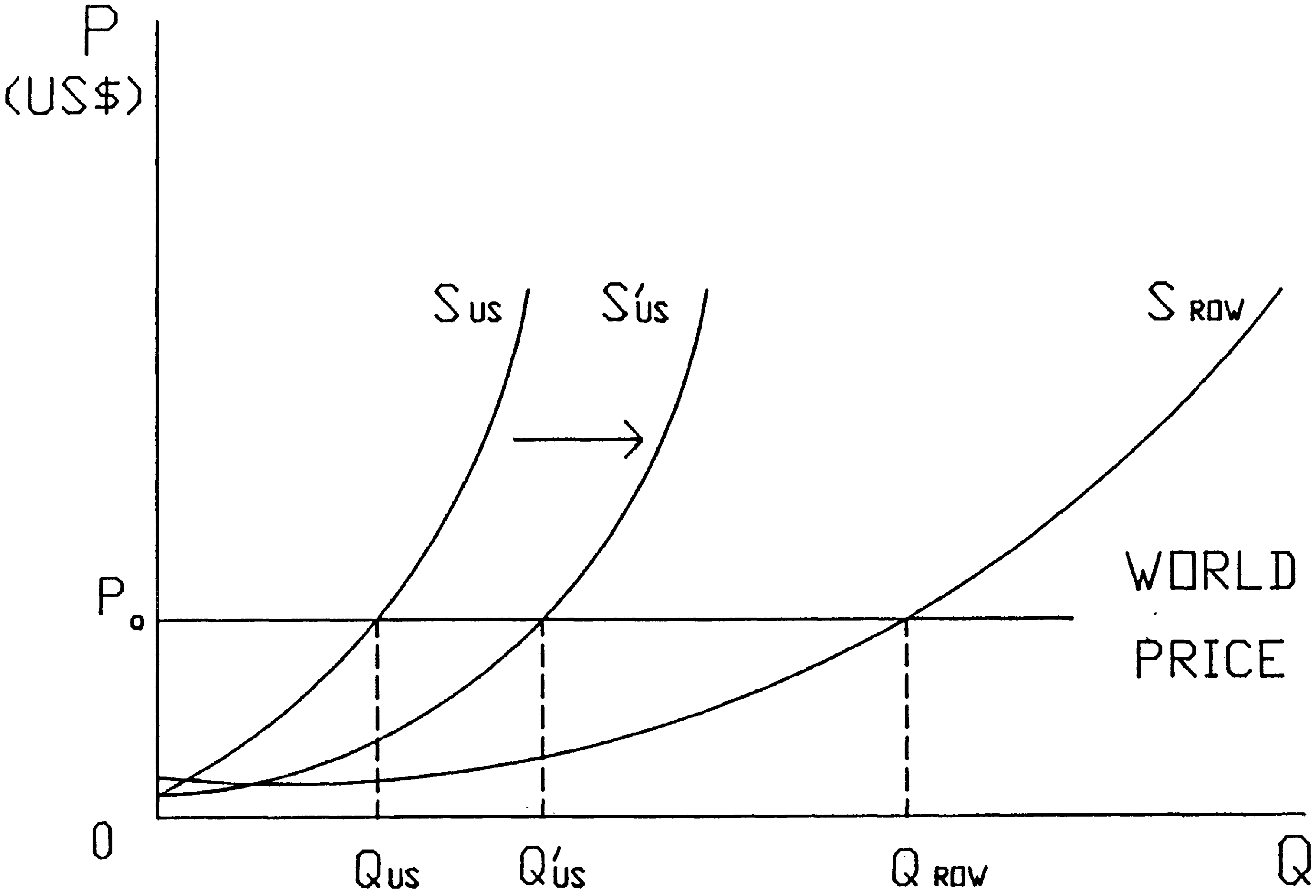


Figure 2.4: Effect of Increased U.S. Exploration and Discovery
(U.S. and Rest of World)

exclusive technology. As the United States and certain others discover more of the bulk-mineable deposits, their supply curves move right and downward, indicating improvement in share of world production.

2.6 Impacts of Public Policy

Public policies can provide benefits to a gold producer or discourage production. In the United States, government policies have not influenced domestic gold producers as much as they have energy producers. This may be because gold mining in the United States is such a minor contributor to gross domestic production. Although corporate tax changes may have made some small impacts on gold miners over the years, their overall effects have not been of consequence to most operations. Nevertheless, public policies do affect mining significantly elsewhere around the world. Australian and Canadian gold miners have benefited appreciably from government policies, and Chapter 5 will examine those effects in greater detail.

Figure 2.5 illustrates the potential effect of positive government policy on gold producers. Government encouragement in the form of tax and investment incentives motivates production, causing the supply curve to shift right and downward as unit costs fall. Conversely, a left

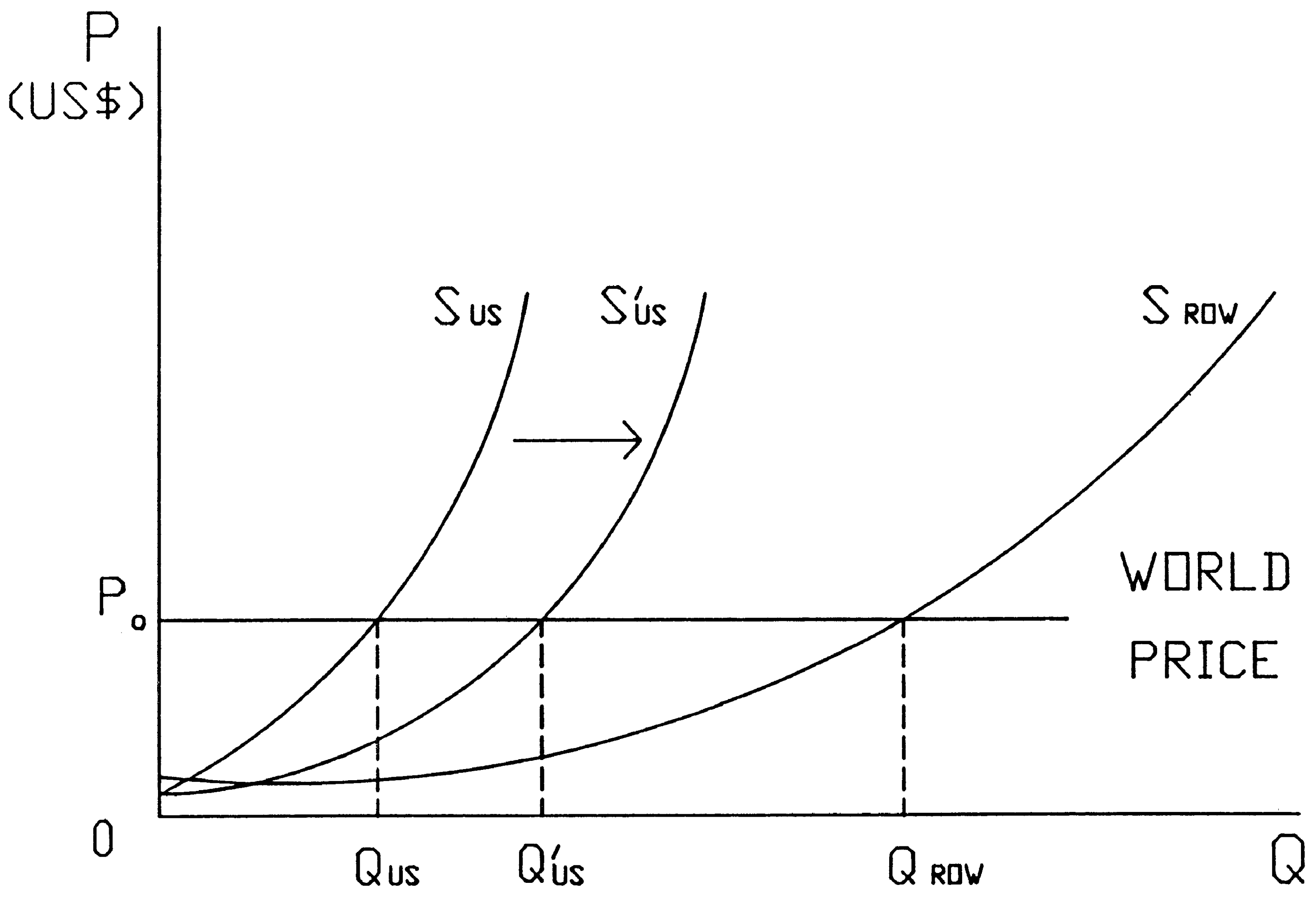


Figure 2.5: Effect of U.S. Public Policy Encouraging Domestic Gold Mining (U.S. and Rest of World)

and upward shift of the supply curve reflects a negative impact, a decreasing capability to absorb additional costs imposed by public policy.

2.7 Impacts of Labor and Other Costs

As mentioned earlier, there are many types of mining costs. They are quantified and qualified in several different ways. Production costs are the easiest to define and refer to the variable costs of labor, supplies, administration, and inventory. In the case of U.S. surface mines, labor costs are negligible compared to those for an underground mine, such as those in South Africa. Nevertheless, for purposes of simplification, Figure 2.6 illustrates the impacts of labor costs. As foreign labor costs rise, those producers will cut back on production (their supply curve shifts left), leaving the low-cost U.S. producers in a position which reflects a larger market share.

Probably the largest share of total costs to a gold producer is that of capital costs. The average surface mine in the United States may have half of the capital costs of the average underground mine. This is a result of the need for expensive, specialized equipment and safety precautions necessary to mine below the surface. Countries

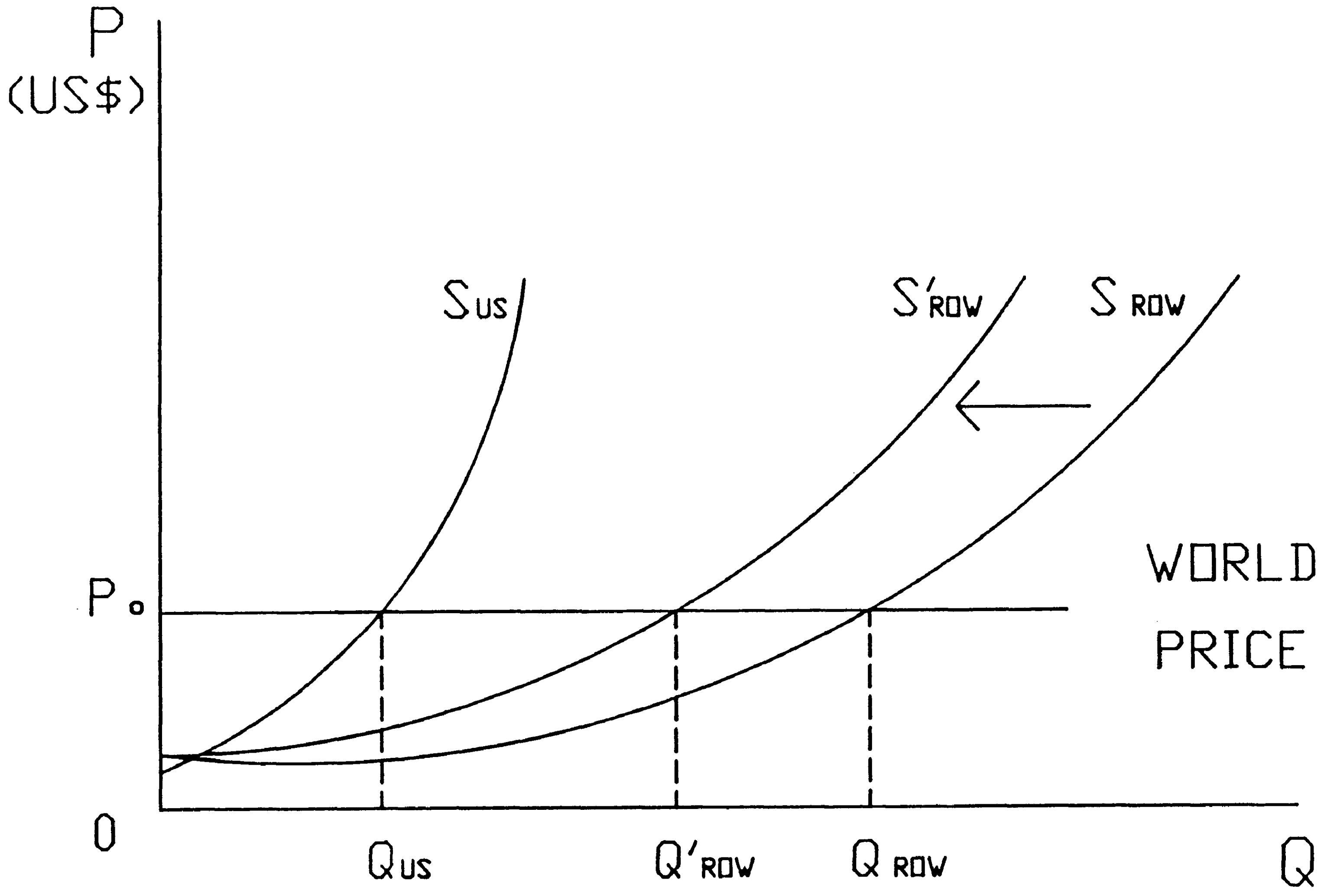


Figure 2.6: Effect of Increased Foreign Labor Costs
(U.S. and Rest of World)

which must mine underground to take advantage of their endowed gold resources naturally have higher costs per ton of ore than those who mine at the surface.

One must not neglect the costs associated with location and climate. The United States is fortunate in that many of its gold reserves are located near to each other. This permits shared infrastructure, a typically large expense for operations located far from the centers of population. Similarly, amenable climatic conditions can benefit a gold producer by permitting the use of heap leaching technology. The restrictions of this technique are examined in Chapter 4. Furthermore, costs associated with cold climates are well known by Canadian miners and may include the costs of housing, heating, and other necessary considerations for workers and machinery.

CHAPTER 3

HISTORY OF THE U.S. GOLD INDUSTRY

Since this thesis will deal primarily with modern technologies and the reasons for U.S. market share improvements in gold production since 1979, the historical perspective should be recent. Consequently, data compiled by the U.S. Bureau of Mines for 1960-1986 will be considered. Nevertheless, for purposes of introduction and comparison, the entire history of U.S. gold production, beginning with its initial discovery along the eastern coast, will be outlined.

3.1 The Nineteenth Century

The first United States gold rush occurred in 1798 in North Carolina as a result of the discovery of placers and easily-mined, weathered bedrock in the Appalachian Mountains. The rush quickly spread to Georgia, but, by 1847, the miners had exhausted these rich, near-surface deposits and headed to California. Not long after the 49ers staked their claims, California placers were contributing greatly to world production. These were "bonanzas" which, by 1870, were nearly depleted. Claims also were staked in Colorado and Nevada in the 1850s, and

Idaho and Montana started producing gold in the 1860s. The underground mines in Colorado became major contributors to U.S. production in the 1870s primarily due to the importation of Cornish miners from the English tin mines and the invention of dynamite in 1866 (Green, 1982). The 1870s also witnessed the discovery of America's most productive gold mine, the Homestake Mine in Lead, South Dakota. By 1882, Alaskan placers began to draw attention and were largely responsible for the sustained rise in U.S. gold production from 1890 to 1905.

Lode gold has been the main source of U.S. production while some historical periods show surges in byproduct output from base metal operations. Placers were heavy producers early on and through the 1930s. But, due to the mining-out of placer deposits and the ongoing development of underground and open-pit technology, exploitation of this source of gold has virtually ceased (Fig. 3.1).

3.2 The Twentieth Century

U.S. gold production fell drastically with the advent of World War I as the government encouraged base metal production. This decline in production hit a lowpoint in the late 1920s as many large gold mines closed. Following the crash of the stock market, gold production resurged as

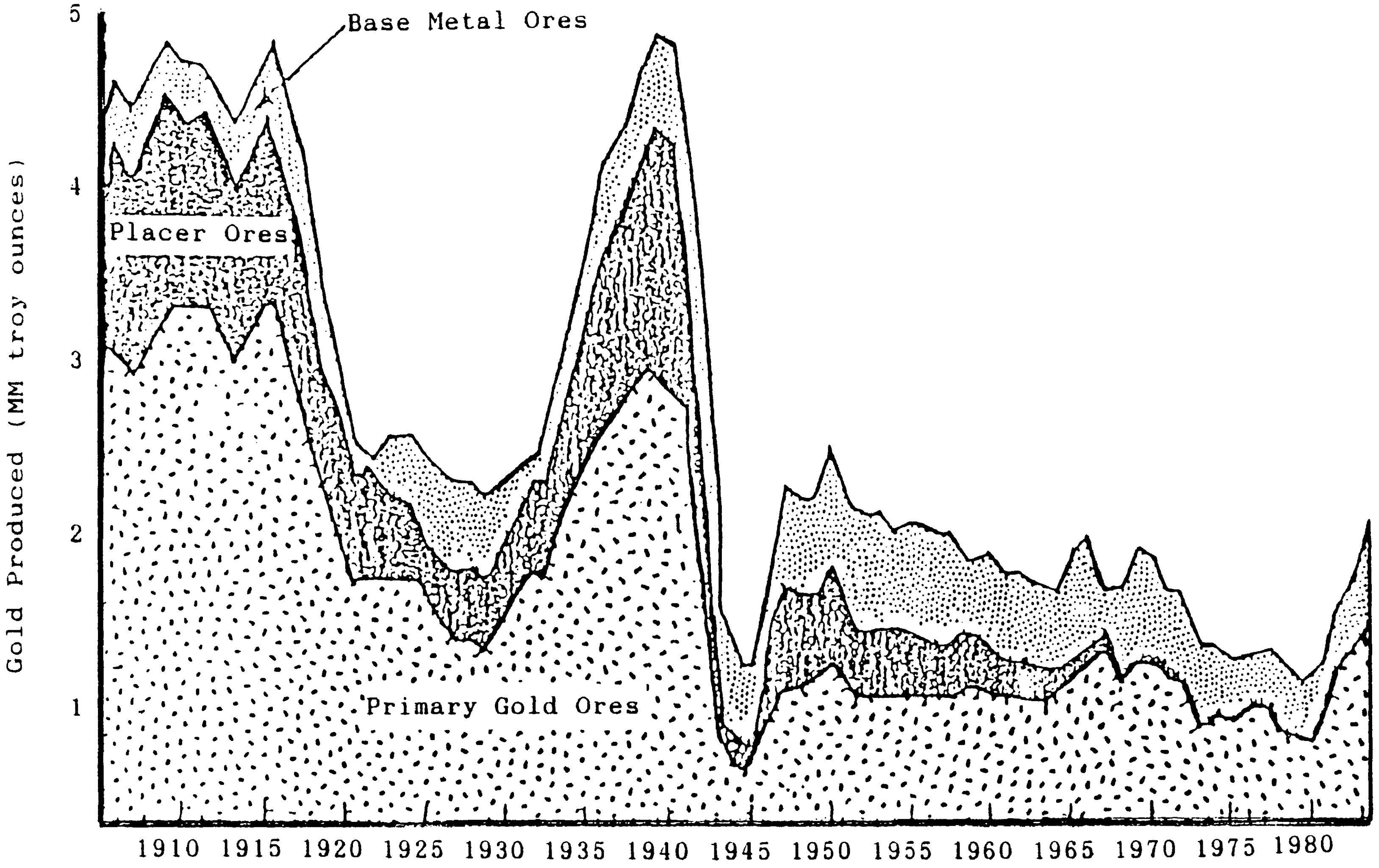


Figure 3.1: U.S. Gold Production by Ore Source (Thomas, Paul R. and Boyle, Edward H. Jr. 1986. "Gold Availability-World: A Minerals Availability Appraisal." U.S. Bureau of Mines IC 9070. Washington, D.C.)

small operators with low overhead costs began to dominate within the industry. Furthermore, in March 1933, the United States discontinued the use of the gold standard. This allowed the metal, for a short amount of time, to rise from its long established value of $20.67 per ounce. Nevertheless, in order to limit price increases and maintain control of gold supplies, an artificial stabilization point of $35.00 was implemented by the Gold Reserve Act in January of 1934. This "new" U.S. gold standard was unique to the world in that it defined the dollar in terms of gold managed by the U.S. Treasury. Additionally, the Treasury Department modified its policies by buying more gold and discouraging its exportation (Jastram, 1977). What resulted was increased exploration and discovery which, in turn, caused an all-time high in production in 1939.

During the 1940s, a large war need for base metals combined with unstable precious metals markets caused a radical drop in gold production. Ironically, this improved market for base metals contributed to the development of sources of byproduct gold. This source continued to provide appreciable gold stocks until declining base metal prices prevailed in the early 1980s. As an example, Bingham Canyon, a copper pit near Salt Lake City, produced an appreciable portion of the U.S. gold supply as byproduct in the late 1960s and the 1970s. In the early 1970s, byproduct gold from copper ores accounted for over 30% of U.S. production (Simons et al. 1973). But by 1982, many base metal mines had closed or were experiencing drastic personnel and budget cutbacks.

3.3 The Rising Price of Gold

The end of World War II was a turning point for the United States as well as its gold industry. Not only had byproduct output increased, but primary ore production had recovered from a modern-time low. This was a period when many new high-grade mines came on line. U.S. industrial uses were growing in number and extraction techniques were becoming automated. Many of these mines continued producing until the early 1960s, at which time their high-grade potential was depleted. U.S. miners began to look for other types of gold in order to stay in the business. It was at this time that a few new prospects were found, particularly along the Carlin geologic trend. But, it was the price of gold which spurred exploration and discovery in the late 1960s. In 1968, the price of gold was partially deregulated by the U.S. government. Licensed traders were allowed to take physical delivery of the metal. As a result, gold price breached $40.00 by the end of 1968, demand continued to grow, and world markets were more active than they had ever been (Green, 1982). Price fluctuations between $35 and $45 were commonplace until August 1972 at which time the gold price reached a high of $70. In 1974, the average gold price was over $150.00 per ounce. But two years later, in 1976, the average price fell to $125.00. Following the collapse of the dollar in 1977, inflation motivated the demand for gold, and its futures markets began to expand. As gold trading became popular and modern-day factors affected it (Fig. 3.2), the gold price rose, reaching an incredible peak of $850 in mid-1980. As a result of this popularity, producers began to develop their leaner ores, causing a temporary decline in production in 1979-1980. Nevertheless, production in 1981 was 42% higher than in 1980. This growth trend has continued with the United States nearly quadrupling its 1980 output in 1986. (See Appendix Table A.2)

3.4 The "New" Gold

The dramatic growth of U.S. gold production and market share in the 1980s is a partial result of the exploration and discovery of several new "disseminated gold" deposits, examples of which are the Carlin-type deposits. The

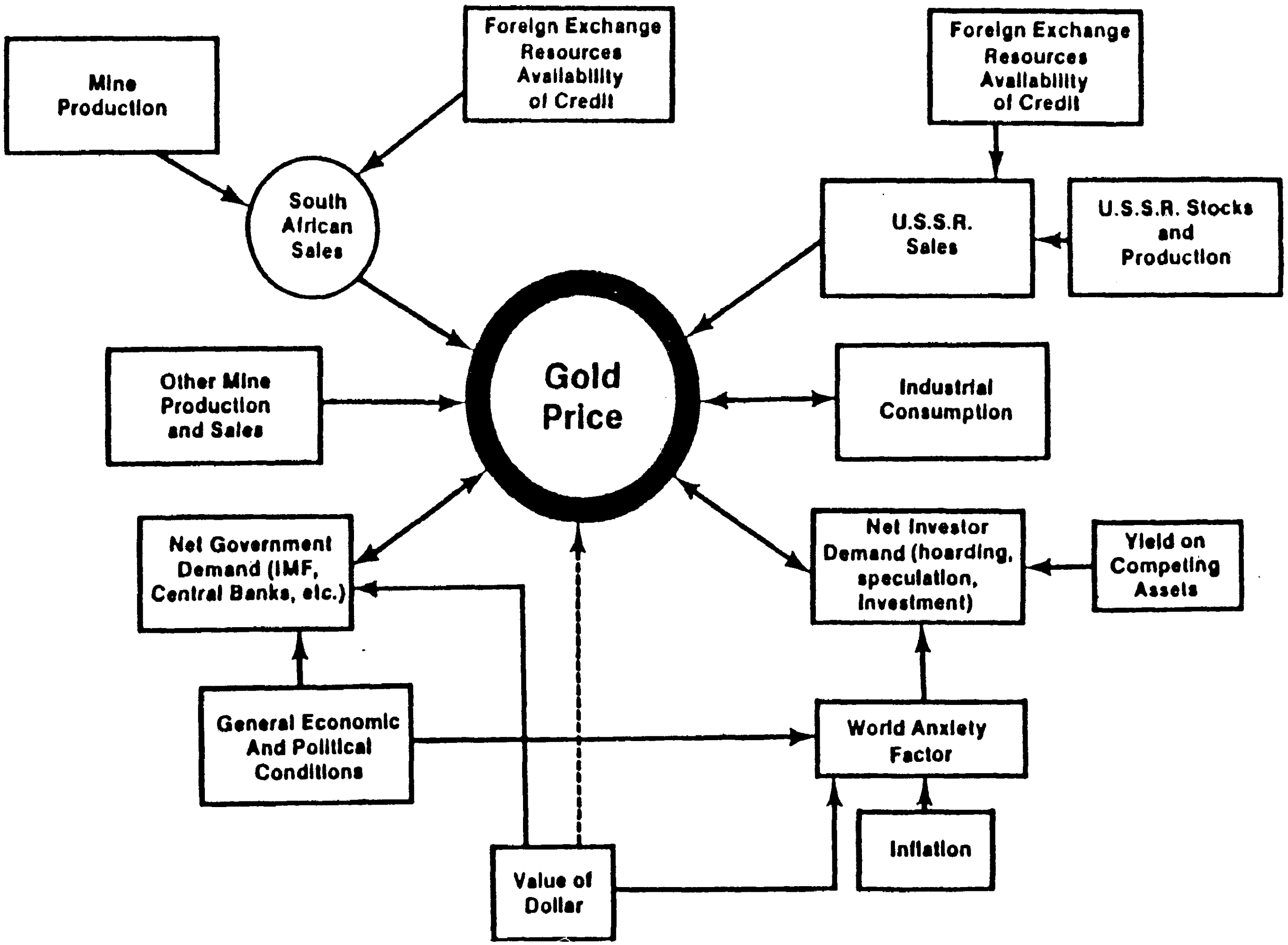


Figure 3.2: Price-Making Influences for Gold (Poole, James L. "Review of the Gold and Silver Markets," in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago, February 22-26, 1981. Society of Mining Engineers.)

Carlin-type deposits consist of micron-sized and submicron-sized gold particles randomly disseminated in silty or carbonaceous, dolomitic limestones of Silurian age (410 to 435 million years old). The gold is encapsulated in or closely accompanied by silica, sulfides, barite, or a combination thereof and the orebodies were formed by hydrothermal replacement of the host rock in Tertiary times (at least 65 million years ago). This ore contains approximately 0.30 ounce per ton of gold with minor amounts of silver (Simons et al. 1973). Further discovery of new types of gold ores, as well as the Carlin-types, has resulted in a large increase in the number of projects in the 1980s. For example, in 1984, seven of the sixteen producing mines in the United States were less than five years old (Thomas et al. 1986). By 1986, the growth was even more dramatic with over fifty deposits located in the state of Nevada alone (Fig. 3.3). The reasons for this dramatic increase go much deeper than merely the reaction to price increases. Technology was developed and perfected during the 1960s and 1970s, allowing domestic producers to gain a competitive advantage over countries lacking the U.S. endowment. According to Thomas and others (1986), nine of the sixteen U.S. producers in 1984 utilized heap leaching. The remaining seven are likely to use it at some

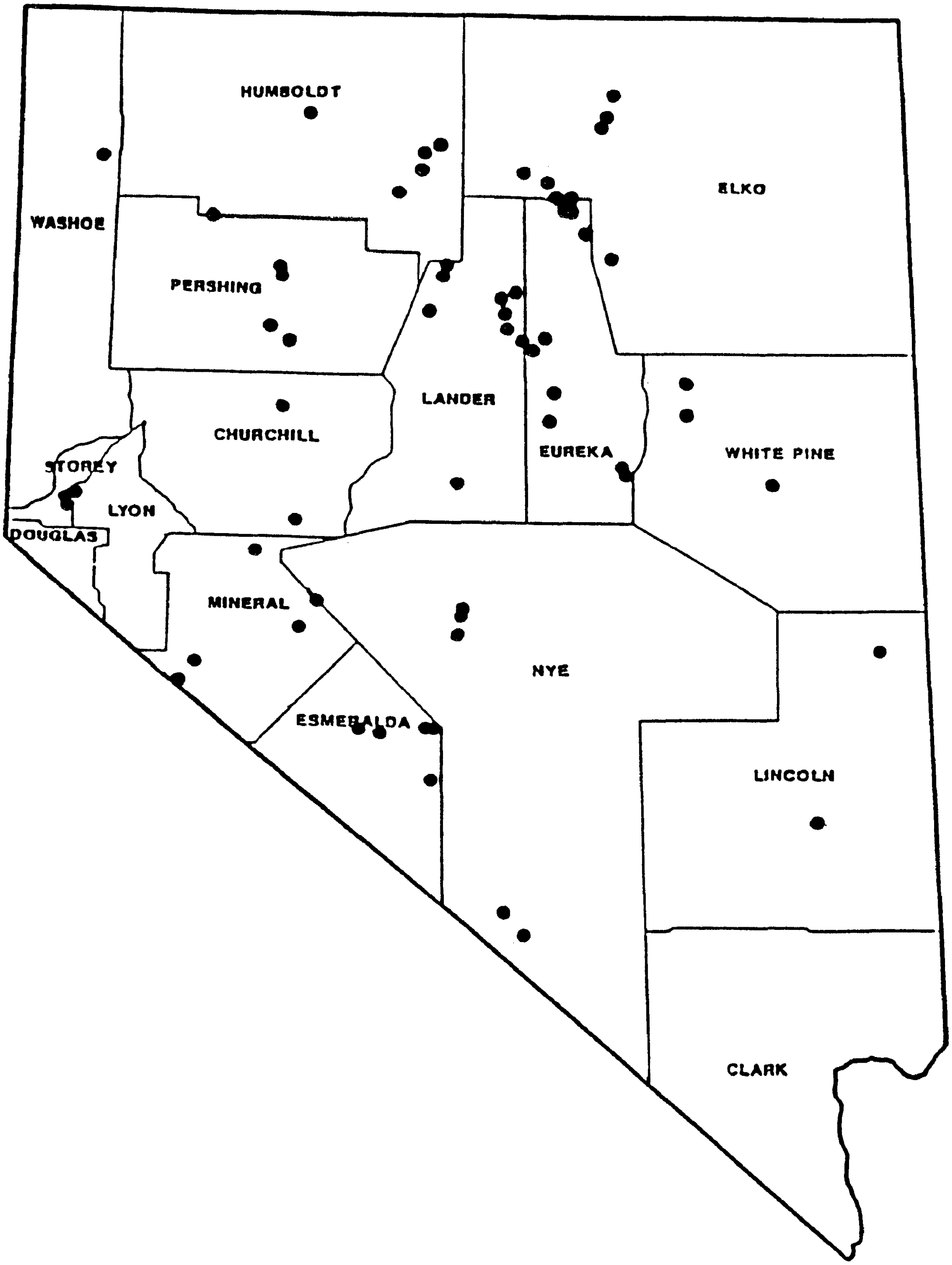


Figure 3.3: Bulk-Mineable Gold Deposits in Nevada (Bonham, Harold F. 1986. Bulk-Mineable Precious-Metal Deposits and Prospects. Map 91. Nevada Bureau of Mines and Geology. Mackay School of Mines. University of Nevada-Reno.)

point to process their leanest ores.

3.5 The New Technology

As alluded to earlier, the most important technological developments have been implemented in the processing and recovery stages of gold mining. Because over 90% of all U.S. gold producing properties are surface operations (7% are underground mines and active placers are few), heap leaching has shown to be an extremely critical development. It has helped to make feasible the exploitation of low grade, open-pittable deposits which formerly were not economical. From 1983 to 1986, approximately 30% of all gold produced in the United States was recovered by heap leaching, an eightfold increase over 1979 (Thomas et al. 1986). This is reflective of its applicability to the recovery of disseminated gold ores, some of which currently are mined at grades below 0.010 ounce per ton. Although, other technological developments have helped the United States to increase its market share, no individual development seems to have provided the magnitude of benefit for the United States as that of heap leaching. This technique and its offshoots could ensure long-term advantages for the United States as long as amenable ores remain to be found.

Chapter 4

THE IMPACTS OF TECHNOLOGY

4.1 Exploration

Like most U.S. industries, gold mining, and the technology that moves it, has changed markedly in the twentieth century, especially since World War II. It has evolved from a primitive business in which gold exploration relied on basic prospecting techniques virtually unchanged since the days of the California 49ers. These early prospectors typically found gold by searching creek beds for dark-colored, lustrous sands, sometimes following these signs to bedrock sources holding a hydrothermally-emplaced vein of native gold or a sulfidic, gold-bearing lode. This relatively crude method of locating gold was used by individual prospectors and companies alike until techniques of mass detection of orebodies were developed. By the 1930s, explorationists were using mass detection technologies, primarily in the form of aerial photography, or photogrammetry, ground geophysical methods, aeromagnetic surveying, and geochemical assaying. As with all exploration techniques, they are used to detect the subsurface presence of metallic orebodies. Some of these methods are accurate to great depth, depending on the desired detection levels.

Another very important tool of exploration is the geologic model. These theoretical ideas of how and where ore deposits occur are the focal points of geology and are the subjects of continuous revision. Often their application is specialized, and in this sense, they may remain the property of the innovator. But generally, their use diffuses as does much new information which can lead to the economic development of an industry or mining operation.

In summary, the technologies utilized in the stage of exploration typically become public domain due to their informational nature. Any long-term benefits lie in special use for development of domestic, disseminated gold ore deposits located primarily within the United States.

4.2 Mine Development and Extraction

As with exploration techniques, extraction technologies are numerous and continuously under development. Developmental drilling, processing plant construction, the development of infrastructure, permitting, equipment and manpower planning, as well as the actual extraction, storing, and marketing of the unprocessed ore, are all elements of mining which take place between the exploration and processing stages.

Among the leading developers of mine extraction technologies are the Republic of South Africa, the United States, and Canada. Because South Africa and Canada do most of their mining below the surface, they are on the forefront of underground technical development. In contrast, the United States excells in surface, or open-pit, mining. Nevertheless, one concept is universal: as techniques are developed and applied, their use diffuses. In some instances, this diffusion is deliberate because the technology is developed for use by all. The U.S. Bureau of Mines is continually working on new technologies and publishing its results.

Development and extraction technologies tend to diffuse quickly throughout the world. The South African developments in deep-mine technology are known throughout the world, as are the surface techniques used by the United States. Exclusive benefit and long-term advantage can be gained only if the endowed reserve also is exclusive. This is not the case for South Africa because many other countries mine deposits which apply South African technologies. Similarly, the rudimentary surface mining techniques used by U.S. producers only provide advantages when they are utilized on the bulk-mineable endowment.

4.3 Processing

The processing stage of gold mining encompasses all operations following the extraction of ore up to a point at which the gold metal is concentrated. Following the processing, a carbon adsorption or zinc precipitation method of recovery is implemented. The actual dividing line between processing and recovery often is not clear. Some consider the recovery systems mentioned above as part of processing. The actual definitions are not as important as the realization that changes in these stages of mining have influenced U.S. market share greatly since the 1960s.

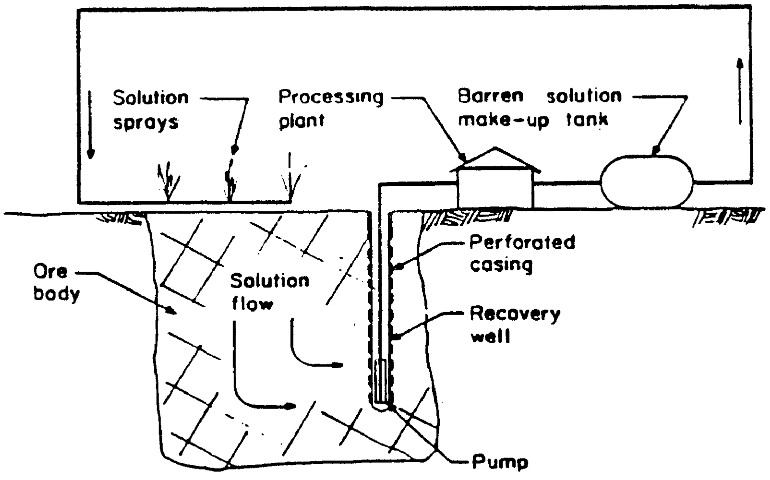
Prior to the development of heap leaching, most companies utilized conventional milling techniques exclusively. In fact, milling is still the primary method of processing for nearly 70% of U.S. gold mining. A milling operation may consist of crushing, separating and roasting of the ore, and various chemical treatments, in an effort to prepare it for concentration. Following the milling, cyanide leaching within a container, or vat, may be implemented to put the gold into solution. Obviously, this type of processing is limited by container size and physical plant restrictions, as well as financial capabilities. Heap leaching operations eliminate many of these physical constraints, thereby lowering the necessary costs.

In addition to heap leaching, other types of leaching have been developed. Some are offshoots and refinements of heap leaching, while others are in container leaching, such as Homestake's pressure-oxidation process. Furthermore, the USBM and others continue to experiment with non-cyanide leach reagents, many of which recently have become commercially viable.

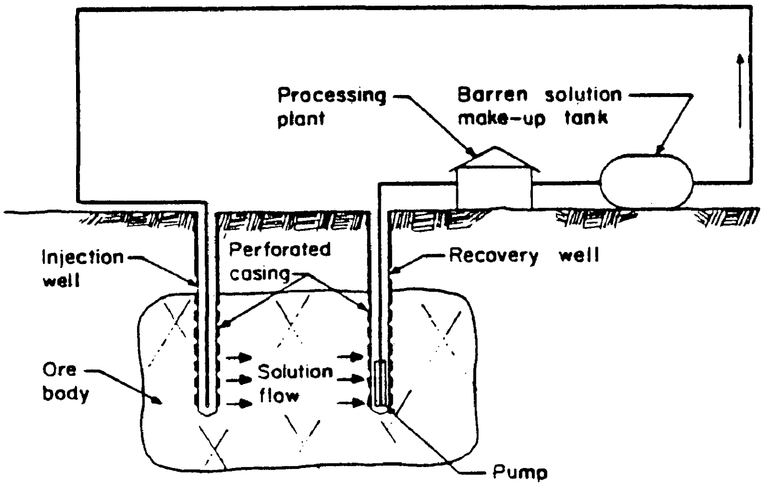
Another innovation in gold recovery is that of in-situ leaching (Fig. 4.1). Currently, in-situ leaching is used to recover copper. Although it is not commercially feasible for gold recovery at this time, as engineering problems are solved it will open up many new opportunities in the U.S. gold industry.

4.3.1 Non-Cyanide Leaching

Currently, there are several types of non-cyanide leach reagents being tested. The reasons for developing other reagents relate to climate, environmental risk, cost, and oretype. Many of the developments in leaching have been made by Canadian mining companies in an effort to make heap leaching applicable in cold climates. The reactivity of cyanide solutions decreases at temperatures below 50 degrees Fahrenheit; therefore, non-cyanide reagent research



Exposed Ore Body



Buried Ore Body

Figure 4.1: In-Situ Leaching System (Chamberlain, Peter G. and Pojar, Michael G. 1981. "The Status of Gold and Silver Leaching Operations in the United States," in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago, February 22-26, 1981. Society of Mining Engineers.)

and experimentation is vigorous.

Concerning the environmental aspects, although the risk of using cyanide is very low and accidents have been few and minor, its toxicity is a potential problem. In cases where groundwater contamination is possible, non-cyanide lixiviants (leach reagents) such as thiourea, bromine, and ammonium thiosulphate have been tested. Furthermore, some of these new reagents exhibit better leach rates than cyanide, although often with higher reagent cost. Verifiable data on the economics of most non-cyanide reagents are not yet available due to the lack of commercial scale applications (von Michaelis, 1987).

Another area of non-cyanide leaching is bacterial leaching. As with other leaching types, it has been used for the past forty years in the recovery of copper. But, it has been tested only recently on refractory gold ores not amenable to conventional cyanidation. Certain bacteria efficiently oxidize the elemental sulfur contained in the ore and produce acid ferrosulphate, encouraging oxidation that, without its presence, would occur very slowly if at all (Engineering and Mining Journal, 1987). Bacterial leaching provides benefits of environmental safety and potential cost savings. One of its prime advantages is that it neutralizes the toxicity of arsenic.

Unfortunately, it requires the use of a container and a temperature of 35 to 40 degrees Centigrade.

Non-cyanide leaching developments complement the heap and vat leaching advances. Therefore, one could expect that advantages gained by the heap leachers would be a partial result of the non-cyanide improvements.

4.3.2 Pressure-Oxidation Process

The Homestake Mining Company, owner of the largest underground gold mine in the United States at Lead, South Dakota and, previous to 1986, the largest domestic gold producer, discovered a large, open-pittable orebody in northern California in the late 1970s. The McLaughlin Mine, named after a former president of Homestake, required a capital investment of 280 million dollars. This investment reflects the massive amount of research, development, and infrastructure necessary to bring the mine on line. Major environmental concerns prompted many of the McLaughlin developments and resultant mine features. Several processing and recovery methods were tested before the best one, pressure-oxidation, was chosen as a pretreatment to cyanidation.

The McLaughlin ore represents an epithermal, hotspring geologic model. The gold is micron-sized and disseminated throughout a siliceous stockwork within a two million year old fault zone. It is associated with silver-antimony sulphosalts and typically occurs as an electrum having a silver content of 18% to 26%. The ore is clayey and carbonaceous in places, two conditions which contribute to its refractory nature. Because of this, conventional cyanidation recovery rates were 5% to 80%, unsatisfactory considering the magnitude of the capital investment. In addition to normal cyaniding, other technologies were tested to find the method which would process and recover gold most efficiently. Roasting, chemical oxidation, and non-cyanide leaching were tested as pretreatments to container cyanidation. The best results were obtained by autoclaving the ore with oxygen at elevated temperatures and pressures, followed by sodium cyanidation and the carbon-in-pulp recovery process (Kunter et al. 1984). Figure 4.2 illustrates the pressure-oxidation circuit in use at McLaughlin. It represents only a small portion of the entire flowsheet of the McLaughlin Mine. Nevertheless, it is an extremely important part, allowing previously unrecoverable gold to be recovered at a rate exceeding 90% with production costs near $200 per ounce. Homestake has had such environmental and engineering success with its pressure-oxidation process that, as of late 1986, it was

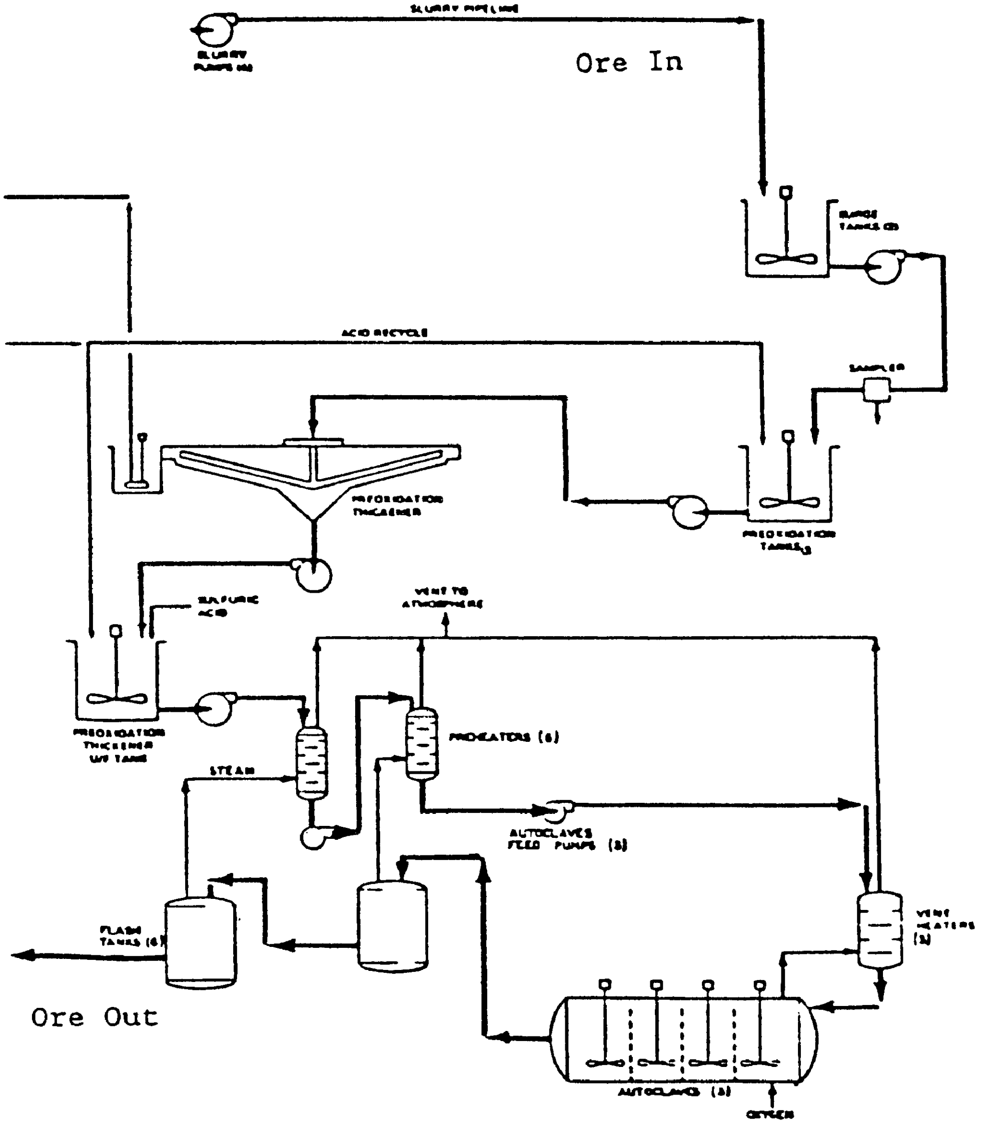


Figure 4.2: Pressure-Oxidation Circuit at Homestake's McLaughlin Mine
(Kunter, R. S., Turney, J. R., and Lear, R. D. 1984. "McLaughlin Metallurgical Development." <u>International Precious Metals Symposium, Los Angeles, February 26-March 1, 1984</u>. Metallurgical Society of AIME and International Precious Metals Institute.)

considering selling the technology to other companies which mine refractory ores containing hazardous constituents (Argall, 1986).

The pressure-oxidation process in use at McLaughlin is one example of how a technique can assist in preferentially benefiting a country.

4.3.3 Heap Leaching

This section will examine in detail the heap leaching process in order to understand why heap leaching, also known as solution or bulk mining, has provided the benefits it has to the United States, and to a lesser extent, Australia and Canada. The heap and dump leaching systems illustrated in Figures 4.3 and 4.4, have grown in use due to their typically low capital costs and applicability to disseminated gold ores.

To understand fully the way that heap leaching works, an understanding of the chemical reaction between cyanide and gold must be gained. Gold's reaction to caustic cyanide (NaCN or KCN), the active ingredient in heap leaching solutions, has been known to chemists since the 1700s, but it was not until 1846 that the Germans discovered the role of oxygen in the dissolution process. This made leaching possible, and by 1889, MacArthur and

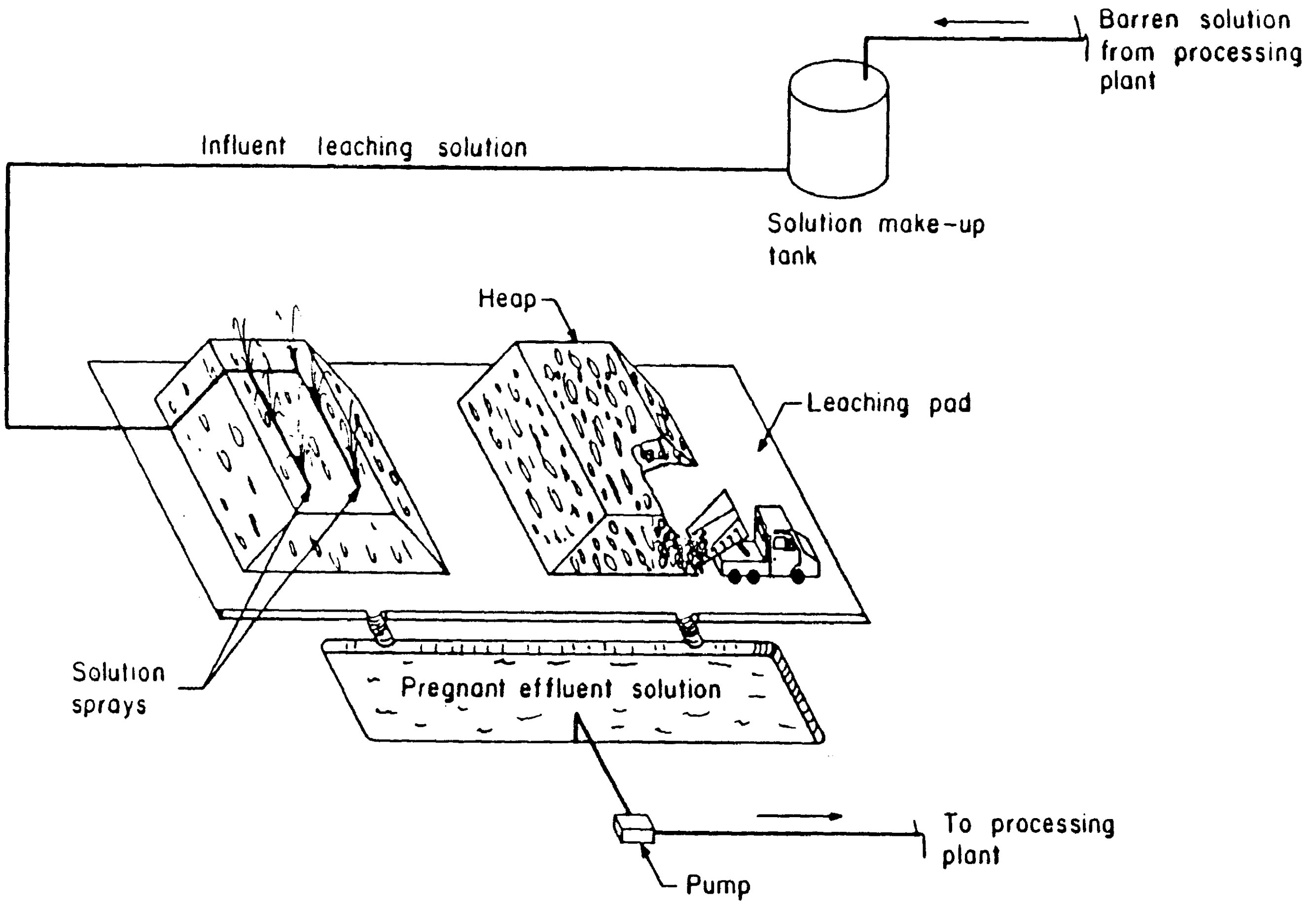


Figure 4.3: Heap Leaching System
(Chamberlain, Peter G. and Pojar, Michael G. 1981. "The Status of Gold and Silver Leaching Operations in the United States, " in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago, February 22-26, 1981. Society of Mining Engineers.)

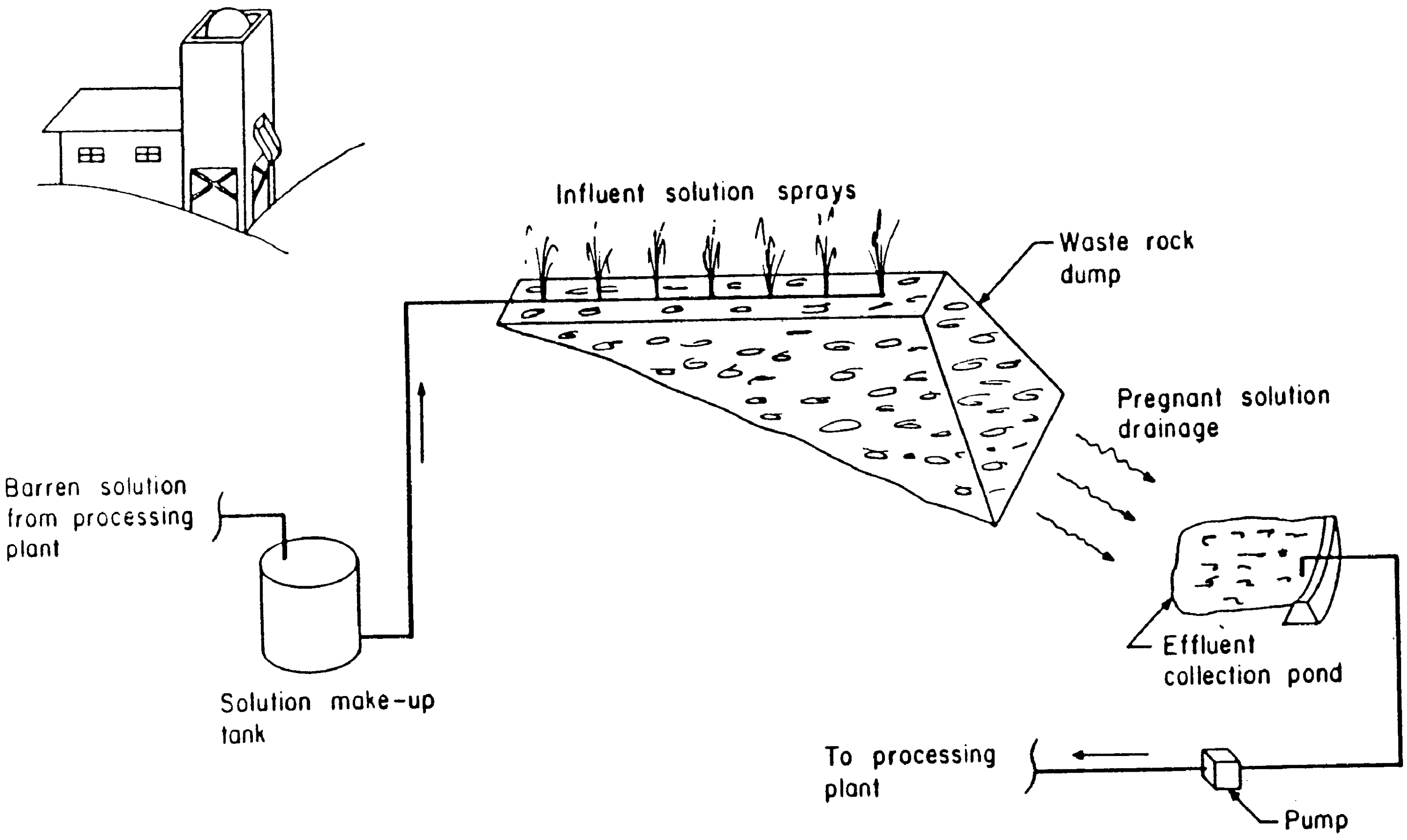


Figure 4.4: Dump Leaching System
(Chamberlain, Peter G. and Pojar, Michael G. 1981. "The Status of Gold and Silver Leaching Operations in the United States, " in Schlitt, Larson, and Hiskey, eds. <u>Gold and Silver: Leaching, Recovery, and Economics</u>. Proceedings from the 110th AIME Meeting, Chicago, February 22-26, 1981. Society of Mining Engineers.)

Forrest utilized this information to patent the use of cyanide for gold metal processing. Since that time, cyanidation has replaced mercury amalgamation and chlorination processes in gold recovery (Worstell, 1986).

There are several cyanide leaching processes, but all the chemical equations that govern the solubility of gold during cyanidation resemble the following (Lewis, 1983):

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4Na(Au(CN)_2) + 4NaOH$$

As mentioned earlier, heap leaching with a cyanide solution is useful and efficient only under certain specific conditions. There are several types of ore which are not completely amenable. Ores which contain substantial cyanicides (consumers of cyanide which inhibit complete beneficiation), carbonaceous materials (which adsorb metal cyanides and cause premature precipitation), organic substances (which consume vital dissolved oxygen) or clays (which prevent complete percolation of the cyanide through the ore) are not good candidates.

Various groups have developed methods of dealing efficiently with those refractory ores. The USBM, the Carlin Gold Mining Company, and the Homestake Mining Company have developed specific ways of processing refractory ores. The solutions to these problems range from a simple increase in cyanide to a complicated reengineering of the entire process flowsheet.

The most common host mineral for gold is pyrite; the second most common is arsenopyrite. Both are sulfide minerals and cyanicides which consume large amounts of cyanide per unit of weight. Cyanicides are very common, the primary ones being iron, copper, arsenic, antimony, and zinc. Their presence prohibits the initial use of heap leaching, causing the necessity of a pretreatment process, such as roasting or flotation. Roasting pyritiferous ore in an oxidizing atmosphere to form iron oxides or treating it with hot acid followed by chlorination to form iron chlorides frees up the gold particles for cyanide leaching. In the case of arsenopyrite ore, unwanted ferrocyanide complexes form during heap leaching. Oxidizing arsenopyrite is more complex than oxidizing pyrite because arsenic compounds are formed during roasting, causing an environmental problem (Worstell, 1986). In the cases of heap and dump leaching operations, environmental precautions often are the most costly.

A significant portion of the gold ores in the Carlin trend in Nevada are carbonaceous and require pretreatment before cyanidation can be attempted. They usually need roasting or some other form of carbon removal because dissolved gold adsorbs to the carbon present in the ore instead of moving freely to the carbon adsorption circuits for efficient recovery. Carlin Gold and Newmont Mining invested many millions of dollars and several years in their projects, a great portion of it allocated to cyanide mill construction and other technological developments (Gries, 1979).

Another major problem concerns those companies with fine-grained ores or tailing operations. "Fines" prevent efficient extraction by causing settling, compaction, and "sliming" of the heap as well as creating ponds on the surface of the heap. Clay particles can clog potential passageways for the gold solutions, promoting impermeability. The USBM, realizing this was a major stumbling block, developed agglomeration technology to reduce and remove the problem of slimey and clayey ores (McClelland et al. 1985). As alluded to earlier, dump and tailings operations have become noticeable producers of gold in the the United States in the last several years. Because tailings typically consist of more than 50% fines, they are not prime candidates for simple heap leaching. They must be agglomerated via solution application and mechanical tumbling. The typical solution, or binder, is a precise mixture of lime and cement, rendering a moistened mixture easily pelletized during the ensuing tumbling operation.

According to Herkenhoff and Dean (1987), another process can replace agglomeration. "Desliming" requires crushing, scrubbing, washing, screening, and classifying an ore heap to remove the slimes, thus improving the permeability of the heap. Agglomeration would be unnecessary and porosity and oxygen availability would increase. This process has been done commercially for iron ores and phosphates. Apparently, the desliming process is an inexpensive one and could be an economical move even for a small operator. In an experimental program, desliming provided a net gain on capital investment as compared to an operation using agglomeration.

Therefore, the potential economic advantages to be gained by the United States, Australia, and Canada as a result of these aforementioned accessory technologies lay hand-in-hand with the advantages made possible by heap leaching.

From 1983 to 1986, nearly 30% of the gold produced in the United States was via heap leaching. In that period of time, U.S. gold production grew from 2 million ounces to

3.7 million ounces. In 1986 alone, the United States produced nearly one million ounces of gold by heap leaching. This advancement has provided an inexpensive method of gold recovery for small and large operators alike. The gold mine at Round Mountain, Nevada, owned by Homestake Mining and Echo Bay Mining, was the largest heap leach facility in the world until recently. It recovered 140,000 ounces of gold in 1985 at $213 per ounce (Mining Journal, 1986). Additionally, Silver State Mining's small heap leach operation at Tonkin Springs, Nevada produced 25,000 ounces at $85 per ounce. In contrast, mines using conventional milling methods typically have production costs of $250 per ounce of recovered gold metal (Thorstad, 1988).

According to Lewis (1983), direct costs of heap leaching usually are under $6.00 per ton of ore processed and as low as $0.66. Conventionally processed ores typically cost more than $10.00 per ton. This means that milled ore must be of higher grade than leachable ore simply because of the higher costs of production. One must also remember that economically feasible, heap-leachable ores may grade less than 0.03 ounce per ton compared to milled ores which often exceed 0.10 ounce per ton. Heap and Dump Leaching, an industrial newsletter which monitors the U.S. gold industry with an emphasis on leaching, reported that there were 75 domestic heap leaching operations in 1986 with 35 more in the planning stages. Furthermore, Karpov (1986) states that U.S. gold mining capacity has doubled since 1982 as a direct result of heap leaching.

It is easy to see how the heap leaching technology is used profitably by the U.S. producers. These benefits were not afforded necessarily to many other producers around the world because they lacked the specific endowment of ore amenable to heap leaching. Certainly, this technique is not a very expensive or complex one, but has been used profitably for small and large operations alike, usually requiring only simple equipment.

4.4 Recovery

The predominant techniques of recovering gold from leachates are the carbon adsorption and zinc precipitation (Merrill-Crowe) processes. The application of active carbon (in the carbon adsorption process) to recover gold from cyanide leach solutions was patented in 1894 by W. D. Johnson. The Merrill-Crowe process was pioneered by Merrill in the late 1890s and improved by Crowe in 1919. A primary advantage of a carbon-based system is its ability to tolerate a dirty solution, thus eliminating the need for additional filtration. Furthermore, it is generally accepted that carbon adsorption will give a lower soluble loss, will tolerate heavy metal concentrations in the gold ore, and is easier to operate. A simple carbon adsorption recovery circuit for gold is shown in Figure 4.5. The basic steps are loading, or adsorption, of the gold from the solution onto the active carbon column; stripping, or desorption, of the gold from the loaded carbon into a concentrated solution; recovery from that solution; and acid washing and heating in order to recycle the carbon (Halbe, 1985). The main economic concern of the carbon adsorption process is the reuse of the carbon. A good recycling method can keep costs of replacing carbon at a minimum.

A refinement of the carbon adsorption process is the carbon-in-pulp (CIP) circuit (Fig. 4.6). It was first developed by T. G. Chapman at the University of Arizona in the 1930s. This basic system utilized finely ground, activated charcoal to adsorb dissolved gold after which the charcoal was separated from the pulp by flotation. The gold then was recovered by smelting the loaded charcoal. The first major commercial user of this process for gold recovery was Homestake Mining Company in 1970. In order to

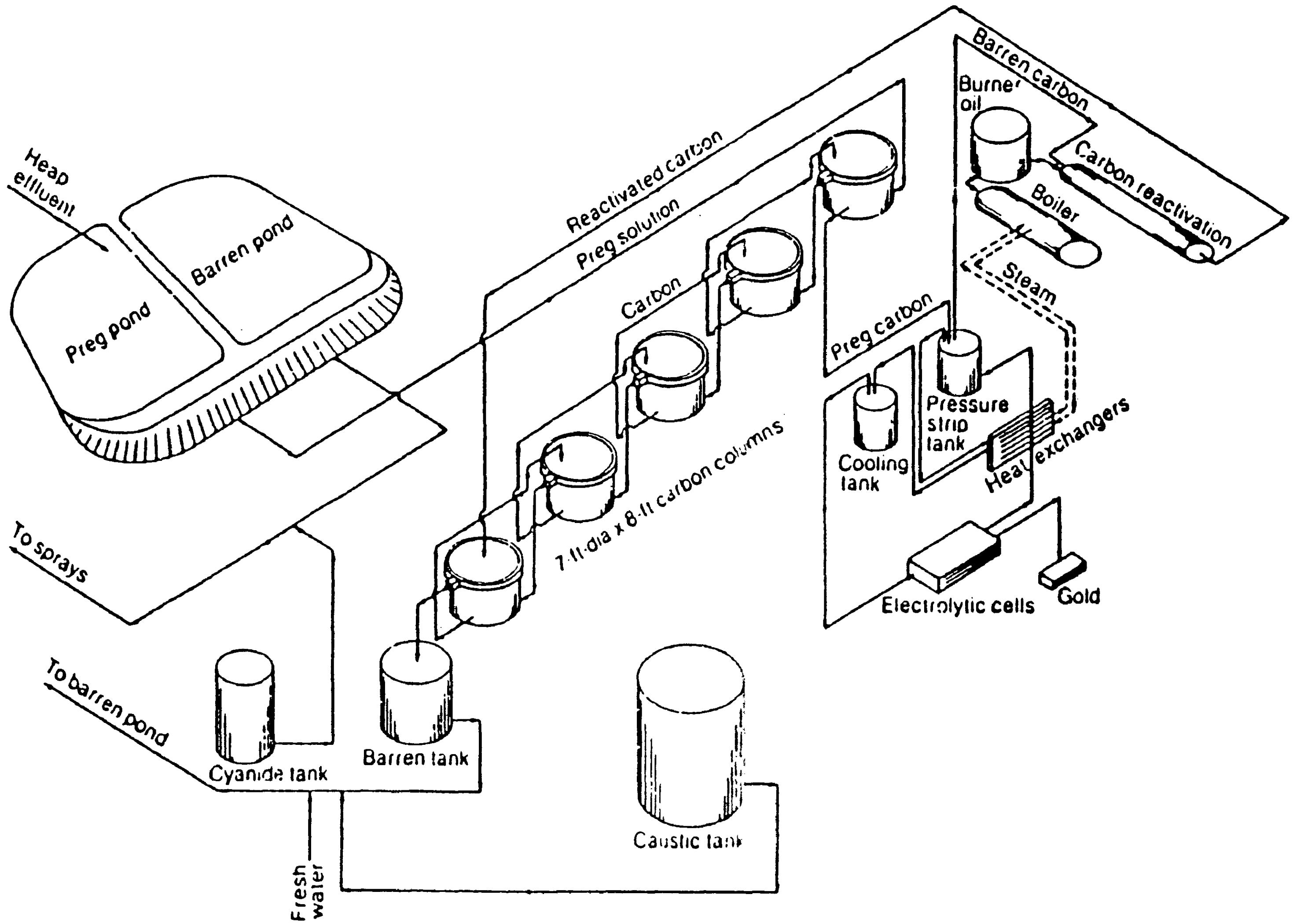


Figure 4.5: Treating Heap Leach Solution (Shoemaker, R. S. and Dasher, John. 1981. "Recovery of Gold and Silver from Ores," in George Foo and Myron E. Browning, eds. Symposium on Recovery, Reclamation, and Refining Precious Metals, Sheraton Harbor Island, San Diego, March 10-13, 1981. The International Precious Metals Institute.

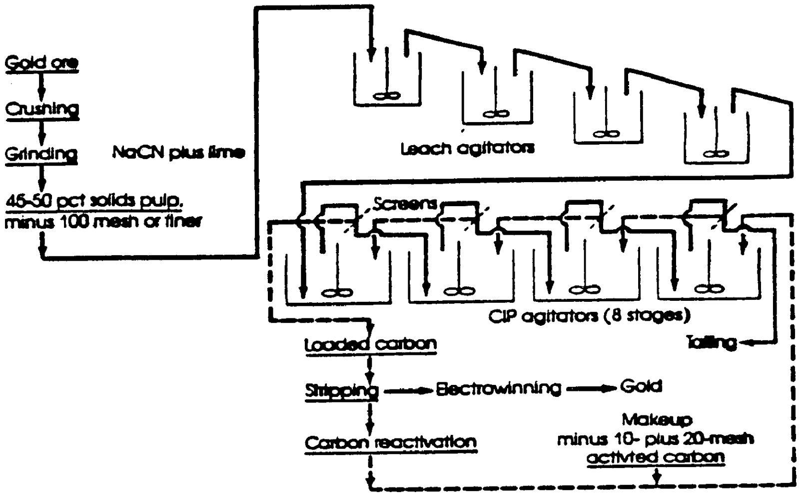


Figure 4.6: Carbon-in-Pulp Process
(Dayton, Stanley H. 1987. "Gold Processing Update." E&MJ. (June): 25-29.

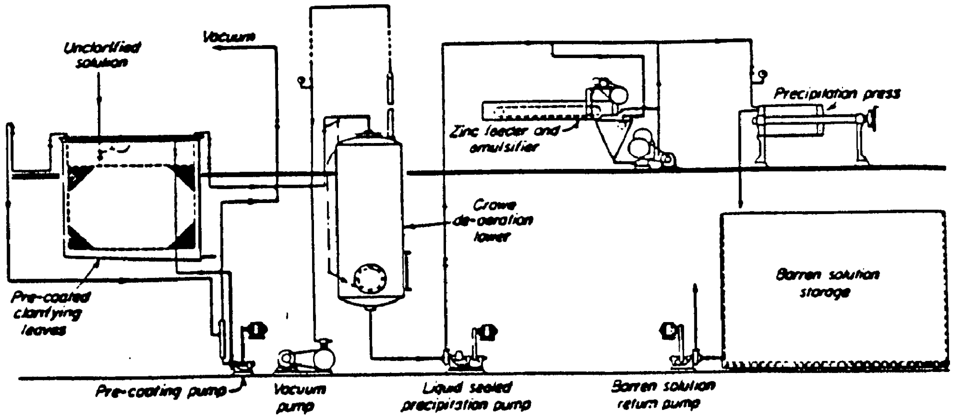


Figure 4.7: Merrill-Crowe Process
(Shoemaker, R. S. and Dasher, John. 1981. "Recovery of Gold and Silver from Ores," in George Foo and Myron E. Browning, eds. Symposium on Recovery, Reclamation, and Refining Precious Metals, Sheraton Harbor Island, San Diego, March 10-13, 1981. The International Precious Metals Institute, Inc.

eliminate hazardous mercury contamination of ground water from its mercury amalgamation operation, it installed a CIP circuit. Following this effort and research and development by the USBM, numerous plants were built throughout the world. One advantage of carbon-in-pulp is that it is applicable to most gold ores.

Many refinements to CIP have been made: the USBM has been working on ion exchange (IX) processes (Dayton, 1987) while resin-in-pulp (RIP), also an IX development, is being developed by South Africa's Council for Mineral Technology (MINTEK); carbon-in-leach (CIL) supposedly eliminates the need for separate cyanide leaching and carbon adsorption circuits; alcohol, or glycol, stripping is another method of recovering gold from carbon columns (Fast, 1987); elimination of the entire carbon adsorption process has been suggested by Elges and Wroblewski (1986) via the use of staged heap leaching-direct electrowinning. The USBM has conducted research to develop this process for commercial use and has obtained promising results.

The Merrill-Crowe process (Fig. 4.7), an old yet reliable method of gold recovery, has at least two advantages of its own: it has been marketed as small, "packaged" units at low cost, and the active agent, zinc filings, are cheaply replaced. As of 1986, over 40% of

North America's heap-leaching operations used zinc precipitation methods.

The methods of gold recovery used in mining operations where conventional milling is implemented are universally known and utilized. Thus, the carbon adsorption and Merrill-Crowe recovery processes do not preferentially benefit the U.S. producers. It appears that heap leaching has been the strongest determinant of market share growth for the United States. Undoubtedly, its impact in Australia and Canada will grow as the technical applicabilities in those countries advance.

Chapter 5

THE IMPACTS OF OTHER DETERMINANTS

The central question of this thesis deals with the impact of technological advances on the U.S. gold industry. The subsidiary concern dealt with other possible determinants such as gold prices, monetary exchange rates, exploration and discovery, governmental policies, and other costs. The author is convinced that technology has been a necessary and driving force behind the U.S. market share increase, but is, by no means, the only one. Not surprisingly, the other determinants have provided appreciable collective and singular motivation for long-term comparative advantage. Chapter 4 pointed out the important and lasting effects of certain technologies on the U.S. market share. Nevertheless, it was the interaction among technology and the other factors which motivated the improvement of this share in the 1980s.

5.1 The Gold Price Motive

Gold price influences market share in various ways. As price rises, producers want to mine, process, and sell more gold. Marketing of gold is not as time- and capital-intensive as its production. But, capacity, or the capability to produce and process, is dependent on the time needed to gain financial backing, buy and upgrade equipment, hire manpower, and develop resources. If a country is already a low-cost producer, or if it has developed reserves during prior times of low costs and can process and recover the gold quickly, it can take advantage of rising gold prices in the short to medium term. In these ways, a country may develop a comparative cost advantage (Tilton, 1983). Of course, a geologic endowment must exist, as it does in the U.S. and, to an extent, in Australia and Canada. Figure 2.2 illustrates how the United States, with its appreciable disseminated gold resources, gained an advantage by developing and producing those deposits rapidly during periods of rising prices. As the price increased, the equilibrium point shifted to the right, the U.S. gaining a larger share of new sales than other producers who had less capability to develop bulk-mineable reserves.

The United States began exploiting its bulk-mineable (epithermal, disseminated, Carlin-type) deposits in the 1960s as technology developed. Significant results did not occur quickly; in fact, production dropped throughout the 1970s as inflation and rising energy costs dissipated the effect of increases in the price of gold. Table B.1

illustrates how the real price of gold moved erratically from 1960 through the mid-1970s as the nominal price trended upward. From this, there seems to be less of a direct relationship between price and market share than one might suspect as bulk-mineable deposits came on line. Certainly, the concept of lag time had a significant effect. Nevertheless, by the late 1970s, price had become a driving force and eventually motivated producers to develop their lower grade reserves. These sources began to provide profit margins formerly brought by higher grades. As a result, the majority of the deposits being mined today are relatively low in ore grade.

One must conclude that gold prices were a dominant force behind the rise in U.S. market share of world production because of its price elastic supply curve for bulk-mineable gold ores. Although the total effect on Australia and Canada certainly has been of a smaller magnitude the proportion of effects of price exceeded that of technology because heap leaching of bulk-mineables was implemented less frequently.

5.2 Changes in Exchange Rate

For the purposes of this paper, foreign exchange rate is defined as U.S. dollars per unit of foreign currency.

Table 5.1 shows a general trend of declining rates since 1980, disregarding the small reversal occurring in 1987. As exchange rates declined, the value of the U.S. dollar increased. Considering the costs (in U.S. dollars) to foreign producers, it is clear that they also declined with increases in the value of the dollar. One would expect that similar effects would be felt in all three countries.

For Australian gold producers, exchange rate changes have been quite beneficial. The value of the Australian dollar has fallen appreciably relative to the U.S. dollar, causing the gold price in Australian currency to soar, and motivating more than a fourfold surge in Australian production since the early 1980s (Mining Journal, 1987).

This situation has been replicated in Canada. Table 5.1 indicates a devaluation of the Canadian dollar with respect to the U.S. dollar. Though this devaluation is of less magnitude than the Australian, the Canadian gold industry also has shown positive effects. Appendix Table A.1 shows how each of these countries has increased its market share, perhaps in response to exchange rate declines.

One would expect the South African situation to be similar. But, political and cultural events may have

Table 5.1: Foreign Exchange Rates: Major Gold Producers

(Averages in US$/unit of foreign currency)

YEAR	AUSTRALIA	CANADA	SOUTH AFRICA
1980	1.1400	0.8553	1.2854
1981	1.1495	0.8341	1.1477
1982	1.0165	0.8101	0.9230
1983	0.9014	0.8114	0.8985
1984	0.8794	0.7723	0.6953
1985	0.7003	0.7323	0.4557
1986	0.6709	0.7196	0.4395
1987*	0.7112	0.7635	0.4879

*/ October 1987.

Sources: Statistical Abstract of the U.S. 1987.

Federal Reserve Bulletin. 1988.

overshadowed the benefits provided by exchange rate declines. Costs of production in South Africa have risen appreciably and the rand has lost over half of its value in relation to the U.S. dollar, yet these conditions have not buoyed South African gold production. Apparently, encouraging exchange rate conditions are not visibly reflected in the production and market share records.

5.3 Exploration and Discovery

The effects of exploration and discovery are much the same as those of technology. In these days of highly technical sensing devices and sophisticated geologic models, only a small portion of exploration is considered "grassroots" prospecting. This high-tech trend is expected to continue because traditional geologic frontiers are disappearing. Figure 2.4 assumes a unique endowment of disseminated, bulk-mineable deposits which permit the exploration and discovery of such deposits to shift the U.S. supply curve right and downward.

Data documenting the increases in bulk-mineable gold deposits are difficult to locate because most common databases do not distinguish between ore deposit types, especially for non-U.S. stocks. Nevertheless, over forty new mines opened in the United States during 1985-1986, the majority being surface deposits. Similarly, according to Sutill (1987), the majority of new mines in Australia are surface deposits within old mining districts. Initially, it would appear that Australia has been influenced as strongly by exploration and discovery as the United States. But, one could infer that the exploration and discovery involved in these "new" deposits is partly the expansion of old mines and the reprocessing of old tailings now made economically recoverable by higher gold prices. As mentioned, precise itemized data are not readily available, although Lucas (1986, 1987) in his work with the U.S. Bureau of Mines, has disclosed that the reserve bases for the United States and Australia have increased by 25% and 33%, respectively. The reserve base is a U.S. Geological Survey term defined as those resources currently economic (reserves), marginally economic (marginal reserves), and currently subeconomic (resources). Thus, the reserve base amounts to the in-place demonstrated resource from which reserves are estimated.

Although Canada has made dramatic advances in its gold production and market share, it has begun only recently to implement heap leaching. As mentioned earlier, heap leaching is not applied easily to Canada's deposit types or in its cold climate. Thus, exploration and discovery have not been as much of a market share determinant for Canada as for the United States or Australia. This hypothesis is supported by the fact that the Canadian reserve base has not changed since 1983.

As mentioned previously, South Africa has had considerable political and cultural unrest in the last decade which may have contributed to its decline in gold production and loss of market share. Thus, it is difficult to measure the effect of exploration and discovery. One could assume that it has been small, but perhaps it has been overshadowed by those aforementioned problems. Nevertheless, South Africa has been using bulk-mineable techniques to reprocess its old tailings, but these operations do not contribute more than two percent of South Africa's gold production (Janisch, 1986). Like Canada's reserve base, South Africa's has not changed since 1983.

5.4 Public Policy

As mentioned in Chapter 2, examples of the effects of public policy on the U.S. gold producers are not as prevalent as those existing in Australia and Canada. This is because the U.S. economy is less dependent on its mining industry and more dependent on its high-tech R&D and manufacturing industries. But as described in Section 5.2, Australia and Canada do depend on their gold production for advantageous foreign exchange. Furthermore, they each have governmental policies which motivate producers to increase output.

Australia has enacted a law which provides that gold mining profits shall remain tax free. This has provided an incentive for entry into gold exploration and production by domestic and foreign producers alike. Consequently, many joint ventures between U.S. and Australian concerns have taken place as well as immigration of South African companies in their efforts to increase total production. Because of these influences, Australia has recently proven reserves of surficial, disseminated deposits, as well as Witwatersrand-type gold. In addition to the federal tax law, lease rents, local taxes, and state royalties are prime examples of governmental policy which have provided benefit to Australia (Sutill, 1987).

Public policy also has provided benefits to Canadian gold producers through an unusual form of tax shelter. In 1978, the Flow-Through-Shares Program was set up by the Canadian Federal Government. Many exploration companies are nontaxable, thus they usually are not in a position to benefit from the tax deductions arising out of their activities. Nevertheless, via the Program, these deductions can be transferred to an investor who then receives common shares in the exploration company. Further incentive exists in the federal provision for a one-third markup on qualifying expenses incurred by the company giving the investor a $1.33 deduction for every $1.00 invested. Needless to say, this provides a market mechanism attractive to the exploration company as well as the investor. As a result, total flow-through expenditures in Canada have risen fourfold since 1984. Though the program originally was intended for the benefit of junior Canadian exploration companies, senior mining companies have been attracted because of the recent depression in base metal prices (Carlson et al. 1987). Thus, the entire Canadian mining industry has benefited from those public policies originally thought to be advantageous initially only to small gold exploration firms.

In summary, it appears that the most measureable effects of current public policy reside in Australia and Canada, not within the United States.

5.5 Labor and Other Costs

For the U.S. gold producers, labor costs are small relative to total production costs. This is not surprising because over 90% of all U.S. gold mining is done within a few hundred feet of the surface. But, labor costs are typically a strong consideration for those producers who must mine underground. As an example, the Republic of South Africa mines a large percentage of its output from mines as deep as four thousand meters. Each year they are forced to mine deeper and costs are rising commensurately (Janisch, 1986). Therefore, Figure 2.6 adequately illustrates how producers, such as the United States who have experienced declines in labor costs, are gaining market share relative to those who have decreased production and lost share, such as South Africa.

Other costs often assumed are related to the location and climate of a potential mine. The United States has the advantage that many of its gold mines are located in the same region of the country. In this situation, the benefit of common infrastructure is obtained. Additionally, the climate of the western United States, the primary region of its producing mines, is relatively amenable to mining. This is not only beneficial to the miners, but permits costs of heating, housing, transportation, and machinery to be minimized. The favorable climate also allows heap leaching, which has temperature and precipitation constraints, to be implemented more easily.

Chapter 6

CONCLUSIONS

At the onset of this thesis, the author was reasonably convinced that technology was a factor which set apart the U.S. gold industry from other major producers around the world, in particular, from the dominating Republic of South Africa. A premise of exclusive, relatively undiffused technical application also was assumed for the United States. Of course, this is a very difficult premise to prove, particularly because it stands against some extremely rigid theory. Our world is becoming smaller by the minute as a result of its telecommunications capabilities. As we deplete certain of our gold resources, we invent techniques for developing others. We also explore for resources in ways unknown to miners of the recent past. These innovations and discoveries rarely remain secret to their founders nowadays because of the speed of modern communications and the power of financial motivation. In effect, most technology becomes the property of whoever can use it in the medium- to long-run.

The United States and other exploiters of bulk-mineable reserves have remained the owners of certain technologies primarily because they have been endowed with particular deposits not located in appreciable quantities in many other countries. Specifically, the U.S., Australian, and Canadian solution miners use techniques that have been developed for their endemic, disseminated gold deposits and that have a level of low applicability for the conventional, high-grade, coarse gold ores mined elsewhere.

Technological motivation does not stand alone as the factor behind the recent market share increases. Gold prices, ongoing exploration and discovery, exchange rates, public policies, and other rising costs contribute strongly. Of course, each country experiencing an improvement in its position has relied on each of those respective factors to a different degree.

6.1 Technology

The United States has been a very dynamic gold producer since the late 1970s, relying on the fortune of its endowment of disseminated and Carlin-type deposits. It has continuously made improvementson its cyanide leaching and carbon-in-pulp techniques in order to efficiently recover the gold from this endowment. Exploration techniques also have been instrumental in that they have been used to discover numerous disseminated gold deposits. Nevertheless, exploration techniques usually are applicable in some form for any type of deposit and really cannot be considered type-specific or exclusive to the U.S., Australian, and Canadian miners. This is true of most of the other technologies used throughout the gold mining process. Chapter 4 attempted to assign a quality of responsibility for market share increases to each of the technologies examined. Undoubtedly, the processing technologies of heap leaching and pressure-oxidation have contributed more strongly than others due to their direct applicability to the U.S. ores. Australia and Canada have been able to use certain of these techniques which are not proprietary (such as pressure-oxidation for Homestake Mining Company) to recover some of their bulk-mineable ores. But these countries continue to mine a large portion of their gold underground, a circumstance which does not permit them to make important use of the solution mining techniques. Thus, a large, but unquantifiable portion of total responsibility for market share improvement can be attributed to the technological innovations examined, particularly heap leaching. As noted in earlier sections, this unique processing method has been used to recover almost thirty percent of the U.S. gold output since the early part of this decade. As the need to develop increasingly lower grades occurs, and as the gold price rises relative to other commodity prices, heap leaching and similar techniques will be used at an increasing frequency.

6.2 Gold Price

Although gold price interacts with other determinants to affect market share, some producers have experienced the influence of gold price more than others. Australia and Canada have been affected by gold price changes to a greater degree than by the development of new technology because techniques such as heap leaching.have not been used to the extent as they have in the United States. Furthermore, gold prices influence foreign exchange rates, which, in turn, have had significant impact on the market growth of Australian and Canadian gold production.

The primary mechanism by which gold price affects different countries differently is via its impact on supply curves. Each country reacts uniquely to gold price changes because each has a uniquely shaped supply curve, or price elasticity of gold supply. Figure 2.2 illustrates exactly how one country can move further along its supply curve towards greater production, while another reaches a constraint due to lack of technology or geologic endowment. In reality, the United States has a flatter supply curve than the Republic of South Africa for bulk-mineable gold ore reserves. Thus, it can expect to compete favorably in this arena of gold production for many years to come.

6.3 Exchange Rates and Public Policies

Interestingly, these two factors have worked similarly on the Australian and Canadian industries. Much less impact has been felt in the United States. Surprisingly, South African market share of world production has not reflected the benefit provided domestic currency devaluation such as that felt by Australia and Canada. Although rand devaluation surely helped in an absolute sense, the resulting benefits may have been dissipated by the enactment of South African public policies regarding social and political activity.

It is not unreasonable to expect that the United States should have suffered some loss of market due to increases in foreign production. But as indicated in Appendix Table A.1, it has gained appreciably more market share relative to any other producer in the last few years. Based on this circumstance, the effects of exchange rate changes appear to have influenced the U.S. gold industry very little, if at all.

6.4 Exploration and Discovery

The responsibility of exploration (and ensuing discovery) for market share growth is great. Its effects are inextricably intertwined with endowment, technology, price, climate and location, and even with exchange rates and public policy. The key factor most related to exploration is endowment. The United States has explored, discovered, and developed its endowed gold resources to great advantage. Australia and Canada also have done well in this respect. South Africa does not own the particular endowment necessary to qualify, thus has not made the inroads of the other three producers. Furthermore, if South Africa would have discovered more deposits of the type they currently mine, one would not expect them to be mining forever deeper in the same locations.

Exploration and discovery surely are methods of gaining comparative advantage for the United States, Australia, and Canada, even though a quantification is not easily made.

6.5 Labor and Other Costs

The crux of this thesis lies in the effect of costs on market share. The country with the lowest cost per ounce of recovered metal should be the strongest producer, assuming that production capabilities are equivalent. Of course, capabilities not only differ with each producer, but endowment has an undeniable effect on each. Thus, the elasticity of supply controls a country's ability to produce and is a measurement of its endowment. Furthermore, the human element must be considered when measuring costs, and this is often reflected directly in labor costs, although not entirely.

Labor costs are not easily documented for a specific portion of the gold mining industry. Often they are included within production costs as a whole, or grouped within labor costs of the entire mining industry. Therefore, labor cost data for the gold industries of the four, major, non-central-economy producers are not precisely available. Nevertheless, Chapter 5 did mention that new mines in the United States, Australia, and Canada came on line in previously unknown numbers. This gave those countries the comparative advantage seemingly lost by the Republic of South Africa during the 1980s.

As mentioned in Chapter 5, U.S. labor costs are not proportionally large primarily because most of its mines are at the surface, requiring relatively small manpower forces even for the largest operations. This was not always the case. When underground gold mining was the main type, labor costs were a larger part. Therefore, in the

U.S. case, labor costs have declined as the phenomenon of surface mining has evolved. There is no reason to expect that Australia and Canada have not experienced similar decreases in labor costs due to automation and growth in the number of surface operations, especially as the rising price of gold has transformed resources into reserves.

Other costs of production and capital costs have affected the major producers, some more than others. Beneficial climate and location were found to save the United States costs that other producers would have had to absorb in order to develop reserves.

6.6 Summary

This thesis has been one of qualitative analysis. Technology, gold price, exchange rate, public policy, exploration and discovery, and other costs have been determined to be the prime factors of motivation for the increases in market share for the United States, Australia, and Canada. These countries have gained while the Republic of South Africa, the dominant producer, has lagged and lost ground from its impressive position of ten years ago.

Technology in interaction with gold price and exploration and discovery has been determined to be a primary motivator for the U.S. industry. Gold price, exchange rate changes, and public policies have helped Australia and Canada to gain market share. For the United States, Australia, and Canada, endowment has played a part. The United States has the concentrated presence of the type of gold deposits and the technology with which to process it. Australia has begun developing its bulk-mineable reserve base only recently and surely will gain additional market share in the coming years. Canada may benefit slightly in the near future as heap leaching and carbon-associated recovery methods become more advanced and applicable to its ores and amenable to its climatic conditions. South Africa will gain some benefit from the reprocessing of its vast tailings supply, but lacks the endowment of primary bulk-mineables necessary to make appreciable gains in market share.

REFERENCES CITED

Argall, George O. Jr. 1986. "Perseverance and Winning Ways at McLaughlin Gold." Engineering and Mining Journal. (October): 26-32.

Bonham, Harold F. 1986. Bulk-Mineable Precious-Metal Deposits and Prospects. Map 91. Nevada Bureau of Mines and Geology. Mackay School of Mines. University of Nevada-Reno.

Bradford, Bill. 1987. "Gravity Concentration for Gold Recovery". Engineering and Mining Journal. (June): 64-65.

Carlson, Gerald G. and Stevenson, Harold D. 1987. "Gold Exploration: Flow-Through Financing and the Canadian Junior," in Brawner, ed. Gold Mining 87. First International Conference on Gold Mining. November 23, 24, 25, 1987. Vancouver, British Columbia, Canada. Society of Mining Engineers. Littleton, Colorado.

Chamberlain, Peter G. and Pojar, Michael G. 1981. "The Status of Gold and Silver Leaching Operations in the United States," in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago, February 22-26, 1981. Society of Mining Engineers.

Coetzee, C.B., ed. 1976. Mineral Resources of the Republic of South Africa. South Africa Department of Mines, Geologic Survey.

Dayton, Stanley H. 1987. "Gold Processing Update." Engineering and Mining Journal. (June): 25-29.

Elges, C. H. and Wroblewski, M. D. 1986. "Staged Heap Leaching-Direct Electrowinning." Precious Metals Recovery From Low-Grade Resources, pp. 10-17. Proceedings: Bureau of Mines Open Industry Briefing Session at the National Western Mining Conference, Denver, Colorado February 12, 1986. U.S. Bureau of Mines IC 9059. Washington, D.C.

Engineering and Mining Journal. 1987. Bacteria Leaching Enhances Recovery from Refractory Ores." (June): 67.

Fast, John L. 1987. "Glycol Stripping." Engineering and Mining Journal. (June): 48-49.

Federal Reserve Bulletin. 1988. International Statistics. Table 3.28. V. 74, No. 1. U.S. Department of Commerce. Washington, D.C.

Green, Timothy. 1981. The New World of Gold. 260 pp. New York: Walker and Company.

Gries, John Paul. 1979. "Providing New Sources of Mineral Supply." U.S. Bureau of Mines IC 8789. Washington, D.C.

Guay, W. J. 1981. "The Treatment of Refractory Gold Ores Containing Carbonaceous Material and Sulfides," in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago, Illinois, February 22-26, 1981. Society of Mining Engineers.

Halbe, Doug. 1985. "Recovery of Gold and Silver from Leach Solutions," in Webb Callicutt, ed. Heap and Dump Leaching. V. 2. Nos. 1,2. Lakewood, Colorado.

Henriques, Diana. 1987. "Glut in Gold." Barrons. 67 (June): 6-7, 18-22.

Herkenhoff, Earl C. and Dean, Dr. John G. 1987. "Heap Leaching: Agglomerate or Deslime?" Engineering and Mining Journal. (June)

Hiskey, J. Brent. 1985. "Gold and Silver Extraction: The Application of Heap-Leaching Cyanidation." Arizona Bureau of Geology and Mineral Technology Fieldnotes. Vol.15, No.4: 1-4.

Janisch, P. R. 1986. "Gold in South Africa." Journal of the South African Institute of Mining and Metallurgy. (August): 273.

Jastram, Roy W. 1977. The Golden Constant. 231 pp. New York: Ronald Press Publication. John Wiley & Sons.

Karpov, Sasha A. 1986. "Gold Production," in Webb Callicutt, ed. Heap and Dump Leaching. V. 3, No. 4. Lakewood, Colorado.

Kunter, R. S., Turney, J. R., and Lear, R. D. 1984. "McLaughlin Metallurgical Development." International Precious Metals Symposium, Los Angeles February 26-March 1, 1984. Metallurgical Society of AIME and International Precious Metals Institute.

Lewis, Alvin, ed. 1983. "Leaching and Precipitation Technology for Gold and Silver Ores." Engineering and Mining Journal. 184 (June): 48-56.

Lucas, John M. Various editions, 1970-1985. "Gold." Mineral Facts and Problems. U.S. Bureau of Mines Washington, D.C.

Lucas, John M. 1986. "Gold." Minerals Yearbook. U.S. Bureau of Mines. Washington, D.C.

Lucas, John M. 1987. "Gold." Mineral Commodity Survey 1987. U.S. Bureau of Mines. Washington, D.C.

McClelland, G. E.; Pool, D. L.; Hunt, A. H.; and Eisele, J. A. 1985. "Agglomeration and Heap Leaching of Finely Ground Precious-Metal-Bearing Tailings." U.S. Bureau of Mines IC 9034. Washington, D.C.

Mining Engineering. 1987. "Solution Mining." Solution Mining Committee. 39 (May): 349-350.

Mining Journal. 1986. "More Mineral Leaching." (May): 385-387.

Mining Journal. 1987. "The Australian Gold Scene." (March): 161-163.

Poole, James L. 1981. "Review of the Gold and Silver Markets," in Schlitt, Larson, and Hiskey, eds. Gold and Silver: Leaching, Recovery, and Economics. Proceedings from the 110th AIME Meeting, Chicago February 22-26, 1981. Society of Mining Engineers.

Ryan, Brendon. 1987. "Mintek Researching RIP As An Alternative To CIP." Engineering and Mining Journal. (June): 59.

Sandberg, R. G. and Huiatt, J. L. 1986. "Recovery of Silver, Gold, and Lead from a Complex Sulfide Ore Using Ferric Chloride, Thiourea, and Brine Leach Solutions." U.S. Bureau of Mines RI 9022. Washington, D.C.

Shoemaker, R. S. and Dasher, John. 1981. "Recovery of Gold and Silver From Ores," in George Foo and Myron E. Browning, eds. Symposium on Recovery, Reclamation, and Refining of Precious Metals, Sheraton Harbor Island, San Diego March 10-13, 1981. The International Precious Metals Institute.

Simons, Frank S. and Prinz, William C. 1973. "Mineral Resource Estimates and Public Policy," in D.A. Brobst and W.A. Pratt, eds. United States Mineral Resources. U.S. Geological Survey PP 820. Washington, D.C.

Statistical Abstract of the U.S. 1987. 1986. Table 1470. U.S. Department of Commerce. Washington, D.C.

Sutill, Keith. 1987. "Australian Gold." Engineering and Mining Journal. (November): 26-28.

Thorstad, Linda E. 1988. "The Desert Heap Leachers." Investment News. 2 (February): 24-25.

Thomas, Paul R., and Boyle, Edward H. Jr. 1986. "Gold Availability-World: A Minerals Availability Appraisal." U.S. Bureau of Mines IC 9070. Washington, D.C.

Tilton, John E. 1983. Comparative Advantage in Mining. Institute for Applied Systems Analysis. Working Paper A-2361. Laxenburg, Austria.

von Michaelis, Hans. 1987. "The Prospects for Alternative Leach Reagents." Engineering and Mining Journal. (June)

Worstell, Jonathan, H. 1986. "Precious Metal Heap-Leaching in North America." Mining Magazine. (May): 405-411.

Appendix A

WORLD GOLD PRODUCTION: THE TOP 5 PRODUCERS

TABLE A.1: WORLD GOLD PRODUCTION: THE TOP 5 PRODUCERS
(Market share in %)

YEAR	WORLD (MM tr.oz.)	UNITED STATES	SOUTH AFRICA	SOVIET UNION*	CANADA	AUSTRALIA
1960	38.20	4.40	55.97	10.73	12.12	2.85
1961	39.70	3.95	57.78	11.08	11.26	2.72
1962	42.30	3.69	60.26	11.35	9.88	2.53
1963	44.20	3.33	62.06	11.54	8.98	2.31
1964	44.84	3.26	64.92	10.37	8.56	2.14
1965	46.23	3.70	66.08	10.88	7.81	1.90
1966	46.58	3.86	66.29	11.53	7.13	1.98
1967	45.71	3.46	66.79	12.47	6.48	1.75
1968	46.17	3.21	67.51	12.78	5.83	1.69
1969	46.61	3.71	67.11	13.41	5.47	1.54
1970	47.53	3.66	67.66	13.68	5.07	1.30
1971	46.51	3.23	67.49	14.41	4.82	1.44
1972	44.84	3.23	65.23	15.39	4.64	1.69
1973	43.00	2.74	63.95	16.51	4.53	1.28
1974	40.12	2.82	60.79	18.20	4.29	1.27
1975	38.48	2.73	59.62	19.49	4.30	1.37
1976	39.23	2.67	58.46	19.63	4.31	1.28
1977	38.91	2.83	57.84	20.05	4.46	1.62
1978	38.98	2.56	58.10	20.52	4.45	1.66
1979	38.77	2.49	58.34	20.89	4.24	1.54
1980	39.14	2.48	55.36	21.21	4.16	1.40
1981	41.25	3.34	51.20	20.36	4.06	1.43
1982	43.11	3.40	49.54	19.84	4.82	2.01
1983	45.00	4.45	48.55	19.11	5.25	2.19
1984	46.48	4.49	47.04	18.61	5.77	2.79
1985	48.67	4.99	44.31	17.87	5.78	3.87
1986	50.94	7.33	40.27	17.37	6.61	4.87

*/ Soviet data are estimated.

Sources: U.S. Bureau of Mines Publications: Mineral Facts and Problems, Bulletin 675, 1985; Minerals Yearbook (Various eds.) 1963-1986.

TABLE A.2: WORLD GOLD PRODUCTION: THE TOP 5 PRODUCERS
(MM troy ounces)

YEAR	WORLD	UNITED STATES	SOUTH AFRICA	SOVIET UNION*	CANADA	AUSTRALIA
1960	38.20	1.68	21.38	4.10	4.63	1.09
1961	39.70	1.57	22.94	4.40	4.47	1.08
1962	42.30	1.56	25.49	4.80	4.18	1.07
1963	44.20	1.47	27.43	5.10	3.97	1.02
1964	44.84	1.46	29.11	4.65	3.84	0.96
1965	46.23	1.71	30.55	5.03	3.61	0.88
1966	46.58	1.80	30.88	5.37	3.32	0.92
1967	45.71	1.58	30.53	5.70	2.96	0.80
1968	46.17	1.48	31.17	5.90	2.69	0.78
1969	46.61	1.73	31.28	6.25	2.55	0.72
1970	47.53	1.74	32.16	6.50	2.41	0.62
1971	46.51	1.50	31.39	6.70	2.24	0.67
1972	44.84	1.45	29.25	6.90	2.08	0.76
1973	43.00	1.18	27.50	7.10	1.95	0.55
1974	40.12	1.13	24.39	7.30	1.72	0.51
1975	38.48	1.05	22.93	7.70	1.69	0.50
1976	39.23	1.05	22.94	7.50	1.65	0.53
1977	38.91	1.10	22.51	7.80	1.74	0.63
1978	38.98	1.00	22.65	8.00	1.73	0.65
1979	38.77	0.97	22.62	8.10	1.64	0.60
1980	39.14	0.97	21.67	8.30	1.63	0.55
1981	41.25	1.38	21.12	8.40	1.67	0.59
1982	43.11	1.47	21.36	8.55	2.08	0.87
1983	45.00	2.00	21.85	8.60	2.36	0.99
1984	46.48	2.09	21.86	8.65	2.68	1.30
1985	48.67	2.43	21.57	8.70	2.81	1.88
1986	50.94	3.73	21.51	8.85	3.37	2.48

*/ Soviet data are estimated.

Sources: U.S. Bureau of Mines Publications: Mineral Facts and Problems, Bulletin 675, 1985; Minerals Yearbook (Various eds.) 1963-1986.

APPENDIX B

AVERAGE ANNUAL GOLD PRICES

TABLE B.1: AVERAGE ANNUAL GOLD PRICES

YEAR	NOMINAL PRICE (US$)	REAL PRICE (1982 US$)
1960	35.00	112.90
1961	35.00	110.06
1962	35.00	109.72
1963	35.00	108.02
1964	35.00	106.38
1965	35.00	103.55
1966	35.00	100.00
1967	35.00	97.22
1968	39.26	103.86
1969	41.51	104.30
1970	36.41	86.69
1971	41.25	92.91
1972	58.60	126.02
1973	97.81	197.02
1974	159.74	295.81
1975	161.49	272.33
1976	125.32	198.92
1977	148.31	220.37
1978	193.55	268.07
1979	307.50	391.22
1980	612.56	714.77
1981	459.64	489.50
1982	375.91	375.91
1983	424.00	408.08
1984	360.66	334.25
1985	317.66	284.90
1986	368.24	322.88

Sources: U.S. Bureau of Mines Publications: Mineral Facts and Problems 1985; Minerals Yearbook 1986.