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AN ECONOMIC EXPLORATION STRATEGY

FOR WORLD TIN RESOURCES

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ABSTRACT

World consumption of primary tin has far exceeded primary tin supply capabilities in the past several years. Tin prices have increased dramatically in the past two years, almost doubling, and are currently near six dollars per pound. Whether this trend continues and prices keep increasing is of considerable interest to both producers and consumers.

The purpose of this study is to recommend whether investment in primary tin production is, in general, a worthwhile risk for a U.S. mining corporation to take. A thorough examination of the tin industry, a commodity study, is the first step in formulating such a recommendation. The second part of the study involves project evaluation studies of hypothetical producers in four different areas of the world, using Discounted Cash Flow Rate of Return as the main criterion for the investment decision.

The results of the study indicate that conditions are not favorable, generally, for a U.S. mining corporation to become actively involved in primary tin exploration and development. The reasons for this involve the poor results of the hypothetical project evaluation studies for typical tin producers and the fact that political and economic instability in the current market make investment subject

to a great deal of uncertainty and risk, particularly in third-world countries.

The author's conclusion is that the production of tin as a by-product from a complex orebody in a developed country is probably the best current alternative for a U.S. mining corporation interested in tin.

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CHAPTER 1. INTRODUCTION

In recent years, the world market for tin has been extremely volatile. Prices for tin have increased substantially from 1976 to 1978. Tin is a unique commodity in many ways. The world tin market operates under the only base metal commodity agreement, the International Tin Council, and is not dominated by large producers to any significant degree. Furthermore, almost no tin is produced in developed countries and only one U.S. mining corporation actively mines tin at the present time.

The following study first seeks to answer whether or not, in light of recent trends in the world tin industry, active exploration and development of tin would be an economically worthwhile undertaking for a U.S. mining corporation. Secondly, it provides a comprehensive commodity study on tin. The emphasis in this study is more upon production of primary tin than on consumption. The various aspects and problems involved with tin production are analyzed in an attempt to formulate recommendations regarding the viability of commencing tin exploration and/or development.

The strategy involved in exploration for a mineral deposit can be depicted by P.A. Bailly's (1968) Exploration Discovery Model. It states that the following four components are part of the exploration/production decision.

Exploration Discovery Model 1/

Probability of Occurrence		Present Value of the Expected Ore Deposit		Probability of Detection / Exploration Cost		Security of Land Tenure
Does a mineral deposit exist in this area?	x	What is the best estimate of the deposit's value? Is it worth it?	x	Detailed feasibility study; How much money?	x	Legal questions; Political risks

This study assumes the first component as given, and that the application of scientific methods of geological investigation has established a tin deposit. The second component in the discovery model is basically what this study analyzes. The second component considers economic parameters in establishing the best preliminary estimate of the present value of a deposit. In other words, it establishes whether or not tin is, in general, a worthwhile investment for a producer. The last two components further define the conditions necessary under which successful exploration and development for tin may take place.

1 mt -> 2204.6 pound
x -> 2240. pound

CHAPTER 2. DEFINITIONS

The following terms are used throughout this study and are frequently found in the tin industry:

Consumption - The amount of tin actually used or consumed

Demand - That which consumers are willing and able to buy at world prices

Effective tax rate - percent rate taxed on gross profit minus depreciation

Long ton - unit of weight, 2240 pounds

Non-Communist - refers to all nations except Albania, the People's Republic of China, East Germany, Mongolia, North Korea, Vietnam, and the Soviet Union

NSR - net smelter return: total revenue minus charges for smelting and further processing

Picul - Malaysian unit of weight, 133.33 pounds

Primary tin - tin which is produced from an original deposit in the ground

Secondary tin - scrap or recycled tin

Tonne - one metric ton, 1,000 kilograms, or 2,204.6 pounds

Tin Concentrate - tin bearing material which has been prepared for use by tin smelter

Tin-in-concentrate - the actual content of tin metal within the tin concentrate

1 U.S. Dollar =	2.38	Malaysian ringgits (or dollars)
	0.52	British pounds sterling
	20.0	Bolivian pesos
	20.4	Thai baht
	0.87	South African rand

CHAPTER 3. TIN MARKET STRUCTURE - OVERVIEW

The market structure for tin is unique in several ways. Although a certain amount of vertical integration exists in the tin industry, integration is neither as direct nor complete as it is in other base metal industries. Tin mining currently is based on numerous small to medium scale producers in the seven major producing nations. The market structure for tin has the following salient characteristics: 1) it is totally involved in international trade and follows a classic pattern of less developed countries being the producers and developed countries being the consumers, 2) it operates under the International Tin Council, and 3) the U.S. stockpile is a very important element in the current market.

The International Tin Council

The International Tin Council (ITC) is unique in that it presides over the only commodity agreement between producers and consumers in the base metals industry. The ITC, through its International Tin Agreements, attempts to ensure adequate supplies of tin at reasonable prices by preventing excessive supply/demand imbalances and resulting fluctuations in the price of tin. To accomplish this, the ITC maintains a buffer stock, the manager of which may buy or sell tin stocks as needed to maintain stability. The stock is funded by both producers and consumers. Floor and ceiling prices are established by the ITC and are designed to maintain long term supply, demand, and price stability. If circumstances warrant, the ITC can also impose export controls on tin production, which it has done as recently as 1975.

The ITC is very opposed to being compared to a cartel. Its goal is not for price control, but to balance the interests of both producers and consumers so that a fair price results.

The price range for the ITC buffer stock manager includes a floor price, at which the buffer stock manager must buy, a lower sector where he may buy, a middle sector, an upper sector where he may sell, and a ceiling price at which he must sell. The current price range for the ITC, which was revised upward in July, 1978 is as follows. 2/

Floor price (must buy)	Lower sector (may buy)	Middle (no action)	Upper Sector (may sell)	Ceiling (must sell)
4.35¢/lb	4.35 to 4.67	4.67 to 5.16	5.16 to 5.48	5.48¢/lb.

The Fifth International Tin Agreement began on July 1, 1976 and is expected to extend until June 30, 1981. The basic objectives of the Fifth Agreement are the same as the previous agreements and have been outlined above. The rhetoric of the Fifth Agreement, claiming to be in the spirit of a new international economic order, is somewhat ironic. The International Tin Council is currently experiencing more turmoil than ever before. This is due primarily to its current impotency in controlling the market and to conflict between Bolivia, which constantly demands a higher price range, and the United States, which attempts to keep prices down. The United States has only been a member of the ITC since July, 1976. At that time, the U.S. joined the ITC as a consuming country and received significant voting power in Council proceedings, proportional to its consumption. 3/ Table 3.1 lists the members of the ITC and their respective voting power.

The ITC's buffer stock holdings of tin metal were exhausted on January 13, 1977. 4/ Furthermore, the average world price of tin has been well above the ITC ceiling price since 1976. This situation supports criticism that the ITC has done an adequate job in maintaining high prices when supply is abundant but has failed to control price when scarcity exists, thus favoring producers.

Table 3.1

Members of the Fifth International Tin Agreement

Consumers	Votes
Austria	7
Belgium	23
Bulgaria	10
Canada	29
Czechoslovakia	23
Denmark	7
France	58
Germany	78
Hungary	12
India	20
Ireland	6
Italy	38
Japan	166
Netherlands	24
Poland	29
Romania	21
Spain	30
Turkey	12
United Kingdom	71
United States	267
U.S.S.R.	58
Yugoslavia	11
Total	1,000
Producers	
Australia	70
Bolivia	193
Indonesia	156
Malaysia	368
Nigeria	30
Thailand	155
Zaire	28
Total	1,000

Source: Tin International, September, 1978

The price of tin has, on numerous occasions, been above the ceiling price. For only a few days in the past 22 years, however, has it been below the floor price. This situation of an almost guaranteed price might have been expected to attract a flow of new capital investment, but it has not. There are no signs that other non-ferrous metals, without a floor price, have had serious difficulty in raising capital to expand production. The situation portrayed above supports another criticism of the ITC; that neither its members nor outside interests in tin have faith in the ITC's ability to control price effectively in periods of wide fluctuation.

The ITC is currently in a precarious position in maintaining its strength because of 1) the depletion of its buffer stock, 2) its apparent inability to control price, especially upward movement, and 3) increased tension between members of the Council.

The direct mechanisms through which the ITC attempts to fulfill its objectives of stability are the buffer stock and the application of export controls. Since the exhaustion of the buffer stock, the ITC has lost all its direct control methods. This situation, along with the ITC's recent record in controlling excessive price movement, leads to the conclusion that the ITC is generally very ineffective.

The ITC has, justifiably, been widely criticized as being a "paper tiger" in recent years.

While this is generally true, an important qualification must be made. The ITC poses apparently little or no economic influence on the tin market, particularly since the buffer stock was depleted. But the ITC remains an effective political force in the tin industry, and thus lends a degree of psychological stability. The ITC would not have lasted since 1956 without some sort of control over the tin industry. Its influence is indirect, yet the ITC's presence can always be felt in the tin industry in some way.

A situation of oversupply and lower prices would enable the ITC to regain temporary control of the market, since the buffer stock manager would then be able to replenish his stock. In the long term, however, the ITC seems to have little chance of gaining the significant control over the market it is designed to have.

The GSA Stockpile 5/

The General Services Administration for the United States government has jurisdiction over a large strategic stockpile of tin which has been accumulated since 1946. The military objective of this stockpile is for self-sufficiency in wartime, since the United States has few exploitable reserves. The specific tonnage objectives of this stockpile have changed thirteen times in the past 34 years, from a high of 341,000 long ton in 1955 to the present objective of 32,500 tonnes. Annual world consumption is about 200,000 tonnes. The United States now has a stockpile of 199,500 tonnes of grade "A" tin (99.8% or more). Therefore, approximately 167,000 tonnes of tin are available for release, subject to Congressional authorization. The timing and amounts of tin to be released are the subjects of great concern and uncertainty in the international tin market. The stockpile has an immense influence on the world tin market. A mention of even the possibility of GSA releases can have a downward effect on prices. The situation of uncertainty over which congressional stockpile release bills will be passed, and when, has been further exacerbated by an indefinite suspension on all sales due to a pending fraud investigation in the GSA. It is likely that tin stocks will not be released until mid-1979 at the earliest.

The number of committees through which any stockpile release bill must pass are numerous and time consuming. The major figure in stockpile legislation is Representative Charles Bennett (D.-Fla.), the Chairman of the House Subcommittee on Strategic and Critical Materials. The Senate Committee on Armed Services is chaired by Senator Gary Hart (D.-Colo.).

Several stockpile release bills are being considered 6/. Among them is a transfer of 5,000 tonnes of tin to the buffer stock of the ITC. President Carter has indicated he favors this legislation. Senator Mollahan has sponsored a bill which would immediately release 30,000 tonnes of tin for domestic use. This type of release would be disasterous to tin producers and to the ITC's objective of stability in price. Congressmen from Arizona and other states support a bill which would sell stockpiled tin for the purpose of buying and stockpiling copper. Chairman Bennett favors this revolving fund concept of using revenue from stockpile sales to purchase other stockpile commodities, and some form of this bill is likely to be passed eventually.

The importance of releases from the 167,000 tonne GSA stockpile is enormous, though perhaps overemphasized by the current market. It is most unlikely that the United States would flood the international market with an inordinately large release of tin over a short period of time.

The important point concerning the GSA stockpile is that no one knows what legislation will be passed and what amount of tin will be released or when. This uncertainty contributes to the current instability and lack of investment in the tin industry.

Pricing of Tin 7/

Almost all trading of tin metal occurs on three markets: Penang, London, or New York. These markets, particularly the Penang market in Malaysia, set the international price for tin.

The Penang Tin Market, or the "Straits" Tin Market, is actually a complex operation involving the smelting, pricing, and marketing of Malaysian tin. The two large Malaysian smelting companies, Straits Trading Company and Syarkiat Eastern Smelting, conduct the trading on the Penang market. Pricing on the Penang tin market is rather complex. The price is determined by a daily bidding system, in which buyers bid for specific quantities and prices of tin. The price of tin is determined by matching available supplies from the two smelters and the bids received. If supplies at the smelter are abundant, the lower bids control the price. If supplies are relatively scarce on a given day, the higher bids control the price. The Penang market thus directs the original movement of price as a response to the daily available supply and bidded demand in Malaysia.

The London Metal Exchange (LME) provides a different pricing system than the Penang market. Transactions on the LME may be either physical trade in five tonne lots, or simply trade on paper for forward delivery, thus providing a method of hedging for producers and consumers. The price of tin on the LME is determined by hundreds of transactions that take place in the "ring", or circular trading area, at the LME in London. While this trading provides added complexities to the pricing structure of tin, such as hedging, the LME generally follows the pricing patterns set by the Penang market.

The New York Market exists basically to serve North America. Its prices are largely determined by the LME and Penang prices. New York prices for tin are higher than the other two, due to freight, further speculation, and so forth.

Table 3.2 shows the average prices on each market over the last decade.

Political Considerations

Political factors necessarily have as much importance in determining a U.S. corporation's interests in exploiting a mineral deposit as geologic or economic factors. Tin is a very international commodity, and because most trade in this commodity is between the less developed countries (LDCs) and the developed countries, tin is very sensitive to both international and local politics.

Table 3.2

Historical Tin Prices on the Three International Markets (yearly averages)

	Penang ($m/picul)		LME (L/tonne)		New York ($/lb)
1968	565.5		1323.3		1.48
1969	626.1		1451.3		1.64
1970	664.8		1529.5		1.74
1971	631.7		1437.4		1.67
1972	626.8		1505.9		1.77
1973	686.3		1960.4		2.27
1974	1136.6		3493.6		3.96
1975	963.8		3090.8		3.39
1976	1146.6	($3.61)	4254.6		3.74
1977	1588.0	($5.00)	6181.2	($5.04)	5.33
1978 (Aug.)	1770.4	($5.71)	6700.6	($5.93)	6.01

Source: The International Tin Council

The basic organizational pattern in the mining of tin, for many LDCs, has become oriented toward domestic control by one central planning authority, usually a government agency. Examples of this can be seen in Bolivia's COMIBOL and Thailand's Offshore Mining Organization (OMO). With governmental agencies thus directly involved with investment and operating decision, political factors have become more important in tin production than ever before.

One of the central political issues confronting potential foreign tin production by a U.S. corporation is the conflict over the mineral rights of third world countries. Developed countries continue to need large quantities of tin which are not available domestically. Third world leaders are increasingly demanding control over and income from their tin deposits, yet need the capital and technology of western corporations to develop them. The general aversion for transnational or U.S. corporations on the part of third world countries makes potential investment in tin mining in these countries contingent on specific conditions such as how friendly or hostile the LDC is to American "capitalists", how badly the LDC needs to develop its deposits, and how much it needs technological assistance in doing so.

With a substantial restructuring of the international politics of mining in the last fifteen years--the fact that international mining companies can no longer explore for and develop mineral deposits anywhere in the world--the exploration and development plans for producers in the developed countries must be changed significantly. Despite a paucity of known reserves and the higher costs needed to meet various regulations, attract skilled labor, etc., it is reasonable to assume that U.S. and other trans-national mining corporations will become more interested in developing base metal deposits, perhaps including tin, within the developed countries. In the case of tin, this would mean greater emphasis on the exploration and development of primary deposits (underground mining) in Canada, Australia, South Africa, and areas of Alaska. In these areas, the investment climate for the mining industry is fairly clement and political uncertainties such as a restrictively high or unstable tax structure, radical changes in government policies, or the threat of local military disruptions are not high.

As trans-national or U.S. corporations find it increasingly difficult to develop tin deposits in LDCs due to mitigating political risks, it is probable that more emphasis will be placed on production technology in developing geologically less favorable deposits in more politically stable areas. This would include better recoveries and more efficient, large-scale operations.

Most of the world's tin is produced in Southeast Asia, which historically has had a very unstable political climate. A brief discussion of the internal politics of Malaysia, Thailand, and Indonesia might be indicative of some of the politically related problems in producing tin in the third world.

Malaysia is a parliamentary democracy. Within the country, political affiliations are usually based on race. The population is segmented into native Malayans (bumiputra) and others, mostly of Chinese origin. Because of race problems, the New Economic Policy was adopted to give native Malayans a larger share of participation in the national economy. Other political factors relating to tin exploitation involve an extremely high tax rate, often over 70 percent of gross mining profit, and reluctance on the part of state governments to lease new areas for mining. Malaysia can remain a fairly politically stable country only if racial tensions are relaxed and the national economy stays healthy.

Indonesia is not an attractive area, politically, for tin investment on the part of foreign producers. This is due to two common factors in Southeast Asian countries. One factor involves the laws controlling foreign investment, the other is the alleged existence of corruption and smuggling.

Indonesian laws require all foreign investment to be in the form of a joint venture with an Indonesian national, with an eventual 51 percent share required for Indonesians. Foreign companies must also train and employ as many Indonesians as possible. Such policies tend to make foreign investors very wary.

Widespread corruption may make participation by foreigners additionally difficult. A producer not familiar with the local procedures for various payments, or who is subject to laws which prohibit such action may be at a serious disadvantage.

Although American Metal Market has stated in August, 1978 that "the door is closed to foreigners" in Indonesia, there could be exceptions. The politically related risks, however, would be very high.

Thailand appears to have less restrictions on foreign investment in tin mining. The government does control foreign development, through such agencies as the OMO (Offshore Mining Organization), but profitable joint venture operations are possible. Agreements between Billiton and OMO illustrate this. The Thai government, however, is unstable and prone to military takeover, which has occurred as recently as Autumn, 1977. Disruption of tin production by military action is a possibility.

Because tin is so often produced in such politically sensitive areas of the world, involvement or lack of involvement on the part of a U.S. corporation will necessarily be dictated by the political climate of whatever area may be of interest. The political stability of the producing countries cannot be predicted. The purpose here is to indicate that tin which is produced by foreign corporations in less developed countries is almost always prone to significant political risks, and increasingly, hostility toward the United States.

CHAPTER 4. TIN COMMODITY STUDY

Primary Tin Production

World Trends in Tin Production 1968-1977 8/

The following commodity study on tin, as mentioned earlier, emphasizes primary production. In order to develop an economic exploration strategy for world tin, it is essential to analyze in detail world production trends.

The overall trend in tin production in the last ten years, vis-a-vis demand, is deficit. Since 1968, world consumption of primary tin has exceeded production of primary tin by 64,300 tonnes. This has been possible through the depletion of various world stocks. Table 4.1 illustrates these figures.

As shown, world production over the last decade has not experienced substantial growth and has declined in recent years from a high of 190,700 tonnes in 1972 to 179,200 tonnes in 1977. Production has declined in this period and is generally expected to continue to decline, despite spectacular increases in the price of tin. Table 4.2 shows the relationship between production and prices.

Table 4.1

Historical World Tin Supply and Demand
(in tonnes)

	Primary Production	Primary Consumption	Surplus/ Deficit
1968	187,800	179,600	+8,200
1969	183,300	186,600	-3,300
1970	183,600	185,600	-2,000
1971	185,900	189,400	-3,500
1972	190,700	192,000	-1,400
1973	187,300	214,200	-26,900
1974	179,800	200,200	-20,400
1975	176,900	173,900	+3,000
1976	181,800	194,400	-12,600
1977	179,200	184,600	-5,400

Source: The International Tin Council

Table 4.2

Production vs. Price

	Production (tonnes)	Average N.Y. Price (¢/lb.)
1972	190,700	177.5
1973	187,300	227.2
1974	179,800	396.3
1975	176,900	339.6
1976	181,800	374.7
1977	179,200	553.6

Source: Tin International Statistical Supplement, Sept., 1978.

Further world primary tin production statistics are given in Table 4.3. This table gives detailed production figures for all producing countries of the world and their trends since 1968.

The seven major producing countries account for about 85 percent of non-Communist primary tin production. Table 4.4 illustrates this situation. Table 4.5 presents the data in terms of percentages of world total. Table 4.6 includes ITC estimates of production from the People's Republic of China and the Soviet Union. Communist countries are thought to produce about 18 percent of total world tin.

Overall, world production of tin is stagnant. The reasons for this stagnation in supply will be discussed below. They include: lack of capital investment and investor confidence, lowering grades of both lode and alluvial tin, restrictive government policies on areas available for mining, burdenous tax rates, skyrocketing capital and operating costs, and a general lack of stability and confidence in the future of tin.

Trends in Tin Production and Production Potential by Country

Given the aggregate figures above, the next step is to analyze the recent production trends by country as they might relate to exploration and/or production potential for tin mining in each country.

Table 4.3

World Production of Tin-in-Concentrates
(in Tonnes)

Country	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Argentina	712	869	1,172	711	559	432	555	538	600	
Australia	6,642	8,308	8,828	10,035	11,997	10,801	10,480	9,310	10,389	10,694
Bolivia	29,568	30,047	30,100	30,290	32,405	28,568	29,151	28,324	28,122	32,615
Brazil	1,865	2,033	3,610	2,098	2,813	3,742	4,400	5,000	4,900	
Burma	300	300	314	493	500	580	600	750	750	
Canada	162	131	120	145	164	127	475	306	265	
China, P.R.					21,000	22,800	23,000	23,000	23,000	
Czechoslovakia	-165	157	166	169	160	153	143	176	180	
France	374	256	322	322	313	311	142	51	--	
East Germany					1,000	1,000	1,000	1,100	1,100	
Indonesia	16,940	16,542	19,092	19,767	21,766	22,648	25,630	25,346	23,418	24,022
Japan	946	739	793	788	873	811	550	654	634	
South Korea	76	76	76	76	76	63	24	24	24	
Laos	489	522	575	672	787	746	612	518	576	
Malaysia	76,274	73,325	73,794	75,445	76,830	72,260	68,122	64,364	63,401	58,703
Mexico	526	510	541	479	355	293	400	450	310	
Niger	75	35	67	80	91	93	84	84	84	
Nigeria	9,804	8,741	7,959	7,326	6,731	5,828	5,455	4,652	3,710	3,267
Peru	20	20	20	20	20	20	20	20	20	
Portugal	634	445	435	555	607	524	424	388	342	
Rhodesia	600	600	600	600	600	600	600	600	600	
Rwanda	1,320	1,320	1,320	1,320	1,440	1,380	1,300	1,250	1,200	
South Africa	1,866	1,823	1,986	2,021	2,126	2,628	2,490	2,771	2,709	
Spain	142	266	442	402	379	523	643	737	720	
Thailand	23,980	21,092	21,779	21,689	22,072	20,921	20,339	16,406	20,453	24,205
Uganda	172	166	122	117	72	44	199	117	120	
U.K.	1,827	1,648	1,722	1,816	3,327	3,573	3,239	3,330	3,323	
U.S.A.	72	72	72	72	72	72	72	72	72	
U.S.S.R.					12,000	13,000	14,000	14,000	14,000	
Zaire	6,264	6,647	6,458	6,456	5,960	5,442	4,675	4,562	4,000	3,607

Note: Some of these figures are ITC estimates; some may include tin in mixed concentrates.

Source: Tin Statistics, 1966-1976.

Table 4.4

Production of Tin-In-Concentrates for the Seven Major Producing Nations*
(in tonnes)

Country	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Malaysia	76,270	73,322	73,794	75,445	76,830	72,260	68,122	64,364	63,401	58,703
Bolivia	29,567	30,045	30,100	30,290	32,405	28,568	29,151	28,324	28,122	32,615
Thailand	23,979	21,091	21,779	21,689	22,072	20,921	20,339	16,406	20,453	24,205
Indonesia	16,898	16,541	19,092	19,767	21,766	22,648	25,630	25,346	23,418	24,022
Australia	6,996	8,259	8,876	10,035	11,997	10,801	10,480	9,310	10,389	10,694
Nigeria	9,803	8,741	7,959	7,326	6,731	5,828	5,455	4,652	3,710	3,267
Zaire	6,264	6,647	6,458	6,440	5,960	5,442	4,675	4,562	3,723	3,560
Others	13,423	13,545	17,642	16,108	18,139	22,332	20,248	28,596	26,384	29,634
World Total	183,200	178,100	185,700	187,100	195,900	188,200	184,100	181,200	179,600	186,700

*World Total does not include Communist Countries

Source: Tin International Statistical Supplemenet, September 1978.

Table 4.5

Production of Tin-In-Concentrates in Percentages of World Total* For The Seven Major Producing Nations

Country	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Malaysia	41.6%	41.2%	39.8%	40.3%	39.2%	38.8%	37.2%	36.2%	35.7%	31.5%
Bolivia	16.1	16.9	16.2	16.2	16.5	15.3	15.9	15.9	15.8	17.5
Thailand	13.1	11.8	11.7	11.6	11.3	11.2	11.1	9.2	11.5	13.0
Indonesia	9.2	9.3	10.3	10.6	11.1	12.2	14.0	14.3	13.2	12.9
Australia	3.8	4.6	4.8	5.4	6.1	5.8	5.7	5.2	5.8	5.7
Nigeria	5.3	4.9	4.3	3.9	3.4	3.1	3.0	2.6	2.1	1.8
Zaire	3.5	3.7	3.5	3.4	3.0	2.9	2.5	2.6	2.2	1.9
Others	7.4	7.6	9.4	8.6	9.3	10.6	10.6	14.1	13.7	15.8
	100.0%									

*Excluding Communist Countries

Source of Data: Table 4.4.

Table 4.6

Production of Tin-In-Concentrates in Percentages of World Total Including Communist Countries

Country	1972	1973	1974	1975	1976
Malaysia	33.5%	32.9%	31.0%	30.8%	30.2%
Bolivia	14.1	13.0	13.3	13.5	13.4
Indonesia	9.5	10.2	11.7	12.1	11.1
China	9.1	10.0	10.5	11.0	11.0
Thailand	9.6	9.5	9.2	7.8	9.2
U.S.S.R.	5.2	5.5	6.4	6.7	6.7
Australia	5.3	4.7	4.8	4.4	5.0
Others	13.7	14.2	13.1	13.7	13.4
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Roskill Information Services, 1977.

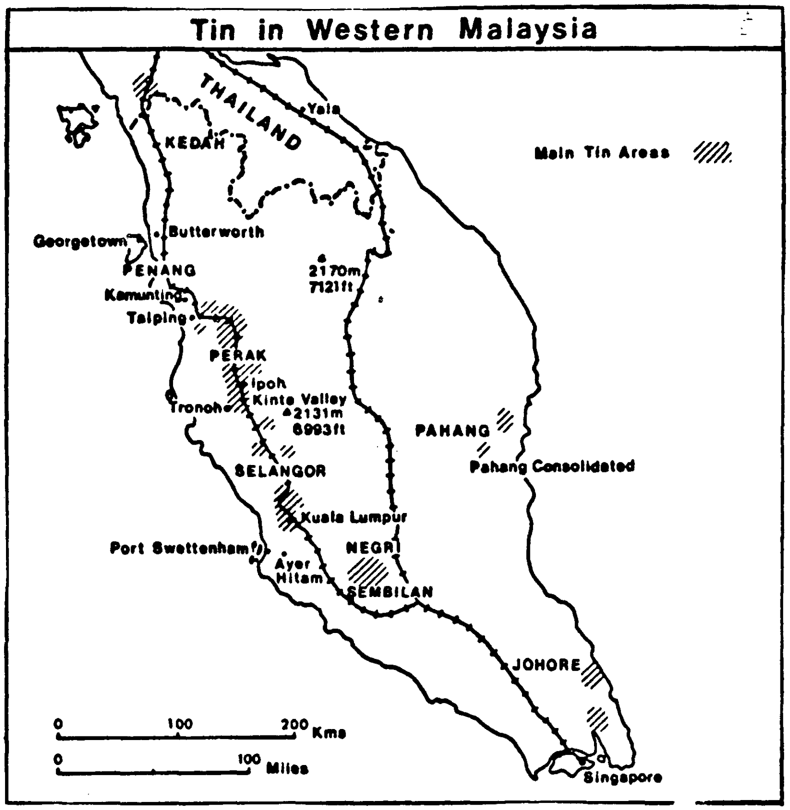
Malaysia 9/, 10/. Malaysia is by far the world's largest tin producer, but has experienced steadily declining production since 1972 when it produced 76,830 tonnes of tin-in-concentrates. The following tabulation shows the trend in Malaysian primary tin production.

	1972	1973	1974	1975	1976	1977
Tin-in-concentrate production (tonnes)	76,830	72,260	68,122	64,364	63,401	58,703

Source: Tin International Statistical Supplement, Sept., 1978.

Most of Malaysia's tin deposits lie within a strip about 400 miles long and 50 miles wide along the western coast of the Malay peninsula. The deposits are generally found in a contact zone between sediments and a granitic mass called the Main Range. The stages of Perak (the Kinta Valley) and Selangor (near Kuala Lampur) account for a great deal of Malaysian production. The Kinta Valley, Batang Padang, Batang Berjuntai, and Kuala Lumpur tin fields contain the country's major tin occurrences and produce at relatively low cost. The Kinta Valley in Perak is the world's most productive area for alluvial tin and has been for decades. On the eastern side of the Malay peninsula the Pahang region provides additional production. Figure 4.1 shows these main areas of Malaysian tin production.

Figure 4.1



Malaysia's production comes primarily from two methods of mining; gravel-pump extraction and dredging. Almost all Malaysian production is from alluvial deposits, as opposed to lode deposits. Table 4.7 breaks Malaysian tin production into percentages of mining methods.

The trend in Malaysian production is toward dredging. Gravel pump production has decreased its relative production in the last five years. Another trend illustrated in Table 4.7 is a reduction in the number of working units for both

Table 4.7

Malaysian Tin Production by Mining Method
(in percent)

	1972	1973	1974	1975	1976	1977
Gravel Pumping	55.7%	53.9%	53.3%	54.7%	50.0%	50.9%
Dredging	31.2	31.1	32.4	31.6	36.4	35.0
Hand Panning	3.9	4.2	4.5	4.8	4.8	5.3
Open Casting	3.4	5.0	4.3	4.0	3.6	3.9
Underground	3.3	3.2	3.4	3.0	2.9	2.9
Other	2.5	2.5	2.1	2.1	2.3	2.0
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Number of Dredges	58	58	56	55	51	53
Gravel pump units	940	983	932	810	724	784

Source: Peter Rich, International Tin Symposium, 11/77.

dredges and gravel pumps. This seems to indicate that larger, more efficient operations are becoming increasingly important.

The most anomalous feature of Malaysian supply statistics is that the most drastic reductions in tonnes of tin produced have occured in the face of substantial increases in the price of tin. While the average Penang price of tin rose 38 percent from 1976 to 1977 ($3.61/lb. to $5.00/lb.), production of tin actually declined by 7.5 percent. The main explanation for this is that Malaysia is now faced with rapidly declining grades. In years past, Malaysia had mined high grade ores and more recently ores of medium grade. Malaysia now seems to be entering the final stage of mining low grade tin deposits.

The Malaysian Mines Department shows that in 1972 the average grade mined by a dredge was 0.31 pounds cassiterite per cubic yard. In 1973, the figure dropped to 0.38 pounds per cubic yard, and in 1974, 0.27 pounds per cubic yard. Table 4.8 illustrates the trend. Since 1975, cut-off and average grades have decreased further, to the current average figure of about 0.2 pounds cassiterite per cubic yard. Gravel pumps have shown a similar decline.

In addition to the basic problem of depleting reserves of all but low grade ores, Malaysia is faced with a situation of steeply rising costs. This is particularly true in the

Table 4.8

Grade Statistics of Some Malaysian Dredge Producers
(in lbs. per cubic yd.)

Company	1972	1973	1974	1975
Berjuntai	.29	.30	.26	,23
Kamunting	.29	.28	.26	.19
Malayan Tin	.25	.28	.24	.21
Southern Kinta	.25	.23	.22	.19
Southern Malayan	.23	.23	.19	.23
Pengkalen	.47	.31	.35	.21
Tanjong Tin	.43	.27	.33	.22

Source: Peter Rich, International Tin Symposium Paper, 11/77.

gravel pump sector, whose production costs,of which a large percentage are energy costs, have increased dramatically over the last decade to the present average of about $4.33 per pound. Costs will be discussed in detail below.

Other factors that explain Malaysia's declining production include restrictive government policies. A high tax rate, which miners complain erode profits and stifle exploration for new deposits, is well known as the highest in the tin industry. Malaysian tin producers are subject to a variety of different taxes such as an export duty and surcharge, tin profits tax, sales tax, development tax, and income tax. The total effective tax rate is often 70 percent or more 11/. Another government policy which disfavors increased production is the policy of restricting the land available for mining or dredging. There is generally strong opposition to increased mining development at the state government levels, primarily because state governments receive relatively little tax revenue from the tin industry. Land utilization and environmental issues will provide more controversy and uncertainty in future Malaysian tin production.

Tin production in Malaysia can be expected to continue to stagnate or decline in the next decade as it has in the past decade. The reasons for this have been stated above. Slight increases in tin-in-concentrate production are likely for the near term, from the relatively low 1977 figure of 58,703 tonnes, but further declines will probably occur in the 1980's.

Bolivia. 12/ Bolivia, the world's second largest tin producer, has held steadily near 30,000 tonnes tin-in-concentrate per year for the last ten years. Bolivia has a long tin mining tradition that extends several thousand years. Bolivia's production is almost entirely from underground mines.

The mining area in Bolivia is a distinct belt which is 500 miles long and 100 to 200 miles wide. All Bolivian tin mineralization discovered thus far has been within this mountainous belt known as the Antiplano, which runs North-South along Bolivia's western border. The most important region of Bolivian tin production is the Catavi-Llallagua-Huanuni region, 200 miles south of La Paz. Potosi, which is located in the center of the belt, is another major tin producing center. 13/

Bolivia exports almost all of its production either in concentrates or as tin metal. Traditionally Bolivia has exported large amounts of concentrates to three companies; Capper Pass in the United Kingdom, Metallgesellschaft in West Germany, and Gulf Chemical in Texas City, Texas. The current trend, however, is toward nearly total domestic smelting capacity.

Most of Bolivia's tin mines are divided into three categories: the Corporacion Minera de Bolivia (COMIBOL), the medium miners, and the small miners. Comibol is the state-owned mining company. It is large scale and produces most of the country's tin. The medium-sized mines are privately owned by Bolivian and outside interests. The number of medium mining companies is about twenty. Their biggest advantage is that they seem to have the largest reserves (at least 135,000 tonnes of tin), giving them a working life of over 30 years. The grades of medium miners are also usually higher than those of COMIBOL's. The small mines are ubiquitous within the Bolivian tin belt. One man operations often produce next to highly mechanized large mines. The following table portrays the relative importance of each source of tin-in-concentrates for export.

Table 4.9

Origin of Bolivian Tin-In-Concentrates Exported
(in tonnes)

	1973	1974	1975	1976
COMIBOL	14,672	15,184	14,344	15,090
Medium Miners	4,198	3,531	2,857	2,759
Small Miners	2,407	2,834	1,516	2,128
Other	328	300	268	501
Total	21,605	21,849	18,985	20,478

Source: Roskill Information Services, 1977.

No new major mines have been found in the last forty years, grades have been decreasing, and the underground mining methods of Bolivia are the highest cost per pound of tin in the world. It is also considered probable that most of the future production will come from extensions of known reserves.

The major problem in Bolivian tin production is and will continue to be high production costs. These costs currently average near five dollars per pound and threaten to place Bolivian miners out of competition with other world producers. Lower grades have also begun to threaten production potential. COMIBOL mines maintained an average head grade of 0.82 percent from 1960 to 1966. In 1967 the figure dropped to 0.75 percent, and in 1974 to 0.70 percent tin.

Given these problems, it would appear that Bolivia is in serious trouble in maintaining its share of the production load. The fact is, however, that Bolivia is a remarkably tenacious producer and has remained steadfast over the last ten years in the 30,000 tonnes per year range and appears capable of continuing to do so in the next ten. Bolivia's biggest trend is toward major investment in sophisticated milling and smelting facilities in the hope of increased recoveries from the same tonnages mined.

Indonesia. Of all the major producing countries of the world, Indonesia seems to have the brightest future. Indonesian output has grown the fastest in recent years. Indonesia possesses by far the world's largest reserves of tin, about 2.5 million tonnes.

Indonesia and Thailand virtually share the position of the third largest tin producer in the world. Both countries produced approximately 24,000 tonnes of tin-in-concentrate in 1977. Indonesia, unlike Malaysia, has significant reserve potential and has increased its output steadily over the last ten years. Intensive prospecting and evaluation work has taken place in recent years in and around the various islands of Indonesia by the State Mining Company. Offshore potential in Indonesia has been found to be substantial and promises to comprise a larger percentage of total production in the future. Extensive offshore deposits have been found off the East coast of Belitung and the West-central coast of Bangka.

Production of tin in Indonesia is generally confined to a few islands. The major areas of Indonesia production are: Bangka, Belitung, Sinkep, and Bangkinang. Bangka is by far the biggest region and output has increased consistently in recent years 14/. Table 4.10 illustrates this.

Table 4.10

Indonesian Production of Ton-In-Concentrates by Area (in tonnes)

	1972	1973	1974	1975	1976
Bangka	14,694	15,989	17,659	17,180	16,064
Belitung	5,452	5,232	5,403	5,209	4,719
Sinkep	1,465	1,220	1,775	1,801	1,269
Bangkinang	155	142	185	201	151
Other	-	156	608	955	-
Total	21,766	22,648	25,603	25,346	22,203

Source: Roskill Information Services.

Tin mining is now generally under the control of the State Mining Company, P.T. Timah. Recent trends under P.T. Timah are toward increased offshore exploitation and increased domestic smelting capability.

Private companies are allowed to operate in Indonesia to a limited extent.15/ A newly discovered deposit near Tujah Island, southwest of Banka, with expected production of 2,500 tonnes per year is currently being developed by Billiton, a subsidiary of Royal Dutch Shell. Other companies, such as Australia's Broken Hill Proprietary and K.T. Koba Tin are also involved in Indonesian exploration. Japanese companies are also exploring for tin in areas near Bangka.

The Indonesian tin belt, which runs through the islands mentioned, is probably a submerged extension of the Malaysian Main Range. Radiometric dating of both Malaysian and Indonesian stanniferous granites help prove this theory. Extensive shallow sea stretches between the known Indonesian deposits. Offshore tin production is thought by geologists to have more potential in this region than anywhere in the world. Although offshore drilling and exploration is more expensive than land-based exploration, offshore reserves promise greater rewards in grades and more efficient production at lower unit cost.

Onshore reserves and production continue to dominate in Indonesia and will continue to do so in the next decade. Potential for substantial increases in output will involve traditional methods and offshore exploration and exploitation in ever larger degrees. Indonesia's annual output is likely to increase steadily over the next decade.

Thailand 16/. Thailand generally has very good potential for future production. Like Indonesia, reserves are substantial, production has increased in recent years, and offshore deposits are being explored. Exploration in Thailand has not been carried out to the same extent as Malaysian or Indonesian exploration.

Thai production peaked in 1968 at 23,979 tonnes tin-in-concentrate and has since steadily produced about 20,000 tonnes per year. The low output in 1975 to 16,406 tonnes was due to political unrest and the nationalization and creation of the Thailand Exploration and Mining Company (TEMCO). Since then, production has increased to the 24,000 tonnes per annum level.17/

Tin mineralization found in Thailand is part of the Southeast Asian tin belt which enters Thailand from Malaysia and runs northward through the Thai peninsula. The most concentrated activity occurs on the southern part of the peninsula in a 300 mile long strip between Ranong and Yala.

The current center of tin production is in the area of Phuket Island.

The deposits in Thailand, like other Southeast Asian deposits, are nearly all alluvial or eluvial. Thai cassiterite is generally pure and smelts easily.

Foreign owned or controlled tin mining companies comprise a relatively small percentage of tin output in Thailand. Among these are Aokam Tin and Tongkah Harbor of Malaysia, Billiton of the Netherlands, and Kamunting Tin of the United Kingdom.

The most notable trend in Thai production is the increase in gravel pumps and the decrease in onshore dredges since 1960. This trend is the opposite of Malaysia and indicates that Thailand is experiencing a different phase in its mining life than the older Malaysian industry. Table 4.11 shows the trend in recent Thai tin production methods.

Table 4.11

Trend in the Number of Thai Working Units

	1952	1962	1976
Number of gravel pumps	74	128	300
Number of onshore dredges	23	24	14
Number of offshore dredges		1	4

Source: International Tin Council

In 1976, 39 percent of Thai production came from dredging operations, 45 percent from gravel pumping and hydraulicking, and 16 percent from small lode mines or other production methods.

An important development in Thai production has been the expansion in offshore dredging in the last ten years. The offshore dredging trend is for larger tonnages, higher grades, and a more important share in future production. The Offshore Mining Organization (OMO) is a government body set up to own and operate offshore properties. Billiton is involved with the OMO and other companies are also negotiating Obtaining concession rights, such as offshore exploitation permits, is a problem which confronts both domestic and foreign producers.

Thailand can expecte moderate increases in annual output in the next decade if the political situation remains stable.

Australia 18/. Australia is the fifth largest producer in the non-Communist world. Australia has consistently supplied about 10,000 tonnes of tin per year in the 1970's, and probably has the most stable tin industry in the world. In 1976, 70 percent of Australian production came from hardrock deposits in Tasmania and New South Wales. Tasmanian low-grade tin reserves are substantially large. Dredging has become less important in recent years, as massive underground and open pit methods have taken over.

The Ardlethan, Renison, and Cleveland tin companies account for most of the tin mined in Australia. The trend for these producers, as in other non-ferrous metal production, is toward large-scale, low-grade production requiring significant capital investment. Metallurgical difficulties are thus a constant concern for these producers.

Active exploration for lode deposits in Australia continues. Offshore dredging in the Bass Strait off Tasmania is a long term possibility.

Australian production costs in recent years have proved to be quite competitive with other producers, falling in the lower range of world production costs. The future of Australian tin production is good in both the short term and long term. Production of tin-in-concentrates will probably remain above the current level of about 10,000 tonnes per year during the next decade.

Nigeria 19/. Nigeria was one of the major producers in the world in the first half of the 20th century. In the past ten years, however, Nigerian production has dropped steadily from nearly 10,000 tonnes in 1968 to only 3,267 tonnes in 1977. A complete lack of new investment, labor problems, and increasing costs have been major factors in the decline of Nigerian production, but the real problem is that Nigerian tin fields are nearly at the end of their lives.

Zaire. Zaire's supply history shows wide fluctuations. Output reached 16,000 tonnes per year during the World War II years. In the last ten years, production has decreased from 6,264 to 3,607 tonnes. This decline is generally attributable to an uneasy political situation, but declining grades have also played an important part. The difficult political situation has caused exploration and the development of mines to stagnate in recent years.

The United States Department of the Interior has stated that Zaire potentially contains one of the major tin reserves in the world. However, political and military factors have, and will continue, to influence profoundly the status of Zairian tin production and production in the short term will probably continue its stagnant trend.

Brazil 20/. Brazil has considerable reserves and potential as a tin producer and is pursuing plans for increased exploitation. The Brazilian government has adopted a program of expanding the non-ferrous mineral industry and the formidable task of achieving self-sufficiency in tin in the next five years. The Brazilian tin mining industry is controlled by the government and is basically comprised of four domestic companies.

During the last ten years, tin output has risen spectacularly, primarily from the development of the Rondonia province, a belt of alluvial or elluvial deposits running about 200 miles along the Brazil-Bolivia border. This area will undoubtedly help Brazil continue to increase its production in the next decade. The Rondonia deposit has very high grades, but is extremely inaccessible and mining conditions are very difficult:

> "The local labor is of Indian origin, has no concept of wage bargaining, is illiterate, cheap, and is wide open to exploitation; it is naturally inefficient...up to 40 percent of the labor force may be expected to have debilitating malaria." 21/

Production in Brazil has risen from 447 tonnes in 1962 to 3369 tonnes in 1970 to about 5,000 tonnes in 1977. Thus Brazil has become one of the world's large producers, and significantly, one of the lowest cost producers. Any increases in Brazilian production are likely to come from domestic, government controlled sources and be internally consumed.

United Kingdom 22/. The tin districts of Cornwall in southwest England have been worked since the time of the Phoenicians. Since the beginning of this century, large amounts of tin have not been produced. In the past ten years, interest in Cornish tin has been substantially renewed with the opening of the Wheal Jane and Mt. Wellington mines. Production almost doubled from 1,827 tonnes in 1968 to 3,573 tonnes in 1973. Production in 1977 was 3,323 tonnes. Very recently, however, Wheal Jane and Mt. Wellington have experienced enormous problems including flooding, strikes, very high costs, and finally have been forced to close. Production increases in the United Kingdom in the last ten years have been encouraging. The future depends on overcoming some of the recent problems, which are very discouraging.

China/U.S.S.R. 23/ 24/. China and the Soviet Union are usually not included in world tin statistics because so little is known about production and consumption in these countries. Chinese reserves of tin are large and China is thought to be one of the world's major tin producers, with a mine and smelter production of over 23,000 tonnes per year. This estimate, made by Metallgesellschaft, has not changed since 1970. China has become increasingly important as an exporter of tin metal in recent years. Whether this trend continues depends on the degree of internal Chinese consumption.

The U.S. Bureau of Mines/Central Intelligence Agency estimate for Soviet primary production in 1976 was 31,000 tonnes. Overall, the Soviet Union has been a net importer of tin, though it is the second or third largest producer of tin in the world. This trend is expected to continue and the Soviet Union will proabably import anywhere from 5,000 to 10,000 tonnes per year over the forthcoming decade.

World Reserves 25/

World reserves of tin are considered to be adequate well into the next century. The nations with the greatest reserves are Indonesia (2,360,000 long tons), Thailand (1,217,000 long tons), China (1,500,000 long tons), and Bolivia (985,000 long tons) (Sainsbury and Reed 1973). The figures for world tin reserves were calculated in 1973 by Sainsbury and Reed at a price of approximately $3.50 per pound and are shown in Table 4.12. Some "conditional resources" at that time have become reserves in the last five years. Thus world reserves currently exceed 10 million tonnes.

In addition to the response in increased prices, world reserves may also be significantly extended with improved technology in recovering tin from complex ores in locations such as Bolivia.

Reserves of tin are particularly difficult to define, given the geologic nature of tin deposits. Moreover, grades of alluvial deposits are interpreted and reported in different ways and may be somewhat subjective. Alluvial reserves which extend into offshore areas are highly dependent on price. Specific delineation of lode deposits may also be difficult to estimate, because of very often complex structural features.

A detailed discussion of tin reserves by country is contained in Sainsbury (1969). Of particularly interest in a U.S. mining corporation considering tin production are potential reserves in the United States. Although the United States

Table 4.12

Tin Reserves and Resources of the World
(in long tons of tin metal)

Country	Reserves: Measured	Reserves: Indicated	Conditional Resources
North America:			
U.S.A.	8,435	33,100	43,000
Canada	10,000	10,000	28,000
Mexico	1,000	5,000	--
South America:			
Bolivia	485,000	500,000	500,000
Brazil	300,000	300,000	1,075,000
Argentina	3,000	3,000	--
Europe:			
England	128,700	128,700	600,000
Spain & Portugal	15,000	15,000	150,000
France	--	4,000	4,000
Asia, Non-Communist:			
Indonesia	500,000	1,860,000	1,080,000
Malaysia	600,000	230,000	1,000,000
Thailand	217,000	1,000,000	1,860,000
Burma	250,000	250,000	--
Others	17,500	90,000	--
Africa:			
Nigeria	138,000	138,000	100,000
Zaire	65,000	130,000	1,000,000
Others	117,000	117,000	22,000
Australia & Tasmania	94,330	94,000	200,000
China	500,000	1,000,000	2,000,000
U.S.S.R.	200,000	420,000	600,000
World Total	3,649,965	6,327,800	10,261,000

Reserves: Identified deposits from which minerals can be extracted profitably with existing technology and under present economic conditions.

Conditional Resources: Identified deposits whose minerals are profitably recoverable with existing economic and technological conditions.

Source: Sainsbury and Reed (1973), pp. 646.

is generally considered to have no substantial tin reserves, Alaska has reserves of at least 40,000 tonnes within a belt that extends eastward from the Bering Strait through the Seward Peninsula. Production from the main deposit in Lost River, Alaska, has taken place off and on since the early part of this century. Over 2,000 tonnes have been recovered. The Lost River lode tin deposit also contains tungsten, fluorite, and beryllium in potentially economic amounts. Exploitation of tin from this property would probably be as a by-product or co-product of fluorite and tungsten.

Other areas of the Seward Peninsula are known to contain tin reserves. These areas, near Lost River, include Potato Mountain, Ear Mountain, and York Mountain. Other regions in central Alaska and perhaps the Aleutians have favorable tin geology and have not been fully explored for tin potential.

Alaskan reserves are insignificant by world standards, but could be significant to a single producer given reasonable costs and high prices.

Other small tin reserves exist in the Black Hills in South Dakota, New Mexico, California, and as a by-product from the Climax mine in Colorado.

Geology of Tin Deposits

Any exploration strategy must first depend on geologic considerations, regardless of the economics involved. A brief discussion of the nature of tin ores, then, is essential to the development of an economic explortion strategy.

Properties of Tin. Tin is a silver-white, malleable, corrosion-resistant metal with a melting point of 232 degrees Centigrade. It is a soft metal, having a hardness of only 1.8 on the Moh's hardness scale. Pure tin is mechanically weak and tin is almost never used in its pure form. Tin, however, is almost indispensible as an alloy due to its unique properties. Over 90 percent of tin is used in the metallic form.

The most important use of tin, that of tinplating of food and beverage cans, is possible because of its non-toxicity, its corrosion resistance, and its ability to conform to steel bending and drawing. Tin also has uniquely useful properties in its low melting point, excellent wetting characteristics (conformability), and ability to react with other metals and is thus well suited for soldering. Other important properties are that tin alloys, under certain conditions, are electrical superconductors and that tin atoms can be linked to carbon structures to form "organotin" compounds which have a variety of uses.

Types of Deposits. Tin is produced almost exclusively from the mineral cassiterite (SnO_2), which is found all over the world. Tin's crustal abundance, or Clarke number, is only three parts per million, which is small compared to other base metals such as copper (70 ppm) and zinc (80 ppm). Tin bearing sulfides may be of local importance in some Bolivian locations.

Tin deposits may be simply classified as either primary (vein deposits) or residual (placer deposits). Almost 80 percent of all tin produced is from the residual sources. Tin's primary occurrence, however, is usually restricted to narrow bodies or veins associated with granite or other acidic rocks.

More specifically, economic lode deposits are almost always associated with biotite or biotite-muscovite granites (Sainsbury, 1969). In Bolivia, the association is with volcanic equivalents, quartz latites, or dacites. The shallower depths of deposition in the Bolivian ores have resulted in complex mineralogy due to the telescoping of zones (Park, 1975).

Lode tin deposits can be classified into five distinct types: (after Sainsbury, 1969)

1. Pegmatite deposits
2. Pneumatolytic-hydrothermal deposits
3. Subvolcanic deposits
4. Disseminated deposits
5. Contact metamorphic deposits

1. Pegmatite deposits are of little economic importance. Pegmatites containing tin usually contain other uncommon minerals such as tantalum. Zaire has deposits of this type.
2. Pneumatolytic-hydrothermal deposits comprise the bulk of the world's production. Lodes of this type are structurally controlled (fissure fillings) and occur in or near granites or greisens. The famous tin deposits of Cornwall, England are of the hydrothermal type. Hydrothermal deposits vary widely in individual characteristics, but a high temperature environment is common to all tin genesis. The expected zoning sequence for a tin deposit would start with cassitierite closest to the heat source, followed outward by zones of tungsten, copper, zinc, and lead, respectively.
3. Subvolcanic deposits are of the Bolivian type, which were deposited in a near-surface environment and are mineralogically complex or telescoped. These deposits may contain tin sulfides in addition to cassiterite and be associated with silver.
4. Disseminated deposits contain low grades of cassiterite in highly altered granite.
5. Contact metamorphic or skarn deposits are relatively uncommon. Cassiterite is found in tactites (silicate rock of complex mineralogy) near granites in this type of deposit. Fluorite, beryllium, and various sulfides may be associated with the cassiterite in these skarns. Lost River, Alaska is an example of this type of deposit.

Residual or placer deposits are the most important and productive deposits in the world because they are easier and less expensive to mine than lode deposits and are metallurgically pure. Residual deposits can be economically mined at grades as low as 0.2 pounds per cubic yard or about a .007 percent grade.

Residual deposits result from the weathering and transporting of cassiteritic igneous sources. Cassiterite's high specific gravity (6.4 to 7.1) and resistance to chemical weathering result in it being concentrated in placer deposits. Placers can be either eluvial (concentrated by slope), alluvial (streambeds), or marine. Alluvial placers are the most important and comprise the major Southeast Asian reserves. In Southeast Asia, stream placers, formed during the Pleistocene age when sea level was eustatically lowered, currently lie in offshore areas. This is a fact which will become increasingly important in future production as conventional sources are depleted.

Two geological features associated with tin occurrences are important to recognize in tin exploration. These are the relationships of plate tectonics and fault patterns to the deposition of tin.

Inspection of the major stanniferous areas of the world immediately reveals that the major deposits lie on or near the boundaries of tectonic plates. The tin deposits of the world generally lie in distinctly linear belts, apparently related to orogenic regions of granitic composition which have been intensely folded and faulted. Many tin deposits are generally distributed along miogeosynclinal (shelf) belts surrounding the Pacific Ocean. The subduction zone hypothesis of tin deposition has been postulated by Sillitoe (1972), but is of more academic than practical interest. The various plate tectonic theories may have general validity but are incapable of explaining in detail the geologic complexity of a single deposit within a tin belt.

Faults are ubiquitous features in the major tin fields of the world, and often provide structural controls to ore deposition. This is apparent in Southeast Asia, where the tin belt extends from Malaya through Burma along a complex fault pattern.

The genesis of primary tin is a controversial topic which has not been resolved. It is generally known that tin is genetically related to granites in some way, but specific genetic and spatial relationships are controversial. A thorough discussion of tin genesis is not possible here. Mr. K.G. Hosking, a world authority on tin, perhaps puts the subject in perspective best with the following statement.

"We do not know the source of the tin; we do not know how it travels to the site of deposition: we do not know the chemical reactions leading to the deposition of cassiterite or of any of the other primary tin species: we are not certain if the economically important primary tin deposits are always, sometimes, or never genetically related to the granites with which they are usually spatially related." 27/

Exploration for tin should always recognize basic characteristics and be aware of the relationships discussed below.

Due to the relationship of tin to granitic rocks, structural features which may have localized granitic rocks are of prime importance. Therefore, in regional exploration of granitic areas, a study of the major jointing and fault patterns is very helpful.

Another feature to recognize in tin exploration is that the margins of granitic masses, which Hosking terms "cusps", are particularly favorable for the occurrence of tin. This is exemplified by the extensive deposits found along the margin of Malaysia's Main Range. These margins of granitic masses are particularly good sources for placer tin deposits, especially where streams have followed the margins for long distances (Hosking, 1965).

Other tin experts, such as Sainsbury (1969), consider postgranite fracturing, both locally and regionally, to be extremely important in localizing rich lode deposits.

> "When one studies the descriptions of the great lode mining districts of the world, one cannot escape the conclusion that most rich veins are localized along fractures which formed long after the consolidation of the enclosing granite." (Sainsbury & Reed, 1973).

This is true in Lost River, Alaska, where the major tin mineralization occurs in a regional pattern of dikes which postdate the surrounding granites by a considerable amount.

Cassiterite sulfide tin deposits are often associated with fluorine and boron, in the form fluorite and tourmaline. Theories of why this is so need not concern us; the association of fluorine and boron with tin is a useful geochemical tool to remember in tin exploration. Geochemical prospecting techniques involving analysis of stream sediments are also a very important tool in tin exploration.

It is wise for a tin exploration geologist not to be overly concerned with theory on how tin originally forms. Rather, a more practical approach is to identify world or regional tin distribution patterns based on proven facts and to recognize known geological relationships.

Mining Methods - Technology of Tin Production 28/

Tin is produced basically by four methods throughout the world. These include underground mining, dredging, gravel pump and hydraulic mining,and open cast mining.

Underground tin mining exploits vein deposits and is more costly and higher risk than the alluvial methods. Underground mining usually employs the sinking of a vertical shaft from which horizontal stopes are extended to follow the tin-bearing veins. Blasting and excavating ore to the surface for processing necessitates smaller tonnage operations than the average open pit mine. Cut and fill or shrinkage stoping are the usually employed underground tin mining methods. Cornwall and Bolivia have the world's most extensive underground mines.

Dredges today are huge multi-million-dollar processing plants that can excavate up to 10 million cubic yards of material per year. The overall cost per cubic yard is lower for dredging than for any other type of mining, but grades are also very low. The grades for a dredging operation are more than 100 times lower than for underground mining. Most dredges are rectangular and are constructed on pontoons. The dredge is maneuvered by a mooring winch connected to anchor points on the shore. A large digging ladder containing numerous buckets is suspended to the sediments underwater, where the buckets, on a rotating belt, scoop up the tin-bearing gravel and sand. The sediments are then processed on screens and jigs to obtain the heavier cassiterite. The waste material is released through a tailings chute at the rear of the dredge. The efficiency of large-scale dredging may be attractive to large corporate interests, but capital costs for large dredges are steeply increasing.

Gravel pumping and other hydraulic mining methods comprise a large share of world tin production, about 40 percent. Gravel pumping has the advantage of not being capital intensive. It does, however, require special conditions such as availability of water and relatively high alluvial or eluvial grades. Operating costs for gravel pumps have risen more steeply in recent years than any other method. This is primarily due to fuel costs. Gravel pumping basically entails directing high pressure water jets at tin-bearing alluvial faces. The alluvium is disintegrated and flows to an area from which the gravel pump elevates the material to sluice boxes. The sluice boxes, or "palongs", then trap the heavy cassiterite in baffles. The tin concentrates are then removed and upgraded in the tin shed.

Open cast mining is not widely employed. It involves a pit from which tin material is excavated, by conveyors or other means, to the surface for beneficiation. Open casts may operate in wet, tropical conditions such as Malaysia or in dry areas such as Tasmania. Australia has large-scale open cast mining operations.

As in many other areas of industry, technical innovation in tin production has a tremendous potential for influencing the future of the tin supply/demand situation. Within the forecast period of this study, technologies of tin production are not expected to improve with dramatic significance, but continue to move toward larger-scale operations and greater economies of scale.

The trend in tin production in the last decade, in many areas, has been toward larger capacity operations, usually larger dredges. Capacities for dredges have increased dramatically. Large dredges now have buckets with 36 cubic feet of capacity, and cost three times the amount the standard 20 cubic foot dredge did in 1967. The mining of larger areas of lower grade seems to be the most salient trend in recent production technology.

Offshore dredging is another technological development that has increased in the past ten years, particularly in Indonesia and Thailand, and promises to become more important in the future. Vast deposits of high grade tin exist in offshore areas of the world and the technology of recovering these deposits has improved, moderately, in the last decade.

Depths of about 150 feet can now be achieved. Rough seas, the approximate 150 foot depth limitation, and other technological problems represent major limitations to offshore mining at the present time. The main limitation to rapid offshore development is the high cost of capital equipment. Prices must be stable and remain sufficiently high before the large amounts of capital investment required will be risked in offshore tin dredging.

In underground tin mining, relatively little is new technologically. The greatest hope in underground technology is in metallurgical recovery. Because of the mineralogical complexity of most primary cassiterite deposits, recovery at the present time is poor relative to other metals. Improved recoveries would be a boon to underground producers, particularly Bolivia. Research continues in this area, in part through the Tin Research Council of the ITC.

Future expectations in tin production technology involve the continuation of recent trends. Larger amounts of future tin supply will come from technologically complex, larger capacity dredging and mining facilities. Moreover, in the next few decades more offshore reserves will be exploited, and in deeper waters. Enhanced mill recoveries for the major world producers is likely. The huge, high capital facilities required for these technological developments will necessarily involve government control or participation to greater degrees.

Whether significant improvement in production technology does take place in the next decade depends, to an extent, on the amount of capital devoted to research and development which the larger operations require. Hence adequate future supply depends, in part, on improved production technology, which largely depends on future availability of capital.

Major Tin Producing Corporations. 29/

Tin production is not dominated by large corporate producers, but comes from numerous small sources. Although four countries dominate world tin production, the largest tin mining corporations comprise a relatively small share of total world tin production. This may explain why the International Tin Council has had any success at all; individual corporate interests are not a powerful force in the tin industry.

The two largest tin mining companies in the non-Communist world are both state-owned companies. They are P.T. Timah of Indonesia and COMIBOL of Bolivia. The largest private tin producers are Berjuntai Tin Dredging in Malaysia, Renison Ltd. in Australia, and Rooiberg Minerals in South Africa.

The following table lists the sixteen largest producing members of the Fifth International Tin Agreement, their production, and percentage of world output in 1977.

Table 4.13

Producing Members of the Fifth Tin Agreement, 1977

	Production in tonnes	Percent of non-Communist World Total
Malaysia		
Berjuntai Tin Dredging	4,718	2.5%
Malayan Tin Dredging	2,828	1.5
Selangor Dredging	2,314	1.2
Ayer Hitam Tin Dredging	2,051	1.1
Southern Malayan Tin	2,031	1.1
Pahang Consolidated Co.	1,946	1.0
Pacific Tin Consolidated (Largest U.S. tin mining corporation)	774	0.4
Bolivia		
COMIBOL	23,306	12.5
Medium and Smaller Miners (non corporate entity)	9,310	4.9
Indonesia (state controlled areas)		
Bangka	17,721	9.5
Belitung	4,802	2.6
Singkep	1,411	0.75
Thailand		
Aokam Tin Co.	1,703	0.9
Australia		
Renison Ltd.	5,016	2.7
Abminco	1,320	0.70
Ardlethan Tin N.L.	1,193	0.64
South Africa		
Rooiberg Minerals	4,563	2.4
Union Tin Mines Ltd.	1,268	0.68

Source: Tin International Statistical Supplement, September, 1978.

Smelting 30/ 31/

The process of tin smelting involves the reduction of cassiterite in the tin concentrate to the metallic form. The tin content of the concentrate may range anywhere from 20 to 75 percent. In simple terms, smelting of tin involves the following reaction:

$$SnO_2 + C \longrightarrow S_n + CO_2$$

where C is in the form of anthracite coal. A flux is also added.

Tin is generally smelted in one of three types of furnaces; reverberatory furnaces, electric furnaces, and blast furnaces. The tin initially produced in these furnaces generally requires further refining to remove whatever impurities remain in the metal. These may include heavy minerals such as ilmenite, monazite, pyrite, and zircon which have not been removed during concentration or initial smelting. After the refining stage, the pig tin produced is usually 99.80 percent Sn or greater.

Smelting of the two types of ore, residual and primary, requires distinctly different smelting techniques. The alluvial Malaysian type contains relatively few impurities, making concentrating and smelting fairly simple and low cost. Most Malaysian concentrates contain about 70 percent tin.

(Pure cassiterite contains 78.6 percent tin). The primary ores of the Bolivian type require extensive treatment due to their complex mineralogy and impurities. The concentrate received at the smelter usually requires roasting, acid leaching, flotation to remove sulfide impurities, or other methods to upgrade the concentrate for smelting. Extensive refining is then required after smelting.

Tin smelting facilities are very capital intensive. Hence, most mines do not have their own smelter, but have their concentrates toll smelted at a large, often state-owned facility.

Few smelters are capable of accepting concentrates over the whole range of tin content from 20 to 75 percent. Most specialize, and smelt either low grade or high grade concentrates. The dividing line for the smelters is usually in the region of 45 to 55 percent tin. The complex concentrates of the Bolivian type are much more costly to smelt than the Malaysian type, and tin recovery is also lower for the complex concentrates. The total cost of toll smelting tin may range from about $0.25 per pound for 70 percent concentrates to about $1.20 per pound for 20 percent concentrates (Lewis and Streets, 1977).

The present world smelting capacities are more than adequate for world production. Total tin smelting capacity in 1977 was 384,100 tonnes of refined metal per year, more than twice the actual output (G.S. Barry, 1976). World smelting capacity is expected to remain more than adequate for world mine production.

Malaysia is the world's largest smelter of tin metal. It has only two smelting facilities, both located near the port of Penang. These are the Georgetown smelter (70,000 tonnes annual capacity) and the Butterworth smelter (60,000 tonnes annual capacity). These two Malaysian smelters treat approximately 37 percent of the world's production. Thailand's

Private co. not owned by state

state smelter, Thaisarco, and Indonesia's state smelter, P.N. Timah, each account for about 12 percent of the world's annual tin metal output. Bolivia's Vinto smelter has steadily increased its output in recent years.

Table 4.14 shows output of primary tin metal by country. The trend, particularly in Indonesia and Bolivia, has been and is continuing toward internal capability to smelt mine output, rather than to export concentrates for smelting. Bolivia will soon be able to smelt 90 percent of its own concentrates. The only smelter in the United States is located in Texas City, Texas. It produces about 3 percent of the world's tin metal and may lose much of its feed as Bolivia continues its self-sufficiency in smelting.

Table 4.14

Production of Primary Tin Metal
(in tonnes)

	1968	1973	1977
Malaysia	89,600	82,468	66,305
Indonesia	4,630	14,632	24,005
Thailand	24,826	22,927	23,102
Bolivia	60	7,038	13,810
United Kingdom	25,333	20,604	10,114
Brazil	1,743	4,430	6,800
United States	3,553	4,600	6,724
Australia	3,751	6,904	5,561
Spain	2,361	3,800	5,342
Belgium	4,865	3,669	3,520
Nigeria	10,001	5,983	2,315
West Germany	1,528	1,038	2,897
South Africa	1,300	1,800	2,400
Others	14,238	4,823	6,365
TOTAL	187,800	187,300	179,200

Source: 1968 - International Tin Council
1973, 1977 - Tin International Statistical Supplement, September 1978

World Tin Production Costs 32/

The following analysis of world production costs is based on information from the annual reports of tin producing corporations, various periodical literature sources, and a report by C.G. Streets of Consolidated Gold entitled "The Cost of Primary Tin in 1976". The figures for production costs are calculated in U.S. dollars per pound and include all costs to the producer. Government duties and depreciation are included in the figures unless otherwise indicated.

The current average world tin production costs appear to be from $3.80 to $4.00 per pound, including depreciation charges. The current ITC floor price is $4.25 per pound.

The lowest cost areas of the world for tin production are Brazil, Australia, South Africa, and Thailand, all of which are apparently capable of producing tin concentrates for $3.50 per pound or less. Malaysia, the major producer in the world, has costs of closer to $4.00 per pound. Table 4.15 illustrates the range in world costs.

High side production costs are represented by Bolivian miners and are in the $5.00 per pound range, and sometimes even higher. Low side is more difficult to ascertain with credibility, but is near $3.00 per pound for some high grade producers in Southeast Asia.

World Range of Tin Production Costs

High	$5.00 per pound and above	Bolivia
Middle	$3.90 per pound	Malaysia
Low	$3.00 per pound	Australia, some Southeast Asians

Tables 4.15 and 4.16 tabulate some of the information from C.G. Streets' article. Figure 4.2 provides a graphical depiction of this data.

Table 4.15

Tin - 1976 Production and Estimated Costs

Country	Production in tonnes	L/tonne incl. depr.	U.S. $/lb. excl. depr.	incl. depr.	Escalated to approx. 1978 cost
Malaysia	57,562	3,745	2.75	2.90	3.62
Bolivia	23,934	5,039	3.81	3.90	4.88
Indonesia	21,537	4,389	3.25	3.39	4.24
Thailand	19,975	3,561	2.67	2.74	3.43
Australia	7,629	3,016	1.88	2.33	2.91
Brazil	700	2,975	2.24	2.30	2.88
Nigeria	2,889	4,742	3.59	3.66	4.58
United Kingdom	3,595	4,185	2.91	3.24	4.05
South Africa	2,414	3,169	2.36	2.45	3.06
Average	--	4,017	2.95	3.10	3.88

Source: C.G. Streets, 1978.

Table 4.16

TIN - Breakdown of 1976 Production Costs - by Country

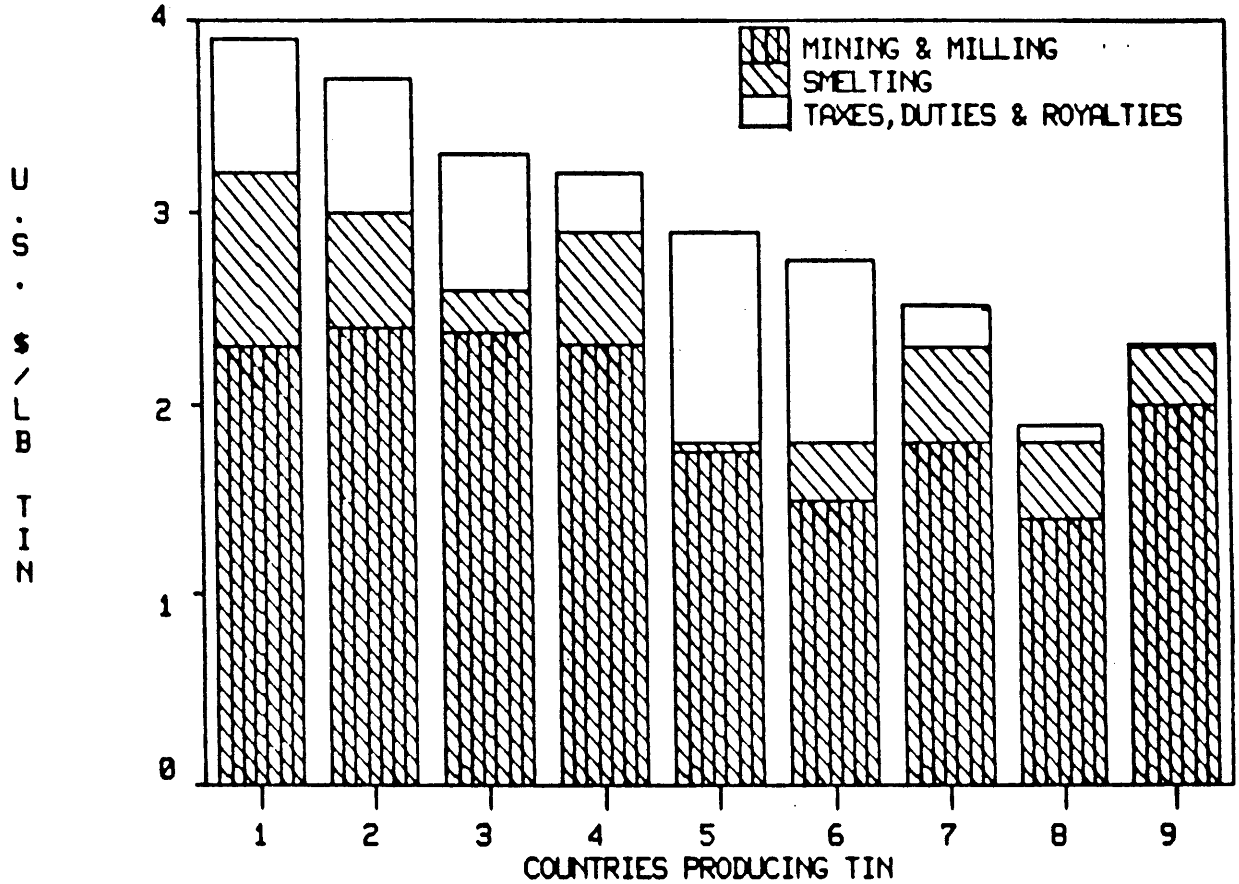
Country	Production covered by survey (tonnes)	Costs (U.S. ¢ per lb. tin metal) Mining & Milling	Smelting & Realization	Total Operating	Escalated 19% to Approx. 1978 Cost	Government duties*	Total Cost	Depre. Charges	Total (including deprec.)	Escalated 25% to Approx. 1978 cost
Malaysia	57,652	1.76	0.08	1.84	2.19	0.91	2.75	0.15	2.90	3.62
Bolivia	23,934	2.34	0.87	3.21	3.82	0.60	3.81	0.09	3.90	4.88
Indonesia	21,537	not available		2.66	3.16	0.59	3.25	0.14	3.39	4.24
Thailand	19,975	1.63	0.21	1.84	2.19	0.83	2.67	0.07	2.74	3.43
Australia	7,629	1.52	0.36	1.88	2.24	nil	1.88	0.45	2.33	2.91
Brazil	700	1.95	0.29	2.24	2.66	nil	2.44	0.06	2.30	2.88
Nigeria	2,889	2.51	0.47	2.98	3.55	0.61	3.59	0.07	3.66	4.58
United Kingdom	3,595	2.38	0.53	2.91	3.46	nil	2.91	0.33	3.24	4.05
South Africa	2,414	1.80	0.56	2.36	2.80	nil	2.36	0.09	2.45	3.06
Totals	140,235	-		2.26	2.69	0.70	2.96	0.14	3.10	3.88

*Based upon average December 1976 tin prices

Source: D.G. Streets, 1978.

Figure 4.2

Cost of Production-by Country
(data from 1976)



1=BOLIVIA 2=NIGERIA 3=INDONESIA 4=U.K. 5=MALAYSIA 6=THAILAND;&
7=S.AFRICA 8=AUSTRALIA 9=BRAZIL

Table 4.17 provides a comparison of 1978 costs assumed by the author, derived from C.G. Streets, and those obtained from an ITC official in July, 1978.

Table 4.17

Comparison of Cost Estimates

	Total Operating Cost Mining & Milling ($/lb)		Total Production Cost ($/lb)	
	Everhart	ITC Official	Everhart	ITC Official
Malaysia				
Dredge	2.19	2.03	3.62	3.56
Gravel Pump	2.43	2.93	-	4.60
Thailand				
Ohshore Dredge	2.19	1.94	3.43	3.69
Offshore Dredge	-	1.52	-	3.33
Indonesia				
Onshore Dredge	3.16	3.68	4.24	4.22
Offshore Dredge	-	2.00	-	2.54
Gravel Pump	-	4.84	-	5.38
Bolivia				
Underground		3.70	4.88	4.85

The following analysis summarizes the available information on Malaysian production costs and provides additional sources other than Table 4.15. Many of the operating costs are for 1977 and include only those costs for mining and milling or direct costs involved in dredging. The range of this minimum operating cost is from $.93 per pound to $2.38 per pound. One of the most reliable, recent Malaysian cost figures in Table 4.18 is that cited by Chan Wan Choong in Metals Week, 5/29/78. An Average total production cost of $3.95 per pound in 1977 and a current total production cost of around $4.22 per pound was reported. These figures are high side relative to most of the figures presented in Table 4.15. Low side for current, total production costs in Malaysia would be the extrapolated $2.75 per pound for Berjuntai Tin Dredging.

The findings of the literature search and annual reports 33/ presented in Table 4.18 are consistently lower than those reported by Streets, and often lack complete cost data. However, they can be generally considered in the range of $3.00 to $3.00 per pound for total production costs.

C.G. Streets' figures concur quite closely with a report on 1977 production costs which appeared in Metals Week on July 4, 1977. A price panel meeting of the ITC at that time reported an average world cost of about $3.57 per pound.

Table 4.18

Malaysian Tin Production Costs

Corporation or Source	Av grade lb/cu yd	Annual Production Rate (concentrate)	Mining Method	Operating Cost	Total Production Cost
Malaysian Miners Assoc. Chan Wan Choong	-	-	all types	-	$3.95 (1977)
Southern Malayan Tin Dredging, Ltd.	.19	4,792,502 lbs	Dredge	$1.20	$2.03 (1976)
Berjuntal Tin Dredging	.21	9,356,032 lbs	Dredge	$1.84	$2.28 (1977)
Austral Amalgamated Tin, Berhad	.22	3,095,600 lbs	Dredge	$0.76	$2.19 (1977)
Tongkah Harbour Tin Dredging	.57	1,352,366 lbs	Sea Dredge	$0.93	$1.94* (1977)
National 976 Averages from the Malaysian Mining Industry Seminar Paper 4.1	-	-	All types	-	$2.03
Pacific Tin Consolidated	.204	1,707,167 lbs	Dredge	$3.72	- (high side)
Tronah Mines Malaysia, Ltd. Ayer Kuning Section	.15	1,422,225 lbs	Dredge	$2.38*	-
Kamunting Tin Dredging	.18	1,142,200 lbs	Dredge	$1.60*	-

* does not include taxes

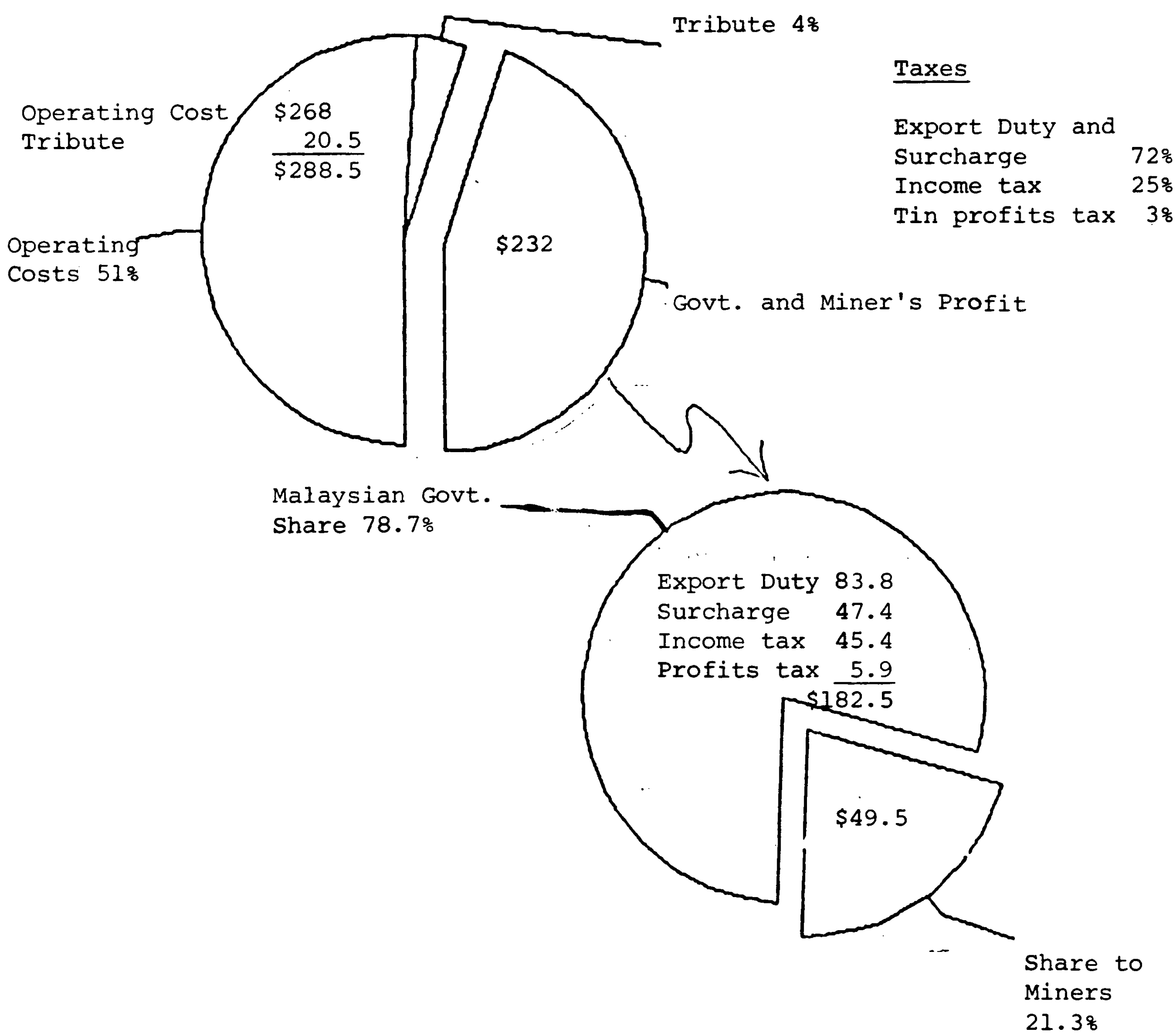
This represented a 15 percent increase in costs from 1976 to 1977. Comparing the Metals Week figures with those derived from the annual reports and literature shows the range to be within $4.00 per pound high and $2.00 per pound low in 1976 and $4.50 per pound high to $2.00 per pound low in 1977.

Malaysian mining taxes are notoriously high in the tin industry. Taxes in Malaysia usually represent the greatest percentage of costs to producers. Figure 4.3 shows the average, national Malaysian tin mining tax burden. It is derived from Paper Number 4.1 of the National Seminar on the Mining Industry, In Kuala Lumpur 1977, entitled "Taxation and the Tin Mining Industry." As shown, total taxes amount to an average of 78.7 percent of mining profit. Most of the tax bite is accounted for in the export duty and export surcharge taxes. Taxes of 70 percent of gross income were reported for Malaysian tin producers in the November 4, 1977 edition of American Metals Market. The range in the effective tax rate for Malaysia is probably between 62 and 78 percent, or an average of 70 percent. Recent indications are for a lowering of the total tin tax rate.

Sources for Bolivian cost data are scarce. COMIBOL is the major producer and basically sets the tenor of Bolivian tin mining. Bolivia has always been the highest cost tin

Figure 4.3

Malaysian Tin Tax Burden
(in millions of U.S. Dollars)



producer in the ITC, because of its underground mining conditions. Recently, Bolivian producers have been quite vociferous in their demands for a higher floor price of at least $4.41 per pound. 34/

The literature search produced only two sources, but both are considered accurate. The best current estimate for an average Bolivian production cost is $4.96 per pound. This compares with $4.88 and $4.75 escalated from the Streets and COMIBOL data, respectively. The high side is around $6.00 per pound claimed by some Bolivian miners. Most producers in Bolivia appear to operate above the current floor price of about $4.25 per pound.

All indications are that current Bolivian total production costs average around $5.00 per pound.

The only obtainable source of Thai cost data was a 1976 consulting firm's report which provided mining and transportation costs only. The average 1976 operating cost per pound for an inland dredge was $1.20. The average operating cost per pound for an offshore dredge was $1.50.

Thai costs are generally similar to Malaysian costs, except that Thailand does not have as high a tax burden.

South African production costs are presented because they were available in the form of two annual reports and because underground and open pit methods there are apparently

Table 4.19

Bolivian Tin Production Costs

Source	Av. Grade	Annual Production Rate (Concentrate)	Mining Method	Operating Cost	Total Prod. Cost	Notes
Comibol	0.9%	45,377,200 lbs	Underground	$2.02	$3.80	1976 costs esc. 1978 cost: $4.75
Latin American Commodities Report 7/7/78	Approx. 1%	--	Underground	-	$4.96	1977 total cost

quite favorable for tin production at low cost. Mining and milling costs for Rooiberg Minerals, Ltd. in 1976 were $1.83 per pound. This compares closely to Streets' South African average of $1.80 per pound. Total production costs in 1977 for Union Tin Mines, Ltd. were $2.75 per pound. Both sources, then, indicate that total current production costs are probably about $3.10 per pound and thus would be on the low side in the world cost range.

Capital Costs 35/ 36/

Capital costs are even more difficult to obtain than production costs and are probably subject to more speculation. Capital costs presented below are mostly for dredges in Southeast Asia. Capital cost information for hardrock tin mining in Australia and South Africa is contained in the hypothetical project evaluation study below.

Malaysia

A large, deep digging dredge capable of excavating 5 to 6 million cubic yards of ground per year (20 cubic foot buckets), the Selangor Dredge No. 1, was built during 1964-1967 for about 3,623,000 U.S. dollars. With the escalation of capital costs over the last ten years, it is not unreasonable to assume a dredge of this type would currently cost from 7 to 8 million dollars.

Selangor Dredging, Ltd. decided to build a second large capacity dredge (24 cubic foot buckets) in 1971. It was completed in 1973 for a cost of approximately 5.1 million

U.S. dollars. Again, current capital cost would be about 8 million dollars.

The CRM dredge, named Sri Timah, can dig 50 meters below water level and has buckets of 24 cubic foot capacity. CRM is planning the construction of a similar dredge, which would take two and one half years to construct and cost approximately 10.1 million U.S. dollars.

The DRT corporation's Dredge No. 2, with a capacity of 10 million cubic yards per annum, had a reported 1977 capital cost of 9.66 million dollars.

Thailand

Thailand's state owned Offshore Mining Organization (OMO) recently awarded IHC Holland a 9.8 million dollar contract for a 17 cubic foot bucket and ladder type offshore dredge to be delivered in 1980.

Indonesia

Mitsubishi Corporation of Japan is making its first large dredge for Indonesia's PN Timah State Corporation for delivery in autumn 1978. The estimated capital cost is 8.82 million dollars.

The Bangka II offshore dredge, equipped with 22 cubic foot buckets and capable of dredging to a depth of 50 meters, has a capital cost of 6.3 million dollars.

Smelting Costs

Smelting charges have increased substantially over the last decade, but particularly since 1972. Of the base metals, tin smelter charges have shown the greatest increase.

Tin concentrates in the range of 20 to 75 percent Sn are commercially produced and sold. This represents a much wider range of concentrate grades than any of the other base metals and few smelters are capable of accepting concentrates over this range. Most smelters are only able to treat either high or low grade concentrates, the dividing line being in the region of 45 to 55 percent.

A mine producing low grade concentrate, incurring high operating expenses, will be further penalized at the smelter. Table 4.20 illustrates the variation of total smelting charges with percent tin.

Table 4.20

Average Charges for Tin Concentrates in current dollars (U.S. ¢/lb)

	1972	1977	Percent change 1972-1977
20% Sn	45.0	118.7	164
35% Sn	26.1	75.1	188
50% Sn	15.7	40.2	156
70% Sn	6.5	21.3	227

Source: Lewis and Streets, 1978.

Tin Demand

Tin is used as a component in a variety of both consumer and industrial products as listed below. Demand for tin, as for other metals, is derived demand. Demand is also price inelastic for tin; consumers, to a degree, are more concerned about a guaranteed supply than about higher prices.

World Consumption

World consumption of primary tin, excluding the Communist countries because of a lack of reliable data, has increased over the past ten years at an average of 1.92 percent per year 38/. This is much less of a growth rate than that experienced by aluminum, copper, zinc, or other metals. In recent years, there have been wide fluctuations in world tin consumption in part due to political and economic instability in the world since the Arab oil embargo of 1973. Table 4.21 illustrates the trend in world primary tin consumption for the past decade. Table 4.22 provides information on primary tin consumption by end use for the four major consuming countries.

The United States is the largest consumer of tin in the world, consuming 47,596 tonnes of primary tin in 1977, or 25.8 percent of the non-Communist world total. Japan is the second largest consumer of tin metal in the world, having

Table 4.21

World Primary Tin Consumption
(in tonnes)

	World*	%change	U.S.	Japan	U.K.	Germany	France
1968	179,600	+2.8	59,801	22,598	17,699	11,278	9,449
1969	186,600	+3.8	58,654	25,879	18,059	13,429	11,278
1970	185,600	+0.5	53,807	24,710	16,950	14,062	10,500
1971	189,400	+2.0	52,814	29,300	16,425	14,202	10,450
1972	192,000	+1.4	54,365	32,341	14,649	14,392	11,030
1973	214,200	+11.5	59,075	38,676	16,600	15,847	11,701
1974	200,200	-6.5	52,439	33,817	14,459	14,539	11,266
1975	173,900	-13.1	43,620	28,115	12,165	11,958	10,340
1976	194,400	+11.8	51,767	34,676	13,500	14,844	10,200
1977	184,600	+5.0	47,596	29,685	12,681	14,115	10,100
Average growth rate		+1.92	-2.05	4.23	-3.4	3.25	0

*(excluding U.S.S.R., China, East Germany)

Source: Tin International Statistical Supplement, Sept. 1978.

Table 4.22

Primary Tin Consumption by End Use
(in tonnes)

	1972	1973	1974	1975	1976
United States					
Tinplate	21,408	21,608	22,686	18,869	20,571
Solder	17,167	19,076	11,559	10,669	10,504
Chemicals	2,502	2,898	3,473	2,735	3,875
Bronze and Brass	3,156	3,562	3,617	2,626	2,034
All others	10,144	11,931	11,104	8,721	16,920
Total	54,366	59,075	52,439	43,620	53,904

	1972	1973	1974	1975	1976
Japan					
Tinplate	13,846	15,612	15,688	11,890	14,574
Solder	10,569	13,182	10,565	10,418	12,711
Tinning	528	764	695	578	922
Bronze and Brass	2,225	2,362	1,411	1,290	1,541
All others	5,173	6,756	5,458	3,939	4,928
Total	32,341	38,676	33,817	28,115	34,676

Table 4.22 (continued)

	1972	1973	1974	1975	1976
United Kingdom					
Tinplate	7,119	8,018	6,997	5,680	6,403
Solder	1,633	1,610	1,393	1,078	1,041
Tinning	1,332	1,207	1,139	1,197	1,155
Bronze and Brass	1,808	1,992	1,803	1,715	1,597
All others	2,757	3,773	3,027	2,495	4,353
Total	14,649	16,600	14,459	12,165	13,109
Germany					
Tinplate	4,242	4,752	5,835	4,484	5,055
Solder	2,012	2,373	2,221	1,893	2,000
Tinning	801	810	575	408	473
Bronze and Brass	229	199	286	342	153
All others	7,108	7,713	5,622	4,833	7,163
Total	14,392	15,847	14,539	11,958	14,844

Source: Tin Statistics (ITC), 1966-1976.

consumed 29,685 tonnes in 1977, or 16.0 percent. Growth rates of tin consumption in the United States are, and are projected to be, much lower than growth rates in other countries. Japan and West Germany expect substantially higher growth in consumption than the United States.

Tin's major end uses are: 1) tinplate, 40-45 percent of world total; 2) solder, 20-25 percent of world total; 3) various tin alloys, 10-15 percent of world total; and 4) tin chemicals, 8 percent of world total.

Tinplate 39/40/

Tinplate is by far the most important end use for tin. The principal application for tinplate is in coating food and beverage containers. Unique qualities such as strength, formability, corrosion resistance, appearance, and perhaps most important, non-toxicity, make tinplate ideal for cans.

Tinplate is a steel product, being over 99 percent steel by weight. Tinplate is produced by imparting a thin coating of tin on rolled steel strips. Today, this is done almost entirely by electrolytic methods. The amount of tin used per area of tinplate has decreased due to this method, a significant factor in reducing tin demand to the current percentage by weight of about 0.6.

Tinplate is used in two different kinds of cans--the three piece steel can and the two piece steel can. The three piece can is the original type. It has a sturdy cylindrical body, on which the two ends are soldered. This type of can has rapidly lost the beverage and beer can market to aluminum and the two piece steel can in recent years. It is still used as a large container for various foods.

The two piece steel can originated in 1971. This type of can is formed from tinplate on a die, which "draws and irons" the can to its full height. In the process, the tin itself acts as a lubricant. The top of the can is seamed to the body. Two piece steel cans appear to be gaining popularity with U.S. can makers, indicating an economic advantage in tin over aluminum. Anheuser-Busch, Inc. has announced plans for a new 20 million dollar two-piece drawn-and-ironed beer can facility.

The advent of the two piece drawn-and-ironed can, which has helped maintain the beverage and beer market for tin, versus the increased efficiency of electrolytic tinplating, have roughly offset each other as factors in tin consumption.

<u>Solder</u> <u>41</u>/

Solder accounts for about 23 percent of world tin demanded. The patterns of usage differ considerably between nations. Historically, solder has been used in plumbing applications and as seams for cans. Recently, it has gained usage as a component in electronics equipment, particularly printed circuit boards. Copper-tin solders are useful for this application because of their ability to conduct.

Tin's use in solder stems from its low melting point, allowing it to adhere to copper, steel, or other surfaces, and its adhering or "wetting" characteristics. Tin is often alloyed with lead in solders to lower the melting point and reduce costs. The most common solder composition, utilized in electronics, is 60 percent tin, 40 percent lead.

The world market for solder has been relatively stable during the past decade. Tin content in solders may be reduced by solder-using industries if prices continue to increase at current rates. However, world solder demand should continue to grow with the electronics industry in the next decade.

Tin Alloys 42/

Tin is consumed in a wide variety of alloys which are used both in industry and for decorative purposes. One of the earliest metals known to man, dating back several thousand years B.C., is bronze, a tin-copper alloy. Pewter and brass have also been used for centuries.

The so-called Babitt metal alloys of approximately 90 percent tin, 7 percent antimony, and 3 percent copper account for about 5 percent of world tin consumption and are used as in various casting processes, and are known for their mechanical strength, corrosion resistance, and bearing properties.

Alloys based on tin, titanium, aluminum, and molybdenum are used in the aircraft and aerospace industries. Tin has also gained use as a component in superconductor alloys.

Pewter and other white metal alloys which contain tin represent a fairly small share of total demand.

Significant growth is not expected for tin consumption in alloys over the next decade.

Tin Chemicals 43/

Consumption of tin for use in tin chemicals has been the fastest growing market for tin in the past decade, and the only use of tin for which significant U.S. growth is forecast. Tin chemicals are divided into two broad categories; inorganic tin compounds and "organotins". Inorganic tin compounds account for more tin usage than organotins.

Tin oxide is used in the ceramics and glass industry as a component in pigments for ceramic glazes and as a strengthening agent in glassware. Tin and tin chlorides are useful as catalysts in a number of complex chemical applications.

Organotin compounds have experienced increased usage over the past decade and consumption for this purpose will no doubt continue to increase. End uses for organotins include uses in polyvinyl chloride (PVC) as stabilizers, in food packaging, in marine anti-fouling paints, fungicides, and in wood preservation. Organotin compounds are categorized as being diorganic (R_2SnX_2) or triorganic (R_3SnX) compounds.

Substitutes 44/

Tin has competition from many substitute materials including glass, paper, plastics, various alloys, tin-free-steel, and of course, aluminum.

In the early 1970's, two piece aluminum cans were introduced in the beer and beverage market and now claim the major share of that market. Aluminum containers have the advantages of being easily recycled, are light-weight, and are easily decorated. Aluminum, however, does not pose as ominous a threat to tin as it has in the past several years due to economic considerations. These include increased bauxite production costs, export taxes, and skyrocketing energy costs involved in aluminum ingot processing. Table 4.23 illustrates the differences and recent increases in raw material costs for aluminum and steel cans.

Table 4.23

Cost Comparison of Raw Materials in the Manufacture of Aluminum & Steel Cans (1)

	Jan 1, 1976	Dec. 1, 1977	Increase
Aluminum	$20.27	$25.61	26.3%
Steel (tinplate)	$15.82	$18.24	15.3%
Difference	$ 4.45	$ 7.37	11.0%

(1) Costs per 1000 12-ounce cans manufactured

Source: Modern Packaging, March, 1978.

Another possible substitute for tin's use in cans is tin-free-steel (TFS). Tin-free-steel is a type of steel, black plate, which has been processed and electrolytically coated with chrome. So far, TFS has not been economic as a substitute relative to tinplate. If tin prices increase significantly, TFS threatens to capture a larger share of the market.

If prices of tin increase, tinplate's use in food and beverage containers will become more vulnerable to substitutes that do exist, but are not currently economic. It has been estimated by Emory Ayers Associates, Inc., New York, in a paper given at the International Tin Symposium, November 1977, that if tin prices approached ten dollars per pound the economics would change in favor of substitutes. A factor just as important to steel can manufacturers is the certainty of tin supply. Serious disruptions in tin supply could not only cause prohibitively high prices, but also cause manufacturers to switch to various substitues due to resource availability considerations.

Environmental concern could seriously affect demand for tinplate cans in the form of the "ban the can" movement. The states of Maine, Michigan, Oregon, and Vermont have passed legislation requiring either a five-cent deposit on cans or some form of banning the can. This type of movement favors recyclable containers, such as glass bottles or aluminum as substitutes for tinplated cans. If recycling becomes a more publicly accepted way of life, tinplate stands to suffer the most.

Elasticity of Demand 45/

With the recent sharp increases in tin prices, the question of price elasticity of demand for tin becomes more important. It has generally been recognized that demand for tin is quite price inelastic. Consumers of primary tin such as the canning or alloying industry are not sensitive to price in terms of their demand. As mentioned above, stability and certainty of supply in the market is probably as important. This study does not involve a detailed analysis of price elasticities. An econometric study done by Wharton Econometric Associates in 1975 has estimated price elasticities of demand as follows:

1976	1977	1978
-.103	-.216	-.311

These figures, though they are estimates and not empirically derived, do indicate the price inelasticity of demand for tin.

The preceeding trends in tin consumption and their implications for overall world demand in the next decade indicate slow growth. Tin consumption in consumer-oriented countries such as the United States or the United Kingdom will probably continue to decrease due to technological advancements in tinplate efficiency, substitution from competing materials, and other factors mentioned above. Tin consumption in Japan and West Germany will continue to increase assuming overall growth rates remain healthy and consumer products such as soft drinks in cans and electronic equipment become more widely demanded. Tin demand from third world countries will increase at the greatest rate, assuming a relatively healthy world economy. Projections by tin industry experts and econometricians for non-Communist world demand for the next decade range from less than 1 percent to over 2 percent per year. The author estimates an average world growth rate in consumption of tin in the range of 1.0 to 1.5 percent per year, with a 1.25 percent rate the most probable. The most salient factors involved in this relatively stagnant growth estimate are continued international economic uncertainty, decreasing demand in the United States and other developed nations, and the threat of substitution as tin prices increase. Offsetting these negative factors are expectations for healthy growth in tin consumption, especially in tinplate, in Japan, West Germany, and the less developed countries.

Projections of Supply/Demand

Specific projections or predictions about supply or demand in the world tin industry vary widely within short periods of time, due to the unstable condition of both tin production and consumption. It would be somewhat foolish for any study of the future of the tin market to attempt to project with certainty what the supply/demand picture will be in the next decade. Attempts to do this in the past several years have proved to be very unsuccessful. This study attempts to adumbrate what might be expected, overall, in the next decade. The supply/demand projections are meant to serve as a guide to what direction tin prices might take in the next decade, and if a seller's or buyer's market might be expected. This has significant implications for the exploration plans of an American mining corporation. The study's supply/demand figures, based on the preceeding analysis of the current tin market and on analyses from various experts, are what is expected, not predicted, by the author.

Despite continued price increases, world tin production over the next decade will not increase significantly. It is probable that world primary tin production will increase at a slower rate than world primary tin consumption. This, however, does not preclude the possibility of having surplus periods within the forecasted decade. The reasons for this situation involve several factors. The main reason for the expected stagnation in both production and consumption is the instability or uncertainty within the tin industry. The uncertainty about the future of this commodity is illustrated in the fact that the market went from a situation of significant deficit in the early summer of 1978, with widely anticipated deficits of 20,000 tonnes annually, to a surplus situation of several thousand tonnes by September, 1978.

Uncertainty about the future of tin, more than any other reasons, explains why world tin production will increase only marginally over the next ten years. The lack of capital investment and investor confidence in exploiting new deposits of tin stems from economic, and more importantly, political uncertainty. An added uncertainty in the area of GSA stockpile releases, an extremely important element in the current market, will probably continue for several years.

The problem that the Malaysian tin industry is having are exemplary of what might be expected worldwide in the future. These problems, as mentioned before, include restrictive government policies, high tax rates, lowering grades, and rapidly increasing capital and operating costs.

The price elasticity of tin supply is low. This is obvious from the fact that as prices have almost doubled since 1975, production has increased by only 1.3 percent. Wharton Econometrics forecasters have projected a 1976 price elasticity of supply at .075 and a 1978 figure of .358. A lag time of the price effect on production was determined to be about three years.

Based on the trends discussed, on projections from Chase Econometrics and others, the Wharton figures above, and revised statistics on 1977 production and consumption, world supply and demand for the next decade might be expected as shown in Table 4.24. The relatively high rates of growth in the first three years are included because several new Southeast Asian dredges are expected to start production during that period and because the full effect of the price increases of 1976 will not be felt until then. The continued overall slow decline in production growth reflects the expected decline in Malaysian production.

The results indicate that, over the entire period, production will not be able to meet demand at an assumed 1.25 percent annual growth rate and that a seller's market is

Table 4.24

Expected World Supply/Demand for Tin
(in tonnes)

Year	Primary Production	% Growth	Primary Demand	% Growth
1977	179,200		184,600	
		2.0		1.25
1978	182,784		186,908	
		2.0		1.25
1979	186,440		189,245	
		1.5		1.25
1980	189,240		191,610	
		1.0		1.25
1981	191,130		194,005	
		0.9		1.25
1982	192,850		196,430	
		0.8		1.25
1983	194,390		198,885	
		0.6		1.25
1984	195,560		201,370	
		0.5		1.25
1985	196,535		203,888	
		0.2		1.25
1986	196,930		206,435	
		0.1		1.25
1987	197,125		209,017	

likely over the next decade. Releases from the GSA stockpile are likely to fill some of the gap in quantity demanded and quantity supplied in the 1980's. How much will be released is completely uncertain. Prices can be expected to remain above the six dollars per pound level and increase at a greater rate than general inflation, contingent upon several economic and political factors. Among these factors, releases of tin from the GSA stockpile will be the major determinant in how much the price of tin will increase over the forthcoming decade. Costs are likely to keep up with the expected high prices.

If the recent surplus trends are sustained for a considerable amount of time and/or if the GSA releases a large amount of stockpile tin, it is possible that prices would plummet and the ITC would again gain some semblance of control. It is not likely that this situation would last for an extended period of time. World production potential is simply too weak.

Projections of Supply/Demand from Other Sources

The preceeding analysis was, in part, based on commodity studies on tin done by econometricians or experts in the field. Below is a brief review of each of five different studies, their techniques, and conclusions.

Chase Econometrics. The Chase Econometrics study was done in November, 1977. Its long-term forecasting model emphasizes the demand side of the tin market and employs regression analysis. The study is not well documented and makes very general assumptions and conclusions.

Chase recognizes the fundamental imbalance in world tin supply and demand, and sees the industry's problems as supply related rather than demand related. Levels of demand of about 198,000 tonnes were predicted for the non-socialist world in 1977 and 1978, and about 215,000 tonnes predicted for the period 1981-82.

The basic conclusion reached by Chase is similar to that of most of the other projectors. Demand for tin will increase at a greater rate than supply of tin will increase, and deficits will continue. The specific projections of Chase Econometrics are shown in Table 4.25.

A gap in supply and demand of between 20,000 and 25,000 tonnes annually is expected over the foreast period. Such predictions are probably excessive due to an expected growth rate in demand of almost two percent annually. Chase sees the GSA stockpile as the major countervailing source of supply during this period of deficit. Nonetheless, by the early 1980's prices should again begin to climb, according to

Table 4.25

Chase Econometrics Long Term Tin Forecast
(for the Non-Socialist World)

	Demand (000 tonnes refined tin)	% Change	Supply (000 tonnes refined tin)	% Change
1977	197.8	0.81	181.9	1.21
1978	197.9	0.08	187.8	3.27
1979	204.3	3.21	192.6	2.52
1980	210.6	3.07	185.6	1.59
1981	213.3	1.32	198.7	1.57
1982	216.9	1.56	201.2	1.25
1983	220.7	1.83	203.1	0.96
1984	224.6	1.79	204.1	0.49
1985	228.6	1.78	204.7	0.31
1986	233.6	2.19	204.9	0.08

Source: Chase Econometrics Long Term Metals Forecast, November, 1977.

Chase, because upply is projected to increase only about one percent per year or less during 1980-85.

Stanford Research Institute (SRI). Standard Research Institute's commodity study on tin was completed in 1975 as part of its World Minerals Availability, 1975-2000 project. The study is fairly extensive but is not highly regarded, particularly by industry. The study emphasizes demand and touches upon the other major aspects of the industry is a cursory manner. Much of the data and projections, three years later, are extremely out of date.

The SRI study does provide a fairly good general review of the tin industry and discussion of some important trends. SRI recognizes two principal factors influencing future prices for tin-- 1) the need for marginal producers to cover increasing costs so as to induce adequate supply, and 2) the role of the ITC in providing some control over price. The study also recognizes that political developments in producing countries are of immense importance in the long term outlook for tin.

The study's methods of projection are not documented, nor are they as quantitative as Wharton or Chase. Significant deficits and a worldwide growth in demand of 1.9 percent per year is forecasted. These projections are probably overstated.

Wharton Econometric Associates. The Wharton Ecometric Associates model for tin was updated in 1976. It is a complex, interactive model taking into account several demand and supply variables. Elasticities from the model have been previously indicated. The projected annual growth rates of 2.25 percent for aggregate tin supply and 3.4 percent for aggregate tin demand in the western world are extremely high relative to other projections.

The Wharton study provides a sophisticated, quantitative analysis of world tin supply/demand and makes specific price projections. This study does not attempt to analyze the ITC or politics in its projections. With a commodity as volatile and politically sensitive as tin, such an approach has limited effectiveness.

Rayer-Harwill, Ltd. Rayner-Harwill, Ltd. is a London-based commodity trading and consulting firm. Each year they publish their "Annual Review of the World Tin Industry" which is apparently well respected for its conclusions and projections.

The conclusion of Rayner-Harwill's June, 1978 study is that deficits of tin supply/demand in the non-socialist world will continue during the next decade from 13,200 tonnes in 1978 to 16,500 tonnes in 1981. These deficits are expected to be made up by GSA stockpile releases. The report anticipates

Table 4.26

Projected World Tin Production for 1986

(in 000s tonnes tin-in-concentrates)

	1976	1986
Malaysia	63.4	51.0
Bolivia	28.1	30.0
Indonesia	23.4	31.0
Thailand	20.5	25.0
Australia	10.4	6.0
United Kingdom	3.3	6.0
Brazil	5.9	6.0
Zaire	4.0	6.0
Nigeria	3.7	4.0
Others	10.3	14.0
TOTAL	173	179
Statistical demand	196	232
Deficit	23	53

Source: Peter Rich, International Tin Symposium, La Pas,1977.

little (or no) improvement in output over the next three years from Malaysia and Thailand and slight increases from Indonesia and Bolivia. Increasing production from Brazil and Australia is expected to be roughly offset by declining output from Nigeria, Zaire, and England. Furthermore, domestic Chinese demand is expected to reduce China's exportable surplus to around 3,000 tonnes per year while the Soviet Union's net imports will range anywhere from 5,000 to 10,000 tonnes per year.

Rayner-Harwill believes that prices in 1978-1979 may reach $6.30 per pound and that "the long term outlook for this metal continues to be good."

Peter Rich, D. Aluvional Ltd., Brazil. This study represents the most pessimistic view of all the projections regarding the ability of supply to meet demand in the future. It was presented at the International Tin Symposium in November, 1977 in La Paz, Bolivia.

Mr. Rich briefly outlines the supply history of each of the world's significant tin producing countries and then makes bold predictions about the future production potential of each. Table 4.26 summarizes the results.

Rich claims these estimates are close to the true production potential of the western world over the next decade. Some estimates are simply based on a "deep personal knowledge".

This report, then, takes a descriptive rather than quantitative approach in forecasting. It seems unlikely, however, that production potential will be as weak as stated.

In Peter Rich's analysis, the past can no longer be the key to the future.

> "Statistical forecasts of 1.5 percent annual increases in consumption become nonsensical if the tin supply is not there to meet demand. There is no possibility of a production level of 313,000 tonnes by the year 2000."

The point is well taken: supply potential largely dictates the future of this commodity.

CHAPTER 5. HYPOTHETICAL PRE-FEASIBILITY PROJECT EVALUATION STUDIES

The economics of four hypothetical projects are evaluated below. The attempt here is to define, preliminarily, the Discounted Cash Flow Rates of Return that might be expected with the assumed costs and production rates of each project. The ultimate goal of this type of analysis is to provide management with the information necessary to decide if projects of these type would meet the objectives of the firm, which would generally involve maximization of future wealth to the stockholders. An investment decision of this type involves three types of analyses: 46/

1) Economic analysis
2) Intangible analysis
3) Financial analysis

Financial factors are assumed as given in this study. Intangible factors such as political uncertainty and GSA stockpile releases have been previously discussed. The economic analysis which follows involves calculation of the future net cash flows in determining the net present value to the investor. The concept of opportunity cost - the advantages foregone in the alternate use of investment capital - is implicitly central to this analysis.

Four countries were selected as being reasonably favorable exploration targets in terms of operating costs and geological potential. They are Malaysia, Indonesia, Australia, and South Africa. The Malaysian and Indonesian projects can be readily compared. They are both dredging operations with the same output, mine life, and basic operating conditions, but have differing grades, costs, and taxes. The Australian and South African projects are both underground operations and can likewise be compared to each other in terms of size, mine life, etc.

Operating costs for each project are taken from a previous section. Capital costs are estimates based on published figures in various periodicals or on unpublished data from a nickel project in Australia of similar size.

General assumptions include a price of tin in 1978 constant dollars of $6.00 per pound. A washout of price and cost escalation is assumed. Net smelter return is used in the projects to calculate revenue. Smelting charges are derived from Streets and Lewis (1977) and Metal Bulletin. Any other assumptions are stated for each project.

All computations were made by computer utilizing a project evaluation program developed by C.W. Berry (1972).

Australian Tin Project Base Case

Assumptions

Underground mine

1000 tonnes of ore per day

315 effective days per year

Average grade of 0.59 percent Sn

1860 tonnes tin concentrate per year

50 percent Sn in concentrate

930 tonnes tin-in-concentrate per year

or

2,00,000 pounds per year

Price: $6,00 per pound

minus $0.65 per pound smelting and transport cost

NSR: $5.35 per pound

Operating cost: $1.90 per pound or $7,788,000 per year

Effective Australian tax rate: 46.0 percent 47/

Capital Breakdown (in 000s $U.S.)

Yr.	Feasibility Study	Pre-prod. Development	Mine Equip.	Surface Constr.	Mill Bldg. (48) Equip. & Tailings Pond	W.C.	Total
1	100						100
2		632		1,000			1,632
3		1,748	1,409	500	1,950		5,607
4		1,532	912	150	1,950		4,544
5		212	1,431	750	1,950	1,950	6,293
							18,176

Australian Depreciation (in 000s $U.S.)

Exploration and Development (expensed)	4,224
Capital Expenditures (150% declining balance)	13,952
TOTAL	18,176

U.S. Depreciation

Exploration and Development (expensed)	4,224
Capital Expenditures (DDB)	12,002
Working Capital	1,950
TOTAL	18,176

Results

The results for the hypothetical Australian project are shown below. The discounted cash flow rate of return (DCFROR) for the base case was only 7.7 percent. At an assumed 12 percent opportunity cost for the capital invested, or a 12 percent discount rate, the net present value (NPV) is -2.7 million dollars.

Sensitivity analyses of the base cases illustrate how the figures can be significantly altered by a change in price, cost, or taxes. The following parameters were increased (since a decrease in any of the factors is very unlikely) to show what effect the changes would have on the projects' DCFROR. Each of the changes are independent, or assume ceteris paribus.

Sensitivity Analysis for Australian Tin Project

	DCFROR	Payback Period	NPV @ 10% (in million $US)	NPV @ 15% (in million $US)	Average Income Per Year (in million $US)
Base Case	7.7	8.3	-$1.7	-$3.6	$1.2
+10% Operating Cost	4.6	10.8	-$3.8	-$4.9	$0.8
+20% Operating Cost	0.8	14.6	-$5.9	-$6.1	$0.4
+10% Capital Cost	6.6	9.0	-$2.8	-$5.7	$1.2
+20% Capital Cost	5.6	9.8	-$3.9	-$5.6	$1.2
+10% Price	11.5	6.2	$1.2	-$1.9	$1.8
+20% Price	14.7	5.0	$3.9	-$0.2	$2.4
+10% Eff. Tax Rate	7.1	8.6	-$2.1	-$3.8	$1.2

The results show that price is more sensitive than any of the other parameters. A 10 percent increase in price caused a 49 percent increase in DCFROR and a 20 percent increase in price caused a 90 percent increase in DCFROR. Operating cost increases affected the DCFROR by less; 40 percent and 88 percent, respectively.

Capital cost increases showed little effect on DCFROR and a tax increase was very insensitive to the project's results.

The indication is that upward movement in constant dollars of both capital and operating cost, in roughly equal proportions, would result in a higher DCFROR for a producer because of price sensitivity.

South African Tin Project Base Case

The South African project is assumed to be identical to the Australian project in terms of production rate and capital expenditures. Other factors, such as operating cost, are different. The smelting-transportation charge for South Africa are assumed $0.10 per pound higher than Australian charges. The assumptions for the South African project which differ from the Australian are stated below.

Assumptions

Smelting and Transport Charges: $0.75 per pound

NSR: $5.25 per pound

Operating Cost $2.20 per pound or $9,017,000 per year

Effective South African Tax Rate: 41.0 percent

Capital Breakdown - assumed the same as Australia

South African Depreciation (in 000s $U.S.)

Exploration and development (expensed)	4,224
Capital Expenditures (straight line)	13,952
Total	18,176

U.S. Depreciation - same as Australia

Results

The DCFROR for the South African case is the worst of the four projects. This is due primarily to lower revenues and higher capital costs. South Africa's higher operating costs and lower NSR than Australia make a substantial difference in project results.

As with the Australian project, results are sensitive to price and operating cost change, and insensitive to capital cost and tax changes.

The South African project would not be acceptable given the assumptions made. Even with substantial increases in price, it would be only marginal.

Sensitivity Analysis for South African Tin Project

	DCFROR	Payback Period	NPV @ 10% (in millions $US)	NPV @ 15% (in millions $US)	Average Income Per Year (in millions $US)
Base Case	2.0	13.9	-$5.3	-$5.8	$.50
+10% Operating Cost	0	21.0	-$8.0	-$7.4	-$.08
+20% Operating Cost	0	21.0	-$10.3	-$8.8	-$.60
+10% Capital Cost	1.2	14.3	-$6.4	-$6.8	$.50
+20% Capital Cost	0.6	14.7	-$7.6	-$7.8	$.41
+10% Price	6.9	8.9	-$2.3	-$4.0	$1.13
+20% Price	10.9	6.5	$0.7	-$2.2	$1.80
+10% Eff. Tax Rate	1.7	14.0	-$5.5	-$5.9	$.50

Malaysian Tin Project
Base Case

Assumptions

Large onshore dredge

1135 tonnes concentrate per year

315 effective days per year

Average grade of 0.25 pounds per cubic yard, decreasing to 0.20 pounds per cubic yard after 5 years

75 percent recovery

900 tonnes tin-in-concentrate per year or 1,983,600 pounds of tin per year

Price: $6.00 per pound

minus $0.40 per pound smelting and transport charges

NSR: $5.60 per pound

Operating Costs: $2.20 per pound or

$5,503,000 first 5 years

$6,754,000 second 5 years

Effective Malaysian Tax Rate: 70 percent

Capital Breakdown (in 000s $U.S.)

Yr.	Explor. & Develop.	Const. of Dredge	Dredge Equip.	W.C.	Total
1	750				750
2	1,000				1,000
3		500			500
4		1,000			1,000
5		9,500	250	1,375	11,125
					$14,375

Malaysian Depreciation (in 000s $U.S.)

Exploration and Development (expensed)	1,750
Equipment (DDB)	250
Dredge (straight line)	11,000
Working Capital	1,375
TOTAL	14,375

U.S. Depreciation

Exploration (expensed)	750
All Capital Expenditures	12,250
Working Capital	1,375
TOTAL	14,375

Results

The results for the hypothetical Malaysian project are the most favorable of the four, but are still only marginal at best. The DCFROR for the base case was calculated at 11.4, which indicates that if a discount rate of 12 percent were assumed, a negative NPV would result.

The results for the Malaysian project again indicate that price is the most sensitive parameter, but relatively less than it was for the Australian project. A 10-percent increase in price resulted in a 22-percent increase in DCFROR. Operating costs for the Malaysian project are relatively insensitive, while tax changes are more sensitive for this project than others.

Sensitivity Analysis for Malaysian Tin Project

	DCFROR	Payback Period	NPV @ 10% (in millions $U.S.)	NPV @ 15% (in millions $US)	Average income per year (in millions $US)
Base Case	11.4	5.1	$.65	-$1.20	$1.23
+10% Operating Cost	10.0	5.6	-$.04	-$1.64	$1.04
+20% Operating Cost	8.4	6.2	-$.72	-$2.07	$0.86
+10% Capital Cost	10.1	5.6	$.07	-$1.76	$1.20
+20% Capital Cost	9.0	6.0	-$.50	-$2.31	$1.16
+10% Price	13.9	4.5	$1.93	-$0.39	$1.56
+20% Price	16.2	4.0	$3.21	$0.42	$1.89
+10% eff. Tax Rate	9.2	6.0	-$.32	-$1.85	$0.97

Indonesian Tin Project Base Case

Assumptions

Offshore Dredge

1135 tonnes concentrate

Average grade of 0.57 pounds per cubic yard, decreasing to 0.46 pounds per cubic yard after 5 years

75 percent recovery

900 tonnes tin-in-concentrate per year or 1,983,600 pounds per year

Price: $6.00 per pound

Minus $0.50 per pound smelting and transport charges

NSR: $5.50 per pound

Operating Costs: $3.25 per pound or

$8,130,000 first 5 years

$9,756,000 second 5 years.

Effective Tax Rate: 41.5 percent

Capital Breakdown (in 000s $U.S.)

Yr.	Explor & Develop.	Permits & Feasibility	Construction of Dredge	Equip.	W.C.	Total
1	1,000					1,000
2	500	750				1,250
3		250	500			750
4			1,000	250		1,250
5			8,820	250	2,000	11,070
						15,320

Indonesian Depreciation (in 000s $U.S.)

All preproduction must be capitalized;	
All depreciation is straight line	
Capital Expenditures	13,320
Working Capital	2,000
TOTAL	15,320

U.S. Depreciation

Exploration (expensed)	1,500
Dredge, equipment (DDB)	11,820
Working Capital	2,000
TOTAL	15,320

Results

The results for the Indonesian project shown below indicate that investment in Indonesian tin, with the assumptions made, would be very undesirable.

Prices for the Indonesian project are the most sensitive of all the projects analyzed. A 10 percent increase in price resulted in a 150 percent increase in DCFROR.

The indication for all the projects is that investment in these foreign tin ventures would be economically undesirable for a corporation which might be able to earn 10 to 15 percent on its investment elsewhere. The results for the hypothetical projects, however, also indicate that upward movement in constant dollars of both price and costs, in roughly equal proportions, would result in a higher DCFROR for a producer because of price sensitivity.

Sensitivity Analysis for Indonesian Tin Project

	DCFROR	Payback Period	NPV @ 10% (in million $US)	NPV @ 15% (in million $US)	Average Income per year (in million $US
Base Case	4.0	8.4	-$2.64	-$3.50	$0.52
+10% Operating Cost	0	-	-$4.70	-$4.75	-$0.05
+20% Operating Cost	0	-	-$6.40	-$5.80	-$0.51
+10% Capital Cost	2.7	9.2	-$3.48	-$5.41	$0.44
+20% Capital Cost	1.6	9.5	-$4.34	-$4.97	$0.35
+10% Price	10.0	5.3	+$0.02	-$1.78	$1.23
+20% Price	14.0	4.2	$1.18	-$0.22	$1.87
+10% Eff. Tax Rate	4.0	8.4	-$2.64	-$3.50	$0.52

CHAPTER 6. RECOMMENDATIONS AND CONCLUSIONS

The main conclusions of the preceeding study are thus:

1) The price for tin will remain strong over the entire forecast period, with periodic decreases in price due to stockpile releases or temporary oversupply. This is due to the expectation that overall world demand for primary tin will be greater than overall production capability.

2) In spite of the apparent seller's market, conditions are not favorable, generally, for a U.S. mining corporation, particularly a large one, to become actively involved in primary tin exploration and development. The reasons for this involve the results of the hypothetical project evaluation studies for typical tin producers and the fact that political and economic instability in the market make investment subject to a great deal of uncertainty and risk.

3) Investment in tin may be feasible in specific areas, subject to sufficiently low costs. The most favorable foreign country for tin investment, all things considered, is probably Australia. Brazil and some Southeast Asian locations are also potentially favorable targets, contingent upon political accessibility.

4) Profitable tin operations will increasingly involve larger operations of lower grade, requiring greater commitment by producers in terms of capital investment.

5) Economically and politically, the production of tin as a by-product or co-product from a complex orebody in a developed country is probably the safest and best alternative for a U.S. mining corporation interested in tin at the present time.

The preceeding analysis of tin may serve as a comprehensive guide to one not familiar with the nature of the current tin industry. Its primary purpose, however, is to formulate an intelligent basis upon which a U.S. mining corporation might base a strategy, economically, for tin exploration. That is, it asks the question: will economic or market conditions for the commodity tin in the next decade be favorable enough for a U.S. mining corporation to undertake exploration and subsequent production of tin?

While tin prices are likely to remain strong over the forecast period and range anywhere from 6 to 10 dollars per pound, based on weak production potential and moderate demand, it must be generally concluded that production of tin on a significant scale by a U.S. mining corporation is not worth the risks required.

This conclusion is based on two overriding factors. One is the poor results of the project evaluation studies conducted for typical, if not slightly above average, producers. The other factor is the unstable nature of the tin market and unacceptably high political risks in many producing countries.

All of the hypothetical projects proved to be unattractive under their base case assumptions. The results of the project evaluation studies indicate that production of tin by a U.S. producer in a foreign country would be only marginally profitable, even in areas which are generally considered to have relatively favorable costs and operating conditions. This analysis, furthermore, does not explicitly account for important political factors. A DCFROR of at least 20 would then probably be needed if all risk factors are included.

The second factor which, in general, precludes U.S. corporate involvement in foreign tin production is risk and/or uncertainty. The risks of producing tin in a third world country are considerably high in themselves, but uncertainty such as political crises or gross fluctuations in costs or prices cannot be foreseen, measured, or insured against.

Many of the tin producing countries of the world are simply too politically unstable for any but the most daring U.S. mining companies to undertake exploration and development. Political uncertainty is often too great for substantial involvement to take place. Moreover, the unstable nature of the industry itself under the currently inept International Tin Council places investment in tin production in a precarious position.

No large U.S. corporations are actively engaged in development or production of any significant amount of tin and current exploration for primary tin deposits is limited. The risks and uncertainty involved in tin are prohibitively high for large corporations, vis-a-vis other projects available with lower risk. A smaller company primarily involved in exploration may be more willing to enter into initial tin exploration, and the risks associated with it, on a relatively smaller scale.

Investment in tin need not be considered totally unacceptable to a U.S. corporation. Specific areas of the world may be favorable, economically and politically, for tin exploration and development. There are known tin-rich belts in many areas of the world; it is within these belts that exploration would be most successful. Tin exploration decisions in specific areas must be based on empirical, scientifically gathered facts from detailed mapping, drilling, geophysical, and geochemical sources so that patterns of tin distribution can be recognized.

The most favorable areas of the world for tin development, economically, appear to be Brazil, Australia, Malaysia, and perhaps Indonesia. The most favorable areas in terms of a politically stable climate for mining are the United States, Canada, Australia, and perhaps South Africa. Overall, Australia is probably the most favorable area for a U.S. mining company to explore for tin. Contingent upon satisfactorily low costs or high prices, and overcoming difficult mining conditions, areas of Alaska or Canada could also be favorable targets.

One of the most salient conclusions regarding the economics of tin for a U.S. company is that tin produced in the United States or Canada would be significantly more attractive than foreign production, at least in terms of risk. A major alternative to primary tin production by a U.S. producer, since so few reserves of tin exist by themselves domestically, is to produce tin as a by-product.

Cassiterite often occurs with a host of by-product or co-product minerals such as tungsten, fluorite, or beryllium. Some co-product minerals may be quite rare and valuable, such as silver. Production of complex ores has an advantage in that prices of all the commodities mined are not likely to be depressed simultaneously. Price fluctuations, therefore, are not as severely felt.

The potential for this type of deposit to be found in areas of Canada and Alaska is fairly good. The lead-zinc mine in Sullivan, British Columbia, which has produced over 10,000 tonnes of by-product tin, and the Climax molybdenum mine in Colorado are a few examples of this type of deposit.

By world standards, tin production will continue to be dependent upon one-commodity sources such as Southeast Asian placers, and by-product tin will not greatly influence world tin in the next decade. For an individual corporation interested in limited tin exploitation, by-product tin could be a very important factor in determining the viability of a potential multi-commodity mineral deposit.

Economically and politically, the production of tin as a by-product or co-product from a complex orebody in a developed country is probably the best alternative for a U.S. mining corporation interested in tin under the current conditions.

CHAPTER 7. RECOMMENDED FURTHER RESEARCH

1) Continuation from where this study leaves off; a complete, technically accurate feasibility study of a specific project with detailed operating information is the bottom line in determining the desirability of becoming involved in tin production for a mining company.

2) An accurate, up-to-date study of elasticities in the tin market; both price elasticities of supply and demand and cross elasticity.

3) A study of how substitution from aluminum, plastic, glass, TFS, etc., might affect tin demand. How high can prices go before significant substitution takes place?

4) The possible future impact of the environmental movement (ban the can) and recycling on tinplate demand. How much of an advantage does aluminum have here?

5) More specific geological study in areas which would aid exploration for tin such as fluid inclusion studies, isotope studies, a practical model for tin genesis, etc.

6) A complete study of the international and local politics involved in and potentially affecting tin production and demand.

7) A critical study of the International Agreements; how might the ITC and the International Tin Agreements serve as a model for commodity agreements in general.

8) The author is particularly interested in the economic potential of exploiting tin from the Lost River deposit in Alaska. Specific information on cost, geological potential, and the conditions under which mining would take place is needed so that a current economic evaluation study can be made. This study would necessarily include an analysis of the economic potential of producing tungsten and fluorite, along with tin.

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