MINERAL RESOURCES:

The Infinitely Finite

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The International Council on Metals
and the Environment

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PREFACE

This is the first in a series of publications discussing issues relevant to environmental and/or health related policies. It is believed that the topics examined are of concern, not only to the non-ferrous metal mining and producing sector, but also to various societal groups, labour, policy makers, educators and the public at large.

The ICME hopes that these publications will provide insight in what are often difficult and complex issues. At the same time, it would welcome questions and comments on the views expressed in its publications, or suggestions as to other issues of public importance that should be addressed in future publications.

Mr. Phillip Crowson, RTZ, has launched this publication series with a discussion of mineral resource depletion in an article entitled "Mineral Resources: The Infinitely Finite". He questions the view that the earth is depleting its economically recoverable mineral resources.

SUMMARY

The crust of the earth - being a mixture of minerals - has provided but a minor amount of its potential to meet the material needs of man. Nevertheless, the question remains, "For all practical purposes, is the earth running out of recoverable minerals"?

The definitions of resources and reserves of minerals need to be understood in order to explore this question properly, especially since these two terms are often confused with one another. A resource is simply the identified or probable physical presence of minerals in the earth. Figures on resources say little about their exploitability, and they tend to be large.

Reserves, on the other hand, represent that portion of the resources which has been more precisely measured and which is, or might be, available for production over a specific time period. For society, reserves of non-ferrous metals also include inventories of all types, and materials that are, or can be available for recycling.

Because of the technical meaning that the mining industry ascribes to reserves, the public may often gain the impression that society has mineral reserves of a particular commodity for a relatively short time period, i.e. 10 or 20 years. This is not surprising since reserve figures are based upon fairly detailed and expensive drilling operations, and companies only conduct sufficient drilling to estimate reserves for the design and operation of a mine for a selected number of years. Consequently, drilling will normally be carried out every year or so, in order to maintain a certain level of reserves. A company may, therefore, have an annual reserve figure of 10 years for many years, which will only begin to decline as the mine approaches the end of its life. It is neither cost effective nor good investment practice for a company to attempt to drill the full extent of existing reserves for

mining purposes on a property, although a company may have some rather general estimate as to what may be present.

When overall reserve figures are aggregated to the national or international level, they commonly tend to be relatively stable over the medium term, i.e. 5 years. Over longer periods, and especially during this century, they have increased as growing demand has been reflected in greater exploration activity.

Better exploration techniques allow companies to identify potential reserves more effectively, whilst improved recovery technologies allow industry to broaden its reserve base by extracting additional material from lower grade[1] deposits, or from previously unexploitable complex ore deposits and from recyclable materials. Lower costs and increased productivity, notably in mining, and more efficient collection and management systems of recyclable materials also allow for greater recovery. Most importantly, higher prices will have a significant positive impact on reserves by encouraging new discoveries, greater recovery and increased recycling, and bringing into production previously uneconomic deposits. Depressed prices and higher costs have the opposite effect. Greater stability of political and regulatory regimes, and other factors affecting the investment climate are also important determinants of reserves, since necessary rates of return from investment can affect the cut-off grade for mineral extraction.

Over the years, improvements in technology have provided industry with the ability to mine from deposits with lower grades, while recycling of lead, copper, and other metal commodities has grown substantially. Today, over 70% of used lead metal is recovered, while the recovery of gold, that is not stored or in use, approaches 100%. Most metals can be recycled indefinitely from most uses to meet society's material needs. They are indeed renewable, with little or no loss in their technical attributes, regardless of how many times they have been recycled. Thus, non-ferrous metals, once extracted from the earth, have the potential to provide employment and income for generations.

Opportunities abound for new resources of mineral reserves, both within existing producing countries and beyond, e.g. off-shore areas. Mineral exploration,

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1 Grade is a measure of the content of the mineral/metal to be recovered from the deposit

leading to new production facilities, continue to offer significant income, employment and trading opportunities for developing countries, not to mention the former Soviet Union and Eastern Europe.

When one takes into account the global aspects of exploration, technology, recycling and pricing factors, then it is highly improbable that society will run out of minerals over the long term, although there may be short term disruptions in supply. For these reasons, any argument that international policies should reflect the need to protect or conserve its mineral resources on the basis that the world is running out of them may not only be misguided, but costly for society. It would be more correct to stress policies in support of the more economically and environmentally efficient methods of exploration, production, use, recycling and disposal of mineral resources.

INTRODUCTION

Based on the unchallengeable proposition that we live in a finite world, fears periodically surface about the imminent depletion of the earth's mineral resources. Typical of such concerns was the Club of Rome's report of the early 1970s on *The Limits to Growth*[2]. This demonstrated, with irrefutable mathematical logic, the consequences of continued exponential growth in demand for minerals and metals. To the extent that the proportion of each element in the earth's crust is limited, the argument appears infallible. For practical purposes however, it is not, as it completely overlooks the dynamic technical and economic interactions between supply and demand, as regulated by the price system. Expanding boundaries of geological and geographical knowledge, improving technology and changing price/cost relationships have led to estimates of the earth's mineral resources being increased. In general, estimated resources have risen faster than the rates of production.

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[2] The Limits to Growth. D.H. Meadows, et al. Earth Island 1972

THE NATURE OF RESERVE/ RESOURCE ESTIMATES

The probabilistic and multi-dimensional nature of published estimates of mineral resources and reserves at any given time is normally overlooked in public debate, no matter how carefully the computers qualify their estimates.

The most commonly quoted definition of resources and reserves, and the most widely distributed estimates are those of the US Geological Survey and Bureau of Mines[3]. The key features of the classification are contained in the diagram reproduced in Appendix A. Other national agencies define reserves in slightly different ways, often using different terminology, or even the same terminology for different concepts, but the US definitions cover the main principles of any estimates. These are that *"resources must be continuously reassessed in the light of new geological knowledge, of progress in science and technology, and of shifts in economic and political conditions"*. In short, it is necessary to assess both the physical characteristics of resources and the potential profitability of extracting and marketing them. Even the physical characteristics of a known ore deposit, such as its grade, quality, tonnage, thickness, and depth are never known with complete certainty, no matter how well explored or developed the mineral province concerned. These characteristics can only be statistically inferred from sample data of varying degrees of accuracy. The true size of an ore body is only definitely known when the ore has been fully extracted. That would be so even if economic conditions never changed over the period of its extraction, whereas they always do.

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3 US Geological Survey Circular 831.1980 & Mineral Commodity Summaries 1991. US Bureau of Mines

Published estimates of the world's resources are based on inferences drawn from knowledge of existing ore bodies. Mineral exploration has been largely concentrated in areas of surface outcrops. That has left substantial regions of the world's surface largely untouched, for exploration methods were too imprecise until recently to tackle the remaining areas. For those large areas of the globe, where underlying geology has been only cursorily mapped, let alone explored, the existence and extent of resources are extrapolated from geological models. Exploration and new discoveries often lead to improved understanding of the genesis of ore, and thus, to the revision or replacement of prevailing models. This may well, in turn, lead to further discoveries which were not considered even remotely likely a few years earlier. Examples of ore discoveries coming from the development of new models include the diamond deposits of Western Australia in the late 1970s, the spate of uranium discoveries of the 1970s onwards, and the flood of gold discoveries of the 1980s.

MINERAL EXPLORATION

Mineral exploration is time consuming and expensive in its use of resources. The ratio of risk to reward is high so that exploration spending often falls substantially when mineral markets are depressed. Typically, exploration spending is highly sensitive to changes in mineral prices and to perceptions of profitability, as the successive boom's in exploration for individual minerals bear eloquent witness[4]. Examples include the nickel boom of the late 1960s, the uranium booms of the late 1940s/early 1950s and 1970s/early 1980s, and the gold fever of much of the 1980s. Very often, one large and well publicised discovery exacerbates any exploration boom, as efforts are directed to similar environments. For much of the last thirty years, exploration for many minerals, including most base metals, has been only marginally economic. Exploration spending is concentrated in areas with known mineral potential where the economic and political conditions for any ultimate mining venture are deemed to be sufficiently attractive. As these conditions change, so the attractiveness of different regions for exploration alters. The natural resources nationalism that characterised the twenty years from the mid 1960s greatly reduced the attractiveness of much of Latin America, Asia and Africa for mineral exploration by international companies. They are by no means the only sources of funds for mineral exploration, but they are much more responsive to changing market conditions than the others.

[4] Metallic Mineral Exploration. An Economic Analysis. Roderick G. Eggert. RFF. 1987.
World Mineral Exploration. Trends and Issues. ed. John Tilton et al. RRF. 1988.

Altering perceptions about the political risks of operating in various countries are only one way in which the frontiers of mineral exploration shift over time. New exploration techniques, including remote sensing and sophisticated geochemical and geophysical methods of detecting ore, have been developed. These have opened new areas to exploration and have also enabled new discoveries in areas that had previously been exploited with older technologies. This widening of exploration opportunities has staved off, and, at times, reversed the need to resort to ever leaner and less accessible ore deposits in order to satisfy rising demand. It is certainly true that the average grades of the mineral deposits worked have tended to decline over extended periods. That decline has, however, been accompanied by static or even slightly falling real prices of metals. The relatively brief history of uranium provides a good example of the erratic movements in average ore grades. Some of the more recent discoveries in Australia and Saskatchewan have average ore grades which are substantially higher than those of many long established mines. Even in a mature commodity, such as copper, new mines are being developed, in for example Chile and Indonesia, with substantially higher ore reserve grades than long established operations elsewhere.

THE ECONOMIC DIMENSION

Not only have exploration techniques improved, but methods of mineral extraction and processing have changed to allow the exploitation of a growing range of types of ore. In part, this has required the application of additional resources of capital and energy, but by no means always. For example, the development and expansion of leaching processes for copper in the past decade or so, especially in the United States, has often allowed the extraction of metal from material that had previously been considered as waste, with very little, if any, additional mining costs. The extension of mining to more remote geographical areas does not automatically imply massive capital requirements for infrastructure nor the encroachment of human habitation on wilderness areas. Long distance commuting and extended shifts are becoming standard practice in such areas, with advantages for labour relations as well as environmental protection.

In summary, estimates of ultimate resources do not only change with improved geological knowledge and developing technology. The expected profitability of mineral extraction is strongly influenced by technical change. That is often a direct response to adverse changes in profitability which force mines to become more efficient or close down. The history of the mining industry in the early to mid 1980s was one of successful and sustained reductions in costs in the face of deteriorating market conditions and weak prices. As price/cost relationships alter, so the amount of the known resource that can be profitably extracted - the reserve base or reserve - will also wax or wane.

Normally, technical change is evolutionary rather than revolutionary. From time to time, however, there are large jumps which radically change the proportion of a resource that can be profitably exploited and, hence, increase reserves. Also, such technical leaps may markedly shift the exploration frontier and offer the prospect of increasing resources. The development of feasible deep sea mining techniques, even on a pilot plant basis, in the past twenty years for example, greatly increased world resources of cobalt, manganese, and nickel. Conversely, the closure of the Antarctic Sub-Continent to mineral development effectively reduced the world's potentially exploitable resources.

While remote sensing and other advanced exploration techniques can indicate the existence of mineralized deposits, the grade and extent of those deposits can only be properly ascertained by drilling and underground sampling. That is expensive, and mining companies of all types normally only prove the existence of sufficient tonnages of ore to justify their investments in mining and processing equipment. As mining proceeds, knowledge of the ore body and its characteristics is enhanced. Further exploration will be undertaken to justify further capital spending and mine development. The aim will often be to maintain a given forward inventory of ore reserves. This means that most mines have much longer lives than initial estimates of their ore reserves might imply. A good example in this respect is provided by the Canadian mines of Inco, which have had reserves of some 30 years for the last half century. A chart depicting the development of Inco's reserves for the 1978-1991 period is included in Appendix B.

The experiences of Palabora Copper in South Africa demonstrate the dynamics of changing ore reserves at the level of the individual mine. At its start up in 1966, the ore deposit was estimated to contain almost 1.8 million tonnes of copper. Today's estimate is almost 4.7 million tonnes. The mine's life was originally estimated at 24 years but it is now assessed at 34 years. If an underground mine were to be developed, the reserves and life would be further extended. Improved technology and changing economics help explain the increase in reserves, as shown by changes in cut off grades and mill capacity in *Figure 1*.

In many instances, ore deposits are sharply defined by physical or chemical differences from their host rocks. In others, however, their size is a function of the economic grade for extraction. The example of Palabora shows that to an extent. In many instances, a change in the cut off grade - the lowest grade of rock which is treated as ore rather than waste - can substantially alter estimates of reserves. A reduction in cut off grades can greatly increase reserves, often with no change in mine life or increase in absolute mining costs. Increased cut off grades, however, often mean that previously economic ore is treated as waste. The configuration of

Palabora Copper's Estimated Reserves

	As defined at start up 1966	Full potential as seen in 1991
Reserves before mining		
Tonnage	259 mn t	854 mn t
Grade	0.69% Cu	0.55% Cu
Contained Copper	1.79 mn t	4.67 mn t
Cut off grade	0.3% Cu	0.15% Cu
Capacity: ore milled	30000 tpd	80000 tpd
Mine life (from start up)	24 years	35 years

Source: RTZ

Figure 1

the mine may also alter, and material that would have been extracted will remain inaccessible, even if it meets the lower cut off grade. There is some evidence that cut off grades were raised and estimated ore reserves were lowered during the mining industry's cost/price squeeze of the 1980s. Such trends are depicted in Appendix C.

OVERALL RESERVES

Moving from the individual mine level to the industry, *Figure 2* shows how estimates of world reserves of four major base metals increased over a forty year period, relative to the rate of growth of world mine production. Figures for these metals are more readily available than for many others, but in most respects, the

The Growth of World Reserves of Selected Products

(million tonnes contained metal near the end of the relevant decade)

	Copper	Lead	Zinc	Aluminum (a)
1940's	91	31 to 45	54 to 70	1,605
1950's	124	45 to 54	77 to 86	3,224
1960's	280	86	106	11,600
1970's	543	157	240	22,700
1980's (b)	566	120	295	23,200
% p.a. growth				
1950's-1970's	7.5	5 to 5.75	4.75 to 5.25	9.75
1980's	0.4	-2.7	2.1	0.2
% p.a. growth mine production				
1950's-1970's	3.75	1.75	2.75	7.0
1980's	1.4	-0.6	1.0	1.7

(a) gross weight of bauxite
(b) reserve base in 1989

Source: Minerals Handbook 1990-1. P. Crowson - Macmillan 1991 - based on data from US Bureau of Mines

Figure 2

Estimated Corporate Reserves in the Western World

All operating mines and development/exploration ventures, million tonnes of contained metal.

	Copper	Lead	Zinc	Nickel
1973	215.39	45.32	85.82	15.64
1977	240.59	48.12	102.46	21.74
1981	248.59	49.68	91.07	21.11
1985	229.33	45.98	88.67	19.48
1989	205.0	41.96	84.50	16.68

Source: RTZ Mine Information System

Figure 3

pattern shown is typical; estimated reserves grew at least as fast as production until the 1980s. In the first half of the 1980s, a decline in prices, relative to costs, led to reductions in reserves, as hitherto economic ore bodies became uneconomic. The position was not fully reversed in the second half of the decade. Hence, production tended to rise more rapidly than reserves in the 1980s, but not by enough to invalidate the longer term trends.

The US Bureau of Mines' data used in this table have sometimes been criticised as being too dominated by the relationship between US costs and prices. The use of other estimates of reserves, where this is so, as possibly in South Africa, would however tend to strengthen the argument, in that the proportion of resources to be treated as reserves would increase.

Figure 3 shows a completely different set of data on reserves for the past twenty years, built up from figures for individual operating mines, and development and exploration ventures. In terms of the US Bureau of Mines' diagram in Appendix A, it probably covers much less than the economic and marginally economic identified resources. The data refer only to the Western World. The estimates fluctuate with the economic conditions influencing the various metals. As noted earlier, the industry's recession of the early to mid 1980s tended to depress reserves.

A chart showing comparable annual data from 1973 onwards is included in Appendix C. That and *Figure 3* bring out the economic dimension of reserves. The annual changes are far greater than can be explained by depletion resulting from cumulative production. Shifts in the price/cost ratio moved the boundary between reserves and resources.

In most instances, published estimates of resources/reserves give only the physical dimension of tonnages of contained mineral. For non-ferrous metals, details are seldom, if ever, given of ore grades nor of the costs of extraction and processing, whether with or without capital costs.

This failure to quote the costs associated with estimated reserves means that the data have limited value. That recognized, the life of the estimated reserves of a broad range of minerals at present production rates is shown in the first column of *Figure 4*. The data again come from the US Bureau of Mines.

The "Adequacy" of Reserves

	Static Reserve Life (years)	Ratio of Identified Reserve Base to Cumulative Primary Demand 1989-2010
Bauxite	217	12.2
Antimony	66	2.7
Arsenic	24	1.3
Asbestos	25	1.3
Barytes	30	3.2
Beryllium	very large	very large
Bismuth	25	2.5
Boron	289	18.7
Cadmium	25	1.7
Chromium	123	7.1
Cobalt (land only)	123	12.9
Copper (land only)	40	1.9
Fluorspar	55	1.9
Gallium	very large	very large
Germanium	large	large
Gold	22	0.8
Indium	17	1.4
Industrial Diamonds	19	1.3
Iron Ore	122	8.2
Lead	20	1.4
Lithium	very large	40
Magnesium	very large	11 (exc. brines)

The "Adequacy" of Reserves (cont'd)

	Static Reserve Life (years)	Ratio of Identified Reserve Base to Cumulative Primary Demand 1989-2010
Manganese (land only)	98	16.4
Mercury	20	42
Molybdenum	58	3.9
Nickel (land only)	57	4.9
Niobium	260	5.2
Phosphate	very large	8.0
Platinum Group	205	9.0
Potash	over 500	36.9
Rare Earths	very large	35
Rhenium	108	18
Selenium	55	3.6
Silicon	extremely large	very large
Silver	19	1.1
Sulphur	24	2.3
Tantalum	91	0.9
Tellurium	94	5.9
Tin	21	0.74
Titanium	116	4.1
Tungsten	59	3.1
Uranium	62	2.5
Vanadium	135	18.4
Vermiculite	86	11.5
Zinc	21	1.55
Zirconium	78	1.7

Source: Minerals Handbook 1990-91. Phillip Crowson - Macmillan

Figure 4

The reserve life at present levels of output is a static measure, which takes no account of changing demands. The second column of Figure 4 contains a dynamic measure that relates the identified reserve base to forecast cumulative demand over the period 1989-2010. In most instances, the ratio comfortably exceeds unity. Even in the few cases where it does not, the world will not necessarily run out of ore reserves, and not just for all the reasons to qualify the estimates of reserves listed earlier.

DEMAND FOR MINERALS

Technological change and evolving price/cost relationships affect demand for minerals as much as the supply. As prices rise so substitution is encouraged, and the rate of growth of demand falls back. The use of previously mined material is also encouraged, whether through the depletion of above-ground inventories (e.g. gold and silver) or the encouragement of recycling. The response of users of silver to the sharp rise in silver prices of 1979-80 provides a good example of that effect. Sizeable proportions of total demand for most metals are now met from recycling of various types in the major industrial countries. The supply/demand mechanisms in the recycling chain are complex. In some instances, the recycling from some uses may involve a greater use of resources than reliance on new primary output. In general, however, the shares of secondary supplies are likely to continue rising.

Whenever prices of a mineral have risen sharply and unexpectedly, demand has been curtailed over the longer term. Relatively recent examples include cobalt in 1978-79, molybdenum in 1978-80, silver in 1979-80, and zinc in 1973-74. The price mechanism is effective in choking off demand, encouraging substitution, hastening technical change, and stimulating the development of new sources of supply, whether from primary mining or from recycling.

CONCLUSION

Concerns over environmental degradation and rising energy usage are re-emphasising the finiteness of the world's resources. Yet, the inclusion of previously unregarded environmental and rising energy costs will not hasten the exhaustion of such resources. Shortages of individual materials will occur periodically. To the extent that supplies are not increased, then substitutes of one form or another will evolve as they have in the past. There is no certainty, no room for complacency about mineral resources, but equally, no reason for undue pessimism. That is particularly so when, more than even before, the world's surface is opening up to modern techniques of minerals exploration and development.

APPENDIX A

Note: The certainty of the estimate of physical tonnages improves from right to left, and the economic profitability improves from bottom to top of the chart.

THE CLASSIFICATION OF RESOURCES/RESERVES

	Identified Resources			Undiscovered Resources	
CUMULATIVE PRODUCTION	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		
OTHER OCCURRENCES	Includes nonconventional and low-grade materials				

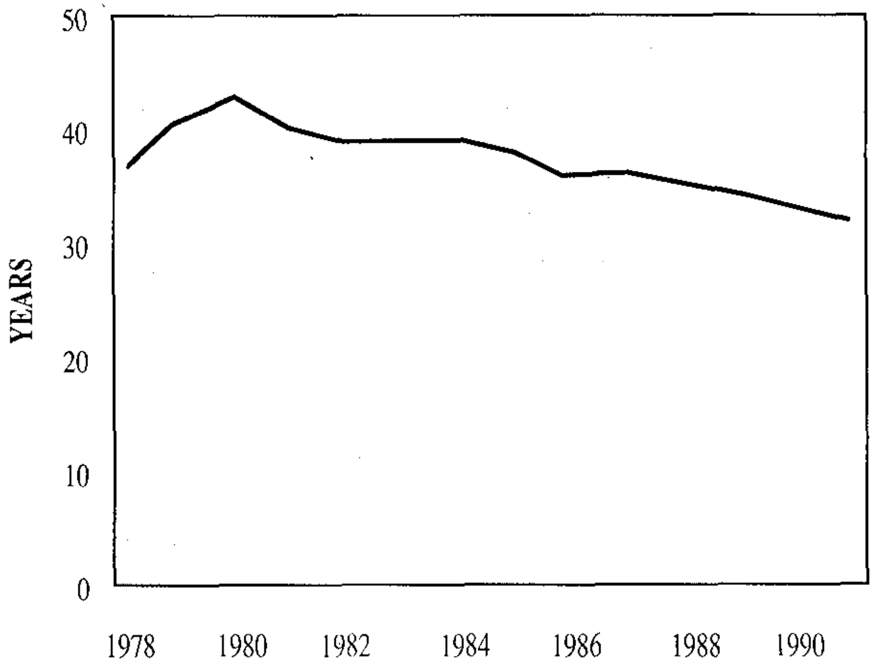
The Reserve Base includes all identified resources in the demonstrated category which are economic, and marginally economic, and part of which are sub-economic.

The Inferred Reserve Base includes all identified resources in the inferred category which are economic, and marginally economic, and part of those which are sub-economic.

Source: Mineral Commodity Summaries 1991. US Bureau of Mines.

APPENDIX B

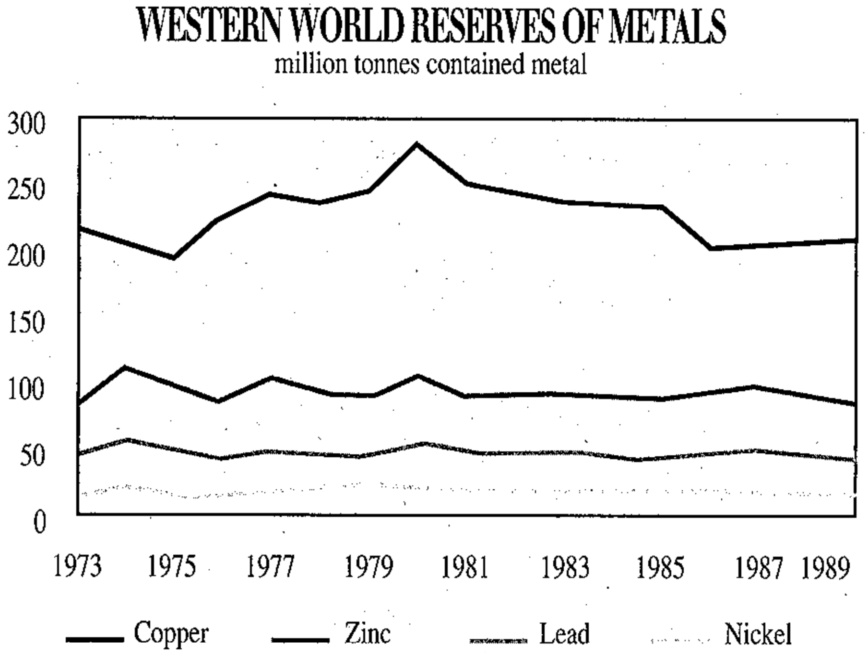
LENGTH OF LIFE OF INTERNATIONAL NICKEL'S CANADIAN RESERVES



Source: Inco Ltd.

Calculated on the basis of total proven and probable ore reserves divided by the average annual production for the 1978-1991 period.

APPENDIX C



Source: RTZ Mine Information System

Notes