manganese mining. Although they are spread very thinly, averaging a wet mass concentration of about ten kilograms per square metre, the area they cover in places is immense. In fact over 300 000 square kilometres of the most promising area lies to the south of Honolulu estimated to contain 500 million tons of manganese, 25 million tons of copper and 4 million tons of cobalt - equivalent to 75 per cent of the land based resources of cobalt.

It is not surprising that in recent years the manganese nodules have attracted the attention of several large mining companies and there are presently six international consortia actively engaged in investigating their possibilities. As the United States is ideally situated geographically to mine what is regarded as the richest area in the oceans and further, as these nodules contain potential resources of three stragetic metals for the United States (manganese, nickel and cobalt), that country has taken the lead in pioneering their exploitation. One consortium, Ocean Minerals Company had spent $ 220 million on investigation by the end of 1982, including sending the research vessel Glomar Explorer specially equipped on a pilot mining cruise.

The return from recovering cobalt could possibly decide whether ocean floor mining is likely to become economically feasible. While the increase in sources is not likely to affect the supply of this metal to South Africa, except possibly to reduce the purchase price, other effects of ocean mining could have a very serious and detrimental effect. In fact it is the possible impact of such large scale production of metals <u>other</u> than cobalt on world markets that has caused some delay in schemes for exploitation, except of course by countries such as the United States who would benefit by obtaining independent supplies of nickel and manganese and Japan which imports large quantities of copper.

High rates of ocean mining would have disastrous results on the world nickel, cobalt and manganese industries. The most promising regions for ocean mining lie at a depth of some 5 000 metres and as a result of the complexity of mining at this depth together with the very high costs of preliminary investigations only a very large scale operation would prove viable. Roskill estimates the minimum production rate to be 1 million tons annually contributing 11 400 tons of copper, 275 000 tons of manganese, 13 300 tons of nickel, 3 500 tons of cobalt and 570 tons of molybdenum to the world's metal market.

Considering the United States, one of the largest consumers of cobalt, reveals that they consume annually about 9 250 tons of cobalt. This means that only three operations of the scale discussed above would be required whereas cobalt is presently imported from Zaire, Belgium (Zairean origin), Zambia, Finland, Norway, Canada and a few minor producers. The effect on world metal trade of mining seabed nodules would be extremely disruptive in the long term.
However, Duke[14] states, the technical feasibility of mining a layer only a few centimetres thick at a depth of only 5 000 metres has still to be demonstrated and, far more important, the economics of mining under these conditions and the recovery of the metals at an economic cost must be proved. The legal position of a company mining mid-ocean has not yet been determined in spite of fifteen years arguing in the United Nations and at least four international conferences on the Law of the Sea. Claims have been put forward by Third World countries, especially those that have no coastline, no technical expertise and very little uncommitted capital. Needless to say, such claims have been favourably received by the United Nations. The seabed rocks have become the prize in a fierce political and ideological struggle between the developed and the developing worlds and until that struggle is resolved the nodules are likely to remain on the sea floor.

5.3. World Production

The principal producers of cobalt in the world are given in detail in Appendix Three including company, primary or secondary producer and sources of supply.

Despite transportation problems between Zimbabwe and Zambia and closure of the Benguela railway resulting from the civil strife in Angola, both Zambia and Zaire have been able to maintain shipments via alternative routes to destinations on the East coast of Africa and to Zaire's own port of Matadi. The East coast ports include East London (S.A.) and Dar es Salaam in Tanzania. The Tazora railway, linking Dar es Salaam with the interior, has been the principal route of export for copper and cobalt from Zambia.

Table 14 records the Western World cobalt output divided into ten main categories for the last fifteen years.

Page 80 (a) contains a graph of Western World cobalt production while Western World cobalt production is depicted graphically on page 81 (a).

Table 14

Cobalt production (tons contained metal)[28]

	1968	1969	1970	1971	1972	1973	1974	1975
Zaire	10 600	10 600	14 000	14 500	13 000	15 100	17 500	13 600
Zambia	1 300	1 800	2 400	2 000	2 100	2 000	2 000	1 900
Canada*	2 000	1 700	2 200	2 000	1 500	1 900	2 100	1 400
U.S.A.	237	206	147	140	-	73	-	100
Finland	1 700	829	1 000	926	800	1 000	812	821
France	x	x	x	x	x	x	x	1 100
Japan	-	-	-	-	-	-	-	125
Morocco	1 500	1 500	664	1 300	1 500	1 400	1 600	+
Germany	820	850	826	601	457	370	356	340
Other	155	166	166	163	166	169	147	24
TOTAL	18 300	17 650	21 400	21 650	19 500	22 000	24 500	19 400

	1976	1977	1978	1979	1980	1981	1982
Zaire	10 700	10 200	13 300	13 000	14 000	11 200	6 000
Zambia	1 700	1 700	1 700	3 250	3 300	2 500	2 250
Canada*	1 900	1 400	1 700	2 000	2 100	2 600	1 600
U.S.A.	100	250	300	200	500	300	350
Finland	900	985	1 000	1 200	1 300	1 300	1 300
France	1 200	1 200	1 100	1 200	1 100	600	400
Japan	550	1 150	1 700	2 500	2 855	2 400	1 800
Morocco	+	+	+	+	+	+	+
Germany	250	350	300	+	+	+	+
Other	100	200	300	800	300	600	800
TOTAL	17 400	17 450	21 400	22 950	25 450	21 500	14 500

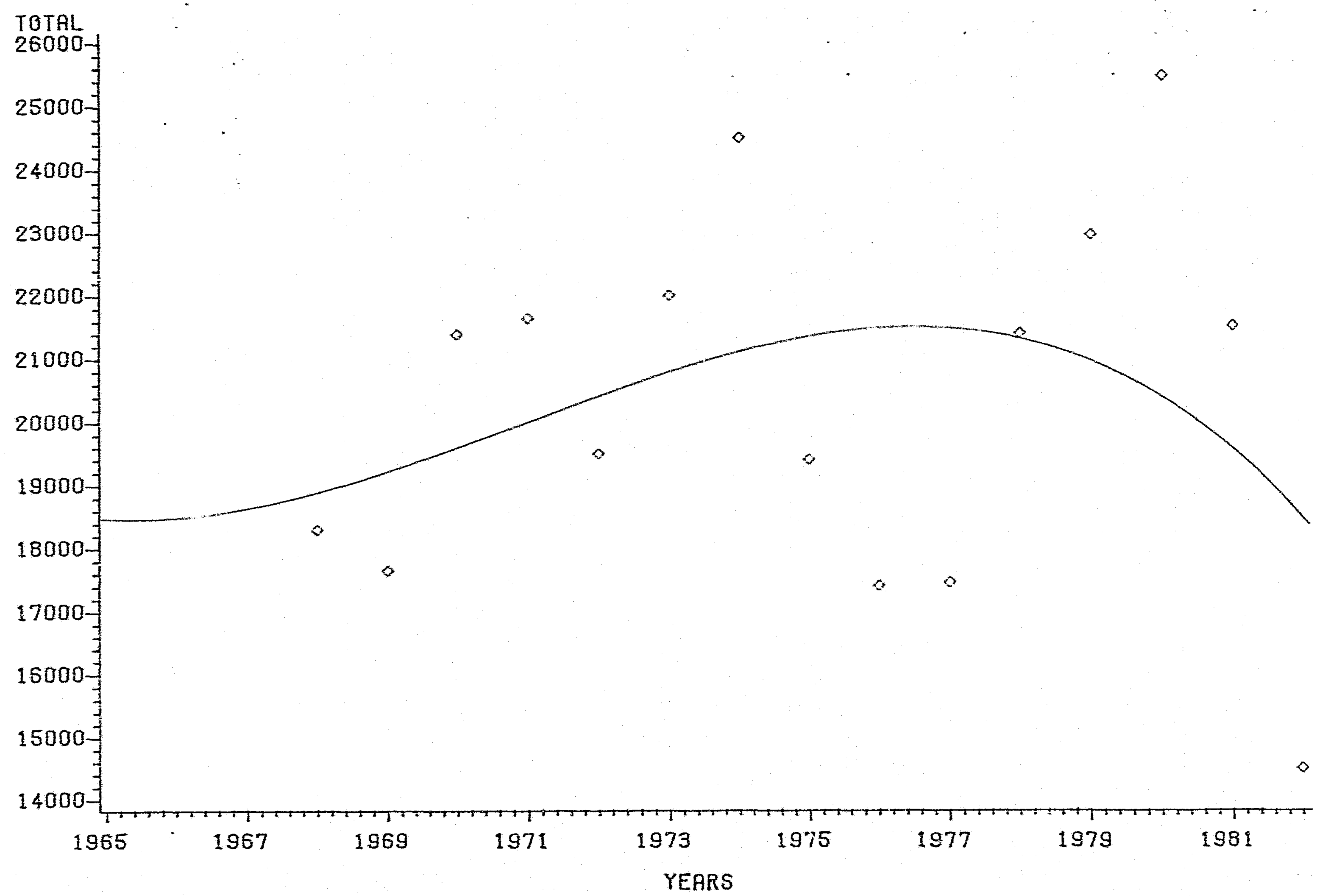
* including British and Norwegian production from Canadian ores

x included under Other for pre-1975 years

\+ included under Other

In addition, Roskill[33] estimates the total cobalt production of Centrally Planned economies to be around 4 000 tons in 1982, 15 per cent less than the demand from this sector. China, in particular, imports large quantities of cobalt from the Western World.

These figures must be considered with reservation. For instance, neither France, West Germany or Japan mine any significant quantities of cobalt yet they produce much cobalt from imported concentrates and ores. Belgium, which is not shown in the table, is a large refiner of cobalt, mainly from Zaire, but does not publish any sales figures. There



WESTERN WORLD COBALT PRODUCTION
TONS CONTAINED METAL

is considerable reserve capacity among the different cobalt producers and planned expansions may to some extent offset the drop in production from Zaire due to internal turmoil. This has created a serious shortage in the supply of cobalt. The United States formerly held a stragetic stockpile of cobalt amounting to 18 570 tons but this was increased to 38 775 tons in 1976 to 1978 and in 1981 they purchased another 2 361 tons. This decision and a consequence of poor economic conditions in 1982 aggravated shortages throughout the world.

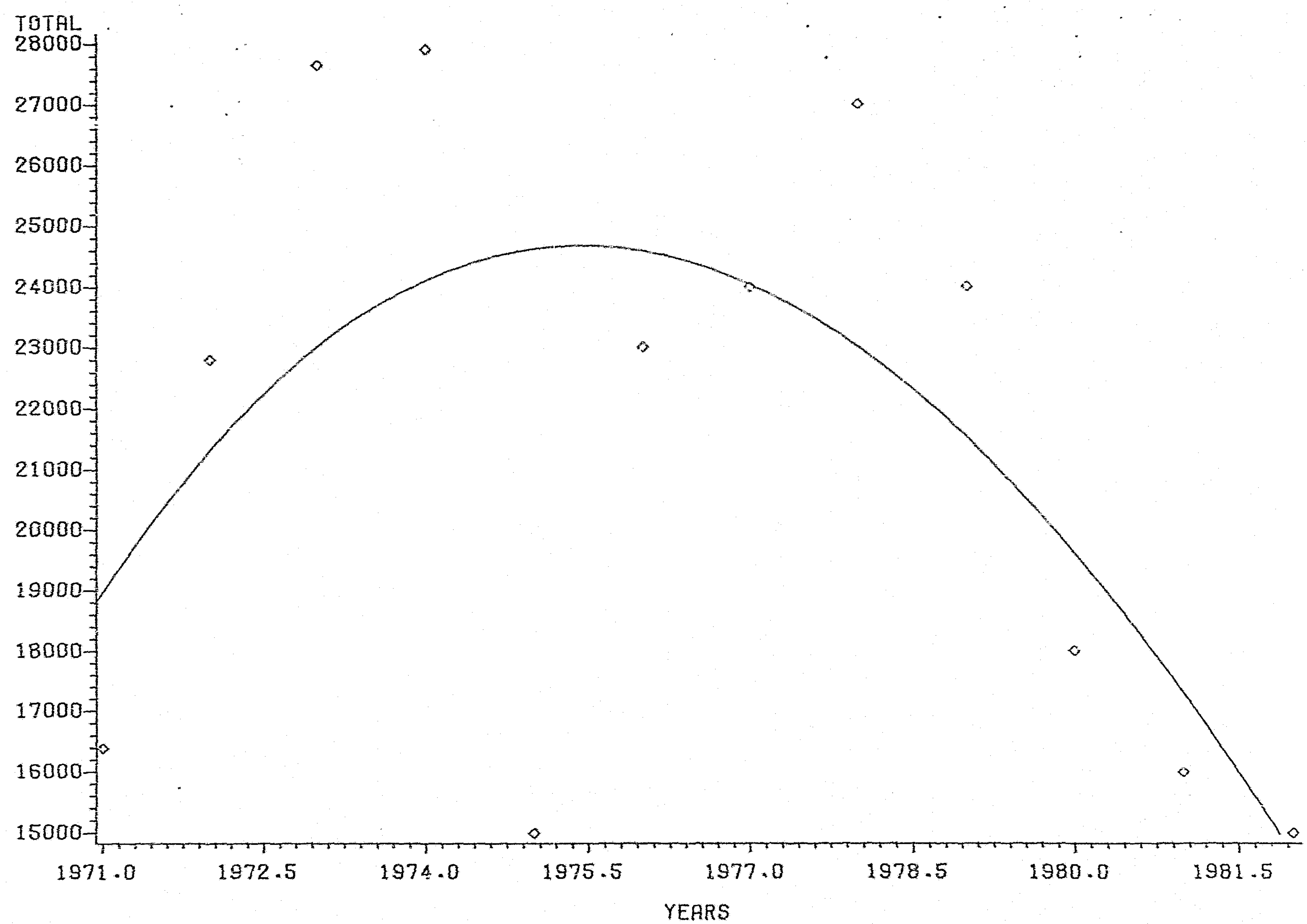
5.4. World Consumption

It is almost impossible to estimate actual consumption of cobalt in the absence of published statistics. Deliveries by prime producers are not a good measure of consumption but reflect consumer confidence in respect of inventory in addition to demand. However, it is possible to glean reasonably accurate figures from the Mining Annual Review reports and to build up a table of consumption in markets serviced by Western World producers:

YEAR	1971	1972	1973	1974	1975	1976	1977
CONSUMPTION (tons)	16 400	22 800	27 650	27 900	15 000	23 000	24 000
	1978	1979	1980	1981	1982		
	27 000	24 000	18 000	16 000	15 000		

During 1980 the results of a long time period of inflated prices due to the invasion of the Shaba province in Zaire became apparent. Most consumers made a determined effort to reduce their stocks having regard to the very high cost of financing and, in expectation of a reduction in the producer price, being faced with writing down huge stock investments. Consequently the large producers found their deliveries almost halved in 1980. Further compounding the problem of demand is the level of substitution resulting from a long period of high prices. The consumption figure for 1980 is about 25 per cent down on 1979 and possibly 15 per cent of this reduction is attributable to the recession.

A large part of the drop in demand for prime cobalt metal in 1981 is accounted for by the severe rescheduling of superalloy bar stock supplies by the aero-engine builders as a result of widespread cancellations of commercial aircraft options by airlines beset with enormously high interest charges and declining business. The long overdue re-equipment of the civil airlines with modern fuel efficient aircraft has been repeatedly postponed but eventually this will become a necessity.



WESTERN WORLD COBALT CONSUMPTION
TONS CONTAINED METAL

Until then the superalloy business seems prepared to make do with revert alloys, even to the extent of remelting and re-alloying bar stock inventories. This important application is the largest single end use of prime cobalt in the world.

The downward momentum was continued in 1982 which virtually saw the end of the original producer contract, based on 'sellers terms' in favour of spot purchases at 'merchant terms'. The general lack of demand, coupled with the existence of high producer stocks and the desperate financial position of leading producers, gave rise to vicious competition for any business. The predatory actions of some merchants added impetus to a downward price spiral by selling forward at even lower prices, covering in short positions progressively from willing producers prepared to sell at free market prices for the sake of cash flow. The steady decline in prices caused consumers to delay purchases until the last possible moment and to procure the absolute minimum quantity at any one time. Under these market conditions and in the light of poor physical demand there was no incentive for inventory buying. Investment in new aircraft was further postponed; the chemicals market sector was affected by the continuing low level of activity in the consumer durables industry but the magnet sector enjoyed growth as a result of increased interest in computers for home use and greater sales of video tape recorders and high technology electronic applications.

5.5. <u>Local production</u>

South Africa does not figure internationally as a producer of cobalt. There is a small production of cobalt in mattes and concentrates... small by world production but significant in terms of South Africa's requirements.

Apart from the shipment of 143 tons of handpicked cobalt from the Kruisrivier deposit in 1889, the only known production of cobalt locally has been as a by-product from the recovery of platinum at the Rustenberg Platinum Mine ($CoSO_4$), Impala Platinum and Western Platinum (Co). Occurrences of cobalt have been reported in the geological literature, none of which has been large enough to justify exploitation.

Much more important are the low but consistent concentrations of cobalt in the platinum and nickel bearing Merensky reef and in the gold bearing reefs of the Witwatersrand series. Although cobalt concentrations are low the ore reserves of the platinum and gold bearing deposits are so immense that these sources must be considered important.

In the neighbouring territories of Zimbabwe and Botswana cobalt is a constituent of ores being mined and treated for the recovery of nickel.

5.5.1. Production estimates - platinum mines

The potential production from nickel and copper ores is often underestimated because of losses which occur in the smelting process. Usually only 20 to 25 per cent of the cobalt present in the concentrates fed to the smelter reports in high grade matte or finished metal. The loss occurs in the converting process where nickel is oxidised and slagged off in the converter slag. For this reason large low grade reserves of cobalt exist in smelter slag dumps.

Historically in South Africa the older platinum producers made no effort to recover cobalt but between 10 and 20 per cent of the cobalt contained in concentrates was recovered in electrolytic nickel. The cobalt content was around 1 per cent. Because it is no longer easy to dispose of nickel containing this level of cobalt South African producers are investigating methods for recovery of the metal.

In 1979 the refinery jointly owned by Rustenburg Platinum Mines Limited and the Johnson Matthey Company commenced recovering the cobalt as a crude hydroxide sludge prior to the electrolytic refining of by-product nickel. At Impala and Western a similar product is also recovered. In both cases the crude cobalt is exported as such to refineries overseas, although small amounts of crude cobalt were once sold by Impala Platinum to a local chemical manufacturing company who produced cobalt sulphate as an additive for cattle feeds. Late in 1979, Rustenburg Platinum Mines established a plant for the production of high purity cobalt sulphate, a proportion of which is sold overseas by contract:

YEAR	1979	1980	1981	1982	1983(est.)
TONS(Co)	155	189	189	525	525

The figures represent tons contained cobalt as $CoSO_4.7H_2O$ at 21 per cent cobalt.

Production figures are not available for Impala Platinum but the company claims an extraction capacity of around 250 tons annually of contained cobalt metal.

If the above processes were utilized by all South African producers, the quantity of cobalt available from this source would be in the range of 600 to 1 000 tons of cobalt per year.

5.5.2. Production estimates - gold mines[32]

It is well known that the gold ores of the Witwatersrand series contain low concentrations of cobalt. This element, nickel and copper are associated with pyrite which is a constituent of the ore.

In South Africa there are several operations in which gold tailings are being reclaimed and concentrated by flotation for the recovery of sulphur (in pyrite), gold and uranium. Enormous tonnages are being treated in this way and reserves are sufficient to support operations for at least 20 years. The degree of concentration is about 40:1 and the finished concentrate which is roasted to produce sulphuric acid, is then leached to recover gold and uranium.

Solution concentrations may be:

gold	6 - 12 grams per ton
cobalt	500 - 1500 grams per ton
copper	1 500 - 2500 grams per ton
nickel	2 500 - 4000 grams per ton
uranium	classified

Each ton of concentrate produces 1 ton of sulphuric acid saleable in South Africa for about Ø60 per ton. With the average gold value of the concentrate about Ø120 per ton it appears that the combined copper, nickel and cobalt value of about Ø100 per ton is well worth recovering. The present production of concentrates is more than 1 million tons per year and so the potential production from this source is around 1 000 tons per year of cobalt. Indeed, ERGO and JMS (Joint Metallurgical Scheme) produced 316 tons of contained cobalt in 1979, the last available production figure.

In addition to dump re-cycling, current gold mining operations are a potential source of between 1 000 and 3 000 tons per annum. Cobalt is to a significant extent dissolved in the cyanide solution used to leach gold and methods for it's recovery are well known. In fact dissolved cobalt has a considerable nuisance value to gold mines operating uranium plants because it poisons the ion exchange resin used in that operation.

Cobalt, whether in the form of refined sulphate, crude oxide or hydroxide could be worked at established plants for the production of cobalt metal, oxides, salts or soaps. This is already being carried out by manufacturers using imported crude or semi-refined material.

5.6. Local consumption

It is somewhat difficult to obtain accurate figures on the consumption of cobalt in South Africa as much is imported in various finished forms such as tungsten carbide tipped tools, magnets, dental alloys and frits for enamelling. These are declared as such in the Customs statistics, with no mention of the contained cobalt. The following tables, abstracted from the annual trade statistics of South Africa (Department of Customs and Excise) record the following imports and exports of cobalt.

Table 15

Cobalt oxides and hydroxides (item 28.24)[30]

YEAR	IMPORTS		EXPORTS	
	Quantity(kg)	Value (R current)	Quantity(kg)	Value(R current)
1968	14 336	35 235	x	x
1969	15 244	37 714	x	x
1970	12 756	38 874	4 200	2 076
1971	13 000	38 821	8 500	3 252
1972	14 700	51 998	x	x
1973	18 300	67 430	x	x
1974	15 200	73 426	x	440
1975	15 900	92 360	x	599
1976	12 100	82 946	x	118 320
1977	x	20 302	x	9 677
1978	x	264 141	x	235 836
1979	x	293 392	x	60 829
1980	11 700	367 323	x	123 361
1981	14 700	413 206	x	135 693
1982	8 700	201 542	x	92 000

x indicates figures not recorded for public use

Table 16

Cobalt metal, wrought and unwrought (item 81.04.20)[30]

YEAR	IMPORTS		EXPORTS	
	Quantity(kg)	Value (R current)	Quantity(kg)	Value(R current)
1968-1974	+	+	+	+
1975	112 500	1 144 139	x	x
1976	66 900	793 590	x	171 608
1977	90 100	1 229 887	x	699 712
1978	139 100	1 932 199	x	673 856
1979	64 600	4 137 372	x	326 669
1980	99 900	4 558 825	x	561 287
1981	82 600	3 344 966	x	1 567 448
1982	77 380	3 152 562	x	1 286 098

+ statistic not recorded pre-1975

x indicates figure. not recorded for public use

As mentioned, the Customs figures probably do not reflect all of the cobalt imported into South Africa.

Enquiries to end users in various forms elicited the following information:-[14, 41]

(i) dental and medical alloys: consume about 500 kilograms annually

(ii) cobalt sulphate: a company that has manufactured cobalt sulphate from locally produced oxide when available quotes an estimated demand of 16 tons per month and a plant capacity to match this demand. Cobalt sulphate is used locally for glass clarification, cattle feeds, anodizing aluminium although the greatest use is in paint driers.

(iii) vitreous enamelling: three companies that produce the desired frits report their total demand for cobalt around 18 tons of cobalt oxide annually. Allowing for other suppliers of this type of material the total annual consumption of cobalt oxide is probably about 28 tons.

(iv) sintered carbides: the percentage of cobalt used as the matrix of tungsten carbide inserts varies from about 2 to 18 per cent of the finished article, depending on the application. For applications under highly abrasive, low stress conditions (jackhammer drill bits) the cobalt content is 7 to 8 per cent. For bits used for heavy drills the cobalt content is 12 to 13 per cent. The total annual demand is about 65 tons of which 30 per cent is obtained by recovery of worn or scrapped inserts. For this purpose the cobalt is obtained as 'cathode metal' from Zambia, but considering that the metal still has to be refined and reduced as a powder of the desired grain size it could possibly be made from locally produced cobalt oxide.

(v) permanent magnets and magnetic steels: one of the major uses as regards size and number of magnets is in the magnetic separators used in heavy media separation plants - however it appears these magnets are a ceramic type based on strontium ferrites and not cobalt. A very large number of permanent magnets based on cobalt alloys is used in the telecommunications industry. Three years ago one manufacturer embarked on a project requiring 600 000 Alnico based permanent magnets, and although they were very small, all had to be imported. The manufacturer

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Based on the information obtained it is estimated that the annual consumption of cobalt in all forms in South Africa is around 88 tons of cobalt metal, or its equivalent in cobalt chemicals.

This total quantity of cobalt is modest when compared with the total world consumption but it is still vital to the South African economy. More important is that this quantity is well within the amount of cobalt compound that is actually being produced for the export market as a by-product of platinum mining. The total value of cobalt required, at the average Zaire producer price for 1982 of $12.50 per pound amounted to $2,48 million. Considerable savings could have been obtained if the cobalt was purchased on the free market at an average 1982 price of $7.00 per pound but local consumers experience considerable difficulty in obtaining even small amounts of cobalt from other overseas sources.

The consumption trend is impossible to establish from published statistics and a model of imports data would be meaningless in this case since large quantities of cobalt appear to be exported annually at considerable value. A rough prediction of local demand can be obtained by utilizing the most probable average annual rest-of-world demand growth rate of 3,1% as determined by Sibley in Mineral Facts and Problems.[39]

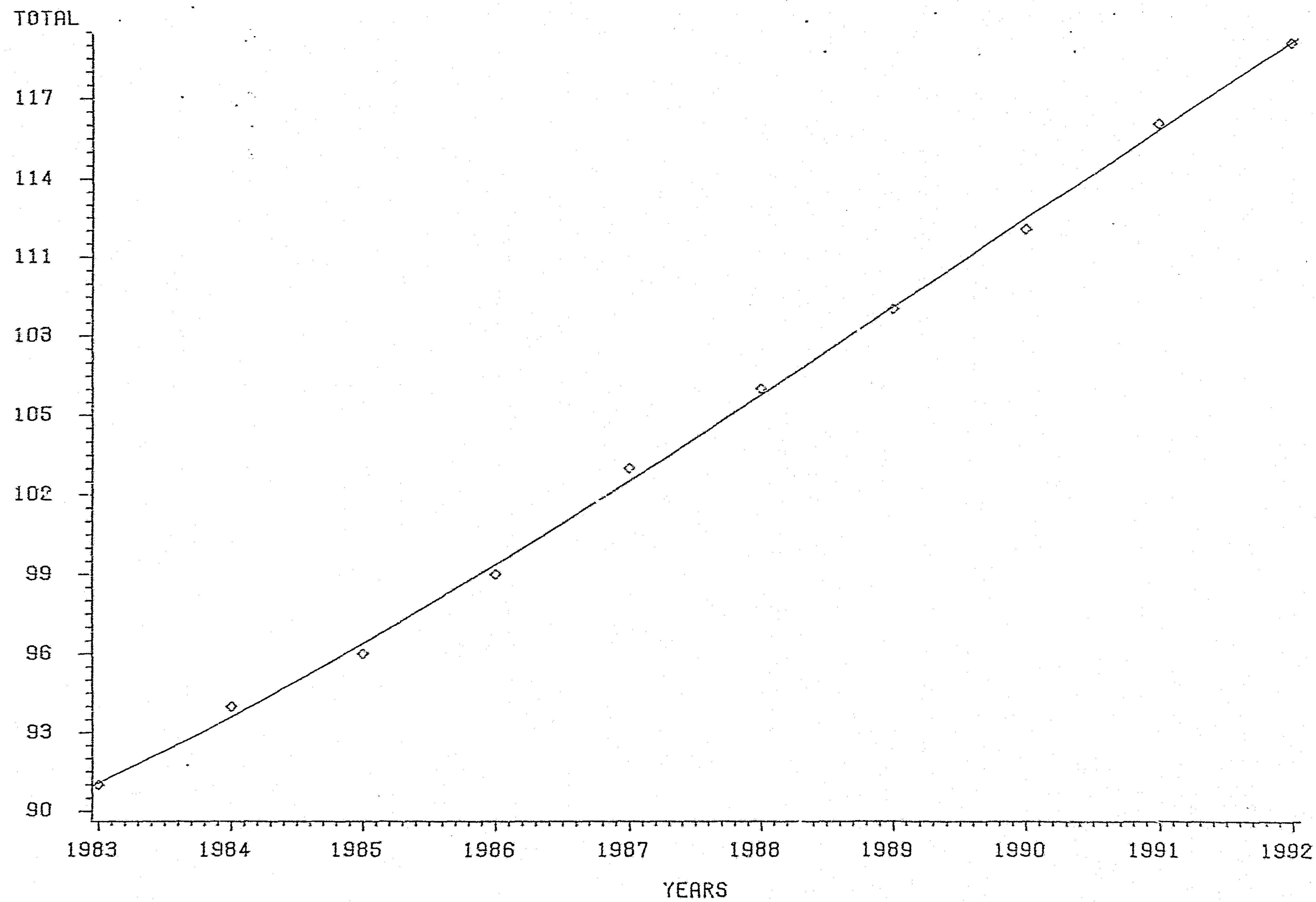
The prediction of South African consumption for the next decade would thus be:

YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
DEMAND (tons Co)	91	94	96	99	103	106	109	112	116	119

This trend is depicted graphically on the following page. Following the long period of industrial stagnation in the Western World, some growth is anticipated in the near future. Total non-communist consumption should reach a demand of 27 000 tons per annum by 1990, which is well inside the the existing capacity of established producers and thus no shortage of supply is likely to occur. But although the potential output of cobalt from South Africa will never be very large by world standards, it is highly desirable that local reserves be developed to meet the modest local requirements of this essential metal.

6 MAJOR MARKET PRODUCTS

Cobalt is usually marketed in the form of refined metal or compounds, such as the oxide and salts, but sometimes also as ore.



SOUTH AFRICAN CONSUMPTION
OF COBALT IN TONS

6.1. Ores

As most of the ore mining companies have long term contracts for both metal extraction and refining with the comparatively few plants that are available, cobalt ores are not normally dealt with on the open market.

6.2. Metallic cobalt

This accounts for about 75 per cent of the market in refined cobaltic products. It usually assays 98 to 99 per cent cobalt and is sold mainly as rondels which are small slugs or cylinders between 1o and 12 millimetres in both diameter and length. In addition, but to a lesser extent, the metal is marketed in granules of no fixed mesh size, and as shot, cathodes, fines or powder. The rondels and granules are exported in small drums of 250 kilograms net mass. Cobalt fines, a mixture of coarse and fine powder, is sold in 300 kilograms containers. Powder of sated mesh size is offered in containers of up to 45 kilograms net mass.

6.3. Cobalt oxides

These are marketed as the black variety and as the grey or ceramic grade oxide. The impurities present depend upon the method of manufacture but are usually under 3 per cent - some nickel, with small amounts of copper and manganese, being tolerated in vitreous enamelling, pottery, glass and paper manufacture. The ceramic grade oxide which is normally quoted as containing 70 to 71 per cent or 72,5 to 73,5 per cent cobalt is employed in the pottery industry as a glaze stain and decolouriser. Both of these oxides are marketed in 225 kilogram barrels, 160 kilogram containers or in small quantities from 2 to 10 kilograms in metal containers.

6.4. Cobalt salts

These are used mainly as driers in paint and varnish trades and hence are marketed in the form of organic compounds such as napthenate, acetate, resinate and oleate. Inorganic salts such as the carbonate, chloride, hydrate, oxide, phosphate and sulphate are also commercially available. All these compounds are packed for marketing in steel or fibre drums, their prices being on quotation for gross mass rather than on cobalt metal.

The specification of a typical cobalt sulphate compound for cattle feed is given for information in Appendix Five. To what extent it would be necessary for a producer in South Africa to match the strict specifications in all cases is not known. Certainly the requirements for cobalt metal powder must be met (for rockdrill tips) but Boart Hardmetals in Springs have been producing cobalt powder themselves to match their very exacting standards for a number of years.

7 INDUSTRY, AVAILABILITY AND PRICES

7.1. Industry

Zaire, the primary producer of cobalt in the world, contributed 40 per cent of total world metal production in 1982 but historically has provided between 55 and 60 per cent annually. One company, the Government owned Générale des Carriéres et des Mines (Gécamines) mines most copper and cobalt in Zaire. To assist in mining, refining and maintenance, Gécamines maintains a technical co-operation agreement with the Belgian Company, Sté. Générale des Minerais (SGM), a subsidary of Sté. Générale de Belgique. Société Zairoise de Commercialisation (SOZACOM) is the official marketing agency for Zairian cobalt. A U.S. company, African Metals Corporation of New York, holds exclusive rights for sale of Zairian and Belgian cobalt in the United States. This relationship may change if, as anticipated, SOZACOM takes over more of the marketing functions now handled by SGM.

Belgium processes to various forms and compounds about half of the refined cobalt exported by Zaire and, in turn, exports about half of its production to thr United States. Nearly all cobalt from Morocco is refined in France. In addition, about 450 tons per year of cobalt is refined in the United States, principally from imported matte produced in Botswana and New Caledonia. Cobalt recovered at the Panda-Likasi complex as matte is refined in Belgium by Metallurgie Hoboken Overpelt.

Cobalt is also a by-product of Zambia's copper industry. There were two major state owned mining companies: Nchanga Consolidates Copper Mines Ltd. (NCCM) and Roan Consolidates Mines Ltd. (RCM), which merged in the first half of 1982 to form Zambia Consolidated Copper Mines Ltd. (ZCCM), effective from April 1st. 1981.

Mining for cobalt, copper and nickel was begun in Botswana at the Selebi-Pikwe deposit in 1973. The ore is smelted there by Bamangwato Concessions Ltd., a subsidary of Botswana RST Ltd., and the matte shipped to the United States for refining.

In Canada, INCO Ltd. produces commercial grade cobalt oxide in Ontario and Manitoba. Falconbridge Nickel Mines Ltd. exports its cobalt bearing matte to its refining operation in Norway. Currently all of the concentrate produced in the Philippines is refined in Japan. In 1978, Marinduque Mining and Industrial Corp. and Sumitomo Metal Mining Corp. reached an agreement that half of the cobalt produced in Japan would be marketed by Marinducue.

Cobalt concentrate produced in Australia by Freeport Queensland Nickel, Inc. and Metals Exploration Queensland Pty., is shipped to the Nippon Mining refinery in Japan.

All other major producers belong to centrally planned economies and overall the communist market is a nett importer of cobalt.

7.2. Availability

Strictly on the basis of global resources, it appears that there is no long-term availability problem if the rich cobalt resources, especially the ocean sources can be converted to economically feasible reserves. However, economics and technology are not the only considerations in such conversions.

Foreign mineral reliance is not in itself undesirable if the mineral sources are diverse, noninteracting, secure and elastic to demand. Unfortunately these criteria do not describe the cobalt situation. On the other hand, international cartel formation by cobalt producing nations is not likely because the economic driving force for cartel formation may not be strong enough.

Perhaps because of the relatively small market for cobalt, and because it occurs naturally with other metals like copper and nickel, cobalt has by-product status at most producing mines. This general status, in conjunction with current and projected depressed prices for copper and nickel, results in a relatively inelastic situation for cobalt production. This is the most severe problem governing cobalt supply presently since a sudden drastic lowering of production by one major source cannot be easily compensated for by expansions at other sources - unless there are concurrent increasing needs for the associated metals. This inelasticity in supply governs even when consumers are willing to pay much higher prices for cobalt.

A mineral availability and pricing problem would be expected to spur efforts to circumvent the problem through elemental or systems substitution. In applications involving other stragetic elements it is known with confidence that the need in the alloys is technically justified. However, recent research in the U.S. has shown that such confidence may not be justified for cobalt in superalloys-the major end use.

7.3. Prices

Cobalt in various forms is quoted by Metal Bulletin and Metals Week but the most realistic import price is the average annual producer price based on the weighted average for the year determined by the African Metals Corporation price list (although South African enquiries may be for the European free market price for spot sales).

There does not appear to be any cartel in the trading of cobalt but the simultaneous increases in price worldwide historically does suggest some degree of collusion between the major producers. The production of primary cobalt is to some degree dominated by Hoboken SA of Belgium who are the main refiners of material from Zaire but cobalt appears to be freely available to smaller processors and the industry is sufficiently diversified to be classified a 'free market'. In fact, until the sudden sharp rise in prices in 1978 related to the political disturbances in Zaire, the price of cobalt in real terms appears to have remained constant or decreased.

7.3.1. Price forecast

The time-price relationship for cobalt in U.S. Ø per lb for the three major market products is contained in Table 17 in current terms.

Table 17

African Metals Corp. contract price (U.S.Ø/lb.)[33]

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Cobalt granules (99%)	2.20	2.45	3.00	3.46	3.98	4.44	5.58	11.53	24.58	25.00	15.85	12.90
Cobalt oxide (76%)	2.20	2.41	2.88	3.48	4.09	4.42	5.55	10.17	20.71	21.11	13.38	10.89
Cobalt 'S'powder (99,9%)	2.35	2.55	2.96	3.73	4.00	4.33	6.02	11.20	x	x	x	x

x price no longer quoted publicly

Best fit curves for price determination in current money terms are:

Cobalt granules (99%) : $PRICE = 1{,}550e^{0{,}225YR}$ $r = 0{,}912$

Cobalt oxide (76%) : $PRICE = 1{,}694e^{0{,}203YR}$ $r = 0{,}912$

Cobalt 'S' powder(99,9%): $PRICE = 1{,}693e^{0{,}196YR}$ $r = 0{,}942$

Curves considered where linear, expontential, logarithmic and power.

However, if the years 1979 and 1980 are ignored when the market reaction to the threat of reduced supplies from Zaire became apparent in the prices, the following best fit curves are obtained:

Cobalt granules (99%) : $PRICE = -0{,}836 + 1{,}250*YR$ $r = 0{,}924$

Cobalt oxide (76%) : $PRICE = -0{,}092 + 1{,}024*YR$ $r = 0{,}933$

Cobalt 'S' powder(99,9%): $PRICE = 0{,}160 + 0{,}996*YR$ $r = 0{,}843$

with YR an integer with base of 1971 = 1, and r the correlation coefficient.

Although the statistical correlation is only improved slightly it is felt that in the long term the realistic price model is linear since expontential increases in pric(may only result in reduced demand in non-strategic areas.

Prices for the next decade would thus be estimated as (U.S.$/lb):

	1983	1984	1985	1986	1987	1988	1989	1990	1991
Cobalt granules (99%)	:15.41	16.66	17.91	19.16	20.41	21.66	22.91	24.16	25.41
Cobalt oxide (76%)	:13.21	14.24	15.26	16.28	17.31	18.33	19.36	20.38	21.40
Cobalt'S' powder(99,9%)	:13.11	14.11	15.10	16.10	17.09	18.09	19.09	20.08	21.08

These trends are depicted graphically on the following page.

Recent prices quoted for the above cobalt products (Metals Week) are:

Cobalt granules (99%) : 12.50 U.S. $ per lb

Cobalt oxide (76%) : 9.81 U.S. $ per lb

Cobalt 'S' powder (99,9%): classified

The prices of cobalt chemicals are given in the Chemical Marketing Reporter and in general these appear to have followed the price fluctuations of cobalt metal. The effect of the increase in the basic price of cobalt metal is evident particularly in those compounds containing a relatively high percentage of cobalt and as stocks from cobalt obtained at earlier, lower prices are consumed.

8 COBALT IN SOUTH AFRICA

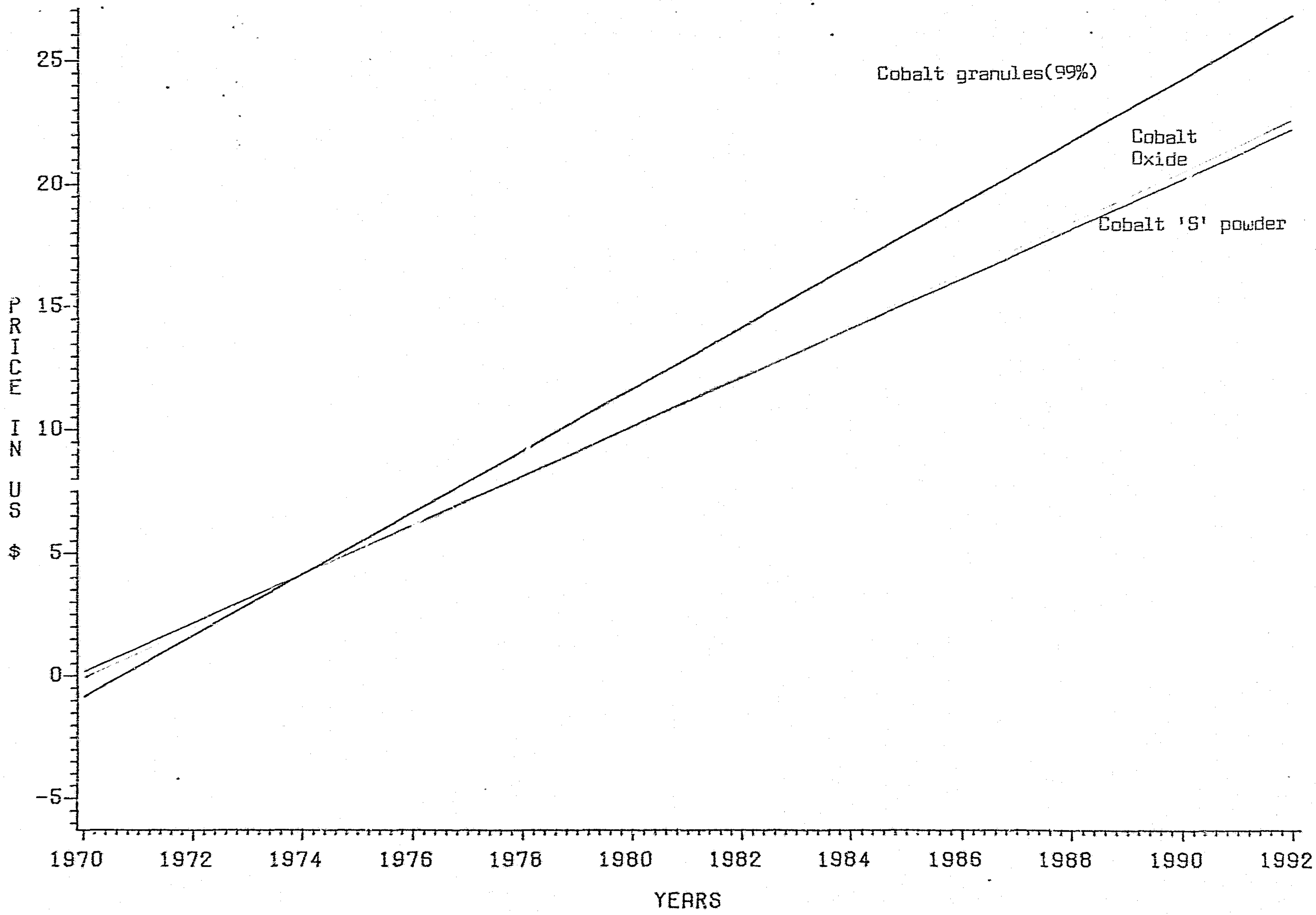
8.1. Known deposits

After diamonds, gold and coal, cobalt was one of the first metals to be mined after the settlement of Whites in the Transvaal yet South Africa never became an important producer of this metal. Hammerbeck, in Mineral Resources of South Africa, records the occurrences of cobalt in South Africa:

(i) Kruisrivier Area, Groblersdal District

In 1886, 143 tons of handpicked ore averaging 15 per cent cobalt and 68 g/t gold were exported (value R50 224). In 1929 the workings were re-opened and 2,7 tons of ore averaging 17 per cent cobalt were produced and 1 ton of sorted 20 per cent ore (value R200) was exported. In 1932 the deposits were again prospected and the average grade of the ore exposed in the old workings was found to be about 2 per cent cobalt. However, an intensive survey carried out in 1940 failed to reveal any further deposits of ore.

The deposits on the adjoining farms Kruisrivier 74 JS, Roodewal 193 JS, Mineral Range 190 JS, Winterhoek 189 JS, Laagersdrift 76 JS (D14) and Kameeldoorn 71 JS are situated in highly dissected country formed by the drainage system of the Kruis and Selons Rivers about 48 kilometres due north of Middelburg.



AFRICAN METALS CORPORATION
CONTRACT PRICE IN U.S. $ PER POUND

The area includes a portion of a small norite protuberance on the eastern rim of the Bushveld Igneous Complex that is characterised by the presence of several narrow xenolithic masses of Pretoria quartzite and shale. Elsewhere, as on Laagersdrift, the norite itself exhibits evidence of mineralisation. Samples here were found to contain 1,8 to 5,7 per cent cobalt. On Roodewal the ore is found in quartzite at least 6m above the contact with the underlying norite. Samples produced contain up to 1,13 per cent cobalt. On Loskop Suid 53 JS in the area adjoining Kameeldorn 71 JS and De Wagendrift 79 JS there are anorthositic lenses in the norite carrying cobaltiferous arsenopyrite. Specimens of smaltite-bearing anorthosite have been found on Kameeldoorn 71 JS (D14). The nature of the deposit is unknown but appears to be a secondary enrichment along the outcrops of the Merensky Reef.

The ore at Kruisrivier occurs in thin, well defined veins lying parallel to the plane of contact between quartzite and norite and to the bedding planes of the quartzite and as a dissemination in the quartzite between the veins and the norite. Stringers of safflorite tend to follow the contacts between dense altered feldspathic material and quartzite layers. Niccolite is occasionally an accessory constituent of some of the ores and at a few places chalcopyrite is the dominant ore mineral. The average cobalt grade is 0,72 per cent.

The available evidence suggests that the contact lodes containing cobalt and gold are unlikely to persist to any appreciable depth. The 1940 investigations proved that they have no appreciable lateral extent either. The nature of the deposits shown that hydrothermal solutions originating in the norite were responsible for the mineralisation.

(ii) Balmoral Area

On the farm Eenzaamheid 534 JR (D13), 3 kilometres south of Balmoral, workable lode deposits of cobalt were discovered at the beginning of the century - described as mineralised dykes in highly altered quartzite and slate belonging to the upper Pretoria beds. The dykes are connected with a large neighbouring intrusion of gabbro. The cobalt minerals are safflorite and cobaltite with erythrite at the outcrop. In many respects the lode matter is similar to that of the Kruisrivier deposits.

Old records report considerable exploration work on this occurrence including a prospect shaft. Assays range from trace to 7,3 per cent cobalt but appear to have been highly erratic and over narrow widths. More recently the exploration division of one of the large mining companies did considerable surface trenching and sank boreholes in 1978 on the property. The results are reported as 'not very encouraging' even though

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From the latest evidence is does not appear as if either the Kruisrivier or Balmoral deposit is likelt to prove a viable source of cobalt, even in small quantities.

(iii) Bushveld Complex

Cobalt has been recorded in the following deposits which are associated with the Bushveld Igneous Complex in the Central Transvaal:
On the farm Witfontein 430 KR (C13)about 13 kilometres northwest of Warmbad a mineralised brecciated zone in granite and felsite carrying cassiterite, pyrite and arsenopyrite was found to contain 1,5 per cent cobalt and 3,6 g/t of gold.
On the farm Waaikraal 396 JQ (D12), Rustenburg District, the presence of cobalt in the pyroxenite gold ore has been recorded.
On the farm Hartbeesfontein 511 KQ (C12) in the Warmbad District, about 3 kilometres southeast of the Rooiberg Tin Mine, there is a fissure lode containing scheelite, malachite, pyrite, arsenopyrite and small quantities of cobaltite. The associated gangue minerals are coarse red feldspar and tourmaline.
On the farm Roodepoort 467 KR (C13) in the Warmbad District small, lenticular mineralised bodies in Bushveld granite were exposed in an old prospecting pit. These were found to contain nickelferous danaite - a variety of arsenopyrite containing 3 to 9 per cent cobalt. The gangue consists of albite and quartz. A concentrate of the ores was found to contain 4,4 per cent cobalt. A thorough investigation by the Geological Survey proved that the bodies have no appreciable lateral or vertical extent and they are of no economic importance. The available evidence showed that mesothermal solutions were responsible for the mineralisation.
On the farm Hartbeestfontein 93 JS (D14), Bronkhorstspruit District, granitic veins cut the Rooiberg felsite and sediments. The granite is said to contain arsenopyrite, molybdenite and erythrite. The occurrence has yet to be properly investigated.
Up to 0,008 per cent cobalt has been determined in kimberlites from the Premier Mine.

(iv)The Merensky Platinum Reef

Cobalt occurs as a very minor element in this reef of the Bushveld Igneous Complex. The cobalt probably occurs in solid solution in copper, nickel and iron sulphides that make up an appreciable portion of the reef material. Cobalt also occurs as a trace element in the chromite ore seams closely associated with the Merensky reef. Concentrations in the Merensky Reef are not known but believed to amount to about 25 to 50 kilograms per ton of nickel. Thus although the total amount of cobalt present is probably very large, it is only recoverable as a minor by-product from the extraction of such nickel as is obtained as a co-product of the production of platinum group metals.

(v) Other possible local sources

So far as can be ascertained cobalt is not found in any of the copper ores at present being mined in South Africa, or if present would only report in very small amounts in the anode sludge during electrolytic refining.

As mentioned in section 5 a surprising source of cobalt, albeit small, is the gold reefs of the Witwatersrand and Orange Free State Mines. Cobalt usually occurs as a trace element in variable amounts but cobaltite occurs as discrete crystals in the Black Reef of Randfontein Estates gold mine. Coetzee in an MSc. thesis for the University of the Witwatersrand reports that from 0,06 to 0,1 per cent cobalt is present in the gold reefs of the Witwatersrand.

The presence of cobalt has been observed in both effluents of mining wastes from mines in the Orange Free State and in pelitic sediments in the evaporation dams in the area, as well as in effluents from the platinum mines and refineries - but no attempt has been made to recover this cobalt. In general the quantities are very low, of the order of 7 to 200 parts per million, but may reach much higher values in some effluent streams. It is possible to recover this cobalt, along with other heavy metals which are also present, from solutions as low as this by modern techniques. It is conceivable that selected effluent streams from the gold mines might [illegible]ve to be a commercial source of cobalt in sufficient quantities to [illegible]fy the somewhat restricted local demand.

8.2. Security of supply

There is no absolute shortage of reserves of cobalt. If there is a problem it lies in the import dependency of an industrialized nation coupled with the concentration of reserves in countries that have common hostile political attitudes or face a common political or politico - economic problem. This issue is indeed critical in the case of cobalt. The concentration of potential supply in Zambia and Zaire is compounded by the fact that there are presently no significant cobalt deposits classified as reserves in the major industrialized countries. Even allowing for future exploitation of U.S. cobalt resources, the country's dependence on African supply will still remain severe.

For a stragetic supply crisis to emerge as a realistic scenario, however, limited reserves with a high degree of reserve concentration must coincide with a low potential for substitution of the material in question. Chase Econometric's research activities suggest there is substantial potential for substitution of cobalt in many applications and more so than is commonly supposed. A quantitive analysis of cobalt consumption by intermediate use sectors indicated a relatively high price elasticity[1] of demand for cobalt in many applications (Cobalt: a critical material?). This is arrived at by considering that substitution can occur at several levels as well as over different time frames. One material may directly replace another; alternatively less of a given material may be used in an existing application or the function performed by the material may itself be eliminated or substituted.

In the case of cobalt, the severe degree of concentration of land based reserves is consequently in large part offset by a relatively high potential for substitution. Policy and strategy considerations of the major producers has proved historically that dislocations brought about by sudden shortages have been more temporary and less severe than were commonly envisaged at the time.

Thus, although the potential for the disruption of supplies to South Africa is fairly high considering the origin of the majority of raw cobalt goods, the effect is ameliorated by two facts:

(i) the commodities are actually marketed in Europe through SOZACOM

(ii) the extremely depressed market presently existing should favour consumers for at least the mid-term future.

9 SUBSTITUTES, RECYCLING AND TECHNICAL POSSIBILITIES

9.1. Substitution

Nickel can be substituted for cobalt but only by a sacrifice of important properties / characteristics of end products made with cobalt. The current trend is toward greater use of alloys with less cobalt rather than the elimination of cobalt altogether in the alloy. This is true in the fields of both hard-facing and wear-resistant applications, and superalloys. In aircraft turbine applications, Alloy 713C (no cobalt) might replace Waspalloy with 13 per cent cobalt.

Substitutes for cobalt as a catalyst or as a drier in paints are usually not effective. In drier applications, manganese and lead each can act either as a complement or substitute while in catalytic applications, molybdenum and aluminium are complements while nickel and tungsten are substitutes. However, the use of nickel in petroleum catalysts reduces octane and requires higher pressures to be effective.

The properties that cobalt imparts to permanent magnets exceed those that can be contributed by other elements. Any substitution for cobalt results in loss of weight advantage or other physical properties. Nevertheless, ceramic magnets, which are made from barium and strontium ferrite are potential competitors. Since ferrite magnets are relatively inexpensive, they are used in a number of automotive applications. In comparison with Alnico magnets, a net cobalt saving of 30 per cent can be achieved by the use of cobalt-rare earth magnets. In magnetic usage, demand is very sensitive to price thus rendering replacement more likely.

No satisfactory substitutes have been developed for the use of cobalt as a binder for carbides. However, with further experimentation, molybdenum based tool steels, which can contain up to 12 per cent cobalt, may achieve the performance characteristics of cemented carbides. Recent advances in powder metallurgy have afforded an opportunity to attain competitive performance levels. With research, it may also be found that alloys with a base of nickel, vanadium, chromium or tungsten can be developed that have properties equal or superior to those of cobalt containing alloys.

Especially in South Africa, cobalt napthanate is used as a top drier in paint. 50 per cent of the cobalt may be replaced by zirconium or cerium but the remainder of the cobalt content is vital. There is no substitute for cobalt hexoate or cobalt octoate as accelerators for unsaturated polyester resin finishes. There also appears to be no substitute whatsoever for cobalt as an additive in cattle feed.

9.2. Recycling or secondary sources

Dissipation in the diverse end uses for cobalt prevents significant recycling. Foreign processors recover significant quantities of cobalt contained in mixed scrap but domestic interest was hightened around 1979 when quantum leaps in cobalt prices were experienced. There are only a few significant sources of cobalt bearing scrap - one of the most important being waste material discarded in forming and fabricating cobalt-bearing superalloys. Moreover, high temperature alloy components of jet engines are replaced periodically, providing a major source for recycled material.

A significant new source of secondary material is spent petroleum catalysts, those used in desulphurisation of crude oil. Other chemical wastes are becoming increasingly important and at least one American Company has produced a crude cobalt oxide from this source.

Several American companies are also using a process patented by the U.S. Bureau of Mines to recover the cobalt binder from cemented carbide scrap. In the process molten zinc is used to dissolve the cobalt. The molten zinc is then recovered by distallation and refractory cobalt and the carbides remain in a mass that can be recycled.

Other cobalt bearing products are largely dissipated. Superalloy scrap is mostly reprocessed directly to make new alloys rather than refined for it's individual metallic content. Grinding swarf generated in the production of Alnico magnets is another source of material.

Besides secondary material, large percentages of cobalt metal in low grade cobalt ore are retained in slag, which is frequently stockpiled - Zambia and Zaire have slag dumps up to 1 per cent cobalt still not utilized. If prices rise again to 1979 levels when it became economical to transport all Zambian cobalt by air to foreign markets, these countries may well invest in the necessary equipment for slag treatment.

In South Africa a large proportion of the cobalt is used in tungsten carbide tips for rock drills. Due to the relatively concentrated mining industry and the system of renting rock drill borers and similar equipment to the end users there is considerable recovery of cobalt from this source (about 30 per cent of requirements).

One company in South Africa has a division that specializes in the dismantling of aircraft engines and similar equipment for sale as scrap. Such equipment is carefully handled and the various components sorted into scrap according to their metal content. Most of the cobalt based alloys are thus recovered, but most is exported, being returned to the manufacturers. If necessary the cobalt could be recovered locally but in general a better price is obtained for the scrap alloy rather than it's individual constituents.

9.3. Technical possibilities

The technology exists to improve cobalt recovery in smelters by cleaning molten converter slag and if adopted universally might increase the world supply of cobalt significantly. In superalloy research, industry has made significant strides in directionally solidified alloys and single crystals for use in jet engine component parts but has not emphasised the development of new alloys. The purpose of this research is the attainment of higher operating temperatures in jet engines, considered important because engine efficiency is increased at higher temperatures while pollution is decreased. Superalloy producers are now putting more emphasis on improving techniques of fabrication such as hot forging, extrusion, hot isostatic pressing and precision metalwork.

Perhaps the most significant cobalt research in progress is in the development of techniques for mining and processing cobalt-bearing manganese nodules from the ocean floor. Many patents have been issued on all phases of the technology.

10 CONCLUSIONS AND RECOMMENDATIONS

Although the potential output of cobalt from South Africa will never be very large by world standards it is highly desirable that this potential be developed to produce cobalt products for local consumption and not utilized as at present to supply about 2 per cent of the United States consumption.

Although world reserves of cobalt and theoretical mine capacity appear adequate for the foreseeable future, the threat of political disturbances in two of the main producing countries (Zambia and Zaire) remains a distinct possibility which would result in an immediate shortage of the metal and consequently a sharp increase in price.

All cobalt used in South Africa is at present imported and consumers such as Boart Hardmetals have had to tolerate using a relatively impure metal or oxide requiring appreciable purification before reduction to the metal powder.

Apart from the platinum mines there do not appear to be any sources of cobalt in South Africa likely to prove commercially viable to supply the present demand of around 90 tons of cobalt metal or it's equivalent annually.

The establishment or extension of national stockpiles have been considered by France, Japan, Germany and the United Kingdom in the last year and it seems logical that South Africa should consider this option for security of supply and take advantage of the relatively low prices likely to prevail in 1984 to acquire a modest tonnage of cobalt.

Cobalt, both as a metal and as a chemical, is presently being derived and produced from thelocal raw material when available from the platinum producers, thus active encouragement should be given to indigenous processors or consumers to enable them to obtain fixed period, internal supply contracts.

D: ALUMINIUM

INTRODUCTION

The name ALUMINIUM (Aℓ) is derived from the Latin word 'alumen' and from 'alumine', a term suggested by L.B.G. Morveau during the eighteenth century for the earthy base of 'alum', a naturally occurring double sulphate of potassium and aluminium long used in dyeing, tanning and papermaking. The word 'alumine' subsequently became anglicised to 'alumina'. A.L. Lavoisier in 1782 suggested that alumina was probably the oxide of a metal with an affinity for oxygen so strong that neither carbon nor any of the reducing agents then known was able to overcome it. Sir Humphry Davy, who had unsuccessfully attempted to isolate the metal by electrolysis, suggested that the name 'alumium' should be applied to it, but later it was changed to 'aluminium'.

H.C.Oersted may have been the first to isolate an impure form of elementary aluminium in 1825 by heating aluminium chloride with potassium amalgam. A purer form of metal was obtained two years later by Friedrich Wöhler who treated aluminium chloride with metallic potassium. Wöhler's method gave the metal only in a finely divided form. However, by 1845 he had succeeded in isolating a sufficient quantity to permit determination of the metal's melting point and some other properties. Nine years later Henri Sainte-Claire Delville obtained the metal by reducing aluminium chloride with sodium and using sodium aluminium chloride as flux; in this process Delville was able to obtain aluminium in the form of small ingots with a purity of 97 per cent.

With financial backing from the government of Napoleon III, Delville established a large scale experimental plant for the production of aluminium at the Favel Chemical Works near Paris. Here he was able to produce various objects made from the metal and these were shown at the Paris Exhibition of 1855. Commercial production followed a year later.

Commercial production of aluminium grew slowly during the latter half of the nineteenth century but output remained small and the product expensive. The development of the Castner process for the production of metallic sodium led to a corresponding drop in the cost of producing aluminium by chemical means. Nonetheless, investigations continued into the possibility of reducing costs even further.

During the first half of the nineteenth century abortive efforts had been made to produce aluminium by the electrolysis of fused alumina and aluminium salts. However, in 1854 both Bunsen and Delville did succeed in producing the metal by the electrolysis of fused sodium aluminium chloride. In the following decades electrolytic methods began to hold more industrial promise with the introduction of cheap dynamo-generated power.

The major technical innovation that was needed to launch the modern aluminium industry finally came in 1886. Almost simultaneously the American C.M. Hall and the Frenchman P.L.T. Héroult discovered that fused cryolite ($A\ell F_3 . 3NaF$) would act as a solvent for alumina which could then be decomposed electrolytically. Named the Hall-Héroult process after its' originators, this technique rapidly became the exclusive industrial method for the mass production of aluminium.

Prior to 1940, virtually all of the world's aluminium was produced in the industrial countries of Europe and N. America and in Japan. Today these areas still predominate, but the pattern is changing. Previously, as the product of an advanced technology, long protected by patents, aluminium was destined to be tightly held by the handful of firms who had access to the technology. These firms were often national monopolies and were not under competitive pressure to seek lowest-cost production sites on an international basis. They preferred to operate in the familiar home institutional environment near their markets, protected by tariffs and benefitting an industrial environment.

Perhaps what has occassioned most speculation about the future of the world aluminium industry is the concern that there will be insufficient low-cost energy available in developed countries in contrast with the possibilities in under- and semi-developped countries. Power cost is a major locational factor in the aluminium industry as the universally employed basic Bayer process for converting bauxite to alumina to aluminium consumes vast amounts of energy.

Bauxite is plentiful but the principal deposits are located in less developed countries far from the main aluminium producing and consuming centres. Because South Africa imports it's raw material for aluminium production, political and economic actions in other countries can effect the availability and costs of inputs for domestic alumina and aluminium plants.

1 PROPERTIES OF ALUMINIUM

The versatile use of aluminium in many applications is based upon an unique combination of desirable physical and chemical properties. The element has a low atomic number (13) and possesses a specific gravity of 2,7 - about one third that of steel. It's great ductility permits it to be rolled to very thin guages or extruded into many different shapes. Aluminium foil is a widely used product which exploits this property of the metal to the full.

As aluminium possesses a considerably lower melting point than steel, the production of castings and the handling of molten metal are relatively uncomplicated. The pure metal has a melting point of 659°C although that of some aluminium alloys may be as low as 550°C.

The thermal conductivity of aluminium is less than that of copper but greater than that of cast iron, wrought iron or steel and it is suitable for the manufacture of cooking utensils. Aluminium is a good electrical conductor. A copper bar will have the same resistance to an electric current as an aluminium bar of 1,6 times it's cross-sectional area, but the weight of the aluminium conductor will only be half that of the copper. Round bars of aluminium also offer an advantage over copper conductors in showing less 'corona loss'.

Although aluminium is a chemically reactive element (valency 3, rarely 1) and a strong reducing agent, it is far more resistant to corrosion than most other industrial metals. A freshly exposed surface of aluminium metal, either solid or molten, immediately oxidises upon exposure to the air or other oxidising agent and the thin film of aluminium oxide so formed stops the process of corrosion. The natural oxide layer can be thickened by anodising or anodic oxidation. Other properties include high reflectivity, high scrap and re-use value and weldability.

Both the metal and it's salts are non-toxic and can be ingested without harm. Through surface treatment processes of various kinds aluminium can be used to give a wide variety of decorative effects and in this respect it is superior to other metals.

The properties of super-purity aluminium (Aℓ 99,98+ per cent), high purity aluminium (Aℓ 99,80 to 99,98 per cent) and pure aluminium (Aℓ 99,00 to 99,80 per cent) can, for specific purposes, be improved or modified by alloying with other elements.

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2 APPLICATIONS OF ALUMINIUM

On an element basis, about 10 per cent of the aluminium consumed is used as bauxite or alumina in non-metal applications. Although a minor market sector for aluminium use, they are, however, vital to industry.

2.1. BAUXITE [42]

About 90 per cent of the total world production of bauxite is consumed in the manufacture of alumina which, in turn, is principally used in the production of aluminium metal. Both bauxite and alumina also have important non-metallurgical uses for which they are to some extent interchangeable. Alumina, being more expensive, is preferred only where high purity is specified.

The design of an alumina refinery is specific to a certain type of bauxite, whether gibbsitic, boehmitic or a mixture of the two. Most of the bauxite which is utilized directly, rather than converted first to alumina, is simply calcined. Fused calcined bauxite can be used for abrasives where the purer but more costly calcined alumina is not essential. Such abrasives are used in grinding wheels and polishing powders for which fused bauxite has largely replaced corundum and other abrasives.

Calcined bauxites can be used for refractory purposes where furnace conditions are not exacting enough to demand the use of pure calcined alumina. Bauxite is chemically inactive and it's firing characteristics compare favourably with those of other refractories. Material containing the alumina monohydrates, boehmite and diaspore, offers certain advantages over that containing the trihydrate gibbsite in that it is denser and is subject to less shrinkage. Two main forms of refractory are manufactured from bauxite. Aluminous firebricks can be made by mixing ground calcined bauxite with about 10 per cent of bonding material. Fused aluminous refractories are made by fusing calcined bauxite in electric arc furnaces and casting the product into moulds.

Interest has been expressed in the possibility of using calcined bauxite as a skid resistant aggregate for road surfacings. The high cost of this material is however likely to limit it's use to particularly hazardous sectors of roads like the approaches to traffic lights and pedestrian crossings.

Some uncalcined bauxite is used directly in the manufacture of various alums and aluminium salts. The most important of these products is aluminium sulphate used in the manufacture of paper, for water purification and for the decolourisation of mineral oils. Other chemicals made from bauxite include ammonium chloride, used in the refining of mineral oils, the carbonising of wood and the manufacture of various compounds, and also aluminium fluoride which is used as a flux in ceramic glasses and enamels.

Uncalcined bauxite can also be used in the manufacture of high-alumina cement. It is characterised by ultra-rapid hardening and good chemical and temperature resistance.

2.2. ALUMINA

Alumina, Al_2O_3, is the only known stable oxide of aluminium and contains 52,9 per cent of that element by weight. However, it has a number of different crystalline and textural forms, each possessing distinct physical properties.

Corundum, the only naturally occurring form of unhydrated alumina is the hardest mineral known after diamond. Emery is a naturally occurring mixture of corundum and iron oxides being slightly less harder than pure corundum.

The main demand for calcined alumina is as feedstock for electrolytic aluminium smelters. For use in the production of primary aluminium it is desirable that the alumina should be free of titanium, phosphorous and potash. Calcined alumina is in demand for a number of industrial uses other than the production of aluminium, often as a purer, but more expensive substitute for calcined bauxite. Calcined alumina may be used alone in a pure sintered form or it may be mixed with up to 15 per cent SiO_2, MgO or Ca O for many ceramic uses such as capacitor and resistor cores, spark plug bodies and grinding balls and rods. Calcined alumina is consumed in the manufactured of refractories where it's presence increases the load bearing capacity, resistance to heat shock and spalling.

In the abrasives industry fused alumina is used as coating abrasives and polishing compounds. Some alumina is also used during the manufacture of glass, whiteware and certain catalysts. Low soda alumina possesses particularly good dielectric properties and can be used in high grade electrical insulators in certain electronic applications. Tabular alumina is a dense inert calcined alumina with enhanced resistance to thermal shock which coupled with a high electrical resistance, makes it suitable for specialised refractory and electrical applications. Activated alumina has a high absorptive capacity for water vapour and can be used for the dehydration of gases, organic liquids and powders.

The commodity marketed under the name of 'hydrated alumina' is pure gibbsite, $Al_2O_3.3H_2O$, and is used as a source for the pure aluminous chemicals required by the paper, petroleum and paint industries.

2.3. PRIMARY ALUMINIUM AND Aℓ ALLOYS

Aluminium is light, corrosive resistant, easily fabricated and a good electrical conductor. These properties contribute to its widespread use and its increase in consumption, which has been more rapid than that of any other metallic commodity. Much of this growth has resulted from replacing other materials such as glass or steel in packaging, wood in structural applications such as doors and windows, steel or cast iron in automotive applications and copper in electrical transmission.

Aluminium maintains a strong market growth as the material for beverage cans and the container market continues to develop rapidly. The major markets for aluminium by end use are:[35]

(i) containers and packaging (23 per cent) - foil, flexible packaging, beverage and food containers, other cans and closures

(ii) building and construction (22 per cent) - residential and non-residential awnings, doors, windows, roofing and siding, mobile homes, pre-engineered structures and bridges, and end highway uses

(iii) transportation (22 per cent) - aircraft, ships, automobiles, trucks, trailers, buses, recreational vehicles and military transport

(iv) electrical goods (11 per cent) - electrical machinery and equipment, power transmission and distribution lines, telephone cable, lighting fixtures and electric lamps

(v) consumer durables (8 per cent) - air conditioners, home appliances, cooking utensils, furniture and adornments

(vi) machinery and equipment (7 per cent) - irrigation pipe, equipment for handling agricultural products, and for special industrial processes and services

(vii) miscellaneous metal applications (7 per cent) - dissipative uses such as in the production of steel and aluminium chemicals.

Super purity aluminium has a number of small but important applications, including use as an electrical capacitor foil and for consumer products such as automobile and appliance trim.

Aluminium alloys can be classified in various ways. One of the most important distinctions is that between non-heat treatable alloys and heat treatable alloys. The non-heat treatable alloys obtain their strength as a result of being subjected to cold working processes such as stretching, drawing or rolling. Solution treatment (around 500°C) followed by quenching and natural ageing is referred to as single heat treatment. The term full or double heat treatment is applied when artificial ageing is involved.

The other major basis for classifying aluminium alloys is the distinction between those used for coating and the wrought alloys which are suitable for mechanical working. A summary of the various categories of alloy and their usage is given in Table 18.

Table 18 [43]

Classification and uses of Aluminium alloys

Alloy Composition	Uses
GROUP A	NON-HEAT TREATABLE WROUGHT ALLOYS
Aℓ 99,99%	Chemical industry, foils for electrolytic capacitors
Aℓ 99,0 to 99,8%	cooking utensils, containers, chemical apparatus, electrical equipment, foils
Aℓ-Mn	roofing, containers, packaging
Aℓ-Mg(Mn)	work hardening structural material, ship building, rail and road vehicles, architecture, materials handling equipment
Aℓ-Cu Pb Bi	free machining alloys
GROUP B	HEAT TREATABLE WROUGHT ALLOYS
Aℓ-MgSi	decorative anodising, structural engineering, electrical applications, the main architectural alloy, vehicles
Aℓ-Cu Mg Zn	very high strength structural materials
Aℓ-Cu Mg	high strength structural materials
Aℓ-Mg Zn	medium strength structural materials
GROUP C	NON-HEAT TREATABLE CASTING ALLOYS
Aℓ-Si	medium strength with good casting properties
Aℓ-Mg	moderately good castability, easily worked and suitable for anodising, resistant to sea water
GROUP D	HEAT TREATABLE CASTING ALLOYS
Aℓ-Si	used for components difficult to produce and requiring high strength
Aℓ-Cu Ti	highest strength alloys suitable for impact or repeated stress, poor chemical resistance
Aℓ-Zn Mg	naturally ageing alloys of medium strength, specially suitable for sand casting and decorative anodising

In addition to it's main uses, aluminium finds use in a number of specialized miscellaneous applications. Iron-nickel alloys containing some aluminium are used for permanent magnets. Nitrided steels for improved water resistance and fatigue strength are produced by heating steel containing about 1 per cent aluminium in ammonia. Brass containing about

2 per cent aluminium is employed in marine condenser tubes.

Anhydrous aluminium chloride is produced as a vapour and then condensed. The major use is as a catalyst in the manufacture of ethyl benzine, dyes tuffs, detergent alkylates, ethyl chloride and pharmaceuticals. To a lesser extent it is utilized in the manufacture of titanium dioxide, hydrocarbon resins and in oil refining.

Powdered aluminium is consumed in the manufacture of explosives and pyrotechnics. Aluminium granules are added to ammonium nitrate to form a slurry containing 20 to 30 per cent aluminium. The aluminium functions as a sensitiser which enables the ammonium nitrate to explode when ignited by a fuse. This slurry replaces conventional explosives in certain mining and quarrying applications. It's particular advantages are safe handling and the ability to work underwater.

3 ALUMINIUM MINERALS AND COMPOUNDS

Although aluminium can be extracted from practically any rock or mineral rich in alumina such as clay, anorthosite, nepheline, syenite, alunite and feldspar, bauxite is at present for all practical purposes the only ore of this metal. Minerals containing more than 60 per cent Al_2O_3 are: [12]

corundum	Al_2O_3
boehmite diaspore	$Al_2O_3\ H_2O$
gibbsite	$Al_2O_3.3H_2O$
andalusite, kyanite, sillimanite	$Al_2O_3\ SiO_2$

Bauxite is not a mineral, but is regarded as a rock consisting of one or more of the following hydrated aluminium oxides - gibbsite, boehmite and diaspore, together with impurities such as silica, iron oxides and titanium minerals. For extraction by existing processes, alumina (Al_2O_3) should amount to at least 30 per cent of the ore. In these processes the solubility of the aluminium minerals is the most important consideration. There are rocks and minerals which contain higher percentages of alumina but which cannot be regarded as ores of aluminium as the alumina is so closely bound that it cannot be profitably extracted.

'Red Mud', the residue that results after alumina is extracted from bauxite, commonly by the Bayer process, consists largely of a complex sodium aluminium silicate and iron oxides. In a combination process, the red mud is the feed to a subsequent lime-soda sinter step. The residue from the combination process is called 'brown mud' and contains calcium silicates and iron oxides, but little sodium aluminium silicate.

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4 DEPOSIT TYPES

By far the most significant occurrences of aluminium raw materials are, and will be in the foreseeable future, the bauxite deposits. The following characteristics are found in bauxite classification systems:

(i) Geological age and setting of deposit

The geological age can be used to distinguish subrecent and recent bauxite formations from fossil deposits. The subrecent and recent bauxite deposits are found in the present day regions of humid and tropical climatic conditions in which lateritic weathering and bauxite formation can still occur. That lateritic weathering occurred during all geological periods is shown by examples of fossil bauxite deposits in France, Yugoslavia, Hungary and Greece (Cretaceous to Tertiary), the People's Republic of China and America (Jurassic) and Siberia (Precambrian).

Fossil bauxite deposits are of secondary importance. This is because more recent geological events have caused large portions of the original deposits to be eroded away. The only remaining deposits are those that have been protected by burial or by the morphology of the rock beneath it. Such deposits are usually mineable only by deep mining and the mineralisation is often discontinuous. In addition, fossil deposits are often monohydrated (boehmite, diaspore) - recent deposits are trihydrated and require less energy during the digestion period of the Bayer process.

(ii) Geotechnic position of the deposit

Bauxite deposits in shield regions can be distinguished from those in orogenic zones since they are usually more extensive and exhibit greater consistency of mineralisation.

(iii) Parent rock for bauxite formation

Bauxite can be formed from all native rock. The chemical and mineral composition of the starting material and its permeability are, however, decisive in determining the composition and quality of the bauxite. Weathering can form karst pockets in carbonate sediments in which bauxite can accumulate.

(iv) Chemical and mineral composition

Chemical classifications consider primarily the silica: Al_2O_3 ratio. The ratio should be less than 0,5 for an economic deposit and is generally less than 0,2 for high grade ores. Mineral classifications consider the relative amounts of monohydrated and trihydrated minerals. Also important are the type and quality of gangue minerals such as kaolinite and quartz.

(v) Geometry and extent of the deposit

Classification according to geometry and extent of the deposit seems to be the most suitable for a division according to economic importance. Blanket deposits, pockets and detrital deposits can be distinguished. There is also a series of transition types as in Jamaica where some bauxite deposits have formed an extensive blanket although they are overlain by limestone.

Several climatic and geological conditions are of special importance for the choice of prospective areas for bauxite and exploration for deposits:

- present day humid (average annual rainfall over 1 500 millimetres), tropical (average annual temperature over 25°C) climate or such conditions in the geological past
- extensive areas of peneplanation.

Areas which still hold promise for the discovery of young bauxite formations according to the present climate distribution are the Amazon Basin, extensive areas in Central and West Africa, Madagascar, Northern Australia and the Southeast Asian island arc.

The chances of finding older formations is considerably less. There are known deposits throughout the World but they predominantly occur in Europe, Australia, America, Surinam and Guinea. It is not likely that new fossil discoveries will be made outside of these regions. It is also improbable that dry deposits will add significantly to the reserves.

Consequently, prospecting for bauxite deposits within the boundaries of the Republic of South Africa is not likely to lead to significant new finds. A reduction in the dependence on imports of aluminium raw materials is therefore not to be expected.

5 WORLD RESERVES, PRODUCTION AND CONSUMPTION

The average aluminium content of the Earth's crust has been estimated at 8,3 per cent and deposits containing over 15 per cent aluminium are common. Information on bauxite reserves and resources ranges from reports based on thorough exploration for some deposits to reports giving only a total quantity estimate based on unspecified fieldwork for other deposits. The quality of bauxite deposits cannot be assessed by the alumina content alone as many factors affect the cost and quantity of alumina that can be recovered. Table 19 gives an estimate of the world bauxite resources and reserves as determined by Kurtz in Mineral Facts and Problems.[39]

Table 19

Estimated World Bauxite resources and reserves - 1980 (million tons)[39]

Area	Bauxite Reserves	Recoverable aluminium equivalent Reserves	Other	Resources
N. America				
United States	40	9	36	45
Jamaica	2 000	417	54	471
Other	210	45	27	72
TOTAL	2 250	471	117	588
S. America				
Brazil	2 500	554	554	1 108
Guyana	700	172	73	245
Surinam	490	118	73	191
Other	300	64	118	182
TOTAL	3 990	908	818	1 726
Europe				
Greece	700	145	54	199
Hungary	300	64	18	82
U.S.S.R.	300	54	64	118
Yugoslavia	400	77	77	154
Other	90	18	100	118
TOTAL	1 790	358	313	671
Africa				
Cameroon	1 000	181	109	290
Ghana	570	118	45	163
Guinea	6 500	1 361	363	1 724
Sierra Leone	130	27	-	27
Other	5	-	399	399
Total	8 205	1 687	916	2 603
Asia				
China	150	27	163	190
India	1 000	204	204	408
Indonesia	700	136	59	195
Other	65	14	195	209
TOTAL	1 915	381	621	1 002

Table 19 continued

Oceania				
Australia	4 500	907	499	1 406
Other	20	5	27	32
TOTAL	4 520	912	526	1 438
WORLD TOTAL	22 670	4 717	3 311	8 028

The growth in reserves has roughly paralleled the rapid growth in world bauxite production. The increases in reserves are largely attributable to major bauxite discoveries. Production economies resulting from technological advances and large-scale operations have also permitted the inclusion of lower grade bauxite previously considered uneconomic. The mining of some of these deposits may be restricted because of environmental considerations such as their proximity to populated or scenic areas.

The measured and indicated reserves that are economically recoverable at present amount to 22 670 million tons of bauxitic ore containing about 4 720 million tons of recoverable aluminium. With respect to strategic supplies, the Western World is fortunate regarding aluminium in that 90 per cent of potential world resources occur in market economies and no shortage of supply is anticipated. No economic reserves of bauxite are found in South Africa.

Australia (19 per cent), Guinea (29 per cent) and Jamaica (9 per cent) have the greatest portion of the measured and indicated reserves. These three countries, in the same order, are also the most important bauxite producers. About 75 per cent of the proven reserves are in the present-day tropical climate regions: Africa (36 per cent), Australia (19 per cent) and Latin America (19 per cent). When total world resources are considered a distributional disparity is evident since 70 per cent of the resources occur in developing countries with free economies and only 20 per cent occur in the western industrial countries. Present world reserves are sufficient for more than a 350 year supply at current production.

5.2. World production

5.2.1. Bauxite

Although in principle many minerals and rocks may be used to produce aluminium, in practice almost only bauxite is used. Only in the U.S.S.R. and the People's Replublic of China are other raw materials (nepheline and alunite) utilized. For comparison purposes, their amounts have been estimated and recalculated as 'bauxite'.

Table 20 lists the ten largest producers of bauxite in the Western World for the last fifteen years while Appendix Six contains a Table of the contribution to world production by minor capacity countries and the Eastern Bloc during this period. Historically, bauxite production has steadily increased with an overall average annual growth rate of about 6 per cent but in the last five years there has been an alarming decrease in production averaging about 2,5 per cent per year.

Table 20

Western World production of bauxite (million tons)

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Jamaica	9,8	10,5	11,8	12,5	12,8	13,5	15,3	11,6	10,3	11,4
Australia	7,4	7,9	9,4	12,5	14,4	17,6	20,1	21,0	24,1	26,1
Surinam	5,8	6,2	6,0	6,7	6,8	6,7	6,9	5,1	4,6	4,9
Guyana	4,0	4,3	4,3	4,2	3,7	3,6	3,2	3,8	3,1	3,3
France	2,6	2,8	3,1	3,2	3,3	3,3	2,9	2,5	2,3	2,1
Guinea	2,3	2,5	2,6	2,6	2,6	3,5	7,6	10,6	11,3	11,3
Yugoslavia	2,0	2,1	2,1	2,0	2,2	2,2	2,4	2,3	2,0	2,0
Greece	1,8	1,9	2,3	2,9	2,7	2,7	2,8	2,8	2,8	2,9
United States	1,7	1,8	2,1	2,0	1,8	1,9	2,0	1,8	2,0	2,0
India	0,9	1,0	1,3	1,5	1,7	1,3	1,3	1,3	1,4	1,5
TOTAL* (W.World)	43,3	46,2	50,4	55,7	57,9	61,9	70,0	68,0	69,0	74,1
TOTAL (World)	50,9	54,4	59,0	64,9	67,4	71,8	x	x	x	x

	1978	1979	1980	1981	1982
Jamaica	11,7	11,5	12,1	11,6	8,6
Australia	24,3	27,6	27,2	25,5	23,0
Surinam	5,3	4,7	4,9	4,0	2,9
Guyana	3,5	3,4	3,1	1,9	1,5
France	2,0	2,0	1,9	1,8	1,6
Guinea	12,1	12,2	13,3	12,8	10,2
Yugoslavia	2,6	3,0	3,1	3,3	3,3
Greece	2,6	2,9	3,3	3,2	3,4
United States	1,7	1,8	1,6	1,5	0,7
India	1,7	1,9	1,7	1,9	2,0
TOTAL* (W.World)	72,9	76,3	80,8	76,2	65,2
TOTAL (World)	x	x	x	x	x

* this figure includes the additional output from the small producers listed in Appendix Six

x figures not published for Eastern Bloc production

It is of great interest to note that the 'top ten' producers actually contributed almost 90 per cent of the total annual Western World production of bauxite and of these ten, Jamaica, Australia and Guinea provide 75 per cent of their output. With such a pseudo-oligopolistic producer's structure it was inevitable that (March 1974) the seven bauxite producing countries of Australia, Guinea, Guyana, Jamaica, Sierre Leone, Surinam and Yugoslavia agreed to establish a producer's organization titled the International Bauxite Association (IBA). Since that time the Dominican Republic, Haiti, Ghana and Indonesia have joined the IBA. Their objectives are:

(i) to promote the orderly and rational development of the baoxite industry

(ii) to secure for member countries fair returns from the exploitation, processing and marketing of bauxite, bearing in mind the recognized interests of consumers

(iii) to generally safeguard the interests of member countries in relation to the bauxite industry.

The more active role now being played by producing countries has provided a number of important benefits for them. Many now have considerably more influence over their important bauxite operations than was the case a decade ago. In a growing number of countries, the government is a shareholder and participates actively in domestic ventures. Also, the tax revenues and unit values of their exports of bauxite have risen appreciably over the last ten years.

More than 70 per cent of measured and indicated bauxite reserves and 80 per cent of current W. World production are found within the IBA countries. This already very high percentage could still be increased by the entry of other bauxite producers but this would probably result in greater difficulties in reaching agreement within the IBA.

5.2.2. Alumina

It is estimated that approximately 95 per cent of the world bauxite production is processed to alumina. Twenty years ago the location of alumina production paralleled the location of primary metal on a regional basis except for countries such as Jamaica and Guinea which did not produce metal. This pattern entered a transitional period,

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Table 21 contains the breakdown of world alumina production by economic regional grouping at five year intervals.

Table 21

Alumina production by region (kilotons and%)[45]

Region	1965		1970		1975		1980	
North America	5 815	(42,0)	6 615	(31,1)	8 200	(26,7)	8 045	(23,0)
Latin America	1 480	(10,7)	3 390	(15,9)	4 790	(15,6)	5 600	(16,0)
Africa	490	(3,5)	620	(2,9)	680	(2,2)	795	(2,3)
Europe*	1 890	(13,7)	2 645	(12,4)	4 240	(13,8)	4 960	(14,2)
Asia*	810	(5,9)	1 875	(8,8)	2 425	(7,9)	3 685	(10,5)
Australia & Oceania	290	(2,1)	2 535	(12,0)	5 235	(17,0)	7 350	(21,0)
W. WORLD TOTAL	10 775	(77,9)	17 680	(83,1)	25 570	(83,2)	30 435	(87,0)
E. BLOC TOTAL	3 065	(22,1)	3 605	(16,9)	5 150	(16,8)	4 550	(13,0)
WORLD TOTAL	13 840	(100,0)	21 285	(100,0)	30 720	(100,0)	34 985	(100,0)

* without Eastern Bloc production

The trend towards more refining in the developing countries is clearly demonstrated by the decrease in the percentage of alumina produced by North America (almost halved) and the quantum increase for Australia and Oceania (ten times larger) in the fifteen year period of 1965 - 1980. A number of the major bauxite producers now have a high alumina production as well mainly because of reduced transportation expenditure for the primary consumers but also because of the availability of large quantities of cheap energy for processing in the developing countries.

5.2.3. Primary aluminium

The major bauxite producing countries in Latin America, Asia and Africa as well as Australia have only limited primary aluminium producing capacity. Guinea, the second largest bauxite producer, Jamaica and Guyana produce no primary aluminium yet. In contrast, the western industrial countries, which except for the United States and France have little or no bauxite, produced most of the primary aluminium in the world, about 75 per cent. These countries are completely, or almost completely, dependent on the import of aluminium-bearing raw materials for their smelters.

Table 22 lists those countries with a primary aluminium production of more than 250 000 tons in 1982 and their development over the last fifteen years.

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Table 22

Primary aluminium output by major producing countries (kilotons)[28]

W.World	1968	1969	1970	1971	1972	1973	1974	1975
United States	2 950	3 440	3 600	3 560	3 740	4 110	4 450	3 520
Canada	890	980	960	1 000	910	930	1 010	880
Germany (F.R.)	260	260	310	430	440	530	690	680
Norway	470	500	520	530	560	620	650	590
France	370	370	380	380	390	360	390	380
Australia	100	130	210	220	210	210	220	210
Spain	90	110	120	130	140	160	190	210
Japan	480	570	730	890	1 010	1 100	1 120	1 010
Brazil	40	40	60	80	100	110	110	120
Venezuela	10	10	20	20	20	30	40	50
Other *	980	1 020	1 140	1 370	1 680	1 980	2 210	2 240
W. WORLD TOTAL	6 640	7 430	8 050	8 610	9 200	10 140	11 080	9 890
Eastern Bloc								
U.S.S.R.	1 500	1 550	1 700	1 800	1 900	2 000	2 100	2 150
China (P.R.)	120	130	140	150	160	160	160	160
Rumania	80	90	100	110	120	140	190	200
Other +	250	250	270	270	260	310	280	280
E. Bloc TOTAL	1 950	2 020	2 210	2 [illegible]	2 440	2 610	2 730	2 790
WORLD TOTAL	8 590	9 450	10 260	10 [illegible]	11 640	12 750	13 810	12 680

W. World	1976	1977	1978	1979	1980	1981	1982
United States	3 860	4 120	4 360	4 560	4 650	4 490	3 270
Canada	630	980	1 050	860	1 080	1 120	1 070
Germany (F.R.)	700	740	740	740	730	730	720
Norway	620	640	660	670	660	640	650
France	390	400	390	400	430	440	390
Australia	230	240	260	270	300	380	380
Spain	210	210	210	260	390	400	370
Japan	920	1 120	1 060	1 010	1 090	770	350
Brazil	140	170	190	240	260	260	300
Venezuela	50	40	80	210	330	310	270
Other *	2 490	2 560	2 520	2 700	2 860	2 950	2 960
W. WORLD TOTAL	10 240	11 220	11 520	11 920	12 780	12 490	10 730

Table 22 continued

Eastern Bloc	1976	1977	1978	1979	1980	1981	1982
U.S.S.R.	2 200	2 200	2 250	2 400	2 420	2 400	2 400
China (P.R.)	200	260	300	300	350	350	360
Rumania	210	210	210	210	240	230	230
Other +	270	280	290	290	280	250	250
E. Bloc TOTAL	2 880	2 950	3 050	3 200	3 290	3 230	3 240
WORLD TOTAL	13 120	14 170	14 570	15 120	16 070	15 720	13 960

* including Netherlands, United Kingdom, Italy, India, Yugoslavia, Ghana, Bahrain, New Zealand, Dubai, Egypt, Argentina, Greece, South Africa, Austria, Sweden, Cameroun, Iceland, Switzerland, Surinam, Mexico, Turkey, Indonesia, Iran, South Korea, and Taiwan.

+ including Poland, Hungary, Germany (G.D.R.), Czechoslovakia and North Korea.

The shift of processing of ores to developing countries with their cheaper sources of power is again evident from the above table.Over the last fifteen years industrialised countries with indigenous fuel supplies such as the United States, Canada and Germany have experienced very little growth in the output of primary aluminium while Japan, which relies on imported oil for it's electric power has actually experienced drastic decreases in production. The high price of foreign oil, coupled with a steady decline in the free market price of primary aluminium has left a large gap between the price of imported metal and the cost of the home product. However, countries such as Brazil, Venezuela and Australia with vast energy resources (hydroelectric or coal) and local bauxite reserves have increased their share of the primary aluminium market vastly.

The Eastern Bloc countries show little evidence of changes in location of production or reaction to shortages of available energy and in fact have maintained a very steady annual growth of about 3,5 per cent per annum.

5.3. World consumption of aluminium

The consumption of primary aluminium is calculated annually by the Metallgesellschaft, Frankfurt for fifty-one of the world's countries[27] and is published in the periodical Metallstatistik. There are problems of a conceptional and statistical nature inherent in almost any definition of consumption. These problems are especially acute in the case of aluminium where losses occur as the material passes through several stages of refining, forming and fabrication, is incorporated in other products (often of a durable nature) and may finally return in the form of scrap for reuse. Except in the case of destructive uses, it is not possible to select some point in this process and unequivocally say the metal has been 'consumed'. To make matters more difficult, as the process of fabrication proceeds, aluminium often loses it's identity and becomes impossible to trace statistically.

However, the world consumption of primary aluminium cannot be determined for an index of use because in most applications the demand is not for primary but rather for raw aluminium, irrespective of whether it is of primary or secondary origin. So long as secondary metal is satisfactory for the purpose and available at a competitive price, it will increase its proportion of use in primary consumption. [44]

The Metallgesellschaft figure for individual countries is in effect consumption of primary aluminium. Since it includes in consumption only that part of secondary metal which enters international trade in crude form (a small figure), it offers a fair approximation to the absorption of primary metal. Table 23 shows the trend in consumption of primary aluminium according to economic region, for the last fifteen years.

Table 23

Primary aluminium consumption (kilotons)[28]

	1968	1969	1970	1971	1972	1973	1974	1975
Europe	2 070	2 410	2 610	2 490	2 790	3 210	3 390	2 820
Asia	850	1 030	1 210	1 310	1 560	1 980	1 710	1 600
Africa	50	60	70	90	90	110	120	130
America	3 960	4 120	3 910	4 430	4 880	5 710	5 870	4 200
Australia/Oceania	110	120	140	150	130	180	210	160
W. WORLD TOTAL	6 990	7 740	7 940	8 470	9 450	11 190	11 300	8 910
E. BLOC TOTAL	1 830	1 920	2 050	2 190	2 310	2 420	2 600	2 700
WORLD TOTAL	8 820	9 660	9 990	10 660	11 760	13 610	13 900	11 610

	1976	1977	1978	1979	1980	1981	1982
Europe	3 510	3 390	3 390	3 600	3 600	3 364	2 835
Asia	1 950	2 114	2 277	2 441	2 590	2 291	2 141
Africa	140	141	142	143	165	155	145
America	5 180	5 435	5 690	5 945	6 035	5 665	5 294
Australia/Oceania	190	384	578	772	775	728	680
W. WORLD TOTAL	10 970	11 464	12 077	12 901	13 165	12 203	11 095
E. BLOC TOTAL	2 890	2 839	2 789	2 738	2 800	2 739	2 432
WORLD TOTAL	13 860	14 303	14 866	15 639	15 965	14 942	13 527

World production and consumption trends of primary aluminium are depicted graphically on the following page , illustrating firstly actual tonnages and secondly the spline of best fit as determined by the computer package SAS-GRAPH.

5.4. Local Production

5.4.1. Primary aluminium

Primary aluminium is produced by ALUSAF at Richards Bay by fused-salt electrolysis of alumina which is at present imported from Australia and Canada. The price of alumina has been rising markedly and is likely to continue to do so due to increased energy costs in the bauxite/alumina conversion and increased ocean freight rates resulting from higher prices of crude oil. Brubaker states that if the electrolytic smelting process remains the standard, then the alumina feed material is likely to continue to be made by the Bayer process from bauxite and that the best substitute for bauxite is lower-grade bauxite.

The country's first and only aluminium smelter complex started up in May 1971. It was a joint project between Alusuisse (22%) and the South African Government (presently the Industrial Development Corporation of South Africa holds a 54 per cent major share holding). In spite of alleged power difficulties, the smelter operated at it's full design capacity producing about 29 000 tons of metal. Escom installed a second, alternative power supply line from the national grid to ensure continuous operation. Alcan Aluminium of South Africa, which had been apprehensive about the displacement of supplies of aluminium from it's parent company by more expensive metal from the new smelter (in which it has only a small interest) actually reported a higher income from a lower tonnage turnover. USCO Aluminium Corporation, a subsidiary of Union Steel Corporation of South Africa, was formed to build a continuous casting and fabricating unit near the Richards Bay smelter.

In 1972 it was decided to expand the smelter's capacity of 55 000 tons by 20 000 tons due to increasing South African demand. The expansion was completed early in 1974 and production was immediately boosted to match capacity.

Despite the increase in capacity of the smelter, it was still considered most inadequate for satisfying indigenous demand since local industries were discovering or implementing a variety of uses for a secure supply of aluminium from within the country's borders.

In the same year Alusaf completed plans for the construction of a carbon anode plant at a cost of about R50 million with a capacity to produce 50 000 tons of carbon anodes per annum. A further 6 000 ton expansion for graphically on the following page , illustrating firstly actual tonnages and secondly the spline of best fit as determined by the computer package SAS-GRAPH.

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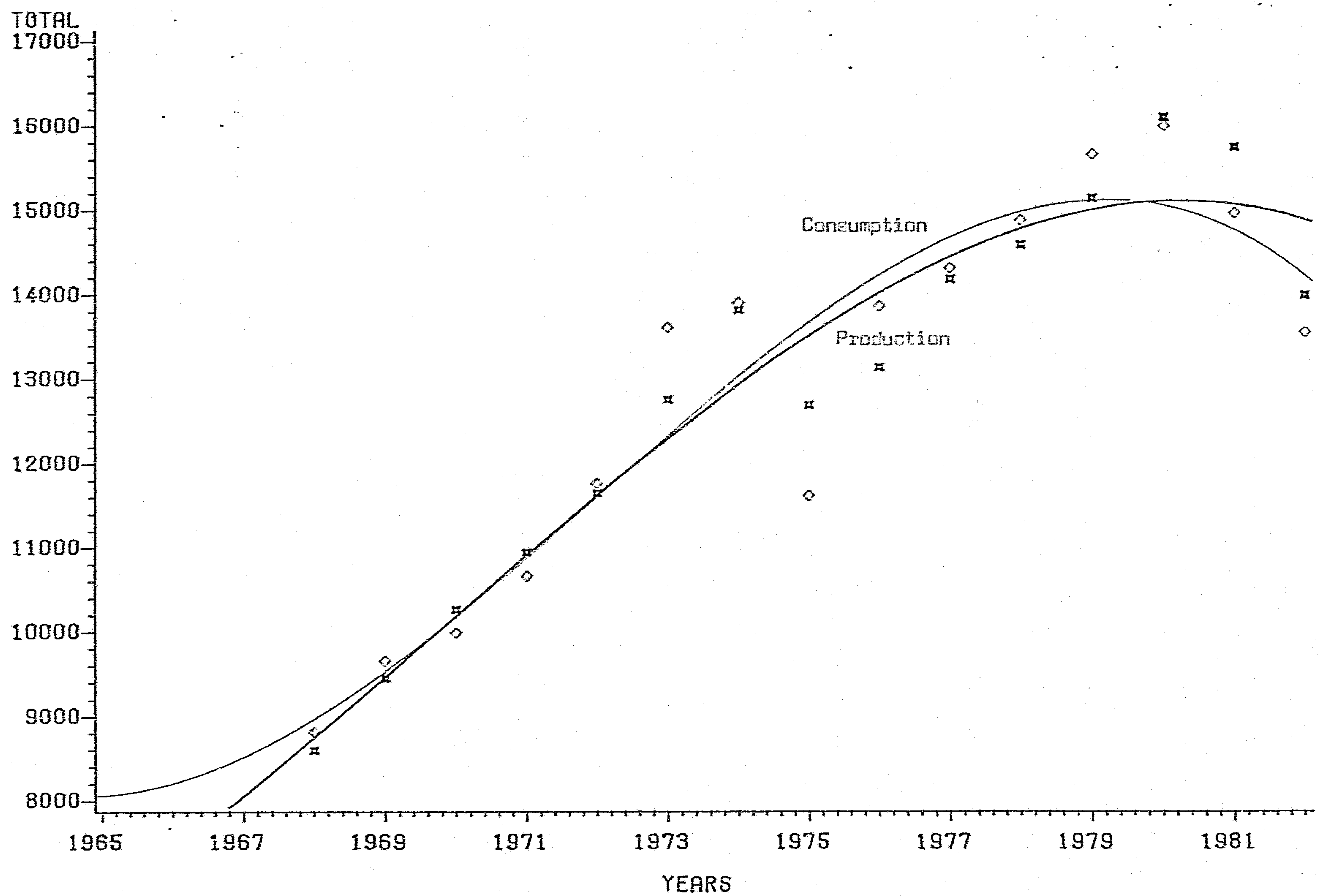

WESTERN WORLD PRIMARY ALUMINIUM
PRODUCTION AND CONSUMPTION (KTONS)

the smelter was completed in 1978 and again the plant operated at full capacity despite decreases in smelter output throughout the rest of the world. In 1980, negotiations were completed for the smelter's capacity to be augumented by the installation of an 87 000 tons per year facility acquired from Nippon Light Metal Co.'s Niigata smelter. This had been closed as part of the Japanese industry's rationalisation plans after rising oil costs had made many of Japan's smelters uneconomic. Reconstruction began in January 1981 and the first 24 furnaces were operating a year later. The new capacity implies that Alusaf will have to find an export market for around 100 000 tons per year.

Production figures, since inception, of the Richards Bay smelter complex are:

YEAR	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
KILOTONS(Aℓ)	29,4	53,0	53,0	75,0	76,0	78,0	82,0	81,0	86,0	88,0	85,0	107,0

The greater portion of the alumina required is derived from Australian sources (Kwinana and Pinjarra) as pre-baked, 100% alumina. The smelters are driven by thermal power being totally coal fired. The planned year-end capacity of the complex is 168 000 tons per year for the period 1983 to 1985, thereafter a possible further expansion to 300 000 tons per year.

Future expansions would undoubtly be subject to the ready availability of sufficient imported alumina or indigenous alumina in the case of international sanctions and boycotts. The additional energy required could be derived from local coal reserves to be utilized in coal - fired power stations.

5.4.2. Secondary Aluminium

Table 24 contains a list of producers of secondary alloys of aluminium in South Africa, together with estimates of capacity, where available:

Table 24

Companies producing secondary aluminium (1982)[46]

COMPANY	Location	Capacity(tpa)	Major Shareholders
H.H. Benesel (Pty)	Alberton	x	x
Metal & Chemical Industries	Heriotdale	2 000	x
Metals and Residues (Pty)	Benoni	x	A. Cohen & Co.
Metal Sales Co. (Pty)	Benoni Pinetown Cape Town	8 000	x x x
Modern Alloys	Alberton	x	A. Cohen & Co.
M. & R. Metal Refiners (Pty)	Alberton	3 000	A. Cohen & Co.

Table 24 continued

COMPANY	Location	Capacity(tpa)	Major Shareholders
National Scrap Metals (Pty)	Alberton	x	A. Cohen & Co.
Non-Ferrous Metal Works(Natal)	Jacobs	2 000	Non-Ferrous Metal Works (Israel)
S.A. Smelting Works (Pty)	Industria	200	x
Supreme Aluminium & Brass Co.	Benoni	x	Metal Sales Co. (Pty)
Supreme Metal Works (Pty)	Industria	2 000	A. Cohen & Co.
Cu-Base Foundry	Woodville	50	x
Hulett's Metals (Pty)	Benoni) Industria) Pinetown)	10 000	Huletts Industries Ltd.

x indicates data not available

The nature of the secondary market is such that comparatively little secondary metal moves in international trade in refined form. There is a fairly active international trade in scrap, but for the most part a country that seeks to produce it's own metal, like South Africa, will rely upon domestically produced primary and scrap aluminium.

Secondary metal is produced from scrap originating in two broad sources: new or current industrial scrap generated from the fabrication of metal and old scrap recovered from finished products previously in use. It is difficult to forecast precisely secondary metal production but generally there exists a fixed ratio of recovered industrial scrap generated by the industrial processes in the range of 12 to 15 per cent of total consumption.

The secondary industry is currently coming to the notion of market development; that is, finding new applications for secondary aluminium ingot and perhaps even looking for new alloys to meet customer requirements. This is an expensive activity and should be undertaken by a pooling of resources of many companies.

5.4.3. Aluminium semis

The bulk of primary aluminium produced is used for the manufacture of wrought products or 'semis' such as sheet, plate, strip, circles, bar, section, tube, wire and forgings. There is a strong correlation between aluminium consumption per capita and income per capita. With the ever improving quality of life for the majority of the population of South Africa it is foreseeable that this section of industry will prosper in the future.

The outstanding growth areas anticipated are in the major sectors of the road transport market (trucks, buses and passenger cars) and packaging markets (canning).

However, aluminium semis will probably achieve a lower rate of penetration of new markets in the future than in the past due to marginal losses to plastics and painted steel.

Excluding the negligible tonnage of forgings, the aluminium semis industry divides itself into three clearly defined sectors based on the different product groups - rolled products, extrusions and tube and wire. Table 25 contains a list of semis producers in South Africa with production data where available:

Table 25

Companies producing 'semis' (1982)[46]

COMPANY	Location	Products	Capacity(tpa)
African Aluminium Co.(Pty)	Port Elizabeth	rod	x
African Cables Ltd.	Peacehaven	cable	x
Alustang	Richards Bay	Properzi rod	30 000
Avon Wire (Pty) Ltd.	Randfontein	strip, wire	x
Craig Bros.Aluminium(Pty)	Germiston	extrusions	x
Huletts Aluminium Ltd.	Pietermaritzburg	sheet	45 000
	Olifantsfontein	extrusions	25 600
	Epping	foil	7 600
		conductor	6 000
		paste	500
		wire	1 000
Hulett's Metals (Pty)Ltd.	Benoni	powder	15 000
Scottish Cables (S.A.)Ltd.	Pietermaritzburg	cables	x
Union Steel Corporation	Peacehaven	wire, cable	x
USCO Cable Co.(Pty)Ltd.	Empangeni	cable	x

x indicates data not available.

The equipment employed in the fabrication of aluminium is standard metal working equipment and theoretically mills would be able to convert between aluminium and other metals with only minor modifications of their lines. Capital and operating requirements for fabrication plants vary enormously. A continuous hot rolling mill for sheet is expensive and requires large tonnages to be justified. The same is true for rod mills. However, the use of less sophisticated equipment with much lower capacity makes it feasible for a smaller plant to perform at least some range of fabrication for a domestic market. Extrusions and castings in particular can be fabricated on a small scale, and cold rolling mills are commonly of much smaller capacity than hot roll mills. It should be recognized, however, that for truly modern and complete facilities the investment required may match that of other stages of the industry.

5.5. Local consumption

5.5.1. Alumina

All of South Africa's primary aluminium is produced from imported alumina. Since 1971, all the alumina has been imported either at Richards Bay or Durban and processed at Richards Bay. No supply difficulties have ever been encountered and none are anticipated since the material is obtained from two reliable trading partners - Australia and Canada. Total imports of alumina to Richards Bay have been:

YEAR	1971	1972	1973	1974	1975	1976	1977	1978	1979
KILOTONS (Aℓ)	61,7	111,3	112,2	157,5	159,6	163,8	172,2	170,1	180,6

1980	1981	1982
184,8	178,5	224,7

It is expected that future import figures will contine to rise to satisfy local demand since extraction of local alumina is at present not economically feasible.

5.5.2. Aluminium

The annual trade statistics for South Africa, published by the Department of Customs and Excise records the imports and exports of aluminium in it's various forms. However, a detailed analysis of this data would be very onerous since in 1982 there were listed no fewer than 196 individual aluminium categories. For brevity these are divided into sixteen major classifications, which are defined and coded as in Table 26.

Table 26

Aluminium trade statistics codes[30]

CODE	DESCRIPTION
76.01	Unwrought aluminium, aluminium waste and scrap
76.02	Wrought bars, rods, angles, shapes and sections of aluminium, aluminium wire
76.03	Wrought plates, sheets and strip, of aluminium
76.04	Aluminium foil of thickness not exceeding 0,2mm
76.05	Aluminium powders and flakes
76.06	Tubes, pipes and blanks: hollow bars of aluminium
76.07	Tube and pipe fittings, of aluminium
76.08	Structures, complete or incomplete, and parts of aluminium
76.09	Reservoirs, tanks, vats and similar containers, for any material (excluding compressed or liquefied gas) of aluminium, of a capacity exceeding 300 litres, whether or not lined or heat insulated, but not fitted with mechanical or thermal equipment
76.10	Casks, drums, cans, boxes and similar containers of aluminium for the conveyance or packing of goods.

Table 26 continued

CODE	DESCRIPTION
76.11	Containers of aluminium, for compressed or liquefied gas
76.12	Standard wire, cables, cordage, ropes, plaited bands and the like, of aluminium wire
76.13) 76.14)	Included under 76.16 post-1976
76.15	Articles of a kind commonly used for domestic purposes, sanitary ware for indoor use, and parts of such articles and ware of aluminium
76.16	Other articles of aluminium

The imports and exports of items 76.04 to 76.16 for the last fifteen years are contained in Appendix Seven while the following tables record the trade statistics for items 76.01 to 76.03 (the greatest volume categories) during that period.

Table 27

Unwrought aluminium, aluminium waste and scrap (item 76.01) [30]

YEAR	IMPORTS		EXPORTS	
	Quantity(tons)	Value(R current)	Quantity(tons)	Value(R current)
1968				
1969	90 810	16 826 749	4 220	387 863
1970	108 289	21 314 601	2 218	102 453
1971	22 500	8 923 582	945	147 742
1972	1 590	590 640	1 869	382 998
1973	1 318	585 092	×	2 318 309
1974	1 044	626 019	×	8 183 340
1975	1 251	1 155 358	×	8 173 719
1976	957	879 182	×	15 310 396
1977	1 096	1 135 261	×	24 825 417
1978	1 132	1 310 544	×	36 154 751
1979	1 022	1 550 773	×	36 268 033
1980	2 047	2 527 539	×	18 679 669
1981	11 578	13 344 133	×	15 300 381
1982	3 339	4 400 093	×	33 335 844

× indicates figures not recorded for public use.

This sector of the market exhibits a thriving export trade with historically international sales greatly exceeding imports. The tonnage of scrap imported into South Africa would be mainly pure aluminium, whereas the quantity of scrap exported would be in the form of alloys. The commencement of production

Page 124 omitted in the Pagination

at the Alusaf smelter in 1971 is distinctly evident in the above import statistics.

Table 28

Wrought bars, rods, angles, shapes and sections of aluminium, aluminium wire (item 76.02)[30]

YEAR	IMPORTS		EXPORTS	
	Quantity(tons)	Value(R current)	Quantity(tons)	Value(R current)
1968				
1969	4 283	1 157 793	1 285	537 391
1970	7 014	3 814 822	943	882 175
1971	3 479	1 805 640	735	690 706
1972	900	802 638	300	348 399
1973	474	620 381	x	262 982
1974	648	795 236	x	456 866
1975	2 312	2 119 32[illegible]	x	200 481
1976	1 575	1 603 282	x	2 202 100
1977	489	[illegible] 747 620	x	579 826
1978	421	[illegible] 078 274	x	2 172 134
1979	371	1 079 955	x	5 060 288
1980	647	1 728 599	x	4 326 214
1981	1 337	3 030 947	x	1 042 659
1982	1 481	3 514 191	x	467 229

Table 29

Wrought plates, sheets and strip, of aluminium (item 76.03)[30]

YEAR	IMPORTS		EXPORTS	
	Quantity(tons)	Value(R current)	Quantity(tons)	Value(R current)
1968				
1969	7 672	2 556 521	1 853	605 141
1970	11 537	3 567 101	2 719	851 713
1971	6 431	4 451 872	941	658 439
1972	4 506	3 807 936	1 386	1 043 825
1973	6 103	5 098 382	x	1 125 044
1974	9 149	8 151 112	x	1 665 718
1975	8 600	9 139 472	x	671 523
1976	9 226	9 502 482	x	961 083
1977	5 087	8 247 703	x	1 392 843
1978	6 025	11 210 117	x	1 229 514
1979	5 916	11 360 699	x	1 662 979
1980	8 600	15 764 357	x	1 778 250
1981	10 524	18 883 670	x	675 982
1982	8 435	20 095 465	x	657 491

x indicates figures not recorded for public use.

The above tables illustrate the gap that exists in domestic technology between the production of raw aluminium and it's subsequent conversion into more refined products. Although annually the data in Table 28 is not comparable, over the period 1968 - 1982, there has however been a compensating effect in the market whereby the value of imports has almost equalled the value of export trade. In Table 29, it is evident that virtually all local requirements of aluminium wrought plate and strip are imported as finished products. This particular market sector has vast potential for domestic expansion.

The pattern of domestic production, consumption and trade of aluminium can thus be established. Assuming an optimum capacity utilitization of the Alusaf plant, then imports plus local production minus exports provides a representative consumption figure. Where export statistics of quantities are not available, an approximate figure can be derived by proportioning the import quantity in the ratio export value/ import value. The approximation is considered realistic since with such precisely defined categories of trade the components, and hence value, are not likely to differ greatly. (A similar problem was encountered in the section on tungsten, but the categories were considered too diverse to utilize this approach).

The consumption trend of aluminium in South Africa would therefore be represented by:

YEAR	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
DEMAND (kilotons Aℓ)	61,6	58,2	56,9	72,8	76,9	72,2	65,9	74,3	68,8	77,6	100,1	98,9

The best-fit curve was determined to be exponential and had a correlation coefficient of r = 0,827. The equation of the demand curve was:

$$\text{CONSUMPTION} = 55{,}521^{\;0{,}041\ \text{YR}}$$

with YR as integer with a base of 1971 = 1.

The demand figures for South Africa for the next decade would thus be estimated as:

YR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Kilotons (Aℓ)	94,9	98,8	103,0	107,3	111,9	116,6	121,5	126,6	131,9	137,4

These trends are depicted graphically on the following page. The use of the exponential model for predicting purposes is verified by considering the average annual growth rate expected in the period 1980 - 1992. The model indicates a value of 4,2 per cent per annum which corresponds well with two

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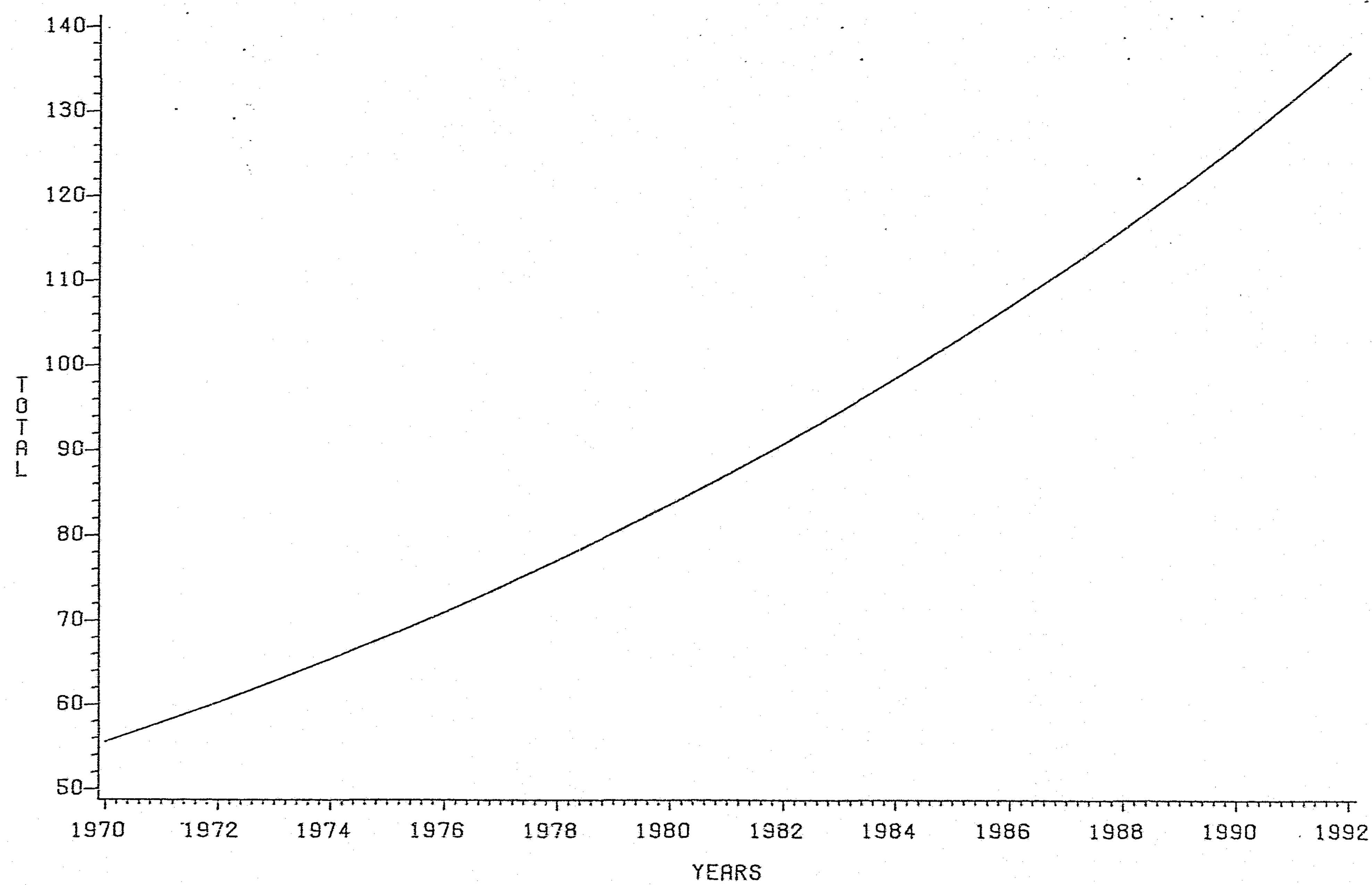

SOUTH AFRICAN CONSUMPTION
OF PRIMARY ALUMINIUM IN KTONS

forecasts. Firstly, that of Chase Econometrics and secondly, that of G. Haymarket of Alcoa. In fact a review[37] of nine sources of such projections revealed an average expected annual growth rate of 4,5 per cent for the period 1980 - 1992.

6 ENERGY AND THE PRIMARY ALUMINIUM INDUSTRY

The large changes in the supply conditions of oil since October 1973 and the changes in the relative prices of many industrial products since that time, have within the context of the energy intensive aluminium industry, raised the question as to what impact has the changed energy situation had on the cost structure of primary aluminium production, and in the medium and longer term, what effect will it have on possible product substitution and future locational patterns of new smelters.

6.1. Sources of energy for Primary Aluminium Production [47]

The cost of energy is one of the most important cost variables in the production process of the primary aluminium industry and, accordingly, the location of reduction works has been strongly influenced by proximity to cheap, reliable and abundant power. Not surprising, therefore, is the fact that over 50 per cent of the energy supply for the Western World primary aluminium production is hydro-electric power.

Oil, in terms of energy sources, occupies a relatively small percentage of total power supply to the industry, and in terms of the overall oil-fired source including natural gas, less than 25 per cent of the energy base. Notwithstanding this fact, the energy crisis, through changes in the availability and cost structure of alternative energy sources and alignment to high oil prices, can be expected in the longer term, to bring about some changes to the source of energy supply utilized by the industry.

Hydro-electric power would appear to remain the most important source of electrical power for aluminium production works. However, as a share of total energy sources in European countries, it could slightly decline as primary aluminium production is increased, reflecting the fact that this source of power has already been exploited to a fairly high degree. Outside European countries, however, hydro-electric power will probably be the basis of many new reduction works since it is in the developing countries that hydro resources are the most extensive and undeveloped, although questions relating to investment risk and the political climate in the resource rich countries could be key factors in determining investments in large hydro power plants.

The probability of new reduction plants being in the future based on oil or gas-fired power stations appears nil except in those countries well endowed with these resources.

In the established primary aluminium countries there appeared to be growing problems with regard to the availability of power for existing smelters in the medium term. For the new smelters, nuclear power and coal-thermal power would appear to provide an increasing share of the power for the reduction works. The planned increase in electricity generation from nuclear power stations will then in the longer term provide some new opportunities for the industry and assist in reducing the reliance on combustible fuels in a number of countries. However, the share of this energy source is still expected to be quite modest compared to that of hydro and coal based power. For coal, in some countries possible labour problems and environmetal questions may be limiting factors in the development of this source of energy for reduction plants; it should be noted however that alternative fuel sources to coal are also subject to pollution control and that the labour problems in the coal industry have not yet had a significant influence on the competitive position of coal in aluminium production.

A possible trend with regard to aluminium companies not having access to almo.' 'cheap' power sources is the purchasing of greater quantities of electricity, due to the large capital costs and long pay back periods of additional captive generating capacity. This possible development could be accentuated if the price of primary fuels (oils, natural gas, coal)rises more rapidly than electricity prices and that the past trend of aluminium companies being able to negotiate very favourable tariffs because of their larger consumption of electricity continues.

6.2. Energy requirements for primary aluminium production

The production of primary aluminium is but one facet of the energy content of the whole aluminium system where low energy re-cycling of scrap is widely practised. It is difficult to generalise on energy requirements for aluminium production since they vary markedly between plants, being related to such factors as the management decision to operate smelters to maximise efficiency (minimum kWh/t) or maximise production of ingot (output); modernization and installation of new pot lines, capacity considerations of the plant, scrap recovery and recycling rates. In considering energy requirements per ton of aluminium it is important because of problems of conversion, to draw a distinction between the electrical energy required (mainly for electrolysis) and the thermal energy required (for calcining, process steam, baking and reheating) since converting the electricity component to equivalent amounts of thermal energy is misleading and can lead to erroneous conclusions. Typically, electrical consumption is of the order of 18 000 kWh/t of aluminium.

6.3. Energy costs and efficiency

High electric power consumption has stimulated efforts to reduce power requirements in the reduction stage of aluminium production. This reduction in electricity consumption has in the past not come through any major technological shift but rather through improvements in the efficiency of the basic Hall-Héroult process. For the future, new processes now at pilot plant stage indicate that future consumption may fall to around 9 900 kWh/t.

Electricity power prices either from captive sources or purchased under long term contracts are confidential to the parties concerned and can vary markedly between countries and between plants. Although no specific cost data is available on electricity supply for the industry, some countries estimated that in their own countries they have risen by some 40 per cent since the energy crisis. For most countries, new smelter capacity will probably require new power installations or new power contracts with the incremental power prices being considerably higher than present levels.

6.4. Effects of changes in energy costs

6.4.1. on possible product substitution and competitiveness

Energy costs are clearly of substantial significance to the industry. At today's typical electricity and fuel costs and total energy, total energy represents between one-fifth and one-third of the total production cost of the raw ingot. However, many variables differ between plant and country - for example, besides efficiency considerations of the reduction works there are such factors as non-market constraints imposed by Governments, the type of energy mix used and special arrangements with electricity supply companies.

The increased energy costs could be expected to have important effects on the total costs and therefore the competitive position of aluminium and certain other materials. As the pattern of energy use by the aluminium industry is so varied and particular to each plant, it is hazardous to make energy costs and output price comparison with competitive material and to deduce from these comparisons conclusions on possible substitution. Although the energy component in the production of aluminium is high, governments have indicated no evidence to suggest that significant substitution of aluminium by other competitors (notably copper and steel), will take place as a result of the energy crisis.

For a number of countries, power costs increases have been of only secondary importance in relation to the increased costs of labour and raw materials in the primary aluminium industry. The price increases in other factors of production have also to be considered as has the cost structure of the production of competing materials as these also have been subject to increasing cost pressures. The ultimate evaluation of aluminium in the context of it's overall energy characteristics will be determined only in the market place and in this evaluation, the apparent competitive disadvantages caused by the energy crisis will be considered against the technical properties of the product. Because of the diversity of the energy resources used by the industry, it has been comparatively well sheltered from the full effects of the oil crisis. For a number of individual countries, however, the impact of the changed energy supply conditions have affected the competitive position, especially those countries which rely for the major part of their production on oil-fired thermal power.

6.4.2. <u>on structure and locational patterns</u>

The main effect on the structure of the industry of the energy crisis is expected on the future locational pattern of new reduction plants. Although any new project for new capacity will take into account a number of other factors including the likely trend in selling prices, total costs of production and comparable profitability levels in alternative locations, the location of new works will be heavily influenced by the availability and price of new energy supplies. Accordingly, the availability of large quantities of power in developing countries in the form of untapped hydraulic resources, or natural gas could be expected to attract future new capacity. Government incentives and tariffs are a further element which could modify the economic data and affect the choice of location. Already there has recently been announced a number of plans to erect new smelter capacities in some countries, for example, a number of the Middle East countries, Brazil, Venezuela, Indonesia.

Undoubtedly, the main reasons for the interest shown by some of the European aluminium producing countries in the overseas projects has been the greatly increased cost of oil-based and thermal-electric power and strict anti-pollution regulations, both of which pose far less problems in many of the overseas sites. The more abundant and relatively cheaper power would enable aluminium tonnage to be exported as "stored energy" to the industrialized countries with their high aluminium consumption. The extent to which there would be such a geographical shift will depend upon the relative importance of power availability or closeness to the consumer market. Historically, closeness to the market (given power availability) has been in most countries a major determinant of location.

It appears also likely that the location of some new smelter plants will be influenced in the longer term by the development and location of future nuclear plants. Since the development of nuclear power will be in most cases restricted to the more industrialized countries, the increased share of nuclear power in the total energy power source of the industry could revive the historical trend of new plants being located near the market.

6.4.3. on reduced power consumption and conservation measures

There is continuing research and development in both improving existing processes and finding new processes for the better use of resources. A related aspect has been the energy savings resulting from the recycling of aluminium. The enrgy necessary for the recycling of aluminium from 'clean' scrap (new scrap or cans)is approximately 5 per cent compared with a total energy required for making aluminium from bauxite. As a result of this factor waste recovery programmes are, in many countries, being re-examined and intensified. However, progress in these two fields will imply not only new and important investments and effective energy management, but also co-operation between governments and industries in fixing the goals in a comprehensive energy conservation programme.

7 INDUSTRY, TRADING AND PRICES

7.1. Industry

Outside the Communist Bloc a small handful of major North American and European firms own most of the known bauxite deposits, produce most of the World's alumina, smelt most of the metal, and fabricate a major share of that which is produced. These firms typically have great financial power and operate on an increasingly international scale. They are fully integrated, occupying strategic positions in the industry from raw materials to marketing, and they maintain extensive research, sale and customer-service staffs.

Apart from the major international firms there are a number of lesser producers whose operations are more restricted. They lack the organizational, technical and financial resources to impinge seriously on the international scene and are sometimes allied with or partially owned by a multinational company. In other cases metal is produced in diversified firms in which aluminium is not the major interest. Finally, there are some state-owned firms which tend to be restricted in area of operation.

7.1.1. Major International Companies

There are six companies that operate on a major international scale. Four are originally North American firms and all six have smelting operations in North America and Europe. The six comapnies represent slightly more than 40 per cent of the total world smelting capacity and about 50 per cent of the Western World's capacity. Although their share has been decreasing slightly in recent years and will continue to decrease as developing countries harness their energy potential and build their own smelters, these six companies will remain the predominant producers and price leaders.

The principal suppliers in the alumina/aluminium market are, at present:

(i) Alcan Aluminium Ltd. - fully integrated, boasting diverse bauxite holdings in Guyana, Jamaica, France, Malaya and Sarawak. Alcan has major plants worldwide and contributes through partnership in many more.

(ii) Aluminium Company of America (Alcoa) - has an advantage in America of a strong domestic base but also has principal bauxite holdings in Surinam, Jamaica and Australia.

(iii) Reynolds Metal Company - a highly diversified operation leaning heavily towards participations abroad rather than outright ownership. Reynolds has a reputation for pushing new and unusual applications of aluminium with a special emphasis on packaging.

(iv) Kaiser Aluminium and Chemical Corporation - established an extremely good position in bauxite reserves of Jamaica and Australia. Kaiser has moved to obtain both production and fabricating facilities in the principal consumption centres.

(v) Péchiney-Ugine-Kuhlmann(P.U.K.) - enjoys the predominate position in the French national market. It has bauxite interests in Guinea, Australia, Greece and France and is expanding internationally due to increased domestic power costs.

(vi) Schweizerisches Aluminium A. G. (Alusuisse) - does not have a predominantly national base and mines bauxite in Greece, France, Italy and Sierre Leone. It is known as an exceptionally well-managed firm which, despite it's modest size has been really producers whose operations are more restricted. They lack the organizational, technical and financial resources to impinge seriously on the international scene and are sometimes allied with or partially owned by a multinational company. In other cases metal is produced in diversified firms in which aluminium is not the major interest. Finally, there are some state-owned firms which tend to be restricted in area of operation.

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One or more of these firms are involved in virtually all of the aluminium projects of international significance in the free world. Development of large scale bauxite and alumina operations usually involve consortium type arrangements. The high growth rate which has been maintained by the world aluminium industry in the period since 1965 can be attributed to aggressive marketing on the part of these multi-national companies and the continuing effort they have made to improve production efficiency and develop new uses for aluminium.

7.1.2. Smaller firms

While the major international firms account for an impressive share of the world's industry, the competitive situation and policy climate of the industry are also affected by the existence of the smaller firms. Their degree of integration varies, some are only divisions of large diversified firms whose major interests lie in other fields, while others are exclusively aluminium firms.

Some of the smaller firms resemble their competitors in controlling their own bauxite and alumina supplies, but this is by no means universal. Nearly all of the bauxite produced is mined by aluminium companies and those who do not have their own supplies must often buy from their competitors. At the fabricating level they run from those who are strictly sellers of metal to those who are fabricators on such a scale as to find it profitable to have their own supply.

Among North American companies with bauxite mining and alumina capacity are Amax, Anaconda, Martin-Marietta and Noranda. Martin-Marietta's interests include bauxite mining in Guinea and aluminium refining in the Virgin Islands.

Almost as important in the industry are the various non-affiliated European producers - mainly state owned or controlled companies with a small overseas investment in raw material supply. The most prominent are Vereinigte Aluminium Werke A.G. (VAW) of West Germany; Italy's state owned EFIM Group; Empressa Macional del Alumino S.A. (Endasa) of Spain; and the Norwegian concern, Ardal og Sunndal Verk (ASV). There are various other state owned companies producing aluminium in Third World countries, often in association with the multinationals. An example is the Guyana Bauxite Co. (GUYBAU) which is wholely state owned and controls all bauxite/alumina/aluminium production in the country.

There are a few producers outside the control of the state, all multinationals, in Europe, for example, Billiton (Royal Dutch Shell). However, only one of the five Japanese producers of primary metal -

Nippon Light Metal (NLM) - is affiliated to the majors and, even then, the arrangement does not seem to affect its independence. In their own right, Japanese producers participate singly or as a group in overseas development - including smelting.

There are about fifty minor firms whose aluminium operations are restricted in scope, but which account for about 25 per cent of the world production capacity of bauxite, alumina and metal. In some countries of Europe and Japan, however, they may comprise the majority of domestic production.

7.2. Trading

Aluminium differs from other futures - trade commodities since:-

(i) captive consumption at the ingot level exceeds that of any other exchange commodity and a high percentage of the balance is sold to relatively large consumers

(ii) the high degree of supply and demand concentration reduces the need for future exchange in favour of direct dealings between buyers and producers

(iii) it not subjected to uncontrollable weather and other factors that affect the production of most agricultural commodities

(iv) it's raw materials are plentiful and it is produced in politically stable countries

(v) it's added value from bauxite to ingot, far exceeds the value added to any other commodity on a futures market

(vi) price volatility has not played an important role, because the result of higher costs has not been price instability, only higher prices.

The later the stage of production at which a mineral commodity enters international trade, the more value added accrues to the ore producing country. This is particularly true for aluminium since the value at the alumina stage is several times the value of bauxite and similarly the value added at the aluminium ingot stage is several times the value of the alumina. There are number of reasons why the bauxite producing countries, despite their inroads into alumina production, have not yet become major producers of aluminium. First, abundant supplies of low-cost energy, which are essential for producing aluminium competively, are not available in some of these countries. Secondly, smelting is capital intensive and investment is difficult to raise in developing countries. Thirdly, access to markets is complicated by the high degree of vertical integration of the major aluminium firms into fabrication. Fourthly, aluminium producers situated in or near major markets enjoy certain locational advantages - communication with customers is easier and supply pipelines are reduced.

World trade in bauxite, virtually all of which is seaborne, has grown steadily if somewhat slowly. The last fifteen years has seen the emergence of of both Australia and West Africa as major sources of bauxite supplies, and a gradual restructuring of international trade, which had previously centred on Caribbean shipments to North America. The slow growth of world bauxite trade has been the result of the establishment of new alumina refining capacity at, or near, sources of bauxite supply which limited the expansion of exisitng plants in the three main bauxite importing areas - North America, Western Europe and Japan. The U.S.S.R.,on the other hand, has been the largest importer of Greek bauxite for many years and while the U.S.S.R. (the world's second largest producer of aluminium) has been able to meet a large part of it's raw material requirement from domestic mines in the Urals and elsewhere producing low grade bauxite, as well as other aluminous ores, the growth of smelting capacity will require imports of bauxite and alumina on an increasing scale. Although a large part of the trade is overland, the U.S.S.R's imports of aluminium raw materials are already substantial. The U.S.S.R. is making an effort to secure long term supplies by collaborating in developments in COMECON countries and by providing aid to developing countries such as Guinea.

Alumina shipments have assumed increasing importance in trade in aluminium raw materials. They are widely distributed among the countries where aluminium is smelted, although the tonnages are relatively small. The growth of world alumina trade has mainly been sustained by the rapidly rising import requirements of Northern America and Western Europe - especially Scandinavia with it's cheap hydroelectric power. All of South Africa's primary aluminium production is produced from imported alumina.

7.3. Prices

Historically, the aluminium industry has been dominated by six multinational companies and this structure has led to the market being dominated by producer determined prices. Aluminium prices in current terms have followed a rather stable upward trend with real prices remaining rather steady from the mid-fifties onwards. In some ways, the current structure of the aluminium market is not dissimilar to that of the oil market before the emergence of OPEC - dominant pricing in the Seventies.

There are, however, some major differences. Firstly, the cost of the basic raw material bauxite represents only a relatively small proportion producers situated in or near major markets enjoy certain locational advantages - communication with customers is easier and supply pipelines are reduced.

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There are, however, some major differences. Firstly, the cost of the basic raw material bauxite represents only a relatively small proportion of primary aluminium production costs. Conventional estimates put the cost of bauxite at roughly 10 per cent of the final aluminium cost; even after conversion into alumina, the material is no more than 30 per cent of final cost - the remainder being capital and energy. This feature means that large percentage changes in the price of bauxite can occur without necessarily having a major impact on the final aluminium price. Secondly, the IBA, whose members account for some 80 per cent of total free world aluminium production, has attempted to alter aluminium's terms of trade in favour of producing countries by significantly increasing taxes and levies on bauxite. However, the cartel's impact has been limited by two factors: the world's largest producer Australia has not imposed any export levies; and Brazil which could be one of the largest producers in the future is not presently a member of the IBA.

There are two prices for Alumina - contract and spot. Multiyear contracts for large tonnages are the backbone of the smelters' supply. Over the long run they must be based on full costs otherwise the industry will not be able to finance new plants. Long-term contracts tend to be more expensive, giving the user a supply guarantee for the safe operation of his smelter. A constant quality of alumina from the same source brings control benefits as well.

Due to high inflation the contract based price can be less important than the escalation formula. The international alumina trade has to contend with the often abrupt exchange rate variations in currency as well. It appears that a consensus is developing towards pricing alumina as a fraction of some international separate aluminium metal price. A possible final solution is that of cashfree barter, by paying for the alumina with aluminium at an agreed alumina/metal ratio.

Spot alumina can come on the market for many reasons such as smelters with electricity problems, smelters with metal sales difficulties or alumina plants running at over nominal capacity.

A small free market exists in London but as mentioned the vast proportion of aluminium is traded at prices set by the major producers. Even so, looked at on a yearly basis the discrepancies between producer and LME prices have not been too great.

7.3.1. <u>Price forecast</u>

The system of producer pricing has generally succeeded in insulating aluminium prices from fluctuations in world economic activity. Even though it is anticipated that some changes in the organizational structure of the industry will occur, the major companies will still be the dominant force in the market so that a relatively stable time-path for aluminium prices is expected. This should be an important factor in a high rate of growth of the industry relative to other metal-producing industries and the general economy.

The time-price relationship for aluminium in U.S. c/lb historically determined by the annual average of the major producers quoted prices for unalloyed primary aluminium ingot (Metals Week) and is listed in the following table.

Average annual price (U.S. c/lb)

YEAR	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Aluminium ingot	28.8	25.9	25.2	34.1	39.9	45.1	52.2	55.6	60,0	71.5	75.8	76.0

The best fit curve for price determination in current money terms is:

Unalloyed primary aluminium ingot: PRICE = 15,627 + 5,161 * YR; r = 0,981 with YR as integer with base of 1971 = 1 and r the correlation coefficient. Best curves considered were linear, exponential, logarithmic and power.

YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Aluminium ingot	82.7	87.9	93.0	98.2	103.5	108.5	113.7	118.9	124.0	129.2

These trends are depicted graphically on the following page. This is, however, a somewhat greater price rise than is expected in other metal markets, reflecting an expected continuing buoyant aluminium demand and further substitution for other materials (average annual increase of 5,1%).

A recent price quoted for primary aluminium on the U.S. producers' list was 81.5c/lb for unalloyed ingot.

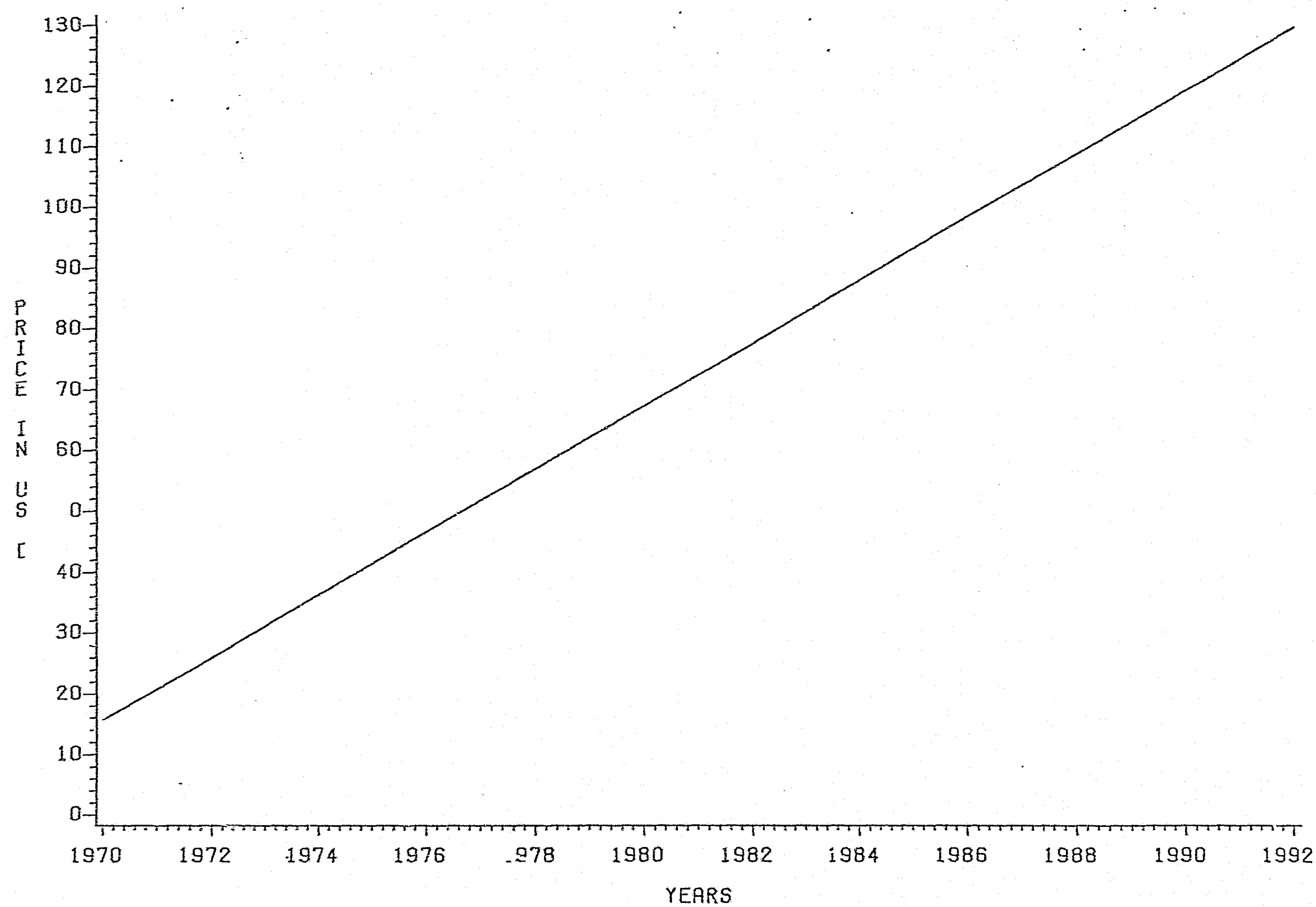
For bauxite and alumina, there are really no reliable historical series available, since bauxite tends to be traded on long term contracts and/or within the multinationals, while alumina is often swopped for equivalent quantities of primary aluminium. Any such price series would thus only be a broad average of what amounts to a whole range of different prices according to producer, grade and transfer pricing method.

8 ALUMINIUM IN SOUTH AFRICA

From 1962 to 1972 extensive field and laboratory work was carried out by the Geological Survey[48] and MINTEK[49] to assess the possibilities of the local sources of aluminium. The areas and occurences investigated were:

(i) diaspore-bearing shales of the Gamagara Formation near Postmasburg (G8) having an unusual alumina content of around 42 per cent and is probably a fossil bauxite.

(ii) microcline syenite of the Phalaborwa Complex (B16) having 12 to 18 per cent alumina



AVERAGE ANNUAL PRICE
IN U.S. CENT PER POUND

(iii) nepheline-rich ijolite from the Spitzkop Alkaline Complex (B16)

(iv) andalusite and staurolite from the contact zone around the Bushveld Complex containing about 48 per cent alumina

(v) anorthosite from the Bushveld igneous complex and from the Mopane area in the Northern Transvaal (A14) but undesirable magnetite is present

(vi) sericitic rocks of the Dominion Reef System in the Klerksdorp area (E11)

(vii) flint clays from the Karoo System between Hammanskraal and Bronkhorstspruit in the Transvaal containing about 40 per cent alumina; the deposits are layered with siliceous or carbonaceous sedimentary material present but any one clay basin holds only about 1 million tons.

Plastic refractory clay occurs as layers two to five metres thick at the base of the Ecca Series on the East Rand and as thick deposits (20 to 40 metres) in outliers of the Ecca Series between Lawley and Carletonville. The inferred reserves in the latter area exceed 200 million tons and the alumina content of the raw, uncalcined material averages about 24 per cent.

During the course of these investigations gibbsite was discovered in a brown-red or yellow-brown clays resulting from the lateritic weathering of basic rocks in the high rainfall areas of South Africa. These areas extend from the Soutpansberg in the Northern Transvaal southwards along the Drakensberg escarpment into Natal and the Transkei. Free alumina is present as gibbsite in these clays, but the percentages are too low and the occurrences too erratic to make them profitable sources for the production of aluminium.

Nodules of gibbsite were discovered in the Humansdorp district (L8-9) on the uplifted coastal plain between the Tsitsikama Mountains and the sea. They are only found sporadically and in completely insignificant amounts in sediments of Tertiary age which cover steeply dipping rocks of the Cape System.

During 1976 appreciable resources of ferruginous bauxite were discovered by Helmuth Redinger Exploration and Development (Pty) Ltd. in the Ngome area (F16), in the Weza Forest Reserve (I14) and elsewhere in Natal. The deposits have resulted from residual weathering under specific climatic conditions of dolerite sills or of baked shale overlying the sills. In places clay occurs within the bauxite or underlies it. Analysis of a composite sample considered typical of the bauxite (average thickness 2,4 metres) over 12 hectacres on Mooiplaats 537 in the Ngomi area revealed 25 per cent Al_2O_3. According to the diffractograms of the sample abundant minerals are gibbsite, goethite, quartz, chlorite and montmorillonite; smaller amounts of mangnetite, ilmenite and orthoclase are also present. Because of extraction costs and restricted availability (in the case of flint clay and gibbsitic clay), some of these materials cannot at present be considered as practical sources of aluminium.

During the past few years, the Geological Survey of South Africa evaluated several bauxite deposits in the Howick-Mooi River area of Natal. Reasonably large tonnages were established at some deposits, but the grade of alumina is predominantly low and the ore unsuitable, in it's natural state, for the Bayer process. The direct reduction of low grade bauxites to alumina by other processes is extremely costly and complex.

8.2. Non-bauxitic sources [50]

No significant deposits of bauxite have been found in South Africa (Weza is considered medium quality ore, mineable only by open cast methods) but the non-bauxitic sources of alumina are abundant though varied. Two non-bauxitic routes to alumina production are being operated on an industrial scale in the Soviet Union. The raw materials used in one of the processes are syenite and limestone which occur in large quantities in parts of South Africa, but considerations of the country's infrastructure indicate that other raw materials should be examined first. The following factors should be considered:

(i) The Bauxite-Bayer route to alumina is long established. Improvements and efficiencies that have been implemented through the years make that route a very formidable obstacle to the introduction of a viable new process based on different raw materials.

(ii) Other than the two Russian operations, there is only a Polish Grzymek non-bauxitic process (which treats power station fly ash and limestone to yield alumina and cement) which approaches industrial scale operations. However, unlike the Bayer process, they all have useful and marketable co-products, thus a novel alumina process utilizing a raw material with co-product possibilities is desirable.

(iii) The cost of the raw material should be less than bauxite.

(iv) The use of raw materials as far down the processing line as possible such as material that has already been mined and comminuted. Power station fly ash is such a material. It may also be possible to obtain reasonable quantities of aluminium in solution from uranium plants.

(v) The availability and price of required reagents and the existence of a suitable infrastructure.

(vi) The size of the deposit.

Considering the possible future demand for alumina (section 5.5) it is best to select deposits capable of yielding 300 000 tons of alumina yearly for, say, 25 years. On the basis of 80 per cent extraction of alumina from an ore having an alumina content of 35 per cent the deposit should be of the order of 27 million tons.

In consideration of the size of the ore-body, the possibility of obtaining low-cost raw material and co-products, and questions of suitable infrastructure, the following sources of alumina should be taken into account:

(i) Phlogopite: a typical analysis from the Phalaborwa Complex reveals 14,4 per cent Al_2O_3; 11,0 per cent K_2O and 22,8 per cent MgO. This material has a possibility of yielding two co-products, K_2O and MgO. There is, however, no direct rail link between Phalaborwa and Richards Bay.

(ii) Sasol gasifier ash: the Transvaal Sasol produces large quantities of ash in the form of clinker which may be porous and thus accessible to reagents. Sasol is not unfavourably sited as far as infrastructure is concerned and the ash should be available at very low cost (Al_2O_3 content around 33 per cent).

(iii) Power station fly ash: Pulverized coal is used for heating the boilers in the more modern stations. About 85 per cent of this coal finally becomes fly ash (smaller than 200 mesh). Useful co-products do not appear to be possible unless the Grzymek process is used. If 300 000 tons of alumina per year is to be produced fly ash from one of the larger power stations will have to be used. These are Arnot, Camden, Hendrina, Kriel, Matla and Dhuva, which are all reasonably favourably situated for the transport of alumina to Richards Bay.

(iv) Coal mine wastes and shale: There are two sources of aluminous material associated with coal mines. One is the tailing from the coal-washing plant and the other is the shale above or below a coal seam. The latter appears to be preferred raw material for the P.U.K.H -Plus process. With the advent of strip mining, shale has become easily accessible and the small amount of potassium co-product can also be expected.

(v) Plastic refractory clays: The clay deposits on the West Rand are large. They appear to be somewhat less favourably situated than coal ash and shale for transportation to Richards Bay but since the U.S. Bureau of Mines 'Mini-Plant Programme' proved one of the routes used on clay to be economically viable, these deposits could become attractive.

The most successful of the processes tested by MINTEK was the production of alumina from Sasol power station fly ash by the ammonium sulphate roasting technique. Of the mini processes proposed for the production of alumina from non-bauxitic sources, very few have been developed to the pilot plant stage. No reliable estimates of the cost of production can be made on most small scale work, and it is not known what problems will arise on scale-up. The discouraging feature is the enormous cost involved in the erection and running of a pilot plant. Other countries - the U.S.A. and France for example - have greater incentives to become at least partly self-sufficient in alumina.

8.3. Barriers to entry

The tightly integrated nature of the involvement of the multinational companies in the industry highlights what is essentially a captive market for the majority of the world output at the various stages of the productive chain from bauxite to end product. This, in itself, represents a barrier to entry for would-be competitors irrespective of the point of the chain chosen. Additionally, economies of scale dictate that to be competitive,mining, refining and smelting units must be of a size which prescribes substantial amounts of initial capital. It is unlikely that these funds would be forthcoming without the involvement of an integrated company, as financiers tend to view it's participation as an indication of the feasibility of the project, availability of management skills and access to markets. Government involvement cannot provide these aspects.

Most shipping movements are also controlled by the multinationals, although some producing countries have entered into arrangements to transport part of their bauxite and alumina under national fleets. The multinationals do not own large fleets, but control most of their movements through long term charters and contracts of affreightment using ships registered under flags of convenience. These conditions give scope for transfer pricing arrangements whereby profits may be shifted to countries in which taxation is low or non-existent.

Thus, the mutually interactive barriers to entry may be technology, marketing, economies of scale, management, transport and finance. The natural barrier to entry at the smelting stage may be the lack of adequate and economic energy supplies from an already over subscribed Escom.

9 SUBSTITUTES, RECYCLING AND TECHNICAL POSSIBILITIES [51]

9.1. Substitution

Copper, steel, wood, zinc, magnesium, titanium and plastics are a few of the materials that could be substituted for aluminium in some of it's applications.

Steel, stainless steel, magnesium or zinc can be substituted for aluminium in the automotive industry. Magnesium could replace aluminium for certain components in aircraft and stainless steel, and titanium could replace aluminium in high speed jet aircraft. Fibreglass, titanium and wood can substitute for aluminium in ships.

However, it is rarely possible to make a direct substitution of one material for another in an ongoing manufacturing process. Substitution almost invariably requires new types of manufacturing equipment or major modifications to existing equipment, and the substitute material must offer rather decisive advantages in costs and performance over the long term to justify the cost of adapting a manufacturing process or designing and constructing a new manufacturing plant to use it.

As a consequence, substitution of one material for another usually takes place over a relatively long time and only when one material offers desirable properties at low cost, is seen to be available in sufficient quantities and is adaptable to commercial manufacturing plants to use it.

Because aluminium often meets these requirements it has been substituted for many other materials through the years. The strong growth of aluminium markets over several decades has been largely at the expense of other materials. For example, aluminium has replaced copper for high-voltage transmission of electric power over long distances. It has captured a significant portion of the metal can market from steel, has penetrated the markets of both steel and wood in residential and industrial siding, window frames and doors, and has gained part of the former market for zinc-base diecasting and chromium plated steel in the automotive industry.

9.2. Recycling and secondary sources

Generally speaking, modern aluminium industry technology makes it possible to recycle all aluminium that is recovered from waste or scrap into useful aluminium products. Although recovered aluminium is not recycled commercially into every type of aluminium product, the range of products for which aluminium can be, and is used, is so broad that there is no danger of aluminium once recovered from waste or scrap, not being recycled into useful products.

The recovery of a ton of aluminium from waste or scrap means a saving of virtually all the raw material and 95 per cent of the energy required to produce a ton of aluminium. The savings in material would be: 4 tons or more of bauxite (depending on the quality of the ore); the materials used to refine the 4 tons of bauxite to 2 tons of alumina - 450 grams of soda and 115 kilograms of lime; the materials used to process the 2 tons of alumina into primary aluminium - 680 kilograms of petroleum coke and pitch, 27 kilograms of cryolite and 36 kilograms of aluminium fluoride. The energy required would decrease from 50 000 kilowatt hours per ton of primary aluminium to only 2 500 kilowatt hours per ton.

The Australian experience supports the economic viability of recovering aluminium from most forms of scrap. However, the authorities cautioned that while savings are realised in energy and raw materials, there are other costs. For instance for the collection, transportation, storage and emission control equipment. Additionally, the primary metal is a high energy user - for example the aluminium can requires 2,5 times the amount of energy to produce a steel can. Thus, while the nett energy saving in the aluminium recycling process is considerable, this must be viewed in relation to its high gross energy use.

Over 90 per cent of the new aluminium scrap generated in the production of end products is recycled to the production cycle almost immediately after it is generated. However, the recycle time for old scrap, virtually all of which is purchased, varies considerably on the form and end use and is normally much longer than for new scrap. Some aluminium products may be in use ten to thirty years before they are scrapped. Aluminium cans and certain types of foil are exceptions and may return to the production stream a few months after the aluminium industry has shipped metal for their manufacture.

Given present technology and industry practices, about 15 per cent of the aluminium being put in use in manufactured industrial and consumer aluminium end products is expected to be recovered over the next twenty years. Only a fraction of the aluminium metal used in dissipative applications (alloys, chemicals and explosives) is ever recovered. Some can and beverage manufacturers have extensive aluminium can reclamation programmes and in recent years aluminium cans have become the largest single source of old aluminium scrap.

By-products of the aluminium production cycle are relatively insignificant to the industry and do not influence domestic aluminium supply. However, a substantial portion of the U.S. production of gallium, is a by-product of bauxite processing. In Europe, iron and vanadium have been produced as a co-product of the bauxite processing operation. In the U.S.S.R., potash, soda ash and cement materials are the important co-products from processing non-bauxite ores for aluminium.

Section 5.4.2. discusses the distribution and capacities of the major producers of secondary aluminium in South Africa.

9.3. Technical possibilities

The occurence of bauxite in relatively remote tropical regions suggests that small additional reserves will be discovered as exploration continues. Development of a commercially viable process for producing alumina from non-bauxite materials such as clay and oil shale may greatly increase future availability of supply. Other technological trends, inclduing improvements in alumina reduction methods and efficiencies, such as the addition of other compounds to the processing electrolytic cell and the development of new electrode materials will tend to keep aluminium competive with other materials. A shift to a fluoride-free electrolyte as means of reducing energy requirements and air pollution could be developed commercially. Such a development could lower power requirements and costs.

10 CONCLUSIONS AND RECOMMENDATIONS

Energy cost constitutes a very significant part of total primary aluminium production costs and increasingly decisions on smelter site will favour locations where low cost energy sources are available. In South Africa this could be obtained from supplies of low-quality coal unsuitable for export.

Only three IBA countries produce alumina and primary aluminium as well as bauxite thus the threat of severed supply by cartelization is greatly diminshed.

Unless the present inflation or some other kind of upheaval makes itself too great a burden, an annual growth rate of 4,2 per cent in aluminium consumption can be assumed for the next ten years. The growth rate may be even higher for a time while the Black population is increasingly being introduced to an industrial-consumer economy.

Close contact should be developed and maintained with both the U.S. Bureau of Mines and P.U.K. alumina projects, before any research and development work is undertaken locally. However, it will be necessary to determine precisely whether the selected indigenous raw materials are amenable to treatment by the processes.

The anticipated average annual increase in price for aluminium is 5,1 per cent, which could possibly be somewhat optimistic considering current depressed metal markets. An upswing in demand or substitution for other metals in the future could, however, provide the stimulus for approaching the predicted figure.

Sodium hydroxide is the main chemical input at ALUSAF and is expensive in South Africa. Expansion of the potash and soda-ash industries from which it is derived, may reduce this cost.

ALUSAF currently holds three months stock of alumina which together with industrial metal stocks and reclamation provides an effective stockpile to one year's demand for aluminium.

Although imported finished metal could be utilized (from diverse producers) if the alumina supply was threatened, the short term and long range strategic positions of South Africa with respect to aluminium are vulnerable to political and economic actions in other countries. Further exploratory work should thus be carried out to determine the extent of local bauxite reserves.

E: INDEX FOR STRATEGIC METALS[16]

INTRODUCTION

A resumé of the book 'THE STRATEGIC METALS WAR' by J. Sinclair and R. Parker is included to provide insight into the procedure companies or even countries could adopt to enable them to assemble a balanced investment portfolio which would minimize possible fluctuations in the global supply and demand of the metals considered.

As a political lever, the strategic metals concept has been a major factor in every serious conflict since World War Two. It has gained particular momentum from the growth of electronics in industry since 1960. It has taken on a further dimension following the political changes in several of the supply countries and it has been thrown into a state of confusion by the rapidly changing balance of world economy. The international market for industrial raw materials is now of major significance for both commercial and military reasons.

All categories of consumer reliant on mineral imports - from individuals and companies to countries and political unions - need to establish their opinion on security of supply and costs to them of any disruption. An adequate assessment would include:

(i) the major resource locations
(ii) the major production sources
(iii) the political safety of labour disruption
(iv) the possibility of labour disruption
(v) the existence of external threats
(vi) the stability of the economy
(vii) the vulnerability to outside supply of natural resources
(viii) the vulnerability to energy supply disruptions
(ix) the vulnerability of the producer countries within the volatile framework of international finance.

Other considerations, extending beyond the boundaries of producer countries, must also be considered. These include risks associated with transporting raw or semi-processed materials and their liability to manipulation through collusive action on prices and embargoes. Finally the changing, how it is likely to do so in the future and the impact any shortage would make on industry and the economy generally. The availability of substitues and the long term probability of substitution are important elements in the assessment.

1 METAL RISK ASSESSMENT

Firstly, the risk is broken down into four primary components associated with the principal stages of:

(i) production

(ii) transportation

(iii) consumption (application and use)

(iv) trade.

These components are then analysed in their turn under the two headings of the likelihood of supply disruption and the economic cost resulting from that disruption. Table 30 lists the thirteen sub-components for which individual risk assessments are made and their relationship within the assessment matrix.

Table 30

Structure of the metal risk assessments

COMPONENTS	SUB-COMPONENTS	
	Likelihood of supply disruption	Cost of such disruption
Production risks	- existing capacity	- range of primary supply sources
	- labour disputes	- time lags for new supplies
	- violent conflict	
Transportation risks	- primary links (raw materials)	
	- secondary links (semi/finished metal)	
Consumption risks	-	-total economic impact
		-effect on key industries
		-availability of substitutes
		-long term possibility of substitution
Trade risks	- collusive price agreements	
	- embargoes	

Ratings from 1 to 10 are employed to quantify the assessment for each of the sub-components,(which were considered qualitively in the individual commodity studies). A low rating implies that the risks or costs of supply disruption are considered low. How each metal compares within these sub-components is shown in Table 31. As discussed later in this section, these component ratings form the basis of the total strategic rating. A short discussion on each of the sub-components of risk follows Table 31.

Table 31

Metal Assessment Ratings

PRODUCTION RISKS

	Existing Capacity	Labour disputes	Violent conflict	Range of primary supply sources	Time lags for new supplies
ALUMINIUM	1	2	1	5	8
COBALT	1	3	9	8	8
MOLYBDENUM	1	6	1	5	8
TUNGSTEN	1	1	5	6	5

TRANSPORT RISKS

	Primary	Secondary
ALUMINIUM	5	3
COBALT	9	2
MOLYBDENUM	1	1
TUNGSTEN	6	1

APPLICATION/USE RISKS

	Total economic impact	Effect on key industries	Availability of substitutes	Long term substitutability
ALUMINIUM	10	9	9	8
COBALT	4	9	7	7
MOLYBDENUM	5	9	9	8
TUNGSTEN	5	7	6	6

TRADE RISKS

	Collusive price agreements	Embargoes
ALUMINIUM	8	1
COBALT	7	4
MOLYBDENUM	3	1
TUNGSTEN	3	1

1.1. Production Risks

Table 30 identifies five sub-components which fall within this category. Three fall under the heading of likelihood of supply disruption and two under that for the cost of such disruption.

1.1.1. Existing capacity

Is existing capacity sufficient to meet current demand? Total capacity includes both primary production plus that from scrap. Recycled material is of growing importance for aluminium, where recycling requires only 5 per cent of the energy needed to produce primary metal from the ore.

Surpluses arose in 1982 in aluminium when the U.S.A. and Japan made notable production cutbacks in the face of a weakening recession-hit demand.

Molybdenum provides another instance of sudden and severe production cutbacks occurring shortly after major expansion in the late 1970's. In a high - volume metal large stocks are accumulated which can be considered as 'above ground' mines, available to be utilised in the event of a sudden increase in requirements.

1.1.2. Labour disputes

What is the historical record of labour relations in the major production areas of a metal? Do the disputes arise during the mining or the refining links of the production chain?

Generally by-product metals suffer less from labour problems since they are extracted in the later refining stages of a major metal and a smoothing effect often operates in the sense that slags may be accumulated before the low-volume by-products are separated out. This means that strikes must exceed several months duration before their effects are felt.

1.1.3. Violent conflict

What is the likelihood of wars, insurrections and rebellions in the major production countries? What is the expected effect of a war in the major production areas? It is chiefly a geopolitical assessment and reference should be made to sub-section 2.9. for each country concerned.

In the event of a war in Southern Africa, mines would be targets for destruction in addition to the havoc associated with a state of national emergency in the countries involved. The changing trends of metal production during World War Two provide a useful guide to the possible effects of a future localised or generalised war. Metals susceptible to supply disruption in the event of local war include cobalt with it's large-scale export-orientated mines in Central Africa. The effect of a war can be considered as affecting not only current production, but the purchasing and investment policies of consumers in the longer term.

1.1.4. Range of primary supply sources

Are reserves and existing mine/refinery capacity concentrated in a few countries or are they geographically widespread? It is important to determine whether the state-controlled economies are major exporters of a metal and whether they contribute significantly to Western World supply. Any examination of supply sources must now consider the possibility of obtaining the material from previously uneconomic ores in untroubled areas, using national strategic or industrial stockpiles or in investing time and capital into improving recycling efficiency.

1.1.5. Time lag for new supplies

Supposing that alternative sources of supply are available, how long will it take to obtain these supplies?

The development of new ore-bodies typically involves a timescale of between 6 and 10 years - the upper end of the range for underground mines, for those in remote areas of the world requiring extensive infrastructure and for those in difficult terrain. The expansion of existing mines and plants requires less time as does the use of specialized techniques.

The availability of above ground stocks shortens the lead time substantially but their form can vary from stocks of concentrate or alloys through the intermediate stages of partially refined metals to metal stocks of commercial purity. Industrial specifications have been tightened over the past decade to accommodate the demands of technology. Strategic stockpile qualities have to be constantly reviewed to ensure their ready industrial acceptability. Recycling provides only a partial solution given the extended lifetime of vehicles, buildings and durable consumer goods. A possible exception is aluminium used in cans with an effective life of three months.

The metal production risk assessments can be determined by averaging the five sub-components:

aluminium	3.4
cobalt	5.8
molybdenum	4.2
tungsten	3.6

1.2. Transportation Risks

These can be divided into two categories; primary risks involving the movement of raw materials and secondary risks concerned with the transportation of finished and semifinished metals.

1.2.1. Primary

What is the likelihood of disruption in transport links vital to the movement of ore and metal from the site of production to that of fabrication? The movement of materials is normally undertaken by rail, road, ship, air and pipelines.

There are several risks associated with transport by ship - dock strikes, weather and other natural forces and the length and direction of the route to be followed. Dock strikes still occur with monotonous regularity in the U.S.A., Canada and Australia although their severity has declined with the health of the shipping industry. The established concept of freedom of the seas is in some dispute, given the growth in territorial claims which may affect the passage and safety of ships passing in many areas. World shipping route choke points where problems may be expected include the Panama Canal, the Horn of Africa, the Red Sea entrance and the Cape of Good Hope.

Transport by rail can be disrupted by energy shortages, strikes, a shortage of rolling stock (as occurs frequently in Southern Africa), natural disasters or violence. The last factor embraces guerilla attacks such as those which have affected Central African railway lines to the sea.

Transport by road is less liable to disruption since trucks are smaller and can be flexible enough to travel over difficult terrain or damaged roads if necessary. Air transport is often used as a temporary solution rather than as the main type of transport (except for such high-value, low-volume commodoties such as diamonds). Air freight is expensive and can only cope with limited weights, but it is flexible and reliable and has been used in extreme circumstances - to airlift cobalt out of Zaire in the 1978 Shaba invasion.

Transport of ore and intermediate-stage metal still tends to follow traditional colonial patterns with the bulk going from the Third World southern hemisphere plus Australia to tie industrialised countries to the northern hemisphere.

1.2.2. Secondary

What are the risks in transporting fabricated products containing the particular metal to it's final consumer? Here the trade tends to be between industrialised countries and this reduces the risks other than those relating to labour problems. Exceptions include the environmentally related problems attatched to the shipment of toxic reagents and the risk of damage to electronic components.

The metal transportation risk assessments, determined by averaging the two risk sub-components are:

aluminium	4.0
cobalt	5.5
molybdenum	1.0
tungsten	3.5

1.3. Application/Use Risks

In contrast to the production and transportation risks, these are concerned essentially with the costs of possible disruption.

1.3.1. Total economic impact

Is the metal used in large weights or volume worldwide? What is the market size? On this basis it is obvious that aluminium scores highly due to the large tonnages used in almost every type of industry, whilst tungsten would rate much lower.much lower.

1.3.2. Effect on key industries

What is the end-use pattern of demand for the metal? Is it vital in the growth industries of defence, aerospace and electronics or is it merely price related?

Is consumption of the metal actually increasing in these industries or does each technological development within a sector reduce the unit requirements of the metal?

There has been a pronounced move in the developed countries towards the service industries and towards closer control of material consumption within each industry. There is a declining trend in the income elasticity of demand for a high-volume metal such as aluminium and is a function of a drive towards smaller and lighter, overall cost-competitive products in all sectors of manufacturing industry.

1.3.3. Availability of substitutes

Are substitutes available? Do they come from the same area or mine as the metal whose supplies have been interrupted? What is the cost of chenging to the substitute and the cost of the substitute itself? Is a reformulation of the final fabricated product needed or merely a simple change of process? How long would it take to adapt to using the substitute and how closely does the possible substitute resemble what it is replacing: metal for metal or plastic, glass, ceramic for metal? How would the consumer feel about the change in terms of cost, appearance and performance?

These complex questions must all be considered and the overall substitutability tends to be a compromise between cost and ability for purpose.

1.3.4. Longer term substitutability

If the disruption of supplies of a particular metal is regarded, temporary policy makers may not consider it worthwhile to obtain and adapt to substitutes. However, if the disruption is lengthy then a substitute may prove to be so effective and economical that it permanently retains a significant portion of the market. Cobalt lost a large section of it's permanent magnet market following the 1978 peak in price.

Other factors which affect longer term substitution include energy costs and environmental requirements. Energy costs cover both the energy required in extracting and fabricating the metal plus that consumed during the lifetime of the fabricated component. After the 1973-74 oil crisis, aluminium consumption increased steeply in the automobile and aircraft industry due to it's low density/strength ratio. Environmental legislation has become tighter since 1970 affecting the usage of certain compounds in industry.

The metal strategic application risk assessments, determined by averaging the four risk sub-components are:

aluminium	9.0
cobalt	6.8
molybdenum	7.8
tungsten	6.0

1.4. Trade Risks

Two trade risk sub-components, both falling under the umbrella of disruption probability are identified.

1.4.1. Collusive price agreements

Are the prices for a metal and it's ores determined by a free market or are they fixed by agreement; be it a formal international association or just an informal agreement between companies ostensibly in competition? Such price agreements vary from the formal cartels such as the IBA (comprising mainly Third World producers) through the range of international organisations including producers and consumers to informal arrangements between distinctly opposed nations.

Third World organisations have seen little success due to the lack of economic power yielded by their members, who depend heavily on the revenues from raw mineral sales. Other U.N. proposed organisations, including those for tungsten, have met with no enthusiasm from consumers and have rarely moved beyond the committee stage. Informal cartels can violate E.E.C. regulations and U.S. anti-trust legislation but remain in existence.

In several cases, one company effectively dominates Western World supplies of a particular metal such as AMAX with almost 60 per cent of world molybdenum production in 1982. This often allows the group almost total freedom of price fixing when demand is buoyant. However, during a recession, producer price wars are common and the free market mechanism grows in importance.

Terminal free markets such as the London Metal Exchange and the New York Commodity Exchange provide the markets and are much less open to individual manipulation. A merchant free market operates for most metals and published prices and records are available in most cases to provide at least a semblance of competitiveness.

1.4.2. Embargoes

Are trade patterns or prices likely to be affected politically? There have been instances of governments imposing total or partial bans on the export of particular minerals to South Africa.

The imposition of an embargo affects both parties adversely by disrupting trade and tends to be a tactic of last resort. A pessimistic analysis suggests that Third World countries could in the future halt mineral exports as an economic blackmail. Fears have prompted the build-up of huge strategic inventories world wide. Even without these safeguards, embargoes are unlikely to establish any lasting effect on trade in the foreseeable future.

The metal trade risk assessments, determined by averaging the two risk sub-components are:

aluminium	4.5
cobalt	5.5
molybdenum	2.0
tungsten	2.0

1.5. Comparative strategic ratings

The sub-component ratings, as listed and quantified in Table 31, form the basis for the overall assessment for each mineral. Firstly the sub-components are grouped under the two risk factor categories of (i) probability of supply disruption and (ii) the economic cost of that disruption. An average is calculated for each which appears at the beginning of each metal profile in Section Three.

The two factor assessments are then multiplied together to give the overall strategic assessment for each metal. The assessment ranges from 1 to 100. In broad terms it can be concluded that metals with overall ratings lower than 10.0 can be considered low risk while the medium risk range would be from 10.0 to 25.0.

The total strategic ratings for the metals under consideration would thus be:

aluminium	24.5	(HIGH) risk
cobalt	35.8	HIGH risk
molybdenum	14.7	MEDIUM risk
tungsten	15.0	MEDIUM risk

2 COUNTRY RISK ASSESSMENT

The risk assessment for each country is based on seven primary components divided into nineteen sub-components. These are listed in Table 32. The countries under consideration are:

(i) aluminium (bauxite) - Australia
(ii) cobalt - Zambia, Zaire
(iii) molybdenum - Canada, United States of America, Chile
(iv) tungsten - Canada, United States of America, Namibia (?)

Table 32

Structure of country risk assessments

COMPONENTS	SUB-COMPONENTS
Labour Risks	- incidence of strikes
	- quality of labour
	- general unrest
Political Risks	- history
	- stability
	- external dangers

Table 32 continued

COMPONENTS	SUB-COMPONENTS
Location Risks	- hostile borders
	- critical land/sea routes
Mineral Resource Risks	- adequacy of reserves
	- costs of production
	- development appeal
Financial and Economic Risks	- currency performance
	- vulnerability to manipulation
	- external indebtness
	- domestic productivity
	- foreign ownerships
Energy and other Natural Resources Risks	- domestic energy sources
	- domestic energy production
	- sources of outside supply
Dependence on Foreign Natural Resources	- contribution to industry

Table 33 highlights the component ratings determined for each country. The sub-component ratings can be found in the risk assessment tables which appear within each country profile in Appendix 8. Each country is assessed on a scale from 1.0 (lowest) to 10.0 (highest) risks.

Table 33

Country assessment ratings

COUNTRY	COMPONENTS						
	Labour	Political	Location	Mineral reserves	Financial & economic	Energy reserves	Foreign reliance
Australia	4.0	4.0	3.5	5.3	6.0	5.0	2.0
Canada	5.3	5.7	1.5	5.0	6.8	1.3	2.0
Chile	6.3	6.3	5.5	5.0	5.0	6.3	6.0
Namibia	7.7	8.0	7.5	5.7	5.2	7.7	6.0
U.S.A.	3.0	2.7	1.5	6.3	5.6	4.0	7.0
Zaire	7.0	7.3	7.5	6.0	7.0	5.7	7.0
Zambia	7.7	5.3	6.0	6.3	6.8	7.7	8.0

2.1. Labour Risks

Manpower represents the most volatile risk factor in mineral production, impinging upon every sector and being for the most part unpredictable. Labour disruptions have an immediate effect and are likely to occur in the most simple and the most advanced economies, throughout the political spectrum. The occurrence of a labour dispute can be the end product of any one of a number of problems - political, financial, locational or organisational.

Table 33 shows that on advanced economy such as Canada can be highly vulnerable alongside a much poorer developing country such as Zaire. The Polish experience of 1980 onwards has similarly shown that the centrally planned economies have problems of no lesser intensity than the West. The U.S.S.R. is also known to have major labour difficulties and low productivity.

The labour risk component within a country or region is critical to the ability to attract investment from abroad or to prevent domestic capital flowing overseas. In the developing world investment decisions by foreign parties are based less on the quality of labour and effect of unionism than they are on state of general unrest and financial viability. Certain developed countries have reversed their good position since the 1960's due to deteriorating labour performance, a rising incidence of strikes being aggravated by rising costs and falling or stagnant productivity.

Australia is a particular example, it's poor record affecting plans for the further expansion of bauxite and alumina and almost certainly curtailing it's ambition to become the world's number two aluminium producer by 1990. Canada is also afflicted with a po.. labour record particularly in the far north.

2.2. Political Risks

Metals have been used as a political weapon for centuries. Most wars have territorial gain as their incentive and the value of the territory is greatl. enhanced by the presence of economic minerals. The continuity of supply depends upon political stability and the outlook, both short and long term, is strongly influenced by the presence of external political dangers. The present relationship between politics and metals owes much to the historic background.

The three sub-components (under political risks) are important elements in the risk assessment for each country. In some cases they can prove critical. For example, Canada's political rating of 5.7 includes a below average 6 for stability because of the danger of fragmentation of federal government through the increasing power and political differences at provincial level (see the Canadian profile in Appendix Eight). Zambia's stability factor is one better at 5 because of the continuation of leadership under President Kaunda since independence in 1964 and in spite of severe economic difficulties.

The political risk component is probably the most critical of all the components covered, given that it is the most volatile. A mine or mineral production source can only be established where a suitable deposit exists and this is invariably a lengthy and costly operation. The commercial risk can be reasonably assessed and changes within it can be accomodated to a degree.

The labour risk tends to change only slowly. The political risk can and often does, change rapidly, totally and without any opportunity of redress. It is the factor now receiving more attention by investors worldwide in their choice of a minerals production location. The political factor in minerals supply is being seen more aggressively in marketing where government agencies are tightening their grip like Zaire and Zambia.

An increasing political risk factor for a country indicates that the immediate availability of it's major metals is in doubt and the maintenance or expansion of it's long term facilities is in danger. Included in this category are bauxite and cobalt.

2.3. Location Risks

These risks relate to the supply of a mineral by virtue of a hostile location and not with the economies of production from that location - a matter for the market place. The two ingredients are the presence or absence of hostile borders and the necessity to use transport routes which could easily be disrupted by hostile acts or natural disasters.

Typical of the location risks pertaining to a mineral are it's production in either one single or very few locations worldwide such as Zairean cobalt. Where within a country production is further restricted to only one or two locations the risk is measurably increased.

A history of hostilities between neighbouring countries further increases the location risk. Since 1980 the inter-African risk has all but dissolved with the exception of the border terrorists activities against South Africa. The Canadian, U.S.A., Mexican alliance appears set in spite of Mexico's financial problems and Europe's East-West demarcation is not seriously in dispute.

Commercial problems of location apply to the high mountain regions of the Andes (Chilean molybdenum) and the long road and rail routes connecting mines and ports in Central Africa and parts of Australia. In some cases these spill over into military significance. Certain routes are recognised as potential choke-points and have been the subject of close attention by the World's naval powers. The interraction between land and sea based transport systems is critical to the entire risk assessment. It is ironic that several countries use the South African railway and port network to bring their minerals to the world market and in doing so have to run the gauntlet of two critical transport choke points, one internal and one external.

But, as noted, mines can only be built where ore bodies exist. The location factor is therefore practically a constant whose effect on the market is a variable. A persistently high location risk rating can deter investment but only to a degree.

2.4. Mineral Resource Risks

When the post-World War Two commodity boom was at it's height during the 1960's and the annual demand for the major minerals was increasing at rates of between 5 and 10 per cent, it was a popular belief that world resources were in danger of total depletion. It is now obvious that they are not. The U.S. Bureau of Mines gives a broad resources base which includes, in years of total world consumption at 1981 rates:

bauxite (260 years), cobalt (116 years), molybdenum (97 years) and tungsten (56 years).

However, resource determination is a dynamic procedure and more relevant, strategically and economically, is the world distribution, the cost of production and the development appeal. Sub-economic deposits at present are:

(i) bauxite - clays, coal wastes and oil shales containing alumina

(ii)cobalt - western U.S.A., sealed nodules and lateritic nickel/irons.

The adequacy of reserves is obviously a prerequisite to development but in a market which has become distorted by the effects of a high growth era ending with an abrupt recession, production costs and overall development appeal dictate the direction of investment. Developing nations have lost some of their investment attraction but the established lenders, who are also the major commodity consumers, have recognised that unless the emerging nations are encouraged to produce a high level of raw materials output they will be unaole to sustain themselves. The problem would then be thrown back at the establishment: trade or aid. The mineral resource component does not consider this aspect; it confines itself to the existing mining investment attractions, balanced between the availability of resources and the ability to exploit them efficiently.

2.5. Financial and Economic Risks

Although the causes and effects will long remain a source of debate, there can be no argument that inflation and general monetary and economic instability closely followed the 1973 OPEC oil crisis. The commodity consumer boom halted, raw materials price control began to break down and the rational analysis of investment in minerals production was rendered more difficult. It was not a simple case of reassessing the situation in the light of raw circumstances - the minerals industry was geared to expansion and had incurred a heavy borrowing commitment.

The succession of financial and economic traumas afflicting the 1973-82 period resulted in the state of total uncertainity which surrounded the metals industry in 1983. By 1983 it was reluctantly accepted that prospects of a sustained world economic recovery were slender. Overspending by developing need to sustain their economies by export sales.

2.7. Dependence on Foreigh Natural Reserves

This factor is more important to the established industrial nations and the rapidly developing regions than to the lower range of underdeveloped countries. But to each individual country, the factor is measured as it's dependence on supplies not found or produced domestically. South Africa emerges favourably with a rating of 4.0 because of it's wide range of domestic resources, required by the countries holding the stocks of strategic metals which South Africa requires.

This final factor encapsulates the whole question of strategic minerals policies of nations. Is it satisfactory to secure outside sources of supply if the economic and political conditions surrounding them are acceptable? As a matter of prudence should a sovereign nation develop at least partial supply domestically? Should it stockpile or develop substitutes?

A strategic stockpile should be constantly under review as to both content and volume. The development of even sub-economic domestic resources of critical materials should also be under constant investigation. As an established trading nation, South Africa must maintain a balance between national security and economic reality. A stockpile should not be planned for the traditional war scenario but to provide a short-term hedge against a disruption of mineral supplies.

The focus on financial and economic problems rather than immediate military and political threats has characterised the early 1980s to the detriment of the resource dependency issue. It would only need a single serious disruption in a critical metals supply region to bring attention back to the awareness of a growing danger: that the supply of strategic metals is increasingly capable of immediate disruption with a degree of relative ease.

2.8. Comparative strategic ratings

It might be considered that the mineral-rich developed western democracies such as the U.S.A., Canada and Australia should receive the highest strategic ratings. Yet the controls established by the 20 sub-factors ensure that fair weighting is given to every aspect which impinges on the vulnerability of a nation in respect of key minerals.

Many of the underdeveloped nations are bunched together in the 6.0 to 6.6 range because they share common problems - ample natural resources but a lack of capital funding, mounting debts and a market in surplus.

The ratings generally would only undergo a serious and rapid revision nations, encouraged by over-eager bank lending was the most serious threat to economic order. Extreme volatility in all sectors - currency parities; interest rates and commodity prices was inevitable.

With many contributing factors, this sector has the most important strategic weighting, representing 20 per cent of the total. In the greatly changed circumstances of the 1980's, countries with a poor rating in this sector are finding it increasingly difficult to attract investment of vital strategic metals. The loss of output from any of these countries would affect the market immediately. Moreover, if such a loss became long term or investment confidence ebbed it would result in a serious geographical shift in investment direction.

2.6. Energy and Other Natural Resource Risks

In a Western energy market dictated purely by cost and availability the Middle East would produce most of the oil for international consumption; Australia, the U.S.A. and South Africa the coal and uranium whilst hydro-electricity would be generated wherever possible. Until 1973 this was not far from reality since low production costs dictated price levels. Once OPEC emerged as not only a commercial but a political force the direction changed radically.

Higher oil prices encouraged higher energy costs generally. These combined with strategic uncertainity to persuade the non-OPEC world to seek energy self-sufficiency.

The supply of oil is critical to every serious economy and in spite of a weakening of the OPEC position, still has political connations. South Africa occupies a unique position. Although without domestic natural oil sources as yet, it has expanded it's coal industry into synthetic fuel production which accounts for 50 per cent of it's domestic oil requirement.

Many of the more important metal producers lack economic sources of energy, such as:

(i) Chile - molybdenum
(ii) Guyana, Jamaica - bauxite
(iii) Zambia - cobalt

The energy resources risk has changed considerably since 1973, moving from complacency, through fear, political manipulation and acute shortage into recession and surplus. It will undoubtedly become acute again since it contains so many obvious potential problems - political, geographical and commercial. The major exporters, the U.S.S.R. and the OPEC bloc, are financially and therefore politically, less strong than in 1973, having a greater if the world economy took a decisive swing away from the period of low growth and inflation control which is characterising the 1980's. Financial constraints would recede in favour of acute supply shortages and political considerations would become less onerous.

The total strategic ratings for the major or future suppliers of the four metals under consideration are averaged as:

Australia	4.26	Aℓ(bauxite)	LOW RISK
Canada	3.94	Aℓ,Mo,W	VERY LOW RISK
Chile	5.77	Mo	MEDIUM RISK
Namibia	6.83	W	VERY HIGH RISK
U.S.A.	4.30	Mo,W	LOW RISK
Zaire	6.79	Co	VERY HIGH RISK
Zambia	6.83	Co	VERY HIGH RISK

It is of interest to note that a similar risk determination gave a value of 5.30 for South Africa.

2.9. Suppliers of strategic metals for South Africa

2.9.1. Australia (country risk factor 4.26)

Australia's development as a leading minerals producer and exporter has largely come about since 1960. Production is concentrated on high-volume raw materials such as bauxite - of which it produces almost a third of the world supply - coal, manganese, lead, zinc, copper, iron ore, titanium sands and nickel. It is also an important source of gold, tin, tungsten, cadmium and antimony. Large uranium reserves have been proved but their development has been fraught with political and environmental constraints.

2.9.2. Canada (country risk factor 3.94)

Canada is the world's leading exporter of minerals in value terms and is the foremost producer of molybdenum,nickel, zinc and asbestos. It is also a major supplier of aluminium, lead, silver and copper together with by-products including cadmium, cobalt, selenium and platinium. The country is deficient in chromium, bauxite,manganese and tin. Gold output is second only to South Africa in the Western World and production is currently being expanded.

It's unusual natural advantages of long term reserves of a wide range of economic minerals are assisted by an abundance of energy resources. Offsetting these are historic political problems, a recent history of poor labour relations and a current economic crisis in which high unemployment, inflation, poor industralisation and the nationalisation of natural resource projects are dampening investment appeal. If the political-economic climate can be improved the risk rating could drop towards 3.0 to 3.5.

2.9.3. Chile (country risk factor 5.77)

largest level of known reserves and being the second largest producer in annual output terms in 1981. It's high dependence on this mineral, however, underlines it's vulnerability although it does hold the number two position in molybdenum.

The country has undergone a series of political and economic transitions since 1970 and now enjoys one of the few recent successes amongst South American countries. After a brief flirtation with communism under Allende in the early 1970s, a period which saw the U.S. multinationals dismissed and the copper industry nationalised, Chile is once more under the firm control of a right-wing military regime. The country's politics have earned it enemies in both international political camps but it's economic recovery since 1979 has been impressive. The peso is now tied to the U.S. dollar, the annual inflation rate was reduced from a high of 200 per cent to single figures although by late 1982 it was again climbing.

New incentives for foreign investments have attracted back multinational companies. The emphasis remains on copper but precious metals and fuels are also being actively pursued.

2.9.4. Namibia (country risk factor 6.83)

SWA/Namibia is administered by South Africa under a trusteeship which dates back to the League of Nations in 1919. For many years there has been intense international pressure for this to be relinquished in favour of independence for the region's one million inhabitants. South Africa has absolutely refused on the grounds that none of the constitutions so far proposed would protect either ethnic interest or the integrity of the long common border. The issue is complicated by the political problems of Angola, Namibia's immediate northern neighbour. An effective state of guerilla warfare exists in Namibia, the anti-South Africa SWAPO group using Angolan territory as a springboard. The country is rich in diamonds, uranium and base metals, to which coal finds have been recently added. It is geographically unattractive and greatly lacking infrastructure but could attract large scale foreign investment given a permanent political solution. Namibia may become a vital supplier of tungsten for South Africa.

2.9.5. U.S.A. (country risk factor 4.30)

The rise of the U.S.A. from underdeveloped status to first place as an industrial and military power took less than 60 years. It profited from the key elements of a young immigrant population, a large scale landmass, a compatible climate and a wealth of resource minerals. The outcome is an economy which, whilst now showing some premature ageing cracks, leads the world in minerals production and consumption and is the focal point of the international currency system. In broad terms the U.S.A. consumes 30 per cent of the world's raw materials which produce 35 per cent of it's GNP. It ranks in the top ten in production of no fewer than 20 of the most critical industrial minerals. With minor and temporary exceptions, the direction of the U.S. economy governs that of the world generally.

2.9.6. Zaire (country risk factor 6.79)

One of the largest countries in Africa and one of the more industrialised, Zaire is important for it's minerals output as well as it's strategic location. It ranks first in cobalt and industrial diamonds and is listed in cadmium, tin and tantalum. The country's desperate finances, which deteriorated rapidly between 1975 and 1979, have received criticial attention from the IMF and the Western banking system. Under strict guidelines, the performance has begun to improve, although low metal prices and a poor diamond market have held it back. Although President Mobutu has retained power for over a decade, his grip has been challenged on both ethnic and economic fronts. Foreign exchange levels, external indebtness and a dearth of vital manufactured supplies remain severe problems and the country is not equipped to weather a prolong market recession.

2.9.7. Zambia (country risk factor 6.83)

Zambia's position as the non-communist world's third largest producer of copper and cobalt makes the established nature of it's economic difficulties and it's critical geographical location in Central Africa all the more serious. It's politically admirable severence of links with Zimbabwe during the critical 1965 - 79 period hurt the economy deeply, a condition aggravated by the growing world surplus of copper, upon which Zambia relies for about 90 per cent of it's foreign exchange. The mining industry is losing it's competitive edge on a world basis, irrespective of the increased cost of oil upon which the country is totally import-dependent. During the independence period Zambia has swung from a modest exporter of foodstuffs into a serious importer and the entire economic structure relies heavily upon sympathetic treatment by the IMF. The political regime led by the sole President since 1964, Kaunda, is now an official one-party system. This introduces a degree of stability but, with the attendant economic problems, an undercurrent of unrest is ever present. Unfortunately no immediate relief appears in sight for the market in either major mineral so that any improvement can only come via productivity and marketing.

3 METAL STRATEGIC PROFILES SUMMARY

This section highlights the major features of the commodity profiles of the metals studied and briefly records the most vital facts to be considered in constructing a foreign minerals supply portfolio for the metals.

3.1. ALUMINIUM (Aℓ)

Factor for likelihood of supply disruption	3.0
Factor for cost of such disruption	8.2
Total strategic factor	24.5

Components of Risk Assessment (ratings 0 to 10)

(i) Production risks

Existing capacity (1):	current surplus capacity but mothballed plants could be brought on stream should demand warrant it
Labour disputes (2):	most likely in the later production stages during electrolytic reduction or fabrication processes largely undertaken in the developed countries
Violent conflict (1):	unlikely in most of the important supplier countries
Range of primary supply sources (5):	reasonably broad for bauxite although five countries control 75% of world output
Time lags for new supplies (8):	supply lines and lead times are long in almost all cases

(ii) Transportation risks

Primary (5):	interruptions feasible considering the extended shipping routes involved which incorporate several choke points
Secondary (3):	transportation of aluminium metal and fabricated products generally undertaken between industrialised countries; history of strikes at Canadian ports

(iii) Application/use risks

Total economic impact (10):	large volume market with world consumption around 16 million tons per annum
Effect on key industries (9):	high technology base with bias towards aerospace, improved performance vehicles etc.

Availability of substitutes (9):	alternative aluminium ores are available but currently not viable for bulk output; alternative end-use materials available but with cost, density or other disadvantages
Longer-term substitutability (8):	adequate long-term substitutes unlikely for aluminium

(iv) Trade risks

Collusive price agreements (8):	likelihood of IBA toughening up on prices and producer country revenues within the next decade; host government involvement in projects initiated by multinationals is growing
Embargoes (1):	unlikely given the dependence of many countries on the income derived from bauxite and alumina output

3.2. COBALT (Co.)

Factor for likelihood of supply disruption	5.0
Factor for cost of such a disruption	7.2
Total strategic factor	35.8

Components of Risk Assessment (ratings 0 to 10)

(i) Production risks

Existing capacity (1):	current surplus capacity both at mining and processing stages
Labour disputes (3):	mineworkers in Southern Africa have a poor strike record, as do those in Sudbury, Canada which is however a less important source
Violent conflict (9):	Southern Africa has never been considered a stable area and future coups must be expected
Range of primary supply sources(8):	65 per cent of annual Western output derives from Zambia, Zaire, Zimbabwe and Botswana
Time lags for new supplies (8):	supply lines are long and lead times depend on nickel/copper project plans

(ii) Transportation risks

Primary (9):	the main producers are landlocked with poor links to ports; extended length shipping lines to most consumers
Secondary (2):	transportation of cobalt metal and compounds is relatively risk-free

(iii) Application/use risks

Total economic impact (4):	medium volume market with consumption at about 30 000 tons per year
Effect on key industries (9):	bias towards important growth industries of aerospace; military equipment and power generating machinery
Availability of substitutes (7):	substitutes viable for magnetic applications but often inferior on performance basis in superalloys and paints
Longer term substitutability (7):	would involve the development of a whole series of alternative alloys which is currently unlikely

(iv) Trade risks

Collusive price agreements (7):	Zairean and Zambian producers attempt to co-ordinate prices but are often undercut by Canadian and U.S.S.R. producers

3.3. MOLYBDENUM (Mo)

Factor for likelihood of supply disruption	2.0
Factor for cost of such a disruption	7.3
Total strategic factor	14.7

Components of Risk Assessment (ratings 0 to 10)

(i) Production risks

Existing capacity (i):	market currently glutted with 1981 year-end surplus of about 6 months world production
Labour disputes (6):	the copper and molybdenum mining industries of Canda, the U,S.A. and South America are particularly prone to extended strikes

Violent conflicts (1): unlikely to affect molybdenum output since the main producers are relatively stable

Range of primary supply sources (5): reserves are large but concentrated in the U.S.A., Canada and Chile; in 1981 the U.S.A. produced 65 per cent of the world mined output

Time lags for new supplies (8): up to 10 years for new mine; with a high degree of infrastructure to support operations which are often in remote locations; several major projects in N. America near the development stage

(ii) Transportation risks

Primary (1): major transport routes from North and South America to Europe, Japan and Russia

Secondary (1): transport of steels and other alloys containing molybdenum have rarely been disrupted

(iii) Application/use risks

Total economic impact (5): medium-sized market around 100 000 tons per year

Effect on key industries (9): use is concentrated in steels for energy generation, oil and gas pipelines and weight sensitive applications plus superalloys for military and aerospace industries

Availability of substitutes (9): main substitute as alloying element is tungsten but molybdenum is usually preferred due to lower cost and superior performance

Longer term substitutability (8) molybdenum's optimum combination of physical properties has encouraged industry to develop new materials containing it and is thus a long term growth metal

(iv) Trade risks

Collusive price agreements (3): occurs due to small number of major producers but effectiveness of

	informal 'cartel' limited by U.S. antitrust laws, the free market and current glut
Embargoes (1):	unlikely except as a component of high-strength low-alloy steels for gas pipelines

3.4. TUNGSTEN (W)

Factor for likelihood of supply disruption	2.6
Factor for cost of such a disruption	5.8
Total strategic factor	15.0

Components of Risk Assessment (ratings 0 to 10)

(i) Production risks

Existing capacity (1):	currently in over-capacity with major cutbacks by producers in Canada, the U.S.A. and Australia; also large stockpiles in Europe and the Far East
Labour disputes (1):	unlikely to affect the bulk of output derived from Communist countries
Violent conflict (5):	output concentrated in below-average stability countries whilst demand/ prices would increase during a war
Range of primary supply sources (6):	China provides 26 per cent of world mined output with another 18 per cent from the U.S.S.R. and North Korea
Time lags for new supplies (5):	up to 8 years to develop new underground mines but wolfram ore bodies occur erratically and are difficult to assess

(ii) Transportation risks

Primary (6):	transport routes are long and Chinese exports are erratic in timing and volume; main importers are long distances from major producers
Secondary (1):	few problems in transporting tungsten products or ammonium paratungstate (APT)

(iii) Application/use risks

Total economic impact (5):	market volume totals about 52 000 tons per year
Effect on key industries (7):	mainly used for carbide for tool tips and to improve the properties of tool steels, superalloys, special armour plating and heavy duty steels
Availability of substitutes (6):	available and often cheaper; molybdenum is an alternative alloy constituent and titanium or tantalum carbides may be used for tool tips
Longer term substitutability (6):	extensive engineering changes required to effectively replace tungsten, particularly unlikely in the electrical sector

(iv) Trade risks

Collusive price agreements (3):	UNCTAD conferences on the stabilisation of tungsten prices failed in 1981 and the producer countries' working committee has had limited success in balancing supply/demand and stabilising prices
Embargoes (1):	unlikely since China needs foreign exchange generated by exports and limits set elsewhere on tungsten trade are not expected

3.5. Summary

Aluminium has a moderately high strategic factor (24.5) due to it's vital importance in all aspects of modern technology, from cars to supersonic jet aircraft. Energy requirements and long haul transport remain problems but the ore is mainly mined in politically stable countries. Substitutes for the metal and it's ore are difficult to exploit and currently not viable or inferior in quality. Aluminium is a high volume metal with particular involvement in growth industries due to it's unique combination of properties.

Cobalt has a high strategic factor (35.8) due to it's importance in the electrical, aerospace and machine tool sectors and fears that the supply disruptions of 1978 could be repeated. Over 60 per cent of all cobalt derives from Southern Africa and it is largely a by-product of nickel or copper mining.

Substitutes are usually of inferior quality and not suitable for cobalt's performance sensitive markets. Viable land-based reserves are relatively limited.

Molybdenum has a moderate strategic factor (14.7) due to the optimum combination of it's physical properties which encourage it's extensive use in the manufacture of alloy steels and other materials for defence applications. Reserves are heavily concentrated in the U.S.A. and Chile. Over half of the annual mined production derives from the U.S.A. although large capital investment in the 1970s has helped develop deposits in other countries. The metal is currently in gross over-supply but it has shown an excellent record of growth in consumption since 1946, mainly in energy-related and high technology applications, Substitutes are, in most sectors, inferior on cost and performance grounds.

Tungsten has only a moderate strategic factor (15.0) despite the heavy dependence on China and North Korea for mined supplies. It is a fairly low tonnage metal and substitutes are available in most applications. It is valued for it's useful combination of strength and wear resistance, especially at high temperature, and is mainly used in metal working and construction machinery. In South Africa it is vital to the mining industry in the form of tungsten carbide tipped rockdrill bits. New projects are coming on stream to reduce the West's dependence on erratic Chinese exports and major supply disruptions are unlikely.

APPENDIX ONE

PRINCIPAL WORLD MOLYBDENUM MINES IN 1980

Country	Company	Mine
Bulgaria	Government (?)	Medet
Canada	Bethlehem Copper(P)	Iona
	Brenda Mines(P)	Brenda
	Gibralter Mines(?)	Gibralter
	Lorrex Mining(P)	Lornex
	Noranda Mines(?)	Boss Mountain
	Gospé Copper (P)	Copper Mountain, Needle Mountain
	Placer Development(?)	Endako
	Utah Mines (P)	Island Copper
Chile	CODELCO (P)	Chuquicamata, El Taniente, El Salvador, Andina
Republic of Korea	Korea Tungsten Mining(V-C)	Sangdong
Peru	S. Peru Copper (?)	Toquapala
Phillipines	Atlas Consold. Mining and Dev. (?)	Biga
	Marinduque Mining and Ind. (P)	Sipaloy
United States	ASARCO (P)	Mission, Silver Bell
	Anamax Mining (P)	Twin Buttes
	Cities Service (?)	Pinto Valley
	Climax Molybdenum (R)	Climax, Henderson
	Cyprus Mines (P)	Bagdad, Pima
	Duval (P)	Esperanza, Mineral Park, Sierrita
	Eisenhower Mining (?)	Palo Verde
	Inspiration Consold. Copper (P)	Inspiration
	Kennecott (P)	Bingham, Chino, Ray
	Magma Copper (P)	San Manuel
	Molycorp Inc. (V)	Questa
	Union Carbide (C-M)	Pine Creek
U.S.S.R.	Government (?)	Kalmakyr, Balkhash, Umaltinok, Tyrny Auz, Kadzharan

CODE:

R : disseminated replacement deposits

P : porphyry copper deposits

V : vein deposit

C-M : contact metasomatic deposits

? : unknown