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FUTURE SUPPLY AND DEMAND OF CERTAIN STRATEGIC METAL IMPORTS IN SOUTH AFRICA - A COMMODITIES STUDY

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A Project Report submitted to the Faculty of Engineering,
University of the Witwatersrand, Johannesburg, in Partial Fulfilment
of the Requirements for the Degree of Master of Science in Engineering.

Johannesburg 1984

SYNOPSIS

While South Africa is richly endowed with minerals it is unfortunately almost wholly dependent on external markets for certain metals. Some of the most strategic metals are molybdenum, tungsten, cobalt and aluminium - essential in the steel, petrochemical and defense industries.

With ever changing international markets and sources of supply it is possible that the supply of these critical metals may be severed. The problem is further enhanced by the unwillingness of certain governments to officially recognise South Africa as a trading partner because of its political structure. This places the country in an extremely vulnerable position.

From the economic aspect, there is loss of currency through the import of raw metals and in addition there is also a considerable internal market for imported finished goods containing these metals. This market could be exploited by local entrepreneurs if an assured domestic supply of the metals could be achieved.

The objective of this study is to investigate the probable future dependence of South Africa on its four most strategic metal imports. The project covers the uses of the metals locally, historical trends of supply and demand and a forecast of consumption for the next decade. Alternatives and substitutes for the metals as well as the possibility of reclamation after use are also considered. Existing local deposits and their potential economic viability were investigated to establish the possibility of extraction and processing in future years to enable South Africa to decrease it import dependence on these strategic metals.

To formulate the detailed metal commodity studies, extensive contacts were established in industry to determine local market conditions and information was obtained from academic and statutory institutions. The limited information available in print was invariably outdated rovided only a minor contribution to the project.

DECLARATION

I declare that this project is my own, unaided work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

JON STEPHEN JAMES DUDAS

20th day of January, 1984.

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A: MOLYBDENUM

INTRODUCTION

The metal MOLYBDENUM (Mo) derives its name from the Greek word for lead. For many centuries plumbago, graphite and certain forms of galena were confused with the mineral molybdenite, MoS_2, since all are very similar in appearance and some of their physical properties. By the seventeenth century it was recognised that neither graphite nor 'molybdeana' did in fact contain lead. In 1782, Hjelm succeeded in separating the metal itself as a black powder and called it molybdenum. He could not fuse the new metal into a solid mass with the equipment he had available, but in 1893, Moissan, using his newly invented electric furnace succeeded in obtaining solid metal at 99,88 per cent pure molybdenum.

The hardness of the newly produced metal, nearly equal to that of tungsten, as well as it's high melting point, immediately attracted attention as a possible alloying element for steel. The French armament manufacturer, Schneider, used it to produce armour plate. Limited use was also made for the manufacture of self tempering steels, paint pigments and chemicals. Supplies were however limited.

The shortage of tungsten, the supplies of which had been largely cornered by Germany during 1913, led to an increased demand for molybdenum. Even after this war period it was only due to the opening up of the famous Climax mine on Fremont Pass, Colorado, in 1923, that the use of molybdenum was developed during the ensuing years.

During the post-war years, virtually all molybdenum produced came from the Climax mine, still the largest single producer of molybdenum. In 1933 it was discovered that the small amounts of molybdenite present in the poryhry type copper deposits of Western U.S.A. could be recovered profitably. These deposits now constitute a major source of molybdenum e.g. Bingham Canyon, Utah.

The demand for molybdenum again increased sharply during the Second World War to 32 000 tons in 1943 from 16 000 in 1938. An increased production from Mexico, Peru and Chile as well as an appreciable amount of U.S. production came as a by-product from mining

porphyry copper deposits.

Following the end of the war demand for molybdenum again dropped but has subsequently built up to the present world production of about 73,6 million kilograms Mo exclusive of the Communist Bloc. The increase is largely due to increasing technology in the usage of molybdenum in alloy and stainless steels.

1 PROPERTIES OF MOLYBDENUM

Molybdenum is a silvery-white metallic element having a relative density of 10,2 at 20°C and a melting point of 2620° ± 10°C. Only carbon, rhenium, osmium, tantalum and tungsten have higher melting points but it retains its strength and hardness almost to its melting point. Molybdenum has good thermal conductivity, half that of copper and it coefficient of expansion is among the lowest of the pure metals. It is characterised by the ability to function both as a metal and a non-metal.

When alloyed with iron, it increases the hardenability of steel and contributes to the toughness of quenched and tempered steel. When added to the austenitic Cr-Ni stainless steels, molybdenum increases the resistance to corrosion under reducing conditions and in the presence of chlorides.

Molybdenum has five valencies, a chemical property that renders it useful as a catalyst for many reactions, including some in the petrochemical industry. Molybdenum is attacked only slowly by acids and has a strong carbide forming tendency.

Molybdenite, the sulphide of molybdenum, is the most important source of the metal. It contains 60 per cent Mo, has a lead gray colour, a hardness of 1,0 to 1,5 and a relative density of 4,6 to 4,8. Except for wulfenite, $PbMoO_4$, a lead molybdate which has been worked in some parts of the world as a source of molybdenum, the other molybdenum minerals are comparatively rare and of little practical importance.

2 APPLICATIONS AND LOCAL DEMAND

Because of it's high melting point and the fact that it retains its strength and hardness at high temperatures, molybdenum metal and its alloys are used for special high temperature applications and chemical reactions.

2.1. Stainless and other alloy steels

Molybdenum is used principally as an alloying element to impart hardenability, strength, toughness and corrosion resistance to steel, cast iron and non-ferrous metals. It is used either as the sole alloy material or in combination with others such as chromium (stainless steel), manganese, nickel and tungsten.

Molybdenum may also be applied as a coating to steel, iron, aluminium and other metals to provide resistance to wear. More recently it is being used in tool steels and in high strength/ low alloy constructional and pipeline steels in which it is in competition with vanadium and to a lesser extent, with manganese.

Molybdenum is consumed in the steel sector in both ferro-molybdenum and oxide forms in the ratio of about 1:1. Molybdenum additions in amounts of two per cent or more increase resistance to pitting corrosion. Molybdenum additions also increase surface corrosion resistance of the austenitic grades of stainless steel to a number of acids including sulphuric and phosphorus. Types 316 and 317 contain molybdenum to provide better aqueous corrosion resistance as encountered in paper and soap manufacture, and also for electroplating tanks. Type 317 actually has the highest aqueous corrosion resistance of all standard stainless steels and in this specific usage molybdenum cannot be substituted by other elements.

Ferromolybdenum is essential only as a final top-up ladle addition, the usage of which constitutes from ten to twenty per cent of total demand in this sector. The other thirty to forty per cent of ferromolybdenum consumption may be substituted by the oxides. The total demand is at present around 450 tons of contained molybdenum per year. Southern Cross Steel (Barlows) would use about 225 to 280 tons, Union Steel about 55 to 75 tons and the remainder would be consumed by the other smaller steel manufacturers and foundries.

2.2. Paint Pigments

Molybdenum is used in the paint industry as a pigment in the form of molybdates for use as catalysts and dyes. As paint pigments molybdenum compounds are widely used not only for their brilliant colours but also as anti-corrosion primers, competing with well known materials such as zinc chromate. Total consumption amounts to between 33 - 35 tons per year of molybdenum contained in oxide.

2.3. Catalysts

As a catalyst, molybdenum compounds, especially ammonium molybdate, are used in the petrochemical industry, particularly for certain synthesis reactions. They are highly selective in their action,

have high performance and a relatively low cost. The use at the Sasol II plant is by far the largest end use in South Africa of contained molybdenum. Approximately 2 800 tons per year of catalyst material is imported by the petroleum and petrochemical industries. The catalyst is a molybdenum impregnated clay (five to ten per cent Mo) which is imported as such and for this reason catalyst consumption does not form part of the local market for molybdenum oxide.

2.4. Fertilizer additive

Molybdenum is an essential trace element in plants and in particular acts as a catalyst in legumes for fixing bacterial nitrogen. It is virtually impossible to grow certain vegetables along a belt extending from Vereeniging through Benoni to Bronkhorstspruit due to a molybdenum deficiency in the soil. Similar effects appear to be quite widespread in South Africa. Molybdenum oxide is thus consumed in the fertilizer industry as a trace element additive. Usage is unknown but is judged to be very small at around 12 tons of contained metal annually.

2.5. Lubricants

Molybdenum sulphide, which is the principal ore mineral of molybdenum, is used in a highly purified form as a solid state lubricant. Molybdenum sulphide has fine laminar cleavage similar to that of graphite and slipping occurs between the parallel sheets of sulphur atoms. Usage is also unknown but is considered to be of minor importance (approximately 12 tons per year).

2.6. Other uses

Small quantities are imported in the form of molybdenum metal wire and foil and manufactured components for use in electric and electronic equipment as filament supports, anodes and grids.

Other molybdenum compounds, particularly sodium molybdate are used as corrosion inhibitors in cooling systems, especially against chloride action.

Very small quantities of molybdenum are used in the formation of superalloys, welding and alloy hard-facing rods and medicines. It is finding increasing use in propulsion applications, space auxillary power and nuclear power generation.

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3 MOLYBDENUM MINERALS

By far the most common molybdenum mineral is the sulphide, molybdenite, MoS_2. More than ninety-nine per cent of all molybdenum produced occurs as molybdenite. It is a very soft, silvery grey mineral which is similar to graphite with a pronounced lamellar cleavage.

Other less common molybdenum minerals include:

molybdite	$Fe\ O_3\ 3Mo\ O_3 + H_2O$
wulfenite	$Pb\ Mo\ O_3$
lindgrenite	$Cu_3\ (Mo\ O_4)_2\ (OH)$
koechlinite	$Bi_2\ Mo\ O_6$

These four minerals are oxidation products found in the oxidation zones of sulphide molybdenum deposits and have little commercial value.

Powellite, $Ca\ (MoW)\ O_4$, is a mineral very similar to scheelite, in which some of the tungsten is replaced by molybdenum. It is of limited commercial value and is in fact mainly a nuisance in tungsten mining.

The mineral molybdenite appears to be almost the only source of the rare element rhenium. The amount contained ranges from 200 grams per ton to 1650 grams per ton in molybdenite concentrates produced from porphyry type copper deposits. The rhenium content is usually ignored and probably lost in the roasting of the concentrate. Rhenium has solely been used for some experiments with Mo-Re alloys.

4 MOLYBDENUM DEPOSITS

4.1. Hydrothermal Deposits

These are at present by far the most important deposits being mined.

4.1.1. Disseminated replacement deposits

In this type of deposit, of which the famous Climax molybdenum mine is the classic example, the ore consists of countless veinlets, usually less than ten millimetres wide, intersecting the mass of country rock which is most commonly altered, silified granite. The grade of ore at Climax average 0,35 per cent $Mo\ S_2$ and that of the Henderson mine (a deposit very similar) is 0,5 per cent $Mo\ S_2$.

4.1.2. Brecciated ores

This type of deposit includes all of the porphyry type copper deposits. They are characteristically chimney shaped and the brecciation took place prior to mineralisation. Molybdenite is not so susceptible to oxidation, dissolution and reprecipitation as the copper minerals and tends to remain in situ. Most deposits consist of three distinct zones:

(i) an oxidized cap of leached-out copper minerals and a grade of molybdenite too low to be economically extracted on its own account

(ii) a zone of secondary enrichment between the cap and water table containing high copper values in oxidized minerals which are recovered by leaching and not flotation - as a result it is not possible to recover molybdenum

(iii) a primary zone below the water table of low grade unaltered sulphide mineralisation - concentrated by flotation and molybdenite can be recovered even down to 0,01 per cent.

By-product extraction of molybdenum from these deposits account for at least half of the world's annual output.

4.1.3. Vein Deposits

Probably the most numerous and common but they are generally small and few have proved economically viable. The largest deposit is at Questa mine, New Mexico, with reserves of 150 million kilograms at a grade of 0,173 per cent MoS_2.

4.2. Magmatic Deposits

These are rare and nearly all occur in pegmatites in association with other minerals such as cassiterite, apatite and rutile.

4.3. Contact Metasomatic Deposits

Deposits of this type are somewhat rare and generally take the form of irregular tabular ore bodies in limestones or sandstones commonly associated with chalcopyrite, pyrite and iron oxide minerals.

4.4. Current Working Deposits

The largest number of working molybdenum deposits are the brecciated ores where molybdenum is recovered as a by-product from porphyry type copper deposits. However, the major production in the Western World is still from the disseminated replacement deposits like Climax. In both of these types of deposit the

mineralisation is simple and consequently so is the recovery of molybdenum. Many of the other types of deposits have very complicated mineralisation and the recovery of molybdenum is difficult.

5 WORLD RESERVES, PRODUCTION AND CONSUMPTION

5.1. World Resources and Reserves

It is difficult to make an accurate assessment of the world reserves of molybdenum since a very large proportion is closely tied to the reserves of copper in the porphyry type deposits. Reserve data, for the most part, are restricted to quantities of molybdenum in ore deposits of producing mines or deposits under development. In a few cases, deposits judged as reasonably certain for future production are included. Table 1 gives an estimate of the world molybdenum resources and reserves as determined by Kummer in Mineral Facts and Problems[39] (' tons contained metal).

Table 1

Estimated world resources and reserves - 1980 (million kilotons)

Area	Reserves	Other	Resources
N. America			
United States	4 991	3 675	8 666
Canada	635	953	1 588
Mexico	136	363	499
Other	-	590	590
Total	5 762	5 581	11 343
S. America			
Chile	2 450	2 995	5 445
Peru	227	454	681
Other	-	272	272
Total	2 677	3 721	6 398
Europe			
Bulgaria	5	9	14
U.S.S.R.	681	681	1 362
Other	-	635	635
Total	686	1 325	2 011

'Other' is the total sum production of the minor contributors in the geographical domain.

Asia			
China	227	227	454
Iran	136	136	272
Other	5	177	182
Total	368	540	908
Oceania			
Australia	-	23	23
Other	-	181	181
Total	-	204	204
Africa	-	45	45
WORLD TOTAL	9 483	11 436	20 919

The total world resources are about twenty-one million tons of molybdenum metal - but of this the U.S.A. holds forty one per cent, South America thirty one per cent, Canada eight per cent and the Communist Bloc holds only eleven per cent of this strategic metal. The regional distribution of resources, a vital factor, seems advantageous to South Africa with almost fifty five per cent of the world resources held by North American countries with well established economic ties and trade links with South Africa.

5.2. World Production

Appendix One contains a list of the known molybdenum producing mines in the world. The two largest producers are both of disseminated replacement deposit types. It is only comparitively recently that molybdenum production from porphyry type copper deposits has become a major source of the metal. In fact many well known copper mines operated for many years before attempting to recover the molybdenum from their ore. The value of the molybdenum they produce has probably enabled them to work lower grades of copper ore.

The reserves at certain mines are very large e.g. Climax has around 500 million tons of ore containing over 1 million kilograms of molybdenum. The reserves at the Henderson mine, owned by the same company are estimated at greater than 300 million tons containing 0,49 per cent molybdenum. At the present rate of mining both mines should be active producers for at least the next forty years.

Table 2 records the Western World molybdenum output divided into four main categories for the last fifteen years as published in Mining Journal's 'Mining Annual Review'.

Table 2

Western World output (kilotons)[28]

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
United States	43	46	51	50	52	53	51	49	50	55
Canada	x	x	x	13	10	12	13	15	14	15
Chile	x	x	x	6	6	6	8	10	10	11
Other	17	21	27	2	1	1	1	1	1	1
TOTAL	60	67	78	71	69	72	73	74	75	82

x indicates Canadian production included in U.S. production and Chilean production included in other Western World output.

	1978	1979	1980	1981	1982
United States	59	65	68	64	38
Canada	15	10	15	16	11
Chile	13	14	14	16	19
Other	1	2	4	4	6
TOTAL	88	91	101	100	74

In addition, Roskill[33] reports that the total production achieved in Centrally Planned economies in 1982 amounted to 13 150 tons of molybdenum metal, this being consumed in the U.S.S.R. and it's satellite states.

There has been no production of molybdenum in South Africa.

5.3. World Consumption

The apparent consumption of molybdenum[28], produced in non-communist countries, over the last fifteen years, is listed in Table 3.

Table 3 Molybdenum consumption (kilotons)

	1968	1969	1970	1971	1972	1973	1974	1975
United States	26	27	24	22	26	32	34	25
Western Europe	+	+	+	28	24	29	35	30
Eastern Bloc	x	x	x	x	x	x	x	7
Japan	+	+	+	8	8	10	12	10
Other	30	33	38	3	4	5	6	5
TOTAL	56	60	62	61	62	76	87	77

x indicates values were included with Western Europe before 1975

+ indicates values are included under Other

Table 3 continued

	1976	1977	1978	1979	1980	1981	1982
United States	26	27	31	32	27	26	16
Western Europe	32	32	33	34	30	26	23
Eastern Bloc	7	8	10	10	8	8	7
Japan	11	11	11	11	13	12	11
Other	5	5	6	6	5	5	4
TOTAL	81	83	91	93	83	77	61

World production and consumption trends are depicted graphically on the next page , initially depicting real trends and secondly the spline of best fit to the data as determined by the computer package SAS-GRAPH.

5.4. Local Consumption

It is not possible to accurately determine the annual consumption of molybdenum in South Africa as it is not reported separately in the Customs returns. Ferromolybdenum is grouped under other minor alloys. Catalysts are grouped under articles made from molybdenum which may also include electronic components.

However assuming that of the 28 000 tons (approx.) of stainless steel produced in South Africa annually, half of it contains an average of three per cent Mo, then the demand for this application is around 420 tons. This suggests that the probable total consumption of molybdenum is less than 450 tons annually since the molybdenum containing catalysts are imported as impregnated clays ready for immediate consumption.

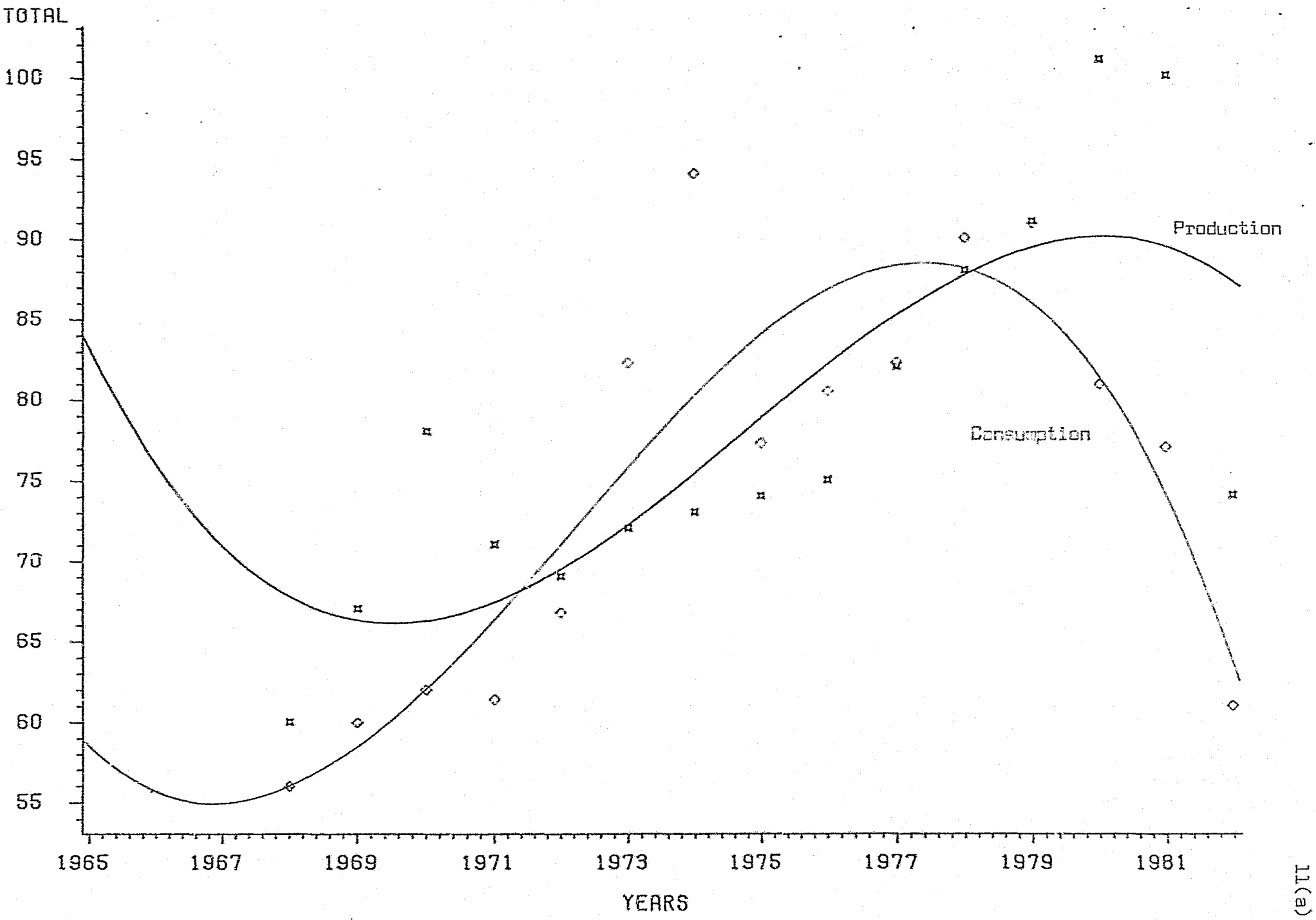
Assuming that South African consumption trends would follow the 'Other' trends in Table 3 which includes Third World and developing countries, the best fit curve determined for the data was:

$$\text{CONSUMPTION} = 3525{,}55 * YR^{0{,}188}$$

with YR an integer with a base of 1971 = 1

Curves considered were straight line, exponential, logarithmic and power. The power curve had the highest coefficient of correlation at $r = 0{,}78$.

This however gives the total 'Other' consumption. South African consumption in 1976 was estimated at 330 tons for stainless steel and



WESTERN WORLD MOLYBDENUM PRODUCTION AND CONSUMPTION (KTONS)

a total demand of 400 tons (Minerals Bureau) . This represented 8,5 per cent of 'Other' demand. Due to rapidly increasing technology in South Africa it is likely to increase it's market share of the category 'Other' by one per cent annually.

This suggests that on average the South African consumption graph would be modelled by:

$$CONSUMPTION = 0,065 * 3525,55 * YR^{0,188} * 1,01^{YR}$$

or

$$CONSUMPTION = 299,67 * YR^{0,188} * 1,01^{YR}$$

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

YR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
TONS (Mo)	552	566	579	592	605	617	630	642	655	667

These trends are depicted graphically on the following page. It is interesting to note that GENCOR in 1979 attempted a molybdenum price forecast and consumption model for South Africa and predicted a total local demand of 580 tons of contained molybdenum by 1985.

It seems that at the present predicted demand and growth rate of 4,5 per cent annually for the World molybdenum consumption, estimated by the U.S. Bureau of Mines, the need for new output is certain and should provide the stimulus for increased exploration and development. The Bureau also predicts that at the year 2000 only 35 per cent of World resources of molybdenum will have been extracted.

6 MAJOR MARKET PRODUCTS

Molybdenum is commonly marketed in the following forms.

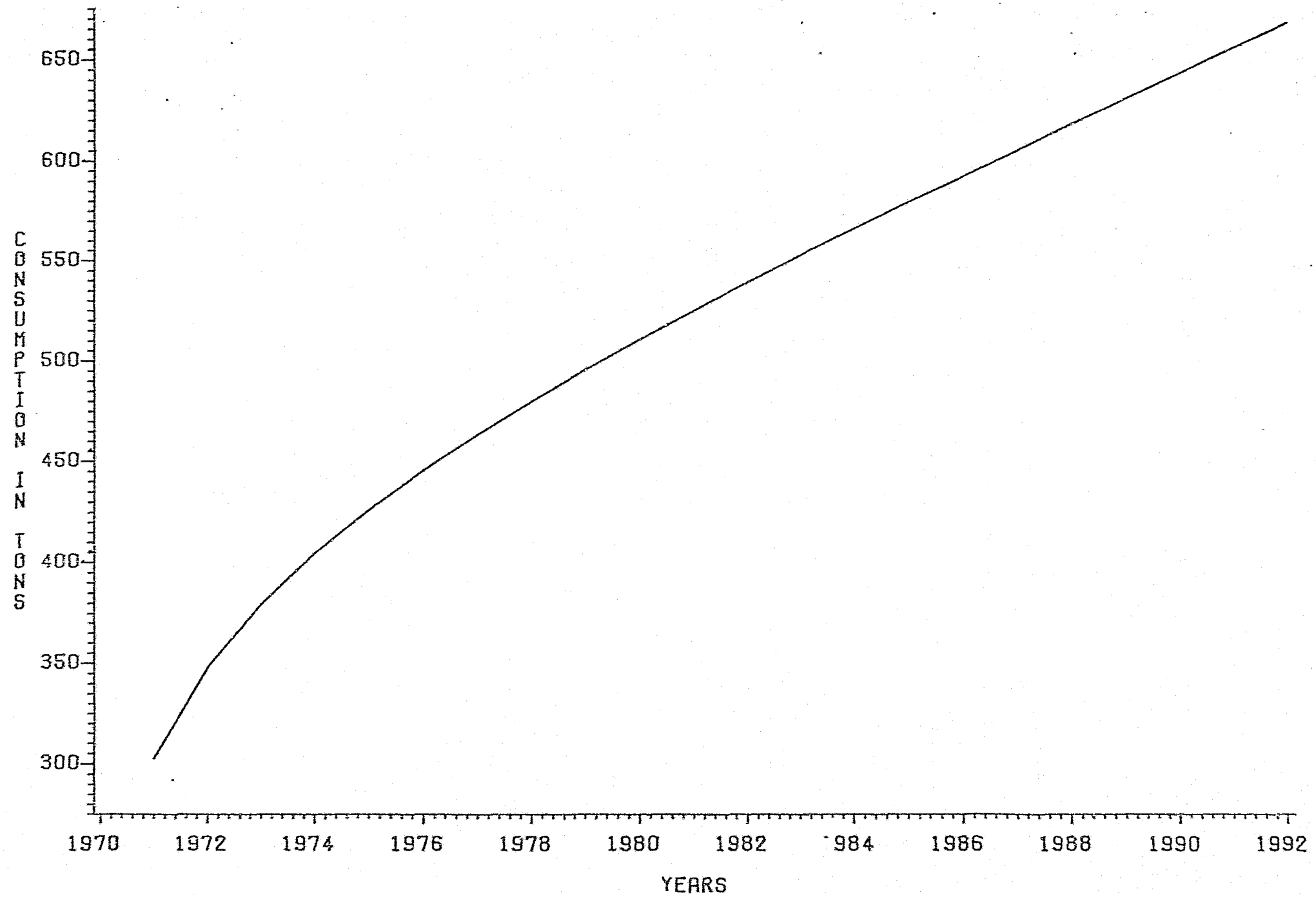
6.1. Molybdenum Sulphide

Molybdenum is produced from the mines in the form of a fairly pure flotation concentrate of molybdenite. The minimum international market grade is about eighty per cent MoS_2. In practice most molybdenite concentrates as marketed contain at least ninety per cent MoS_2. Contaminants may be copper, lead, phosphorus, tin and arsenic.

For use in lubricants, a concentrate containing more than 99,9 per cent MoS_2 is required, free of all abrasive material such as silica. This is usually done by sulphiding a refined molybdic oxide.

6.2. Molybdic Oxide

This is the first product made in the further treatment of molybdenite concentrates. Molybdic oxide is produced in two grades:



SOUTH AFRICAN MOLYBDENUM CONSUMPTION
MEASURED IN TONS

12(a)

(i) technical grade molybdic oxide (MoO_3) 57 per cent(min)Mo

(ii) refined grade molybdic oxide 99,975 per cent Mo

Technical grade molybdic oxide is supplied in bags, cans, drums, barrels and briquettes for foundry and steelmaking processes. Refined grade molybdic oxide is required for the production of molybdenum metal and certain chemicals.

6.3. Ferromolybdenum

Ferromolybdenum, as with technical grade molybdic oxide in powder or briquette form is used to add molybdenum to steel. The specification is usually sixty per cent Mo with a minimum of 0,1 per cent carbon. The balance comprises mainly iron. It is supplied as lumps or nuts in drums.

6.4. Molybdenum metal

The metal is normally supplied in powder form as obtained by the direct reduction of high purity molybdic oxide with hydrogen. The resulting powder is 99,8 to 99,95 per cent pure. Impurities may include potassium, tungsten, iron, calcium and chromium.

6.5. Molybdenum Silicide

This compound is used in a similar manner to ferromolybdenum; supplied normally as sixty per cent molybdenum, thirty-four per cent silicon and four per cent iron. The remainder consists of trace impurities.

6.6. Calcium Molybdate

Calcium molybdate is used mainly as a steel additive but is a relatively impure product containing on average only 42,5 per cent molybdenum.

6.7. Sodium molybdate and Ammonium molybdate

Both these chemicals are prepared by either reacting caustic soda or ammonia with technical grade molybdic oxide. The purity of both chemicals depends on the particular requirements as both can be purified by re-crystallisation and ammonium molybdate, when refined, is the purest form of molybdenum available.

7 INDUSTRY, MARKETING AND PRICES

7.1. Industry

It is apparent from a study of the major molybdenum producing mines of the Western World and the Communist Bloc countries, that with the exception of a few small producers, all of the World's molybdenum is produced by very large mines. These are most commonly low grade copper mines of the porphyry type which produce molybdenum as a by-product. Such mines require massive capital investment and there appears to be very limited scope for small producers to establish a new molybdenum mine.

In so far as the molybdenum producers of the Western World are concerned, they are grouped into or controlled by a few large mining corporations. This is a natural synthesis due to the nature of the deposits and their capital intensive development requirements. The corporations do not reflect any attempt to form a producer's cartel. Indeed, such a cartel would be difficult to form because the major companies involved are North American and would immediately be subject to Anti-Trust legislation in their own countries.

The methods of extracting molybdenum in usable form from concentrates is an expensive operation requiring elaborate equipment and considerable expertise. It is not a process that can be easily performed by a small scale operator. A possible exception is a method utilizing electro-oxidation followed by solvent extraction, being developed by the U.S. Bureau of Mines. There is no record of this method being applied in practice but it may prove commercial on the scale of operation that might be used in South Africa.

Unless a very large molybdenum deposit is discovered in South Africa capable of justifying a full extraction plant (of which the minimum size appears to be 4000 to 5000 tons of molybdic oxide per annum), it will be difficult for South Africa to enter the molybdenum industry or even to satisfy the local demand from internal production.

The known occurrences of molybdenum in South Africa are discussed in detail in section 8 of this investigation. There are only two deposits that might prove of sufficient size for extraction but neither so far appear encouraging.

Therefore, even if as much as 5000 tons of molybdic oxide were to be required annually in South Africa, it would most probably be necessary to import this material on a long term contract basis from reliable sources of supply.

7.2. Markets

The principal suppliers presently in the molybdenum market are:

(i) American Metal Climax Corporation (AMAX)

(ii) Kennecott Corporation

(iii) Molybdenum Corporation of America (MOLYCORP)

(iv) Duval Corporation (division of PENNZOIL CORP.)

(v) Corporacion del Cobre of Chile (CODELCO)

These companies not only produce molybdenum concentrates but are sufficiently vertically integrated to produce molybdic oxide and other products. Other companies produce concentrates at the mine but do not attempt further reduction to other products.

Both Amax and Duval have agents in the United Kingdom, Europe and Japan which process concentrates, as well as their main plants in the United States. Amax operates molybdenum treatment plants at Stowmarket (U.K.), Rotterdam (Holland), Nippon Moribuden KK (Japan) and Treibach (Austria).

Duval market in Europe through Duval Sales International in Brussels (Belgium) and also advertise ferromolybdenum produced by Continental Ores of Luxembourg.

Noranda Mines Limited mainly appear to market molybdenum concentrates in Canada from their own and sundry other mines.

Three companies convert molybdenite concentrates to molybdic oxide in Chile, namely, Carburo y Metalurgica (CARBOMETAL), ARMO Chilena and Quimetal (a subsidiary of the Chuquicanata operation of Anaconda Corporation).

It is apparent that many sources of supply are available to South Africa and it would be possible to reduce the risk of severance of supply by diversifying rather than concentrating all its resources in one or two companies. It would be possible to establish a portfolio of contracts with a commitment of no more than fifteen to twenty per cent of total imports being awarded to a single supplier. In addition, the country's supply would have flexibility under changing prices, market conditions and foreign government trade policies.

7.3. Prices

Molybdenum in various forms - mainly molybdenite concentrates, molybdic oxide and ferromolybdenum are quoted in trade journals such as Metal Bulletin and Engineering and Mining Journal. Although in practice there is no cartel for the sales of molybdenum, the prices are determined by Amax which is the largest single producer, and most other producers concur. This applies to routine sales and spot shipments since large tonnages would be sold on negotiated long term contracts.

But although Amax have more or less determined molybdenum prices, they have in practice, to a very large extent, stabilized the market. The price of molybdenite concentrates (current) rose from US $ 0,45 per lb of contained molybdenum in 1940 to US $1,72 per lb of contained molybdenum in 1973. This represents an increase of only 280 cents over thirty three years or an average annual increase of about four per cent per annum without any adjustment for inflation. Since 1973 the price increase has been considerably sharper but only to account for the increasing inflation rate. Real prices have remained remarkably stable. The market for molybdenum is expanding steadily but supplies appear to be more than adequate for the forseeable future and sharp fluctuations in price are not anticipated.

7.3.1. Price forecast

Data are derived from Metal Bulletin and all prices are in US $ /lb of contained molybdenum. Table 3 depicts the trend historically for the four major market products.

Table 4

Dealer export price (US $ per lb.)

	1971	1972	1973	1974	1975	1976	1977	1978	1979
Molybdenite Conc. (f.o.b. Climax)	1.72	1.72	1.72	1.99	2.48	2.94	3.68	4.52	7.61
Molybdic Oxide (briquettes)	1.95	1.95	1.95	2.24	2.79	3.25	3.70	4.90	6.10
Ferromolybdenum	2.21	2.21	2.21	2.59	3.25	3.77	4.43	5.62	7.99
Molybdenum powder	3.28	3.52	4.00	4.52	5.76	6.44	8.36	10.03	12.66

Table 4 continued

	1980	1981	1982
Molybdenite Conc. (f.o.b. Climax)	9.78	8.50	8.00
Molybdic Oxide (briquettes)	8.90	8.52	8.13
Ferromolybdenum	10.15	9.88	9.10
Molybdenum powder	14.44	15.95	15.31

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

Molybdenite concentrate : PRICE = 1,125 e $^{0,182\ YR}$; r = 0,962

Molybdic Oxide(briquettes) : PRICE = 1,337 e $^{0,162\ YR}$ r = 0,973

Ferromolybdenum : PRICE = 1,532 e $^{0,164\ YR}$; r = 0,974

Molybdenum powder : PRICE = 2,556 e $^{0,166\ YR}$; r = 0,985

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

Prices for the next decade would thus be estimated as (US ¢/lb):

	1983	1984	1985	1986	1987	1988	1989	1990
Molybdenite Conc.	12.06	14.47	17.37	20.84	25.01	30.02	36.03	43.24
Molybdic Oxide	11.03	12.97	15.26	17.95	21.12	24.84	29.22	34.37
Ferromolybdenum	12.98	15.17	17.87	21.05	24.79	29.20	34.40	40.52
Molybdenum powder	22.16	26.16	30.89	36.47	43.07	50.85	60.04	70.89

	1991	1992
Molybdenite Conc.	51.90	62.29
Molybdic Oxide	40.43	47.55
Ferromolyndenum	47.73	56.22
Molybdenum powder	83.70	98.83

These trends are depicted graphically on the following page, for (a) Molybdenum concentrate, (b) Molybdenum powder, (c) Molybdic acid and (d) Ferromolybdenum, respectively.

Recent prices quoted for various molybdenum products in the United Kingdom and Europe (Metal Bulletin) are:

Molybdenum concentrate	3.80	US ¢ per lb.
Molybdenum powder	6.86	US ¢ per lb.
Molybdic oxide	4.10	US ¢ per lb.
Ferromolybdenum	6.42	US ¢ per lb.

It is apparent from the above prices that the molybdenum metals market has experienced a dinstinct downswing. This can be attributed to a worldwide recession in the iron and steel industries and the corresponding decrease in demand for molybdenum additives.

IN U.S. ¢ PER KG MOLYBDENUM

Table 4 continued

	1980	1981	1982
Molybdenite Conc. (f.o.b. Climax)	9.78	8.50	8.00
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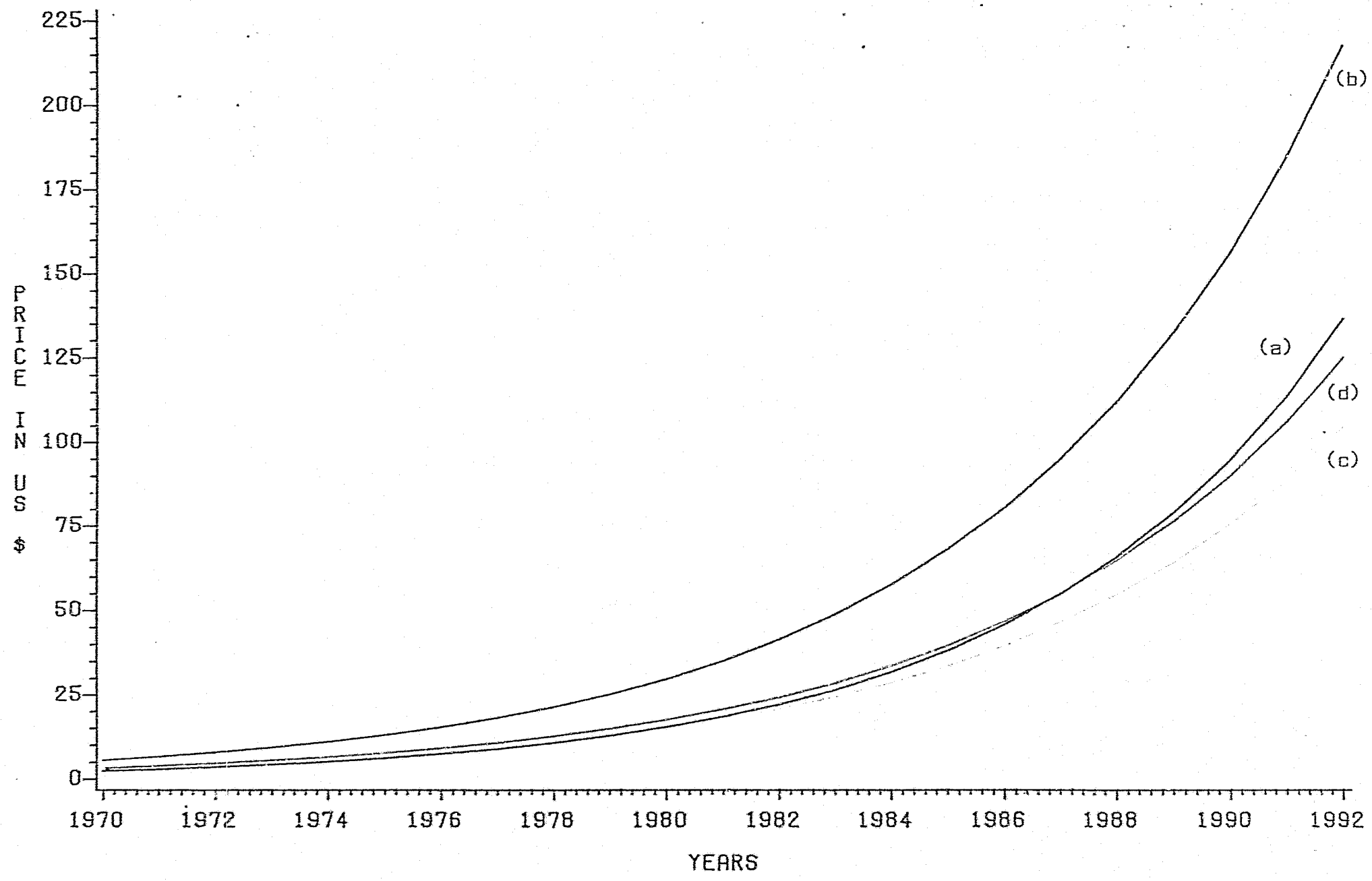
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17(a)

DEALER EXPORT PRICE IN U.S. $ PER KG MOLYBDENUM

8 MOLYBDENUM IN SOUTH AFRICA

8.1. Known Deposits

In South Africa molybdenite has been recorded at a considerable number of localities by the Geological Survey. In most cases the mineral merely occurs as an accessory mineral in deposits where other exploitable minerals predominate. No deposits of appreciable size have been located, nor has this mineral been recovered as a by-product in the exploitation of other minerals.

Molybdenum is mostly derived from acid or quartz bearing igneous rock, such as granite, pegmatite and quartz veins.

A detailed account of all known molybdenum occurences in South Africa is given in the Geological Survey unpublished report No. Eg 18/15, Molybdenum Deposits of South Africa, by Stephan L.A., of February 1977. Apart from describing forty one known occurences of molybdenum in South Africa in detail , the author gives an account of the types of molybdenum deposits that occur throughout the World. From this it is deduced that ninety-three per cent of the World's molybdenum reserves occur in Mesozoic or Cenozoic orogenic belts (which are the areas in which porphyry type copper deposits occur) and only about six per cent in Paleozoic orogenic belts. This implies that the probability of discovering molybdenum in large quantities in South Africa is poor in spite of the numerous small occurrences

Considerable interest was aroused about 10 years ago in the possibility of there being porphyry type copper (containing molybdenum) in the North-Western Cape and Southern South West Africa region; known to be highly mineralised, although very much older than the other regions elsewhere in which porphyry copper deposits are known to occur. One such deposit was prospected primarily for molybdenum near Ecksteenfontein in the Richtersveld, known as the Rooiberg II Complex. Although molybdenum mineralisation occurs together with fluorite over a considerable area, the values obtained were too low to warrant further development according to the Messina (Transvaal) Development Company who prospected the region. In addition, the deposit occurs in a remote desert area with little or no infrastructure and establishing a large mining operation would be a long and costly process. A large local market, may

however, encourage Messina Development Co. to investigate further.

Although numerous occurrences of molybdenum in and around the Bushveld Igneous Complex have been examined, all of these deposits appear to be small and erratic. Small trial shipments of molybdenite have been extracted in the past, mainly from former tin mines - in 1957 (14 tons), 1958 (8 tons) and in 1964 (1 ton). There does not seem to be any possibility of attempting to mine these small deposits and sending the ore so produced to a central recovery plant. This applies also to the numerous observations of molybdenum in the N.W. Cape and Namaqualand area where the molybdenum is usually found associated with pegmatitic tungsten.

A peculiar occurence of molybdenum in the Mpendle District has been described by DuToit. The deposit lies below the Drakensberg escarpment in the Hlatimbe Valley. An unidentified molybdenum mineral occurs as an impregnation in the sandstone containing up to 1,75 per cent molybdenite. The ore body appears irregular and small.

In S.W.A., at Tsumeb mine, molybdenite occurs as an accessory mineral in the complex lead-zinc-copper ore. The molybdenite is recovered in the smelting plant of the Tsumeb Corporation.

The most promising area is in the Karoo where molybdenum has been reported from several small occurrences, notably in the Beaufort West district, commonly in association with uranium. It is believed that molybdenum may prove more abundant in this area than uranium. Until recently, though, molybdenum when associated with uranium in Karoo rocks was regarded as a contaminant. With continued exploration for uranium in the region there is a distinct possibility of locating payable molybdenum concentrations in the area, to be recovered either as a primary or by-product. Such a discovery would be unlikely to be the main ore mineral molybdenite but probably oxides such as jordosite and ferromolybdite which offer possibilities for extractions by leaching, thus avoiding some of the difficulties of extracting molybdenum from conventional sulphide concentrates.

The analyses of samples taken along the outcrop indicate molybdenum contents ranging from 0,1 to 1,2 per cent MoS_2.

The higher values alone would indicate deposits that might be worth working for their molybdenum content alone, apart from their uranium components.

The Nuclear Development Corporation tend to discount the molybdenum content of these uranium ores in the small and scattered deposits as a poison. They have tended to turn away from such occurences that do contain molybdenum. The limited assays that have become available indicate values of the same order as those at Climax and Henderson, around 0,5 per cent contained molybdenum.

Union Carbide Exploration (Pty) Ltd. tend to agree with the Nuclear Development Corporation in that the deposits are too small to be extracted economically but have exercised their rights to mineral options in certain areas of the Beaufort West District. This company have no present plans for developing any of the uranium deposits in the region in the immediate or forseeable future. However, the suggestion that there may be a local market for a very large tonnage of molybdenum may prove an inducement to renewed interest in the area.

In summary, it appears that although numerous occurences have been known in South Africa for many years, only two fairly recent discoveries (Richtersveld and Beaufort West) offer any hope for establishing an operation with an annual production of the order of 5000 tons of molybdic oxide. Even these two discoveries seem rather doubtful propositions in the light of current depressed markets for molybdenum.

8.2. Forms in which molybdenum is required in South Africa

Overseas, molybdenum is marketed in a wide variety of forms ranging from run of mine concentrates to articles fabricated from molybdenum metal. In South Africa the range of molybdenum products required would be to the advantage of a company producing molybdenum on a comparitively small scale.

It is unlikely that pure molybdenum metal would be required; as any metal used as such in South Africa would be imported as finished components for electrical equipment such as X-Ray apparatus.

The metallurgical industry which requires molybdenum mainly for the manufacture of stainless steel uses molybdenum in two forms, ferromolybdenum and molybdic oxide which are

usually imported as briquettes and reduced to the metal in a furnace.

For chemical applications, including the manufacture of catalysts and paint pigments, the most common form required is likely to be ammonium molybdate, a compound that is not difficult to produce from relatively impure 'technical' grade molybdic oxide. However, the manufacture of molybdenum based catalysts is a highly specialized science of its own. The supply of molybdenum, initially in most cases in the form of ammonium molybdate, is probably the simplest part of the whole operation which involves depositing the molybdenum, either as the metal or the oxide, on the inner surfaces of the pore structure of materials such as alumina or certain clays.

Molybdenum sulphide used for blending into lubricants is a highly refined material which might be produced by 'super-cleaning' of the molybdenite produced as a flotation concentrate. It is usually produced by reforming the sulphide from the purified molybdic oxide.

Considering the ability of a relatively small mining operation producing molybdenum, it would most probably be best to produce either a high grade molybdenum concentrate or molybdic oxide. The latter could probably be achieved on a small scale by means of a process developed by the U.S. Bureau of Mines, but which has not yet been applied commercially.

8.3. Possible sources of supply for South Africa

There does not appear to be any possibility of any world shortage of molybdenum arising in the forseeable future, neither is the price of molybdenum likely to increase faster than the current rates of inflation - in fact the opposite may be more probable.

With the World trade in molybdenum well entrenched in the hands of a few very large companies and the fact that these companies have developed a very considerable expertise in the extraction and refining of molybdenum, entry by a newcomer into the world molybdenum market would be difficult. There is therefore very little incentive for any South African company to develop any molybdenum deposit, except under the guarantee of a very much larger potential market internally than exists at present.

The following alternatives for meeting South Africa's

demand may be considered:

8.3.1. Direct importation of molybdenum

It is obvious that the simplest and easiest method of obtaining molybdenum would be to import it from one or other of the well established major producers.This would obviate the cost of establishing a large scale mining operation and processing plant and acquiring the necessary knowledge to run the plant and mine. The present major suppliers of molybdenum are all large companies of the highest integrity and there does not appear to be any form of restrictive cartel between them. Supplies of molybdenum in the quantities envisaged would be obtained under a long term contract and most probably at an appreciable discount on current market prices, which are usually those for spot sales.

It would probably be preferable to import the molybdenum in the form of 'technical grade' molybdic oxide, rather than as a molybdenite concentrate to avoid the difficult step of calcining the concentrates and disposing of the resultant SO_2 fumes. The molybdic oxide could be used as a starting point for the local manufacture of ammonia molybdate and ferromolybdenum. Apart from its strategic use as a catalyst, ammonium molybdate is also a most effective method of refining molybdic oxide.

There are, however, serious disadvantages to relying on imports of molybdenum, especially when the major portion of this material is playing a vital role in a key industry such as petroleum synthesis. Firstly, the import of 5000 tons of molybdic oxide annually would represent at present prices at least U.S. $ 44 631 000 in foreign exchange, even allowing for a slight reduction in price for the supply in bulk and not in cans. An annual turnover of U.S. $45 million would justify the erection of a considerable sized plant anywhere.

Secondly, South Africa would continually be in the situation of wholly depending on the goodwill of overseas countries, in this case America, Canada and Chile and possibly Peru, for supplies of an essential material. Even if the suppliers were willing to furnish the molybdenum there would always be the risk of the supply lines being broken in times of war, boycotts or embargoes. It would therefore seem desirable (if not essential) to carry a very large stockpile of molybdic oxide in South Africa against

such possible emergencies.

8.3.2. Development of local sources

This is highly desirable but unfortunately only two areas appear to show promise - the Richtersveld and the Karoo sandstones near Beaufort West. The Messina Development Corporation view the Stinkfontein occurence as a 'complete flop'. The views of the Union Carbide Exploration are less pessimistic but still not encouraging.

Apparently the possible local and virtually captive market for about 5000 tons of molybdic oxide annually has been offered to both companies as an inducement to initiate the recovery of molybdenum locally. MINTEK have stated that they are confident that they could develop the technology to recover and process any molybdenum ores that might be recovered. This confidence is based on detailed expertise in similar fields.

8.3.3. Collaboration with the Chilean Government

A few years ago the South African Legation in Chile was approached by Chilean nationals who appeared to be acting with the approval, if not actually on behalf of, the Chilean Government. The Chilean copper mines presently produce about 12 000 tons of molybdenum annually in the sulphide form. The material is at present said to be sold as the sulphide which is unusual since the state owned company CODELCO, advertises molybdic oxide as well as the sulphide. The Chilean Government wish to process the molybdenite further locally and require private enterprise to submit proposals for the venture. They are considering utilizing a South African firm to supply the necessary technology and probably some of the plant and equipment on a contract or partnership basis.

The proposal offers interesting possibilities. Not only does it offer an opportunity for the export of South African expertise (even if this atill has to be developed) but there is also the trade benefits of supply of plant and equipment, as well as the opportunity for investment of South African capital in a friendly country. Far more important in the present context is that collaboration could lead to a reliable source of supply of molybdenum on terms favourable to South Africa.

The expansion of a proposal of this nature to fruition would of necessity involve the South African Government and local entrepreneurs such as the Industrial Development Corporation and Anglo American Corporation, especially as the latter already have

some interests in South America.

However, it was impossible, with the limited sources of information available, to obtain accurate and reliable details regarding the current status of negotiations concerned with the above proposal. Such agreements, because of the sensitivity of World affairs, may of necessity have to be completed with the strictest security.

8.3.4. Collaboration with Iranian interests

This is a proposition very similar to that of Chile, again proposed a few years ago. Iran, however, already has interests in South Africa through the petroleum refining industry. A syndicate in Iran wished to develop a molybdenum deposit, to which they had the mineral rights, located about 35 kilometres from Teheran. The mine, which was reported as being high grade. They also had the tacit approval of the Iranian Government to proceed with raising capital. A firm of local consulting engineers showed interest in the project but had real fears regarding the stability of the region and it's long term potential.

Their anticipation of a shift in governmental power showed exceptional foresight. Since the inception of the Khomei regime, investment attraction in the region has slumped to a historic low. It is possible though that the current status quo may change this highly volatile region and yield an improved investment climate.

The mine has not, however, been fully explored and proven but if results prove sufficiently encouraging development could commence, except that in this case it would be necessary to develop and equip a mine as well as the treatment plant.

8.3.5. Processing of molybdenum locally

No specialized knowledge of the treatment of molybdenum ores or of the recovery and processing of the resultant concentrates at present exists with a commercial background in South Africa. MINTEK has built up a considerable expertise in the techniques that would be required and have also developed an appreciable knowledge of molybdenum technology at laboratory scale while engaged in a sponsored project. MINTEK therefore feel that they do have the necessary expertise to be able to assist in molybdenum extraction projects.

As mentioned, unless adequate deposits of molybdenum are discovered in South Africa, it would be preferable to import calcined molybdenite concentrates such as 'technical grade' molybdic oxide for further processing. There are companies already operating on

similar material locally who have the necessary technology for the production of refined ammonium molybdate. Three of these companies are:

Hard Metals Limited in Springs

Wickman (S.A.)(Pty) in Brakpan and

Hicksons Chemicals in Roodepoort.

Hard Metals treat tungsten concentrates which are refined in the same manner as the ammonium leaching method for refining molybdic oxide, while Hicksons manufacture more inorganic chemicals - if not in South Africa they can obtain the information from their parent company in the United Kingdom.

Ammonium molybdate is an intermediate product in one of the routes to the production of highly refined molybdic oxide. The method employed is very similar to that already used by both Hard Metals and Wickmans for the production of refined tungsten oxide; while the reduction of the molybdic oxide to the metal powder is very similar in equipment and technique to that used to produce tungsten metal powder and tungsten carbide. The possibility is suggested of extending the treatment of molybdic oxide from a source to the production of molybdenum metal powder, sponge or sintered ingots for export.

In addition, the metal rhenium contained in the molybdenite concentrates may be recovered. This suggests that South Africa becoming a major source of a very rare metal, for which numerous uses exist if available supplies were to be increased. It is useful as a catalyst in the production of low-lead, high octane gasoline that is much in demand since the use of lead additives to improve octane ratings has been restricted. Rhenium is also useful in X-ray machines and thermacouples, and it may find additional future demand in superalloys for jet engine turbine blades.

9 SUBSTITUTES, RECYCLING AND TECHNICAL POSSIBILITIES

9.1. Substitution

There is little substitution for molybdenum in its major applications as an alloying element in steels, cast irons and non-ferrous metals and historically molybdenum has been

a relatively inexpensive alloying agent readily available. As a result, metallurgical applications for molybdenum were broadened and industry sought to develop new materials which benefit from the alloying properties of molybdenum. Recently however, the potential for substitution has received attention owing to the substantial rise in the price of molybdenum raw materials since 1974.

Several factors mitigate the possible replacement of molybdenum to the degree that it's overall demand would be significantly affected:

(i) there is no acceptable substitute in numerous metallurgical and chemical applications

(ii) it is commonly added to steels and alloys to enhance several desired properties. In such cases, molybdenum could be replaced for particular effects, but at a sacrifice in overall performance. Moreover, the molybdenum content of alloy and speciality steels ranges from less than one to a few per cent.

Nevertheless, possible alternatives exist in most applications of molybdenum. Boron, chromium and manganese can replace molybdenum in steels where hardenability is the only desired effect. In certain low-alloy steels, columbium, manganese and vanadium act in similar fashion to molybdenum. Chromium, nickel and tungsten are possible substitutes in steels and other alloys. Molybdenum has substantially replaced tungsten in commonly used high speed tools. Nonmetallurgical materials such as plastics and ceramics can replace steels and alloys containing molybdenum in certain applications.

Tungsten and tantalum can be substituted for molybdenum in certain refractory metal uses, but at a cost disadvantage. Molybdenum can be replaced by graphite for refractory elements in electric furnaces in the range of 1 000 ° to 1 600° C, but at the expense of slightly greater difficulty in operation and control. Chrome orange, cadmium red and organic orange pigments are possible substitutes for molybdenum orange. Acceptable substitutes for molybdenum are not found in most of it's major catalytic applications. Graphite and other solid lubricants generally do not perform as well as molybdenum disulphide,

a relatively inexpensive alloying agent readily available. As a result, metallurgical applications for molybdenum were broadened and industry sought to develop new materials which benefit from the alloying properties of molybdenum. Recently however, the potential for substitution has received attention owing to the substantial rise in the price of molybdenum raw materials since 1974.

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especially under high pressure and high temperature conditions.

9.2. Recycling or secondary sources

Some secondary molybdenum is recovered in the production of alloy steels, superalloys and metal but no detailed data is available. Most of this recycled material is generated and reused directly at metal forming or fabricating plants or shipped to plants that reclaim it. Very little molybdenum containing obsolete scrap is processed for it's molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on it's molybdenum content. An increasing but indeterminate quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

9.3. Technical possibilities

Increased molybdenum recovery through improvement in efficiency of flotation techniques. The development and application of new molybdenum containing steels and alloys particularly if resistance to oxidation at high temperatures improves solar energy panels.

10 CONCLUSIONS AND RECOMMENDATIONS

World reserves of molybdenum are adequate for the forseeable future. No shortage of this metal is anticipated and no increase in prices other than as the result of inflation.

There is no real incentive for the development of any new molybdenum deposit in South Africa, except to supply the possible requirement of around 5 000 tons annually for use as a catalyst by Sasol.

Although numerous occurences of molybdenum are known in South Africa only two offer any promise of being potential sources of this large a quantity of molybdenum, but even these are doubtful under present economic conditions.

The easiest method of obtaining molybdenum in any quantity would be by importing the oxide which could be processed further locally with the expertise being developed by MINTEK.

The total cost of 5 000 tons of 'technical grade' molybdic oxide at present prices is of the order of R43 million annually.

Both Messina Development Corporation and Union Carbide exploration could be actively encouraged to look at their known molybdenum deposits with a view to monopolise the local market.

For metallurgical purposes a strategic stockpile of about 400 tons of ferromolybdenum and molybdic oxide, in the form of sintered briquettes would appear adequate. A stockpile for molybdenum catalysts would have to be decided between Sasol and the oil refining companies. Indeed it might be preferable to develop an alternative to molybdenum as the catalyst in the petrochemical industry.

B: TUNGSTEN

INTRODUCTION

The TUNGSTEN mineral wolframite was known in the tin mines of the Saxony - Bohemia region and later in Cornwall, long before the element itself was discovered. Tungsten, a heavy metal, was first isolated in the form of tungstic acid $H_2 WO_4$, in 1781 by Scheele from a calcium acid compound. The acid forming element thus discovered was named tungsten by Constedt in 1755. He derived the name from the Swedish words 'tung' (heavy) and 'sten' (stone). In 1783 the Spanish brothers, D'Elhujar found that wolframite also contained tungsten, but with iron and manganese instead of calcium, and succeeded in obtaining metallic tungsten by the reduction of the oxide with carbon. Later, in 1863, Liebe described nearly pure iron tungstate in Spain and named it ferberite.

However, tungsten remained rarely known in the industry until Oxland (1847) patented his manufacturing process of sodium tungstate, tungstic acid and the metal. In 1857 Oxland also patented the manufacturing method of iron-tungsten alloys, but the metal itself found no application until nearly fifty years later when it was used as electric filaments to replace carbon filaments in incandescent lamps.

But tungsten salts had been used very much earlier by the Chinese Emperor, Kang Hsi (1662 - 1722) to produce a series of peach shades of face powder! Today tungsten is used for rather more mundane purposes but it is vital to South Africa's mining and manufacturing industry.

Tungsten, because of its properties, has many uses that are basic to a modern, rapidly diversifying technology; consequently the metal will continue to be an increasingly desirable, if not critical, commodity of world wide importance.

1 PROPERTIES OF TUNGSTEN

Tungsten, a silvery-gray metal, is one of the heaviest of the elements and has the highest melting point of any metal, 3 410 °C. It has a relative density of 19,2 and its structure is normally body centred cubic.

The major uses of tungsten relate not only to the special characteristics of the metal itself but also to the properties that it

imparts to its compounds and alloys - extreme hardness, the ability to retain hardness and strength at high temperatures, high tensile strength, adequate electrical conductivity and high wear resistance.

Mechanical properties vary widely depending upon the mechanical treatment to which the metal has been subjected although at temperatures above 1650°C tungsten outranks all other metals in tensile strength. In practice tungsten is not particularly hard, but it can be used to develop extreme hardness when alloyed with steel and certain other metals, particularly in the form of tungsten carbide (WC).

A remarkable characteristic of tungsten is its ductility once it has been forged into the solid metal by pressing, sintering and subsequent hot swaging. After swaging down to a rod about 1 millimetre in diameter, the rod can be drawn into a wire only 0,012 millimetres in diameter.

Natural tungsten is a mixture of five stable isotopes with a complex chemical behaviour since the element may have all valencies from one to six.

2 APPLICATIONS OF TUNGSTEN

The commercial applications of tungsten depend upon its extremely high melting point, high ductility under suitable treatment, and extreme hardness in a carbide form or when alloyed with certain other metals. The basic forms in which tungsten is consumed are approximately:

tungsten carbide	45 percent
all alloys	54 percent
chemicals and others	1 percent

A further sub-division can be made into tungsten carbides, alloys, tungsten steels, heat and wear resistant alloys, unalloyed tungsten and chemical.

2.1. TUNGSTEN CARBIDES

In the industry, tungsten carbides are divided into two categories - the cemented tungsten carbide and the fused or cast carbide.

2.1.1. Cemented tungsten carbide

The major use of cemented carbide is in the cutting tool application which includes turning, facing, milling, boring, reaming, threading, filing, broaching, shearing and glass cutting.

It was early appreciated that the real effect of tungsten in tool steel was the formation of extremely hard carbides, either of tungsten itself, principally the monocarbide WC, and the iron-tungsten carbide (Fe,W) C. The presence of these in the tool steel allowed very much heavier and faster cuts to be made, even under conditions when the tool

steel actually reached a dull red heat. Attempts to make use of the carbides themselves failed initially because of the brittleness of the carbides. This problem was solved by Krupps in 1927 by sintering the tungsten carbide granules in a softer metal, most commonly cobalt.

Consumption of carbide cutting tools was probably stimulated by the development of disposable carbide inserts which appeared in 1954-1956. These inserts, instead of being brazed into position, are clamped or screwed into a steel shank and have a number of cutting edges. After each edge becomes dull, the insert is turned to another edge, and after all the edges are used, the insert is recycled rather than reground.

Although sintered tungsten carbide wa_ used after 1927 for making the tips of machine tools and such articles as dies for wire drawing, it was not until about 1948 that the technique was perfected sufficiently to produce tungsten carbide tips tough enough to withstand the shocks of percussion rockdrills. The application of tungsten carbide tipped rockdrills since 1949 has probably been the most important single innovation in the mining industry since the introduction of the handheld jackhammer type rockdrill.

When jumpers with forged bits were used for drilling one jumper was used for each hole of about 1,2 metres. The large number of jumpers required for this work together with the problems of sending them down the mines to the working faces, returning them to surface for resharpening as well as the work involved in resharpening required enormous logistical effort. In practice a tungsten carbide tipped jumper can drill about 6 metres of hole in hard rock efficiently and then only requires regrinding before reuse. The regrinding can be done underground and even adjacent to the working places. The total length that can be drilled with one tungsten carbide tipped jumper with simple regrinding is over 60 metres. The cost savings are thus enormous.

The advantages of using tungsten carbide tipped jumpers are even greater on the smaller outside mines and construction works as the need for establishing sophisticated rockdrill sharpening shops is obviated. Virtually all mines, quarries and construction works now use tungsten carbide tipped jumpers.

2.1.2. Fused or cast carbide

This material is usually produced by melting a mixture of tungsten powder, graphite and a considerable percentage of scrap tungsten carbide. Fused carbide, in the form of castings or crushed particles, and cemented carbide is used for wear resistant applications such as spraying, injection and blasting nozzles, as guide sleeves in machines,

thread guides in textile machinery, burnishing tools, ballpoint tips and as teeth and jaws for excavators.

2.2. ALLOYS

Tungsten base alloys are generally developed to improve ductility or high temperature strength of the metal and are used as substitutes for unalloyed tungsten in some applications in spaceship or nuclear industries.

2.2.1. Tungsten alloys

Tungsten-molybdenum alloys are used as substitutes for unalloyed tungsten because of their improved mechanical properties. The family of tungsten-rhenium alloys has excellent low temperature ductility and high temperature strength. They are commonly used for thermocouples in furnaces, electrical contacts in high humidity and corrosive environments, as lamps and electronic tube wires and as X-ray targets.

2.2.2. Tungsten composites

Heavy alloys are used as gyroscope rotors, rim componente of flywheels, shielding material for radioactive isotopes, backup discs for semiconductors and as projectile cores. Silver or copper infiltrated tungsten is used for electrical contacts.

2.2.3. Tungsten containing refractory alloys

With the addition of tungsten to refractory metals such as niobium and tantalum elevated temperature properties are vastly improved. They are used as gas turbine vanes, rocket nozzles and as chemical corrosive resistant tubing.

2.3. TUNGSTEN STEELS

Tungsten is an imported alloying element in high speed steel, hot work steel, cold work steel, shock resistant steel and stainless steel.

2.3.1. High speed steel

For soft metals such as low-carbon steels, high speed tools may be used while for alloy steels, tools of tungsten carbide are employed. High speed steels can be machined and easily shaped and thus can be used for complex shapes. Typical applications are as drills, taps, gear cutters, power tools and wood working tools.

2.3.2. Other tungsten steels

Hot work steels are used extensively for extrusion dies, shear blades, piercers or for other occasions where resistance to abrasion and shock is required. Cold work steels have longer lives and better manufacturing qualities than low carbon steels. They are generally used for blanking, bushes, gauges and taps. Tungsten-chromium steel is a shock resisting

steel used by pneumatic tools such as chisels. Some tungsten is used in heat resisting and stainless steels such as distilling tubes and turbine materials.

2.4. HEAT AND WEAR RESISTANT ALLOYS

The heat resistant alloys are called superalloys while the wear resistant alloys are known as stellites or cobalt-chromium-tungsten alloys.

2.4.1. Superalloys

These alloys have bases of either nickel, iron or cobalt and are used as gas turbine vanes, stationary power units, combustion tubes and other high temperature applications.

2.4.2. Hard facing alloys

These are produced in the form of welding rod or powder and are widely used for valves, bearings, blades and rock crushers. The cobalt-chromium -tungsten alloys may be used in massive forms and casts may be made for metal cutting tools which are harder than high speed steels.

2.5. UN-ALLOYED TUNGSTEN

This is metallic tungsten in the form of mill products, as sintered slabs, and in forms consolidated by other means.

2.5.1. Tungsten wire

The major use in unalloyed form is for incandescent lamp filaments, heating elements in fluorescent lamps, electronic heaters and grid wire. Tungsten is the most practical material for this application. Only at temperatures below 2 000°C is molybdenum generally preferred because of its lower cost.

2.5.2. Tungsten rods

These are used essentially for lamp filament supports, electrical contacts and in welding machinery. The general advantages for using tungsten are its adequate electrical conductivity and its resistance to wear and arc erosion. Tungsten is used for lamp filament supports because of its high strength at elevated temperatures.

2.6. CHEMICAL USES

Tungsten bronze is used as a substitute for bronze in paints. Sodium tungstate produces pigments used in printing inks, plastic, rubber, paper and waxes. Calcium and magnesium tungstates are used as phosphors in fluorescent lights and television tubes.

Ammonium tungstate and other compounds like WO_3 or WS_2 are used as catalysts in the petroleum industry for hydrotreating, hydrocracking, dehydration and polymerization. $W(CO)_6$ and WF_6 are used for chemical

vapour deposition to provide a hard acid resistant coating on bearings. Tungsten selenide is used as a dry lubricant under high temperature conditions. Tungsten sulphide forms a self lubricating surface on razor blades.

3 TUNGSTEN MINERALS

Tungsten is a relatively rare element in the earth's crust at 0,000 048 percent of the igneous rocks of the earth's upper layer. Tungsten has never been found in the elemental form naturally.

Minerals of tungsten that occur in sufficient abundance to be of economic significance can be divided into two groups.

3.1. Wolframite group

The wolframite group consists of three important minerals:

ferberite	$FeWO_4$	(iron rich)
huebnerite	$MnWO_4$	(manganese rich)
wolframite	$(Fe,Mn)WO_4$	(20 to 80 percent of each of $FeWO_4$ and $MnWO_4$)

At high temperature these three minerals form a continuous solid solution series. The detection of calcium in the wolframite series is probably due to inclusions of scheelite.

3.2. Scheelite group

This group contains only one economically important mineral - scheelite, $CaWO_4$. Molybdenum may substitute for tungsten in scheelite, forming a series with powellite, $CaMoO_4$. Most scheelite contains only a minor amount of molybdenum. Scheelite has the remarkable property of fluorescence under ultra violet light, a property that is of considerable assistance when prospecting for the mineral. This property could also be used for sorting scheelite ore from waste by hand or mechanical means.

3.3. Minor tungsten minerals

These are presently not of commercial importance but include:

tungstenite	WS_2
tungsiite	$WO_3.H_2O$
cuprotungstite	$Cu_2 (WO_4) (OH)_2$

4 TUNGSTEN DEPOSITS

All economic tungsten deposits can be related to the magmatic hydrothermal process. Thus different tungsten deposits can be placed in a classification system according to what specific changes occur as the hydrothermal fluid moves away from the source.

4.1. Skarns

Skarns are the most common form in which economic deposits of tungsten occur. Their characteristic features are that tungsten generally occurs as scheelite, an intrusive rock is frequently associated and the mineral body is generally small and of irregular shape.

The Sang Dong deposit in South Korea is considered to be a skarn of six parallel scheelite beds, although only one is worked. This has an average width of 4,5 metres, strike length of 1000 metres and dips at 15° to 30°. The grade varies from a marginal low grade zone of 0,2 to 0,3 percent WO_3 to a central rich zone of greater than 2 percent WO_3.

4.2. Hydrothermal tungsten deposits

The tungsten minerals occur within or adjacent to quartz veins. The veins may form discrete lodes, vein swarms or stockworks. Tungsten is mainly present as wolframite.

Numerous deposits occur in the mountains of Cordillera Real in Bolivia as sheeted vein systems. Tungsten at the La Chojlla mine is carried in veins up to 1,4 metres wide, average dip of 65° and varying in length from 100 to 250 metres. The veins are quartz filled and contain wolframite, tourmaline, pyrite and cassiterite on the lower levels.

4.3. Tungsten deposits associated with porphyries

Certain tungsten deposits are genetically related to igneous rocks, particularly granitic porphyries. Two types of deposit can be distinguished.

4.3.1. Tungsten associated with molybdenum bearing porphyry

The Climax deposit is a major molybdenum orebody but the mine has sufficient coproduction of huebnerite to make it the second largest tungsten producer in the U.S. The present grade milled is about 0,03 per cent WO_3 and all tailings from the molybdenite recovery circuit are recycled and approximately 30 percent of the tungsten contained is recovered.

4.3.2. Tungsten associated with multi-metal porphyry

Mount Pleasant has two main mineral deposits centred on two plugs. The largest mineral deposit has molybdenum, bismuth and tungsten mainly present as ferberite. The bulk of the deposit was formed by replacement of the host rock.

4.4. Vulcanogenic tungsten deposits

A number of strata bound tungsten deposits are present in the Alps. Tungsten occurs mainly as scheelite. At Felbertal, Austria the series

is up to 300 metres thick and extends along strike for 2 500 metres. There is some substitution of molybdenum and gold and silver are also present.

4.5. Tungsten bearing brines

The largest single tungsten deposit in N. America is Searles Lake containing 77 million kilograms of WO_3 contained in brine. Searles Lake is dry and consists of a body of 3 billion tons of salt about 30 metres thick. Slightly over half of this body is actually solid and the interstices are occupied by a dense brine.

4.6. General

Usually wolframite and scheelite are mutually exclusive in any one tungsten deposit and usually in any particular mineral field, although on occasions both minerals do occur together. The initial processes for extracting tungsten from the concentrates are different with the result that consumers normally prefer concentrates of one mineral or the other.

Both wolframite and scheelite are attacked and dissolved by many solutions that can occur naturally, but in all cases this attack is very slow with the result that secondary enrichment of tungsten deposits by dissolution and reprecipitation does not occur.

Just about every mineral that is likely to occur in vein deposits, particularly those formed at high temperatures may be found associated with both wolframite and scheelite. Guangue minerals may include quartz, felspar, mica and arsenic.

5 WORLD RESERVES, PRODUCTION AND CONSUMPTION

5.1. World Resources and Reserves

Any attempt at estimating the World reserves of tungsten must at the best be highly speculative due to the notorious fluctuations in tungsten prices, especially over recent years. World knowledge of the geological parameters required for the formation of tungsten deposits makes it possible to delineate prospective areas reasonably precisely. The potential for finding tungsten deposits in these prospective areas is so high that the development of new tungsten reserves to meet predictable economic needs in the long term will be possible without a forseeable exhaustion of the resources. However this satisfactory situation appears less encouraging considering the regional distribution of measured and indicated reserves, which is a decisive factor for availability. Table 5 gives an estimate of World tungsten reserves and resources as determined

by Stafford in Mineral Facts and Problems.[39]

Table 5

Estimated World resources and reserves - 1980 (million kilograms)

Area	Reserves	Other Resources
N. America		
United States	125	327 452
Canada	270	318 588
Mexico	20	5 25
Other	1	2 3
TOTAL	416	652 1068
S. America		
Bolivia	39	86 125
Brazil	18	41 59
Other	2	2 4
TOTAL	59	129 188
Europe		
Austria	18	54 72
France	16	2 18
Portugal	24	27 51
U.S.S.R.	213	318 531
United Kingdom	1	64 65
Other	32	9 41
TOTAL	304	474 778
Africa		
Zimbabwe	5	5 10
Other	5	14 19
TOTAL	10	19 29
Asia		
Burma	32	73 105
China	1361	2268 3629
North Korea	109	136 245
Rep. of Korea	82	77 159
Malaysia	14	32 46
Thailand	18	18 36
Turkey	77	14 91
Other	5	5 10
TOTAL	1698	2623 4321

Area	Reserves	Other	Resources
Oceania			
Australia	109	259	368
Other	1	2	3
TOTAL	110	261	371
WORLD TOTAL	2597	4158	6755

The measured and indicated reserves that are economically recoverable at present amount to 2,6 million tons. Only 35 percent of the reserves are held by countries with free market economies. The country with the largest percentage of all presently known measured and indicated tungsten reserves is the People's Republic of China with 52 percent.

The situation is similar with regard to potential world resources. These amount to 6,76 million tons but 62 percent of these resources are accounted for by the U.S.S.R. and the People's Republic of China - a very alarming fact for the Western World to consider.

Reserves at certain mines are very large. Tungsten is frequently produced as a by-product of working other metals, most commonly tin, but in the case of the famous Climax mine, tungsten is produced as a by-product from the mining of molybdenum ores.

5.2. World production

Appendix Two contains a list of the largest known tungsten producing mines in the world. Historically tungsten production has fluctuated greatly with an overall average annual growth rate of about 3,5 percent. Over the years the share of the most important contributors to world production as a group has increased but the relationship between these countries outputs has remained nearly the same. Only the newcomers such as Brazil, Thailand, Japan and France have increased their share.

Table 6 lists the Western World tungsten production divided into seven main categories for the last fifteen years, as published in Mining Journal's 'Mining Annual Review'.

Table 6

Western World production (kilotons)[28]

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
United States	4,6	4,3	4,4	3,1	3,2	3,4	3,4	2,5	2,6	2,7	3,1
Australia	1,2	1,4	1,3	1,5	1,5	1,3	1,1	1,5	1,9	2,2	2,7
Bolivia	2,0	1,8	1,8	1,9	2,3	1,9	2,0	2,5	3,0	3,3	3,1
Canada	1,3	1,5	1,4	1,8	2,0	1,7	1,3	1,2	1,6	1,8	2,?
Rep. of Korea	1,9	2,0	2,1	2,1	1,7	2,0	2,3	2,4	2,4	2,5	2,3
Portugal	1,3	1,3	1,4	1,4	1,4	1,5	1,5	1,4	1,3	1,0	1,1
Other	3,2	4,4	5,1	7,7	8,9	8,8	7,6	7,0	8,1	9,2	10,2
TOTAL	15,5	15,9	17,5	19,5	21,0	20,6	19,2	18,5	20,9	22,7	24,9

	1979	1980	1981	1982
United States	3,0	2,7	3,5	1,5
Australia	3,2	3,4	3,5	2,4
Bolivia	3,1	3,3	3,3	2,3
Canada	2,6	3,2	1,8	2,8
Rep. of Korea	2,4	2,4	2,4	1,8
Portugal	1,4	1,5	1,4	1,4
Other	9,0	9,8	9,3	8,8
TOTAL	24,7	26,3	25,2	21,0

The remaining countries which comprise the row 'other' in the table are virtually all small producers and their annual productions vary widely from year to year due to the small deposits being mined and the wildly fluctuating market price of tungsten. During periods of high prices numerous small mines come into operation and close up within a relatively short period either when their small reserves have been mined out or when the price of tungsten falls.

Stafford[39] estimates Eastern Bloc production in 1979, the last available figures, to be around 20,8 kilotons growing annually at an average rate of 3 percent.

5.3. World consumption

The true pattern of World consumption by countries is rather difficult to determine for tungsten. Some countries that have a large apparent consumption actually use considerably less than is shown because they re-export appreciable quantities in the form of manufactured goods such as tools and dies. Although unalloyed tungsten consumption in the electric and electronic applications is quite stable, the major market

presently rests upon tungsten carbide followed by tungsten steels.

The apparent Western World consumption of tungsten produced in non-communist countries over the last fifteen years is given in Table 7, determined from figures published in Mining Journal's 'Mining Annual Review'.

Table 7 [28]

Tungsten consumption (kilotons)

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
United States	5,7	5,9	6,1	5,4	6,4	7,0	7,4	6,0	7,4	7,5
Japan	3,4	3,5	2,8	2,1	2,3	3,4	3,2	1,5	1,9	2,0
Western Europe	11,8	12,2	12,8	12,5	11,1	12,6	13,0	7,5	10,2	10,1
Eastern Europe	3,3	3,4	3,6	3,5	3,6	3,6	3,6	2,8	3,8	3,9
Other	0,4	0,4	0,6	0,5	1,1	1,2	1,2	2,2	2,6	2,7
TOTAL	24,6	25,4	25,9	24,1	24,5	27,8	28,4	20,0	25,9	26,2

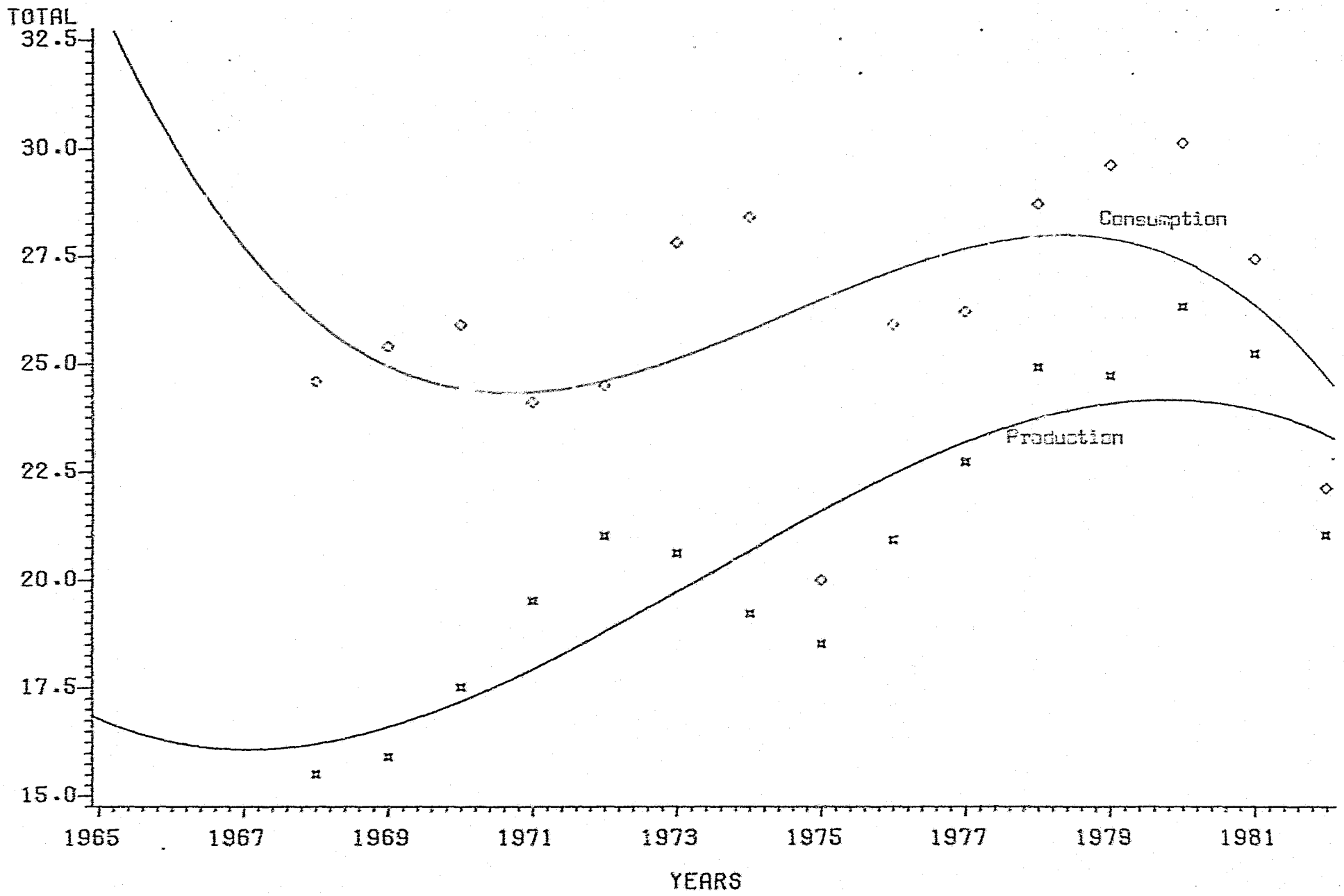
	1978	1979	1980	1981	1982
United States	8,3	9,2	9,3	9,8	5,4
Japan	2,0	2,6	2,5	2,2	1,8
Western Europe	11,1	11,0	10,5	8,3	8,5
Eastern Europe	4,3	3,8	4,9	4,1	3,9
Other	3,0	3,0	2,9	3,0	2,5
TOTAL	28,7	29,6	30,1	27,4	22,1

World consumption and production trends are depicted graphically on the following page , firstly the real trends and secondly the spline of best fit to the data as determined by the computer package SAS-GRAPH.

Under normal circumstances it is usually possible to relate the demand for a product to its consumption. However, for a large number of strategic products and especially for tungsten ore, the creation of the U.S. strategic stocks following the Korean war introduced very important elements of distortion. Excessive demand in the United States resulted in the creation of a stockpile representing several years consumption for the entire Western World. This demand created a disequilibrium in the market and the consequences are still apparent by the large fluctuations in consumption annually.

5.4. Local Production

The production of tungsten concentrates in South Africa and South West Africa/Namibia is given in Table 8 (pg.41).Wolframite and scheelite are shown together and although the grade of the concentrates is not stated it averaged about 65 percent.



WESTERN WORLD TUNGSTEN
PRODUCTION AND CONSUMPTION (KTONS)

Table 8

Local production of tungsten concentrates (tons) [15, 19]

	SOUTH AFRICA		SWA/NAMIBIA	
Year	Production	Sales	Production*	Sales+
1960	32	-	320(-)	56
1961	25	-	649(7)	403
1962	23	5	644(3)	594
1963	7	8	843(-)	852
1964	4	21	739(0,02)	762
1965	4	5	659(0,6)	572
1966	7	4	680(-)	695
1967	25	40	x	x
1968	48	36	x	x
1969	61	66	x	x
1970	6	19	x	x
1971	12	21	x	x
1972	1	-	x	x
1973	1	1	x	x
1974 — 1983	-	-	x	x

* The first figure represents combined tin-tungsten concentrates and the figure in brackets the tungsten concentrate production - mainly from small workers and individual diggers who sold small parcels of hand wrought ore to buyers who accumulated the small amounts until they had a quantity worth shipping or the price was favourable.

+ The figure represents sales of combined Sn/W concentrates.

x No figures are available from 1967 onwards.

The first recorded production figures are in 1936 and through to 1960, a total of 5 222 tons of tungsten concentrates were produced in South Africa of which 58 tons were sold locally. During the same period, 924 tons of tungsten concentrates were produced in SWA/Namibia, all of which was exported.

From 1941 to 1946 the main production was from the Nababeep Tungsten West, Nababeep Tungsten East and Tweedam mines near O'okiep. These mines were owned by O'okiep Copper Company, but they were leased to and operated by the Witwatersrand Consolidated Exploration and Finance Company until 1946 when their leases expired. O'okiep Copper Company then worked these mines for their own account until 1949.

O'okiep Copper Company reopened portions of the old mines and also worked the Tweedam East mine from 1952 to 1956, since which time

there has been no mining of tungsten on any scale in the vicinity of O'okiep.

Associated Tungsten Mines commenced operations in the area of Van Rooi's Valley and Dyason near Upington in 1948, where they were joined by P. Broude in 1950. These companies were listed as producers until 1957 when they ceased operations. Other established mines were Kliphoog, Narrap, Ezelsfontein Prospect and Biesies.

All other production in South Africa has been listed as by 'sundry diggers - Namaqualand and Gordonia Districts'. They are mainly Cape Coloureds who eke out an existence around the more easily worked outcrop occurrences of scheelite, mainly in the area to the south of Vioolsdrift on the Orange River. They have limited knowledge and even more limited capital and equipment and have seldom worked deeper than 5 metres. They have sold the more readily obtained ore as hand-cobbed scheelite to local buyers.

It is rather unfortunate that the large known deposits of tungsten appear to have been worked out just as a considerable industry for the manufacture of tungsten carbide tools and rock drill bits was developing in South Africa.

The present production of tungsten is negligible except for an appreciable amount of tin-tungsten concentrates, the tungsten content of which is not declared and all of which is exported. In the Transvaal such Sn/W concentrates have provided all the tungsten that has been produced. The most recent serious attempt at tungsten mining in the Northwest Cape was initiated by Redbank Mining Company at Noubestaan, 30 kilometres south of Vioolsdrift. Their 100 ton per day mill was designed to be fed partially from ore mined on their own claims and partially from ore recovered from claims held and worked by local Coloured miners. They decided to purchase tungsten ore from the small workers within a radius of approximately 25 kilometres on contract and to assist these miners with technical advice, the loan of compressors and drilling equipment and to undertake blasting operations for those which may not be qualified to obtain blasting permits. The grade of ore on which the company has planned its operation is about 1,0 percent WO_3, but exploration has indicated appreciably higher grades. The possibility of expansion to two or three similar plants operating on a customs treatment basis exists.

One of the two major producers of tungsten in SWA/Namibia closed down twelve years ago, namely Brandberg West Tin mine near Omaruru. Brandberg West was owned and operated by the South West Africa Corporation, managed by Gold Fields of South Africa. The mine commenced operations in 195[illegible]d in 1970 the ore reserves were estimated at 8 million tons of ore containing 0,20 percent combined tin and wolframite. The mine produced both tin concentrates (32 to 35 percent Sn) and combined tin-tungsten concentrates (16 to 19 percent WO_3). In 1972 it was decided to close down the mine temporarily pending improved metal prices.

The other major producer, the Krantzberg mine, (also near Omaruru), is owned by Nord Mining and Exploration (Pty.) Ltd. of Windhoek. There is no associated tin and the main mineral is wolframite. A concentration plant having a designed capacity of 400 tons per day is in operation, utilizing gravity concentration followed by cleaning by magnetic separation. The production was about 300 tons per day and the ore reserves are unknown. This mine had a great deal of labour unrest and is at present running at heavily reduced production.

5.5. Local consumption

The following tables, abstracted from the annual trade statistics of South Africa as determined by the Department of Customs and Excise record the imports and exports of tungsten and tungsten products into and from South Africa over the last fifteen years.

Table 9

Ores and concentrates of tungsten (item 26.01.65)[30]

Year	IMPORTS		EXPORTS	
	Quantity(tons)	Value(current R)	Quantity(tons)	Value(current R)
1968	292	638 938	61	93 543
1969	286	577 519	47	76 550
1970	607	1 682 466	185	495 961
1971	416	938 176	100	234 656
1972	543	773 527	-	-
1973	444	681 527	55	127 400
1974	542	1 787 259	x	776 890
1975	424	1 846 357	x	1 915 025
1976	344	1 719 624	x	2 939 831
1977	485	4 743 102	x	3 696 221

Year	IMPORTS		EXPORTS	
	Quantity(tons)	Value (current R)	Quantity(tons)	Value(current R)
1978	508	4 556 658	×	3 110 188
1979	335	2 810 293	×	804 382
1980	650	6 090 669	×	×
1981	401	3 624 668	×	×
1982	294	3 368 978	×	×

Year	RE-EXPORTS	
	Quantity(tons)	Value (current R)
1968	-	-
1969	-	-
1970	-	-
1971	61	125 106
1972	-	-
1973	35	62 543
1974-1982	-	-

The quantity recorded is the tons of contained tungsten metal in the ore or concentrate.

The decreasing trend of imports is occurring not as a result of diminished demand over the last few years but as a consequence of more efficient extraction and processing techniques. The absence of re-exports for the last decade demonstrates good trade management in a situation where the commodity traded is vital and strategic to indigeneous industries. It is desireable that this trend is maintained in the future.

Table 10

Tungsten metal, wrought or unwrought articles (item 81-01)[30]

Year	IMPORTS		EXPORTS	
	Quantity(tons)	Value(current R)	Quantity(tons)	Value(current R)
1968	87	416 940	10	40 630
1969	41	324 858	38	110 750
1970	125	706 064	25	103 942
1971	63	520 901	15	49 808
1972	47	417 888	12	13 716
1973	75	612 573	21	52 475
1974	72	648 364	×	147 551

Year	IMPORTS		EXPORTS	
	Quantity(tons)	Value(current R)	Quantity(tons)	Value(current R)
1975	34	608 466	x	20 308
1976	14	446 873	x	44 563
1977	34	686 410	x	235 923
1978	142	1 429 067	x	310 028
1979	202	1 989 477	x	221 163
1980	x	1 774 556	x	12 457
1981	x	720 616	x	71 130
1982	x	341 508	x	100 518

Year	RE-EXPORTS	
	Quantity(tons)	Value(current R)
1968	6	16 781
1969	1	9 891
1970	2	13 533
1971	0,2	2 060
1972-1982	-	-

x indicates figures not recorded for public use.

Tungsten metal imports have virtually halved each year since 1980. This was a market reaction under two influences:

(i) a decreased price in 1978 and 1979 caused increased buying

(ii) consequent entry into the downward portion of the business cycle with large stockpiles.

The imports of tungsten metal should increase over the next four years as stockpiles are consumed since tungsten wire in lighting is one field in which substitution is virtually impossible at present.

Imports and exports of tungsten carbide are not recorded separately. Prior to 1969 this material was included under item 514-950: Other Carbides. Since 1 it has been recorded under item 28.56.30: Tungsten, Tantalum, Titan and Vanadium carbides. Imports and exports of tantalum and titanium carbides are probably quite small, but exports of vanadium carbide in the form Carvan and similar steel additives are substantial and probably exceed exports of tungsten carbide, either as the powder or in the form of drill and tool tips.

Table 11

Rock drill bits (assumed to be of WC, item Y82-05-40) [30]

Year	IMPORTS		EXPORTS	
	Quantity(No.)	Value(current R)	Quantity(No.)	Value(current R)
1968	+	+	+	+
1969	45 800	788 904	+	+
1970	31 187	1 525 300	+	+
1971	39 406	1 336 116	+	+
1972	28 821	808 383	111 770	375 380
1973	8 011	427 134	12 326	296 389
1974	17 922	439 185	x	530 228
1975	197 272	1 994 287	x	449 004
1976	46 989	1 253 402	x	1 161 503
1977	47 603	1 131 825	x	2 053 740
1978	18 322	1 292 996	x	1 794 840
1979	25 800	837 859	x	2 426 138
1980 *	52 587	849 090	x	x
1981	76 063	1 410 504	x	x
1982	25 698	1 106 301	x	x

Year	RE-EXPORTS	
	Quantity(No.)	Value(current R)
1968	+	+
1969	+	+
1970	+	+
1971	+	+
1972	1 134	453 798
1973	317	61 012
1974-1982	x	x

\+ indicates not recorded for the particular year

x indicates not recorded for public use

* item classification changed to 82.05.05.85

Import figures for rock drill bits appear to fluctuate rather widely. But if figure four in Appendix Three is considered (ignoring 1975), where the data are plotted graphically- a cyclical trend is observed which possibly coincided with expansions in the mining industry as a consequence of the normal business cycle. However, the consumption of rock drill bits manufactured locally over this period would have to be determined first in order to establish such a relationship.

The particularly high unit value of imports and re-exports compared with the exports during 1972 and 1973 suggests that the bits imported and re-exported were probably very special, elaborate bits for drilling oil wells, whereas those exported were normal mine rockdrill bits.

Table 12

Tool tips and plates, sticks for tool tips, unmounted, of sintered metal carbides (item Y82-07: all carbides, item Y82-07-10: tungsten carbides) [30]

Year	IMPORTS		EXPORTS	
	Quantity(No.)*	Value(current R)	Quantity(No.)	Value(current R)
1968	524 369	418 588	294 838	413 018
1969	812 679	775 828	341 711	440 265
1970	1 259 831	1 122 774	501 366	601 843
1971	563 485	398 224	+	+
1972	553 629	448 918	627 957	430 409
1973	839 498	512 394	1 102 972	785 801
1974	735 848	742 334	x	1 235 508
1975	592 500	1 518 513	x	1 090 357
1976	62 236	1 302 678	x	1 285 617
1977	137	1 355 428	x	622 725
1978	201	2 008 638	x	615 472
1979	217	3 218 840	x	1 402 836
1980	300	4 838 841	x	2 093 273
1981	362	6 665 077	x	2 336 491
1982	305	6 228 858	x	2 242 947

Year	RE-EXPORTS	
	Quantity(No.)	Value(current R)
1968	6 212	12 067
1969	11 294	44 207
1970	5 114	20 363
1971	+	+
1972-1982	x	x

x indicates not recorded for public use

\+ indicates not recorded for particular year

* unit used from 1977 onwards in 100 kilograms

This item classification, seemingly innocuous, contains the greatest

monetary value of all tungsten imports. This is due to the many components contributing to this sector, for example: chisels, electric drill bits, grinders, cutting blades, scrapers and even ploughshares. A steadily increasing market would thus be anticipated with the effect of fluctuations greatly diminished due to its multi-commodity composition. This is apparent from figure four in Appendix Three where the data is depicted graphically. A definite, slow, stable consumption is evident from 1976 onwards - very stable considering the pre-1976 trend but the use of ambiguous figures (in the opinion of the Minerals Bureau) may refute the above argument. This is explained as follows.

From the year 1971 onwards the figures refer to components comprised of specifically tungsten carbides. It is strongly suspected because of the large number involved that many of the items recorded in this table as item Y82-07-10 are actually inserts for rock drill bits and should have been entered in table 7 under item Y82-05-04.

Although after 1977, 100 kilogram units were used, the Department of Customs and Excise records for 1976 either 62 236 articles or 622 units, implying on average, 1 kilogram per unit. Also these returns would not include possible production in SWA/Namibia.

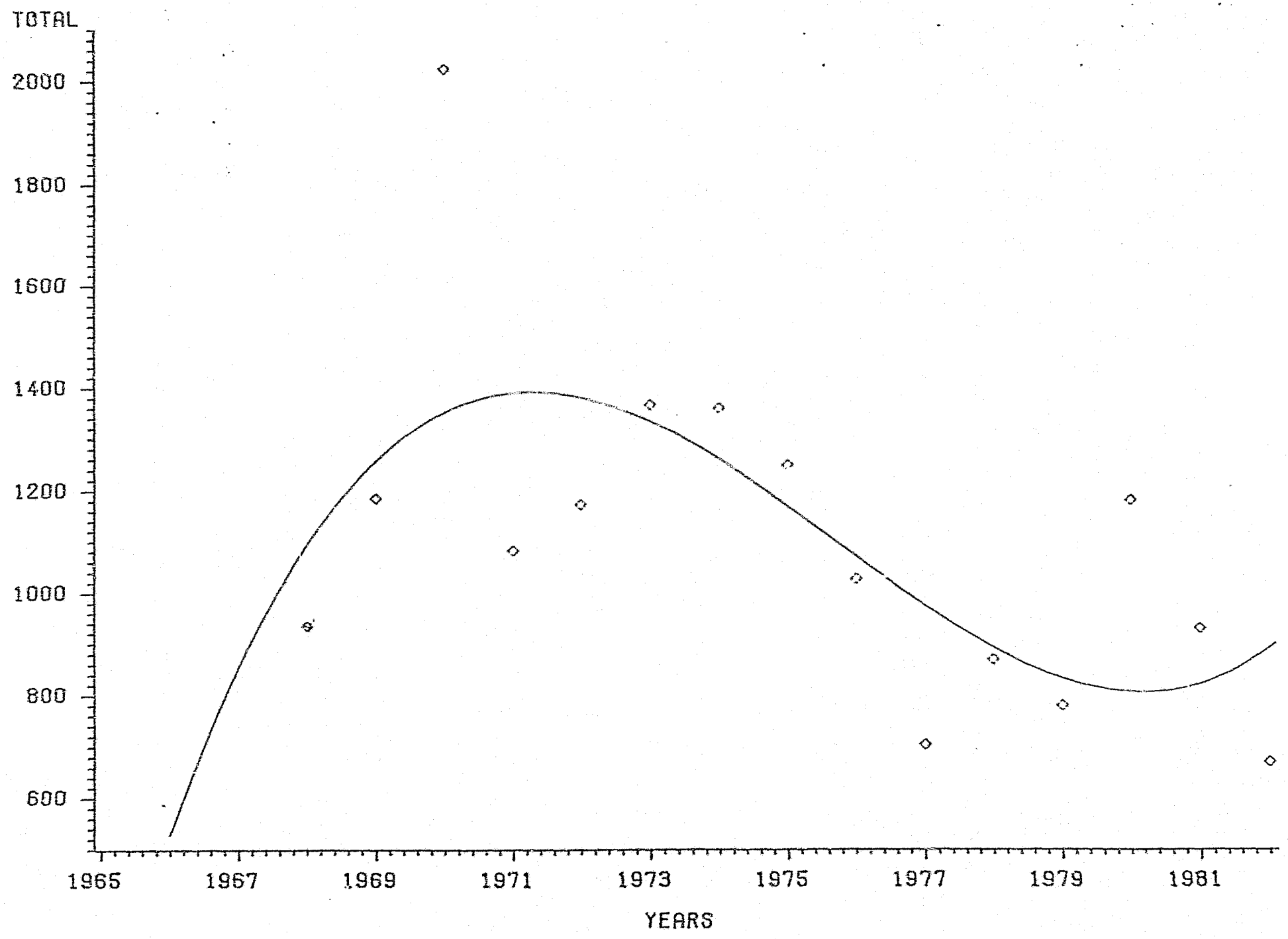
The total consumption of tungsten in South Africa can be estimated for the period 1968 to 1982. Any tungsten applications other than those covered by the previous tables would comprise insignificant amounts. Internal consumption is determined by imports less exports; but due to export figures not being published after 1974, the only recorded measure is that of imports.

YEAR	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
IMPORTS (tons W)	935*	1186	2023	1082	1173	1367	1360	1248	1027	704	969	780

1980	1981	1982
1180*	930*	670*

* estimated

This trend is depicted graphically on the following page.Appendix Three contains the trend graphs for the four components of the total imports. It is obvious from the graphs that no attempt can be made of a realistic model as the data are very erratic. To predict the demand for the next decade the most probable average annual rest-of-world demand growth rate of 4,5% from the base of 1978, determined by the Stanford Research Institute, is utilized.



SOUTH AFRICAN TUNGSTEN
IMPORTS IN TONS

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 W)	1085	1130	1185	1235	1290	1350	1410	1475	1540	1610

This trend is depicted graphically on the following page. No significant technological developments are foreseen in the near term that would affect demand projections appreciably. World reserves and resources of tungsten are limited- however, significant price increases for tungsten would stimulate the search for new deposits. The apparent shortfall between production and consumption can be accounted for by the recovery of scrap tungsten from worn tools and tool bits. This is the case of one company at least in South Africa which accounts for about 30 percent of requirements.

6 THE MANUFACTURE OF ARTICLES FROM TUNGSTEN

Apart from relatively minor applications for tungsten chemicals, the three principal uses of tungsten are in the form of ferrotungsten, tungsten carbide and tungsten metal.

6.1. Ferrotungsten

Ferrotungsten is normally produced by the direct smelting of tungsten concentrates, either scheelite or wolframite based, the impurities contained not being of much importance. Smelting can be carried out by carbon or metallo-thermic or silico-thermic reduction in electric furnaces. Production of ferrotungsten is a small scale batch operation as the temperatures involved are most detrimental to the linings of the furnaces or crucibles used.

6.2. Tungsten metal and tungsten carbide

Both these products make use of tungsten oxide, WO_3, as an intermediate product and this oxide must be of extremely high purity. Therefore impurities in the concentrates are not desired and as a result carry heavy penalties in all contracts for the purchase of concentrates. The presence of arsenic is particularly objectionable. Wolframite concentrates are fused with soda ash while scheelite concentrates are most commonly decomposed with hydrochloric acid. Most users thus prefer to operate on either wolframite or on scheelite and not to keep changing their nature of supply.

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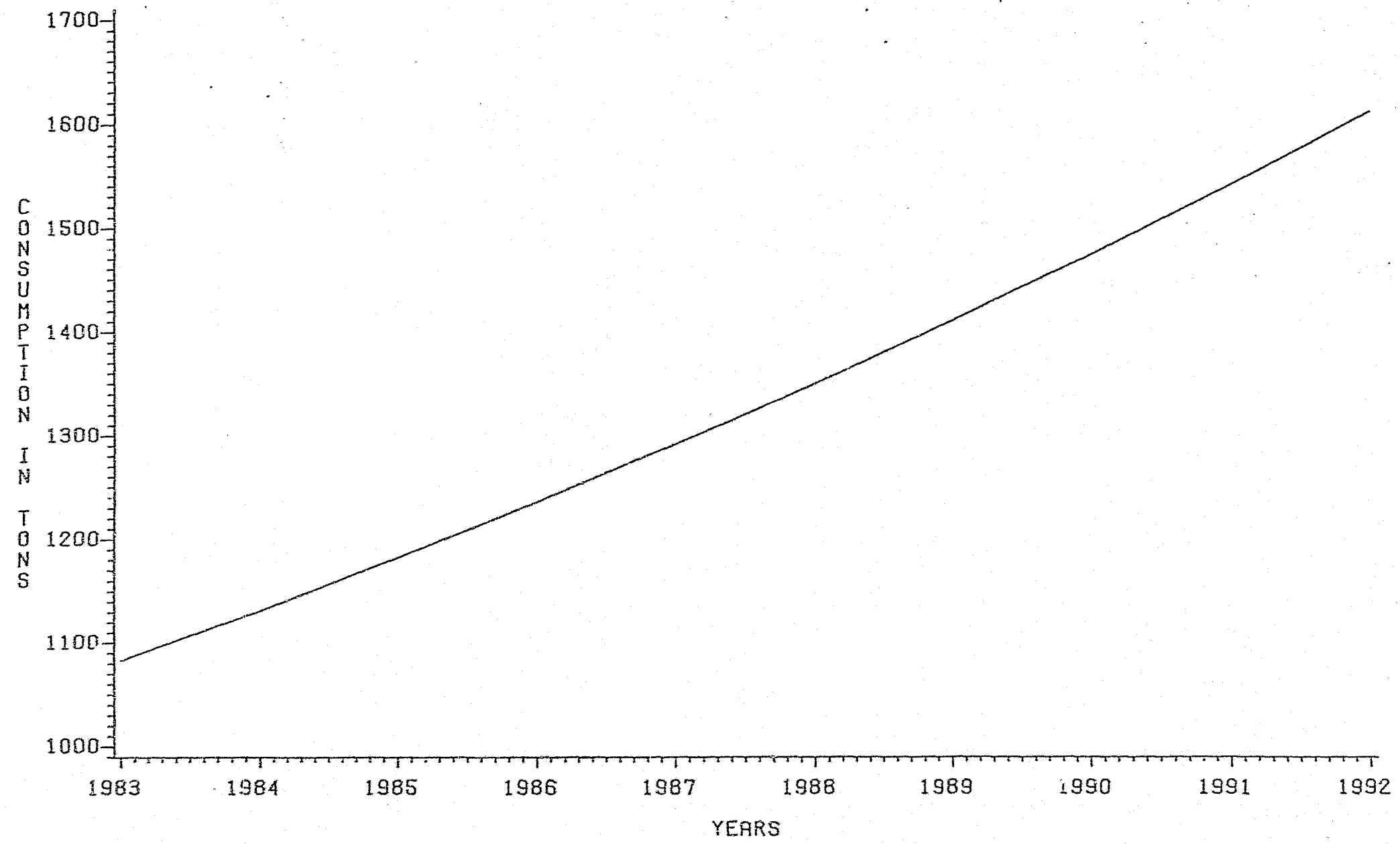
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SOUTH AFRICAN TUNGSTEN CONSUMPTION MEASURED IN TONS

49(a)

Tungsten metal is produced in powder form by the reduction of tungstic oxide by hydrogen. Subsequent working is based on established techniques of powder metallurgy complicated by the very high sintering temperature of tungsten. The production of extremely fine wire for the filaments of incandescent lamps requires highly specialized equipment. It is unlikely that tungsten metal will be produced in South Africa in the forseeable future.

6.3. Tungsten carbide powder

This is produced by the direct reduction of tungstic oxide with carbon. Tungsten carbide is used in the form of suitably shaped compacts of carefully sized grains sintered into a matrix most commonly of cobalt metal. For each particular application the size of the grains of carbide and the proportion of cobalt in the matrix are critical. There are over 200 patents relating to the preparation and use of tungsten carbide. A great deal of this knowledge is held as part of the technical expertise of companies in the industry. South Africa is fortunate in that even if local reserves of tungsten ores appear to be scanty there is a great deal of local expertise in the manufacture and working of tungsten carbide available.

7 MARKETING, PRICING AND TRADING

7.1. Markets

There is a completely free market for tungsten, in fact in the opinion of many people connected with the industry, far too free, as the vagaries of the price of tungsten are notorious and cover a wide range with a complete lack of stability. This appears to be due not only to a fluctuating demand for tungsten, but also to such influences as wild speculation in tungsten futures and even unfair dealing! The market for tungsten is unusually susceptible to major variations of a temporary nature. Changes in defence programs,in Socialist country purchasing, in Chinese selling, in U.S. Government stock adjustments can each have sufficient effect upon the tungsten market to move prices up or down 20 percent or more. The investment cycle and its effect on tungsten demand, particularly at the end of the cycle when investment orders drop drastically, also influence market sensitivity.

Where governments are involved in control of mines or of marketing such as China, Bolivia and Peru there is the danger that the governmental hard currency requirements will lead to expansion and sales activity out of line with demand.

This combination of volatile demand, significant and changeable government involvement in the market and a lack of price sensitivity in tungsten production creates a market in which wide price fluctuations are almost inevitable.

7.2. Prices

Given tungsten's past history of instability and the industry's dependence on the Metal Bulletin quotation for its pricing information (based on very little consumer/producer business), it is not surprising that producer countries have sought for many years some buffer arrangement to even out the drastic, temporary variations in demand/supply; or that consumer companies have sought to establish an alternative pricing index to represent more accurately what is actually being paid for tungsten concentrates - an effort in which producer companies joined when the International Tungsten Indicator (ITI) was developed. The Primary Tungsten Association supported this development believing that wide fluctuations in MB quotations of the past have inhibited growth in tungsten usage. The objectives of the ITI proponents will not be realised unless the ITI is used as a basis for contracting. The greater the coverage developed by the ITI of consumer purchases and producer sales, the greater confidence consumers can have in contracts based on the ITI, the more ITI quotations will relate to the average prices paid by and to the industry as a whole, and the smaller will be the influence of intermediaries.

The two years 1974 - 75 saw the first real progress in the UNCTAD Committee on Tungsten towards a tungsten stabilisation agreement. Producer countries displayed a unified front but progress has been slower in subsequent years - although for once UNCTAD's activities appear to be meeting with fairly general approval, so far they seem to have met with a singular lack of success. It is hoped that the tungsten market may be able to be controlled by some body similar to the Tin Council, possibly by means of a buffer stock but so far there does not seem to be much likelihood of this happening. It also appears that tungsten is as yet one of the few commodities which the Japanese are not endeavouring to corner.

Tungsten concentrates, either scheelite or wolframite, are sold on the basis of the 'metric ton unit' of contained WO_3, namely the price quoted is 1 per cent contained tungsten oxide. Penalties are incurred for the presence of deleterious impurities, principally arsenic and molybdenum.

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The two years 1974 - 75 saw the first real progress in the UNCTAD Committee on Tungsten towards a tungsten stabilisation agreement. Producer countries displayed a unified front but progress has been slower in subsequent years - although for once UNCTAD's activities appear to be meeting with fairly general approval, so far they seem to have met with a singular lack of success. It is hoped that the tungsten market may be able to be controlled by some body similar to the Tin Council, possibly by means of a buffer stock but so far there does not seem to be much likelihood of this happening. It also appears that tungsten is as yet one of the few commodities which the Japanese are not endeavouring to corner.

Tungsten concentrates, either scheelite or wolframite, are sold on the basis of the 'metric ton unit' of contained WO_3, namely the price quoted is 1 per cent contained tungsten oxide. Penalties are incurred for the presence of deleterious impurities, principally arsenic and molybdenum.

Although tungsten prices are very mercurial, Roskill's Metal Databook[33] gives historical arithmetic averages of weekly price quotations for WO_3, 65% basis as quoted in MB. The price in 1962 was $10.95 per s.t.u. (1 percent of a short ton) rising to $35.62 in 1972 corresponding to an average annual increase of around 8,5 percent - in times of very low inflation. The average price in 1982 decreased from $123.00 per m.t.u. in January to $80.00 per m.t.u. in December which on a constant dollar basis was the lowest level since the early 1960s. The 1982 average annual price was $106.32 per m.t.u. versus $143.46 per m.t.u. for 1981 again indicating the severity of fluctuations in price in the tungsten market.

Recent prices quoted for various tungsten products are:

(i) Tungsten concentrates

United Kingdom and Europe (Metal Bulletin)	
Wolframite, std.min: 65% WO_3, C.I.F.	78.46 $ per m.t.u.
United States (American Metal Market)	
about 65% WO_3, London price	79.43 $ per m.t.u.

The above price is used as a basis to determine long term and spot prices in New York, at negotiated premiums and discounts.

(ii) Tungsten powder

United States (American Metal Market)	
Hydro Red 99,9%	3.56 $ per lb.
Carbide	4.41 $ per lb.
Ammonium paratungstate: per s.t.u. of WO_3	62.41 $ per lb.

(iii) Ferrotungsten

United States (American Metal Market)	
High purity, 87 - 93%W	4.12 $ per lb.

In the Economic Analysis of the Tungsten Industry[8] by the Charles River Associates 62 pages of econometric modelling of the tungsten price is attempted - finally declining to make any forecasts!

However, the pricing of tungsten with its unpredictable vagaries may not affect the future of tungsten mining in South Africa as greatly as it might seem. The primary objective of endeavouring to develop tungsten mining locally should be to satisfy the requirements of internal industry - which are considerable, especially for the manufacture of tungsten carbide inserts for rockdrill bits. The producer price to local industry should therefore be more stable than that obtained on the overseas markets. This will be to the benefit of the local tungsten manufacturing industry and in turn to the mining

industry. Further, it will help to stabilize prices of South African articles manufactured from tungsten. South Africa is already exporting tungsten carbide and the local rockdrill steel is as good as, if not superior to, that used overseas. It would thus be preferable to export tungsten from South Africa in the form of manufactured articles on a comparitively stable market than tungsten concentrates on a highly unstable market.

7.3. Trading in tungsten

Few, if any, producers of tungsten ores or concentrates are directly connected to manufacturers of tungsten products. Such manufacturers purchase their supplies in the form of scheelite or wolframite concentrates.

Ferrotungsten may be produced directly by smelting tungsten concentrates and this alloy is sold to manufacturers of tool steels and hard facing welding rods.

The majority of tungsten is first extracted in the form of ammonium paratungstate which may be sold to other end users as such, or more commonly converted to pure tungstic oxide WO_3, which may then be reduced to the metal powder or converted to tungsten carbide.

The metal powder and carbide manufacturer may then work the metal into ingots by sintering and forging, and the carbide into specially shaped compacts by sintering in a matrix of cobalt metal. These finished compacts are the form in which the tungsten carbide is used, by mounting onto special holders or brazing onto the tools themselves. Alternatively the carbide may be sold to other manufacturers of tools and dies who form the compacts themselves.

There is thus a considerable trade in all forms of tungsten and it may pass through many processors before reaching the final end user. With such a high priced commodity there is a considerable trade in scrapped and worn out tungsten tipped tools. This is particularly the case in South Africa where about half the tungsten consumed is used in the form of tungsten tipped rock borers in the mining industry. These tipped borers are commonly leased to the gold mines on contract and returned to the manufacturers when worn down too far for resharpening by grinding.

8 TUNGSTEN IN SOUTHERN AFRICA

8.1. Known deposits in South Africa

Although there has been appreciable production of tungsten from deposits

in South Africa and SWA/Namibia in the past, the general impression gained from published literature and discussions is that the only deposits worth working have been mined out at least 25 years ago and that all other deposits are small pockets of no interest. Closer investigation of certain areas in which tungsten is known to occur could reveal sufficient reserves to supply the local tungsten carbide industry.

In the tin fields of the Bushveld region of the Central Transvaal the occurence of tungsten in the form of scheelite at the old Stavoren tin mine is recorded. Tin-tungsten concentrates were produced at Stavoren on a small scale by Zaaiplaats Tin Mining Company during the 1950's and were sold to Hard Metals, who recovered the scheelite and returned the tin to Zaaiplaats for smelting. Production was very small and it is not likely that any further work on this property will be rewarded. Tungsten as scheelite, wolframite and ferberite occurs at the Zaaiplaats tin mine, near Potgietersrus, but the quantity does not warrant recovery from there or from the adjoining Groenfontein property which is being worked by Zaaiplaats under lease from the Transvaal Consolidated Land and Exploration Company Ltd.

There is an occurence of wolframite in association with cassiterite, nickel and corundum a few kilometres south-west of Melmoth, Natal but the deposit does not appear to be of economic value. However, a broad belt of the Nodlweni schists appear to be quite heavily mineralized and the whole area might repay re-investigation.

At Kuilsrivier, Cape Province, wolframite occurs with cassiterite at the old Good Hope mine in quartz-tourmaline reefs in granite and also in alluvial deposits. Little information about these deposits is available except that they occur in a belt of mineralization extending from Yzerfontein in the North to the Bonte River, Somerset West in the South. The worthwhile tin-tungsten occurences could only be worked at the expense of seriously damaging valuable vineyard areas.

Scheelite has been variously reported from near the Murchison Range, close to the Cobra Emerald mine south of Gravelotte, near Leydsdorp and from the Forbes Reef in the Barbeton district. None of these occurences are promising except that by analogy with certain scheelite deposits in Zimbabwe, scheelite might well occur in some of the other gold reefs in the Barbeton area. Any explorations for gold in this area should also include a search for scheelite. A more promising occurence occurs near Shangoni, a few kilometres south of the old Louis

Moore gold mine in the National State of Gazankulu. This deposit was investigated to some extent in 1974, but for company reasons the prospecting was discontinued. In 1977 it was re-investigated by one of the larger local mining houses with encouraging results.

Namaqualand and the Northwestern Cape Province are the areas from which most of the tungsten produced locally has come and which is considered to hold out the most promise for the future. The area extends in a wide arc from around Springbok and O'okiep in the southwest, north to the Orange River near Vioolsdrift and then eastwards to about 15 kilometres west of Upington. This covers a total area about 415 kilometres long and 65 kilometres wide, much of it arid and almost in inaccessible regions. The detaile geology is highly confused but appears to consist of highly metamorphosed and folded sediments of the Kheis System. Much of the area is characterized by a number of pegmatites of all shapes and sizes - some containing tungsten, associated with quartz veins. Recent exploration work has indicated that the area may be one of the great mineral provinces of the world e.g. Gamsberg (zinc), Broken Hill and Black Mountain (lead, zinc, copper, silver), Rosh Pinah (Namibia - zinc), Prieska (copper, zinc). In view of this and the numerous reported occurrences of tungsten minerals it may be possible that some of the tungsten deposits are large and two main areas warrant further investigation, namely, the area around O'okiep and Nababeep and the so-called pegmatite region that extends from south of Vioolsdrift up the Orange River to near Upington.

Although it was presumed that all workable tungsten deposits had been located by the O'okiep Copper Company, fairly recent reports suggest other nearby occurences although they contain appreciable quantities of arsenic. The pegmatite region has produced a little mica and felspar but poor transport facilities have militated against the production of minerals of relatively low value - which is not the case for tungsten. Throughout the whole belt, all tungsten deposits appear to be small and erratic. The heavily dissected country on both sides of the river valley has shown mineralized veins to a depth not exceeding 270 metres, but the mineralization in the vertical extent is just as erratic as in the horizontal. Mining to date has been by small workers who picked out the most obvious ore and any disseminated ore such as occurs in the tourmaline has either been left in situ or dumped. On Van Roci's Vley (near Upington) tungsten occurs mainly as wolframite associated with cassiterite - worked previously but

values were diluted by the necessity of mining waste material in between the erratic veins. This area would be worth re-investigating.

The occurence of tungsten near the Octha Diamond Mine on the Orange River appears similar to that on Van Rooi's Vley and is at present being explored. Tungsten was also being worked on a small scale at Dyasons Klip during 1970 to a depth of about 30 metres. Deeper than this arsenic impurities were encountered and mining was halted. MINTEK claim the impurities can be removed by flotation and this area also merits further prospecting.

8.2. Known deposits in SWA/Namibia

Numerous occurences of tungsten have been reported and in the past there has been considerable production as shown in section 5.4. There are four principal areas of tungsten deposits.

Numerous small deposits occur in the Namaqualand Granite-Gneiss Complex in the Warmbad district. All deposits located in this area appear to be small erratic pockets that have been worked spasmodically over the years by local farmers or small time miners. It is felt that these tungsten deposits form part of the mineralized belt of northern Namaqualand.

Numerous small occurences of wolframite have been reported from the Karibib district extending westwards into the Swakopmund district. Production from these deposits, if any, has been small.

The principal occurence in the Rehoboth district was the old Natas mine, 80 kilometres west of Rehoboth. The tungsten occurs mainly as scheelite in mineralised pegmatites although much of the main orebody has been oxidized with the formation of tungstite, WO_3. There is no indication as to whether the Natas mine would merit re-investigation but scheelite in small crystals has been found in similar rocks and conditions on the farm Rostock, 50 kilometres southwest of Natas and might repay further exploration.

Most of the tungsten occurences reported from SWA/Namibia occur in the Damara System but the most promising area is in the Omaruru district. These are mainly pegmatitic deposits in which the tungsten is associated with quartz veins. This area includes the two major producers of tungsten in SWA/Namibia, though one is now closed. They are the Brandberg West tin mine consisting of narrow quartz veins intruded into an anticlinal structure containing cassiterite, wolframite-ferberite and scheelite (this mine has closed); and the Krantzberg mine consisting of intensely folded and steeply dipping

schists of the Damara System containing wolframite, fluorite and tourmaline. There is no associated tin or molybdenum and in addition there are narrow quartz veins with locally strong wolframite which has not been mined. Impurities are very low.

Many other small deposits usually associated with cassiterite proliferate - all of which have only produced small quantities of wolframite and scheelite over the years and do not hold much promise for developing into viable mines. The area is, however, covered to a large extent by surface alluvium and limestone which obscure much of the underlying rock formations. In view of the widespread mineralisation in the area it is possible that one or more large deposits may be discovered but the chances are fairly remote.

8.3. Forms in which tungsten is required in South Africa

The tungsten industry in South Africa is unique in that it has been developed primarily to meet the requirements of the mining industry and not as a result of entrepreneurship utilizing idigeneous raw materials. The industry has developed to the stage where it can supply the mining industry with all its requirements for rock drilling, except for certain special types of bit which being required in small quantities do not warrant local manufacture. It can supply a very large proportion of the tungsten carbide used in the engineering industry, including special dies for wire drawing and it has already developed a considerable export trade in finished and semi-finished products of tungsten carbide. All of this has been achieved with the use of imported tungsten ore and concentrates. This emphasizes the vulnerability of South Africa to any embargo or curtailment of supplies of tungsten and the need to find and develop local sources.

8.3.1. Tungsten metal

So far as it known, no tungsten metal is produced as such in South Africa and all tungsten metal for such applications as the filaments of lamps and electrical contact points are imported.

8.3.2. Ferrotungsten

Small quantities of ferrotungsten have been produced on occasion by the Thermometallurgical Corporation using basically the alumina-thermic reduction method. The demand for ferrotungsten is very small, amounting to a few tons annually. The reason for this is that

few tungsten bearing alloy steels are produced locally that contain sufficiently high percentages of tungsten to require the use of ferrotungsten. Alloy steels containing low percentages of tungsten are made by the addition of special low melting tungsten base alloys - all of which are proprietary articles and are imported.

Considerable amounts of wear resistant components such as scraper and graderblades, crusher parts etc. are reinforced initially and rebuilt by the addition of tungsten steels applied by the use of proprietary 'hard facing' electric welding rods, all of which are imported. Actually these welding rods do not contain ferrotungsten but consist of steel tubes packed with tungsten carbide granules and coated with suitable fluxing material. Seeing that tungsten carbides of most grades are produced in South Africa, the possibility of producing hard facing rods should be investigated even though special equipment different from that used for making normal coated rods would have to be installed.

8.3.3. Tungsten carbide

By far the major use of tungsten in South Africa is in the form of tungsten carbide, and to a lesser extent in the form of combined carbides with titanium and tantalum. The tungsten carbide usually bonded with cobalt metal is used for the tips of metal cutting tools, dies, especially for wire drawing and the tips of rockdrill bits - the largest application.

The tungsten carbide may be:

(i) imported as the finished bits e.g. special designs for oil well and large hole application;

(ii) imported as inserts for mounting into machine tool bits;

(iii) imported as the powder for forming into tools, dies and inserts;

(iv) manufactured in South Africa.

Figures for the imports and exports of tungsten in various forms are given in section 5.5 of this report. Although these figures have been obtained from official sources, local manufacturers have expressed doubts as to their accuracy. There are numerous companies which import tungsten and tungsten carbide but only two companies are engaged in the production of tungsten carbides from ores and concentrates and its working into finished components. Both companies have built up an appreciable export trade. They are:

Sandvik (Pty) Ltd. and

Boart Hardmetals (Pty) Ltd.

Sandvik head office is in Benoni with their tungsten carbide works at Brakpan. The Sandvik-Coromant Company of Sweden acquired Wickmans of Great Britain in 1973 and continued to operate the South African subsidary under the name of Wickman until 1977. The tungsten carbide plant of Wickman (S.A.)(Pty) Ltd. is now known as the Brakpan factory of Sandvik. This now means that whereas the Sandvik-Coromant company used imported tungsten carbide for their rockdrills, they will now obtain their inserts from Brakpan. The plant previously operated on wolframite concentrates from the Krantzberg mine. It consumes around 200 tons of tungsten annually and reclaimed tungsten amounts to about 30 percent of requirements. They are concentrating their production on the manufacture of tungsten carbide inserts for rockdrill borers and import the inserts for machine tools. The latter comprises about half of their business, the cost of the tungsten carbide insert amounts to about 10 percent of the total cost of a standard 1,5 metre jumper.

Management complains about the high cost of reagents used by them. These, they say, are up to 40 percent higher than is paid by their overseas parent company. Their major consumption is caustic soda imported as solid. They have found the use of caustic lye from local manufacturers little cheaper and unsatisfactory. Processing of scheelite, requiring hydrochloric acid which is more expensive would render their tungsten carbide barely competitive on the overseas market. Another problem encountered by Sandvik and presumably by Hardmetals as well, is the disposal of a works effluent consisting of solutions of $CaCl_2$, $NaCl$ and NH_4Cl. At present these are evaporated to dryness in plastic lined dams which is not satisfactory.

Sandvik do not lease the jumpers they manufacture but sell them outright claiming an expected footage of between 100 and 150 metres depending on conditions and care. The selling price of all jumpers is subject to an escalation clause based on the current London price of tungsten. This variation amounts up to 15 percent on the cost of a normal stope jumper. With regard to the tungsten concentrates, Sandvik are only concerned about the molybdenum and arsenic impurities. Molybdenum passes straight through into the carbide and is most deleterious. The other impurities are volatilized off during carburization if not removed during prior processing but the arsenic produces poisonous fumes

which are best removed at the mine.

Hardmetals head office is in Springs and their parent company is the Anglo American Corporation of S.A. Through Boart International the local company has built up a very considerable export business even to countries who normally would not like it known that they are trading with South Africa. This export business consists of physical goods and a great deal of locally acquired expertise. They consume about 1 200 tons of tungsten annually.

They operate entirely using imported scheelite concentrates (although it would be possible for them to use wolframite) together with tungsten from reclaimed bits and tools. Formerly all their scheelite was obtained from Zimbabwe but deposits there are nearly exhausted and politically inaccessible and thus supplies must be obtained from elsewhere. They presently purchase their concentrates at 68 - 70 percent WO_3 which calls for a higher tungsten content than normal. With a lower tungsten content there is a higher silica content which causes problems in the residues in subsequent processing. They cannot remove arsenic as being in an urban area would require elaborate anti-pollution devices. Hardmetals have occasionally used small quantities of Sn/W concentrates from the old Stavoren tin mine. Removal of the tin from cassiterite is accomplished by electrostatic separators.

The manufacture of inserts for rockdrill bits accounts for only half of the production by Hardmetals, even for the South African market. They produce a wide range of tungsten carbide both in the form of powder for use by other consumers both locally and overseas and also a wide range of sintered carbide inserts. The supply of tungsten tipped rockdrill borers for mining and construction purposes is probably the largest market and this has been extended to cover the export of finished borers, using lined hollow steel supplied by USCO in Vereeniging. The majority of the rockdrills produced are leased on a contract footage basis. All cobalt used for bonding the carbide is imported from Zambia and Zaire and no shortage is experienced.

The total value of sales of the above two companies is very much more than the value of the tungsten carbide, even in finished form, representing the value of many other products, again emphasising the value of tungsten to South African industry and trade.

8.3.4. Rock drill steel

Although South African producers are already successfully exporting finished tungsten carbide products, in order to complete the most finished product it would be desirable to export the complete jumper or borer. Objections raised were (i) there is no future in exporting lumps of steel because of high transport costs but Highveld Steel and Vanadium presently export steel rails profitably (ii) there is not enough rock drill steel locally to permit a surplus for export but USCO could increase production (iii) the quality of local drill steel is not up to the standards demanded in most mining fields especially in tensile strength and quality control of the axial water hole but if these problems could be overcome this would improve the chances of exporting complete tungsten carbide tipped rockdrills and also improve drilling performance on South African mines.

8.4. Possible sources of supply for South Africa

Most of the projected world production capacity through to 1995 will continue to be in the United States, mainland China, the U.S.S.R., Bolivia, Canada and North Korea. Because of tungsten's partial association with molybdenum about 20 percent of future U.S. domestic production capacity may be determined by the level of molybdenum mining operations. However, it is anticipated that the tungsten supply situation will be improved by development of old mine deposits and new discoveries, and by more efficient extractive processes for high volume, low grade deposits.

Since the exhaustion of ores and concentrates from Zimbabwe, local companies have had to purchase their supplies on the open market which is not altogether a satisfactory situation. The predominant position of Red China, N. Korea and the U.S.S.R. on the world tungsten market is apparent. In fact the annual Canton Fair at which a very large proportion of Chinese production is sold on the open market has a very considerable influence on the vagaries of the world tungsten market.

Tungsten is readily available on the open market and South Africa could reduce uncertainty and improve planning for ore and concentrate purchases by:

(i) entering into longer time frame contracts with producers for a larger portion of their requirements;

(ii) seeking and obtaining fixed price forward contracts with mines (with escalation provisions);

(iii) investing in mines themselves.

In practice the future demands for tungsten will only affect South Africa if these demands cannot be met as the result of exhaustion of workable ore deposits. The effect of particular events or developments can be minimised by spreading contracts through various market segments and geographical locations, avoiding undue dependence on any outlet.

Tungsten is frequently produced as a by-product or co-product of working other metals, most commonly tin or molybdenum but very little hope is held for sufficient local production from these possible sources. However, it is estimated that there are 10 000 tons of tungsten reserves in South Africa and SWA/Namibia but although the patchy occurences would not attract a large mining company a deposit that could mine about 100 tons per day and produce 1 ton of concentrates daily could well be a payable proposition and extremely valuable asset. Two areas suggest themselves as being promising - the northeastern Transvaal where Archean rocks have been widely intruded by granite, with the formation of numerous pegmatites and the Namaqualand region where tungsten has been known for many years. The technology already exists to process ores locally but new deposits need to be discovered and extracted in order that South Africa's potentially vulnerable position due to complete reliance on imported tungsten, is reduced. The curtailment of supplies of tungsten as concentrates or finished products could arise as a result of ill-disposed countries or persons organizing an embargo due to them being politically opposed to South Africa or because the local tungsten carbide industry is making inroads into the markets thought to belong to established overseas producers.

9 SUBSTITUTES, RECYCLING AND TECHNICAL POSSIBILITIES

9.1. Substitution

In practice there is very little that can be done in the field of effective and economic substitution of tungsten.

In the electrical industry there are virtually no alternatives to tungsten. In some applications molybdenum (another strategic metal) could be used and platinium could replace tungsten in contact points at a price. Although the consumption of tungsten metal comprises only a small proportion of the total usage of this metal, there are no effective substitutes when it is used in fluorescent or incandescent

lamps. Other metals such as tantalum, titanium and molybdenum do not have the necessary high melting point.

In the engineering industry ferrotungsten used in hard wearing and tool steels could be replaced by other alloys, including high carbon steel, but only at a considerable loss in production efficiency.

Tungsten can be substituted for by titanium and tantalum as carbides. The best quality inserts for cutting tools for machine shop use such as Kennametal are mixed carbides with tungsten the major constituent. This could be achieved in South Africa using high titanium slag from the Richards Bay smelter as the source of titanium, but it would mean developing an entire new industry for the manufacture of titanium carbide and new techniques and expertise in its use as a substitute for tungsten carbides. This would be costly and take a considerable time.

Tips for rockdrill bits are made of pure tungsten carbide and no other carbides have proved as satisfactory. Removal of tungsten carbide in this application would result in decreased efficiency and reverting to integral forged jumpers or replaceable tips.

Tungsten in hard facing by welding could be substituted for by manganese alloy steel welding rods, but the amount of metal to be added for effective facing would be appreciably greater.

9.2. Recycling or secondary sources

A significant portion of total tungsten supply is provided by scrap. Segregated superalloy scrap containing tungsten is reused without separation of the constituent elements. Scrap tungsten generated at producing wireworks is collected for sale for recycling. Tungsten carbide can be reclaimed from cemented carbide scrap using a U.S. Bureau of Mines process. The cost ratio of tungsten carbide made from pure tungsten metal powder compared with that recovered from scrap is about 3:1. After drying, some high purity tungsten sludge collected from the cooling systems of abrasive cutting wheels used in preparing tungsten contact points has been added directly to steel melts.

9.3. Technical possibilities

A recently reported development involving photometric sorting in processing low grade tungsten resources could increase present estimates markedly. Research continues on developing and improving adherent electrodeposited coatings of various metals and compounds

that could improve the use and life of tungsten and tungsten carbide materials. Coatings have improved the cutting and wear resistance of cemented carbide tool inserts and ion implantation can drastically decrease the quantity of tungsten required. Advances in the technology of tungsten alloy preparation and fabrication could lead to increased demand in high temperature applications such as aerospace and nuclear reactors. If the price of tungsten should increase substantially and remain high for several years, programs to develop alternatives would intensify and usage of tungsten would drop to the essential applications. The uncertain supply of tungsten beyond 2000 should stimulate technological advances in exploration, mining, beneficiation and extractive metallurgy.

10 CONCLUSIONS AND RECOMMENDATIONS

The most important factor is that the use of this metal has now become essential to the operation of the mining, manufacturing and electrical industries with no domestic production and sole dependence upon imports of concentrates and finished products.

Although the demand for tungsten locally cannot be accurately determined it is probably of the order of 2 200 tons annually of which 1 600 tons would be consumed internally.

The value of all tungsten imported is very small compared to the articles subsequently produced and the work that is provided by industry.

There may be payable tungsten deposits in South Africa and SWA/Namibia and active steps should be taken to investigate the Shangoni area in the N.E. Transvaal (although it lies in the National State of Gazankulu, the pegmatite belt along the Orange River in the N.W. Cape and the tin fields of the Omaruru district. The export of any tungsten concentrates produced should be actively discouraged or banned until vastly increased reserves are discovered locally.

Even if no further deposits that may prove commercially viable at the present time are discovered, an accurate record should be kept for possible use in times of emergency when costs might be no object.

Efforts should be made to keep the prices or reagents required by the tungsten carbide producers within reasonable limits.

From the environmental point of view roasting of any domestic ores should be done at the mine to prevent noxious fumes in urban areas. Also better techniques for disposal of liquid effluents at plants must be devised.

The usual bonding agent for forming compacts of tungsten carbide is cobalt metal. At present this is obtained from Zambia or Zaire as the local producers of cobalt (the platinum mines) do not refine the cobalt oxide that they produce to pure metal. This is a line of development that could be pursued further.

The only practical safeguard against a curtailment in supplies of tungsten through embargoes would be to create a large strategic stockpile of tungsten in the form of concentrates, sintered compacts and wire for light bulb filaments - under Government sponsorship. It is considered that the stockpile should amount to not less than a year's supply of concentrates, with corresponding amounts of tungsten carbide in the form of powder and two years supply of filament wire. This at the present price of tungsten would cost about U.S. $20 million but this would probably be less than the disruption to South African industry that would occur from a serious shortage or lack of tungsten. It would also give a period to develop alternatives such as detatchable drill bits for mining and the possible change to titanium carbide or some similar product.

C: COBALT

INTRODUCTION

COBALT (Co)is a hard metal similar to nickel in many of it's properties. It has a high melting point and magnetic properties second only to iron. It is a metal that is rarely seen as such but is used daily in a multitude of ways.

The name, cobalt, was given to it by the Swedish chemist Georg Brandt, who first identified it as a separate element in 1735 - using the German word Kobold meaning subterranean gnome. These gremlins were believed to infest the metal mines of Bohemia and Saxony. The presence of cobalt in these sulphide ores caused considerable trouble in smelting and was alleged to cause sores on the miners but this was almost certainly due to the arsenic associated in the cobalt bearing minerals.

Although this metal was not isolated until the first half of the eighteenth century, the use of the ore goes back to over 2000 years B.C. when it was used in China, Persia and Egypt for imparting a blue colour to glass and ceramics. The first mention of zaffre, the crude roasted ore mixed with sand was in A.D. 1540 by Biringuecio . This is a crude cobalt oxide used for preparing smelt, a blue glass. Cobalt stained glass is evident in medieaval churches and cathedrals and provides the delicate blue glazes of the famous Delft chinaware.

Today cobalt is still used for making stained glass, glazes and paint pigments, but enters into daily life in a wide variety of applications such as permanent magnets, the manufacture of tungsten carbide tipped tools and the formulation of synthetic resins for glass reinforced plastics. The radioactive isotope Co-60 plays an important role in medicine and as a gamma ray source. The greatest use of cobalt is in nickel-base superalloys, which are widely applied in such critical high-temperature environments as turbines.

1 PROPERTIES OF COBALT

Duke,[14] provided a comprehensive review of the properties of cobalt. Cobalt is a hard, silvery-white metal with a faint blueish tinge, closely resembling iron and nickel in appearance. Its relative density is 8,9; the melting point is 1493°C and it is harder than iron. In practice the physical properties of cobalt may be affected considerably by even small traces of impurities or alloying elements and

by the presence of the two widely differing allotropic forms - alpha cobalt with a face centred cubic structure and beta cobalt which has a close packed hexagonal structure.

The high melting point of cobalt and other attributes tend to make cobalt alloys difficult to machine although they have excellent heat and corrosion resistant properties. However, cobalt metal and cobalt alloys have good sintering properties when in powder phase and thus are readily formed into components by powder metallurgy techniques, often to the finished sizes, thereby obviating further machining. These sintering properties make cobalt the standard material that is used as the matrix for the manufacture of tungsten carbide cutting and boring tools.

The artificial isotope Co-60 has a particularly long half-life. This renders it most suitable as a source of gamma radiation for medical and measurement purposes, but can be dangerous if, for instance, traces of Co-60 enter into stainless steel that is used in nuclear reactors.

The magnetic properties of cobalt, which can sometimes be greatly enhanced by alloying with non-magnetic materials such as aluminium, make cobalt alloys the standard material for modern high-duty permanent magnets while other alloys are used for soft magnets.

The chemical properties of cobalt are also interesting, for the metal is very active and similar in this respect to nickel and iron e.g. cobalt readily forms a wide range of both organic and inorganic compounds, being both divalent and trivalent. Being one of the transition elements cobalt has considerable catalytic properties for a wide range of reactions. Cobalt reacts with carbon monoxide to yield cobalt tetracarbonyl and may react with many other elements to produce halides, nitrides or silicides. Reference will be made to specific cobalt compounds in the next section of this report (dealing with the applications for cobalt).

1.1. Health and safety of cobalt use

Although cobalt forms a wide range of readily soluble compounds which can be ingested by human beings, animals and plants, it does not appear to present any serious health or environmental hazard. In fact in some instances it may be highly beneficial in medical and veterinary applications. Even small doses of some cobalt salts may cause nausea, vomiting and diarrhoea in humans - but these effects are not serious or long lasting. Co-60 presents a serious hazard unless adequate and known precautions are taken.

2 APPLICATIONS

The distribution of cobalt by major application[37] is generally divided up as:-

all chemical applications	30 per cent
high temperature corrosion resistant alloys	30 per cent
magnets	12 per cent
tungsten carbide cements	7 per cent
steel alloys	49 per cent
others	5 per cent

Chemical applications are comprised of paints and plastics (39%); ceramics, glass and vitreous enamels (32%); chemicals including catalysts (24%) and other uses including cattle feed (5%).

2.1. Metallurgical uses

2.1.1. Magnetic alloys

The use of cobalt alloys for both electrical and permanent magnets dates from the early work in Japan by Honda and Saito in 1920 and Mishima in 1931 who developed the aluminium-nickel-cobalt series of alloys or the ALNICO's. Permanent magnets are widely used in the electrical-equipment industry. Cobalt additions raise the saturation magnetization and Curie temperatures to higher values than those obtained with other ferromagnetic meterials. Because of their high coercivity, cobalt containing magnets are used in telecommunications, magnetic couplings, meters, loudspeakers, permanent magnet motors and repulsion devices.

Of the cobalt used in magnets, Alnico magnets represent the largest consumption category. However, samarium-cobalt and mischmetal-cobalt magnets may become very strong competitors. These magnets have definite weight advantages in certain applications because of their high coercivity.

It is intersting to note that the widespread introduction of automatic telephone exchanges has largely been due to the possibility of making powerful minature direct current electric motors as a result of the use of cobalt based permanent magnets. The same applies to other portable battery operated appliances such as electric shavers and hand drills.

2.2.2. High temperature and superalloys[14]

The development of the gas turbine, especially for aircraft, has called for materials that can withstand high stresses at high temperatures under corrosive atmospheres without failure due to creep. In fact the entire development of the jet aircraft engine was dependent upon the availability of suitable materials of construction. These superalloys are largely cobalt-nickel based with the addition of large amounts of chromium to

provide resistance to corrosion and small amounts of molybdenum and tungsten to strengthen the matrix by means of precipitation hardening. These alloys contain 1 to 65 per cent cobalt. Expansion of usage has occurred recently in industrial turbine engines, natural gas transmission pipelines and marine equipment. 30 per cent of the cobalt used in superalloys is utilized in industrial turbines for power generation.

There is considerable consumption of superalloys containing cobalt in South Africa, but these are almost entirely imported as jet engine and gas turbine components, and spares. Almost all the superalloys are proprietary bearing such names as René41, Stellite and Inconel and their compositions are protected by patent rights.

2.1.3. Machinery components

Cobalt is an important constituent in tools requiring very high strength and abrasion resistance. It is used by existing tools as the metal matrix or cement for tungsten carbide, titanium carbides and alloyed tungsten carbides containing tantalum, titanium or vanadium. These are reffered to as cemented carbides and generally contain 10 to 15 per cent cobalt. Cemented carbide bits are used in mining and drilling operations and it is probable that the main use of cobalt at present imported into South Africa is used for this purpose - one that is vital to the mining and engineering industry.

Coating with a cobalt alloy provides greater resistance to abrasion, heat impact and corrosion. Valves used in automobiles and the petrochemical industry, chain saws, dipper teeth of power shovels and the surfaces of ploughshares may be treated in this manner. Cobalt alloys may also be thermal sprayed in powder form on worn construction machinery parts to provide a protective coating. The increasing use of plasma-arc hard facing is resulting in greater efficiency in production of surfaces that require protective coatings of cobalt-base alloys.

One specific application was as thickener blades for use under highly acid conditions in a germanium recovery plant, for which purpose special blades cast in Stellite had to be imported.

2.1.4. Miscellaneous

Surgical implants are a growing use of cobalt based alloys due to improvements in medical technology. Cobalt is biologically more compatible with body tissues and fluids than are nickel based alloys and stainless steel. In this application cost is not a factor and cobalt is used in significant quantities in corrosion resistant prosthetic

devices such as hip and arm joints and dental alloys. Extremely strong such alloys can be easily worked into intricate shapes by inverted casting techniques which require little finishing.

Dental alloys, which are sold under various proprietary trade names such as Vitallium, Durallium, Dentorium and Niranium, commonly consist of not less than 85 per cent combined cobalt, nickel and chromium.

Whereas cobalt is an essential metal for certain types of alloy and some grades of steel, it's presence is highly undesirable in most steels and especially in stainless steels. Precautions must be taken to avoid the addition of trace cobalt into steel that may result from the use of cobalt containing scrap. This can occur for instance from remelting old refrigerator and stove bodies that have been vitreous enamelled or from scrap rockdrill steel, unless the tungsten carbide tips have first been removed.

2.2. Chemical uses

2.2.1. Paints and Plastics

Cobalt compounds are used in the formation of paints and certain plastics either as pigments for colour or as driers.

As driers in paints and plastics use is made of the catalytic action of cobalt to polymerize the oils and resins that form the body of the paint. The cobalt compounds used are nearly all metallic soaps including linoleates, napthenates, oleates and stearates, which are made by using cabaltous hydroxide or cobaltous acetate with the respective fatty acids at temperatures of about 150°C. They can also be made by treating the appropriate sodium soap with an aqueous solution of a soluble cobalt salt.

Although cobalt based pigments could be used for paints, it appears that of recent, very little is used in the production of industrial paints in which the blue colours are based either on Prussian Blue or organic dyes which have proved cheaper and more satisfactory.

2.2.2. Ceramics, vitreous enamel and glass

Cobalt oxide is used in compounding the ground coat used in vitreous enamelling of iron and steel wares. The ground coat is the black layer that is observed when the upper white or coloured coat is chipped or broken. Typically the frit for the ground coat contains about 35 per cent iron oxide, 32 per cent cobalt oxide, 13 per cent nickel oxide, 12 per cent manganese oxide and 8 per cent chromium oxide. The cobalt oxide plays an essential role in bonding the ground coat to the metal, helping to provide a substrate for the top decorative coating.

Various compounds of cobalt are used as the base for certain

decorative pigments used in the top coat of viteous enamelling and as glazes for ceramic wares. The cobalt based pigments are generally blue e.g.ultramarine (cobalt silicate), violet (cobalt phosphate), Cerulean Blue (cobalt stannate), Rheinman's Green (cobalt oxide plus zinc oxide). In practice the amount of pigment used is very small except when very dark colours are required.

In glass-making cobalt oxide is used to provide a blue glass which may have a wide range of colours depending on the amount of cobalt used - a colouration being just discernible at 1 part in 500 000 while a dark blue glass may contain 1 part in 5 000.

Small amounts of cobalt (less than 0,02 per cent) decolourize the clay mixes used in ceramics giving a blue tinge having the same effect as the blue in laundering.

The use of appreciable quantities of cobalt in articles that have been vitreous enamelled leads to a difficulty in recycling scrap enamelled wares especially refrigerators, stoves and washing machines. These are normally made of thin guage steel on which there is a relatively thick facing containing up to 30 per cent cobalt. During remelting the enamel layer can be removed as a slag but the cobalt passes into the reclaimed steel from which it cannot be recovered, adversely affecting the properties of most grades of steel.

The majority of the frits for making vitreous enamel coatings and glazes are produced locally, although a few are imported. However, at the present time all the necessary cobalt is imported.

2.2.3. Cobalt based catalysts

Apart from it's use as a drier in paints and varnishes in which the action of the cobalt is virtually that of a catalyst, cobalt is used specifically as a catalyst in a variety of processes. In the manufacture of glass reinforced plastics a complex organic cobalt compound is used as the accelerator for setting the synthetic resin. Cobalt catalysts have been proposed for the catalytic converters to be fitted to automotive exhaust systems for emission control but it appears that presently the use of platinium group metals is preferred.

Cobalt catalysts are widely used in the petrochemical industry for the synthesis of petroleum by hydrogenation of coal through the conversion of olefins to alcohols. Also, the conversion of methanol into formaldehyde is used in thermosetting plastics. The exact form of cobalt used in catalysts varies, but it is commonly cobalt oxide or cobalt metal. The cobalt

is usually placed on an inert carrier material, often a porous clay or ceramic, by impregnation with a solution of cobalt salt. This is converted to either the oxide or the metal on the surface in such a manner as to form an ultrathin layer, possibly down to molecular thickness. Many of the catalysts are proprietary e.g. Co-0301 E 3/16" used in the synthesis of hydrogen sulphide; proprietors being the Harshaw Chemical Company, Cleveland, Ohio, U.S.A.

The same company also supplies cobalt molybdate catalysts (containing alumina) as a common petroleum desulphurization catalyst e.g. HT-400 E 1/32". As the use of high polymers and plastics increases in automobiles to decrease weight and as coal liquefaction and other energy related processes grow, the demand for cobalt catalysts will increase rapidly.

2.2.4. Biochemistry

Traces of cobalt appear to accelerate the formation of red blood cells and haemoglobin in the treatment of pernicious anaemia. Cobalt is also essential to humans as a component of vitamin B_{12}. Dietary sources for vitamin B_{12} are meat and dairy products but this can be supplemented by trace concentrations produced artificially.

Investigation of the effect of cobalt upon plant growth has not revealed the metal to be an essential plant element although it occurs in minute traces in some common vegetables, fruits, cereals and the leaves and bark of trees.

The lack of cobalt in trace amounts can lead to serious deficiency diseases in ruminants, variously known as bush sickness, nutritional anaemia and pining. In fact, although the actual quantity required is very small, the addition of cobalt to cattle feeds and mineral licks is one of the most important applications of cobalt in South Africa. Cobalt in itself is not a foodstuff and indeed appears to be excreted by the animal fairly rapidly. However, in passing through the digestive system it assists enzyme reactions in the stomach and colon by catalysis, thereby substantially improving the appetite and amount of haemoglobin in the blood stream. The necessary cobalt may be added in controlled doses to feeds and salt licks or to fertilizers to provide cobalt in hay and grazing. It may also be supplied in a special pill containing about 90 per cent Co O, bonded in such a manner that it is released over a period of six to twelve months in the animal's stomach. Cobalt deficiencies in the soil are especially prominent in the west, southwest and southeast coastal regions.

2.3. Cobalt 60

An isotope of cobalt, Co-60 is produced by the irradiation by radium of cobalt metal. The isotope has a half-life of 5 years and is a source of gamma rays comparable to emmission from a radium source. As a result, this property enables cobalt to be substituted for radium for therapeutic purposes in medical beam units, non-destructive testing and measuring devices at a lower cost .

Other uses for Co-60 are for feed sterilisation for livestock, control of bacteria in meat and milk, beneficial mutations in plants and improved cross breeding. An interesting application is the development of machinery by the Nuclear Development Corporation which utilizes gamma rays to sterilize a wide range of materials from surgical dressings to packaged soft fruits.

2.4. Other uses

Many other applications for cobalt exist such as cobalt acetate for a sealing solution in the anodizing of aluminium, cobalt salts as mordants in dyeing textiles, intensifiers for light sensitive printing plates, heat resistant transfers, improving the stability of beer foam and moisture detecting papers.

The lead-cobalt tri-polar storage battery is an improvement on the conventional lead-acid battery, in which a third pole of cobalt is used to absorb and recombine the hydrogen and oxygen released during charging thus permitting much higher rates of charging and discharging. The use of cobalt sulphate in the electrolyte prevents the dissolution of antimony used to harden the lead plates and thus to prevent the formation of the toxic gas stibine, SbH_3. The tri-polar battery offers excellent prospects for use in battery driven vehicles.

3 COBALT MINERALS

The more important ore minerals of cobalt are listed below. Cobalt almost invariably occurs in lesser quantities together with other metals such as copper, nickel, iron, arsenic, lead, zinc, manganese, silver and gold, and is generally produced as a by-product, but it's extraction is a difficult and costly process. Of the seventy cobalt minerals, less than ten occur in sufficient concentration to be worked, including:

smaltite	$(Co,Ni)As_2$
safflorite	$(Co,Fe)As_2$
skutterudite	$(Co,Ni)As_3$
cobaltite	$(Co,Fe)AsS$
carrolite	Co_2CuS

linnaeite	$(Co,Ni)_3 S$
erythrite	$Co_3(AsO_4)_2 . 8H_2O$
heterogenite	CoO.OH
sphaerocobaltite	$CoCO_3$

The recognition of cobalt minerals is often aided by the presence on outcrop material of specks and patches of erythrite occurring as encrustations in cracks and on the exposed surface of the ore. While not usually present in sufficient quantities to provide a commercial ore, the characteristic crimson colour is unmistakable and is not easily confused with the colours found in other oxidised metallic ores thus serving as an indicator for the presence of cobalt. The earthy black secondary mineral, transvaalite, an impure hydrous cobalt sesquioxide, is a feature of the Kruisrivier deposit.

The metal cobalt is the thirty-fourth element in order of prevalence in the Earth's crust, of which it comprises 0,0023 per cent, rather more abundant than lead and very much more so than silver.

4 COBALT DEPOSITS

Although the average crustal abundance of cobalt is 23 ppm the greatest crustal concentration occurs in mafic and ultramafic igneous rocks, with a lesser concentration at the silica rich end of the series. The average concentration of cobalt in ultramafic rocks is about 270ppm while in sedimentary and metamorphic rocks it varies from 4 to 40ppm.

Although cobalt minerals are fairly widespread they are invariably associated in small amounts with other metal ores. It is rare that an orebody is exploited for cobalt alone. Indeed, the only mines worked specifically for cobalt are the Bou Azzer and El Graara mines in Morocco. Although the famous mining district of Cobalt in Ontario takes it's name from this metal, in practice it was primarily a silver mining district although some cobalt may have been produced as a co-product. Cobalt may be recovered either as a co-product or by-product in the mining of copper ore, but as with nickel it is invariably mined as a by-product. Cobalt has also been mined as a by-product of iron, zinc, lead, silver and uranium.

The deposits of Zaire and Zambia are of varied geological ages although typically one metal (usually copper, lead or zinc) predominates. The largest production of cobalt is from cupriferous strata bound deposits. These deposits occur in an area with the shape of a large folded arc. The cobalt bearing ores contain bornite, chalcocite, chalcopyrite, linnaeite and carrolite and the secondary minerals heterogenite,

sphaerocobaltite and erythrite. In some places the ore beds and veins contain cobalt grading as high as 3 or 4 per cent.

The Sudbury District of Ontario, Canada, considered to contain an intrusive body, is rich in copper and nickel and contains about 0,07 per cent cobalt. Some of the ore minerals in this deposit are pyrrhotite, pentlandite, marcasite, magnetite and cobaltite. These minerals occur in pods, lenses, veins and disseminated grains in a layered sequence of norite, quartz diorite and rocks of transitional composition. Other similar iron-nickel-copper sulphide deposits are found in the Duluth gabbro complex southeast of Ely, Minnesota.

Laterite deposits result from deep weathering of basic igneous rocks in tropical climates with abundant rainfall. By this weathering process, magnesia and silicia are selectively leached out and deposited at a lower level, or they are completely removed, whereas iron, manganese and cobalt are residually enriched relatively close to the surface. Nickel is also leached out and often concentrated below and apart from the cobalt. Laterite deposits with relatively high concentrations of cobalt occur in Australia, Cuba, New Caledonia, Indonesia and the Philippines. Asbolane (Co bearing material) may take the form of nodules, lenses or small veins in a matrix of red iron-rich clay, usually without a high concentration of nickel in direct association with cobalt. In Cuba, however, both nickel and cobalt are often found more closely associated.

One potential source of cobalt is small nodules on the ocean floor. Under oxidizing conditions, cobalt exhibits a strong tendency to follow nickel geochemically and to concentrate with manganese. This is probably the primary reason for the association o cobalt and nickel in manganese nodules on the ocean floor. According to Mero in The Mineral Resources of the Sea[23], magnesium oxide precipitates as submicroscopic colloidal particles that capture nickel, copper, cobalt, zinc and molybdenum in the water. A typical assay of metal in the nodules reveals: 24 per cent manganese, 6 per cent iron, 1 per cent nickel, 1 per cent copper and 0,35 per cent cobalt. Although the question of ownership has not been settled by the United Nations, they do represent a vast resource of these metals.

There does not seem to be any definite pattern for occurrences of cobalt as there is for say, chrome or for molybdenum. Most sulphide nickel deposits, especially those generally believed to have originated from magmatic segregation (Sudbury and Norilak, northern Siberia) as well as the Merensky Reef in the Bushveld Complex contain some

cobalt. The massive pyritic copper ores of the Ural Mountains also have trace cobalt but the main production of cobalt is derived from the mineralised ore deposits of the Zambian and Zairean copper belt.

5 WORLD RESERVES, PRODUCTION AND CONSUMPTION

5.1. World reserves and resources

Table 13 lists the areas possessing identified resources of cobalt. Speculative resources in both the United States and the world amount to many billions of kilograms more, but cobalt mining is only likely if the associated metals such as nickel, iron, lead, zinc and silver are in high demand and are mined. In terms of estimated reserves, Zaire ranks first, followed by Zambia, U.S.S.R., Cuba, the Philippines and New Caledonia.

To provide current resource information the U.S. Bureau of Mines maintains a data bank under it's computerized Minerals Availability System in which reserve and resource data on cobalt is compiled:

Table 13

Estimated world resources and reserves - 1982 (million kilograms)

Area	Reserves	Other	Resources
N. America			
United States	0	772	772
Canada	27	227	254
Cuba	182	953	1 135
TOTAL	209	1 952	2 161
Europe			
Finland	18	5	23
U.S.S.R.	227	23	250
TOTAL	245	28	273
Africa			
Botswana	27	5	32
Morocco	45	23	68
South Africa	23	5	28
Zaire	1 180	227	1 407
Zambia	363	227	590
TOTAL	1 638	487	2 125

Table 13 (continued)

Area	Reserves	Other	Resources
Oceania			
Australia	45	250	295
New Caledonia	91	295	386
Philippines	182	23	205
TOTAL	318	568	886
WORLD TOTAL*	2 410	3 035	5 445
WORLD TOTAL+	0	227 000	227 000

* World Total of land based estimates

+ World total of seabed nodules, estimated by Holser, U.S. Dept. of Interior.

It appears that the present known reserves of cobalt in land based deposits are totally adequate for the next 90 years at the rate of consumption forecast by Sibley of the U.S. Bureau of Mines.[39] However, if only a portion of the identified resources (including seabed nodules) prove viable there should be no shortage of cobalt in the foreseeable future. This assumes both Zambia and Zaire remain relatively stable politically so that production from these countries can be maintained.

A curious anomaly of Table 13 is that countries with no diplomatic representation in South Africa hold 65 per cent of the world's resources of cobalt - a harrowing statistic until this category is broken down into it's constituents. Both Zaire and Zambia are members of a sub-group of the Organisation of African Unity that publicly reject the establishment of trade links with South Africa. But it is common knowledge that most of the cobalt consumed locally is derived from these sources. Assuming that the interdependence on trade is maintained in the future then these countries would continue to represent accessible sources of cobalt and the countries unwilling to trade with South Africa only then hold 30 per cent of the world's resources, placing the regional distribution of cobalt suppliers in South Africa's favour. However, Zambia and Zaire, holding between them 37 per cent of known resources do represent a very tenuous supply for South Africa and this places great pressure on the Government to maintain harmonious relationships (albeit covertly) with these countries.

5.2. Ocean Nodules

Wide areas of the floors of all oceans are covered with a layer, only a few centimetres thick, of manganiferous nodules which contain significant amounts of cobalt. The nodules offer a very large potential source of cobalt that could be obtained as a co-product of copper, nickel or

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