Courtesy A. V. Roe Canada Limited, Malton, Ont.

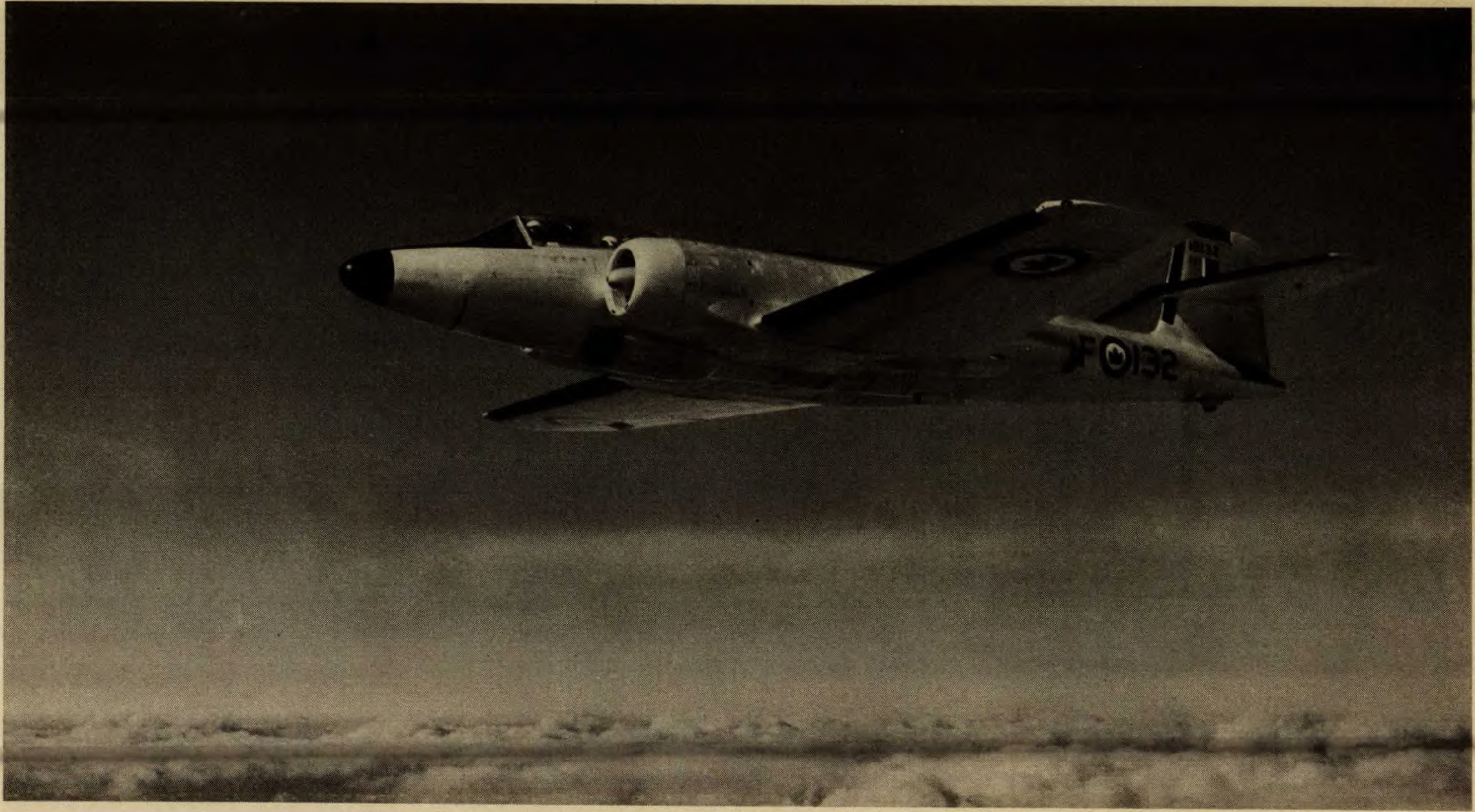

FIGURE I. A CF-100 "Canuck" all-weather, long-range interceptor as used by the Royal Canadian Air Force. This aircraft is equipped with two Orenda turbo-jet engines.

DEPARTMENT OF MINES AND TECHNICAL SURVEYS, OTTAWA

COBALT IN CANADA

R. J. JONES

MINES BRANCH No. 847

89218—1½

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PREFACE

The importance of cobalt metal has increased immeasurably in recent years, because of its widening use in both industrial and defence applications. Cobalt metal and its alloys, in addition to a wide variety of other uses, perform vital functions in turbo-jet engines, guided missiles, magnets, rockets and in the field of atomic energy developments.

The President's Materials Policy Commission, in its "Resources for Freedom", has estimated that by 1975 consumption of cobalt in United States will have increased some 344 per cent over that of 1950. With the sole exception of magnesium, this is the largest increase predicted in the field of metals.

The large-scale and continuing expansion of the Canadian nickel industry is the most important commercial opportunity for a substantial increase in Canadian cobalt production.

Very little published information is available on cobalt in Canada, and that is either widely scattered or incomplete. It is the purpose of this report, therefore, to collect all such information and to present it, together with the most recent developments, between the covers of one book.

The author tenders grateful acknowledgment to Canadian producers, processors and consumers of cobalt who supplied much of the information contained in this volume.

JOHN CONVEY,

December 7, 1953.

Director, Mines Branch.

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CHAPTER I

GENERAL HISTORY

New Caledonia, a French island in the South Pacific, enjoyed a monopoly of the world cobalt ore markets for many years by reason of its large nickel-cobalt reserves. However with the discovery of the silver-cobalt ores of Cobalt, Ontario, in 1903 it was suddenly supplanted in these markets by Canada. Production from New Caledonia which exceeded 2,360 metric tons in 1908, fell to 548 tons in 1909, to 54 tons in 1910 and to nothing in 1911.

The sudden influx of Canadian ores caused the prices of cobalt compounds to fluctuate wildly. In 1905 the price offered for cobalt contained in 6 per cent ore fell from 65 cents to 35 cents a pound. Between 1905 and 1909, 10 cents a pound was paid for cobalt in 6 per cent ore or over, except when it contained more nickel than cobalt. Consumption of cobalt during this period was confined mainly to the ceramic trade and in the manufacture of the cheaper varieties of whiteware as a corrective for the yellowish tone of the ware and to impart a clearer hue to white goods.

Between 1909 and the outbreak of World War I cobalt was almost unsaleable, except in high-grade ores. Producers received nothing for the cobalt content of their lower grade ores; consequently the cobalt veins remained more or less unmined and output of the Cobalt camp dropped very sharply from 1909 to 1915.

However, Mr. Elwood Haynes, President of Haynes Automobile Company, Kokomo, Indiana, had begun experimenting with cobalt and chromium alloys. Because of the great impact his work was to have on the future demand and uses of cobalt, his statement in The Iron Trade Review of August 4, 1910 is quoted in part:

> *A pocket-knife blade and several table-knife blades were made from this material and were found to be satisfactory in every respect. One of these table-knife blades has now been in use for more than two years in the kitchen, where it was used for all sorts of purposes, such as cutting bread, turning griddle cakes, peeling and paring vegetables, and for various other purposes, such as are known only to the culinary art. After all this use and abuse, the knife shows not the slightest trace of tarnish, and has held its lustre so well that when exposed to the sun it shows a reflection which dazzles the eyes. . . . An alloy of 75 per cent cobalt and 25 per cent chromium, to which small quantities of other metals are added, is not only sufficiently hard for good edge tools, but is quite tough and can be bent much beyond its elastic limit without cracking; resembling in this respect the alloy steels, but, generally speaking, it is much harder.*

> *It is especially adapted to the manufacture of pocket knives, on account of the beauty of its colour and the brilliancy of its lustre, both of which remain permanent under all circumstances, thus giving the blades a particularly attractive appearance. Knives of this description may be used for cutting fruit without danger of marring their lustre in the slightest degree. Alloys in certain proportions will also doubtless find a wide use in surgical instruments, since they resist perfectly all sterilizing solutions. The alloy is perhaps better adapted for table cutlery than anything that has ever yet been produced. We all know too well that a silver-plated knife, for example, is ill adapted for any service requiring a sharp edge, and it cannot be sharpened without destroying the plating. Steel knives, on the other hand, while they cut well, require endless labour to keep them in presentable condition, and at best, they are unsightly in appearance. . . .*
>
> *It is admirably adapted for the manufacture of fine weights for balances, scrapers, spatulas and other laboratory appliances. . . . The alloy is also particularly well adapted for the manufacture of standard, weights and measures. . . .*
>
> *The alloy could readily be made into laboratory vessels, cooking utensils, spoons, forks, etc., and is limited in this respect only by its cost.*

Little did Mr. Haynes realize the effect that his alloy—which he named "stellite"—would have on future consumption of cobalt metal in that form. The modern high-temperature alloy metallurgist will no doubt smile when he considers the simple uses which Haynes advocated for his new alloy.

The advent of World War I stimulated the demands for alloy steels and the use of metallic cobalt, and consequently the price in United States had risen from a low of about $1.50 a pound to $2.50 a pound by November, 1918. Furthermore, the uses of cobalt had widened to such an extent and the production in Canada had decreased to such a low ebb by 1921, that the price continued upwards to the $6.00 level. Thereafter, production of cobalt in Canada began to rise and reached a high of about 550 tons in 1925 when the price was stabilized at $2.50 a pound.

Silver, which was the main product of the Cobalt mines, fell in price from a peak of $1.33 an ounce in January, 1920, to about 69 cents an ounce in 1925. The large mines in Cobalt were closed down by this time and within the next seven years, when the price of silver dropped successively to a new low of 25 cents an ounce in December 1932, the remaining mines closed down and Cobalt became, for mining purposes, almost a ghost town.

By this time groups of lessees began to appear on the scene. They obtained leases from the former operators, employed up to 10 men and commenced to produce cobalt ore by picking over the waste dumps. Some sold bagged ore containing over 10 per cent cobalt directly to the Deloro smelter and to purchasers in the United States, while others produced ore which had to be concentrated in custom mills operated by individuals who rented the mills from the original companies. After the dumps had been largely picked over the lessees began to operate underground. The mines were shallow, the operators pumped out the old mines to the first or second levels and followed narrow cobalt veins which had been left behind by the former operators and also slashed off small pockets of ore when it was found.

A great aid in this type of operation was the cheap supply of air which was compressed by falling water at Hound Chutes, a few miles from Cobalt. The plant was built during the more prosperous days and relieved lessees of expense involved in electrical and compressing equipment. The compressed

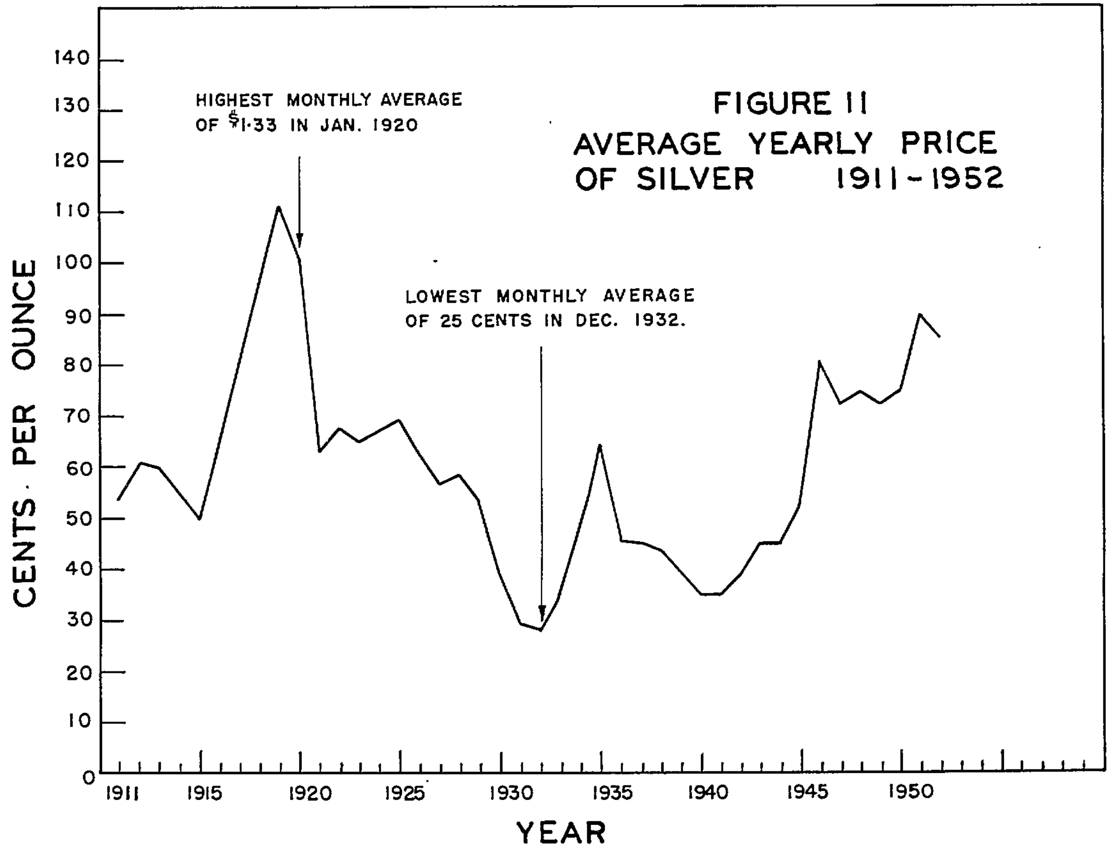


FIGURE 11
AVERAGE YEARLY PRICE OF SILVER 1911-1952

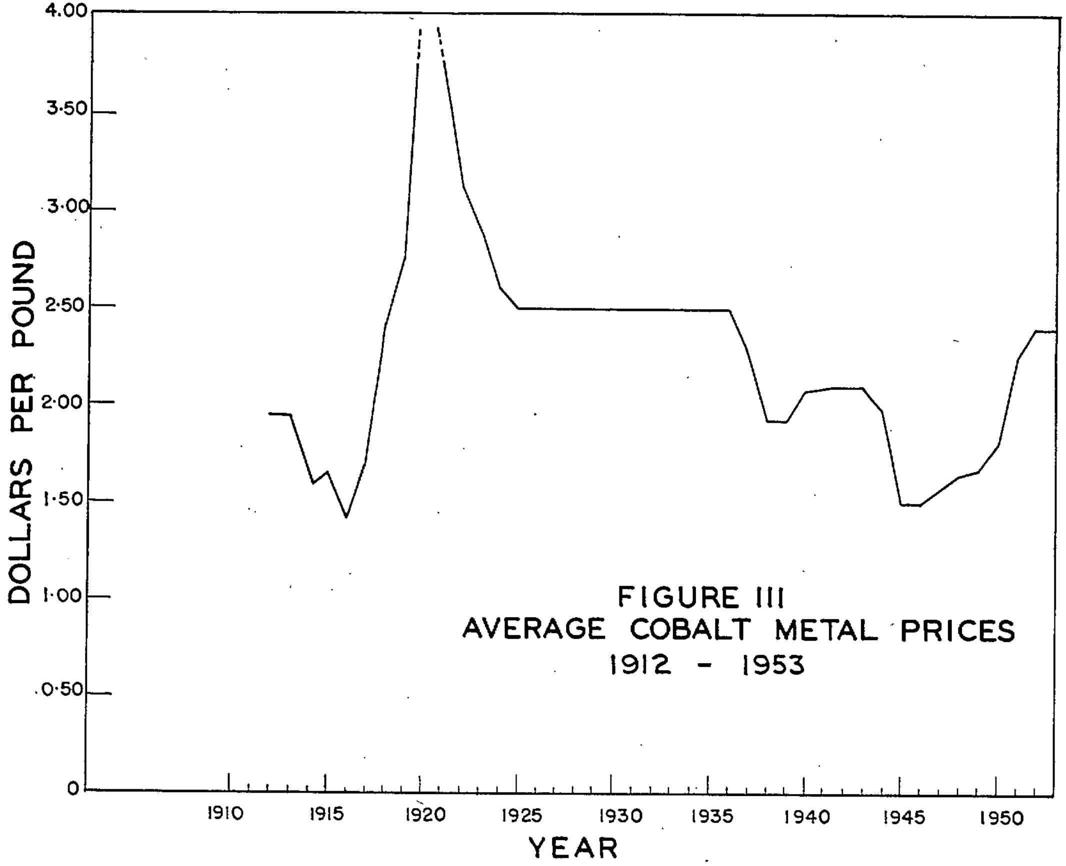


FIGURE III
AVERAGE COBALT METAL PRICES
1912 - 1953

air was simply piped to the leasing operations and the operators paid for the amount of air by metered consumption. Aid was also forthcoming from the Ontario Government which set up the Temiskaming Testing Laboratories. This plant operated as a sampling, assaying and weighing agent for the producers. Nearly all shipments of cobalt ore were handled by the Temiskaming Testing Laboratories who also weighed and loaded the assayed concentrates into railway cars for shipment. The weight and assay certificates of the Laboratories became acceptable to all buyers of ore.

About 1920, the Union minière du Haut Katanga began to recover cobalt from the copper-cobalt ores of Katanga in the Belgian Congo. In 1926 the Belgian Congo became the leading producer and its production is still increasing. Production was commenced from the high-grade copper deposits of the Rhokana Corporation Limited at Nkana, Northern Rhodesia in 1932, the same year that production was commenced from the nickel-gold-silver-cobalt ores of La Société minière de Bou Azzer et du Graara at its property near Bou Azzer, French Morocco.

In the early 1930's, Deloro Smelting and Refining Company, Limited at Deloro, Ontario, and the Union minière du Haut Katanga established an agreement to control the marketing of their products and to maintain the cobalt price. When the Rhodesian and Moroccan producers entered the market they also entered the Cobalt Association. During 1935 the Association, which then consisted of Union minière du Haut Katanga, Deloro Smelting and Refining Company, Rhokana Corporation, Limited and La Société minière de Bou Azzer et du Graara, signed a trade pact with the Association of German Cobalt Producers in respect to the marketing of cobalt and cobalt salts. The German producers were dependent upon the importation of foreign low grade ores for their raw material and the trade pact supplied facilities for selling their output in the world market. In 1936, the Finnish Corporation, Osakeyhtio Vucksenniska Aktiebolag of Vucksenniska, Finland joined the association which then controlled almost 90 per cent of the world output. The agreement was renewed in August, 1936 for a further five-year period but was dissolved during the early part of World War II, following which the Union minière du Haut Katanga became the principal producer and its quoted price became the established world price, now generally followed by all producers of the metal.

During the early years of World War II the Cobalt, Ontario ores and concentrates were marketed for the most part with United States chemical firms and the remainder was stockpiled at the Deloro smelter. No Canadian concentrates were treated, as the Deloro smelter was operating mainly on cobalt-copper-iron alloy residues from Northern Rhodesia plus a supplementary supply from the Belgian Congo.

To stimulate Canadian production when supplies of cobalt from Africa and other overseas points were being seriously threatened by the German U-boat fleet, a contract was entered into between Metals Reserve Company of the United States Government and the Canadian Crown Company, War Supplies Limited, under which War Supplies Limited appointed Deloro Smelting and Refining Company, Limited as its buying agent for cobalt ores from Cobalt, Ontario. The producers were advised that all their output of cobalt concentrates up to a total of 7,000 tons would be purchased at premium prices and stockpiled for the account of Metals Reserve Company. Under this contract, slightly more than 3,000 tons were delivered between April 1, 1942, and February 22, 1944, when the contract was cancelled as the period of emergency had passed.

The prices effective under this contract were f.o.b. rail cars, Cobalt, Ontario as follows:

Cobalt Content	*Price per lb. of Contained Cobalt*
8·00 — 8·99%	$0.88
9·00 — 9·99%	0.99
10·00 and over	1.10

Payment for the nickel and silver content of the ores was also provided for, with a penalty for copper content exceeding 1·5 per cent.

Upon termination of the Metals Reserve Company's contract, the uncertainty as to the intentions of the United States Government regarding the stockpile of its accumulated cobalt ore at Deloro, Ontario, coupled with the fact that the Deloro smelter had accumulated for its own account a large stockpile of untreated ores, resulted in an unsettled market and a number of operators closed their mines pending stabilization. Only one carload of cobalt ore left the Cobalt area in 1944 following termination of the contract, and it was exported to Shepherd Chemical Company of Cincinnati, Ohio. During 1947 and 1948, the United States Government withdrew its stockpile from Deloro, Ontario to New Jersey.

Following World War II, production from Cobalt, Ontario remained at a low level with most of the output coming from the Agaunico mine of the Silanco Mining and Smelting Company. In August, 1943 this company took over the mines and 100-ton concentrating plant of Cobalt Products Limited and in 1945 began the erection of a cobalt smelter 5 miles south of Cobalt, on the Ontario Northern Railway. The company had stockpiled all its concentrates in anticipation of the erection of its smelter, which was to operate as Cobalt Chemical and Refining Company, Limited. However, just as the smelter had reached the production stage it was destroyed by fire in April, 1950, and operations were suspended.

In 1940 International Nickel Company of Canada, Limited, commenced the recovery of cobalt at its nickel refinery in Clydach, Wales, from nickel matte shipped from Canada. Such output has not been reflected as part of Canadian production in any statistics issued by various sources. In June, 1947, the company also began extracting an impure cobalt oxide at Port Colborne, Ontario which it shipped to Clydach for refining into salts. In July, 1952, Falconbridge Nickel Mines, Limited, began the production of electrolytic cobalt at its refinery at Kristiansand, Norway from nickel-copper matte produced at its Falconbridge, Ontario smelter.

Production of cobalt ores and concentrates from the Cobalt area was at a low ebb at the beginning of 1951. In order to stimulate further production to meet future defence and essential requirements in the light of the Korean emergency, the Right Honourable C. D. Howe, Minister of Trade and Commerce, announced in the House of Commons on February 15, 1951 that the Canadian Government would purchase concentrates for a period of three years on the following basis:

Cobalt Content	*Price per lb. of Contained Cobalt*
10·00 — 11·99%	$1.35
12·00 — 13·99%	1.40
14·00 and over	1.45

The Deloro Smelting and Refining Company, Limited, Deloro, Ontario, was appointed governmental agent and authorized to purchase ores and concentrates on the basis of assay and weight determinations by the Temiskaming Testing

Laboratory at Cobalt, Ontario, in minimum shipments of 5-ton lots. The prices quoted were on a f.o.b., Cobalt, Ontario basis with freight and further processing costs to Government account. The silver content of such shipments was settled for by the Deloro smelter to the producer on the basis of the customary smelter tariff.

On March 30, 1951 this price plan was revised as follows on authority of the Minister of the Department of Defence Production:

Cobalt Content	*Price per lb. of Contained Cobalt*
7·00 — 7·99%	$1.00
8·00 — 8·99%	1.15
9·00 — 9·99%	1.30
10·00 — 10·99%	1.40
11·00 — 11·99%	1.50
12·00 and over	1.60

By the end of 1951 it became apparent that cobalt production was not sufficient to meet the Government's requirements and accordingly on December 28, 1951 the Minister of Defence Production announced that effective January 1, 1952 and until 600,000 pounds of recoverable cobalt metal had been accumulated or until March 31, 1954, the premium prices paid to producers would be set as follows:

Cobalt Content	*Price per lb. of Contained Cobalt*
7·00 — 7·99%	$1.20
8·00 — 8·99%	1.50
9·00 — 9·99%	1.80
10·00 and over	2.00

It was further stipulated that in the event that the 600,000 pounds of recoverable cobalt metal was accumulated before March 31, 1954, the price schedule would revert to that in effect prior to January 1, 1952, up until March 31, 1954.

The Temiskaming Testing Laboratories shipped 484,186 pounds of contained cobalt during 1952 in cobalt ore shipments weighing 4,382,820 pounds and also containing 140,843 ounces of silver, 202,807 pounds of nickel and 37,483 pounds of copper. The main producers of cobalt ore during 1952 were Silver Miller Mines Limited and Silanco Mining and Refining Company Limited with the following making smaller shipments: Mensilvo Mines Limited, Harrison Hibbert Mines Limited, Norbert Silver Mines Limited, Penn Cobalt Silver Mines Limited, Cross Lake Lease, Siscoe Metals of Ontario Limited, Shag Silver Mines Limited (Nipissing O'Brien), J. H. Sutherland and C. Tasse, Jr.

Cobalt ore shipments to the Deloro smelter under the premium price plan during the first quarter of 1953 were 264,435 pounds of contained cobalt plus 37,778 ounces of silver, 126,483 pounds of nickel and 24,694 pounds of copper contained in 2,328,089 pounds of concentrate. This amount of cobalt plus 1952 shipments was more than enough to make up the 600,000 pounds of recoverable cobalt metal and hence during the first quarter of 1953, the incentive price schedule was reduced to that in effect prior to January 1, 1952, to remain in effect until March 31, 1954.

Since the beginning of 1951 and until January, 1953 the Canadian Government did not grant permits for the export of cobalt in the form of ores and concentrates. The principal reason for this ban was to assure the stockpiling plan of the Government and to prevent cobalt from reaching undesirable outlets.

TABLE 1

PRICE CHANGES IN COBALT METAL 1921-1953

	per pound
January, 1921	$5.10
February, 1921	4.50
April, 1921	4.20
May, 1921	4.00
July, 1921	3.12
January, 1923	2.85
June, 1923	3.00
February, 1924	2.50
September, 1937	1.92
January, 1940	2.11
October, 1944	1.50
July, 1947	1.65
April, 1949	1.80
January, 1951	2.10
September, 1951	2.12
October, 1951	2.40
November, 1953	2.60

CHAPTER II

COBALT AND ITS ORES AND MINERALS

Cobalt is generally considered as a by-product metal and occupies position number 27 in the periodic system with an atomic weight of 58·94. It is a bluish silvery, magnetic metal and resists corrosion like nickel which it closely resembles. Its melting point is 1480°C or about 2696°F and its boiling point about 5250°F. Its specific gravity is 8·9. Its hardness is about 5·5 on Mohs scale.

Chemically, its normal valence is two (cobaltous) while it is trivalent in some compounds (cobaltic). Electrochemically it behaves similarly to iron and nickel. The metal can be isolated in pure form by hydrogen reduction of the oxide.

The tensile strength varies from about 34,000 p.s.i. for cast and unannealed metal to around 100,000 p.s.i. when swaged into wire.

The important minerals of cobalt are sulphides, arsenides and oxidized compounds.

Cobaltite ($CoAsS$ or $CoS_2.CoAs_2$).

Cobaltite, or cobalt glance, contains 35·5 per cent cobalt and is the most important cobalt mineral of the Cobalt, Ontario area. It has a hardness of 5·5 and a specific gravity of about 6·3. Cobaltite has a silver-white colour, with a pink tint.

Safflorite ($CoAs_2$).

Safflorite is the second cobalt mineral of the Cobalt, Ontario area. It has a hardness of about 4·5 with a specific gravity of about 7. It has a bright metallic colour but tarnishes quickly. Safflorite has a cobalt content of 28·2 which is decreased when iron is present.

Skutterudite ($CoAs_3$).

This mineral has a cobalt content of 20·8 per cent and occurs in the ores of Cobalt, Ontario.

Smaltite ($CoAs_2$).

Smaltite is the last cobalt mineral in order of abundance in the Cobalt, Ontario, ores. It has a hardness of 5·5 and a specific gravity of about 6·5. It is steel grey in colour when fresh but tarnishes to a darker grey. The cobalt content is 28·2 per cent.

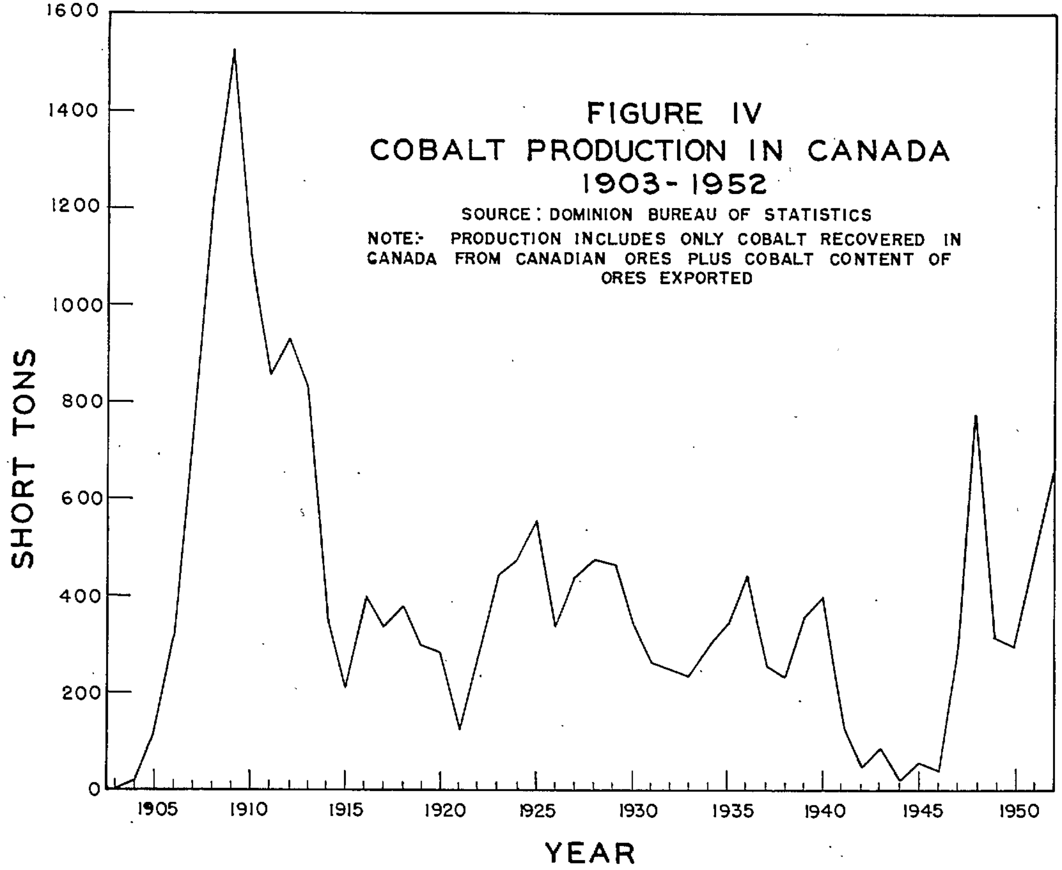


FIGURE IV
COBALT PRODUCTION IN CANADA
1903 - 1952
SOURCE: DOMINION BUREAU OF STATISTICS
NOTE:- PRODUCTION INCLUDES ONLY COBALT RECOVERED IN CANADA FROM CANADIAN ORES PLUS COBALT CONTENT OF ORES EXPORTED
SHORT TONS
1600
1400
1200
1000
800
600
400
200
0
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
YEAR

Erythrite ($CoAs_2O_8.8H_2O$).

Erythrite, or cobalt bloom, is a mineral of secondary origin, found commonly in the upper weathered portion of cobalt-bearing deposits. It is soft, having a hardness of about 2, and a specific gravity of about 3. It contains 29·5 per cent cobalt. It serves as a valuable indication of mineral outcrops containing cobalt, and has a characteristic peach-red colour.

Heterogenite ($CoO.2Co_2O_3.6H_2O$).

This mineral contains from 48 to 60 per cent cobalt and is one of the principal minerals of the deposits at Katanga, Belgian Congo, and Nkana, Northern Rhodesia. It has a hardness of 3·5 and a specific gravity of 3·45. Like erythrite, it is a secondary mineral.

Linnaeite (Co_3S_4).

Linnaeite is another important ore mineral of the Katanga and Nkana deposits. It contains from 30 to 40 per cent cobalt, depending upon the amount of iron, nickel or copper that may be available to replace cobalt. The mineral in the form of Co_3S_4 has a hardness of 5 and a specific gravity of 4·6. Carrollite ($CuCo_2S_4$) is a variation of linnaeite.

Asbolite ($CoO_2.MnO_2.4H_2O$).

Asbolite, or cobaltiferous wad, is a mixture of manganese and cobalt oxides. It is the chief ore mineral of New Caledonia, and contains from 4 to 35 per cent cobalt.

Other cobalt minerals and their formulae are as follows:

gersdorffite — $(Ni, Fe, Co)\ AsS$
sphaerocobaltite — $CoCO_3$
glaucodot — $(Co, Fe)\ AsS$
stainerite — $(Co, Fe, Al)_2O_3.H_2O$
roselite — $(Ca, Co, Mg)_3\ As_2O_8.\ 2H_2O$
forbesite — $H_2(Ni, Co)_2\ As_2O_8.\ 8H_2O$
bieberite — $CoSO_4.7H_2O$
badenite — $(Co, Ni, Fe)_2(As.Bo)_3$
cobaltnickelpyrite — $(Co, Ni, Fe)\ S_2$
bismuthosmaltite — $Co(As, Bi)_3$
willyamite — $Co_2NiS_2.\ CoSb_2.\ NiSb_2$

ACTIVE PRODUCING AREAS

9. Sudbury District
3. Eldorado Mine
11. Gowganda Area
12. Cobalt Area
7. Lynn Lake Mine

OTHER OCCURRENCES

1. Little Gem Mine
2. Nickel Plate Mine
   Hedley Mascot Mine
4. B.M. Group
5. Francois River
6. Goldfields-Beaverlodge
   Lake Area
8. Werner Lake
10. Massey Claims
13. Kluane Lake
14. Estella Mine
15. Victoria Mine
16. Hart Township
17. Lake Shebandowan
18. Calumet Island
19. Mount Wright
20. Western Nickel Mine
21. Maskwa and Oiseau River
    Area
22. Palmer Township
23. Otter Township

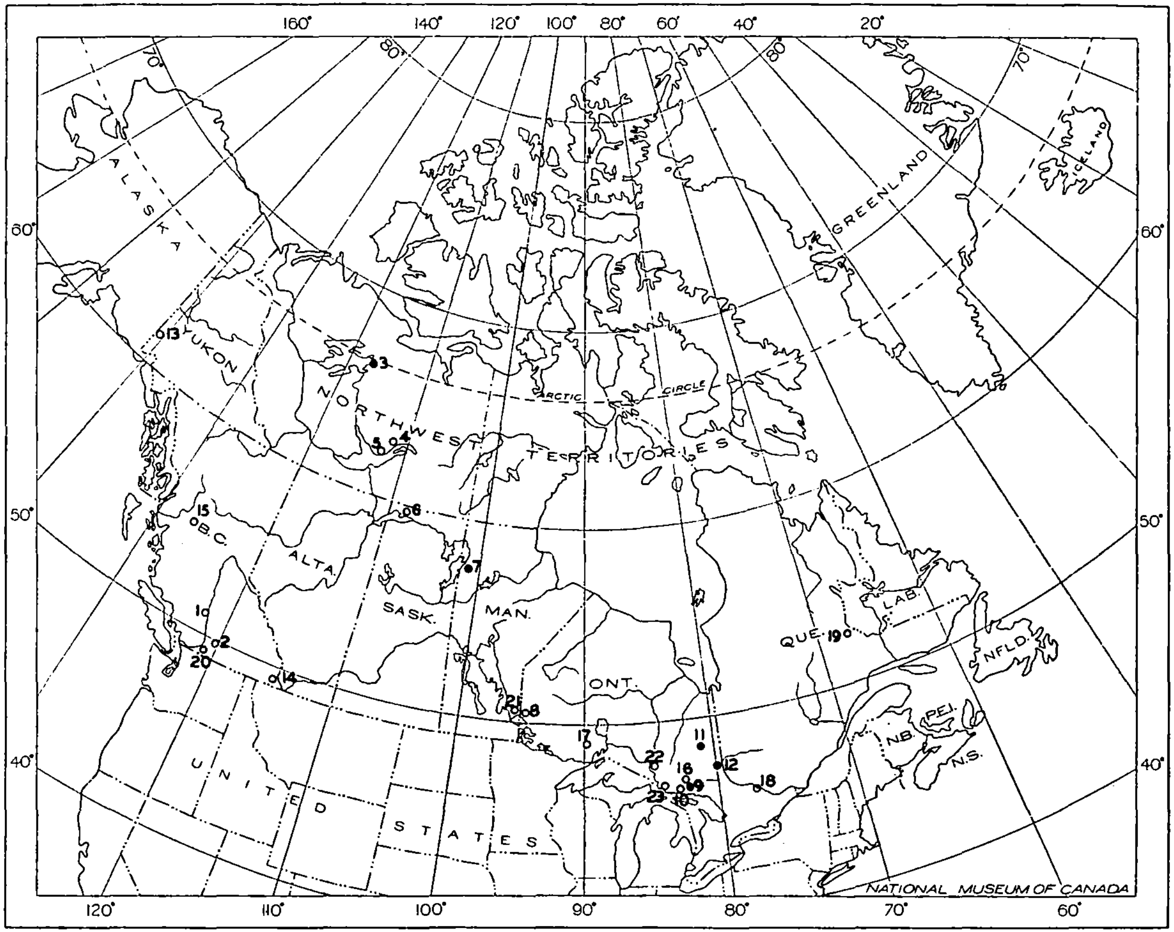


FIGURE V. KEY MAP OF CANADA SHOWING COBALT OCCURRENCES.

● PRODUCING AREAS
○ OTHER OCCURRENCES

CHAPTER III

CANADIAN MINE PRODUCTION OF COBALT

Mine production of cobalt in Canada is derived from the following sources:

(*a*) by-product from the refining of copper-nickel ores from the Sudbury nickel district, Ontario.

(*b*) Cobalt and silver ores and concentrates from the Temiskaming silver-cobalt area.

(*c*) by-product from the refining of uranium-radium ore of Great Bear Lake, Northwest Territories, plus a small intermittent production from the hand-cobbing of this ore.

In early 1954 production of cobalt will commence as a by-product from the refining of nickel-copper ores from Lynn Lake, Manitoba. Some cobalt was produced during World War II from the Werner Lake area of Ontario.

Official statistics on cobalt production in Canada from 1903 to 1952 are given in graphic form in Figure IV. These include cobalt recovered in Canada from Canadian ores plus the cobalt content of ores and concentrates exported, irrespective of the year when the cobalt ores and concentrates were actually mined or shipped. Consequently these statistics tend to be misleading until it is realized that, contrary to the Figure IV graph, production rose during World War II due to the Canadian Government's incentive price plan. The ore output, however, was stockpiled and not counted as production until the concentrates were shipped from Deloro to the United States some years later (1947-1948). Actual production from the Temiskaming silver-cobalt area fell off steeply following World War II until the Korean emergency necessitated another incentive price plan. Figures in Table 5 give a more accurate picture, as they indicate shipments via the Temiskaming Testing Laboratories.

References to Key Map of Sudbury Nickel District, Ontario (Fig. VI).

Active Producing Mines and Operators

1. Creighton (International Nickel Co.)
2. Murray (International Nickel Co.)
3. McKim (Falconbridge Nickel Mines Ltd.)
4. Frood (International Nickel Co.)
5. Stobie (International Nickel Co.)
6. Garson (International Nickel Co.)
7. Falconbridge (Falconbridge Nickel Mines Ltd.)
8. East Rim (East Rim Nickel Mines Ltd.)
9. Milnet (Milnet Mines Ltd.)

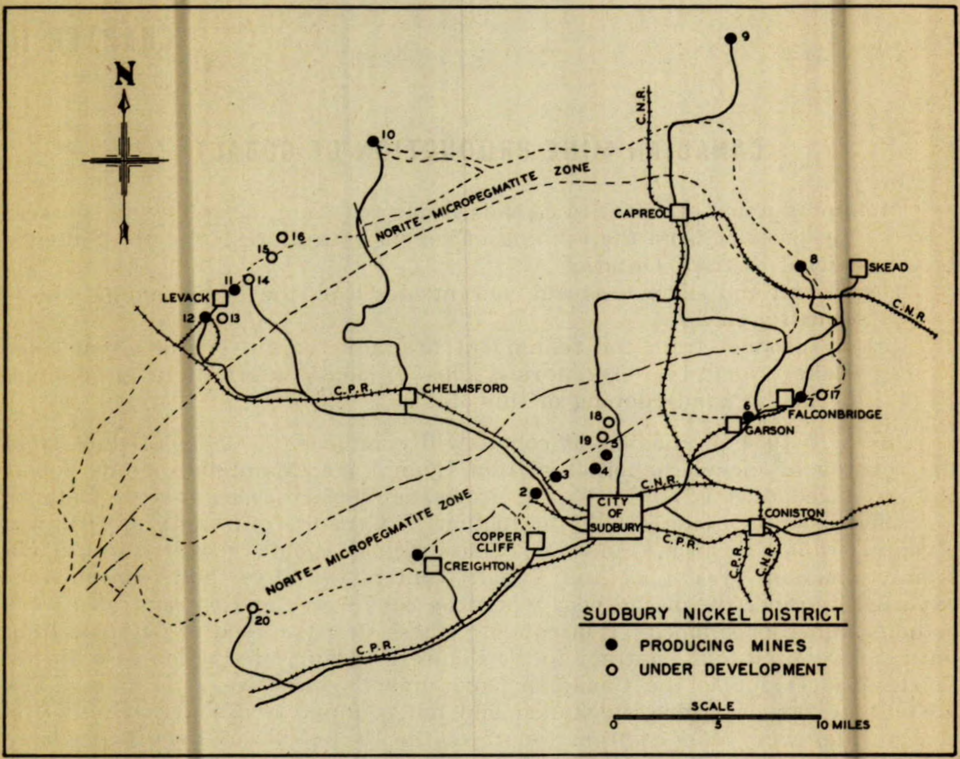


FIGURE VI. KEY MAP OF SUDBURY DISTRICT, ONTARIO.

10. Nickel Offsets (Nickel Offsets Ltd.)
11. Levack (International Nickel Co.)
12. Hardy (Falconbridge Nickel Mines, Ltd.)

Mines Under Development and Operators

13. Boundary (Falconbridge Nickel Mines, Ltd.)
14. Fecunis Lake (Falconbridge Nickel Mines, Ltd.)
15. Strathcona West (Falconbridge Nickel Mines, Ltd.)
16. Longvac (Falconbridge Nickel Mines, Ltd.)
17. East Falconbridge (Falconbridge Nickel Mines, Ltd.)
18. Mount Nickel (Falconbridge Nickel Mines, Ltd.)
19. Blezard (Falconbridge Nickel Mines, Ltd.)
20. Crean Hill (International Nickel Co.)

Reference numbers following sub-headings refer to numbers on the key map of Canada, showing cobalt occurrences (Fig. V).

ONTARIO

Sudbury Nickel District (9)

Cobalt is believed to occur in the ores of the Sudbury district as a complex suite of cobalt-nickel-iron arsenides and is closely associated with the nickel mineral, pentlandite. Minerals that have been identified are cobaltite and gersdorffite. No analytical control is carried out by the operators in respect to cobalt content of the ores, as this element is determined with nickel. However, the average content of some of the ores of the district is roughly about 0·07 per cent.

Recovery of the cobalt present in nickel matte from Sudbury was commenced in 1940 by Mond Nickel Company, Limited at Clydach, Wales. The Clydach nickel refinery of Mond Nickel Company was erected in 1902 and produces nickel by the carbonyl process developed by the late Dr. Ludwig Mond. Cobalt produced from this source has never been included in official Canadian statistics.

Since 1947, International Nickel Company of Canada, Limited has recovered cobalt oxide from the electrolyte at its nickel refinery at Port Colborne, Ontario. The cobalt is separated by precipitation and is shipped as an impure cobalt oxide, containing approximately 71 per cent cobalt, to the Clydach works of the Mond Nickel Company, Limited. This crude oxide together with that produced at the Clydach nickel refinery forms the feed for the chemical salts plant at the Clydach works for the production of high grade black and grey cobalt oxides and an extensive range of cobalt salts including sulphate, hydrate, acetate and chloride. The cobalt output of the Clydach salts plant is sold to consumers in the United Kingdom and many foreign countries.

Production of electrolytic cobalt metal was commenced in mid-1952 from the nickel-copper matte exported by Falconbridge Nickel Mines, Limited to its nickel refinery at Kristiansand, Norway. The nickel-copper matte is refined by the Hybinette process. The separation of cobalt involves the precipitation and removal of an impure nickel-copper product from the nickel electrolyte. The cobalt content of this product is increased by chemical treatment and the resultant product is dried, melted and cast into cobalt anodes which are refined electrolytically.

A large proportion of the company's production for some years has been sold to the United States Government. The rest is sold commercially, mainly in the United States.

The largest known commercial reserves of cobalt in Canada are contained in the nickel-copper deposits of the Sudbury district.

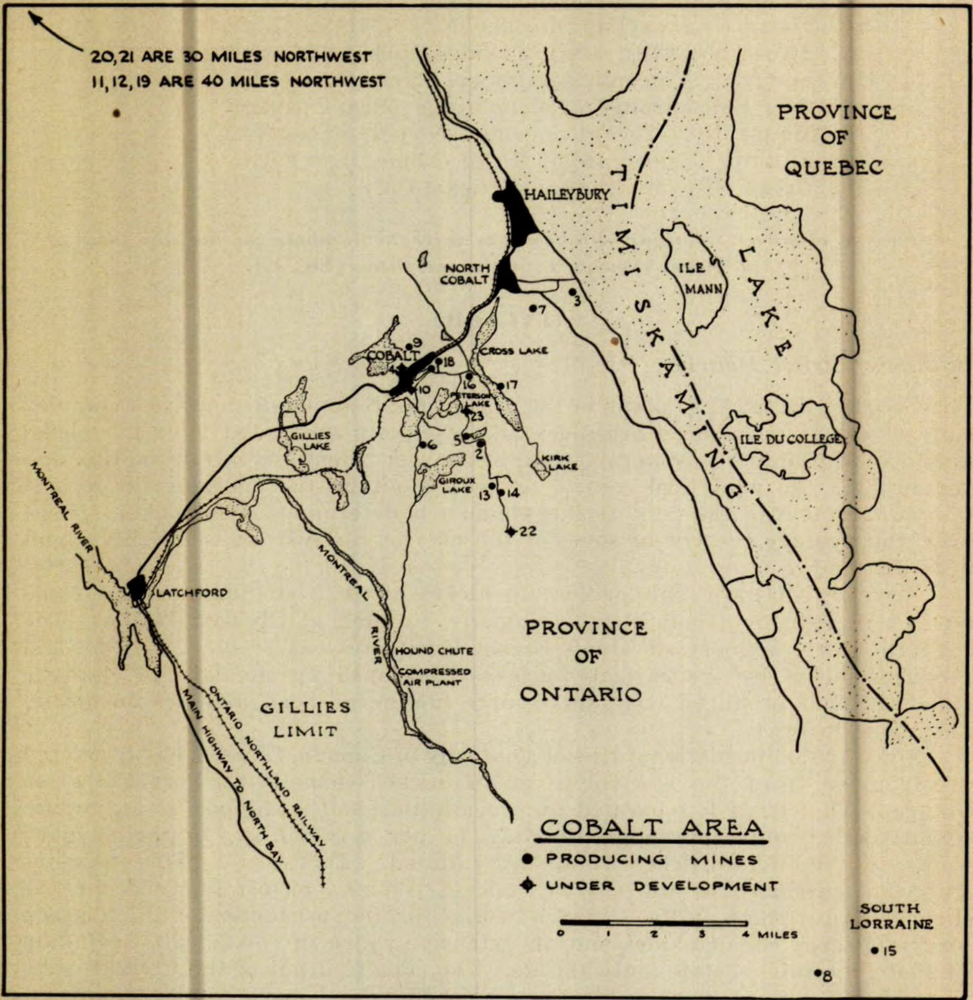


FIGURE VII. KEY MAP OF COBALT AREA, ONTARIO.

TABLE 2

OPERATING COMPANIES IN COBALT AREA, ONTARIO (NOVEMBER, 1953)

Key Map Reference	Operator	Name of Property	Original Name of Property	Mill Capacity in Tons	Ore Custom Milled By	Notes
	Cobalt Ore Shippers					
1	Silver Miller Mines, Limited	Larose	Larose	200		
2	“	Lawson	Lawson			
3	Cobalt Consolidated Mining Corp.	Agaunico	Agaunico	200		
4	“	Cobalt Lake	Mining Corp., Right of Way, Buffalo.			
5	“	Penn Cobalt	Penn Canadian, Crown Reserve, Kerr Lake.			
6	Mensilvo Mines, Limited	Mensilvo	Silver Bar	50	Some by United Cobalt Mill.	
7	Harrison Hibbert Mines, Limited	Harrison	Ruby		United Cobalt.	
8	Norbert Silver Mines, Limited	Norbert				Hand Cobbed Ore.
9	Cordon Cobalt Mines, Limited	Hudson Bay	Hudson Bay		United Cobalt.	
10	Nipissing-O'Brien Mines, Limited	Nipissing	Nipissing	125		Starting in Dec. 1953
	Silver Ore Shippers					
11	Castle Trethewey Mines, Limited	Castle Trethewey	Castle Trethewey	100		
12	Siscoe Metals of Ontario, Limited	O'Brien	Miller Lake-O'Brien	300		
13	Silver Miller Mines, Limited	Brady Lake	Lumsden Rochester	100		
14	Cobalt Consolidated Mining Corp.	Cobalt Lode	Adanac	200		Same mill used for cobalt ores.
15	“	Gilgreer	Canadian Lorraine			
16	“	Colonial	Colonial			
4	“	Cobalt Lake	Right of Way, Mining Corp.	750		Tailings mill.
7	Harrison Hibbert Mines, Limited	Harrison Hibbert	Ruby		United Cobalt.	
17	Shag Silver Mines, Limited	Cross Lake	Cross Lake O'Brien, Reinhardt.		Cobalt Consolidated Mining Corp.	
18	Nipissing-O'Brien Mines, Limited	O'Brien	O'Brien	125		Same mill used for cobalt ores.
19	New Morrison Mines, Limited	Tonapa	Tonapa		Siscoe Metals of Ont., Ltd.	
	Possible New Producers					
20	Roy Silver Mines, Limited	Roy Silver		50		Cobalt ores.
21	Cotley Mines, Limited				Siscoe Metals of Ont., Ltd.	Silver ores.
	Exploration Companies					
22	Mayfair Mines, Limited	Mayfair	John Black	75		
23	Juno Metals Corporation	Juno	White			

Temiskaming Silver-Cobalt Area (11, 12)

The town of Cobalt is situated about 100 miles north of North Bay, Ontario on the main line of the Ontario Northland Railway. The ore-bodies at Cobalt were discovered in 1903 during the construction of the railway. Other ore-bodies were found in areas some distance from the town in South Lorrain (south-east of Cobalt), in Casey township (15 miles north-east), and Gowganda, 27 miles west of Elk Lake lying 40 miles north-west of Cobalt.

Most of the mines at Cobalt were grouped within an area of about 6 square miles. A sill of Nipissing diabase about 1,000 feet thick intrudes the gently dipping strata of the Cobalt series which are laid down on steeply folded Keewatin lavas, tuffs, and iron formation. The Nipissing diabase sill dips gently east, and erosion has removed part of it so that the western part of the area is occupied by Keewatin and Cobalt strata that lie below the sill, whereas the eastern part is underlain by the sill itself, together with some areas of Keewatin or Cobalt strata that overlies the sill.

The silver-cobalt ores emanated from the diabase sill. All the ores were found within a few hundred feet of the diabase contact. About 80 per cent of the production veins occurred in the Cobalt series within 100 to 200 feet of the Keewatin contact the remaining 20 per cent being divided between the Keewatin and Nipissing diabase.

The high-grade veins contained a great variety of minerals, of which the chief were calcite, cobaltite, smaltite, niccolite, and native silver. Typical high-grade ore averaged about 10 per cent silver, 9 per cent cobalt, 6 per cent nickel, and 39 per cent arsenic. Some silver ores ran as high as 7,000 ounces to the ton.

J. A. Reid in his "Special Report on the Mineral Resources of the Temiskaming Silver-Cobalt Area" written in 1943, gives an interesting table on the character of the ore, as under:

Mineral	Composition	Percentage
Silver	Predominantly native	14·0
Cobaltite	$CoAsS$	13·5
Safflorite	$CoAs_2$	10·5
Arsenopyrite	$FeAsS$	8·7
Rammelsbergite	$NiAs_2$	8·2
Skutterudite	$CoAs_3$	8·0
Niccolite	$NiAs$	6·1
Lollingite	$FeAs_2$	6·0
Chalcopyrite	$CuFeS_2$	4·4
Galena	PbS	4·1
Smaltite	$CoAs_3$	2·9
Chloanthite	$NiAs_3$	2·6
Gersdorffite	$NiAsS$	2·6
Tetrahedrite	$3Cu_2S\ Sb_2S_3$	2·4
Pyrite	FeS_2	1·8
Pyrrhotite	Fe_7S	1·7
Breithauptite	$NiSb$	1·3
Sphalerite	ZnS	1·2
Total		100·0

The above mixture or aggregate has a calculated specific gravity of 6·58 and a chemical composition as given below:

Element	Percentage	
Arsenic	42·6	
Silver	14·0	(4183·3 oz. per ton)
Sulphur	10·6	
Cobalt	10·0	
Iron	7·8	
Nickel	6·9	
Lead	3·5	
Copper	2·6	
Antimony	1·2	
Zinc	·8	
Total	100·0	

Table 2 and Figure VII give the location of operating companies of the area together with the original name of the property being worked, the capacity of the mill, or where the ore from the mine is milled on a custom basis.

Werner Lake Area (8)

The property known as the Werner Lake Cobalt Mine consists of four claims at the west end of Werner Lake which is situated about 13 miles east of the Ontario-Manitoba boundary, and 36 miles from Minaki on the Canadian National Railway.

The property was discovered in 1920 but the claims were allowed to lapse. The property was restaked in 1928 by Kenora Prospectors and Miners Limited, a subsidiary of Ventures Limited. A shaft was sunk to 35 feet and in 1932, 67 tons of hand-cobbed ore was shipped by air. This shipment contained about 20,000 pounds of cobalt and was exported to the United States.

The property lay dormant until 1940 when Norman B. Davis of Ottawa, Ontario leased the property from Ventures Limited and commenced shipping out sorted ore running about 12·5 per cent cobalt from mine ore assaying 1·2 per cent cobalt. These ores were bagged and moved to Werner Lake for shipment by air to Kenora, from whence they were sold to Shepherd Chemical Company, Cincinnati, Ohio. Following some diamond drilling carried out in 1942 and the discovery of further ore, a contract was entered into with the Metals Reserve Company, the then U.S. stockpiling agency. A small mill was erected in the spring of 1943 and operated for a little over a year, and then closed down because of the termination of the supply contract at the end of 1943 and the lack of further developed ore. Total production during the war period amounted to 123,386 pounds of contained cobalt.

Cobaltite, pyrite, pyrrhotite, chalcopyrite and a little arsenopyrite occurred in a band of gneiss on the contact of granite into Keewatin sediments. The high grade ore occurred in lenses over a width of 3 to 4 feet with good milling ore over widths of up to 12 feet.

TABLE 3

TOTAL SHIPMENTS FROM COBALT AREA, 1904-1952

Source: Ontario Dept. of Mines

Year	Ore Raised Tons	Ore and Conc. Shipped Tons	Cobalt Content		Silver Content		Nickel Content		Copper Content		Total Value $
			lbs.	$	oz.	$	lbs.	$	lbs.	$	
1904	475	158	32,500	19,960	75,693	96,296	27,679	3,467	......	......	119,723
1905	2,598	2,084	326,300	100,015	2,451,356	1,355,306	79,885	9,030	......	......	1,464,351
1906	7,708	3,531	448,964	82,017	5,401,766	3,667,551	20,000	3,000	......	......	3,752,568
1907	32,180	14,739	354,675	93,315	9,996,887	6,146,904	65,557	1,255	......	......	6,241,474
1908	52,310	19,670	1,083,874	110,342	19,430,393	9,130,083	......	......	......	......	9,240,425
1909	109,147	27,774	1,030,788	92,957	25,779,150	12,531,425	118	14	......	......	12,624,396
1910	257,218	26,034	616,279	53,052	30,099,367	15,227,483	......	......	......	......	15,280,535
1911	254,935	16,416	......	......	29,981,423	15,183,449	......	......	......	......	15,183,449
1912	361,275	28,293	2,900	174	28,607,083	16,465,616	7,920	396	......	......	16,466,186
1913	489,700	43,746	33,380	3,324	28,177,232	15,663,116	......	......	......	......	15,666,440
1914	618,014	52,996	13,428	1,609	24,110,786	12,297,397	......	......	......	......	12,299,006
1915	555,543	43,743	58,600	7,967	23,811,588	11,688,986	......	......	......	......	11,696,953
1916	467,884	75,714	674,712	75,205	18,960,372	12,039,316	......	......	......	......	12,114,521
1917	......	59,013	914,046	138,187	18,327,258	15,224,478	4,058	203	......	......	15,362,868
1918	......	51,950	877,163	199,410	16,482,824	16,506,512	......	......	......	......	16,705,922
1919	......	18,016	322,211	120,316	10,285,027	11,722,801	......	......	......	......	11,843,117
1920	......	77,074	811,170	523,287	10,402,124	10,224,525	......	......	......	......	10,747,812
1921	342,922	87,777	138,881	28,071	7,664,304	5,149,034	......	......	......	......	5,177,105
1922	243,352	8,709	322,407	147,037	9,226,809	6,653,452	......	......	25,170	1,950	6,802,439
1923	401,215	18,795	506,898	113,230	7,257,460	4,660,267	......	......	65,512	5,210	4,778,707
1924	353,775	56,332	560,635	153,515	6,719,140	4,534,205	......	......	22,643	1,572	4,689,292
1925	261,851	63,838	418,041	93,585	7,193,782	4,954,138	......	......	114,114	13,794	5,061,517
1926	248,723	62,419	369,468	103,667	5,706,426	3,477,507	......	......	15,840	1,567	3,582,741
1927	208,066	54,055	324,876	90,718	4,526,427	2,603,652	......	......	31,077	2,364	2,697,481
1928	180,003	62,556	333,416	89,662	3,934,021	2,297,561	......	......	20,412	1,526	2,370,749
1929	151,424	52,471	384,440	140,884	4,819,571	2,512,241	......	......	7,800	1,014	2,654,139
1930	139,168	32,708	689,206	328,199	5,240,077	1,946,616	2,567	250	33,054	3,728	2,278,793
1931	114,434	6,638	1,105,819	511,790	3,706,619	1,173,374	......	......	57,941	5,438	1,692,618

1932.........	38,941	2,886	130,711	48,122	3,261,715	1,007,915	....	....	36,714	2,152	1,058,953
1933.........	29,293	1,594	121,182	36,862	2,397,118	864,428	1,861	350	38,052	2,802	904,927
1934.........	32,545	2,691	255,898	76,330	1,989,973	910,726	....	....	24,745	86	987,187
1935.........	30,959	7,815	498,273	154,402	2,678,974	1,711,176	137,519	20,025	35,969	234	1,891,101
1936.........	34,174	5,761	583,815	210,615	1,504,953	664,593	137,593	15,874	37,644	3,445	895,240
1937.........	34,215	8,504	227,217	115,350	1,060,073	470,533	3,677	576	45,910	6,057	593,687
1938.........	31,799	4,242	194,521	112,357	814,787	351,386	21,367	3,714	29,822	2,910	470,974
1939.........	33,995	2,556	330,519	279,341	920,963	354,053	63,446	7,648	20,821	528	641,694
1940.........	15,414	2,835	558,139	522,995	785,867	263,124	158,966	9,779	10,832	699	796,662
1941.........	11,299	2,515	427,278	369,280	345,772	106,463	112,635	3,945	....	....	479,688
1942.........	6,173	3,394	403,338	400,519	512,076	169,728	127,091	4,064	53,687	3,758	578,069
1943.........	2,750	2,409	411,963	427,844	450,439	166,068	104,881	3,256	56,462	5,383	602,551
1944.........	2,687	757	174,472	154,212	242,175	93,365	63,951	10,964	22,644	317	258,858
1945.........	34,965	680	130,834	96,560	107,569	46,490	71,300	10,631	6,297	629	154,310
1946.........	29,939	982	76,537	72,328	287,013	234,412	30,601	5,508	10,455	1,338	313,586
1947.........	13,464	756	181,853	55,756	321,970	223,764	30,095	7,223	12,350	2,099	288,842
1948.........	5,837	872	142,282	209,844	362,412	313,943	....	....	8,537	1,651	525,438
1949.........	16,778	361	91,708	43,562	707,775	522,674	....	....	....	....	566,236
1950.........	37,719	1,485	78,136	34,857	2,625,996	2,190,595	9,870	1,081	12,186	3,104	2,229,637
1951.........	87,960	3,424	276,811	633,986	3,195,873	3,021,758	39,121	21,829	51,069	14,137	3,691,710
1952.........	67,441	3,492	613,698	1,441,985	2,502,129	2,089,887	37,246	20,373	90,403	25,800	3,578,045

TABLE 4

TOTAL SHIPMENTS FROM GOWGANDA AREA, 1910-1952

Source: Ontario Dept. of Mines

Year	Ore Raised Tons	Ore and Conc. Shipped Tons	Cobalt Content		Silver Content		Total Value $
			lbs.	$	oz.	$	
1910.....	855	463	5,592	1,084	481,883	239,235	240,319
1911.....	5,923	190	....	....	469,197	239,618	239,618
1912.....	9,623	338	....	....	549,976	319,128	319,128
1913.....	56	183	....	....	502,370	293,664	293,664
1914.....	3,620	132	....	....	399,300	211,180	211,180
1915.....	6,790	110	....	....	242,229	116,856	116,856
1916.....	9,891	182	....	....	383,393	253,218	253,718
1917.....	....	356	....	....	1,064,635	888,393	888,393
1918.....	....	190	26,994	4,049	638,198	617,597	621,646
1919.....	....	226	27,404	3,886	723,764	825,927	829,813
1920.....	....	188	15,236	1,989	434,780	423,441	425,430
1921.....	11,703	133	9,187	950	258,292	176,757	177,707
1922.....	11,322	85	8,478	912	170,651	113,363	114,275
1923.....	1,147	670	7,494	750	160,721	103,201	103,951
1924.....	19,848	190	18,148	2,623	598,057	400,925	403,548
1925.....	51,087	509	41,135	6,026	1,355,156	931,579	937,605
1926.....	48,105	441	36,731	5,503	1,236,640	742,534	748,037
1927.....	62,321	698	49,284	6,032	1,741,614	976,643	982,675
1928.....	66,855	595	59,860	7,451	1,677,429	967,022	974,473
1929.....	72,002	643	72,112	11,185	2,081,894	1,041,722	1,052,907
1930.....	65,467	668	107,264	15,067	2,140,017	761,211	776,278
1931.....	28,542	507	104,223	11,356	1,697,242	532,004	543,360
1932.....	30,130	530	72,081	10,469	1,374,780	422,446	432,915
1933.....	30,932	366	40,729	....	1,244,812	497,799	497,799
1934.....	21,680	270	32,273	....	1,039,565	506,494	506,494
1935.....	21,402	807	20,818	....	829,195	532,460	532,460
1936.....	22,532	282	24,724	187	640,114	288,460	288,647
1937.....	21,519	201	20,848	674	522,151	234,922	235,596
1938.....	25,665	204	16,778	1,036	502,871	218,448	219,484
1939.....	20,877	202	19,433	2,933	498,043	206,086	209,019
1940.....	1	5	207	47	5,343	1,811	1,858
1941.....	....	....	......No recorded production.....			....	....
1942.....	69	69	7,194	1,587	191,526	67,910	69,497
1943.....	70	60	5,205	883	172,698	67,697	68,580
1944.....	105	71	9,000	2,264	250,676	100,270	102,534
1945.....	75	11	1,185	194	44,585	18,896	19,090
1946.....	....	....	......No recorded production.....			....	....
1947.....	95	....	....	....	94,301	63,795	63,795
1948.....	3,068	507	....	....	183,163	169,883	169,883
1949.....	20,714	723	6,000	1,900	626,254	491,342	493,242
1950.....	22,972	1,182	18,470	1,370	836,047	711,020	712,390
1951.....	32,542	1,427	38,009	87,040	1,359,714	1,285,609	1,372,689
1952.....	60,931	1,833	36,557	85,908	1,869,493	1,561,400	1,647,308

TABLE 5

SHIPMENTS FROM COBALT-GOWGANDA AREAS OF ONTARIO, VIA TEMISKAMING TESTING LABORATORIES, COBALT, ONT., 1940-1952.

Source: Ontario Dept. of Mines

Year	SILVER ORE SHIPMENTS					COBALT ORE SHIPMENTS				
	Contained Silver oz.	Contained Cobalt lbs.	Contained Nickel lbs.	Contained Copper lbs.	Gross Weight lbs.	Contained Silver oz.	Contained Cobalt lbs.	Contained Nickel lbs.	Contained Copper lbs.	Gross Weight lbs.
1940	278,170	13,465	3,817	....	610,867	167,521	445,324	162,031	....	4,344,406
1941	705,836	34,934	6,989	....	607,715	137,694	411,328	123,724	....	4,037,340
1942	606,627	24,844	896	288	464,417	112,276	384,652	130,419	55,330	3,816,767
1943	298,002	11,933	1,742	176	176,203	51,385	161,992	48,745	23,549	1,620,872
1944	410,634	17,302	1,254	92	339,683	81,096	173,928	48,076	17,296	1,499,920
1945	219,146	21,683	17,067	6,024	398,468	9,723	106,935	58,331	6,638	953,310
1946	288,982	5,946	755	3,320	193,134	12,281	73,900	30,590	9,902	657,787
1947	270,015	5,730	1,124	471	416,162	95,543	188,247	43,016	16,061	1,873,424
1948	481,072	10,096	493	9,191	1,526,480	30,467	139,024	53,360	10,709	1,230,021
1949	1,124,068	19,476	2,181	....	1,701,695	27,239	73,031	20,792	5,253	718,918
1950	2,979,810	105,820	14,609	28,556	4,955,177	30,983	92,360	30,248	17,106	583,912
1951	3,547,164	213,447	45,494	31,237	3,661,440	40,365	88,674	31,788	19,954	935,203
1952	2,979,923	171,708	37,485	17,817	3,167,474	146,844	484,185	202,810	37,482	4,382,820

TABLE 6

TOTAL PRODUCTION OF COBALT FROM ONTARIO ORES, 1904-1952

Includes (1) Shipments from the Deloro Smelter of Ontario ores as metal, oxides and salts.
(2) Export shipments of Ontario ores.
(3) Cobalt oxide shipments from International Nickel Company since 1947.
(4) Cobalt metal production from Falconbridge matte since 1952.

Source: Ontario Dept. of Mines

Year	Cobalt Tons	Value $	
1904	....	36,620	includes content from Sudbury nickel ores
1905	118	100,000	
1906	321	80,704	
1907	739	92,751	
1908	1,224	111,118	
1909	1,533	94,965	
1910	1,098	54,699	
1911	852	170,890	
1912	934	315,781	
1913	821	420,386	
1914	351	546,479	+ 45,189 nickel and cobalt compounds
1915	206	379,657	+ 9,227 " " " "
1916	400	762,327	+ 60,956 " " " "
1917	337	1,122,779	+ 42,026 " " " "
1918	380	1,615,130	+ 73,347 " " " "
1919	298	868,107	+188,083 " " " "
1920	238	1,603,736	
1921	126	502,370	
1922	776	1,080,873	
1923	476	1,456,583	
	Cobalt lbs.		
1924	1,279,777	1,662,526	
1925	1,466,262	2,328,517	
1926	664,778	1,136,014	
1927	880,590	1,764,534	
1928	954,860	1,671,900	
1929	929,415	1,801,915	
1930	694,163	1,144,007	
1931	521,051	651,179	
1932	490,631	587,957	
1933	466,702	597,752	
1934	594,671	592,497	
1935	681,419	512,705	
1936	887,592	803,580	
1937	507,064	848,145	
1938	459,226	790,913	
1939	732,561	1,213,454	
1940	794,359	1,235,220	
1941	263,257	255,904	
1942	83,871	88,444	
1943	175,961	191,407	
1944	36,283	34,106	
1945	109,123	90,026	
1946	75,848	64,471	
1947	578,403	955,917	
1948	1,545,744	2,624,410	
1949	619,065	952,469	
1950	583,806	964,003	
1951	951,607	1,999,612	
1952	1,421,923	3,226,903	

NORTHWEST TERRITORIES

Great Bear Lake Area (3)

The Eldorado mine, which lies about 35 miles south of the Arctic circle, at Port Radium on Echo Bay, Great Bear Lake, was discovered by G. Labine and E. C. St. Paul in May, 1930.

Associated with the pitchblende-silver veins is a system of cobalt-nickel-bismuth-copper-quartz veins. These usually cut across the pitchblende veins and the metallic minerals occur in the carbonate filling of small vugs in the quartz. Cobalt occurs as skutterudite and smaltite-chloanthite.

In 1932 shipments of pitchblende and high grade silver ores were commenced. A refinery was completed at Port Hope, Ontario early in 1933, when concentrates from Great Bear Lake were first shipped out. The concentrates shipped later were (1) pitchblende-silver, (2) silver-copper, (3) cobbed pitchblende-silver, and (4) cobbed cobalt ores. The pitchblende-silver concentrates were treated at Port Hope, while copper-silver concentrates went to Tacoma, Washington for treatment. A cobalt-copper-nickel speiss was later produced at the refinery and shipped together with hand-cobbed cobalt ores to Deloro, Ontario.

By Order in Council P.C. 535 of January 27th, 1944 the Canadian Government expropriated all the issued stock of the then operating Company, Eldorado Mining and Refining Limited and then by a further order in council set up a Crown company, Eldorado Mining and Refining (1944) Limited to operate the mine, plant and refinery as a source of urgently required uranium.

The Port Hope refinery residue now contains 3·5 per cent cobalt from which a speiss is produced averaging 12·7 per cent cobalt. This is shipped to the plant of Deloro Smelting and Refining Company, Limited for refining. A small amount of hand-cobbed ore is occasionally shipped, the last being in 1951.

TABLE 7

PRODUCTION OF COBALT FROM ELDORADO MINE, 1950-1952

Year	Speiss lbs.	Cobalt Content %	Cobalt Content lbs.
1950	604,216	13·99	84,500
1951	489,820	12·57	61,552
1951	(cobbed ore)	....	6,409
1952	481,248	11·46	55,166

MANITOBA

Lynn Lake Area (7)

The Lynn Lake deposit of Sherritt Gordon Mines, Limited is located in Northern Manitoba, 10 miles south of the 57th parallel and 36 miles from the Manitoba-Saskatchewan border.

The first discovery was made in 1941 by Austin McVeigh who noticed a small exposure of sulphides. In 1945 a diamond drilling program outlined a large orebody. By the end of 1952, 14,055,000 tons of ore containing 1·223 per cent nickel, 0·618 per cent copper and some cobalt had been blocked out. Present plans call for the mining and milling of 2,000 tons of ore per day.

Professor F. A. Forward of the University of British Columbia commenced an investigation during 1947 on a leaching process to treat the nickel concentrate. It was found that a concentrate with the following analysis gave the best economic return:

nickel	10-14%
copper	1-2%
cobalt	0·3-0·4%
iron	33-40%
sulphur	28-34%
insolubles	8-14%

Precious Metals—less than 0·02 oz. per ton.

A flotation pilot plant was installed during 1948 at Sherridon, Manitoba with a capacity of 50 tons a day. During 1949 and 1950 the pilot plant was operated at Lynn Lake, the mine site. The first ammonia-leach pilot plant was operated at the Mines Branch at Ottawa under the supervision of Sherritt Gordon Mines Limited and Chemical Construction Corporation of New York. After a series of successively larger pilot plants, a 3,000 pound per day operation commenced in Ottawa in March, 1953 which reproduced every operation of the commercial plant being built at Fort Saskatchewan near Edmonton, Alberta. It is expected that the Fort Saskatchewan plant will commence production during 1954. When in full-scale production the plant will produce about 17,000,000 pounds of nickel, 9,000,000 pounds of copper, and 300,000 pounds of cobalt a year.

A contract was made with the stockpiling agency of the U.S. Government for the sale of a substantial portion of the nickel, copper and cobalt output for the first five years of production. This contract covers about 60 per cent of the nickel output or 50,000,000 pounds; 55 per cent of the copper or 25,000,000 pounds and 50 per cent of the cobalt or 750,000 pounds. Deliveries are to commence in 1954. The balance of the company's output of nickel has been contracted to U.S. steel companies.

Normal production of cobalt powder will have the following analysis:

cobalt	99·5%
nickel	0·18%
iron	0·11%
sulphur	0·02%
copper	nil

Among the cobalt salts which could be produced as intermediate products from the circuit are:

(1) Cobaltous ammonium sulphate—25% cobalt. $2\ CoSo_4\ (NH_4)_2\ SO_4.\ H_2O$ which can be obtained from the decomposition of cobaltic hexammine sulphate, and

(2) Cobaltous ammonium sulphate—14% cobalt which can be obtained by dissolving cobaltous ammonium sulphate in water and the adding of $(NH_4)_2\ SO_4$ and crystallization.

Pilot plant work has shown that 50 to 75 per cent of the cobalt contained in the nickel concentrate should be recovered.

CHAPTER IV

OTHER CANADIAN OCCURRENCES

There are many small showings of cobalt in Canada, but most of them are too small to have any economic significance. However, in certain instances cobalt may or could be produced as a by-product.

Reference numbers following sub-headings refer to numbers on key map of Canada showing cobalt occurrences (Fig. V).

YUKON

Quill Creek, Kluane Lake (13)

This deposit, known as the Wellgreen property, was discovered in June, 1952 by prospectors of Hudson Bay Exploration and Development Company.

Work during 1952 consisted of building a 10 mile rough road into the property from the Alaska Highway, erecting camp buildings, carrying out geological mapping and a limited amount of diamond drilling. During 1952, five diamond drills were at work. Early channel samples yielded the following assays:

nickel	3·2%
copper	2·2%
cobalt	0·14%

plus some platinum group metals.

However the drilling results of 1952 work outlined a conservative 67,000 tons of ore having average assay values as follows:

copper	1·33%
nickel	1·96%
cobalt	0·056%
gold	0·004 oz. per ton
platinum	0·078 " " "
palladium	0·053 " " "

BRITISH COLUMBIA

Nickel Plate Mine, Hedley (2)

The Nickel Plate Mine, operated by Kelowna Mines Hedley Limited, is situated 4 miles north of Hedley, Osoyoos Mining Division, and has been in production since before 1900. The company ships a gold-copper flotation concentrate averaging 1·1 ounces of gold, 1·1 per cent copper, 0·6-0·8 per cent cobalt, 30 per cent arsenic, and 20 per cent sulphur, the balance being iron, silica and insolubles. The flotation concentrate is shipped to the Tacoma, Washington smelter of the American Smelting and Refining Company. The company receives payment for the gold and copper content of the concentrate, but the cobalt is not recovered. It is estimated that about 70,000 pounds of cobalt is lost yearly.

The ore deposits lie in the upper portion of Nickel Plate Mountain where basic igneous rock has intruded inclined sedimentary beds of Triassic age. The ore is of the contact metamorphic type and replacement has played an important part in determining the position and size of the ore shoots.

Cobalt in the Nickel Plate ore occurs as cobaltite and safflorite.

A considerable amount of work was done in the laboratories of the University of British Columbia at Vancouver during the war in an endeavour to recover this cobalt. A process of roasting and leaching the flotation concentrates was devised whereby up to 90 per cent of the cobalt and 95 per cent of the copper could be abstracted, with the acid-leached residue going to the cyanide circuit to recover the gold.

However a problem was raised by the effect which the fumes from the roaster would have on the fruit districts near the mine and also the disposition of a sizeable quantity of arsenic, plus capital cost of equipment.

During 1950 an investigation was carried out in the Mines Branch Laboratories, Ottawa to check the chemistry of the process used in the laboratories of the University of British Columbia. The recoveries of copper, cobalt and gold claimed for the process were substantiated.

Cobalt occurs in a similar manner at the Hedley Mascot mine adjoining the Nickel Plate Mine. This also is not recovered.

Western Nickel Mines Limited (20)

This property was formerly known as B.C. Nickel Mines Limited and also as Pacific Nickel Mines, Limited and is now controlled jointly by Pacific Nickel Mines Limited and Newmont Mining Corporation. It is situated 7 miles from Choate on the C.P.R., 95 miles east of Vancouver.

The property was developed during the early 1930's. During 1936 and 1937, about 5,000 tons of development ore plus concentrates were shipped to Japan. In 1940 ore reserves were estimated to be 1,000,000 tons averaging 1·39 per cent nickel and 0·5 per cent copper.

The property is now being developed for large scale mining, and production is expected to begin in the early part of 1955 with concentrates being shipped to the Fort Saskatchewan refinery.

A shipment of 2,500 pounds of ore was tested at the Mines Branch Laboratories, Ottawa during 1940 and it was found that the amount of cobalt in the feed was 0·20 per cent.

Little Gem Mine (1)

The Little Gem prospect is situated close to the top of a 7,000 foot ridge near Roxy Creek, a tributary of Gun Creek, in the Lillooet Mining Division.

The ore occurs as rich sulphide lenses in a shear zone and consists of a mixture of arsenopyrite, danaite, and lollingite-safflorite, with a little gold, uraninite and molybdenite in a gangue of quartz, feldspar, and altered country rock.

Samples of ore from the prospect analyzed at the University of British Columbia Laboratories during World War II, ran as follows:

cobalt	6·8%
nickel	0·5%
iron	22·1%
arsenic	39·0%
sulphur	14·1%
insolubles	11·4%
gold	1·43 oz. per ton

A considerable amount of work was carried out in developing a treatment process for this ore in order to recover both gold and a cobalt residue high enough in grade to be shipped to a refinery. It was found that by sintering the crude ore, and smelting the sinter with the addition of some crude ore plus silica in an electric furnace, a speiss was formed which was then roasted at 875°C. in a small hand-rabbled furnace. An analysis of the roasted speiss was as follows:

cobalt	30-35%
iron	35-40%
arsenic	3-5 %
gold	5-8 oz. per ton

It was claimed that this process would recover about 90 per cent of the cobalt and 98 to 99 per cent of the gold.

Estella Mine (14)

The mill site is at Wasa, 11 miles north of Fort Steele, and the mine is about 5 miles to the east, in a basin at the head of Tracy Creek in the Rocky Mountains. The property was first staked in the 1890's. Milling commenced on November 1st, 1951 by Estella Mines, Limited. The ore is a replacement by sphalerite, galena, and pyrite containing a relatively high percentage of cobalt, and for that reason was not acceptable at the Trail smelter. The British Columbia Department of Mines assayed over 100 samples of mine ore and the soluble cobalt in each ranged from 0·0007 to 0·06 per cent. The arithmetical mean of the samples was 0·0153 per cent soluble cobalt. The lead concentrate only was shipped to the Trail smelter during 1951 while the zinc concentrate was smelted at Bartlesville, Oklahoma.

There are small amounts of cobalt present in other British Columbia zinc ores but the amount is insufficient to make recovery worthwhile at the Trail smelter.

Victoria Mine (15)

The Victoria group of claims are 5 miles south of Hazelton, on the north-west slope of Rocher Déboulé Mountain. Between 1916 and 1928 a vein was developed and several lots of gold-molybdenum-cobalt ore were shipped in the period 1918-28 and in 1940 and 1941. Data on the analysis of some of the shipments are based on information obtained from the Annual Reports of the Minister of Mines of British Columbia. The analyses are shown in the following table:

Year	Tons	Au oz./ton	Ag oz./ton	As %	Mo %	Co %	Zn %
1918.......	26·6	1·24	....	8·98	0·96	1·18	....
1926.......	22·0	4·65	....	42·3	....	4·6	....
1940.......	7·7	2·18	0·2	6·6	....	2·6	Nil
1941.......	7·3	2·02	0·2	6·1	....	1·4	0·6
1941.......	3·4	3·92	0·3	33·3	....	....	4·40

Arsenopyrite, cobalt-nickel arsenides, cobalt bloom, molybdenite, and small amounts of other sulphides occur in veins in the fault-fissures and fractures and are irregularly disseminated in the hornblende rock. The sulphide veins are generally less than a foot wide.

NORTHWEST TERRITORIES

B.M. Group (4)

The B.M. group of sixteen claims is 80 miles east of Yellowknife, and 4 miles northwest of Sachowia Point on the north shore of the east arm of Great Slave Lake. The claims were staked in August, 1940 on behalf of the Consolidated Mining and Smelting Company of Canada, Limited. The property is reported to contain a small deposit of cobalt and nickel arsenides.

Francois River (5)

This deposit lies east of Francois River on the north shore of Great Slave Lake, one and a half miles south of Caribou Lake. Niccolite occurs in two veins lying within a hundred feet of each other. The veins have a maximum width of 15 inches and are formed chiefly of massive niccolite, with some smaltite and chloanthite, in a carbonate gangue. The surfaces of the nickel and cobalt arsenides are coated with green and pink, nickel and cobalt bloom.

SASKATCHEWAN

Goldfields-Beaverlodge Lake Area (6)

This area is situated near Goldfields, about midway along the north shore of Lake Athabasca.

Uranium is the principal mineral of the various deposits and occurs as pitchblende in veins and uraninite in pegmatites. Variable amounts of cobalt-nickel minerals occur in the complex pitchblende deposits. The main operator of the district is the Crown-owned, Eldorado Mining and Refining Limited which brought its Ace-Fay property into production in 1953. However cobalt will not be recovered by the company from this operation.

MANITOBA

Maskwa and Oiseau River Areas (21)

Cobalt occurs in the nickel-copper occurrences of the Maskwa River and Oiseau (Bird) River areas, Lac du Bonnet Mining Division, southeast Manitoba. Maskwa Nickel Chrome Mines, Limited a subsidiary of Falconbridge Nickel

Mines Limited and Ventures Limited, acquired a number of claims in 1951. Electromagnetic and geophysical surveys have been made and diamond drilling carried out.

Diamond drilling carried out prior to 1930 indicated 300,000 tons averaging 1·17 per cent nickel and 0·78 per cent copper on the Maskwa deposit and 400,000 tons averaging 1·31 per cent nickel and 0·35 per cent copper on the Oiseau River deposit.

Preliminary examination during recent years by Falconbridge Nickel Mines, Limited has indicated a higher proportion of cobalt to nickel than in the Sudbury nickel-copper ores.

ONTARIO

Hart Township (16)

A small occurrence of cobalt in a body of magnetite is found in lots 7 and 8, concession V, Hart township, about 4 miles west of Cartier, a division point on the main line of the Canadian Pacific Railway. The mineralization is similar to that of the Cornwall, Pennsylvania magnetite deposit from which cobalt is being recovered. A mineralographic examination of the primary cobalt mineralization shows it to consist almost entirely of a ferriferous and nickeliferous cobaltite.

Massey Claims (10)

These claims are located in the north-central part of Harrow Township, about 5 miles from the town of Massey on the Canadian Pacific Railway line to Sault Ste. Marie, about 75 miles west of Sudbury. A small amount of surface work such as stripping and shallow pits has disclosed a small amount of cobalt. The main vein averages 3 feet in width. A sample submitted to the Ore Dressing and Metallurgical Laboratories, Department of Mines and Resources in 1942 indicated that the metallic minerals occur as skutterudite together with smaltite-chloanthite in a gangue of milky white quartz with abundant, finely disseminated carbonate. In come places the quartz is a pinkish brown to red colour, probably due to the presence of erythrite.

A head sample cut from the shipment, was assayed and reported as follows:

cobalt	2·13%
nickel	0·21%
arsenic	3·32%
sulphur	1·43%
silver	0·20 oz. per ton

It was found that the ore responded readily to table concentration and that with flotation of the table tailing, a recovery of 90 per cent of the cobalt could be expected.

Palmer Township (22)

A copper-gold prospect is being developed in the central part of the township in the Sault Ste. Marie Mining Division by Glenrock Gold Mines, Limited. It is situated a few miles north of Batchawana Bay on the east shore of Lake Superior about 40 miles from Sault Ste. Marie.

Cobalt bloom was discovered in late 1951 and further work showed that cobaltite was present with gold and minor amounts of nickel and silver. According to samples assayed by the company a width over 3 feet averaged 0·56 per cent cobalt and 0·13 ounces of gold per ton.

Otter Township (23)

Cobalt occurs with gold, bismuth and nickel in some deposits north of Thessalon in the Sault Ste. Marie Mining Division.

A shipment of 3·7 tons of ore was made to the Temiskaming Testing Laboratories and the concentrate produced assayed 14·66 per cent cobalt, 9·16 per cent nickel and 9 ounces of silver per ton.

In 1943 a sample of 150 pounds of ore was received by the Mines Branch Laboratories, Ottawa, for testing which assayed as follows:

gold	0·96 oz. per ton
silver	0·38 " " "
nickel	1·01%
cobalt	1·41%
bismuth	4·18%
iron	7·54%
sulphur	3·38%
arsenic	1·24%

The metallic minerals were examined by polished sections and were found to be smaltite-chloanthite, native bismuth, niccolite, and erythrite in order of decreasing abundance.

The ore was tested by flotation, table concentration and a combination of both but these tests were unsatisfactory because it was impossible to separate the bismuth from the cobalt and nickel, or to obtain a satisfactory recovery of any of the metals.

QUEBEC

Mount Wright (19)

This occurrence which was examined during the past three years by Quebec Cobalt and Exploration Limited in cooperation with Quebec Metallurgical Industries Limited lies about 185 miles north of Seven Islands in New Quebec. Nickel and a small amount of gold and silver occurs with cobalt as cobaltite. Some trenching was carried out in 1951 and 1952 but it is understood that the results were not encouraging.

Calumet Island (18)

There are numerous occurrences of nickeliferous pyrrhotite and pyrite in the southern part of Calumet Island. Some development work was carried out on the Ostram claims during the early 1930's.

An analysis of a 3-ton sample submitted to the Mines Branch Laboratories, Ottawa in 1933 was as follows:

nickel	0·88%
cobalt	0·17%
iron	18·8 %
insolubles	54·9 %
gold	0·02 oz. per ton

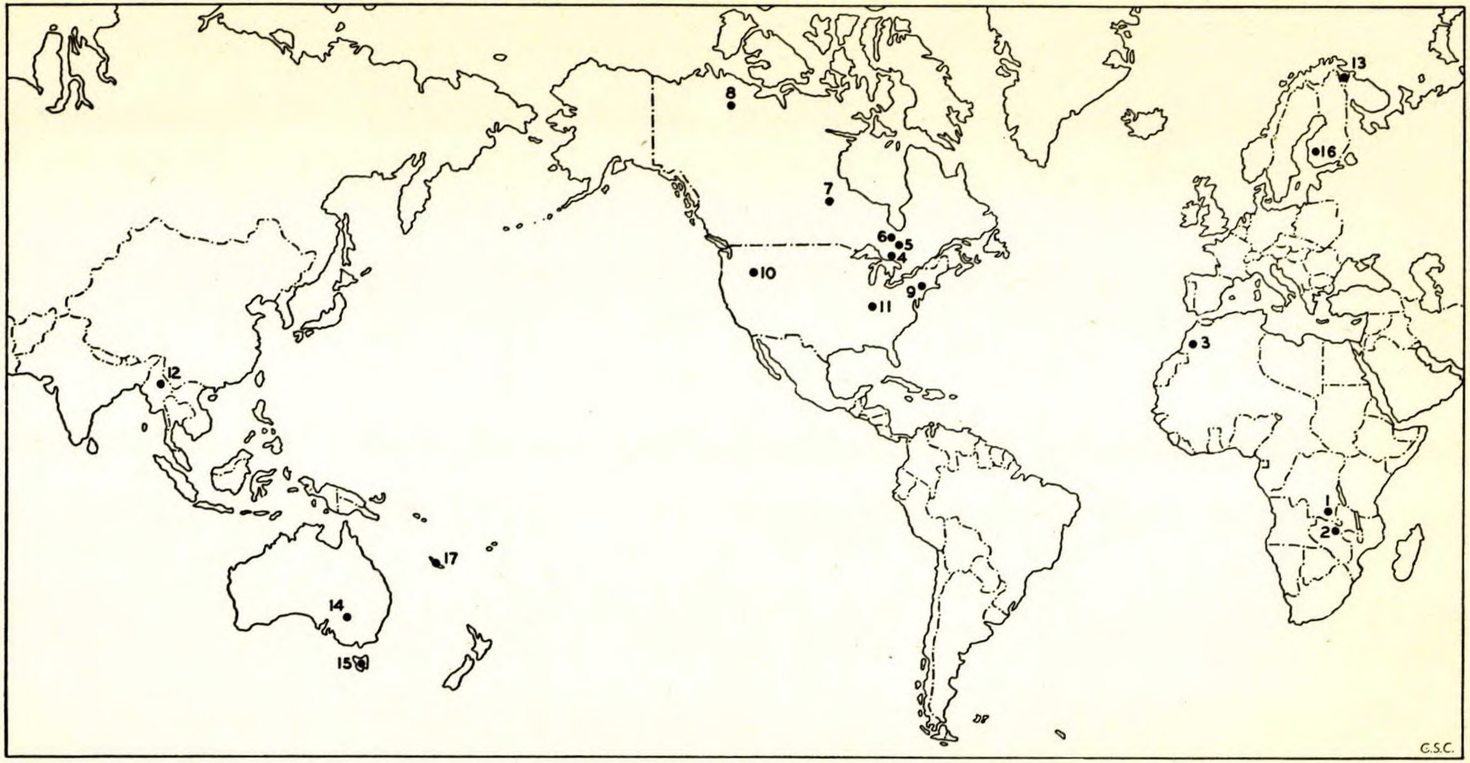


FIGURE VIII **KEY MAP OF WORLD MINE PRODUCTION OF COBALT**

MINES AND OPERATORS

1. KATANGA, BELGIAN CONGO. (UNION MINIERE DU HAUT KATANGA)
2. NKANA, NORTHERN RHODESIA. (RHOKANA CORPORATION LTD.)
3. BOU-AZZER, FRENCH MOROCCO (LA SOCIETE MINIERE DE BOU-AZZER)
4. SUDBURY AREA, CANADA. (VARIOUS OPERATORS)
5. COBALT AREA, CANADA. (VARIOUS OPERATORS)
6. GOWGANDA AREA, CANADA (VARIOUS OPERATORS)
7. LYNN LAKE MINE, CANADA (SHERRITT GORDON MINES, LTD.)
8. ELDORADO MINE, CANADA. (ELDORADO MINING & REFINING (1944) LIMITED)
9. CORNWALL MINE, U.S.A. (BETHLEHEM STEEL CO.)
10. BLACKBIRD MINE, U.S.A. (CALERA MINING CO.)
11. FREDERICKTOWN, U.S.A. (NATIONAL LEAD CO.)
12. BAWDWIN MINE, BURMA. (BURMA CORP. LTD.)
13. PETSAMO AREA, RUSSIA.
14. BROKEN HILL, AUSTRALIA. (BROKEN HILL PROP. CO.)
15. READ ROSEBERY, AUSTRALIA. (ELECTROLYTIC ZINC CO.)
16. OUTOKUMPU, FINLAND. (OUTOKUMPU OY.)
17. NEW CALEDONIA. (VARIOUS OPERATORS)

CHAPTER V

WORLD MINE PRODUCTION OF COBALT

Reference numbers following sub-headings refer to numbers on key map of world mine production of cobalt, (Fig. VIII).

Belgian Congo (1)

The Belgian Congo is the world's largest source of cobalt. Production began in 1924 and is a by-product in the refining of copper ores of Union minière du Haut Katanga. Metallic cobalt is produced at the electrolytic refinery at Jadotville while cobalt white alloy is exported to the Niagara Falls, New York refinery of African Metals Corporation, operated by the Electro Metallurgical Company, and also to the Oolen, Belgian refinery of Société générale métallurgique de Hoboken. The refinery at Niagara Falls produces mainly cobalt metal, while metal, oxides and salts are produced in Belgium. The cobalt content of the oxidized copper ores is a little less than 0·5 per cent cobalt.

Northern Rhodesia (2)

Northern Rhodesia is the second largest source of cobalt production and it is derived as a by-product from the refining of the Nkana copper ores of the Rhokana Corporation, Limited. During World War II the cobalt white alloy was smelted in Canada by the Deloro Smelting and Refining Company, Limited. However since the termination of the Deloro contract the alloy has been treated by Murex, Limited at Rainham, United Kingdom for the production of metal and oxides. An electrolytic plant has been built at Nkana and has been producing electrolytic cobalt since 1952.

French Morocco (3)

The ores at Bou Azzer contain nickel, gold and arsenic in addition to cobalt. Arsenical ores can only be treated in smelters which specialize in this raw material. In the past the ores were treated at three refineries in France, namely: Société d'electrochimie, d'electro-métallurgie et des aciéries electriques d'Ugine at Savoie, Bozel-Maletra at Paris and Société d'utilisation des métaux at Paris.

However, since 1948, ever increasing amounts of these ores have entered Canada for treatment at the Deloro smelter for the account of the United States Government.

Canada (4, 5, 6, 7, 8)

These producers have been described in a preceding chapter.

Cornwall Mine, U.S.A. (9)

The magnetite mined at Cornwall, Pennsylvania by the Bethlehem Steel Co. contains sulphides in which cobalt occurs and which has been recovered since 1940. A calcine which contains the cobalt is shipped to the Pyrites Company at Wilmington, Delaware where the cobalt is recovered by a chemical process. Cobalt metal, sulphate, oxide and hydrate are produced.

Blackbird Mine, U.S.A. (10)

The Blackbird property is situated in the Salmon National Forest of Idaho and is operated by the Calera Mining Company, a subsidiary of the Howe Sound Company. The ore contains about 14 pounds of cobalt and 32 pounds of copper per ton plus a little gold. A flotation concentrate is produced at the mine which is shipped to Garfield, Utah for refining by an acid high-pressure leaching process. Cobalt metal is produced under contract with the United States Government, but to date production has been small because of corrosion problems.

Fredericktown, U.S.A. (11)

The St. Louis Smelting and Refining Division of National Lead Company have been producing since 1944 an iron concentrate containing cobalt, nickel, and copper at its property at Fredericktown, Missouri. A plant was constructed by Cobalt-Nickel Reduction Company during 1952 to produce cobalt, nickel and copper. The expected annual rate of cobalt production is 1,386,000 pounds. It is believed that this operation is also troubled with corrosion problems.

Bawdwin Mine, Burma (12)

Until 1949, The Burma Corporation operated a silver-lead-zinc-copper-nickel-cobalt mine equipped with a concentrator and refinery. Production was resumed on a small scale in mid-1952 by The Burma Corporation (1951), Limited but it is not known whether any cobalt bearing matte or speiss is being produced. Before World War II this matte and speiss was treated at the Nord-Deutsche Affinerie, Hamburg, Germany.

Petsamo Area, Russia (13)

No doubt cobalt is recovered in the U.S.S.R. from the nickel-copper deposit at Petsamo, formerly Finnish territory. The ore is said to contain approximately 1·6 per cent nickel, 1·3 per cent copper and 0·06 per cent cobalt.

Broken Hill, Australia (14)

Cobalt occurs in the zinc concentrates produced at Broken Hill, New South Wales by Broken Hill Proprietary Co. Ltd. The concentrates are treated by the Electrolytic Zinc Company at Risdon near Hobart, Tasmania and cobalt oxide is produced as a by-product. The cobalt content of the ores ranges from 0·002 to 0·007 per cent.

Read-Rosebery, Australia (15)

Zinc concentrates from the property of the Electrolytic Zinc Co. of Australasia, Ltd. at Rosebery, Tasmania are refined at the company's electrolytic plant at Risdon, Tasmania and cobalt oxide is produced. The average cobalt content of all zinc concentrates treated amounts to about 0·015 per cent.

Outokumpu Mine, Finland (16)

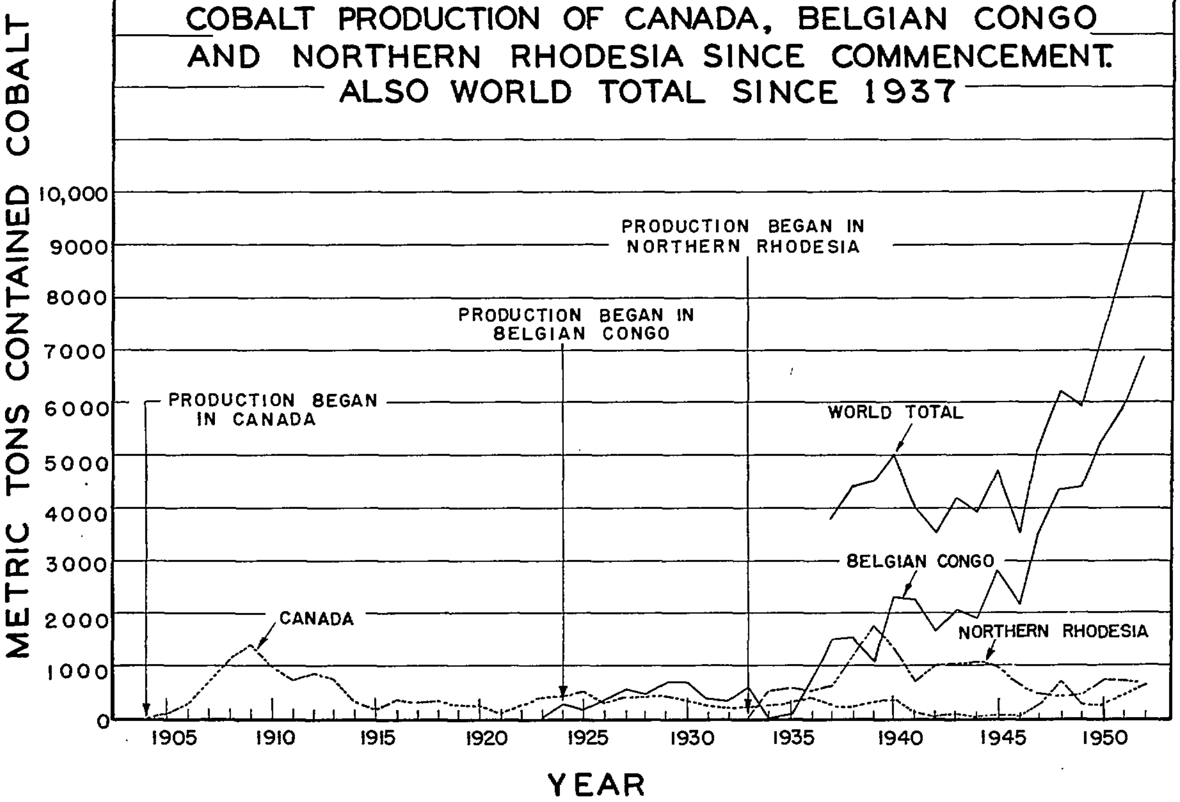
The cupriferous pyrite of this government-owned mine contains 3·5 per cent copper, 25 per cent sulphur, 28 per cent iron, 1 per cent zinc, 0·2 per cent cobalt, 0·1 per cent nickel and a little gold, silver and tin. A pyrite sinter containing about 0·5 per cent cobalt is shipped to Germany and treated on a toll basis by Duisburger Kupferhutte, Duisburg. Some cobalt metal is returned to Finland. Experiments have been carried out in Finland with a view to the construction of a cobalt recovery plant there.

New Caledonia (17)

Cobalt oxide is produced intermittently from the asbolite ores of the French island of New Caledonia. The ore is shipped to foreign smelters for refining into commercial products. Prior to the commencement of production from Cobalt, Ontario, New Caledonia was the world's largest supplier of cobalt.

FIGURE IX

COBALT PRODUCTION OF CANADA, BELGIAN CONGO AND NORTHERN RHODESIA SINCE COMMENCEMENT. ALSO WORLD TOTAL SINCE 1937



CHAPTER VI

METALLURGY

In 1902, the Ontario Government commenced the building of a railway with the object of opening up the clay belt of Northern Ontario for colonization. During the summer of 1903, workers employed by the construction companies discovered silver ores at Long Lake, later called Cobalt Lake.

Prior to 1904 the only recorded production of cobalt was a small amount which had been derived from the nickel-copper ores of Sudbury, Ontario. In 1906, the Canadian Copper Company established near its nickel-copper smelter at Copper Cliff, a plant for the treatment of cobalt-silver ores from Cobalt, Ontario. The plant closed down in 1913 because of the extended treatment of silver ores in cyanide plants at the mine sites. Cobalt and nickel oxides produced by this company from Cobalt, Ontario ores amounted to 2,318,916 pounds of contained cobalt and 1,585,712 pounds of contained nickel.

The smelter at Deloro, Ontario which had been operated as an arsenic refinery by Canadian Goldfields was refurnished with new equipment in 1907 and commenced to produce mixed nickel-cobalt oxides in 1910. The smelter's main work was the smelting of ores and concentrates from the O'Brien and Miller-Lake O'Brien Mines at Cobalt and Gowganda, respectively, although it processed purchased ores and concentrates in order to run the smelter at capacity.

The early exports of cobalt were to England, France, Germany and the United States in the form of oxide and mixed nickel-cobalt oxide. The European buyers in turn refined the oxides and sold the final oxide in the world market as their own brand. The producers at Cobalt were usually paid only for the silver content of the ores and concentrates and consequently the cobalt veins were either incompletely developed or entirely disregarded.

With a view to encouraging the production of refined nickel, refined cobalt metal, oxides, and salts, the Ontario Government in 1907 passed the "Metal Refining Bounty Act" under which a bounty of six cents a pound was payable to smelters on the cobalt content of their finished products. The Act was in force for five years until April 20, 1912 at which time it was extended for a further period of five years until its expiry in April, 1917.

The quantity of the various cobalt products upon which the bounty was paid was as follows:

oxide	1,209	long tons
metal	203	" "
sulphate	38	" "
stellite	53	" "
carbonate	3	" "
hydroxide	3	" "

Courtesy Deloro Smelting and Refining Co. Ltd., Deloro, Ont.

FIGURE X. Plant of Deloro Smelting and Refining Company, Limited, at Deloro, Ontario.

TABLE 8

BOUNTIES PAID UNDER THE METAL REFINING BOUNTY ACT, 1907-1917

Company	Cobalt	Nickel	Total
	$ cts.	$ cts.	$ cts.
Deloro Smelting and Refining Co., Ltd........	48,930 93	8,166 96	57,097 89
Coniagas Reduction Co., Ltd................	67,174 99	27,539 01	94,714 01
Metals Chemical, Ltd......................	9,577 60	6,766 04	16,343 65
Canadian Smelting & Refining Co., Ltd.......	1,026 05	681 84	1,707 89
Standard Smelting and Refining Co., Ltd.....	214 92	....	214 92
Dominion Refineries, Ltd..................	62 59	....	62 59
	$126,987 08	$43,153 85	$170,140 95

As may be seen from the foregoing table several new cobalt refineries came into being during the term of the Act although it cannot be claimed that the bounty was the main cause but rather the large rise in production of silver and cobalt ores.

In 1907, the Coniagas Reduction Company, Limited commenced the erection of a smelter at Thorold, Ontario, a site chosen because of the abundant cheap power available in the Niagara Peninsula. Smelting commenced in May, 1908 on ores from the Coniagas Mine at Cobalt. The company produced refined silver, cobalt metal, cobalt oxide, nickel oxide, and white arsenic. The plant closed down in 1925.

During the early part of 1911 the plant of Canadian Smelting and Refining Company, Limited, at Orillia, Ontario commenced the production of refined silver, white arsenic and mixed cobalt-nickel oxide. Capacity of the plant was 13 tons of ore per day. The plant was destroyed by fire in 1913, rebuilt in 1914 and closed down shortly afterwards.

Dominion Refineries, Limited at North Bay entered the field of cobalt oxide recovery in 1912. This company went into bankruptcy and the smelter was taken over by the Standard Smelting and Refining Company, Limited during 1914. The plant was moved to Orillia in 1915 and closed down in 1916.

Metals Chemical, Limited erected a plant during 1913 at Welland, Ontario. It had a capacity of 30 tons of ore per day and the products were refined silver, cobalt oxide, cobalt carbonate, cobalt sulphate, nickel oxide, nickel sulphate, and white arsenic. This plant was sold in March, 1920 to Ontario Smelters and Refiners Company, Limited, who operated the plant until 1922 when it closed down.

After the Coniagas plant at Welland was closed in 1925, the Deloro Smelting and Refining Company, Limited at Delora, Ontario remained as the only smelter in Canada capable of treating the Cobalt, Ontario ores. This plant operated on ores and residues from Cobalt, Ontario and residues from the refining of radium ores at Port Hope, Ontario until the outbreak of World War II in 1939. Prior to 1939 only very minor amounts of foreign cobalt ores and residues had been treated in Canada, but in order to assure a continued supply of refined cobalt from the copper-cobalt-iron alloy residues of the Northern Rhodesian copper mines, it was decided to treat these residues at the Deloro smelter. The Deloro smelter erected a new plant which commenced production in 1940. The residues from Africa contained about 40 per cent cobalt as compared with 10 per cent in the ores from Cobalt, Ontario, and

Courtesy Deloro Smelting and Refining Co. Ltd., Deloro, Ont.

FIGURE XI. Research Laboratory of the Deloro Smelter.

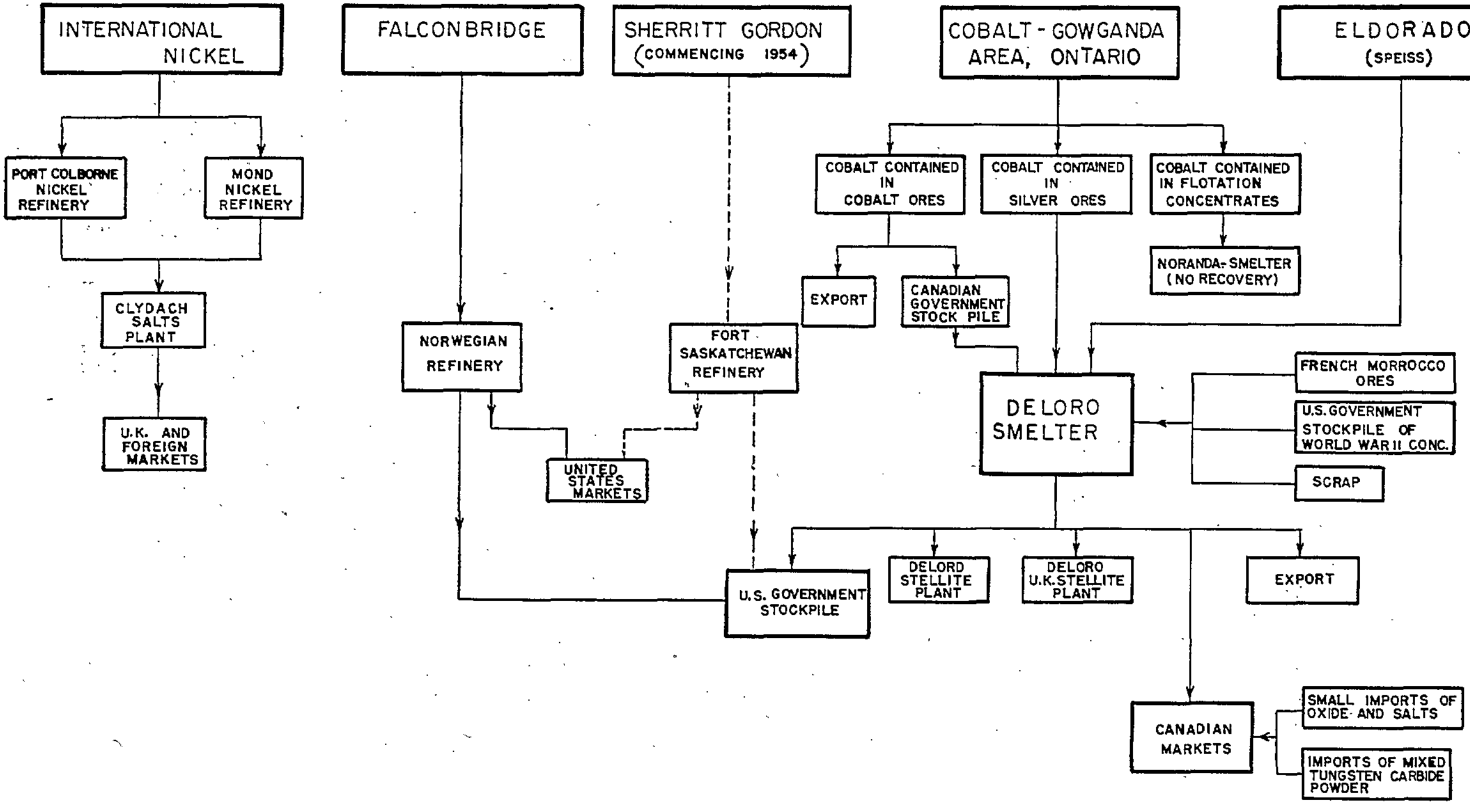


FIGURE XII. FLOW OF COBALT IN CANADA, OCTOBER 1953

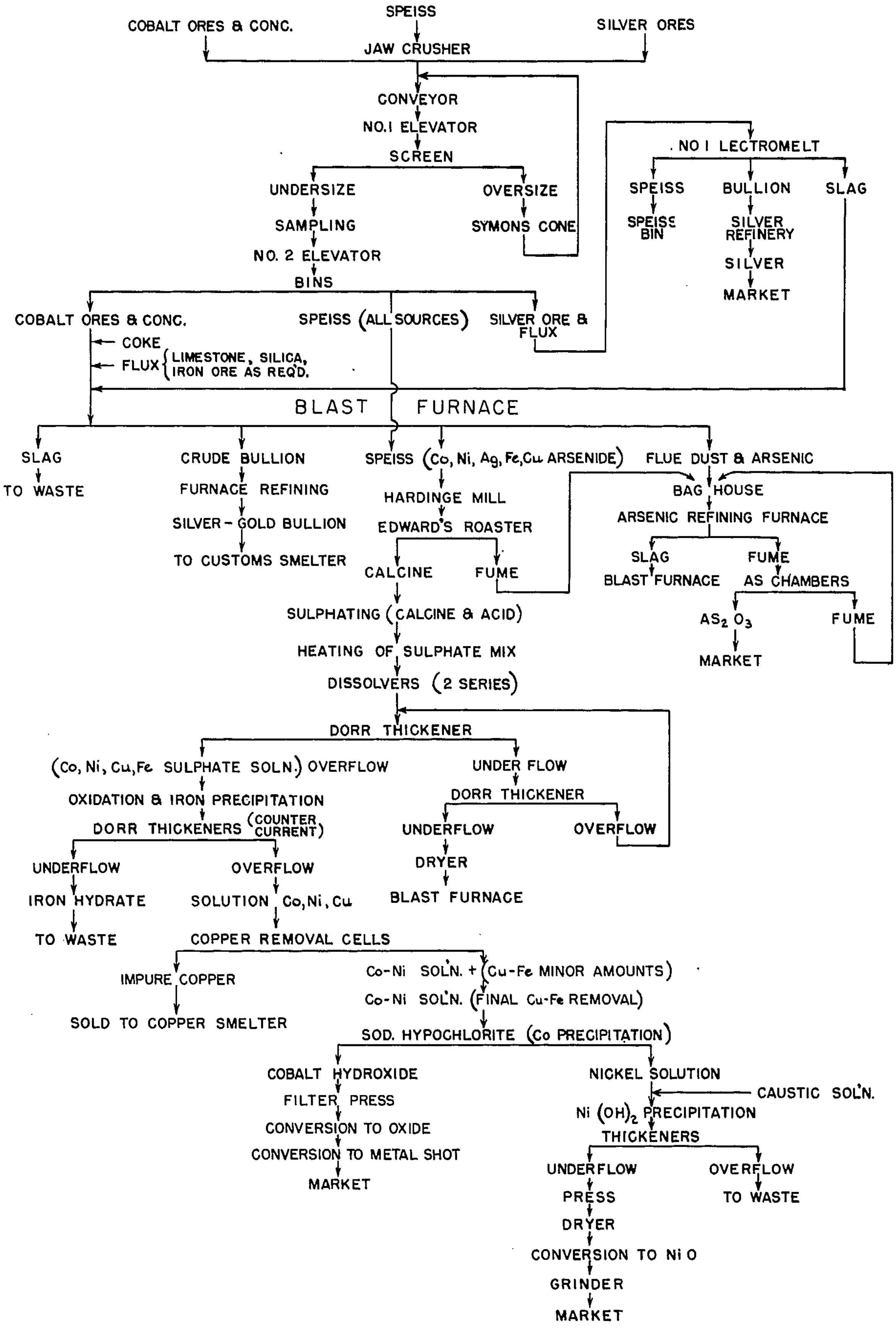


FIGURE XIII. FLOW SHEET OF PROCESS USED BY DELORO SMELTING & REFINING CO. LTD., DELORO, ONTARIO AS AT NOVEMBER, 1953.

no arsenic. In 1940 the Deloro smelter changed its whole plant over to the treatment of Northern Rhodesian residues because the supply of cobalt ores and concentrates from Cobalt, Ontario was not sufficient to keep the plant operating at capacity. Rhodesian supplies were augmented by imports of a similar alloy from the Belgian Congo. The Deloro smelter continued operating on these materials until May, 1946, when imports ceased and production ended in 1947. The Deloro smelter then commenced to draw from its stockpile of Canadian concentrates and in 1948 arranged a contract to treat ores from French Morocco containing about 9-12 per cent cobalt, 50 per cent arsenic and a little gold. This contract is still in effect.

In 1952 the Deloro smelter also entered into a contract with the United States Government for the treatment of Canadian ores and concentrates which were mined at Cobalt, Ontario during 1942-1944, purchased by the Metals Reserve Company of the United States Government, and moved from Deloro to New Jersey in 1947 and 1948. They were returned to Canada in 1952 and 1953 for this purpose.

Quebec Metallurgical Industries, Limited are at present engaged in the rehabilitation of the smelter which was operated by Cobalt Chemical and Refining Company, Limited 5 miles south of Cobalt, Ontario, and destroyed by fire in April, 1950. Unfortunately nothing is available as to the plans and metallurgical processes of the company.

Deloro Smelting and Refining Company, Limited

Modern treatment of Ontario and Moroccan cobalt ores is carried out at Deloro Smelting and Refining Company, Deloro, Ontario.

Typical analyses of cobalt bearing materials processed are as follows:

—	Canadian Cobalt Ores	French Moroccan Ores	Canadian Silver Ores
Ag (oz. per ton)	100–900	6·7	2500·0
Co %	11·3	9·6	5·56
Ni %	9·0	0·33	0·92
Cu %	0·90	0·11	0·13
Fe %	6·00	1·8	20·8
As %	31·0	43·0	11·5
S %	10·0	1·7	3·0
SiO_2 %	10·7	27·5	19·4
CaO %	3·5	4·5	9·3

Ores are crushed in jaw and cone crushers to $\frac{1}{2}$-inch and sampled by a Vezin sampler which cuts about sixty pounds from a fifty ton lot.

The crushed ore and concentrate are charged to a 36 x 72-inch Traylor blast furnace with coke, iron scrap, limestone, or silica as required. Arsenic fume and dust are collected in a bag house and purified by sublimation in a small reverberatory type furnace to yield 99 per cent As_2O_3 and a residue of silver, cobalt, lead and nickel, returnable to the blast furnace.

The slag runs continuously from the furnace on to an inclined bucket conveyor delivering to waste. Slag percentage composition is approximately 26·5 SiO_2, 13·0 Fe, 20·0 CaO, 12·0 Al_2O_3, 7·0 MgO with under 1 per cent Co plus Ni. Speiss, matte, and bullion are tapped together into pots to separate into layers, bullion on the bottom, speiss next, matte on top. On cooling, the layers can be broken apart and separated.

The bullion is fluxed and air blown in an oil-fired Schwartz furnace to remove arsenic, sulphur, lead and copper to yield silver 998 fine or silver-gold bullion suitable for electrolytic separation of silver and gold.

The speiss and small amount of matte are crushed and ground to minus 80 mesh for roasting in an oil-fired Edwards roaster to eliminate arsenic and sulphur and oxidize the iron at 650-750°C.

The roasted speiss containing 10-12 per cent As as arsenate, 2·5 Cu, 23 Co, 9 Ni, 21·5 Fe, 8·6 S and 700-1,000 ozs. Ag is mixed with water and sulphuric acid to convert the cobalt, nickel, copper and iron to water soluble sulphates. Solution of the sulphated material is carried out in mechanical agitators which discharge to Dorr thickeners. The solids are returned to the smelter while the solution passes to the iron-arsenic removal tanks comprising first oxidation of the iron by sodium chlorate, followed by neutralization with lime to a pH of 3·5 to precipitate ferric arsenate, ferric hydroxide, and calcium sulphate. Copper remains in solution if the pH does not exceed 3·5.

The iron precipitate is washed in Dorr thickeners counter currently and discarded. Copper is next removed by scrap iron or in electrolytic cells. In either case the residual iron and copper in the solution are removed by lime precipitation. The pulp is filtered in pressure filters, the filter cake being re-treated for cobalt recovery and the solution containing cobalt and nickel, passes to the final stage of cobalt precipitation. Cobalt separation depends on the fact that in neutral solutions cobalt is more readily oxidized than nickel. The oxidized cobalt compound hydrolyzes and precipitates, leaving nickel in solution.

Oxidation and precipitation is effected by sodium hypochlorite to yield, first pure $Co(OH)_3$ and then a mixed hydroxide of $Co(OH)_3$ and $Ni(OH)_3$ which are recirculated.

The cobalt precipitate is filter-pressed, the solution going to the nickel recovery plant and the cobalt hydrate heated to convert to oxide. Soda ash is also added to convert sulphur to Na_2SO_4 which is removed by washing.

The washed oxide is mixed with charcoal and reduced to metal fines in an oil-fired rotary kiln at 1,000°C. The metal fines are then melted in an electric furnace and granulated in water.

TABLE 9

PRODUCTS OF THE DELORO SMELTER

	Form of Cobalt			
	Metal	Black Oxide	Grey Oxide	Sulphate Amorphous
	Composition—Per cent			
Co	98·3–98·6	70–71·5	75–76	35–36
Ni	0·65–0·75	0·9–1·2	1·0–1·3	0·5–1·5
Fe	0·30–0·50	0·3–0·7	0·4–0·8	0·4–1·0
Cu	0·03–0·05	0·02–0·03	0·03–0·04	
Mn	0·08–0·12	0·15–0·18	0·16–0·18	
Si	0·09–0·11			
	0·03–0·15C	0·1–0·2S	0·2–0·3S	1·2% water insol.
		0·3–0·5CaO	0·4–0·6CaO	

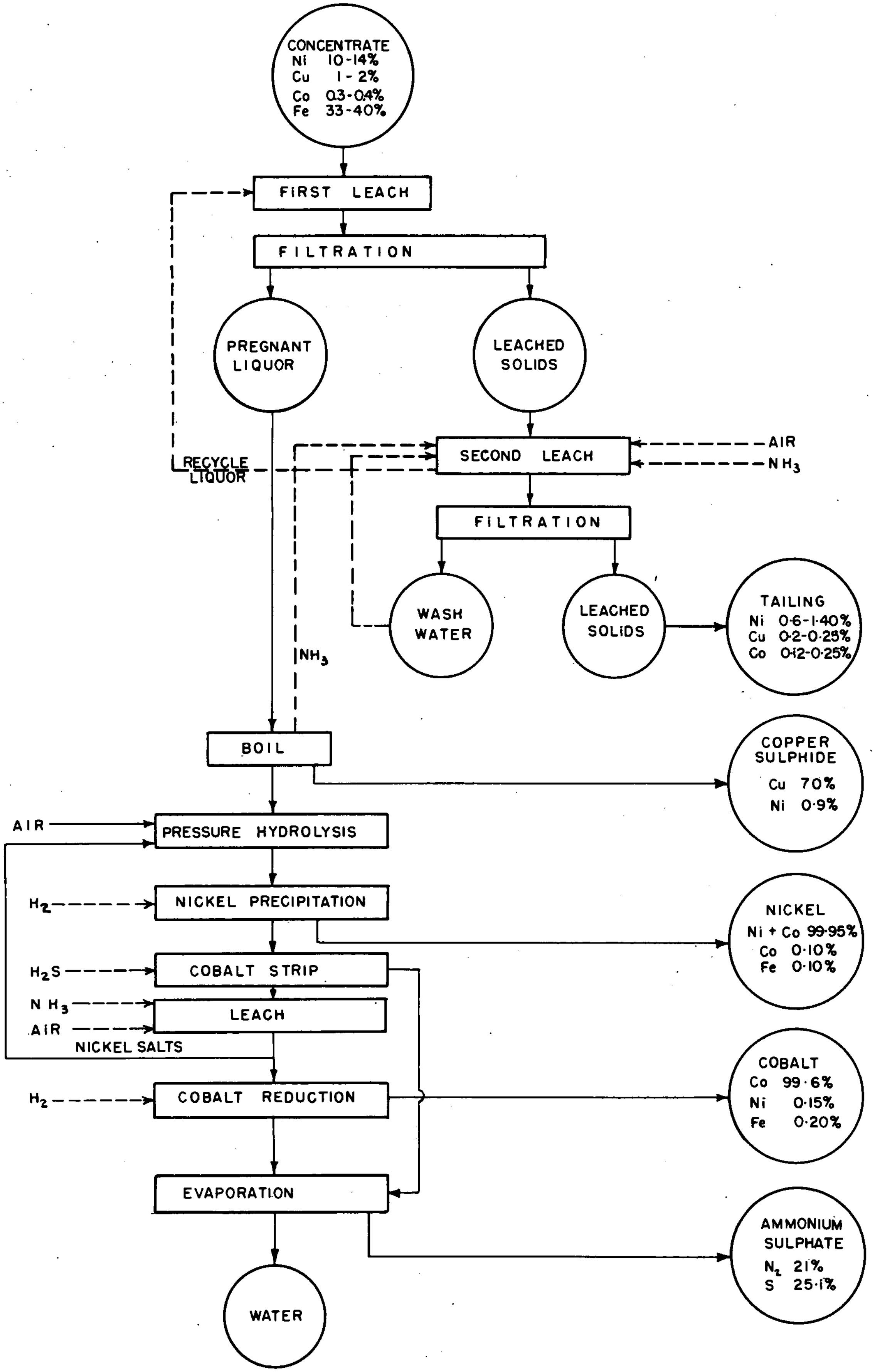


FIGURE XIV. FLOW SHEET OF PROCESS USED BY SHERRITT GORDON MINES. LTD., FORT SASKATCHEWAN, ALBERTA.

Sherritt Gordon Mines, Limited

The nickel-copper-cobalt concentrate from the Lynn Lake concentrator will be shipped by rail to the refinery at Fort Saskatchewan. A novel process is used to separate the valuable metals. The concentrate is leached in two stages at a temperature between 150°F. and 220°F. and under a pressure of less than 125 pounds per square inch. The leached solids are filtered and sent to waste.

The pregnant liquor from the leaching operation is boiled in a still to remove some of the excess ammonia and with the resultant effect of precipitating the copper as a sulphide.

The remaining liquor is then heated under pressure in the presence of air. Precipitation of the nickel then takes place by agitating the liquor with hydrogen in high pressure autoclaves. The nickel salts react with hydrogen more readily than do cobalt salts. The nickel is removed from the circuit as small particles of from 50 to 80 microns in diameter.

The remaining solution which contains about 95 per cent of the cobalt is treated with H_2S to precipitate the cobalt and the rest of the nickel. The cobalt-nickel precipitate is leached with NH_3 and air, the cobalt is removed and reduced with hydrogen under pressure to metallic cobalt powder. The residual nickel is returned to the nickel circuit for further treatment and recovery.

The final solution is evaporated to produce ammonium sulphate.

Between 50 and 75 per cent of the cobalt is recovered by the process. The cobalt powder runs 99·6 per cent cobalt with 0·15 per cent nickel and 0·20 per cent iron.

PORT COLBORNE FLOW SHEET

IMPURE ANOLYTE FROM NICKEL ELECTROLYSIS

↓

PRECIPITATION AND REMOVAL BY FILTRATION OF IRON, LEAD, ARSENIC.

↓

PRECIPITATION AND SEPARATION OF COBALT AS MIXED HYDRATE OF COBALT AND NICKEL

↓

REDUCTION AND RESOLUTION

↓

PRECIPITATION AND REMOVAL BY FILTRATION OF IRON AND COPPER

↓

PRECIPITATION AND REMOVAL OF COBALT AS HYDRATED OXIDE

↓

CALCINATION TO BLACK COBALT OXIDE

↓

TO CHEMICAL SALTS PLANT OF MOND NICKEL CO., LTD., CLYDACH

CLYDACH FLOW SHEET

RESIDUE FROM NICKEL REFINING PROCESS

↓

LEACHING PROCESS, COPPER REMOVED AS RESIDUE, MOST OF COBALT GOES INTO SOLUTION

↓

COPPER BEARING RESIDUE LEACHED FOR RECOVERY OF COPPER FOR PRODUCTION AS COPPER SULPHATE

↓

RESIDUE FROM ABOVE RETREATED FOR RECOVERY OF REMAINING COBALT

↓

COBALT BEARING SOLUTION TREATED FOR IRON ELIMINATION BY PRECIPITATION AND FILTRATION

↓

COBALT PRECIPITATION

↓

CRUDE COBALT CAKE

↓

TO CHEMICAL SALTS PLANT

FIGURE XV. FLOW SHEET OF COBALT PRODUCTION OF INTERNATIONAL NICKEL COMPANY OF CANADA LIMITED.

TABLE 10

COBALT CONSUMED IN UNITED STATES, 1946-1952, BY USES, IN POUNDS OF COBALT

Use	1946	1947	1948	1949	1950	1951	1952
Metallic:							
High speed steel	224,049	223,148	289,391	283,496	235,227	316,064	208,957
Other steel	201,949	386,354	503,082	472,193	252,885	79,885	104,014
Permanent-magnet alloys	1,463,539	1,016,147	1,352,371	1,194,920	2,834,040	2,052,042	1,664,842
Soft-magnetic alloys	....	....	....	42,965	37,552	58,652	18,727
Cast cobalt-chromium-tungsten molybdenum alloys	526,504	642,452	826,329	928,528	2,226,199	4,899,591	6,414,352
Alloy hard-facing rods and materials	53,874	71,545	116,313	82,965	260,371	575,268	505,132
Cemented carbides	45,100	51,917	85,314	118,522	136,935	297,751	610,750
Other metallics	81,988	99,476	115,255	116,344	208,574	276,222	132,730
Total Metallic	2,597,003	2,491,039	3,288,055	3,239,933	6,191,783	8,555,475	9,659,504
Nonmetallic							
Ground-coat frit	412,766	607,316	613,745	424,051	683,358	448,983	308,217
Pigments	170,662	207,928	232,725	188,606	262,441	50,073	75,582
Other Nonmetallics	39,596	51,439	66,699	84,336	43,826	60,462	42,410
Total Nonmetallic	623,024	866,683	913,169	696,993	989,625	559,518	426,209
Salts and Driers (Estimate)	885,000	797,000	818,000	765,000	1,102,000	818,000	701,000
Grand Total	4,105,027	4,154,722	5,019,224	4,701,926	8,283,408	9,932,993	10,786,713

CHAPTER VII

CONSUMPTION AND USE

The main cobalt consuming countries in the free world are the following, in order: (1) United States, (2) United Kingdom, (3) Germany, (4) France, (5) Japan, (6) Sweden and (7) Canada.

An indication of the breakdown of world consumption according to uses of cobalt may be had by an examination of the United States consumption in Table 10. The United States consumes over one-half of the free world supply. In the period 1949 to 1952, consumption in the United States increased by well over 100 per cent. It will be noted that the largest increase was in the cobalt-chromium-tungsten-molybdenum alloys, consumption of which increased to about 7 times that of 1949. However the decrease in consumption of non-metallic salts and driers may be due to the effect of Control Order M-10 issued by the United States National Production Authority effective February 1, 1951. By this order the consumption of cobalt was placed under allocation, inventories were limited and certain uses prohibited. Prohibited uses are mainly reflected in the consumption of cobalt in the form of oxide, salts and driers.

Statistics on the consumption of cobalt in Canada are not available. However from an examination of allocations of cobalt to Canada by the International Materials Conference during 1952, domestic consumption is apparently in the neighborhood of 150 tons of contained cobalt per year. Most of the domestic supply for consumption comes from Deloro Smelting and Refining Company, Limited. Some cobalt is imported in the form of metal, oxides and salts by the ceramic and drier trade. In addition, the Canadian producers of tungsten carbide products import mixed tungsten carbide powder, chiefly from the United States, which contains from 3 to 25 per cent cobalt.

High Temperature Alloys

A striking feature of the alloys used in high temperature applications is the amount of cobalt, nickel, chromium, molybdenum and tungsten employed in their manufacture. Most of the cobalt supply is consumed in this field, which is continually widening its applications. It is reasonable to expect that with the increasing speeds required of military aircraft, guided aircraft and rockets, more cobalt will be directed into this use.

The first cobalt-base high temperature alloy used for gas turbine blading, etc. was a modification of vitallium, a dental alloy.

Both the turbine wheel blades and nozzle guide vanes of a modern jet engine are subject to temperatures as high as 1500-1600 degrees F., and to hot expanding gases, while the blades also undergo high stresses in transmitting the

TABLE 11

ANALYSES OF SOME COBALT HIGH-TEMPERATURE ALLOYS

Name of Alloy	Co	Cr	Ni	Fe	Mo	W	Mn	Si	Cb	C	Other Elements	
Refractalloy 26	20	18	38	16	3·2	....	0·8	1·0	....	0·03	Ti 3·0	Al 0·2
Stellite 27	30	26	36	1	6·0	....	0·5	0·4	....	0·42		
Stellite 30	51	26	15	1	6·0	....	0·5	0·4	....	0·42		
Stellite 21	64	26	2	1	5·5	....	0·3	0·6	....	0·2		
Nimonic 90	18	18	62	1	....	....	....	....	....	0·1	Ti 2·0	Al 1·5
Vitallium	64	27	2	2	5·0	....	0·3	0·25	....	0·3		
Multimet	20	20	20	30	3·0	2·0	1·0	0·5	1·0	0·15	N 0·14	
K-40	54	25	10	0·6	....	7·0	....	....	....	0·5		
Low-carbon N-153	13	16	15	48	3·0	2·0	1·50	0·5	1·0	0·15	N 0·14	
S-816	41	20	20	4	4·0	4·0	1·5	0·6	4·0	0·37		
K-42B	22	18	42	14	....	....	0·7	0·7	....	0·03	Ti 2·1	Al 0·2
N-155	20	21	20	30	3·0	2·5	1·5	0·6	1·0	0·12	N 0·15	
G-32	45	19	12	15	2·0	....	....	....	1·2	0·30	V 2·8	
S-590	20	20	20	27	4·0	4·0	1·5	0·6	4·0	0·43		

Courtesy *A. V. Roe Canada Limited, Malton, Ont.*

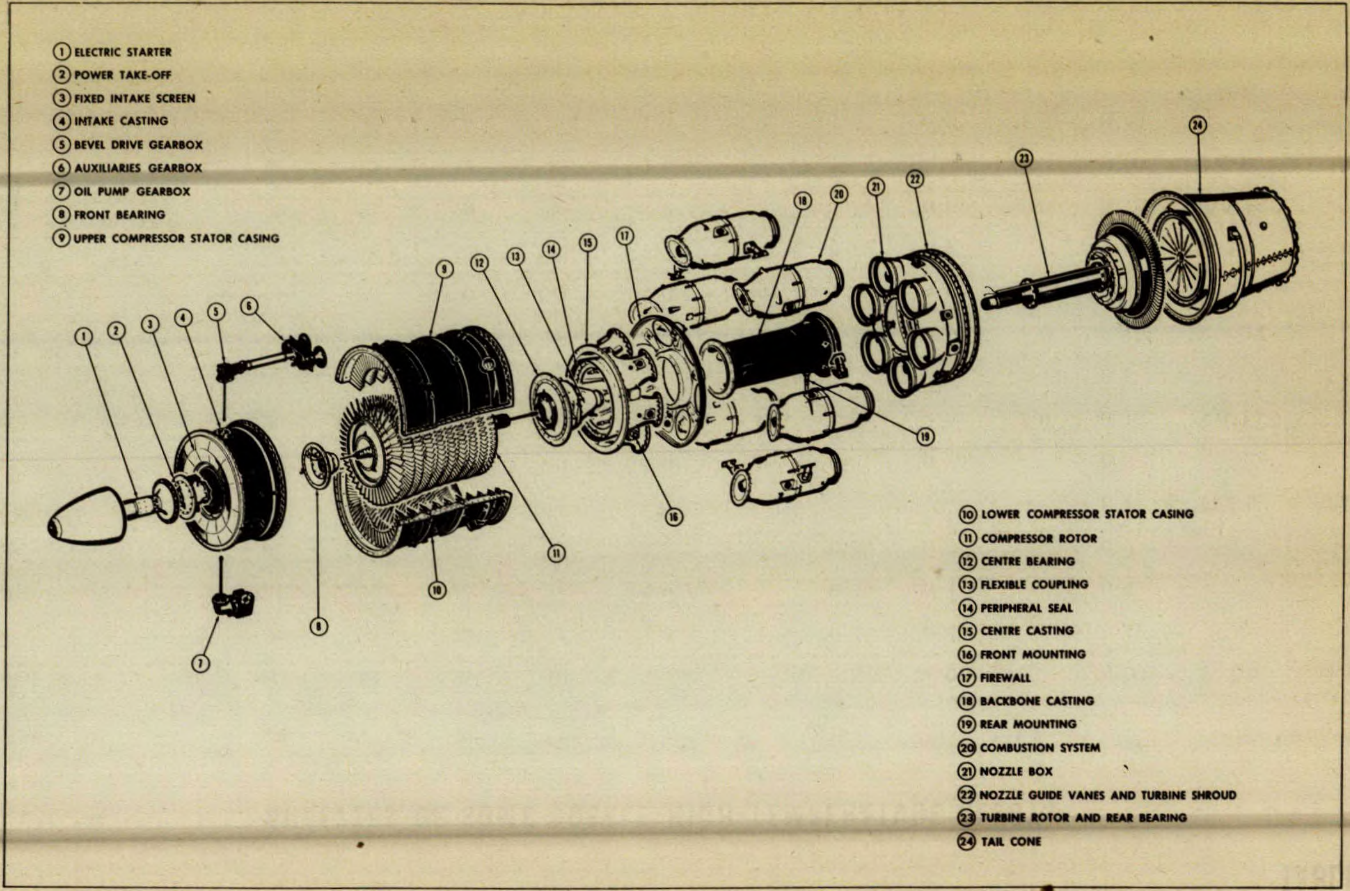


FIGURE XVI. Exploded view of an Orenda turbo-jet engine.

Courtesy A. V. Roe Canada Limited, Malton, Ont.

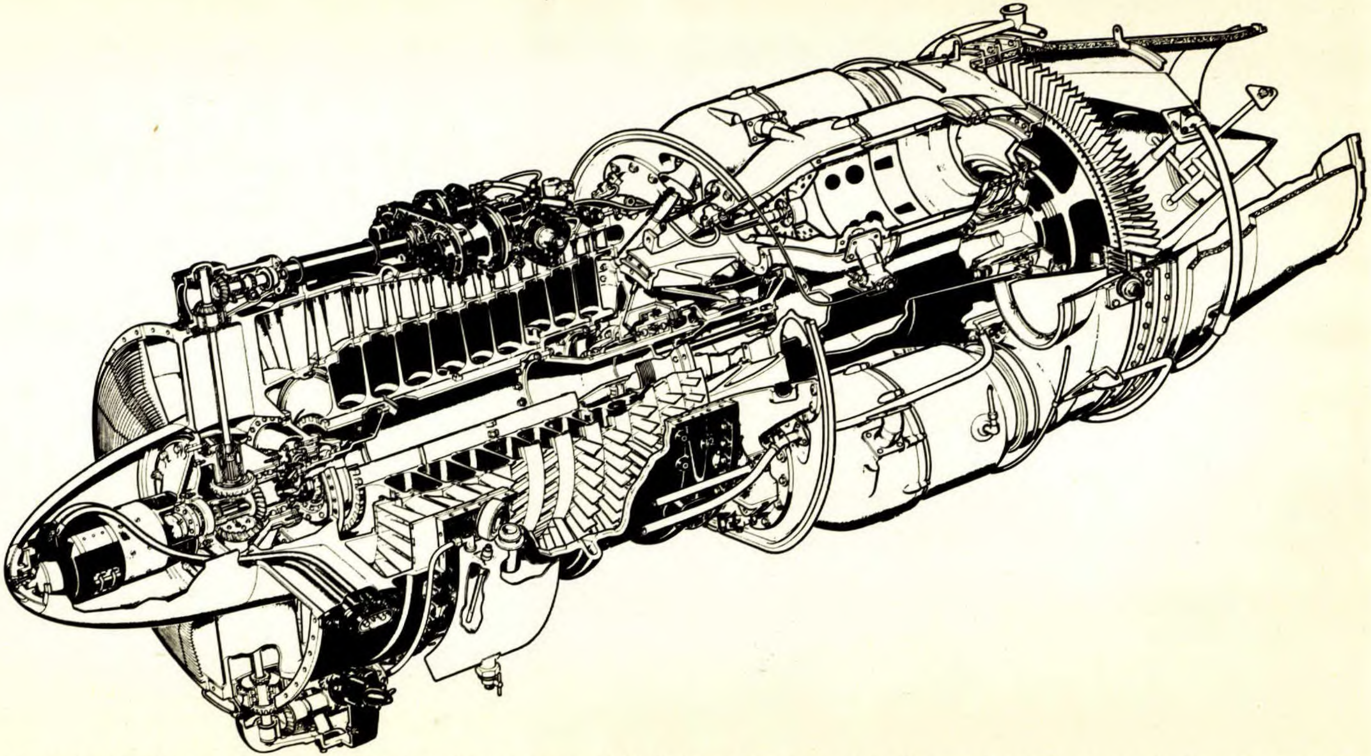


Figure XVII. Cross-section of an Orenda turbo-jet engine. Cobalt-base alloy is used in the nozzle guide vanes. Each engine contains about 27 pounds of cobalt.

Courtesy Deloro Smelting and Refining Co. Ltd., Deloro, Ont.

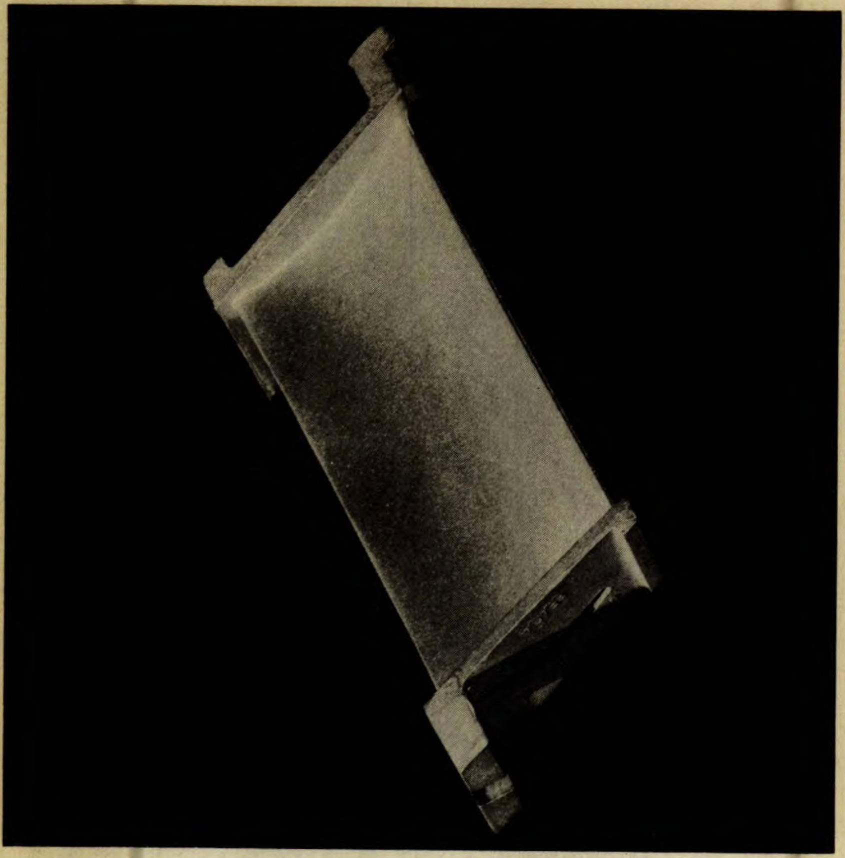


FIGURE XVIII. Nozzle guide vane for Orenda turbo-jet engine.

power to the turbine wheels which, in some cases, rotate at speeds up to 10,000 r.p.m. Such parts as the linings of the combustion system and nozzle box, and the tail cone are also subjected to high temperatures.

Turbine blades are manufactured by forging, by sintering metal powders and by the precision or investment casting method depending upon the alloy used.

Due to the ease of manufacture, elimination of machining operations, and low scrap loss in the investment casting method, mass production of blades and certain other components is carried out by this process. It is an adaptation of the lost wax process which has been practiced on other metals and alloys for centuries. The first step in the process is to make a master pattern of steel or some other metal. From this pattern the expendable patterns of wax or plastic are made and placed in a very fine refractory slurry. The assembly of pattern and feeders are placed in a cylinder which is then filled with refractory material. The refractory material is allowed to cure and the molds are then placed in a furnace which causes the wax or plastic pattern to evaporate, leaving a well-defined and clean cavity in the mold.

The molds are pre-heated and the molten alloy is then poured into the mold by static, centrifugal or pressure means. After a controlled cooling period the ceramic material is removed and the gates sawn or ground from the casting. The casting is then cleaned by sand blasting or a caustic base salt bath and inspected by radiograph.

The Deloro Smelting and Refining Company Limited, Deloro, Ontario, manufactures a wide range of cobalt-base products by the investment casting method both for high-temperature and other uses. Among their products are nozzle guide vanes for jet engines, cams, valve rotors, extrusion die inserts, die cores and components for small arms.

Stellites

Stellites are a group of cobalt-chromium-tungsten alloys containing about 2 per cent carbon together with a small amount of silicon and iron. Chromium imparts hardness and strength, tungsten gives red hardness and cobalt renders stellite more resistant to oxidation.

Stellite is produced by melting cobalt, chromium and tungsten metal in an electric furnace together with the required quantity of carbon. In order to obtain the required crystal structure the metal is cast into graphite molds which causes the stellite to cool rapidly. Any further work required on the cast alloy is done by grinding.

In Canada, stellite is produced by Deloro Smelting and Refining Company, Limited who supply three types of welding rod chiefly used for hard facing. The application of stellite on a metal surface is carried out with either an oxy-acetylene torch or electric arc. It is used for the surfacing of such equipment as drill chucks, drill sharpening dies, dipper teeth, bucket lips, pump shafts and sleeves and other parts of machinery which are subject to rapid wear.

Another grade of Deloro stellite is used in the manufacture of high speed cutting tools and cutting tool bits for machining cast iron and steel.

Permanent Magnets

Two types of permanent magnets are in use today, namely the magnet steels which contain carbon as a hardening constituent, and the more recent magnet alloys which are free from carbon.

Commercial types of magnet steels contain from 8 to 41 per cent cobalt, 1 to 9 per cent tungsten, 2 to 9 per cent chromium, 0·30 to 0·90 per cent manganese and carbon up to 0·90 per cent. Magnet steels are generally made in a similar manner to tool steels.

Tungsten steels were used as magnets in the early part of the century but were replaced with chromium steels during World War I due to the high price of tungsten at that time. In 1916 it was discovered that by replacing part of the iron in a tungsten magnet steel with cobalt, a much better permanent magnet material could be produced. This led to the development of the cobalt magnet steels which produced much stronger magnets than those used before and permitted the use of smaller magnets.

Until the early 1930's this type of magnet was used almost exclusively, when it was found that certain carbon-free permanent magnet alloys were even stronger than the cobalt magnet steels. The first of these alloys was "Alnic" which contained no cobalt, only iron, nickel and aluminum. This alloy was developed into the "Alnico" group by the replacement of part of the nickel with cobalt. It was then found that by increasing the cobalt content still further and adding a little copper, the coercive force could be increased further; this resulted in Alnico 2. From these initial alloys a whole series of Alnico magnets were developed. They are now made by the sintering process and the precision-cast process.

Courtesy Deloro Smelting and Refining Co. Ltd., Deloro, Ont.

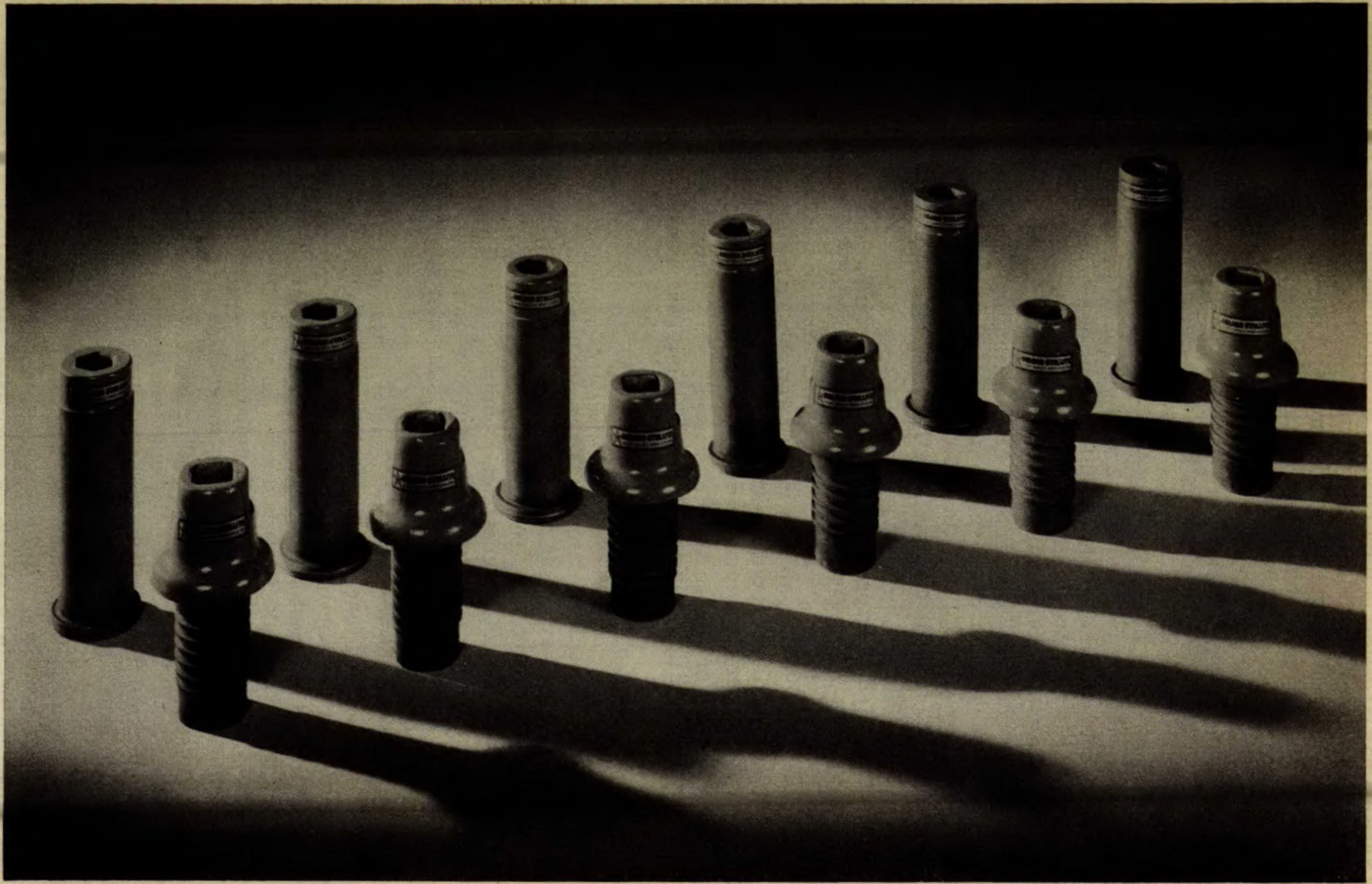


Figure XIX. Worn bores of drill chucks rebuilt with Stellite facing.

Courtesy Deloro Smelting and Refining Co. Ltd., Deloro, Ont.

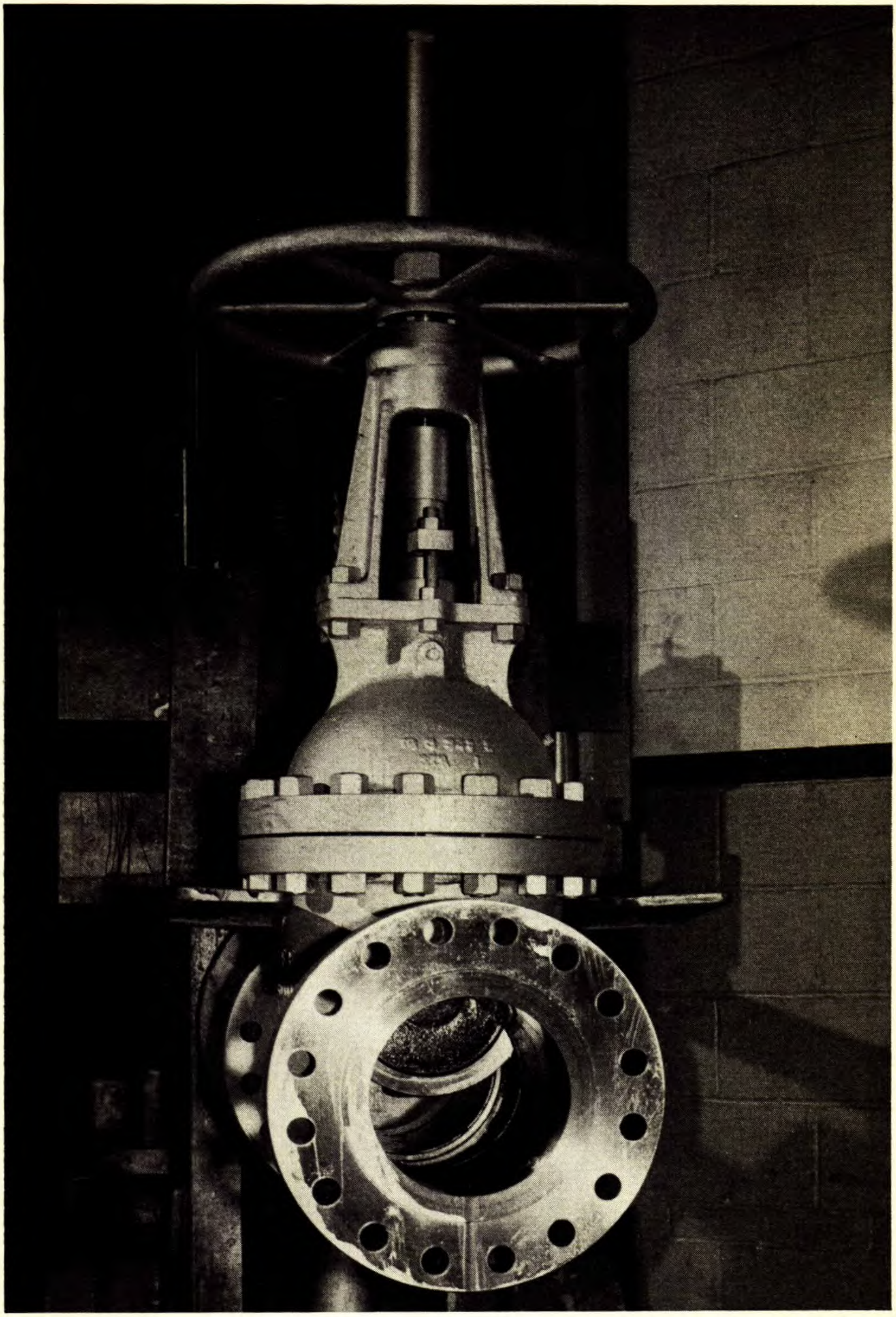


Figure XX. Discs and rings of an 18-inch valve for oil pipe line, faced with Stellite.

TABLE 12

COMPOSITION AND HARDNESS OF DELORO COBALT BASE ALLOYS

Designation	Composition—Per cent								Rockwell "C" Scale
	Co	Ni	Cr	W	Mo	Fe	C	Si	
No. 1 Welding Rod	50·0	....	33·0	13·0	....	2·0	2·0	1·0	54–56
No. 6 " "	64·0	....	25·5	4·7	....	2·5	1·0	1·7	39–42
No. 12 " "	58·0	....	29·0	9·0	....	1·5	1·8	1·5	48–51
Cutting Alloys (Grade 100)	42–48	....	30–35	15–19	....	1·5	1·75–2·5	1·5	59–68
Grade 4	50–65	....	28–32	5–15	....	1·5	0·75–1·25	1·0	45–50
Alloy "C"	....	Bal.	17·5	5·0	17·0	5·5	0·20	0·80	....
Delfer	16·5	0·50	13·50	5·50	8·70	52·50	2·50	0·80	55–60
Dental	58·0	6·0	29·0	....	5·0	0·80	0·40	0·30	30–32

TABLE 13

PHYSICAL PROPERTIES OF DELORO STELLITE ALLOYS

Alloy Designation	Grade 1	Grade 12	Grade 6	Grade 100	Grade 4
Yield Strength—p.s.i.	....	....	....	....	....
Tensile Strength—p.s.i.	79,550	95,400	118,300	60,700	....
Elongation—%	0	0	1–2	0	0–1·0
Hardness—Rockwell "C"—Graphite Cast	59	54	44	66	50
Sand Cast	56	51	42	62	47
Density lb./cu in.	0·315	0·303	0·303	....	....
Specific Gravity	8·50	8·43	8·39	8·70	....
Melting Point °C.	1250	1263	1275	1290	....
Specific Heat, Cal per Deg. C	0·0983	0·0978	0·1010	....	....
Thermal Exp. Coeff. x 10^{-5}/deg. C. 25–100°C	1·09	1·15	1·29	....	....
100–200°C	1·11	1·21	1·42	1·37	....
Thermal Conductivity (32–212°F), Btu/sq. ft./hr./°F/in.	....	....	102·7	....	....
Electrical Resistivity (25°C) Ohms per cm. cube	94 x 10^{-6}	88 x 10^{-6}	84 x 10^{-6}	111 x 10^{-6}	87 x 10^{-6}
Young's Modulus of Elasticity x 10^6 p.s.i.	34·95	....	30·4	40·95	32·27
Torsional Modulus of Elasticity x 10^6 p.s.i.	13·8	....	12·75	....	13·12
Impact—Charpy—Izod Notch—ft. lbs. 20°C	1·08	1·80	2·53	....	1·45
250°C	1·08	1·45	2·90	....	1·80
Electrical conductivity compared to copper at room temperature—%	1·74	1·84	1·85	1·50	....

Courtesy Canadian General Electric Co., Toronto, Ont.

FIGURE XXI. Pouring Alnico magnet alloy from induction melting furnace into a stack of cores.

Canadian General Electric Company, Limited—In 1938 Alnico manufacture was begun in the Peterborough works of the company. It was originally produced for use in the company's watt hour meters only. The company commenced marketing Alnico magnets in Canada in 1941 upon importation from the United States. However due to expanded sales, operations were commenced in Canada and by 1947, all Canadian requirements came from the Quebec works just outside of Quebec City, Quebec.

Courtesy Canadian General Electric Co., Toronto, Ont.

FIGURE XXII. Inspection of precision-cast Alnico magnets.

Cobalt metal is purchased from Deloro Smelting and Refining Company, Limited. The allowable limits on impurities for processing into Alnico are as follows:

CaO	0·35%
Mn (max)	0·12%
Si	0·16%
C	0·15%
S	0·05%
Ni	0·75%
Fe	0·35%
Cu	0·10%
Zn	Trace

The process used by the company is as follows:

Preparation of Molds—Sharp core sand, with synthetic resins as a binder, is shaped on a permanent pattern molding machine and baked. The resultant molds are called "cores".

Courtesy Canadian General Electric Co., Toronto, Ont.

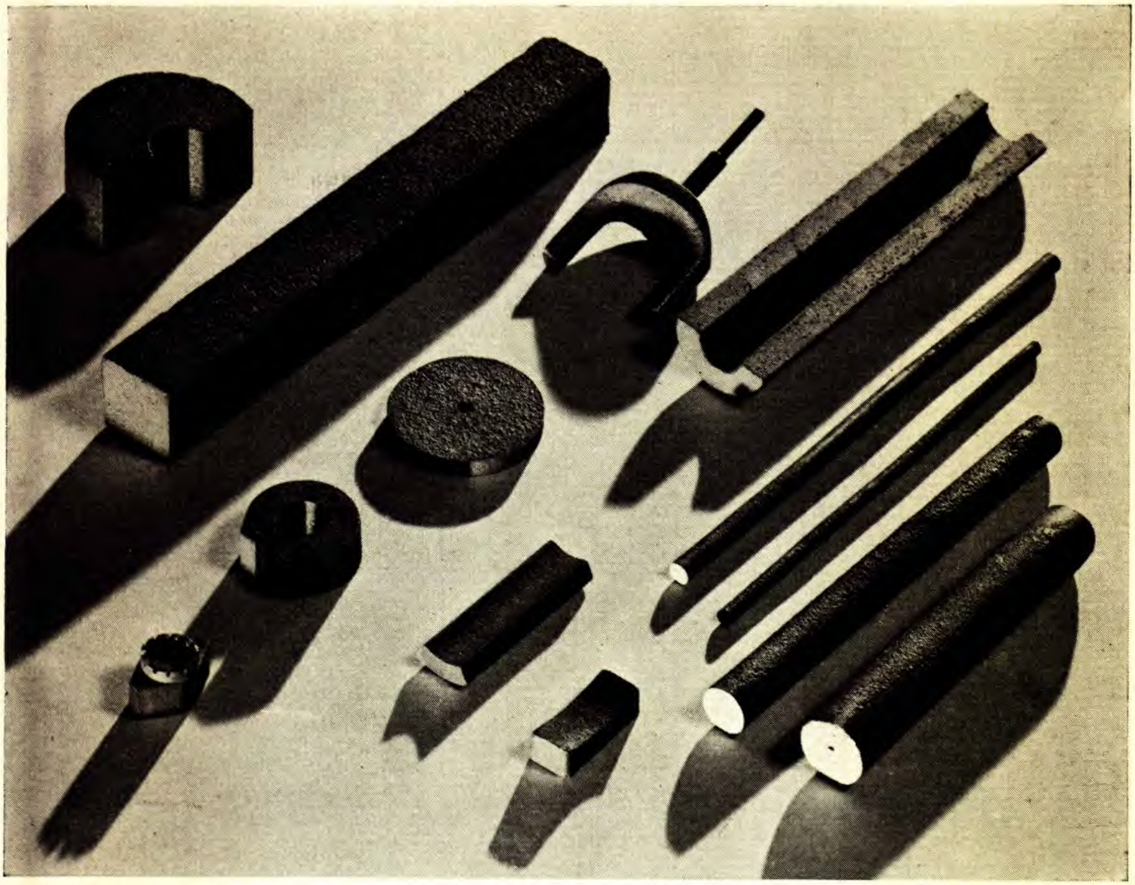


FIGURE XXIII. Precision-cast Alnico magnets.

Melting—The raw materials, cobalt, electrolytic nickel, aluminum and iron, are carefully weighed and placed in a crucible in an Ajax Induction Melting Furnace. Two furnaces are used, one with a capacity of 50 pounds and the other 100 pounds. Melting takes approximately one-half hour and the aluminum is not added until shortly before pouring. The pouring temperature is in the order of 3500°F.

Pouring—Cores are stacked in sufficient numbers to use up a complete heat from the melting furnace and the metal is poured down a central gate, through horizontal sprues and fills the actual mold. A large number of small magnets can be cast in one melt and pour by this method of stacking. Control over the direction of grain growth (directional grain magnets) is obtained by inserting chilling plates so that most of the grain growth occurs from one surface of the magnet.

Heat Treatment—In the heat treatment, theoretically all phases go into solid solution. Heat treatment can be carried out at either 1700°F. or around 2300°F. With the aid of small chemical additions, it is possible to heat treat Alnico 5 at approximately 1700°F. After a soak of about 20 minutes at this temperature, Alnico 5 is transferred from the furnace to water-cooled solenoids and allowed to cool through the Curie point in a magnetic field whose direction is parallel to the direction of final magnetization of the magnets. Magnets

TABLE 14

MAGNETIC PROPERTIES OF PERMANENT MAGNET MATERIALS

Magnet Material	Typical Chemical Composition Percent	Form	Magnetizing Force H max Oersteds	Magnetic Induction B max Gausses	Minimum Residual Induction B_r* Gausses	Minimum Coercive Force H* Oersteds	Minimum External Energy			Maximum Permeability	Commercial Methods of Fabrication
							(BdHd) max*	Occurs at B	Occurs at H		
Carbon Steel........	1 C, 0·5 Mn, Bal. Fe...	Bar..........	300	14,800	8,600	48	180,000	6,000	25	110	Hot Forge, Machine, Punch
Tungsten Steel......	5 W, 1 C, Bal. Fe......	Bar..........	300	14,500	10,300	70	320,000	7,400	50	120	Hot Forge, Cast, Machine, Punch (Thin Sections)
Chromium Steel.....	3·5 Cr, 1 C, Bal. Fe...	Bar..........	300	13,500	9,000	63	290,000	6,000	35	105	Hot Forge, Cast, Machine, Punch (Thin Sections)
36% Cobalt Steel....	36 Co, 3·5 Cr, 3 W, 0·85 C, Bal. Fe	Bar..........	1,000	15,500	9,000	210	936,000	6,300	140	35	Hot Forge, Cast, Machine, Punch
Alnico 1............	12 Al, 20 Ni, 5 Co, Bal. Fe	Cast.........	2,000	12,350	7,100	400	1,300,000	4,200	300	14	Cast, Grind
Alnico 2............	10 Al, 17 Ni, 12·5 Co, 6 Cu, Bal. Fe	Cast.........	2,000	12,600	7,200	540	1,600,000	4,500	365	11	Cast, Grind
Alnico 2............	10 Al, 17 Ni, 12·5 Co, 6 Cu, Bal. Fe	Sintered......	2,000	12,000	6,900	520	1,430,000	4,300	350	12	Sinter, Grind
Alnico 3 (Cross Section under ⅝″ x ⅝″)	12 Al, 25 Ni, Bal. Fe...	Cast.........	2,000	12,000	6,700	450	1,380,000	4,300	320	12	Cast, Grind
Alnico 4............	12 Al, 28 Ni, 5 Co, Bal. Fe	Cast, sintered.	3,000	11,850	5,200	700	1,200,000	3,000	380	6	Cast, Sinter, Grind

Alnico 5	8 Al, 14 Ni, 24 Co, 3 Cu, Bal. Fe	Cast	2,000	15,700	12,000	575	4,500,000	9,050	500	18	Cast, Grind
Alnico 6	8 Al, 15 Ni, 24 Co, 3 Cu, 1·25 Ti, Bal. Fe	Cast	3,000	14,300	10,000	750	3,500,000	7,000	475	11	Cast, Grind
Alnico 12	6 Al, 18 Ni, 35 Co, 8 Ti, Bal. Fe	Cast	3,000	12,800	5,800	950	1,500,000	3,000	500	4	Cast, Grind
Cunife (under 0·155″ diameter)	60 Cu, 20 Ni, 20 Fe	Wire, strip	2,400	8,400	5,400	550	1,500,000	4,000	375	8	Cast, Cold Roll, Machine, Punch
Cunico	50 Cu, 21 Ni, 29 Co	Strip, rod, wire, cast	3,200	8,000	3,400	660	800,000	2,000	400	3·8	Machine, Punch, Cast, Cold Roll
Vectolite	30 Fe_2O_3 44 Fe_3O_4 26 Co_2O_3	Sintered	3,000	4,800	1,600	1,000	600,000	900	670	3	Sinter, Grind
Silmanal	86·75 Ag, 8·8 Mn, 4·45 Al	Rod, strip, sheet	20,000	20,830 † Bi=830	550	550 † Hi=6,000	76,000	275	275	1·11	Cold Roll, Machine, Punch

* Guaranteed minimum values.

† Bi and Hi values are on the basis of intrinsic induction.

TABLE 15

PHYSICAL PROPERTIES OF PERMANENT MAGNET MATERIALS

Magnet Material	Form	General Mechanical Properties	Average Density lbs./cu. in.	Tensile Strength lbs./sq. in.	Transverse Modulus of Rupture lbs./sq. in.	Hardness Rock-well Scale	Coefficient of Thermal Expansion 1° C ($\times 10^{-6}$) $\left\{\begin{matrix}20^\circ\text{ C}\\300^\circ\text{ C}\end{matrix}\right.$	Resistivity Microhms per cm per cm^2 at 25° C	Remarks
Carbon Steel.........	Bar...........	Hard, relatively strong	0·280	....	....	C-60	....	35	High aging and low coercive force offset very low cost except where space permits very large magnets.
Tungsten Steel........	Bar...........	Hard, relatively strong	0·292	....	....	C-65	....	35	Highest Br for lowest cost but generally replaced by chrome steel with slight loss of quality but considerably lower cost.
Chromium Steel......	Bar...........	Hard, relatively strong	0·281	....	....	C-65	....	45	Low cost material for magnets of comparatively good magnetic external energy and uniformity where space or weight is not too limited.
36% Cobalt Steel.....	Bar...........	Hard, relatively strong	0·296	....	....	C-56–64	....	76	Used where good magnetic quality combined with machinability is required, but Alnicos are less expensive.
Alnico 1.............	Cast, grind....	Hard, brittle....	0·249	4,100	13,900	C-45	12·6	75	General purpose grade of cast Alnico having good magnet qualities at reasonable cost.
Alnico 2.............	Cast, grind....	Hard, brittle....	0·256	3,000	7,200	C-45	12·4	65	Better magnetic qualities than Alnico 1 at slight additional cost.
Alnico 2.............	Sintered, grind	Hard...........	0·243	65,000	70,000	C-43	12·4	68	For small or complicated shapes.

Alnico 3 (cross section under $\frac{5}{8}''$ x $\frac{5}{8}''$)	Cast, grind....	Hard, brittle....	0·249	12,000	22,500	C-45	13·0	60	Lowest cost grade of cast Alnico commercially available.
Alnico 4.............	Cast, grind....	Hard, brittle....	0·253	9,100	24,000	C-45	13·1	75	High coercive force grade of low cost Alnico. Used where short magnets are required.
Alnico 4.............	Sintered, grind	Hard, brittle....	0·232	60,000	85,000	C-42	13·1	68	For small or complicated shapes.
Alnico 5.............	Cast, grind....	Hard, brittle....	0·264	5,450	10,500	C-50	11·3	47	Highest external energy and residual flux Alnico. Magnetically directional.
Alnico 6.............	Cast, grind....	Hard, brittle....	0·268	23,000	45,000	C-56	11·4	50	Higher coercive force than Alnico 5, with lower residual induction and external energy. Magnetically directional.
Alnico 12............	Cast, grind....	Hard, brittle....	0·264	39,500	50,000	C-58	11·0	62	Highest coercive force of Alnicos. Should be cast to size as material is very difficult to work.
Cunife (under 0·155 inches in diameter)	Wire, strip.....	Ductile, malleable	0·311	120,000	....	B-73	14·0	22	Good fabricating properties combined with magnetic hardness. Magnetically directional in direction of working.
Cunico..............	Strip, rod, wire, cast	Ductile, malleable	0·300	85,000	....	B-95	14·0	32	Readily workable, highly coercive force alloy.
Vectolite............	Sintered.......	Low strength, brittle	0·113	....	2,600 4,000*	....	8·5	225 x 10^5	High coercive force, low residual, high resistivity material. Light weight. Magnetically directional. Permits short magnets with long air gaps.
Silmanal............	Rod,strip,sheet	Workable........	0·325	....	....	B-95	....	19	Extremely high coercive force and permanency. Low residual and relativity high cost. Limited applicability for special purposes.

* Transverse modulus of rupture when impregnated.

are allowed to cool down to almost room temperature and are then put in a draw furnace for an extended period of time depending upon the size. The time is in the order of one hour at a temperature of 1100°F.

All steps in the heat treatment are of the utmost importance in developing good magnetic properties. In general during the initial heating cycle the aluminum is taken into solid solution and upon cooling to room temperature most of the aluminum stays in solid solution. The re-heating actually produces a form of secondary hardening and results in the controlled precipitation of aluminum particles within the grains.

Products—The company is producing Alnico 1, Alnico 2, Alnico 3 and Alnico 5, and are in a position to produce Alnico 4 and Alnico 6. These magnets are supplied to Canadian customers for radio speakers, watt hour meters, instruments, magnetos, alarm systems, television focussing assemblies, telephones and toys.

High Speed Steel

Cobalt is added to tool steels to increase the strength or hardness of those required to operate at high speed and high temperature, but is not used in various grades of high speed steel where it can be replaced for certain uses by a cheaper additive metal.

Steels required for machining operations, where the temperature of cutting points or edges of the tools exceeds 300°F., are known as high speed steels. When reference is made to that field of tool steel applications known as "hot work", it is intended to include all applications that become heated over 300°F. with the exception of high speed and die block steels. Tool steels required for hot work must have red hardness or resistance to deformation, resistance to wear or erosion at the operating temperature, and resistance to thermal shock when suddenly heated and cooled in operation.

Atlas Steels Limited, Welland, Ontario—This company has manufactured a wide range of tool steels since 1931, including several grades containing cobalt. Prior to 1931 cobalt bearing tool steels were rolled or hammered only at the company's works, the billets being imported.

Cobalt is purchased in the form of rondelles or granules and is added to the electric melting furnace charge or the molten bath. In the application of cobalt to these specialized steels it is important that the cobalt content of the metal be as high as possible with other elements as low as possible. The company supplies such steels as finished toolbits or in the form of bars to be manufactured by users into various forms of tools and dies.

Two cobalt bearing high speed steels manufactured by the company contain the following:

(A)	Co	8·00%	(B)	Co	5·00%
	C	0·78		C	0·75
	Mn	0·25		Mn	0·25
	Si	0·30		Si	0·30
	W	19·00		W	19·00
	Cr	4·00		Cr	4·00
	Va	2·00		Va	1·25
	Mo	0·80			

Type (A) steel is recommended for heavy cuts and feeds at high speeds on hard, gritty or scaly metals as well as for the machining of material such as the austenitic stainless steels, which work harden under any form of stress

Courtesy Atlas Steels Limited, Welland, Ont.

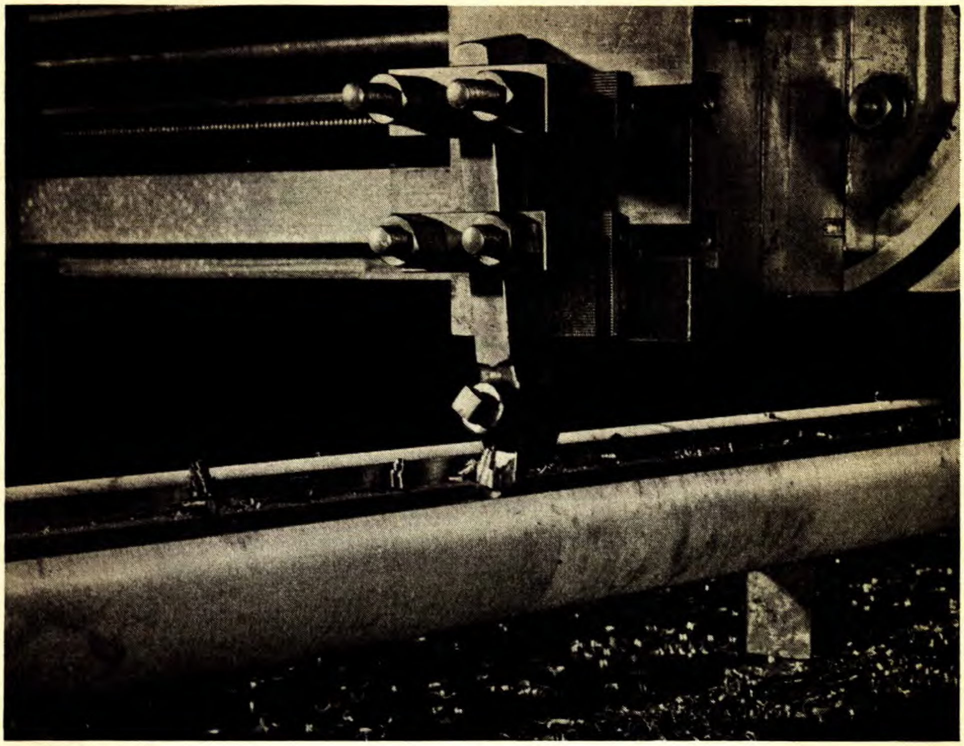


FIGURE XXIV. An 8.00 per cent cobalt tool bit making a deep hogging ⅞-inch cut the full length of a 15-ft. steel bar on a large planer. The heat generated turns the steel chips dark blue, yet the cutting edge of the tool remains sharp even after it becomes visibly red after repeated cuts.

and machining operation. The degree of toughness possessed by this type usually limits its use to single point and single edge cutting tools such as lathe, shaper, and planer tool bits and form cutters.

Typical applications are heavy duty turning, boring, planing, form cutting, and slotting on rough castings, car wheels, locomotive tires, rolls, heat-treated alloy steels and die blocks, and the machining of stainless steels.

Type (B) is designed to supplement Type (A) for heavy duty single point and form cutter applications requiring somewhat better toughness. This additional toughness is obtained at some sacrifice in red hardness. Typical applications are similar to those for Type (A) but Type (B) is preferable for jobs where a cobalt high speed steel is required for a multiple point or a multiple edge cutting tool, such as a milling cutter or hob cutter.

Atlas Steels Limited have developed a series of steels for hot work and typical applications are extrusion dies for brass, bronze, austenitic steels, valve steels, etc., hot forming dies, flat coining dies, hot tie-plate dies and punches, hot shear blades and trimming dies for light sections, glass forming dies, hot nut piercers, hot cut-off tools, spike dies, hot creasers, and die casting cylinder liners.

The company manufactures one cobalt bearing hot work steel which contains the following:

Co	0·50%
C	0·35
Mn	0·30
Si	1·00
W	4·50
Cr	5·00
Va	0·30
Mo	0·30

This steel is especially suitable for extrusion mandrels, accurate jobs such as certain die casting and extrusion dies, and intermittent water-cooled jobs such as shell piercing tips.

Radioactive Cobalt

The radioisotope cobalt 60 is finding an increasing use in the field of industrial radiography and in beam therapy units in the war against cancer.

Courtesy Defence Research Board, Department of National Defence, Canada.

FIGURE XXV. Cobalt 60 and lead container used in industrial radiography.

The main value of these isotopes is the radiation which they emit. In the case of industrial radiography the isotope is placed on one side of the material to be checked such as a weld, forging, casting, etc. and photographic film is placed on the other side. Flaws permit more radiation to penetrate the material being tested and cause greater film exposure. Cobalt 60 has certain advantages over radium, chief of which are its lower cost and the fact that its container is much smaller and therefore more easily placed in out-of-the-way or difficult locations.

At the Naval Research Dockyard Laboratory at Halifax, Nova Scotia, the source of radiation for checking the new all-welded naval vessels is a cylindrical pellet, 1·94 mm. in diameter and consists of 50·3 mgms. of cobalt 60. This is enclosed in an aluminum container which in turn is enclosed in a hexagonal dural container. It has a radiation output equivalent to that produced by 621 mgms. of radium filtered with $\frac{1}{4}$ inch of lead and $\frac{1}{4}$ inch of aluminum. A comparable radium source would cost about $10,300.00 whereas the cobalt 60 costs $600.00. Special lightweight aluminum tools are used to handle the material because of the radiation hazard. Cobalt 60 has a half-life of 5·3 years.

Courtesy Defence Research Board, Department of National Defence, Canada.

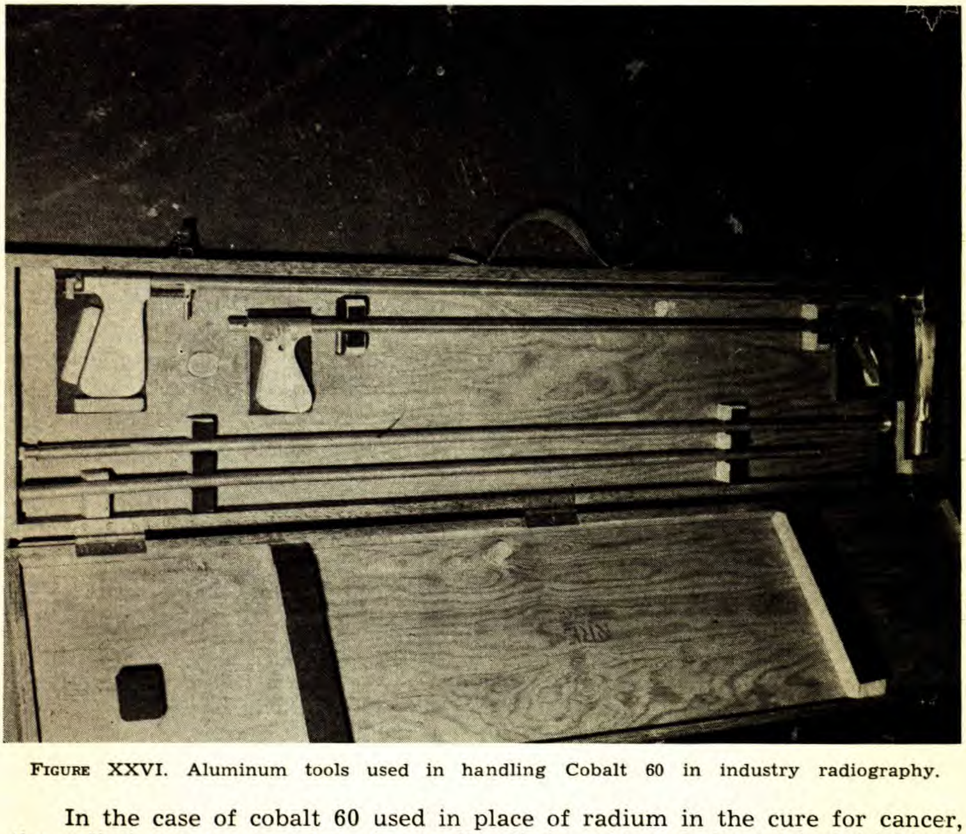


FIGURE XXVI. Aluminum tools used in handling Cobalt 60 in industry radiography.

In the case of cobalt 60 used in place of radium in the cure for cancer, the radiation source consists of a small cylinder of metal about $\frac{1}{4}$ inch high and 1 inch in diameter. In Canada the metal is exposed to the radiations of the atomic pile at Chalk River, Ontario, which produces the radioactive isotope. The isotope is then placed in a beam therapy unit in which it is surrounded by over a ton of lead in order to control the radiation emitted in all directions.

Experiments have also been conducted on the use of cobalt 60 as a means of controlling bacteria in meat and milk.

Cobalt 60 is sold in Canada to industry and hospitals by Eldorado Mining and Refining Limited, Ottawa, Ontario.

Cemented Carbides

Cobalt is used as a cement or binder for particles of tungsten, molybdenum and tantalum carbides.

In the case of tungsten carbide, cobalt oxide or a cobalt salt is reduced to cobalt metal powder by means of a reducing gas such as hydrogen. The powder is added to tungsten carbide powder in varying proportions of from 3 to 25 per cent of the total weight of the mixed tungsten carbide powder, and thoroughly mixed in a porcelain or stainless steel ball mill.

The mixed powder is then treated with a small amount of paraffin wax dissolved in carbon tetrachloride in order to assist in pressing. Pressing is accomplished in hydraulic presses at a pressure of from 10 to 40 tons per square inch. The ingots so produced are then prefired at a temperature varying from 700° to 1000°C. for about one-half hour, which strengthens them and enables them to be handled and worked more easily, besides removing the wax. The shaped ingots are cut to a size which will allow a shrinkage of approximately 20 per cent during final sintering and also to allow a small oversize allowance in the sintered product.

The shaped pieces are then packed in alundum, in graphite boats and are sintered in an electric furnace with a hydrogen atmosphere at 1400° C. for about 30 minutes; the exact period of sintering depends on the composition of the piece. This operation causes the cobalt to fill the cavities between the carbide particles and, on cooling, cements the tungsten carbide product.

Tungsten carbide inserts are used in detachable bits for mining drills, tips for high speed cutting tools, drawing dies, drills, lathe and grinder centres and wear-resistant parts such as gripping discs for gauge tips, valve balls and seats.

Another important use and a large consumer of cobalt in wartime is the tungsten-carbide armor piercing shell core. A cavity in the body of the shell contains the core, covered by a nose-piece which in turn is covered by a windshield. Such cores were used during World War II and were successful in penetrating the armor of German Tiger tanks in France. The Afrika Corps of the German Army however had made prior successful use of these projectiles against British tanks in North Africa.

Several companies such as Canadian General Electric Company, Limited, Toronto, Ontario; A. C. Wickman (Canada) Limited, Toronto, Ontario; and Kennametal of Canada Limited, Victoria, B.C., manufacture tungsten carbide products from imported mixed tungsten carbide powder.

Kennametal Incorporated of Latrobe, U.S.A. has established its Macro Tungsten Refinery at Port Coquitlam, B.C. where tungsten carbide powder is produced directly from tungsten ores. No doubt when this operation has progressed beyond the development stages, cobalt metal powder will be consumed in the manufacture of mixed tungsten carbide powder.

Ceramics and Porcelain Enamels

Probably the oldest use of cobalt oxide and salts is in the ceramic industry where these materials assume a very important role. They are mainly used for the following purposes:

(a) As a body stain

Clays usually contain colourizing substances such as iron, titanium, etc. These impurities introduce a cream or straw-like unattractive discolourization. Cobalt added in the form of oxide or sulphate counteracts this by producing a complementary blue colouration which neutralizes the cream or yellow colour and gives a pure white. At Medalta Potteries Limited, Medicine Hat, Alberta,

Courtesy Canadian General Electric Co., Toronto, Ont.

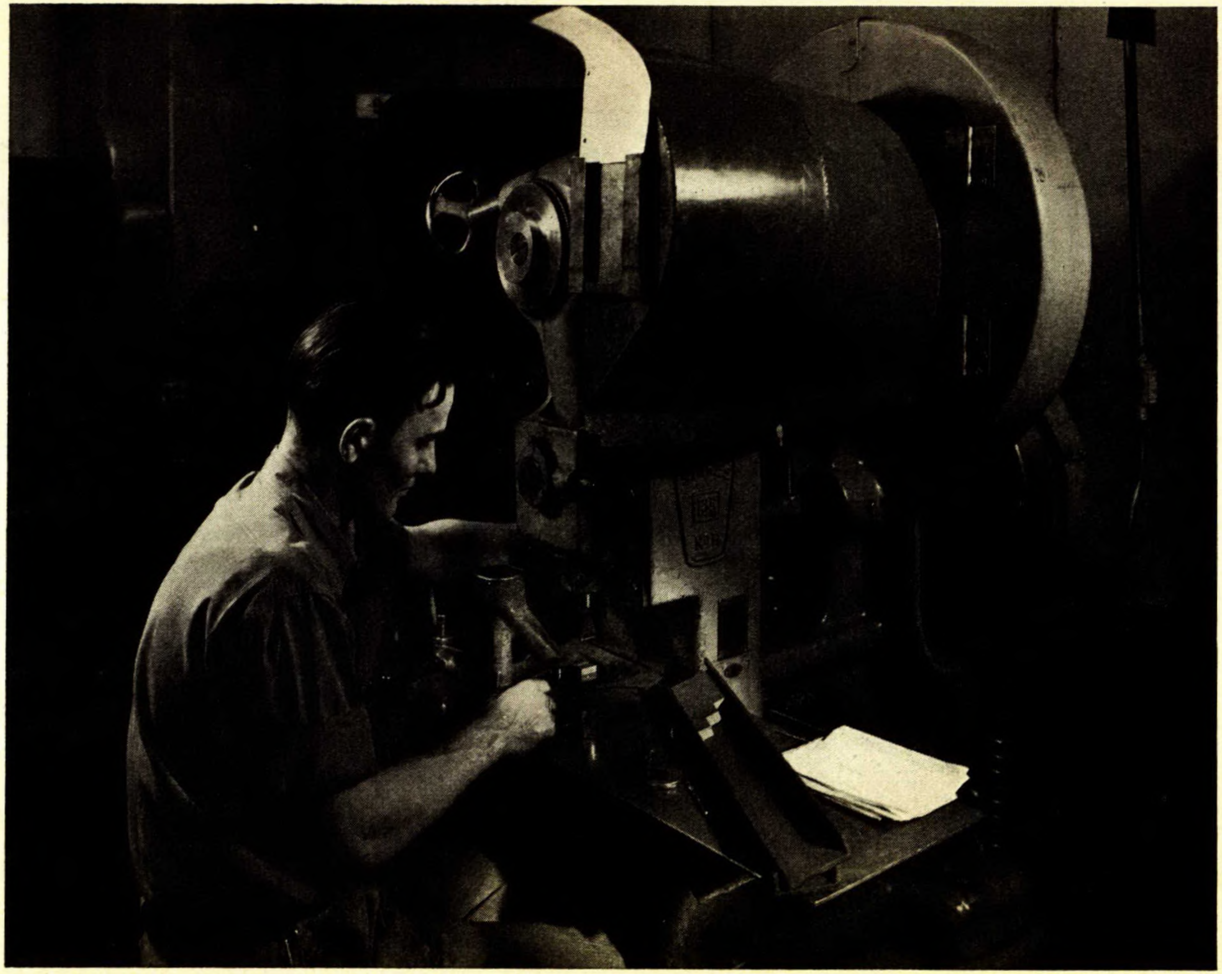


FIGURE XXVII. Pill pressing of tungsten carbide tool inserts.

Courtesy Canadian General Electric Co., Toronto, Ont.

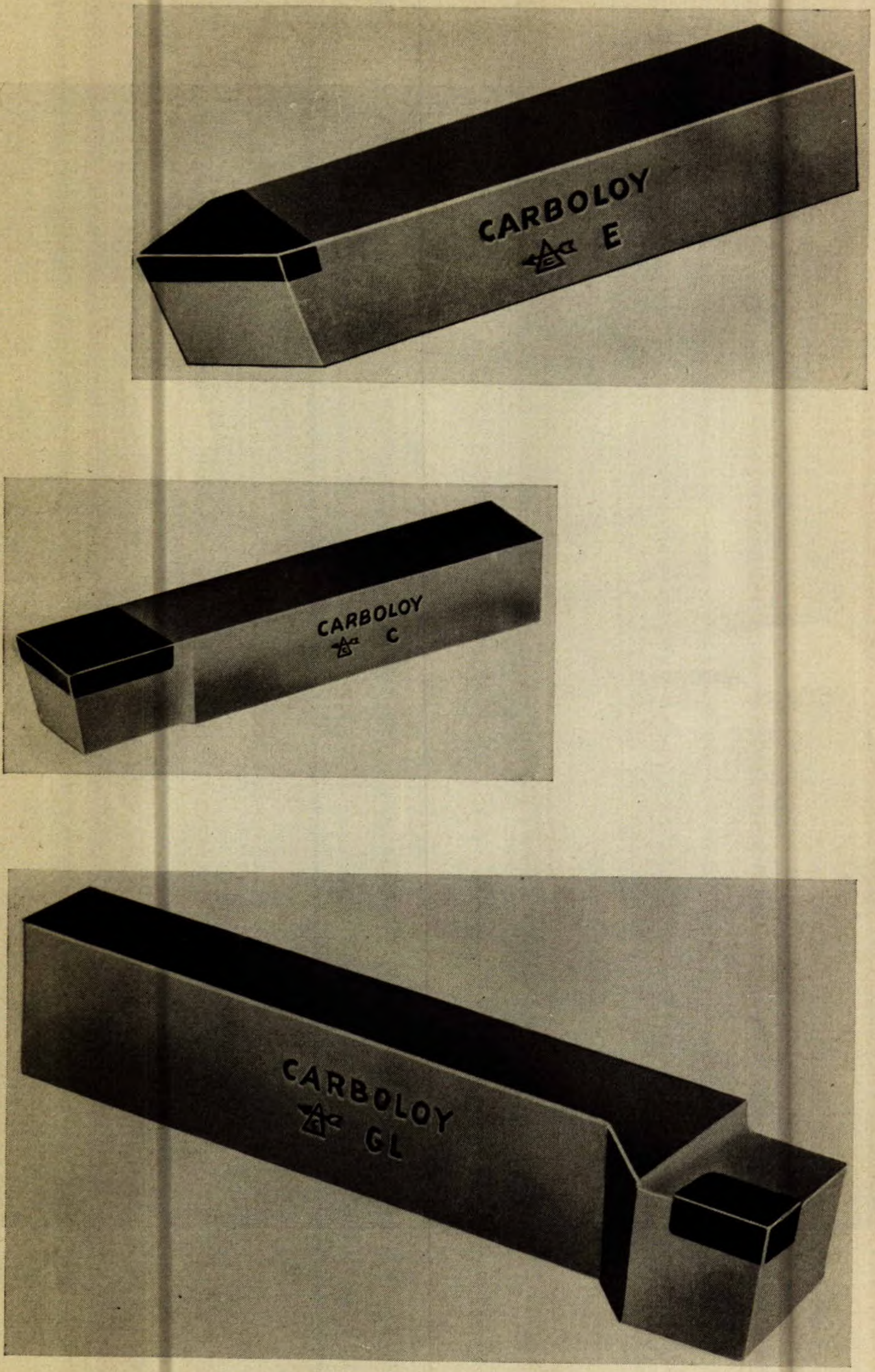


Figure XXVIII. Tungsten carbide tipped cutting tools.

TABLE 16

PHYSICAL PROPERTIES OF CEMENTED CARBIDES

Composition	Density (gm/cc)	Rockwell Hardness (A scale)	Transverse Rupture (psi)	Young's Modulus (psi x 10^6)	Compressive Strength (psi)	Proportional Limit in Compression (psi)	Impact Strength (ft./lbs.)	Endurance Limit (psi)	Coefficient of Thermal Expansion
97% WC, 3% Co	15·25	92·7	170,000	97·5	815,000	780,000	....	....	....
95·5% WC, 4·5% Co	15·05	92·3	200,000	90·5	890,000	740,000	....	....	....
94% WC, 6% Co	14·85	90–92	225,000	88	750,000	600,000	0·73	95,000	5·0 x 10^{-6}
91% WC, 9% Co	14·60	89·5–91·5	275,000	....	685,000	540,000	....	....	....
87% WC, 13% Co	14·15	87·5–90	300,000	80	625,000	525,000	1·10	105,000	5·9 x 10^{-6}
80% WC, 20% Co	13·55	85–87	350,000	....	550,000	425,000	1·75	....	....
Predominantly WC, with TaC and 13% Co	13·90	87–88	275,000	....	610,000	475,000	....	....	7·25 x 10^{-6}
Predominantly WC, with TaC and 6% Co	14·70	91–92	220,000	....	752,000	670,000	0·65	85,000	....
Predominantly WC, with TiC and 6% Co	11·20	92–93	160,000	....	700,000	....	0·40	90,000	6·8 x 10^{-6}
Predominantly WC, with less TiC than above and 8% Co	12·80	91·5–92·5	250,000	....	570,000	560,000	0·60	90,000	....
Predominantly WC, larger amount of TiC, 7% Co	9·00	92–93	150,000	....	725,000	....	....	....	7·0 x 10^{-6}
Predominantly WC, with TaC and TiC, 8% Co	11·7	91·5–92·5	165,000	72	720,000	....	....	....	6·75 x 10^{-6}
Predominantly WC, with TaC and TiC, 11% Co	11·6	90·5–91·5	175,000	....	680,000	....	0·60	85,000	6·0 x 10^{-6}
Predominantly WC, with TaC and TiC, 15% Co	11·4	89·5–90·5	190,000	67	670,000	....	0·92	....	7·5 x 10^{-6}

cobalt sulphate is consumed at the rate of 1 pound per ton of clay to decolourize whiteware. The cobalt sulphate as purchased is dissolved in warm water, the non-solubles are removed by decantation, and the sulphate is introduced into the liquid clay "slip".

Cobalt oxide is also used in larger proportions than for its neutralizing effect for colouring pottery bodies various shades of blue. More generally a coloured "slip" or film of coloured clay is applied over a non-coloured body. An example of this is the famous Wedgewood jasper which is obtained by adding cobalt oxide to a body containing a large proportion of barium compounds. In combination with oxides of manganese, chromium, and nickel all shades of blue and green slips may be made with cobalt oxide.

(b) As an enamel colour and glaze stain

Base or blended colours are used by the porcelain enamelling industry for colouring of enamels, and by the pottery industry for colouring of glazes.

Cobalt oxide is used as a raw material in the production of these ceramic colours. A typical formula might be:

cobalt oxide	50%
chrome oxide	10%
silica	10%
aluminum sulphate	20%
zinc oxide	10%

The batch is carefully weighed out in 600 lb. lots and charged into a ball mill with porcelain lining and porcelain grinding balls, and ground with a large proportion of water, usually 60% to 70%. Grinding is continued for several hours in order to obtain a homogeneous admixture of a high degree of fineness. The slurry is discharged from the mill and dried in trays in a forced air drier, using electrical heating elements to heat the air. When completely dry, it is removed and broken into small fragments which are placed in porous refractory (fire clay) saggers, each containing about 30 lbs. of material.

A number of loaded saggers are placed in a kiln heated by electricity, gas or oil, and heated up to a predetermined temperature usually between 1000°F. and 2500°F. It is soaked at this temperature long enough to attain the desired degree of chemical combination. Temperature cycle and soaking time must be carefully controlled to consistently produce the desired tone and hue of colour.

The batch is cooled in the saggers, where it has formed a fairly hard cake during the calcining operation. It is broken out of the saggers into small pieces which are charged into a porcelain-lined ball mill and ground with an appropriate amount of water to a fineness of 100% passing a 325 mesh sieve.

The slurry is removed from the mill and allowed to settle in porcelain enamelled steel drums, and surplus water, which contains soluble salts, is removed by syphoning. It is then washed by decantation with hot water several times till soluble salts have been removed. In some cases this operation is carried out on an Oliver Filter.

The material is then dried and put through a micropulverizer, which produces the colour as a fine homogeneous powder. Two or more base colours may be mechanically blended to produce a wide range of colours.

In the enamelling plant, the colour is added to the ball mill along with the frit and clay in an amount to give the desired colour. In the case of pastel blues, an opaque frit is used, and, for medium blues, a semi-opaque frit. For very dark blues, normally a blue frit would be used which would not require any colour, at the mill.

In the pottery industry, glaze stains are added at the mill in the same way, though in this case the glaze may be either fritted or raw glaze, or a combination.

(c) *As overglaze and screening colours*

One or more base colours are ground with a fritted flux by a wet ball milling operation with alcohol; the alcohol is then removed by evaporation. This is done to obtain an extremely fine product which is used by the pottery industry for applying overglaze decoration on their glazed ware, which is fused on by a separate firing operation. It is also used, by blending with oils as a vehicle, to produce “screening colours” used by the porcelain enamelling industry. The design or decoration is applied over fired enamel and fused by a separate firing.

(d) *As underglaze colours*

One or more base colours are ground by wet ball milling with alcohol to produce a product of a high degree of fineness. The alcohol is removed by evaporation and the dry powder is used by the pottery industry for “underglaze decoration”. The colour, using oil or water as a medium, is applied to the fired ceramic body and covered with a transparent glaze. The decoration and glaze are fired in one operation.

A full range of base colours and glaze stains, etc. are manufactured by Ferro Enamels (Canada) Limited at Oakville, Ontario.

(e) *As ground coat frit*

Cobalt, in the form of black oxide (Co_3O_4) is used in all ground coat enamels and its main function is to promote adherence between enamel and the steel to which it is applied. It is also used in finish coat blue and black enamels, for both steel and cast iron, for its strong blue colour. The blue finish coat enamels depend solely on cobalt for their colour, while in the black cover coat enamels, cobalt oxide is used in conjunction with other metallic oxides, such as those of iron, copper, manganese and nickel.

Required analysis of black cobalt oxide is as follows:

cobalt	71·0 %	minimum
nickel	1·25%	maximum
Fe_2O_3	0·50%	“
copper	0·05%	“
chlorides as NaCl	0·75%	“
sulphates as Na_2SO_4	0·50%	“

A minimum of 99 per cent must pass a 100 mesh screen while 98 and 96 per cent must pass 150 mesh and 200 mesh screens, respectively.

Porcelain enamels are made by melting a glass-forming batch in a furnace at temperatures ranging from 2200°F. to 2500°F. At the end of the smelting cycle the molten mass is poured slowly over a stream of running cold water which shatters the molten chemicals to form a frit, which is the basic ingredient of porcelain enamels applied as a protective vitreous coating to sheet steel and cast iron articles, chiefly household appliances (stoves, refrigerators, washing machine tubs, driers), kitchen utensils, sanitary ware, and outdoor signs.

In the most modern method of production, the molten enamel glass is passed through water-cooled steel rolls which form a vitreous sheet which is subsequently broken down into flakes. The enamel frit is subjected to a milling or grinding operation with clay, water, chemicals, and sometimes inorganic colouring pigments to produce an enamel “slip”. The “slip” is applied to the ware, usually by means of dipping or by a spray gun, and the water is removed in a drier. The dried, biscuit-like coating remaining on the steel is then fused in a furnace at approximately 1500°F. to a thin, smooth, glossy coating.

The ground coat, between the steel article and the cover coat, may be considered as a clear glass that has been coloured by the addition of low percentages of metallic oxides, the most important being that of cobalt. It is usually used in conjunction with nickel oxide and very often also with manganese dioxide. Though the cobalt oxide colours the glass a deep blue, which is darkened by the green and brown colouring effects of the nickel and manganese oxides, respectively, the enameller does not think of them in this role, as colouring materials, but as "adherence-promoting oxides". Without the cobalt, the ground coat would have little or no adherence to the metal, and could be easily knocked off. The addition of some nickel oxide usually improves the adherence-promoting properties of the cobalt. Manganese oxide sometimes improves the adherence, but it is not essential for this purpose, and is often added to darken the colour of the fired ground coat.

There are a number of theories, all supported by some experimental evidence, as to how cobalt oxide in ground coat enamels promotes their adherence to the steel. However, the following facts seem firmly established:

(1) The steel surface becomes oxidized during the firing process before the enamel melts. The formation of this oxide film is essential to good adherence.

(2) Part of the iron oxide film is taken into solution by the enamel while in the molten state.

(3) There is a precipitation of metallic particles at the iron-enamel interface. The metallic cobalt may be formed by chemical reduction of the cobalt oxide by the iron in accordance with the formula:

$$2\ \mathrm{Fe}\ {+}{+} + \mathrm{Co_2O_3} \rightarrow \mathrm{Fe_2O_3} + 2\ \mathrm{Co}$$

It has also been suggested that the cobalt may be plated out of the molten enamel glass by electrolytic action.

Several companies in Canada such as General Steel Wares Limited, London, Ontario; Ferro Enamels (Canada) Limited, Oakville, Ontario and Standard Sanitary & Dominion Radiator Company, Limited, Toronto, Ontario manufacture ground coat frit. Ferro Enamels (Canada) Limited manufactures the material for sale to porcelain enamelling plants who do not make their own frit. The source of supply of cobalt oxide consumed by General Steel Wares Limited is the Deloro Smelting and Refining Company and that of Ferro Enamels (Canada) Limited is the Deloro Smelting and Refining Company and the Mond Nickel Company, Limited, Clydach, Wales.

Paints and Driers

Driers are added to drying oils as a catalytic agent to accelerate polymerization and oxidation. Cobalt is the most active drier metal and is usually added as an organic compound such as linoleate, resinate, napthenate or acetate.

It is sometimes used alone but usually in conjunction with auxiliary driers such as lead, zinc or calcium. Zinc tends to delay the strong surface-oxidizing effect of the cobalt in thick films and allows the entire thickness of film to have freer access to the air. Thus the film hardens throughout its thickness and by the time it is tack-free, it is cured.

Cobalt driers are added to varnish, enamels, paints, linseed oil, printing inks, etc.

Manganese and lead driers are also used but their respective drying times are generally 1½ to 6 times that of cobalt. The faster drying time of cobalt compounds enables the use of lower priced oils such as fish, soybean, cotton-seed, etc., instead of linseed oils.

Some varnishes and enamels are more responsive to manganese driers than to an equivalent percentage of cobalt in cobalt driers when dried at elevated or baking temperatures. This is particularly true in the case of black enamels.

Cobalt oxide is used in small proportions to produce white enamel paints, since any yellow colour, due to the presence of impurities such as iron oxide, is neutralized by the complementary blue cobalt colour, producing a pure white.

Nuodex Products of Canada, Limited, Leaside, Ontario—This company has been manufacturing cobalt naphthenate in Canada since 1937, engaging in both the domestic and export trade.

The drying compound or soap is manufactured by a direct metal reduction process using naphthenic acid chiefly, but also 2-ethyl hexoic acid and tall oil acid. The chemical reaction is as follows:

$2\ Co$	$+$	$4\ (R\text{-}COOH)$	$+$	O_2	$\rightarrow$	$2\ Co\ (R\text{-}COO)_2$	$+$	$2\ H_2O$
Cobalt		Naphthenic				Cobalt		
Metal		Acid				Naphthenate		
Powder								

The water is removed from the soap by drying in a vacuum.

Until the above process was developed, cobalt soaps were produced by a double decomposition process as follows:

$CoSO_4$	$+$	$2\ (R\text{-}COO\ Na)$	$\rightarrow$	$Co\ (R\text{-}COO)_2$	$+$	$Na_2\ SO_4$
Cobalt		Sodium		Cobalt		Sodium
Sulphate		Naphthenate		Naphthenate		Sulphate

The company states that the newer process produces a purer and more uniform drier as, with the former process, it was impossible to eliminate entirely the sodium sulphate from the finished product. The cobalt content of the cobalt drier produced is 6 per cent.

Animal Nutrition

The great grassy ranges of coastal Australia and central New Zealand contain very valuable pasture lands. However, for geological reasons these areas are deficient in cobalt which causes the "coast" or "bush sickness" in cattle and sheep and also the "pining disease" which causes the animals to go off their feed. However, it was found after many years of scientific research that additions of cobalt nitrate, cobalt sulphate or cobalt acetate to fertilizers for top dressing of pasture lands overcame this condition in the animals. Once overcome a small amount of cobalt given in animal feed or licks was sufficient to prevent recurrence of the disease.

In Canada, certain areas of pasture land are deficient in cobalt and the discussion of this subject has been made possible through the courtesy of S. R. Haskell, Animal Husbandry Division, Central Experimental Farm, Department of Agriculture, Ottawa.

J. E. Bowstead states that interest in cobalt as a nutrient in the feeding of ruminants in Canada began, following the discovery in 1938, at the University of Alberta, that the feeding of cobalt to breeding ewes cured the debilitating symptoms that developed after a seven-to-nine month period of non-leguminous rations.

The clinical symptoms of sheep fed on cobalt-deficient rations appeared to be similar to those of malnutrition. Reproduction was seriously impaired in that lambs from affected ewes were smaller and weaker than lambs from unaffected ewes. Ewes that became unthrifty on cobalt-deficient rations produced insufficient milk to nourish their lambs, and also produced fleeces that were weak in fibre. With the development of the deficiency symptoms there was a decrease in the cobalt content of certain tissues. This corresponds with results reported from areas elsewhere known to be deficient in cobalt.

E. E. Hancock and G. R. Smith observed a progressive debility in cattle on cobalt-deficient feed, the animals showed a depraved appetite, and drank little or no water. These workers state that the animals recover if moved inland from the coastal areas of Nova Scotia where the deficiency is encountered. The calves born in the deficient areas frequently died during the first few months of age.

R. A. McIntosh has stated that in Ontario the administration of cobalt proved effective in the treatment and prevention of a condition in young stall-fed cattle characterized by loss of appetite, pica, wasting, and anemia. Sheep showing poor appetite and unthriftiness during the winter feeding period also respond to treatment with cobalt.

Beneficial effects of cobalt feeding have also been shown in southwestern Saskatchewan in an experiment with range ewes at the Dominion Experimental Station at Swift Current.

V. A. Ellis states that the treatment of the lactating cows with one-half a fluid ounce of cobalt sulphate solution once a day resulted in a remarkable beneficial response. R. Hamilton in his studies with cobalt deficiency dissolved one ounce of cobalt sulphate in one gallon of water and administered one tablespoon once a day. The results obtained were remarkable. After the third or fourth dose, the animals began to improve, with appetite good, increasing in flesh, bowels regular, and milk increased to 3½ gallons.

In 1946 the Sub-committee on Nutrition of the National Sheep Committee appointed a special committee of representatives of Governmental and University institutions carrying experimental flocks of sheep, to investigate the problem of cobalt deficiency in Canada. This sub-committee outlined a survey, but no data are yet available, and the only provinces taking an active interest are Alberta and Saskatchewan.

According to Bowstead, one of the problems encountered in conducting cobalt research in Canada has been the disagreement in the results of cobalt analyses between the various methods that have been published. As a result Miss D. J. Hiscox of the Division of Chemistry, Science Service, Dominion Department of Agriculture, has made a study of these methods and published the results of her findings.

Other workers studying methods are A. J. Sutherland and G. R. Smith of the Nova Scotia Agricultural College, and J. W. T. Spinks of the Department of Physics, University of Saskatchewan. Bowstead appropriately concludes that available evidence shows that cobalt-deficient areas exist throughout the entire breadth of Canada. While no specific areas have as yet been delimited, the results of controlled feeding experiments and the effects of administering cobalt to numerous individual flocks suggests that cobalt research should be continued till sufficient evidence has been accumulated to warrant specific recommendations for cobalt feeding.

In Canada, cobaltized salt is manufactured and sold by a number of companies such as Canadian Industries, Limited, Maritime Industries, Limited, The Dominion Salt Company, Limited, Canadian Salt Company, Limited, Vancouver Salt Company, Limited, Standard Chemical Company, Limited and Bell & Sons (Canada) Limited.

These companies either purchase the amorphous cobalt sulphate direct from the Deloro Smelting and Refining Company or as other cobalt chemicals from Canadian chemical firms such as Mallinckrodt Chemical Works, Limited, Montreal and St. Lawrence Chemical Company, Limited, Montreal.

One type of cobaltized salt manufactured in Canada contains 0·02 per cent cobalt carbonate, 0·022 per cent potassium iodide stabilized with calcium stearate and 0·025 per cent ultramarine blue for colouring purposes with the remainder being pure salt. The light blue coloured salt is sold in loose form in 100 pound bags, in 50 pound salt blocks and in 5 pound licks. A large amount is exported to New Zealand and Australia.

Miscellaneous Uses

Glass Manufacture—A small amount of cobalt in the form of oxide is used to neutralize yellow discolourization, where this is objectionable, in the end use of glass. In addition, cobalt oxide is used to produce royal blue glass, an example of which is the well known bromo seltzer bottle.

The colouring power of cobalt oxide is very strong and as little as one part in 5,000 produces a characteristic colour. For this reason it is customary to use cobalt oxide in the diluted form known as "powder blue" which is a glass or enamel containing about 5 per cent cobalt oxide. Another method of adding cobalt is to dilute the oxide with sand or ground feldspar. This procedure enables an even distribution of cobalt oxide throughout a batch of glass.

Electroplating—During World War I a government sponsored research program was set up under Dr. Herbert T. Kalmus at Queens University, Kingston. Kalmus and his associates carried out fundamental research on the subject of electro-plating with cobalt. However, due to the price of cobalt in relation to nickel and chromium, this application has not been put to extensive use, although cobalt is now added to nickel for plating purposes in a number of special applications where more than normal hardness and ductility of the plate is essential.

Beryllium Copper—Low-berryllium copper contains 97 per cent copper, 2·6 per cent cobalt and 0·4 per cent beryllium while normal beryllium copper contains 1·75 to 2·5 per cent beryllium, up to 0·5 per cent cobalt plus nickel and other elements.

These alloys are noted for their fatigue resistance, toughness, hardness and low sparking. They are used for springs, non-sparking tools and strong mechanical parts and are very important in aircraft-component assemblies, communication equipment, signalling devices, and various ordinance accessories.

Sealing Wires in Glass—Several alloys have been developed for sealing into glass. These alloys have a coefficient of expansion which approximates the glass in which they are sealed. Fernichrome containing 25 per cent cobalt, 30 per cent nickel and 8 per cent chromium is used for sealing into soft glass while Kovar and Fernico containing 17 and 18 per cent cobalt and 29 and 28 per cent nickel, respectively, are used for sealing into hard glass. Cobalt improves the "wetting" characteristic of these alloys.

Perminvar—This alloy, containing from 20 to 75 per cent nickel, 5 to 40 per cent cobalt, and sometimes molybdenum, is used in the loading of long submarine telegraph and telephone cable, because of its high resistivity. Another alloy which has similar uses is Permalloy, containing 78 per cent nickel, 21 per cent iron and 0·37 per cent cobalt, also used in telephone relays and telephone and radio transformers.

Catalysts in Petroleum Processing—Cobalt is used in catalysts in desulphurization, hydrogenation, catalytic cracking, polymerization, Fischer-Tropsch synthesis, etc. In general it is not as important as nickel in these uses but for certain specific uses is better.

One form of catalyst is a solid cylindrical pellet about $\frac{1}{4}$ inch in diameter by $\frac{1}{2}$ inch in length, containing 10 per cent cobalt molybdate in an aluminum oxide base. It is used as a desulphurization and hydrogenation catalyst.

In the Fischer-Tropsch synthesis of hydrocarbons from water gas, a cobalt-thoria catalyst is used.

Cobalt has, perhaps its most important use in promoting desulphurization and hydrogenation processes. As the petroleum refiner is forced to utilize more of the low grade, high-sulphur oils for the production of quality distillate types of products, processes which will remove all types of organic sulphur compounds and other objectionable non-hydrocarbons will become increasingly important.

Cobalt catalysts show much promise in techniques which permit desulphurization and up-grading operations on high sulphur crudes as well as stocks derived from shale and bituminous sands. Thus cobalt is a key material in research programs directed towards the increased utilization of low grade crudes and in the development of other sources of hydrocarbons for petroleum fuels manufacture.

Such research developments are of major importance to the petroleum fuels industry in Canada, particularly in their effect on the greater utilization of western Canadian heavy crudes of high sulphur content. The Mines Branch of the Department of Mines and Technical Surveys is presently conducting a research program in Ottawa on the Athabasca bituminous sands and is working on the problem of desulphurization using a cobalt molybdate process.

CHAPTER VIII

FOREIGN TRADE

Imports of cobalt ores during the period 1937-52 are given graphically in Figure XXIX. Table 17 shows imports of cobalt ores and oxides during the same period. Prior to these years imports of cobalt ores and concentrates were relatively small. The graph would be misleading without some further explanation because of the types of material imported from various sources. For instance the material imported during the period 1939 to 1946 consisted mainly of a copper-cobalt-iron alloy from the electric furnaces of Rhokana Corporation, Northern Rhodesia. This product assayed about 40 per cent cobalt, 15 per cent copper and 45 per cent iron.

During the period 1948 to 1952 the imported material consisted of ores from La Sociètè minière de Bou-Azzer et du Graara, French Morocco, which averages from 9 to 12 per cent cobalt, and Canadian ores re-imported from the United States averaging about 10 per cent cobalt.

The imports of cobalt oxides shown in Table 17 are small compared with Canadian consumption and were imported mainly for ceramic use.

TABLE 17

CANADIAN IMPORTS OF COBALT ORES AND OXIDES, 1937-1952

Source: Trade of Canada

Year	Ores		Oxides	
	lbs.	$	lbs.	$
1937	300	5	617	871
1938	....	9	736	1,094
1939	541,500	148,410	525	301
1940	3,920,600	1,164,616	60	116
1941	4,600,100	1,543,086	50	114
1942	4,336,200	1,485,370	164	433
1943	2,236,300	785,721	55	130
1944	3,676,400	1,327,755	1,720	2,595
1945	2,390,000	869,415	16,072	22,390
1946	1,170,000	451,115	16,250	21,550
1947	....	....	740	753
1948	848,100	64,857	100	205
1949	81,400	2,465	1,000	1,390
1950	3,912,500	435,655	25,880	23,044
1951	3,687,800	760,000	....	....
1952	14,943,400	2,318,419	....	....

During the years prior to World War II most Canadian exports of cobalt ores went to Germany and France. The Japanese purchased some ores during the early years of World War II, but from 1941 to 1952 nearly all the exported cobalt ores were sent to the United States. The large export to the United States in 1948 was mainly the ores purchased by the Canadian government for United States government account during World War II and stockpiled until 1947-48.

The large exports of cobalt metal during World War II are the result of the conversion of the Rhokana alloy by the Deloro Smelting and Refining Company, Limited, and well illustrate the importance of that smelter during emergency periods.

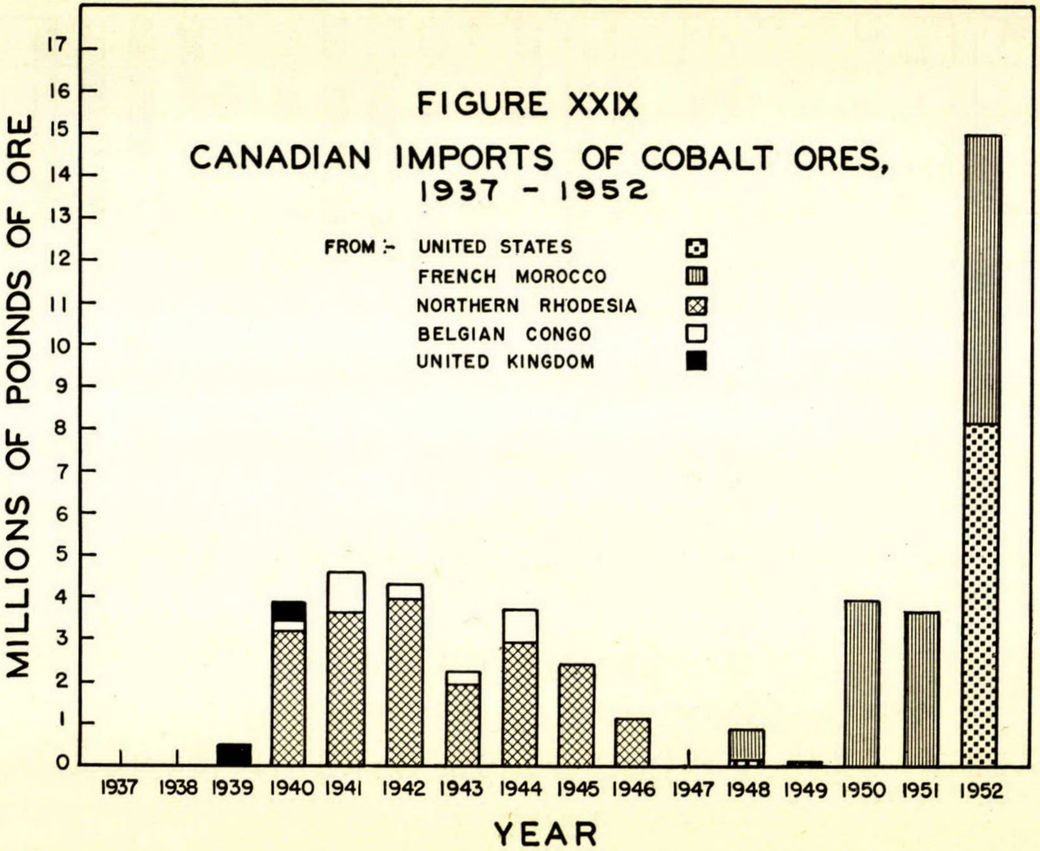


FIGURE XXIX

CANADIAN IMPORTS OF COBALT ORES, 1937 - 1952

SOURCE : TRADE OF CANADA

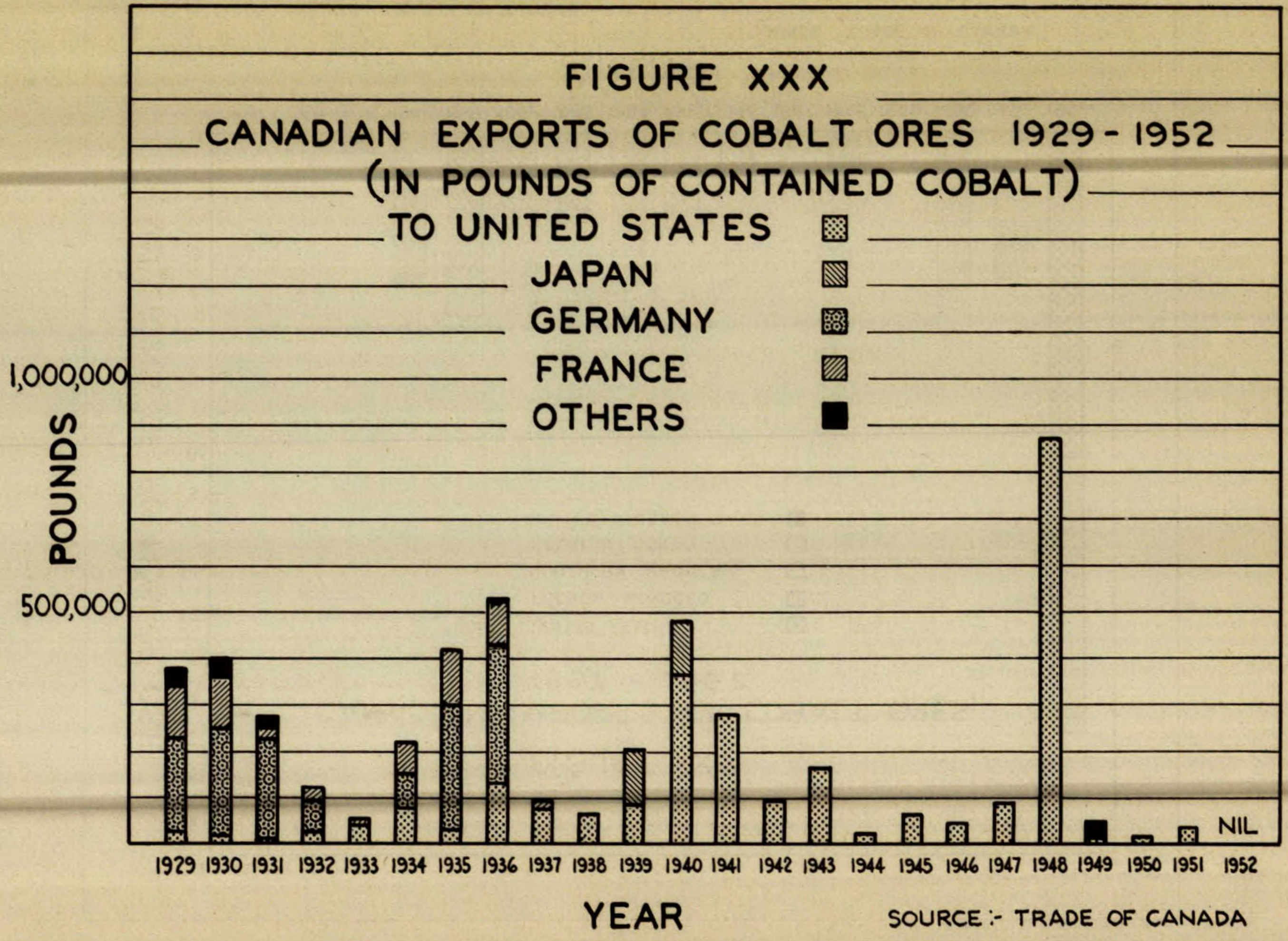
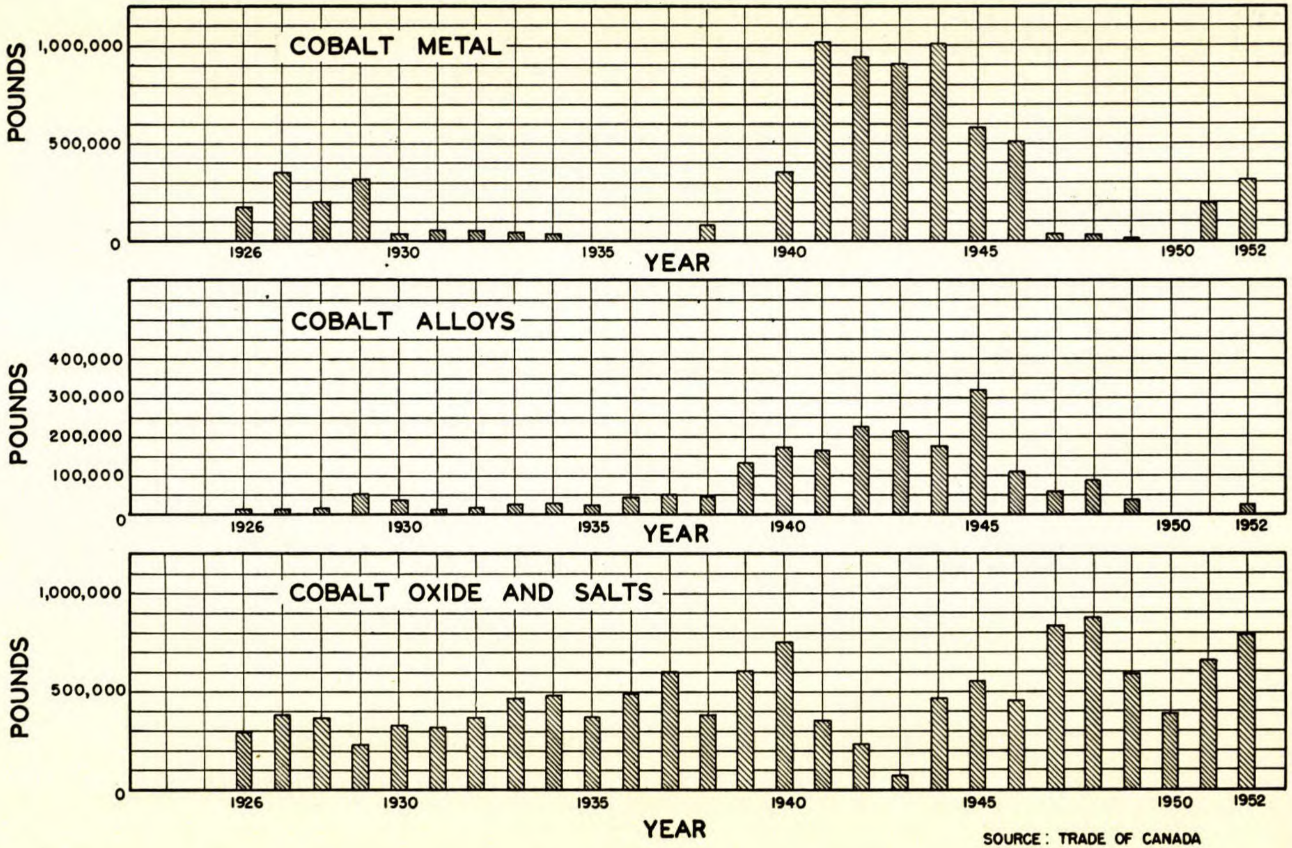


FIGURE XXX

CANADIAN EXPORTS OF COBALT ORES 1929 - 1952 (IN POUNDS OF CONTAINED COBALT)

SOURCE :- TRADE OF CANADA

FIGURE XXXI CANADIAN EXPORTS, 1926 - 1952



SOURCE: TRADE OF CANADA

TABLE 18

CANADIAN EXPORTS OF COBALT METAL, ALLOYS, OXIDES, SALTS, ORES AND RE-EXPORTED FOREIGN METAL, 1928-1952

Source: Trade of Canada

Year	Metal		Alloys		Oxides and Salts		Ores (contained Cobalt)		Re-exported Metal	
	lbs.	$	lbs.	$	lbs.	$	lbs.	$	lbs.	$
1928	240,966	467,663	17,601	84,920	369,783	650,981	....	530,897		
1929	315,700	608,444	56,520	242,358	236,873	450,870	379,300	484,491		
1930	39,000	71,809	39,822	173,623	326,955	632,015	399,600	442,423		
1931	58,510	79,313	16,508	73,008	322,146	416,995	273,000	165,909		
1932	58,439	63,779	20,394	77,436	377,250	389,998	124,700	58,121		
1933	48,168	49,516	27,347	53,941	467,012	429,846	53,700	19,147		
1934	38,595	43,519	31,343	50,027	479,676	435,907	219,300	84,911		
1935	1,803	2,253	26,405	44,462	378,274	370,160	419,300	124,679		
1936	2,376	2,970	43,211	70,372	484,541	556,791	526,200	212,814		
1937	7,576	10,834	51,939	84,629	597,869	754,965	92,400	58,712		
1938	83,579	122,101	49,674	79,278	382,408	523,218	66,400	40,983		
1939	2,600	3,250	133,679	264,861	606,942	814,807	204,100	178,043		
1940	355,227	438,728	172,553	614,188	746,991	1,126,785	478,100	387,640		
1941	1,021,132	1,526,911	165,456	860,849	353,282	494,580	279,700	281,345		
1942	943,632	1,471,024	226,963	1,253,264	232,808	285,424	93,400	97,266		
1943	911,107	1,507,635	214,202	1,021,663	67,040	135,630	163,100	188,510		
1944	1,009,068	1,665,984	176,589	789,202	462,656	829,469	25,900	24,379		
1945	583,334	954,257	321,047	1,247,249	555,522	975,035	65,000	57,119		
1946	510,526	854,282	111,651	345,012	456,088	608,767	48,100	41,091		
1947	40,366	72,095	59,728	316,849	837,405	835,141	89,300	69,060		
1948	31,410	61,824	88,734	466,478	876,895	1,032,710	871,000	641,320		
1949	12,000	23,638	34,179	206,800	590,538	742,088	49,300	37,301		
1950	nil	nil	1,011	9,619	388,203	583,939	16,700	15,302		
1951	192,260	375,383	730	7,308	659,486	1,172,343	35,300	46,754	85,485	154,543
1952	315,500	674,758	20,445	98,118	785,976	1,636,193	nil	nil	38,032	73,766

CHAPTER IX

INTERNATIONAL CONTROLS

The International Materials Conference

In the summer of 1950 the raw materials markets of the world were disrupted by a rush of buying set off by the war in Korea. The surge in demand came in part from speculation, in part from emerging defence requirements, and from consumers' efforts to lay in stocks against future shortages. Prices rose steadily during the summer and autumn of that year.

The British Prime Minister and the President of the United States met in Washington in late 1950 and reached tentative agreement upon plans for an intergovernmental organization designed to handle the problem. The government of France also entered into the discussions and as a result invitations were sent to other free world countries, and the International Materials Conference was born.

Membership in each Committee was limited to those countries which had a substantial producing or consuming interest in the commodities concerned. The Manganese-Nickel-Cobalt Committee first convened on March 12, 1951, and its membership at first consisted of Belgium, Brazil, Canada, Cuba, France, Federal Republic of Germany, India, Norway, Union of South Africa, United Kingdom, and United States. The task of the committee was defined as follows:—"To consider and to recommend to governments the specific action that should be taken in the case of each commodity in order to expand production, increase availability, conserve supplies and to ensure the most effective distribution of supplies among the consuming countries."

In the case of cobalt, each producing country submitted their forecast of production for a future quarterly period and each consuming country submitted their requirements for a similar period. After careful study of the supply and demand position, the committee then established a plan of allocation which was recommended to participating governments. An allocation plan was adopted commencing with the fourth quarter of 1951. The supply and demand situation improved steadily during 1952 with a result that cobalt was not allocated by the International Materials Conference after the end of the fourth quarter of 1952.

TABLE 19

ALLOCATIONS OF COBALT BY THE INTERNATIONAL MATERIALS CONFERENCE IN METRIC TONS OF CONTAINED COBALT

Country	4th Quarter 1951	1st Quarter 1952	1st Half 1952	3rd Quarter 1952	4th Quarter 1952
Argentina	2·5	2·5	5·0	2·0	2·0
Australia	13·3	12·7	22·0	11·0	11·0
Austria	20·0	18·9	36·0	18·0	18·0
Belgo.-Lux. Econ. Union	26·0	26·0	52·0	26·0	20·0
Bolivia	......	......	0·2	0·1	0·1
Brazil	5·1	4·7	9·4	4·7	5·0
Canada	29·3	34·2	70·2	33·0	33·0
Chile	......	......	0·1	0·1	0·1
Colombia	0·1	0·1	0·2	0·1	0·1
Cuba	......	......	0·7	0·4	0·2
Denmark	4·2	3·9	8·5	4·5	4·5
Egypt	......	......	0·2	0·1	0·1
Finland	0·4	1·5	1·5	5·0	2·5
Formosa	......	......	......	0·1	0·1
France	75·0	87·7	185·7	111·0	111·0
Germany	127·5	128·7	265·7	147·0	147·0
Greece	......	......	0·2	0·5	1·0
India	14·1	13·1	5·0	2·5	3·0
Ireland	......	0·4	0·6	0·3	0·4
Italy	14·5	13·6	31·6	20·0	31·0
Japan	60·4	57·7	67·7	40·0	55·0
Mexico	0·8	0·7	1·0	1·0	1·5
Netherlands	39·8	37·7	81·7	35·0	20·0
New Zealand	14·6	13·7	20·0	3·4	3·4
Norway	3·7	4·4	9·3	4·7	5·5
Portugal	0·4	0·4	1·4	1·0	1·5
Southern Rhodesia	0·2	0·2	0·5	0·2	0·1
Spain	5·0	4·8	10·3	5·2	4·5
Sweden	42·2	40·0	80·0	40·0	40·0
Switzerland	1·9	1·7	15·0	8·0	8·0
Turkey	1·4	1·4	2·2	1·1	0·1
Union of South Africa	5·2	4·8	9·6	4·8	5·6
United Kingdom	329·1	318·1	648·1	360·0	360·0
United States	1,212·4	1,362·4	2,762·4	1,583·9	1,987·8
Uruguay	......	......	......	......	0·2
Yugoslavia	0·5	0·5	1·3	0·7	0·7
TOTAL	2,049·6	2,196·5	4,405·3	2,475·4	2,884·0

CHAPTER X

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APPENDIX A

CANADIAN INCENTIVE PRICE SCHEDULE DURING WORLD WAR II

Second Issue

Department of Munitions and Supply
Office of the Metals Controller
Ottawa, Canada

October, 15, 1942

Tariff Basis for Purchase of Cobalt Ores

To continue building up a reserve stock of cobalt ores and concentrates and at the same time furnish an outlet for Canadian production, Mr. G. C. Bateman, Metals Controller, Department of Munitions and Supply, announces that supplementary arrangements have been completed for the purchase of such ores or concentrates containing 8 per cent or higher cobalt element and up to 500 ounces of silver, providing for an increase in the price paid on silver.

Until further notice, all purchases shall be made through Deloro Smelting and Refining Company Limited, acting as buying agent for the Metals Controller, as and from April 1, 1942 and up to December 31, 1943, all ores or concentrates shipped after April 1, 1942 will be purchased on the following tariff basis but subject to review, should conditions warrant.

Purchases will be made F.O.B. rail cars, Cobalt, Ontario, or other equalized freight shipping point to destination, specified by the buyer.

PRICES

Cobalt

For ores or concentrates containing 8 per cent but less than 9 per cent cobalt, the price shall be 88¢ per pound contained cobalt.

For ores or concentrates containing 9 per cent but less than 10 per cent cobalt, the price shall be 99¢ per pound contained cobalt.

For ores or concentrates containing 10 per cent and over cobalt, the price shall be $1.10 per pound contained cobalt.

Nickel

Provided the nickel content is 5 per cent or over, the nickel shall be paid for at the rate of 5·5¢ per pound of contained nickel.

Silver

Provided the silver content exceeds 50 ounces, it will be paid for on the basis of 50 per cent of the content at the average price quoted for silver by Handy & Harman and printed in the weekly E. & M.J. Metal & Mineral Markets Service covering the months during which delivery of the ore is made. No payment will be made for silver over a content of 500 oz. per short ton of ore. The above price for silver content is made effective as and from September 1, 1942.

Copper Penalty

When the copper content exceeds 1·5 per cent a penalty of 24·75¢ per pound of copper shall apply on the excess copper over 1·5 per cent.

Sampling, Assaying and Weighing

Ores or concentrates purchased under this tariff shall be paid for on the basis of assay and weight certificates furnished in quintuplicate by either Temiskaming Testing Laboratories, Cobalt, Ontario or Deloro Smelting and Refining Company Limited, Deloro, Ontario, and the cost of such sampling, assaying and weighing shall be for the account of the seller. The buyer reserves the right to have a representative present at the time of sampling and to have an independent assay made at his own expense.

Payments

Payments shall be made by the buyer on receipt of weight and assay certificates in quintuplicate except in the case of silver payments which of necessity have to be delayed until the end of each month when the average price as specified can be determined.

APPENDIX B

CANADIAN INCENTIVE PRICE SCHEDULE DURING KOREAN EMERGENCY

Statement on Cobalt by the Right Hon. C. D. Howe, Minister of Trade and Commerce, in the House of Commons, February 15, 1951

In order to stimulate further production of cobalt to meet future Defence and essential requirements for the metal, the Canadian Government will purchase Northern Ontario concentrates for a period of three years on the following basis:

For ores and concentrates

containing 10-11·99% cobalt—$1.35 per lb. of cobalt contained
containing 12-13·99% cobalt—$1.40 per lb. of cobalt contained
containing 14% or over cobalt—$1.45 per lb. of cobalt contained

This incentive price schedule will be posted immediately by the Deloro Smelting and Refining Company, acting as buying agents for the Government, and that company's smelter facilities will be used to convert such ores and concentrates into metal to establish a Canadian emergency stockpile.

The new price schedule represents an increase of approximately 50¢ per pound of metal. The ores and concentrates shall be purchased by the Deloro Company on the basis of assay determinations by the Temiskaming Testing Laboratory at Cobalt, Ontario, and in minimum shipments of 5-ton lots. The silver content of such shipments will be paid for on the basis of Deloro Company's customary tariff.

Cobalt metal is in short supply today. In a Defence program cobalt plays a vital role for such essentials as jet blades, tool steels, alnico magnets and tungsten carbide.

Note:—The reader is referred to Chapter I for the complete story of the incentive price plan.

APPENDIX C

CANADIAN INCENTIVE PRICE SCHEDULE DURING KOREAN EMERGENCY

Department of Defence Production

OTTAWA, December 28, 1951:—The Right Hon. C. D. Howe, Minister of the Department of Defence Production, announced today that the premium prices paid to cobalt producers would be increased, effective January 1, 1952, in accordance with the following schedule:

Contained Cobalt in Ores or Concentrates f.o.b. Cobalt, Ontario	*Price Per Pound of Contained Cobalt*
7·00 — 7·99%	$1.20
8·00 — 8·99%	$1.50
9·00 — 9·99%	$1.80
10·00% plus	$2.00

The Deloro Smelting and Refining Company will continue to act as agent for the Canadian Government in the purchase of the cobalt content of the ores or concentrates. The above prices will prevail until 600,000 pounds of recoverable cobalt has been accumulated under the above price schedule for the Government account or until March 31, 1954, whichever event occurs first. In the event that the 600,000 pounds of recoverable cobalt is accumulated before March 31, 1954, the price schedule outlined above will revert to that in effect prior to January 1, 1952.

This increase in the buying price schedule for cobalt in ores and concentrates is to maintain incentive for the producers, particularly in the Cobalt district of Ontario, to continue to mine cobalt ores in the face of increased operating costs.

Note:—The reader is referred to Chapter I for the complete story of the incentive price plan.

APPENDIX D

UNITED STATES GOVERNMENT STOCKPILE SPECIFICATIONS

National Stockpile Specification P-13-R

10 March 1953
(Supersedes issue of
11 December 1951)

General Services Administration

Emergency Procurement Service
Washington 25, D.C.

Material Purchase Specification

COBALT

1. *Description*

These specifications cover refined cobalt metal suitable for the production of ferrous and nonferrous alloys.

2. *Chemical and Physical Requirements*

Each lot of cobalt metal purchased under these specifications shall conform to the following requirements:

a. *Chemical Requirements:*

			Percent by Weight
Cobalt	(Co)	Minimum	97·00
Nickel	(Ni)	Maximum	0·75
Iron	(Fe)	Maximum	0·30
Carbon	(C)	Maximum	0·50
Copper	(Cu)	Maximum	0·10
Sulphur	(S)	Maximum	0·05
Phosphorus	(P)	Maximum	0·02

b. *Physical Requirements:*

Material shall be supplied in rondelles or in small lump or granular form. All material shall pass a two-inch screen and none shall pass a Tyler Standard Sieve mesh No. 6 (U.S. Standard Sieve No. 6). All material in any lot shall be approximately the same size.

3. *Packaging and Marking*

a. *Packaging:*

(1) The containers shall be capable of containing the cobalt for an indefinite storage term since no deterioration of the material is indicated. One of the following containers shall be used:

(a) Wooden barrels equal to Grade No. 1, Federal Specification NN-B-109; Barrels, Wood, Slack, with hardwood staves. Pack about 500 pounds in 18 gallon size. Smaller sizes are acceptable.

(b) Steel barrels or drums, with removable heads, equal to the specifications of the Interstate Commerce Commission for Type 6C, U.S.S. 18 gauge, or Type 37D, U.S.S. 19 gauge. The containers shall be about 15 gallons; 480 pounds capacity, and shall be lacquered or enameled both inside and outside.

(c) Wooden boxes equal to Federal Specification NN-B-62 lb.: Boxes, Wood, Nailed and Lock-Corner, with strapping; or Federal Specification NN-B-60 lb.: Boxes, Wood-Cleated-Plywood, for Domestic Shipment. The preferred weight shall not exceed 250 pounds per box.

(2) All containers comprising any lot shall be of the same nominal size and shape.

b. *Marking:*

Each container shall be permanently and legibly marked and such markings shall include the name of the product, form, gross and net weights, government contract number, and, where applicable, the number of containers. The containers shall not carry a security classification or any marking, other than the contract number, indicating National Stockpile ownership. Appropriate identifying documents shall accompany each shipment.

4. *Inspection and Analysis*

Each lot of cobalt shall be subject to inspection and analysis by the purchaser or his designee.