

INTRODUCTION

One by one new metals come forward to share the burden of modern industry. Long before the Christian era potters and glass workers employed fine and costly blue pigments that contained cobalt. Cobalt blue glass has been found in the tombs of the Egyptians and in the ruins of Troy, and many of the colors used by the ancient Greeks and Romans contained cobalt. The ancients, however, were apparently unaware that the colors they used were caused by cobalt, and it was not until late in the 17th century that the existence of the element was recognized. Writers in the Middle Ages referred to "cobalos" as an evil spirit that haunted mines and caused trouble to the miners. Subsequently the German word "Kobold," meaning goblin, came to be applied to any baffling mineral and particularly to minerals that resembled ores but failed to yield metal when smelted. Even to-day there is something of an air of mystery about cobalt, and a medieval cloak of secrecy still surrounds many of the metallurgical processes employed in its production.

"Zaffre" was mentioned about the middle of the sixteenth century by Biringuccio, and in 1735 the metal was first prepared by G. Brandt. The preparation of cobalt compounds, however, must have been carried on in at least a small way ever since the opening of the silver-cobalt deposits of Schneeberg in 1470. By 1790 there were 25 works engaged in the industry, most of them located in Saxony, but the total output of these works probably did not exceed 300 tons of cobalt annually, mostly in the form of smalt. The smalt which contained approximately 6 per cent cobalt was sold in Venice in 1520 at about 16 cents a pound. A few refineries in Holland supplied the Irish linen trade, contributed a large amount to the Dutch linen industries, and also provided smaller quantities for the manufacturer of litmus in Holland. A complete description of the early history of the cobalt industry in Saxony, is given by Mickle in the Report of the Bureau of Mines of Ontario, vol. 19, 1913, pt. 2, pp. 234-251.

Smalt is used now only in a few enamel works. It is a blue compound which owes its color to the presence of cobalt silicate, but as formerly prepared it contained various impurities. The oxides of cobalt are now preferred in the ceramic industry because of their purity, uniformity, and lower cost.

Only within the last two decades has cobalt found extensive application outside of the glass and pottery industries.

DESCRIPTION

Cobalt is a silvery white metal strongly resembling nickel in its appearance and properties. The atomic weight (58.94) is a trifle higher than that of nickel (58.69), but in the periodic system it is actually placed before nickel because chemically and physically it is intermediate in its properties between iron and nickel. According to Mellor, the specific gravity is 8.5; the atomic volume, 6.94; and the melting point, 1,467° C.³ Drury⁴, however, gives the specific gravity as ranging from 8.79 on an unannealed sample to 8.92 on a swaged

3 Mellor, J. W., Modern Inorganic Chemistry: London, 1918, p. 501

4 Drury, Charles W., Cobalt, Its Occurrence, Metallurgy, Uses and Alloys: Rept. Ontario Bur. Mines, 1918, vol. 27, pt. 3, Sect. 1, p. 70.

sample and the melting point as being 1,478° C. The tensile strength is quoted by the latter authority as being 34,400 pounds per square inch. Cobalt is magnetic, more so than any other metal except iron. When reduced from the oxide it is in the form of a gray powder.

The metal is soluble in dilute acids. It forms two series of compounds. Cobaltous compounds (bivalent) are yellow or green in the anhydrous state but form pink crystals and are pink in aqueous solutions, turning blue, however, in the presence of strong hydrochloric acid. No simple cobaltic salts have been prepared, but cobalt is trivalent in potassium cobaltinitrite and other complex compounds, including a variety of cobalti-ammonia derivatives. There are three oxides: cobaltous oxide (CoO), greenish gray; cobaltous-cobaltic oxide (Co₂O₄), black; and cobaltic oxide (Co₂O₃), brownish. These may be prepared by heating the cobaltic hydroxide at a red heat, but when any of the three oxides is dissolved in acid, only cobaltous compounds are formed. Precipitated cobaltous hydroxide, however, gradually turns brown in contact with the air, forming cobaltic hydroxide. In the absence of ammonium salts ammonia precipitates a blue basic salt, but this is soluble in excess of ammonium chloride. The dirty yellow ammoniacal solution slowly becomes reddish on exposure to air, forming stable cobalti-ammonia salts: $\text{Co}(\text{OH})_2 + 2\text{NH}_4\text{Cl} + 2\text{NH}_3 = \text{Co}(\text{NH}_3)_4 \text{Cl}_2 + 2\text{H}_2\text{O}$. Complex cations and anions containing cobalt are very numerous and very stable.

USES

Cobalt is used both in the form of the metal and in the form of the oxide and other compounds. In the United States, metallurgical uses account for fully 50 per cent of the total, and probably not more than about one-third of the consumption is now absorbed in the ceramic and chemical industries.

The largest single use of cobalt is in the cobalt-chrome series of alloys known as "stellite." These nonferrous alloys--often modified by the addition of tungsten, molybdenum, and other metals--are widely employed to replace tool steel and for other purposes in which hardness and strength (even at a red heat) combine with corrosion resistance are desired. Substantial amounts of cobalt metal are used in magnet steels, tool steels (including high-speed steel), and certain rust-resisting steels. Some magnet steels contain as much as 60 per cent cobalt. Small quantities have been used in electroplating. A new metal, called "Konel" and containing cobalt, nickel, and ferrotitanium, is claimed to be a satisfactory substitute for platinum in many of its uses. It was originally developed for use in filaments for radio tubes, but since it is harder than cold steel even when it is red hot, it seems well-adapted for a variety of uses. It may find extensive employment in the moving parts of internal-combustion engines and in other hot places. Another interesting use of cobalt, though one which does not afford an outlet for any substantial tonnage, is as a binder for tungsten carbide, the super-hard tool material which has gained wide recognition since it was first introduced

in the latter part of 1928. This remarkable material, surpassed only by the diamond in hardness, will cut a screw thread in a glass rod, machines porcelain, and retains a keen edge even when forming mica board or ivory. A little cobalt is used in certain electrical resistance alloy wires and even in bearing metal.

Next to stellite, probably the main consumption of cobalt is in the ceramic industry where the oxide is used not only in colored ware but quite generally in the glaze of white ware, much as bluing is employed in laundering white clothing. As a body stain, likewise, cobalt is used to convert the yellow or slightly orange tint caused by traces of iron, in the proportion of about 1 pound of cobalt oxide to 1 ton of clay. In the aggregate a very substantial amount of cobalt oxide is used in the manufacture of cobalt acetate, oleate, borate, linoleate, tungstate, and oleoresinate used as driers in paint and varnish. In linseed oil paints, the acetate is widely used, the proportion usually ranging between 0.2 and 0.4 per cent.

MODE OF OCCURRENCE

Cobalt is not found native and is nowhere mined except in conjunction with other metals. In Cobalt, Ontario, the leading metal is silver, and in addition to cobalt, nickel and arsenic are present in the ores. In the Belgian Congo, cobalt is only a minor constituent of the copper ores. Bismuth is the most important constituent of the cobalt ores of Schneeberg, Germany. The New Caledonian deposits have been worked mainly for cobalt, but even there the cobalt is associated with manganese.

The commonest cobalt minerals are linnaeite (Co_3S_4 , generally containing also some nickel and iron), smaltite (CoAs_2), cobaltite (CoAsS), and erythrite ($\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$). Erythrite has a beautiful and quite characteristic peach-blossom color, but the first three minerals mentioned are silvery-looking and not easily distinguishable from several other minerals having a metallic lustre. Manganese ores containing cobalt have a characteristic blue lustre on the fresh, dry fracture. Such ores ordinarily contain 5 per cent or less of cobalt, but the writer has found samples containing 15 per cent of cobalt and 35 per cent manganese in the southern United States.

IDENTIFICATION

Even a small quantity of cobalt imparts an intense blue color to a borax or salt of phosphorus bead, both in an oxidizing and in a reducing flame. If copper or nickel interferes, the bead may be heated on charcoal in a reducing flame with a granule of tin, thereby reducing the nickel or copper to the metallic state and enabling the characteristic blue color of the cobalt to be seen. Iron in quantity sufficient to interfere may be removed in the wet way, but it is generally possible to detect the presence of even a fraction of 1 per cent of cobalt in either iron or manganese ores, provided only minute quantities of the material are taken up in the bead and provided the color of the iron or manganese is reduced to a minimum by prolonged heating in the reducing flame.

METALLURGY

Arsenical ores, such as those from Cobalt, Ontario, are usually smelted in blast furnace to form a speiss, and this speiss, a mixed arsenide of iron, cobalt, and nickel, is later roasted to remove the bulk of the arsenic which is recovered as a by-product. The residue, usually containing about 10 per cent arsenic and from 20 to 30 per cent or more cobalt, is reserved for treatment by wet chemical processes.

The separation of nickel from cobalt is the only phase of the treatment that presents unusual features. Calcium hypochlorite (bleaching powder) solution added to the clear chloride solution (freed from arsenic, iron, and copper) precipitates the cobalt in the form of black cobaltic hydroxide, $\text{Co}(\text{OH})_6$. Nickel does not precipitate unless an excess of the hypochlorite is used; it is recovered from the filtrate by adding milk of lime. The filtered cobalt oxide when dried and gently calcined, carries 76 to 77 per cent of the element. A newer process for separating nickel and cobalt is described briefly by Dyson⁵. It involves the reactions of complex ammonia compounds. An ammoniacal solution containing cobalt chloride is oxidized by hydrogen peroxide (or merely by blowing air through it) as to form what is known as roseocobalt chloride, the formula of which is $[\text{Co}(\text{NH}_3)_5 \cdot \text{H}_2\text{O}] \text{Cl}_3$. This aquo-pentamino-chloride when boiled is converted into chloropentamino-chloride or chloropurpureocobalt, having the formula $[\text{Co}(\text{NH}_3)_5 \cdot \text{Cl}] \text{Cl}_2$.

Manganese is another interfering element. There is practically no manganese in the cobalt ores found at Cobalt, Ontario, but practically all the cobalt ores from New Caledonia, previously in large use, carried a high percentage of this metal. In the manipulation of the New Caledonia ores, the cobalt and nickel were precipitated together by means of sodium sulphide, leaving practically all of the manganese in solution.

Various other means have been devised for getting the cobalt into solution, and despite the secrecy that has surrounded most cobalt enterprises, the number of processes described in the literature is legion. Details of a variety of such methods will be found in the excellent review by Drury⁶ published by the Ontario Bureau of Mines.

Metallic cobalt, according to this report, may be obtained by:

- (1) Reduction of the oxide in a carbon crucible or by added carbon (or starch).
- (2) Reduction of the oxide or oxalate in a stream of hydrogen or hydrocarbons, the reduction being complete at 500 to 600°C.

Dyson, G. Malcolm, The Extractions and Utilizations of Cobalt: Chem. Age, vol. 19, Nov. 3, 1928, pp. 33-34, Mon. Met. Sec.
 Drury, Charles W., Cobalt, its Occurrence, Metallurgy, Uses and Alloys: Rept. Ontario Bur. Mines, 1918, vol. 27, pt. 3, pp. 31-69.

- (3) Reduction of the oxide by carbon monoxide.
- (4) Reduction of the oxide by ammonium chloride.
- (5) Reduction of cobalt chloride in a current of hydrogen.
- (6) Reduction of the oxide by aluminum (Goldschmidt or thermit process).
- (7) Precipitation from cobalt solutions by metallic magnesium or zinc.
- (8) Distillation of cobalt amalgams.
- (9) Electrolytic methods.

WORLD PRODUCTION

Early in the nineteenth century the limited supply of cobalt (in the form of smalt or zaffre) came from Norway, Sweden, and Saxony. Later, New Caledonia became the chief producer. Early in the twentieth century practically all of the world's cobalt began to come from the newly-discovered silver-cobalt-arsenic ores of Ontario, and for some time the potential supply as a by-product of silver production far exceeded the demand. An active search for new uses, however, soon resulted in increased sales. By 1926 the Belgian Congo, which produces cobalt as a by-product of copper, had become a close rival of Ontario and even forced a temporary curtailment in Canadian production. At present more than half of the world production comes from the ores of Cobalt, Ontario. The metal and its oxide are produced chiefly in Canada, Great Britain, and Belgium from ores mined in Ontario, Belgian Congo, and Queensland. Germany's contribution is rather small, though the mines in Saxony are still productive and cobalt residues and ores are purchased abroad for treatment in German works. The United States, though by far the leading consumer, is an unimportant factor in production.

The cobalt production data published by the several producing countries are given in such indefinite figures that the estimates are far from exact. According to Drury⁷ the world's annual output of cobalt oxide previous to 1913 amounted to approximately 250 tons. In 1916 it increased to 400 tons but shortly after the outbreak of the World War the production of cobalt metal increased from practically nothing in 1913 to 165 tons in 1916 and 158 tons in 1917. The following figures (Table 1) have appeared in the annual chapters of Mineral Resources:

⁷ Loc. cit., p. 31.

Country	Cobalt-bearing material	1924		1925		1926		1927		1928		1929	
		Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content	Gross weight	Cobalt content
Australia: Queensland	Cobaltite, concentrates, etc.	200.4	2.60	417.6	91.4	137.2	27.4	--	--	40	8	(3)	(3)
Belgian Congo	Copper-iron-cobalt alloy	976	2273	684	2192	794	4360	2,100	5588	(3)	450	(3)	(3)
Canada: Ontario	Cobalt, alloys, and chemicals	(3)	209.2	665	246.1	794	302	(3)	599	(3)	434	(3)	422
Chile	Arseno-sulphide ore	34.6	2.1	--	--	6.4	(3)	(5)	(6)	11	2	(3)	(3)
China: Yunnan	(3)	--	--	250	(3)	4250	(3)	250	(3)	4250	(3)	250	(3)
Germany: Saxony	Cobalt-bismuth-nickel ores	102	26	145	6.9	155	27.4	92	(3)	82	(3)	(3)	(3)
India, British: Bihar	Cobaltiferous nickel speiss	--	--	--	--	--	--	4,770	167	3,878	136	3,834	134
New Guinea: Concentrates		--	--	--	--	--	--	275.6	23.5	(3)	(3)	(3)	(3)

1. Mineral Resources of the United States, U. S. Bureau of Mines; statistics compiled by I. M. Jones.

Figures not available prior to 1924.

2. Estimated. The Belgian Congo alloy is said to carry 28 per cent of cobalt.

3. Data not available.

4. Cobalt in metal, oxide, and salts produced at Colen, Belgium.

5. Estimated.

6. Less than 1 ton (471 kilograms).

7. Year ended June 30, of year stated.

8. Cobalt-bearing manganese oxide.

9. Exports.

DOMESTIC PRODUCTION AND DEPOSITS

Statistics are available showing a production of cobalt oxide in the United States year after year from 1869 to 1904, inclusive. Most of this was recovered in refining the copper-nickel ores of Sudbury. From 1905 to 1913 during the operation of the cobalt plant (a few hundred yards south of its main nickel-copper smelter), of the Canadian Copper Co. (International Nickel) at Copper Cliff, Ontario, a total of perhaps 2,500,000 pounds of cobalt was separated and purified in this country.⁸ Previous to 1900, the Mine la Motte Co. shipped cobalt ore to Swansea and in 1903 produced 120,000 pounds of oxide in a Missouri plant. Another cobalt refinery erected in 1906 by the North America Lead Co. at Fredericktown, Mo., operated intermittently until 1910. In 1909 it produced 83,384 pounds of cobalt oxide, 328,403 pounds of nickel, 8,314 tons of nickel-cobalt concentrates, 600 tons of copper concentrates, and 1,353 tons of lead concentrates. This plant was purchased at a forced sale in 1915 by the Missouri Cobalt Co., which produced a certain amount of oxide in 1918 and in 1920 recovered 102,410 pounds of cobalt oxide and cobalt hydrate, valued at \$262,801. It then closed down.

Oregon has been credited with spasmodic shipments of arsenical ore containing cobalt, gold, and silver; a few tons were sent to France in 1905. Nevada, also, has produced one or two carloads of cobalt ore. In 1917 the Haynes Stellite Co., a large consumer of cobalt, began mining at Blackbird, Lemhi County, Idaho, where a large number of veins were said to contain cobalt. Prospecting and concentrating experiments were carried on for two or three years, but since 1921 nothing further seems to have been done in this district.

Cobalt occurrences have been reported in at least 12 States, and various attempts have been made to open them up, but beyond spasmodic outputs from Missouri, Idaho, Oregon, and Nevada, there has been practically no commercial production. It is only fair to say, however, that there has been little incentive to develop cobalt properties, and for this reason a brief review of reported occurrences may be of interest.

Alabama.— Manganese ores containing cobalt have been found near Rock Run, Cherokee County. At one locality a total of about one carload of 4 per cent ore was taken out, some of which was shipped for making ferromanganese. The cobalt content, of course, was lost.

Alaska.— During the summer of 1922 a little erythrite was found in a narrow vuggy quartz vein on Hot Springs Dome near Hot Springs, on the lower Tanana River.

Arizona.— Specimens of erythrite containing kernels of cobaltite or smaltite have come from the Fort Apache Reservation, 50 miles north of Rice. A large deposit ($4\frac{1}{2}$ miles long and from half a mile to a mile wide) of nickel and

⁸ From 1906 to 1913, inclusive, the Canadian Copper Co.'s cobalt plant produced 2,318,916 lbs. of metallic cobalt contained in crude oxides shipped to the United States.

cobalt has been reported 36 miles north of Tucson, and a small vein of cobalt was reported to have been found in 1927 on the 200 level of a mine in Final County, across the canyon from the old Silver King property. According to S. F. Wright (Engineering and Mining Journal, Dec. 1, 1928), "Arizona can boast of the best and perhaps the only real cobalt field in the United States. The veins are from 1 inch to 3 inches thick, and the ore assays from 29.45 to 49.15 per cent cobalt. As yet the owners have done nothing but prospect."

California.- The Mar-John Mining Co. in recent years has prospected a deposit of cobaltiferous arsenopyrite on a claim known as the "Hauselt Patent," 2 miles southeast of Sheepbranch, Calaveras County. In addition to cobalt the ore is said to contain a sundry rare earths and other metals.

Colorado.- As early as 1882 smaltite was reported near Gothic, Gunnison County. A more recent find of cobalt-nickel ore was reported in 1929 by the Clark Mining Co., operated in the East Fork district; the vein is said to be about 6 feet wide.⁹

Connecticut.- About the middle of the nineteenth century there was a small production of arsenical cobalt-nickel ores from Great Hill, known locally as Cobalt Mountain, between Middletown and Middle Haddan. The railroad station still goes by the name of Cobalt. Little trace of the mining operations now remains. The ore is chloanthite, but evidently the quantity was too small to pay for working.

Idaho.- For several years, beginning about 1917, the Haynes Stellite Co. of Cocomo, Ind., mined and experimented upon cobalt ore in the narrow valley of Blackbird Creek, Lemhi County, Idaho. Work on these properties was eventually discontinued, but the following description by Hess is of interest:¹⁰

"Haynes Stellite Co.'s property, composed of two groups of claims, 30 claims in all, 21 of which were formerly owned by J. M. Beliel, the main group (Haynes Camp) being on the north side of the main creek; about 4 miles above its mouth and about 2 miles below the old mining camp of Blackbird, and the other group 2 miles southeast, on the West Fork of Blackbird Creek: The deposits are in a banded, thin-bedded, very fine grained gray and black quartzite, with some interbedded dark-green schist. Both rocks are very resistant to weathering, so that the valleys cut through them are narrow, with steep walls buttressed by great accumulations of sharp-edged talus lying at angles as great as 41°. Narrow zones in the quartzite have been shattered, and in these zones solutions have deposited quartz, tourmaline, and minerals containing cobalt combined with arsenic and sulphur, probably mostly cobaltite, the arsenosulphide (CoAsS), as indicated by the pinkish color; there is also some smaltite, the arsenide (CoAs₂). It is probable that arsenopyrite (the iron arsenosulphide, FeAsS) is also present, and, as shown by the green efflorescence

Denver Min. and Financial Rec., vol. 39, May 25, 1929, p. 1.

Hess, F. L., Cobalt, Molybdenum, Nickel, etc.: Mineral Resources of the United States, 1917, pt. 1, U. S. Geol. Survey, 1921, pp. 899-901.

or "bloom" (annabergite) in some places on the outcrops, nickel is present in small quantity.....The tourmaline in the veins on these claims is in crystals so minute that they are indistinguishable to the unaided eye; consequently, tourmaline was not recognized in the field. It forms so large a part of the gangue that the vein is black and can not ordinarily be told from the country rock. Most of the particles of cobalt minerals are so minute that they can not be seen in the rough rock, and whether ore or barren rock is at hand can be ascertained, at least by the inexperienced, only by crushing and panning. The country rock is hard and dense, but the vein matter is harder and denser, and this in itself gives some guidance to the miner in places where the infiltration of vein matter has been insufficient to make its characteristics visible. Such masses weather more slowly and stand out from the quartzite and schist. Microscopic measurements of the minerals from these claims showed many grains to be less than 0.01 millimeter (0.0004 inch) in diameter; probably most of the grains in specimens collected by the writer are about 0.03 millimeter (0.0012 inch) in diameter, and the larger grains reach 0.25 millimeter (0.01 inch). In places, however, the grains are of the size of popcorn or even larger, but these are exceptional. It is claimed that the ore as mined gave, in an experimental mill run before the property changed hands, more than 1 per cent of cobalt. . . .

"At Blackbird a large number of veins carry cobalt minerals. Here the veins are in schists and gneisses as well as in quartzites. They contain less tourmaline, larger particles of cobalt minerals, more nickel, and so much copper that considerable money has been spent in prospecting for that metal. . . . Quartz veins reach a thickness of 10 feet, with subsidiary veins through a further thickness of 5 to 10 feet. Here and there, tourmaline is found in visible crystals. No mill test has been made of the numerous properties for cobalt, but it seemed probable that some of the properties, to be selected by sampling, would be well worth testing if there is sufficient demand for cobalt. There is much more nickel, as well as very much more copper in the ores immediately around Blackbird, and in most of the deposits the particles of cobalt minerals are very much coarser than at Haynes Camp. At Blackbird the Gray Eagle, owned by Wiley J. Rose, and other claims are located on a vertical crushed zone about 5 to 12 feet thick in schist on the northeast side of and parallel to Meadow Creek, one of the forks of Blackbird Creek. Where cut by a prospect tunnel on the Gray Eagle, this crushed zone strikes N. 40° W. and is in schist impregnated with quartz, which makes a very tough mass 10 to 12 feet thick that carries cobalt minerals. Ten feet southwest, pyrrhotite is found in bunches not over 6 inches thick, but on the St. Joe claim, adjoining the Gray Eagle claim on the northwest (owned by John E. Dubois, Dubois, Pa.), pyrrhotite 6 feet thick is said to have been cut at a depth of 100 feet and again at 250 feet, and is also said to have carried \$18 a ton in gold and some cobalt and nickel. The dumps on these claims where wet by Meadow Creek are nearly covered with the beautiful peach-bloom pink erythrite (cobalt arsenate)."

Cobalt has also been reported in Kootensi and Latah Counties, Idaho.

Maryland.- A sample of gahnite found at Mineral Hill mine, Carroll County, in 1923, showed the presence of 1.48 per cent cobalt oxide.

Missouri.- Near Fredericktown, in southeastern Missouri, occur the chief commercial deposits. In the Flat River district, to the northwest of the Fredericktown area, cobalt and nickel sulphides are sometimes recovered as a middling product. The following description of the Fredericktown deposits is quoted from the chapter on rare metals in "Mineral Resources of the United States, 1917:"

"The cobalt-bearing deposits of southeastern Missouri: The sulphides of cobalt and nickel occur associated with the sulphides of lead, iron, and copper in certain parts of the disseminated lead region of southeastern Missouri. The chief deposits of commercial value occur near Fredericktown, in the southern part of the region. In the Flat River district, to the northwestward of the Fredericktown area, cobalt and nickel sulphides are occasionally recovered as a middlings product on the tables of the lead mills and shipped to smelters for refining. The ore bodies in the vicinity of Fredericktown occur in the lower part of the Bonnetterre dolomite and in the underlying LaMotte sandstone. The ore consists of a mixture of lead, copper, cobalt, nickel, and iron sulphides. The sulphides other than that of lead occur in greatest quantity in the lower part of the workings, next to and in the sandstone, especially near the granite and porphyry. The quantity of cobalt and nickel sulphides varies considerably in the different working. . . . At Mine LaMotte, cobalt and nickel have been produced in small quantities for many years, even prior to 1857. . . . the chief source of the nickel and cobalt was the dressed galena, which usually carried from 0.2 to 0.3 per cent of these metals. Next in importance was a middlings product of the concentrating plant, which usually carried 20 to 23 per cent lead, 0.5 to 1 per cent of copper, and 2.5 to 3.5 per cent of cobalt and nickel. A larger percentage of copper was accompanied by a correspondingly larger percentage of cobalt and nickel. Besides these products of the mill, a small quantity of true cobalt-nickel ore was produced. In recent years, developments in the deeper workings have disclosed the presence of extensive deposits of copper-cobalt-nickel ore. The chief source of cobalt and nickel in Missouri has been the mine of the North American Lead Co., adjoining Fredericktown. From 1900 to 1906 this property was operated as a lead mine. In exploiting the property large quantities of copper, nickel, and cobalt sulphides were found associated with the lead sulphide. . . . Owing to the complexity of the ore, serious difficulties were encountered in both milling and smelting operations. In 1907, the company succeeded in producing 2,731 pounds of cobalt oxide. In 1909, 83,394 pounds of cobalt oxide, 328,403 pounds of nickel, 8,314 tons of nickel and cobalt concentrates, 600 tons of copper, and 1,353 tons of lead concentrates were produced. . . ."

Nevada.- Occasional shipments of cobalt have come from Nevada. In 1921 a carload of heterogenite was shipped from Good Springs, Clark County. "Rich mines" of erythrite are reported in the northeast part of Churchill County and this same mineral has been mined at the Lovelock mine, Cottonwood Canyon, Pahute Range, Humboldt County.¹¹

North Carolina.- The United States Geological Survey, in a report for 1897-98, reported ores with a small percentage (0.03 per cent) of cobalt in the Dannemora mine, Rockingham County.

Oregon.- A. E. Kellogg¹² describes the cobalt deposits in Jackson County as follows:

"About twenty years ago cobalt was discovered in Jackson County, Ore., by Dr. W. P. Chisholm, of Gold Hill, Ore., the pioneer of the quicksilver industry in that district, while he was developing his gold-copper mine in the 'Meadows', twelve miles north of Gold Hill. This property, known as the Chisholm group, is still owned and under development by the doctor. It is situated not far from Chisholm's quicksilver properties, also in the 'Meadows'. Early in the development of the gold-copper property, large orebodies were opened up, which, besides producing gold and copper, also carried from 4 to $4\frac{1}{2}$ per cent of cobalt. This work extended over a period of several years and it is estimated that at least 30,000 tons of this ore will produce not less than $4\frac{1}{2}$ per cent cobalt.

". . .Development of the quicksilver properties shows that the cinnabar ore, besides producing gold, silver, nickel, zinc, and arsenic as by-products, also gives evidence of cobalt values. Other localities in this region are believed to contain cobalt in commercial quantities, but the Chisholm mine is the only property in the district that has been reliably and systematically tested for cobalt.

"The Chisholm mine is in a heavily timbered district, at an elevation of 1,760 feet. About \$45,000 has been spent in its development. In part, the ore is a primary constituent of the norite country rock, and the vein deposits were probably derived from the same source. . . .

"The Gold Hill district is a mountainous region cut by one narrow east-west valley and its tributaries from the north and south. The elevation varies from less than 1,000 to 4,000 feet. The district is occupied chiefly by old Paleozoic sediments interbedded with stills or flows of andesite and greenstone. Everywhere the sedimentary rocks strike northerly, usually about N 15 deg. E and dip eastward at angles ranging from 65 deg. nearly 90 deg. Diller has shown that Jurassic beds west of the district

11 Schrader, F. C., Stone, R. W., Sanford, Samuel, Useful Minerals in the United States: U. S. Geol. Survey Bull. 624, 1917, p. 193.

12 Kellogg, A. E., Cobalt in Jackson County, Oregon: Eng. and Min. Jour., vol. 112, Oct. 22, 1921, p. 650.