Strategic Mineral Supplies
4. Chromium

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The strategic situation with regard to chromium is in many ways similar to that of manganese: domestic output previous to the World War was negligible, but expanded to cover a material proportion of the demand during 1916-1918, and then dropped back to the pre-war level; both have moderate domestic ore reserves, but of too low a grade to be economically operated at normal prices; both are consumed largely by the steel industry, but while manganese is used almost entirely in the metallic form, chromium is used extensively in the form of chromite, as a refractory material in furnace construction.

In this connection, the consumption of chromium has undergone a considerable transformation since the pre-war period. At that time the use as a refractory predominated, and only a comparatively small proportion was reduced to the metallic condition, mostly as ferrochromium, for use in the production of chromium and nickel-chromium steels, and of nickel-chromium-iron alloys for heat-resistant and electrical alloys. But since the development of the so-called stainless steels, carrying up to 30 per cent chromium, as against 1-2 per cent in the former steels, the use of chromium in alloy steels has been much increased. The development of electrical heating equipment in both household and industrial uses has multiplied the demand for chromium in this direction, and many new applications have similarly expanded the consumption in heat resistant alloys. As a result, the consumption of chromium in metallic form is several times what it was twenty years ago, and absorbs the greater percentage of the supply of raw material. Previous to these developments, chromite was regarded primarily as furnace construction material, but now more attention is given to it as a metallurgical ore, and the growing list of new uses for chromium alloys has caused a marked development in the metallurgy of the metal.

Another point of similarity with manganese is found in the fact that all of the commercially important deposits of chromium ores are found in countries having little or no local demand for the material, since the steel industry is either nonexistent in the country, or is developed only to a minor degree. This means that the chromium supplies for the important steel-producing countries must be imported from comparatively remote sources. Also, as with manganese, these sources are fairly numerous and widely distributed, there being a score or more of countries that have contributed to the world supply.

Requirements—Uses—Substitutes

Being dependent so largely on the steel industry for consumption, the chromite production fluctuates with the demands of this industry, although the correlation is not as close as in the case of manganese. Inspection of the accompanying graph of chromite production, or of the world production figures in Table I, shows that in the years preceding 1915, and again in 1919 and 1921-1922, the world output averaged about 150,000 metric tons, while in 1916-1918 and in 1920 it rose to an average figure of about 260,000 tons. With the recovery from the post-war depression, production increased rapidly and steadily up to 1929, closely paralleling the growing steel output, and reaching a maximum of 635,000 tons. Beginning in 1930 there was a uniform annual decline, to 305,000 tons in 1932, with a recovery to about 355,000 tons in 1933. Of the period under review, the first half showed a minimum of 131,000 tons, a maximum of 287,000 tons, an average just under 200,000 tons, and a total of 2,059,000 tons. The second half had a minimum of 204,000 tons, a maximum of 635,000 tons, an average of nearly 400,000 tons, and a total of about 4,152,000 tons, or more than double that of the first half.

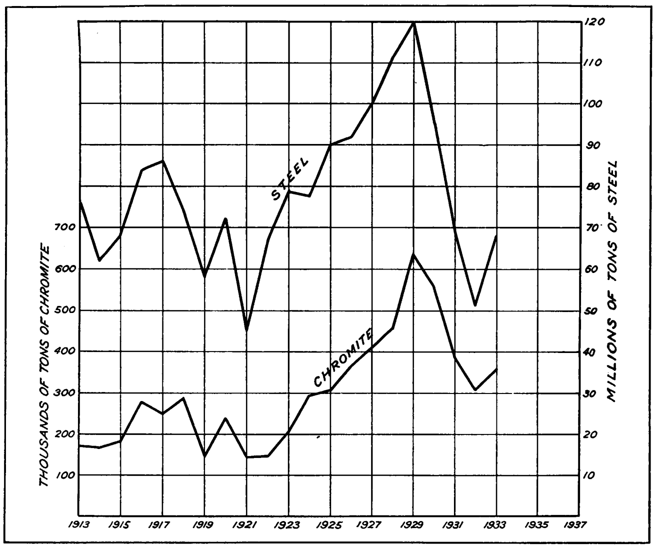
Industrial Uses.—The industrial uses of chromium may be classed under three headings: metallurgical uses, refractory uses, and chemical uses. The chemical uses are small as compared with either of the others. No definite data are available on which a distribution by uses can be made, but estimates of the distribution to consuming industries in the United States have been made at various times. These estimates are as follows:

Percentage Distribution of Chromite by Industries

	1918	*1922*	*1925*	*1927*
Metallurgical industries	52	40	32	46
Refractories industries	17	35	41	41
Chemical industries	31	25	27	13

With the increasing development of new chromium steels, as well as other alloys, the metallurgical uses have taken a decided upward trend during recent years, mostly at the expense of the chemical industries. Previous to the increase in metallurgical demand incident to the World War, refractories consumed the greater proportion. Consumption of chromium has decreased in all lines since 1929, but the graph shows that the chromium output has not decreased at the same rate as the steel output. Such statistics as are available indicate that the production of chromium-bearing steels has been at a higher level than the general average for all steels, while the amounts of chromite used as a refractory would decrease more nearly in proportion to the total steel output; hence it is probable that during the last few years the proportion of the chromium supply going into metallurgical uses has been materially higher than the 1927 estimate cited above. This increased consumption of chromium in alloy steels has been promoted not only by expanding uses for the alloys, but also by the development of alloys using higher and higher percentages of chromium. A ton of stainless steel with 18 per cent of chromium requires as much chromium as 10 to 20 tons of the ordinary chrome steels with 1-2 per cent, and many of the newer alloys call for chromium contents of two and even three times this amount.

Metallurgical Uses.—The leading metallurgical uses of chromium are in alloys in which the other major constituent is either iron, nickel, or cobalt, but in many cases other metals are also incorporated in the composition. Depending on the percentage of chromium used, and on the other alloying agents present, quite a wide variation of properties may be obtained, centering largely around strength, toughness, hardness, resistance to abrasion and wear, resistance to chemical and atmospheric corrosion, resistance to oxidation and mechanical weakness at high temperatures, and high electrical resistance. In some cases only one of these properties is desired, but in others a combination of two or more is needed. For example, in a stainless steel for hospital use, corrosion resistance is the chief requirement, but for architectural use strength also becomes a factor, and in both cases a pleasing appearance is important. In electrical resistance wire, not only the high electrical resistance is essential, but also resistance to oxidation at high temperature. In oil refinery stills strength at high temperature must be accompanied by resistance to oxidation and chemical corrosion at the same temperatures. As a result, there is a multitude of varying compositions on the market, with chromium contents ranging from a fraction of a per cent, up to 50-60 per cent.



World Production of Chromite and of Steel

Some are fundamentally binary alloys, with only minor percentages of other elements, but many have three or four, or even more constituents in their make-up. Some are fundamentally steels—that is, they depend on carbon in amounts up to 3 per cent for some of their basic properties—while in others carbon, if present at all, is merely an impurity that can not be readily eliminated below a certain point, just as is the case with sulfur or phosphorus, and the same may be said of silicon and manganese, after making due allowance for metals added as deoxidizers. Among the other elements added to these alloys, for the sake of some special improvement, are aluminum, copper, molybdenum, nitrogen, titanium, tungsten, vanadium, and zirconium.

Since we are here primarily concerned with the alloys as consumers of chromium, we shall classify them mainly on the basis of their chromium content, with only secondary consideration for the other constituents, or for the specific use for which the alloy may have been designed.

Low Chromium Steels (0.5 to 5 per cent chromium).—The older chromium steels and most of the newer compositions for automotive work, in which high strength and ductility are required, fall within the range 0.5-2 per cent chromium, but certain of the special steels for connecting rods and gears use up to 4-5 per cent. In many cases 1-4 per cent nickel, or small percentages of molybdenum, tungsten, or copper are used in addition to the chromium. The steels used for armor plate and armor-piercing projectiles also come in the lower range of this group.

Cast Chromium Steels (0.6 to 1.1 per cent chromium).—There are several low chromium steels carrying 1-3 per cent of nickel that are used in the cast condition, for work requiring a higher resistance to stress and shock than can be obtained with ordinary steel castings.

Chromium Cast Irons (0.2 to 4 per cent chromium).—Alloy cast irons carrying 0.75-3 per cent nickel in addition to the chromium are now used for many types of high grade castings. A special corrosion-resistant cast iron containing 1.5 per cent chromium, 12-15 per cent nickel and 5-7 per cent copper is used in oil refinery and power plant equipment, and in many of the chemical industries. A high-strength nickel-bearing cast iron for gears, turbine castings and rotors, sheaves, bushings, heavy machinery frames, and similar uses, is sometimes modified by the addition of 0.35-0.8 per cent chromium. An extra hard and tough type of chilled cast iron carries 1.4-1.6 per cent chromium and 4.25-4.75 per cent nickel.

Intermediate Chromium Steels (3 to 12 per cent chromium).—This group includes the high-speed tool steels, which in addition to tungsten carry 3.5-5 per cent chromium, and steels for valves for automotive engines; American steels of the latter type contain 7-9 per cent chromium and 2.5-4 per cent silicon; British steels use up to 12 per cent chromium and 9 per cent nickel, with sometimes the addition of molybdenum. A number of the compositions for steels with mild corrosion or oxidation resistance fall within the range 4-12 per cent chromium, although in most cases the protective action of the chromium is supplemented by 15-35 per cent nickel, or sometimes by small percentages of molybdenum or tungsten.

Stainless Irons (12 to 15 per cent chromium).—These alloys are very low in carbon (usually 0.05-0.12 per cent) and were among the first to be developed in the stainless group. Their marked characteristics are resistance to corrosion and oxidation at ordinary and moderately elevated temperatures; these properties are sometimes modified by the addition of small percentages of nickel, molybdenum or zirconium. In some cases the chromium content is increased beyond the usual range, to 18 per cent, and occasionally even as high as 21 per cent.

Stainless Steels (12 to 18 per cent chromium).—These steels usually carry 0.25-0.4 per cent carbon, but in some cases go considerably higher, even up to 1.15 per cent. The chromium content is also often carried beyond the normal range, up to 30 per cent being used where oxidation resistance is desired at high temperatures. The normal percentage range gives resistance to atmospheric and chemical corrosion, with greater strength and hardness than the stainless irons.

Super Stainless Steels (12 to 30 per cent chromium).—The super stainless steels are modifications of the regular stainless type by the addition of varying amounts of nickel, with sometimes small percentages of aluminum, copper, molybdenum, tungsten, or vanadium. The normal composition of this type of steel, and the one most used, is 18 per cent chromium and 8 per cent nickel, hence the common technical designation of 18-8 steels. In the various commercial brands the chromium varies from 16 to 20 per cent, and the nickel from 7 to 10 per cent. This, however, is not by any means the only composition range used, the details of the compositions varying widely with the variations in the work required of the steel, the degree of corrosion resistance, the particular acids, chemicals, or other agents to which it is to be rendered inert, the degree of oxidation resistance required at high temperature, and the plant practice of the manufacturer. In many cases, chromium contents as low as 12 per cent are supplemented by abnormally high percentages of nickel, particularly for oxidation resistance, the nickel content in this case usually being from 25 to 40 per cent. For high temperature equipment, requiring the maximum of oxidation resistance the chromium usually ranges from 20 to 30 per cent; for the lower chromium percentages the nickel is usually about equal to the chromium content; in the intermediate ranges the nickel is about one-half the chromium; and in the upper ranges the nickel is about one-third the chromium content, although there are numerous variations from this generalization.

Chromium-Nickel Ferrous Alloys (14 to 30 per cent chromium).—As the chromium and nickel contents of the super stainless steels increase, they gradually merge into alloys that can hardly be considered as steels; while there is no specific point at which a division can be made, it is convenient to consider the upper limit of the steels as 50 per cent chromium plus nickel, and to designate those compositions in which iron is definitely in the minority as ferrous alloys of nickel and chromium. These alloys are mostly used for high temperature work, and contain 14-20 per cent chromium and 60-80 per cent nickel, although some have nickel contents as low as 35-45 per cent.

Electrical Resistance Alloys (8 to 20 per cent chromium).—A section of the chromium-nickel-iron alloys group, with 8-20 per cent chromium, 54-80 per cent nickel, and the remainder iron, have been extensively used as resistance elements in all types of electrical heating equipment, due to their combination of high electrical resistance and freedom from oxidation at elevated temperatures. While the percentage range is such as would include these alloys in the preceding group, their special properties and applications justify this separate designation for them.

Chromium-Cobalt Alloys (20 to 35 per cent chromium).—After having undergone a certain amount of variation in composition in the course of their development, these alloys have largely settled down to a content of 30 per cent chromium, 50-65 per cent cobalt, with tungsten (and sometimes molybdenum) for the remainder. This makes an exceedingly hard alloy, which is used as a substitute for tool steel for very heavy work, and, when spread in place by electrical or oxy-acetylene welding, as a surfacing material for all types of equipment subject to heavy wear by abrasion. The alloys also have a considerable resistance to chemical corrosion by many acids and chemicals, making them useful where corrosion resistance is needed along with abrasion resistance.

Chromium Metal (97 to 100 per cent chromium).—The so-called chromium metal of commerce is usually 96-98 per cent pure. It has no use as such, but is used in the compounding of non-ferrous chromium alloys in which very little iron is permissible.

The only commercial use of 100 per cent pure chromium metal is in the form of an electroplate on other metals. This, however, does not call for anode material of corresponding purity, as is the case in electroplating with other metals, such as nickel and copper. Because of its characteristic high resistance to corrosion, which makes chromium so useful in the production of permanent alloys, which owe their immunity to corrosion largely to their chromium content, chromium anodes can not be dissolved in the plating bath, and the metal as it is deposited from the bath must be replenished by addition to the bath in the form of a chromium salt, usually chromic acid, CrO_3. This results in the rather contradictory condition that the only commercial use of the pure metal appears as a part of the chemical side of the industry, rather than of the metallurgical. Although chromium plating has become an operation of wide application and great industrial importance, the layer of metal deposited is so thin (0.000002-0.0005 inch) that the amount of metal consumed is insignificant.

Refractory Uses.—The second largest use of chromium is in its crude form, as chromite, in refractory materials for furnace construction. In some cases the entire furnace hearth has been built of chromite, but the commoner application is as an insulating layer between a basic hearth and an acid roof, since the chromite is neutral in composition, and will not react with either hearth or roof. Most of the chromite used as a refractory is in the form of bricks, but crushed chromite and chromite cements are also used to some extent.

In the past, consumption of chromite refractories has been considerably restricted by high prices. Twenty years ago chromite brick cost four to five times as much as magnesite, limiting the use to places where magnesite would not serve the purpose. Since about 1922, prices have been more nearly on a par, and this has resulted in an increased use of chromite, particularly since 1927. For some time the price of chromite bricks has been less than that of magnesite, and this has led to still greater use, even to a point of substitution of chromite for magnesite in uses that formerly were considered as belonging to magnesite alone. In 1918 the price of chromite brick rose to a point where they cost in excess of $1 each, and naturally their use was restricted as much as possible, as is indicated in the table of distribution by uses. Since then, declining prices have permitted increased use, and the proportion absorbed by refractory uses has grown at the same time that total uses were expanding rapidly, so that the amounts used in refractories in 1927 were about three times the amount used in 1922.

Chemical Uses.—Chromium goes into a number of chemicals for industrial use, of which the following are the more important:

Chromates and bichromates are used extensively in dyeing and tanning, bleaching oils, treating boiler feed water, as an oxidizing agent (bichromates), as paint pigments, and in the production of other chromium chemicals.

The oxide Cr_2O_3 is used in the production of pure chromium metal, and also as a pigment; the oxide CrO_3 and the sulfate are used in making up chromium plating baths, and the basic sulfate is used in tanning.

The acetate, chloride and double sulfate (chrome alum) are used in dyeing and tanning.

Military Uses.—The military uses of chromium are all directly connected with the corresponding industrial uses. Chrome steel, on account of its hardness and toughness, is used in the production of armor plate and armor-piercing projectiles, and during recent years there has been considerable use of stainless steels in naval construction. As a chemical, chromium is important in the tanning of leather for shoes and other items of military equipment. Also important from a military standpoint is its use as a dye for olive drab cloth.

Substitutes.—There has been little direct work done in the development of substitutes for chromium. In case of necessity, certain of the other alloy steels might be made to serve in place of the low chrome steels, but for armor plate and the stainless steels there is no adequate substitute. For some types of equipment requiring resistance to chemical corrosion certain other alloys may be used, particularly high silicon cast irons, but the physical properties of these are such that their applications are much restricted. As an electrical resistance material there is nothing as good as the nickel-chromium alloys for the higher temperatures. Other alloys are available for lower temperatures, but their resistivity is materially lower, and in addition, most of them contain appreciable amounts of nickel, so that their use would depend on the supply of that metal, as well as of the chromium. In the refractory field, magnesite may be substituted for many uses where the physical properties, cost, and availability are the deciding factors, but where the chemical neutrality of chromite is required, there is nothing that can replace it.

Chromium Ores

The only commercial ore of chromium is chromite, $FeO.Cr_2O_3$, which when pure carries 68 per cent Cr_2O_3 and 32 per cent FeO. As it occurs in nature these constituents have always been partly replaced by others, chiefly alumina (Al_2O_3), ferric oxide (Fe_2O_3), magnesia (MgO), lime (CaO), and silica (SiO_2), bringing the Cr_2O_3 content down to 45-55 per cent, or even lower. For purposes of rough comparison the general average of chromite production may be considered about 45 per cent Cr_2O_3, or 30 per cent metallic chromium. Deposits of chromite are found in numerous countries, although only a few of them are rich enough or large enough to be worked consistently; the more important of these deposits will be discussed briefly in a later section of this article.

At the present time Indian ores are quoted on a basis of 45-47 per cent Cr_2O_3 or 50-51 per cent; Russian ores, 45 per cent and 48 per cent; Rhodesian ores 48 per cent, and New Caledonian 55-57 per cent. Silica is usually limited to 5 per cent, as a high silicon content would be undesirable in ferrochromium when used for the making of many alloys. Other impurities, such as magnesia, alumina and lime, are objectionable chiefly because they increase the slag volume in smelting, and thus complicate and increase the cost of the smelting operation. For the manufacture of ferrochromium, as will be pointed out later in this discussion, a certain amount of magnesia is desirable.

Domestic ores are low in chromium and high in iron, and, hence, are little in demand except when there is a decided shortage in the supply from other countries.

As is the case with manganese, there are enormous supplies of iron ore carrying small percentages of chromium, particularly in Cuba and Celebes. While these deposits are of no present value as a direct source of chromium, they yield a pig iron to which the chromium content imparts exceptional qualities, and the uses for which are gradually growing. They also provide a reserve of low grade chromium which future developments may make available as metal.

Beneficiation.—The replacement of the normal constituents of chromite by impurities falls into two definite classes, depending on whether it is the FeO or the Cr_2O_3 that is replaced. The FeO may be replaced by magnesia, or to a lesser extent by lime, while the Cr_2O_3 may be replaced by alumina or ferric oxide, and in addition to these there may be varying amounts of silica present. The combined action of these impurities frequently reduces the normal 68 per cent of Cr_2O_3 to such a point that the ore is useless unless it can be improved by ore-dressing methods.

The response of a chrome ore to beneficiation depends greatly on the character and extent of the impurities present. Purely mechanical impurities, like silica, are fairly readily removed, but as a rule silica is a minor impurity, although cases are known where it runs as high as 10-20 per cent. The impurities received by chemical replacement are more difficult to handle, and if the replacement is uniformly disseminated throughout the body of the ore, little can be done; but if the replacement is not uniform, and has been carried to an extreme in certain portions of the ore and not in others, some separation of the poorer parts may be effected. For example, a complete replacement of the Cr_2O_3 by Fe_2O_3 would give magnetite, which can be removed by magnetic separation; and a complete replacement by Al_2O_3 would give a product responding to gravity concentration.

A moderate replacement of FeO by MgO is an advantage, rather than a disadvantage, in a metallurgical ore, since it improves the Cr:Fe ratio of the ore, and makes it possible to produce a higher grade of ferrochromium. Since the Cr:Fe ratio desired in the ferrochromium is 2:1 or better, and since there is some loss of chromium in the smelting operation, the ore for metallurgical use should have a Cr:Fe ratio of about 2.5:1. As the Cr:Fe ratio in pure chromite is about 1.9:1, an ore with some FeO replaced is required for the best grades of metallurgical ore, and the more Cr_2O_3 replacement there has been in the ore, the more FeO replacement is required to offset it, in order to maintain the desired Cr:Fe ratio, particularly if the Cr_2O_3 replacement has been by Fe_2O_3 rather than by Al_2O_3.

Too much iron in the ore not only spoils it for metallurgical use, but also may reduce the normal infusibility to a point where the ore is of no value as a refractory. The Cr:Fe ratio in refractory ores varies within wide limits, depending on the temperature to be withstood and the particular combination of impurities in the ore, but roughly 2:1 may be set as the upper limit and 1:1 as the lower limit, although the latter is greatly influenced by the fusibility of the impurities present.

While beneficiation may be satisfactorily applied to many low grade ores to bring them within the limits set for the various requirements, no general rules can be laid down, for the response of each ore to concentration methods is determined by the character, extent, and distribution of the impurities, as well as by the methods applied. Beneficiation was used quite extensively on low grade ores during the war period, especially in the United States and Canada, the treatment usually being confined to crushing and gravity separation. Due to the intimacy of the mixture of the impurities in most cases of chemical replacement, mechanical separations are limited in their application, and economic considerations have prevented the use of chemical methods of beneficiation such as have been tried out with manganese, but as yet without any very great degree of success.

Another point of considerable importance in the beneficiation problem is the fact that while mechanical methods may improve the Cr_2O_3 content of the ore, they usually increase the iron content in about the same proportion, so that the Cr:Fe ratio is not improved. The chief exception to this rule is found where magnetite can be removed from the ore.

Metallurgy.—The so-called chromium metal of commerce may be produced by the reduction of Cr_2O_3 with carbon in the electric furnace or, if a very low carbon content is desired, by reduction with aluminum in the thermic process. Various chemical methods are possible, but are little used, as they involve the separation of the reduced metal from other products of the reaction, and the fusion of the chromium. Pure chromium is produced only by electrodeposition of the metal from a solution of a chromium salt, and is not available except as a plating on other metals; it is not produced in thicknesses great enough to be stripped from the cathode and marketed.

Most of the chromium is placed on the market in the form of ferrochromium, of which the standard grades carry 66-72 per cent chromium, varying percentages of carbon, up to 0.5 per cent manganese, and 2.5 per cent silicon, and the remainder iron, except for small amounts of impurities such as sulfur and phosphorous. Most of this alloy is produced by smelting chromite in the electric furnace with appropriate fluxes, and with carbon as a reducing agent. Since chromium has a high affinity for carbon the product normally carries 4-6 per cent C; if lower percentages are required, as is necessary in the compounding of many alloys, particularly the low-carbon stainless irons and steels, the ferroalloy is resmelted with an oxidizing slag to remove carbon to the desired extent, or the alloy is produced by the use of aluminum or silicon as a reducing agent in place of carbon. Since the latter is more expensive, the former is the method most used.

Forms in which Chromium Appears on the Market.—The chromium metal regularly quoted in the market carries 96-98 per cent chromium. It is cast into a slab when produced, and broken into lumps.

Ferrochromium is listed in three grades: 66-70 per cent chromium and 4-6 per cent carbon; 67-72 per cent chromium and 2 per cent carbon; and a maximum of 0.1 per cent carbon.

As already stated above, the ore is listed in various grades, according to the sources from which they are derived.

For refractory use, a special grade of Grecian ore is listed, as are also chromite brick and chromite cement.

Although a wide variety of chromium chemicals are listed by laboratory supply houses, only a few of these are of industrial importance, as mentioned above under chemical uses. The various chromium pigments are also listed in publications in the paint trade.

Secondary Production.—There is no wide-spread public junk-pile recovery of chromium alloys of any kind, such as exists for many of the more important metals, like nickel, lead, copper, and iron, but there is a considerable recovery of used material among the heavier industrial consumers of the metal. The comparatively high value of the metal assures a fairly complete recovery of scrap among manufacturers and fabricators of the alloys, and consumers of any great amount of the alloys, particularly in units of appreciable weight, such as car-

TABLE I
WORLD PRODUCTION OF CHROMITE
(In thousands of metric tons)

	Canada	*Cuba*	*Greece*	*India*	*Japan*	*Russia*	*Southern Rhodesia*	*South Africa*	*Turkey*	*Yugoslavia*	*United States*	*World[2] Total*
1913	—	—	7	6	1	15[3]	63	—	14[3]	[1]	[1]	171
1914	[1]	—	7	6	2	15[3]	49	—	14[3]	[1]	1	167
1915	11	—	10	4	3	15[3]	62	—	14[3]	[1]	3	181
1916	25	[1]	10	20	8	15[3]	81	—	14[3]	1	48	279
1917	33	[1]	10	27	9	[5]	66	—	[5]	2	44	250
1918	20	9	3	59	6	14	28	—	14	1	84	287
1919	8	15	4	37	6	4	32	—	4	—	5	145
1920	10	1	12	27	4	3	55	—	25	[1]	3	239
1921	3	1	8	35	3	4	46	1	10	[1]	[1]	141
1922	1	—	9	23	4	1	85	[1]	3	[1]	[1]	146
1923	3	11	15	55	5	3	88	—	—	[1]	[1]	205
1924	—	20	15	46	5	12	157	5	3	[1]	[1]	291
1925	—	30	8	38	6	30	123	14	8	12	[1]	308
1926	—	37	20	34	7	30	164	12	7	16	[1]	364
1927	—	17	17	58	10	19	198	17	18	9	[1]	410
1928	—	34	21	46	10	22	199	32	12	17	1	457
1929	[1]	54	24	50	9	53	266	64	16	43	[1]	635
1930	—	42	23	51	11	67	206	14	28	52	[1]	559
1931	—	15	6	20	10	67[3]	82	23	25	58	[1]	384
1932	[1]	1	2	18	12	68[3]	16	19	55	44	[1]	305
1933	[1]	24	14[4]	16	15	68[3]	35	34	88	23	[1]	355[3]

[1]Less than 500 tons.
[2]Including output of minor producers.
[3]Estimated.
[4]Exports.
[5]Data not available.

burizing boxes, cyanide and lead pots, retorts, heavy electrical heating units, furnace equipment, et cetera. These make a regular practice of returning worn out parts to the makers for credit on the scrap value, which amounts to 10-20 cents per pound, or in some cases more, depending on the composition of the alloy. There is no information available as to the amounts of metal that are recovered for reuse in this way.

It is quite probable that as the expanding demands for the high chromium steels put more and more metal into everyday use, a more extensive secondary recovery program will be built up, particularly as so many of the chromium alloys also carry large percentages of nickel, which materially increases the value of the scrap. There is also a possibility of developing a secondary recovery of chromium salts from the solutions used in dyeing and tanning.

In addition to the regular secondary supply, the newer uses of chromium alloys, particularly the more decorative ones, and the more specialized applications, as in cooking utensils, are gradually building up a potential reserve of metal in use that can be drawn on in case some future emergency should demand a shift from non-essential to essential uses.

World Output and Supply

In the years immediately preceding the World War the world output of chromite was gradually increasing, having passed the 100,000-ton level in 1906, and reached 171,000 metric tons in 1913. War demand raised this to 287,000 tons in 1918, and the post-war depression dropped it to 141,000 tons in 1921. From 1922 to 1929 there was a rapid increase in demand, due to the superposition of many new developments in the use of chromium on top of the generally increasing industrial demand, and in 1929 the output reached a top figure of 635,000 tons. The next three years showed successive uniform decreases, to 305,000 tons in 1932, while 1933 brought a recovery to about 355,000 tons.

As nearly as can be ascertained from the figures available, the total output to date of chromite from all producers has been about 8,700,000 metric tons, of which about 2,400,000 tons was produced before 1913, and about 6,300,000 tons from 1913 to 1933. The percentage distribution of this output among the producing countries in the three periods is shown in the second, third, and fourth columns of Table II, while the first column shows the date when production began in each country, or the date when the first statistics are available. In addition, in order to give more detail during the period 1913-1933, in which we are most interested, the remaining columns show the percentage of the total output contributed by each country at the various critical years of the period—pre-war, 1913; at the peak of war demand, 1916-1918; the post war depression, 1921; the peak of inflation, 1929; and the turn of the depression in 1932 and 1933—where the amount contributed by the country is 1 per cent or more of the total. Following the status of each country through these various stages gives an interesting picture of the response of the producing facilities to current conditions affecting production, of which more will be said in the discussion of individual countries.

TABLE II

PERCENTAGE DISTRIBUTION BY COUNTRIES OF TOTAL WORLD PRODUCTION OF CHROMITE

	Date	*Total to 1913*	*Total 1913-1933*	*Total to Date*	*1913*	*1916-1918*	*1921*	*1929*	*1932*	*1933*
United States	1827	12	3	6	—	20	—	—	—	—
Turkey	1860	27	6	12	8	5	7	3	18	25
New Caledonia	1875	25	16	19	37	19	20	8	23	14
Russia	?	17	8	11	9	4	3	8	22	19
Greece	1881	5	4	4	4	3	6	4	1	?
Canada	1886	2	2	2	—	10	2	—	—	—
India	1903	2	11	7	3	13	25	8	6	5
Rhodesia	1906	8	34	27	37	21	32	42	5	10
Cuba	1916	—	5	3	—	—	1	8	—	7
South Africa	1921	—	4	3	—	—	1	10	6	10
Yugoslavia	1925	—	4	3	—	—	—	7	14	6
Others	——	2	1	1	1	2	1	1	1	?

Southern Rhodesia.—Chromite production in Rhodesia began in 1906, and by 1909 had reached second place in the list, with 23,000 metric tons against 39,000 tons in New Caledonia; in 1910 the two were about on a par, and in 1911 Rhodesia took the position of leading producer, with an output that increased rapidly, reaching 63,000 tons in 1913, or 37 per cent of the world total. Since then Rhodesia has held first place in most years, but it was not until the recovery following the post-war depression that the gap between the two became so large, due to rapid expansion on the part of Rhodesia, while recovery in New Caledonia was slow, not reaching the war-period level until 1928, by which time Rhodesia had risen to 48 per cent of the world total. During the war period the Rhodesian output decreased materially, and with a generally increasing output elsewhere, Rhodesia's share for this period dropped to 21 per cent, with a minimum of 10 per cent in 1918. The reaction to the 1930 depression was also very pronounced; although the output dropped from 266,000 tons in 1929 to 82,000 tons in 1931, this was still the leading figure, but in 1932 Rhodesia dropped to seventh place, with only 16,000 tons, or 5 per cent of the total. Reaction to the recovery was evident in 1933, the output being 35,000 tons, or 10 per cent of the total.

The chromite deposits of Southern Rhodesia lie on or near the Great Dyke, an outcrop of basic rock about 4 miles wide and stretching across the central part of the country for a distance of 330 miles in a southwest-northeast direction. The bulk of the output is from the vicinity of Gwelo and Victoria, near the southern end of the dyke, with a comparatively small amount from the region of Lomagundi and Hartley, in the northern section. There is no local consumption, and the entire output is exported, mostly by rail to the port of Biera, in Portuguese East Africa, and thence by boat. Published analyses of Rhodesian ores show a composition ranging from 45 to 55 per cent Cr_2O_3. Total production to the end of 1933 was about 2,300,000 metric tons.

New Caledonia.—Chromite production began in New Caledonia about 1875, and, with that of Turkey, and to a lesser extent Russia, furnished the greater part of the world supply until development was started in Rhodesia. New Caledonia supplied 25 per cent of the total output recorded up to 1912, and 16 per cent during 1913-1933. In 1913 the New Caledonian percentage reached 37 per cent, and in 1914 was 43 per cent, but due largely to the remoteness of the source and the consequent transportation difficulties, production declined during the war period. Even after the post-war depression it did not show much recovery until 1925, except for a brief boom to 40 per cent in 1920. In the meantime, the expansion of the demand had increased outputs in other countries, particularly Rhodesia, to such an extent that even though the New Caledonian figures materially improved, the 1929 output was only 8 per cent of the world total, against 20 per cent in 1921, 19 per cent during the war, and 37 per cent in 1913. New Caledonia was almost the only producer to show a marked improvement in output after 1929, and this continued increase and the simultaneous decreases in other countries brought the 1932 proportion up to 23 per cent, but this was followed by a decline to 14 per cent in 1933, when most of the other producers were showing increases.

The ores range from 42 to 57 per cent Cr_2O_3, and the higher grades furnish most of the world's supply of ore for chemical uses. Total production to date is about 1,620,000 metric tons.

Turkey.—With production dating back to 1860, Turkey was for many years the leading producer, and furnished 27 per cent of the world supply up to the year 1912, although during the later years New Caledonia and Rhodesia were gradually forging ahead; the results of this transition are shown in the 6 per cent of the total output furnished by Turkey during 1913-1933, and it was not until within the last few years that operations again became active. Turkey's proportion of the total output increased from 3 per cent in 1929 to 18 per cent in 1932 and 25 per cent in 1933, and in the latter year headed the list.

The ore deposits are rather widely scattered over Asia Minor, especially in the north, near the Sea of Marmora, and in the south, along the Mediterranean coast, with a few scattered deposits in outlying districts. Most of the current development is in the first named group. Several mines furnish ore with 50-52 per cent Cr_2O_3, while others range from 43 to 50 per cent. Production to date is estimated at 1,040,000 metric tons.

Russia.—Although the leading producer of chromite in 1907, Russia was superseded by New Caledonia and Rhodesia, and after the collapse of the Czarist government the output was only nominal for a number of years. The first year to show an important tonnage was 1925, and while there was a decline in 1927 and 1928, the output has since more than doubled. Consistent with the current Soviet policy of expanded mineral production, which ignored declining outputs in other countries, Russia increased her share of the world total from 8 per cent in 1929 to 22 per cent in 1932, declining to 19 per cent in 1933, not from any decrease on her own part, but only because of the partial recovery in other countries, with increases in their outputs.

The leading deposits are in the Urals, but smaller occurrences are known, and have been worked to a limited extent, in other regions, particularly Orenburg, Bashkirian, and Kazaksky. The concentrates produced range from 42 to 48 per cent Cr_2O_3. Russia probably has the largest domestic consumption of any important chromite producer; about half of the output is used in the production of ferrochromium at Cheliabinsk and in chromium chemicals at Shaitansky, and the remainder is exported. Production to date has totaled about 930,000 metric tons.

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Loading Chrome Ore from Lighters at Néhoué, New Caledonia

India.—Chromite production in India was only a few thousand tons a year until the war period, increasing to 59,000 metric tons, or over 20 per cent of the world total, in 1918, and averaging 13 per cent of the total during 1916-1918. This increased to 27 per cent in 1921, when India was the second largest producer, but dropped to 8 per cent in 1929 and 6 per cent in 1932.

The principal deposits are in Mysore, most of the ore averaging 52-53 per cent Cr_2O_3. Smaller deposits in Baluchistan yield ore of 50 per cent grade or better, and still smaller ones are worked in Bihar and Orissa. There is little local consumption, and practically the entire output is exported to Europe and the United States, mostly through Indian ports, with smaller amounts through Mormugao, in Portuguese India. Total production to date has been about 635,000 metric tons.

United States.—Chromite was discovered in Maryland in 1810 and mining was begun near Jarrotsville in 1827, for use in the manufacture of yellow and green paint pigments. Later, other deposits were discovered, and although the production was small as compared with present-day standards, the United States became the world's leading producer, and continued to hold the lead until the Turkish deposits were developed. The output then gradually declined, and ceased entirely in 1897; in 1900 production was renewed, but remained on a small scale until the war period. In 1918, the year of maximum output, mine production was 127,000 metric tons, of which only 84,000 tons was shipped, the excess remaining in stock at the mines.

Up to 1912 it is estimated that the United States had produced 12 per cent of the total recorded output, but since then the proportion has been only 3 per cent, nearly all of which was during 1916-1918, when the United States output was 20 per cent of the total. Total production to date has been 486,000 metric tons.

The bulk of the later production has been from California. The deposits are small and widely scattered, and most of them can be worked only when the product commands an exceptionally high price, which accounts for the small output in normal times. The small size of the individual deposits and their scattered character can be judged from the fact that the 1918 shipments were contributed by four hundred and fifty shippers, distributed as follows: California, three hundred and seventy-four; Oregon, sixty; North Carolina, five; Montana, three; Pennsylvania-Maryland, three; Alaska, three; Georgia, one; Wyoming, one; and Washington, one. The ore varied widely in grade, from as low as 20 per cent to as high as 55 per cent; of the total mine output about one-quarter was better than 45 per cent, one-half ranked between 35 and 45 per cent, and one-quarter contained less than 35 per cent. The average of the 1918 shipments was 42 per cent.

Greece.—Although one of the older producers, Greece has never had a large output, its proportion of the world total usually ranging from 3 to 6 per cent, but in 1932 it dropped to less than 1 per cent. The maximum output was 24,000 metric tons in 1929. The deposits lie mostly along the eastern coast, approximately in a line with the Serbian deposits to the north. Although there are numerous small and scattered deposits, the main output is from two mines in Thessaly. The ore is only of moderate grade, much of it running 38-42 per cent Cr_2O_3, and is used mostly for refractories. Production to date is about 370,000 metric tons.

Cuba.—A small output of chromite was developed in Cuba during the war period, and was then discontinued, but in 1923 active operations were begun again, with a gradual increase in output to 54,000 metric tons or 8 per cent of the world total in 1929. Later, during the depression, production declined, and almost ceased in 1932, but recovered to 24,000 tons in 1933, or 7 per cent of the world total. Production to date has been 300,000 metric tons.

The chief Cuban deposits are in Camaguey Province, with less important ones in Oriente and Matanzas. The ore is of low grade, 33-43 per cent Cr_2O_3. In addition to the chromite output there are extensive deposits of iron ore carrying small percentages of chromium and nickel, which, while not recoverable separately, appear in the pig iron reduced from the ore, with corresponding improvement in the quality of the iron.

South Africa.—Beginning in 1924, South Africa built up an output of 64,000 metric tons by 1929, or 10 per cent of the world total, but declined to 6 per cent in 1932, recovering again to the former figure in 1933. Practically the entire output is from Transvaal, and averages about 43 per cent Cr_2O_3. A small tonnage of 56 per cent ore is produced in Natal. Extensive reserves indicate that in the future South Africa will likely be a strong competitor of its neighbor Rhodesia in the world markets. Production to date has been 233,000 metric tons.

Yugoslavia.—While there was a minor pre-war output of 200 to 500 tons of chromite in Bosnia, production from the territory now included in Yugoslavia did not become important until 1925, increasing by 1929 to 43,000 metric tons, or 7 per cent of the world total, and to a maximum of 58,000 tons in 1931. Although production declined in the succeeding years, this was largely offset by decreases in other countries, with the result that the output in 1932 was 14 per cent of the total, and in 1933 was 6 per cent.

In addition to the deposits formerly worked in Bosnia, mostly in the Dubostica Valley about 25 miles north of Sarajevo, there are a series of deposits extending from Užice and Čačak southward along the Kapaonik Mountains through central and southern Serbia, and across the Macedonian border into Greece.

Canada.—Chromite deposits are known in Quebec, Ontario, and British Columbia, most of the production having come from those in Quebec. Only during the war period was the Canadian output of importance, amounting then to 10 per cent of the world total, with a maximum of 33,000 metric tons in 1917; a minor production was maintained from 1886 to 1911, and later, from 1914 to 1923 the war period output was built up and then died away.

Japan.—Chromite production began in Japan in 1907, gradually increasing to 12,000 metric tons in 1932. The output has never been large enough to be of importance in the world market, and is of interest chiefly because it is sufficient to make local consumption practically independent of foreign supplies.

Other Countries.—The occurrence of chromite has been reported in numerous other countries, widely scattered over the world, and a small amount of production has been made at various times from a number of these, some with a fair degree of regularity. Among the localities in this list are Algeria, Argentina, *Australia,* Borneo, *Brazil,* Celebes, Ceylon, Chosen, Colombia, *Cyprus,* Czechoslovakia, Dominican Republic, Egypt, France, Germany, Greenland, *Guatemala,* Indo-China, Italy, Mexico, Newfoundland, New Zealand, *Norway,* Palestine, Persia, *Philippines,* Portugal, Rumania, *Scotland,* Sierra Leone, Spain, Sweden, Syria, and Togoland. The length of this list is quite impressive, but the outputs that have been made are insignificant in most cases. The names given in italics indicate the localities that made the more important contributions to the supply during the World War period, and those that have since seemed worthy of consideration in the event of a future emergency demand.

(*To be continued*)