McMASTER UNIVERSITY

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

A DISSERTATION
SUBMITTED TO THE ARTS FACULTY
IN CANDIDACY FOR THE DEGREE OF
MASTER OF ARTS

DEPARTMENT OF GEOLOGY

BY
E. LLOYD BOWLER

BRANDON, MANITOBA.
APRIL, 1932.

TABLE OF CONTENTS

...

PART I

...

INTRODUCTION

...

PART II

...

OCCURRENCE AND GENESIS OF COPPER DEPOSITS

...

...

TABLE OF CONTENTS
(continued)

...

PART III

...

THE METALLURGY OF COPPER

...

PART IV

...

USES OF COPPER

...

...

TABLE OF CONTENTS

(concluded)

...

PART V

...

PRODUCTION, CONSUMPTION, AND CONTROL

...

...

PART VI

...

THE FUTURE OF THE COPPER INDUSTRY

...

... ...

LIST OF TABLES

.. ..

.. ..

LIST OF CHARTS

... ...

... ...

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

PART I

INTRODUCTION

I. INTRODUCTION

HISTORICAL.

Many divergent opinions have been expressed concerning the possible priority of the use of copper or iron in the early history of mankind. Too often have archaeologists based their conclusion solely upon the relative abundance of these metals, which have since been found in ancient ruins, especially in graves and tombs. It is true that among such remains copper has usually proven to be the more predominant metal. This need not, however, be too readily regarded as an indication of its earlier use by mankind, as some writers have been prone to conclude. The higher corrodibility of iron as compared with copper, and particularly with its alloys, would tend to destroy evidences of that metal within a relativeely short time. Furthermore, it must be remembered that it was the custom of early peoples to place in the graves of their kindred, articles of intrinsic value, and this practice would tend to account for the absence of iron in such ruins. Excavations of the Lake Dwellings of Switzerland have revealed intermingled remnants of both stone and bronze implements. It has been found however, that the latter are of such perfection as to be attributable only to a later civilization, and thus they were probably introduced at a subsequent date. Moreover, from the standpoint of economic geology and metallurgy it would seem that the use of either iron or copper would depend largely upon the nature and accessibility of the particular deposits, as well as upon the cultural background of the people. Ordinarily, iron can be more readily reduced and worked than copper, while the production of bronze requires considerably more skill, and tin, an essential constituent of the alloy, has never been an abundant metal.

It would seem therefore, that under certain conditions iron might feasibly have been the first metal worked and utilized by mankind, while under other circumstances copper might have predated it. With different environments and the varying availibility of the metals, either the iron or the copper might have been the predecessor in a particular region.

The assignment of distinctly successive ages to the developement of mankind has likewise been somewhat unduly emphasized. Hesiod, the Greek poet, writing about 700 B.C., outlined in fable the early history of mankind, dividing it into separate ages to which he applied the names "Golden age", "Silver age" , "Bronze age", and the present "Iron age". Such writings have been sometimes taken too seriously and the belief that man became acquainted with the metals in the order gold, silver, bronze and finally iron, has not been uncommon, but this order has been disproven by archaeological research. It would also seem somewhat fallacious to assume in the history of mankind the successive occurrence of a "Stone age", a "Copper age" or an "Iron age" as coincident in time over the surface of the earth. Such a succession of ages would imply a uniformly similar cultural development of all the widely scattered masses of mankind. This has not been substantiated by history. Moreover, at the present time in parts of Africa and in some Pacific islands certain isolated races are to be regarded as little beyond their "Stone age" while but a few thousand miles distant are to be found highly civilized and cultured races. If, therefore, any definite succession of these ages is applicable, it must be applied to distinct peoples and not to humanity in general.

In ancient Babylonian ruins, the records of which date back to 5000 B.C., copper has been found along with gold ornaments and stone tools. Concerning a contemporaneous or probably later race, James H.Breasted in his book "AHistory of Egypt" (1905) writes about the "pre-dynastic Egyptian" race, which had previously been invaded by the Semitic race from Asia in an epoch lying far beyond our historic horizon. He describes their remains as being decidedly indicative of a knowledge of the production and use of copper implements, and suggests their age as being one of slow transition from stone to copper. The time of this period is from 4500 to 4000 B.C. Here it is to be noted that bronze was not found, and, in view of the fact that this alloy is even less susceptible to corrosion than is copper, it would seem apparent that it was then unknown. Even in the third and sixth dynasties, (2980-2475 B.C), Breasted states that bronze was not used. It is probable, however, that by the end of the year 2300 this alloy had come into use, likely having originated with the Semitic race in ancient Babylonia. It was introduced into Egypt about 2000 B.C.

The most ancient mines known are the Egyptian copper mines in the Valley Wadi Meghara, in the Sinai peninsula. Their beginning was probably before 5000 B.C. and they seem to have become exhausted about 1300 B.C. From about 1600 to 1400 B.C. copper mines were also worked on Mt.Sinai, the ores being mostly oxidized and therefore easily worked. The Phoenicians were the greatest commercial people and the most skilled metallurgists of the ancient world. Those of Sidon founded a colony on the island of Cyprus about 1300 B.C. and there they extensively mined and smelted copper ores. They were also skilled in the making and casting of bronzes, most of which alloy having about 90 percent copper and 10 percent tin, was characterized by its great toughness and strength. As indicated in the legends of the Iliad and the Odyssey of Homer (900 B.C.) the Greeks even in prehistoric times were familiar with copper, but bronze was unknown. The latter was introduced by the Phoenicians at a somewhat later date. Since ores with intimately mixed minerals of copper and zinc occur on Cyprus and other islands along the coast of Asia Minor, it seems probable that the Greeks were early familiar with zinc in the form of an alloy with copper, i.e. brass.

At the time of the supremacy of Rome in the civilized world, the use of metals for armour, tools, implements, money, and for certain structural purposes, had become widespread. Spain was the most prominent mineral producing province, and in Huelva great copper mines, previously worked by the Phoenicians, were later operated by their Roman successors over a period of 400 years, until about 412 A.D. The slag dumps of this time contained about 18,000,000 tons. The largest operations were at Rio Tinto and Tharsis from which fields it has been estimated that the average annual production by the Romans amounted to 2400 tons. From these primitive beginnings modern mining and metallurgical practices have gradually attained their present status. Discovery of the alloying qualities of copper and of the many technical applications of the metal have greatly increased its commercial importance. The introduction of electricity alone has provided a very great impetus to the development of the copper industry. Increasingly large quantities of copper of an improved quality are continually being produced, with the result that the output of the last two decades was considerably greater than all previous production of the metal.

DESCRIPTIVE.

According to Pliny, the Roman historian, much of the Roman supply of copper came from Cyprus and then became known as "Aes Cyprium" (Cyprium copper). This name was gradually shortened to "Cyprium" and later corrupted to "Cuprium", whence has been derived the English term "Copper", the French "Cuivre" and the German "Kupfer".

The Metal: Copper is a brilliant metal of a peculiar red color which assumes a pinkish or yellowish tinge on a freshly fractured surface of the pure metal. It takes a brilliant polish, is highly malleable and ductile, and in tenacity second only to iron. As an electical conductor copper stands next to silver, of which the conducting power is set at 100, while that of perfectly pure copper is 96.4 at 13°C.[1] Another feature of copper which is of commercial significance is its resistance upon exposure; in dry air it is unaffected, while in moist atmosphere containing carbon dioxide it becomes coated with a green basic carbonate.

Ore Minerals: "Copper ore" may be defined as an accumulation of metalliferous minerals in which the copper content is of sufficient economic value and in such quantity as to render extraction profitable under the prevailing conditions. The term " ore mineral of copper " applies to any mineral carrying that valuable metal. Copper-bearing minerals are numerous and widely though irregularly distributed. Moreover, copper frequently occurs with many different metals under varied conditions. There are, however, but relatively few ore minerals of commercial importance, while the number of copper producing districts is likewise comparatively small.

---

[1] Encyclopaedia Britannica. Vol.Vll. (1910-11).

The ore minerals of copper, together with their theoretic composition and percentage of copper, are as follows:[1]

TABLE I

Ore Mineral	Composition	Per Cent Copper.
Chalcopyrite	$CuFeS_2$	34.5
Chalcocite	Cu_2S	79.8
Bornite	Cu_5FeS_4	63.3
Enargite	$3Cu_2S.\ 2As_2S_3$	48
Covellite	CuS	66.5
Tetrahedrite	$Cu_8Sb_2S_7$	52.06
Tennantite	$Cu_8As_2S_7$	57.
Native Copper	Cu	100.
Azurite	$2\ CuCO_3\ Cu(OH)_2$	55.10
Malachite	$CuCO_3.\ Cu(OH)_2$	57.27
Chrysocolla	$CuSiO_3.\ 2H_2O$	36.06
Cuprite	Cu_2O	88.8
Melaconite	CuO	79.84
Brochantite	$CuSO_4.\ 3Cu(OH)_2$	62.42
Atacamite	$Cu(OH)Cl.\ Cu(OH)_2$	59.45
Chalcanthite	$CuSO_4.\ 5H_2O$	25.4

It must be pointed out here that very few ores are pure enough to contain or even approach the theoretical copper content given above. For example, the famous Butte, Montana

---

1. Ries, H: "Economic Geology" (1925) p.568.

deposits may be cited. There the important **copper minerals are** chalcocite, enargite and bornite, but in the year 1923 the ore actually mined averaged only 2.12 percent metallic copper. In fact most of the ores now mined are of low grade, but with increased plant capacities, improved concentration and metallurgical practices, the profitable treatment of lower grade ore is possible.

Based on the estimated percentages of the world's copper output of 840,000 tons in 1909, the most important ore minerals are as follows: [1]

TABLE II

Ore Minerals:	Per cent of Total
Native Copper	about 12%
Carbonate-oxide minerals	about 15-20%.
Enargite	about 5%
Tetrahedrite and other sulpho-salts.	about 1-2%
Chalcopyrite, Bornite, Chalcocite	about 60-65%.

The importance of chalcopyrite, bornite and chalcocite can readily be seen. Furthermore, approximately one-half of the copper produced comes from chalcopyrite and cupriferous pyrite. The latter mineral together with pyrrhotite, ($Fe_{11}S_{12}$) accounts for a very large proportion of the world's

[1] Beyschlag-Vogt-Krusch: Ore Deposits (1916) p.872.

copper. These minerals contain the copper either as a mechanical intermixture of chalcopyrite or as a solid solution. Copper is often obtained from these ores as a by-product in the manufacture of sulphuric acid (H_2SO_4).

Brief descriptions of the more important ores of copper follow:[1]

Chalcopyrite or Copper Pyrites ($CuFeS_2$) is undoubtedly the most important primary ore of copper and may be regarded as the ultimate source of many of the other copper-bearing minerals derived from it by oxidation and subsequent reduction. It is very common in primary metalliferous veins of igneous origin. The mineral has a deep yellow color and is relatively soft.

Chalcocite or Copper Glance (Cu_2S) is a common mineral in the enriched parts of veins and is of a lead gray color.

Covellite (CuS) is a peculiar mineral of indigo-blue color and is usually found as an encrustation in the zone of secondary enrichment.

Bornite, or Peacock Copper ($3Cu_2S.Fe_2S_3$)[2] is, as the formula indicates, a double sulphide of copper and iron. Usually it occurs in the massive form and possesses a peculiar purple or brownish lustre. It is also a mineral of the zone of secondary enrichment.

---

[1] Rastall: The Geology of the Metalliferous Deposits (1923)

[2] Ries gives bornite the following formula: Cu_5FeS_4.

Tetrahedrite, or Grey Copper Ore ($Cu_8Sb_2S_7$), is a typical member of a large group of sulphantimonides and sulphansenides, and very characteristic of the zone of secondary sulphide enrichment.

Enargite ($3Cu_2S.\ 2As_2S_3$) is a sulpharsenide of copper, which in some localities appears to be a primary ore. It often contains some antimony replacing arsenic.

Cuprite (Cu_2O) is easily distinguished by its submetallic lustre and ruby-red color, which sometimes becomes black and dull on exposure to light.

Malachite ($CuCO_3.\ Cu(OH)_2$) is a hydrated copper carbonate commonly occurring in botryoidal, stalactitic or reniform concretionary masses of a bright green color. It is rarely crystalline.

Azurite ($2CuCO_3.\ Cu(OH)_2$)commonly occurs in deep blue monoclinic crystals, frequently well developed.

Atacamite ($Cu(OH)Cl.\ Cu(OH)_2$)is a basic copper chloride which is very characteristic of the oxidation zone in regions where the percolating waters contain chlorides, as common in the arid regions of Chile. The mineral usually occurs in dark green masses and is rarely crystalline.

Chrysocolla ($CuSiO_3 . 2H_2O$) is essentially a hydrated copper silicate of a blue or green color, commonly occurring as encrustations in the oxidation zone.

Native Copper (Cu) is an important source of copper in the Lake Superior region.

Gangue Minerals: Ordinarily the copper minerals are found in association with other minerals of a worthless nature, to which the term "gangue" has been applied. Of the gangue minerals found in copper deposits, quartz (SiO_2) is most common and is usually clear, glassy and finely to coarsely crystalline. Calcite ($CaCO_3$) and siderite ($FeCO_3$) are common in some deposits, but in relatively few of the great mines of the world. Barite ($BaSO_4$) is exceptional but is abundant at Shasta County, Cal., Mt.Slicker, Vancouver Island; Hasaka, Japan and at Mt.Lyell,Tasmania. Rhodochrosite ($MnCO_3$) and fluorite (CaF_2) sometimes occur, the latter especially in the tin and copper mines of Cornwall,England, and rarely at Butte,Montana. Tourmaline, a complex silicate ($R_9Al_2 (BOH)_2(SiO_5)$)[1] is confined to tin - copper and gold-copper veins. Commonly an earthly gangue composed of highly altered country rock is found, while at times, as in Montana, Japan and Tasmania, alteration has produced sericite, a form of muscovite ($H_2KAl_3 (SiO_4)_3$).

---

[1] R.represents a variable radical which may contain any of the following elements: Mg., Fe., Ca., Na.,K.,or Li., often Fe.

Not infrequently the presence of such gangue minerals as quartz may have a favorable influence in the metallurgy involved in the extraction of the metal content. In smelting copper-bearing iron sulphides into matte by the pyritic process it is necessary to add silica in the form of quartz which is then termed a "flux" and affects an added fluidity of the products in the furnace. Ores in which quartz is contained as a gangue mineral may thus be "self-fluxing" thereby reducing the metallurgical costs, other things being equal.

Mineral Impurities: There are in practically all ores certain minerals of a deleterious nature ,which must be substantially reduced if not completely eliminated in the metallurgical processes, if the refined metal is to possess the most desired physical and chemical qualities. Metallurgists particularly those of recent years, have done much creditable work in this connection and these impurities have been either entirely eliminated or else reduced to an almost negligible minimum in the refined products.

In copper ores probably the most objectionable impurity is zinc. Its elimination has been a matter of much conern with metallurgists and even until quite recently the presence of this mineral in non-commercial quantities in copper ores, has been objectionable to, if not actually penalized by, smelter operators. Bismuth, though rare, is very undesirable but may now be eliminated by electrolytic refining. Arsenic, antimony, tellurium and selenium may be partially removed in smelting, but complete elimination, essential if the product is to be utilized in electrical work, is accomplished only by electrolytic methods. The presence of silver, even in amounts as small as 0.5 percent, lowers the electrical conductivity of the metal, while more than 3% adversely affects its toughness and malleability. Up to 0.25% sulphur content decreases the malleability of the copper, while 0.5% renders the metal "cold-short"[1]. With 0.4% or more of phosphorous the copper is made "red-short"[2]. An excess amount of silica is detrimental should it require too much basic flux to neutralize it.

FACTORS INVOLVED IN EVALUATING A COPPER DEPOSIT.

The correct **appraisement** of a copper deposit involves the consideration of many factors which to different persons may present highly divergent aspects. The physical evaluation of any deposit requires the careful consideration of such matters as the general geological features exhibited by the deposit, its strength and character of mineralization, the width and persistence of any associated veins, shear zones, fractures or contact zones, together with the possible grade, size and continuity of the ore bodies.

[1] "cold-short"- Brittle in its cold state.
[2] "red-short" - Brittle while red hot.

While there are many such factors to be considered, the following extract from an article appearing in a recent publication may be quoted:[1.]

> "(1) Transportation Facilities- In the first place, this factor includes a consideration of the hauling and handling charges; secondly, an estimation of the possible size of the body or its proximity to a large property. In both of these cases, certain facilities may be so improved as to greatly lower the cost of transportation.
>
> (2) Type of Ore:- This necessitates a consideration of the metals contained; whether these be gold, silver, lead or zinc, or any special metal, or a combination of two or more.
>
> (3) Grade of the Concentrate:- This depends on the grade of the original mineral and on the amounts of the precious metals contained. This data may only be obtained from mill tests.
>
> (4) Mill Recoveries, Smelter Rates, and Losses.
>
> (5) Prices and Markets for the metal produced.
>
> (6) The Net Cash Value of the Concentrates produced per ton of ore, after allowing for mill losses, freight and handling costs of the concen-

---

1. McKechnie, D.C., in "The Canadian Mining and Metallurgical Bulletin" (Nov.1930) p.1454.

trates, and the smelter charges and losses."

The writer goes on to point out that " this last item is, in fact, a combination of all the preceding ones, and on it directly depends the profits to be expected from the ore. If one deducts the costs of mining, milling, overhead expenses, and freight charges between mine and mill, from the net cash value of the ore at the smelter, one thus obtains the probable profit to be derived from the ore."

THE GEOLOGIC AND EECONOMIC ASPECTS OF COPPER

PART II

OCCURRENCE AND GENESIS OF COPPER DEPOSITS

II. OCCURRENCE AND GENESIS OF COPPER DEPOSITS

OCCURRENCE.

Geologic Distribution: Generally speaking, the workable deposits of the world are, with few important exceptions, closely related to occurrences of igneous rocks, usually intrusive, or to metamorphic derivatives of these rocks. While the presence of such metallic deposits usually presupposes some association with igneous rocks, the converse does not necessarily hold. Characteristically, copper deposits cluster about the borders of large bodies of granitoid rocks; thus batholithic margins are more favorable for copper deposition and concentration than are the centres of such bodies. Old and schistose rocks, as well as the recent and recognizably igneous rocks, may be copper-bearing, as in Norway. In the crystalline schists, deposits are mainly of the Huelva (Spain) type. They are often associated with igneous rocks.

There is a world-wide association of copper ores with the Red Beds of Permian and Triassic ages. These formations occurring on every continent, consist of thin but well-defined beds, of which the red rocks are generally most conspicuous, although gray and green sandstone and shales are equally abundant. In these beds the copper ores are usually found in gray patches. The peculiar nature of the Red Beds is significant in revealing evidences of exceptional conditions of climate and sedimentation, continental uplift, igneous activity and concentration of the salt water to form gypsum and salt in enclosed basins.

Copper deposits occur in rocks of all ages, although the deposits themselves are in large part post-cretaceous. The Algonkian and early Cambrian rocks contain deposits which are associated with more or less schistose volcanics and, in a few cases, with altered biotite and quartz deposits, as at Ducktown, Tenn. The Cambrian and Silurian rocks are known to carry copper only as an intruded material. The Devonian and Carboniferous rocks contain copper which is, however, of a later age. In the Americas there are three great periods which stand out: The pre-Cambrian, the Triassic and the Tertiary. The latter period is most important in these continents, and is a period of igneous activity which has continued interruptedly to the present time. The rocks of this period carry workable ore bodies.

Geographic Distribution: Geographically, copper minerals are widely though irregularly distributed while deposits of economic importance usually occur in well-defined districts of relatively limited areal extent; or if in larger areas, the copper producing mines are commonly grouped in a few localities. In the

Americas, which produced in 1930 about71.91% of the world's copper, the larger deposits of this metal are found distributed along the mountainous western coasts of both continents, and in eastern North America and in Northern Canada. Across the Atlantic, Europe, accounting for 10.58% of the world's output in 1930, receives its main copper supply from Spain and Portugal, Russia, Germany, Jugo-Slavia and Norway, with smaller amounts from Austria, France and Sweden. To the south, Africa is rapidly demonstrating its possibilities as a future source of copper. With the discovery and development of large ore bodies of a relatively high grade, the central and southern parts of this continent, beginning production only in 1911, supplied 10.44% of the world's copper for 1930, and seems destined to become one of its leading producers. Asia and Australasia are smaller factors in world copper production with Japan accounting for 5.02% of the 1930 world output, other parts of Asia 0.74% and Australasia (including Australia, New Zealand,Tasmania and Papua) producing in the same year 0.98%.[1]

Types of Deposits: Copper deposits occur in various forms in different rocks. Bedded veins in crystalline schists are of world-wide occurrence. Commonly the ore bodies are lenticular in shape and frequently overlap as a result of distributed faults displacing a formerly continuous body of ore. Such are the deposits at Mt.Lyell,Tasmania and at

---

[1] Above percentages are based on figures by the American Bureau of Metal Statistics

Bershi, Japan. Contact metamorphic deposits are of common occurrence and are also likely to be lenticular bodies. The majority of workable copper deposits of the world are, however, in the form of veins, usually cutting igneous rocks. They commonly occur in well-defined and limited shoots, or, less frequently, as simple and regular vein fillings. Impregnations of the walls by the metal may produce a low grade, copper-disseminated contact deposit. Any type of country rock may be found but most frequently the profitable copper deposits are found in igneous rocks.

Extreme diversity of occurrence, even when the deposits are due to one series of ore depositing factors, is especially well shown at Morenci, Arizona, where Lindgren has distinguished the following varieties based upon occurrence and form:[1.]

"(1) Deposits in limestone and shale, not connected with fissure veins.(all carry oxidized ores almost exclusively; rarely chalcocite)

- a. Irregular bodies near contacts of main stocks and dikes.
- b. Tabular bodies near contacts of main stock or dikes, following stratification.
- c. Tabular bodies following contacts of porphyry dike.

(2) Fissure veins:

- a. Normal veins in porphyry or in any of the other rocks near porphyry contacts. The pay part includes both the central sharply defined veins and the surrounding partly replaced porphyry, forming together a lode. They carry chalcocite as the important ore. In the upper levels they sometimes carry

---

1. Weed, W.H. "The Copper Mines of the World" (1908)

oxidized ores also.

b. Normal veins following porphyry dikes in granite and carrying chalcocite and oxidized copper ores.

c. Normal veins following diabase dikes. These carry chalcocite and oxidized copper ores.

d. Stockworks. Irregular disseminations in phorphyry, quartzite and other rocks. These contain chalcocite and oxidized copper ores."

Commonly, in addition to the occurrence of various types of ore deposits, there are within a copper ore body, different zones resulting from certain processes operative after the original deposition has taken place. All deposits of copper are more or less altered upon exposure to the atmosphere. While this alteration process varies, it usually results in the formation of a capping of leached and frequently worthless material resting upon a more or less altered and enriched part of the ore body. The term "gossan" or "iron cap" is usually applied to these residual masses capping pyritic deposits when the oxidation of the ore leaves behind a more or less impure brown hematite or limonite. The width of such a body may be greater than that of the original ore deposit, provided that lateral extension of the downward percolating waters has taken place. The depths vary with the particular physical, chemical or mineralogical factors involved. Many copper deposits exhibit three zones or belts to which the following terminology has been applied: the zone of weathering, or surface zone; the zone of sulphide enrichment; and the lower pyritic zone of lean primary ore. These zones will be discussed in connection with the genesis of copper deposits.[1]

GENESIS OF COPPER DEPOSITS.

The geologic and economic significance of the mode of origin of any ore deposit cannot be over-emphasized. In comparatively recent years the study of the genesis of ore bodies has done much to promote a more reliable appraisement and intelligent development of metalliferous deposits in general. Increasing appreciation of the significance of such a study has undoubtedly advanced hand in hand with metallurgical progress, so as to render mining operations distinctly less haphazard.

The science of "ore genesis" involves a study of the mode of origin of ore minerals, the manner in which they became concentrated and the various agents involved in both their formation and concentration. The genesis of ore bodies, like other scientific phenomena, was in its early stages of study regarded largely as a matter of chance. As more careful investigation followed and scientific conclusions were reached, an increased knowledge of the genesis of ores resulted.

The old view concerning the origin of ore bodies was that these deposits were produced merely by chance, and that they bore

---

[1] Postea, pp. 44-53.

no genetic relationship to the contact rock. Discovery of such bodies could therefore be made only by chance. This early view gradually became modified as it was next assumed that all ore minerals came from the interior of the Earth, and while an ore body could only be located by chance its values when found should increase with depth. Another attitude, apparently quite inconsistent with the preceding one, maintained that all ores were concentrated at, or near to, the Earth's surface, and thus the values, when discovered would tend to decrease with depth. The modern view concerning the genesis of ores may be regarded as a different application of parts of the two preceding theories and containing in addition other more significant principles of ore formation. The present generally accepted opinion is that ore deposits are formed by natural processes still operative and by agents or forces which are still effective. Concentration of ore minerals to produce ore deposits may be accomplished by either descending or ascending concentrating processes. Furthermore the ore is regarded as being definitely related to the country rock in which it is found. By a study of the content of the ore, its associated minerals, and its geologic position, one may obtain much valuable information concerning the genesis of the deposit. From this study, the probable nature of the ore below, its possible variation in value, and its estimated depths, may be anticipated with a reasonable degree of accuracy, other things being equal.

In the general classification of ore deposits there may be distinguished two main types: those of primary , and others of secondary origin. Primary deposits are those which have originated in the position in which found, while secondary deposits on the other hand, have actually been changed from their original position. The former group of deposits may with respect to the origin of the enclosing rock, be of either contemporaneous or subsequent genesis, and accordingly the terms "syngenetic" and "epigenetic" deposits have been respectively applied. Syngenetic deposits are those formed at the same time as the enclosing rock and by the same geologic process or processes. In this class are to be found those deposits known as "magmatic segregations" as well as those termed "sedimentary ore beds"". The second sub-group , called "epigenetic deposits", includes those ore bodies which have been formed after the enclosing rock, and which are thus younger than the country rock in which they are contained. This class includes such important deposits as:

1. Fissure veins, which are fillings in fissures.
2. Cavity Fillings, including any type of cavity fills.
3. Replacements produced by chemical substitution.
4. Contact-metamorphic deposits along igneous rock contacts.
5. Impregnations or mineral disseminations.

The secondary group of ore deposits may be formed by two processes: they may be chemically transported and concentrated, thereby producing chemically enriched ores, or they may, in the second case, be mechanically concentrated to produce placers and such other mechanically enriched bodies.

In the genesis of copper deposits, all the above modes of origin are not necessarily involved, some rarely being instrumental in the formation of commercial bodies of copper, though possibly more effective in the genesis of some other mineral concentration. Detailed study of the copper deposits of the world seems to indicate that the original source of copper is the hot, potentially molten material of the Earth's interior. The chief means of its transportation has been the uprising magma which consolidated near the surface as intrusive igneous rock. Sometimes magmatic differentiation has occurred to an extreme degree and resulted in the formation of magmatic ore deposits of either an acidic or basic character. Other metalliferous material may have been transported by igneous emanations from cooling and crystallizing magmas to produce ore deposits of a contact metamorphic genesis. Again, the final phases of igneous activity may be that of hydrothermal activity manifested as hot springs. The waters of these springs may be magmatic entirely, or they may be admixed with meteoric or surface waters, but in either case they form both vein fillings and replacements. The deposits formed by the preceding agents are not commonly of commercial importance, and are seldom worked for their copper content. There may be, and frequently is, a concentration of the mineral content of such bodies however, by a process of leaching and redeposition through the instrumentality of atmospheric or magmatic waters, thereby producing deposits in which the metal content is sufficiently concentrated as to be workable. Leaching of igneous rocks, or their sedimentary and metamorphic derivatives is a common process in ore concentration.[1] Contact-metamorphic deposits and disseminated sulphides in igneous rocks or in lean ore deposits , in veins and masses may become re-concentrated and enriched. Meteoric and magmatic waters carrying a metallic material in solution may come in contact with such sedimentary rocks as limestone and calcareous shale, to react with them and deposit any metal content and produce thereby a commercial body of ore. Regional metamorphism may cause a segregation of previously disseminated materials, and **thus** form an ore body. Practically all the workable deposits of copper ore result from concentrations by means of circulating waters, usually of atmospheric origin, which have leached the originally lean ores and redeposited the metallic content in a favorable location relatively adjacent. Not infrequently repeated concentrations of this nature have been indicated. Ore deposition at the present time, may, according to one authority at least [2] be in operation in three different ways, namely:

1. From volcanic emanations.
2. From hot-spring waters.
3. From sea water.

---

[1] Postea pp. 44-53.
[2] Weed,W.H.: "The Copper Mines of the World" (1908)

Copper salts and copper oxide (Tenonite; may be in the first case, deposited by volcanic vapors and gases in the rifts about active volcanoes, but no such bodies of commercial value have been thus formed. Illustrative of the second mode of present day origin, the Boulder Hot Springs in Montana are forming copper minerals. Similarly the Boccheggiano vein of Tuscany,Italy, is regarded as the final phase of ore depositing hot-springs. In the third place, deposition of the metal in organic muds of certain sea lagoons is a matter of scientific curiosity only. Thus no contemporaneous deposition of ore of industrial importance has been found to definitely establish conclusions reached regarding the genetic processes in ore formation.

Copper ore deposits have been formed in many different ways and in some instances more than one mode of origin may be represented by the deposits of one locality. This fact is the cause of considerable difficulty in attempting to differentiate between the various occurrences purely on a genetic basis. Furthermore, differences of opinion sometimes are found concerning the origin of a particular deposit, as for example that of Rio Tinto, Spain. The following grouping of the various modes of origin of copper deposits is suggested, and will be used in this paper:

1. Magmatic segregations.
2. Contact-metamorphic deposits.
3. Deposits from Hydrothermal solutions.

  - a. Hypothermal deposits.
  - b. Mesothermal deposits.
  - c. Epithermal deposits.

4. Deposits formed by superficial alteration.

  - a. Deposits in the zone of oxidation.
  - b. Deposits in the zone of secondary sulphide enrichment.

Magmatic Segregations: The slow cooling of an intruded magma and consequent crystallization of the mineral solutions may give rise to a gradual differentiation and concentration of the mineral content. There are varied opinions regarding this process and no definite conclusions have as yet been reached. "Differentiation" means the separation of a homogeneous rock magma into chemically unlike portions (Iddings). For each region, in each separate"magma basin" there is probably one essentially homogeneous magma from which, by some process of differentiation, the various rock types have been derived. Evidences that this phenomenon has actually occurred are revealed by: (1) the consanguinity of different rocks in a given district;(2) the successive effusion of unlike lavas from the same vent; (3) different products found in the same intrusive body; and (4) by the study of individual flows.

According to Lindgren some of the earlier attempts to account for differentiation may still prove to be of some value. They include the application of "Soret's principle" which states that when two parts of a solution are at different temperatures there is a tendency toward selective concentration of certain ingredients in the cooler portion. G.F.Becker, however, showed that such diffusion in a viscous mass would require almost unlimited time, while H.Backstrom explained that the action could not alter the relative proportions among the dissolved constituents. Gravitative adjustment was thought by J.Morozewicz and R.A.Daly , to be a considerable factor in magmatic differentiation . It was G.F.Becker who first advanced the view that fractional crystallization was an important factor and regarded differentiation as a consquence of the general cooling process. This view has been well-developed by N.L.Bowen and his theory of differentiation by crystallization is now accepted by many petrographers.[1]

While copper sulphides, particularly chalcopyrite, may crystallize from a magma under such conditions, there are but few cases known where copper ores have had this type of origin. Furthermore, there is considerable difficulty in such cases in ascertaining with any degree of certainty, whether such ore bodies originated in this manner, i.e.,whether the copper sulphides have crystallized from fusion, or have been deposited from solution. Certain criteria which may be employed in this connection, should conditions permit and provided metamorphism has not obscured the original characters of the ore body, have been suggested by Ries[2] as follows: (1) primary intergrowths of sulphides and silicates, (2) inclusions of sulphides in

1. Lindgren, Waldemar: "Mineral Deposits" (1928) p.125.
2. Ries,Heinrich: "Economic Geology" (1925) p.799.

silicates, (3) corrosion of silicates by sulphides, if the latter crystallized later, and (4) absence of hydrothermal effects. Copper ores of this genetic class fall into two groups: (1) those representing crystallization from the magma with sulphides closely **associated** with the silicates- though their contemporaneous formation is often a matter of dispute, and (2) those bodies of comparatively pure sulphides which some authorities **believe**to be **injections**.

It has been shown that sulphide minerals may undoubtedly crystallize from a magma and that they are as essentially magmatic as are the silicates. The number of minerals which may thus originate however, is comparatively limited but includes among others, pyrrhotite, pyrite and chalcopyrite. The mode of origin of magmatic deposits has been much studied and discussed but as yet no general agreement seems to have materialized. It is generally conceded that the Sudbury, Ont., nickel deposits may have had this type of genesis. Somewhat similar deposits occur at Insigwa and at **Ookiep** , Namaqualand, both in Cape Colony, Africa. The disseminated bornite and chalcocite deposits in Norite , at the Engels Mine, Plumas County, Cal., is also believed due to magmatic processes.

The Sudbury deposits lie in an undulating **rocky** plain where an immense laccolithic sheet of synclinal form encloses tuffs and ordinary sediments within a natural basin. The country rock is a basic **n**orite on the outer border and grades inward to micropegmatite and then granite. The ore bodies occur on the outer margin of the norite of which the more or less continuous outcrop encloses an oval-shaped basin of about 35 miles by 8 miles. The deposits are of two types. The first, or marginal deposit, consists of irregular stock-like shapes, often having a distinct footwall, while on the opposite side the ore fades gradually into the contact rock. The second type is of cylindrical or chimney-like form in the offshoots from the main igneous mass. The ore mineral is of chalcopyrite associated with nickeliferous pyrrhotite and in general the metal content consists of two parts of nickel to one of copper, with an average of 3 to 4 percent of the combined metals.[1] The genesis of this particular deposit has been under discussion for over 35 years, and probably may continue to claim the attention of geologists for some time to come. The general opinion at present seems to be, however, that the genesis is a result of magmatic differentiation, with a minor reconcentration by magmatic waters especially when brecciation or fissuring has provided channels for the circulating solutions.

CONTACT-METAMORPHIC DEPOSIT: The class of ore bodies known as "contact metamorphic deposits" includes those bodies formed under the influence of contact-metamorphism near or along the boundaries between plutonic

---

[1] Ries, Heinrich: "Economic Geology" (1925) p.799.

eruptive masses and other rocks. The intruded magmas are usually surrounded by an area of changed rock exhibiting gradually fading metamorphic effects, sometimes over a width of even one or two miles, but usually of considerably narrower extent. Ordinarily the immediate contact is sharply defined with no evidence of melting. Present day petrographers (as Alfred Harker, and A.Lacroix) seem inclined to favor the view that water and other gases containing CO_2; H_2S; S; Cl; B,and F; must emanate from the magmatic body into the surrounding rocks while these are still heated by the intrusion. The escape of these gases may not have been uniform and according to Harker a large portion was doubtless given off while the magma was still fluid, more may have been liberated at the time of consolidation, still another amount may have issued from the relatively cooled body, and finally fissuring may then have permitted the escape of gases from the still fluid magma within. These magmatic solutions and vapors enter the adjacent rocks and produce a series of changes. The ultimate character of the rock depends upon the composition and temperature of these solutions, together with the particular type of country rock affected.

Rarely are ore deposits of this type found in argillaceous shales, sandstones or quartzite, but the more permeable limestones, dolomites and calcareous shales seem to be most receptive to these mineralizing solutions and also appreciably facilitate their action by a characteristic fissuring and crushing along the contact. When the solutions are sufficiently concentrated and contain much silica, sulphur, iron and other metallic substances, the replacement of carbon dioxide of the contact rocks will proceed rapidly so that the calcareous rock may thus be converted to a mass of ore and gangue minerals. In places whole beds of pure limestone or dolomite may be changed to garnet, diopside, and other silicates, as well as to recrystallized calcite together with magnetite, specularite and simple metallic sulphides. Characteristic of such deposits are to be found ore minerals of simple composition such as pyrite, chalcopyrite, bornite, pyrrhotite, zinc blende, molybdenite, arsenopyrite, and galena. The oxides are represented by such minerals as: magnetite, ilmenite, hematite, quartz, corundum and various spinels. Silicates, especially those containing lime, magnesia and iron, are abundant and include garnet, epidote, zoisite, diopside, vesuvianite, anorthite, wollastonite and others. On the whole, iron and copper deposits are of most frequent occurrence in such bodies while zinc, lead, gold, silver and tin are much less abundant.

Some of the most important copper deposits of the world belong to this class which is particularly important in the United States. The ores of some of these deposits are, however, not entirely of this origin, but include others of close genetic relationship. Contact-metamorphic deposits carrying chalcopyrite as the predominant mineral are not abundant in Europe or South America but are most common in North America, particularly in New Mexico, Arizona and Mexico. Such deposits have also been found in Australia, Japan and in Korea. As a rule these deposits occur at the contacts of small intrusive masses against limestone and they are often of irregular or tabular form. The ore is usually massive and coarsely granular while the ore minerals commonly consist of chalcopyrite, bornite, pyrite, and less frequently pyrrhotite and zinc blende. Enrichment often results from the oxidation of the copper, as at Ely,Nevada.[1] but in many cases the primary ore is of sufficient richness as to be workable. Outstanding deposits of this class include those of the San Pedro Mine, New Mexico; those of the Clifton,Bisbee and Silver Bell districts in Arizona, and those of Cananea, Mexico, and of Bingham,Utah.

The San Pedro Mine in New Mexico is in a deposit produced by the metamorphic effects of a granodiorite porphyry laccolith intruded into limestone beds of a thickness of 700 feet, the lower 200 feet of which has been but partially metamorphosed. A purer limestone bed of about 50 feet in thickness has undergone strong metamorphism and garnetization over an extent of a halfmile. At this horizon occur irregularly dis-

---

[1] Postea, pp. 44-53.

tributed bunches of chalcopyrite, and the beds have been followed for a distance of 300 feet. This locality is the most important of fourteen such districts found in the state of New Mexico alone.

Deposits from Hydrothermal Solutions: The ascending thermal waters operative in the class of deposits formed by deposition from hydrothermal solutions are believed to have originated in a magmatic intrusion below, having previously formed a part of that body either as a chemical constituent or else locked up within it as connate waters. It seems quite possible that these solutions emanated from the magma while differentiation [1] and cooling were taking place following the intrusion. The heat of the solutions was mainly derived from the intrusive body itself, although the possible generation of heat through chemical activity after the solution had left the parent mass, may have been a contributory, though probably a less important, factor. The temperature of the solutions following their emission would be expected to approximate that of the intrusive body itself. As the solutions worked their way outward from the magma, and became gradually cooled, the various minerals would be deposited approximately as their crystallization temperatures were reached. Rather distinct variations in this order of

---

[1] Ante, p.

deposition might however, be expected as a result of the varying chemical nature of this particular solution of the contact rocks, so that only a very approximate order of mineral deposition can therefore be assumed. Sufficient information has nevertheless been obtained to distinguish three theoretical zones of ore deposition. These are known as the "Hypothermal", the "Mesothermal" and the "Epithermal" zones and are respectively characterized by intense, moderate, and slight conditions of temperature and pressure. The mineral content of the solutions is considered largely of primary origin in that it mainly originates in the magma. However, under certain conditions minerals may be taken into the solution as it ascends a fissure or other channel, while certain substitutions may also be made. It is obvious, therefore, that the dissolved content of hydrothermal solutions may vary greatly from place to place along the passageway.

Hypothermal Deposits: Of the deposits produced by ascending hydrothermal solutions those formed at greater depths under relatively intense conditions of temperature and pressure, are here referred to as "hypothermal deposits" The solutions concerned may be further differentiated by the term "hypothermal solutions", as contrasted with "mesothermal" and "epithermal solutions" of the two higher zones. Hypothermal deposits are formed at very considerable depths below the surface and these bodies together with contact-metamorphic deposits, pegmatite dikes, replacement deposits and ordinary veins are all developed very soon after the intrusion of the magma and while the temperature is declining. Characteristic of hypothermal deposits are such minerals as the pyroxenes, spinel and magnetite, molten only under conditions of high temperature (300-500°C), together with those minerals more dependent upon high pressures and the presence of mineralizers for retention in the molten state, including topaz, chondrodite and the micas. The most common metals to be found in this zone are gold, copper, iron, tin tungsten and arsenic. The texture of the veins is generally coarse-grained and irregular, while crude banding may result from deposition but not of as pronounced or as delicate a nature as is the banding found in deposits nearer the surface. The mode of fissure-filling at such depths still remains open for argument. It is difficult to conceive of spaces occurring under the conditions of high pressure which characterize this zone. Varied opinions have been offered concerning this question but almost as many pertinent suggestions of a controvertive nature have been made by others. There have been advanced such theories as: that crystallizations would tend to force the walls apart and thus provide space for the ore; or that mineral solutions were injected under great pressure along planes of weakness, thus opening fissures for themselves; or again, that hydrostatic pressures and previous fillings may keep the walls apart yet not hinder the passage of the ascending solutions.

Probably the most outstanding copper ore body representing this class of deposit is in the copper-tourmaline deposit of the Braden Mine [1] situated near Santiago,Chile. Here in the Western Cordillera at an elevation of 8,000 feet, a very extensive ore body has been developed over a vertical distance of 2,500 feet and is capable of producing about 15,000 tons of 2 to 3 percent ore daily. In the Cordilleran region of the United States a number of smaller but similar deposits occur, the most productive having been the Cactus Mine in southern Utah, but this property is now closed, poorer ores having been encountered at depth. A second type of copper deposit characteristic of this genetic class, is the gold-copper deposit in which tourmaline is absent or rare. The deposits of the Rossland district [2] of southern British Columbia are of this class. They consist of replacement veins along **shear** zones in monzonite and augite porphyrite, with granodiorite occurring somewhat adjacent and thought to be an extension of the Trail batholith, the emanations from which are believed to have formed the deposits. The ore minerals are chalcopyrite and pyrrhotite, with some pyrite, arsenopyrite, molybdenite and bismuthinite, the ores containing about $5. to $10. in gold, o.3 of an ounce in silver as well as o.5 to 3 percent copper.

[1] Lindgren, Waldemar: "Mineral Deposits" (1928(pp.771-2.
[2] " " " " (1928) p. 773.

In Western New South Wales, Australia, the deposits of the Cobar copper mining district are also representative of this type of deposit.

Mesothermal Deposits: Mesothermal deposits are those formed under intermediate conditions of temperature and pressure by ascending hydrothermal (or, in this zone, mesothermal) solutions, genetically related to a magmatic intrusion. No distinct line of demarcation indicates the boundary of the zones for there is a gradual transition into the hydrothermal zone below and the epithermal zone above. This intermediate zone is therefore characterized by conditions of moderate intensity as contrasted with those of higher intensity in the zone below, and with those of the lesser degree in the upper zone. Mesothermal deposits are believed to have been formed at depths varying from 4,000 to 12,000 feet, shortly after magmatic intrusion, with temperature conditions ranging from 150 to 300°C., and at pressures estimated from 140 to 400 atmospheres. The deposits, due to the pressures involved, are fairly regular in strike and dip and the veins commonly have smooth walls and slickensides, while replacement bodies are sometimes developed. The most frequently occurring minerals are those deposited under comparatively moderate conditions, such as the sulphides, arsenides, sulphantimonides and sulph-

-arsenides, and most commonly include pyrite, chalcopyrite, arsenopyrite, galena, zinc blende, tetrahedrite, tennantite and native gold. The predominent metals are gold, silver copper, lead and zinc. The usual gangue mineral is quartz but the carbonates, calcite and dolomite, are also common.

This class of deposit, yielding a large proportion of the world's production of gold, silver, copper, lead and zinc is of particular importance in the Cordilleran region of the Americas, as well as in other parts of the world where igneous activity has been followed by deep erosion. Copper-bearing veins resulting from filling are not so important, unless replacement or descending surface waters have been instrumental in enlarging and enriching the ore body. Many of the great copper deposits are mainly pyritic replacements of igneous or sedimentary rocks while other bodies are rendered commercially important through an accumulation of secondary chalcocite either in wide replacement veins or in broad mineralized zones.

Chalcopyrite-Quartz and Bornite-Quartz veins are locally common but rarely of much economic significance. Pyrite-Enargite veins are less common, but in places are of importance. The latter mineral, enargite, is relatively rare but if occurring it seems to favor mesothermal deposits. The most common example of this particular type of deposit is to be found in the vicinity of Butte,Montana[1] for some time the most productive copper district of the world. There the copper deposits consist of a system of steeply dipping veins cutting quartz monzonite, and a few dikes of aplite and granite porphyry have been intruded into the granular rock as well. The ore bodies are in the main pyritic replacements along fissures, the ore being a heavy, coarse-grained sulphide aggregate in which pyrite predominates and with which are also associated such minerals as enargite, tennantite, bornite, chalcocite, zinc blende, and a little chalcopyrite and covellite. The ores average from 3 to 4 percent copper and 4 ounces of silver per ton.

Pyritic replacement deposits formed in this zone are characteristically of a fine-grained massive texture, and though consisting mainly of pyrite, they derive their commercial importance from the small percentage of chalcopyrite contained. Illustrative of this type of deposit might be mentioned those of Jerome,Arizona; Shasta County, Germany. The most important mine of the Jerome district is the United Verde[2] which during the period 1888-1922 produced over 500,000 tons of copper with some gold and silver. The deposit is in the form of a pipe of several hundred feet in diameter, and has been followed to a depth of 3,500 feet. The ore is fine-grained, containing from

---

[1] Lindgren,Waldemar: "Mineral Deposits" (1928) pp.696-700.
[2] " " " " (1928) pp.701-2.

4 to 6 percent copper and in addition to chalcopyrite, the iron sulphide is associated with sphalerite and tennantite. The gangue minerals are quartz, chlorite, dolomite, calcite and sericite, while high temperature minerals are practically absent.

Epithermal Deposits: Epithermal deposits are those bodies formed relatively near the surface by ascending hydrothermal (in this zone "epithermal") solutions, which are genetically related to some magmatic intrusion. Again, no distinct line of demarcation of the zone is to be expected, but rather a transitional change occurs between this and the mesothermal zone below. Prevalent temperature and pressure conditions (the important factors in the formation of such deposits) are here considered to be of relatively slight intensity. Such deposits are believed to have been formed comparatively near the surface under temperatures estimated from 100 to 200° C., and usually in igneous flow rocks, commonly the andesites, latites, trachytes and rhyolites, and frequently associated with stockworks or conduits of various kinds. The fissuring of the rocks as a result of the reduced pressure, increases the abundance of open cavities, the irregularity of the veins, and the amount of splitting and brecciation. Banding resulting from deposition, is commonly well and delicately developed as contrasted with the crude banding of lower deposits. Quite extensive vein systems commonly occur in which the extent of any one vein is relatively short. The most common ore minerals are native gold and the tellurides, native silver, argentite, complex silver sulphantimonides and sulpharsendies, including proustite, pyrargyrite and tetrahedrite. Of the metals, gold and silver are decidedly most important, while the base metals are present in some cases but seldom are mines here worked for these metals. In some places large bodies of galena and zincblende occur, but it is decidedly rare to find an important copper deposit in the epithermal zone, while the pyritic deposits are absent. The common gangue mineral is quartz but locally calcite, dolomite, barite and fluorite may occur.

As suggested above, the mining of base metals from epithermal deposits is rather exceptional and heavy deposits of pyrite and chalcopyrite are very rarely found. At the Los Pilares Mine, Mexico, however, a large body of low grade pyrite and chalcopyrite has been mined, while at Ashio, Japan, somewhat similar veins are worked. The ores of the San Juan region, Colorado, sometimes contain copper, as tetrahedrite and enargite, but the principal values are in gold and silver.

Native Copper Deposits: The great deposits of native copper in the volcanic flows and conglomerates of the pre-Cambrian in Michigan, are the source of metal for one of the principal copper producing districts of the United States. These deposits are mainly located in northwestern Michigan on the Keweenaw peninsula on the southern shore of Lake Superior. Mining operations were commenced as early as the year 1846, and the beds are now being worked by a dozen large mines. The deposits yielding the greater part of the output of the district, are the beds of amygdaloid rocks, although much copper is also obtained from a bed of volcanic conglomerate. A third mode of occurrence of the ore is in the form of veins following fracture zones. During the early years, the veins were mined but they are now of little importance.

Concerning the genesis of the deposits, authorities differ. Van Hise concludes that " the almost universal association of small quantities of copper with the Keweenawan lavas is the most conclusive evidence that these lavas are the source of the metal" Lindgren[1] believes that " the deposits indicate eruptive after-effects at a temperature not higher than 250°C., and that they were formed shortly after the effusion of the lavas, and that they were concentrated from elements contained in the flows. The origin of the water, which was undoubtedly present, may be left an open question. If ascending, its volume must have been extraordinarily large". More recently the deposits have been examined by Messrs. Graton, Butler and Broderick for the Calumet and Hecla Consolidated Mining Company, and it seems that they attribute the concentration of the ores to ascending thermal waters. They suggest that the structural faults, folds and fractures are earlier than the ore.

---

[1] Lindgren, Waldemar: "Mineral Deposits" (1928) p.511.

The hot solutions containing copper sulphide of magnatic origin are believed to have ascended through the porous conglomerate and through the vesicular tops of the flows, and to have deposited copper under the impermeable and next overlying flow. These solutions were reducing and so bleached the rock. The abundance of Fe_2O_3 in the tops of the flows oxidized the copper sulphide to sulphate, at first cuprous sulphate, from which the copper was precipitated upon cooling and dilution. R.C.Wells [1] in discussing the chemistry of the deposits of native copper from ascending solutions, gives the following scheme of reactions:

$$(1) \quad Cu_2S \;\&\; 5Fe_2O_3 \;\&\; 11H_2SO_4 = 10\,FeSO_4 \;\&\; 2\,CuSO_4 \;\&\; 11H_2O.$$

$$(2) \quad Cu_2S \;\&\; 8\,CuSO_4 \;\&\; 4H_2O = 5\,Cu_2SO_4 \;\&\; 4H_2SO_4.$$

$$(3) \quad Cu_2S \;\&\; 3Fe_2O_3 \;\&\; 5H_2SO_4 = 2\,Cu. \;\&\; 6FeSO_4 \;\&\; 5H_2O.$$

Deposits Formed by Superficial Alteration: The uppermost part of a mineral deposit, within the zone of weathering, is usually more or less altered by surface waters containing free oxygen. While the direct effects of weathering are noticeable above the water table, certain indirect alterations are to be found below this level of ground water. The upper and outer zone of the lithosphere lying roughly parallel to the topographic surface and typically above the

---

[1] Bull 778, U.S.Geology Survey, 1925.

water table is known as the zone of oxidation and within it weathering is usually pronounced. The two influential processes of significance in mineral concentration are oxidation and hydration. The downward circulating surface waters containing important quantities of oxygen enter a mineral body and tend to form various soluble compounds of the materials of the mass, and to carry these to lower levels or else reprecipitate them nearby. Below the water table the dissolved content of the downward percolating solutions may, under changed conditions, be deposited, and thus lead to mineral concentrations of considerable significance, in a region known as the zone of secondary sulphide enrichment. Deposition of the dissolved content of these solutions is due to the deficiency of oxygen found below the level of ground water, together with the reducing effect of the primary sulphides there, the actual precipitation being thus dependent upon the presence of such pre-existing primary ores. Deposits formed by descending surface waters, through the alteration and rearrangement of the mineral content of the material affected, are known as "supergene deposits". Frequently by such processes, previously worthless but mineralized materials have been worked over so that valuable ore deposits have been formed. The term "protore" has been suggested to designate such primary material of too low tenor to constitute ore but which may be thus concentrated. A "gossan" or capping of residual material may be developed on the top of the oxidized zone as a result of the solution and removal of certain soluble constituents of the original rock. Frequently this capping is a spongy mass of cellular limonite, the hydrated oxide of iron ($FeO. 3H_2O$). Between the zone of oxidation and that of secondary enrichment is an intermediate zone marked by the upper and lower limits of fluctuation of the water table, and in which oxidizing and reducing conditions might be expected to alternate, accordingly as the water level drops or rises. While the zone of oxidation is being developed the lower zone of secondary enrichment is being simultaneously established intimately and dependently upon the pre-existing primary ore or leaner mineralization. It is the presence of the latter mineral body which provides the reducing conditions instrumental in the deposition of the enriching minerals. The supergene sulphide zone is generally of limited thickness, though commonly it is the richest part of the deposit. Obviously from the physical standpoint the ground water level is the decisive factor involved in the formation of the enriched deposit in that it controls the equilibrium between oxidation and reduction.

Copper is one of the most easily dissolved and transported metals and in that it is also readily precipitated, its supergene deposits are often of much importance. Migrating downwards through the oxidized zone and through the supergene sulphide zone, it may become concentrated in deposits of considerable commercial importance. Chalcopyrite, one of the most common primary sulphides of copper and iron, is readily oxidized by oxygen and by ferric sulphate and slightly by dilute sulphuric acid. Bornite is more strongly attacked by the acid, but is easily decomposed by ferric sulphate. Chalcocite, like covellite, is very slightly reactive to sulphuric acid, but is decomposed by ferric solutions which change it to a sulphate and probably also to covellite. Enargite and tetrahedrite are also slowly decomposed by dilute solutions of ferric sulphate. The cupric sulphate in the oxidation process is more or less fixed by the formation of malachite, azurite, brochantite, chrysocolla, as a result of solutions containing carbonates or silica. These minerals being slightly soluble in water containing carbon dioxide and readily in dilute sulphuric acid, may likewise be leached, or they may be reduced to cuprite and it to native copper, which again may go into solution with sulphuric acid.

In the Zone of Oxidation: Illustrative of the chemical and mineralogical changes which occur in these zones of alteration the example of chalcopyrite in a quartz gangue may be cited. With erosion and ultimate denudation of the vein, weathering agents, particularly oxidation and solution assisted by carbon dioxide, attack the rather unstable chalcopyrite which is readily oxidized. The iron molecule first oxidizes to ferrous sulphate and further to insoluble hydrated iron oxide, and remaining as a limonite, gives rise to a goassan" formation.[1.]

[1.] Ante.p.20.

The copper molecule is oxidized to copper sulphate and may be reprecipitated there as a solid carbonate (malachite or azurite), silicate (chrysocolla), or chloride (atacamite), according to the chemical content of the meteoric solutions and the contact rock. Such dissolved mineral content as is not fixed in this manner may proceed downwards with the meteoric solutions to be deposited under the changed conditions of the zone below. The depth of the zone of oxidized and reprecipitated minerals generally extends to the ground water level. This zone is seldom more than 100 to 200 feet below the surface, often only a few feet; unless in some such arid region as Chile, the level of ground water is very low. The copper-bearing minerals commonly fixed in this oxidized zone includes the carbonates, (malachite and azurite), the hydrous silicate (chrysocolla), while under arid conditions the chloride, (atacamite) may be found. In addition to these, native copper also occurs. The hydrated oxide of iron is characteristic especially of the upper capping, the goasan, if such has been developed. The necessary conditions for this zone are excess oxygen and not too rapid leaching. It is typically an oxidizing and acidic zone, as compared with the lower one of basic and reducing characteristics.

The reactions of the oxidized zone are essentially those occurring between the sulphides, oxygen, water, carbon dioxide and sulphuric acid, followed by any reactions between the pro-

-ducts thus formed or between these and other minerals.

Chalcopyrite is oxidized as follows:

(1) $CuFeS_2 \;\&\; 8O = CuSO_4 \;\&\; FeSO_4$

Oxidation of the sulphate at the surface would likely form sulphuric acid. At any rate pyrite would probably react as:

(2) $FeS_2 \;\&\; 7O \;\&\; H_2O = FeSO_4 \;\&\; H_2SO_4$

Ferrous sulphate oxidizes to ferric sulphate:

(3) $2FeSO_4 \;\&\; H_2SO_4 \;\&\; O = Fe_2(SO_4)_3 \;\&\; H_2O$

Ferrous sulphate may yield limonite as represented in the following equations:

(4) $6FeSO_4 \;\&\; 3O \;\&\; 3H_2O = 2Fe_2(SO_4)_3 \;\&\; Fe_2(OH)_6$

(5) $Fe_2(SO_4)_3 \;\&\; 6H_2O = 2Fe(OH)_3 \;\&\; 3H_2SO_4$

(6) $4Fe(OH)_3 = 2Fe_2O_3 \;\&\; 6H_2O = 2Fe_2O_3 \cdot 3H_2O \;\&\; 3H_2O$

(7) $2Fe_2(SO_4)_3 \;\&\; 9H_2O = 2Fe_2O_3 \cdot 3H_2O \;\&\; 6H_2SO_4$

The copper sulphate, as oxidized from chalcopyrite according to equation (1), may be held in the oxidized zone by the following reactions:[1]

(8) $2CuSo_4 \;\&\; 2H_2Ca(CO_3)_2 = CuCO_3(CuOH)_2 \;\&\; 3CO_2 \;\&\; 2CaSO_4 \;\&\; H_2O$

(9) $3CuSO_4 \;\&\; 3H_2Ca(CO_3)_2 = 2CuCO_3(CuOH)_2 \;\&\; 3CaSO_4 \;\&\; 4CO_2 \;\&\; 2H_2O$

(10) $2CuSo_4 \;\&\; 2FeSO_4 \;\&\; H_2O = Cu_2O \;\&\; Fe_2(SO_4)_3 \;\&\; H_2SO_4$

(11) $Cu_2O \;\&\; H_2SO_4 = Cu \;\&\; CuSO_4 \;\&\; H_2O$

(12) $CuSO_4 \;\&\; H_2Ca(CO_3)_2 \;\&\; H_4SiO_4 = CuO \cdot H_4SiO_4 \;\&\; CaSO_4 \;\&\; H_2O \;\&\; CO_2$

[1] Ries, Heinrich: "Economic Geology" (1925) p.480.

In Zone of Secondary Sulphide Enrichment: The downward penetrating waters carrying dissolved copper salts eventually reach a region where oxygen is deficient, where the amount of free acid is decreased, and where reduction, rather than oxidation, is actually favored. There, in the zone of secondary sulphide enrichment, the copper and other metals in solution tend to form new combinations and to be reprecipitated as insoluble solid compounds. This is accomplished mainly as a result of the contact of these solutions with the sulphides and other unoxidized ore minerals of the primary pre-existent zone of relatively leaner mineralization, upon which minerals the deposition is made, and upon the presence of which deposition depends. The enriched zone is commonly characterized by the formation of secondary sulphides, sulpharsenides, sulphantimonides and bismuth-bearing minerals, as well as cuprous oxide and metallic copper. Probably the most common copper mineral occurring at this horizon is chalcocite, which is subsequently altered to form covellite. Bornite is likewise common while secondary chalcopyrite may also be found. The most frequently occurring complex sulphides of this zone include tetrahedrite, tennantite, famatinite, enargite and sometimes bournonite. The extent of this zone as previously noted[1.] is relatively limited and of variable thickness and richness. The concentrating process may be affected by a number of factors including climate,

---

1. Ante.p. 46.

altitude, relief, permeability of the rock, geologic history of the locality and the chemical and mineral composition of the ore. Lowering of the water table permitting the oxidation of the previously enriched minerals may cause a progressive downward enrichment and an enlargement of the zone for, when the cupric sulphate solution comes in contact with the primary or enriched ore, fresh cupric or cuprous sulphide will be formed [1]. Moreover, secondary enrichment of the copper sulphides need not be confined below the water level, for should there be a deficiency of oxygen or of ferric sulphate in a part of the oxidized zone, secondary sulphides may be deposited. Such occurrences are however, usually of a spotted and irregular nature.

Many reactions have been written to explain the precipitation of metallic sulphides in the zone of secondary enrichment. Frequently several intermediate steps may be involved in the process of change from one mineral to another. For example, it has been shown that in the conversion of pyrite to chalcocite by the action of copper sulphate, the order of transformation in some cases at least is probably as follows: Pyrite- Chalcopyrite- Bornite- Covellite- Chalcocite. The following reactions seem to be approximately representative of some of the more important changes;

(13) $5FeS_2$ & $14CuSO_4$ & $12H_2O$ = $7Cu_2S$ & $5FeSO_4$ & $12H_2SO_4$

(14) FeS_2 & $4CuSO_4$ & $3SO_2$ & $6H_2O$ = $2Cu_2S$ & $FeSO_4$ & $6H_2SO_4$

---

[1] Lindgren, Waldemar: "Mineral Deposits" (1928) p.942.

(15) $CuFeS_2$ & $CuSO_4$ = $2CuS$ & $FeSO_4$

(16) $2FeS_2$& $CuSO_4$& $2O$ = $CuFeS_2$& $FeSO_4$ & SO_2

(17) $CuSO_4$& H_2S = CuS & H_2SO_4

Examples of the oxidation of copper deposits and resulting secondary enrichment are numerous and widespread. Of the outstanding deposits of this nature might be mentioned those of Ely,Nevada; Bingham,Utah; Ray and Miami,Arizona; Rio Tinto, Spain and the Chuquicamata deposit of Northern Chile. The deposits at Ely,Nevada are now being worked on a large scale as a secondary chalcocite proposition. Intrusive activity causing contact metamorphism was instrumental in the development of copper deposits, but few of these have proven of economic importance, the post-intrusive mineralization producing disseminated pyrite of the porphyry mass with lesser amounts of chalcopyrite. Upon exposure by erosion, however, the oxidizing supergene waters produced a downward migration of the soluble copper sulphate from the porphyry itself and from the contact deposits above. This resulted in a marked chalcocitization of considerable extent and of sufficient richness to warrant the large scale operations now being carried on at this mine. The leached zone is from 50 to 200 feet in depth and consists of a soft iron-stained mass containing in some places oxidized copper ores. The chalcocite zone lying below is comprised of a white earthy porphyry in which occur disseminated flakes and grains of chalcocite and lesser amounts of pyrite. This zone has a maximum depth of about 500 feet, the copper mineralization gradually decreasing with depth until only pyritic valueless "protore" is reached. At this particular locality the level of the ground water is estimated at 385 feet below the surface.

....

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

PART III

THE METALLURGY OF COPPER

111. METALLURGY OF COPPER

INTRODUCTION.

Early Development: "The art of metallurgy as practised during the centuries preceding the great scientific awakening of the last one hundred years was more in the nature of a craft, the rules of which had been handed down from father to son for countless generations. New discoveries and new processes were few and far between and then were based most frequently on accident rather than on premeditated improvements. The advent, however, during the eighteenth century of the new era in the physical sciences gave an impetus to the metallurgy of the economic metals, which, while slight at first, for the art seemed not to see the significance of the bearing of physics and chemistry on metallurgy, rapidly grew, until at the present day metallurgic processes are carried out for the most part on a rigorously scientific basis, resulting in an enormous production, at low cost relatively speaking, and of such composition or such purity as to make the metals available for almost any purpose desired in industry on the arts".[1]

Little is known to us concerning the earliest methods used for the extraction of copper from its ores. There are still

---

[1] Fulton, C.H." Principles of Metallurgy" (1910) p.1.

to be found on the slopes of Mt.Sinai and in the valley of Wadi Meghara in the Sinai peninsula, remains of slag heaps, furnaces and crucibles. Apparently the ores worked there were self-fluxing and were almost entirely oxidized. The fact that these ores were readily reduced would largely explain the early production of copper in this area. Simple pit-smelting of the ores with charcoal would yield 18 per cent of their copper content. On Metterberg Mountain in the Austrian Alps discovery of the remains of about a score of roasting and smelting places, as well as a furnace, constitutes evidence of a prehistoric copper metallurgy dating back to about 1300-1000 B.C. The furnaces with interior cross-sections of about five square feet, were made of broken stone and clay. Masses of slag weighing about forty pounds are to be found and these were probably pulled out of the furnaces by means of poles. Resmelting was the probable means of refining the coarse,black copper of the first smelting operation in that refining slags have been found to contain copper shot, which have but little sulphur content. Copper utensils were used by the Lake Dwellers at Hallstatt, Austria, the metal probably being derived from such operations.

The earliest historical though somewhat confused records of the metallurgy of copper are furnished by Pliny in his "Natural History of the Roman" and in the works of

Dioscorides and Galen (100-200 A.D.). According to the former historian all the ores were first roasted in heaps until they took on a red color, then the roasted product was removed and smelted in small shaft furnaces charged with alternate layers of charcoal and ore. Air was introduced near the bottom by means of hand bellows. The product of this operation was black copper, with some matte, slag and furnace accretions. Much of the copper of the ancients was an impure, brittle, black metal suitable only for casting and was then sharply distinguished from the malleable and workable material. Pliny referred to the possibility of improving the metal by repeated smelting operations which were then done by means of small hearths, fueled with charcoal and having air blown upon the surface of the molten copper. Brass was produced by the smelting of metallic copper with powdered calamine mineral ($2ZnO.SiO_2.\ H_2O$) or with zinc furnace accretions. Bronze was widely produced by smelting copper with tin. The period extending from the third century to the beginning of the sixteenth century saw only a slight advance in the metallurgy of copper. In Austria during the thirteenth century the precipitation of copper from certain mine waters was practised, although the Romans had probably been familiar with the reactions involved. In 1272, in Graslitz, Bohemia, sulphide-iron-copper ores were smelted to a matte, roasted in heaps to convert the copper to sulphate, then leached with water and the metal precipitated on iron. The metallurgy of copper as at the beginning of the sixteenth century is discussed at considerable length by Georges Agricola, in his work Vom Bergwerk (1556). There were then seven separate operations as follows:[1]

> " (1) The roasting of the ore in heaps.
> (2) The smelting of the roasted ore in blast furnaces with open breast and an exterior hearth, with the production of matte and slag.
> (3) Roasting the first matte in heaps.
> (4) Smelting this matte in blast furnaces into one of a higher grade.
> (5) Roasting this matte to expel practically all sulphur.
> (6) Smelting this roasted matte in blast furnaces to "black copper"
> (7) Refining the black copper on hearths or in simple reverberatory furnaces resembling ancient cupeling furnaces."

The presence of appreciable quantities of silver in a copper ore requires its extraction by the smelting of the black copper, or the rich matte with lead, which thus accomplished the partial removal of the silver. The lead was then cupeled for its silver content.

Thus had the main principles of copper metallurgy been fully realized. In succeeding centuries important developments included suchtypical processes as the German Blast Furnace, and the English Reverberatory practice by Wright in 1698. The latter process has shown certain advantages over the former as regards capacity and economy of operation. During the last half century the metallurgy of copper has developed remarkably and has at the present time reached a very high degree of efficiency. Further progress can be expected as the copper deposits of high grade become gradually exhausted and as metallurgists concentrate their

---

1. Fulton C.H.: "Principles of Metallurgy" (1910) p.18.

skill upon the treatment of low grade ores, so extensively distributed over the world and which are doubtlessly the potential copper producers of the future.

MINING.

Mining methods have developed simultaneously with metallurgical progress. The application of high explosives and later, the use of the mechanical rock drill, and other mining machinery have combined to successfully supply the greatly increased demand for the raw material. Frequently underground methods of mining copper ores are adopted but extensive open-cut mining and the use of steam shovels, as at Bingham, Utah, has been found successful where circumstances permit. Recovery of copper from mine drainage water has long been practised, and at Butte, Montana such operations are on a large scale. The leaching of ore in place is closely related to mining operations, in that this is one method of removing the metals from the ground, a process which may become of considerable significance in operating the low grade copper properties of the future. At the Ohio Copper Company, Bingham, Utah, an entire mine is being leached in this manner. This particular property was at one time worked by the usual mining methods, until the high grade ore became exhausted and such operations were no longer profitable. Subsequent caving and shattering of the remaining rock resulted in its exposure to the action of the ground waters which drained to the main adit of the mine. Consequently precipitating "launders" have now been placed in this adit and spent solutions are being pumped back over the surface of the ground to assist the leaching process. The reports of the operating company reveal remarkable recoveries at a surprisingly low cost.

At Cananea,Mexico, stope leaching has been practised. In this process the low grade material of those stopes which have yielded their high grade ore, is broken. Sometimes the solutions are drained to lower levels and the copper precipitated on iron, after which the spent solutions are pumped back over the ore. In certain other cases the solutions are pumped to the surface for precipitation. Care must be exercised in having the solutions evenly distributed over the ore, and for this purpose a rubber hose has been found satisfactory. Part of the solution must be continuously withdrawn for "stripping" and discarding, in order to prevent the excessive building up of iron salts. In the precipitation process the introduction of air has been found beneficial. The cost of production of copper by these methods, and including smelter charges, has been as low as 6.87 cents per pound [1].

[1] Hayward C.R.: "An Outline of Metallurgical Practice" (1929) p.124-6

CRUSHING. In most cases the ore coming from the mine must be crushed finely, or if for flotation concentration[1] even pulverized. There are other instances where medium crushing is sufficient, while in a few places, as with certain rich ore bodies, coarse crushing is adequate for the product which is to be either directly smelted or first subjected to but a rough method of concentration.

Three main methods of crushing have been used with considerable success. The "Jaw Crusher" equipped with an oscillating jaw is fed from the top and discharges the crushed ores between the lower edge of the jaw and the front plate, in sizes depending on the width of that opening, which varies in different crushers and which, to a limited extent, is adjustable in each machine. The "Gyratory Crusher" is made in various sizes, some quite large. The ore is crushed between a gyrating head and a fixed cone. Fine grinding is best accomplished in the "Ball Mill". In one type (the "Hardinge Ball Mill") the machine somewhat resembles a slender toy top and revolves on its axis in an almost horizontal position, with a slight slope toward the smaller end, i.e. in the direction of movement of the ore. Within this cone-shaped receptacle are steel balls of varying size, the largest by centrifugal forces being retained at the section of greater circumference and higher speed of revolution, while the smallest balls are kept near the smaller

[1] Postea pp. 61-5.

and more slowly rotating end. The ore is introduced at the larger end as the mill rotates and the material is first coarsely crushed by the larger and most rapidly moving balls, and continually more finely by the successively smaller balls, until a finely-ground product is discharged from the opposite end of the mill. This crushed material is frequently classified and that which is not sufficiently fine is returned for re-grinding.

CONCENTRATION.

Copper ores are generally of too low grade to be directly smelted and so methods for their concentration have been developed. The object of ore concentration is the separation of waste rock known as "tailings" from the "concentrates" which contain the valuable constituents of the ore in a more concentrated form.

Various types of concentrators have been used for this purpose, the principle of them all being the separation of the heavy metallic mineral from the lighter waste rock. With but one or two exceptions of minor importance these machines operate with the ore wholly or partly immersed in water.

Flotation: Concentration processes which have tended to revolutionize metallurgical practice, include those based on the principle of flotation. In such procedures the separation of minerals in water results from the tendency of certain types of solid particles to adhere to gas bubbles generated within, or introduced into, the pulp, together with the simultaneous adhesion of other kinds of solid particles to the water in which suspended. Flotation of the solids adhering to the bubbles permits their removal as a "froth" of different composition than the pulp.[1.]

Earliest flotation methods centred around two extreme types of processes. The first class, basing its operation upon the recognized differences of wettability of minerals by water, made use of large quantities of oil to separate those particles that were well wetted by water from those that were wetted less. The second process was known as "skin-flotation" and in it dry or drying mineral particles were approached by a free water surface which exerted a selection between the two classes of ore particles. From 1901 to 1905 developed the Australian flotation process in which the buoyant medium was a gas produced by the reaction of a strongly acid pulp with suspended sulphides and carbonates. Direct introduction of gas by a "beater" or "impeller" revolving in a pulp was the next development (1906) and was the forerunner of the flotation machines of the "agitation" type used at the present time. Later developments of this method of direct introduction of gas include those methods using porous bottoms (1914) and submerged pipes.

---

1. Gaudin, A.M. "Flotation" (1932) p.1.

With the replacement of oil by a gas as **the buoyant** medium there came first the recognition that large amounts of oil are unnecessary and finally the realization that at times oil was even objectionable. Differences in the floatability of various oil substances were next recognized and the use of soluble "frothing" agents, such as ketones, fatty acids and esters (including the present widely use pine-oil) were finally recommended (1909). During the period 1915-22 Perkins discovered the association of the collecting property with nitrogen in the valent state and sulphur in the divalent state, in certain non-oleaginous organic compounds, while in 1924, Keller introduced the use of xanthate for the same purpose. These latter developments markthe beginning of a flotation technique in which oil as a distinct phase has ceased to exist. The newer process may be termed "chemical flotation" in contrast to "oil flotation". In the last five years considerable research has been directed towards the discovery of specific collectors for each of the metals and while much progress has been made, no complete success has as yet been attained. The development of selective agents permits the flotation of one mineral but inhibits that of another, so that a separation may be attained. Such a process is called "selective" or "differential flotation" as contrasted with "collective flotation" in which all the metals are collected in one concentrate.

The process which has become the most prominent method of concentration of copper ores is one in which the finely crushed or pulverized ore is agitated in water to which has been added small amounts of oil and other reagents. The froth which is thus produced floats the metallic mineral which is but slightly mixed with waste rock. The floated product is continually skimmed off, the water content removed by continuous rotating filters and the sulphides sent to the smelter.[1.] Usually the first concentrate is further purified by repeated flotation. Formerly flotation processes merely separated sulphides from the other minerals, but recent developments have made possible the separation of copper and lead, zinc and iron sulphides, and this advance has had a marked influence upon smelting practice. Concentration of the sulphide ores of copper is the largest industrial application of flotation, and in many cases the simplest and most universally successful. The commercial importance of the process is indicated both by the large scale operations (70,000,000 tons of sulphide copper ore handled annually) and by the fact that fully nine-tenths of the tonnage of sulphide ores of copper is concentrated by this process instead of being smelted directly, leached or concentrated by other methods. The Utah Copper Company has by this means been able to increase mill recoveries from 65 to 90 percent, while the grade of the concentrate has been at the same time improved.[2.]

---

1. Hayward, C.R.: "An Outline of Metallurgical Practice" (1929) pp.27-
2. Gaudin, A.M. "Flotation" (1932) p.156.

Future developments of the flotative processes in connection with the treatment of the complex sulphide ores of lead-copper-zinc-iron and of copper-iron will likely be confined to attempting an improved recovery in the case of the very coarse or the extremely fine particles, and in the improved selection among the finer particles of these ores. For the separation of sulphide copper-zinc and copper-lead ores, however, more and improved collectors will yet need to be developed. The flotation of oxidized ores, and of oxide, carbonate, sulphate, and silicate ores will in all probability be a feature of the next decade of development in flotation practice.[1.]

ROASTING.

The roasting of copper ores may be accomplished by such methods as open-heap roasting and by the use of stalls, kilns, and hand or mechanically stirred or rabbled reverberatory furnaces. With standard large scale operations, however, the modern cylindrical multiple-hearth furnace is most commonly employed. The typical furnace (MacDougall type[2]) has from six to nine hearths, and occasionally more. These are equipped with a central rotating shaft supporting two rabble arms over each hearth. The rabble teeth are so adjusted as to gradually move the ore from centre to circumference on one hearth, whence it is dropped to a lower hearth and similarly moved, but in the opposite direction to the centre, where it once more drops to a still lower hearth. Much of the roasting takes place while

1. Gaudin,A.M.:"Flotation" (1923) p.6

39-

the ore is falling from one hearth to the next lower one and the tendency now seems to be towards the use of more and smaller hearths. Thus, at the present time, eight, nine and even eleven hearths are being used. The air required for the roasting is admitted in the proper amounts through an opening near the bottom of the hearth. Oil or gas burners or fireplaces situated outside the furnace may be used to supply heat for admission to any hearth, though usually such is not required in that the burning of the sulphur ordinarily supplies sufficient heat. If, however, all the sulphur is to be removed, or if such content is below 24 percent, an extraneous source of heat is necessary. Ideal temperature conditions for roasting vary gradually from 600-700°C. in the earlier stages, to 800-850°C at the end. The usual daily capacity of such furnaces is about 125 to 150 tons, though a furnace handling 280 to 300 tons a day has been recently put into operation.

Many chemical reactions are obviously involved in the roasting process. These do not take place simultaneously but are influenced by conditions of temperature and pressure within the furnace. In general, the roasting of sulphide ores causes the sulphur to be oxidized to SO_2 and SO_3 which substances either pass off as gases or remain combined with other elements in the ore. Metallic oxides are at the same time formed. Low temper-

-atures and a high SO_2 or SO_3 content in the furnace favor the formation of sulphates, while high temperatures and lesser amounts of the gases are conducive to oxide formation. It is doubtful if much copper oxide is formed in such a process, in that there is a tendency for the iron sulphides to be oxidized before those of copper, thus with but a partial roast much of the copper will remain as a sulphide or as a sulphate. FeO, a transitional substance, is probably never present in the product of this operation. Though magnetic iron oxide (Fe_3O_4) is an undesirable substance in the roasted product, it is usually present. Considerable sulphur must be left in the furnace product and usually tends to provide semi-reducing conditions resulting in Fe_3O_4 rather than Fe_2O_3 being the final condition of much of the iron. It can thus be readily seen that the resulting product of this operation constitutes a mixture of oxides, sulphates, unoxidized sulphides and unaffected gangue minerals. Hayward[1.] suggests the following chemical reactions as being representative of the possible changes involved in this process:

(1) Cu_2S & $3O$ = Cu_2O & SO_2
(2) Cu_2O & SO_2 & O = $2CuO$ & SO_3
(3) CuO & SO_3 = $CuSO_4$
(4) Cu_2S & $3SO_3$ = Cu_2O & $4SO_2$

---

1. Hayward, C.R.: "An Outline of Metallurgival Practices" (1929) pp.36-7.

(5) $Cu_2O \,\&\, SO_3 = 2CuO \,\&\, SO_2$

(6) $FeS \,\&\, 3O = FeO \,\&\, SO_2$

(7) $3FeO \,\&\, O = Fe_3O_4$

(8) $SO_2 \,\&\, O \,\&$ catalyser $= SO_3$

(9) $2Fe_3O_4 \,\&\, SO_3 = 3Fe_2O_3 = SO_2$

(10) $FeO \,\&\, SO_3 = FeSO_4$

(11) $2FeSO_4 \,\&$ heat $= Fe_2O_3 \,\&\, SO_2 \,\&\, SO_3$

(12) $4FeSO_4 \,\&\, O_2 = 2\ (Fe_2O_3 : 2SO_3)$

(13) $4FeS_2 \,\&\, 11O_2 = 2Fe_2O_3 \,\&\, 8SO_2$

(14) $FeS_2 \,\&$ heat $= FeS \,\&\, S$

(15) $FeS_2 \,\&\, O_2 = FeS \,\&\, SO_2$

(16) $FeS_2 \,\&\, 3O_2 = FeSO_4 \,\&\, SO_2$

(17) $Cu_2S.\ Fe_2S_3$(chalcopyrite). The reactions involved are a combination of those given for Cu_2S, FeS_2 and FeS.

SMELTING.

Smelting is a metallurgical process by means of which ores or furnace products are reduced to a molten condition with or without the addition of a flux. In order to obtain fluid products it is frequently necessary to add some substance, known as a flux, which by combination with the ore material will produce fluid compounds. For example, in the smelting of copper bearing iron sulphides by the pyritic process[1] it is necessary

[1] Postea p. 89-90.

to add silica as a flux. In the early treatment of oxide ores the presence of a reducing agent was essential so that the development of the shaft furnace with the ore and fuel mixed was the natural outcome and has culminated in the large blast furnace of today. The use of this type of furnace has however, been on thedecline in more recentyears and it is being gradually replaced by the reverberatory furnace. The possibilities for electric smelting have been probed, but for economic reasons this process has not as yet been extensively developed. Investigations by the Canadian Government have shown that a very low cost of power would be necessary if electrothermal methods are to be commercially practicable. The most encouraging results todate have been obtained in Norway, where a furnace operated to produce 25 tons of copper matte daily, used power at the rate of 700 K.W. hour per ton of charge. Some of the principles of smelting have already been discussed in connection with the roasting process [1]. It is now proposed to deal with the typical methods commonly used in smelting practice.

Reverberatory Furnace Smelting: Up to about 1909 the development of the reverberatory furnace was slow, but subsequently with the increased production of ore concentrates, and the introduction of the use of fuel oil and powdered coal, progress in this method of smelting has been greatly stimulated. Essentially, the reverberatory furnace

---

[1] Ante, pp.65-8.

consists of a hearth of furnace sand or magnesia, an arched roof of silica brick, and at one end a firebox, separated from the hearth by a fire bridge, or "Bridge wall" equipped with an air-cooling system to counteract the high operating temperatures at this part of the furnace. The fuel is usually a long flame bituminous coal, which burns in the fire box to produce combustible gases which are carried over into the hearth by means of a suitable draft. There the gases burn with the air admitted, either directly from the outside or from the cooling system of the bridge wall. The furnace charge is introduced through hoppers in the roof. As the process continues, the charge is levelled off, rabbled,(stirred) by long tools operated through doors along the sides of the furnace. These openings may also serve to admit extra air for the combustion of unconsumed gases. Such a method of adding air, however, is not very desirable, due to the loss of heat thus incurred. The heat generated by the fire and by the combustion of its gaseous products in the hearth itself, acts upon the charge through the effectiveness of the arched and reverberating roof. The material on the hearth is melted and the products of the reverberatory furnace- matte, slag, flue dust and fume- are thus formed.

The matte consists of a union of the fusion products of the charge, mainly copper and iron sulphides. These, being the heaviest products of the operation, tend to settle to the bottom of the furnace, taking with them any precious metal content which might be present. The matte is withdrawn through a tap-hole conveniently located along the side or the end of the furnace. It is run into a ladle which is handled either by a crane or a locomotive and then conveyed to the converters as required. A complex mass of fusible silicates resulting from the smelting process constitutes the slag. It is usually run off continuously through a tap-hole at the end of the furnace and either caught in slag cars and taken directly to the slag dump, or is granulated with water and disposed of according to convenience. The large amount of fine material introduced into the modern reverberatory furnace accounts for a considerable fine dust content in the waste gases. Volatile constituents such as arsenic are also contained and removed by the gases. A portion of the dusts and fumes is collected in dust chambers, or such dust and fume collectors as the Cottrell precipitator, designed to clean the gases before they enter the stack.

The chemical complexity of the roasted ore that is charged into the reverberatory furnace precludes the possibility of attempting to write the equations of the reactions involved in the fusion of the furnace charge. Contained in it may be such compounds as Cu_2S., Cu_2O.,CuO., $CuSO_4$., FeS.,$FeSo_4$., Fe_2O_3., Fe_3O_4., and SiO_2., together with various complex silicates of iron,aluminium, etc. Certain basic salts of copper and iron may also be present. If raw ores are added there may also be FeS_2 and $CuFeS_2$ and other sulphides with silica, limestone and silicates. Many ores also contain the precious metals, gold and silver, and possibly other rarer metals may occur. Hayward [1] outlines the following changes:

(1) The copper in copper oxides, sulphates and complex sulphides, is changed to Cu_2S through various reactions due to heat and the interaction of sulphides.

(2) The sulphur, which after the various reactions does not remain combined with the copper, is in part fixed by the iron as FeS and in part eliminated as SO_2 or SO_3. These latter gases may result from the decomposition of the sulphates by heat-forming oxides, and SO_3, or by reactions between oxides and sulphides, such as: $3Fe_2O_3 \& FeS = 7FeO \& SO_2$. Some sulphur is also retained in sulphides or such minor metals as arsenic, etc.

(3) The iron which is not combined with sulphur reports as silicate in the slag or as magnetic oxide. The latter may be in part in the slag or dissolved in the matte. The presence of an oxide dissolved in a sulphide is a strange phenomenon, but is apparently a fact.

(4) The lime, magnesia, alumina etc., enter the slag as silicates.

(5) The precious metals enter the matte as sulphides or as dissolved metallics.

(6) Arsenic, antimony, lead, zinc, tellurium and selenium compounds undergo oxidation or reduction, or both, and report as sulphides in the matte or as various compounds in the fume.

(7) Nickel for the most part enters the matte as a sulphide.

---

[1] Hayward, C.R.: "An Outline of Metallurgical Practice" (1929) p.65.

Blast Furnace Smelting: Early practice with blast furnaces of circular shape charged with an oxide or roasted ore mixed with coke and suitable fluxes, produced an impure copper called "black copper" and a fluid slag often containing two or three percent copper and sometimes more. Later, the partly roasted ore or a mixture of oxide and sulphide ore was smelted in round or oblong furnaces, the product being a matte containing 25 to 45 percent copper and a slag with usually less than o.5 percent copper. With present practice and the availibility of lump sulphide ore, smelting, with suitable fluxes, a minimum of fuel (3-5 percent) and a large volume of air, produces a satisfactory matte and slag. The decreased amount of fuel is possible because of the oxidation of the excess sulphur and iron. Free silica flux in lump form makes the mass about the tuyeres more porous and permits ready circulation of the air, thus promoting oxidation. Being free, it is also more chemically active, and assists in slag formation. If it is desired to smelt fine concentrates in the blast furnace they must first be either roughly roasted or sintered on some type of sintering machine , when about 12 percent coke is required. The purpose of sintering is to agglomerate the fine ore and render it more porous, and at the same time remove part of the sulphur content and reduce thereby the burden of the roasters.

The shaft of the copper matting blast furnace, instead of being built of the usual fire brick, is made of steel or cast iron water jackets. These are boshed or sloped inwards (the end ones excepted) and serve to relieve some of the pressure of the charge near the bottom of the furnace. The main jackets contain feed-water pipes and discharge overflow pipes. These serve to eliminate corrosion of the furnace lining, in that with the use of such jackets a slag crust rapidly builds up on the inside of the jacket to form the actual smelting surface and thus protect the iron plate and reduce the cost of repairs. Although the loss of heat is much higher than if a fire-brick lining were used, the general convenience obtained readily outweighs this disadvantage. A hood and flue attachment is provided at the top of the furnace to collect and convey the fumes to the dust chambers for "settling out". The flue is connected with the chimney. The furnace charge is introduced through doors from the charge floor near the top of the furnace. Here specially adapted scales are frequently used to weigh the various charge materials in order to obtain the proper mixtures. The blast is introduced from the blower by means of the bustle pipe and tuyeres. A tap-hole and spout at the lower part of the furnace permit the discharge of the molten material into a forehearth or "settler". This is ~~a~~ lined either with fire-clay or magnesia brick and is usually mounted on a truck as a matter of convenience. In this settler the separation of the matte and slag is accomplished by gravity. Tapping may be either intermittent or continuous, depending upon the size and type of furnace concerned. The matte in the forehearth settling by gravity, may be tapped into pots from time to time by means of a spout situated near the bottom of the receptacle. The contents of the forehearth must be kept "open" i.e. in a molten state. This is accomplished by having the forehearth of a size suitable for the particular furnace, so that the inflowing material is able to prevent the whole mass from chilling and freezing. From the settler the slag runs continuously to the slag car for conveyance to the slag dumps or to a granulating launder. The matte is tapped as it is required by the converter department.

With the decreasing supplies of rich lump ores and an increased and improved concentration practice, the utility of the blast furnace has been lessened. It is cheaper to roast and smelt the concentrates in a large reverberatory furnace fueled with oil or powdered coal, than it is to first sinter them and smelt the sintered product in the blast furnace with coke, particularly if, prior to sintering, the ore should require a rough roasting. Coke fuel, moreover, is usually more expensive than is coal or oil. Small blast furnaces, however, are considered more economical than small reverberatories, while the initial cost of a blast furnace is less than that of the reverberatory type, and its salvage value is greater. Future installations of blast furnaces will probably be confined to small plants, to short-lived operations, or to such locations wherein special conditions would favor the use of the blast furnace.

The chemical reactions of ore fusion in the blast furnace are much the same as those in the reverberatory process. The ore charged into both furnaces is somewhat similar, although the blast furnace charge usually contains more sulphides and is ordinarily coarser. The added factors in this operation are the coke, the fuel and the air blast. The coke, to a considerable extent, persists down to the region of the tuyeres where a mixture of coke, molten matte and slag will probably produce a variety of simultaneous reactions. In that the carbon has the greatest affinity for oxygen, carbon dioxide and carbon monoxide will certainly result. The sulphur will likely be somewhat oxidized, as will some of the iron from the matte, producing thereby the desired copper enrichment of the product.

CONVERTING COPPER MATTE.

The object of converter practice is essentially the concentration of the smelter matte to metallic copper through the elimination of the iron, and by the reduction of the sulphur. This process is frequently referred to as

" bessemerizing" after the name of the originator of this practice in steel production, Sir Henry Bessemer. The process was first adapted to copper metallurgy by John Halloway and later successfully operated by M.Manhes in France. The basis of copper converting is the blowing of air through the molten matte, producing an oxidation of FeS and later that of Cu_2S. With the addition of a siliceous flux during the operation the FeO that forms is removed thus leaving Cu_2S, the precious metals, and small amounts of impurities. Further blowing then oxidizes the Cu_2S until, at the point when the sulphur is burned off, the operation is stopped, when the copper is in the metallic state.

The converter used in this process is essentially a horizontal, cylindrical steel shell supported by ties resting on rollers to permit partial revolution about its longitudal axis. At a point about ten inches above the bottom of the shell, several tuyeres for the introduction of the blast, penetrate the thick brick lining. The so-called "acid-lined convertor" was the first type used, and was characterized by a thick lining of siliceous material designed to slag the FeO formed in the oxidizing process. Certain features of this type of converter which were deemed objectionable include (1) small capacity, (2) expense and space required for the frequent and necessary relining, (3) difficulty of control, and (4) the variability of the resulting slag. Research efforts were thus stimulated and culminated in the introduction and growing use of the modern "basic-lined converter" which only came into use as recently as 1909. This converter is lined with magnesite brick, which is frequently protected by a magnetic slag produced by "over-blowing" some of the copper matte before any flux is added. Of this class of converter there are two general types, known as the Great Falls Type and the Pierce-Smith Type. The former is really a remodelled acid bessemer converter which has been lined with basic material. The standard size is about 12-foot shell, but 20-foot converters have also been used (Anaconda). The Pierce-Smith type is somewhat similar to, but larger than, the old barrel type acid converter. Its size ranges from 12 to 36 feet in length, although a 30 foot converter is the common size.

The converter is charged with the copper matte brought from the smelting furnace either in a ladle by an over-head crane, or in matte cars. The charging operation requires the position of the converter to be such that the molten matte will not run into the tuyeres. With the proper amount of charge introduced into the converter, it is placed in its normal position and the blast, furnished by a blowing machine at 6 to 8 pounds pressure, is turned on. Siliceous flux may be added in definite quantities during the operation. To prevent the over-heating of the lining, cold material, such as any high copper scrap, is added from time to time. The tuyeres must be kept clear and frequent punching with a special rod is necessary in order to prevent the accumulation and chilling of metallic copper in these air passages. By a simple rotation of the converter, the slag, and later the metallic copper, may be removed. This product known as "blister copper" or "converter copper" may be directly poured into a refining furnace, but generally it is poured into a casting furnace, from which it is cast into cakes.

The chemistry of copper converting is somewhat less complex than that of the preceding operations. The matte which is charged into the converter consists principally of FeS and Cu_2S, which two compounds alone are concerned in the earlier stages of the operation. The first significant reaction is expressed as follows:

(1) $2FeS \& 3O_2 = 2FeO \& 2SO_2$

The FeO immediately reacts with the SiO_2 of the flux as :

(2) $FeO \& SiO_2 = xFeO.ySiO_2$

The oxidation of any Cu_2S at this stage is ineffective because it is immediately reduced as indicated in the next equation-

(3) $Cu_2O \& FeS = Cu_2S \& FeO$

However, when the FeS is practically eliminated the oxidation of the Cu_2S, without subsequent reduction, may to a certain extent take place as follows:

(4) $Cu_2S \& 3O_2 = 2CuO \& 2SO_2$

Here the CuO formed will tend to unite with the SiO_2 to form a silicate and join with the iron silicate as a slag. Upon removal of the slag metallic copper will be produced, according to the equation:

$$(5)\quad Cu_2S \,\&\, O = Cu_2 \,\&\, SO_2$$

Any oxide of copper produced at this time will immediately be reduced:

$$(6)\quad 2Cu_2O \,\&\, Cu_2S = 6Cu \,\&\, SO_2$$

If insufficient Cu_2S is present, as is sometimes the case towards the end of the operation, the Cu_2O formed will, to a certain extent, dissolve in the blister copper.

REFINING BLISTER COPPER.

Blister copper, the product of the converter, contains precious metals, provided they were present in the ore, and also some sulphur, iron and minor impurities. It is also porous and brittle. The purpose of refining methods is therefore to increase the purity of the copper as well as to improve its physical properties. Usually the precious metals are present in amounts which warrant the expense involved in their extraction, in which case electrolytic refining is the process used. In the absence of a precious metal content of appreciable amount, furnace refining [1.] is practised, which process will be dealt with briefly before **proceeding** to the more common electrolytic methods.

[1.] Fulton, C.H. "Principles of Metallurgy" (1910) p.237.

Furnace Refining: This process is accomplished in the reverberatory furnace by an oxidizing smelting. The molten copper is rabbled, or stirred by long iron tools in order to promote the formation of cuprous oxide (Cu_2O). This compound diffusing through the molten copper, gives up part of its oxygen content to such impurities as arsenic, antimony, iron, bismuth, etc., when they are changed into oxides. These either pass off entirely with the slag, as in the case of iron, or they are partly eliminated in the form of slag and partly in the volatile state, as with arsenic and antimony. When the copper has become more or less saturated with Cu_2O, the "fining" slag is skimmed and the copper is "poled" i.e. worked through with long poplar wood poles so that the gases thereby produced reduce the Cu_2O to a small amount. Upon completion of the operation, as determined by an examination of the appearance and fracture of sample bars, the copper is cast into market shapes.

Electrolytic Refining: Electrolysis is a highly important factor in the refining of blister copper, and at the present time it is the most common practice at copper refineries. The basic principle in electrolytic refining has been aptly stated by Hayward[1.] as follows:

> "If two strips of pure copper are inserted without contact with each other in an acid solution of copper sulphate, and each connected to one pole of a battery or dynamo, it will be found that the one connected to the positive pole will decrease

---

[1.] Hayward C.R.: "Outline of Metallurgical practice" (1929) p.88

> " in weight and the other will increase at the same rate, while there is no change in the composition of the solution. If the copper connected to the positive pole is impure it will be found that part of the impurities go into solution and part accumulate on the surface of the electrode as slime and gradually drop to the bottom of the vessel, while the deposit in the other strip is pure copper. What actually happens is that the copper acts as a carrier of the current from the positive electrode or anode, to the negative electrode or cathode, and deposits as it gives up its charge."

Metal for electrolytic refining should be rather pure to avoid excess fouling of the electrolyte, therefore it should first be considerably purified by fire methods. In the process of electrolysis not only is the copper highly purified, but a valuable by-product is obtained with the recovery of the precious metal content, which usually warrants the use of this comparatively expensive operation. Two general processes are known as the Multiple process, producing about three-fourths of the electrolytically refined copper of the United States, and the Series process which produces the remainder. The processes are so named because of the peculiar arrangement of the electrodes; in the former the electrodes in each tank are in parallel, while in the latter process the arrangement is that of a series. The Multiple process will here be discussed at greater length, while the less important Series process will be observed in contrast.

The Multiple Process: In this process for the refining of blister copper, the preparation of electrodes involves a separate operation. The blister copper is sent to the electric plant to be made into anodes and cathodes. The furnace used is of a reverberatory type with a shorter and deeper hearth. Usually it is fueled with oil, but some plants favor the use of powdered coal. To oxidize the charge, air is introduced by means of steel or iron pipes located below the surface of the copper, and a violent agitation is thus produced. Additional air may be taken in through the doors of the furnace. As a result of this operation, impurities are either slagged or volatilized. Part of the copper is oxidized, some of which is slagged and some causes a saturation of the molten bath with Cu_2O. The operation is considered complete when a sample bar fractures easily and shows a brick red color. The product is known as "set copper". Upon the removal of the slag, the charge is next covered with coke or charcoal, or a mixture of the two. Green tree trunks are then inserted in the furnace with their ends submerged in the copper. Violent agitation results from the distillation of the moisture and hydrocarbons of the wood, so that sprays of copper are projected almost as high as the furnace roof. Chemically the reduction of any Cu_2O previously formed , is accomplished through the agency of the carbon covering and the reducing constituents of the green wood. This operation is completed when the amount of Cu_2O in the bath is less than 0.5 percent; the presence of some of this compound being necessary to assure **sound** casting. Two types of machines are used to cast the molten copper into anodes, the straight line endless chain type, and the more common Walker wheel, a large wheel revolving in a horizontal plane. The copper flows from the furnace into a tipping ladle which fills each mold as it is brought into position below the ladle lip. In the walker **wh**eel the speed of the operation is so regulated that the copper is solidified during the time required for a half-turn of the wheel. It is then slightly raised by a plunger, caught in the lugs by hooks, raised, and placed upon a rack. As the mold proceeds by rotation into position to receive a second charge, it is sprayed with bone-ash or some other wash in order to prevent the copper from sticking.

The cathodes are thin sheets of electrolytic copper prepared by deposition on a rolled copper plate, which has been either covered with a thin coating of oil or grease, or dipped in a solution of mercury salt. The plate has a sharp groove near the edge along which the precipitated copper sheet tears when being stripped off. The sheets are about one-sixteenth of an inch in thickness and have two loops through which a copper bar is inserted for the suspension of the cathode in the electrolyzing tanks.

The tanks in which the electrolysis takes place are usually made of wood lined with lead, but concrete and a lining of mastic[1] are sometimes used. The usual size of the tanks is 10-15 feet long, 3 to 4 feet wide and 3½ to 4 feet deep. A wooden framework is frequently provided to protect the lead lining. The flow of the electrolyte may be promoted by having the tanks arranged on two or more levels, but sometimes one level is used, with a pumping system to circulate the solution. A plug in the bottom of the tank connected with a lead pipe, permits the removal of the slimes. The arrangement of the electrodes is important and various systems are used. In the"Walker" system [2] the current is brought in by a heavy copper "bus bar" along one end of a row of tanks, and it leaves by the opposite end. Between the tanks are copper "equalizing bars" of triangular cross-section and carefully insulated from the tanks. The anodes of the first tank are in contact with the bus bar, while the cathodes of that tank are insulated from the bus bars, but are in contact with the equalizer between the first and second tanks. In the second tank the anodes are in contact with the first equalizer and the cathodes with the second, and so to the end of the series. The current therefore, proceeds from the positive bus bar to the anode of the first tank, through the electrolyte to the cathode of the first tank, thence

---

[1] Mastic- a compound made of one part asphalt and four parts sand.
[2] Hayward, C.R.: "An Outline of Metallurgical Practice" (1929) pp.101-2

by the equalizer to the anode, electrolyte and cathode of the second tank, to the second equalizer and the anode of the third tank, and in this manner on to the final cathode which is connected with the negative bus bar. The current is usually supplied by several independent circuits, so that one or more may be turned on or off at will, without affecting the entire operation. At the Raritan Works in Perth Amboy, New Jersey, there are four 1250 Hp.generators, each of which furnishes 396 tanks in series, with a current of 7200 amperes at 135 volts. The usual voltage of each tank is 0.3 to 0.35 and the current density 15 to 20 amperes per square foot of cathode area [1].

The electrodes are handled by means of a crane which is so equipped as to be capable of placing in a tank or removing therefrom all the anodes or all the cathodes of a tank at once. The anodes are usually removed every 20 to 30 days, while the **cathodes** must ordinarily be replaced every 10 to 15 days. A new set of starting sheets tend to warp and so after 24 hours they must be individually removed, and straightened so as to prevent any short-circuits. The corroded anodes, upon being removed from a tank by means of a crane, are washed by means of a hose in order to remove the slime. They are then taken to the furnace department to be remelted. The cathodes, also removed by a crane, are taken to a washing tank, dipped in warm water and hosed-off before they proceed to the refining furnace.

1. Hayward C.R.:"An Outline of Metallurgical Practice" (1929)pp.103.

The Series Process: This refining method differs from the Multiple process mainly in the arrangement of the electrodes and the passage of the circuit through them. There are no separate cathodes except one at the negative of end of the tank. The circuit is completed by introducing the current through the electrode at one end of the tank and withdrawing it at the other end, after it has passed through the various bi-polar electrodes between the two end plates. The current thus follows the following circuit: From the first electrode through the electrolyte to the adjacent face of the second electrode, which then becomes a cathode, i.e. one face of the electrode acts as an anode and the other as a cathode. The operation continues until the copper in each electrode, except the last one, has been transferred to the succeeding electrode. The anodes for this process must obviously have smooth surfaces and are therefore either rolled or carefully cast. The size of the electrodes is usually from 3½ to 4½ feet in length, 10 to 12 feet wide and of a thickness ranging from ½ to 3½ inches. When practically all the original anodes have disappeared and the copper deposited on succeeding plates, they are removed and the particles of adhering anode copper are stripped off by hand. The copper is then remelted and refined as in the Multiple process. Hayward [1.] has listed

---

1. Hayward C.R.: "An Outline of Metallurgical Practice" (1929) pp.107-8

briefly the favorable features of the two systems as follows:

"Points in Favor of Multiple System

1. Low voltage across the tanks and therefore few short circuits.
2. Anodes require no special preparation.
3. No stripping of the cathodes.
4. Large electrodes mechanically handled.

Points in Favor of the Series System

1. Less floor space required than in the Multiple system.
2. Less space and therefore less voltage between electrodes and fewer loose contacts, save from one-third to one-half of power over Multiple.
3. No starting sheets required which saves labor and interest on stock.
4. Less length of bus bars and smaller cross-section than in Multiple system."

Casting: As previously noted the cathodes from both of these processes are sent to the refining furnace where great care must be taken in order to ensure the highest possible purity of the completed product, which is cast into such forms as wire bars, cakes, ingots, slabs, billets etc. The operations involved are much similar to those required in the preparation of anodes, while the actual casting is the same except that the molds vary according to the desired form of the product. The refinery slag which is small in amount, is returned to the smelting furnace. Should the anodes contain much Cu_2O this compound dissolves in the electrolyte to cause its enrichment in copper, with a corresponding decrease of the acid content.

To counteract this some of the solution must be continuously withdrawn during the electrolytic process and passed into tanks containing insoluble anodes in order to plate the excess copper and to liberate the acid. To overcome the tendency of certain impurities to build up in the electrolyte, part of the solution is withdrawn and replaced by a new solution. Probably the most satisfactory method of recovering values from the withdrawn solution is to first treat it in tanks using lead anodes to remove some of the copper, the balance of the metal may then be obtained by an evaporation of the solution producing thereby "blue vitriol" ($CuSO_4$). If nickel is also present and the market warrants its recovery, this metal may be obtained as a sulphate by means of a further concentration of of the electrolyte. The electrolytic slime which accumulates in the tank is allowed to settle after the electrodes have been removed. The electrolyte is then siphoned off and the slime sluiced into a large settling tank, after passing through a screen to remove any large pieces of copper. Further treatment may result in the recovery of some more copper as well as the production of such valuable by-products as the precious metals i.e. gold,silver and platinum, which may accumulate in the slime during the refining process.

OTHER PROCESSES.

Pyritic Smelting: This method, frequently termed the "American Process" consists of an oxidized smelting which is carried on in a shaft or blast furnace wherein the heat is mainly derived from the oxidation of the iron sulphides present in the ore. The amount of carbonaceous fuel required is comparatively small, commonly from 2 to 4 percent of the charge. The weight of the charge is partly sustained in the furnace by the "boshes" or inwardly sloping lower walls of the furnace, also by the buoyant effect of the rising gas current, and by resting upon the liquid content of the furnace. In the smelting process the solid material in the "focus" i.e. immediately above the tuyeres, consists chiefly of a mass of incandescent silica or quartz, and the earthy base constituents of the charge. A short distance above this focus the sulphides, as a result of the distillation of part of their sulphur content, become molten. They trickle down through the silica below and into contact with hot oxygen of the air, to be rapidly changed into ferrous silicate ($2FeO \cdot SiO_2$) which, absorbing the earthy constituents, passes into slag. The matte is the portion of the charge which escapes oxidation. Both these products must be in a sufficiently molten state to readily permit gravitative separation in the forehearth or "settler". Pyritic smelting has met with varying economic success. Its best chance for success would seem to be in those localities where fuel is expensive.

Native Copper Smelting: The smelting of native copper ores requires a variation of the usual methods. The famous Michigan ore is crushed in stamp mills and concentrated before treatment in reverberatory furnaces which somewhat resemble the refining furnaces of this type. The furnaces are coal fired and the charge is admitted through two holes- a small one for the fine concentrates and a larger one for the admission of the mass copper. With the ore is also added some slag and coal, while sometimes a limestone flux is necessary. The slag melts in about 24 hours and is then skimmed off, the metal is tapped into a refining furnace situated at a lower level. The hearth is then repaired with sand in preparation for a new charge. The refining is accomplished in furnaces much similar to those used for smelting, except that the charge holes in the roof are lacking. If arsenic is present, in the charge, soda-ash is blown below the surface of the copper, the arsenical slag being later treated to recover the arsenic as a calcium arsenate.

Oxide Copper Smelting: Early treatment of oxide copper ores consisted of a crude smelting process whereby impure "black copper" was produced. Later, with the development of concentration methods, such ores were mixed with those of sulphide and smelted to produce a matte for further treatment. At Katanga in the Belgian Congo, Africa, there is an extensive oxide deposit estimated at 68,000,000 tons of 6.62 percent copper, but sulphide ores are lacking.

Thus the richer portions of the ore together with some concentrates are being treated in blast and reverberatory furnaces to directly produce metallic copper. The slags are however, high in copper, so that the operation is a wasteful one. Plans are now under way to adopt leaching for the low grade material and possibly substitute it for all the smelting operations.[1]

Leaching of Copper Ores: The leaching of copper ores has been commercially practised only on low grade material. Processes have been developed for the leaching of high grade ores or concentrates, and while no installations have yet been made, it is possible that with certain conditions such processes may prove less expensive than the usual smelting. Various leaching agents which have been successfully used include: sulphuric acid, ammonia and ammonium carbonate, ferric salts, hydrochloric acid, and sulphur dioxide, the relative effectiveness of which varies with different conditions. Precipitants which have proven successful are the electric current (electrolysis), hydrogen sulphide, burnt lime, and sulphur dioxide. The earliest and most crude form of this operation is heap-leaching, but it is still being used under certain conditions, and has also

---

[1] Hayward, C.R.: "An Outline of Metallurgical Practice" (1929) p.115

been practised at various places for the recovery of copper from mine dumps and mill tailings. Heap-leaching requires little labor and no expensive agents except the iron for precipitation. Two disadvantages however are the amount of copper stock tied up for a considerable time, and the losses of copper-bearing solutions through seepage into the ground.

PROPERTIES OF REFINED COPPER [1]

Physical Properties:

Melting point: 1083°C. (1982° F)
Boiling point: 2310°C. (4190° F)
Heat of Fusion: 43.20 Cal.
Atomic Weight: **63.57**
Specific Gravity: 8.65
Specific Heat: 0.0939
Linear Coefficient of Expansion at 40°C.x 10^4: 0.1678
Specific Resistance, Michroms: 1.58
Electrical Conductivity (Cu 100): 100.5
Thermal Conductivity: 0.7196
Hardness, Mohs Scale: 3.0
Color: Reddish

Mechanical Properties:

Tensile strength: Rolled annealed copper, 30,000-40,000 lbs. per Sq. In.
Hand drawn copper, 60,000-70,000 lbs. per Sq. In.

Reduction of Area: 30-60%
Elongation: 25-40%

---

[1] Hayward, C.R: "An Outline of Metallurgical Practice" (1929) pp. 138-9

Alloying Properties:

Alloys readily with with Mg., Al., Mn., Zn., Cd., CO., Ni., Hg., and the precious metals.

Slightly alloyable with Fe., Mo., W., Cr., if the metal is pure and more readily in the presence of Si.

Alloys easily with its own compounds, especially with Cu_2O and Cu_2S

In a molten state, alloys somewhat with H., CO., and SO_2.

Chemical Behavior:

In the solid state, it **is fairly** resistant to dry oxygen at lower temperatures, but above 400°C. it is easily oxidized, with CuO and Cu_2O forming on the surface. In a damp atmosphere basic salts with oxygen and weak acids are readily formed.

In the molten state copper exhibits a great affinity for sulphur. Immersed in boiling sulphur it is gradually changed to Cu_2S. Of the acids, only those oxidizing acids, HNO_3, hot concentrated H_2SO_4 and aqua regia act as solvents of copper. Diluted and weak acids will affect copper in the presence of air. Copper does not evolve hydrogen from acids.

SPECIAL VARIETIES OF COPPER.

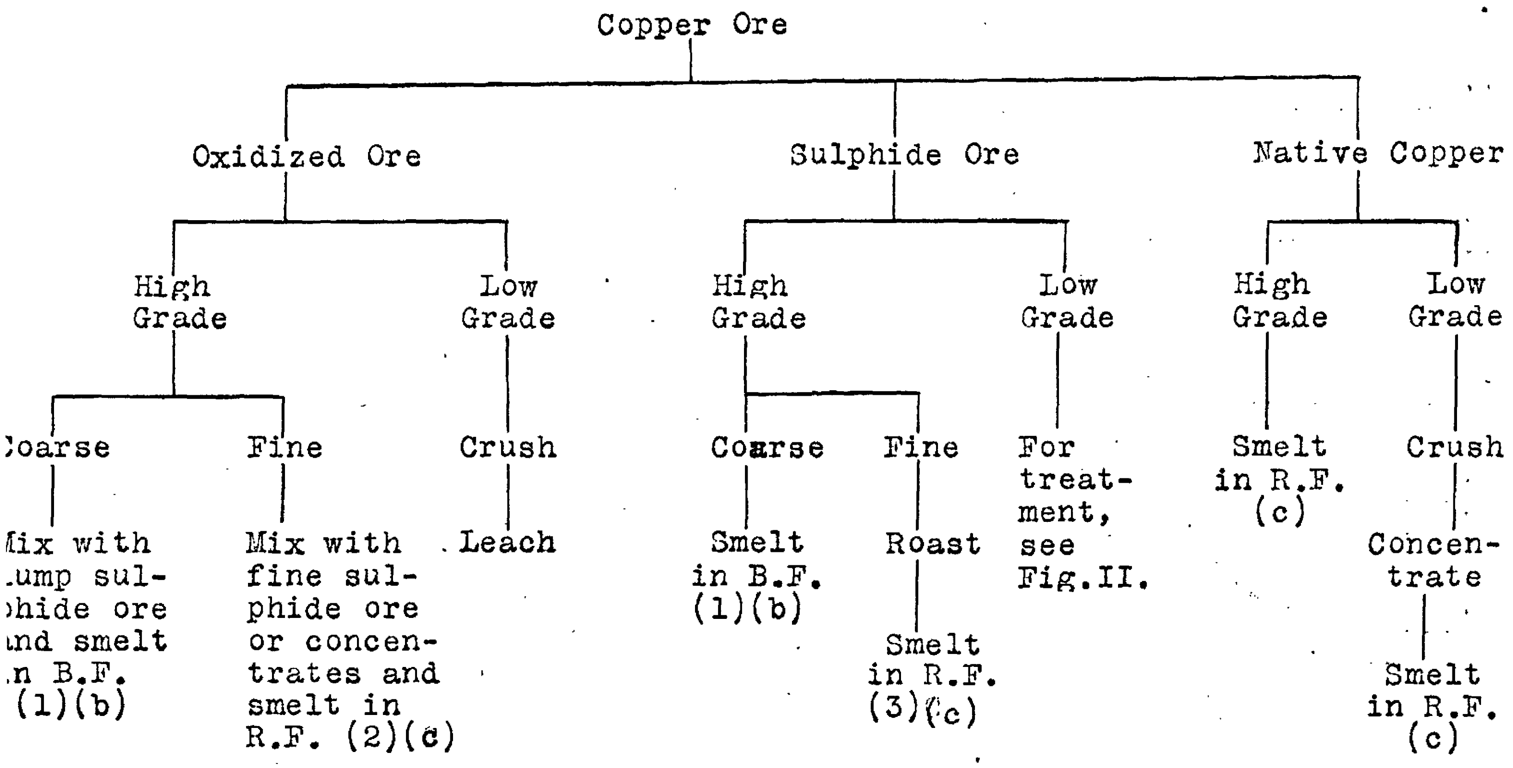
In addition to the usual forms of refined copper, certain other special varieties[1] are produced by some peculiar variation in the treatment of the molten metal.

---

1. Encyclopedia **Britannica**, Vol.VII (1910-1) pp.103-4.

"Bean-shot" copper is obtained by throwing the molten metal into hot water, while if cold water be substituted, the resulting product is called "Feathered-shot" copper. "Rosette" copper is obtained as thin plates of a characteristic dark-red color, by pouring water upon the surface of the molten metal and removing the crust thus formed. If the copper is poured into ingots weighing from six ounces to one pound, and rapidly cooled by immersion in water, "Japan" copper of a purple-red color is produced. "Tile" copper is an impure copper obtained by refining the first furnace tappings, while the purer metal is included in the variety termed "Best selected" copper.

Fig. I. OUTLINE OF METHODS FOR THE TREATMENT OF COPPER ORES (a)



(a) From Hayward,C.R.: AnOutline of Metallurgical Practice (1929) p.20.

(b) "B.F." represents Blast Furnace.

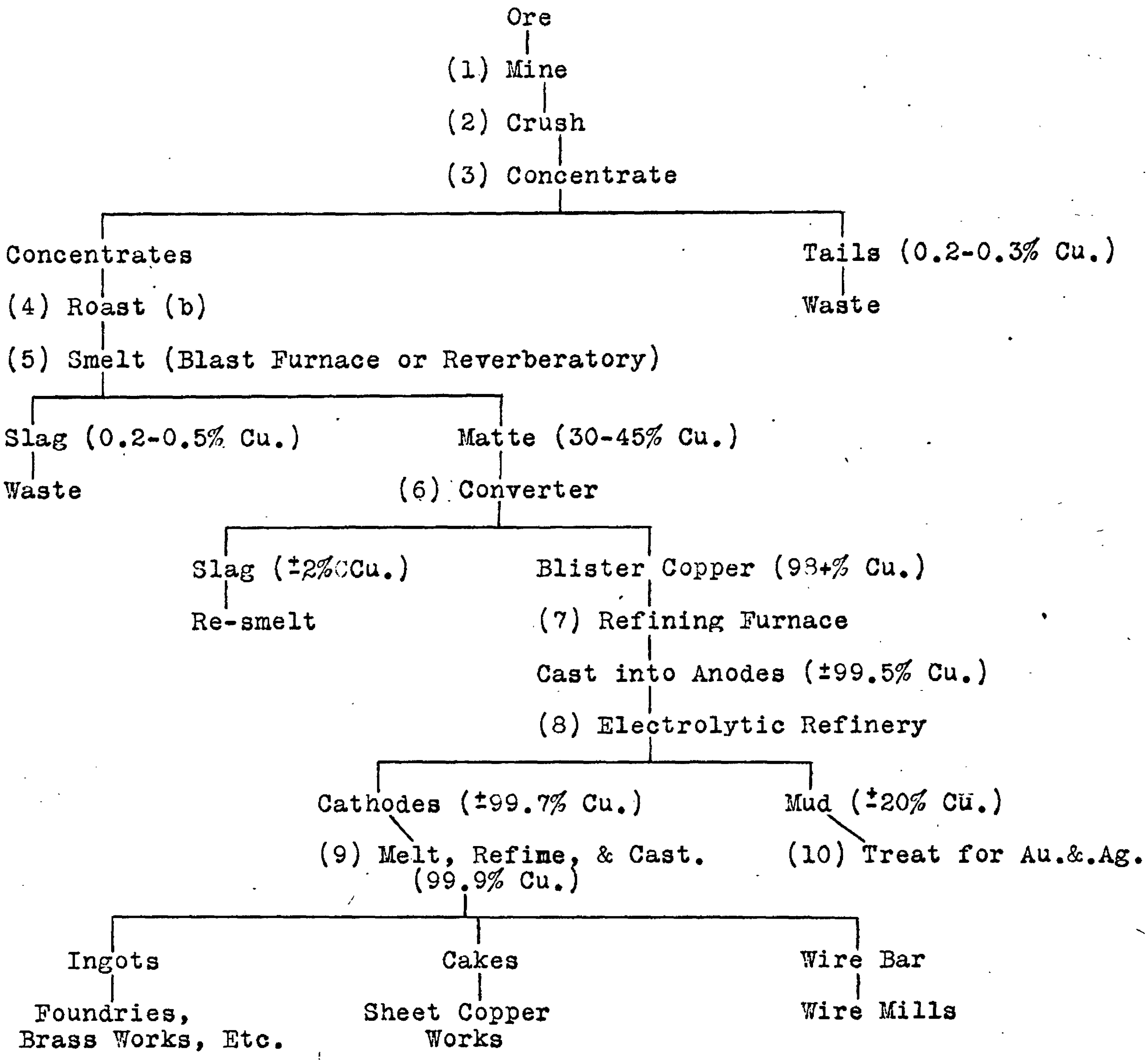
(c) "R.F." represents Reverberatory Furnace.

(1) If preferred may be crushed and treated as fine ore.

(2) In order to pre-heat it may be mixed with the fine sulphide ore before roastimg or added on one of the lomer roaster hearths.

(3) If preferred it may be sintered and smelted in the blast furnace.

Fig. II. OUTLINE OF THE TREATMENT OF A LOW-GRADE SULPHIDE COPPER ORE (a)



(a) From Hayward, C.R.: An Outline of Metallurgical Practice (1929) p.21.

(b) This is omitted in pyritic smelting.

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

PART IV

USES OF COPPER

IV. THE USES OF COPPER

GENERAL.

While the marked utility of copper is at the present time generally conceded it is probable that comparatively few persons fully appreciate the extent of the uses to which this metal may be applied. Containing as it does, several desirable physical and chemical qualities, copper occupies a prominent place in modern civilization. With the development and use of electrical power copper has been one of the essential minerals utilized. The improvement of transportation and communication facilities have opened new fields for the metal. Today steamships, railways, automobiles and aeroplanes are using increasingly large quantities of copper, while telephone, telegraph and radio developments have depended much upon the availability of the metal. Light and power, modern conveniences so common in every day activities, are brought to us and utilized by means of copper conduction wire and apparatus of varied types. Construction and structural work have proven copper to be both useful and ornamental. Many more spheres of human activity have demonstrated the adaptability of this versatile metal. Innumerable articles are either made partly of copper or fashioned by copper tools and machinery. Thus at the present time this metal has a very wide range of uses and its importance cannot be over-emphasized.

Based on deliveries from refineries the total primary copper used in the United States in 1926 for the production of pure or unalloyed copper products was about 79%, the remaining 21% being used for brass, bronze and other copper alloys. These respective amounts of copper were made into the following forms:

TABLE III

COPPER USED FOR COPPER-METAL PRODUCTS, 79%

UNITED STATES, 1926[1]

Form	Percentage of Copper used for Pure Copper Products	Percentage of total Copper consumed in U.S.
Wire and rod.	79.4	62.7
Sheet	16.1	12.7
Tube	3.5	2.8
Miscellaneous	1.0	.8
	100.0	79.0

---

1. Roush, G.H.: "The Mineral Industry during 1926" (1927) p.204.

TABLE IV

COPPER USED FOR COPPER-ALLOY PRODUCTS, 21% UNITED STATES, 1926.[1]

Form	Percentage of Copper used for Copper Alloys	Percentage of total Copper consumed in U.S.
Sheet	35.	7.4
Rod and Wire	20	4.2
Tube	30	6.3
Castings	10	2.1
Miscellaneous	5	1.0
	100	21.0

To illustrate the diversified utility of copper the estimated consumption of the metal in the United States in 1926 is given, in the following Table, in terms of short tons.

---

[1] Roush, G.A: "The Mining Industry during 1926" (1927) p.204

TABLE V

ESTIMATED CONSUMPTION OF COPPER[1]

UNITED STATES,1926

Electrical manufactures	201,000
Telephones & telegraphs	90,000
Light and power lines	117,000
Trolley wire	7,000
Wire and rods	74,000
Wire cloth	7,000
Steam railways electrified	400
Automobiles	102,800
Automobile brake-linings	1,700
Buildings	50,200
Locomotives	2,900
Railway cars	6,150
Air-brakes	2,000
Ships, commercial	2,100
Ships, naval	400
Bearings and bushings	38,000
Valves and pipe-fittings	26,000
Ammunition	5,700
Lubricators etc.	5,000
Condensers	2,000
Fire-fighting apparatus	2,700
Agricultural machinery	1,100
Cash registers	400
Copper-bearing steel	1,350
Coinage	950
Radio-receiving sets	5,000
Clocks and watches	4,500
Washing machines	4,700
Water heaters, household	4,000
Water meters	3,750
Refrigerators, electric	15,000
Other uses	55,900
Manufactures for export	49,900
Total	890,600

---

[1] Roush,G.A.: "The Mineral Industry during 1926" (1927) p.205.

ALLOYS OF COPPER.

When quantitatively considered, alloys in general are of more importance in industry and the arts than are the pure metals, and their application is steadily increasing. A metallic alloy is a mixture or union of metallic substances which, after melting does not separate into two **distinct** liquid layers. The components of an alloy are separate bodies having distinct and peculiar entities of their own, and may be either elementary substances or chemical compounds of substances. The number of copper alloys that have been produced is almost infinite, and only some of the more important groups will here be discussed.

Copper-Tin Alloys: This group is important because it contains the bronzes so widely used for art castings and for certain industrial purposes. Bronze is an alloy formed wholly or chiefly of copper and tin in variable proportions, ranging from 100-70 percent copper to 0-30 percent tin. Characteristic properties of the bronzes are the greater fusibility and hardness, and the decreased malleability as compared with copper. The bronzes are particularly adapted to casting. Certain varieties, differentiated by the relative proportions of the constituent metals include the following :

Gun-metal	a soft bronze; Cu : Sn :: 16 : 1
Steel-bronze	Copper plus 8% tin. Tenacity and hardness are increased by rolling.
Bronze	Cu : Sn : 7 : 1. a hard brittle, sonorous alloy which is temperable to a fine edge.
Bell-metal	Cu : Sn :: 3-5: 1
Speculum-metal	Cu : Sn :: 2-2-5: 1
Statuary Bronze	80-90 percent Cu plus Sn. or Sn-Zn-Pb.
British & French Copper Coinage	95% Cu; 4% Sn; 1% Zn.
Anti-friction Metals:	Copper-tin alloys, with antimony in addition. eg. "Babbit's Metal" originally Sn : Sb : Cu :: 24: 8: 4: but now **the tin content is often** higher.
Phosphor-bronze	a bronze alloyed with phosphorous, which increases the quality and strength.
Manganese-bronze	a bronze alloyed with manganese.
Aluminium-bronze	a bronze alloyed with aluminium, often nearly or completely lacking in tin.
Silicon-bronze	a bronze alloyed with silicon and having increased tensile strength, and therefore is frequently used for telegraph wires.

Copper-Aluminium Alloys: These alloys constitute an important series in that they contain the "aluminium bronzes". In this group the range of composition for industrial purposes is limited for the bronzes, and lies between 100-89 percent copper and 0-11 percent aluminium. Aluminium bronzes have great tensile strength and are especially resistant to rapidly repeated alternating stresses.

Copper-Zinc Alloys: This is an important series, as it contains the well-known brasses which are mainly, if not entirely alloys of copper and zinc. Brass is widely used in the arts. Its superior hardness makes it wear well and it can be cast or readily drawn into fine wire or formed into rolled sheets and rods. It takes a high polish but tarnishes on exposure to the air. Depending upon the purpose for which the alloy is to be used, its composition varies.

"Wire-brass" has the composition 72% Cu, 28% Zn.

Common brass has the composition 66 2/3% Cu, 33 1/3% Zn, and is used for sheets, wire, tubes and pipe-fittings.

"Muntz" metal is 60% Cu, and 40% Zn. It is malleable and is used for bolts, nuts, etc.

"Delta metal" is 56% Cu, and 42% Zn, with frequently a small percentage of iron. It is used where added strength is desired.

The brasses range in composition from 90% Cu and 10% Zn to 16% Cu and 84% Zn, but they usually contain more than 50% Cu.

Copper-Gold Alloys: Particular interest centres around these alloys in that they are largely used in coinage and in the manufacture of jewellry. The alloy is harder, less malleable and more elastic than the pure metals. The addition of a little copper gives to the gold a reddish tint, while more than 12 percent renders the alloy less malleable and more difficult to work.

Copper-Silver Alloys: These alloys are of great industrial importance in the manufacture of such silver articles as silver-plate, jewellry and also coinage. Standard sterling silver is somewhat less ductile and malleable than pure silver, as well as harder, but it is readily rolled into thin sheets or drawn into fine wire.

Copper-Nickel Alloys: These enter into the composition of German-silver alloys of copper-nickel-zinc and an alloy of copper-nickel is also quite extensively used in sheet-metal work of various kinds. "Monel-metal" is an alloy of copper and nickel with some iron added, and is of the composition Ni 68-72%, Cu:26.5-30.5%, Fe:1.5%. At Sudbury,Ontario, it is possible to produce this product by the direct refining of the nickel-copper matte into an alloy instead of first separating the respective metals. The alloy is ductile, flexible and easily worked, while it can be readily soldered and brazed. It is used quite extensively for roofing purposes in the place of copper, than which it has much greater strength and resistance to corrosion.

Copper-steel Alloys: Small amounts of copper impart properties to steel similar to those obtained with nickel. Additions up to 0.30 percent also retard corrosion. Increasing quantities of this material are being marketed in the form of sheets and tubes.

Of the lengthy list of alloys issued by the American Society for Testing Materials, Philadelphia, some representative members in general use are given in Table VI.

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

PART V

PRODUCTION, CONSUMPTION, AND CONTROL

V. COPPER PRODUCTION CONSUMPTION AND CONTROL

THE PRODUCTION OF COPPER.

Prior to the last few centuries the quantity of metals available for man's use was almost insignificant in comparison with the supply now utilized. In earlier times copper was jealously guarded in the treasuries of kings, nobles and persons of considerable wealth. Mining operations were usually confined to ores of a metallic or oxidized nature and generally to those near the surface, so that large-scale production was not commonly practised. The increased demand for copper following a growing appreciation of its utility, stimulated research in an effort to produce larger quantities of more utilizable metal. Discovery of the alloyable qualities of copper proved a deciding factor in the increased production and use of the metal. By the end of the eighteenth century, improved mining methods through the introduction of gunpowder, the mine pump, the rock drill and the steam engine together with a better understanding of metallurgical principles and processes, ultimately resulted in an increased production of a better grade of metal. It is probable that the annual output of 18,200 tons (See Table VII) as indicated at the beginning of the nineteenth century, represented the culmination of mining and metallurgical progress of several centuries. The development of electricity, however, provided the most pronounced impetus to the technical applications of the metal, and by virtue of its electrical conductivity alone copper is now produced and used in enormous and increasing quantities for all types of electrical work. The rapid increase in copper production is one of the outstanding features of the metal industry of the last few decades.

In considering the development of copper production all tonnage figures given in this paper are expressed in terms of the standard short ton of 2000 pounds. Where necessary the required conversions to this denomination have been made in order to lend uniformity for purposes of comparison.

World Production: Since 1800 world production of copper has exhibited phenomenal increases. While output from the time of the first utilization of the metal, up to the beginning of the eighteenth century, has been estimated at less than one million tons, this is a relatively insignificant amount as compared with a world production of over 45,000,000 tons up to the year 1930. Of the output of copper between 1800 and 1925 about 1.25% was produced in the first quarter of the last century; 2.5% from 1826 to 1850; 5.75% in the next twenty-five years; 18.75% in the last quarter of a century and as much as 63.5% between 1901 and 1925 (See Fig.III). A second significant feature of world production

TABLE VI. COPPER ALLOYS, with percentages of the various metals[(a)]

	Percentage of				
	Copper	Tin	Lead	Iron	Zinc
Gilding	95				5
Commercial bronze	90				10
88-10-2	88	10			2
Rich low brass	85				15
Low brass	80				20
Admiralty	70	0.9			29
Cartridge brass	66.5-69.5		0.07	0.05	Remainder
2:1 Mixture pipe	65-68		0.8	0.07	Remainder
High brass	64.5-67.5		0.30	0.05	Remainder
Nickel silvers	55-70 (Ni.18%)				Remainder
Nickel silver (18%)	64 (Ni.18%)				Remainder
Nickel silver (10%)	64 (Ni.10%)				Remainder
Free-turning brass	60-63		2.25-3.25	0.15	Remainder
Naval brass	59-62	0.5-1.5	0.20	0.06	Remainder
Forging brass	58.5-61.5		1.50-2.5	1.15	Remainder
Manganese bronze	57-60 (Mn.0.3)	1.5	0.2	2.0	Remainder
Muntz metal	59-62		0.50-10	0.07-0.1	Remainder

(a) Roush, G.A.: "The Mineral Industry During 1926" (1927) p.207

since the beginning of the last century is the marked change in the geographical production of the metal. During the first half of the nineteenth century, Europe produced 63% of the world's copper; South America 17%; Asia 13% and North America 5%. In the succeeding fifty years North American output increased to 37% of the world's total production, while Europe produced less than 30% of the total production, South America accounted for 21% while Australasia, Asia and Africa contributed the balance. Considering the nineteenth century, North America has in the first twenty-five years produced 66%; South America 11%; Europe 10% and Africa,Asia and Australasia the remainder. In the period 1926-1930 North America accounted for approximately 56.3% of the world's copper; South America 18.01%; Europe 8.2%; Africa 7.6%; Asia 4.5% and Australasia 0.7%. While the North American continent has relatively fallen in production it is still undoubtedly the leading copper producer of the world. Further, it is to be observed that the Americas have together produced in the last five year period almost 75% of the world's copper of those years. Table VII has been compiled to show the production statistics for the world with the amounts and percentages of continent output by decades from 1801 to 1930. During this period the copper production of the world constantly increased, and this fact is strikingly represented in the accompanying

TABLE VII, COPPER PRODUCTION OF THE WORLD - By Continents and Decade - 1801-1930. (In short tons of 2000 pounds.) (a)

DECADES	WORLD	NORTH AMERICA		SOUTH AMERICA		EUROPE		AFRICA		ASIA		AUSTRALASIA	
	PRODUCTION	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%
1801-1810	182,000			26,320	14.46	124,320	68.31			31,360	17.23		
1811-1820	188,496			26,320	13.96	130,816	69.40			31,360	16.64		
1821-1830	273,504	896	0.33	39,760	14.54	188,048	68.75			44,800	16.38		
1831-1840	364,448	10,730	2.94	59,920	16.44	248,999	68.33			44,800	12.29		
1841-1850	493,808	65,856	13.33	108,192	21.91	257,376	52.13			44,800	9.07	17,584	3.56
1851-1860	759,079	94,640	12.47	251,227	33.10	324,844	42.80	3,753	0.49	44,800	5.90	39,815	5.24
1861-1870	1,149,344	138,081	12.01	510,641	44.43	367,789	32.00	8,512	0.74	39,200	3.41	85,120	7.41
1871-1880	1,423,744	221,245	15.54	551,779	38.75	446,880	31.39	42,112	2.96	38,080	2.68	123,648	8.68
1881-1890	2,488,591	870,904	34.29	462,014	19.09	853,065	34.45	71,033	2.85	117,032	4.70	114,543	4.72
1891-1900	4,149,353	2,393,506	37.08	322,130	7.92	968,428	23.84	75,213	1.85	248,329	5.98	141,747	3.30
1901-1910	7,628,334	5,127,971	67.23	537,067	7.04	1,078,876	14.14	65,659	0.86	441,542	5.79	377,219	4.94
1911-1920	12,187,347	8,219,061	67.44	1,221,012	10.02	1,172,806	9.62	288,606	2.37	857,930	7.04	427,932	3.51
1921-1930 (b)	15,210,687	8,994,308	59.13	2,797,122	18.45	1,307,800	8.59	1,142,952	7.51	771,185	5.07	154,330	1.01
TOTALS	46,498,735 (c)	26,137,198	56.2	6,913,504	14.9	7,470,047	16.1	1,697,840	3.6	2,755,218	5.9	1,481,938	3.2

(a) Adapted from Statistics of the United States Bureau of Mines.

(b) From the Year Book of the American Bureau of Metal Statistics, 1930.

(c) This total includes 42,900 tons from sources other than those listed; this represents but 0.09% of the world tonnage from 1301 to 1930.

diagrams(Figs.III and Iv) which respectively represent the increase by quarter centuries and by decades. Table VIII gives the world production of copper by five-year periods from 1881 to 1930, while the accompanying diagram (Fig.V) graphically represents the trend. It indicates that production was high during the period 1916-20 and that in the succeeding five years output receded, but in the last period it had resumed approximately its normal rate of increase. Consideration of the annual production of copper from 1881 to 1930 (Table IX) reveals the fact that the output of this metal was remarkably steady until disturbed by the World War, when, during the years 1916-18 a marked increase is noticeable, followed by a more decided reaction towards decreased production until a gradual recovery commenced about 1922 and continued until 1929. Production in 1930 showed a decrease of 377,132 tons. The corresponding diagram (Fig.VI) gives a graphic representation of this annual production from 1881 to 1930. In it has been included a trend line based on a five-year moving average up to the year 1913, when the production disturbance began. Its dotted projection is continued to the year 1930. The increasing rate of production as indicated by the trend line can hardly be expected to normally continue. Since the beginning of the nineteenth century production has shown an average increase

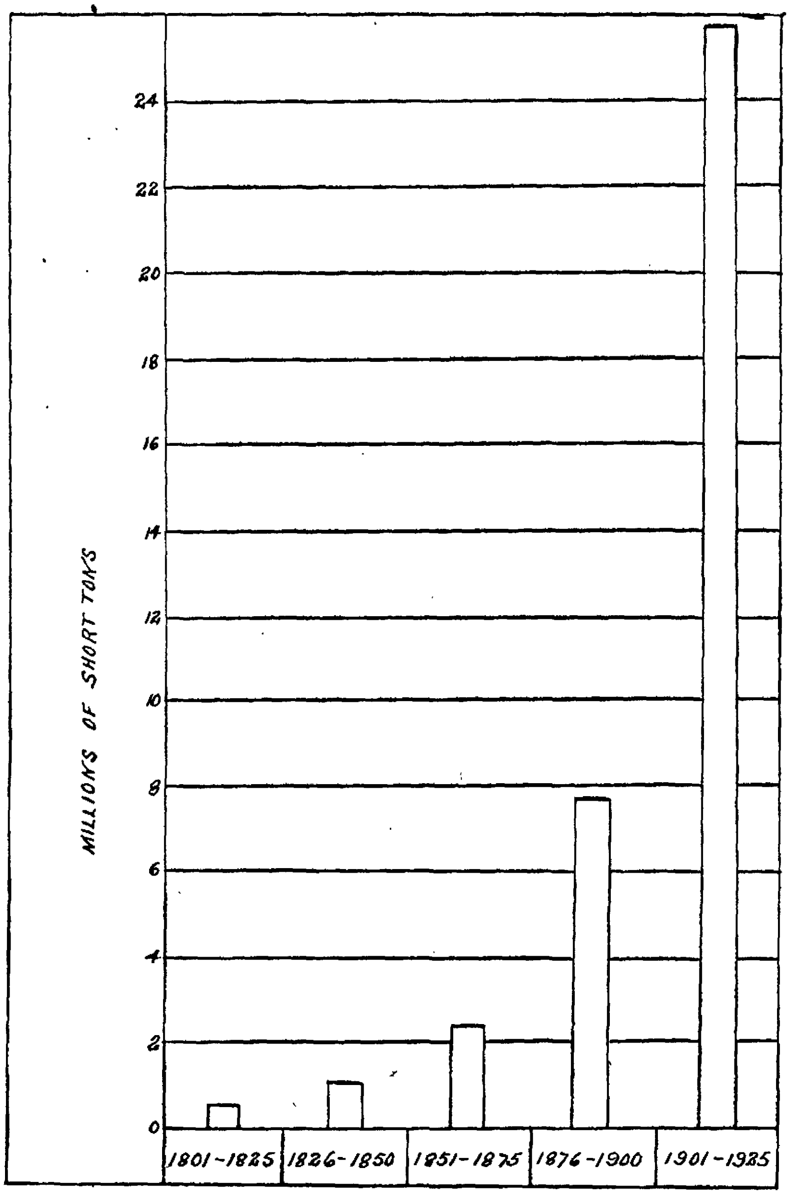


FIG. III. World Production, by Quarter Centuries, 1801-1925.

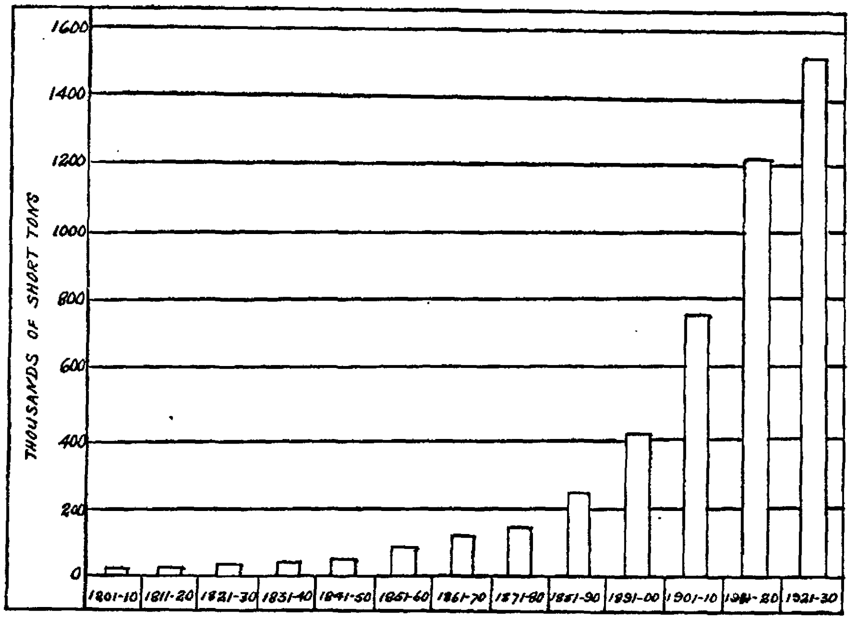


FIG. IV. Average Annual World Production, by decades, 1881-1930.

TABLE VIII. WORLD COPPER PRODUCTION, BY FIVE-YEAR PERIODS(a)

1881-1930 (In Short Tons)

FIVE-YEAR PERIOD	PRODUCTION	ANNUAL AVERAGE
1881-1885	1,105,809	221,162
1886-1890	1,382,782	276,556
1891-1895	1,726,305	345,261
1896-1900	2,423,048	484,610
1901-1905	3,357,378	671,476
1906-1910	4,270,956	854,191
1911-1915	5,366,397	1,073,279
1916-1920	6,820,944	1,364,189
1921-1925	5,910,731	1,182,146
1926-1930(b)	9,088,536	1,817,707

(a) United States Bureau of Mines, Economic Paper 1. (1928).

(b) Year Book, American Bureau of Metal Statistics, 1930.

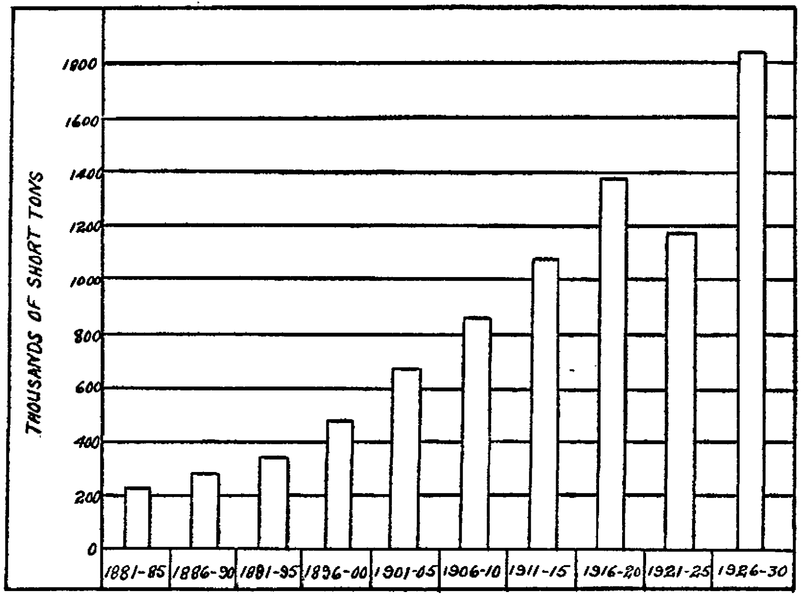


FIG. V. Average Annual World Production, by Five-year Periods 1881-1930.

TABLE IX. World Production of Copper, by Years - 1881 - 1930.(a)

(in short tons)

YEAR	PRODUCTION		YEAR	PRODUCTION
1881	181,342		1906	797,777
1882	202,036		1907	794,704
1883	224,306		1908	820,104
1884	245,005		1909	912,241
1885	253,120		1910	946,130
1886	241,089		1911	980,761
1887	250,538		1912	1,102,509
1888	294,803		1913	1,090,629
1889	291,018		1914	1,027,051
1890	305,334		1915	1,165,447
1891	316,672		1916	1,518,622
1892	352,249		1917	1,575,281
1893	334,928		1918	1,574,256
1894	353,493		1919	1,095,617
1895	368,963		1920	1,057,168
1896	422,838		1921	614,636
1897	454,531		1922	934,927
1898	480,904		1923	1,354,796
1899	519,336		1924	1,479,377
1900	545,439		1925	1,526,995
1901	580,011		1926	1,629,140
1902	615,052		1927	1,764,818
1903	656,482		1928(1)	1,891,610
1904	726,992		1929(1)	2,127,104
1905	778,841		1930(1)	1,749,972

(a) United States Bureau of Mines, Economic Paper 1. (1928).

(1) Year Book of the American Bureau of Metal Statistics, 1930.

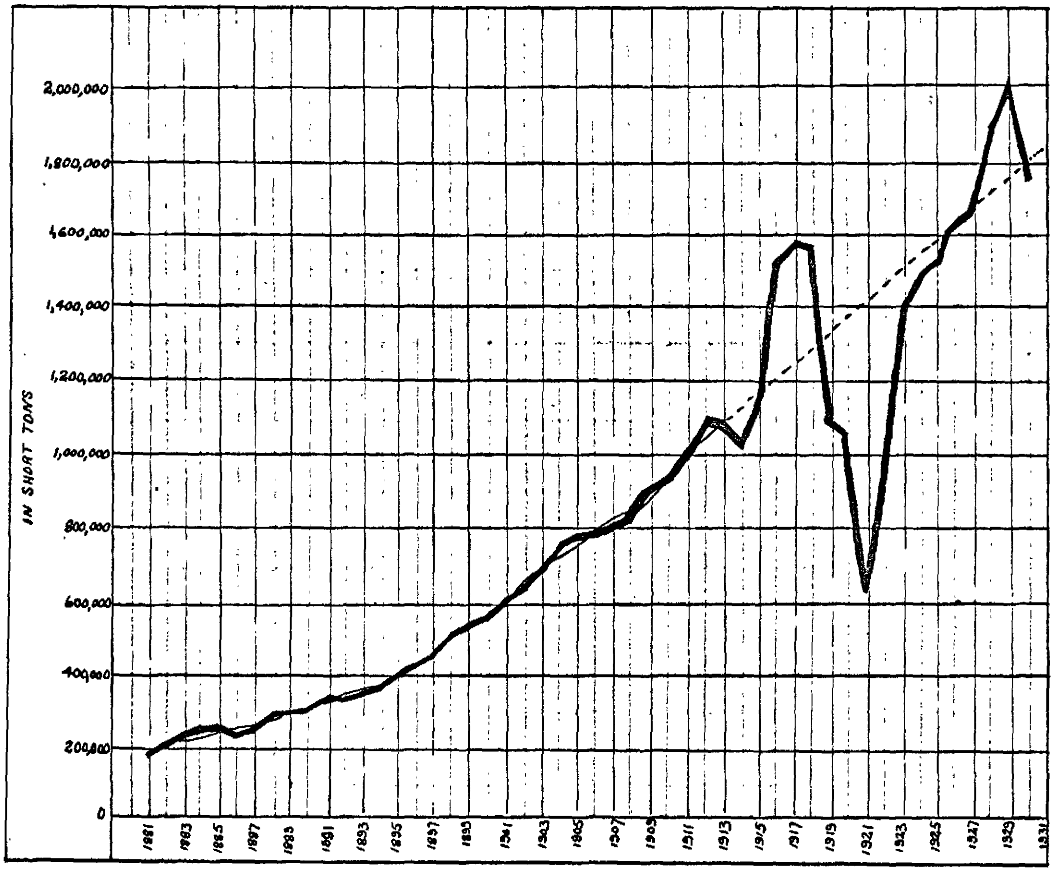


FIG. VI. Annual World Production of Copper, 1881-1930, with trend-line (1881-1913) based on five-year moving average and projected to the year 1930.

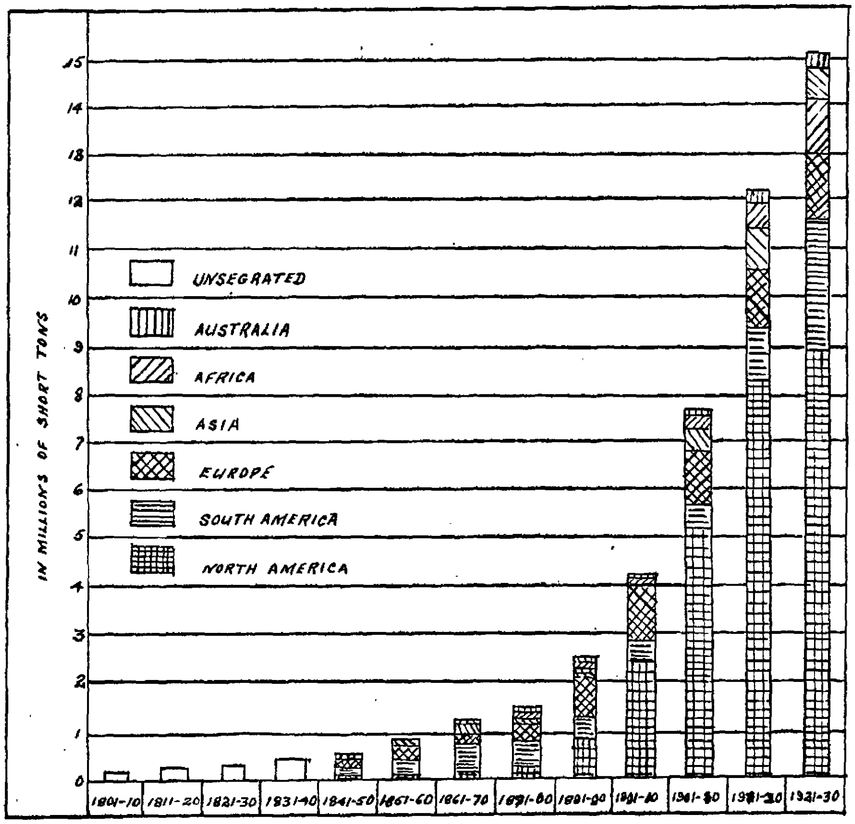


FIG. VII. Production of Copper by Continents and by decades, 1801-1930.

of 180 percent for each quarter century. This rate of increase would require an output of 72,000,000 tons in 1926-50, 200,000,000 tons for 1951-75 and 565,000,000 tons for 1976-2000; a total of 862,000,000 tons for the present century as compared with that of less than 12,000,000 for the preceding one. World copper resources could hardly be expected to adequately meet any such demand.

Production by Continents: Reference to Table VII reveals the fact that the world production of copper for the 130 years between 1801 and 1930 was approximately 46,498,735 tons, of which total North America, though not beginning production until the third decade of the last century, produced over 56% with a total output of about 26,137,198 tons. Europe produced the second largest amount during this same period with an aggregate tonnage of 7,470,047 tons, which represents about 16.1% of the total. South America was third with 6,913,504 tons, or 14.9%. Asia, Africa and Australasia (the latter including Australia, New Zealand, Tasmania and Papua) combined to produce a total of 5,934,966 tons, or 5.9%; 3.6% and 3.2% respectively. Europe was the leading producer of copper up to and including the decade 1851-60, when it accounted for 42.80% of the output, while South America was second, producing 33.10% and North America third with 12.47%. In the following decade South America displaced Europe as leader, the two continents producing respectively 44.43% and 32.00%, while the North American output represented 12.01% of the world's copper production of that period. Two decades later (1881-90) South America was obliged to give first and second places to its northern rivals- Europe and North America, the former once more assuming the leadership with 34.45% while North America was but fractionally behind with 34.29% of the world's copper production for the decade. South America dropped sharply to 19.09%. The following ten years saw North America assume the leadership which it has since held undisputedly. This continent reached its highest proportion of production in the War decade (1911-20) when it produced 67.44% of the world's output. In the same period South America once again resumed second place with 10.02%, while Europe accounted for 9.62% , Asia rose to 7.04%, Australasia receded to 3.51% and Africa increased its output to represent 2.37% of the copper produced during the period. In the last decade (1921-30) the order remained the same except that Africa, increasing its production, accounted for 7.51% and moved up to fourth place, while North America, Australasia, Asia and Europe all lost relatively. South America, fast recovering from its temporary lapse in production earlier in the century, accounted for 18.45% of the copper produced. The accompanying chart (Fig.VII) has been prepared in an effort to represent these relative production movements of the period under discussion.

Production by Countries: The United States is decidedly the largest copper producer of the world and in 1930 its output was 710,690 tons or 40.61% of the copper production for that year. Chile and Canada followed in second and third places with 244,683 and 151,833 tons respectively. These three countries have been the leading producers of the world, accounting in 1930 for 1,107,206 tons, or over 63% of the total tonnage for that year. Fourth and fifth places in 1930 were held by Japan and Mexico with 87,924 and 75,365 tons respectively. Russia with a 1930 output of 53,643 tons; Peru with 52,476 tons and Spain and Portugal with 46,475 tons, were next in line, followed by Germany and Jugoslavia, with respective tonnages of 29,762 and 28,064 tons. Other countries producing over 10,000 tons a year were Norway, with 18,688 tons, and Cuba with 17,963 tons.

United States: At the present time the United States is the leading copper producer of the world, beginning production in the decade ending 1850, in which period it accounted for but 0.54% of the world's production. It assumed the leadership in the decade 1891-1900 when its output was equal to 37.08% of the world total. Production gradually increased until in the war and post-war period (1916-20) this country produced 60.24% of the world's copper with a tonnage of 4,108,993. Subsequently United States production has receded relatively and in the period 1921-25 its output represented 52.4%, while in the last five-year period (1926-30) an aggregate tonnage of 4,397,656 tons, or 46.34% was produced. Production in 1927 in this country fell slightly below that of the previous year and in 1930 less than 70% of its 1929 tonnage was produced. The latter recession is probably due to the marked curtailment practised by American producers in which policy other countries have since cooperated in the experimental manipulation of copper production and marketing and in an effort to stabilize the price of this commodity.[1.] Table X contains the production figures of the United States by five-year periods from 1846-1930 in terms of total tonnages, while Fig.VIII graphically represents the copper output by five-year periods from 1881-1930.

Of the various producing states of this country, Michigan was the earliest producer of importance, until 1887 when it was surpassed by Montana, which was in turn displaced

1. Postea, pp.127-30

TABLE X. COPPER PRODUCTION IN THE UNITED STATES, by FIVE-YEAR Periods - 1846-1930.

(In short tons and based on smelter output)

PERIOD	PRODUCTION	PERIOD	PRODUCTION
1846-1850	2,576	1891-1895	846,638
1851-1855	10,360	1896-1900	1,327,718
1856-1860	31,136	1901-1905	1,830,473
1861-1865	46,980	1906-1910	2,451,242
1866-1870	62,272	1911-1915	3,051,566
1871-1875	85,680	1916-1920	4,108,993
1876-1880	124,880	1921-1925	3,099,996
1881-1885	294,337	1926-1930	4,397,656(1)
1886-1890	526,067		

(1) From the Yearbook of the American Bureau of Metal Statistics; other figures are those of the United States Bureau of Mines.

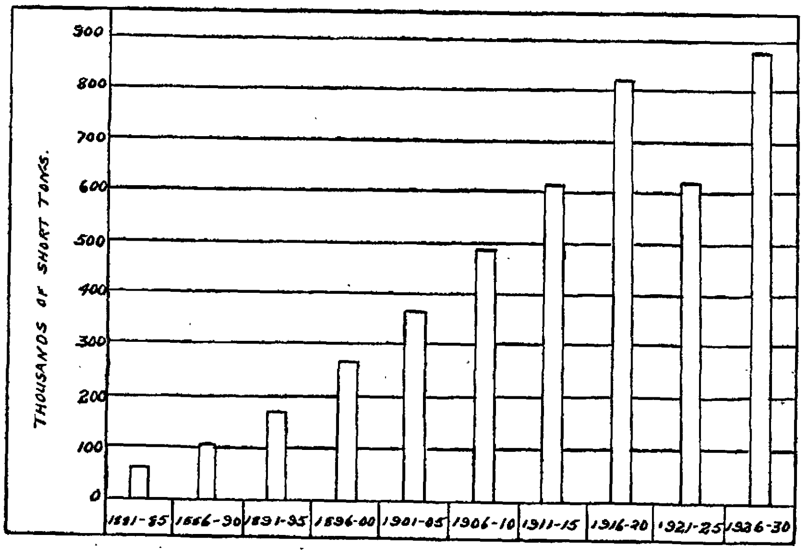


FIG. VIII. Average Annual Production of the United States, by Five-Year Periods - 1881-1930.

in 1907 when Arizona assumed the leadership in copper production of the States. With the exception of one year, this producer has held the leading position. In 1903 Utah rose to assume fourth place, while in 1926 it ranked second, the order of the first six producers then being as follows: Arizona (41.93%); Utah (14.92%); Montana (14.78%); Michigan (10.05%); Nevada (6.27%) and New Mexico (4.76%).

Chile: During the nineteenth century Chile produced 18.42% of the world's copper while in the first quarter of the present century 7.56% of the total output was Chilean copper. From 1801 to 1850 production in this country gradually increased, then more rapidly to 1870, after which a recession continued until the end of the century. The first quarter of the twentieth century showed the Chilean copper output to be rapidly increasing and this continued to 1929, when 348,365 tons were produced. In the succeeding year, production dropped violently to about 70% of the 1929 tonnage, a movement noticeably paralleling that for the same time in the United States.

Canada: In 1930 Canada held third place among the copper producers of the world. It began production on any appreciable scale in the five-year period ending 1885, for which period its output amounted to 5,365 tons. From 1886 up to and including the year 1930, Canadian production of copper amounted to 1,466,137 tons[1.] The most noticeable increase in copper production in Canada was during the first five years of this century when more than three times as much copper was produced as in the preceding five years. Table XI contains the production statistics of Canada from 1886 to 1930 annually, and by five-year periods.

The present copper-producing areas of Canada lie in British Columbia, Ontario, Quebec and Manitoba, while small quantities of the metal have been intermittently produced in the Yukon. Occurrences of copper are known to exist in that part of Northern Canada included in the Northwest Territories, but any such potential producers are only in the initial stages of exploration, and do not come within the scope of the present discussion. Prior to 1886 very little copper had been produced in Canada, the five-years preceding that date having accounted for only 5,365 tons for the whole area. In 1886 Quebec ores supplied 1670 tons of copper, which tonnage then represented 95.3% of Canadian output, the balance of which came from Ontario. In the year 1894 British Columbia came into production with 162 tons, which at that time represented about 4.2% of Canadian copper tonnage. Previous to

---

1. Figures from Annual Report on the Mineral Production of Canada, 1929, and Preliminary Report on the Mineral Production of Canada,1930. These figures slightly exceed (by 243 tons) those of the American Bureau of Metal Statistics (1930) and of the U.S.Bureau of Mines (1928).

TABLE XI. ANNUAL PRODUCTION OF COPPER IN CANADA - 1886-1930

Including Production tonnages of the Provinces, with their corresponding Percentages of the Dominion Total.

YEAR	CANADA	BRITISH COLUMBIA		ONTARIO		QUEBEC		MANITOBA		YUKON	
	PRODUCTION	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%	PRODUCTION	%
1886	1,752			82		1,670					
1887	1,630			161		1,469					
1888	2,781					2,781					
1889	3,391			733		2,658 (7.5)					
1890	3,007			652		2,355					
1886-90	12,561			1638	13.0%	10,933	87.0%				
1891	4,765			2064		2,701					
1892	3,544			1102		2,442					
1893	4,055			1821		2,234					
1894	3,854	162		2604		1,088					
1895	3,885	476		2288		1,121					
1891-95	20,103	638	3.1	9879	49.2%	9,586	47.7%				
1896	4,697	1,909		1584		1,204					
1897	6,650	2,663		2750		1,237					
1898	8,874	3,636		4188		1,050					
1899	7,539	3,861		2862		816					
1900	9,469	4,989		3370		1,110					
1896-1900	37,229	17,058	45.8%	14,754	39.6%	15,417	14.6%				
1901	18,914	13,802		4,348		764					
1902	19,342	14,818		3,704		820					
1903	21,342	17,180		3,586		576					
1904	20,692	17,855		2,457		380					
1905	24,047	18,846		4,390		811					
1901-05	104,337	82,501	79.1%	18,485	17.7%	3,351	3.2%				
1906	27,883	21,495		5,319		991				78	
1907	28,483	20,416		7,052		759				256	
1908	26,721	18,521		7,503		641				56	
1909	26,246	17,829		7,873		544					
1910	27,846	17,635		9,629		439				143	
1906-10	137,179	95,896	69.9%	37,376	27.2%	3,374	2.5%			533	0.4%
1911	27,824	17,640		8,966		1,218					
1912	38,915	25,263		11,125		1,641				886	
1913	38,489	22,896		12,943		1,728				922	
1914	37,869	20,610		14,474		2,101				684	
1915	50,393	28,346		19,681		2,099				267	
1911-15	193,490	114,755	59.3%	67,189	34.7%	8,787	4.6			2,759	1.4%
1916	58,575	31,821		22,498		2,852				1,404	
1917	54,595	28,865		21,434		2,508		558		1,230	
1918	59,385	31,433		23,537		2,935		1,170		310	
1919	37,527	22,251		12,173		1,346		1,674		83	
1920	40,800	22,660		16,030		440		1,531		139	
1916-20	250,882	137,030	54.6%	95,672	38.1%	10,081	4.0	4,933	2.0%	3,166	1.3%
1921	23,812	17,224		6,411		177					
1922	21,440	15,968		5,472							
1923	43,440	27,612		15,828							
1924	52,229	32,726		18,557		946					
1925	55,725	34,611		19,859		1,255					
1921-25	196,646	128,141	65.2%	66,127	33.6%	2,378	1.2				
1926	66,547	44,554		20,656		1,337					
1927	70,074	45,843		22,671		1,560					
1928	101,349	51,142		33,304		16,849					
1929	124,061	51,952		44,440		27,669					
1930	151,679	46,616		63,865		40,155		1,043			
1926-30	513,710	240,107	46.7%	184,936	36.0%	87,570	17.%	1,043	0.2%	54	0.01%
TOTALS.	1,466,137	816,127	55.6%	496,047	33.84%	141,475	9.5%	5,976	0.40%	6,512	0.44%

1906 Yukon had produced some copper which was included in the amount for that year, making a total of about 78 tons. In 1917 the Province of Manitoba began production, turning out 558 tons which at that time represented slightly over 1% of the Canadian Copper output. Production during this and the succeeding three years was from the relatively high grade ores of the Mandy Mine. Exhaustion of these ores necessitated the curtailment of operations until such time as improved mining and treatment facilities in that part of the province make profitable the extraction of the lower grade ore remaining in that particular property. From 1921 to 1929 this Province shipped no ore, but in 1930 a shipment of 1,043 tons was made from the newly opened Flin Flon mine in the same part of the province.

The writer has compiled Table XI which gives Canada's annual production by provinces from 1886 to 1930, with the totals and percentages which each province contributes every five years to the corresponding Dominion totals.

Japan: The main producer of copper in Asia has been Japan, which country in 1930 accounted for over 87% of the Asiatic copper, though this was then but little over 5% of the world's copper. Production in Japan showed a very rapid increase during the period 1881-1920, and while the following five-year period revealed a recession, succeeding years have indicated a recovery.

Mexico: This country yielded third place to Canada as a copper producer only in the year 1926, but has since consistently fallen farther behind the latter country. The greatest expansion of Mexican production was during the first five years of the present century, when copper output was advanced more than three-fold as compared with that of the preceding period.

Russia: An increasing production from 1881 to 1895 occurred in Russia, while in the following period the output was decreased. In the last five years under review, however, Russian copper output increased more than five-fold and this advance was maintained to the end, the increase being from 9,967 tons in 1925 to 53,643 tons in 1930.

Peru: The second largest producer in South America is Peru. Coming into prominence in the last five years of the nineteenth century, it continued its spectacular increase of production up to the general recessive period (1921-25), following which recovery was made and maintained to 1929. Production in 1930 showed a decline.

Spain and Portugal: Together these two countries were the leading European copper producers from 1801 to 1929, but in 1930 Russia assumed the European leadership when the former countries produced 46,475 tons as compared with the 53,643 tons of Russia.

Other Countries: England, the leading producer of Europe in the earlier part of the nineteenth century, accounted for 44.25% of the world's copper in the decade 1831-40 when it produced 161,280 tons. Decreased production has since been pronounced, so that at the present time its output has been relatively insignificant. This striking decrease may be chiefly attributed to the exhaustion of the Cornwall and Devon ores. Australasian production, which in this paper includes the combined output of Australia, New Zealand, Tasmania and Papua, commenced in the 1841-50 decade, and increased to a maximum in 1911-15, after which it has steadily decreased until in 1927 a slow but gradual recovery was begun and maintained until 1930. Belgian Congo has rapidly increased production since 1871. In 1930 the total amount of copper produced by Africa amounted to 10.4% of the world's total tonnage of the metal for that year.

The accompanying table (Table XII) of the world production of copper reveals in comprehensive form the copper producers of the world, together with continent and world totals, covering the post-war period, 1919-1930.

Recovery of Secondary Copper: With favorable market conditions the recovery of scrap copper seems to offer considerable possibilities as a factor in adding to the available copper supply of the world In the years 1925 and 1926, with the average New York price of copper at 14.042 and 13.795 cents respectively, recoveries in the United States were reported in short tons, as in Table XIII.

THE CONSUMPTION OF COPPER.

With an increasing knowledge and appreciation of the utility of the metal, the consumption of copper has grown. Progress from the earliest times, when the value of copper was first recognized in the making of crude weapons, tools and other implements, until the present day with its finely finished copper products, represents a wide scientific and cultural advancement of mankind. Any estimate of the amount of copper consumed in a given period is rather a difficult task, even in the case of recent or current times.

TABLE XII.(a) WORLD'S PRODUCTION OF COPPER (1919-1930 (in short tons)

COUNTRY:	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
NORTH AMERICA:												
United States	604,642	635,248	238,420	511,970	754,000	819,000	854,000	878,000	847,419	935,199	1,026,348	718,690
Mexico	66,661	49,866	13,576	29,842	60,538	57,139	59,123	62,303	63,760	72,579	86,759	75,365
Canada	39,789	39,121	22,632	25,300	40,230	50,072	56,238	64,124	70,698	96,634	121,151	151,833
Cuba	10,991	7,491	8,600	11,788	11,963	12,742	13,128	13,034	15,538	18,869	15,740	17,963
Total North America	722,083	731,726	283,228	578,900	866,731	938,953	982,490	1,017,461	997,415	1,123,281	1,249,998	955,851
SOUTH AMERICA:												
Bolivia	7,714	10,910	10,674	10,154	11,744	8,200	7,500	7,100	7,850	8,300	7,700	5,400
Chile	87,721	109,075	65,299	142,830	201,042	208,964	212,150	223,015	264,242	319,549	348,365	244,683
Peru	43,243	36,356	36,689	40,133	48,684	37,410	40,635	48,327	52,644	58,453	59,980	52,476
Venezuela	700		800	1,075	1,175	1,230	1,500	1,000	150			
Total South America	139,378	156,341	113,462	194,192	262,645	255,804	261,785	279,442	324,886	386,302	416,045	302,559
EUROPE:												
Austria	713	1,747	4,600	5,050	5,327	4,242	3,665	4,099	3,968	3,638	3,856	4,028
France	962	1,718	2,395	3,199	6,204	2,568	3,769	2,370	2,612	2,203	2,205	3,307
Germany	17,384	19,015	20,944	19,841	20,282	25,132	26,235	29,983	30,534	28,109	31,967	29,762
Jugoslavia	1,332	2,684	4,376	5,756	7,536	8,978	8,048	10,692	14,220	16,629	22,790	28,064
Norway	482	613	6,311	10,598	8,816	10,913	13,779	13,779	13,227	14,200	16,280	18,688
Russia				2,205	2,205	3,637	9,967	11,711	14,988	22,046	40,823	53,643
Spain & Portugal	38,581	25,353	36,596	40,234	57,115	61,839	63,933	63,933	60,351	54,605	53,599	46,475
Sweden	4,442	1,793	1,465	67	5,180	3,086	2,500			1,000	3,500	1,323
Total Europe	63,896	52,923	76,687	86,950	112,665	120,395	131,896	136,567	139,900	142,430	175,020	185,290
ASIA												
Japan	86,468	74,727	60,579	59,663	65,417	69,507	73,289	74,256	73,381	75,213	83,189	87,924
Other Asia	1,098	593	1,280	1,162	810	2,315	3,600	6,100	6,100	5,600	8,800	13,000
Total Asia	87,566	75,320	61,859	60,825	66,227	71,822	76,889	80,356	79,481	80,813	91,989	100,924
AUSTRALASIA	18,118	29,327	20,869	13,754	19,995	15,711	13,578	11,244	12,800	13,244	15,979	17,156
AFRICA	34,548	33,708	42,501	58,219	80,410	115,300	118,670	108,010	123,470	141,131	172,561	182,680
OTHER COUNTRIES	4,409	3,307	3,307	3,307	3,307	4,409	4,409	4,409	4,409	4,409	5,512	5,512
GRAND TOTALS:	1,069,998	1,082,652	601,913	996,147	1,411,980	1,522,394	1,589,717	1,637,489	1,682,361	1,891,610	2,127,104	1,749,972

(a) From the Year Book of the American Bureau of Metal Statistics,1930

TABLE XIII. RECOVERY OF SECONDARY COPPER IN THE UNITED STATES (a)
(In short tons.)

SOURCE	1925	1926
Recoveries from new scrap (not including brass)	50,000	55,000
from old scrap (not including brass)	200,600	226,700
from new brass scrap (averaging about 70 % copper	79,200	87,500
from old brass scrap (averaging about 70% copper	90,410	110,600
Total Recoveries	420,210	479,800

(a) Roush G. A.; The Mineral Industry During 1926, p158.

TABLE XV. ESTIMATED COPPER CONSUMPTION BY IMPORTANT AMERICAN USERS (a)
in 1929 and 1930.
(In short tons)

USER	1929	1930	INCREASE	DECREASE
Electrical Manufactures	261,000	221,000		15.3%
Automobile Manufactures	137,600	86,900		36.8%
Building	59,000	50,000		15.2%
Manufactures for Export	74,900	71,100		5.1%
Telephones and Telegraphs	164,000	122,000		25.6%
Light and Power Lines	127,000	130,000	2.4%	

(a) Figures from the American Bureau of Metal Statistics.

The accompanying table (Table XIV) of the estimated copper consumption of the world has been prepared by the American Bureau of Metal Statistics [1]. It covers the Post-War period 1919-1930. Here, as is pointed out by the Bureau, the consumption is computed, except in the case of the United States, according to the formula of production, plus imports, minus exports, with certain allowances for changes in stocks where such figures are available. Wherever possible the statistics of refined copper have been used. Obviously, this method arrives at an estimate of the copper available for consumption, rather than at the amount actually used; therefore conclusions from this table must not be drawn too closely. The figures used are in metric tons of 2,204.6 pounds.

A study of Table XIV, with particular reference to the 1930 statistics, indicates that the United States is the chief copper-consuming country of the world, utilizing about 46.7% of the 1930 consumption of copper, and 53.5% in the peak year , 1929. Germany in 1930, held second place as a copper consumer, but used slightly less than one-quarter the amount of metal consumed by the former country. Great Britain and France followed closely in third and fourth positions respectively, while Japan, Russia and Italy, considerably smaller

---

[1] Yearbook of the American Bureau of Metal Statistics, 1930 p.39.

TABLE XIV. WORLD'S CONSUMPTION OF COPPER - 1919-1930 (in metric tons)[a]

COUNTRY	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
United States	516,992	605,564	296,985	500,813	662,912	686,364	738,000	820,300	748,600	892,200	1,015,500	733,700
Canada	13,000	13,000	13,000	10,000	10,500	15,400	11,500	15,900	15,600	17,400	20,600	18,000
Total America	529,992	618,564	309,985	510,813	673,412	701,764	749,500	836,200	764,200	909,600	1,036,100	751,700
Austria	4,000	5,600	9,600	12,300	12,400	13,900	18,800	15,200	16,900	18,600	17,300-	13,500
Belgium	9,000	8,100	2,500	5,900	8,200	11,100	17,500	21,000	24,000	25,000	25,000	29,000
Czechoslovakia	8,000	8,000	9,000	8,100	8,900	12,300	15,700	12,800	13,300	19,400	14,600	17,000
France	55,400	68,400	50,500	82,500	115,200	132,300	118,100	114,000	90,600	125,600	138,800	133,200
Germany	24,000	73,700	126,500	148,200	97,300	131,300	232,200	167,400	263,000	253,700	216,400	185,900
Great Britain	97,500	102,200	67,900	45,700	101,200	135,900	136,500	139,000	149,400	157,100	149,700	145,400
Italy	68,400	14,700	10,000	35,000	42,800	52,400	65,600	67,500	60,900	77,300	55,000	50,900
Russia	--	4,800	6,000	7,000	9,000	8,000	9,500	24,000	44,000	50,400	58,000	70,000
Spain	8,100	5,500	7,200	9,800	12,600	9,900	13,000	14,200	12,800	17,800	14,000	9,300
Sweden	18,100	19,500	4,300	10,300	9,700	16,000	17,000	16,700	18,100	21,600	26,500	26,900
Switzerland	8,200	7,000	4,500	7,500	9,400	11,300	9,200	8,800	12,900	15,600	13,600	14,900
Other Europe	3,000	3,000	3,000	5,500	4,500	9,000	16,500	22,500	28,000	38,000	40,000	35,000
Total Europe	303,700	320,500	301,000	377,800	431,200	543,400	669,600	623,100	733,900	820,100	768,900	731,000
Japan	61,900	84,900	78,500	74,400	70,400	64,000	74,400	81,800	75,800	82,100	71,200	70,300
Other Asia	10,200	8,900	10,100	22,100	22,500	31,600	13,000	12,200	9,100	9,300	8,200	9,500
Total Asia	72,100	93,800	88,600	96,500	92,900	95,600	87,400	94,000	84,900	91,400	79,400	79,800
Total Africa	3,000	3,000	3,000	3,000	3,000	3,000	3,500	3,500	3,500	3,500	3,500	3,500
Total Australia	8,000	8,000	3,800	6,000	7,000	9,700	8,500	9,500	9,000	7,900	9,000	5,000
GRAND TOTALS;	916,792	1,043,864	706,385	994,113	1,207,512	1,353,464	1,518,500	1,566,300	1,595,500	1,832,500	1,896,900	1,571,000

(a) From the Year Book of the American Bureau of Metal Statistics, 1930.

consumers, were successively next in line. With relatively few exceptions the increased consumption of copper has been quite consistent during the twelve-year period for which statistics are available. Aggregate world consumption, however, receded in 1921 but rapidly recovered once more, while in 1930 another sharp decrease was indicated, both of which, recessions in consumption may be attributed to the acuteness of the corresponding economic situations in those years.

Despite the decreased production of copper during 1930 there was a wide gap between production and apparent consumption. In fact consumption in 1930 was reduced to the point where it was not quite equal to that of 1927. The most marked falling-off was in the United States where the use of copper was decreased by about 17.5 percent, due mainly, as shown in Table XV, to slackness in automobile manufacture, and decreased utilization of copper by telephone and telegraph companies.

Consumption in other countries was reduced to a lesser degree, the greatest decline occurring in Germany where fabricators and other users of the metal, having practised economy during the World War, resorted to a considerable extent to the use of copper scrap.

THE TREND OF COPPER PRICES.

The study of the general price movements of the last fifty-odd years, has lead economists to distinguish two distinct cycles, viz. the period of falling prices from 1874 to 1896 and that of rising prices from 1896 to 1920.[1] The causes of the former recessive movement have been attributed to such factors as improved machinery and the application of scientific principles and methods in the production of cheaper substitutes; to increased foreign supplies; to decreased interest rates, and importation and transportation charges; and to improved communication facilities. The succeeding cycle of rising prices has been regarded as closely related to the increasing gold supplies of the period, particularly as a result of the influx of this precious metal from South Africa at that time. The latter cycle thus corresponds to the period of rising prices associated with the increasing supplies of gold during the period 1851-1875, chiefly as a result of the opening up of the American and Australasian fields.

In general, the prices of non-ferrous metallics fell more than the average during the former period and rose above the average in the second cycle. The supply of copper increased rapidly during the first period and it has been estimated that the copper stocks of the world increased 97 percent during the

---

[1] K.W.Taylor and H.Michell: "Statistical Contributions to Canadian Economic History" Vol.II (1931)

years 1872 to 1885. In the second period it is evident that the increased use of copper, particularly in the United States outweighed the increased output of the metal. In that period the price of this commodity rose from 11.3 cents to 16.8 cents per pound.

In the year 1872 copper reached a high of 30 cents on the Toronto market. The general recession of prices then took copper down accordingly and with the exception of the extreme temporary rise to 30 cents on the same market in the summer of 1876, the general price trend was distinctly downward to 19.33 cents in 1879. A temporary recovery for three years culminated in the rise of the price to 21.04 cents (Toronto) in 1882. In the succeeding year came a world-wide financial crisis and general commodity prices fell drastically. Copper at the same time was swept to a low of 11.0 cents (New York market) in 1886.[1]

The accompanying table and chart (Table XVI, Fig.IX) represent the trend of average prices from 1886 to 1930, as based on the quotations of the New York market. On the chart are revealed five distinct and rather evenly distributed price peaks. The first three peaks, of about similar proportions but successively higher, are followed by the abnormally high war-time peak of 1916-17. Since the World War prices of copper have been most erratic. Reacting to a low of 12.5 cents in 1921

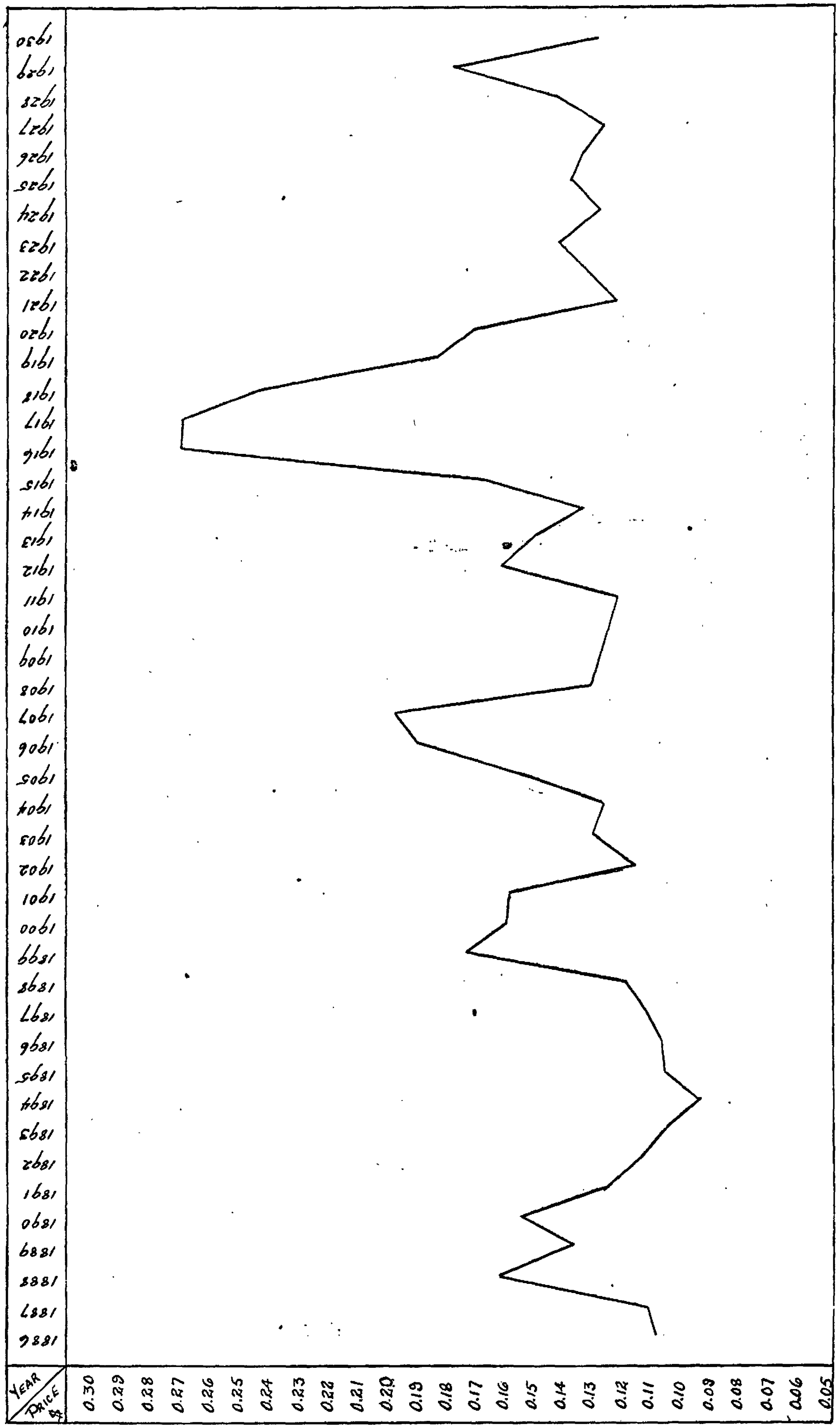
[1] It has been found necessary to use Toronto prices of copper for the period up to 1885, after which the New York market quotations

TABLE XVI. AVERAGE PRICE OF COPPER, PER POUND, NEW YORK MARKET.

1886-1930

YEAR	PRICE ($)	YEAR	PRICE ($)
1886	0.1100	1909	0.12982
1887	0.1125	1910	0.12738
1888	0.1666	1911	0.12376
1889	0.1375	1912	0.16341
1890	0.1575	1913	0.15269
1891	0.1287	1914	0.13602
1892	0.1155	1915	0.17275
1893	0.1075	1916	0.27202
1894	0.0956	1917	0.27180
1895	0.1076	1918	0.24628
1896	0.1088	1919	0.18691
1897	0.1129	1920	0.17456
1898	0.1203	1921	0.12502
1899	0.1761	1922	0.13382
1900	0.1619	1923	0.14421
1901	0.16117	1924	0.13024
1902	0.11626	1925	0.14042
1903	0.13235	1926	0.13795
1904	0.12823	1927	0.12920
1905	0.15590	1928	0.14570
1906	0.19278	1929	0.18107
1907	0.20004	1930	0.12982
1908	0.13208		

FIG. IX. Trend of Copper Prices, 1886-1930 - New York Market.



prices gradually recovered and in 1928 and 1929 soared to an average high of 18.1 cents in the latter year. In the following years a rapid recession of prices has been recorded, with 1930 showing an average of 12.98 cents. The year 1931 continued the decline, and in March, 1932 an all-time low record of 5.75 cents was reached, and to date very slight recoveries have been made.

COST OF PRODUCTION.

There is a wide range in the production costs of copper. They depend upon such variable factors as the location and nature of the deposit and the efficiency of operation and management. Curtailed production increases the cost per pound of copper. In 1930 nineteen copper mining companies produced 685,000 tons of copper at a net cost, exclusive of depletion, of 9.73 cents per pound. These companies included organizations in the United States, Canada, Mexico and Chile. In 1929 the same number of companies(of which all but three were the same) produced 1,045,500 tons of copper at a net cost, exclusive of depletion, of 9.65 cents. While the two estimates (See Table XVII) are not strictly comparable, certain interesting observations may nevertheless be made. The influence of a year of depression upon the industry is suggested in the reduced operating expenses, decreased taxes

TABLE XVII. WEIGHTED AVERAGE COSTS OF AMERICAN COPPER PRODUCTION (a)
(All figures in cents per pound of copper)

	1929(b)	1930(c)
Operating	9.92	9.51
Taxes, interest	1.21	0.84
Depreciation	1.07	1.05
Miscellaneous expense	0.13	0.01
Total	12.34	11.41
Sundry Metals	1.52	1.20
Miscellaneous income	1.17	0.48
Net costs, after depreciation	9.65	9.73
Copper output, millions of pounds . .	2,091	1,370

(a) After Strauss, S. D., Assistant Editor, Engineering and Mining Journal.

(b) Includes Phelps Dodge, Kennecott, and Cerro de Pasco, not in 1930 list. This estimate made by G. W. Tower.

(c) Includes Consolidated Coppermines, Greene Cananea, and Walker Mining, not in 1929 list. This estimate made by S. D. Strauss.

and interest charges, and lessened depreciation charges. As a whole, and before deducting credits, the 1930 charges in the accompanying estimate were nearly 0.9 cents per pound lower than in 1929, that is 11.4 cents as compared with 12.3 cents.

COPPER RESERVES AND WORLD OPERATING CAPACITY.

World Copper Reserves: A compilation (Table XVIII) of the copper ore reserves, has been made by the American Bureau of Metal Statistics.[1] It includes the names of the various producing companies, the location of their operations as well as the officially reported ore resources at the time indicated. The production of each company for the year 1929 has been included to give some idea of the number of years of prospective production, if one assumes the output of 1929 as more or less of a maximum.

The estimates are admittedly subject to considerable change, especially as regards developing properties, so that the actual reserves may be found to be either greater or smaller than those included in the table. Probably the group most subject to radical changes of estimate are the African properties now in the initial exploration and development stages. Recent as are these estimates, several marked changes

[1] Yearbook of the American Bureau of Metal Statistics,1930 p.18.

TABLE XVIII. COPPER ORE RESERVES, as officially reported.(a)

COMPANY	Mine Situation	Year	Tons Ore (2000 lbs.)	Aver. Grade of Ore - %	Tons Copper.	1929 Copper Production.
UNITED STATES						
Bagdad	Arizona	1930	48,000,000	1.20	576,000	[illegible]
Consolidated Coppermines	Nevada	1930	35,000,000	1.10	385,000	11,366
Inspiration	Arizona	1925	96,010,935	1.40	1,344,200	53,654
Miami	Arizona	1930	91,276,737	0.95	869,700	29,421
Nevada Consolidated	Nevada, New Mexica, and Arizona	1930	300,000,000	1.47	4,410,000	133,137
Old Dominion	Arizona	1930	1,720,070	2.10	36,100	9,472
Phelps Dodge (Burro Mountain)	New Mexica	1930	11,725,000	1.95	228,600	[illegible]
Phelps Dodge (Morenci)	Arizona	1930	379,349,000	1.02	3,369,400	88,590
Phelps Dodge (Copper Queen)	Arizona	1930	24,600,000	1.55	381,300	
United Verde Extension	Arizona	1930	600,000	7.00	42,000	29,589
Utah	Utah	1930	640,000,000	1.07	6,848,000	148,313
CANADA						
Abana	Quebec	1930	477,200	2.70	12,900	
Falconbridge	Ontario	1931	2,279,453	1.08	24,600	
Granby Consolidated	British Columbia	1930	14,601,149	1.81	264,300	30,427
Hudson Bay	Manitoba	1930	18,000,000	1.71	307,300	
International Nickel	Ontario	1930	206,704,000	2.00 (b)	4,134,100	35,000 (b)
Noranda	Quebec	1931	7,891,000	4.09	323,100	25,813
Sherritt Gordon	Manitoba	1930	5,254,500	2.50	131,400	
Waite Ackerman Montgomery	Quebec	1930	446,500	5.90	26,300	1,100
CUBA, MEXICO, SOUTH AMERICA						
Metahambre Mines	Cuba	1930	980,933	4.75	46,600	15,740
Phelps Dodge (Moctezuma Mine)	Sonora, Mexico	1930	3,745,000	2.69	100,700	21,035
Andes	Chile	1924	137,400,000	1.51	2,074,700	81,332
Braden	Chile	1930	230,750,000	2.18	5,030,300	88,163
Chile Exploration (b)	Chile	1921	688,629,389	2.12	14,599,000	149,788
AFRICA						
Katanga	Belgian Congo	1929	85,979,000	6.41	5,512,000	151,006
Baluba	Northern Rhodesia	1930	21,000,000	3.47	728,700	
Chambishi	Northern Rhodesia	1930	24,000,000	3.68	883,200	
Kansanshi	Northern Rhodesia	1930	8,000,000	4.15	332,000	
Mufulira	Northern Rhodesia	1930	102,000,000	4.39	4,477,800	
N'Changa Copper	Northern Rhodesia	1930	64,641,000	3.90	2,521,000	
N'Kana	Northern Rhodesia	1930	100,000,000	3.90	3,900,000	
Rhodesian Congo Border	Northern Rhodesia	1930	30,000,000	6.60	1,980,000	
Roan Antelope	Northern Rhodesia	1930	108,000,000	3.44	3,715,200	
Messina	Transvaal	1930	1,145,000	2.75	31,500	7,529
OTHER						
Indian Copper	India	1929	798,154	3.33	26,600	1,832
Mount Lyell	Australia	1930	4,593,748	3.01	138,300	9,903
TOTALS			3,495,598,318	2.01	70,312,400	1,122,210

(a) From the Year Book of the American Bureau of Metal Statistics,1930.

(b) Since 1921, additional ore has been developed but not estimated. (c) Estimated.

in the reported ore reserves of this new copper producing area have already been made. In a recent article appearing in Barron's Financial Weekly, New York, the northern Rhodesia field is reported to contain much larger bodies of even richer ore than stated in the table. Concerning this famous African copper district, Rhokana Corporation Limited (formerly Rhodesian Congo Border Concessions, Limited) in its annual report states that a recalculation of its ore reserves now amounts, in three deposits, to 270,780,000 tons of ore averaging 4.3% of copper. The same company holding a third interest in the Mufulira Copper Mines, Limited, reports that this property has reserves estimated at 162,000,000 tons of 4.14% ore. Rhokana's reserves together with those of Mufulira and Roan Antelope thus make a total proven tonnage of 540,780,000 tons of ore which average over 4% copper. The magnitude and richness of these ores assure the greatness of this field as a leading copper producer of the future.

World Operating Capacity: The installed mining and metallurgical equipment of the world is in excess of present needs. The annual refining capacity of the world in 1930 was estimated at 3,027,000 tons[1.] while it is planned to increase this to 3,402,000 tons in the near future. This capacity should prove adequate to meet all demands for some few years to come.

[1.] A.H.Richards, General Manager, Tacoma Smelter.

MARKETING AND CONTROL OF PRODUCTION.

The decreased production of recent months has been largely due to two main factors. The accumulated stocks of copper resulting in decreased demand for the metal has consequently lowered prices and eliminated those marginal producers, or high-cost mines, which are able only to operate under favorable market conditions. In the second place a voluntary curtailment of production has been practised by certain large producers, particularly in the United States, with a view to decreasing the stocks of available copper and thus allowing consumption to more closely approach production figures.

Copper Exporters, Inc.: In the year 1926, a cartel known as Copper Exporters Inc., was organized to control about 90 percent of the world production of copper. It is an organization of American copper producers associated with whom are certain foreign producers and sellers of copper, so that it embraces virtually all the leading copper producers of the world. The purpose of this organization is to try to eliminate in foreign countries the speculation which tends to cause wide price fluctuations, and to destroy the stability of the industry. The movement developed as a result of the trend of foreign markets, particularly since the World War , and the motivating power behind the organization was to establish the copper prices of Europe according to general business as it developed from day to day. An effort was made to sell directly to consumers wherever possible, and eliminate harmful speculation in this commodity. To date the organization has met with little success, if the stabilization of the price of copper through manipulation of production and market conditions, is to be regarded as its prime object, for despite any and all preventative efforts the price of this commodity has continued downwards to a new all-time low of 5.75 cents in March, 1932.

Table XIX, a compilation of the American Bureau of Metal Statistics, gives the total stocks of copper on January 1, of the years 1925 to 1931 inclusive, in terms of short tons. The table is incomplete in that the stocks of copper at smelteries and refineries in several foreign countries are not included.

Recent Curtailment of Production: In the face of accumulating stocks of copper, a conference of the representatives of 90 percent of the world's copper producers decided to curtail production about 15 percent in order to bring the output more nearly in line with consumption. While the agreement was apparently fulfilled, the possibility of a continued decline of consumption in the first half of 1931 had not been anticipated, and the curtailment program was thus not very effective, and stocks continued to increase. A further conference was held at New York in May, 1931 but at it no agreement on further curtailment could be reached. All

TABLE XIX. Total Stocks of Copper on Jan. 1st, 1925-1931 (d)

(in short tons)

	1925	1926	1927	1928	1929	1930	1931
NORTH AMERICA:							
In blister at smelteries	5,596	7,525	10,079	8,844	9,684	10,764	6,108
In blister at refineries	26,640	30,851	30,514	24,543	28,581	57,843	45,515
In transit to refineries (a)	64,378	56,802	64,464	53,830	65,115	47,892	22,878
Total blister, North America . . .	96,614	95,178	105,057	87,217	103,380	116,499	74,501
SOUTH AMERICA							
In blister at smelteries	3,710	2,936	5,770	4,974	4,661	2,545	1,174
In transit to U.S.	6,588	4,339	4,140	8,306	10,952	8,756	3,460
Total blister, South America . .	10,298	7,275	9,910	13,280	15,613	11,301	4,634
In Process of Refining, N. and S. America . .	130,616	146,422	158,168	134,561	131,002	140,606	139,664
Refined, N. and S. America	136,434	73,082	85,501	95,298	65,466	171,320	367,175
Grand Total, N. and S. America .	373,962	321,957	358,636	330,356	315,461	439,726	585,974
GREAT BRITAIN (b)							
Refined	2,833	6,242	3,525	564	1,074	3,240	6,443
Other Forms	40,196	56,531	35,267	11,657	6,543	4,044	2,153
Total, Great Britain	43,029	62,773	38,792	12,221	7,617	7,284	8,596
HAVRE (b)	8,042	3,375	9,688	1,384	2,334	5,165	3,896
JAPAN (c)	11,042	5,543	5,099	5,611	6,362	14,109	4,581

(a) From North American smelters only. (b) As reported by London Metal Exchange; official warehouses only.
(c) Bonded stock excluded. (d) From the Yearbook of the American Bureau of Metal Statistics, 1930.

agreed that too much copper was being produced, but some of those whose operation costs were not above current prices were unwilling to curtail further while the high-cost companies continued to produce.

Meanwhile the statement issued by the American Bureau of Metal Statistics in June, 1931 and covering North and South America refining operations (reflecting mine operations three months earlier) showed an unabated production in excess of shipment. Thus refined stocks of the Americas, for the first time in the history of the industry reached the large figure of 826,948,000 pounds, an increase during June alone of 29,614,000 pounds of refined copper. Including the "copper in process" the total reached 1,200,000,000 pounds which then meant that if all the mines were closed down for five months, existing stocks could, on the basis of consumption fill all orders for that period.

In October 1921, copper producers met in New York, hoping to finally arrive at some common understanding regarding curtailment. In view of the fact that stocks were continuing to accumulate, the problem before the conference was to ensure that for some time to follow, world production would be below consumption in order that the equilibrium might be restored. Failing this, the only alternative seemed to be the abandonment of the copper market to its fate. At this conference the greatest difficulty was experienced in endeavoring to arrive at terms suitable to the representatives of the Belgian interests, while other producers were prepared to curtail production to the extent of 26 percent of estimated capacity, Belgian interests preferred to be allowed to produce at the rate of 100,000tons a year, and to store two-thirds of the output. This procedure was deemed undesirable in that the sudden release of the stored stocks upon the return of a favorable market, would further upset that market. The counter-proposition offered the Belgian interests was that they be allowed to produce about 90,500 tons annually, to be free to sell 57,500 tons a year and to have the remaining 33,000 tons impounded, so that in the event of a breaking up of the curtailment agreement, the latter portion of the output could not be sold, except under terms which would hold it off the market for a considerable period. It was not until the latter part of November that the Belgian copper interests as represented by the "Union Miniere de Haut Katanga" accepted the curtailment proposals outlined by the New York Conference, agreeing to curtail production by over 40 percent. Other producers on December 21,announced a voluntary curtailment of production to the extent of 26 percent of estimated capacity. To ensure that these steps should not unduly advance the price of copper, the agreement further provided that when the total stocks of metals above ground do not equal the total deliveries in the preceding four months, curtailment is to cease. Furthermore, quoting from the statement issued by the Copper Institute " If the price of copper shall exceed for a period of 15 days the price of 12 cents a pound, the curtailment shall cease, no matter what existing stocks may be". The life of the agreement is conditionally limited for " should the total stocks of copper above ground not have been reduced by December 31,1932 so as to equal in the aggregate the total deliveries in the preceding four months, any company may, without criticism, nevertheless resume operations as it sees fit on 30 days notice."

Further curtailment is yet being contemplated in order to have production rates more nearly in an equilibrium with consumption. In a recent article appearing in Barron's, it was reported that the Belgian interests had stated their willingness to cooperate one hundred percent with the American producers in curtailing output, and that they would not ask the privilege formerly accorded them of operating at a somewhat higher rate and storing output in excess of its quota. The plan most recently being discussed involves curtailment to 17.5 percent of estimated capacity. This compromise would represent what is considered by producers as the maximum cut which can be affected and still keep all producers in accord. There are at the same time, two extreme views on the matter of curtailment. The most radical is that of some of the more powerful lower-cost producers, which maintains that the only solution is based on the survival of the fittest, with lower prices forcing out those producers who are unable to operate under existing markets. The second group argues that it is suicidal to curtail further, and present figures to show that it is cheaper in the end to operate another year or so at the present rate, even if a loss of several cents a pound be entailed. They point to the social and political advantages of staying in production and providing employment.

The question of a complete shutdown has had advocates and opponents. Supporters of the idea maintain that as soon as stocks have been substantially reduced the confidence of the buyers will be restored and the price will rise to between 9 and 10 cents. They claim that the companies will fare better to shut down entirely and carry their crews through extending rational credit to them and providing living accommodations, in that such costs would be only a fraction of the increased income the company would receive from the resulting higher price. They contend that continued production at the present rates will break the morale of the industry, destroy cooperation and kill the industry financially. With continued output another year will be required before consumption brings the stocks above ground back to the present tonnage, they estimate, and that a second year will be required to reduce them sufficiently to restore a satisfactory price for copper. Other producers reply in the negative, maintaining that a complete shutdown might be all right for producers with stock, but is of no help to those without stocks.

A tariff on copper has had its supporters in the United States, who believe that producers in that country can be protected by a tariff wall, and cope with the situation among themselves. Opponents of this view maintain however, that such a procedure would be most undesirable in that the resulting disintegration of cooperation among world producers would be most unfortunate. They claim further that industry faces a potential over-production for five years or more and a tariff would probably call forth other tariff walls which would then hamper consumption.

Control of Non-Ferrous Base Metal Operations: Though non-ferrous base metal mines are found in practically all parts of the globe, control is exercised by a comparatively small group of countries. So much is this true that it would be possible to accommodate representatives of this group in a small room for purposes of a round table discussion. The controlling interests of various base metal mines have been discussed in a commercial letter of one of our leading Canadian banks.[1.]

United States interests, it is pointed out, control the base metal mining of Mexico and South America. While they are also reported as being associated with the Mount Isa development in Australia, and exercising their influence in the lead-zinc fields of Silesia. In Canada three copper mines are American owned, while considerable American money has entered other Canadian properties. Control of most of the important copper mines of Spain is exercised by United Kingdom capital, which has also supplied financial backing for most of the mineral developments in British Africa. It has also substantially aided Australian metal producers and has held financial interests in certain mines in Canada, Mexico and other countries. French capital largely owns the producing lead-zinc mines of Spain, while Belgian interests have major control of the Katanga Copper mine in the Belgian Congo. Most of the new and successful Canadian companies are of Canadian origin and largely of Canadian capitalization.

---

1. Monthly Commercial Letter, Canadian Bank of Commerce, Sept. 1930 p.6.

THE GEOLOGIC AND ECONOMIC ASPECTS OF COPPER

PART VI

THE FUTURE OF THE COPPER INDUSTRY

VI. THE FUTURE OF THE COPPER INDUSTRY

A consideration of the present copper situation of the world involves so many uncertain factors that it would seem quite impossible to predict with any degree of certainty the immediate future of the industry, which is so largely dependent upon the general economic conditions of the world. However, it is not essential, in fact it may even be undesirable, that too much emphasis be placed on the immediate situation. Producers and consumers of the metal might profitably show more concern for the distant future of the industry.

Leading authorities are unanimous in the view that the present copper situation is nevertheless extremely serious, and that the need of cooperative effort on the part of copper producers and distribution agencies was never more apparent than at the present time. In accordance with this opinion representatives of the producing and distributing concerns have recently held conferences which have to date accomplished little of an actual remedial nature, yet have done much toward focussing the attention of those concerned upon the actual facts. Various authorities have from time to time offered opinions as to the cause of the present situation and its relation to the general world depression. Over-production, under-consumption and over-buying have all been considered factors contributing to the present acute condition of the industry. Stimulated by the abnormally increased demand for metal, copper producers turned out copper at an unprecedented rate which reached its highest point in the year 1929. Scientific research stimulated industry in the improvement of production methods, but in so doing completely overtaxed the existing machinery for the proper and equitable distribution of industrial products. This is clearly indicated by the increasing accumulation of the products of the farm, the mine and the forest. If some of the talent used to stimulate production could now be devoted to the distribution of these products an important step would have been taken for the benefit of mankind. Meanwhile the purchasing power of the world has been drastically reduced, although money is cheap in the financial centres, interest rates are low and large sums of money are available for investment. Nevertheless the world is not consuming its normal quota of raw materials; under-consumption, or a decreased use of the products, has accompanied their over-production. Over-buying on the part of manufacturers has been considered a predominant cause of the declining price of copper. Buying too far in advance of requirements tends to raise the price, whereupon the producer increases production to the limit in order to meet the demand and thereby derive the greatest possible benefits from high prices. Eventually producers find themselves over-stocked , inevitably the price declines and the confidence of both producer and consumer is severely shaken. Under such conditions the manufacturer must use up the over-bought supply of stocks and sell to the ultimate consumer at a time when the industry is generally depressed. Such would seem to be the situation at the present time; over-production combined with a decreased. consumption, has in the past months resulted in an excess accumulation of stocks, a decreased demand, and consequently falling prices. Efforts toward the control of production the stimulation of consumption and a careful distribution of the product upon a more substantial economic basis, may vastly improve the situation and stabilize the industry. How such may be accomplished is an economic problem receiving at the present time much profound consideration.

Concern should not be too much confined to the immediate future of the industry. Large quantities of copper cannot be consumed until economic conditions of the world improve. The distant future of copper offers a more refreshing picture and will here be discussed in connection with future production, consumption and price possibilities.

Future Production: As previously noted in this paper the geographical production of copper changed from Europe to the Americas during the latter part of the nineteenth century. Present indications are that the world's copper pattern is again in the process of change. Stimulated by increasing demand during the war and post-war periods, expansion in the Americas was most pronounced and during the past decade approximately 80 percent of the world's copper was produced in the western hemisphere, with United States and Canada alone accounting for almost 50 percent of the total output. World-wide development within the industry saw the building of new plants, the enlargement and improvement of the old, and a general stimulation in the exploration and development of new properties. Africa emerged from this period of marked expansion and has already demonstrated its potentialities as an important copper producer of the immediate future. Indications are that before the passing of another decade the African continent may possibly have an annual production of 400,000 tons of copper, and this produced at a comparatively low cost, under conditions now deemed much more favorable than were at first generally conceded. New Canadian properties and refineries point to the probability that Canada will produce a larger proportion of the copper output of the Americas, while these two continents will likely produce a lesser percentage of the world tonnage. In the United States the year 1929 was the culmination of several years of marked increase in production. Several considerations seem to point to the fact that this country might in coming years do well to maintain its present position among the copper producers of the world. The importance and influence of the new producers or potential producers in Canada and Africa can not be doubted. In the United States there are but a comparative few mines which will be able to appreciably increase production. The properties now operating are of limited reserves and have been known for fifty years or more, while others have not been found to take their place. The year 1929 might easily remain the peak year of United States production. In Europe similar conditions exist. Mexico, Australasia and Asia, Russia excepted, offer but very slight prospects of increased output. Thus any increase in production must come from South America, Africa and Canada. A.H.Richards [1] has estimated the 1940 production of copper from the main producing continents as in Table XX. Arthur Notman [2] has

---

[1] General Manager, Tacoma Smelter in a recent address before the Mining Association of Britiah Columbia.

[2] Arthur Notman, Consulting Engineer of New York, in a recent address before the C.I.M.M.

TABLE XX. FORECAST OF WORLD PRODUCTION FOR 1940. (a)
(In short tons)

SOURCE	ESTIMATED TONNAGE, 1940.
North and South America	1,700,000
Europe	303,000
Africa	700,000
Other Sources	124,000
World Total	2,827,000

(a) After Richards, A. H., General Manager Tacoma Smelter, in a recent address before the Mining Association of British Columbia.

TABLE XXI. FORECAST OF WORLD COPPER PRODUCTION, 1931-1940. (a)
(In short tons)

COUNTRY	ESTIMATED TONNAGE
United States	8,500,000
Canada	2,800,000
Mexico	800,000
South America	4,500,000
Europe (excluding Russia)	1,200,000
Africa	4,500,000
All Others (including Russia)	1,200,000
Total	23,500,000

(b) After Arthur Notman, Consulting Engineer of New York, in a recent address before the C. I. M. M.

attempted a forecastof world copper production for the 1931-40 decade and has allocated to various countries the estimated proportions of this output (Table XXI). Russia's influence upon the copper market of the future is somewhat indefinite. It is true that development in that country has been most pronounced in recent years. However, it has in the past been noticed that increased production in a country is usually associated with an expansion of consumption and Russia is a field which should offer a particularly wide scope for the utilization of domestic copper. Japan has been the leading Asiatic producer, but to date that country has been consuming its output and has not been a factor in the world market. Its future influence is not generally expected to be great, but this too is an indefinite factor. The mines of Northern Rhodesia are expected to be a most important influence in the future production of copper. The question arises as to whether or not these fields would tend to keep the price of metal at, or about, its present level. In answer to this a London Correspondent of Barron's replies negatively, on the grounds that if the increase of 421,768 tons in North and South American production, during the few years prior to 1929, and of 514,393 tons in the world's production of the same period, failed to prevent the price from rising to 24 cents early in 1929, an increase of 221,500 tons in the African production during the coming few years should not adversely affect the market.

Future Consumption: It has been stated rather generally that during the past fifty years, the copper production of the world has increased at the rate of 6 percent per annum compounded. It would seem entirely unwarranted to take the 1929 peak figure as a basis for this computation and expect an increase at the above rate for the next ten years, but estimates based on a more normal year might prove significant. An increasing population and a rising standard of living should assure the copper industry of a favorable future. Industrial activity requires electricity which involves the utilization of copper, and if civilization is to advance, then the consumption of more copper would seem assured. Population has increased during the last ten years; United States registered a 15.8% increase, Germany 8%, Belgium and France each 5% and Italy 6%, while the population of Great Britain remained approximately the same. The people of the future will not be satisfied with a lower standard of living than has been prevalent during the past few years and, in fact, they may be expected to demand even higher standards. Over 60 percent of the world's copper is used in the electrical industry and the world is fast increasing it's consumption of electrical energy. In the United States it's increased use has been most pronounced and the greater consumption of copper per capita in that country has been correspondingly marked, advancing from 13.24 pounds in 1923 to 16.53 pounds in 1928 and 19.08 pounds in 1929, but falling in 1930 to 15.52 pounds per capita. In the year 1928 the copper consumption of Great Britain was in comparison rather low, when it amounted to 7.89 pounds per capita. Similarly consumption was also low in France and Germany. Slight increases had nevertheless been registered in all countries and today the use of electricity is rapidly expanding; consequently an increased demand for copper may be reasonably expected. An indication of such a movement is that of Lord Weir's scheme for the electrification of British railways. This is the largest undertaking of its kind ever attempted, and its successful consummation would more than triple the world's present electrified mileage of railways, and require approximately 500,000 tons of copper. Briefly, the Weir Committee's plan comprises the electrification of all British main lines, and involves a total route mileage of 20,300 miles, a total main track mileage of 36,000 miles and an additional 15,500 miles of sidings. The total net outlay for the complete electrification of the main lines of Great Britain is estimated at $1,300,000,000. At the present time electrified railroads have in service more than 250,000 tons of copper so that the British project offers a market for twice the amount of the metal at present utilized on some

21,000 miles of former steam track now electrically operated. Thus does railroad electrification alone offer vast possibilities. The public utility companies are taking advantage of current conditions when in 1930 more copper was used for light and power lines than in any other year in history. In the same year a new record was set for the consumption of copper for wire cloth and for heat radiators, while the ship-building industry used more copper than in any year since 1923. Such facts would suggest that both new and old spheres for the utilization of copper might well be aggresively extended at this time when the metal is at its lowest price in history.

Estimating but a 5% increase in consumption compounded upon the 1930 figure, the prediction for 1940 consumption as contained in Table XXII has been made[1] Notman[2] in discussing the possibilities for future consumption of copper points out that the output for the last thirty years has increased 3,683,000 tons per decade, while the average increase in consumption (having made allowance for present stocks) has been about 3,500,000 tons per decade. During the last ten years consumption has been practically doubled and a similar increase in the next decade would result in a total of 24,000,000 tons. Admittedly this would seem a rather optimistic estimate and at least represent a maximum. During the early part of last year (1931), in a period of severe business depression,

[1] By A.H.Richards, Gen.Mgr.Tacoma Smelter in address before Mining Association of British Columbia.

[2] Arthur Notman,Consulting Engineer of New York, in a recent

TABLE XXII. ESTIMATED CONSUMPTION OF COPPER IN 1940. (a)
(In short tons)

North and South America	1,351,000
Europe	1,314,000
Elsewhere	156,000
Total	2,821,000

(a) After Richards, A. H., General Manager Tacoma Smelter, in a recent address before the Mining Association of British Columbia.

TABLE XXIII. ESTIMATED COPPER CONSUMPTION, 1931-1940. (a)
(In short tons)

YEAR	MINIMUM	MAXIMUM	PROBABLE
1931	1,650,000	1,850,000	1,750,000
1932	1,695,000	1,972,000	1,833,000
1933	1,739,000	2,094,000	1,917,000
1934	1,784,000	2,217,000	2,000,000
1935	1,828,000	2,339,000	2,083,000
1936	1,872,000	2,461,000	2,167,000
1937	1,916,000	2,583,000	2,250,000
1938	1,961,000	2,706,000	2,333,000
1939	2,005,000	2,828,000	2,417,000
1940	2,050,000	2,950,000	2,500,000
TOTALS	18,500,000	24,000,000	21,250,000

(a) After Arthur Notman, Consulting Engineer of New York, in a recent address before the Mining Association of British Columbia.

deliveries of copper averaged an annual rate of 1,620,000 tons. A return to more normal conditions could be expected to increase demand about 10 percent, to about 1,850,000 tons which is the average annual consumption needed to meet the minimum figure of the ten-year period as indicated in Table XXIII. The attainment of the probable figures included in the estimate will largely depend upon the speed of recovery of general business and upon the growth of the electrical industry of the world.

Future Price: Since the year 1929, the price of copper has drastically receded despite any and all efforts to sustain it, so that in Marcy,1932, it reached an all time record low of 5.75 cents on the New York Market. Efforts have been made to control production with a view to brining production more nearly on an equilibrium with consumption, though consumption itself has shown a decline. Further steps will in all probability be taken to increase consumption by the stimulation of sales. The present day, with prevailing low prices, would seem the logical time in which to consider sales promotion. It is a difficult matter to predict the future price movements of this commodity with any degree of certainty. Any estimate of the future price must take into account certain important factors such as ore reserves of the world, production and consumption capacities and the costs of production.

and statistics covering such factors vary widely with time, place and operator. From the year 1886 until the beginning of the World War, when the great price disturbance commenced, the price of copper on the New York Market averaged about 13.69 cents per pound. Meanwhile costs of operation were much higher than in more recent years. In 1930 operating costs of the majority of the large mines of the western hemisphere were estimated at about 9¾ cents per pound of copper produced.[1]

In view of the large quantities of ore already in sight the price of copper for some years to come will not need to be so high as to stimulate efforts toward the discovery and development of new properties. While attempts have been made to control prices the usual result seems to have been an accumulation of stocks and consequently a lowering of prices. At the present time experiments in production control are being made with no attempt to fix prices. The outcome of these efforts is being awaited with much interest in order to ascertain their possible effect upon future prices. Further, it is probable that the consumption of copper will be stimulated by large projects and by sales propaganda, both of which should be favored by the present low prices of the commodity. All the above factors will be concerned in the

---

[1] Ante.pp.123-4.

ultimate price of the metal. Such price will, nevertheless, need to be such as to make normal production adequately profitable for the low-cost producers and sufficiently profitable for the marginal producers so as to bring future production in line with future demand. A normal price of 11 or 12 cents might adequately satisfy all conditions, but an actual estimate involving as it does numerous and indefinite economic factors can be at best little more than a matter of careful conjecture.

While the immediate present of the copper industry is by no means favorable to the producers of the metal, its ultimate future is nevertheless bright. The copper market will in all probability be rather low during the next few years , and production will likely be confined to those companies which are able to produce at a low cost. Already the metal has however, proven itself to be an essential factor in industrial and social development. If one believes that the world population will continue to increase, and that its standard of living will steadily improve, one cannot but believe in the ultimate prosperity of the industry. Copper may therefore be reasonably expected to play a very significant part in future world progress, and its saturation point will not be reached before all people of every nation have at least as high a standard of living as have any people of the world today.

WORKS OF REFERENCE USED

... .

Heinrich Ries: "Economic Geology", Fifth Edition, John Wiley & Sons, Inc., London, 1925.

W. H. Emmons: "General Economic Geology", First Edition, McGraw-Hill Book Company, Inc., New York, 1922.

Waldemar Lindgren: "Mineral Deposits", Third Edition, McGraw-Hill Book Company, Inc., New York, 1928.

R. H. Rastall: "The Geology of the Metalliferous Deposits", University Press, Cambridge, 1923.

F. Beyschlag, J. H. L. Vogt, and P. Krusch: "Ore Deposits", Vols. I and II., 1909; translation by S. J. Truscott, Macmillan & Company, Ltd., London, 1914.

W. H. Weed:"The Copper Mines of the World", New York, 1908.

C. R. Hayward: "An Outline of Metallurgical Practice", D. Van Nostrand Company, Inc., 1929.

C. H. Fulton: "Principles of Metallurgy", First Edition, McGraw-Hill Book Company, Inc., New York, 1910.

A. M. Gaudin: "Flotation", First Edition, McGraw-Hill Book Company, Inc., New York, 1932.

W. H. Weed in "The Mineral Industry During 1926", edited by G. A. Roush, McGraw-Hill Book Company, Inc., New York, 1927.

K. W. Taylor and H. Michell: Statistical Contributions to Canadian Economic History", Vol. II., Toronto, 1931.

... .

"Encyclopaedia Britannica", Vol. VII., Eleventh Edition, University Press, Cambridge, 1911.

... .

WORKS OF REFERENCE USED

(concluded)

... ...

"Year Book, 1930", American Bureau of Metal Statistics, Maple Press, York, Pa., 1931.

C. E. Julihn: "Economic Paper 1", United States Bureau of Mines, Government Printing Office, Washington, 1928.

"Mineral Production of Canada"; Annual Reports, 1928 and 1929, Preliminary Report, 1930; Dominion Bureau of Statistics, Ottawa.

"The Canadian Mining and Metallurgical Bulletin"; Nos. 149, 216, 223, and 229; Montreal

"The Miner", Gordon Black Publications, Vancouver, B. C.

"Barron's Financial Weekly", New York.

"Metal and Mineral Markets", New York, (July 23, 1931.)

"Engineering and Mining Journal", New York, (July 27, 1931).

"Monthly Commercial Letter", Canadian Bank of Commerce, September, 1930.

"Monthly Commercial Letter", Royal Bank of Canada, March, 1930.

... ...

Brandon College,
Brandon, Manitoba,
May 11, 1932.

Professor McNairn,
Department of Geology,
McMaster University,
Hamilton, Ontario.

Dear Sir,-

In my thesis, "The Geologic and Economic Aspects of Copper", a copy of which was forwarded you some days ago, I have noticed that the typist in making typographical corrections over-looked certain errors. In case corrections were not made in the copy submitted for your consideration I would like to draw your attention to the following typographical errors which tend to alter the meaning of the text.

Page 30 - Line 4 - Substitute "35 miles by 16 miles" for "35 miles by 8 miles".

Page 35 - Line 2 - Substitute "of the particular solution and of the" for "of this particular solution of the".

Page 49 - Line 4 - Substitute "sulphide" for "sulphate"

Page 140 - Line 4 - Substitute "consumption" for "production".

Yours respectfully,

E. Lloyd Bowler.

E. Lloyd Bowler.