J. S. Afr. Inst. Min. Metall., vol. 85, no. 3.
Mar. 1985. pp. 73-80.

Copper in South Africa—Part I

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SYNOPSIS

This paper is the first part of a two-part review on the subject.

Here, reference is made to the place of copper among the elements, its properties, its historical significance, and its end uses, both in general and in South Africa. Its current market situation and its prospects are dealt with briefly. Some account is then given of the mining and metallurgical techniques employed in South Africa in the production of copper, together with the names of the companies at present involved and brief descriptions of their operations.

The operations of these companies are described in greater detail in Part II (April 1985 issue of the *Journal*).

SAMEVATTING

Hierdie referrat is die eerste deel van 'n oorsig oor die onderwerp in twee dele.

Daar word hier verwys na die plek van koper onder die elemente en die eienskappe, historiese betekenis en eindgebruike daarvan, oor die algemeen en in Suid-Afrika. Die huidige marksituasie en vooruitsigte met betrekking tot koper word kortliks behandel. Daarna word daar verslag gedoen oor die mynbou- en metallurgiese tegnieke wat in Suid-Afrika vir die produksie van koper gebruik word, tesame met die name van maatskappye wat op die oomblik daarby betrokke is, met kort beskrywings van hul bedrywighede.

Die bedrywighede van hierdie maatskappye word in meer besonderhede in Deel II (in die April 1985-uitgawe van hierdie *Tydskrif*) beskryf.

COPPER IN NATURE

The Metal

The atomic number of copper is 29; it appears in Period 4, Group 1B of the Periodic Table, related elements of the same group being silver and gold, with atomic numbers of 47 and 79 respectively. All three crystallize in the face-centred cubic mode. Neighbouring elements with atomic numbers 26, 27, 28, and 30 respectively are the important metals iron, cobalt, nickel, and zinc. Metallic copper is red and lustrous; the density is $8,89 \times 10^3\ kg \cdot m^{-3}$, and the melting point 1083°C.

Copper occurs as two stable isotopes; the nucleus contains either 34 or 36 neutrons in such proportions that its atomic mass averages 63,54. The copper atom is the first in the atomic number series in which all three inner electron shells are fully occupied and only one electron occurs in the fourth shell. The configuration is 2:8:18:1. Removal of the outer electron yields a cuprous ion, Cu^+; an additional electron can also be detached from an inner shell to yield a cupric ion, Cu^{2+}.

These fundamental structural features confer properties on atomic aggregates (i.e. metal itself) that have proved extremely valuable to mankind. When certain critical impurities are excluded, copper, silver, and gold are notable for very high electrical and thermal conductivities as measured on a volumetric basis. Furthermore, these metals are remarkable for their corrosion resistance, ductility, lustre, and ability to form alloys with one another and with other metals[1,2].

Occurrences

Deposits of metallic copper have been mined in several parts of the world. These days, however, copper is found naturally as simple or complex sulphides, or as compounds such as hydroxides or carbonates produced from sulphides by local weathering[3].

Common copper minerals of economic importance are listed in Table I, the sulphides being the most significant.

TABLE I
COPPER MINERALS OF ECONOMIC IMPORTANCE

Mineral	Formula	Copper content %
Chalcopyrite	$CuFeS_2$	34,6
Bornite	Cu_5FeS_4	63,3
Chalcocite	Cu_2S	79,9
Covellite	CuS	66,4
Malachite	$CuCO_3 \cdot Cu(OH)_2$	57,5
Azurite	$2\ CuCO_3 \cdot Cu(OH)_2$	55.3
Cuprite	Cu_2O	88,8
Chrysocolla	$CuSiO_3 \cdot 2\ H_2O$	36,2

Copper sulphides are often associated with sulphides of iron, nickel, lead, zinc, and molybdenum, and frequently contain significant quantities of gold and silver. Massive sulphide deposits were common in the past, and are still encountered and mined today, but in most orebodies the copper sulphides are finely disseminated and constitute only a small proportion of the total mass.

END USES OF COPPER

The usage of copper per unit of gross national product and by market sector varies between States, and is sensitive to the level of development and the maturity of the economy[4].

Today copper makes a vital contribution to the operations of modern industrial States. For example, in 1983 copper-mill products in the U.S.A. were consumed in various economic sectors as follows:

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SA ISSN 0038-223 X/$3.00 + 0.000. Paper received 15th Aug. 1985.

	kt	%
Building construction	922	35
Transportation	276	11
Industrial and marine	430	17
Electrical and electronics	670	26
Other sectors	284	11
	2 583	

The largest consumers of pure copper are the electrical and electronics industries (wires, cables, and strip) and the building industry (tubes and sheet). Other sectors utilize cast or wrought alloys, especially those made with zinc (the brasses), tin (the bronzes), nickel, beryllium, silicon, and manganese.

CURRENT MARKET SITUATION AND PROSPECTS

In the past ten years, copper producers in the main producing countries (the U.S.A., Chile, Canada, Zambia, Zaire, and Peru) and also in South Africa have found it increasingly difficult to run profitable operations. Many have failed to do so. They have been caught between rising costs and declining 'real terms' prices. Rising costs are largely attributable to inflation and also, especially in the U.S.A., to very strict legislation requiring expensive environmental protection. During 1984, 'real terms' prices, quoted in either sterling or dollars, reached their lowest level for fifty years, although the numerical value of the revenues received by producers can be significantly increased by a superficially 'favourable' exchange rate between the local currency and sterling[5].

The situation has attracted, and will continue to attract, much economic analysis. So far as the managements of copper companies are concerned, it confirms the adage that mining is a risky business. It compels them to direct perplexed attention to such varied price-determining factors as business sentiment in the U.S.A., possible U.S. import restrictions, potential demand in China, a national need for foreign exchange, the likelihood of strikes and political disturbances in producing countries, the loss of markets to alternative materials such as aluminium, plastics, fibre-optics, and the possibility of 'improved' exchange rates.

These factors and the pressures and benefits arising can never be forecast and appraised correctly. Collectively, however, they have affected the prosperity of producers adversely. In South Africa these pressures have prompted a relentless search for cost-saving procedures, sometimes gratifyingly successful when better technology can be adopted, and sometimes disappointing, involving recourse to unorthodox financing and the contraction or closure of socially and regionally significant and hitherto successful operations[6].

Regarding market sectors, the industry, through the Copper Development Association and the International Copper Research Association, is continuously involved in efforts to defend established usages against competing materials, such as aluminium and plastics. For example, it is now believed that copper automobile radiators fabricated with new zinc-based solders will be preferred to aluminium radiators. New copper–nickel alloys are expected to be used increasingly in the protection of marine structures, and copper sheeting is again finding favour for roofing in the U.S.A.

In the medium and long term, however, the demand prospect is confused, discouraging optimism and suggesting that managements proceed with special determination to minimize their costs and take maximum advantage of any favourable local factors, such as good-quality or valuable byproducts. Massive investment in major new mines or in expansions seems likely only in centrally-managed economies[7]; elsewhere it will be avoided unless local factors happen to be exceptionally favourable.

COPPER IN HISTORY

Green, blue, black, and red copper minerals in weathered outcrops, upon which wood fires burn with green flames, must have attracted man's attention in prehistoric times. Metallic copper may have been first produced in such fires by accident. However, perhaps the coloured flames, and the colour changes caused by the heating of coloured minerals, prompted the first pyrometallurgical experiments, including in due course the invention of skin bellows and the blast furnace. Liquid copper can be produced with blast furnaces, pottery, charcoal, oxidized ores, and skilful manipulation. Tin, with a melting point of only 232°C, can also be produced with similar equipment[8].

In the World

Copper and tin were the two most important metals produced by ancient man. Bronze, the alloy made from them, with a tin content of about 10 per cent or more, is tougher than copper and better for many practical uses. Bronze was so important and its use so widespread in ancient Europe and Asia that its name has been given to the period between man's use of stone tools and his later discovery of the arts of iron-smelting and smithing.

The coming of the Iron Age did not diminish man's interest in copper. In classical times, important mines and smelters were operated on Cyprus, known in Greek as Kupros, the island where, according to legend, sea-born Aphrodite came ashore. The Romans corrupted *Kupros* to *Cuprum*, and came to associate the metal with the island, whence the English word *copper* and the abbreviation *Cu* (not *Co*). The Greek word for copper, *khalkos*, is preserved in the names of several copper minerals.

The Roman goddess Venus also became identified with Cyprian Aphrodite, and her zodiacal sign, ♀, was later adopted as the alchemical symbol for copper. That symbol is still used today, e.g. in the logos of the Palabora Mining Company and the Copper Development Association, and on the indicator board of the London Metal Exchange.

During the first and second millenia, other important copper-producing centres were established in Europe and Asia. Copper was used widely, either alone or in bronze or brass, the last-mentioned being an alloy with zinc. The art of founding was developed to facilitate the production of bronze statuary, church bells, doors, and cannons.

The Industrial Revolution multiplied the uses of copper, and increasing demand stimulated a worldwide search for new deposits. Methods of production were improved, and international trade expanded.

It is quite remarkable that one of the first metals produced by primitive man possesses the properties essential to two of modern man's greatest technical achievements: the generation and transmission of electricity, and the transmission of information. In the middle of the last century, the world's production of copper averaged about 60 kt; in 1983, 6,1 Mt were produced by non-Communist countries alone.

In South Africa alone, about 80 kt of high-quality electrolytic copper is used annually for the production of conductors and high-quality tubing, and about 30 kt of lower-grade material and scrap for the production of alloys.

Two important organizations have been established to study the properties and promote the usage of copper. Thus, the International Copper Research Association, with headquarters in New York, sponsors research at various centres into the physical chemistry, metallurgy, and physical properties of copper and its alloys, and publishes definitive works on these subjects[9]. The Copper Development Association, which is represented in Johannesburg, 'encourages the use of copper, brass, and bronze and promotes correct and efficient application'. Among other things, it provides a telex link with a comprehensive Copper Data Centre established in the U.S.A.[10].

Most of the copper traded in the Western World outside the U.S.A. is priced according to the daily fixings on the London Metal Exchange (L.M.E.), either for immediate settlement or settlement at some future date. L.M.E. prices are quoted in pounds sterling per tonne[11].

In South Africa

In 1498 on his first voyage to India, Vasco da Gama landed at the mouth of a 'small river', possibly the Limpopo, on the east coast of Southern Africa. The copper armlets and other ornaments worn by the local people were so plentiful that he called it the Rio de Cabre — the River of Copper[12].

Two centuries later, Simon van der Stel, the Governor at the Cape, led a well-founded expedition northwards into Namaqualand. His instructions, from the Dutch East India Company, were to find the source of the ore samples and metal artefacts that had been brought to the colony by natives. The expedition was successful. The diary[13] Van der Stel wrote in 1685 was discovered in Dublin during the 1930s. It is probably the first technical report in the history of South African mining and metallurgy, and can be read with fellow feeling by modern professionals:

> The mountains were coloured from top to bottom with verdigris — giving the Honourable Commander and the foreman miner good hope — after work had been in progress for some time the latter expressed the opinion that there would be no result and lost heart. The Honourable Commander remained optimistic and pointed out the places where work ought to be started.
>
> On Tuesday the 23rd, the miners began work at two points and found themselves on an unusually wide vein. The deeper they dug the better the mineral appeared.
>
> Meanwhile the Honourable Commander sent out a number of men to see what timber and water there was in the neighbourhood. . .
>
> On their return they reported dry water courses . . . and an unknown kind of hard wood, whereupon several wagons were dispatched to cut wood for the purpose of making charcoal for smelting and testing samples, which wood was considered very suitable for the purpose.
>
> On Friday the 26th, the Honourable Commander began to build the testing and smelting furnaces which occupied him the whole day. Meanwhile the work in the excavations was diligently pushed forward.
>
> On Saturday, the 27th, the miners began to bore and fired the first charge, which was very successful, disclosing particularly good mineral.
>
> The Honourable Commander had some of it smelted to see if it was as good as it seemed, but it turned out to be still volatile, having lain too near the surface.
>
> On Monday the 29th, the miners fired two more charges disclosing excellent mineral. The Honourable Commander again decided to smelt samples and found that they contained copper.

The discovery was about 70 km from the west coast, but the absence of a good harbour and the remote and arid environment postponed development for about two hundred years.

In the 1840s and 1850s, this part of Namaqualand and the north-western Cape Province became the scene of South Africa's first mining rush, which was for copper, and not for diamonds or gold as is commonly believed. The event was accompanied by much company flotation and speculative fever. Although many ventures failed, the mining of copper ores and the production of metal became firmly established at O'okiep in Namaqualand[14], where operations continue to the present day.

Native mining and smelting first attracted Van der Stel to Namaqualand. It is now also evident that most of the other major copper deposits, as well as the tin and iron deposits of South Africa, had been found and worked by the indigenous people long before the arrival of Europeans. These native skills appear to have died out in the latter part of the nineteenth century, when superior European-made articles became available, but they remain of great interest to archaeologists[15,16]. Subsequently, the ancient excavations, furnaces, and slag heaps were discovered by Europeans.

Today, all three of South Africa's primary copper producers — O'okiep, Messina, and Palabora Mining Company — conduct their operations on the sites of native mines and smelters. In retrospect, it seems certain that the copper artefacts described by Vasco da Gama originated at the ancient mining and smelting sites of Messina and Phalaborwa, and were traded to the coast along the Limpopo and Olifants Rivers[17] (Fig. 1).

South Africa is not a major copper producer by world standards, and its annual output of about 200 kt in all forms is exceeded by eleven other countries. However, Palabora Mining Company, which in 1966 started operations in the eastern Transvaal, has developed one of the world's biggest open-pit mining and smelting operations. It is the first South African producer of electrolytic copper and can more than satisfy local demand.

The price of Palabora copper for local sale is known as the 'Republic Copper Price', and is fixed and published at the beginning of each calendar month as the equivalent in rands of the average cash settlement price on the L.M.E. for the preceding month[11]. Other transactions are related to the daily L.M.E. price converted at current exchange rates.

COPPER OCCURRENCES IN SOUTH AFRICA

South Africa's copper occurrences, which are not to be compared with the huge deposits in Zambia and Zaire, have been comprehensively identified and discussed by Hammerbeck and Schoeman[18]. Six of these occurrences have supported major operations (Fig. 1).

The producing companies are identified and classified below, and are described in detail in Part II of this review.

Producers of Concentrate

The following companies produce only copper sulphide concentrates for smelting elsewhere.

(1) Foskor operates on the Phalaborwa Igneous Complex in the Lowveld of the north-eastern Transvaal, and draws ore from the open-pit mine operated by the Palabora Mining Company.

(2) Prieska Copper Mines (Pty) Limited produces zinc, copper, and pyrite concentrates at Prieska in the north-western area of the Cape Province.

(3) Black Mountain Mineral Development Company (Pty) Limited produces copper, zinc, and lead concentrates at Aggeneys, in the Namaqualand Mobile Belt of the north-western Cape Province.

Secondary Producers

The following companies produce metallic copper as a byproduct of platinum and nickel production: Rustenburg Platinum Holdings Limited (a subsidiary of Johannesburg Consolidated Investment Company Limited), Impala Platinum Holdings Limited (a subsidiary of Gencor Limited), and Western Platinum Limited (a subsidiary of Lonrho).

Their operations are sited along a limb of the Merensky Reef near Rustenburg, part of this reef being located within the national state of Bophuthatswana.

Primary Producers

The following companies are equipped to produce metallic copper as their primary product, by pyrometallurgical means, from adjacent orebodies, which they own.

(a) The O'okiep Copper Company Limited, with mines, concentrators, and smelter in the late Pre-Cambrian area of Namaqualand in the north-western Cape Province, which was first explored by Van der Stel. O'okiep produces blister copper.

(b) The Messina Company, with mines, concentrator, and smelter situated about a 15 km fault running in a north-easterly direction across the Limpopo Mobile Belt of the northern Transvaal. Messina can produce fire-refined copper.

(c) The Palabora Mining Company Limited, on the Phalaborwa Igneous Complex in the Lowveld of the eastern Transvaal. Palabora processes its fire-refined copper into high-purity electrolytic cathode and continuously cast rod.

The three primary operations are located near the western, northern, and eastern frontiers of the country, and contribute greatly to local socio-economic development.

Processors of Scrap

In this context, it is appropriate to mention that about 20 kt of scrap copper is collected annually in South Africa for remelting and further processing.

Mining

In South Africa today, seven companies operate underground copper mines, and only one, Palabora Mining Company, operates an open-pit mine. The feasibility of either mining method is highly dependent upon local factors, such as mass of orebody, location, grade, form, and depth. When the development of newly discovered orebodies is considered, detailed comparative studies are usually made. For example, Black Mountain Mineral Development Company made such a comparison before adjudicating in favour of underground mining at Aggeneys.

Labour-intensive underground mining permits higher selectivity and entails lower ratios of waste to ore than open-pit mining. It is favoured when these features enhance profitability, or when copper alone or in association with other minerals occurs at depths or in forms that preclude open-pit mining. Stoping and hauling procedures are chosen according to local conditions.

Capital-intensive open-pit mining is favoured for large, near-surface deposits of ore. Generally speaking, ores with average copper grades that are too low for profitable underground mining can be exploited successfully provided that operations are conducted on a sufficiently large scale to achieve low unit costs. Open-pit design and operating procedures, relying heavily on the use of computers and practical equipment such as rotary drills, electric shovels, and high-capacity haul-trucks, have been developed during this century, largely at the instigation of copper-mining companies. Open-pit mining is comparatively unselective and entails much waste-handling (stripping)[19].

Some idea of the differences between underground and open-pit mining in terms of annual gross tonnages and tonnages per employee is conveyed by Table II, which gives production statistics for three South African companies in 1983.

TABLE II
PRODUCTION STATISTICS FOR 1983

	O'okiep*	Prieska*	P.M.C.†
Ore + waste, Mt	NA	NA	101
Ore treated, Mt	1,6	3,0	28,9
Employees	2855	3467	3944
Ore treated per employee, t	554	865	7739
Own Cu treated per employee, t	8,3	9,4	37,4
Own Zn treated per employee, t	NA	28,2	NA

*Underground mines
†Palabora Mining Company: open pit
NA = Not available.

Concentration

During the nineteenth century and the early part of the twentieth, copper ores were found and mined in massive form in the O'okiep and Messina districts. When concentration was necessary, gravity methods were used.

After the rich deposits had become exhausted and only lean, finely disseminated ores remained, the operations would have ceased permanently had it not been for the timely invention of the froth-flotation process. This process not only saved the old operations, but provided the

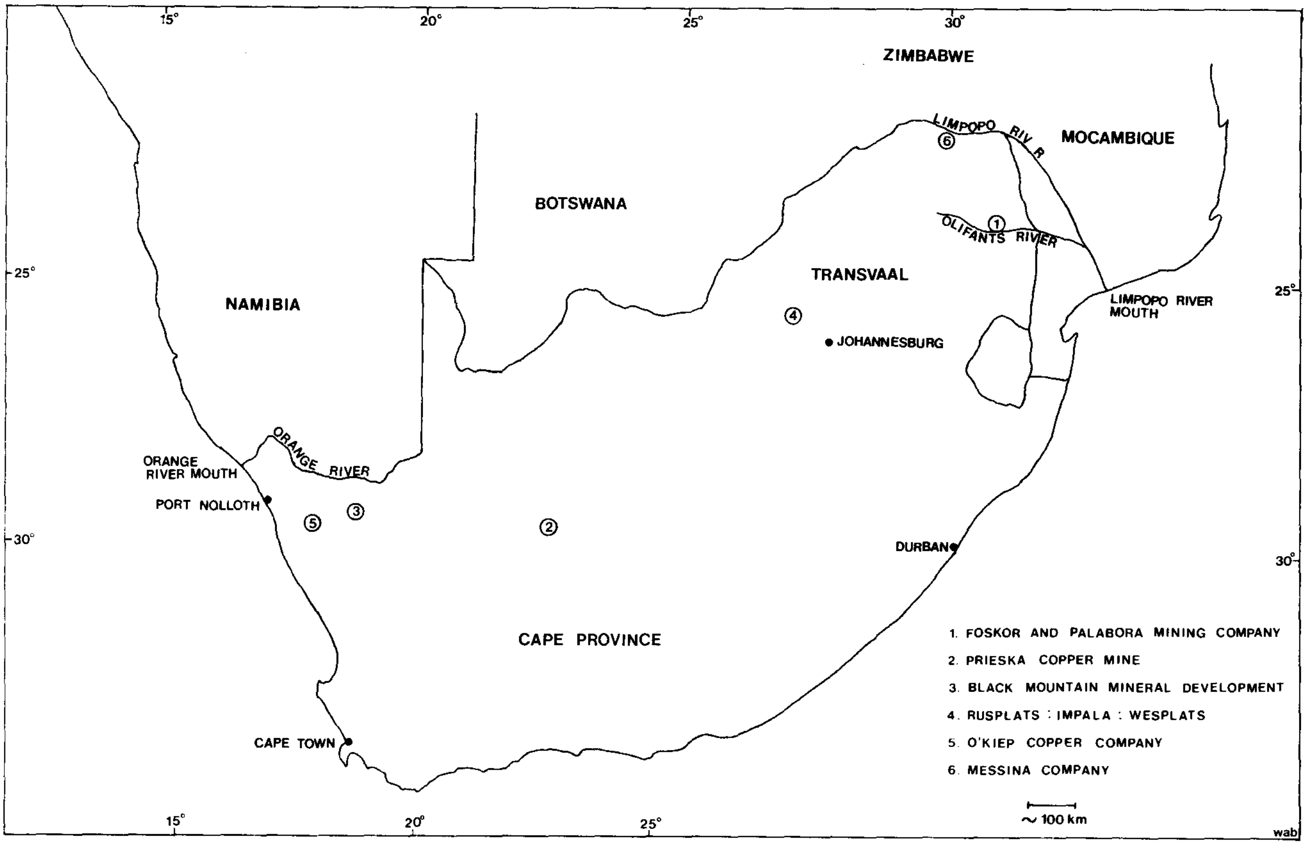

Fig. 1—Copper operations in South Africa

key to treasures in other lean base- and precious-metal deposits that would otherwise have been worthless. Today, froth flotation is the vital concentration process used by all eight companies mining copper-bearing ore in South Africa. Without it their operations would not exist, and the efficient control of flotation is, accordingly, an important responsibility of their managements.

The science, technology, and art of flotation are fascinating, and the literature on the subject is enormous; only an outline can be given here[20-23].

In the case of copper, the finely disseminated sulphides in an ore are first liberated from the barren matrix in which they occur. This is achieved by dry-crushing of the ore, followed by wet-grinding to produce a slurry in which the sulphide particles are suspended in water along with particles of barren gangue, which greatly outnumber them.

By the addition of certain chemicals to the slurry and careful control of the physicochemical condition of the liquid phase (the 'water'), the exposed sulphide surfaces are altered and 'waterproofed' so that, given the opportunity, they (and not the gangue particles) exchange contact with the liquid in favour of a more stable contact with air. If finely dispersed air bubbles are now distributed efficiently throughout the slurry, the sulphides are collected at their surfaces and are floated to the top of the vessel. These bubbles can be stabilized to form a persistent froth that traps the valuable mineral. The froth is then removed and condensed, and the valuable solids are recovered by thickening, filtration, and drying. Such finely divided solids are known as froth-flotation concentrates.

Flotation reagents fall into three main classes[22]:

(1) *collectors*, which render the valuable mineral water-repellent or hydrophobic,
(2) *frothers*, which facilitate the formation of dispersed bubbles and a froth of adequate surface and stability, and
(3) *modifiers*, which are divisible into three sub-groups as follows:
   (a) activators, which enhance the attachment of the collector to the valuable mineral,
   (b) depressants, which inhibit the flotation of gangue or minerals unwanted at that stage of the process, and
   (c) pH modifiers, which establish an optimal environment for collection, activation, or depression.

On operating plants, the preparation of flotation-plant feed, the reagents used, and the selection and manipulation of equipment and circuits are all matters for close and continuous professional attention. Copper recoveries of between 82 and 92 per cent are usually achieved, but, whatever they may be, the losses have to be explained and minimized with proper regard to recovery costs.

Attention has also to be given to the grade of the concentrates. Very careful control is required on flotation plants treating complex sulphides of copper, lead, zinc, and iron. The valuable metals are usually recovered separately in a sequential float, and it is important, and often difficult, to control the misplacement of a particular metal to the concentrate of another, which it might contaminate.

Extraction of Metal

Although in the past the O'okiep Company has recovered small quantities of copper from oxidized ores by leaching followed by precipitation of metallic copper with iron (cementation), the first step in all current South African operations is the recovery of a finely divided sulphide flotation concentrate from the ore. Some companies sell such concentrates in South Africa or abroad; others process them to the form of metal, together with any other concentrates that they have purchased or have contracted to process on a toll basis.

Copper flotation concentrates are then treated by recovery processes that involve pyrometallurgical operations as the first step. Copper sulphide minerals can be partially or completely roasted to oxide, and the oxides then reduced with carbon in the presence of fluxes to yield cupriferous black metal and ferruginous slag. However, such processes are not used in South Africa. Instead, skilful use is made of the relative stabilities of copper and iron sulphides and of copper and iron oxides in the presence of oxygen at high temperatures to operate a reduction process that does not require carbon.

A rational appreciation of these relative stabilities, and the ways and means of exploiting them industrially was evolved in the last century and the early part of this, especially at Swansea (Wales) and in the U.S.A. The recent development of thermodynamic theory and the accumulation of data have expanded and quantified the understanding of the reactions involved, and have facilitated the development of continuous processes not yet used in South Africa[1,2,24-26].

The processes and equipment used locally mainly reflect American and British developments. They entail a sequence of batchwise operations conducted in different units, with intermediate transport. They start with concentrate, involve the disposal of waste slags and sulphurous gases *en route*, and end with metal.

Smelting, or Production of Matte[27]

The sulphide concentrates, containing say 36 per cent copper and 21 per cent iron, are heated with a silica flux to about 1200°C or higher in reverberatory furnaces fired with pulverized coal or in electric furnaces. The copper and iron sulphides melt, reject sulphur, and compose themselves into cuprous sulphide and ferrous sulphide, forming a miscible liquid of low viscocity, called matte, with a density of about 4500 $kg \cdot m^{-3}$. The 'demand' by copper for sulphur has priority over the 'demand' by iron for sulphur; iron may oxidize, copper does not.

Any iron oxide formed reacts with the silica flux to form a slag with a density of about 3700 $kg \cdot m^{-3}$, which then collects other gangue oxides and floats to the surface of the matte, with which it is immiscible. The viscosity of this slag is kept low to facilitate disengagement of entrained globules of matte. It is skimmed from the surface of the matte and transported to disposal areas. Some sulphur joins the furnace gases as sulphur dioxide. The matte, now containing about 49 per cent copper, is tapped from the furnace and transferred to the converters.

Converting

Peirce–Smith converters, are used on several South African plants, are unfired basic-lined horizontal steel cylinders with a mouth and rows of air-fed tuyères along one side. The vessel can be rotated so as to receive feed or to discharge part or all of its liquid contents through the mouth, and also to vary the submergence of the tuyères.

The purpose of converting is to decompose the liquid sulphides of the matte, transferring iron as oxides to a siliceous slag, and sulphur as sulphur dioxide to an off-gas. Once this has been accomplished, only liquid copper, with residual sulphur and oxygen, remains. The conversion of matte to copper is achieved in two distinct steps.

In the first, the 'slag blow', ferrous sulphide is decomposed as air is blown through the matte and silica flux:

$$2\ FeS + 3\ O_2 \rightleftarrows 2\ FeO + 2\ SO_2.$$

The reaction of ferrous sulphide with oxygen takes priority over the oxidation of cuprous sulphide. Iron is oxidized to ferrous oxide and some magnetite, although the operations are controlled so as to restrict the latter. The ferrous oxide reacts with the flux to form an immiscible slag, which entrains some magnetite and, unfortunately, about 4 per cent copper in the form of matte globules. This slag is recycled to the matte furnace so that copper can be recovered.

Most of the sulphur joins the off-gases as sulphur dioxide, from which, depending on local circumstances, sulphuric acid can be produced. Lead, arsenic, tin, and antimony, if present in the matte, also largely report to the off-gas as oxides.

When the ferrous sulphide has been eliminated, cuprous sulphide (white metal) remains. As will be explained, some South African platinum-mining companies terminate their pyrometallurgical operations at this point, and cast a so-called converter matte, which is rich in nickel and copper.

The second step in normal operations involves further blowing, 'the copper blow,' with the tuyères set just below the surface. Because the reaction of cuprous sulphide with oxygen proceeds vigorously and takes priority over the reaction of copper with oxygen, metallic copper is formed and remains unoxidized, or is reduced so long as any cuprous sulphide is present:

$$Cu_2S + O_2 \rightleftarrows 2\ Cu + SO_2.$$

The oxidation reactions just described are sufficiently exothermic to permit, and require, scrap and recycled copper from various sources to be remelted within the converter, maintaining the temperature therein at 1225 to 1250 °C. The metallic copper is immiscible with the white metal and is denser. It therefore sinks to the bottom of the vessel and away from the higher zone in which oxygen and cuprous sulphide are reacting.

Blowing continues into the cuprous sulphide layer until it has been eliminated, care then being taken, by reference to flame temperature and colour and to the appearance of small samples, that an unacceptable degree of copper oxidation is avoided. At the end of a successful blow, about 0,5 per cent oxygen and 0,05 per cent sulphur remain in the copper.

On solidifying, these elements react to liberate sulphur dioxide, which causes internal porosity and irregular surfaces on the casting. Accordingly, this converter product is known as blister copper. Some companies, such as O'okiep, terminate their operations with blister copper and then sell it to others for the necessary further refining prior to its industrial use.

Fire-refining

If the blister copper produced in the converter is not cast and sold to others, it is transferred immediately in the liquid state to a fire-refining furnace. Fire-refining has two purposes, the first being chemical; that is, to further remove sulphur and any remaining iron, zinc, lead, and tin. The second is physical; that is, to adjust the oxygen and hydrogen contents of the purified copper to levels that facilitate the production of dense castings with smooth surfaces.

Fire-refining proceeds in two steps: blowing and poling. During blowing, air is injected into the bath through hand-operated steel lances, agitating it and oxidizing the residual sulphur to sulphur dioxide, and some copper to cuprous oxide. In the second step, the cuprous oxide is reduced back to metallic copper by the forcing of wooden eucalyptus logs beneath the surface. The carbon of the wood and its distillation products agitate the bath and reduce much, but not all, of the cuprous oxide to metal. After this stage the concentration of sulphur in the copper has been reduced to about 15 g/t, and the oxygen concentration to about 1500 g/t.

If blowing and poling are managed correctly, dense castings with a good, regular, level surface can be produced from the refined copper. If not, residual gases (oxygen and hydrogen) form cavities and blisters in the solidifying metal, or else cause it to 'spew' irregular excrescences[9]. The process is controlled by skilled operators, who take a series of small samples and examine their physical condition when solidified.

In South Africa, the Messina Company has for many years produced and sold good-quality fire-refined copper.

Electrolytic Refining

For electrical purposes, copper with the desired properties and the necessary purity can be produced only by the submission of fire-refined copper to an additional process — electrolytic refining. An incidental benefit of electrolytic refining is the recovery of any precious metals contained in the copper. Palabora Mining Company operates a large electrolytic refinery.

If the fire-refining has been controlled correctly, rectangular anodes with smooth surfaces and of precise and regular dimensions can be cast on a large rotating wheel fitted with heavy copper moulds. Electrolytically refined copper is then produced from these anodes.

The anodes are suspended in a solution of copper sulphate and sulphuric acid, a short distance away from a thin sheet of pure copper — the cathode — and a constant voltage is applied. The cupric ions in the solution migrate to the cathode, combine with electrons, and are deposited as coherent metal on the cathode. At the anode, a corresponding quantity of copper dissolves and ionizes, the net effect being a migration of copper from anode to cathode. As no compounds are decomposed, the power consumption is low — about 250 kW·h/t. Nickel and other impurities in the anode enter the solution or are deposited as a sludge on the floor of the cell, but are not transferred to the cathode.

The high-purity cathodes so produced are subsequently melted with sulphur-free fuels in furnace atmospheres so controlled as to maintain the residual oxygen content at about 200 g/t. The casting behaviour, ductility, and electrical conductivity of such 'tough pitch' electrolytically refined copper renders it highly suitable for the production of electrical conductors.

Electrowinning

As indicated above, the platinum-mining companies in South Africa produce a converter matte containing nickel and copper sulphides among other things. The nickel and copper are not recovered from the matte by pyrometallurgical means; instead, the matte is dissolved and treated in various ways, one purpose being the production of a purified solution of copper sulphate. The copper is then recovered from this solution by electrowinning, i.e. by electrolysing it in much the same way as in electrorefining, except that the anode is non-consumable and made of antimonial lead. As in electrorefining, cupric ions in the solution migrate to the cathode and are deposited there.

However, the anode reactions are quite different; apparently sulphate ions migrate to the anodes, and react with water to form sulphuric acid and liberate oxygen. Thus, whereas in electrolytic refining copper is merely transported from anode to cathode through a sulphate solution, in electrowinning copper is deposited at the cathode by the decomposition of cupric sulphate in addition to which other chemical reactions occur at the anode. These additional reactions consume energy. As a result of this and other factors, the power consumption is much higher than in electrorefining, i.e. about 2200 kW·h/t as against about 250 kW·h/t.

For various reasons, electrowon cathodes are rarely as pure as electrorefined cathodes, and they tend to be used for mechanical rather than electrical applications.

OPERATIONS OF SOUTH AFRICAN COMPANIES

The operations of the nine main copper-operating companies in South Africa are described in Part II of this review (April 1985 issue of this *Journal*).

ACKNOWLEDGMENTS

The writer thanks the many friends and colleagues in the local industry, libraries, and associations who provided him with valuable advice and assistance. He also thanks Rio Tinto South Africa Limited for the opportunity to prepare this paper and for permission to publish it.

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Gold 100

Gold 100, an International Conference on the Mining, Extractive Metallurgy, Industrial Uses, and Economics and Marketing of Gold will be held in Johannesburg from 15th to 19th September, 1986. The Conference is being planned to coincide with Johannesburg's centenary celebration.

The Conference will be organized jointly by
The South African Council for Mineral Technology
The School of Business Leadership, University of South Africa
The South African Institute of Mining and Metallurgy
in association with
The Johannesburg Centenary Festival Association
The Electra Mining Exhibition.

Technical papers on recent advances and modern trends, as well as papers of a review nature, are invited on the following topics.

Extractive metallurgy of gold
- Grinding and concentration
- Sampling and assay practice
- Leaching
- Recovery with carbon and resins
- Refractory gold ores
- Refining

Mining technology
- Valuation and gold distribution, and its effect on gold-mine design
- Stoping technology
- Environmental control
- Ground control
- Transport and hoisting
- Alluvial methods of gold mining

Economics and marketing of gold
- Gold and world liquidity
- Gold producers' viewpoint
- Evolution of markets and intermediaries
- Industrial demand for gold
- Gold as an investment medium—its position in the modern portfolio

Industrial uses of gold
- Gold in electronics
- Gold in dentistry and medicine
- Decorative uses
- Jewellery
- Other industrial uses.

The language of the Conference will be English. Deadline dates are as follows:

Titles and synopses (maximum 200 words)	1st August, 1985
Extended abstracts	1st December, 1985
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