The Evolution of Early Copper Smelting Technology in Australia

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PART I

This paper describes some changes in the technology employed to smelt copper in Australia from the industry's origins in the mid-nineteenth century until the First World War. As case studies, it examines seven smelters built between 1847 and 1909 and looks at the physical evidence found on these and other Australian copper smelter sites today.[1]

Copper

Copper mining has been carried out in Australia continuously since 1843, and for most of that 167 years it has been an industry of major economic significance. The distribution of economic copper ores and thus of successful mining throughout Australia however is very uneven, with the bulk of production coming from a few widely-separated operations. The largest Australian copper producer is Mount Isa which has now produced about seven million tonnes of copper metal, but only commenced copper smelting in 1943, long after the historical period covered in this account. Mount Lyell in Tasmania was the only early producer to smelt over a million tonnes, and three other major deposits at Mount Morgan in Queensland, Cobar in New South Wales and Moonta/Wallaroo in South Australia each produced less than a million tonnes of metal. The scale of the modern industry is much greater: Olympic Dam is already the second-largest Australian producer, approaching three million tonnes after 22 years of production.

The first copper deposits discovered, and economically the most significant throughout the nineteenth century, were those in South Australia. The amazingly rich Burra mine first put Australia on the world mining map, but was closed in a little over thirty years and later overshadowed by the much larger deposits at Moonta and Wallaroo Mines which remained in production from the 1860s to the 1920s. A host of other small copper deposits were also worked in the surrounding ranges. Up to 1907, South Australia had produced 53 percent of Australia's copper.[2] The Northern Territory, which was part of South Australia to 1911, produced copper at half a dozen small mines in its highly mineralised northern half. New South Wales (19 percent to 1907) and Queensland (11 percent) have a similar pattern of small copper deposits widely dispersed throughout the eastern highlands, with a number of extremely rich gold-copper deposits such as Cobar, discovered in the 1880s, and Mount Morgan, which only became a copper producer in the early twentieth century. Both remained in production until recent decades. Besides Mount Isa, the remote north western ranges of Queensland also hosted the Cloncurry copper field, which boomed when the copper price rose during the first World War. Tasmania is virtually devoid of significant copper deposits except for the extraordinary Mount Lyell that also began life as a gold mine in the 1880s, to become a major copper mine at the turn of the century (15 percent to 1907). Victoria had only about two copper mines of any note, and Western Australia about four (under 2 percent total for the two states to 1907).

Smelting Technology

In the mid-nineteenth century, smelting was the process most commonly used to separate copper metal from its ore. Successful smelting requires two things to happen: chemical reactions free the copper metal from the compounds in which it occurs naturally, and the copper's temperature is raised to melting point. The higher density of the metal then causes it to separate from the lighter rock in which it is found. It is rarely sufficient simply to heat the ore in air; almost always other material must be provided both to join in the reactions which free the metal from the ore, and to lower the melting temperature of the mixture. This additional material is called flux. Thus the three essential materials for any smelting process are ore, fuel and flux.

It was usually necessary to prepare the ore before smelting. Most mines crushed and screened the ore to a uniform particle size, which might be anything from the size of fine sand grains up to fist-sized, depending on which smelting process was to be used. There was usually an attempt to concentrate the ore, that is, to discard the waste rock. This could be as rudimentary as the traditional Cornish process of having retired miners and young boys - ‘picky-boys’ - manually removing pieces of barren rock from ore-floors and in later years from conveyors. Later various kinds of jigs and buddles were used to separate the metal compounds by exploiting their higher density, and by the turn of the twentieth century many large mines were fine-grinding their ore and concentrating by means of shaking tables and flotation tanks.

Besides these physical processes, some ore required chemical preparation before smelting. Much copper was mined in the form of sulphides, which presented difficulties in early smelters. These sulphide (or pyrite) ores were usually roasted by heating them in a furnace at relatively low temperature for a time to oxidise the sulphur before smelting.

After the smelting process proper, the copper did not emerge as metal, but as a hard black mixture of copper, copper sulphide and ferrous silicate, containing about 40 to 60 per cent metal and known as matte. In a small outback smelter, that was usually the end of the process, and the matte was sent off to a more sophisticated smelter for refining, which in the mid-nineteenth century meant smelting it again under more precisely controlled conditions. By the turn of the twentieth century, converters were added to the process. A copper sulphide ore might go through four different kinds of furnaces for roasting, matte smelting, converting and refining before it was recognisable as copper metal. Later, electrolytic plants replaced furnaces for refining.[3]

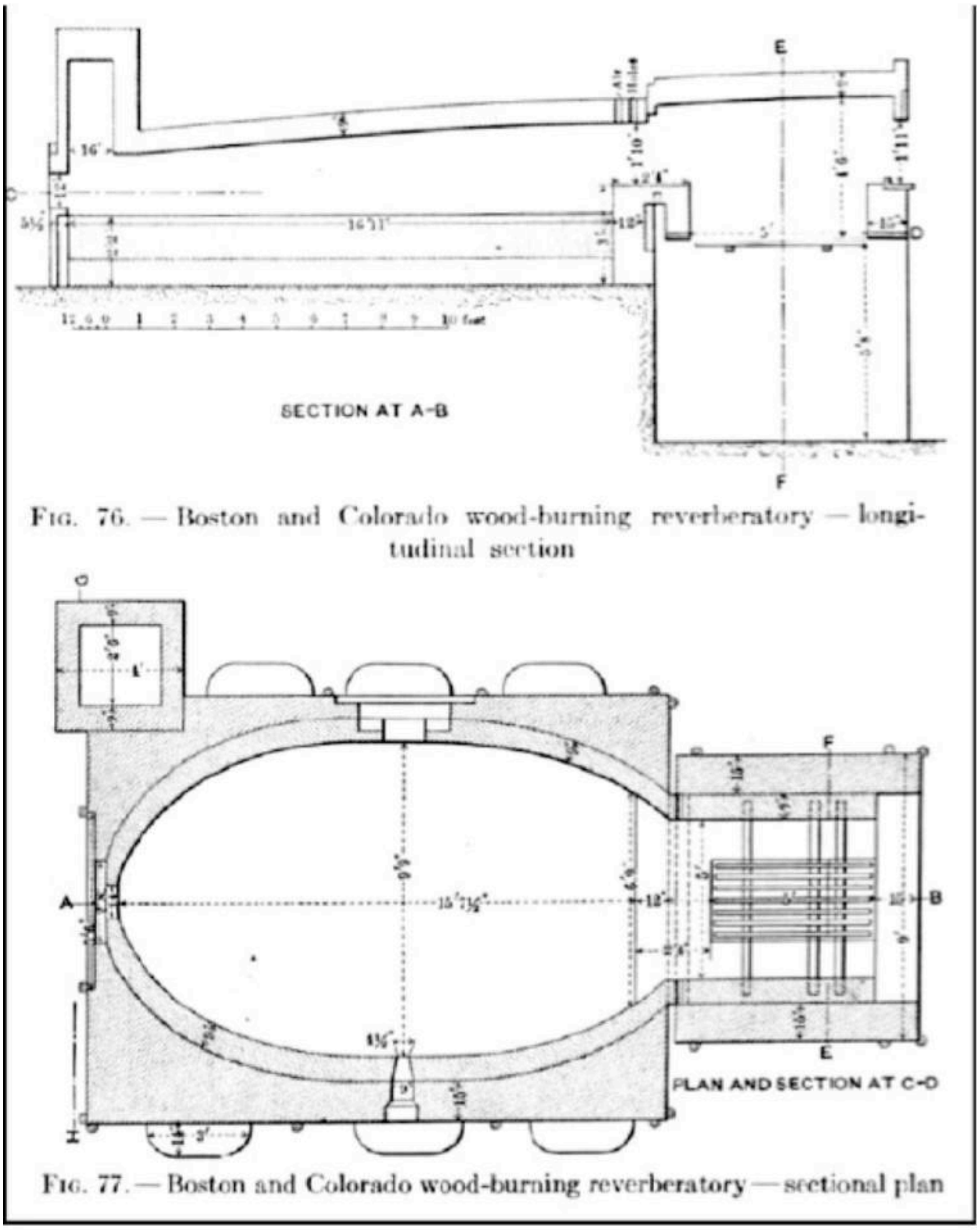
When base metal mining commenced in Australia in the 1840s, Cornwall was the principal source of underground mining expertise, and Cornish methods were enthusiastically adopted, and dominated the copper mines of Australia until the 1920s. However, opinion on the best model of smelting technology was for a time divided between the reverberatory furnaces of Wales and the blast furnaces of Germany (A listing of copper smelters built in Australia to 1918 will be presented as an appendix in Part II of this article).

Reverberatory Furnaces

Australia's first copper smelter was built at Burra in 1846-47 by Georg Ludwig Dreyer and his son, experienced smelter builders from the Harz Mountains.[4] There is no detailed description or illustration of it, but we know exactly where it stood, and there are some enigmatic traces remaining on the site. We should also know exactly what it looked like, because in 1849, Samuel Thomas Gill sat down in a sheep paddock and did two lovely detailed watercolours of the Burra mines, showing the Dreyer's old blast furnace still standing in the background and the newly-built Welsh reverberatory furnaces in the foreground. But in both depictions, Gill faithfully recorded all the billowing black smoke from the Welsh smelter stacks, almost completely hiding the German one.[5] It was described as a hot blast furnace, its air provided by bellows made by an Adelaide organ-builder and powered by a two-horse whim. Agricola would probably have recognised it as very like an illustration from *De Re Metallica*, and it appears to have been built against a masonry wall, like the smelters Agricola illustrates.[6] The Dreyers' smelter was a failure; it produced a quarter of a ton of copper, but at greater cost than freighting the ore to Europe for smelting.[7]

It was not a good beginning for those of the German persuasion. The South Australian Mining Association responded to this setback by continuing the orthodox practice of shipping the ore to the experts in Swansea, but they realised it made more economic sense to bring the experts to Burra. The second smelter at Burra two years later was a classic Welsh reverberatory, built by Thomas Williams of Swansea and first fired in 1849.[8]

Figure 1: *Section and plan of a Reverberatory Furnace.*



Source: E.D. Peters, *The Practice of Copper Smelting,* McGraw Hill, New York, 1911, pp. 391-92.

A reverberatory furnace is essentially a masonry hearth with a roof over it. Copper ore which has been finely crushed and concentrated is mixed with flux and spread on the hearth, and an intense fire is lit in a firebox at one end of the furnace so that the flame passes over the charge on its way to the flue. The charge is heated by a combination of direct radiation from the flame, heat reflected (or reverberated, in nineteenth century terminology) and focused by the vaulted roof, and radiation from heat stored in the masonry. There is relatively little opportunity for chemical reaction between the charge and the combustion gases, and reactions in a reverberatory furnace are principally those that occur between ore and flux, hence the need for both of these substances to be finely divided and well mixed. In nineteenth century practice, the furnace was fired for up to twenty-four hours, then the fire was drawn and the matte and slag were tapped from separate openings at different levels on the side of the furnace. After any necessary repairs were made to the furnace, a new charge was shovelled in and the cycle recommenced.

The process of alternately heating and cooling a masonry structure is very damaging, and reverberatory furnaces had a high proportion of down-time, constantly needing repairs to minor or major damage brought about by thermal expansion and contraction, corrosion of brickwork by matte and slag, or even fusion of the bricks. Skilled bricklayers and good quality firebricks were crucial to the durability and efficiency of a reverberatory furnace, and both were in short supply in Australia. The vaulted ceiling of a reverberatory was its weakest point, and several promising copper prospects in the Australian bush came to an abrupt end as the company's expensive new furnace roof collapsed in a fiery shower of molten slag.

The cost of refractory bricks was a serious impost on any smelting operation, as good quality ones were generally imported from the British Isles. Bricks with brand names such as Clackmannan, Cowen, Dougall, Gartcraig and Glenboig are found on mine sites all over Australia. Even as late as the turn of the twentieth century imported firebricks cost £11 per thousand at the wharf and Australian made, £5 or more per thousand.[9] But in earlier times and more remote locations the added cost of transport could raise the price tenfold; in 1865 the Thomson River company paid 2/6d each, or £125 per thousand, for firebricks at its Gippsland smelter.[10] To illustrate the scale of the expense involved in importing firebricks, a large smelter such as Wallaroo could require as many as 10,000 refractories a month for repairs and rebuilding.[11] The few copper mines such as Burra which had good quality fireclay in their local district were very fortunate.

The ascendancy of the reverberatory furnace created a class of expert Welsh metallurgists and smelter hands who, like their colleagues the Cornish captains and miners, were indispensable to the copper mining industry for several decades. The brothers Charles and Mauris Thomas from Cornwall have been traced through a career during which they built and managed copper smelters at Bremer in South Australia, Newcastle in New South Wales, Peak Downs in Queensland and Cobar in New South Wales again between 1848 and 1877.[12] These were decades in which the technology of smelting was a craft rather than a science, learned on the job by trial and error and experience.

Waterjacket Blast Furnaces

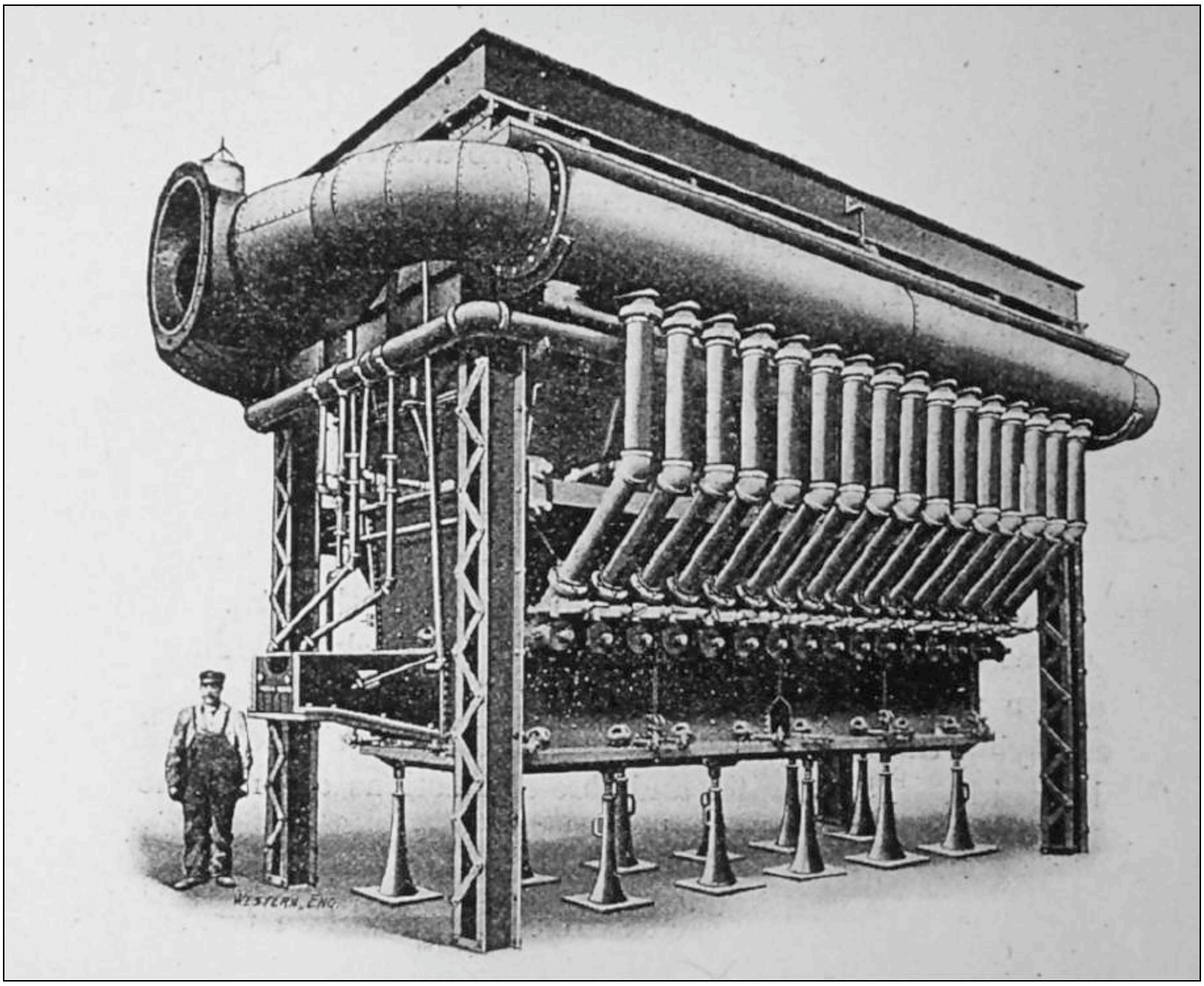
There were a few experiments with blast furnaces from the earliest days of copper smelting in Australia. We have seen that the first smelter at Burra was a hot blast furnace of German design, but cobbled together out of locally made parts. A few years later another hot blast furnace was built at Yatala, now in the suburbs of Adelaide, apparently consciously modelled on an English iron-smelting furnace.[13] Neither lasted long. The success of the Welsh reverberatory in smelting the early discoveries of rich carbonate ore suited the industry's needs, and for most of the period from 1850 to 1890 it was virtually unchallenged throughout Australia.

The mid-1880s saw a resurgence of the German cupola or blast furnace, with examples being built at Cloncurry in Queensland and Cobar and Lake George in New South Wales. There were problems in the design of blast furnaces: the power needed for the blowers, the tall and inherently unstable form, and the need for the charge to be of a large particle size and sufficiently stable to support its own weight. The most intractable problem was the intense heat to which the bricks were subjected during the blast smelting process, for the furnace's temperature could rise well above copper's melting point of 1,080°C, perilously close to the melting point of many bricks. During the 1880s this problem was being solved by metallurgists in North America.

The United States had become a leader in the international copper smelting scene in the years since the industry began in Australia. In 1850 the USA produced barely 1 per cent of the world's copper, but this grew steadily during the second half of the nineteenth century as large copper deposits were opened up in Michigan, Montana and Arizona, so that by 1900 the USA led the world with 60 per cent of total production. Nearly half of that output came from just three smelters operated by the Anaconda, Boston & Montana and Calumet & Hecla companies.[14] This expansion had been achieved by tremendous technical progress, and in those fifty years metallurgy had matured from a craft to a science. The American ascendancy was characterized by vertical integration of the copper industry and technical mastery of new techniques for smelting low-grade sulphide ores, both achieved at Swansea's expense.[15]

The Americans took the German cupola furnace as their starting point. From the mid-1870s there were experiments in the USA to control the temperature of blast furnace walls by the use of waterjackets, in much the same way as a radiator is used to cool an internal combustion engine.[16] At first these were metal additions to shield the hottest zones in brick furnaces, but soon whole furnaces were being made as iron castings incorporating a waterjacket in their walls, and as they grew in size they were later fabricated of steel plate.[17] By the early 1890s the tall rectangular all-metal waterjacket blast furnace had reached its mature form[18] and for the next two decades the world would turn to America for copper smelting know-how.

Figure 2: *Waterjacket Blast Furnace.*



Source: E.D. Peters, *The Practice of Copper Smelting,* McGraw Hill, New York, 1911, p. 152.

Many Australian miners were following these new developments, but needed an economic incentive to adopt them. That came with the rising copper price later in the century. In 1885 there was a plan to build a waterjacket furnace at Blinman in South Australia, but nothing eventuated.[19] Australia's first waterjacket copper furnaces were probably the two small (50 ton) cylindrical furnaces erected at Cloncurry in 1885, ushering in the new era.[20] Another was erected at Cobar in 1893.[21] The new furnaces were American-designed, and indeed the first generation of them were probably imported from the USA, although they were being produced in Australian foundries within a few years.[22] The waterjacket furnace was utterly different in appearance from the reverberatory. It was a tall box, usually rectangular in plan and supported by a steel frame. The charge was loaded at the top, and slag and matte were tapped at the bottom; both processes were normally carried out while firing continued. It was surrounded by pipes - large ones carrying the air blast from mechanical blowers, and smaller ones carrying the cooling water that circulated through the hollow steel jacket. The manufacturers supplied the furnaces in modular parts, so they could be made larger by bolting on a new end section.

There were three features which endeared waterjacket furnaces to company directors. First, they were relatively light and portable; they could be taken anywhere and bolted together according to an instruction book. Although they still used firebricks, their demand for them was slight in comparison with the tons of masonry that made up a reverberatory. Second, they were durable. Their waterjacket cooling and robust steel body made for very little down-time, unlike reverberatories they worked continuously, and in competent hands they could be fired for years without ever cooling down. Third, they were far more forgiving about their charge than reverberatories. Their chemistry was fundamentally different in that the fuel and air blast actively participated in the process, so that previously intractable sulphide ores could successfully be oxidised as part of the matte smelting process.

On the other hand, blast furnaces needed their ore, fuel and flux in large particle sizes, and were clogged by dust. As all crushing processes produce a proportion of fines, this presented a problem. Blast furnaces were wasteful, for they blew a proportion of the charge, including the copper, up the chimney as gas and dust. The air blast was extremely powerful; for every ton of ore that was loaded into a blast furnace, two tons of air would be blown through it during the smelting process.[23] Soon canny smelter managers began erecting dust traps on their flues and briquetting the dust for re-smelting; at Wallaroo, the flue dust could yield 230 tons of copper metal in a year.[24] Coke was the best fuel for blast furnaces because it could stand the weight of the charge above it without crushing, but in many parts of Australia coke was prohibitively expensive. Not surprisingly, reverberatories continued to be built in approximately equal numbers to blast furnaces, and remained in use alongside them for specific smelting tasks at many Australian copper smelters. While the great era of the blast furnace was from about 1896 to 1918, they never achieved the dominance that reverberatories once had. Nor had the design of reverberatory furnaces stood still in the fifty years since they first appeared in Australia. Scientific research into fuels and fluxes, more efficient crushing and concentrating machinery and better quality refractories had given them much greater size and sophistication, transforming them an order of magnitude in scale from the twelve feet long designs of the 1840s to 120 feet long by the First World War.[25]

The blast furnaces' ability to oxidise sulphide ores made some of them very economical of fuel, because the energy released by the oxidation process contributed to the heat required for smelting. In 1895 a smelter in Newfoundland achieved pyritic smelting, in other words smelting entirely by means of the heat generated by the oxidation of sulphur in the ore: using the ore itself as fuel.[26] All over the world smelter managers were galvanised into experimentation. The little smelter at Gulf Creek in New South Wales went over to partial pyritic smelting in 1901, and cut its fuel down from 10 percent to 2.5 percent of the ore charge.[27] In 1902 Robert Sticht, superintendent of the Mount Lyell smelters in Tasmania, repeated the North American precedent with his sulphide ores, and put pyritic smelting into large-scale commercial practice.

There is a legend in Australian mining history that Mount Lyell started successful pyritic smelting when it opened in 1896, and retained the technique in use for the rest of the smelters' life - a legend that Sticht's own writings did nothing to contradict.[28] In fact it took him (and a team of collaborators) six years of experimentation to get it right, and they soon found the consequent fuel saving was not worth the constant strain the technique placed on metallurgists and charge hands. Within a year or so, Mount Lyell was running as a partial pyritic smelter and this practice was adopted more widely, wherever high sulphide ores were treated. Chillagoe experimented with pyritic smelting in 1903, and while the results were disappointing, seems to have had a relatively low fuel consumption thereafter.[29] Cobar went over to partial pyritic smelting in 1905.[30]

The waterjacket blast furnace was extremely versatile. Large smelting companies built monster furnaces with capacities of hundreds of tons per day, but manufacturers also provided small portable cylindrical furnaces with capacities of five or ten tons. In the copper boom of the early twentieth century, great numbers of these were erected on remote sites throughout Australia. Their cheapness and portability probably encouraged production at many small copper shows that would never have repaid the cost of transporting ore out to an established smelter. ‘Every miner his own smelter’ became as appropriate a slogan in Australia as in the USA.[31]

That boom at a time when Australia was producing about 5 to 6 percent of the world's copper saw the country's greatest upsurge in copper smelter construction. In the eleven years from 1898 to 1908 there were about 65 copper smelters built throughout Australia. That was about the same number that had been built in the previous fifty years 1847-1897. This boom ended with the great copper price crash of 1907. The London copper price, which had been riding high since the turn of the century, abruptly plunged by 45 percent in the course of the year, from £112 per ton in March to £98 in June, and £62 in December. This was well below the cost of production in many base metal mines, and copper mines and smelters closed all over the world. In the remaining ten years to 1918, fewer than 20 smelters were built in Australia, nearly half of them by the companies of the Cloncurry copper field.

Converters

Copper converters were adapted from the Bessemer converter of the iron industry. They evolved out of experiments in both Europe and the USA, and were in full production in Montana by the turn of the twentieth century. The converter takes as its charge the molten matte from the furnace and a silica flux. A powerful air blast is blown through the charge for a few hours, converting copper sulphide to blister copper with a metal content close to 99 percent, and a slag which is mostly ferrous silicate. Converters were only suited to a few large smelters in Australia, but they were quickly adopted at these. Sticht commenced converting at Mount Lyell in upright Stallmann converters in 1897, but the preferred form at most Australian smelters was the cylindrical or barrel converter, which required less air pressure and blew through the matte layer without disturbing the reduced copper below it.[32] The first barrel converters in Australia were probably those installed at Chillagoe in 1904, although it was another five years before the company bought blowers powerful enough to produce true blister. The first converters in New South Wales were at Blayney in 1908.[33] Wallaroo installed them in 1910 and Cobar had them by 1912.

Figure 3: *Pouring copper ingots from a converter, Wallaroo.*

Source: Primary Industries and Resources South Australia, N010755.

Fuel

According to all the textbooks, copper smelters use coke as fuel. However in Australia, while coal is widely distributed throughout much of the eastern part of the country, very little of it is suitable for coking. The best coke available came from Newcastle in New South Wales, and most smelters in the country were a very long distance from an economic supply. As a result, smelting practice in Australia used coke when it was available, but also burnt coal, charcoal and firewood when necessary. In 1849 a Mr Penny of London patented a smelting process which used 'leaves, chips of wood, charcoal, or other carbonaceous matter', and this unorthodox fuel was said to have been used by his brother in the reverberatory furnace at Apoinga in South Australia.[34]

Fortunately most of Australia is blessed with abundant native hardwood forests which make excellent firewood. A number of species of Eucalypt and Acacia trees produce dense high energy fuels which could be harvested in close proximity to many smelters. Thus a large proportion of Australia's copper, particularly in the smaller and more remote smelters, was smelted with firewood as fuel, or at least supplementing the fuel. Some smelter managers preferred firewood to coke in reverberatory furnaces because of its long hot flame.

The legacy of this era is a landscape denuded of trees around many former copper smelting sites. Its clearest and most spectacular evidence is the bare mountainsides around the Mount Lyell smelters, where a combination of tree felling for fuel, the toxic sulphur dioxide from the pyritic furnaces, wildfires, and high rainfall on steep slopes has eroded the entire landscape for kilometres around back to bare rock. More gentle is the Burra landscape, where within two years the smelters consumed all the trees on the company's freehold.[35] This was grazing country, and nibbling sheep have prevented regrowth to this day, over 140 years after the smelters closed. The trees begin again at the boundary of the company's land.

Slag

The principal product of a copper smelter is not copper, it is slag. Smelting students were taught that they should seek to produce an ideal slag, and the metal would look after itself. For every ton of copper metal that a mine produced in the nineteenth century, typically five to ten tons of molten slag were poured onto a slagheap.

Slag is typically composed principally of ferrous silicate, with silicates and oxides of calcium and aluminium. Its characteristic black colour is mostly caused by iron oxides. In theory the slag should represent the reaction products of the flux and the waste rock in the ore, with the economic metal removed, but in practice as much as 2 percent metal may remain. There is often a peacock sheen of copper on pieces of smelter slag, and an old slagheap sometimes begins to develop a malachite green patina as copper carbonate forms on its surface.

We usually know far more about the slag that a smelter produced than the copper. After being refined and alloyed the metal may remain in use for centuries, but is unidentifiable. Only occasionally does the metal product of a smelter survive in recognisable form, and then usually as the result of a wharf accident or a shipwreck. Intact copper ingots marked 'Wallaroo' have been found by divers beneath the Wallaroo wharf, apparently dropped during loading.[36] The steamship *Admella* struck a reef off the South Australian coast in 1859 with a shipment of copper belonging to the Kapunda Mining Company, and copper ingots stamped 'Kapunda' have been recovered from the wrecksite.[37]

In contrast to the vanished copper, the slagheaps are perhaps the most durable works of human hands on the Australian continent. In the early decades of copper smelting, slag was simply poured onto a heap and allowed to cool and solidify into a solid mass. By the late nineteenth century the larger smelters that were close to their mines, such as Wallaroo and Mount Lyell, were granulating the slag by pouring it into water and trucking it back down the mine as fill. These have left only very modest surface evidence of their monumental slag production. A few slagheaps have since been re-worked for their metal content, mined for use as building materials or crushed into sand for grit-blasting. But in remote areas of Australia, some of the slagheaps associated with early copper smelters survive little altered. Not yet showing a trace of erosion and shunned by vegetation, they appear on aerial photographs like great black inkblots, monuments to industrial processes and environmental attitudes which have both vanished.

Case Study 1: Burra

The Burra Burra copper deposit was discovered by a shepherd 140 kilometres north of the young town of Adelaide in mid-1845, not the first copper discovery in South Australia but the most significant to that time. The South Australian Mining Association which acquired it was a hopeful syndicate which had been in search of a mine; in that era before mining leases were invented they were horrified that the new colonial government required them to buy 10,000 acres of freehold land at £1 an acre before they could begin mining the copper! It was among the most profitable investments in Australian history. The mine paid them £800,000 in dividends; for the eighteen consecutive years from 1847 to 1864 it returned shareholders between 200 percent and 800 percent of their initial investment in every year.[38]

The source of this wealth was a geological freak, a 'bubble of copper' unlike anything else found in Australia: oxidised copper carbonate ore with negligible sulphide content, averaging from 40 to 50 percent copper with patches up to 70 percent, outcropping as a great shallow mass. It was easy to mine and easy to treat. If a Cornish miner and a Welsh smelter hand were asked to design a copper deposit ideal for both mining and smelting, the result would be very like Burra.

It has been suggested that the very wealth of Burra did the company a disservice, allowing it to operate the mine inefficiently and without regard for future development, while still making enormous profits.[39] Certainly they gouged out the richest ore for thirty-two years until the mine closed, leaving more valuable ore still in the ground than many successful mines ever had at the outset. Probably their good fortune held the whole Australian mining industry back, for its example led miners to concentrate on discovering another Burra instead of learning to mine lower grade ores at a profit.

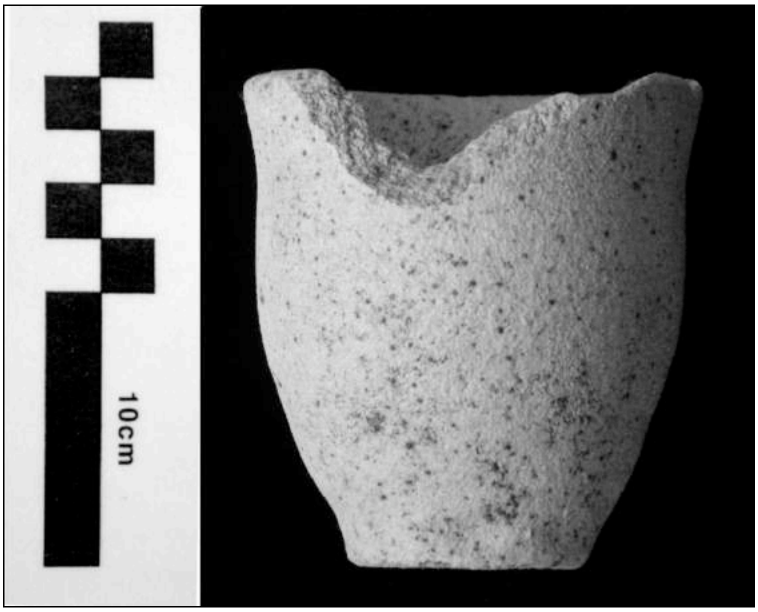
The first copper smelter in Burra (and Australia) was built in 1846-47 by the Dreyers. It stood near the entrance to the mine, within what is now a walled enclosure called the mine storeyard. Construction was underway in early 1846, and the company called tenders for 25,000 bushels (over 600 tonnes) of charcoal fuel. The smelter was built at a cost of about £1,000, and tested early the following year. The air blast was insufficient, so a blowing machine was ordered from an Adelaide organ builder in March 1847 and fitted to a new furnace. Still the trials dragged on for months. There is a published account of a smelting operation at Burra in 1847 which gives an optimistic description of the process, but the eyewitness must have been present on one of the more successful days.[40] About 230kg of copper matte was produced eventually, but it would have been cheaper and quicker to freight the ore to Swansea. In October 1847 the Superintendent drew up a plan for a new smelter with its blower powered by a steam engine, but the directors had heard enough about blast furnaces. The experiment was over.

The reasons for the failure are not entirely clear. It seems that the air blast remained inadequate throughout the life of the furnace, for there were repeated references to improving it. The Dreyers probably did not understand the oxidised ore of Burra, as they spent some time in preliminary roasting, which should not have been necessary. We know that they used limestone as flux, but all the materials they gathered in the Burra landscape must have been unfamiliar to them. The company papers also hint at language difficulties and personality clashes among those in authority; there were three Superintendents in the course of the project.[41] Given all the imponderables they faced, it is a miracle that the Dreyers managed to produce any matte at all in the face of demands from an impatient company secretary.

The remaining physical evidence of this Australian metallurgical milestone is tantalisingly slight. There is a ground scatter of hand-made crucibles, and firebricks made by

G.H Ramsay & Company of Newcastle-on-Tyne, both of uncertain date. At two points in the storeyard walls, there are pairs of brick piers spaced fourteen feet apart, attached to the stonework. These are of interest because illustrations of German blast furnaces from the time of Agricola through that of Diderot to the mid-nineteenth century consistently show a tall square brick structure, usually attached to the surface of a wall and stabilised by means of two flanking piers.[42] The site requires archaeological investigation before any conclusions can be drawn from it.

Figure 4: *Burra Crucible.*



Source: Peter Bell.

When their first smelter failed, SAMA did not persevere in the smelting business, but entered into an agreement with the Patent Copper Company of Swansea who started building a Welsh reverberatory plant close to the mine in 1848.[43] It was a good choice, for the rich carbonates of Burra would prove to be ideally suited to Welsh smelting methods. The Burra company's subsequent smelting record was confused by their indecision over the economics of smelting at the mine or at other sites. In the 32-year history of the Burra mine, its ore was smelted at the mine, at Apoinga 30km away where there was a good firewood supply, at the Port and Yatala smelters in Adelaide, in Newcastle and in Swansea.[44] For most of the 1850s, mule teams carried coke to Burra for smelting the lower grade ore, and back-loaded richer ore to the coast for shipping.

The first phase of the smelter, operating by 1849, was a row of six reverberatories built of stone and brick. Within a few months two new furnaces were added, forming an L-shaped plan. The artist S.T. Gill recorded the Burra smelters with their eight brick stacks at this stage of their development.[45] Then between 1850 and 1854 the works were greatly expanded, first with the construction of three refining furnaces, and then by a whole new matting works with a bank of nine reverberatories linked by a flue to a 25m stack, the tallest structure in South Australia. The company was fortunate in having both good red clay and fireclay in close proximity, and was able to make all its own bricks on site.

The heyday of the new works was brief, from 1854 to about 1862. In that year, the company had completed its new smelters at Port Adelaide and the railway was advancing toward Burra. Less and less ore was smelted at the mine until in 1869 the Burra smelters closed, and all ore was railed to Port Adelaide until the mine was closed in 1877 by a copper price fall. The smelters the company erected at Port Adelaide and Newcastle were also orthodox reverberatories, reflecting their faith in Swansea technology.

The company kept the Burra smelting works standing for many years, although there are records of bricks and other materials being sold off as time passed, and the quantities involved suggest that the reverberatories themselves were being dismantled. For decades the Burra mine was regarded as temporarily closed pending a rise in the price of copper, and it was not until 1914 that the South Australian Mining Association began selling off its assets in earnest. Two new companies were formed to crush and treat slag on the site in the early twentieth century, and the site of one of their small cylindrical waterjacket furnaces can be seen today. The stone shell of the smelter buildings stood until about 1920, and then disappeared from photographs, most likely cannibalised for their building materials. The great red brick stack of 1853 stood alone in a sheep paddock until as recently as 1956. It was then dynamited by the local Council because they believed it was dangerous - presumably to the sheep! Fragments of the furnaces remain on the site, which is publicly accessible and interpreted for visitors.

Burra played a crucial role in early Australian copper smelting history, for the events of 1846-49 would shape the dominant technology of the industry for the next fifty years. There is no question that the cost of the German process as practised at Burra was vastly greater than the Welsh alternative. However, the directors must have realised that economy of scale had a great influence on those relative costs; during 1847 while the Dreyers were struggling to smelt their few tons of ore, Burra shipped 7,000 tons of ore to Swansea.[46] One cannot meaningfully compare the costs of a small experiment with those of a vast industrial complex. Probably of more influence than the costs were the uncertainty and delay; after two years of effort, the German furnace had failed to produce a drayload of copper.

Nor was the Burra case the only one that company directors were following with interest. In 1848 the Thomas brothers built Australia's second smelter at Bremer, a successful

Welsh reverberatory. At Yatala in the Adelaide suburbs, another hot blast furnace built in 1849 performed poorly, while reverberatories built at Apoinga and Kapunda the same year worked well.[47] These outcomes may have been no more than coincidence, they may have been determined by the nature of the local copper ores, but the pattern was that by end of 1849, South Australia had seen two blast furnaces fail and four reverberatories succeed. All smelting experiments so far were leading to inescapable conclusions, and by the early 1850s the Welsh reverberatory had become the preferred smelter of the Australian copper industry.

Case Study 2: Wallaroo

As Burra was beginning to fade, two much larger copper deposits were discovered at Wallaroo (now Kadina) and Moonta on the Yorke Peninsula of South Australia in 1859 and 1861. These discoveries that were also made by shepherds could hardly be described as accidental; by that time every shepherd in South Australia must have known what malachite looked like.

These new finds were initially worked by two separate companies, which later amalgamated in 1889. One of the companies, the Wallaroo Mining Company, established a smelter to treat all these local ores on the coast at Port Wallaroo in 1861. Initially only matte copper was produced; high grade ore and matte were exported for further refining. Soon however, the company extended its operations to finish all of its own and Moonta ore as well as custom ores from as far away as Tasmania. The company also set up a smelting works in New South Wales to treat low grade ores sent as backloading on the ships bringing coal and coke from Newcastle.

The Wallaroo smelters operated for 65 years, producing about 330,000 tons of copper metal as well as significant quantities of gold, silver, lead and sulphur-based by-products. They were struggling against falling prices after 1918, but did not finally wind up their operations until 1926. This was a remarkably long-lived and profitable enterprise due to flexible adaptation to changing conditions, responsiveness to new technology, fair work practices, inventiveness, and good management. Its adaptability meant that there was continual and extensive change in the smelters' plant, and by the time the smelters closed, large areas of the site had seen demolition of old structures and erection of new ones more than once in six decades of production.[48]

The development of the smelters can be divided into three main phases: the first from 1861 to 1889 was dominated by the old Welsh method of copper smelting. This phase commenced with the establishment of the smelter and was characterised by the use of calciners and reverberatory furnaces. Unlike Burra, Wallaroo was smelting sulphide ores almost from the outset. The ore was first roasted slowly in open-topped kilns to reduce the sulphur content of the ore. The product was then crushed and fed to the reducing furnaces in a mixture with Moonta ores, Wallaroo carbonates and sinter from the roasting furnaces. The slag from this furnace was tapped off into a sand bed and then used for building or land reclamation purposes. The remaining copper matte was tapped into sand moulds, cooled and taken to the roasting furnaces. It then passed through a couple of roasting operations to produce rough copper. In turn, these slabs of rough copper (known as pigs) were transported to the refinery building where there were a further four furnaces. Here the rough copper was fired yet again, the slag removed and the pure copper ladled into moulds and sent to the storeroom for stamping and weighing.

By 1868, seven years after smelting commenced, Wallaroo had 13 large stacks and numerous small ones so that the overall effect was a 'forest of chimneys'. There were 33 furnaces of which 24 were reducers and 9 roasters. Many of their flues led to a central stack, a massive brick chimney, square in plan in the Welsh tradition. It was known as Hughes Stack in honour of Walter Watson Hughes, the landowner and director of the mining companies, and his initials were picked out in brickwork on the eastern (town) side of the stack: 'W.W.H. 1861'. The company was producing on average 4,200 tons of refined copper per year which increased to 6,400 tons per year by 1876.[49]

The ores of Wallaroo and Moonta were a much more demanding proposition than those of Burra. The copper was in deep vein deposits which were more expensive to mine, they were of lower grade, and much of the ore was in the form of sulphides which required careful roasting before reverberatory smelting. In 1869 there was an experiment by Hughes to construct new fan-forced or blast furnaces to roast, reduce and smelt the copper in one continuous operation to improve efficiency and save fuel.[50] The idea was years ahead of its time, but it was a failure as the fuel and blowers available produced insufficient heat.

Phase 2 lasted from 1889 to 1907 following the amalgamation of the companies to form the Wallaroo and Moonta Mining and Smelting Company. This was a period of innovation and diversification which saw the introduction of new technology, greater production and greater efficiencies. New plant included waterjacket blast furnaces, a gold and silver works, a lead works, an acid works and a copper sulphate plant. In 1890 smelter manager Thomas Cloud was sent to Europe and America to examine the latest advances in smelting copper, gold and pyritic ores. On his return many modifications were made and new technology adopted; significantly, it was principally from America that the innovations came. Gold was present in the rough copper being produced and this was then treated electrolytically. The gold and silver works treated not only the local ores but also Western

Australian gold ores from Kalgoorlie and silver ores from Tasmania. The plant operated as a separate entity until 1902 when the recovery process was integrated into the copper smelting process.

A copper sulphate plant was set up in 1894 using sulphuric acid from the acid plant and either refined copper or flue deposit. Copper sulphate or bluestone was used for telegraph batteries, pickling wheat, sheep dipping, and spraying vines and fruit trees, but the market proved fickle. After electrolytic refining began it was found that more profitable use could be made of the flue dust to produce copper metal, and the sulphate plant closed in 1907.

One of the main innovations of the period was to treat the tons of sulphurous flue gases which escaped from the chimneys stacks every day. They could be used to produce sulphuric acid - an essential ingredient of superphosphate - as well as in the precipitation of the tailings dumps at the Moonta Mines, in the bluestone plant and in the electrolytic refinery. A sulphuric aid plant was set up in 1898 and another company - the Wallaroo Phosphate Company - established itself in close proximity to the acid plant. By November 1902, 80 tons of acid was being produced each week.

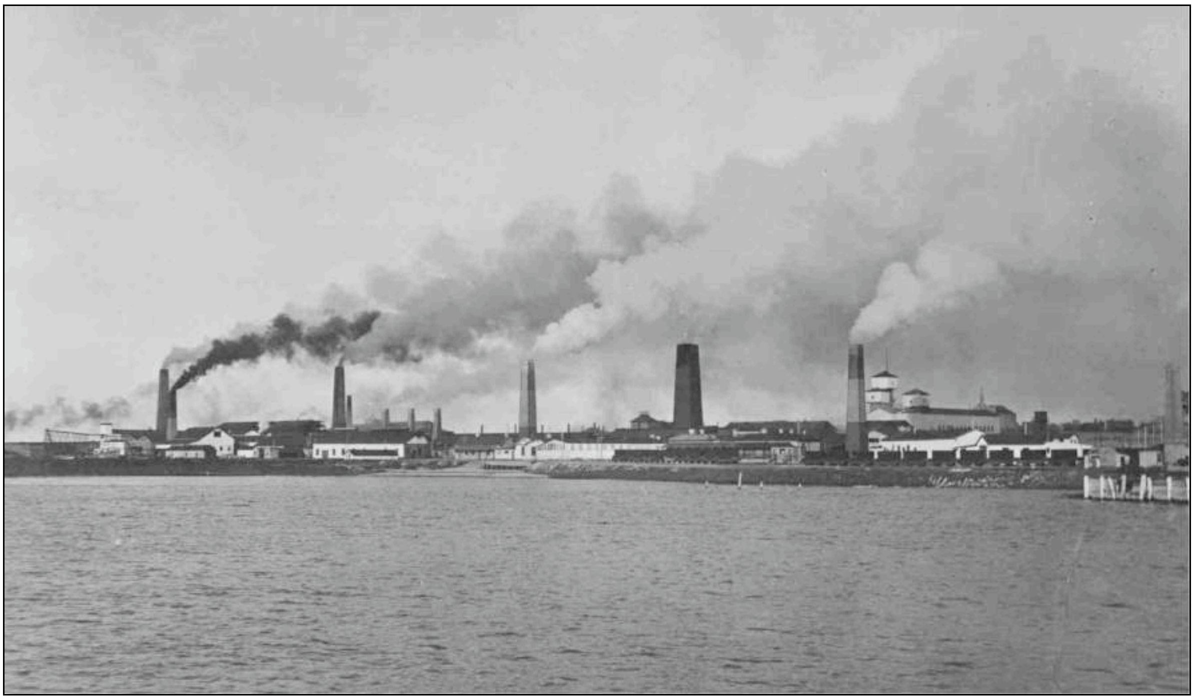
The other major development of this phase was the establishment of a lead works to treat ores from Broken Hill and Tasmania. Testing commenced in 1894 using a rotating copper calciner; this was successful so five rotating calciners were eventually built to process lead. Two 80 ton waterjacket blast furnaces of American design were constructed by the end of 1899 and the lead plant commenced operations. Due to the falling price of lead and the high cost of producing it, the plant had a short life and was closed by the end of 1902.

However, the unsuccessful lead experiment was to have a profound effect on the efficiency of the smelters. Early in 1902, one of the two furnaces was adapted to treat copper ores to produce copper matte. Results were encouraging, and by 1903 both blast furnaces had been enlarged and fitted with more powerful blowers, and proved to be very successful at treating copper sulphide ores. Another simultaneous development was upgrading the electrical power plant and converting the old lead plant to a new electrolytic refinery.

In 1905, the rotating calciners of the lead plant were replaced by three McMurtry sintering pots on the upper level. The McMurtry pots were a new process, invented by the staff at Wallaroo for desulphurising copper concentrates. They were cast iron cylinders 2.6m in diameter and 1.4m deep, fitted with a perforated false bottom or grate. A charge of eight or nine tons of finely-divided ore or concentrate was mixed with fuel such as wood chips or sawdust and ignited, then a forced air draft was blown through the bottom of the pot until the charge was oxidised and sintered ready for smelting.[51] Another three McMurtry pots were added in 1911.

All this led to increased production and a plant for granulating slag was built; granulated slag was mainly used as deep filling in the mines, with some material being stockpiled on the site. The transition from reverberatory to blast smelting was not abrupt or clear-cut, for the two processes remained in use side-by-side for over ten years, depending on the ores being treated. It was only after 1910 with the introduction of converters that blast furnaces took the ascendancy.

Figure 5: *General view of Wallaroo smelters from the harbour, 1902.*



Source: Primary Industries and Resources South Australia N010758a.

Phase 3 (1910 to 1923) saw the successful introduction of converters which meant large savings in time, labour and fuel. The converter came between the furnaces and the refinery in the production process, and was charged with the molten matte from the furnace, plus a silica flux. Transferring the matte while it was still molten made a large energy saving, as previously the copper had been allowed to cool between operations and later had to be re-melted. A powerful air blast was blown through the charge for a few hours, converting the remaining copper sulphide to blister copper with a metal content close to 99 percent, and slag. The converters commenced operation in August 1910 and quickly made much of the existing plant redundant. The old smelting furnaces (reducers and roasters) were replaced by the converters; some were dismantled soon after 1910 and their bottoms smelted to recover absorbed copper. After the slag had been tapped from the converters, molten copper was cast in moulds in the form of anodes and then taken to the electrolytic refinery. Recovery of gold and silver by electrolysis continued.

The operations at the smelters had been steadily moving north over the years, and most of the early stacks and furnaces at the southern end of the site had been demolished by the early twentieth century. From the multiple operations in small reverberatory furnaces that had characterised the first four decades of smelting, ore treatment at Wallaroo was now streamlined down to essentially three steps: blast furnace, then converter, then electrolytic refinery. By 1910, the old Welsh processes had been entirely replaced by newer American methods.

But even this modern technology could not compete against depressed world copper prices, declining ore quality and increasing fuel and mine dewatering costs. By 1921 the company was experiencing problems, especially as the declining world copper price and increasing costs resulted in substantial losses. It was decided to close the mines in 1923. The smelters kept going for a further three years, smelting stockpiled ore and concentrates and stripping the site of anything of value. Machinery and building materials were sold, brick chimney stacks were dynamited, the surviving old furnaces were demolished, and their bricks put through the blast furnaces to extract the few pounds of copper they contained. Over its life the smelter had produced 332,600 tons of fine copper valued at £20,365,000 plus quantities of other valuable minerals. Indeed it is said that the value of the gold recovered from the Moonta Mines ores alone paid for the cost of all processing at the smelters.

In August 1925 hundreds of spectators gathered at the site to watch as the tallest chimney stack at the smelters, built in 1899 to take the draft from the blast furnaces, was brought down by a gelignite charge. By the time the company abandoned the site at the end of 1926, most buildings and structures had been demolished, and everything made of metal or other salvageable materials had been removed and sold. The only thing of any size still standing was Hughes Stack, dating from the smelters' very beginning in 1861. It had deliberately been left as a monument: 'The big stack' as it is familiarly known in Wallaroo, also bears the letters 'W.W.H. 1861, a memorial to the late Sir Walter Watson Hughes, who was so closely associated with the discovery and development of the mines. It is hoped that the old stack will ever remain'.[52] The demolition of the smelters extended over years. An aerial photograph of Wallaroo in 1930 shows two large buildings - the workshops and converter shed - still standing. It also shows masonry remains of furnaces and flues which are now gone.

The site today is dominated by Hughes Stack, the oldest and single survivor of the forest of chimneys which once stood on the site. The topography and layout of the site itself with its two distinct levels and large retaining wall, is a result of development from the very beginning of operations. Other remains include low level foundations of the powerhouse, electrolytic refinery, converters, coal conveyors and sintering pots, all from the last decades of operations. Little survives on the surface from the earlier period, but below ground the remains of the extensive flue system of the reverberatories is still discernible and appears to be intact in many places. The fertiliser factory alongside continued to operate until the 1990s, but has recently been demolished.

Note: Part II of this paper will look at five further case studies: the copper smelters at Mount Lyell and Crotty in Tasmania, Chillagoe and Mount Elliott in Queensland, and The Peake in South Australia. It also includes an appendix listing 156 copper smelters recorded as having been built in Australia between 1847 and 1918.

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