The Copper Triangle's Spanish Legacy: Leaching the Waste Dumps at Moonta Mines 1901-1944

By PETER BELL

Most accounts of South Australian history say that the copper mining era at Moonta ended when the company went into liquidation in 1923 and the mines closed. However, that was not the end of the story, for copper extraction continued for twenty years longer, not from the flooded mines, but from the waste dumps stockpiled at the surface. The techniques that made possible those forgotten twenty years of metal production had been pioneered at the other end of the world, in the Huelva province of southern Spain.

For the beginning of the story we need to go back to 1900. The price of copper was very high that year. If a prospector had arrived in Moonta and said he had found a mineral deposit nearby containing 25,000 tons of copper metal, that would have caused more than a flicker of interest in the local mining industry. But if the prospector then added that the mineral deposit was already extracted, crushed and neatly stockpiled on the surface, that would be very exciting news indeed! In 1900 there really was such a mineral deposit: the waste dumps at Moonta Mines. The prospector was Henry Lipson Hancock, General Manager of the Wallaroo and Moonta Mining and Smelting Company.

The Moonta waste dumps

By 1900, copper had been mined at Moonta Mines for nearly forty years, and the Wallaroo smelters had produced about 100,000 tons of copper metal from Moonta ore. The legacy of those decades of mining was piled all around the skyline at the mines: nearly two million tons of waste from the treatment plants.

There were two kinds of waste dumps. The first consisted of mill tailings - they were called ‘skimps’ at Moonta - which were composed chiefly of the crushed waste from the jigs at Richman's and Ryan's treatment plants. In a range of particle sizes roughly comparable to beach sand, the skimps were fairly coarse. In 1900 there were estimated to be about 1.5 million tons of tailings in the jig dumps, and because all treatment processes are imperfect, they still assayed about 0.9 percent copper, or 13,500 tons of metal. Then there were 330,000 tons of fine slimes, or waste from the buddles, with a consistency closer to talcum powder. The slimes were much richer, assaying about 3.5 percent, or another 11,500 tons of copper.[1]

In all, the copper metal in the dumps totalled something like 25,000 tons. To put this in perspective, it was equivalent to about five years of average production from the Moonta and Wallaroo mines combined, or about half the entire output of the Burra mine in its working life from 1845 to 1877.

Henry Lipson Hancock had become General Manager of the company on the retirement of his father Henry Richard Hancock in 1898. He knew there was a very large asset in the dumps, but the challenge was to find a way of treating it at the lowest possible cost. There was no suitable technique being practised in Australia, but Hancock knew that for decades the Rio Tinto and Tharsis mines in the south-west of Spain had been extracting copper metal at very low cost by leaching copper from mine dumps and precipitating the dissolved copper on to scrap iron. The low cost of the process was possible because two of the most expensive elements of copper mining - underground extraction and ore dressing - had already been paid for.

Accounts by Oswald Pryor suggest that the process was developed at Moonta following the serendipitous local observation that rainwater seeping from Richman's tailings heap deposited copper onto scrap iron, but this seems fanciful.[2] In every aspect of the company's operations - extraction, ore dressing, transport and smelting - Hancock demonstrated familiarity with international mining practice, and did not hesitate to adopt any techniques that worked. He brought the mines out of the mid-nineteenth century Cornish and Welsh orthodoxy of his father's time, introducing recent technological innovations from Germany and the USA to transform their operations. He would certainly have been aware of treatment practices at Rio Tinto, the third-largest copper producing mine in the world at the time.[3] There was a period of small-scale local experimentation at Moonta before the commitment of major expenditure to the leaching process, and Pryor writing decades later may have believed this was independently inspired, but the early experiments were modelled on the process used in Spain.

The mines of southern Spain

The process of leaching or lixiviation involves removing a valuable mineral from its ore by dissolving it. At the Rio Tinto mines the leaching process had first been applied from about the 1750s onward to ores containing copper sulphate, simply using water as the lixivant.

However, the copper sulphide which made up the bulk of the mines' output at Rio Tinto as at Moonta is insoluble in water, so natural oxidation was used to convert the ore to sulphates and oxides. The process could be accelerated by adding a reagent to the leaching solution which would assist in converting the sulphides to a soluble compound. Experimentation showed that an acid leach would assist in dissolving copper from sulphide ore, and from 1845 onward, sulphuric acid was being added to the leach solution.[4] In 1873 the mines were taken over by the London-based Rio Tinto Company Ltd. The chemistry of the leaching process at Rio Tinto continued to rely partly on facilitating natural oxidation in the heaps, but was accelerated by the addition of sulphuric acid which converted the sulphide to copper sulphate in solution, provided abundant free oxygen was available:

$$2Cu_2S + 2H_2SO_4 + 5O_2 \rightarrow 4CuSO_4 + 2H_20$$

At the Tharsis mines nearby, the Tharsis Sulphur and Copper Company Ltd of Glasgow had evolved similar techniques to deal with similar ores. Another oxidising technique used at both mines was heap-roasting the sulphide ore in large heaps in the open. The sulphur dioxide fumes generated by roasting led to perennial public complaints and resistance from the provincial government. The practice was banned at Tharsis in the 1890s, and last used at Rio Tinto in 1907. By the early twentieth century, natural oxidation and acid leaching had become standard practice at both mines.[5]

It is not known how Hancock first heard of the Spanish techniques; a search of journals such as the *Mining Journal* of London and the *Engineering and Mining Journal* of New York has found nothing in the professional literature that might have attracted his attention. We know roughly the timing of his quest: Hancock was certainly seeking information within the profession by April 1900, and actively conducting experiments in leaching at Moonta in the following months, for in August that year he told the Wallaroo and Moonta Board that the local trials were showing promising results.[6] Unfortunately, none of the company correspondence from that period survives, and we can only piece his search together from the limited information in the board minutes.

The initial contact between Hancock and the Spanish mines apparently took place through the international network of mining engineers. In April 1900 Hancock had recommended the Board to engage 'Messrs. MacArthur and Eaglesham' to 'report on a process for leaching the copper from the tailings heaps at the Moonta Mine'.[7] This was none other than John Stewart MacArthur of Glasgow, co-inventor of the cyanide process for gold extraction. Eaglesham's identity is unknown; he was presumably a colleague of MacArthur.

The timing of Hancock's recommendation is intriguing, as MacArthur was in Australia in early 1900. He had been engaged by the North Lyell Company to advise on a plant to treat its copper sulphide ores at Crotty, and spent the month of January on the west coast of Tasmania, designing what would prove to be a hopelessly unsuccessful smelter.[8] Hancock visited New South Wales in early April, and his recommendation of MacArthur and Eaglesham to the Board came days after his return.[9] Hancock and MacArthur were certainly in some form of communication between January and April 1900, and we can speculate that they may have met face-to-face somewhere in the eastern colonies, but there is no direct evidence for the meeting.

Eaglesham visited Moonta about July 1900 and inspected the pilot leaching plant that Hancock already had in operation, giving a favourable report. However, MacArthur had declined Hancock's offer, and instead in a cablegram dated 13 August 1900, strongly recommended the company employ Spanish leaching specialist Antonio Delgado of Rio Tinto.[10] MacArthur's link with Rio Tinto was that he had earlier been a chemist with the Tharsis Sulphur and Copper Co Ltd of Glasgow, whose Spanish mining properties were near neighbours of Rio Tinto in the Huelva province of Spain.[11] MacArthur's own reminiscences on the development of gold cyanidation begin with the statement: ‘My training in practical chemistry and metallurgy began in the Glasgow laboratory of the Tharsis Sulphur & Copper Co. This company owns mines of copper pyrite at Tharsis and Clanas in the south of Spain.’[12]

Hancock's interest in leaching the Moonta dumps may have been encouraged by the events MacArthur's patent of 1887 had put in train in the gold mining industry, for in Australia the first intensive application of cyaniding was in treating the waste dumps of long-established gold mines, especially those with refractory ores. Queensland's gold production had reached an all-time peak in 1899, principally because of the success of MacArthur's techniques in treating the tailings dumps of Charters Towers.[13] While the chemistry of cyaniding is quite distinct from acid leaching, the engineering aspects of the two processes are broadly similar in involving the application of a solvent to tailings. It appears that Hancock had originally contacted MacArthur in the hope he would help design a leaching plant at Moonta, but MacArthur, whose background was in copper sulphide metallurgy and who knew of the techniques used at Rio Tinto and Tharsis, recommended

Delgado for the job. MacArthur himself was too preoccupied by the problems of the Crotty smelter in 1900 to take on the work. It was probably a good thing for Moonta Mines that MacArthur stayed away, for despite his reputation as a chemist, he had an abysmal record as a designer of treatment plants.[14]

Hancock took MacArthur's advice, and in August he recommended to the Board that they 'engage Senor Delgado a Spanish expert for two years to conduct conclusive experiments with a view to dealing effectively with the heaps'.[15] Experts of many kinds were in great demand throughout the mining industry at the turn of the twentieth century, so much so that the term often became a shorthand synonym for mining engineer.[16] The Board approved, agreeing to pay Senor Delgado £100 expenses, a salary of £400 the first year and £500 the second year, with an unfurnished house.

The expert arrives

It is obvious that the necessary arrangements had already been made. MacArthur had agreed to act as agent, and ten days after Hancock received approval from the Board on 21 August, Delgado sailed from Glasgow on the Orient Line steamer *Oruba.* He had already signed a provisional agreement with the company while in Glasgow, and MacArthur claimed £132.5.0 in out-of-pocket expenses in connection with his recruitment.[17] Delgado arrived in Moonta in mid-October.[18] His arrival did not produce immediate action, as no-one had realised that he spoke no English. At its next meeting the Board noted, 'Mr Hancock should take immediate steps to obtain a Spanish interpreter so as to sooner utilise Mr Delgado's services.'[19] Spanish interpreters familiar with metallurgical engineers' vocabulary were not easily found in South Australia in 1900, and a succession of people attempted that role until Delgado's English was sufficiently fluent to dispense with them.

Delgado is something of a mystery. He is not mentioned in any published account of the Rio Tinto mines before or after his excursion to Australia. He was obviously highly competent, strongly recommended by MacArthur and presumably fairly senior in the company's technical hierarchy, yet he spoke no English. It is difficult to imagine how he fitted into the picture painted in Avery's history of Rio Tinto as a rigid English technocracy overseeing a menial Spanish workforce.[20] We do not even know whether Delgado was a chemist or an engineer by training. He remained in Moonta until 1903, by which time a successful leaching plant was in full production. He became a popular local figure during his stay, although he never acquired a taste for Cornish cuisine. After he returned to Rio Tinto he entertained the Hancocks on a visit to Spain in 1908.[21]

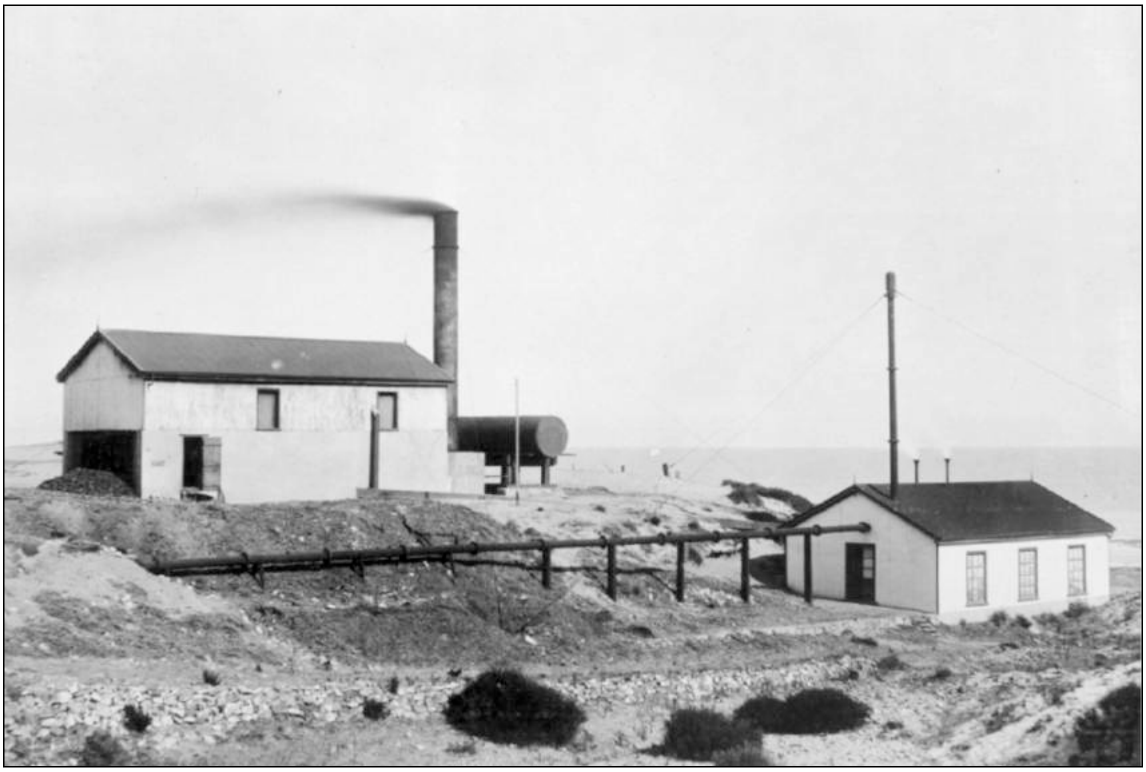
By December 1900 Delgado had designed a plant, which he estimated would cost £20,000, and be capable of producing 1,000 tons of additional copper per year. At the then current copper price of around £70 per ton, the plant would pay for itself in less than four months! The Board ordered the scheme be put into operation as soon as possible.[22]

The process introduced by Delgado appears to have been copied almost exactly from that in use at Rio Tinto's plant at Cerda in Spain.[23] The lixivant was to be acidified seawater. By January 1901 a new pumping plant was being built at Rossiter's Point in Moonta Bay.[24] Here a steam engine pumped seawater from a 600 mm diameter cast iron pipe extending 100 m out onto the shallow seabed of the gulf; it could only be used at high tide. Once the system was operating the water was recycled endlessly, and the Rossiter's Point pumps only needed to run intermittently to top up losses from evaporation and seepage. The pipe ran 4km inland to the purpose-built Ryan's Pumping Station on the mines, equipped with steam-powered Worthington pumps which controlled the circulation of the leaching solution around the waste dumps. The local press reported on these developments, bemused by the new industry of gathering scrap iron:

> The large amount of work necessary for carrying on the precipitating works at Moonta Mines on improved and up-to-date methods is being rapidly pushed on with. At the Bay, near Simms' cove, an engine is being erected for the purpose of pumping seawater into large mason work reservoirs, which are being built near Ryan's skimping heap. The water will be run from the Bay to the Mines in 12-inch iron pipes, which are being laid down for that purpose. A large number of men are employed on these works, but some weeks must elapse before the whole of these arrangements will be completed. Old tins, scrap iron, &c, which will be extensively used in carrying on this work, are being largely purchased by the company from all parts of the district, and truck-loads of similar scraps and shavings are being brought from Adelaide and other places. The gathering of these materials, which have hitherto been regarded as good for nothing, promises to become a remunerative occupation to those who care to undertake it. Altogether about £20,000 will be spent by the company on these precipitating works, after which it is anticipated handsome profits will be reaped therefrom. The arrangements are being carried out under the direction of Signor Delgado, an expert, who recently arrived here from Spain under special engagement with the company.[25]

Ryan's pumping station was sited so that when leachate was pumped out to most of the skimps heaps, it flowed by gravity back through the precipitating works to the pumphouse. This worked for Richman's 1 and 2 heaps and Ryan's 3 and 4; only Hancock's number 5 heap to the south was over a slight rise, and leachate had to be pumped back.

Figure 1: *The Pumping Station at Rossiter's Point on Moonta Bay.*



Source: Courtesy, Primary Industries and Resources South Australia, 030223

The water arriving from the sea was acidified with a small amount of sulphuric acid. It was important to the economic feasibility of the scheme that the company was able to supply its own, as the Wallaroo smelters had recently installed a plant to manufacture by-product sulphuric acid, completed in 1900. The leachate was then pumped to the tops of the skimps heaps and directed into soak beds confined by low earth walls, so that leaching could be concentrated on one area at a time. Once the leachate had percolated through the heap, it was 'pregnant', that is it contained copper sulphate in solution, and flowed by gravity down channels to the precipitating ponds, which were packed with scrap iron. After 40 years of production, with changes to pumps, headframes and railways, all maintained by its own large engineering workshops, Moonta Mines had an enormous supply of scrap iron on site, and the precipitating works were supplied by scrap from the workshops and collected around the site and from outlying mines

The sulphate radical has a greater affinity for iron than for copper, and reacts with it, forming ferrous sulphate in solution. In the process the copper that had been in the leaching solution was precipitated in metallic form onto the iron surface.[26] Roughly two tons of iron was consumed to produce one ton of copper.

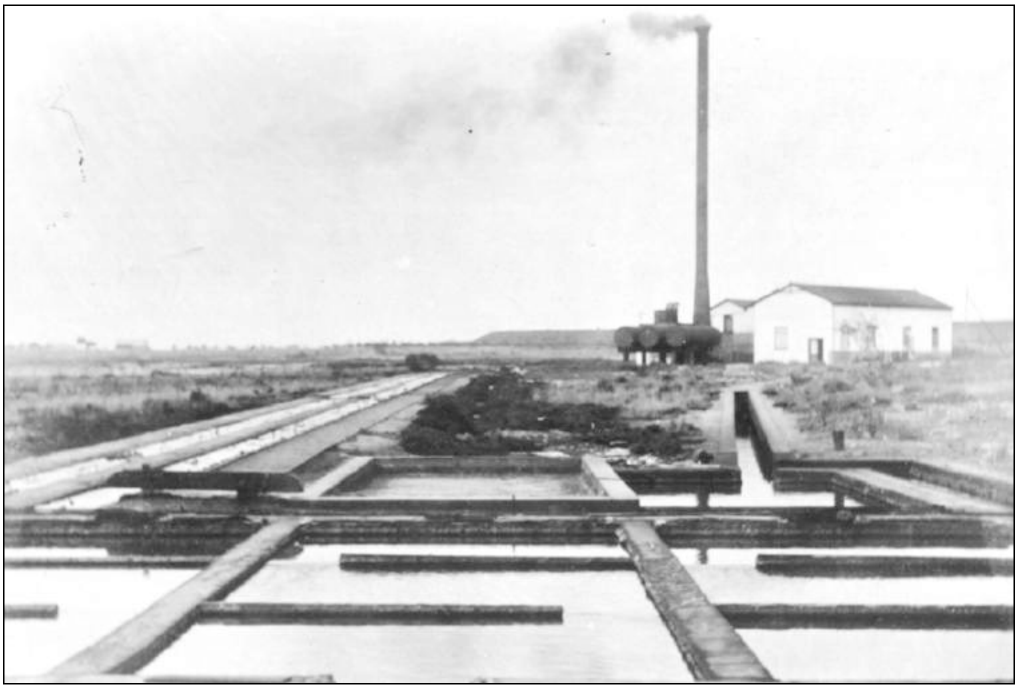
$$CuSO_4 + Fe \rightarrow FeSO_4 + Cu$$

Or, as one former worker at the plant put it:

> On contact with the scrap iron, a wonderful transformation took place. The copper content in the flowing liquor solidified on contact with the scrap iron, gradually eroding the iron until only the precipitate remained.[27]

The general name for this process is precipitation, but at Moonta it was called ‘cementation’. The use of the word at Moonta dates from the time of Antonio Delgado's arrival at Moonta Mines in October 1900. Previously, in the minutes of Board meetings, Hancock had always used the word ‘leaching’ to describe the new process. From that time on, he referred to it as ‘cementation", the word in use at Rio Tinto.

Figure 2: *The Precipitating Tanks, with Ryan's Pump House at right.*



Source: Courtesy, Primary Industries and Resources South Australia, 030220

In contemporary metallurgical textbooks, Manuel Eissler's *Hydro-Metallurgy of Copper* describes the Spanish techniques using the word in the sense in which it was introduced to Australia by Delgado, to describe the whole process including lixiviation and precipitation.[28] Carl Schnabel's *Handbook of Metallurgy* on the other hand uses the word cementation to describe a completely different and ancient process for separating gold and silver from mixed ores by converting the silver to a chloride, leaving the gold in metallic form.[29] This process was still in use in Latin America in the nineteenth century, and the word in Spanish mining practice may have widened to mean any process, which precipitated metal out of solution.

After a week or so in the precipitation tanks, the iron with its adhering copper was removed from the lixivant, washed in fresh water and dried, then the copper was separated manually from the iron and other material. The product, consisting of about 70 percent copper metal, was sent for smelting. The exhausted leachate was allowed to flow back to Ryan's, re-acidified, and pumped out to the skimps heaps to begin the cycle again.

Figure 3: *Removing precipitate from the canals at the Wash and Dry House.*

Source: Courtesy, Primary Industries and Resources South Australia, 030222

The acidic and saline environment of the works required design features to keep the leachate out of contact with iron and other metals. The acidified lixivant was pumped through earthenware or wood-lined pipes. The Worthington pumps at Ryan's were lined with a specially developed inert alloy to resist corrosion by the leachate: composed of 85 percent copper, 10 percent zinc and 5 percent lead, it was called Moonta Precipitation Alloy. Workers recovering precipitate from the cementation tanks and canals wore boots with wooden soles attached by copper nails.[30]

There is no record of how the leaching and cementation processes were monitored, but there must have been reasonably tight control over the chemistry of the processes. Crucially, the lixiviate could not be allowed to flow into the precipitating tanks until all the sulphuric acid was consumed, or any remaining acid would simply convert the scrap iron directly to ferrous sulphate without producing any copper metal.

The leaching plant in action

In October 1901 Hancock reported to the Board that the first precipitate from the new plant had been sent to the smelters, and by the end of that year 633 tons of copper had been produced. The following year saw production of over 1,000 tons, just as Delgado had forecast. The total cost of the finished works was higher than his estimate at £27,000, but it seems to have included the book value of £8,000 worth of scrap iron.[31]

The Moonta cementation plant appears to have been the first successful application of acid leaching to mineral extraction in Australia. The nearest parallel was the Henderson process, which had been used for a few years at the Kapunda copper mines from 1867 onward.[32] William Henderson, like MacArthur, had been a chemist with the Tharsis company thirty years earlier, and in 1860 had devised a process for treating copper sulphide ores by roasting them with sodium chloride to generate hydrochloric acid and create copper chloride in solution. The process was used successfully in Britain.[33] However, the older Henderson plant at Kapunda had differed in three fundamental ways from the Delgado plant at Moonta: (a) its copper chloride process was far more costly and technically demanding, (b) it was applied to crushed ore, not tailings, and (c) although it was technically successful, the plant's output failed to pay its costs.

With the Moonta cementation works up and running by 1902, Delgado next turned his attention to the larger dumps at Wallaroo Mines. However, the process was never a success there. Production figures from Wallaroo were never more than a fraction of the amount of copper coming from the Moonta plant, and after 1913 cementation figures were simply included in the mine's total. The Wallaroo ore seems to have been metallurgically different in some way, and did not respond to oxidation or readily form sulphates in the leach solution. Production from the Wallaroo cementation works between 1903 and 1913 was only about 4.5 percent of that from Moonta: 422 tons, as opposed to 9,281 tons from Moonta in the same decade. Once the Devon Concentration Plant was operating at Wallaroo Mines in 1911 the dumps were found to respond well to flotation, and cementation was abandoned there.[34]

Figure 4: *The Slimes Treatment Plant situated on Ryan's Heap.*

Source: Courtesy, Primary Industries and Resources South Australia, 030212

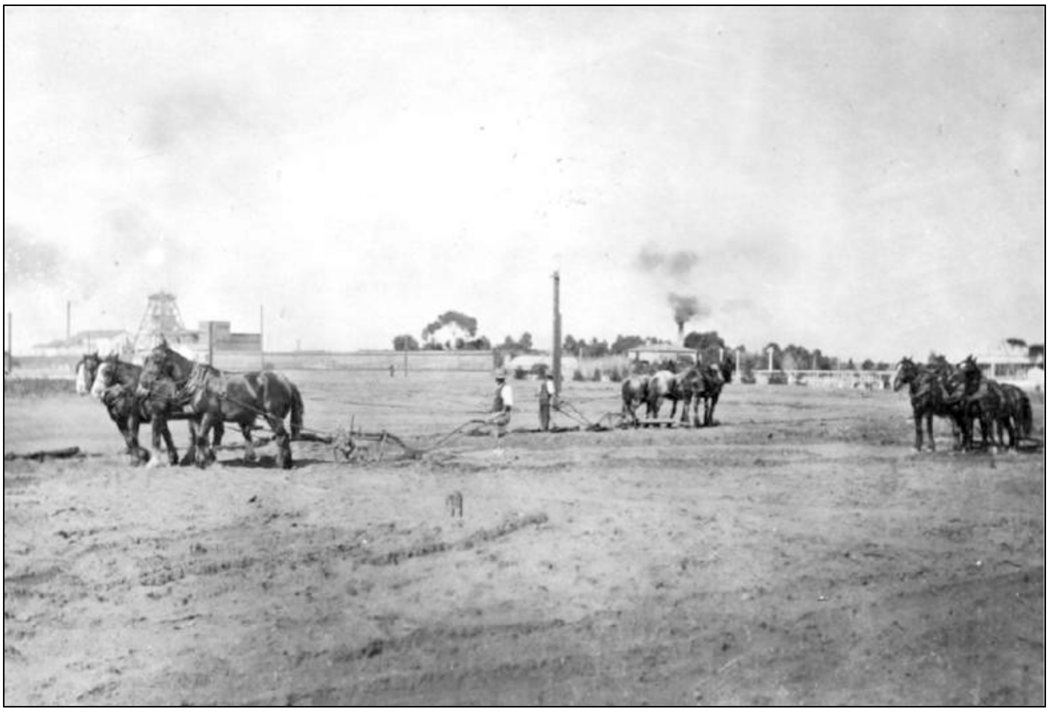
Tests of the mine tailings at the Hamley Mine proved more encouraging. Rather than building another plant there, the Moonta and Wallaroo Company purchased the tailings from the Hamley Company and railed them to Moonta, and later did the same at other outlying mines. This central accumulation of tailings at the Moonta cementation works is probably responsible for the conspicuous lack of mine waste at most of the outlying mine sites of the district.

Ploughing the mines

Delgado's efforts at Moonta were directed to the coarser tailings, which were similar to those treated at Rio Tinto. It was only after the skimps plant was running and Delgado had left Moonta that Hancock turned his attention to the slimes. They presented bigger challenges than the coarse skimps, first because they were not porous - their densely packed fine particles repelled water; and second, they were anaerobic - there was no oxygen available in the heaps to oxidise the sulphides. Yet tantalisingly, because of these difficulties in treating the slimes, they still retained four times the grade of copper contained in the skimps.

There seems to have been no precedent for re-treating base metal slimes by leaching, and the techniques were developed on site at Moonta.[35] The process began by flattening out the slimes heaps and ploughing them with agricultural ploughs to turn the surface over and encourage aeration. The large flat areas of bare earth surrounding Moonta Mines today are the legacy of decades of aerating the slimes before leaching. As the slimes had to be kept agitated during the leaching process, after a period of aeration they were scooped up by horse-drawn scoops and dumped into rail trucks to be taken to a purpose-built leaching plant by the railway. In later years, caterpillar tractors replaced the horse teams. To shorten the hauling distance from the eastern slimes deposits to the treatment plant, a tramway tunnel was excavated through Ryan's heap, forming another distinctive element of the Moonta Mines landscape.

Figure 5: *Ploughing the slimes to encourage oxidation.*



Source: Courtesy, Primary Industries and Resources South Australia, 030210

At the leaching plant, the slimes were agitated in lixivant in large tanks for several hours. After a period of settling, the pregnant liquor was decanted and flowed to the cementation tanks with the leachate from the skimps. The remaining slurry was piped back to the slimes area and allowed to dry before ploughing and aeration re-commenced. The slimes treatment plant was far more labour-intensive than the simple percolation of leachate through the skimps, but its returns were also greater.

Both processes remained in use until the Wallaroo and Moonta mines closed, and formed a conspicuous part of its operations in those years. The workforce at the cementation plant was given the rather grand title of Heap Attendants in the company's books, but they called themselves 'skimp jerkers'. The precise economic benefit of the cementation plant is difficult to calculate, but its overall output was nearly 6 percent of the total copper production from the Wallaroo and Moonta mines. In most years from 1902 to 1923 between 20 percent and 30 percent of Moonta's copper output came from the precipitation works. Each ton of that copper was produced at only a fraction of the cost of copper coming as ore from the mines.

Under new management

The First World War brought an end to the old copper industry. Its early effects for the mining industry were positive, a shortage of munitions in 1915 raising demand for base metals and bringing a boom in copper prices. All over the world, copper mines took advantage of the demand by increasing production, and governments began stockpiling copper metal. They produced too much and stockpiled too much, and by 1917 the copper price had already peaked. The Armistice of 1918 which ended the period of artificial demand saw prices falling and a glutted metal market, and by 1920 copper mines were closing all over the world. The Moonta and Wallaroo mines had survived disastrous price crashes before in 1877 and 1907, but now the mines were down to 1,000m below ground, production costs were high and all the ore bodies were patchy and falling in grade. The company struggled on until October 1923 before stopping the mine pumps and going into liquidation. The smelters finished up the last concentrates and closed in 1926.

But there was still a copper resource which was not 1,000m below ground, and where the production costs remained low. In December 1924, Adelaide metals broker Wilfrid Snow formed the Moonta Copper Recovery Company NL with capital of £20,000 to acquire the freehold of the cementation plant, skimps and slimes dumps from the liquidators of the Wallaroo and Moonta Company. The estimate now was that 7,000 tons of copper remained in the dumps. Oswald Pryor, who would later be a prominent chronicler of Moonta's history, became a shareholder and subsequently a director of the company.[36] The new company hired some of the skilled hands from the cementation works, including Vic Dawson as manager, and work resumed early in 1925.

The Copper Recovery Company could not operate on the scale of its predecessor - in its best year it produced 200 tons of copper, less than 20 percent of the old company's best years - and much of its plant had to be down-sized. The old company's steam engines had been sold, and the new company installed a little Petters twin cylinder two-stroke engine to power the seawater pumping plant at Rossiter's Point. At Ryan's pumping station, a 90 hp Blackstone diesel engine drove a centrifugal pump.

Although the company's prospectus had referred enthusiastically to the copper content of the slimes, in practice the Copper Recovery Company's operations were restricted to the less technically demanding skimps heaps. There were plans to re-open the slimes plant, and in March 1929 the company advertised for contractors to recommence ploughing the slimes. But experiments throughout 1929 and 1930 were very discouraging, and the remaining years of operation were confined to the coarser tailings. Even there, the cost of pumping leachate to and from Hancock's heap deterred the company, and they restricted their operations to the four northern skimps heaps at Richman's and Ryan's. From 1925 to 1943, the Moonta Copper Recovery Company's operations had shrunk back roughly to the part of the cementation plant that Antonio Delgado had designed before 1903.

Figure 6*: Cleaning out scrap iron from a precipitating canal.*

Source: Courtesy, Primary Industries and Resources South Australia, N007170

Most of the history of the Moonta Copper Recovery Company was played out against the background of falling copper prices; from its wartime peak of £125 per ton in 1917, copper had fallen to £56 in 1927, and £33 by 1934. On the other hand, many of the company's production costs were higher. The Moonta and Wallaroo Company had produced its own sulphuric acid, but after 1925 the Copper Recovery Company was forced to buy it, adding a new element to production costs. It is likely that they skimped on the acidity of the leachate, reducing its efficiency. The mines' copious supply of scrap iron dried up after 1923, and in some years it was necessary to buy iron.

Then there was the difficulty of marketing the product. The old company simply railed the copper precipitate ten miles to its own smelter at Wallaroo; but with that smelter gone, the Copper Recovery Company had to ship its product to Burnie in Tasmania or Port Kembla in New South Wales for smelting. In all the circumstances, there was not much margin of profit from the cementation works. In most years the plant provided direct employment for about four to six workers, but even this was a valuable economic contribution to the depressed Moonta district.

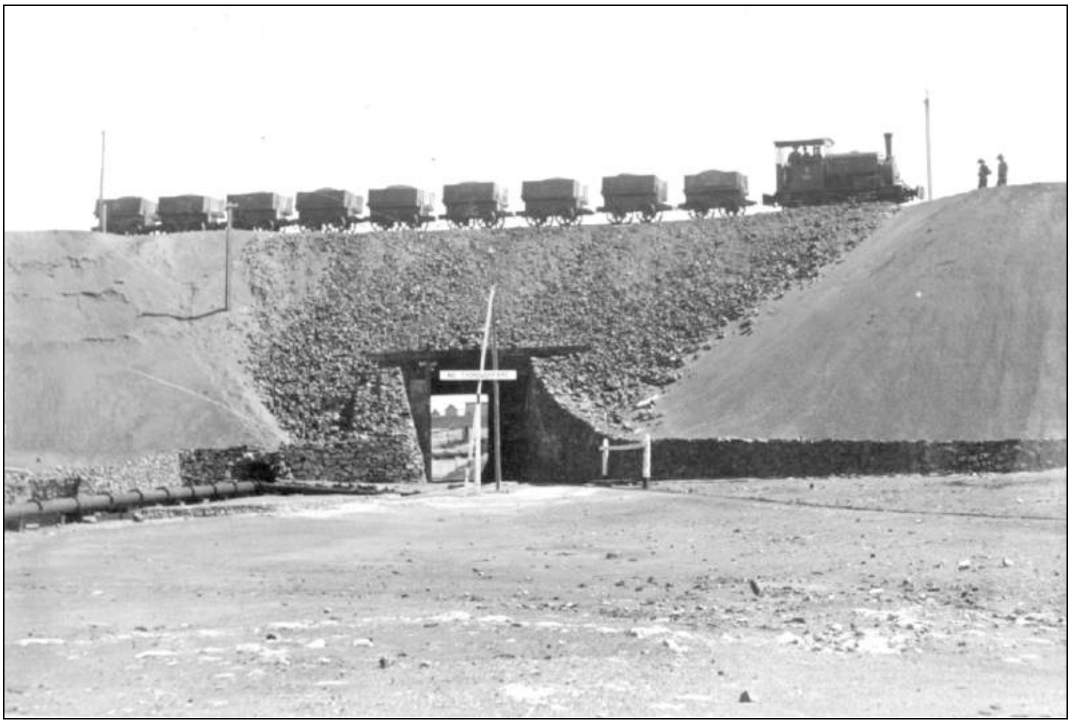
Inevitably, over time, both the leaching and precipitation processes became less efficient. Progressively the dumps became exhausted of copper. The original estimate had been that there might be ten years worth of leachable copper available; that figure eventually stretched to forty, but as time passed, every ton of leachate passing though the dumps was extracting less and less copper.

There seems to have been no provision to flush the leachate and refill the system with fresh seawater. Hence, although the levels were regularly topped up, evaporation from the canals and ponds would inexorably have increased the salinity of the leachate, and over decades there must have been a huge build-up of ferrous sulphate in solution and as sludge in the pipes and channels. In addition the chemistry of the leaching process must have been more complex than the basic equations, and copper oxides, chlorides and carbonates must have been created in solution, but not reacted with the iron in the ponds. The net effect of all these extraneous substances was to make the leachate less reactive, by reducing the probability of molecules of sulphuric acid coming into contact with molecules of copper sulphide and oxygen. For all these reasons the first sixteen years of operation by the Copper Recovery Company saw erratic but generally declining production figures; in the depths of the Depression from 1931 to 1934 they appear not to have operated at all, or did not put in any reports to the Mines Department. There was probably a tacit understanding that the department only wanted to know about significant levels of production.

Wartime struggles

The outbreak of war in 1939 brought a series of crushing blows to the cementation plant's operations. In quick succession all sulphuric acid was diverted to explosives manufacture, then diesel fuel was rationed; in 1940 manpower was controlled, and even scrap iron became virtually unobtainable except at great cost. Simultaneously, the price of copper rose dramatically during the Second World War - back up to £100 a ton by 1942 - providing a greater incentive to increase production at a time when that was nearly impossible. Copper output rose to 195 tons in 1941, but the company was struggling with shortages of fuel, materials and labour. The Federal government undertook a review of base metal production, and in 1943 the Controller of Mineral Production enforced a rationalisation of the copper industry. All over Australia, less-efficient mining operations were forced to close down, while others - notably Mount Isa Mines - received government subsidies to encourage production.[37]

Figure 7: *The Tramway Tunnel through Ryan's Skimps Heap.*



Source: Courtesy, Primary Industries and Resources South Australia, 030225

In May 1943 the Controller told the Moonta Copper Recovery Company to close the cementation plant. A few hands were kept on to clean up the last of the copper in the canals and dismantle the pumping plant for sale; the last production recorded was 31 tons in 1944. The Copper Recovery Company paid off Cementation Plant Manager Vic Dawson in January 1945 after exactly 20 years of production.[38] The company went into liquidation the following June, ending 84 years of copper production at Moonta Mines.

The heritage of leaching

The visible legacy of the Moonta cementation operations today is their impacts on the landscape at Moonta Mines. There are the obvious relics of the operation in the form of the pumphouse ruins at Rossiter's Point and Ryan's, the tramway, buildings, tanks and canals at the cementation works. Of the major structures of the cementation process, only the slimes leaching plant has vanished without trace. But forty years of leaching has also had more subtle effects on the landscape: (a) it centralised much of the district's mine waste at this one site, (b) it sculpted the skimps dumps into their tall engineered forms to facilitate leaching, (c) it flattened the slimes out into broad level areas like claypans all around the mines, and (d) it created the whimsical tunnel where the slimes trains passed through Ryan's skimps heap on their way to the treatment plant. Without that subsidiary copper extraction process, the mining landscape of Moonta Mines would look very different today.

The Cementation Plant at Moonta Mines now plays an important part in the interpretation of the site for visitors. In 1984 engineer Jack Connell of the State Heritage Branch interviewed Fred Osborn and Les Martin who had both worked for the Copper Recovery Company, and compiled a detailed historical account of the cementation plant with maps and a flow diagram. This was incorporated into an interpretation trail and tramway tour of the plant, funded principally by the Department of Mines & Energy and Tourism SA, which was completed for South Australia's Jubilee 150 celebrations in 1986.

Endnotes

[1] J. Connell, Moonta Mines: Cementation Process of Retrieving Copper Residues from Tailings and Slimes, unpublished research paper for South Australian Department of Environment and Planning, 1985, held in Jack Connell Papers, PRG 1152, State Library of South Australia (SLSA).
[2] O. Pryor, 'The History of Moonta Cementation', *People's Weekly*, 5 June 1943; Oswald Prior, *Australia's Little Cornwall,* Rigby, Adelaide, 1962, p. 89.
[3] H. Stevens, *The Copper Handbook*, the author, Houghton, Michigan, 1900, p. 76.
[4] D. Avery, *Not on Queen Victoria's Birthday: the Story of the Rio Tinto Mines*, Collins, London, 1974, p. 118; M. Eissler, *The Hydro-Metallurgy of Copper*, Crosby Lockwood & Son, London, 1902, pp. 66-67; J. Newton & C. Wilson, *Metallurgy of Copper*, John Wiley & Sons, New York, 1942, p. 313; C. Schnabel & H. Louis, *Handbook of Metallurgy,* Macmillan, New York, 1898, vol. 1, p. 236.
[5] S. Checkland, *The Mines of Tharsis*, Allen & Unwin, London, 1967, pp. 58-59 & 164-165; Avery, *Not on Queen Victoria's Birthday*, p. 181; Eissler, *Hydro-Metallurgy of Copper*, p. 43.
[6] Board Minutes of the Wallaroo and Moonta Mining and Smelting Company, 21 August 1900, BRG 40/5, SLSA.
[7] Board Minutes 24 April 1900, BRG 40/5, SLSA.
[8] G. Blainey, *The Peaks of Lyell,* Melbourne University Press, Carlton, 1959 (2nd edition), pp. 124-125.
[9] Board Minutes 10 & 24 April 1900, BRG 40/5, SLSA.
[10] Board Minutes 21 August 1900, BRG 40/5, SLSA.
[11] Alan Lougheed, 'The Cassell Company, Cyanide, and the Gold Mining Industry 1887-1927', paper at First International Mining History Conference, Melbourne, 1985, p. 2.

[12] J.S. MacArthur, 'The Discovery of Cyanidation', *Mining and Scientific Press*, 10 June 1916, p. 851.
[13] Alan Lougheed, 'The Cyanide Process and Gold Extraction in Australia and New Zealand 1888-1913', *Australian Economic History Review*, vol. *27*, no. 1, March 1987, p. 53.
[14] Blainey, *Peaks of Lyell*, pp. 145, 156, is scathing about MacArthur's work in Tasmania, and says of the North Lyell Company that 'their metallurgical policy, dictated by MacArthur, ultimately wrecked the company'.
[15] Board Minutes 21 August 1900, BRG 40/5, SLSA.
[16] A.H. Fay, *A Glossary of the Mining and Mineral Industry*, US Bureau of Mines, Washington DC, 1920, p. 255.
[17] Board Minutes 4 September & 9 October1900, BRG 40/5, SLSA.
[18] *Ibid.*, 16 October 1900.
[19] *Ibid.,* 20 November 1900.
[20] Avery, *Not on Queen Victoria's Birthday*.
[21] Pryor, 'History of Moonta Cementation'; Pryor, *Australia's Little Cornwall*, p. 89.
[22] Board Minutes 18 December 1900, BRG 40/5, SLSA.
[23] Avery, *Not on Queen Victoria's Birthday*, p. 175.
[24] *Yorkes Peninsula Advertiser*, 11 January 1901.
[25] *Moonta People's Weekly,* 16 February 1901.
[26] Newton & Wilson, *Metallurgy of Copper*, p. 319.
[27] F. Osborn, *The Moonta Cementation Story*, the author, Moonta, n.d., PRG 1152, SLSA.
[28] Eissler, *Hydro-Metallurgy of Copper*, pp. 66-69.
[29] Schnabel & Louis, *Handbook of Metallurgy*, vol. 1, p. 846.
[30] Connell, Moonta Mines; Osborn, *Moonta Cementation*.
[31] Board Minutes 19 November 1901, BRG 40/5, SLSA.
[32] J. Drexel, *Mining in South Australia: a Pictorial History*, Department of Mines & Energy, Adelaide, 1982, p. 29; Schnabel & Louis, *Handbook of Metallurgy*, vol. 1, p. 220.
[33] Checkland, *Mines of Tharsis*, pp. 94-96; Eissler, *Hydro-Metallurgy of Copper*, pp. 87-92.
[34] D.J. Flint, Moonta-Wallaroo Mining Field Production Statistics 1860-1938, Report Book no. 83/11, Department of Mines and Energy, Adelaide, 1983, pp. 8-10.
[35] There were simultaneous experiments with cyanide leaching of gold slimes at the Hannan's Star and Oroya Brownhill mines at Kalgoorlie; see R. Allen, *West Australian Metallurgical Practice*, Chamber of Mines, Kalgoorlie, 1906, pp. 19-23. This suggests another tenuous link between MacArthur and Moonta: MacArthur advised on the Brownhill cyanide process, and in 1900 Brownhill concentrates were being sent to Wallaroo for smelting. See Board Minutes 10 April 1900, BRG 40/5, SLSA.
[36] Moonta Copper Recovery Company NL 1924-1945, GRS 513/3 190/1924, SA State Records.
[37] S.J. Butlin & C.B. Schedvin, *War Economy 1942-1945*, Australian War Memorial, Canberra, 1977, pp. 455-56.
[38] Pryor, 'History of Moonta Cementation'; Connell, Moonta Mines; Osborn, *Moonta Cementation;* Interpretation signs on Cementation Plant site.

APPENDIX

Production from Moonta and Wallaroo Cementation Plants 1901-1944 (tons Cu)

Year	Moonta	Wallaroo	Year	Moonta	Wallaroo
1901	633	-	1923	376	-
1902	1,065	-	1924	-	-
1903	922	7	1925	192	-
1904	977	27	1926	6	-
1905	868	62	1927	20	-
1906	1,088	53	1928	110	-
1907	841	37	1929	200	-
1908	724	56	1930	63	-
1909	683	31	1931	-	-
1910	687	52	1932	-	-
1911	734	45	1933	-	-
1912	873	36	1934	-	-
1913	964	16	1935	46	-
1914	957	-	1936	129	-
1915	954	-	1937	135	-
1916	892	-	1938	133	-
1917	759	-	1939	102	-
1918	803	-	1940	78	-
1919	171	-	1941	195	-
1920	660	-	1942	145	-
1921	435	-	1943	95	-
1922	288	-	1944	31	-

Sources: D.J. Flint, Moonta-Wallaroo Mining Field Production Statistics 1860-1938, Report Book No. 83/11, Department of Mines and Energy, Adelaide, 1983; Company Annual Reports, BRG 40, SLSA; Record of Mines Summary Cards, GRS 11072/1 S15312/101C A & B, SA State Records; Primary Industry and Resources South Australia in-house records courtesy of Greg Drew.

Notes: Totalling production figures for the cementation process at Moonta and Wallaroo is not easy, as company sources sometimes inexplicably give two different figures for the same period, some records do not distinguish clearly between precipitate and smelted copper, and in some years the figures for production from Wallaroo Mines and at the Copper Recovery Company's plant are unavailable. However, the total recorded production from the Moonta plant under the Moonta & Wallaroo Mining & Smelting Company's ownership in 1901-1923 was about 17,274 tons of copper metal. Another 422 tons came from Wallaroo Mines between 1903 and 1913. The recorded production from the Moonta plant under the Moonta Copper Recovery Company's ownership in 1925-1944 was 1,680 tons. The grand total from both plants between 1901 and 1944 was 19,376 tons of copper, or about 78 percent of Hancock's estimate of the copper remaining in the Moonta dumps in 1900. The overall contribution of the cementation plants was about 5.8 percent of the 333,000 tons of copper produced from the Moonta and Wallaroo mines.