A CENTURY OF ZINC PRODUCTION IN AUSTRALIA

A Short History of the Zinc Industry

By Roderick J. Sinclair

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PREFACE

The discovery of silver, lead and zinc at Broken Hill in 1883 marked the start of large-scale industrial development in Australia. At first the presence of zinc in the ores was troublesome in achieving high recoveries of lead and silver, but this was overcome by an innovative research and development effort, and eventually zinc became of greater commercial significance than both lead and silver.

The advent of the First World War and the demand for high-quality zinc for the manufacture of armaments accelerated the development of zinc metal production in Australia, leading to the commencement of large-scale operations using the then novel electrolytic technology. It is now a century since that endeavour commenced and the purpose of this book is to provide a short historical record of the zinc industry in Australia over that time, the changes which have occurred in production technology, the players involved, and the various factors that have influenced the conduct and fortunes of the industry.

Having been associated with many aspects of the business for half that time it has been of great interest to me to assemble the information into this format and I hope that it will be of interest to others who might have connections with the mining and metals industry.

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INTRODUCTION

Following the gold and copper booms of the middle to late 19th century, interest developed in the extraction of silver and lead from a number of deposits which had been located throughout Australia by the early prospectors in their search for gold and copper. Initial mining operations were in oxide ores of lead and silver from which zinc had been largely removed by the weathering process. Many of the early mining fields were opened on this basis, in particular the Broken Hill and Tasmanian – Zeehan fields, where major mining booms took place. As the oxide ores were depleted, attention turned to the deeper primary orebodies which consisted of sulphide minerals and usually contained greater quantities of zinc than lead and silver. There was little interest in zinc at the turn of the century and in fact it created major problems for the recovery and concentration of lead and silver to the extent that many mines and associated smelters were unable to continue profitable operations. The 'zinc problem' was seriously addressed at Broken Hill with the development of froth flotation as a means of separating; first sulphide minerals in general, and then individual sulphide minerals by differential flotation. This enabled the production of separate zinc sulphide concentrates as potential feed for zinc smelters.

Zinc metal production commenced in Australia in a small way for local consumption at Cockle Creek, near Newcastle, New South Wales in 1902 following a failed attempt to produce zinc by an electrolytic process at that site between 1897 and 1899. That initial production used the retort process, but was commercially unsuccessful and only operated for five years. A second attempt was made using the retort process at Port Pirie in 1909, but was also unprofitable although it did continue operating until 1920. Those operations used the plentiful supply of zinc concentrates from the Broken Hill mines to supply local demand, but the large bulk of zinc concentrate was exported to European smelters, particularly in Germany and Belgium under the control of the German trading company Metallgesselschaft. At that time the United Kingdom imported much of its zinc metal from those European smelters.

The commencement of the First World War in 1914 created a crisis for both the supply of metal to the United Kingdom, and the markets for zinc concentrates from the Broken Hill mines. The solution to this problem was the formation of the Electrolytic Zinc Company of Australasia Limited in December of 1916 to construct a zinc smelter using the then newly developed electrolytic zinc process, thus commencing the large-scale smelting of zinc in Australia and a major export industry. The smelter developed at that time at Risdon in the suburbs of Hobart, Tasmania, continues on today covering a period of one hundred years, and is now over five times its original size. Other operations such as the Imperial Smelting Furnace at Cockle Creek and the small electrolytic plant at Port Pirie have come and gone, but a relatively new large electrolytic plant is now operating at Townsville in North Queensland, significantly expanding the production of zinc metal in Australia introducing the latest technology and environmental controls.

Australia remains the world's largest exporter of both zinc concentrates and zinc metal, although far from being the largest producer – which is now China – well and truly surpassing the United States of America which held that position in the early part of the 20th century and is now heavily reliant on imports.

The following provides a brief record of zinc production in Australia over the past century. The mining operations which have contributed to the output of zinc concentrates have been briefly described in the first section of the text; however, emphasis has been given to the zinc metal production operations, their origins; and technical aspects of the processes used and the changes that have occurred over the past 100 years.

CHAPTER 1 – THE BEGINNINGS

BROKEN HILL

A large part of the beginnings of industrial Australia can be traced back to Broken Hill in outback New South Wales. The discovery of lead and silver and the wealth it created sparked unprecedented development in the industrial fabric of the country. Zinc smelting became a key and integral part of this development.

Following the gold rush, the interest in prospecting was widespread and during the 19th century many ventured into new territory to try their luck. Prospectors from the Cobar field in central New South Wales drifted west and one of those, Paddy Green had his attention drawn to mineral samples taken from a well sunk at Thackaringa which he identified as galena (lead sulphide) containing high levels of silver. This resulted in the pegging of leases and the formation of the Pioneer Mining Company in 1876. A parcel of ore was extracted and shipped to England for smelting, but was jettisoned by the ship in a storm. A second parcel was sent and arrived in 1880 and returned a handsome profit. The levels of silver in the ore were exceptionally high at over 10 000 ounces per ton, and news of this resulted in a rush to the area. New deposits were found, particularly near Umberumberka in 1882, where a townsite was established, later changing its name to Silvertown and then Silverton as it is known today. There were many small mines of short life extracting surface lodes and many with exceptionally high grades of silver. The Umberumberka, Day Dream, Apollyon and Pinnacles Mines were larger and deeper operations.

Mount Gipps pastoral station was located in the nearby Barrier Ranges and in 1883 employed a young boundary rider named Charles Rasp who had followed the activities at Silverton and developed an interest in prospecting. He noticed a heavily mineralised outcropping at Broken Hill which he thought may have been tin and together with two friends, David James and Jim Poole who were excavating a dam at the time, paid for the samples to be assayed in Adelaide. This revealed that the material was indeed galena, but with a relatively low silver content compared with nearby Silverton. However, they decided to persist and fund a drill hole to see how far the deposit might extend below the surface, and to this end took on three more partners including the station manager George McCulloch. The syndicate pegged seven leases at that time (Block numbers 10 to 16) covering about 300 acres. Assay results of the drilling did not show higher silver values and in fact returned only about ten to 12 ounces per ton, but it did indicate the presence of a large orebody. Membership of the syndicate changed and increased to 14 in order to secure more capital, and it was agreed to sink a shaft to further explore the deposit. The shaft was named the Jamieson Shaft after the Government surveyor William Jameson who had joined the syndicate. On this occasion a section of silver chloride was encountered and the ore returned 700 ounce of silver per ton.

In August 1885 the syndicate floated "The Broken Hill Proprietary Company Limited" (BHP) in order to fund full scale development of the orebody at a price of £9 per share. The interest and speculation was so great that within three years those shares were worth £409. Many others took up adjacent leases, and BHP floated off three subsidiaries – Broken Hill Proprietary Block 14 Company, British Broken Hill Proprietary Limited and Broken Hill Proprietary Block No. 10 Company Limited, leaving BHP with three leases Blocks 11, 12 and 13. William Jameson became the first manager of BHP.

Early companies operating the Broken Hill leases up to 1900 were:

The Broken Hill Proprietary Company Limited (BHP) Broken Hill Proprietary Block 14 Company British Broken Hill Proprietary Limited Broken Hill Proprietary Block 10 Company Ltd Sulphide Corporation Ltd (Central Mine) Broken Hill South Silver Mining Company Ltd North Broken Hill Ltd Junction Lead Mining Company

Early smelting operations

Early parcels of high-grade ore were shipped to England from the Silverton field and from Broken Hill to the Intercolonial Smelting and Refining Co. at Spotswood in Melbourne as a trial. The initial treatment was confined to oxidised lead-silver ores using established blast furnace practice. Following successful treatment and starting in 1886, blast furnaces were built at Silverton (Day Dream Smelters), at Broken Hill by four of the operating companies, and at Dry Creek, Port Adelaide for the Broken Hill Proprietary Block 14 Company and the Junction Lead Mining Company. Concentrators were also installed to essentially separate gangue minerals and upgrade the feed to the blast furnaces in terms of the lead and silver content. Most of the lead bullion was initially shipped to the UK through Port Pirie in South Australia for refining and separation of silver. However, BHP subsequently established a lead refinery at Port Pirie at about the same time as the British Broken Hill Proprietary Company built a blast furnace in Port Pirie in 1889. One year later the smelting operation was leased to BHP who purchased it in 1892. In 1897 BHP transferred all smelting operations from Broken Hill to the Port Pirie site.



FIG 1.1 Smelting operations at Broken Hill, 1890.

Soon after 1893 most of the higher-level oxidised ores rich in lead and silver and relatively low in zinc had been depleted, and the mines were moving into sulphide rich zones of the orebody and more complex mineralisation. Similar changes had been faced in Europe and lead sulphides had been used as feed to the blast furnace by prior roasting of the ore to eliminate sulphur and produce a hard clinker suitable for blast furnace feed. Early roasting methods used open heaps soon replaced by sintering processes using the Huntington-Heberlein sintering pot and later the updraft sintering machine.

The zinc/sulphide problem

Sulphide ores differed from the surface oxide material in that they contained high levels of zinc. Oxide ores derived from the weathering of primary sulphide ores usually lost the zinc content into groundwaters as a result of the weathering process during which the zinc could be precipitated as a carbonate or silicate to form a separate zinc rich orebody elsewhere. Hence, as the mining operations moved through the weathered zone into the base sulphide ores substantially greater quantities of zinc were encountered. The separation of lead mineralisation for smelter feed became much more difficult and this simply created large volumes of slag for the smelters, reducing efficiency and rendering the operation uneconomic. It therefore became necessary to separate zinc from the lead and silver mineralisation. At first the only separation methods available were those which relied on the differences in density of the lead and zinc mineralisation. This was practical in high-grade areas of the orebody, but in some operations such as those of the North Broken Hill Silver Mining Company it was impossible to economically separate lead and silver and the company closed its operations and went into liquidation in 1894. Other operations and BHP in particular installed elaborate concentrating mills consisting of crushers, jigs, tables and vanners. The ore was separated into two concentrates - one high in lead and silver and other high in zinc. The lead concentrate still contained significant amounts of zinc which presented a problem to the smelters in terms of the large amount of slag produced and low lead recovery, but also in terms of its effect on furnace operation and brickwork.

It was hoped to sell the zinc gravity concentrate, which still contained high levels of lead and silver, to zinc retort smelters, allowing the lead and silver to be recovered from the retort residues. This practice was starting to be used in German zinc smelters at Freiberg and Silesia due to the changing nature of local ores, but was costly in terms of the need for roasting to remove sulphur, the effect of lead on retort life and the degradation of the product zinc metal. However, the accessible smelters at the time, such as those in Belgium and the UK still had access to oxide ores without the need for roasting or subsequent treatment of retort residues, and were uninterested in purchasing such materials from the Broken Hill mines.

Consequently, the tailing material containing most of the zinc as well as significant lead and silver values generally continued to be stockpiled at the mine site, which represented a huge loss of value to the mining companies. In 1904 the dumps were estimated to contain over 6.5 million tons. This posed a severe threat to the ongoing viability of the Broken Hill field.

TASMANIAN LEAD AND ZINC

The Mount Bischoff tin deposits were discovered in 1871 as a result of a Governmentsponsored survey to search for gold; Tasmania had been left behind and depleted of resources by the gold rush in Victoria, and wished to redress the balance. Mount Bischoff became the world's greatest tin mine for many years to come. The Emu Bay Railway was built by a private company to serve the tin mine and the town of Waratah from the Port of Burnie. This discovery and new access created a rush of prospectors to the Tasmanian West Coast. Only small amounts of gold were found, although gold claims were pegged on Mount Lyell in 1883. The Mount Lyell Gold Mining Company was formed to exploit these deposits in 1888. Significant amounts of copper were discovered in the mine and in 1892 Adelaide financiers, Orr and Bowes-Kelly (a substantial BHP investor) recognised the potential of a rich copper orebody and purchased the mine. They also realised the need for a railway to service the mine and reformed the operation as the Mount Lyell Mining and Railway Company, completing a railway from the mine to the port of Strahan in 1896. A copper smelter was completed in 1901 by the then manager and renowned metallurgist Robert Sticht.

The Zeehan-Dundas silver-lead deposits were first discovered in 1882, with the Silver Queen Mine opening in 1887. Full development of the field was delayed until the Zeehan to Strahan railway was completed by the Tasmanian Government in 1892, allowing access from the port of Strahan. Previous access had been very limited due to the difficult access through Trial Harbour. Because of the extent of this field, it was regarded at the time as another Broken Hill, but in fact this was not the case as the mines were generally shallow and ore ran out at depth. In the early 1890s there were 159 companies operating in the field and Zeehan was a boom town and the third largest in Tasmania – then known as 'Silver City'.



FIG 1.2 The town of Zeehan – early 1900s.

Gold was discovered on Mount Read by Alfred Conliffe in 1890 and the Mount Read Mining Company was formed to work the deposit. Rich silver-lead-zinc mineralisation was found below the mine and later became the basis of the Hercules Mine which reached full production in 1900. The township of Williamsford was established to service these operations and was connected to Zeehan by the North East Dundas Tramway in 1898.



FIG 1.3 Williamsford Station, 1900.

The Mount Black/ Rosebery deposits were discovered by Tom McDonald in 1893 and he floated the Rosebery Gold Mining Company to work the deposits and later the South Rosebery Mining Company to work the southern extensions of the orebody. In 1896 the names were changed to the Tasmanian Copper Company and the Primrose Mining Company.

Tasmanian Smelters

The ores from the Zeehan-Dundas field were shipped to Europe for smelting and a large portion went to German smelters through trading arrangements with the Australian Metals Company, owned by Metallgesellschaft (MG). It made economic sense to smelt locally and so MG formed The Tasmanian Smelting Company and proceeded to erect a smelter at Zeehan in 1898. A tramway was also constructed from Dundas to the smelters and extended to serve the Hercules Mine at Williamsford. The smelter superintendent, Max Heberlein understood the processing requirements for sulphide ores and indeed ores rich in zinc and devised a sintering process to enable these ores to be smelted. The Huntington-Heberlein furnace was a significant advance and became widely used in the smelting industry at that time for the sintering of sulphide concentrates.



FIG 1.4 The Zeehan Smelters, 1920.

The zinc problem

The Tasmanian ores differed from those at Broken Hill in being more complex and finer grained. Consequently, the separation of zinc from lead and silver was more difficult and this particularly applied to the ores from the Rosebery field.

An extension of the Emu Bay Railway to Zeehan enabled ores from the Rosebery Mines to be transported to the Zeehan Smelters in 1905. However, the treatment of zinc rich ores was difficult, supplies from the Zeehan and Dundas mines were diminishing and coupled with low lead and silver prices, the smelters became unprofitable and closed in 1909. At the instigation of the Tasmanian Government they were reopened in 1911 with plans to devise new ways to treat zinc rich ores. A merger was also proposed with the Primrose and Hercules mines; however, finance could not be organised and the Mount Lyell Mining and Railway Company pre-empted the deal by purchasing the Read and Rosebery field in 1913

SOLUTIONS TO THE ZINC PROBLEM

Both at Broken Hill and the Tasmanian West Coast the need to achieve efficient zinc separation as a revenue stream became critical to the viability of the mining operations and a great deal of research was directed to this end. One approach was through improved physical separation of the mineral components of the ore to produce separate lead and zinc concentrates and the other was through the development of smelting processes to handle the complex ores and achieve separation as product metals.

Improved mineral separation processes

In an attempt to solve the problem, the Australian Metal Company built a magnetic separation pilot plant in 1899 using a machine from Mechernick Electro Magnetisch Gesellschaft in Germany, and a unit was installed at the Central Mine at Broken Hill in 1901. This was only a marginal improvement and did not provide a real solution to the

problem; only two-thirds of the lead was being recovered to concentrate and any zinc that appeared in the lead concentrate attracted a penalty imposed by the lead smelter in their purchase terms.

In 1899 chemist Charles Potter recognised that sulphide particles attached themselves to gas bubbles which formed when sulphide ores were digested in acid, and demonstrated that he could separate sulphide minerals treating crushed ore with warm dilute sulphuric acid. A patent was obtained in 1901 and Potter cooperated with G. A Goyder of the South Australian Mines Department to produce a flotation machine known as the Goyder-Laughton flotation machine which was first installed at the Broken Hill Block 14 mine in 1904.

At the same time the General Manager of BHP, Guillaume Delprat devised a procedure for treating sulphide ore with hot saltcake (sodium bisulphate) solution which similarly separated the sulphide minerals as a scum which could be skimmed from the surface. The so-called Delprat process was patented in 1902 and installed for the treatment of tailings at the BHP operations. With a commercial sale of the Delprat Process to a German firm in 1904 Potter took court action for infringement of his earlier patent. After a prolonged legal battle he lost the case and had to pay court costs, however he obtained a generous arrangement with Delprat to merge their interests as the Delprat-Potter flotation process.

G D Delprat had retained the services of Belgian chemist A J De Bavay to assist in his litigation with Charles Potter. De Bavay was employed by a major shareholder in BHP – Montague Cohen at the Fosters Brewery in Melbourne, but took an interest in the problem and concluded that flotation of the sulphide minerals was by means of the carbon dioxide generated by the action of acid on the ore. He demonstrated that aeration by vigorous agitation will work just as effectively and the performance was enhanced by the addition of oils to the pulp. He took out patents on the so-called De Bavay Process in 1904 and formed the De Bavay Treatment Company to exploit that technology.

At about the same time another process which had been developed in England and known as the Cattermole Process was drawn to the attention of Sulphide Corporation. This process mixed quantities of a heavy oil with a pulp of the ore in water causing the sulphide particles to clump together as granules enabling them to be physically separated from the gangue minerals which remained suspended in the pulp. In March 1904 Sulphide Corporation imported a small-scale plant for installation at the Central Mine. It came with an expert - G A Chapman from Minerals Separation Limited of London, who subsequently found that the quantity of oil could be significantly reduced and with vigorous agitation the oil coated sulphide minerals tend to float on the surface of the pulp as a froth or scum which can be skimmed off for collection as a concentrate. This became the Mineral Separation Process at the Central Mine.

All this development activity encouraged a group of investors from Melbourne to visit Broken Hill to examine the commercial opportunities of treatment of the huge tailings dumps and recovery of the contained zinc. The group included W S Baillieu, who held shares in the North Mine, a stockbroker – Lionel Robinson and his journalist brother W S Robinson. Shortly after, a consulting mining engineer – Herbert Hoover (a future President of the USA) was sent by the group to Broken Hill to review the opportunity and to purchase the rights to treat the South Mine tailings dumps on behalf of a syndicate of investors. That syndicate became the Zinc Corporation in 1905 which erected a pilot plant to evaluate a number of processes. At first they tried the Potter Process and then the Cattermole Process but without any real success. At this point Zinc Corporation was running out of money and needed to find a viable treatment solution. Herbert Hoover encouraged them to try the Elmore Vacuum Process which had been applied at the Pinnacles Mine in 1907. In this case crushed ore was agitated as a pulp in acidified water with a small amount of oil and then fed into a vacuum vessel. Dissolved air and other gases came out of solution under vacuum to form small bubbles which attached to the sulphide mineral particles and floated to the surface where they could be skimmed off. Hoover went to Broken Hill at that time to supervise the construction and initial operation of a plant using the Elmore Process, which was brought into operation in 1908. With improvements in the Mineral Separation Process this was progressively adopted and fully replaced the Elmore Process in 1911. With this success Zinc Corporation had the funds to expand and purchase its own mining operations in Broken Hill South Blocks Company Ltd in 1911.

In parallel with these developments North Broken Hill Limited engaged the De Bavay Treatment Company to treat its tailing dumps over a period of five years. A plant was constructed based on the De Bavay Process in 1909 and the company reformed as Amalgamated Zinc De Bavay Limited. As well as treating tailings from the North Mine, this operation also treated material from Broken Hill Proprietary Block 10 Ltd and from Broken Hill South Ltd.

These processes enabled the concentration of sulphide minerals in total and rejection of waste gangue minerals, but did not achieve any separation of zinc and lead. In practice this still required the use of methods relying on differences in density or the use of gravity to separate out the heavier lead sulphides from the bulk. A breakthrough in separation came in 1910 from E J Horwood, the manager of the BHP operations. By means of a short low temperature roast of the recovered bulk sulphides he was able to oxidise the surface of galena so that it would no longer be collected in a second stage float.

F J Lyster at the Zinc Corporation found that changing the pH of the pulp could result in lead being more easily floated than zinc and was employed in their operations from 1912. He also used Eucalyptus oil for the first time.

L Bradford at the BHP operations found that sulphur dioxide addition would depress the flotation of zinc blende while allowing the lead to continue to float. Bradford further discovered that by adding small amounts of copper sulphate to the residual pulp, the flotation of any sulphides present and zinc in particular would be greatly enhanced or 'promoted'.

Around the same time T Owen at the Junction North Mine introduced the controlled injection of fine air bubbles to the pulp to enhance the collection of the more readily floatable galena.

An amalgamation of these techniques led to the efficient separation of lead and zinc into separate sulphide concentrates by differential flotation to satisfy the requirements of the smelting industry, and by 1912 the zinc problem had essentially been solved. Broken Hill had become a centre for mineral dressing technology and the flotation process soon spread throughout the world. It was particularly important to the copper industry as it allowed the exploitation of low-grade ores which could otherwise not be economically treated. The issue now was to develop markets for the zinc blende concentrates. Apart from developing overseas markets one option was the development of local zinc smelting operations. These could be based on existing retort smelting technologies or the possibility of new technology based on the electrolytic deposition of zinc.

EXTRACTION PROCESSES FOR THE SEPARATION OF ZINC

Pyrometallurgical methods

In a search for methods to separate zinc from complex lead-zinc ores the Metals Extraction Company in Britain had invented a process for leaching zinc from roasted ores which left a lead-silver residue for smelting and converted the leached zinc into zinc oxide for sale to zinc smelters. Tasmanian ores were tested at Llansamlet near Swansea in Wales and it was decided to form a subsidiary the Tasmanian Metals Extraction Company (TEM) to erect a plant at Rosebery. Construction began in 1909 for a plant to treat 100 tons per day of ore and the facilities included a coal fired power station built on a siding of the Emu Bay Railway. The plant commenced operation in 1912, but was a complete technical failure and was abandoned in 1914.



FIG 1.5 The Tasmanian Metals Extraction Company – Rosebery, 1914.

Great secrecy surrounded both the details of the TEM process and the reasons for its failure. However, it is understood that the principles of the process were to roast the concentrates to eliminate sulphur and then to leach the calcines using water and excess sulphur dioxide gas in tall absorption towers. The zinc oxide dissolved as zinc bisulphite and that solution was separated from residual solids containing lead and silver which were sent to the smelter. The filtered zinc solution was precipitated. The resulting zinc sulphite was dried and calcined to produce zinc oxide and sulphur dioxide gas, which was sent to the leaching towers. Part of the zinc oxide was recycled to the sulphite precipitation stage with the remainder as product. Any oxygen present in the system would have resulted in the formation of highly soluble zinc sulphate, which had to be precipitated as a basic zinc sulphate by the addition of zinc oxide or lime. It is likely that excessive sulphate formation would have defeated the efficient operation of the process and is possibly a major cause of failure.

The electrolytic process

The electrolytic deposition of copper was first described in 1800 by Cruikshank. It was commercially used for electrorefining after 1870, stimulating the interest in application to electrowinning other metals and in particular zinc.

Electrolysis had been proposed by Leon Letrange in Paris in 1881 in which he suggested roasting the zinc blende, leaching the zinc in sulphuric acid solution and electrolysing the resulting zinc sulphate solution to produce zinc metal. However, all his attempts failed as did others attempting to use sulphate solutions. As a result, attention was turned to the use of chloride solution and a patent was taken out by Carl Hoepfner in 1890. He subsequently constructed a plant at the Mond and Company's site at Winnington, England in 1896 which was successful, but was integrated with the nearby chemical plant which could provide the calcium chloride leaching reagent and accept back the chlorine generated by electrolysis for chemicals manufacture. This was not practical in the Australian context.

Edgar Ashcroft was an electrical engineer working for BHP to install electric lighting. He became interested in the zinc problem at Broken Hill and thought that electrolysis may be a possible solution. He experimented with the potential of a process to dissolve zinc in a chloride solution and recover zinc metal by electrolysis, and in 1894 patented a complex chloride-based process for the electrolytic production of zinc. Chlorine produced at the anode can be used to directly attack zinc sulphide to form soluble zinc chloride and elemental sulphur. With the support of a number of the mining companies he tested the process on a small scale in Broken Hill and in London, and with some confidence, the Sulphide Corporation (Ashcroft Process) Ltd was floated in London in 1895. In 1897 a 10 ton per day electrolytic zinc plant was constructed at Cockle Creek to Ashcroft's specifications. The process experienced major problems with impurity build-up in solutions, particularly manganese, the zinc deposits became spongy and the situation could only be rectified by discarding the solution and starting again. He experimented with sulphate and alkaline solutions as well as his original proposal of chloride solutions, but all without success. Cost over-runs were high and in 1898 the project was abandoned as a failure and Sulphide Corporation turned its attention to lead smelting on the Cockle Creek site.

Ashcroft returned to England where he continued to work on chloride electrolysis in the laboratories of James Swinburne and published details of work on the electrolysis of molten chlorides. However, there were no practical outcomes from this effort.



FIG 1.6 The Cockle Creek (Ashcroft) zinc plant, 1898.

Following the failure of the Ashcroft Electrolytic Process, Sulphide Corporation commissioned a zinc distillation retort furnace at the Cockle Creek site in 1902. A second was added in 1906 but this proved to be uneconomic, probably because of the fact that only low-quality zinc feed material was available from Broken Hill at that time, and the operations were closed in 1908. However, lead smelting continued at Cockle Creek until 1922.

BHP also decided to install a retort plant at its Port Pirie smelter to use higher zinc content materials and the first trial furnace was commissioned in 1906. This was troublesome and new furnaces of German design each holding 144 retorts were selected. The first of the new furnaces was commissioned in 1908 and the full installation completed in 1915 with five operating furnaces. The retorts processed zinc calcines from roasting concentrates using Hegler Hearth roasters. This plant operated until 1921 and produced a total of close to 40 000 tons of 'spelter' over that period. However, recovery was poor and it was never a profitable operation.

MARKETS FOR ZINC MATERIALS PRIOR TO WORLD WAR I

The first European zinc smelting operation was by John Champion at Warmley near Bristol, England in 1743, based on calamine deposits in the Mendip Hills. It is understood that he brought the technology from China. Although Champion went bankrupt, his business survived and an expanded zinc smelting industry was also formed around Swansea in Wales, which was also a well-established centre for the smelting of copper. The extensive zinc carbonate (calamine) deposits around Aachen in Belgium and in Silesia saw a zinc smelting industry arise in these areas, eventually dominating the trade in zinc metal, or spelter as it was called in those days. In England the smelting industry became scattered around small calamine deposits which closed as soon as the deposits were exhausted and by the end of the 19th century there was only one smelter remaining which imported its raw materials – The Swansea Vale Spelter Company. Swansea Vale imported calamine ores from Italy, Spain and America and was reluctant to convert to the use of zinc blende because of local problems with the emissions of sulphur into the atmosphere and its effect on the countryside. In contrast the Belgian and German smelters maintained

their dominance of the zinc business by embracing the use of zinc blende to replace depleting sources of oxide ores and to enable expansion of their businesses.

In 1880 the German family trading enterprise run by Henry Merton floated as a public company named Metallgesellschaft, specialising in the trade and manufacture of metals and oxides. They established worldwide links and associations in the metals business and through their subsidiary Henry Merton and Company in London, and had substantial interests in the Upper Bank Smelter of Pascoe, Grenfel and Sons of Swansea. Another German firm, Aron Hirsch and Sohn from Halberstadt, also had a major interest in the Swansea Vale Spelter Company. Further afield Metallgesellschaft had associations with the Hoboken Smelter in Belgium, Penoles in Mexico and the American Metal Company Limited in the USA. They had developed close ties with the Zinc Corporation in Australia and marketed most of the zinc blende concentrates from Broken Hill into the European smelters through their subsidiary the Australian Metal Company.

Of the total zinc concentrate produced in Australia in 1913, 54 per cent went to Belgium, 31 per cent went to Germany, 7 per cent to France, 6 per cent to Holland and only 2 per cent to England.

Although Britain was a large consumer of zinc metal it imported around 70 per cent of its requirements in 1913, mainly from Belgium and Germany.

FURTHER ATTEMPTS AT THE PRODUCTION OF ZINC BY ELECTROLYSIS

Prominent metallurgist at the time, James Gillies, had worked at Broken Hill on development of flotation equipment and saw the opportunity to ultimately process the new zinc concentrates and produce zinc metal by use of electrolytic deposition. He realised that the key to this was securing adequate supplies of low-cost electric power, and Tasmania was the obvious location, since the potential was widely known and in fact the first hydroelectric power station had been installed at Launceston Gorge in 1899. Gillies came to Tasmania in 1908 to investigate the development of hydroelectric power for this purpose, and was attracted to the proposals by landowner Harold Bisdee and Professor Alexander McAuley of the University of Tasmania for a scheme on the Great Lake in the central highlands. There was also a similar zinc issue with the ores from Tasmanian West Coast Mines in the Rosebery area for which the Tasmanian Government was keen to develop a solution. In that case the mines were running out of lead ores to supply the local smelters and would have to close if outlets for the considerable quantities of zinc material could not be found.

Gillies devised an electrolytic process based on initial roasting of the concentrates which he claimed eliminated many of the problems experienced by Edgar Ashcroft. He set up an experimental facility in Melbourne capable of treating 80 tons of ore per week and successfully tested ores from the Hercules Mine on the Tasmanian West Coast. This encouraged him to establish the Complex Ores Company Limited which held patents for his electrolytic zinc process. The process was also reviewed and endorsed by Mr James Taylor formerly New South Wales Government Metallurgist and Fellow of the Royal School of Mines and the Institute of Chemistry.

A laboratory was set up locally at Salamanca Place in Hobart for further testing and the Complex Ores Company Limited purchased an industrial site at Snug on North West Bay south of Hobart for the purpose of building both an electrolytic zinc plant and a calcium carbide plant, which was also in high demand at that time. Gillies negotiated with the Tasmanian Government for the right to construct the Great Lakes Power Scheme which was authorised by State Parliament under the Complex Ores Act in1909, and a new subsidiary company was formed to undertake the project; The Hydro-Electric Power and Metallurgical Company in 1910. Construction of the power scheme commenced, but there were significant setbacks due to an extremely bad winter season when all work ceased and there were significant cost pressures. In 1913 it became apparent that finance was not available either in Australia or London for the Company to complete the Great Lakes Power Scheme and legislation was passed in 1914 for the Tasmanian Government to acquire the partly completed scheme and finish the task. The Hydro-Electric Department was formed and the first two generators at the Waddamana Power Station commenced operation in May 1916. This was progressively expanded over time from 7 MW in 1922 to 49 MW in 1931 and later duplicated with Waddaman B power station at 48 MW.

THE IMPACT OF WORLD WAR I

The First World War broke out on 4 August 1914 placing a substantial burden on Britain to secure supplies of zinc for its industry and for the growing demand for the production of munitions. They were in the invidious position of having minimal domestic production and minimal access to resources and turned to the USA for supplies. The zinc smelters there expanded to meet the demand, but at considerably inflated prices. The main suppliers were the New Jersey Zinc Company, American Smelting and Refining Company and The American Zinc, Lead and Smelting Company. Actual imports did not replace the pre-war imports from Germany and Belgium since the high metal prices dampened demand for other uses such as galvanising at the time. Munitions also required high-grade zinc metal and this was not produced by the local smelters in Britain. The only source of high-quality metal available was from the American producers at the time or the possibility of supply from the new electrolytic process. Hence, considerable emphasis was placed on applying this new technology if at all possible.

The British Board of Trade confiscated the German shareholdings in the Swansea Vale Spelter Company and this ended up in the hands of industrialist R Tilden-Smith; however, the Government dithered over any decisions about support for the expansion of zinc smelting facilities. At that time, they probably held the view that the war would soon be over and normality would be restored.

With the declaration of war the Australian miners lost their major markets and had to begin stockpiling zinc concentrates at the mines. Zinc Corporation made early overtures to the British Government within a month of the outbreak of hostilities, proposing the construction of a smelter in England, however the British Government Board of Trade rejected the offer and in the words of F A Govett, Chairman of The Zinc Corporation, made at a shareholders meeting in 1916; 'If the Government had then grasped the importance of the situation and seen fit seriously to entertain our offer, we should now actually be producing spelter here in England, but, of course, they did not realise the necessities until too late'.

Some attempts were made to sell concentrates into the American market through connections with Herbert Hoover who was then Joint Managing Director of Zinc Corporation and later became President of the USA in 1929. Because the US producers had ample supplies of their own, the prices were poor and unprofitable, so this was not a viable solution for the Australian producers.

Another irritation was the fact that the Broken Hill producers had been attempting to secure through the courts, the cancellation of the long-term contracts of supply to the German smelters, rather than suspension for the duration of the war. This was settled by The Board of Trade in 1916 under its wartime powers and about the same time the Zinc Producers Association was formed with the encouragement of the Australian Government to present a unified front in order to progress a solution to the problem. It was at this time that the idea of an 'Imperial Scheme' arose which would 'build sufficient smelters in England and Australia to supply the Empire with spelter'. A visit to London in June 1916 by William Morris Hughes - Prime Minister of Australia, accompanied by W S Robinson was successful in convincing the British Government of the need for action and secured a deal in which the British Government would take annual quantities of zinc concentrates from the Zinc Producers Association members from 1 January 1921 until 30 June 1930, totalling 250 000 tons per annum up to 1925 and 300 000 tons per annum thereafter. Prices were fixed to 1925 and then regulated in line with the London Metal exchange pricing. There was also a right for supply of 45 000 tons per annum of spelter to the Government at market prices. This deal was widely seen as far too favourable to the Australians and was seriously criticised in the House of Commons. It was estimated that the British Government lost of the order of £8.3 million in total on this deal due to major falls in zinc prices after the war.

In England David Lloyd George was at that time Minister for Munitions in the Asquith Government and was concerned about the need for high-grade zinc metal and that the only source was from American producers at exorbitant prices and onerous loan conditions from American Banks. He was keen to see the establishment of an electrolytic industry and reportedly offered £500 000 to support the construction of an Australian operation. This motivated the Earle Government in Tasmania and Prime Minister Hughes to call a conference in Melbourne in October 1915 with zinc concentrate producers to co-operate in the marketing of zinc concentrates and in developing electrolytic zinc smelting facilities. Hughes approached James Gillies about his Tasmanian proposals and sought a detailed report from his advisor – John Higgins. Higgins reported favourably on the Gillies scheme.

In Tasmania the outbreak of World War 1 in 1914 then saw the confiscation of the Zeehan Smelters from the German owners by the Tasmanian Government.

The Mount Lyell Company saw the opportunities for applying the flotation technology developed at Broken Hill to solve the zinc problem and allow the smelters to operate efficiently on high-grade lead-silver concentrates. They formed a subsidiary, Mount Read and Rosebery Mines Limited, negotiated an option to purchase the Zeehan Smelters and developed plans to erect an electrolytic zinc plant at Zeehan based on electric power from their Lake Margaret hydroelectric power scheme.

ELECTROLYTIC ZINC PRODUCTION IN AUSTRALIA

Following the Tasmanian Government's takeover of the hydroelectric power scheme on the Great Lake it was reluctant to extend its power transmission lines to Snug as the site proposed by James Gillies for the electrolytic zinc plant unless the process could be demonstrated as commercially successful. As an alternative, a site close to Hobart at Risdon was proposed for the purpose of building a demonstration plant to prove the technology. Gillies was amenable to this, and he sought permission to use crown land at Risdon for this purpose. Before giving approval the Government requested advice from the Chief Health Officer – Dr G D Robertson, since public opinion was hostile to the concept, citing the devastation that had been caused by the smelters of the Mount Lyell Company at Queenstown. Dr Robertson reported to the Minister for Mines in February 1916 that he was totally opposed to the company's proposal to roast zinc concentrates on site and emit sulphur bearing gases to atmosphere using a high stack. There was also some failure to demonstrate the integrity of the process as the requested tests had for some reason been abandoned, and so the Tasmanian Government refused to approve the construction of transmission lines.

In the meantime as part of the mission to sell zinc concentrates in the USA, Herbert Gepp, the then General Manager of Amalgamated Zinc (de Bavays) Limited was requested to visit the operations of the Anaconda Company at Butte, Montana to inspect a new process and plant for the production of zinc by the electrolytic method. This was the first plant in the world to successfully apply this technology. Advice about this operation had been obtained by W S Robinson who requested W L Baillieu, chairman of Amalgamated Zinc for Gepp to make the visit. The report was favourable and Robinson travelled to America to meet up with Gepp and Gilbert Rigg, a metallurgist from the New Jersey Zinc Company. Samples of Broken Hill concentrates were supplied for testing at Butte and the results of those tests were 'remarkably successful'. As a result, negotiations commenced with the Tasmanian Government in Hobart and W L Baillieu, representing Amalgamated Zinc, visited Hobart in March 1916 to meet with Premier John Earle who was keen to resurrect the original concept and secure an offtake of power from the new hydroelectric power scheme. This immediately followed on from the breakdown of James Gillies' dealings with the Tasmanian Government.

The technology offered by Amalgamated Zinc was indeed proven by the fact that it was operating at Butte, Montana and tests on Broken Hill material had been successful. The initial proposal also excluded the roasting of zinc concentrates on site as this would be done closer to the mines and zinc oxide calcines would be shipped to the Hobart site, thus eliminating the need to emit sulphur to the atmosphere and overcoming the objections of the Chief Health Officer. Herbert Gepp had recommended proceeding with the construction of a plant on the basis of the tests in America, but on a cautious and progressive basis. First with a small pilot operation and then expanding in a further two stages. This proposal was gratefully received by Premier Earle and an agreement was reached in July 1916 and the Company was given a lease of 50 acres of crown land at Risdon and the rights to a block of power equivalent to 3000 kW. One restriction on the use of the Risdon site related to the emission of "noxious fumes or smoke whereby injury may be caused to persons or property" and to restrictions on discharges to the Derwent estuary which may cause pollution and endanger the lives of people and fish.

Shortly thereafter a new company to undertake the development was formed as The Electrolytic Zinc Company Limited, sponsored by the Amalgamated Zinc Company and the Zinc Producer's association, whose members acquired shares. Construction commenced on the first stage of zinc plant on the Risdon site on 16th December 1916.

The Hydro-Electric and Metallurgical Company abandoned any plans for the production of zinc at the North West Bay site, but did eventually proceed with the production of calcium carbide and installed electric furnaces for this purpose. (Electrona).

The Mount Lyell Company had proposed the construction of an electrolytic zinc plant at Zeehan based on the zinc ores of the Mount Read and Rosebery Mines Limited and its Lake Margaret power scheme. However, with the formation of the Electrolytic Zinc Company and the commencement of construction of the plant at Risdon, Mount Lyell abandoned its plans and in 1920 sold Mount Read and Rosebery Mines Limited to EZ.



FIG 1.7 The Lake Margaret Power Station – Mount Lyell Mining and Railway Co.

Following the purchase of the Rosebery Mines EZ also purchased the Zeehan Smelters and constructed a pilot facility at the smelters to apply flotation technology to the highly complex Rosebery ores. This was successful and construction of a new Rosebery concentrator commenced in 1926. Meanwhile Herreshoff hearth roasters were installed at the Zeehan Smelters to roast Rosebery zinc concentrates and the calcines were transported to Strahan and shipped to the Risdon zinc plant. Lead concentrates were also shipped out through Strahan to Port Pirie for smelting.

Due to the Great Depression the Tasmanian West Coast Mines and the Zeehan smelter closed in 1930, but recommenced in 1936 until final closure of the Zeehan Smelters in July 1948 when all roasting of zinc concentrates was transferred to the Risdon site. During the closure period between 1930 and 1936 major works were undertaken at Rosebery and a change to transport of concentrates on the Emu Bay Railway to the port of Burnie was made. An aerial ropeway to transport ore from the Hercules Mine to the new Rosebery mill was also installed.



FIG 1.8 The Herreshoff roasting plant at the Zeehan Smelters.

DEVELOPMENTS IN ENGLAND

The National Smelting Company was incorporated in 1917 by the British Government (Ministry of Munitions), to construct zinc smelting operations at Avonmouth near an existing munitions site, where the roasting of zinc concentrates could be useful for the production of sulphuric acid needed for munitions and for the production of fertilisers. It also served to utilise the zinc concentrate supplies contracted by the government from the Broken Hill mines. Participation was sought from private enterprise in the smelting venture and competing proposals were put forward by Richard Tilden-Smith and by Zinc Corporation. At the time Zinc Corporation sought British Government support and protection from possible lower prices and the resumption of competition from Germany. This was not accepted and the project came under the control of Richard Tilden-Smith with the Government and Tilden-Smith each sharing the construction costs 50:50. In fact most of Tilden-Smith's share of expenditures was loaned to him by the British Government or borrowed from Lloyds Bank. Progress was very slow and indeed nothing was built on site until well after the war ended. The British Government lost all interest in further expenditure at that time and wished to divest their interests in the Avonmouth site. Lloyds Bank was also concerned about their loans to Tilden-Smith and unwilling to provide further funds for the purchase of the Government share and for completion of the zinc smelter at Avonmouth.

Another of Tilden-Smith's interests was in Burma Mines Limited with substantial mining tenements in Burma and this appears to have been of great interest to W S Robinson and The Zinc Corporation who were willing to negotiate a deal for their purchase along with interests in the National Smelting Company. A particularly complex arrangement was agreed in which the British Government wrote off its loans and Tilden-Smith retained some rights with non-voting preference shares. This occurred in December 1923 but the residual interests caused some constraints on the progress of the company until these were removed by reorganisation into the Imperial Smelting Company in 1929 which included

both the Avonmouth and Swansea Vale smelting operations under the effective control of Australian Zinc Corporation interests.

Under the control of the Imperial Smelting Company zinc production was concentrated at Swansea Vale in south Wales and at Avonmouth near Bristol adjacent to the government munitions factory. In 1934 a vertical retort installation was constructed at Avonmouth following the designs from the New Jersey Zinc Company. The two other major zinc producers in the UK at the time were the New Delaville Spelter Company Ltd at Bloxwhich near Bermingham, and the Seaton Carew operations of the Sulphide Corporation (Central Zinc Company Limited) treating concentrates from the Central Mine at Broken Hill. Both these operations had closed smelting operations from 1930 due to the Great Depression and were purchased by the Imperial Smelting Company in 1933 and 1936 respectively.

The predominance of horizontal retort technology with its high labour and operating costs prompted an examination of a new approach to zinc production by thermal reduction methods. The application of electrolytic technology in the UK was not considered because the relatively high cost of electric power would have rendered it uneconomic. Only places with low-cost hydroelectric power were considered suitable. The main problem with thermal reduction processes was associated with the condensation of zinc from the vapour state to metal without the formation of zinc oxide, and the research group of the Imperial Smelting Company began investigating this in 1938. However, the outbreak of the Second World War stalled this work as effort was concentrated on the production of zinc metal for munitions. Under government promotion zinc production capacity was substantially increased by expanding horizontal retort technology, although this strategy was not favoured by the industry which preferred the application of vertical retort technology with much lower labour requirements. The Bloxwich and Seaton Carew smelters were also restarted in 1941, but closed immediately after the end of the war in 1945. At that time all smaller zinc smelting operations had also closed and Imperial Smelting became the sole producer of zinc in the UK with major supply of concentrates from Broken Hill and effective control by Australian interests.

In 1949 the Imperial Smelting Company Limited merged with its major shareholder, the Zinc Corporation to form the Consolidated Zinc Corporation. Consolidated Zinc Corporation also took over Sulphide Corporation in 1949 and acquired the Australian operations at Cockle Creek near Newcastle.

Research work on zinc condensation technology had resumed in 1943 using the concept of rapid quenching hot gases containing zinc vapour using molten lead to effect condensation to molten zinc without time to oxidise and form zinc oxide. This idea was successful and an experimental furnace was erected at Avonmouth in 1947 as a modified lead blast furnace. It was found possible to produce lead at the same time which was an added bonus for the new process. Because of the need to shut down and regularly clean accretions from the furnace the next step was to build two larger furnaces at Avonmouth with one always in operation. The first commenced in 1950 and the second in 1952. One factor affecting the performance of the furnace and limiting capacity was the high density of sinter produced by the current downdraft sintering machines. A change to the new updraft sintering machine pioneered at Port Pirie resolved this problem and significantly improved the performance of the furnaces. A decision was then made to increase the scale of operation to a new furnace of 70 000 tonnes per year of zinc, to be constructed at the Swansea Vale site. This furnace commenced operation in 1960.

In the 1950s there was a drive by the Australian Government to industrialise the nation and move it from a high dependence on agricultural products. This included a desire to see more of the mine output from Broken Hill being smelted in Australia. In response to this the Consolidated Zinc Corporation decided to also install one of the new Imperial Smelting Furnaces (ISF) at its site at Cockle Creek with ready access to coke supplies from the nearby steel mills owned by BHP. Construction of the furnace was completed in 1961. During this period the electrolytic zinc plant at Risdon was also progressively expanded.

During the 1960s a number of ISFs were licensed and constructed around the world including France, Zambia, Rumania, Germany, Japan and Canada. A larger version of 120 000 tonnes of zinc capacity was designed and installed at Avonmouth in 1967, allowing the smaller furnace at Swansea Vale to close. Although the ISF was seen as the future of zinc production at that time, it had serious deficiencies. It produced low-grade zinc and required a distillation refinery which added significantly to the cost of metal produced. Also operating and maintenance costs for the blast furnace and ancillary equipment were high in comparison with the electrolytic process which had become highly streamlined and highly automated. The ISF became uncompetitive for the treatment of all but low-grade mixed concentrates or secondary materials and eventually was unable to compete even on those materials.

The Avonmouth smelter came under the control of Pasminco Ltd when it was formed by the amalgamation of the interests of Conzinc Riotinto Australia and North Broken Hill Ltd in 1988. The economics of the operation were poor at that time and no longer served as an outlet for the zinc concentrates produced from Australian mines, and so the operation was sold to Mount Isa Mines Ltd in 1993, renamed Britannia Zinc Ltd and integrated with Mount Isa's other interests in the UK, particularly its lead refining operations (Britannia Lead), which refined raw lead bullion from the Mount Isa Smelter in Queensland. However, the Avonmouth smelter continued to perform poorly and was eventually closed as uneconomic in March 2003. From that point all zinc smelting activities in the UK ceased and few Imperial Smelting Furnaces remained in operation.

CHAPTER 2 – MINING OPERATIONS

This chapter reviews zinc mining operations throughout Australia on a state-by-state basis.

2.1 NEW SOUTH WALES

Mines included are:

Broken Hill Mines – various Endeavour / Elura Mine – Cobar Lake George Mine – Captain's Flat Woodlawn Mine Benambra Mine (Victoria)



Broken Hill

The Broken Hill deposit was discovered by Charles Rasp in 1883 following earlier discoveries of lead-silver nearby at Silverton. A syndicate was formed and seven leases (Blocks 10 to 16) were pegged covering about 300 acres. The syndicate expanded and became The Broken Hill Proprietary Company Limited (BHP) in 1885, and in 1887–88 split off three subsidiary mining companies – Block 10, Block 14 and British Broken Hill Proprietary (Blocks 15 and 16) mines, while retaining Blocks 11, 12 and 13 as the BHP mine lease.

Other leases were soon taken up in the field, with the following companies operating at Broken Hill by 1900:

Broken Hill South Silver Mining Company Limited – Blocks 7 and 8 Broken Hill Central Silver Mining Company Limited – Block 9 Broken Hill Proprietary Company Block 10 Limited The Broken Hill Proprietary Company Limited (BHP) – Blocks 11, 12 and 13 Broken Hill Proprietary Company Block 14 Limited British Broken Hill Proprietary Company Limited – Block 15 and 16 North Broken Hill Silver Mining Company Limited – Block 17 The Junction Lead Mining Company Limited – Block 39 Broken Hill Junction North Mining Company Limited – Block 40

In general, the ores were extracted by underground mining methods and Broken Hill established a wide reputation as a leader in underground mining methods. BHP also introduced open pit mining in 1890 to maximise extraction of oxide ores which was unusual at the time. The BHP pit was completed in 1920.

The rich surface ores were all oxidised from the weathered zone of the orebody and were relatively simple to smelt and recover lead and silver. By 1900 most of this ore was depleted and as the mines went deeper, beyond the weathered zone, the composition changed from oxides to sulphides and the content of zinc increased. Concentration methods relied on gravity separation methods to remove lighter gangue minerals from the heavier lead minerals. However, the presence of large quantities of zinc minerals greatly reduced the efficiency of this method of separation of lead and silver as well as complicating the relatively simply smelting processes used. This problem created considerable financial difficulties for the Broken Hill mines at that time and in fact a number of operations closed such as the Central Mine.

Zinc sulphide concentrate was also becoming a sought-after commodity as sources of zinc since oxide ores in Europe were also being rapidly depleted. Thus, the ability to separate and concentrate sulphide ores and to produce zinc concentrates as well as lead-silver concentrates, became a major issue for the Broken Hill mines, and a major research programme was initiated. As covered in Chapter 1, this led to the development of the froth flotation process for the separation of sulphide minerals. Initially lead was first separated by gravity methods and then zinc was recovered from the lead tailings by flotation. Eventually differential flotation of both lead and zinc was developed.

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FIG 2.1 BHP Mine



FIG 2.2 Broken Hill South Mine

The exhaustion of supplies of oxide ores also created problems for the many mine site smelters and most closed, sending their lead concentrates to the Port Pire smelter or to European smelters.

Sulphide Corporation was formed in 1895 with the idea of recovering zinc by a novel electrolytic process and a plant was built at Cockle Creek and the Central Mine purchased to supply raw materials. As discussed in Chapter 1 this was a complete failure and Sulphide Corporation resorted to lead smelting at the Cockle Creek site.

By 1905 there was 6.5 million tonnes of tailings at Broken Hill containing more than 10 per cent zinc. The potential resource was recognised by mining engineer Herbert Hoover (future President of the USA), together with W L Baillieu a substantial investor in the North Mine, and W S Robinson who had wide interests in mining and smelting in Australia and in the UK. They purchased about 4 million tonnes of tailings from various companies and formed the Zinc Corporation Limited to apply new ideas in flotation technology. About the same time Amalgamated Zinc (De Bavay's) Limited was also floated to apply their particular flotation technology to tailings treatment.

This was a time of turbulence at Broken Hill with many mines closing or changing ownership and changing names. It was not assisted by the advent of the First World War which closed off the sales of zinc concentrates to the major European smelters in Germany and Belgium. As a result, there was considerable rationalisation and amalgamation of leases. Zinc Corporation Ltd acquired the leases of Broken Hill South Blocks Limited and eventually ceased treating tailings dumps in 1923, closely followed by Amalgamated Zinc (De Bavay's) Limited in 1924, which ceased operation. By 1930 the following companies were operating in the field:

North Broken Hill Limited (Northern leases) BHP – ceased mining in 1939 Sulphide Corporation Limited (Central and Junction mines) Broken Hill South Limited Zinc Corporation Limited (Broken Hill South Blocks Limited)

The Electrolytic Zinc Company's Risdon zinc plant was well established by the time of the Second World War and took most of the zinc concentrate output from the Broken Hill mines with the lead concentrate going to the Port Pirie lead smelter. Some zinc concentrates were supplied to Imperial Smelting Corporation in the UK in which Zinc Corporation had an interest. In 1949 Zinc Corporation Ltd and Imperial Smelting Corporation Ltd joined together to become Consolidated Zinc Corporation Ltd, joining with British company Rio Tinto Limited in 1962 to form Conzinc Rio Tinto Australia Ltd. (CRA).

In 1948 Zinc Corporation acquired Sulphide Corporation Ltd. and consolidated the leases of the Central and Junction mines.

By 1950 the central leases of the Broken Hill field had largely been exhausted with operations moving to deeper levels at both the northern and southern end of the field. However Broken Hill South Ltd did continue mining until 1972 and also formed Barrier Central Pty Ltd in 1952 to rework Leases 10, 11, 12 and 13. This work ceased in 1960.



FIG 2.3 The Zinc Corporation mine and concentrator.

Zinc Corporation Limited had purchased all the southern leases and began exploring for ore at depth (below 1500 feet). This was highly successful and a new company, New Broken Hill Consolidated Ltd (NBHC) was floated in 1936 to develop mining and concentration facilities on the southern leases. Major construction work was delayed by the Second World War, but commenced in 1946 and was completed in 1952, setting new standards for mine infrastructure on the Broken Hill field. Zinc Corporation also continued to find ore at depth on its own leases and extend its mining operations.

By 1960 the following companies were operating:

North Broken Hill Limited Broken Hill South Limited (incorporating the Central Mine leases) Zinc Corporation Limited New Broken Hill Consolidated Ltd.

The closure of the South Mine in 1972 was a significant change in the fortunes of Broken Hill in the latter half of the 20th century. The leases were acquired by Minerals Mining and Metallurgy Limited (MMM) collectively as CML 7 (Blocks 7 to 16 and Block 39). The old South Mine was reopened in 1972 with a much leaner workforce and an open pit operation commenced in the Block 14 area (Blackwood open pit). Treatment of the old tailings

dumps was also started through the South Mine mill. The mine was finally closed four years later in 1976, but the open pit continued until 1991.

At the other end of the field North Broken Hill Limited mine continued to operate at greater depths and in 1975 discovered the Fitzpatrick lode at depths of over 5000 feet, making it one of the deepest mines in Australia.



FIG 2.4 The North Mine.

Normandy Mining Ltd acquired the central leases around the original Blocks 15 and 16 in the early 1980s and commenced open pit mining (Kintore Open Pit). This was completed in 1996 and with takeover of Normandy Mining by Newmont Ltd in 2002 all operations at Broken Hill were abandoned.

By the end of the 1980s there were only two remaining major operators in the field – North Broken Hill and CRA, with three mines – the North Mine, Zinc Corporation Mine and the NBHC mine. In 1986 the ZC mine and NBHC mine were combined into a single operation called the ZC mine.

At this point North Broken Hill Ltd had acquired Electrolytic Zinc Company, including the Risdon zinc smelter, the Rosebery Mine in Tasmania and the Elura Mine in New South Wales. In 1988 North Broken Hill Ltd and CRA Ltd agreed to merge their lead and zinc interests to form Pasminco Limited, which then became the major mine operator on the Broken Hill field with two major mines at either end of the field.

With mounting losses, Pasminco closed the North Mine in 1993 and finally sold its entire interest in the Broken Hill field in 2002 to Perilya Limited who continued to operate the ZC mine. Shortly after that Pasminco went into liquidation. In 2009 the Chinese company Shenzhen Zhongjin Lingnan Nonfemet Company acquired a 50.1 per cent shareholding in Perilya and in 2013 increased this to 100 per cent.

Perilya has continued mining the southern leases producing around 70 000 t/a of zinc and 51 000 t/a of lead in concentrates from around 1.7 million tonnes of ore per year. There are plans to reopen the North Mine – deep levels as well as smaller outlying operations at the

northern end of the field. These outlying deposits are the Pinnacles area – Henry George and 1130 mines (10 km south west), and the Potosi and Silver Peaks mines (2 km north of the North Mine). The Pinnacles deposit was actually pegged in 1884 at the same time as the Broken Hill field, but was only mined spasmodically on a small scale. The leases were acquired by Perilya Limited from Pasminco in 2002. Presently Perilya Limited is mining the Pinnacles area by open cut and is also developing the Potosi and Silver Peak orebodies by underground decline. A lead concentrate handling and export facility was also installed by Perilya at Port Pirie in 2011. With these resources Perilya has reserves of between 17 and 20 million tonnes, sufficient for continuing production at present levels until 2022. About half of this resource remains within the southern leases.

Consolidated Broken Hill Resources or CBH Resources Ltd had been formed earlier by Normandy Mining to extract remnant ore from the original seven leases pegged by Charles Rasp in 1883. This operation named the Rasp Mine and was planned with access by decline tunnel to the old workings. Development eventually commenced in 2007 but was suspended due to a severe drop in commodity prices in 2008. In 2010 CBH Resources Limited became a wholly owned subsidiary of Japanese company Toho Zinc Limited and approval was granted to resume development in 2011, with completion of construction in 2012. The Rasp Mine now produces about 34 000 t/a of zinc and 24 000 t/a of lead in concentrates, which are railed to the company's port facility at Newcastle for export in combination with output from the company's Endeavour Mine near Cobar.



FIG 2.5 The New Rasp Mine – construction.



FIG 2.6 Timeline for the Broken Hill Mining Field.

The Endeavour (previously Elura) Mine

The Elura Deposit was discovered the Electrolytic Zinc Company in 1973 and is located 43 km north of the town of Cobar.

Copper was discovered in the Cobar area as far back as 1869 and the Great Cobar Mine commenced operation in 1871, including smelting facilities. Many other deposits were found in the area, mainly containing copper, but also with some zinc, lead and silver values. The Elura find was the first predominantly zinc-lead deposit and initially reported ore of 8.5 per cent zinc content with 5.3 per cent lead and 69 g/t of silver. The operation was consequently designed to produce zinc and lead concentrates.

Construction of the mine and mill was completed in 1983 and also required the construction of a rail link to Cobar and construction of concentrate storage and shiploading facilities at the Port of Newcastle. Zinc concentrate was shipped to the Risdon smelter in Hobart and lead concentrates were mainly either shipped by rail to Port Pirie or sold overseas, particularly to lead smelters in Japan. The capacity of the mine and mill was around 1.2 million tonnes per year producing approximately 180 000 tonnes per year of zinc concentrates at 48 per cent zinc.



FIG 2.7 The Elura Mine.

The Electrolytic Zinc Company became part of North Broken Hill in 1984 and then Pasminco Ltd in 1988. The mine was sold by Pasminco in 2003 to Consolidated Broken Hill Limited who later changed their name to CBH Resources Ltd in 2004. The name of the mine was also changed from Elura to the Endeavour Mine. Production was ramped up after the acquisition to 1.4 million tonnes per year, but due to low metal prices was scaled back to 720 000 t/a of ore in 2008 with an output of 44 000 t/a of zinc in concentrates. CBH Resources Ltd became a wholly owned subsidiary of Toho Zinc Limited in 2010 and production was upgraded to 850 000 t/a of ore then reporting 7.9 per cent zinc, 4.5 per cent lead and 66 g/t silver, and output of zinc concentrate was around 110 000 tonnes year containing 49 per cent zinc and 4 per cent lead.
Lake George Mine at Captains Flat

The Lake George Mine is located near the town of Captain's Flat about 45 km south east of Canberra on the Molongolo River. Gold was discovered along the river in 1864, but significant mining on a substantial scale did not commence until 1882. Attention turned to the extraction of copper in 1883, but it was difficult to separate due to the presence of large amounts of lead and zinc. The high levels of silver present diverted attention to lead and silver extraction and a smelter was constructed for the production of lead and recovery of silver values in 1885. The ores were sulphides and were roasted using reverberatory furnaces, although large-scale open heap roasting was also introduced in 1890. This practice used timber beds on which the ore was heaped and then fired. Both the removal of timber and the effects of sulphur dioxide emissions devastated the surrounding country. The adoption of Pyritic Smelting using the techniques pioneered at Mount Lyell in Tasmania, also contributed to that devastation. The two major mines in the area – the Commodore and Koh-i-noor mines combined to form the Lake George Mining and Smelting Company in 1894, which changed its name to Lake George Mines Ltd in 1896.

The complex nature of the ores and the inability to efficiently separate lead mineralisation made the operation unprofitable, and coupled with the reluctance of the NSW Government to construct a railway line to connect to the coast, the mines were closed in 1899.

The solution to the 'zinc problem' at Broken Hill and the development of flotation as a mineral separation technique enabled a reappraisal of the operations to be made in 1929. The Great Depression prevented the raising of capital and any new development until 1935. The Company then reopened the mine, constructed a mill and by 1937 had built a railway line to Bungendore to connect with the Government line to Port Kembla. Full operation was achieved in the late 1930s with the production of separate lead, zinc and copper concentrates, as well as pyrite concentrates which were sold for sulphuric acid production to Australian Fertiliser's plant at Port Kembla. The other concentrates were sold to German and Japanese smelters through Port Kembla and some zinc was shipped to the Risdon smelter in Hobart. At this time the Lake George Mine operations were second only in output to the Broken Hill field. Typical ore reported 5 per cent lead, 9 per cent zinc, 0.6 per cent copper and 32 to 36 per cent pyrite.

The Second World War intervened and interrupted the overseas sale of concentrates, however zinc concentrates were shipped to Hobart and copper concentrates were absorbed by the Port Kembla Copper smelter which had opened in 1908. Pyrite concentrates continued to be sold to the fertiliser plant at Port Kembla. Improved flotation methods were introduced in 1942 allowing for production of higher-grade copper concentrates as well as cleaner zinc and lead concentrates. The following years through the 1950s were relatively prosperous and zinc concentrate production was of the order of 25 000 to 30 000 tonnes per year and supplied to the Risdon smelter. Lead concentrates were shipped overseas.

Industrial unrest developed around 1960, particularly with underground locomotive drivers, and culminated in a seven-month strike in 1962. The Company could not sustain this disruption and closed the mine at that time, leading also to closure of the branch rail line from Captain's Flat to Bungendore, which spelt the end for the town of Captain's Flat. Several environmental disasters have been associated with the Lake George Mine, such as the collapse of a tailings dam into the Molongolo River in the 1940s and acid mine drainage issues in the years following closure, which have required major rehabilitation works. This has been a particularly sensitive issue since the river flows into Lake Burley Griffin in the heart of the city of Canberra.

Over the years of major activity from 1937 to 1962, production from the Lake George Mine has been:

- 406 418 tonnes of zinc in zinc concentrates
- 243 851 tonnes of lead in lead concentrates
- 27 230 tonnes of copper in copper concentrates
- 7.4 million ounces of silver
- 0.22 million ounces of gold.



FIG 2.8 Lake George Mine.

Woodlawn Mine - Tarago

The Woodlawn deposit is located near Tarago approximately 40 km south of Goulburn and 70 km north east of Canberra. The ore is a complex sulphide similar to the Lake George Mine ore, and the orebody consisted of two zones, one predominantly copper sulphides and the second major resource being a complex mix containing 10–14 per cent zinc, 4–6 per cent lead, 1.7 per cent copper and around 70 g/t silver. The complex ore also contained talc which contributed to metallurgical difficulties with mineral separation.

The mine commenced in 1978 as a joint venture between US companies – St. Joseph International Explorations Ltd (an offshoot of the St. Joseph Lead Company) and Phelps Dodge Exploration Corporation, together with New Broken Hill Consolidated Ltd Mining was by open cut methods.

The copper ore and complex ores were separately milled in separate flotation circuits, but separation and efficient recovery of metals into separate concentrates remained quite difficult throughout the life of the mine. Zinc concentrate grade was generally in the range of 45 to 50 per cent with recoveries around 70–80 per cent. The lead concentrate was very poor at 30 to 35 per cent lead and 12 per cent zinc which was not acceptable to most lead smelters, but was suitable as feed to the Cockle Creek Imperial Smelting Furnace where both metals were recovered. Zinc concentrates were high in iron with a trade-off between zinc recovery and selectivity of zinc over iron mineralisation. Acceptance at the Risdon smelter was limited and because of high levels of talc there were also limits of acceptance for the ISF at Cockle Creek. Consequently, most of the zinc concentrates were exported.

Output of zinc in concentrate was of the order of 70 000 tonnes per year.

The mine was operated by Denehurst Limited in the latter stages of its life, however Denehurst went into liquidation in 1998 and the mine was closed. Currently there are plans to reactivate the operation with an underground mine and tailings treatment under a joint venture between TriAusMin and Heron Resources Ltd.



FIG 2.9 Woodlawn Mine.

Benambra Mine – Victorian Alps

The Benambra Mine was originally discovered by Western Mining Corporation, but developed by Denehurst Limited with commencement of operations in 1992. It was located in the Victorian Alps, north of Bruthen and south-east of Mount Beauty. The distance from the Woodlawn mine operated by Denehurst at the time was not great.

The mine produced copper and zinc concentrates, but with low zinc prices was not economic and closed in 1996 after only four years of operation. Planned zinc production was small at around 6000 t/a of contained metal.

There are plans by the Independence Group to reopen the mine – now called the Stockman Mine. However, there is major opposition on environmental grounds since the original tailings dam has contaminated the Tambo River which flows through rich farming lands in Gippsland.

2.2 ZINC MINES – TASMANIA

Mining on the Tasmanian West Coast commenced with the discovery of tin at Mount Bischoff in 1871, once the world's largest tin mine. Discoveries to the south followed with Mount Lyell gold and copper, and the Zeehan – Dundas field which was rich in lead and silver. Zinc was found with lead and silver deposits on Mount Read in 1894, followed by the Mount Black-Rosebery field in 1893. The so-called Mount Read Volcanic rock sequence has hosted most of the zinc discoveries as massive polymetallic sulphide deposits from Mount Lyell in the south, containing copper and gold with little zinc, to the Hercules Mine, Rosebery, Que River and Hellyer Mines further north. The ores are generally high grade in terms of the zinc and lead content and are exceptional in the high silver and gold contents.

Some other deposits occur in adjacent carbonate rocks such as the Zeehan and Dundas field and also the Farrell mine, but these have been small isolated deposits and generally rich in lead and silver.



Rosebery Mine

Gold was first found in Rosebery Creek, and later prospector Tom McDonald also noticed the presence of lead-silver ore, and took out leases in the area in 1893. Somewhat of a rush ensued and by 1898 there were about 25 separate leases in the Rosebery-Mount Read area. The Rosebery and Primrose mines were started, but the terrain was difficult and little could be done without proper transport facilities. At the time there was much argument about railway services to the West Coast mines. The Tasmanian Government had constructed a line from Zeehan to the port of Strahan in 1892 and in 1895 undertook to build an extension to Williamsford. This was completed in 1898 as the North East Dundas Tramway, a small two foot six inch gauge line. The Zeehan Smelters were also completed in 1898 and provided a local market for the lead-silver ores. This enabled the Hercules Mine to operate, however a rail extension to Rosebery was still required and was completed with the extension of the privately owned Emu Bay Railway from Waratah to Rosebery and on to Zeehan in 1905, enabling the Primrose and Rosebery mines to commence large-scale delivery to the smelter.

However, the Zeehan Smelters only produced lead and silver and zinc was a penalty element. With the decline of the lead-silver deposits around Zeehan this became a significant problem. The cost to the smelter was high in producing large quantities of slag with commensurate losses of lead and silver, and the mines were penalised to the extent that they only received about 10 per cent of the contained metal value in the ore as payment. Consequently the smelters closed in 1909. The Tasmanian Government intervened to prevent a major loss of industry to the state and financed the reopening of the smelters. However, the zinc problem remained and the smelters final closed in 1913. World War I commenced shortly thereafter and the smelters were confiscated by the Tasmanian Government from the German owners – Metallgessellschaft.

With the solution of the zinc problem and development of flotation technology at Broken Hill, the Mount Lyell Mining and Railway Company saw an opportunity and acquired the mining leases in the Rosebery – Mount Read area. They had intentions of constructing their own electrolytic zinc smelter based on the Lake Margaret Power station, but were subverted by the approval of an electrolytic plant to be built in Hobart by Broken Hill interests. The Electrolytic Zinc Company subsequently purchased the leases from Mount Lyell in 1920 and also purchased the smelters from the Tasmanian Government with the intention of establishing zinc roasters on that site.

A pilot flotation facility was built at the Zeehan Smelters to trial the milling and flotation of Rosebery ores, and exploration continued on the lease to better define the orebody. With the definition of a suitable flowsheet for the treatment of the Rosebery ore, construction of a new concentrator commenced in 1928 and was virtually completed in 1930 when the severe effects of the Great Depression hit and all work stopped. The operations were placed on a care and maintenance basis until the mine was reopened in 1936.



FIG 2.10 Construction of the Rosebery concentrator in 1929.

Calcines from the roasting of zinc concentrates at the Zeehan site were shipped to the Risdon zinc plant through the port of Strahan, but after closure of the roasters in 1948 all materials were shipped out via the Emu Bay Railway to the Port of Burnie.



FIG 2.11 Garrett locomotives on the Emu Bay Railway 1950s.

The Rosebery Mine is an underground operation with access through an adit in the side of the mountain and internal shaft, as well as lower level declines. It has continued to expand both production and its reserve ore base over the years. The ore reserve in 1927 was 1.4 million tonnes, increasing to 5.5 million tonnes in 1966, 7.9 million tonnes in 1989, 8.9 million tonnes in 2004 and 18 million tonnes today. Ore grades are around 11 to 13 per cent zinc, 3.5 to 4.5 per cent lead, 0.4 per cent copper, 120 g/t of silver and 2 g/t of gold. Ore processed in the mill has increased from 160 000 tonnes per year in 1940 to around 800 000 tonnes per year with zinc concentrate output now of the order of 160 000 t/a of concentrates containing 90 000 t/a of zinc metal. Rosebery is also a significant gold producer with an output of close to 15 000 ounces per year contained in 1500 tonnes of copper concentrate.



FIG 2.12 Rosebery Mine entrance – 1960s.



FIG 2.13 Rosebery mill and mine facilities.

Hercules Mine

The Hercules Mine is located high on Mount Read and was first discovered in 1891 as a silver-lead deposit. It was first mined to feed the Zeehan Smelters. The underlying Hercules orebody was found in 1894 and the Mount Read Mining Company was formed to operate the mine in 1898. A cable railway was installed to convey ore from the mine down the mountain to the mill – a distance of 1.6 km with a fall of 500 m, and a narrow gauge railway then transported ore to the Zeehan Smelters. The high level of zinc was a severe penalty at that time and the mine eventually closed with closure of the smelters in 1913.

Following solution to the 'zinc problem' and recognition of the value of zinc and the means to separate and concentrate the metal, the mine was purchased by the Electrolytic Zinc Company and reopened to feed ore directly to the new Rosebery concentrator. An aerial ropeway was constructed to transport the ore 5 km to the Rosebery mill. The Hercules Mine continued in operation until 1986.



FIG 2.14 The Williamsford haulage to the Hercules Mine.

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FIG 2.15 Aerial ropeway between Hercules and Rosebery mines.



FIG 2.16 The modern Emu Bay Railway.

The Mount Farrell and North Farrell mines

These deposits were located within the limestone belt adjacent to the Mount Read Volcanic sequence. They were similar in nature to many of the small deposits in the Zeehan area and were relatively rich in lead and silver with lesser amounts of zinc.

The Mount Farrell mine commenced operation in 1898 and was serviced by the town of Tullah and a 6 mile narrow gauge railway connecting to the Emu Bay Railway line at Farrell junction. The mine supplied the Zeehan Smelters and closed in 1932. However, a new orebody was discovered in 1934 and the North Farrell mine opened shortly thereafter. It contributed some zinc input to the Rosebery concentrate production, but was mainly a source of lead and silver concentrates. The North Farrell mine closed in 1974.



FIG 2.17 The North Farrell mine.



FIG 2.18 The service railway.

Que River and Hellyer mines

The Que River orebody was discovered by Aberfoyle Resources Ltd in 1974 while exploring from its nearby property – the Cleveland Tin Mine. It is located 90 km south of Burnie and 40 km north of Rosebery on the Tasmanian West Coast. The initial resource was 3 million tonnes of mineable ore at 12.5 per cent zinc, 7.0 per cent lead, 0.4 per cent copper and 171 g/t of silver, and operations commenced in 1981. Mining was by underground methods and ore was trucked to the Rosebery mill under a contract with the Electrolytic Zinc Company, which extended the mill to handle the additional 150 000 to 200 000 tonnes per year of ore feed. The mine was exhausted in 1991 and was closed and the site rehabilitated.

The Hellyer orebody was discovered by Aberfoyle in 1983 about 2.3 km north-east of Que River, with a resource of 17 million tonnes of ore at 12.2 per cent Zn, 6.2 per cent lead, 0.2 per cent copper and 148 g/t of silver. In this case the orebody was of sufficient size to justify construction of its own concentrator. However, prior to construction of a new mill, large-scale trials were conducted in the converted Cleveland Tin Mine mill which had closed in 1986. Mine development started in 1987 and the concentrator was commissioned in 1989 with a capacity of 1.5 million tonnes per year of ore over the life of the mine. Production of zinc concentrates averaged 250 000 tonnes per year at 50 per cent zinc content. In addition, the operation produced around 55 000 t/a of a bulk zinc-lead concentrate (34 per cent zinc and 18.5 per cent lead), and 65 000 t/a of lead concentrate. The concentrates were railed to the Port of Burnie for export via the Emu Bay Railway.

Aberfoyle was taken over by Western Metals in 1998 and the Hellyer mine was closed in June 2000 after 11 years of operation. Plans were developed to re-treat the tailings dumps and possibly reopen the mine to extract ore from the Fossey ore zone – a deeper extension of the main Hellyer orebody. However Western Metals collapsed in 2003 and all operations were mothballed. The property was purchased by Intec Ltd with plans to apply their chlorine leaching technology to the treatment of Hellyer tailings which contained 3 per cent residual zinc and 2.7 g of gold. Bass Metals Ltd was then formed in 2005 to undertake the extraction operations with Intec retaining a 23 per cent share in the new company.

Attention appeared to focus on re-treatment of tailing through the Hellyer mill and the extraction of remnant ore from the Que River and Hellyer mines with mining of the Fossey orebody. The indicated resource was 1.9 million tonnes at 7.5 per cent zinc and 4.2 per cent lead. This activity commenced in 2007, but due to a need to reduce debt, Bass Metals negotiated a sale of the Hellyer mill project to Lion Gold Corporation of Singapore in 2012. However, this deal did not proceed and a sale was subsequently made in 2013 to private company Ivy Resources Pty Ltd.

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FIG 2.19 The Hellyer mine and mill.

2.3 ZINC MINES – NORTH QUEENSLAND AND NORTHERN TERRITORY

The Mount Isa Basin of over 50 000 square kilometres contains mid-Proterozoic rocks which host a number of zinc-lead deposits contained within graphitic black shales. It stretches from about 200 km south of Mount Isa to the south west corner of the Gulf of Carpentaria. Although this encompasses the McArthur River Basin, the rocks contained therein are of a similar deposition sequence but are somewhat older. This region contains a wealth of zinc-lead mineralisation, including such deposits as Mount Isa, Hilton and George Fisher, Lady Loretta, Dugald River, Cannington, Century and McArthur River.

Other small mines close to the Pacific coast include Thalanga and Mount Garnet.



Mount Isa

The Mount Isa deposits were discovered in February 1923 by prospector John Campbell Miles while on a trip from Cloncurry to the Northern Territory in search of gold. He noted a mineralised outcrop near the Leichhardt River which resembled mineralisation at Broken Hill where he had worked in the past. Samples were sent to the Government Assay Office in Cloncurry and reported 78 per cent lead and silver content. Miles then pegged a lease of 42 acres surrounding the outcrop which he named Mount Isa and initial mining operations commenced in January 1924. Miles quickly sold his interests to William H. Corbould a mining engineer from Ballarat, who formed the company Mount Isa Mines Limited (MIM) to develop the lead-zinc-silver deposits, and it acquired all the surrounding leases by the end of 1925. In his efforts to raise finance for large-scale mining, Corbould negotiated an arrangement with American born Leslie Urquhart, chairman of Ruso-Asiatic Consolidated Limited, who in turn involved the giant US mining group American Smelting and Refining Company (ASARCO), part of the Guggenheim industrial empire. ASARCO invested heavily in the development of the Mount Isa mine and Leslie Urquhart relocated from the USA to become the first General Manager of Mount Isa Mines.

The zinc-lead orebody typically contained 6.6 per cent zinc, 6.2 per cent lead and 150 g/t silver. In the initial operations ore was transported by camel trains to the railhead at Cloncurry, but the railway was extended to Mount Isa in 1929 by the Queensland Government on the basis that the company would guarantee their returns. Indeed, the line became the most profitable in the Queensland rail network for many years to come, although Mount Isa Mines paid a heavy price for use of the line.

The first major work was the sinking of a large production shaft into the main orebody in 1930, followed by the completion of a concentrator and lead smelter in May 1931, all to American designs. Lead bullion was exported to a refinery in the UK at Northfleet in Kent (Britannia Lead) which was also founded by the company in 1930. A noted metallurgist Julius Kruttschnidt from ASARCO became General Manager in 1930 and oversaw most of these significant developments. Due to the Great Depression, these times were very difficult and the Company was bordering on bankruptcy. However, with the production of lead bullion from the smelter the fortunes turned and Mount Isa Mines listed its first profit in 1937, thirteen years after its foundation. Zinc concentrates produced from the concentrator were railed to Townsville and exported, particularly to Japan.

The Second World War then intervened and under the direction of the Commonwealth Government all zinc and lead operations ceased and the company turned its attention to the recently discovered copper orebody with the mining and milling of copper ore to produce copper concentrates. Although zinc-lead operations resumed after the war the potential of the copper deposits had become clear and plans were put in place to construct a new copper concentrator and smelter. The Hilton zinc-lead deposit was discovered in 1948 underwriting the ongoing operation of the lead smelter, however attention was given to the construction of the copper concentrator and smelter which were completed in 1953. These operations were progressively expanded and an electrolytic copper refinery was built at Townsville, commencing operation in 1960. In preparation for the opening of the Hilton Mine a new lead – zinc concentrator was completed in 1966 and Hilton opened in 1969. A new copper concentrator was completed in 1973.

The output of zinc concentrates and lead bullion, progressively increased over this period. Zinc concentrates were exported to European (Belgian) and Japanese smelters and some supplied to the Risdon zinc plant in Hobart.

The nature of the lead-zinc ores changed with time and became finer grained and more complex, which made it more difficult to achieve high zinc recoveries at the concentrate grades that were required by the standard electrolytic zinc plants. Consequently, a middling or bulk zinc-lead concentrate was produced from 1986 as a feed stock for smelters operating the Imperial Smelting Process. To this end Mount Isa Mines purchased the Avonmouth ISF smelter in the UK from Pasminco in 1990, also with a view to the processing of concentrates from the new Macarthur River Mine. The change in nature of the ores also provided incentive for research into improvements in the flotation process leading to the development of the Isamill for energy efficient fine grinding, and the Jameson Cell for flotation of very fine particles – avoiding the problems of slime generation.

The main Black Star lead-zinc orebody was converted into an open cut mining operation in 2004, the Handlebar Hill open pit mine commenced operation, and in 2010 the new George Fisher lead-zinc mine (20 km from Mount Isa) was commissioned. With these developments the emphasis of the operations shifted back to a large zinc-lead operation, with copper of lesser importance and even with consideration of closure of the copper smelter and refinery at Townsville.

Mount Isa Mines was acquired by Swiss company Xstrata in 2003 which divided the company into two parts – Xstrata Zinc and Xstrata Copper. In 2013 Xstrata merged with its parent Glencore Limited.

The output of zinc in concentrates from the Mount Isa mill has increased from around 20 000 to 25 000 tonnes per year in the late 1940s to over 350 000 tonnes per year today. Zinc concentrate grades are close to 50 per cent zinc and 3 per cent lead.



FIG 2.20 Early operations at Mount Isa.



FIG 2.21 Mount Isa operations from the city – copper smelter stack on the left, and lead smelter stack on the right.

McArthur River Mine - Northern Territory.

McArthur River is located in the eastern Northern Territory near the town of Borroloola and halfway between Darwin and Mount Isa. It was discovered by Mount Isa Mines (MIM) in 1955, but recognised as extremely fine grained and difficult to process. A pilot shaft was sunk in 1966 to extract samples for testing and a long process of development work commenced. Initial plans for a large-scale open cut operation producing 450 000 tonnes per year of zinc concentrate were rejected in 1979 as uneconomic. One of the difficulties was the poor separation of zinc and lead, and unacceptably high levels of lead in the zinc concentrate, as well as very low recoveries of lead into lead concentrate.

The project was reactivated in 1989, based on the improvements in the handling of finegrained ores achieved in the intervening years. It was also decided to produce a bulk zinclead concentrate suitable for processing using the Imperial Smelting Process, for which there was a significant market. In 1992 a joint venture was formed between Mount Isa Mines (70 per cent) and ANT Minerals Ltd (a Japanese consortium of Toyoha Mining at 50 per cent, and Mitsui, Marubeni and Mitsubishi Materials each 16.6 per cent), to develop the mine. McArthur River Mining Pty Ltd was formed to undertake the project on behalf of the Joint venture partners. An underground mine commenced operation in 1995 and bulk concentrates were trucked 120 km to the port of Bing Bong on the Gulf of Carpentaria. Due to the shallow waters of the Gulf, the concentrates were loaded onto barge and transferred to ships anchored 30 km offshore.

Xstrata acquired MIM in 2003 and subsequently acquired ANT Minerals share of the project to become the sole owner of the McArthur River Mine. Underground operations were becoming costly with a limited future and in 2005 plans were developed to convert to an open pit operation, substantially expanding the potential recoverable resource, although offset to a degree by a reduction in ore head grade from 10–11 per cent to around 8.5 per cent zinc. These plans were approved by the Northern Territory (NT) and Federal governments in 2006 and mining operations transferred from underground to open cut operation. The full pit development was completed in 2008 and the mill expanded from 1.8 million tonnes of ore per year to 2.5 million tonnes. In December 2008 the Full Bench of the Australian Federal Court ruled that the permit for expansion was invalid due to a procedural error on the part of the Commonwealth Government and all mine operations were suspended. This was rectified and the Federal Government issued approval in February 2009, allowing operations to restart.

In June 2009 further approval was given to expand the production from 2.5 million tonnes per year of ore to 5.5 million tonnes per year. This would raise bulk concentrate production from 360 000 t/a to 800 000 t/a at grades of between 42 and 46 per cent zinc and 12.5 per cent lead. Improvements in metallurgy and concentrator performance at this time also opened the opportunity to produce a high-grade zinc concentrate, sufficiently low in lead content to be acceptable to electrolytic smelters, considerably expanding the markets available to the mine. This was indeed necessary as many of the ISF plants had closed and the market for bulk concentrates had become more restricted.



FIG 2.22 McArthur River Mine – underground mining phase.



FIG 2.23 Open pit development at McArthur River Mine.

Century Mine

The Century Mine is located near Lawn Hill in North West Queensland, 250 km northwest of Mount Isa. Base metals were discovered in the area in 1869 and the Silver King mine was worked for lead and silver values from 1887. An exploration licence covering the area was granted to Conzinc Riotinto of Australia Ltd (CRA) one century later in 1987 and the zinc deposit discovered in 1990. The ore was very fine grained and produced a high-grade zinc concentrate (58 per cent zinc and 1.5 per cent lead) very low in iron content at 1 per cent which commanded a premium price. However, it was also high in silica at 4 per cent compared with the usual 1 per cent which created processing difficulties for electrolytic smelters. Considerable research effort was required to develop suitable concentrate processing methods and eventually mine development commenced in 1997. At that time Pasminco was the largest potential customer and planned to convert its Budel smelter in the Netherlands to 100 per cent Century concentrate feed to alleviate problems with residue disposal. As a consequence, Pasminco purchased the project from CRA in 1997 and undertook the mine development. The first concentrates were produced in 1999.

The Century Mine is a large open cut operation and produced over 5 million tonnes of ore per year and around 500 000 tonnes per year of zinc in concentrates. Lead production was relatively small at less than 40 000 tonnes per year of lead in concentrates. Concentrates are pumped by slurry pipeline a distance of 304 km to the port of Karumba on the Gulf of Carpentaria, where they are filtered and dried before transport by barge to ships anchored offshore.

Following the bankruptcy of Pasminco in 2002 the operation was re-floated by the creditor banks as part of Zinifex Limited in 2004. After merging with Oxiana Ltd ownership changed to OZ Minerals in 2008 and was then sold to MMG a subsidiary of the Chinese Minmetals Non Ferrous Metals Company.



FIG 2.24 The Century open pit mine.

Century was the second largest zinc mine in the world after Cominco's Red Dog Mine in Canada, but the resource was exhausted and mining operations ceased in August 2015. However, the milling operations will continue into the future with supply of ore from the newly developed Dugald River mine.

Cannington Mine

The Cannington Mine is located 200 km south-east of Mount Isa and was discovered in 1990 by BHP Ltd. The deposit was predominantly lead, but exceptionally rich in silver with ore grades of around 11.5 per cent lead, 4 per cent zinc and 500 g/t of silver.

Mining commenced as an underground operation in 1997 and reached full production in 1999. Output is of the order of 50 000 t/a of zinc in concentrates and 210 000 tonnes of lead in concentrate also containing around 30 million ounces of silver, making it the world's largest silver producer. Consequently, zinc is only of by-product importance, but does remain a significant contributor to the total Australian zinc production.

In 2015 BHP demerged some of its non-ferrous mining interests into South 32 Limited which now owns and operates the Cannington Mine.



FIG 2.25 The Cannington Mine and concentrator.

Lady Loretta Mine

The Lady Loretta deposit was discovered by Placer Prospecting (Australia) Pty Ltd in 1969. It is located within the Mount Isa Basin and approximately 140 km north-west of Mount Isa. Following some exploration and assessment, the leases were sold by Placer to Mount Isa Mines Ltd in 1975 and subsequently in 1985 to a joint venture between Pancontinental Mining Ltd, Agip Australia Pty Ltd, and Outokumpu Australia Pty Ltd. Pancontinental took full control in 1994, but was taken over by Goldfields Limited in 1995 and the project was sold to Buka Minerals Ltd.

As with many zinc-lead deposits in the Mount Isa Basin the ore is very fined grained with difficulties in separating zinc and lead values. Buka Minerals developed extensive plans and novel processing techniques, but as a start-up company exhausted its capital and was unable to secure additional funds. It was taken over by a series of different interests with no serious development activity until eventually the property was again acquired by MIM now as Xstrata Zinc in 2011.

The total reserve was reported then at close to 14 million tonnes containing 17 to 18.5 per cent zinc, 8 to 8.5 per cent lead and around 125 g/t silver. Xstrata Zinc's plans were to feed ore from Lady Loretta into the mill at Mount Isa as a blend with other ores from local mines in the Mount Isa area. No doubt their experience with the treatment of fine-grained ores at Mount Isa and in particular at McArthur River would have provided confidence in the successful separation of minerals in Lady Loretta ore.

Mine construction commenced in July 2011 with a planned capacity of one million tonnes of ore per year producing 126 000 t/a of zinc concentrate and 40 000 t/a of lead concentrate. Mining commenced in September 2012. The mine uses a decline only as access, and ore is crushed on site before being trucked the 140 km to the Mount Isa mill. Shortly after commencement, plans were announced to expand the operation and to ramp up production to 1.6 million tonnes of ore per year by 2016. Ore grades are reported as 14.2 per cent zinc, 4.8 per cent lead and 84 g/t silver.



FIG 2.26 Lady Loretta Mine facilities.

Dugald River Mine

The Dugald River deposit is located 87 km north-east of Mount Isa and 65 km north-west of Cloncurry. It was discovered as a lead and silver rich gossan outcrop around or before 1880. During the following decade several shafts were sunk in the southern end of the outcrop in the search of silver values, but without success, and little further work was done until 1948 when Zinc Corporation Ltd leased the area and commenced a drilling program. They continued work until 1953 and defined a large orebody which was reported at the time as containing 60 million tonnes grading 10 per cent zinc, 1 per cent lead and 30 g/t silver. With the relatively low lead and silver values this was regarded as uncommercial at the time.

Zinc Corporation Ltd became part of CRA and CRA Exploration undertook a reappraisal in 1987 and a new drilling program commenced in the following year. With the formation of Pasminco in 1989 this became a joint venture between Pasminco and CRA, eventually passing fully to Pasminco. The program defined a resource of close to 40 million tonnes of ore at 13 per cent zinc, 2.1 per cent lead and 42 g/t silver. The difficulty was that the zinc concentrates derived from that ore contained relatively high levels of manganese, which could not be accepted as a significant proportion of feed by any conventional electrolytic zinc smelter. It was consequently shelved until an appropriate means of handling manganese could be devised, although manganese levels are not expected to be as high as initially anticipated.

With the demise of Pasminco the deposit became part of the re-floated Zinifex Ltd and then OZ Minerals after the merger of Zinifex with Oxiana Limited. As part of its divestment of its mining interest the Dugald River deposit was sold to the Min Metals Group (MMG) along with the Century Mine.

With the closure of the Century Mine in August 2015, MMG announced their intention to mine the Dugald River deposit and truck the ore to the existing Century mill and so utilise those facilities. The trucking distance is 325 km. The indicated mining rate is 2 million tonnes per year of ore, producing 220 000 t/a of zinc concentrate and 27 000 – 30 000 t/a of lead concentrate. Reserves now stand at 63 million tonnes containing 12 per cent zinc, 1.8 per cent lead and 31 g/t of silver.



FIG 2.27 Portal for the trial mining operation at Dugald River.

Thalanga Mine

Thalanga is located 60 km west of Charters Towers and 200 km west of Townsville. The deposit was discovered by French owned company Pennaroya Australia Pty Ltd in 1973. The ore reported 8.3 per cent zinc, 2.6 per cent lead and 1.9 per cent copper. It was acquired by Pancontinental Mining Ltd and mining commenced in 1989 producing zinc, lead and copper concentrates, exported through the Port of Townsville. Operations continued until 1998 when the Thalanga mine ceased operation and the mill was converted to treat copper ore from the nearby Highway Reward mine. Up to this time about 300 000 tonnes of zinc had been produced in concentrates over about eight years.

The mill continued to treat copper ore under the control of Thalanga Copper Mines Ltd until it was purchased in 2006 by Kagara Zinc Ltd to treat copper ore from the Balcooma Mine. In 2010 the mill was converted back to handle polymetallic ores from the Vomacka open pit mine and West 45 underground mine, but only produced around 25 000 tonnes of zinc in concentrates before the operations were closed in 2012.

In 2014 the leases and facilities were sold to Red River Resources Limited and there are plans to reopen the mill to treat ore from the West 45 mine.



FIG 2.28 Thalanga Mine and mill.

Mount Garnet Mine – Kagara Zinc

Mount Garnet is located on the western edge of the Atherton Tablelands, 100 km west of Innisfail and 110 km south-west of Cairns. Copper was first discovered there in 1882 and by 1892 the Mount Garnet Freehold Copper and Silver Mining Company had installed a mining operation and smelter to produce copper. The presence of zinc and lead in the ores was known, but of little value at the time. The operation was short-lived and closed in 1906, soon after attention turned to the mining of tin from the areas Heberton Tin Belt.

There are records of some zinc ore being produced in 1916, but there were no local treatment facilities available at that time. Attention returned to the deposit in the 1990s and in 2000 the mine was reopened by Kagara Zinc Limited primarily for the production of zinc concentrates as well as lead and some copper concentrates. Full commissioning was completed in 2003 with a design treatment rate of one million tonnes per year of ore and scheduled production of 70 000–80 000 t/a of zinc concentrates and 15 000–20 000 t/a of lead concentrates. The entire output of zinc concentrates was sold to the Townsville zinc refinery.

Kagara Zinc Ltd went into administration in 2012 and the operations were suspended. In 2013 the mine was sold to the Snow Peak Mining Pty Ltd, a joint venture between Snow Peak Investment Company Ltd of Hong Kong and Consolidated Tin Mines Limited. The operation restarted in November 2013 with an expected output of 25 000 t/a of zinc contained in concentrates (50 000 t/a of concentrates). All output at that time was shipped to China.

In January 2015 it was announced that Consolidated Tin Mines Ltd would purchase the interests of Snow Peak Investment Company in the joint venture.

Woodcutters Mine – Northern Territory

Woodcutters was situated near the town of Batchelor, 80 km south of Darwin. The deposit was discovered in 1967 and the mine was commissioned in 1985 by Normandy Mining Ltd and it operated until 1998. The original resource was 4.7 million tonnes of ore at 12.9 per cent zinc and 5.5 per cent lead. Both open pit and underground mining operations were employed and production of zinc concentrates ranged from 100 000 to 130 000 tonnes per year at a grade of around 55 per cent zinc. Lead concentrates were relatively low grade at 40 per cent lead and contained high levels of antimony with output around 50 000 tonnes per year.

Concentrates were exported through the port of Darwin.

The mine was fully decommissioned in 1999 and the area rehabilitated.

2.4 ZINC MINES – WESTERN AUSTRALIA

Zinc deposits in Western Australia are scattered, but lie in three general regions – The Yilgarn Craton covering most of the south-west and encompassing the Goldfields Region (Golden Grove, Teutonic Bore, Jaguar and Bentley mines), the Pilbara (Sulphur Springs deposit), and the Lennard Shelf on the boundary of the Canning Basin and the Kimberley Block.



Golden Grove Mine

Golden Grove is located 250 km east of Geraldton in Western Australia and 52 km southeast of Yalgoo. Geraldton is used as the port for the export of concentrates.

The Golden Grove formation consists of two major orebodies and mining operations at Gossan Hill and Scuddles, about three km apart. Gossan Hill is predominantly copper and Scuddles zinc, lead and copper. Both mines are underground operations, but an open pit on the upper levels of Gossan Hill commenced operation in January 2012 to expand copper production.

The Gossan Hill deposit was discovered in 1971 by Aztec Exploration Company Pty Ltd. In order to provide additional capital a joint venture was formed with AMAX Exploration in 1972, later expanded to include The Electrolytic Zinc Company in 1973 and EXXON Minerals in 1977. The additional exploration effort discovered the Scuddles zinc, lead copper deposit in 1979 and this was the first on which mining commenced in 1990, under the control of Australian Consolidated Minerals Ltd. The operation was sold to Normandy Poseidon in 1991 which commenced mining the copper orebody at Gossan Hill in 1997. Output at that time was of the order of 16 000 t/a of contained copper, 10 000 t/a of contained lead and 135 000 t/a of contained zinc in concentrates. Zinc concentrates generally reported 54 per cent zinc content and 1.65 per cent lead.

The property was purchased by Newmont Australia in 2002 and then by Oxiana Ltd in 2005. Oxiana merged with Zinifex to form OZ Minerals Ltd in 2008 and when they encountered financial difficulties due to low metal prices, finally sold out in 2009 to Minerals and Metals Group (MMG) a subsidiary of China Minmetals. MMG commissioned the open pit above the Gossan Hill deposit in 2012 to raise copper production of contained copper. At that time zinc and lead output decreased to around 35 000 t/a of contained zinc and 4000 t/a of contained lead, with copper increasing to around 33 000 t/a of contained copper.

Concentrate is generally exported to smelters in Asia as well as Europe.



FIG 2.29 Golden Grove Mine.

Teutonic Bore – Jaguar – Bentley Mines

This field is located in the Eastern Goldfields Province of Western Australia, 320 km north of Kalgoorlie and 56 km north-west of Leonora. Geraldton serves as the port for export of concentrates – a trucking distance of about 720 km.

The Teutonic Bore deposit was discovered by Seltrust Mining Corporation in 1976. Open pit mining commenced in 1980 by BP-Seltrust joint venture and the concentrator was completed in 1981. Pre-mining the orebody reported 1.7 million tonnes of ore at 3.9 per cent copper, 11.1 per cent zinc, 1.2 per cent lead and 160 g/t silver. Zinc output in concentrates was of the order of 25 000 to 30 000 tonnes per year. However the orebody was fully mined out in 1985 and operations ceased, although exploration continued in the area.

The Jaguar deposit was discovered 4 km to the south of Teutonic Bore in 2002 with a similar sized orebody of 1.6 million tonnes containing 3.4 per cent copper and 12.9 per cent zinc. Jabiru Metals Ltd commenced mining in 2006 with an output of around 25 000 t/a of zinc in concentrate as well as 9000 t/a of copper in concentrate. The mining operation subsequently came under the control of the Independence Group and was completed in 2014.

The Bentley orebody was discovered by the Independence Group in 2008 to the south of Jaguar, reporting 1.9 million tonnes at 2.2 per cent copper and 14.3 per cent zinc. It was brought into production in parallel with Jaguar in 2011. This enabled zinc output to be ramped up and current projections of production are 40 000 to 48 000 t/a of zinc in concentrates plus 7000–8000 t/a of copper in concentrates. It is however likely that the deposits will be exhausted by 2017.



FIG 2.30 The Teutonic Bore pit.



FIG 2.31 The Jaguar Mine and concentrator.

Lennard Shelf Zinc Mines

The Lennard Shelf platform sits on the northern edge of the Canning Basin, south of the Kimberley and close to Fitzroy Crossing. It contains a number of orebodies in a carbonate host rock, similar in many respects to the deposits of the Mississippi Valley, producing exceptionally high grade and clean concentrates with high metal recovery. Zinc concentrate is typically 60 to 62 per cent with metal recoveries from ore of around 95 per cent.

The region was discovered in 1978 by BHP and Shell, and the Cadjebut Mine was developed in 1988 under a joint venture of BHP (58 per cent) and Billiton (42 per cent). Production was raised to around 550 000 tonnes per year of ore in 1989 yielding around 100 000 t/a of zinc concentrates. Concentrates were exported through the port of Wyndam. The operation was acquired by Western Metals in 1994.

The Cadjebut Mine was exhausted and closed in 1997, but the mill continued to operate with ore from the nearby Kapok and Goongawa mines. At that time production was raised to 900 000 t/a of ore, but with similar levels of zinc concentrate output.

The Pillara mine and concentrator, 60 km west of Cadjebut was commissioned in 1998 with a throughput of 1.5 million tonnes of ore per year, producing 165 000 t/a of zinc concentrates and 35 000 t/a of lead concentrates. At the same time export operations were shifted to the port of Derby and used a barging system to load ships anchored offshore in King Sound.

The Lennard Shelf operations were closed and placed on a care and maintenance basis by Western Metals in 2003 due to low metal prices and a high Australian dollar. This loss of income together with the strains of a number of costly acquisitions created serious financial difficulties, and the Company subsequently went into administration. The Lennard Shelf operation were purchased by Teck Cominco and Xstrata in joint venture and a decision was made to reopen Pillara in 2007, but this was short lived and the mine was again closed in 2008.

In August 2009 the operations were purchased by Meridian Minerals Ltd who undertook an extensive exploration program and discovered the Palijippa orebody, raising total reserves to 10.8 million tonnes at 6.9 per cent zinc and 3.8 per cent lead. Some finance was provided by Chinese company Northwest Nonferrous International Investment Company Ltd who finally acquired the property from Meridian Minerals in 2011.



FIG 2.32 Lennard Shelf regional map.



FIG 2.33 Pillara Mine site – Lennard Shelf.

Sulphur Springs - Panorama Mineral Zone - Pilbara

The Sulphur Springs deposit is located 110 km south-east of Port Hedland in the Pilbara region of Western Australia, 50 km west of Marble Bar. It has often been slated for development, but remains undeveloped to date, and contains a resource of the order of 15 million tonnes at around 3.8 per cent zinc and 1.4 per cent copper, including adjacent ore zones at Kangaroo Caves and Bernts. Currently the leases are held by Venturex Resources Limited.

2.5 ZINC MINES – SOUTH AUSTRALIA

The history of non-ferrous metal mining in Australia has its origins in South Australia. Specimens of lead-silver minerals were first noted at Glen Osmond in the foothills of the Mount Lofty Ranges in 1839 by a Cornishman with some experience in mining. He wrote a letter home and aroused some interest, which shortly led to establishment of the first mine at Wheal Gawler, named after the South Australian governor of the time. The first production of lead-silver ore was shipped to England aboard the 'Cygnet' in May 1841 and received a good return. This encouraged migration by Cornish miners, and two other mines – The Glen Osmond Mine and Wheal Watkins – soon followed, together with the construction of a small lead smelter in 1849. The discovery of copper at Kapunda and Burra soon diverted the attention of the mining fraternity and eclipsed the operations at Glen Osmond, which closed in 1851. The heritage of the Cornish miners lived on for a long time and was the basis of many of the mining practices and culture at Broken Hill and other mining fields at that time.

In those early times the presence of zinc was of no consequence and interest was primarily in lead, silver and gold values.



Beltana Mine

The Beltana and Aroona zinc silicate deposits were discovered by the Electrolytic Zinc Company (EZ) in the late 1960s. The deposits are located in the Flinders Ranges, 15 km south of Leigh Creek. The resource is high-grade zinc silicate ore containing between 30 and 42 per cent zinc and around 2.5 per cent lead. No concentration was required and the ore only needed to be crushed before shipment to a smelter. However, conventional electrolytic smelters could not treat the materials because of the formation of gelatinous silica when the ore is leached with sulphuric acid. A process was developed by EZ to overcome this problem, but quantities of ore were not sufficiently large to justify installing a specialised facility to treat Beltana ore at the Risdon zinc plant. Consequently, the only outlet for the ore was to pyrometallurgical smelters and in particular the older retort plants, or smelters with zinc fuming operations.

Mining by open pit commenced on a campaign basis in 1974, finishing in 1976, and leaving a stockpile of ore for shipment as sales could be secured. Ore was loaded onto rail at a nearby siding and transported to Port Pirie from where it was exported. Another campaign commenced in 1982 with sales to a vertical retort smelter in Germany. However, mining and sales continued to be spasmodic.

Small quantities of Beltana ore were also processed in the slag fuming furnace at the Port Pirie smelter, which was primarily used to recover zinc from lead blast furnace slag. However, the intake of Beltana ore was not favoured at Port Pirie until a large dump of zinc rich slag on the site had been fully processed in conjunction with current production of blast furnace slag.

The mine became part of North Broken Hill Limited with the takeover of EZ in 1984 and then became part of Pasminco with the merger of interests of North Broken Hill and CRA. Following the financial collapse of Pasminco, the Beltana mine was sold to Perilya Limited in May 2002. All mining activity ceased in 2003, but was resumed in 2007 on a campaign basis which was completed in 2008. At that time a contract was secured to supply ore to the Thai Zinc smelter owned by Padaeng Industries. The Thai Zinc smelter was based on a large zinc silicate deposit at Mae Sod in northern Thailand using technology developed for the processing silicate ores in an electrolytic zinc plant. At that time the Mae Sod mine was becoming exhausted and additional sources of similar feed were being sought as well as conversion to more conventional sulphide-based feed concentrates. The stockpiled ore was progressively sold over a period to September 2010 with a total zinc content of 101 000 tonnes.

In 2009 the Chinese company Shenzen Zhongin Lignan Nonfemet Co. Ltd acquired 50.1 per cent of Perilya Ltd and in December 2013 secured 100 per cent ownership. Currently reserves stand at around 0.5 million tonnes of ore at close to 30 per cent zinc.



FIG 2.34 Beltana open pit.

Angas Zinc Mine

The Angas Zinc Mine is located on the Fleurieu Peninsula 2 km from the town of Strathalbyn and 60 km south of Adelaide.

Mining commenced in the area in 1848 with Wheal Ellen, the largest mine extracting lead and silver. The present Angas zinc-lead deposit was discovered by Aberfoyle Resources Limited in 1991, but was not developed at that time. Terramin Australia Ltd purchased the property in 2006 and commenced mine development with a decline access in 2007. The first ore was extracted in April 2008 and the mill commissioned in July 2008. Reserves at this time were of the order of 2 million tonnes at 10 per cent zinc plus lead content.

The first two years of operation saw the production of 60 000 tonnes of zinc concentrate containing 50 per cent zinc, and 24 000 tonnes of lead concentrate containing 49 per cent lead and 3.5 per cent copper. Zinc concentrates were shipped out through Port Adelaide to South Korea and the lead concentrates were trucked to the Port Pirie lead smelter. Due to decreasing metal prices the mine became unprofitable and closed on a care and maintenance basis in September 2013.



FIG 2.35 The Angas Mine.
CHAPTER 3 – THE RISDON ZINC PLANT



FIG 3.1 The Risdon Foreshore in 1844.

PILOT FACILITIES

The Electrolytic Zinc Company of Australasia Limited (EZ) was formed to produce zinc metal in Australia from local mine concentrates as a result of the loss of concentrate markets and metal supplies to the British Commonwealth arising from the declaration of war against Germany in 1914. High-grade metal was required for munitions production and the electrolytic process, recently developed in North America, was selected as the preferred processing route. The availability of low-cost hydroelectric power was the reason for selecting Tasmania and the Risdon site close to Hobart for the location of the new smelter, as detailed in Chapter 1.

One of the first acts of the new Electrolytic Zinc Company of Australasia Limited (EZ) and at the direction of its new General Manager, Herbert Gepp, was to set up a research facility on the Risdon site to continue work which had been carried out on Broken Hill concentrates in America. This facility included a series of glass cells each capable of producing 2 pounds of zinc per day, as well as a larger pilot plant with a capacity of 250 pounds per day and composed of a cascade of four lead lined cells containing four cathodes each. Work on these facilities commenced on 16th December 1916. Herbert Gepp also commissioned test work at the General Electric testing laboratory at Bully Hill, California and engaged Professor G H Clevenger to work on the project.

It was recognised at this time that the cause of failure of past attempts at electrodeposition of zinc from solution had been the presence of impurities, particularly those metals more noble than zinc which deposited in preference and provided active sites for the generation of hydrogen rather than zinc. The reason why zinc could be electro-deposited from a water solution was that the excess voltage required above the theoretical for hydrogen formation was much higher on zinc than on other metals such as copper. Hence it was necessary to remove these metals from solution to extremely low levels and this was done by displacement from solution or cementation using zinc powder. Consequently, much of the early development work concentrated on the identification of impurities present and devising means for their removal. It was also important to understand the effect of solution conditions such as acidity and zinc concentration, as well as the electrical current density on electrolysis performance. The ultimate measure of performance was the current efficiency or the fraction of electric current used for the deposition of zinc rather than hydrogen.

Manganese was a common impurity in zinc concentrates and although it did not affect hydrogen formation it could accumulate in solution and displace the capacity of the solution to carry zinc. However, it was normally deposited on the lead anodes as manganese dioxide and in fact was found to be essential in order to protect the anode from corrosion giving rise to high levels of lead in cathode zinc. Professor Clevenger found not only high levels of manganese in Broken Hill concentrates, but unusually high levels of cobalt, which was of major concern and had to be removed. He proposed a method of removal based on precipitation from solution as chemical complex of alpha nitroso beta naphthol, but this was both expensive and difficult to use to achieve low cobalt levels without excessive reagent which impacted adversely on the electrolysis stage. However, cobalt could also be removed by zinc dust additions in the presence of arsenic and this was initially used.



FIG 3.2 The Experimental Zinc Plant – March 1917.

With confidence from the test work the next stage was the design and construction of a 10 ton per day plant and this commenced operation in January 1918 and operated successfully until closure in December 1920. Scale up by a factor of 10 to a 100 ton per day plant commenced in 1919 and in order to provide finance for the expansion the company was converted into a public company in October 1920 with the issue of shares. The company also signed a contract with the Tasmanian Government for the supply of 30 000 horsepower of electrical energy for 20 years. Construction of the new plant continued through 1920 and 1921, with start-up of the first unit in November 1921 and with full production reached in 1923. As part of this development the Company had also purchased the Mount Read and Rosebery Mines and the Zeehan Smelter to ensure a local supply of zinc concentrates.

During this period a joint research facility between EZ and The Broken Hill Associated Smelters was set up in Port Melbourne to conduct investigations of mutual interest and under the direction of American metallurgist Gilbert Rigg. Research metallurgist G K Williams from the joint research group was seconded to Risdon in 1923 to further studies into the removal of cobalt from solution and devised an arsenic activated zinc dust purification procedure. It was later discovered that it was possible to operate with much higher levels of cobalt than in other operations if combined with lower solution acidities. Although the arsenic–zinc dust method was originally applied, this later finding eventually enabled adoption of the alpha nitroso beta naphthol method of cobalt extraction, which allowed for the production of cobalt oxide as a by-product.

I W Wark conducted fundamental work on the key electrolysis process parameters at the University of Melbourne under a sponsored program which established many of the foundations and understanding of the electrochemistry of zinc electrodeposition, particularly the relationship between zinc and acid in solution and the expected efficiency of the cell. Ian Wark (later Sir Ian) was to go on to lead the Industrial Chemistry Division of CSIRO for many of its formative years.



FIG 3.3 The 10 ton per day leaching plant – 1919.

By the time of commissioning of the 100 ton per day plant the principles of the process had been firmly established and consisted of the following steps:

- 1. The roasting of zinc concentrates to eliminate sulphur and chlorine and form zinc oxide. Sulphurous gases from roasting were cleaned and used for production of sulphuric acid.
- 2. The roasted material or calcine was leached in dilute sulphuric acid to form a zinc sulphate solution. The leach residue was separated and initially sent to Port Pirie for recovery of lead and silver values.
- 3. The leach solution was neutralised to remove iron by precipitation and then treated with zinc dust to remove impurities deleterious to the electrowinning step.
- 4. Purified solution was subjected to electrolysis to deposit pure zinc at the cathode and form oxygen and sulphuric acid at the anode which was then recycled to the leaching step.

5. Cathode zinc was stripped from the aluminium cathode sheets, melted and cast into ingots.

In the following years the plant was progressively improved in operating efficiency and expanded. As with the initial period, process research into an understanding of the process and to increase performance in terms of metallurgical efficiency and productivity of labour and capital was an important aspect of the Company's operation for many years. Indeed, the Company was prominent in this aspect of zinc technology for at least 70 years of its first century of existence and maintained a high level of technical expertise.

PRODUCTION FACILITIES

At the beginning zinc concentrates were supplied only from the Broken Hill field, however following the purchase of the Rosebery mines in 1920 and successful introduction of flotation to that field and the construction of roasting plant at the Zeehan Smelters, material was also supplied from there in 1926. These two sources remained the mainstay of feed supply until the Broken Hill field declined from the 1990s. However significant supplies were also obtained from Lake George Mines at Captains Flat until 1962, from Mount Isa, and the Company's own Elura Mine in 1982. The Century Mine became a substantial supplier from 2001.

Roasting

Initially the Risdon plant was supplied with calcines from roasting operations elsewhere. Broken Hill concentrates were roasted at Broken Hill and Cockle Creek in New South Wales, and at Port Pirie, Wallaroo and Port Adelaide in South Australia. These sites were used because they had sulphuric acid plants and associated smelters as well as established transport links to Broken Hill. Apart from Broken Hill where the acid was used in the early acid flotation circuits, the acid was used in associated superphosphate manufacturing facilities. Much of the acid for fertiliser manufacture was made from imported sulphur, largely from Italy and at high cost. So, the use of indigenous supplies of sulphur was an important issue and encouraged by the Government, and by Act of Parliament in 1923 a bounty was paid on each ton of sulphuric acid produced from indigenous material. Most of the acid plants at that time used nitrate or 'chamber' processes and produced acid of around 70 per cent strength which could not be transported in bulk due to corrosion and had to be used where produced. Hence the reason for location of the roasters alongside fertiliser plants. At Port Pirie there was no fertiliser plant, but the newer 'Contact' catalytic acid conversion technology was used which enabled the output of 98 per cent sulphuric acid, suitable for transport in bulk using mild steel tanks.

The zinc concentrate roasters used were of various designs but predominantly multi-hearth furnaces. Barrier roasters were used at Broken Hill, Cockle Creek and Port Pirie, although two Skinner furnaces were used in parallel with the Barrier furnaces at Port Pirie. Skinner furnaces were used at Wallaroo and Herreshoff furnaces at Port Adelaide.

Generally roasting was incomplete in these furnaces leaving 6 per cent residual sulphur which tied up almost 25 per cent of the zinc content as unreacted zinc sulphide, insoluble in dilute sulphuric acid. Consequently, it was necessary to use a second roasting stage at Risdon to reduce the residual sulphur and also to eliminate chlorine contamination of the calcine arising from wetting down with saline waters to control dusting during transport.

The first roasting installation at Risdon consisted of four Leggo hearth furnace using coal or oil as a supplementary fuel. Leggo furnaces were horizontal line furnaces consisting of 16 sections each containing four tiered rabbled hearths. A coal fired combustion chamber was located at the discharge end and gases passed up through the furnace counter-current to the flow of calcine. Gases were cycloned to remove solids then scrubbed using estuary water to remove SO₂, passed through an electrostatic precipitator (Cottrell) to remove mist and SO₃ and then discharged up a 40 m stack.

In order to supply acid for the zinc production as well as a superphosphate plant built adjacent to the zinc plant, a primary roasting installation consisting of six 7-hearth Herreshoff roasters was constructed in 1924, together with a chamber style acid plant of Schmiedel design later changed to Mills Packard design. This plant handled 40 tons per day of concentrates.



FIG 3.4 Construction of the roasting plant – August 1921.

Following the purchase of the Rosebery mines and the Zeehan Smelters by EZ in 1920 and the successful introduction of flotation technology to the separation of zinc and lead concentrates, Herreshoff roasters were installed at the Zeehan smelter site for the roasting of zinc concentrates. This roasting plant commenced operation in 1925 and shipped calcines to Risdon through the port of Strahan. Due to the Great Depression and its impact on metal markets, the mines and Zeehan Smelters closed in February 1930. Operations recommenced in March 1936 and supply of calcines from the Zeehan roasting plant continued until final closure in November 1948.

In the late 1930s a flotation stage was introduced into the Risdon leaching plant to recover unroasted sulphide from the leach residue for recycle and consequently two-stage roasting was discontinued in 1940.

In 1943 and 1944 two Skinner Hearth Roasters were installed to increase primary roasting capacity. These roasters were similar but larger than the standard Herreshoff roaster and had a capacity of 90 tons per day per furnace.

The next significant development in roasting plant was the installation of two flash roasters in which dry finely ground concentrate was injected into the top of a hot chamber as a suspension in air and the sulphur burned as the material fell to the furnace grate at the base. The design was based on furnaces developed by Consolidated Mining and Smelting Company at Trail in British Columbia. The first installation was completed in 1948 and at that time local roasting of Rosebery concentrates ceased with closure of the Zeehan Smelters. These roasters required the drying of concentrates using three hearths at the top of the furnace and grinding to an average size of 4 microns in an air-swept ball mill before injection. Roasting was efficient with low levels of residual sulphides. It also allowed for the generation of steam and the gas strength was higher in SO₂ at 7 to 8 per cent and more suited to acid production using the contact process. The first contact acid plant was commissioned in 1948 with a production rate of 150 tons per day and allowed the older chamber plant to be shutdown.

Because of the fine nature of calcines from the flash roasters dust collection from roaster gas was a key issue and the equipment used included cyclones followed by electrostatic precipitators before entering the scrubbing section of the acid plant.

Two additional flash roasting furnaces were installed by 1956 and by that time the external roasting had ceased – at Cockle Creek in 1953, at Port Pirie in 1955, and at Wallaroo in 1956. The roasting plant at Risdon then handled all concentrate input with the four flash roasters and the two Skinner Hearth Roasters which treated all recovered sulphides as well as new concentrates. Oxygen became available on site at this time from the installation of the ammonia plant which produced oxygen from the electrolysis of water to yield hydrogen and from air fraction required to produce nitrogen. This was used in all roasters to enrich air input and substantially increased throughput, particularly for the Skinner roasters. The hearth roasters achieved around 80 tons of feed per furnace day and the flash roasters around 170 tons per furnace day.

At this time a Whirlwind Air Classifier was installed to process flash roaster calcine so as to provide materials for neutralisation in the iron precipitation stage as a replacement for ground limestone. This material was relatively richer in zinc oxide and left minimal residue.



FIG 3.5 Flash roaster building from 76 foot access level – 1960.

The flash roasters, although efficient, were complex with high maintenance and high manning and operating costs. The use of turbulent layer fluid bed technology for the roasting of zinc concentrates had been developed by Dorr Oliver in the 1950s using a slurry feed system but with limitations. A direct feed approach was developed by the Vieille Montagne Company in Belgium and offered a simpler, robust and a substantially lower cost option. Lurgi, the technology offshoot subsidiary of Metallgesellschaft, had been licensed to offer this technology and was commissioned by EZ to construct a unit at Risdon, which came into operation in 1969. This allowed the older hearth roasters to be shutdown, as well as allowing for an expansion in roasting capacity. The (No.5) fluid bed roaster had a hearth area of 55 m² and a roasting capacity of around 400 tonnes per day. Concentrates could be fed to the furnace as received, steam generation was greater and the roasting temperature could be more closely controlled at 900 to 930°C.

The success of fluid bed technology together with the need for increased roasting capacity saw the construction of a second much larger unit (No.6 Fluid Bed Roaster) which came into operation in 1975 and allowed the shutdown of the four flash roasters at a significant operating cost saving. The new roaster had a hearth area of 123 square metres and was the largest fluid bed roaster ever built. Capacity was at least 800 tonnes of concentrate per day and was fitted with two slinger belt feed ports. Calcine overflowed from a weir in the side of the furnace and passed through a rotary cooler and into a surge hopper before feeding to the leaching plant.

With the closure of the flash roasters in 1975 the supply of fine calcine for neutralisation in iron purification ceased and it was necessary to revert to the use of ground limestone with the installation of a new limestone grinding facility.

Capacity of the fluid bed roasters has been increased over the years and the two units remain in use at the present time. Important changes have been to calcine cooling equipment with the addition of rotary coolers to the No.5 Roaster, and the addition of two 10 000 tonne calcine storage bins in 1991 together with facilities for grinding calcine in

plant solution in order to change calcine handling to a slurry system rather than the previous dry-belt conveyor system which caused a significant dust nuisance around the site.



FIG 3.6 No.6 fluid bed roaster - 1975.



FIG 3.7 Timeline for roasting development milestones at Risdon.

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FIG 3.8 No.6 Roaster with acid rail loading in foreground – 1978.



FIG 3.9 Roasting and acid plants with fertiliser plant in foreground – 1990.

Sulphuric acid production

Initially all acid was produced at the primary roasting sites on the mainland which were indeed located in different places in order to be able to dispose of acid in local superphosphate manufacturing facilities. Gases from secondary roasting at Risdon contained relatively small quantities of sulphur and this was removed by scrubbing with salt water from the Derwent estuary.

With the construction of a superphosphate plant at Risdon and the introduction of some primary roasting a chamber sulphuric acid plant of the Schmiedel design was constructed in 1924 and later converted into a Mills Packard design.



FIG 3.10 Original Mills Packard chamber sulphuric acid plant (Left) – 1924. FIG 3.11 No. 4 Contact Unit – 1966.

With the first two flash roasters the quality of roaster gas in terms of SO₂ strength was greatly improved and it was possible to introduce contact catalytic technology with the commissioning of the first plant in 1948, and this replaced the Mills Packard chamber plant, which closed in 1949. A second contact unit was installed in 1953 and a third in 1958, with the full installation of flash smelting and the transfer of all roasting operations to the Risdon site, taking sulphuric acid production capacity to 180 000 tons per year. Sulphuric acid was then utilised in the on-site superphosphate plant and the new ammonium sulphate plant as well as a small unit for the manufacture of aluminium sulphate for use in water treatment. Sulphuric acid was also delivered by rail to a titanium dioxide manufacturing plant located near Burnie, which commenced operation in 1949.

With progressive expansion in concentrates roasted a fourth contact acid unit was installed in July 1966, increasing sulphuric acid production capacity to 290 000 tonnes per year.

The life of sulphuric acid plants is limited due to the highly corrosive nature of many of the materials handled and plans were developed in the 1970s to replace the existing units with modern units matching the capacities of the two fluid bed roasters. The first replacement plant was matched to No.6 roaster and was a Lurgi design of 800 tonnes per day nominal capacity and commissioned in 1981. Since the tail gas scrubbing units using estuarine water were still in effective use the plants were designed as single absorption units, whereas without this facility double absorption would have been required to meet emission standards. This unit also included for the first time, facilities for the removal and recovery of mercury from roaster gas because of tightening specification for sulphuric acid and because of environmental concerns for the Derwent estuary. This unit replaced the older two sulphuric acid units.

The second replacement contact acid plant to match No.5 Roaster at 550 tonnes per day capacity was commissioned in 1993, fully replacing the two remaining older units. At this point the sulphuric acid production capacity was a nominal 1350 tonnes per day or 450 000 tonnes per year.

Over the years the local demand for sulphuric acid in Tasmania receded with the closure of the ammonium sulphate plant in 1986, the aluminium sulphate plant in 1990, and the closure of the Tioxide pigment plant near Burnie in 1996. Consequently, the disposal of sulphuric acid became more reliant on shipping to interstate fertiliser operations. This was carried in the Company's own vessel (The Zincmaster) for many years and then in chartered bulk liquid carriers.



FIG 3.12 Timeline for sulphuric acid plant installations at Risdon.



FIG 3.13 No. 6 Sulphuric acid unit – 1981.

Leaching operations and iron separation

The leaching plant practice was unique among early electrolytic zinc plants in that it was a single stage maintained at acid conditions, whereas other plants used a two-stage countercurrent leach under acid and neutral conditions. This configuration was used due to the poor filtration characteristics of a neutral leach pulp resulting from the presence of gelatinous silica. The flowsheet for Stage 1 is illustrated in Figure 3.34.

Leaching was carried out in 12 ft diameter by 34 ft high wood stave Pachuca tanks. Agitation was by compressed air introduced into the bottom of the tank below a central draft tube causing the pulp to circulate with air up through the draft tube and down the sides of the tank. The advantage of this system was that it handled the coarse fraction of calcine much better than an impeller agitated tank which tended to cause the tanks to silt up. Calcine and spent electrolyte containing 50 g/L zinc and 70 g/L acid were fed into the tank as a batch charge and calcine added until the acidity reached the required level. Once the leach was complete the tank was discharged into a set of six rake classifiers. The fine solids in overflow were sent to thickeners and then to filters. The coarse materials from the rake classifiers contained most of the unroasted sulphides and was ground, leached in dilute spent electrolyte and subjected to flotation to recover a sulphide concentrate which was recycled to the roasters. The fine residue fraction as underflow from the primary thickeners was filtered, washed and dried, and then shipped to the Port Pirie lead smelter for recovery of lead and silver values. Any residual zinc in the residue was retained in lead smelter slag.



FIG 3.14 Construction of the leaching plant – 1921.

The acid leach solution was originally neutralised with ground limestone, resulting in the precipitation of iron as ferric hydroxide. Limestone was replaced with the use of very fine classified calcine after the introduction of the flash roasters and then continued again with the replacement of the flash roasters by fluid bed roasters in 1975. The neutralisation was carried out in air sparged tanks to ensure that all iron present was oxidised to the ferric state and some manganese dioxide as recycled anode slime was also added. The final pulp also contained gelatinous silica with poor filtering properties, and hence large surface area Moore vacuum leaf filters were used. The primary filter cake was repulped and refiltered as a washing step and that second stage cake was again repulped in dilute acid solution to remove any basic zinc sulphates formed during neutralisation. The final iron precipitate filter cake was repulped with water and discharged as a waste stream to the Derwent River estuary. This acid leach practice followed by neutralisation and iron precipitation enabled the bulk of the residue to be readily filtered and the difficult filtration step to be confined to a much smaller volume of material. The amount of iron precipitate represented about 7 per cent of the concentrate intake, whereas the primary leach residue represented about 25 per cent of the concentrate intake.



FIG 3.15 Iron residue filtration – vacuum leaf filters – 1960.

After the introduction of ferrite leach residue treatment in 1971 and the use of limestone for iron precipitation in 1975, the iron residue was mixed with jarosite residue for combined disposal.

Leach residue contained zinc in the form of ferrites (ZnFe₂O₄) which formed during roasting, locking up around 10 to 12 per cent of the zinc content of the feed concentrates. Typical composition of the residues at that time was 21.9 per cent Zn, 31.1 per cent Fe, 6.4 per cent Pb and 170 g/t of silver. Consequently, recovery of zinc in the plant was around 85 to 88 per cent and this was reflected in the purchase terms for the concentrate. As mentioned above, leach residue was initially shipped to the Port Pirie lead smelter for recovery of lead and silver values, but stockpiling on site commenced for part of the residue production in 1940 and all shipments to Port Pirie ceased during the 1950s with stockpiling until such time as a suitable extraction method could be developed.

In 1945 the leaching operations were converted from batch to continuous operation which simplified operations and controls and was one of the early plants to make this change. Many zinc plants retained batch operation particular under the influence of consultant Alan Jephson from ASARCO who had also started his career at Risdon. Jephson provided the design for the Port Pire Electrolytic Zinc Plant as well as many others in Europe, USA and Canada during the 1960s and 1970s.



FIG 3.16 The Risdon leaching plant – 1966.

Operations continued without significant change for many years. Hydrocyclones were introduced to treat primary leach residue fines and improve residual sulphide recovery with underflow joining the granular residue stream and eventually being subjected to flotation. With the introduction of fluid bed roasting in 1972, both hydrocyclone treatment and flotation was discontinued.

Much attention was focused on methods of extracting zinc from the ferrites contained in residue and for many years this was a priority research effort. Many avenues were explored. It was well known the ferrite could be dissolved in hot strong sulphuric acid solutions, but both zinc and iron were dissolved and it was not practical to remove the iron in a manageable form which could be easily filtered from solution leaving most of the zinc in solution. Neutralisation merely precipitated a gelatinous iron hydroxide which could only be filtered with great difficulty and entrained most of the zinc. One significant approach piloted at Risdon was the use of a sulphation roast in which residue and concentrated sulphuric acid were roasted in a fluid bed furnace at around 750°C to form zinc sulphate and ferric oxide. This operated on a pilot scale for several years but was subsequently abandoned.

During research on high pressure precipitation of iron from hot acid leach solution it was discovered that a basic sulphate double salt of iron and potassium (similar to the mineral jarosite) could be precipitated. This was crystalline and could be readily filtered and washed. It was further found that this could be produced at atmospheric pressure, but under high solution temperatures, and also that sodium or ammonium could be used in place of potassium. Ammonia was produced on site and was the most cost-effective reagent for jarosite formation. The company patented the technique, but found that two other companies had independently discovered similar technology at exactly the same time. The three companies EZ, Asturiana de Zinc from Spain and Norzink from Norway decided to pool their resources and market the technology jointly throughout the world.

With similar timing two other technologies were also developed – the Goethite Process by Vieille Montagne in Belgium and the Hematite process involving high pressure precipitation of iron by Ruhr Zinc in Germany.

The jarosite process flowsheet was developed to treat both currently produced primary residue as well as the stockpile and the plant was commissioned in 1971. The flowsheet is illustrated in Figure 3.35 and involved the following steps:

- 1. Hot acid leaching of primary leach residue.
- 2. Separation of the hot acid leach residue, now high in lead and silver, by thickening and filtration using a filter press.
- 3. Preneutralisation of thickener overflow solution using recycled iron oxidation residue.
- 4. Jarosite precipitation of the resulting solution by the addition of calcine and ammonia.
- 5. Separation of jarosite by thickening and then filtration and washing of the thickener underflow using a vacuum drum filter.
- 6. Neutralisation of jarosite thickener overflow using calcine in air sparged agitated tanks to oxidise and precipitate any residual iron in solution.
- 7. Separation of residual iron residue by thickening, and recycle of the solids to the preneutralisation stage (3). Thickener overflow was returned to the main leaching circuit to join primary leach solution flowing to the iron precipitation stage.

Since calcine was used for neutralisation during jarosite precipitation the jarosite precipitate did contain some zinc as ferrites from this material, representing a loss of zinc from the process. However, by application of the process the overall recovery of zinc at the Risdon plant was raised from around 85 per cent previously to 94 per cent.

Jarosite filter cake was repulped in water and pumped to a bottom dump barge from where it was taken out to sea and dumped in deep ocean water beyond the continental shelf.

The preferred conditions for jarosite precipitation were a temperature of 95° C and a free acidity of 5 g/L at which at least 90 per cent of the iron can be precipitated. The incoming ferric iron level was around 35 g/L, reducing to 2 to 3 g/L. Some ferrous iron was also present due to reaction with zinc sulphide, hence it was necessary to include the additional iron oxidation and precipitation as ferric hydroxide. This stage operated at a pH of 4.5.

As a result of the introduction of residue treatment the level of manganese and nickel increased and required steps for removal. Manganese was handled by the discard of plant solution from which zinc had been removed. This was done by neutralisation of solution with limestone at pH 6.5 and a temperature of 95°C. Under these conditions zinc was precipitated as a basic sulphate and manganese, as well as magnesium and chlorine were unaffected. After filtration, the resulting solution was used for displacement washing of the jarosite filter cake and thus exited the circuit with jarosite solids. The basic zinc sulphate cake was used as a neutralising agent in jarosite precipitate zinc and then to neutralise acid during jarosite precipitation.

To handle the removal of nickel an additional hot zinc dust purification stage was added, operating at around 75°C. This stage also precipitated all copper and cadmium from the residue treatment section solution. The zinc dust precipitate was sent to the cadmium section together with zinc dust precipitate from the main circuit, where it was leached in spent electrolyte to extract zinc and cadmium as well as nickel and leave a copper residue.

The flow sheet so developed and applied at Risdon was particularly complex and arose because of the unique nature of the primary acid leach, rather than a neutral leach more

commonly used in other zinc plants at the time. The requirement to produce a separate lead-silver residue also added complexity and without these two features much simpler flowsheets could be used.

As a result of pressures to reduce the level of heavy metals in jarosite waste as well as to improve the recovery of zinc and productivity, a major new flowsheet was proposed and a pilot plant commissioned to test the concepts initiated in 1980. This examined a new approach to leaching based on the more widely used neutral leach, a simplified purification procedure, and the opportunity to increase spent electrolyte acidity to reduce power consumption. The latter required a change to the level of certain impurities in solution, particularly lower levels of cobalt. The pilot plant ran until 1983 followed by a major design study and commitment to modernise the leaching and purification section of the plant commencing in 1985. The first section completed was an additional strong acid leaching stage applied to final leach residue in 1988. New preneutralisation, weak acid leaching and neutral leaching stages were added together with entirely new final residue and jarosite filters. A new purification plant and gypsum removal facility was also added and the total modernisation fully completed in 1991.

The new leaching plant became a single fully continuous counter-current operation from neutral leaching of calcine through to hot strong acid leaching of final lead-silver residue. Details are illustrated in the Stage 3 flowsheet shown in Figure 3.36. Neutral leaching now involved the extraction of most of the zinc oxide content of calcine combined with the removal of all of the iron from solution and operated at a pH of 4.8 to 5.3. The leaching tanks were air sparged to oxidise ferrous iron and also served to remove impurities such as arsenic, antimony, germanium, fluorine, aluminium and silica from solution to low levels.

Neutral leach solution passed to solution purification and the residue as thickener underflow transferred to the weak acid leaching section. Weak acid leaching operated at a pH range of 3.0 to 4 and a temperature of 90°C. Some calcine was added to control pH and ferric iron was precipitated. Solution from this stage passed to neutral leach and solids to the preneutralisation stage. Solids in turn then passed to hot acid leaching and then to strong acid leaching where the acidity increased in turn from 10 g/L to 70 to 90 g/L in hot acid leach to 130 to 160 g/L in strong acid leach. To reach the acidity in the strong acid leach section, spent electrolyte at 165 to 170 g/L acid had to be fortified by the addition of concentrated sulphuric acid. This added extra sulphate to the circuit and in order to reach a balance an outlet was required, achieved using limestone for neutralisation duties and the corresponding formation of gypsum waste.

Solids from the strong acid leach were separated by thickening and underflow filtration using three vertical pressure filters, with the addition of a small dryer to reduce moisture so as to allow for bulk shipment of the residue to a lead smelter.

Solution from the preneutralisation stage at an acidity of 10 g/L and temperature of 80 to 85° C passed to jarosite precipitation where the temperature was raised to close to 100° C with the addition of recycle jarosite as seed, ammonia and calcine to neutralise any acid formed. Iron was reduced from around 25 g/L to 5 g/L by the formation of ammonium jarosite. The jarosite precipitate was separated by thickening and then filtering using three fully automated recessed plate, squeeze action filter presses. Solution from the Basic Zinc Sulphate precipitation section, as described above, was used as wash solution.

As indicated above jarosite waste was disposed of by dumping at sea from a bottom dump barge in deep ocean water of around 1000 m. This operation was closely controlled by the Commonwealth Government as well as by regular surveys of environmental effects by the Company itself. Most detailed scientific studies could find no adverse effects and in fact the addition of iron to the southern oceans was seen as beneficial. However, the weight of public opinion about ocean disposal of waste and an international treaty to end the practice required that the disposal of jarosite in this way should discontinue. There was also little opportunity to dispose of such wastes on land in Tasmania and near the Risdon site, as large areas of pondage would be required. Studies were then initiated into alternatives to the production of jarosite and included the elimination of iron as hematite or as goethite. Processes using these methods were well established elsewhere. Even so there had to be a means of disposal of these materials such as the conversion of hematite into a marketable iron product. At the time, Risdon was part of the Pasminco Group which included the Port Pirie lead smelter and the option existed to produce a single waste stream containing lead, silver and iron to be incorporated into the lead smelter feed – reverting back indeed to the original practice when Risdon commenced. This would mean that the lead, silver and any residual zinc would be recovered at Port Pirie and the iron converted into a slag which could be readily stockpiled at site. However, the quantity of iron was a significant problem and overloaded the Port Pirie smelter. The high iron levels originated largely from Broken Hill concentrates and these were decreasing in volume as the field approached the end of its life, however the availability of concentrates from the new Century Mine offered the prospect of substantially reducing the intake of iron.

A decision was made to adopt the goethite route using a process developed by EZ in 1970 called the Paragoethite Process, in which goethite is precipitated from solution by slow addition of high iron solution to a single stage reactor so as the maintain the ferric iron concentration at low levels. This differed from the Goethite Process developed by Vieille Montagne in 1967 in which all iron was first reduced to the ferrous state and then slowly oxidised under low acid conditions so that ferric iron concentrations were low and goethite precipitated simultaneously. The paragoethite residue was less efficient and resulted in greater zinc loss than goethite from the Goethite Process, however it was more readily incorporated into the existing Risdon equipment with minor change and at minimal cost. It did not require the additional iron reduction stage of the Goethite Process.

Pilot testing of the Paragoethite Process incorporation into the Risdon circuit commenced in 1993. This was complicated by the need to use synthetic rather than plant solution to avoid the presence of ammonium ions in current plant solution which would have caused jarosite formation as well as goethite. It was also realised that Port Pirie could not handle high levels of sulphate in its feed and hence it was necessary to remove gypsum from incorporation in the iron residue as had been the case with jarosite. Thus, separate disposal of gypsum became necessary and in order to do so the zinc content had to be reduced to an acceptable level for a marketable gypsum product. The paragoethite residue did not filter well and had a high moisture content, and hence required drying to below a transportable moisture limit for shipment to Port Pirie.

Construction and commissioning of new facilities was completed in October 1997. Details are illustrated in the Stage 4 flowsheet shown in Figure 3.37. In this flowsheet paragoethite precipitation essentially replaced jarosite precipitation, and the weak acid leaching stage was eliminated with all neutral leach residue directed to the preneutralisation step ahead of paragoethite precipitation. Most of the existing equipment, such as filters and tanks, was fully utilised, with major additions as residue drying and a separate gypsum plant.



FIG 3.17 Filter press used for leach residue separation.



FIG 3.18 View of the current leaching plant – 2000.



FIG 3.19 Timeline for upgrades to the leaching process at Risdon.

Solution purification

Early solution purification operations

There are many impurities present in leach solution which will impair electrolytic deposition of zinc or even render it ineffective. These include copper, arsenic, antimony, nickel, cobalt, germanium and cadmium. Some such as arsenic, antimony and germanium can be largely removed by adsorption on the iron hydroxide precipitate. Others need to be removed by precipitation using zinc powder or cementation. In the case of the early Risdon operations the iron neutralisation stage was effective in removing arsenic, antimony and germanium as well as any traces of nickel. A single batch zinc dust purification stage was used with the addition of arsenic as an activator to remove copper, cobalt and cadmium. After encountering hazards with the generation of arsine, the use of arsenic was discontinued in the late 1920s and a separate cobalt removal stage was added using precipitation as a complex with alpha nitroso beta naphthol. This was practical due to the practice at Risdon of using relatively low acidity in spent electrolyte and relatively high levels of cobalt in electrolyte. This meant that excess reagent was not needed to achieve the required cobalt level and hence reagent concentrations in solution could be maintained below levels which would otherwise have been deleterious to the electrodeposition of zinc. The zinc dust purification stage then produced a copper-cadmium rich cement, filtered from solution using a filter press to ensure no fine particles were carried forward to the electrolysis stage. The flowsheet for Stage 1 is illustrated in Figure 3.34

The copper-cadmium precipitate was oxidised by air in open heaps, then ground and leached in spent electrolyte to extract zinc and cadmium and leave a copper residue which was separated by filtration, dried and shipped to a copper smelter. The cadmium-zinc solution was treated with zinc dust to re-precipitate cadmium, which was separated by filtration, then oxidised in a small furnace, leached in cadmium plant spent electrolyte and subjected to electrolysis to recover cadmium metal. A bleed of solution from the cadmium plant was returned to the zinc circuit ahead of zinc dust purification to provide an outlet for zinc from the cadmium circuit.

The purification section changed from batch to continuous operation in 1967 and a solution evaporation tower was added to assist in water removal and circuit water balance control.

After the introduction of residue treatment and a nickel cementation stage in 1971, the zinc dust precipitate from that stage was also mixed with copper-cadmium precipitate for treatment. The nickel content then appeared in return solution from the cadmium plant at around 30 mg/L and this was removed by precipitation using a caustic soda solution of dimethyl glyoxime to a residual level of 5 to 6 mg/L, before transfer to the main circuit zinc dust purification stage. Flowsheet details are shown for Stage 2 Flowsheet in Figure 3.35.

Following the main zinc dust purification step a portion of the solution was next treated for cobalt removal in batch tanks into which a caustic soda solution of beta naphthol was added. Sodium nitrate was then added followed by some spent electrolyte to raise the acidity to around 0.1 g/L, resulting in the precipitation of the cobalt alpha nitroso beta naphthol complex. The pulp was then neutralised by the addition of lime and processed in flotation cells to separate the cobalt complex which was then filtered in a filter press. The cobalt filter cake was repulped in dilute acid to extract any residual zinc was refiltered, and roasted in a small reverb furnace to form a marketable cobalt oxide. This purification stage maintained the level of cobalt in purified zinc sulphate solution at around 10 mg/L.

The level of chlorine in solution was also important as high levels caused corrosion of the lead anodes during electrolysis giving rise to high levels of lead in zinc cathodes. Chlorine is removed to a large extent during roasting, but this was generally regarded as inadequate in the early operations and a separate chlorine removal stage was necessary to maintain levels in purified solution below 80 mg/L. This was achieved by the addition of silver sulphate to part of the solution stream. The resulting silver chloride was separated by filtration, was reduced by the addition of zinc dust to silver metal, and then heated with sulphuric acid to reform silver sulphate for recycle. With more efficient roasting in the 1960s chlorine elimination improved, and the chlorine solution purification stage was no longer necessary with the total chlorine level stabilising at around 180 mg/L.

Contemporary operations

The old purification plant as described above had become complex and inefficient by various additions to handle increased levels or additional impurities, resulting from the introduction of more severe leaching conditions. The modernisation programme initiated in the 1980s also considered the use of higher spent electrolyte acidities and necessitated a shift to an electrolyte low in cobalt. This in turn required a complete review of the solution purification method and this was incorporated into the pilot plant investigation which operated from 1981 to 1983. As a result, a two-stage zinc dust purification system was devised with only copper precipitated in the first stage and using antimony to activate the second stage for precipitation of the remaining elements including cadmium, cobalt and nickel. The new purification plant was commissioned in 1989. Flowsheet details are illustrated in Figure 3.36 and a timeline for upgrades is shown below in Figure 3.20.

Neutral leach solution entered the first stage at 80°C with only marginally more zinc dust than required to remove copper. The copper-rich solids were separated using a plate and frame filter press, were leached in dilute acid with air sparging to dissolve the copper which was then recovered as copper sulphate using a forced circulation vacuum crystalliser. Copper sulphate was sold as a by-product (particularly for use in the mining industry as a flotation reagent), achieving a much greater returns than sale to a copper smelter, as was the previous practice.

Solution from the first purification stage was then treated with excess zinc dust (containing 1 per cent lead) and potassium antimony tartrate using five tanks in series. Final slurry was filtered using four US Autojet pressurised leaf filters, to give a final solution containing less than 0.05 mg/L copper, 1.0 mg/L cadmium, 0.3 mg/L cobalt and 0.1 mg/L nickel.

Purified solution then passed to the gypsum removal plant which consisted of six cooling towers to drop the temperature of solution from 80°C to 25°C before transfer to electrolysis. Fine seed gypsum was added to the solution passing over the towers and the tower exit solution flowed into a thickener. Thickener underflow was screened and undersize was recirculated as seed and the oversize material was withdrawn as a waste stream and mixed with jarosite residue for disposal. This facility greatly reduced the problem of gypsum build-up and fouling of tanks and pipes throughout the operation. Following the conversion from jarosite to paragoethite the gypsum stream was directed to the gypsum treatment plant to produce a clean marketable gypsum product.

The second stage purification solids were first leached to selectively dissolve excess zinc and the resulting solution returned to the neutral leach stage. The residual solids were further leached in dilute acid to dissolve cadmium and the solution sent to the existing cadmium plant for electrowinning. The final residue containing nickel, cobalt, lead and zinc was sold as the opportunity arose to specialised smelters.

All purification tanks were fitted with nitrogen blanketing to avoid the possibility of hydrogen explosions.



FIG 3.20 Timelines for upgrade of the solution purification circuit.



FIG 3.21 Current purification reactors and gypsum removal towers in the background.

Electrolysis

The electrolytic cells were initially organised as units of 144 cells connected in series to give a total voltage of 440 volts across each unit as a manageable electrical supply. Cell design was based on a zinc cathode sheet size of approximately 3 feet long by 2 feet wide with a deposit weight of around 15 kg each side for a 72-hour deposit, considered suitable for manual stripping of the zinc deposit from the aluminium cathode sheet. Target cathode current density for this deposition rate was 290 amps per square metre and for a supply current 18 000 amps there are 33 cathodes per cell. This then determined the dimensions of the cell units. The cells were arranged in a cascade of six to give 24 rows per unit. Solution was added to each cell to maintain acidity levels at around 90 g/L and overflowed from one to the next in the cascade.

Cooling was achieved by placing three lead cooling coils in the feed end of each cell and two coils at the discharge end. Cooling water was circulated through the coils to maintain a solution temperature of 35 to 40 degrees C.



FIG 3.22 (Left) Construction of the Cascade Cells, showing Cooling Coils at right.

The original '100 ton plant' consisted of three cell units and commenced operation in 1922. A fourth unit was added in 1934.

The anodes consisted of lead sheets with 34 per cell. They become coated with manganese dioxide during operation which does serve to protect the lead from corrosion, but needs to be periodically cleaned off as it increases cell voltage and power consumption. Eventually the extent of corrosion requires replacement of anodes and life was, at the early stages, about two to three years. The removal of manganese dioxide from the anodes balanced and provided an outlet for any manganese entering the plant in concentrates. It was possible to produce zinc cathodes containing 0.003 per cent lead, much lower than other plants using

plain lead anodes and this was attributed to the higher level of cobalt contained in Risdon plant solutions.

In order to improve the density of the zinc deposit and current efficiency, it was found necessary to add dosing chemicals to the electrolyte during electrolysis and this was done by periodic manual additions to each cell. The Risdon solution was unique in its high cobalt levels and the dosing agents required were glue, beta naphthol and antimony. Strontium carbonate was also later added to control lead and further reduce the level of lead in cathode zinc. Under these conditions, current efficiencies of 92 per cent to 94 per cent were achieved.

For stripping, one-third of the cathodes were lifted from the cell at any one time and the deposit manually separated and the clean cathodes sheets returned to the cell. The zinc cathodes were washed and sent to the melting furnaces.



FIG 3.23 Zinc cell house.

Up to 1960 the plant had operated with four cell units and at this time a fifth was added. This unit changed from a cascade arrangement of cells fitted with cooling coils to the use of high-volume circulating electrolyte passing over an evaporative cooling tower. The unit also had 180 cells and a higher current density of 500 amps per square metre compared with 370 in the older units. Another similar unit (No.6 Cell Unit) was added in 1971 to expand capacity to over 200 000 tonnes per year.

Cathode stripping remained a manual operation until 1980 when the first automated stripping machine of Italian – Montedison design was commissioned. Cathodes were still manually lifted from the cells using overhead hoists over each cell row and the cathodes were placed in rail trucks for transfer to the stripping machine and for return of cleaned cathode sheets for return to the cells. This machine handled about 60 per cent of the cell house output. A mobile stripping machine was introduced for an interim period, but eventually a second machine was installed in 1998 to fully automate the stripping operation. Stripped cathodes were transferred by conveyor directly to the casting plant. A timeline for plant upgrades is shown below.

The 1980s modernisation of leaching and purification sections saw the solution composition change and the spent electrolyte acidity increased from 90 g/L up to 170 g/L and the zinc content of neutral cell feed solution rose from 120 g/L to 160 g/L. This substantially reduced the volume of solution flowing through the plant per tonne of zinc cathode produced and improved the efficiency of the equipment – in part allowing more capacity to be squeezed out of existing equipment. As part of the change, particularly the reduction in cobalt, it was necessary to convert all cathodes to silver-lead alloy so as to reduce corrosion and achieve low levels of lead in cathode zinc. The demand for low lead-zinc had also greatly increased by that time.

The limitation for the electrolysis section was of course the current supply to the cell units and this was also progressively increased by increasing bus bar sizes and even by adding bus bar cooling.



FIG 3.24 Timeline for upgrades to the electrolysis plant.



FIG 3.25 Manual lifting of cathodes and stripping from Circulating Unit No. 5 – 1980.



FIG 3.26 An automated mobile cathode stripping machine – 1990.

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FIG 3.27 Aerial view of the Cell House (left) and Purification Plant (centre) around 1995.

Cathode zinc melting and casting

One of the difficulties in melting cathode zinc was the tendency to oxidise and form dross which was dependent on the nature of the deposit. Two coal fired reverberatory furnaces were originally used for this purpose and were installed in 1922. Each furnace contained a crucible holding 180 tons of molten zinc and had two charging ports in the roof through which zinc cathode sheets were dropped into the molten zinc bath. Charging was by hand until the molten zinc reached a prescribed level. Each furnace had two operating tapping ports as well as lower level tapping points to drain the furnace. Doors along one side gave access for drossing using heavy counterbalanced rakes. The drossing operation consisted of charging ammonium chloride into the furnace as a flux, manually mixing this into the dross layer for around 10 to 15 minutes and then scraping the dross out through the doors into a rail mounted truck for transfer to dross treatment.

Dross production was relatively high at up to 17 per cent of the zinc charged. The hot dross from the furnaces was charged to a heated rotary mill, which allowed entrained zinc to separate and run out from the mill, recovering about 65 per cent of the contained zinc for return to the melting furnaces. The resulting dry dross was screened in closed circuit with a hammer mill to separate fine powdered zinc oxide from residual metal prills, which were also returned to the melting furnaces. The final dry dross was returned to the roasting furnaces which served to remove the chlorine content from fluxing chemicals.

Molten zinc was tapped from the melting furnaces into a cast iron pouring pot holding 600 pounds (270 kg) of metal. This was manually moved by overhead gantry over a bench holding ingot moulds and each mould was manually filled, and then skimmed. After the zinc had solidified, taking around 5 minutes, the moulds are tipped to discharge the ingots onto a chain conveyor which delivered them to the wharf area where they were manually stacked into bundles of 60 slabs each.



FIG 3.28 Original manual casting of zinc slabs.

The other duty of the melting and casting facility was the production of zinc dust for solution purification. Reject slabs were generally used for this purpose and were melted in

a separate small reverberatory furnace to provide a small stream of molten zinc which was atomised using compressed air. The zinc dust was collected in a settling chamber.

The plant also incorporated a facility for the production of superfine zinc dust by boiling zinc in a silicon carbide retort and discharging the retort vapour into a stream of nitrogen which allowed the zinc to condense as fine droplets and then cool and solidify to form a very fine powder. This product was sold to the gold mining industry and also for the production of zinc rich paints. This facility was closed in 1976.

Over the years melting capacity was expanded by the addition of two small oil fired reverberatory furnaces for special high-grade cathodes and a 540 kW electric induction furnace for high-grade cathodes in 1960. A timeline for improvements in casting facilities is shown below.

The old casting facility had reached its limits by the mid-1960s and involved arduous and dangerous manual work, with a relatively high labour cost. Consequently, a completely new and highly automated plant was designed and was commissioned in 1970. At the time it was recognised that flexibility in the production of types of ingots and alloys was an essential feature and that provision for ample space within the plant for movement of materials was highly desirable. The plant was thus arranged on three levels, the top level for feeding cathode zinc sheets into the melting furnaces, the main floor holding melting and alloying furnaces and casting lines, and a basement for the handling of dross and scrap materials.

The three melting furnaces were mains frequency channel type electric induction furnaces rated at 1800 kW each, fed continuously through two separate feed chutes on each furnace and with a melting capacity of 20 tonnes per hour. These furnaces could feed into batch alloying ladles which were mechanically agitated and equipped with a hydraulic tilting mechanism, and could feed directly to a casting line or into holding furnaces. Each alloy batch was assayed before transfer to the holding furnace and adjustment made if necessary. Analysis was rapid by the use of spark emission spectroscopy.

Three 450 kW electric induction holding furnaces were used which in turn fed to the casting lines. Transfer of molten zinc is by the use of compressed air operated submerged centrifugal pumps discharging into a constant head box on each furnace, from where it flowed by launder to the next operation. Launder positioning was flexible, depending on the particular need at the time.

Slab casting used four straight line continuous mould chains with water cooling, discharging onto automatic slab bundling and strapping machines to prepare one tonne bundles. Otherwise zinc was cast into large block moulds of various shapes and sizes up to 1100 kg. These moulds were arranged in a semicircular arc, were water cooled and fitted with electric top heaters to prevent shrinkage cavities from forming. Blocks were lifted from the moulds using pillar jib cranes and finally handled by forklift truck.

Product was transferred from the casting plant to the wharf by truck where it was most commonly loaded into containers ready for shipment.

All furnaces were periodically manually raked to remove some of the surface dross which fell through a chute into the basement. From there it passed through three rotary dross coolers to reduce the temperature to less than 100°C. It was then conveyed to three air-swept ball mills discharging through a cyclone to a bag house for collection of fine dross. Zinc prills were separated and returned for remelting. Fine dross was returned to the roasting plant for the elimination of its chlorine content arising from the use of ammonium chloride fluxes in the melting furnaces.

The whole casting plant was fully ventilated through hoods fitted at all points of fume generation such as furnace doors and the vent air is passed through a baghouse. Fume was returned with dross to the roasting plant.

Zinc dust was also produced in the casting plant using a small 6 tonne induction furnace which fed two air atomisation units to produce up to two tonnes per hour of zinc dust rating 90 per cent -65 mesh and 25 per cent -400 mesh. This was essentially all used in zinc dust purification.

Full robotic handling of zinc slabs for the preparation of bundles was introduced in 2005.



FIG 3.29 Timeline for casting plant improvements.



FIG 3.30 Alloying ladle installation and associated holding furnace.

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FIG 3.31 Straight line casting machine.



FIG 3.32 Automatic bundle stacking and strapping machine.

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FIG 3.33 Removing a one tonne ingot from a block mould.

FLOWSHEETS

Flowsheets have been shown for the four major stages of the development of the Risdon plant.

Stage 1 – covers the initial stages of the plant generally up to 1971 when the treatment of residue by the jarosite process was introduced. See Figure 3.34 There have been marginal changes during that time such as the use of limestone for iron purification was replaced by the use of classified calcine after the introduction of flash roasters. Chlorine removal was abandoned in 1967 and many changes were made in roasting practices over the years but without major change to the wet circuit flowsheet.

Stage 2 – represents changes made with the introduction of primary residue treatment by the jarosite process and the need to remove nickel from solution as a result. Otherwise the bulk of the primary circuit was retained. See Figure 3.35.

Stage 3 – represents changes made by modernisation and replacement of much of the old wet circuit to give a more streamlined and integrated approach including the introduction of a new zinc dust purification method which avoided the use of organic complexes for the control of cobalt and nickel. See Figure 3.36. This changed the solution composition significantly to low cobalt and higher spent electrolyte acidity.

Stage 4 – covers the change from elimination of iron as jarosite to paragoethite, resulting from the withdrawal of approval to dispose of the iron waste at sea. See Figure 3.37. As a consequence, zinc recoveries were reduced although the quantity of final residue was also reduced. Residue drying to achieve transportable moisture limits had to be introduced and the residue was shipped to the Port Pirie lead smelter for treatment. Because of the limitations at Port Pirie to handle residues the quantities had to be further reduced and a change to lower iron content zinc concentrates was also made by changing from a major portion of Broken Hill feed to feed from the Century Mine.



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FIG 3.34.




Zinc Concentrates

STAGE 2 FLOWSHEET - With Residue Treatment

FIG 3.35.



STAGE 3 FLOWSHEET – After Modernisation

FIG 3.36.





FIG 3.37.

WHARF AND SHIPPING SERVICES

A key aspect of the selection of the Risdon site was the access to deep water for the shipping in of raw materials and the export of metal and other by-products. The construction of a deep water wharf was one of the first activities to allow for the import of construction materials as well as the servicing of the plant once operation commenced. A wooden wharf parallel to the foreshore was constructed and progressively the area between the wharf and the foreshore was filled to create an area suitable for the stockpiling of concentrates and zinc metal awaiting shipment.



FIG 3.38 The original wharf and bag house installation – 1920.



FIG 3.39 The Risdon wharf in 1960.

Cranes were installed for cargo handling with capacity to handle both bulk materials and break-bulk cargo such as ingot bundles. Initially these were jib cranes and for bulk handling grabs were used which dumped into mobile hoppers, eventually discharging onto a conveyor system. The conveyor system elevated the concentrates which discharged onto

a large open stockpile in the foreshore area. Individual mine concentrates were placed in segregated stockpiles and these were reclaimed using front end loaders and blended to provide roaster feed which was conveyed uphill to the roasting plant.

Up until the 1970s metal was exported as slab bundles handled as break-bulk cargoes. Thereafter containerisation became the norm and it was necessary to upgrade the wharf and install two new cranes capable of handling containers in 1980. This also enabled the use of larger and higher speed grabs for bulk material handling increasing the turnaround of bulk carriers delivering concentrates. Generally, the loading of metal took place on the down-river section of the wharf and bulk concentrate handling as well as phosphate rock handling on the upriver section of the wharf.

The export of sulphuric acid was also another key activity. Initially this involved tanks loaded within the cargo hold, but eventually specialised chemical tankers came into service and high-volume acid discharge capacity from the site storage tanks was required with all the attendant safety requirements.

With the change of flowsheet from jarosite residue to paragoethite, the final residue was shipped to Port Pirie for processing and for recovery of lead and silver values. This necessitated the installation of a shiploader on the wharf and at the same time the open concentrate stockpiles were covered by a large A frame storage shed. This also provided space for storage of residue awaiting shipment.



FIG 3.40 Bulk concentrate unloading.



FIG 3.41 Wharf showing shiploader and covered bulk storage.

ANCILLARY SERVICES AND BY-PRODUCTS

Fertilisers

Principal by-products were centred on the need to dispose of sulphuric acid produced by the capture of sulphur dioxide from roaster gases. At the start this involved the construction of a superphosphate plant which commenced operation in 1924 and eventually supplied all of the requirements for the state of Tasmania. An ammonium sulphate plant was later constructed in 1956 to supply this fertiliser to the Queensland sugar cane industry. However direct application of ammonia or the use of urea eventually replaced the use of ammonium sulphate and the plant was closed in 1986. An aluminium sulphate plant was also installed in 1964 to supply the water treatment industry as a clarification aid, but this use was also replaced in time and the plant closed in 1990. Fortunately, the export of acid by sea to other mainland fertiliser plants expanded and was able to replace the loss of the latter two markets.



FIG 3.42 The Hydrogen, Ammonia and Ammonium Sulphate Plants – 1958. Also showing the ferrite residue stockpile.

Ammonium sulphate required the production of ammonia on site and the installation of a plant for that purpose was part of the ammonium sulphate production facility. This was based on the production of hydrogen by the electrolysis of water and nitrogen from the liquefaction and distillation of air. Oxygen produced as a by-product of nitrogen recovery was used in the roasters, but only to a limited extent. Even though sales of ammonium sulphate diminished over the years and eventually ceased, the ammonia plant was kept in operation to provide ammonia for use as the primary reagent for the precipitation of jarosite as the outlet for iron from the zinc plant. This was introduced with the residue treatment operations in 1971, but ceased in 1997 with conversion of the leaching flowsheet from jarosite to paragoethite.

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FIG 3.43 Electrolytic Hydrogen Cell House – 1990.

Power supply

The provision of direct current electrical supply for electrolysis is a significant component of the overall plant installation. Power is supplied by the State Government power authority from hydroelectric power plants at 110 000 volts to an adjacent transformer station from where it is transmitted at 11 000 volts to the works conversion station. DC power for the first cell unit was supplied by three 1250 kW synchronous motor-generator sets. Subsequently rotary converters of 2500 and 3000 kW capacity were used in three large conversion stations.

Mercury arc rectifiers were used for the hydrogen plant and with expansion in zinc production germanium rectifiers were introduced in 1960. The first silicon rectifiers came into use in 1968, replacing the old rotary converters with considerable improvement in conversion efficiency.

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FIG 3.44 Rotary converters – No.1 Conversion Station.



FIG 3.45 Installation of English Electric silicon rectifiers.

CORPORATE OWNERSHIP

The concept of constructing a zinc plant in Tasmania was developed by the Amalgamated Zinc Company formed from Broken Hill interests, which subsequently incorporated the Electrolytic Zinc Company of Australasia Pty Ltd in June 1916 to undertake the project at Risdon. The company floated as a public listing in 1920.

In 1957 EZ Industries Ltd was formed as a holding company, and The Electrolytic Zinc Company of Australasia Ltd as operator of the Risdon zinc plant became a wholly owned subsidiary. EZ Industries was taken over by North Broken Hill Ltd in 1984, which changed its name to North BH Peko Limited in 1988 after a takeover of Peko Wallsend Limited. The company then had a wide range of interests apart from zinc and lead mining and smelting operations and included copper and gold, heavy minerals, coal and paper.

In 1988 the zinc and lead interests of North BH Peko and CRA Ltd were merged to form Pasminco Ltd, which became the sole owner of The Electrolytic Zinc Company of Australasia Ltd and the Risdon zinc plant. At that time Pasminco also operated a zinc smelter at Cockle Creek and an electrolytic plant at Port Pirie in Australia, an electrolytic plant at Budel in the Netherlands and an ISF smelter at Avonmouth as the sole zinc producer in the UK. Subsequently the Avonmouth smelter was sold to Mount Isa Mines and another electrolytic zinc plant at Clarksville in Tennessee in the USA was acquired as part of a takeover of Savage Resources Ltd.

Pasminco was declared bankrupt in 2002, and after restructuring was re-floated as Zinifex Ltd in 2004. However, with continuing financial difficulties Zinifex divested its smelting interests in 2007, selling the Hobart (Risdon) zinc plant to Nyrstar Ltd, a new company formed to amalgamate the lead and zinc smelting operations of the Belgian company Umicore with the acquired smelting operations from Zinifex. Nyrstar has operated the Hobart zinc plant since that time.



FIG 3.46 Risdon Zinc Plant – 1985.

CHAPTER 4 – COCKLE CREEK SMELTER

Edgar Arthur Ashcroft was an electrical engineer and metallurgist born and trained in England who was appointed by the Broken Hill Proprietary Company to install the first electric lighting at Broken Hill. His interest in metallurgy led him to experiment with the treatment of sulphide ores while working at Broken Hill, and in this endeavour he worked with Dr Carl Schnabel of Claustal, Germany. He patented a complex process for the extraction of zinc using the electrolysis of chloride solutions in 1894 and later that year left BHP to work on the development of that process. The process relied on the use of chlorine produced at the anode to directly attack zinc sulphide to form soluble zinc chloride and elemental sulphur. The handling of these materials was particularly difficult and highly corrosive, and was bound to produce insurmountable difficulties at that time. With the support of a number of the mining companies he tested the process on a small scale in Broken Hill and in London, and with some confidence the Sulphide Corporation (Ashcroft Process) Ltd was floated in London in 1895. The company purchased the Central Mine at Broken Hill from the Broken Hill Central Silver Mining Company and a site at Cockle Creek near Newcastle in New South Wales. This was one of the first major industrial sites in the Newcastle area, well before the establishment of the steelworks by BHP in 1913. It was attractive for smelting operations because of the abundance of coal and established mines in the Newcastle area. The nearby Stockton Borehole Colliery had opened in 1875 and was served by the village of Boolaroo adjacent to the site selected by Sulphide Corporation.

In 1897 a 10 ton per day electrolytic zinc plant was constructed at Cockle Creek to Ashcroft's specifications at a cost of £200 000. The process experienced major problems with impurity build-up in solutions, particularly manganese; the zinc deposits became spongy and the situation could only be rectified by discarding the solution and starting again. He experimented with sulphate and alkaline solutions as well as his original proposal of chloride solutions, but all without success. Cost over-runs were high and in 1898 the project was abandoned as a failure, and the company converted the site into a conventional lead smelter to treat concentrates from the Central Mine and elsewhere.

Ashcroft returned to England where he continued to work on chloride electrolysis in the laboratories of James Swinburne and published details of work on the electrolysis of molten chlorides. However, there were no practical outcomes from this effort.

Following the failure of the Ashcroft Electrolytic Process, Sulphide Corporation Ltd dissociated itself from Ashcroft and continued on as a mining company. However, it did persist with zinc production and in 1902 commissioned the first of five zinc distillation retort furnaces at the Cockle Creek site. A second installation was added in 1906, but this proved to be uneconomic, probably because of the fact that only low-quality zinc feed material was available from Broken Hill at that time, and the operations were closed in 1908 after producing only 3000 tonnes of zinc. The retort plant was then transferred to the company's Seaton Carew works in County Durham, North East England. A lead refinery was added at Cockle Creek in 1917. Sulphuric acid plants were erected in 1913 and 1917 to serve the lead smelter, and to utilise the acid a superphosphate fertiliser plant was established in 1913.

Lead smelting continued at Cockle Creek until 1922 when it closed due to low metal prices. Over half a million tonnes of bullion were produced up to that time. With closure of the lead smelter in 1922 and the need for zinc calcines at the Risdon plant of the

Electrolytic Zinc Company, six Barrier roasters were installed by EZ in 1923 and acid production was expanded with a third acid plant. A fourth acid plant was added in 1941 and zinc roasting operations continued until transfer to the Risdon plant in 1953.

Another enterprise introduced after closure of the lead smelter was the commencement of cement production in 1925, which continued on the site until 1956 when the introduction of the Imperial Smelting Furnace, and the reintroduction of zinc smelting was being seriously considered.



FIG 4.1 The Cockle Creek site in 1926.



FIG 4.2 Cockle Creek Blast Furnace – 1922.

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FIG 4.3 Barrier Roasters treating zinc concentrates at Cockle Creek – 1922.

Sulphide Corporation Limited went into liquidation in 1950 and a new company Sulphide Corporation Pty Ltd as a wholly owned subsidiary of the Consolidated Zinc Corporation was formed to acquire the assets. This was a precursor to the reintroduction of zinc smelting on the site using the Imperial Smelting Process, which had been developed in the UK by Imperial Smelting Limited, also a subsidiary of Consolidated Zinc Corporation.

The Imperial Smelting Process was an adaption of the lead blast furnace with an enclosed hot top. This allowed zinc vapour to exit the top of the furnace in hot gases which were subsequently chilled to allow the zinc to condense. The secret to the process was to chill the hot gases rapidly to prevent reversion of zinc vapour to zinc oxide and for this purpose a spray of molten lead at a much lower temperature than the furnace gases was used. Zinc condensed onto the lead droplets and was absorbed into the molten lead. Subsequent cooling caused the zinc to separate as molten zinc floating on the surface of the lead from where it could be separated by liquation and the molten lead recycled to the condenser. The furnace was thus able to produce lead from the base of the furnace and zinc from the exit gases and this was seen at the time as highly beneficial – two metals from the one unit.

Plans for installation of an Imperial Smelting Furnace at Cockle Creek were put in place in 1957 and construction commenced with commissioning of the new ISP furnace in 1961, just following completion of a similar furnace at Swansea Vale in Wales. Subsequently in 1962, Consolidated Zinc Corporation and Rio Tinto Ltd merged interests with the formation of Conzinc Rio Tinto of Australia Ltd (CRA) which then had 75 per cent control of Sulphide Corporation Pty Ltd.

In 1964 a subsidiary company of Sulphide Corporation – Greenleaf Fertilizers Limited, was formed to concentrate on the fertiliser operations as a separate entity from the smelting activities. This was sold in 1970 to Australian Fertilisers Limited.

Because the zinc produced was collected using lead in the condenser system, the new zinc smelter only produced Prime Western Grade zinc at 98.5 per cent zinc content which is primarily used for galvanising. However, there was a growing demand for High Grade and Special High Grade quality zinc and it became necessary to install a distillation refinery using the New Jersey Zinc process in 1968. This was designed for the treatment of 35 000 tonnes per year of zinc.

The ISF was significantly upgraded in 1972, with features such as the addition of Cowper Stove blast preheaters to raise the blast air temperature from 700 to 900°C. Tuyeres were changed to an inclined arrangement in 1980 and the number was reduced with increased blast rate in 1985. Following research effort at the plant, the blast furnace was converted to continuous tapping of slag and lead bullion in 1985, which significantly changed the operating parameters of the process and this was one of many pioneering efforts in the application of ISF technology at this site. These measures significantly raised capacity to a level approaching 70 000 tonnes of zinc output per annum. The Cockle Creek plant was the first ISF to reach a production of one million tonnes of zinc and lead output in 1974.



FIG 4.4 Tapping lead bullion from the ISF.



FIG 4.5 One tonne zinc block casting.

PRODUCTION PLANT

The basic components of the smelter were the sinter plant, sulphuric acid plant, blast furnace, zinc refinery, and lead drossing plant. Ancillary plants were the lead dross processing facility and the cadmium plant. The plant commenced operation based on highgrade zinc concentrates from the Zinc Corporation mine at Broken Hill and high-grade lead concentrates from the New Broken Hill Consolidated mine. This did not use the facility to its optimum benefit and in time a shift was made to lower grade materials, and zinc and lead rich residues, such as primary leach zinc ferrite residue and final lead residue from the Risdon smelter. There were however restrictions on the intake of these materials due to limits on the intake of both iron and silica which could significantly affect the performance of the blast furnace.

The preparation of a consistent mix of raw materials and fluxes was a key issue for the preparation of feed to the sinter plant, and this required the use of ten bins holding individual feed materials with weigh feeders on each to give the required proportion of each component in the feed mix. To this was added fine recycle sinter representing about 3 tonnes for each tonne of concentrate and sufficient to dilute the sulphur content to about 7 per cent of feed.

The feed mix was evenly spread on the moving grate of the updraft sintering machine, first as a 30 mm ignition layer and then to the full bed depth of 350 mm. The drafted grate area of the sinter machine was 95 m².

Sinter discharged from the end of the machine was crushed using a spiked roll, and screened at 25 mm. The material passing the screen was used for return sinter plus any additions needed from the product stream. Hot product sinter was transferred to refractory lined bins for feeding to the blast furnace.

Sinter plant gases were cleaned first in high temperature electrostatic precipitators and then in a series of three scrubbing towers, followed by electrostatic mist precipitators before feeding the sulphuric acid plant. The fume slurry collected in the scrubbing system was processed to extract selenium and then cadmium, and was then returned to the sinter plant feed.

The blast furnace feed was made up of sinter and hot coke and a small quantity of briquettes of fine oxide material. These materials were batch weighed into one of two charge buckets which were lifted to the top of the furnace and charged through two double bell hoppers which provided a seal to the furnace. Coke was preheated using the combustion of blast furnace gas rich in carbon monoxide (CO).

The furnace was of the standard ISF design with a grate area of 17.2 m² and constructed using a shower cooled steel jacket. The use of a shower cooled furnace casing in place of standard water jackets was a feature pioneered at the Cockle Creek site. At the hearth there were 14 water cooled tuyeres inclined at 25 degrees to the horizontal. Blast air was preheated in Cowper Stoves fuelled using blast furnace gas to 800°C. Zinc was vaporized and exited from the top of the furnace in gases, which were maintained above 1020°C by the introduction of a small amount of air while still keeping the CO content of gas at around 24 per cent. The zinc vapour content of the gas was around 8 per cent. This passed to the condenser where it was rapidly chilled to 560°C using a spray of molten lead. The lead absorbed the zinc to contain around 2.3 per cent in solution, and was then pumped to a cooling launder where the temperature was reduced to 450°C before return to the splash condenser. At this temperature molten zinc separated and floated to the top of the lead

from where it was continuously separated by an underflow – overflow weir and sent to the refinery.

Slag and lead bullion collected in the bottom hearth of the furnace and were tapped continuously through an underflow seal into a forehearth where separation occurred. The slag was granulated and the lead bullion transferred into drossing kettles where it was cooled to allow the separation of a dross containing the bulk of the copper content of the bullion as well as some lead oxide. The drossed bullion was cast into one tonne blocks for transfer to a lead refinery – either exported to a custom refinery or sent to the lead refinery at Port Pirie. In 1989 the lead handling plant was decommissioned with furnace bullion (quenched bullion) being cast directly from the forehearth and sent to the Port Pirie smelter for refining.

The blast furnace was shut down on a weekly to fortnightly basis for the purpose of removing zinc oxide accretions which formed in the furnace offtake and entrance to the condenser. These resulted from the partial reversion of zinc vapour by reaction with CO_2 as it cooled. Removal of accretions from the furnace walls was also necessary and involved the controlled use of explosives.

The zinc refinery consisted of four primary distillation columns for separation of lead in the bottom product, and two secondary columns for the separation of cadmium as overhead product. This produced zinc of 99.95 per cent purity. The combustion furnaces surrounding the silicon carbide columns were gas fired and operated at temperatures up to 1250°C. Recuperators were used to preheat combustion air to around 800°C. The metal stream flowing from the bottom of the primary columns was cooled to allow lead metal to separate as well as a dross consisting of a zinc iron alloy. The liquated lead was recycled to the ISF condenser. The residual zinc was marketed as Prime Western Grade galvanising alloy, or could be recycled to the column feed.

Cadmium was recovered from sinter plant fume by leaching and cementation with zinc, followed by melting and treatment with caustic soda. This was combined with cadmium from the secondary refining columns, fed to another distillation column to separate the bulk of cadmium from zinc and then again treated with caustic soda to yield cadmium metal of 99.95 per cent purity.

Drosses from the lead drossing kettles treating blast furnace bullion were leached with an ammonium carbonate solution to dissolve copper, which was then separated by solvent extraction to produce a solution of copper sulphate which was separated by crystallisation. Annual production was around 5000 tonnes per year of copper sulphate.

FLOWSHEET

The general flowsheet of the Cockle Creek ISP is shown below in Figure 4.6.



FIG 4.6 Cockle Creek Imperial Smelting Process flowsheet.

FINAL YEARS

Pasminco Limited was formed in 1988 as a merger of the zinc and lead interests of CRA and North Broken Hill Ltd and took control of Sulphide Corporation and the Cockle Creek site. All metallurgical research activities for the Pasminco group were then transferred to Cockle Creek from both the Risdon and Port Pirie sites. At this time all zinc smelting in Australia and in the UK were under the control of Pasminco, as well as a major interest in the Budelco zinc plant in the Netherlands, which was the largest in Europe at the time. A major capital improvement programme was commissioned at Cockle Creek in 1989, with progressive improvements up to 1997 when a tail gas scrubber was installed to treat blast furnace gas emissions.

Attempts were made to improve output of the plant without much success and there were growing environmental pressures, particularly in relation to lead in air emissions from the site. A small Top Submerged Lance (TSL) furnace was commissioned to recover zinc from ISF slag by fuming, but this was unsuccessful and was discontinued. However, this was the first commercial applications of TSL technology developed by CSIRO for the fuming of zinc from blast furnace slag.

The economics of the ISF were becoming unfavourable at this time because of the high operating costs, and in particular due to the need for refining for the production of highquality zinc. It became clear that the ISF smelters could not compete with modern largescale electrolytic zinc operations on the basis of normal zinc concentrate feeds. They were competitive only for the processing of low-grade mixed (zinc and lead) concentrates or secondary materials, which were of lower cost and difficult to handle in electrolytic plants. Consequently, with Pasminco in administration and under the control of creditor banks, a decision was made to close the plant in 2003. This ended a period one hundred and six years since the first attempts to establish zinc smelting on the Cockle Creek site.

With closure of the smelter in 2003 a remediation order was issued by the New South Wales Government for all facilities to be demolished and for the site to be cleaned up for alternative industrial use. As the owner Pasminco Limited was under administration, the assets were separated into another entity, Pasminco Cockle Creek Smelter Pty Ltd, and it became the responsibility of the administrator to complete the remediation order. This liability was not passed on to the purchasers of the other assets of Pasminco Ltd but was funded from the proceeds of the sale of those assets. As a result, the smelter was completely demolished apart from the effluent treatment plant, and large quantities of contaminated soil were moved to a containment cell located in one designated area of the site containing old slag dumps.

The associated fertiliser plant owned at first by Australian Fertilisers Limited and then Incitec Pivot Limited, continued in operation but was also served a remediation order in 2005 and chose to close operations in January 2009.



FIG 4.7 Timeline for developments on the Cockle Creek site (note that fertiliser production is under separate ownership from 1970).



FIG 4.8 Cockle Creek ISF Smelter Complex – Fertiliser Plant at top right.



FIG 4.9 View of the ISF Smelter – 1990.

CHAPTER 5 – PORT PIRIE ZINC SMELTING OPERATIONS

Lead smelting operations commenced at Port Pirie under the ownership of the British Broken Hill Proprietary Company with the construction of the first blast furnace in 1889. This was later purchased by The Broken Hill Proprietary Company Limited in 1892.



FIG 5.1 Port Pirie – 1890.

EARLY RETORT PLANT

With the development of flotation technology to solve the zinc problem at Broken Hill, a plentiful supply of good grade zinc concentrates became available and BHP decided to install a trial retort plant at Port Pirie in 1906. The first furnace was troublesome and a new German design was installed in 1908 followed by a further nine furnaces. These furnaces were of a design patented by Paul Schmidt and Adolphe Desgraz, fired using producer gas and operating at around 1340°C. Each furnace contained 144 retorts and processed calcines obtained by the roasting of zinc concentrates using Hegler Hearth roasters. The advantage of these furnaces was the control of the temperature profile over the time of processing each batch of feed material.

The Port Pirie smelter was sold by BHP to the Broken Hill Associated Smelters (BHAS) as a consortium of Broken Hill mining companies in May 1915, and the zinc smelting operation continued until closure in 1921. Production was highly variable reaching a maximum of 5225 tons of 'spelter' in the financial year to June 1918, but was typically in the range of 2000 to 3000 tons per year. The quality of the zinc (or spelter) produced was 98.7 per cent zinc, containing 1.2 per cent lead and was not of suitable grade for the production of armaments at that time. This was the reason for emphasis on zinc production by the electrolytic process at the time and possibly one of the reasons for closure of the

facility in 1921 with competitive supply from the Risdon plant. However, the primary reason for closure was poor recovery of zinc and the fact that it incurred a considerable financial loss.



FIG 5.2 Zinc retort furnace - 1910.

SLAG FUMING

Lead concentrate feed to the lead smelter normally contained around 4 per cent zinc for a lead content of 72 to 75 per cent. The zinc reported to lead smelter slag and could be managed at levels of up to 18 per cent, targeted to minimise the quantity of slag and optimise the opportunity for future zinc recovery. In addition, between 1920 and 1940, leach residues containing around 22 per cent zinc, 6.5 per cent lead and 6.5 ounces of silver per ton were shipped from the Risdon zinc plant to Port Pirie for incorporation in smelter feed and for recovery of lead and silver, further adding to the zinc burden in slag. A considerable zinc resource was therefore accumulated in the slag stockpiled on site and by 1965 this was estimated at 6 million tons of slag containing around one million tons of zinc. Recovery of zinc from slag could be achieved by high temperature reduction to form zinc vapour and the process developed using this principle was 'slag fuming' in which the reduction gases were subsequently oxidised by the addition of air to form a zinc oxide fume. The first slag fuming plant was operated by the Anaconda Copper Mining Company at East Helena, Montana in 1927. This was followed by a slag fumer at the lead - zinc complex of the Consolidated Mining and Smelting Company at Trail in Canada in 1930. The opportunity to install a slag fumer at Port Pirie was investigated by the then general manager O H Woodward in 1934, and various investigations were made to apply the Imperial Smelting Process to simultaneously recover both lead and zinc, but was not suited to high lead versus zinc production. No action was taken until 1964 when Board approval

was given for the installation of zinc production facilities based on a slag fumer and an electrolytic zinc plant to process the zinc oxide fume. Another option at the time was to install only the slag fumer and ship zinc oxide fume to the Risdon zinc plant, which in fact retained ownership of a portion of the zinc in stockpiled slag derived from the earlier treatment of Risdon plant residues. Negotiations for this option between BHAS and EZ Co. broke down at the time and the alternative for construction of an electrolytic zinc plant at Port Pirie was selected. This decision was no doubt aided by the offer of low-cost electric power by the Government of South Australia from the new Playford B coal fired power station built at Port Augusta and completed in 1963.

The slag fuming plant was completed in June 1967 and the electrolytic zinc plant six months later in December 1967. The design capacity was 40 000 tonnes per year of product zinc metal.



FIG 5.3 Port Pirie Slag Fuming Plant – 1970.

The two slag fuming furnaces are of an ASARCO (East Helena) design, but have the unique feature of a heat recovery system to preheat blast air to around 500°C by heat exchange with slag fumer gases after the addition of air and passage through a waste heat boiler. The heat exchange system had to be able to handle high dust loads of zinc oxide fume. The feed to the furnace is both cold recovered dump slag and current molten slag from the lead blast furnace, and as such gives rise to a high energy demand. The batch cycle time varies depending on the proportion of cold slag versus molten slag in the charge, but is generally of the order of two hours, and is based on reducing the zinc content of slag to 2 per cent, equivalent to recovery of about 90 per cent of the initial zinc content. Fine powdered coal is used as the reductant, injected into the slag bath with combustion air through rows of tuyeres on either side of the furnace. The furnace is constructed of water jacketed panels.

Secondary air injected at the top of the furnace oxidises the zinc vapour to a zinc oxide fume and raises the temperature of furnace gases prior to entry to the waste heat boiler which in turn cools the gases to between 800 and 900°C. Gases then pass through the

recuperators to heat blast air and then to a set of coolers to drop the temperature to less than 200°C before entry to the bag house where the bulk of the fume is collected. The final coolers were replaced by an evaporative cooling tower in 1989 because of the extensive fouling problems associated with sticky zinc oxide coating heat exchange surfaces. Extensive soot blowing style cleaning facilities were normally required to keep the heat exchange surfaces of the recuperators and coolers free of collected fume.

Raw fume from the slag fumer contains around 0.25 per cent of each of fluorine and chlorine which are harmful to the operation of the electrolytic zinc plant and need to be removed. This is done by roasting the fume in a rotary kiln with a target exit temperature of around 1150°C. The roasted fume then has a fluorine content of around 0.005 per cent and a chlorine content of 0.015 per cent and is in the form of a clinker which requires grinding before leaching in the electrolytic zinc plant. It also contains around 68 per cent zinc and 10 per cent lead.



FIG 5.4 Zinc fume roasting kilns.

ELECTROLYTIC ZINC PLANT

The electrolytic zinc plant was based on the A C Jephson design similar to the Corpus Christi Zinc Plant (USA), operated at that time by ASARCO. The plant operated with batch leaching and purification rather than continuous operation, favoured because of the small size.

The roasted fume was batch leached with spent electrolyte to dissolve zinc oxide and also convert lead oxide to an insoluble lead sulphate residue. Iron sulphate was added at the end of the leach to cause ferric hydroxide to precipitate and remove some impurities such as arsenic, antimony, tin and germanium. Manganese was also added with the iron solution to maintain a concentration in solution at around 2.5 g/L so as to provide a manganese dioxide coating on the anodes of the electrolytic cells to inhibit chlorine formation and anode corrosion. The residue from the leaching stage was filtered, washed and dried, and returned to the lead smelter. It typically contains 38 per cent lead and 9.8 per cent zinc. This recycle generated a very high recovery of lead units at the Port Pirie smelter.

Solution from leaching was purified by the two-stage addition of zinc dust. In the first stage copper sulphate with arsenic trioxide as an activator were also added, and nickel,

cobalt and copper were removed. In the second stage copper sulphate was added with the zinc dust, and cadmium was removed together with residual traces of arsenic and antimony. The zinc dust precipitates were mixed with leach residue for return to the lead smelter.

Purified solution contained close to 165 g/L zinc and the spent electrolyte contains 60 g/L zinc and 180 g/L sulphuric acid.



FIG 5.5 Zinc oxide leaching plant.

The electrolytic section consisted of one unit of 210 cells each containing 40 cathodes and 41 anodes and all cells were connected in series. The electrodes were relatively small with about 0.9 m² submerged surface area each or 0.45 m^2 face area, and operated at a current density of around 700 A/m². At this current density short deposition times of 16 to 24 hours were necessary. Stripping was originally manual but mechanical stripping was introduced in the 1980s.

Power was supplied to the electrolytic cells using three silicon diode transformer rectifiers, with two capable of supplying the full current load of 26 000 amps.



FIG 5.6 The Zinc Cell House – lifting cathodes.

Cathode zinc was melted in one of two 400 kW electric induction furnaces, each with a bath capacity of 17 tonnes. Molten zinc was pumped from the furnaces and cast into 25 kg slabs using two rotary table casting machines. One tonne block moulds were also used.



FIG 5.7 Rotary table zinc slab casting machine.

Dross from the melting furnaces was milled to separate metallic from oxide fines. The metallics were remelted and cast into blocks and the oxide fines were returned to the slag fuming furnaces.

Minimal process changes were made to the zinc plant since its construction in 1965 and capacity remained at around 40 000 to 45 000 tonnes per year of product zinc. Production

declined in recent years, making the electrolytic plant unprofitable, and in May 2014 Nystar announced the closure of the electrolytic plant in July that year as part of a modernisation programme for the site and the lead smelter. The slag fuming operation was retained and plans were then for zinc oxide from the fuming operation to be shipped to the Risdon zinc plant in Hobart or other zinc operations within the Nyrstar group. In this sense the arrangement is reverting to one of the original proposals for zinc recovery from blast furnace slag, probably rejected more for political reasons at the time.



FIG 5.8 Zinc plant and ingot awaiting shipment.

FLOWSHEET



FIG 5.9 Port Pirie zinc plant flowsheet.

CORPORATE OWNERSHIP

Smelting commenced at Port Pirie in 1889 with the construction of a lead smelter by the British Broken Hill Proprietary Company. Ownership of these operations was transferred to Broken Hill Proprietary Company Limited (BHP) in 1892 and BHP constructed the first zinc retort smelter there in 1906.

The Port Pirie smelter was sold by BHP in 1915 to a consortium of Broken Hill mining companies (BHP, Broken Hill South Ltd, North Broken Hill Ltd and The Zinc Corporation Ltd) with The Broken Hill Associated Smelters Pty Ltd (BHAS) as the owner and operating entity. BHP sold its interest in 1925 to the other partners and terminated its association. The shareholding in BHAS changed over the years, but by 1959 had stabilised at 20 per cent Broken Hill South Ltd, 30 per cent North Broken Hill Ltd and 50 per cent Consolidated Zinc Ltd. Consolidated Zinc's shareholding was transferred to Australian

Mining and Smelting Company Pty Ltd (AM&S) as part of a reorganisation of the CRA group of companies, and in 1974 AM&S purchased the Broken Hill South shareholding to take its ownership to 70 per cent.

With the amalgamation of the zinc and lead interests of CRA and North Broken Hill Ltd and the formation of Pasminco Ltd in 1988, BHAS became a wholly owned subsidiary of Pasminco Ltd.

Pasminco was declared bankrupt in 2002, and after restructuring was re-floated as Zinifex Ltd in 2004. However, with continuing financial difficulties Zinifex divested its smelting interests in 2007, selling the Port Pirie smelter to Nyrstar Ltd, a new company formed to amalgamate the lead and zinc smelting operations of the Belgian company Umicore with the acquired smelting operations from Zinifex. Nyrstar has operated the Port Pirie smelter since that time.



FIG 5.10 / 5.11 Views of Port Pirie and the smelter complex – 1995.



CHAPTER 6 – SUN METALS – TOWNSVILLE ZINC REFINERY

INCEPTION

With significant discoveries of zinc and lead deposits and the production of large tonnages of zinc concentrates in North Queensland, the logical place to construct new zinc smelting facilities was at the railhead and Port of Townsville, already the location of the electrolytic copper refinery of Mount Isa Mines Ltd. Electrical energy was also available in the region from the plentiful supplies of low-cost coal to feed large coal fired power stations. Major zinc producers examined this opportunity in the early 1990s, but it was the Korean based Korea Zinc Company Limited (KZC) which took the initiative and committed to the construction of a new zinc refinery complex at an expansive greenfield site approximately 20 km south of Townsville. Sun Metals Corporation Pty Ltd (SMC) was formed as a wholly owned subsidiary of Korea Zinc to undertake this development. Power supplies were secured from the Queensland state grid under a long-term contract with the North Queensland Electricity Board (NORQUEB).

The proposed plant was subject to a rigorous environmental impact study, involving both the Queensland and Federal governments. The site was adjacent to the protected environment of the Great Barrier Reef.

The project obtained Major Project status from the Queensland government, culminating in specific project facilitating legislation, the Sun Metals Zinc Refinery Act 1996, which received formal assent on 20 November 1996.

DESIGN AND CONSTRUCTION

The plant was designed for a nominal capacity of 170 000 tonnes per year of refined zinc, with scope to duplicate capacity at a subsequent date. KZC drew heavily on the established technology and construction experience with their own operations at Onsan in South Korea. In addition, it utilised the latest electrolytic cell house technology from the Belgian company Union Miniere (Umicore).

The flowsheet used a neutral leach weak acid leach only, with the stockpiling of ferrite residues for subsequent treatment and/ or removal. This negated the immediate issue of residue treatment, and enabled the initial capital cost of the refinery to be considerably reduced and enabled an economic case to be developed. A commitment was made to commence treating or reducing the residues within a certain time frame.

KZC seconded an experienced group of their most senior and experienced design, construction and procurement personnel to Australia (initially in Brisbane, and subsequently on site in Townsville) to implement the project. In addition, Australian personnel were engaged to supplement the Korean group.

Financing was arranged through a US\$225 million project financing arrangement with a syndicate of international banks. In addition, KZC provided substantial owners funds, plus a security for the project financing facility.

Construction of the plant was completed in 1999 at a capacity of 170 000 tonnes per year of zinc and an output of 350 000 tonnes per year of sulphuric acid. The plant was completed both within budget and on schedule, despite a series of major upheavals during the construction (cyclonic weather, labour disputes, Asian financial crisis).

Reflecting the national significance and the strong local support for the project, the formal opening of the plant on 16 May 2000, was attended by the Prime Minister of Australia (Mr John Howard) the Premier of Queensland (Mr Peter Beattie), the Korean Ambassador to Australia (Mr Hyo-Hun Shin), and the Director General of the Korean Ministry of Commerce, Industry & Energy (Mr Myeng Keun Ha).



PLANT OUTLINE

The design of the plant and description below exemplifies the relatively standard configuration of a modern electrolytic zinc plant, except for the absence of facilities to treat ferrite residues.

Roasting and acid production

Concentrates are blended in a storage shed from separated heaps, and are fed to the fluid bed roasters. Initially two turbulent layer roasters of 77 m² hearth area were installed, handling of the order of 610 tonnes of concentrate per day per roaster. Roaster temperature is controlled

at around 950° C by cooling coils as well as water injection – also used as a bleed for plant solutions.

Calcine is collected as overflow from the roaster bed as well as carryover in the gas stream, and is cooled using rotary drum coolers, followed by dry grinding in a ball mill and air conveying to storage bins in the leaching plant.

Sulphuric acid was initially produced using one double absorption contact acid plant with a nominal capacity of 1150 tonnes per day.

Leaching and iron separation

Roaster calcine is leached in two counter-current stages consisting of a neutral leach operating at a pH of 1.5 to 4.8 through a series of tanks, and a weak acid leach. Ferrite residue remaining after the weak acid leach contains of the order of 20 to 25 per cent iron and provides the iron outlet from the plant as well as lead and silver values. The ferrite residue is first separated by thickening and is then filtered using filter presses. It was stockpiled in double lined ponds from commencement of operations with a view to future treatment to extract the remaining zinc which represents around 12 per cent of zinc in feed concentrates. Subsequently plans for local treatment of the residue were abandoned and the ferrite leach residue dried using a filter cake dryer has been shipped to the Korea Zinc plant at Onsan in South Korea, where appropriate treatment facilities using Top Submerged Lance fuming technology were in place.

Neutral leach solution is clarified in a large settling tank and reports of the order of 160 g/L of zinc in solution.

Solution purification

Two stages of zinc dust purification were initially installed – a cold stage for copper and cadmium removal, and a hot stage at 75° C with antimony activation for the removal of cobalt and nickel. Cementates are separated from solution at the end of each stage using filter presses and the final purified solution is clarified in a large 'champagne glass' style settling tank.

Gypsum is removed by cooling feed solution from 75 to 40°C in a series of cooling towers allowing gypsum to crystallise out of solution.

Electrolysis

The tankhouse follows a Umicore design using 3.2 square metre aluminium cathodes and with automated electrode handling and stripping of deposited zinc. The initial plant consisted of two rows of 62 cells each containing 114 cathodes and 115 anodes. Each row was served by one gantry crane and one stripping machine, and deposition time was set at 48 hours. Anodes are regularly removed, cleaned and straightened, and returned to the cells. Spent electrolyte contains approximately 55 g/L zinc and 180 g/L sulphuric acid for return to the leaching stage.

Casting

Cathode zinc sheets are melted using 75 tonne capacity electric induction furnaces of two 200 kW power rating. These furnaces feed both straight line ingot casting machines as well as a range of larger block moulding facilities.



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FIG 6.1 Straight line slab casting machine.



FIG 6.2 Jumbo block casting line.

CONCENTRATE SUPPLY AND PRODUCT MARKETING

Concentrates were sourced from local North Queensland mines – Kagara Zinc (Mount Garnet), Mount Isa, Cannington and Century. Additional concentrates came from the Lennard Shelf mine in Western Australia in the early years as well as imports from Alaska and Peru, which continue at the present time. The plant was designed to be flexible in treating zinc concentrates over a wide quality spectrum, and thus is able to accept input of concentrates from a diverse range of mine sources. Concentrates may be delivered directly by trains from the mines in the hinterland, or via the Port of Townsville from more distant mines in Australia or from offshore mines.

Refined metal slaes were integrated into the established international marketing programme of KZC. In addition, metal was supplied into the relatively small domestic market in Australia. The final metal was in the form of SHG (Special High Grade) zinc ingots in accordance with LME (London Metal Exchange) quality specifications, and the plant specialises in 'jumbo' block alloys for use in modern continuous galvanising lines. In particular a specific alloy was developed to meet the stringent quality requirements of the continuous galvanising plants of BHP Billiton (now Bluescope Steel). The bulk of the production is exported through the Port of Townsville.

Sulphuric acid was sold into the domestic market. In particular, a long-term contract was established for the supply of acid to the newly constructed fertiliser plant at Phosphate Hill in inland Queensland (initially WMC Fertilisers, now Incitec Pivot).

The sulphuric acid is transported almost 1000 km to Phosphate Hill by rail using the GATX system which at the time was new to Australia, but is used widely in North America for transporting large quantities of liquids point to point. Instead of filling each tanker wagon individually, which is labour intensive, the acid is loaded at one end of the tanker string and each tanker overflows by connecting hoses to the next and so on until the last tanker is loaded. The tanker connecting hoses stay in place during transportation and are checked regularly for wear. This way a string of 50 tanker wagons is efficiently loaded, and hazard is minimised.

As with the export of ferrite residue for treatment in South Korea, ancillary facilities for the processing of secondary streams such as purification cementates and cadmium have been limited on site and these materials are also sent to Korea for final processing.

COMMISSIONING AND ONGOING OPERATIONS

Integrated commissioning strategy

One of the biggest risks with any new complex chemical plant, especially one that is project financed, is the commissioning ramp up schedule being substantially delayed, due to new technology risk, and/or the lack of experience and knowledge of the plant operating and maintenance teams.

In the case of the Sun Metals Project an excellent ramp up was achieved. Although the plant was the most modern in the world at the time of construction, almost all the technologies involved had been in operation at Korea Zinc, so the technology risk was minimal. As well, for the commissioning phase, the key Australian operators went to Korea for training and 100 Korea Zinc employees were seconded on short-term visas to Sun Metals to assist with the startup. Although there was an obvious language barrier, with signing and the solid training received by the Australian teams, knowledge was quickly transferred and mistakes
minimised, in many cases simply by the experienced Korean operators putting their hand on the Australian operator's hand to prevent them doing something wrong, without having to say a word in English.

In addition, the composition of the Sun Metals operating teams included approximately 30 per cent trade qualified Australians, who not only contributed greatly to the speed of the knowledge transfer, but with their knowledge of electrical and mechanical risks, they contributed greatly to the excellent safety performance achieved at the plant during commissioning.

Environmental focus

As noted previously, the Sun Metals Zinc refinery is located on the North Queensland coast close to the Great Barrier Reef, one of the most environmentally sensitive areas of the world.

At the design stage, the decision was made to make the plant a zero liquid discharge plant, covering both process liquids and storm water run off from the plant area. Being in the tropics and subject to extreme cyclonic summer rainfall, this was a significant design requirement, with a very large lined storm water run off pond being included in the design. The storm water collected during the summer-wet season is recycled to the plant and consumed during the dry period of the year.

To enable a zero discharge commitment for process waters to be achieved, a reverse osmosis plant was included in the design. The strong solution stream from this plant is contained in a lined pond where the water is evaporated. This is achieved because in Townsville on an average 12-month basis, the evaporation rate exceeds the rainfall.

To maintain a zero liquid discharge plant on an ongoing basis, a major focus on the water balance is required. In a normal year 1.5 million tonnes of water is required to balance the water evaporated in the zinc production process. About two-thirds of this water is supplied from the site rainwater collected in the storm water pond and then recycled back to the plant without pretreatment. Re-using plant runoff water in turn requires a strong focus on plant housekeeping, not only to maintain the zero discharge, but also to minimise the need to purchase extra water.

Production improvements

As noted previously, the design capacity of the plant was 170 000 tonnes per year of zinc, whereas the more recent output levels have achieved a 220 000 tonne rate. This is almost 30 per cent increase in output has been achieved by a number of process improvements.

The roasting and acid capacity was increased by the installation of an additional calcine bed cooling coil in each roaster and with the addition of an oxygen enrichment system. The leaching and purification capacity was increased by process optimisation and the installation of more residue filtration and drying capacity, allowing the full export of zinc ferrite cake for processing in Korea. Electrolysis capacity was increased by the addition of extra rectiformer capacity and the addition of electrodes in each cell. Casting capacity was increased by the addition of an automatic de-moulding system on the jumbo casting line, enabled by the standardising of the size of the jumbo block products.

Energy consumption improvements

In the electrolytic zinc process energy costs are the major operating cost. At Sun Metals the price of power fluctuates every five minutes. An automatic power modulation system was installed to control the rectiformer load, depending on the market power price. This system enabled the power costs to be reduced by 10 per cent compared with steady operation.

As power prices increased over time, a 7.5 MW steam turbine generator utilising waste heat from the roaster boilers was installed in 2013 to further reduce energy consumption.



FIG 6.3 Aerial view of Sun Metals – Townsville Refinery.

CHAPTER 7 – SULPHURIC ACID

The zinc smelting industry is closely linked with the production of sulphuric acid and the principal use of sulphuric acid is for the production of fertilisers.

Early smelting industries emitted the sulphur as sulphur dioxide to the atmosphere which caused damage to vegetation, as exemplified by the devastation caused to the landscape around Queenstown on the West Coast of Tasmania by the Mount Lyell copper smelter, aggravated in that case by the removal of timber to supply the mine and smelter. Ever since the Australian zinc smelting industry commenced this was not acceptable, and conversion of sulphurous gases to sulphuric acid was mandatory. In the smelting of zinc concentrates every tonne of zinc metal produced releases, on average, about 0.6 tonnes of sulphur which convert to 1.8 tonnes of sulphuric acid. To provide outlet for the acid produced it became necessary to closely link with the fertiliser industry.

The fertiliser industry was initially based on the production of superphosphate, produced by the treatment of phosphate rock with sulphuric acid. Australian soils are phosphate deficient and crop yields could be substantially increased by the application of phosphate fertilisers. It was also found that combined with the use of subterranean clover, stocking levels on many sheep farms could be trebled, and since this was a key industry in the 20th century, subsidies on the production of superphosphate were introduced in 1930 and continued until the 1980s.

The first manufacture of phosphate fertiliser was by James Cuming who purchased a bone meal works and a chemical works at Yarraville in Victoria in 1875 in partnership with Robert Smith, and formed Cuming Smith Ltd. They started importing phosphate rock from Florida in 1897, but soon transferred supply to sources from Ocean Island, Nauru and Christmas Island. Sulphur for acid manufacture was first imported from Italy, but later became available in large quantities from Louisiana and Texas. Many other fertiliser operations commenced around 1900 across the country. The Mount Lyell Mining and Railway Company Limited saw the opportunity to source sulphur from by-product pyrite from its mine at Queenstown and shipped pyrite concentrate to its own fertiliser plants at Yarraville in Victoria as well as to plants in South Australia and Western Australia. Other fertiliser plants at Wallaroo and Port Adelaide in South Australia were based on sulphur from smelter gas from the treatment of copper concentrates at Wallaroo and lead smelting at Port Adelaide from the treatment of lead concentrates from Broken Hill field.

The nature of the industry at that time was such that fertiliser plants were located close to agricultural centres for easier distribution to the farms. The cost of imported sulphur was high and it was preferable to use smelter gas for the production of acid as it reduced the overall cost and served as a means of disposal of sulphur gases from the smelters as well as providing a valuable by-product.

In the early days of zinc smelting, zinc concentrates were initially roasted at a number of sites attached to fertiliser plants. Broken Hill zinc concentrates were roasted at Cockle Creek in New South Wales and at Port Pirie, Wallaroo and Port Adelaide in South Australia, each site being equipped with chamber style acid plants. Roasting of concentrates from the Tasmanian West Coast Mines was originally conducted at Zeehan with the gas wasted to atmosphere, but this ceased in 1949 when the roasting was transferred to the Risdon zinc smelter, which by that time had installed its own fertiliser plant (1924) to consume excess acid at that site.

A key reason for the location of acid production adjacent to the fertiliser plants was that the acid production technology at that time used the 'chamber process' which produced low strength acid containing in the range of 70 to 85 per cent H_2SO_4 . This covers the range for maximum corrosion rates on steel, and the strength required to avoid corrosion problems is above 93 per cent. Consequently, it was not practical to transport acid in bulk unless it could be produced at a strength above 93 per cent, and this required the development of the 'Contact Process' for sulphuric acid production.

The first Contact plants appeared around 1900, but used a platinum catalyst and were temperamental and high cost. They also required highly efficient gas cleaning to avoid rapid poisoning of the conversion catalyst. This type of unit was first installed at Broken Hill in 1908 as the Grillo-Schroder process and the plant was later transferred to Cockle Creek in 1923 for the processing of gas from the roasting of zinc concentrates. Vanadium catalysts soon replaced platinum and became the standard for 'Contact' plants from the mid-1920s. A Contact plant was installed at Port Pirie in 1924 for zinc concentrate roasting but proved troublesome due to inefficient gas cleaning. A new acid plant was installed at Port Pirie after zinc roasting had ceased in 1955 and for the purpose of producing acid from gases from the then new updraft sintering machine at the lead smelter.

At Risdon, the first Contact plant was commissioned in 1948 and thereafter three more such units were installed to replace the old chamber plants and allowed the transfer of all zinc concentrate roasting to the Risdon site. This was also facilitated by contracts for the supply of acid to the new titanium dioxide plant at Heybridge near Burnie (Tioxide) which was commissioned in December 1948. Acid was delivered by rail to Tioxide, but in addition, acid use on the Risdon site was increased with expansion of superphosphate production and the construction of an ammonia and ammonium sulphate plant, completed in 1956. A plant for the production of aluminium sulphate for use in water treatment soon followed. Ammonium sulphate was supplied as a fertiliser to the Queensland sugar cane industry, but was eventually supplanted by the direct use of locally produced ammonia or urea and the ammonium sulphate plant was closed in 1986, followed by closure of the aluminium sulphate plant in 1990. These products were no longer necessary to absorb local acid production due to the expanding capacity to transport acid by coastal shipping to other phosphate fertiliser plants. A substantial business had developed in the supply of acid to such plants in Adelaide, Melbourne and Geelong, Port Kembla and Brisbane. Shipments were also made from time to time to New Zealand and elsewhere. The Tioxide pigment plant in Northern Tasmania also closed in 1996, further reducing local demand and placing further emphasis on the shipment of acid from the site.

Two of the older acid units at Risdon were replaced with an 800 tonne per day Lurgi plant in 1981 and the remaining small units replaced with a second Lurgi plant in 1993 of 550 tonnes per day nominal capacity. These units remain in place today.

At Cockle Creek a superphosphate plant was constructed by Sulphide Corporation in 1913 to utilise acid from the lead smelting operation. This was expanded with the zinc concentrate roasting operations in 1923 with the first Contact plant as the third acid unit on site and a fourth unit in 1941. With the transfer of zinc roasting from Cockle Creek to Risdon in 1953, the acid plants were converted to the use of imported sulphur. A new sulphuric acid plant was constructed at Cockle Creek to serve the Imperial Smelting Process and replaced the older plants. It came into operation in 1961. Acid production was fully utilised in the adjacent fertiliser plant. That facility was sold to Australian Fertilizers Limited in 1970. With closure of the ISP smelter in 2003, sulphuric acid was imported through Newcastle to supply the fertiliser plant until it too was closed in 2009.

The Sun Metals zinc smelter at Townsville in North Queensland produces around 380 000 tonnes per year of sulphuric acid and this is widely shipped to fertiliser plants as well as mining industry customers in that State.

Over the period of time since zinc smelting commenced in Australia the disposal of sulphuric acid has remained primarily as a feed stock for fertiliser production, but has shifted from roasting facilities located alongside the fertiliser plants to bulk shipment of acid from the smelters to separate fertiliser production facilities, located around the Australian coast. Except for one fertiliser plant in Western Australia, all sulphuric acid supplies are now sourced as smelter acid, and production from zinc smelting operations remains the major source of acid for this important industry. The use of acid for fertiliser production has also increased in relative terms with a shift from the use of single superphosphate to the use of ammonium phosphate fertilisers, requiring 50 per cent more acid per unit of phosphate. However there has been greater competition from imports of high analysis fertilisers and overall demand for local acid has actually decreased. As an offset there has been a rise in worldwide trading of sulphuric acid through companies such as Interacid Limited, and this now can provide a significant outlet for acid from smelting operations.

CHAPTER 8 – TRANSPORTATION

The transport of raw materials to the smelters and product to world markets has been an important and significant component of the cost structure of the zinc smelting industry.

For the early zinc smelting operations, raw materials were primarily sourced from Broken Hill and required rail transport from the mines to Port Pirie or across to Newcastle for the Cockle Creek site. The rail connection from Broken Hill to Port Pirie originally used the 56 km narrow gauge Silverton Tramway to Cockburn on the border of NSW and South Australia, and then the South Australian narrow gauge line to Port Pirie. The Silverton Tramway was privately operated and hence there was a change of locomotives and crews at Cockburn when transferring to the South Australian Railways. The Silverton Tramway was built by private operators in 1886 following the rejection by the New South Wales Government to construct any rail connections in the area. The line was extended to Broken Hill in 1887 and it was not until 1927 that the New South Wales rail system reached Broken Hill. This system was standard gauge and the other South Australian rail connections from Port Pirie to Adelaide were broad gauge, making broad rail connections difficult. The new standard gauge line linking Sydney and Perth was completed in 1961, bypassing Cockburn and carried all future freight between Broken Hill and Port Pirie.



FIG 8.1 A locomotive on the Silverton Tramway – 1950.

From Port Pirie concentrates were sent by sea directly to Hobart and the Risdon plant's own port facilities on the Derwent River. Concentrates from the West Coast of Tasmania were transported by rail via the Emu Bay Railway to the Port of Burnie and then shipped to Risdon. Risdon also sourced zinc concentrates from the Captain's Flat mine near Canberra and this material was railed to Port Kembla and shipped to Risdon. Similarly, in later years zinc concentrates were sourced from Mount Isa via rail to Townsville and then by ship to Risdon. The Risdon plant thus relied entirely on shipping for the supply of raw materials and dedicated ships were used for that trade.

The Risdon wharf has a relatively deep draft with no significant restrictions on shipping. It was in fact often a first port of call for phosphate rock shipments to lighten their load before calling at the port of Melbourne and being able to enter Port Phillip Bay. Port Pirie was a different situation with the wharf located in a tidal estuary and had significant restrictions on shipping, particularly with large modern bulk carriers. Any dedicated ships for the concentrate trade then had to be of such a size as to navigate access to Port Pirie and limited capacity to around 20 000 tonnes of cargo.

The Electrolytic Zinc Company purchased its own ship – the SS Pareora – in 1918 to carry calcine from Port Pirie to Risdon. Unfortunately, this was wrecked in September 1919 at the entrance to St. Vincent's Gulf with loss of life. A sequence of dedicated vessels flowed over the years such as the SS Leura, the SS Kekerangu, the SS Era, the SS Poolta, the MV Kootara, and the MV Risdon which was operated by the Union Steamship Company from 1959 to 1975. All these vessels were bulk carriers. In 1975 the MV Zincmaster commenced operation as a purpose-built vessel with bulk cargo holds for concentrate and side deck space for zinc ingots loaded by fork lift truck through a side door and ramp. The ship was subsequently extended to include a central 5000 tonne sulphuric acid tank. The Zincmaster remained in service until 2005, but was supplemented by other coastal bulk carriers and chemical tankers to transport acid. The most notable of the supplementary bulk carriers was the MV Lake Illawarra which collided with the Hobart bridge and sank in January 1975 – see Figure 8.6. This collision created considerable disruption to daily life in Hobart until the bridge was rebuilt and a second river crossing added upriver of the zinc plant.



FIG 8.2 The SS Pareora loading at Port Pirie – 1918.

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FIG 8.3 The MV Risdon.



FIG 8.4 MV Zincmaster.



FIG 8.5 The SS Lake Illawarra.



FIG 8.6 The Tasman Bridge Disaster – January 1975.

The Port Pirie smelter relied primarily on rail for the supply of concentrates and of course acted as a major port for the export of zinc concentrates from Broken Hill. Metal from the smelter was also shipped out from the early years, but with the advent of containerisation, metal was railed to Adelaide and exported from Port Adelaide.

The Cockle Creek smelter was similarly placed, receiving raw materials by rail, but also by sea through the Port of Newcastle, and trucked to site. Metal was supplied to local customers by road and rail or was exported through the Port of Newcastle.

CHAPTER 9 – MARKETING

Britain was an exporter of metals from Roman times up until the mid-19th century when it became a net importer as a result of its rapidly expanding industrial production. Traders from all over Europe met in London on a regular basis to deal in a wide range of commodities at the Royal Exchange, established in 1571, and expansion of the metals trade soon required separate meetings of metal traders who founded the London Metals and Mining Company in 1877 for the purpose of conducting and administering metal trading activities. Trading sessions first operated above a hat shop in Lombard Court, London, trading in tin, copper and pig iron. A special purpose exchange building (the London Metals Exchange – LME) was constructed at Whittington Avenue and resided there for 98 years until 1976. Lead and zinc gained official trading status on the exchange in 1920. One of the important features of the LME was to agree on prices for forward delivery of metal so as to cover the long delivery times between purchasers of metal and ores by traders at remote locations, such as Australia and the Far East and delivery to UK or European customers.

In the first instance zinc production from Australia was supplied to UK customers as well as the local market for galvanising. Quality of zinc was poor from the retort plants and only suitable for galvanising applications. One of the primary reasons for adopting electrolytic technology in 1916 was the need for high-grade metal for the production of armaments for the First World War, and the quality of 'High Grade Zinc' was a purity above 99.95 per cent zinc content.

Before the First World War the zinc markets were substantially controlled by the German industry. Demand was high and the Spelter Convention formed in Europe in 1909 as a cartel forced prices to high levels. The Convention was broken by the advent of war, and the zinc industry in the USA expanded considerably to meet the demand. This was followed by zinc smelting developments in Canada and Australia. In the years between the World Wars, Australian zinc output was purchased by the British Metal Corporation Ltd based on LME prices. A European Zinc Cartel was formed in 1928 to support local industry, but this collapsed with the onset of the Great Depression in 1929. Demand and prices also collapsed at that time and the Cartel was resurrected in 1931 to cut production by 45 per cent and further by 55 per cent in 1932. However, some members of the cartel cheated and released stocks to again cause the collapse of the European Zinc Cartel in 1934.

The advent of the Second World War saw price controls and supply underwritten by governments to meet the defence demand. The operations of the London Metals Exchange were suspended in 1939 and did not resume until 1954. During the years of the Second World War the British Government purchased all zinc imported from Australia under direct contract with The Electrolytic Zinc Company of Australasia Ltd.

In Australia, the supply and price of zinc (as well as lead) was regulated and subject to a quota set by the Government as an estimate of local expected demand. Only production in excess of the quota was allowed to be exported. These controls remained in place well after the war ended and were only lifted in 1953. The domestic price was set arbitrarily and was substantially lower than the price achieved for export sales. For instance, in 1950 the regulated price for Australian zinc sales was lifted on the complaints of EZ Co. from £A40 to £A65 per ton, however the export price received was £A180 per ton. Following the

lifting of regulations in 1953 and restoration of the LME pricing, returns substantially improved allowing EZ Co. to expand the Risdon operation.

At this time sales of zinc in the UK and Europe were handled by Austral Metals Limited as agents in London. Markets were developed in India through British Metal Corporation as agents, and in the USA through C Tennant Sons and Co based in New York. Markets were also being developed in Japan and Asia. Demand was particularly high as a result of reconstruction after World War II and the effects of the Korean War. The formation of the European Economic Community in 1957 affected Australian markets in Europe and although the UK was initially excluded by the actions of France, it raised tariffs in line with the EEC to the detriment of Commonwealth suppliers, but protecting the local Imperial Smelting Corporation operating the sole zinc smelter in the UK at that time. At the same time the USA imposed import quotas as well as tariff protection, which tended to push any surplus metal onto the LME market causing a collapse in the zinc price. This was closely followed by the USA embarking on the Vietnam War, creating a new demand for zinc and pushing the zinc price up again to high levels. To counter this volatility a European Producer Price was established as the base price on which smelters sold their contracted tonnages, and a large proportion of metal was sold on this basis as distinct from the London Metals Exchange. An informal club of producers formed in 1964 covering smelters in Europe, Canada and Australia, with the aim of supporting the European Producer Price. The members used stock inventories to set and maintain the price. This significantly stabilised the price of zinc, although the LME did tend to influence movements from time to time.

During this time, it became apparent that Australian zinc metal had to find new markets in the Asian region, reinforced by a significant rebuilding and expansion of old smelting operations within the European Community to provide self-sufficiency in metal production, although still heavily reliant on the import of zinc concentrates. In 1973 the UK joined the EEC and abolished quotas on imports from Commonwealth countries, phased out preferential tariffs and removed all tariffs from other EEC member countries. The Common External Tariff was applied to Australian products, gradually increasing to full application from 1973 to 1977. This effectively removed opportunities to market metal in Europe. However, Asia was industrialising with demand for zinc growing substantially. EZ Co shifted its exports to the Asian region and to the West Coast USA and expanded production to meet the demands. In particular, the output of diecasting alloys was significantly expanded for manufacturing industries located in Hong Kong, Singapore and Taiwan. Other South East Asian countries such as Thailand and Indonesia were also greatly expanding their manufacturing capabilities and became significant purchasers of zinc metal from the Australian smelters. Japan tended to install its own smelting facilities and was primarily a market for zinc concentrates rather than metal. Indeed, market growth was sufficient to accommodate the new ISF smelter at Cockle Creek in 1965 and the Port Pirie electrolytic plant in 1967 as well as allowing expansion of the Risdon plant, and by the end of the 1970s virtually no metal was exported to European markets.

Following a short-term rise in the zinc price in 1970 the US Government imposed a stabilisation programme in 1971, which fixed prices at a low level. This was counterproductive and was lifted in 1973 causing a sharp increase in zinc price. With rising prices, the producers withheld supply and the LME zinc price also increased substantially. A recession in 1974 dropped prices and attempts to limit the fall were made by increasing government held stocks in the USA, Japan and France. Then in 1976 the US Department of Justice invoked Anti-Trust measures against zinc producer members of the

Zinc Club supporting the European Producer Price, and this restricted their ability to do business in the USA causing a collapse of the Zinc Club and the European Producer Price.

High demand in the 1980s again raised zinc prices, particularly aggravated by the introduction of the US Mint Tender for supply of zinc for the production of the newly introduced one cent coin. For a decade the annual US Mint tender, rather than regular purchases caused peaks in demand and zinc prices and contributed to high volatility.

The 1990s saw the collapse of the Soviet Union and the release of large stocks of zinc as well as other metals onto world markets, causing significant falls in the metal price, but after a recession in 2001 to 2003, prices again began to rise dramatically until the collapse brought about by the Global Financial Crisis in 2007. A positive price trend has been maintained since that time.

In 1990 world zinc consumption totalled 6.6 million tonnes of which Asia (excluding China) represented 1.45 million tonnes or 22 per cent and China around 0.5 million tonnes or 8 per cent of total world consumption. Greater Europe consumed 2.3 million tonnes or around 34 per cent. In 2014 total world consumption had increased to 13.6 million tonnes of which Europe consumed 2.6 million tonnes or 19 per cent, Asia excluding China consumed 2.6 million tonnes or 19 per cent, Asia excluding China consumed 2.6 million tonnes or 19 per cent and China close to 5.8 million tonnes or 43 per cent. The extraordinary rise of demand in China did not disrupt global markets to the extent that might have occurred due to the fact that the country had significant zinc resources and was constructing modern electrolytic zinc plants at an unprecedented rate to meet a large part of its growth in demand. The accompanying charts in Figure 9.1 illustrate world zinc production in mines and smelters and how this has changed from 1990 to 2014.

Over the years zinc prices have mainly been set by world supply and demand over the longer term with peaks and troughs as influenced by booms or recessions. Short-term fluctuations can result from trading activity on the LME and indeed the tonnage passing through the exchange on a daily basis is far higher than production and use and represents trading positions rather than physical metal. As illustrated in Figure 9.2, although the annual average price of zinc climbed by almost 20 times over the past century, the average price adjusted for inflation, has indeed changed little at around US\$2000 per tonne in 2014 dollar terms. Peaks and troughs have indeed been extreme, but there is no underlying downward trend over that period.

Cartels have not had a large influence on pricing and indeed were responsive to the longerterm trends on the LME. However, for the Australian zinc producers, the advent of the European Common Market, the rise of Asian manufacturing and the disruptive actions of the US Government in particular, have had the greatest impact on the marketing of its product. It has indeed been fortunate that Australia is located in the Asian region and the Australian zinc industry has been able to take part in market growth in that region as distinct from the foundation markets in the United Kingdom and Europe. Significant potential growth remains particularly with strongly developing economies such as India, and again the Australian industry is well placed to provide supply.



FIG 9.1 World mine and smelter production of zinc.



FIG 9.2 LME price of zinc in \$US per tonne.

CHAPTER 10 – COMPANIES, CORPORATE STRUCTURES AND ACTIVITIES

Brief details of the major players in the zinc mining and smelting business in Australia over the past century or more, are given below.

ABERFOYLE RESOURCES LIMITED

Aberfoyle Tin NL was first registered in 1926 and operated the Aberfoyle mine near Rossarden in North Eastern Tasmania. It also purchased the nearby Storeys Creek tin mine in the late 1950s and closed that operation in 1978. The Aberfoyle mine was sold to Forrestwood Australia Limited and Gold Copper Exploration Limited in 1981.

The company acquired and reopened the old Cleveland tine mine near Waratah in North West Tasmania in 1968 and embarked on an exploration program in the area. This led to the discovery of the Que River zinc-lead deposit in 1979. The mine was commissioned in 1981, feeding ore into the Rosebery concentrator. The Cleveland mine was closed in 1986 and Que River operated until 1991.

Canadian zinc producer Cominco began exploration in Australia in 1966 and took an equity interest in Aberfoyle in 1971 to progress these objectives.

Further exploration in Tasmania near the Que River mine uncovered the Hellyer deposit, leading to construction of a new mine and concentrator which was commissioned in 1987, and operated until 2000.

Aberfoyle had widespread exploration interests and discovered the Angas deposit in South Australia in 1991, as well as other minor deposits in Western Australia and North Queensland, and the Mendarie zircon and heavy mineral deposits in the Murray Basin. In 1996 the company purchased Gunpowder (Mount Gordon) copper mine located 130 km north of Mount Isa. Gunpowder had been mined spasmodically since its discovery in 1927, but Aberfoyle applied novel direct leaching – solvent extraction technology to treatment of the ore and constructed a large-scale operation.

The company was taken over by Western Metals Limited in 1998.

BROKEN HILL PROPRIETARY COMPANY LIMITED (BHP)

The Broken Hill Proprietary Company evolved from the syndicate which first discovered the Broken Hill lead-silver deposits, and was floated in 1885. The company retained three leases and floated off three adjacent leases as separate companies (Broken Hill Proprietary Block 14 Company, British Broken Hill Proprietary Company and Broken Hill Proprietary Block 10 Company Limited).

Lead smelting trials were conducted at Spotswood in Melbourne through the Intercontinental Smelting and Refining Company in 1886 and following that success smelting operations were installed by the Company at Broken Hill.

The first blast furnace operation for lead smelting at Port Pirie commenced operation in 1889 by the British Broken Hill Pty Ltd, and The Broken Hill Proprietary Company Ltd (BHP) built a lead refinery there to process bullion from their Broken Hill smelter. In 1892

BHP acquired the smelter and transferred all its smelting operations to Port Pirie, closing the Broken Hill smelter in 1897.

Zinc smelting commenced with the completion of construction of a retort plant at the Port Pirie smelter in 1908.

With the advent of the First World War in 1914, many of the Broken Hill mines lost their markets for lead concentrates which had previously been predominantly sent to Germany and Belgium. They were thus interested in acquiring an interest in the Port Pirie smelter and expanding its capacity to handle the full output from Broken Hill. Negotiations thus commenced with BHP for this purpose and were successfully concluded in May 1915. A joint company (Broken Hill Associated Smelters Pty Ltd) was formed to own and operate the smelter. Initially it was an equal joint venture between BHP, The Broken Hill South Mining Company, and North Broken Hill Ltd, however Zinc Corporation and The British Broken Hill Proprietary Company also soon acquired an interest. BHP was also, at that time, interested in utilising its iron ore resources from Iron Knob in South Australia and coking coal resources for the production of steel and had constructed a steelworks at Newcastle in 1915. The Company's interests shifted to supplying the growing demand for steel in Australia and it finally sold its remaining interest in the Port Pirie smelter to the remaining three shareholders in 1925 (The Broken Hill South Mining Company, North Broken Hill and Zinc Corporation). This was the end of BHP's interest in the Broken Hill field and associated lead and zinc production.

BHP grew into Australia's largest corporation with many interests in the resources industry. It re-entered the zinc and lead business with the discovery of the Lennard Shelf deposits in Western Australia in 1978 in joint venture with Shell subsidiary Billiton. This was developed as the Cadjebut Mine and was sold together with other prospects to Western Metals in 1994.

Exploration by BHP in North Queensland also uncovered the Cannington deposit in 1990 as one of the world's richest silver orebodies. This was predominantly lead with relatively small amounts of zinc. Mining commenced at Cannington in 1997.

BHP merged with Billiton plc in 2001 to become the world's leading diversified resources company and renamed BHP Billiton with dual listing on the Australian and London stock exchanges.

BROKEN HILL SOUTH LIMITED (BHS)

The Broken Hill South Silver Mining Company Limited was formed in 1885 to acquire and mine the leases – Blocks 5, 6, 7, and 8 on the Broken Hill field. A lead smelter was constructed on site in 1891, but only had a short life of about three years. Eventually BHS took a one one-third interest in the Port Pirie smelter in 1915.

The company changed its name to Broken Hill South Limited in 1918

Block 5 lease was sold to Zinc Corporation in in 1905, although over the years BHS acquired the Central Mine in 1940 and took over Blocks 10, 11 and 12 from BHP in 1943, as well as Block 14 from North Broken Hill Limited, and the British and Junction Mine leases in 1962.

The company ceased mining at Broken Hill in 1972 and sold its leases to Minerals, Mining and Metallurgy Limited (MMM), which reopened the operations on much limited scale.

The company reorganised as BH South Limited in 1973 and concentrated on developing the large phosphate deposits at Duchess in Queensland which it had discovered in 1967. The shareholding in Broken Hill Associated Smelters was also sold to AM&S in 1974 taking the shareholding in the Port Pirie operation to 70 per cent AM&S and 30 per cent North Broken Hill Limited.

BH South was taken over by Western Mining Corporation in 1973.

CBH RESOURCES LIMITED

Consolidated Broken Hill (CBH) Resources was floated by Normandy Mining Limited to acquire the central leases in the Broken Hill field and extract remnant ore from the old workings. Development commenced on the Broken Hill central leases in 2007 – then named the Rasp Mine, but due to low metal prices this was suspended in 2008.

The liquidation of Pasminco provided an opportunity to acquire zinc mining operations and although CBH did not secure the existing Broken Hill operations, it did purchase the Elura Mine near Cobar and the associated concentrate handling and shiploading facility at Newcastle in 2003. The purchase was funded by sale of equity in CBH to a major customer, Toho Zinc Company of Japan, as well as the provision of loan funds by Toho Zinc. The Elura name was changed to the Endeavour Mine.

Due to low metal prices the Endeavour Mine operations were scaled back in 2008. A merger with Perilya was proposed at that time, but did not eventuate, and a takeover offer was subsequently made by Nystar. However, this was countered by a bid from Toho Zinc which succeeded, and CBH Resources became a wholly owned subsidiary of Toho Zinc in 2010. Shortly thereafter development of the Rasp Mine was restarted and a new concentrator constructed and completed in 2012.

CONZINC RIO TINTO OF AUSTRALIA LIMITED (CRA)

Rio Tinto originated as a consortium of British investors led by Matheson and Company and the Deutsche Bank who purchased the ancient copper mines at Huelva in Spain from the Spanish Government in 1873. This became the world's leading copper producer up to the 1920s but then began to decline. The company looked for opportunities elsewhere, particularly in Africa and founded the Rhokana Corporation in Rhodesia. They divested their interests in Spain in the 1950s as operations became more difficult under the nationalistic Franco regime, and embarked on a highly successful exploration program. Needing capital to develop some of these new ventures, an agreement was reached in 1962 to merge the interests of Rio Tinto with Consolidated Zinc Corporation to form Rio Tinto Zinc Corporation (RTZ) and an Australian subsidiary Conzinc Rio Tinto of Australia Limited (CRA).

CRA acquired all the zinc and lead holdings in the Broken Hill mines, BHAS and Sulphide Corporation previously held by Zinc Corporation.

In 1971 CRA and New Broken Hill Consolidated merged their lead and zinc interests to form Australian Mining and Smelting Company Limited (AM&S) which acquired the CRA interest in BHAS and Sulphide Corporation as well as the Broken Hill mining operations. AM&S was fully acquired by CRA in 1976.

Broken Hill South Limited sold their shareholding in the Port Pirie smelter to AM&S in 1974 taking the ownership of BHAS to 70 per cent CRA and 30 per cent North Broken Hill Limited.

CRA, together with North Broken Hill Holdings Limited, divested their zinc and lead interests into Pasminco Limited in 1988 and concentrated on its other mining ventures, particularly iron ore, aluminium and coal.

In 1997 the company structure was changed to dual listing companies in the UK and Australia. RTZ became Rio Tinto plc and CRA became Rio Tinto Limited.

ELECTROLYTIC ZINC COMPANY OF AUSTRALASIA LIMITED - EZ INDUSTRIES LIMITED

The Electrolytic Zinc Company of Australasia Limited (EZ) was formed under the sponsorship of the Amalgamated Zinc (De Bavay's) Limited and the Australian Zinc Producers association in 1915 to construct an electrolytic zinc plant at Risdon in Hobart, for which work commenced in 1916. In 1920 EZ acquired Mount Read and Rosebery Mines from the Mount Lyell Mining and Smelting Company as well as the Zeehan Smelters. New facilities were constructed at Rosebery with a new concentrator which commenced operation in 1936 to supply zinc concentrates to the Risdon zinc plant.

The Risdon zinc plant progressively expanded over the years to 100 000 tons in 1950 and 200 000 tonnes in 1972. Production facilities for superphosphate and ammonium sulphate fertilisers were also added.

In 1956 a holding company was formed to consolidate all associated interests as EZ Industries Limited of which the Electrolytic Zinc Company of Australasia became a wholly owned subsidiary.

An exploration program commencing in the mid-1960s discovered the Beltana zinc silicate deposit in South Australia and the Elura zinc-lead deposit near Cobar in New South Wales. Other joint venture discoveries were at Golden Grove in Western Australia and the Ranger Uranium orebodies in the Northern Territory. Ranger was jointly discovered with Peko Wallsend in 1969 and after protracted environmental enquiries and Federal Government intervention, was eventually established under the control of a new listed company – Energy Resources of Australia (ERA) in which EZ retained a substantial shareholding. Ranger became one of the world's major uranium mines and commenced production in 1981.

The Hercules Mine closed in 1986 and the North Farrell mine closed in 1974, leaving only the Rosebery Mine operating on the Tasmanian West Coast. The Beltana mine in South Australia commenced operation in 1974 and the Elura Mine in 1983.

The EZ Industries Ltd and the Electrolytic Zinc Company of Australasia Ltd became a wholly owned subsidiary of North Broken Hill Limited in 1984.

KOREA ZINC COMPANY (KZ)

Korea Zinc was founded in 1974, and together with its sister company Young Poon produces the total zinc output from South Korea. The Onsan zinc refinery was commissioned in 1978 on the basis of technology supplied by Toho Zinc Company. Since then Korea Zinc has become a leader in the adoption of innovative smelting technology

and has greatly expanded its operations to include lead and copper production. It now controls of the order of 10 per cent of the world's zinc production.

Korea Zinc has always been mindful of the need for securing resources, and made a number of investments in resource companies around the world. It also made judicious investments in technology development companies.

In 1996 KZ purchased the Big River zinc plant at Sauget, Illinois in the USA, and in 1999 completed construction of a new electrolytic zinc plant in Townsville to draw raw materials from the zinc rich mining region of North Queensland.

The Big River zinc plant was closed in 2006 and then sold to ZincOX plc for conversion into a plant to process secondary zinc oxides recovered from electric arc furnace dusts.

MOUNT ISA MINES LIMITED (MIM)

The discovery of the Mount Isa field was made by John Campbell Miles in 1923 and Mount Isa Mines Ltd (MIM) was floated in 1924. The company came under the control of Leslie Urquhart and his Mining Trust, based in London. As part of their investment The Mining Trust constructed a lead refinery at Northfleet in the UK (Britannia Lead), to treat bullion from Mount Isa. However, funding of these facilities and the Mount Isa operations soon ran out, and in 1930 an investment was sought from the American mining and smelting entrepreneurs, the Guggenheim family, through their American Mining and Smelting Company ASARCO. ASARCO not only supplied funding but also supplied management for the new mine and lead smelter. At that time The Mining Trust was owned 12 per cent by Urquhart, 33 per cent by ASARCO and 55 per cent by other interests, and MIM was owned 72 per cent by The Mining Trust and 28 per cent by other local interests.

Zinc concentrates were produced at Mount Isa from 1935 and most were exported to Japan. There was an ongoing saga of difficulties for MIM through the 1930s and into the years of the Second World War, not the least being directives by the Australian Government to switch production from lead to copper and then back to lead again, as well as alleged extortion by the Queensland railways in the transport of product to the Port of Townsville, and loss of their zinc concentrate market. This required the injection of more funding by ASARCO and by 1948 they owned 53 per cent of the company. However, at this time profitability improved markedly and the first dividend was paid in 1947. In 1951 MIM bought out The Mining Trust and acquired Britannia Lead. Zinc became a larger part of the lead-zinc component of the business and copper production was started again in 1953. The Townsville Copper Refinery was built in 1964, and the opening of the Hilton Mine at Mount Isa in 1969 again expanded zinc concentrate production.

MIM grew to be the second largest Australian mining company in the 1980s after BHP. It bought out the ASARCO interest in two tranches, the first in 1987 and the second in 1996 to become an independent Australian corporation.

The large McArthur River mine was opened by MIM in 1995 after 37 years since discovery and a long period of development of suitable mineral processing techniques.

A hostile takeover of Mount Isa Mines was successfully mounted by the Swiss company Xstrata Limited in 2003. Subsequently Xstrata merged with its parent trading company Glencore Limited and the Mount Isa operations became solely owned by Glencore plc in 2014.

MIM opened the George Fisher mine in 2010 replacing closure of the old lead mine and Black Star open pit operations, further expanding zinc concentrate output.

NORTH BROKEN HILL LIMITED (NBH)

The company was established in 1885 as the Broken Hill North Silver Mining Company Limited to mine the Block 17 lease. It was reorganised a number of times with renaming to finish as North Broken Hill Limited in 1912. NBH gradually acquired all the leases in the northern end of the Broken Hill field. British Broken Hill Proprietary Limited (Blocks 15 and 16) was acquired in 1923, the Junction Mine (Block 39) in 1929, and the North Junction Mine (Block 40) in 1930. Operations were revitalised between 1928 and 1936 as a major producer of zinc and lead concentrates.

Mining progressively extended to deeper levels, culminating with the development of the Fitzpatrick lode between 1982 and 1993 at a depth of around 1500 metres.

A 30 per cent interest was acquired in the Port Pirie smelter from BHP in 1925 and retained at that level until the formation of Pasminco in 1988. The company was also instrumental in the formation of Amalgamated Zinc De Bavays Limited and the initial development of the Electrolytic Zinc Company of Australasia Limited in 1916.

The company restructured as North Broken Hill Holdings in 1976 and soon thereafter embarked on an expansion program, taking over Associated Pulp and Paper Mills Ltd (APPM) in 1983 as Australia's major producer of fine paper, and EZ Holdings Limited in 1984. This was followed by a takeover of Peko Wallsend Limited in 1988 with mining interests in gold, copper, mineral sands, iron ore and coal. The name was then changed to North BH Peko Limited. At the same time all zinc and lead interests, including the Broken Hill mine and EZ, were divested into Pasminco in a 50:50 amalgamation with the zinc and lead interests of CRA Limited.

NBH retained interests in uranium miner ERA.

As part of the Peko Wallsend acquisition NBH obtained scrap metal dealer Sims Consolidated Limited which it subsequently sold to Elders Resources Limited in 1989. In 1993 the paper interests were sold to AMCOR Limited.

North BH Peko Limited was acquired by Rio Tinto Limited in 2000.

NYRSTAR

Nyrstar was formed by Belgian company Umicore and acquired the smelting interests of Zinifex Limited in 2007, including the Risdon, Budel and Clarksville zinc plants, and the Port Pirie smelter. To these are added the electrolytic zinc plants at Balen/Overpelt in Belgium and Auby in France.

In May 2014 Nyrstar announced a modernisation of the Port Pirie smelter for which it had obtained Government financial support, and the closure of the Port Pirie electrolytic zinc plant in July 2014 due to ongoing losses over the past four years. Zinc oxide would be treated at the Risdon plant or at other group zinc operations. This leaves only the Risdon zinc smelter in Hobart and the Townsville smelter owned by Korea Zinc in operation in Australia after a period of around 100 years from the commencement of the first large-scale electrolytic plant at Risdon in 1916.

PASMINCO LIMITED

CRA (AM&S) and North Broken Hill Ltd merged their lead and zinc interests on a 50:50 basis into a public float in July 1988, forming Pasminco Limited, which then held all the Broken Hill mining operations as well as BHAS and the Port Pirie smelter, the Tasmanian West Coast Mines, the Elura Mine near Cobar New South Wales, the Risdon zinc plant, and the Cockle Creek zinc-lead smelter. It also held the Avonmouth zinc-lead smelter in the UK and a 50 per cent share with Shell Minerals – Billiton in the Budelco zinc plant in the Netherlands.

Pasminco embarked on a smelter modernisation program in 1990, particularly the Risdon zinc plant. This was followed by a number of years of low metal prices and poor returns. To improve its cash position the Avonmouth zinc-lead smelter in the UK, which was no longer profitable, was sold to Mount Isa Mines in 1993. This operation complemented Mount Isa's existing lead refining operations in the UK and provided an outlet for their production of bulk zinc-lead concentrates, both from Mount Isa and from McArthur River mines. A 40 per cent equity in the Elura Mine was also sold to Korea Zinc at that time. Losses continued to occur in 1993 and 1994 and both CRA and NBH sold down their shareholdings in Pasminco. However metal prices improved and Pasminco returned to profit in 1995.

The Shell Minerals shareholding in the Budelco zinc smelter in the Netherlands was purchased by Pasminco in 1995, so that it became a wholly owned operation and the largest zinc plant in Europe at the time.

CRA had been separately developing the large Century Mine in North Queensland in the mid-1990s and contracted 50 per cent of its output of zinc concentrates to Pasminco operations, particularly total supply of the Budelco zinc plant in the Netherlands. The Century Mine was subsequently sold to Pasminco by CRA in 1997 together with the Dugald River deposit in North Queensland.

In 1999 Pasminco made a hostile takeover of Savage Resources Limited, essentially to acquire the Clarksville Smelter in Tennessee in order to secure a key position in the US zinc market. However, it also acquired low value coal interests and more importantly substantial debt and a hedge book that was considerably greater than originally thought.

Through poor management of metal hedging arrangements and the adverse effects of the hostile takeover of Savage Resources Limited, Pasminco became insolvent and was placed in administration in September 2001 under the control of the creditor banks. The Company was declared bankrupt in 2002 and re-floated in a more streamlined form as Zinifex Limited in 2004. The proceeds from the float barely repaid the loans and there was nothing remaining for the original Pasminco shareholders. During the period of administration, the Broken Hill mines, then in a depleted state, and the Beltana zinc silicate mine were sold to Perilya Limited who also operated other small mines in the area (May 2002). Perilya Limited was subsequently acquired by Shenzen Zhongin Lingnan Nonfemet Company of China in December 2013.

The Cockle Creek ISP zinc-lead smelter was closed in September 2003 as uneconomic.

The Elura zinc mine, which commenced operation under EZ in 1973 was also sold to CBH Resources Limited in 2003, together with the associated shiploading facility at Newcastle. The Elura Mine name was changed to the Endeavour Mine and it was subsequently taken over by the Japanese company Toho Zinc Company in 2010.

PERILYA LIMITED

Perilya was founded in 1987 as an exploration company and grew with the development of the Fortnum gold mine in Western Australia in 1994. In 2002 Perilya purchased the Broken Hill mining operations from Pasminco as well as the Beltana zinc silicate mine in South Australia, which it reopened in 2007.

Shenzhen Zhongjin Lingnan Nonfemet Company Limited, China's third largest zinc producer, acquired 50.1 per cent of Perilya in 2009 and raised this to full ownership in 2013.

SULPHIDE CORPORATION LIMITED

Sulphide Corporation was established in London in 1895 by Edgar Ashcroft to apply his recently patented electrolytic zinc process to the treatment of Broken Hill zinc concentrates. With great confidence he constructed a zinc plant at Cockle Creek near Newcastle in 1897 and the company purchased the Central Mine at Broken Hill to secure a supply of zinc concentrate. The process was a failure and was abandoned in 1898. Eventually a zinc retort plant was constructed on the Cockle Creek site in 1902, although this was uneconomic and was also closed in 1908 and the equipment was transferred to the company's Seaton Carew works in North East England. Meanwhile Sulphide Corporation Limited established lead smelting on the Cockle Creek site and expanded into fertiliser production from the use of sulphuric acid in 1913. A lead refinery was added in 1917.

Lead smelting ceased at Cockle Creek in 1922 and zinc roasters were then installed to treat Broken Hill zinc concentrates for the Risdon electrolytic plant and to enable the sulphuric acid plants to continue in operation and supply fertiliser production. The company also commenced cement production on site in 1925.

The Central Mine at Broken Hill closed in 1940.

In 1948 the shares in Sulphide Corporation Limited were purchased by a group of companies which merged into Consolidated Zinc Corporation Limited in 1949 and reformed the company as Sulphide Corporation Pty Ltd in 1950. Consolidated Zinc Corporation then planned to introduce the Imperial Smelting Process to the Cockle Creek site and construction commenced in 1957 with completion in 1961.

Sulphide Corporation Pty Ltd became a subsidiary of Conzinc Rio Tinto of Australia Ltd (CRA) in 1962 with the merger of Consolidated Zinc Corporation and Rio Tinto.

Fertiliser production was separated as a subsidiary company (Greenleaf Fertilizers) in 1964 and subsequently sold to Australian Fertilisers Limited in 1970.

Ownership of the company passed to Pasminco Limited in 1988 with the combining of the zinc and lead interests of CRA and North Broken Hill Ltd.

The company was liquidated in 2003 with the closure of the Cockle Creek smelter site and the financial collapse of Pasminco Limited.

WESTERN METALS LIMITED

Western Metals commenced in 1986 as an exploration – mining company. In 1994 it purchased the Lennard Shelf zinc mining operations in the Kimberley region of Western Australia from a joint venture between BHP and Shell Minerals – Billiton. This was financed by a major share issue at the time.

The Cadjebut Mine was in operation at the time of acquisition, but was soon exhausted and closed in 1998. Two new mines – Goongewa and Kapok opened in 1997 and supplied the Cadjebut mill. In 1998 the Pilara Mine was opened in the Lennard Shelf field and new port facilities were developed at Derby for export of zinc concentrates. In 1998 Western Metals mounted a successful takeover bid for Aberfoyle Resources and acquired the Hellyer zinc mine in Western Tasmania as well as the newly developed Mount Gordon copper mine and mill in North Queensland. The Hellyer mine was almost finished and closed in June 2000, and the Mount Gordon operation was particularly troublesome in the early stages.

Also, in 1998, Western Metals acquired a 36 per cent interest in Padaeng Industries which operated a mine and zinc smelter in Thailand.

The company had overstretched its finances with rapid growth and found itself in difficulties in 2003. The Lennard Shelf operations were closed and later sold to Teck Cominco and Xstrata in joint venture, and the Tasmanian operations were also sold at this time.

Low metals prices in the period from 2008, coupled with heavy debt finally caused Western Metals to be placed in administration in 2009, and residual assets were transferred to Indigo Resources Limited.

ZINC CORPORATION LIMITED (ZC) AND NEW BROKEN HILL CONSOLIDATED LIMITED (NBHC)

Zinc Corporation Limited was formed in 1905 by W L Baillieu and W S Robinson under the guidance of Herbert Hoover to acquire tailings dumps at Broken Hill and apply the newly developed flotation technology to the extraction of zinc concentrates. In 1911 Zinc Corporation Limited was incorporated in the UK and acquired the assets of the Australian company together with the mining leases of Broken Hill South Blocks Limited within which it commenced underground mine development. By 1923 tailings dump treatment had been completed and Zinc Corporation became solely a mine operator.

In 1929 Zinc Corporation and the British Metal Corporation acquired the National Smelting Company in the UK. This company had been established by Winston Churchill as Minister for Munitions in 1915 for the production of zinc metal for the war effort. Contracts for the supply of zinc concentrates from Australia had been a large part of those arrangements, but little progress had been made in smelter construction and the British Government lost interest after the war ended. The National Smelting Company had old retort smelting facilities at Swansea Vale in Wales and a half completed smelting plant at Avonmouth including zinc roasters and acid plant. After acquisition the company was reorganised as the Imperial Smelting Corporation, and full ownership was achieved with purchase of residual shareholdings by ZC in 1948.

Imperial Smelting Corporation had purchased the Seaton Carew zinc smelting plant from Sulphide Corporation in 1933 and another zinc smelting operation at Bloxwich from the Delaville Spelter Company Limited. At the same time construction of a new vertical retort zinc smelter at Avonmouth commenced with first metal produced in 1934.

Imperial Smelting commenced research on a blast furnace method of producing zinc in 1938, but it was not until 1948 that a breakthrough was achieved and the first furnace was commissioned in 1950. This development evolved into the Imperial Smelting Process and plants were built at Swansea Vale, Cockle Creek in Australia and Avonmouth as well as many other licensed operations to other companies.

ZC progressively acquired the southern leases in the Broken Hill field from Barrier South Ltd and others and in 1936 completed a major expenditure program on a new shaft and concentrator, which included an all flotation operation. New Broken Hill Consolidated Ltd (NBHC) was floated as a separate subsidiary enterprise at that time to explore the southern extremities of the field. NBHC commenced construction of a new mine and concentrator on the southern leases in 1946 and commenced operation in 1952.

Zinc Corporation's interest in the Broken Hill Associated Smelters was increased to 50 per cent in 1945.

In 1947 Suphide Corporation Limited unveiled plans to install an Imperial Smelting Furnace at Cockle Creek, but went into liquidation in 1950 to be taken over by a new company – Sulphide Corporation Pty Ltd, a wholly owned subsidiary of Consolidated Zinc Corporation.

In 1949 ZC amalgamated with its subsidiary Imperial Smelting Corporation to form Consolidated Zinc Corporation Limited.

The plans to erect an ISF on the Cockle Creek site were resurrected and the new facility was completed in 1961.

Zinc Corporation as a subsidiary of Consolidated Zinc Corporation was absorbed into the merger with Rio Tinto in 1962 to become part of CRA (Conzinc Rio Tinto of Australia Limited).

ZINIFEX LIMITED – OZ MINERALS LIMITED

Zinifex was floated by the creditor banks as the remnants of Pasminco Limited. At the time of the float in 2004, Zinifex operations included the Risdon zinc plant, the Port Pirie smelter, the Budel electrolytic zinc plant in the Netherlands, the Clarkesville electrolytic zinc plant in Tennessee, the Century Zinc mine, the Rosebery mines in Tasmania, and the potential new mine at Dugald River in Queensland.

Financial difficulties continued with the Pasminco assets under the management of the new company and Zinifex sought to divest its smelting operations and become a mining only operation. In October 2007 the smelting operations were merged with those of the Belgian company Umicore to form a new smelting company called Nyrstar. For the first time smelting and mining operations were completely separated. This was in stark contrast to corporate philosophy over the past century where integrated mining and smelting operations were regarded as preferable for coverage of the inevitable longer-term swings and roundabouts of the mineral cycles, where fortune favoured the miners at some periods of concentrate shortage and the smelters at other times of excess mine production. A good balance protected the company from excessive swings in fortune from one or other parts of the cycle. Decisions made with the short-term view have no doubt contributed to the subsequent decline of this industry in Australia.

In June 2008, Zinifex merged with rising mining company Oxiana Limited to form OZ Minerals Limited. This added copper and gold mining operations at Sepon in Laos and Prominent Hill in South Australia, as well as zinc, lead and copper mining operations at Golden Grove in Western Australia. However financial difficulties continued and OZ Minerals negotiated a takeover bid from China Minmetals Non Ferrous Metals Company in 2009. This was rejected by the Australian Government under foreign investment guidelines on the basis that it included the Prominent Hill Mine which was located within the Woomera Prohibited Area (defence) in South Australia. This was subsequently

excluded from the deal, and in June 2009 it was finalised, and Minmetals (MMG) secured all operations other than Prominent Hill, which remained with a much-reduced OZ Minerals Ltd.

The Century Mine was closed by MMG in early 2015 after 16 years in operation and will be replaced in part by the Dugald River mine, which will send ore to the concentrator at the Century site.

XSTRATA LIMITED

Originally an old Swiss infrastructure company it was acquired by trading company Marc Rich AG in 1990 and used to diversify into the mining resources business as separate from trading. It was listed on the London Stock Exchange as Xstrata in 2002 and acquired coal mining operations in Australia and South Africa from associated Marc Rich Company and its trading arm Glencore.

In 2003 Xstrata made a successful takeover bid for MIM Holdings Limited and secured the Mount Isa zinc, lead and copper operations. It also made a bid in Australia for WMC Resources Ltd (Western Mining) in 2005 but lost to a competitive bid from BHP.

Many large acquisitions were made in subsequent years including Falconbridge Nickel in Canada making Xstrata one of the world's largest diverse resource companies. In 2013 Xstrata and Glencore merged under the Glencore name. Glencore now has a range of interests in mining and mineral commodities, energy resources and agricultural trading businesses with operations in 18 countries.

CHAPTER 11 – FINAL OVERVIEW

Throughout the past century the zinc smelting industry has seen significant change in the technology used, from the horizontal retort process treating oxide ores to vertical retorts, electrolytic and blast furnace technologies based on the use of zinc sulphide concentrates. The Australian industry pioneered the production of sulphide concentrates through the development of the flotation process which set the industry in a new direction. It also participated significantly in the development and improvement of new smelting technologies.

In the early days, the focus was well and truly on technology development and improvement, and management of the Australian industry was strongly oriented in this direction, leading to its predominance as a world player in the latter part of the 20th century. However. as technologies matured there was diminishing gain from technical improvements. Rather, emphasis was given to productivity and efficiency in smelting operations and the competitive position shifted more to trading positions on the world stage. At the end of this century of activity, management became oriented to this situation and the mines and smelting operations became pawns to play in the trading game. The zinc industry is but one example of this scenario and at the end of a century of development we see a significant demise in the level of expertise devoted to the development of new extractive processes with attention focused on the improvement of well-established technologies. Perhaps with a maturing industry, technology now plays a much smaller part in achieving a competitive position compared with broad geographic control of production facilities and access to a wide range of markets. For these reasons the old locally controlled empires associated with zinc mining and smelting in Australia, and indeed most of the major non-ferrous mining operations, have now all passed into foreign control. These operations are now part of global oriented businesses, and represents a new paradigm in the resources industry.

A view of the production of zinc metal from mining operations up to 2014 is shown in Figure 11.1 and illustrates the long-term, but declining influence of Broken Hill which dominated up to around 1980. Mount Isa is clearly a growing contributor and the new large-scale mines such as Century has had a major impact on output over the past decade. However, these large-scale operations are short lived and the closure of Century in 2015 will require new mines such as Lady Loretta and Dugald River to take up some of the slack.

A summary of zinc metal production from various smelters is shown in Figure 11.2 and reveals the dominance of the Risdon plant up to the end of the 20th century.

Figure 11.3 shows the distribution of zinc mined to smelter feed and concentrate exports. Exports of zinc in concentrates was of a similar level to local metal production for about 50 years up to the late 1980s and then climbed to be almost double local metal production in 2014 at around one million tonnes of contained zinc per annum.



FIG 11.1 Australian mine production of zinc.



FIG 11.2 Australian zinc smelter metal production.



FIG 11.3 Australian zinc output as metal from smelters and in export concentrates.

CHRONOLOGY

1876	Lead-silver discovery at Thackaringa NSW
1882	Lead-silver discovery at Umberumberka (Siverton) NSW
	Lead-silver discovered at Zeehan-Dundas field in Tasmania
	Copper-zinc-lead deposits discovered at Lake George NSW
1883	Lead-silver discovery on the Barrier Ranges (Broken Hill) NSW
1885	Broken Hill Proprietary Company Limited (BHP) founded
	Broken Hill South Silver Mining Company formed
	North Broken Hill Silver Mining Co formed
1886	Lead smelters built at Silverton and Broken Hill
1889	British Broken Hill Co builds a blast furnace at Port Pirie
	BHP constructs a lead refinery at Port Pirie
1890	Zinc production by electrolysis of chloride solutions patented by Carl Hoepfner
1892	BHP purchased the Port Pirie smelter
	Railway completed from Zeehan to Strahan allowing Tasmanian mines to develop
	Zinc-lead-silver mineralisation found at Mount Read, Tasmania – Hercules Mine
1893	Rosebery zinc-lead-silver deposits discovered
1894	North Broken Hill Silver Mining Co closed due to the 'zinc problem'
	Edgar Ashcroft patented an electrolytic zinc process to treat Broken Hill material
	Mining and smelting commenced at Lake George
1895	Zinc rich concentrates from Broken Hill sent to Germany for smelting
	Ashcroft forms Sulphide Corporation and purchases the Central Mine at Broken Hill
1897	BHP transferred all smelting operations to Port Pirie
	Ashcroft electrolytic zinc plant constructed at Cockle Creek NSW
1898	Zeehan Smelters constructed
	The Cockle Creek electrolytic zinc plant abandoned

- Principle of mineral flotation of sulphides discovered by Charles Potter
 A conventional lead smelter constructed at Cockle Creek
 Lake George mines closed due to complications with zinc mineralisation
- 1902 A zinc retort plant was constructed at Cockle Creek by Sulphide Corporation
- First flotation machine introduced at Broken Hill
 Dumps at Broken Hill estimated at 6.5 million tonnes with 10 per cent zinc content
 De Bavay Flotation Process patented and De Bavay Treatment Company formed
 Sulphide Corporation applied the Mineral Separation flotation process at the Central Mine
- 1905 Zinc Corporation formed to process the Broken Hill tailings dumps
- 1906 Zinc Corporation with Herbert Hoover purchased Broken Hill tailings dumpsA zinc retort plant constructed at Port Pirie
- 1908 Cockle Creek zinc retort plant closed and transferred to Seaton Carew, UKNew zinc retort furnaces installed at Port Pirie

Amalgamated Zinc (De Bavay's) Limited formed to treat the North Broken Hill Mine dumps

- 1909 Tasmanian Metal Extraction Company formed to recover zinc at Rosebery, Tasmania
- 1911 James Gillies formed The Hydroelectric Power and Metallurgical Co. in TasmaniaZinc Corporation Limited incorporated in the UK
- 1912 Differential flotation established at Broken Hill to produce a clean zinc concentrate
- 1913The Zeehan Smelters closed

Acid and fertiliser plants constructed at Cockle Creek

- 1914 The Tasmanian Metal Extraction Company failed and closed its operations Commencement of the First World War and loss of zinc concentrate markets Zeehan Smelters confiscated by the Tasmanian Government from German owners Tasmanian Government acquired the Great Lakes Power Scheme
- 1915 The Port Pirie zinc retort plant expanded

The first successful electrolytic plant commenced in the USA BHP sold the Port Pirie smelter to Broken Hill Associated Smelters Ltd

- 1916 Amalgamated Zinc agrees to construct an electrolytic zinc plant in Tasmania Electrolytic Zinc Company (EZ) formed and commences a pilot zinc plant at Risdon The Hydroelectric Power and Metallurgical Co. abandons plans for zinc production Lead refinery completed at Cockle Creek
- 1918 Risdon 10 ton per day plant commences operation
- 1920 EZ purchases Mount Read and Rosebery Mines and the Zeehan Smelters
- 1921Zinc retorts closed at Port PirieZinc roasters erected at Port Pirie
- 1922 Cockle Creek lead smelter closed
- 1923 Zinc Corporation completes tailings treatment at Broken Hill and purchases Southern leases

Zinc Corporation acquires major interests in the National Smelting Co in the UK Mount Isa deposits discovered

Six Barrier zinc roasters installed at Cockle Creek by EZ plus a third acid plant

Risdon 100 ton per day electrolytic zinc plant commenced operation

- Amalgamated Zinc De Bavays ceased treatment of tailings at Broken Hill
 New zinc roasters and acid plant erected at Port Pirie
 Superphosphate plant installed at Risdon
 Mount Isa Mines formed to mine the Mount Isa lead zinc deposits
- 1925 EZ installs zinc roasters at the Zeehan Smelters site Broken Hill Associated Smelters formed
- 1927 The first slag fuming plant for zinc recovery built in USA (Montana)
- 1928 Construction of a new concentrator at the Rosebery Mine commenced
- 1929 UK interests of Zinc Corporation reorganised as The Imperial Smelting Company Imperial Smelting Company purchased the National Smelting Company in the UK

1930	Mine and lead smelter developments initiated at Mount Isa
	The Rosebery Mine closed on a care and maintenance basis
	ASARCO investment in Mount Isa Mines Ltd
1934	North Farrell Mine started operation
	A fourth electrolytic cell unit added to the Risdon plant to raise production
1936	The Rosebery Mine and new concentrator reopened and zinc roasting at Zeehan commenced
	New Broken Hill Consolidated (NBHC) floated
1937	Lake George Mines reopened
	Flotation of sulphides from leach residues at Risdon introduced
1940	Broken Hill South purchased the Central Mine at Broken Hill
1941	Third acid plant commissioned at Cockle Creek
1943	Skinner Hearth Roasters installed at Risdon
1947	Imperial Smelting constructed an experimental zinc – lead blast furnace at Avonmouth UK
1948	Zeehan roasters ceased operation
	The Hilton zinc-lead deposit discovered at Mount Isa
	Dugald River orebody delineated by Zinc Corporation
	Sulphide Corporation purchased by Zinc Corporation
	First contact acid plant at Risdon
1949	Zinc Corporation and Imperial Smelting Co. merged to form Consolidated Zinc Corporation
	First flash roasters installed at Risdon
1950	Conzinc constructed a pilot zinc blast furnace at Avonmouth, UK
	Conzinc plans to build a number of Imperial Smelting Furnaces
	Sulphide Corporation became a fully owned subsidiary of Conzinc
1952	New Broken Hill Consolidated (NBHC) commenced mining of the deep southern leases

1953 Copper concentrator and smelter completed at Mount Isa Zinc roasters closed at Cockle Creek Second Contact Acid plant at Risdon commenced operation 1955 The McArthur River deposit discovered in the Northern Territory Zinc roasting operations closed at Port Pirie 1956 Two additional flash roasters installed at Risdon Ammonium sulphate production facilities installed at Risdon EZ Industries floated to acquire The Electrolytic Zinc Company of Australasia Ltd 1958 No. 3 Contact Acid plant installed at Risdon 1960 Conzinc constructs a new ISF at Swansea Vale UK A fifth circulating electrolytic cell unit added to Risdon First electric induction cathode melting furnace at Risdon 1961 Conzinc commissioned a new ISF at Cockle Creek NSW 1962 Conzinc merged with Rio Tinto Ltd to form Conzinc Rio Tinto Australia Ltd (CRA) Lake George Mine at Captains flat finally closed 1966 New zinc-lead concentrator completed at Mount Isa Fourth Contact Acid plant installed at Risdon 1967 Beltana zinc mine discovered in SA by EZ Co Risdon solution purification converted from batch to continuous operation Slag fuming plant installed at Port Pirie to recover zinc oxide Electrolytic zinc plant installed at Port Pirie 1968 Thermal zinc refinery added at Cockle Creek 1969 The Lady Loretta mine discovered by Placer Prospecting Hilton Mine at Mount Isa commenced operation Installation of the first Fluid Bed Roaster at Risdon and closure of Hearth Roasters 1970 New highly automated cathode melting and casting plant commissioned at Risdon Cockle Creek fertiliser plant sold to Greenleaf Fertilizers Ltd

1971	Commissioning of the jarosite process for leach residue treatment at Risdon
	Closure of leach residue flotation at Risdon
	No. 6 electrolytic cell unit added at Risdon to raise capacity
	Australian Mining and Smelting Ltd formed to acquire CRA's interests in zinc and lead
1972	South Mine at Broken Hill closed, sold to Perilya Ltd and reopened
	ISF at Cockle Creek upgraded
1973	Thalanga mine discovered by Pennaroya Australia
	EZ Co discovered the Elura orebody north of Cobar NSW
	The UK joined the EEC shifting zinc markets from Europe to Asia
1974	North Farrell Mine in Tasmania closed
	Mining commenced on a campaign basis at the Beltana Mine
	Broken Hill South sold interests in Port Pirie smelter to AM&S
1975	Second fluid bed roaster at Risdon and closure of flash roasters
1978	Lennard Shelf orebodies discovered by BHP and Shell
	The Woodlawn Mine near Canberra opened
1980	Teutonic Bore mine WA commenced operation
	Automated electrode stripping introduced at Risdon
	New wharf and cranes installed at Risdon for both containers and bulk cargo handling
1981	Que River Mine, Tasmania commenced operation
	New acid plant at Risdon to replace two older units and match the large fluid bed roaster
1983	The Elura Mine commenced operation supplying Risdon with zinc concentrates
1984	Electrolytic Zinc Company became a subsidiary of North Broken Hill Ltd
1985	Woodcutters mine commenced operation
	Teutonic Bore mine closed
	Modernisation of Risdon leaching and purification sections commenced

Cockle Creek ISF converted to continuous tapping

1986The Hercules Mine in Tasmania closed

Risdon ammonium sulphate plant closed

- 1987 Hellyer Mine commenced operation
- 1988 CRA and North Broken Hill merged their zinc and lead businesses to form Pasminco Ltd

Cadjebut Mine in the Lennard Shelf commenced operation

- 1989 Thalanga Mine commenced operation Major improvement program at Cockle Creek
- 1990 The Century Zinc Mine discovered in NW Queensland by CRACannington mine discovered by BHP
- 1991 Que River Mine closed

Angas zinc-lead orebody discovered in SA by Aberfoyle Resources Ltd

New solution purification plant at Risdon commissioned

Gypsum removal added to the Risdon circuit

- 1992 The Benambra Mine opened by Denehurst Limited
- 1993 The North Mine at Broken Hill closed by Pasminco LtdNew acid plant at Risdon to replace the remaining two older units (3 and 4)Mt Isa Mines purchased the Avonmouth smelter from Pasminco
- 1994 Lennard Shelf operations purchased by Western Metals Ltd from BHP and Shell
- 1995 McArthur River mine commenced operation

Pasminco acquired full ownership of the Budelco smelter in Holland from Shell Minerals

- 1996 Benambra Mine closed
- 1997 Cannington mine commenced operation

Golden Grove mine in WA commenced operations

Cadjebut Mine closed but mill supplied from Kapok and Goongawa mines

Conversion of the Risdon leaching plant from jarosite to paragoethite

	Risdon ammonia plant closed
	Pasminco purchased the Century Mine from CRA
1998	Thalanga mine closes
	Pilara mine in the Lennard Shelf commenced operation
	The Woodlawn mine closed
	The second automatic stripping machine commissioned at Risdon
	Western Metals takeover of Aberfoyle Resources
1999	The Century Mine commenced operation
	Woodcutters mine in the NT closed
	Completion of construction of the Sun Metals electrolytic zinc plant at Townsville
	Pasminco acquired the Clarkesville zinc smelter in Tennessee by takeover of Savage Resources
2000	Hellyer Mine closed
	Mount Garnet mine opened by Kagara Zinc
2001	Expansion of the Townsville zinc plant
	Pasminco placed in administration
2002	Jaguar Mine WA commenced operation
	Pasminco sold remaining Broken Hill operations to Perilya ltd
	Pasminco declared bankrupt
2003	Mount Isa Mines purchased by Xstrata Limited
	Xtrata acquires full ownership of the McArthur River mine
	Lennard Shelf mines closed on a care and maintenance basis
	Elura Mine sold to CBH Resources – renamed the Endeavour Mine
	Cockle Creek ISF smelter closed
2004	Zinifex Ltd floated to operate remaining Pasminco assets
2007	CBH Resources commenced development of the Rasp Mine at Broken Hill but then suspended
	Zinifex sold all its smelting assets to Belgian company Nyrstar and retained the
	mines
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	Perilya reopened the Beltana Mine
2008	Angas mine in SA commenced operation
	Zinifex merged with Oxiana Ltd to form OZ Minerals Ltd
2009	Perilya Ltd under control of Shenzhen Zhongjin Nonferret Company
	OZ Minerals sold all its zinc and lead mines to China Minmetals Non Ferrous Company
	Western Metals placed in administration
2010	George Fisher Mine at Mount Isa commissioned
	CBH Resources taken over by Toho Zinc
2012	Mining commenced at the Lady Loretta mine feeding the Mount Isa concentrator
	CBH Resources commenced operation at the Rasp Mine at Broken Hill
2013	Xstrata merged with Glencore Limited to control Mount Isa operations
	Full takeover of Perilya by Shenzhen Zhongjin Nonferret Co
	Angas mine closed on a care and maintenance basis
2014	Closure of the Port Pirie electrolytic zinc plant by Nyrstar
2015	Development of the Dugald River mine commences
	Closure of the Century Mine