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Kalgoorlie as the Global Centre for Gold Metallurgical Innovation 1902–1907[1]

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ABSTRACT *Faced with the problem of how to process valuable refractory sulphide ore in the early 1900s, Kalgoorlie mining engineers and metallurgist, and their consultants, borrowed ideas from a variety of international sources to develop new equipment and new procedures. This paper examines the sources of these innovations and how they spread with remarkable speed through the medium of the tight-knit group of international metallurgical consultants. The inter-relationship between international technological transfer and increased local inventiveness, stimulated by the rapid changes in technology, and the opportunities and limitations experienced by Australian metallurgical inventers in the 1900s are also examined.*

Keywords: cyanide process, gold metallurgy, gold mining, metallurgical patenting, Kalgoorlie, Western Australia.

Introduction

In June 1895, within the area which was to become known as the Kalgoorlie Golden Mile,[2] a few small embryonic mines were being developed hidden among the eucalypt woodland covering the hills 12 kilometres south-east of the site of the discovery of the first gold in the district by Hannan and party two years earlier.[3] Only one mine, the Great Boulder, had done enough exploration to suggest that its ore extended to depth. Gold extraction rates were very poor because the oxidised ore, when crushed in stamp mills, readily formed slimes from which gold was difficult to separate by traditional amalgamation. Kalgoorlie itself was still an unsanitary village of tents and dust, while a site for Boulder, the future twin town to Kalgoorlie, had yet to be located.

During the boom in 'Westralian' mining shares on the London Stock Exchange from 1895 to 1897, virtually all the mining leases within the Golden Mile were acquired by London promoters and were transferred to newly launched companies, the shares of which were acquired by British speculative investors and also by a significant number from France, Belgium and Germany. In the five years to 1902, the companies with little or no reserves fell by the wayside and a group of

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about 10 potentially long term mines emerged, together with another half dozen or so that appeared potentially profitable. After 1897, five rival London-based speculative financiers vied for control of a number of the largest mines. Several mines ran across a number of small deposits of some of the richest ore ever mined in Australia. Mine managers came under pressure to mine the richer deposits selectively in order to manipulate their companies' share prices. The shipping of rich sulpho-telluride ore to smelters in the eastern colonies assisted this.

By 1900, the two most notorious financiers had been bankrupted, but all the mines on the Golden Mile were facing a new crisis. Their workings were passing into predominately sulphide ores which were not amenable to the cyanide process because of their telluride content but generally were not rich enough to justify smelting. This paper provides an overview of how the Kalgoorlie mining engineers and metallurgists and their British consultants overcame this problem by a mixture of technological transfer from a variety of sources and increased local inventiveness and adaptive skills.[4] The transformation was so remarkable that within five years Kalgoorlie was acknowledged as the leading centre for metallurgical innovation in the world.

Metallurgy on the Kalgoorlie goldfield developed differently from that in use on other major goldfields largely because of the peculiar characteristics of its environment and geology. Kalgoorlie was the first of the major goldfields to adopt the cyanide process from its earliest days. The rival process, chlorination, could not be used because of the large percentage of carbonates in the Kalgoorlie ore. The filter press, one of the most important innovations made in Kalgoorlie, was adopted in order to effectively cyanide the slimes portion of crusher tailings which often contained a disproportionately large percentage of the total gold in the tailings. Its introduction also had an important secondary benefit, which at the time was almost as important as its use for cyaniding slimes. This was the prevention of a major water supply crisis at the Kalgoorlie mines. In 1895, the small early stamp mills on the Golden Mile were using in the order of 2000 gallons of water for every ton of ore crushed. By contemporary international standards, this was a high usage, particularly in such an arid environment. It was necessary, however, because the talcy nature of the oxidised ore tended to clog up stampers unless washed through with a good flow of water. The main water sources, the seasonal lakes to the west and south of Boulder, and the shallow aquifers below them, had, by the end of 1896, already become badly depleted. With the introduction of the filter press it was possible to start recycling process water, and usage fell dramatically to about 500 gallons per ton in 1900.[5] By 1905, when all the major mines were using fresh 'scheme' water, pumped along the 530 kilometres long pipeline from Mundaring Weir in the hills east of Perth, the average water usage had fallen even further to between 200 and 300 gallons per ton.[6]

The Introduction of Filter Presses

There have been conflicting claims about the introduction of the filter press to Kalgoorlie. Herbert Hoover in his *Memoirs* claimed to have been responsible, while John W. Sutherland (metallurgist at Lake View Consols in 1897) was recognised by contemporary leaders of the industry in Kalgoorlie, such as Richard Hamilton and Frank Moss (managers of Great Boulder and Kalgurli Gold Mines) as having introduced the press.[7] As has occurred with the introduction of many new inventions, more people made significant contributions to the successful introduction of the filter press than have traditionally been given credit. The first use of a filter press in the processing of Kalgoorlie ore took place in late 1895 in Hamburg, after the British mining consultants, Bewick Moreing and Company, had commissioned a firm of German metallurgists, Pape, Henneberg and Company, to carry out experiments on ore from the Hannan's Brownhill mine.[8] The type of press used was almost certainly one commonly used in the German sugar beat industry and was made by R. & G. Dehne of Halle near Leipzig.[9] Although these early experiments were inconclusive, they were sufficiently encouraging for Bewick Moreing to commission an English company, S.H. Johnson and Company, to make a press, which was almost identical to the Dehne press, although smaller in size. It was this press which was the first one to be used in Kalgoorlie to treat slimes at the Hannan's Brownhill oxidised ore mill in about February 1897.[10]

Meanwhile, in January 1897, Peter McIntyre was reported to be assisting John Sutherland in the development of the Lake View Consols cyanide plant.[11] McIntyre was one of the original chemists employed by the Cassel Gold Extracting Company, the Glasgow company which held the patents for the cyanide process and was responsible for launching it on the major gold fields around the world. McIntyre was involved in the first commercial use of the cyanide process at Karangahake in the North Island of New Zealand in June 1889, where a filter press was used for the first time as part of the cyanide process, albeit without a great deal of success. He then became manager of the Australian Gold Recovery Company, the company set up by Cassel to market the cyanide process in Australia.[12] After limited success in the eastern colonies McIntyre transferred activities to Kalgoorlie some time in 1895. In February 1897, he resigned from the Australian Gold Recovery Company and took up the post of superintendent of the Lake View Consols cyanide plant.[13] Three weeks later came the announcement that filter presses were to be used in the treatment of tailings slimes at Lake View Consols and that one had been ordered from England. A Dehne filter press arrived in August, and on 26 August, the *Kalgoorlie Miner* announced that the Lake View Consols filter press was 'a complete success' and others had been ordered.[14] In late 1897 or early 1898, Dehne presses were also installed by the London and Hamburg Gold Recovery Company at the oxidised ore treatment plant which it had contracted to build at Hannan's Brownhill.[15]

Initially filter pressing was thought to be a high cost process only suitable for treating ores valued at more than one ounce per ton, but the operating costs at Kalgoorlie improved so dramatically in a very short time that by 1901 the filter press had been adopted around the world for the treatment of ores with a wide range of values. By 1906 it was even being used successfully on the Rand, where mining was characterised by low value ore, and high volume, low cost, production.

Smelting within Western Australia

The discovery of very rich pockets of sulpho-telluride ore in several mines on the Golden Mile in 1897 led to large shipments of ore and concentrates being sent to the eastern Australian colonies for smelting, which over the next four years produced over half a million ounces of gold. Two smelters were also built in Western Australia to avoid the costly shipments to the east. One was a small unit at the Golden Horse-shoe mine in Kalgoorlie. The other, a much larger works on the coast just south of Fremantle, was intended to custom smelt ore from a number of mines on the Golden Mile. Both were closely associated with John Sutherland, who had by then become manager of the Golden Horse-shoe mine, and with George Klug, the mine's metallurgist, both of whom had had experience of smelting at Broken Hill. The two smelters operated on different principles but the design of the main units of each closely followed one of the two types of copper smelter that had been developed in the USA during the 1890s.[16] This illustrates the remarkable speed with which new technologies were adopted for the processing of Kalgoorlie ore.

The first stage of the small smelter at the Golden Horse-shoe, the only one ever built for ore processing in Kalgoorlie, was a small water-jacketed blast furnace similar to ones then in use in Colorado copper smelters.[17] The much larger smelter built by Klug at Fremantle (the second on the site) consisted of several parallel units each consisting of a straight line roasting furnace, similar to the ones used in Kalgoorlie, followed by a Bessemer-style converter.[18] The smelter is believed to have been one of the first on the Australian mainland to have used this type of converter, and was probably one of the few of this type to have been used for smelting gold ore and concentrates.

The Sulpho-telluride Challenge

The high cost of smelting ruled out its use for all but the richest ores. The biggest challenge faced by Kalgoorlie metallurgists and engineers and their companies' consultants was how to devise an economical method of treating the lower grade Golden Mile sulpho-telluride ores. The ways in which they approached the problem were strongly influenced by their previous experience on other goldfields. There were two main options, roasting before cyanide treatment and the use of additional chemicals in conjunction with cyanide. Roasting was preferred by the majority of Kalgoorlie managers and metallurgists. Those from Victoria were familiar with the Victorian tradition of calcining refractory ore. Those from Broken Hill had been associated with smelting and heat treatment, while the handful of American managers in Kalgoorlie would have known of the roasting of telluride ore at Cripple Creek, Colorado, the only other important goldfield mining telluride ores.

However, in the early days in Kalgoorlie, before 1900, most of the decisions on processing methods and equipment were made in London, where directors were more familiar with American furnace technology than with Victorian practice. Consequently, all but one of the roasters built in Kalgoorlie before 1900 were American straight-line reverberatory furnaces.[19] On the other hand, British consultants, after nearly 10 years' experience of the cyanide process, and with limited experience of high temperature metallurgy, were more enthusiastic about a chemical solution. In the end, the only mines to adopt the chemical option were those advised by the two British consultants most active in Kalgoorlie, Bewick Moreing & Company and James Bros.

The first roaster to operate with any degree of success on the Golden Mile was a new type of tower roaster, which was built in the summer of 1898–99 at the Great Boulder mine. It came as part of a completely new process which the London directors of Great Boulder had negotiated with its American inventor, William A. Koneman. The company had agreed to adopt the process, provided the process as a whole proved successful. The general principles of the process followed the conventional roasting option, but what was unusual about the Koneman process was that every stage in the process required the use of new types of machinery to novel designs.[20] Richard Hamilton, the Great Boulder manager, and Koneman and his contractors, struggled against time to overcome the teething problems of the units. Firstly the tower furnace, and then, one by one, the other new units were commissioned, until only the pressurised filtration tank remained. Eventually Hamilton had to telegraph his directors that there was no prospect of the filtration tank operating successfully and that the whole process would therefore have to be abandoned.

Failure of the radical Koneman process came as a salutary lesson to all managers and directors of Kalgoorlie mines. Great Boulder's shares recovered from their post-Koneman crash but no other company on the Golden Mile could afford to risk a similar situation. In the next 10 years more technological innovations were developed in Kalgoorlie than on any other contemporary goldfield, but, with the sole exception of Ridgway's vacuum filter, none was a radical new invention. Rather they were ones which were ingeniously adapted from other industries, or ones already in use in the mining industry which were improved to the extent that the originals were almost forgotten.

The Koneman failure strengthened the hand not only of Hamilton but also of other experienced Kalgoorlie managers. Hamilton became master of his own ship and was able to proceed with trial roastings of Great Boulder ore by the Edwards roaster at the manufacturer's works in Victoria. The great advantage which the Victorian roaster manufacturers (both Edwards and his main rival, Merton) had over their American competitors was that trial roastings of the ore to be treated could be carried out by them at their works in Victoria, and any necessary changes made to the roasters before purchase. By contrast the American furnaces arrived untested, and adaptations, which usually were required, had to be done at the mine.

The Dry Crush and Roast Process

The first process to successfully treat Golden Mile sulphide ore was a roasting process, commonly known as the dry crush and roast process. It was built in 1900 at Great Boulder Main Reef, a small mine at the southern end of the Golden Mile.[21] By coincidence the first mine to build a successful sulphide plant using the chemical processing option, Hannan's Star, was a neighbour of Great Boulder Main Reef.[22] Although they both shared the distinction of being pioneers of successful new processes, both companies also made the same fundamental error of building treatment plants before they had determined whether their mines had sufficient ore reserves to keep their plants operational. Neither had, and both mines had limited lives as independent companies.

The effectiveness of roasting was the most critical factor in obtaining good extraction rates in the dry crush and roast process. Consequently roasters were changed and altered more often than any other type of processing equipment used in Kalgoorlie. No less than 14 different models were tried until a consensus was reached that the Edwards Duplex furnace was the most suitable.[23]

The roasting of sulphide ores resulted in very high levels of sulphur gas pollution in urban areas near the Golden Mile. The author has calculated that, when roasting activity was at its pre-1915 peak (in 1912–13), for a large part of the year, ground level concentrations of pollutants in Boulder and in Trafalgar (one of the small towns on the eastern side of the Golden Mile) would have been close to the highest levels ever recorded in Australia.[24] The important implications of this level of pollution on the incidence of miners' lung diseases in Kalgoorlie has not previously been appreciated. Seen in conjunction with the high level of very fine particulate pollution caused by fine dust blown off the large heaps of dried out slime residues, and particulate emissions from wood burning boilers and roasters, the gaseous pollution levels represent some of the worst possible conditions for increasing the susceptibility to respiratory diseases of residents of the towns around the Golden Mile, and of Boulder in particular.[25] Exposure to these levels during boyhood would have greatly increased the chances of young men developing pneumoconiosis when they went to work in the mines, and of its accelerated development into pneumonia and tuberculosis, from which the majority of Kalgoorlie miners with pneumoconiosis died in the 1900s.

The early dry crushing sulphide ore processing plants on the Golden Mile were built with a lamentable disregard for dust control, and were very unhealthy places in which to work.[26] Effective dust control was well within the capacity of contemporary technology. Its omission might have been explained in terms of the inexperience of the plants' designers, were it not for the excessively long time that a number of the mines took to rectify matters.

As the first successful method of treating Kalgoorlie's sulpho-telluride ore, the dry crush and roast process holds an important place in the history of Australian gold metallurgy. Its importance in world metallurgy is just as significant, because it introduced a new method of treating types of ore which, when crushed, readily formed slimes. For several years, this method, consisting of fine grinding to slimes and filtration, was known as the 'Australian method', but the method was so quickly incorporated into the mainstream of gold metallurgy around the world that the term 'Australian' was soon forgotten. The new method was reinforced by the development of the second process for treating sulpho-tellurides in Kalgoorlie, the chemical or 'bromocyanide process', commonly called the 'Diehl' process, which also relied on the sliming of all pulped ore that could not be concentrated.

The Diehl Process

The Diehl process had its origins in the Sulman Teed bromocyanide process, invented by British chemists in 1894.[27] However, it was the German metallurgists of the London and Hamburg Gold Recovery Company who developed the process into a viable method of treating Kalgoorlie sulpho-telluride ores.[28] The main advantages of the Diehl process were that it was an extension of standard stamp mill practice, and that it did not require all treatable ore to be roasted. Its key stages were fine crushing and concentration. For the former, a new form of crusher, the tube mill,[29] was introduced. For that reason alone the Diehl process has an important place in metallurgical history, as the tube mill was the most enduring of all Kalgoorlie innovations and has a key role in the evolution of modern mineral processing.

The first full-scale trial of the Diehl process was carried out at the Lake View Consols mine in December 1899 and January 1900.[30] News of its success was received with great acclaim in Kalgoorlie because it occurred during a period of crisis in the Kalgoorlie mines, and appeared to show the way to better times ahead. Its success also initiated a significant international debate in the authoritative British and American mining journals on the merits of the two sulphide treatment processes, during which Kalgoorlie first became known as a centre for technical innovation, rather than as a destination for speculative investment.

Despite the technical success of the Diehl process, and its similar cost to the dry process, the Diehl process was adopted by only three Kalgoorlie mines, although two others later chose to treat their tailings with bromocyanide.[31] The majority of mines chose the dry crush and roast process instead. The reasons were, firstly, that by the time the Diehl process was first demonstrated a number of mines had already become committed to the dry crush and roast process, and had ordered machinery for it. Secondly, there was strong opposition within the industry to the payment of royalties on cyanide or bromocyanide,[32] and thirdly, some mines preferred to continue with standard cyanide practice and to add bromocyanide only when it proved necessary.

Probably the most important outcome of the Diehl process was the competition that it initiated between the two processes into ways of reducing treatment costs. Bewick Moreing under Herbert Hoover, one of the main proponents of the Diehl process, was the first organisation to actively promote cost-consciousness in Western Australia.[33] In 1902, it began to use regular reports on the working costs (the cost per ton of mining, raising and treating ore) of the mines it managed, as a means of promoting the company's management expertise. The independent mines were forced to follow suit and commentators in the international mining journals made regular reports on the comparative costs of the different treatment plants on the Golden Mile, and also how they compared with costs on other goldfields. By 1905, average Kalgoorlie unit treatment costs had been halved in less than four years and were comparable with those on other major fields with ores of similar complexity, despite Kalgoorlie's environmental disadvantages.[34]

The variety of sources from which the key elements of the two sulphide treatment processes were derived illustrate the multi-national and innovative nature of the contributions to Kalgoorlie metallurgy between 1898 and 1902. The tube mill was the main German contribution, the Wilfley concentration table the USA's, the Edwards and Merton roasting furnaces Victoria's and the use of bromocyanide Britain's. All except the Wilfley table were either used for the first time in Kalgoorlie, or achieved their first major processing success there.[35] Kalgoorlie's main contribution was the introduction of the 'Australian method' of fine crushing, sliming and filtration, and also a second important procedural innovation, in which very dilute cyanide solutions were circulated as process water throughout the plant. In addition to these, the success of the sulphide plants was based on a remarkable number of rapidly implemented incremental technological improvements. The reduction in treatment plant costs, which was the consequence of these improvements, led to Kalgoorlie being recognised as the leading centre for innovative gold metallurgy for a period of about two years from 1905 to 1907.[36] The men responsible were the Kalgoorlie managers, metallurgists and engineers, about 70% of whom were Australian, 20% American and 10% British.[37]

Vacuum Filtration in Kalgoorlie

As Kalgoorlie's all sliming techniques were more widely adopted on other goldfields outside Australia, so cheaper means of filtration than filter pressing were eagerly sought. Although filter pressing costs on the Golden Mile had fallen by a larger percentage than other treatment costs, it was still a very labour intensive operation with around a quarter of all surface workers engaged in operating filter presses.[38] By 1906 it had become clear that vacuum filtration, a new form of filtration being developed in the USA, was likely to prove considerably cheaper than filter pressing. The large Kalgoorlie mines were placed in a quandary as they had accumulated considerable expertise in filter press operation and were expanding the size of their treatment plants to obtain further economies of scale. To change to vacuum filtration would have involved considerable additional experimentation and reorganisation of their expansion plans. The majority took the conservative option and retained filter presses. Only one mine, Great Boulder, replaced the bulk of its filter presses with vacuum filters. For its manager, Richard Hamilton, the replacement decision was made easier by the invention at Great Boulder of a most remarkable machine, the Ridgway vacuum filter, which had been made by the mine's chief engineer, George Ridgway. It was the only continuous flow, high volume, automatically operated, vacuum filter system in use in the 1900s.[39] It was different in form and construction to other vacuum filters and had a sophisticated yet basically simple control system. Moreover it had a low operating cost and a very high extraction rate and unlike the American vacuum filters did not require full-time attendance and manual control. Unlike the other significant Kalgoorlie innovations, such as the filter press and tube mill, the Ridgway vacuum filter was not the result of intelligent adaptation of machinery from other industries, but was designed specifically for the task in hand. After a lengthy trial of the prototype, Hamilton installed, in 1907, 10 Ridgway filters with the capacity to process all the slimes produced by the mine's sulphide mill.[40]

Few metallurgical innovations in the previous 20 years had been received with such international enthusiasm as the Ridgway filter. Its use spread remarkably quickly and, by the end of 1907, it was already operating in new plants in such geographically diverse fields as Mexico and Korea.[41] Within two years, however, the initial enthusiasm had waned, and many of the units had been replaced by more conventional machines. The Ridgway filter was sold 'off the shelf' from a British manufacturer and was too advanced in its concept for general use around the world without specialised advise being provided to its users, and the adjustment of its controls to suit the particular composition of the slimes being treated. A successful invention in the mining industry had to be far enough ahead of standard practice for it to be difficult to copy, but not so far ahead that it could not be operated successfully by experienced workers at remote mines. The Ridgway vacuum filter failed on the second count.

Vacuum filters were also adopted in Kalgoorlie by two of the mines managed by Bewick Moreing, Lake View Consols and Oroya Brownhill, for the retreatment of slime residues which could not be treated at a profit using filter presses.[42] The system adopted was based on the American Cassel stationary basket vacuum filter, but new standard methods were worked out to solve two of the major problems associated with the Cassel system. Later when Bewick Moreing opened new mines in Western Australia, in the East Murchison and Yilgarn Goldfields, the vacuum filters developed in Kalgoorlie were used at those mines, instead of filter presses, for directly processing slimes from pulped ore.[43] However the company elected to retain filter presses in its main Kalgoorlie treatment plants despite its vacuum filters being considerably cheaper to operate. The decision of the Kalgoorlie mines to retain filter presses was the first sign that the impetus for innovation on the Golden Mile was running out and that the philosophy of 'if there is a cheaper way do it' was no longer paramount.

The internationalisation of the gold mining industry reached its peak in the 10 years before the 1914–18 war. In those years all the leading metallurgists and plant designers were known to each other and the leading American and British mining magazines reported in detail on every major new mine and processing plant around the globe. Kalgoorlie gained very little from this new internationalism except to obtain publicity for its new equipment and processes and to have its position as world leader in innovative gold metallurgy acknowledged for the short period from 1905 to 1907. Its 'Australian' method of fine crushing and filtration was taken up by the designers of new treatment plants in Mexico and the USA, who improved upon them, and by 1908, Mexico had taken over the leadership mantle for innovative metallurgy from Kalgoorlie.[44]

Metallurgical Patenting in Western Australia

The large number of rapidly implemented incremental improvements in gold processing made in Kalgoorlie in the 1900s was reflected in a marked increase in the number of patented mining and metallurgical inventions made on the Western Australian goldfields, which peaked in the years 1904–06. This author examined the Western Australian patentees of mining and metallurgical inventions in the 1900s and their success in exploiting their inventions.

Previous work on Australian patent data has underestimated the influence of technology transferred from overseas because the analysis was done in terms of patent applications rather than sealed patents.[45] Most patent applications from abroad were accompanied by complete specifications and were granted full patents, but the majority of applications from Australian residents contained only provisional specifications and received only provisional patents. A large number of these provisional patents were never sealed, to the extent that only half of the applications from Australian residents eventually received full patents. Australia's degree of dependence on imported technology as measured by overseas-sourced completed patents, for the years between 1895 and 1915, was between 15 and 18% higher than when measured in terms of patent applications. The average degree of dependency in terms of sealed patents was 46%, whereas the average figure in terms of patent applications was 30%. This is a most significant difference.[46] If the degree of dependency is measured in terms of patent applications rather than completed patents, an exaggerated view of Australia's technological self sufficiency is obtained.

Comparing the origins of non-Australian sourced mining and metallurgical patents in the years 1897–98 and 1905, showed that Britain and the USA were the dominant origins in both years but, whereas Britain led the USA in 1897–98, the opposite occurred in 1905, the USA percentage having risen by 21% and the British having fallen by 10%. The increase in American patenting was, however, not complemented by an increase in the adoption of American metallurgical techniques and equipment in Kalgoorlie, as in both years British inventions were more prominent among metallurgical patents and American ones among mining patents. The main exception was the American Wilfley table, several different forms of which were developed in the wet sulphide plants.

An analysis of the 56 applications for Commonwealth patenting of mining and metallurgical inventions made by Western Australian residents during 1904 and 1905 emphasised the self-contained nature of the industry. All but five of the 56 applications came from Western Australian mining centres. Seventy-five percent of applications were made by mining professionals and all but one of the remainder were made by miners and skilled workers associated with the industry. Half were submitted through Kalgoorlie's only patent attorney, W.G. Manners.[47]

Metallurgical patenting, coming almost entirely from within the industry, was very much demand driven. In a time of rapid change inventors were more inclined to patent their ideas for solving problems in the industry because they knew that their ideas were more likely to be taken up then than in times when there was less incentive for change. Even then, the success rate for patentees was still very low. Of the 56 patents applied for in 1904–05, only 22 were sealed. Of these, three were manufactured under licence in Britain, and five others are known to have been used at the mines where their inventors were employed, and in some cases, also at other mines on the Golden Mile. Some of the patentees who worked in other mining centres may also have had their inventions used locally but no records of these exist. The majority of patentees would have gained nothing from their inventions. No doubt, they would have been aware of the odds against success before making their applications. Few would have been dissuaded by the odds.

Inventors in the Australian mining industry in the mid-1900s were at a disadvantage because of the limited and diminishing Australian market for mining equipment, which meant that local manufacture of their inventions was unlikely. Undoubtedly good luck and favourable publicity, such as Ridgway received, played an important part in the initial overseas adoption of patented inventions. However, for an invention to be developed into a viable industrial product, its markets had to be serviced by a permanent organisation with expertise in a range of similar products, particularly where the product was too complicated to be sold as an off the shelf item.

The Decline of Innovation

By 1910 parts of the processing plants of most of the 10 major mines on the Golden Mile needed upgrading or replacement. More economical types of equipment were required to place the mines on a sound long term basis by further reducing treatment costs to counter increased costs due to deeper working and lower grades. These improvements could have been financed through profits as the capital costs of treatment plant equipment generally made up a comparatively minor percentage of the budget of a hard rock mine. However, no further significant plant upgradings took place in Kalgoorlie during the decade after 1912. This was because of the pessimistic views which London boards had of the future of gold mining as a whole and in Kalgoorlie in particular. In a 1910 geological report, the future lifespan of the Golden Mile mines was considered 'distinctly gloomy', especially for the eastern group of mines where some lodes had already run into non-payable areas.[48] The future of mines in the western group, centred on Great Boulder at Fimiston, was far more optimistic, but the three largest each had short term difficulties. The retention in Kalgoorlie of talented metallurgists and engineers capable of continuing metallurgical improvements became more difficult as the challenges of new fields in Rhodesia, West Africa and Mexico appeared more interesting then routine work in Kalgoorlie. Moreover, as most companies only operated one mine, they were able to offer few internal promotional prospects. Bewick Moreing & Co. was the one non-government organisation which could offer career paths for young mining professionals, and, as the number of operational mines in Western Australia continued to diminish, the company was able to attract a number of the most able practitioners. From its newer mines in the northern and western goldfields between 1910 and 1917 came a series of locally initiated metallurgical innovations which contrasted with the company's more conservative approach at its Kalgoorlie mines. Because these innovations took place in wartime at mines which did not have extended life-spans, they received little publicity and, because the company did not obtain further management contracts, it was not able to maintain the development of these innovations in new treatment plants.

The history of Kalgoorlie metallurgy before the First World War reflects the difficulties of developing on a rational basis foreign-owned mines that were acquired largely for speculative purposes. Mine managers found that their directors' requirements to maintain high profitability and share levels on the market did not always coincide with the longer term interests of the mines' development. When profit levels were high the need to continue the continuity of plant improvements so that inevitable rises in mining costs in the future could be offset by reduced treatment costs was seldom appreciated. In such circumstances it was inevitable that Kalgoorlie's technological lead in gold metallurgy should pass to others. When profitability in gold mining began to diminish on a world wide basis due to rising costs and a fixed price product, the 'gentlemanly capitalists' in the City of London found it more attractive to focus their attention on more profitable enterprises elsewhere, rather than make the effort to restructure the Kalgoorlie mines on a more rational basis, which would have enabled better use to be made of their remaining resources and would have further extended their working lives.

Notes and References

1. This paper is based on the last chapter of the author's 1998 Murdoch University PhD thesis, 'A History of Technological Change in Kalgoorlie Gold Metallurgy 1895–1915'.
2. Under a long standing convention of the Department of Minerals & Energy, the mines on the Golden Mile are located in the Mining Centre of Boulder, in the East Coolgardie District of the East Coolgardie Goldfield. The Golden Mile is also much closer to Boulder than Kalgoorlie. It would be logical to call the mines on the Golden Mile the Boulder mines, or even the Kalgoorlie-Boulder mines. However, the mines are known nationally and internationally as the Kalgoorlie mines, and this usage has been followed in this paper.
3. Original (imperial) units have been used in this paper except for distances greater than one mile which are given in kilometres. Ore is measured in long tons (1 long ton = 2240 pounds) although some companies used the short ton (2000 pounds). Gold is measured in troy weight (1 ounce troy = 31.1034 grams) and quantities are in terms of fine (pure) gold, although before 1903 the Department of Mines measured it in terms of bullion (fine gold plus silver which was not usually separated from gold at the mines). Water is measured in imperial gallons (4.546 litres).
4. The author's PhD thesis provides, for the first time, a detailed guide for the non-specialist historian through the complexities of the pre-1915 metallurgical revolution in Kalgoorlie.
5. A. G. Charleton, *Gold Mining and Milling in Western Australia*, London, 1903. The 1896 water usage is from the 1898 usage of a small mill at the North Boulder mine which was very similar to the early mills and for which Charleton was consultant (pp. 220, 232). The 1900 usage is from pp. 131, 133.
6. R. Allen, 'Ore reduction plant and process of reduction on the Lake View Consols Gold Mine', *Monthly Journal of the Chamber of Mines of Western Australia* (hereafter *MJCMWA*), 31 July 1906, pp. 270–71; R. Allen, 'Ore reduction plant and process of reduction on the Oroya-Brownhill Gold Mines', *MJCMWA*, 31 August 1905, pp. 635–36.
7. H. C. Hoover, *The Memoirs of Herbert Hoover: Years of Adventure 1874–1920*, New York, 1952, p. 31; R. Hamilton, 'Progress of mining in Western Australia', *Transactions of the Australasian Institute of Mining Engineers* (hereafter *TAusIME*), 13, 1909, p. 22; F. A. Moss, 'The treatment of auriferous sulphide ores of Kalgoorlie', *TAusIME*, 8–1, 1901, pp. 52–53. See also G.

Blainey, 'Herbert Hoover's forgotten years', *Business Archives and History*, 3–1, February 1973, p. 58; and G. H. Nash, *The Life of Herbert Hoover, The Engineer 1874–1914*, New York, 1983, p. 84, note 101.

8. A. E. Morgans, 'Report on the Hannan's Brownhill reduction machinery and extraction plant, with some notes on the mine', Western Australian Department of Minerals & Energy, Surveys and Mapping Division, Bewick Moreing File 125, pp. 32–33. Morgans claims to have suggested using the filter press in Hamburg and to have supervised the earlier tests carried out there.
9. Manufacturer's name and address are in Richard Hamilton's letter book, LB 1, p. 165. Hamilton's letter books are held by the Hamilton family to whom the author is grateful for allowing him access to them.
10. W. McNeill, 'Filter-press treatment of gold ore slimes (Hannan's, West Australia)', *Transactions of the Institution of Mining and Metallurgy* (hereafter *TIMM*), 6, 1897–98, pp. 249–52; H. E. West, 'Early days at Kalgoorlie', *Mining Magazine*, August 1912, pp. 135–36. Hoover arrived in Kalgoorlie in May 1897 and reported working at Hannan's Brownhill before starting work as an inspection engineer. He may have worked on the Johnson filter press, but was certainly not responsible for its introduction.
11. *Western Argus*, 21 January 1897.
12. Alan L. Lougheed, 'The discovery, development, and diffusion of new technology: the cyanide process for the extraction of gold, 1887–1914', *Prometheus*, 7, 1, June 1989, pp. 61–74; Jan Todd, *Colonial Technology: Science and the Transfer of Innovation to Australia*, Melbourne, 1995, pp. 109–84. For an overview of Cassel's worldwide promotion of cyanidation, see the author's thesis Chapter 1, III.
13. *Mining Journal & Investors' Review*, 6 February 1897, p. 6.
14. The 50 chamber Dehne press became the standard filter press used on the Golden Mile by all but one or two mines (including Ivanhoe Gold Corp.). For several years the Dehne press was manufactured under licence in London by C. Harzer & Co. In about 1902, Dehne presses began to be made by Martin & Co. of Gawler, South Australia, which was then probably the largest manufacturer of mining equipment in Australia.
15. West, *op. cit.*, p. 136. The German metallurgists at London & Hamburg GRC had previously worked for the Hamburg company Pape, Henneberg & Co.
16. For a contemporary history of the development of copper smelters (the type used for gold smelting in the 1890s) see W. Gowland (Professor of Metallurgy, Royal School of Mines), Presidential Address, *TIMM*, 16, 1906–07, pp. 265–95.
17. R. Allen, 'Reduction plants and processes', Department of Mines of Western Australia 1902 Annual Report, pp. 163–65; Charleton, *op. cit.*, pp. 404–5.
18. Report of the Royal Commission on the Ventilation and Sanitation of Mines, *Votes and Proceedings of the Parliament of Western Australia*, 1, A6, 1905, pp. 42–43.
19. A reverberatory furnace, the type used for roasting ore in Kalgoorlie, was one in which the charge and fuel were not mixed. The furnace roof was heated by flames drawn through the furnace, and the heat was radiated down onto the charge from the roof.
20. Summarised details of the Koneman process are contained in Hartley, PhD thesis, Chapter 4, II, 'The Koneman Process'. These are taken from the Richard Hamilton letter books LB 1 and LB 2.
21. Charleton, *op. cit.*, pp. 324–32; Allen, 1902, *op. cit.*, p. 165; J. T. Marriner, 'Roasting and filter-press', *Engineering and Mining Journal* (hereafter *E&MJ*), 5 September 1903, pp. 352–53; A. James, *Cyanide Practice*, third edition, London, 1902, pp. 94–97, 163–64.
22. Hannan's Star Gold Mines, 1901 Annual Report; H. Knutsen, 'The "Diehl" process', *TIMM*, 12, 1902–03, pp. 2–36; Charleton, *op. cit.*, pp. 69–76; D. Clark, *Australian Mining and Metallurgy*, Melbourne, 1904, pp. 65–69. The plant commenced operation on 15 March 1900 but due to teething problems was not handed over to Hannan's Star until 24 June.
23. The 14 types were: Lake View pilot plant, Associated pilot plant, Koneman tower, Brown (Lake View), Brown (S. Kalgurli), Richard tower, Ivanhoe tower, Ropp, Holthoff-Wethey, Edwards, Merton, Edwards duplex, Perseverance duplex, and Associated.

24. Hartley, PhD thesis, Chapter 4, V, 'Health Issues'. Standard air pollution meteorology quantitative methods were used to calculate pollutant ground level concentrations from point sources using 1913 emission quantities and composition, prevailing daily meteorological conditions throughout the year, locations of 10 roasters and stack heights, and terrain variations. The highest levels calculated in residential areas were 2600 and 2700 μg per cubic metre, compared with the 2900, the worst recorded in Australia (Port Kembla copper smelter 1973). Earlier copper smelters, such as those at Queenstown, Tasmania, probably produced far higher levels.
25. For an explanation of the risks associated with a combination of sulphur gas pollution and fine particulate pollution see World Health Organisation, *Sulphur Dioxide and Suspended Particulate Matter : Environmental Health Criteria 8*, Geneva, 1979, pp. 59–61.
26. Gordon Young, who worked briefly in the South Kalgurli dry treatment plant in 1901 recalled that: 'In every part of the huge mill building the air was heavily charged with fine white dust. It was like being in a dense fog. "Abandon health all ye who enter here" might have been written over the doorways'. (*Under the Coolibah Tree*, London, 1953, p. 178.)
27. H. L. Sulman, 'Improvements in gold extraction', *TIMM*, 3, 1894–95, p. 202.
28. Knutsen, *op. cit.*, pp. 4–5.
29. Also known as a grit mill or flint mill.
30. *Kalgoorlie Miner*, 19 January 1900, p. 3; G. Blainey (*The Rush that Never Ended*, third edition, Melbourne, 1978, p. 201) mistakes the official opening, on 14 January 1899, of the Hannan's Brownhill oxide ore treatment plant, which was also built by London and Hamburg GRC, for the launching of the Diehl process.
31. The three mines which adopted the Diehl process were Hannan's Star (1900), Lake View Consols (1900) and Hannan's Brownhill (1901), while Ivanhoe Gold Corporation (1903)and Golden Horse-shoe Estates (1908) treated their slimes with bromocyanide.
32. For details of the action taken in Western Australia by the mining industry to oppose the payment of royalties on the cyanide process see: N. Segal, 'The intervention that wasn't: a new look at the McArthur-Forrest cyanide patent conflict in Western Australia', *Prometheus*, 18, 2, 2000, pp. 175–96.
33. R. Hartley, 'Bewick Moreing in Western Australian gold mining 1897–1904: management policies and goldfields responses', *Labour History*, 65, November 1993, pp. 1–18.
34. Compare costs in Knutsen, *op. cit.*, pp. 20–23 and in Moss, *op. cit.*, pp. 59–64, with those in Alfred James, 'Progress in gold-ore treatment during 1906', *E&MJ*, 5 January 1907, p. 20.
35. Evidence suggests that new models of the Wilfley table were introduced in 1903–08 largely in response to problems of concentration at the Ivanhoe and Golden Horse-shoe mines. See R. Allen, 'Gold reduction plant and processes on Golden Horseshoe gold mine', *MJCMWA*, 31 August 1905b, pp. 322–33, and R. Allen, 'Ore reduction and process of reduction on the Ivanhoe gold mine', *MJCMWA*, 31 July 1905c, pp. 294–306.
36. James, 1907, *op. cit.*, p. 17.
37. Based on data in manuscript: D. A. Cumming and R. G. Hartley (comps), *Biographical Register of Mining Engineers, Mine Managers and Metallurgists in Western Australia 1890–1930* (in preparation).
38. At Great Boulder, for example, in 1906, 27 out of a total of 95 adult surface workers were filter press operators (R. Allen, 'Reduction plant and processes on the Great Boulder mine', *MJCMWA*, 5, 1906b, p. 133).
39. James, 1907, *op. cit.*, p. 19; Great Boulder Pty, 'Description of the Ridgway Atmospheric Slimes Filter', *MJCMWA*, 5, 1906, pp. 463–67.
40. A. James, 'Progress in gold-ore treatment during 1907', *E&MJ*, 4 January 1908, p. 17.
41. By mid-1908 at least four mines in Mexico operated Ridgway filters. See: C. T. Rice, 'Veta Colorado cyanide mill, Parral, Mexico', *E&MJ*, 18 July 1908, pp. 120–22.
42. T. B. Stevens and W. R. Degenhardt, 'The vacuum filter press in Western Australia', *MJCMWA*, 10, 1911, pp. 12–23; T. B. Stevens and W. R. Degenhardt, 'Description of the re-treatment plant and process of the Oroya Brownhill Co.', *MJCMWA*, 10, 1911, pp. 60–68.

43. These mines being the Mountain Queen at Marvel Loch (Yilgarn GF) and Yuanmi Gold Mines at Youanmi (East Murchison GF).
44. Alfred James, 'Progress in cyanidation', in H. Foster Bain (ed.), *More Recent Cyanide Practice*, San Francisco, 1910, pp. 233–36 (first published in *Mining & Scientific Press*, 2 January 1909).
45. In particular; I. Inkster, 'Intellectual dependency and the sources of invention', *History of Technology*, 12, 1990, pp. 40–64.
46. Hartley, PhD thesis, Chapter 7, II, Figure 7.1.
47. The Patent Register of W. G. Manners for the period 1901–22 is held by the Manners family. The author would like to thank Mr Ron Manners for allowing him access to the Register which lists patents applied for by Manners to the patent offices of the Australian colonies, the Commonwealth, Great Britain, Transvaal, Mexico, New Zealand and several other countries.
48. Department of Minerals and Energy, Western Australia, Surveys and Mapping Division, Bewick Moreing Collection, BM 72, M. Maclaren, 'Preliminary notes on the geology and lodes of the Kalgoorlie field', draft of the confidential version of the report, addressed to companies financing Maclaren's geological study, June 1910, last chapter 'The Future of the Field', pp. 35–39. The study was arranged by H. C. Hoover who had intended that it be financed by all the leading Kalgoorlie mines. In the end the full cost was born by companies with which Hoover was associated, Ivanhoe Gold Corp., Oroya Brownhill and Lake View Consols.