The Development of Mining Technology in Australia

1801 - 1945

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Submitted in total fulfilment of the requirements of the degree of Doctor of Philosophy.

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Department of History

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Declaration

This is to certify that

(1) the thesis comprises only my original work towards the PhD.

(2) due acknowledgement has been made in the text to all other material used.

(3) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.
Abstract

From a small beginning at Newcastle in 1801 when convicts began mining coal exposed on the banks of the Hunter River, the mining industry has grown to be a large sector of the Australian economy, providing an export income of A$58 billion in 2004 (almost forty percent of total exports) as well as providing the raw materials for local industries. The changing technologies used to develop this industry are an important part of our development as a nation, but few historians have written about them. This thesis offers an interpretive framework for visualising the mining industry as an historically coherent entity and for understanding the technological innovations in mining over 200 years. It focuses on the period to 1945.

In the first fifty years coal and copper were mined in New South Wales and silver lead and copper in South Australia. Machines were introduced in the 1830s when a British joint stock company took over the coal mine and the use of machines increased in the 1840s when companies financed locally or from Britain began developing silver lead and copper mines. Technologies already developed in the north of England, Scotland, Germany, Cornwall, and Wales were imported and miners from England, Scotland, Germany and Cornwall and smeltermen from Wales migrated to Australia. British mining law was followed without question.

This situation was revolutionised when Edward Hargraves, and his partners, found alluvial gold in commercial amounts at Ophir, 150 kilometres west of Sydney, in 1851. Hargraves had experience in alluvial mining in California and he embarked on a skilful publicity campaign to start a rush on the Californian pattern. His aim was to claim a reward from the government in return for boosting the economy and preventing the resumption of transportation of convicts to New South Wales. In terms of modern management theory his place in history is not the charlatan and fraud that some historians have suggested but an entrepreneur who changed the course of mining in Australia. Unwittingly or not he forced a change from a semi-feudal British legal system dominated by large companies, and enabled the emergence of a more democratic system which permitted both individual and company mining. In the confusion of the first rushes the government allowed the individual miner to peg a small claim on which he
could dig for gold on payment of a licence fee. This small change led to many innovations in mining law and mining technology Australia.

Following the ideas of Joel Mokyr and Roger Burt these innovations are assessed as micro-innovations (successive small changes) or as macro-innovations (radical new concepts without clear precedents); but I extend the latter concept to include several important micro-innovations that combined into what amounts to a singular new concept. Early macro-innovations were wet deep lead mining and the concept of the no-liability company and later ones were dry crushing, roasting, and cyanide filtering of sulpho-telluride gold ores and differential flotation of the complex sulphide ores of lead, zinc and copper.
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Note : Conversion of Units

In this thesis I have followed the convention of using the names and units of currency and weights and measures that were in use at the time I am writing about. As Australia was a British colony in the nineteenth century British imperial units were adopted without question. Change to a metric system occurred from 1966.

Currency

The imperial unit was the pound sterling, the symbol being £1. From 1821 the British monetary system was based on gold, the so-called gold standard, with the pound note being freely convertible to gold. The relative value between the pound note and one ounce of pure gold had been fixed at £4 / 4 / 11½ when Sir Isaac Newton was Warden of the Royal Mint in the late 1600s.1 This was still the price paid for an ounce of pure gold by the Bank of England at the start of the Australian gold rushes in 1851. Australian banks usually paid less than this in order to make a profit and the price was discounted further if the gold was impure.

Due to changes in the economy with inflation and deflation of the currency over time the purchasing value of the pound sterling varied. In the 1851 to 1854 period of the rushes inflation reduced the purchasing power as the price of goods rose due to increased demand but this was corrected after 1854 in a period of deflation, and prices in 1860 were similar to those of 1851. The price of gold did not vary until the 1932, when inflation of the Australian pound led the Australian government to adjust the price to £A1.25 (equal to the £1 sterling). This meant the price of gold was £A5 /6 /3. In 1934 the United States government raised the price of gold to $US34 an ounce, with a consequent rise in price to £A9. The price fluctuated around this value until 1967 when Australian gold producers were allowed to sell their gold indirectly on an unofficial world market. This period ended in 1976 when the sale of gold was deregulated and the price was determined by world supply and demand. The price rose to $A710 per ounce in 1987 and has fluctuated considerably since then due to world demand and varying currency exchange rates.2

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1 S. Close, The Great Gold Renaissance, Kew, Surbiton Associates, 2002, p. 12. Pure gold was specified to be 24 carat while gold coinage was about 22 carat and contained impurities such as silver.
2 Ibid., pp. 20-3.
The Australian pound was converted to the Australian dollar in 1966 with two dollars being equal value to one pound. Various economists have calculated an equivalent purchasing power for the dollar and the earlier pound since 1860 when prices were reasonably stable after the gold rushes. These show that one pound sterling or Australian in 1860 would purchase a similar amount of goods and services as 74.2 dollars in 1992, one pound in 1895 equalled roughly 100 dollars in 1992, but inflation since then has further reduced the purchasing power of the Australian currency by a small amount. We can say roughly that a capital investment of £10,000 in a mining company in 1895 would be about the same as an investment of $1 million in the 1990s.³

In the period 1860 to 1890 the average wage of a miner was between about £2. 10s compared with about $700 at present, so the purchasing power has only changed a small amount for the better.

**Weights and Measures**

For most of the period under review the unit of mass (weight) avoirdupois was the imperial pound (lb), equal to 16 ounces (ozs), with the imperial ton being 2240 lbs. This was sometimes called the ‘long ton’, with a ‘short ton’ being 2000 lbs.

After conversion to decimal the unit is the kilogram of 1000 grams with the tonne being 1000 kilograms.

1 imperial pound equals 0.44 kilogams and 1 ton equals 0.9842 tonnes.

For gold the troy measure was used with 1 troy ounce equal to 20 pennyweights and each pennyweight equal to 24 grains. 12 troy ounces equalled one troy pound. In the decimal system 31.104 grams equals one troy ounce.

For measures the early units were the foot of 12 inches, with three feet equalling one yard and 1760 yards equalling one mile. In the decimal system one inch = 25.4 mm, one foot equals 305 mm and one yard equals 0.91 metres.

For area one acre imperial area equals 0.4 hectares in the decimal system.

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Acknowledgements

Many people have assisted and encouraged me to complete this thesis. I can only thank them for their help.

Dr Brian Hill and Dr Richard Hartley encouraged me to commence the course and have provided assistance with references and articles. James Lerk has been generous in allowing me access to his extensive files on mining in Bendigo and being prepared to spend many hours with me discussing the details of mining technology. Others who have been generous in discussing various aspects of mining technology with me have been the late Frank Cusack, David Bannear, Doug Buerger, Anna Kyu, Amanda Hill, Roland Hill, John Hillman, Alf Lowther, Keir Reeves, Ray Roberts, Ray Terrill, James Whitehead and Clive Willman.

My Supervisory Panel at the University of Melbourne, Alan Mayne, Andrew Brown-May and David Goodman gave me excellent advice. In particular I thank my supervisor, Professor Mayne, for accepting me as a graduate student. He assisted me to clarify themes, insisted that I discussed technical details in a manner that a non-technical reader could understand and that I justify my sometimes radical ideas.

The staff members of several libraries have been of considerable assistance to me in advising where to look for articles on mining technology including the Australasian Institute of Mining and Metallurgy Library, Battye Library, Baillieu Library, Department of Primary Industry in Bendigo and Melbourne, Department of Minerals and Energy Queensland, Department of Minerals and Energy Western Australia, John Oxley Library, Kalgoorlie Library, La Trobe University Library Bendigo, North Central Goldfields Library Bendigo and the State Library of Victoria. In addition staff members at the Public Records Office Victoria, the Melbourne University Archives and the Noel Butlin Archives at the Australian National University have been very helpful in locating source material. Members of the Castlemaine Historical Society Inc, The Bendigo Historical Society, the German Heritage Society Bendigo and the Australian Mining History Association have also helped to broaden my knowledge of mining technology.

The many staff members of Mount Isa Mines Ltd., the Zinc Corporation Ltd., and New Broken Hill Consolidated Ltd., with whom I have worked, gave me an understanding of
how mining companies produce minerals and how the ceaseless drive for improvements in productivity works in practice. I am deeply indebted to them.

Finally my thanks and acknowledgements are due to my wife Marta for her support and encouragement.
Introduction

The Development of Mining Technology in Australia

Australia is now one of the world’s producers of minerals, and the minerals industry is an important part of the Australian economy. The first mining in Australia, that of coal, commenced soon after the establishment of the penal colony in New South Wales in 1788. The mining industry has gradually expanded over two centuries and now produces a wide range of refined minerals including gold, copper, silver lead and zinc, iron and steel, nickel, manganese, aluminium, the rare earth minerals and oil and natural gas. The subject of this thesis is the development of the technology associated with the mineral industry in Australia: whether it was imported from elsewhere, whether it was modified to suit local conditions, whether it was developed to solve problems peculiar to Australia and whether technologies developed locally were exported. The introduction of new technologies in the early years up to 1851 was dependent on the sources of capital and the management structures adopted by the mining companies. These in turn depended on British mining laws and British company law. As mining became more complex, technologies, company structures and methods of financing mines changed to meet changing world conditions. These changes will be considered from the earliest coal mining to recent developments, but because of space limitations the emphasis will be on the period from 1800 to the end of World War II in 1945. The issues of industrial health and safety and environmental degradation and rehabilitation are subjects of great importance in mining. While there is considerable literature available on these topics they will only be commented on briefly in this thesis due to space limitations.

It will be argued that early in the first half of the nineteenth century coal mining began in New South Wales using convict labour and technologies then current in Scotland and the English midlands. When mining of lead and copper ores began in South Australia in the 1840s the sources of mining technology became international, because miners and managers trained in German mines introduced methods based on German practices in mining and smelting. As the majority of miners in South Australia were from Cornwall,

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and preferred the methods they were familiar with, Cornish managers soon dominated mining in South Australia using the technologies then in use in the Cornish copper and tin mines. The early mines were controlled by companies either chartered in the colonies or in England under laws very similar to the current English legal system. The discovery of gold in eastern Australia in 1851 and the subsequent influx of over one hundred and fifty thousand miners to the goldfields, forced the colonial governments to abandon the British laissez faire attitude to gold mining and to attempt to control the tide of miners by allowing claims of small size for individual miners or small parties of miners. Despite the early intention of governments to return to the British system of company mining as soon as possible this did not occur for many years and subsequent laws favoured the small gold miner by limiting the size of mining claims and mining leases. Small lease sizes meant the raising of capital for mine development on overseas money markets was difficult, and for most of the second half of the nineteenth century colonial gold mining companies remained small in size and in capital investment. This resulted in limited funds for the purchase of new mining machinery overseas and the development of new technology locally was restricted. Despite this restriction technologies were introduced from Europe, North America and South America to the early goldfields in eastern Australia. Adaptation to Australian conditions and local innovations led to incremental improvements in equipment, together with the introduction of major changes in mining law.

When new goldfields were discovered in Queensland and northern Australia from the late 1860s Victorian miners and entrepreneurs moved to these fields and took with them the practices they had developed since the early 1850s. When new copper and silver, lead, zinc fields were discovered in New South Wales after 1870 and the goldfields in Western Australia with their refractory ores were developed in the 1890s, Australia had the large numbers of experienced miners and trained gold mining technologists needed to develop these mines, but overseas technologists were also imported to assist with specific problems not previously encountered in Australia. Investment of English and

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5 Soon after the foundation of Sydney, mining of coal on Crown land at Newcastle began in a small way by local merchants but was brought under Government control by Governor King in 1800 with convict labour. Control of the mine was transferred to the Australian Agricultural Company in 1831. Copper mining began in South Australia in 1845 by individuals on alienated land, under the British system that land owners were entitled to mine on their land without interference.

6 The influx of experienced miners from Europe and North and South America who had had experience in mines elsewhere, as well as others who brought new political ideas, led to experimentation on the best methods of extracting gold from many differing types of gold ores and with new management systems.
European capital at Broken Hill and in the rich Western Australian gold mines in the 1890s resulted in the involvement of technologists from Europe and the United States in solving the problems of processing complex ores. It will be argued that after some forty five years of innovation by the migrants of the 1850s, new ideas from overseas were combined with Australian technologies to produce advanced technologies which were exported world wide. The speed of technology transfer and innovation will be discussed in detail. The one exception was the Australian coal mining industry which was wracked by industrial disputation and relatively slow change from hand labour to mechanization until 1945.7

To achieve this analysis of the development of Australian mining technology Chapter 1 will consider the introduction of hand methods from overseas in the extraction of coal, silver lead and copper between 1800 and the early 1850s, and will show that this technology was used with little change except for the introduction of steam driven pumps late in the period. Chapter 2 will cover the development of alluvial and quartz reef gold mining, mainly with hand methods, between 1851 and 1855, when the laws covering mining in Victoria were altered to enable the miners to participate in developing new laws. Chapter 3 will describe the development of mining law in Victoria as technology changed and adapted to deal with deep lead alluvial mining and quartz reef mining between 1855 and 1870 (later applied to all other Australian colonies). Chapter 4 will cover the changes in coal mining and metalliferous mining between 1851 and 1870. Chapter 5 will discuss the changes in the infrastructure supporting the mining industry between 1870 and 1900 as the government in Victoria sought to support the industry, and how this influenced developments in the other colonies. Chapter 6 will be an analysis of the technology changes required for extraction of the ores as new types of copper and silver, lead and zinc orebodies were discovered and developed after 1870; and Chapter 7 will consider the processing of these ores and the very fine grained and complex gold ores discovered in Western Australia. These ores required finer grinding to separate the minerals, which eventually created the difficulties of sliming. The development of fine grinding technologies and the use of

7 Despite this close involvement with overseas capital and the use of overseas technology where advantageous, Australian mining companies have, until recently, been able to maintain control of their own destinies. K. Tsokhas reaches this conclusion in his book Beyond Dependence, Oxford University Press, 1986. It remains to be seen whether recent takeovers by and mergers with foreign companies will result in the control of Australian mining by companies based in Great Britain, the United States and South Africa.
chemical methods to extract the minerals in the period from 1870 to 1900 will be
discussed. Chapter 8 will cover the new processes developed to solve the sliming
problem in the period up to the end of Word War II. Chapter 9 will discuss the years
from 1900 to 1945, a period of progress in the mining of some minerals but the decline
of others. Chapter 10 will analyse the development of mining technology from 1801 to
1945. The epilogue will briefly describe developments in mining technology after 1950.

**The Study of Technology**

Technology has been defined (*The Macquarie Dictionary, 1981*) as ‘the branch of
knowledge that deals with science and engineering, or its practice, as applied to
industry; applied science.’ The industry considered in this thesis is the mineral industry
which extracts minerals from the earth and processes them to produce a commercial
product.

The meaning of the word ‘mineral’ has broadened in recent years from the original
definition of a solid inorganic substance with a fixed crystalline structure formed by
natural processes, to now cover inorganic substances such as oil, coal and natural gas, as
well as liquid mercury and industrial minerals with variable chemical composition
which are extracted from the earth.\(^8\) A reading of recent journals from the various
government departments involved in mining in the Australian states indicates the
broadening of the definition.\(^9\)

In an article written in 1964 Geoffrey Blainey discussed the relevance of technology to
historians:

> Technology is very relevant to historians who are interested in economic
growth. It is very relevant to historians of social and political life. And despite
the magic of economic growth and political change, technology is valid as a
field of study in its own right. Moreover, in the chatterbox war between science
and the humanities, one point of truce is the history of technology; and perhaps
it should be studied more in universities, both by historians and scientists.

It’s easy to say we should be studying technology in Australian history, but it’s
not easy to study it. A historian of farming should know something about soil
science, botany, animal husbandry, plant physiology, farm machinery and so on.

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mineral as a substance having a definite chemical composition and atomic structure and formed by the
inorganic processes of nature.

statistics under the headings, Metallic Minerals, Fuel Minerals and Other Non-Metallic Minerals.
A historian of mining should know something about geology, climate, chemistry, metallurgy and mining engineering.\(^{10}\)

In writing this article Blainey was responding to an earlier article by John McCarty on the role staple products play in the economic structure and growth of a region and also its social and political structure, and he was making the point that technology can not be ignored when writing about economic growth or indeed social and political life. In the forty years which have elapsed since the article was written there have been major advances in the technologies which impinge on the mining of minerals. Notwithstanding Blainey’s perceptive comments in 1964 mainstream historians have not taken up his challenge to relate changes in technology with economic and social change nor have historians of technology demonstrated the broader relevance of their field.

To make valid assessments about the importance or otherwise of technological developments in mining, the historian of mining should now have a knowledge of the disciplines listed by Blainey as well as a knowledge of modern management theory, and the laws of the country in which the mining is being conducted, particularly the laws on mining, mining companies and patents. More than this, laws which impact indirectly on mining must be considered, including those relating to industrial health and safety and the environmental impact of mining projects. In considering the development of new technologies the restrictive impact of these social and legal requirements will be briefly identified.

Education for the mining industry is an important aspect of technological innovation. The Royal School of Mines was established in London in 1865 to provide trained mining engineers and metallurgists for British mines. This development was soon followed in Australia where similar schools were established at Ballarat in 1870 and Bendigo in 1873.\(^{11}\) Universities in Great Britain, the United States and Australia later provided training for engineers and metallurgists.\(^{12}\) As the men trained by these institutions became established in the offices of mining engineering consultants and on the staffs of various mines throughout the world they influenced the attitudes of the

\(^{10}\) Blainey, G., "Technology in Australian History", *Business Archives and History*, vol. IV, 1964, pp. 117-37. He was commenting on an earlier article by J.W. McCarty "The Staple Approach in Australian Economic History" in the February 1964 issue of the same journal (pp. 1-22).


\(^{12}\) The University of Melbourne appointed its first professor of civil engineering in 1882 although it had provided a certificate course in this discipline for some years before that (see *Uni News*, December 2002).
directors of mining companies to the introduction of new technologies. They also applied their scientific training to develop new technologies and saw a need to communicate information about these new technologies to other engineers and scientists. They established technical institutions at which new ideas could be discussed and promulgated through published transactions to their members and others interested.\(^\text{13}\)

Geologists have been employed in increasing numbers in the Australian mining industry since the early years of the twentieth century but until recently their contribution has been hampered by the lack of an adequate theory of how orebodies form.\(^\text{14}\) Since the 1960s the theories about plate tectonics have revolutionised the science of geology.\(^\text{15}\) More recent research on this topic has led to a much better understanding of how orebodies are formed and the relationships between magmas and orebodies.\(^\text{16}\) The impact on exploration technology of these new ideas in plate tectonics will be discussed briefly.

Finally there were major developments in scientific instruments in WWII, followed by the development of portable computers in the last thirty years. The combination of instruments and computers for analysis has provided several very powerful tools for minerals exploration.\(^\text{17}\) Developments in sensing instruments and portable computers have enabled the automation of mineral processing equipment, resulting in better control of the processing and higher recoveries of the minerals in the ores. Automation is now being extended to ore extraction equipment with the aim of removing the operator from dangerous underground situations to safer remote situations and to ore processing.

When studying a development in mining technology it is often difficult to determine whether the scientific aspect was the driving motivation or whether intelligent

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\(^\text{13}\) The Australasian Institute of Mining Engineers held its inaugural meeting in Broken Hill in 1893.

\(^\text{14}\) In his memoirs If I Remember Rightly (edited by G. Blainey and published in 1967), W. S. Robinson wrote ‘At Bendigo, our company, Gold Exploration and Finance, had lost £350,000 in the space of a few years while testing the attractive theories of the geologists’ (the use of the word ‘attractive’ here can be taken to imply sarcasm).

\(^\text{15}\) Tuzo Wilson published an early article on ‘Continental Drift’ in the April 1963 issue of Scientific American.


\(^\text{17}\) G. L. Clark, Built on Gold, (Melbourne, Hill of Content, 1963). Clark discusses several of the new techniques introduced in the post war period.
observation led to engineering developments which were later explained by the scientists.\textsuperscript{18} The application of scientific methods to the development of mineral technology, the communication of these new ideas and processes world wide and within Australia, and the interactions between operators, engineers and scientists as the technologies developed, will all be discussed in this thesis.

As full technical details of equipment under discussion interrupt the flow of the narrative and the consideration of the other aspects of mining history which have affected the technology, these details have been placed in appendices which can be referred to by the reader who wishes to further understand the detail.

**Sources**

Before the formation of the technical institutions in the second half of the nineteen century, articles about new developments in mining were usually written for newspapers by ‘mining reporters’ or ‘mining correspondents’ who were knowledgeable about mining matters. As many of the readers of the newspapers were working miners they would not have been slow to criticise poor reporting on mining matters. They sometimes did so.\textsuperscript{19} Articles and letters in Australian newspapers in the nineteenth century on local mining matters can therefore usually be regarded as authentic. The major exception is government statistics relating to the gold rushes in Victoria before 1864. Even after the Victorian government began printing the *Reports of Mining Surveyors and Registrars* from 1859 it qualified the statistics as not being complete and the numbers of miners on each field were overstated until after the Mines Department was set up in that colony in 1863.\textsuperscript{20}

The formation of technical institutions by professional engineers, chemists and metallurgists in the late nineteenth century resulted in the publication of professional

\textsuperscript{18} As will be discussed later, early developments of the flotation process were the result of observations of natural occurrences. Engineers were involved from the start in developing the machines to implement the process. The scientists later became involved in explaining why the process worked as they searched for improved processes.

\textsuperscript{19} A miner wrote to the editor of the *Bendigo Advertiser* on 15 September 1855 discussing problems with the use of mercury for amalgamating gold in the new crushing machines which were being introduced to the field at that time.

\textsuperscript{20} Governor Barkly admitted this was so in a despatch of November 1861 (Enclosure 1) to the Colonial Office. The reports of the mining surveyors and registrars were produced by the Victorian Department of Mines when it took over this publication in the early 1860s. Some prominent writers on gold mining in Victoria have failed to read the warnings on the statistics included in these reports and have treated them as complete production statistics.
journals containing papers on all aspects of mining, mineral processing and smelting with the aim of disseminating knowledge of new developments, particularly the application of science and engineering analysis to the mining industry. After initially being mainly anecdotal these papers became more technical in the late 1890s. They provide valuable reference material.

The Melbourne University Archives hold several collections of papers of companies and individuals which contain much information on mining development in Australia from the beginning of the twentieth century. These include the W.S.Robinson Papers, and the Minerals Separation Ltd. Papers. The Noel Butlin Archives at the Australian National University, Canberra, hold the papers of the Australian Agricultural Company which contain a great deal of information on coal mining at Newcastle into the twentieth century.

**Review of the Literature**

The literature about the development of Australian mining technology is fragmented. Social histories of Australian mining towns and mining companies contain much information on personalities and social progress but generally lack information about the development of technology in the mines. Geoffrey Blainey, Weston Bate, Geoffrey Bolton, Charles Fahey and Alan Mayne have discussed the impact of mining on the local communities but commented only briefly on technological development. Their books about mining communities have raised the awareness of Australians of their rich mining history with overviews of the various rushes and the effects of physical isolation on the mining industry. They were writing for the general reader who would not be interested in the technical details of mining. *A Mining History of Australia* by Donovan and Associates, covers mining Australia wide, but again the emphasis is on social and

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21 The Australasian Institute of Mining Engineers was founded in 1893 in Broken Hill. The objects were “To promote the Arts and Sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings for social intercourse, and the readings and discussion of professional papers, and to circulate by means of publications among its members and associates the information thus obtained”. These objects were a direct copy of those of the American Institute of Mining Engineers which had been formed in the United States some thirty years earlier. Both Institutes saw ‘mining’ as covering mineral extraction and subsequent processing to the final economic product.

22 The industry reviews published at regular intervals by the Australasian Institute of Mining and Metallurgy are written by participants in new developments. They give valuable reports on progress but generally are uncritical and do not discuss failures (with some exceptions).
Economic historians including Noel Butlin, R. Jackson and John McCarty have written about the sources of capital for Australian mining.

The first comprehensive article on mining technology in Australia was by Oliver Woodward on the Broken Hill mines and their associated industries in 1940, followed in the bicentennial year of 1988 by an overview of mining technology by G. O’Malley. Woodward in his article ‘A Review of the Broken Hill Lead-Silver-Zinc Industry’ gave a comprehensive history of the development of the metal industry at Broken Hill including mining, ore dressing and smelting both at Broken Hill and at associated industries elsewhere in Australia. During his career he had managed mines in Queensland, Broken Hill and the Broken Hill Associated Smelters in Port Pirie and had a wide knowledge of the silver lead and zinc industry. He gave a comprehensive history of the development of the mines and summarised the important developments of the flotation process but his analysis was inward looking in that it had little to say about the contribution of outside participants in the race to separate zinc concentrates nor the extension of the flotation process to separate copper concentrates from low grade copper ores. However he did discuss the machinery developed in implementing the lead-zinc flotation process in considerable detail, the smelting processes used and industrial health and safety. This paper was a valuable contribution to the history of the development of the use of technology in the base metal industry in Australia. O’Malley’s shorter article ‘The Mineral Industries’ gave a wide coverage of the various mining technologies but did not discuss individual technologies in depth.

In more recent years several historians, Sybil Jack, Jan Todd, Alan Lougheed and Richard Hartley, have begun to discuss the scientific basis of the technology itself and how the technology was transferred from one country to another. They have tended to

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concentrate on the problems with patents, the reasons for delays in the transfer of the technology and economic aspects of the introduction of new technology. With the exception of Hartley these authors have not discussed in any detail the development of the equipment involved in the new technology.

In her 1984 paper ‘The introduction of cyaniding in New Zealand’, Jack discusses the early introduction of the process at the Crown mine at Karangahake where it was a commercial success. However there were problems in introducing the process to other mines in New Zealand due to low ore grades. As a result small companies amalgamated to give the advantage of scale. While New Zealand mining is outside the scope of this dissertation the early success of the process there is of relevance to the later introduction in Australia.

In one section of ‘Colonial Technology’, published in 1995, Todd investigates the transfer of anthrax inoculation technology while the other section is a study of the interaction of science and technology in the transfer of the cyanide process from Scotland to the various Australian colonies late in the nineteenth century. Her interest is in whether this transfer occurred in small cumulative steps or in a great leap and she concludes that this was a great leap which greatly increased the technological capability of the Australian mining industry. However she does not give much consideration to the equipment developed during this technological advance. The book also contains useful information on the early introduction of the cyanide process in South Africa and New Zealand as a comparison with the slower acceptance in the Australian colonies.

Lougheed, an economic historian, in ‘Cyanide and Gold’ (2001), has written comprehensively on the technology transfer involved in the introduction of the cyanide process from Scotland to South Africa, New Zealand and the Australian colonies. He discusses the growth of the Cassel Company after it introduced the process, the development of a cartel between English, European and United States companies to control the sales and profits of the process, and how weaknesses in the wording of the patent applications reduced the royalties flowing to the Cassel Company. In his book

Lougheed gives a diagram of the layout of an early South African cyanide plant and a brief summary of the operation.²⁷

In his unpublished thesis ‘A History of Technological Change in Kalgoorlie Gold Metallurgy’, Hartley has dealt comprehensively with the problems encountered in extracting gold from the Kalgoorlie ores both in the oxidised and sulphide zones and how these problems were solved using filter presses and cyanide solutions. His analysis provides an account of how and why changes in technology took place and of how engineers and scientists worked together and with plant operators to develop comprehensive solutions. He describes the equipment developed in some detail.²⁸ He concludes that Kalgoorlie was the leading centre for innovative gold metallurgy for a period from 1905 to 1907 and that the men responsible were the Kalgoorlie managers, metallurgists and engineers, of whom about seventy percent were Australian, twenty per cent American and ten per cent British.

Mouatt, an economic historian, has given a detailed account of the development of the flotation process in Broken Hill following earlier experiments in the United States and Britain. He argues that this was the genesis of modern mining. However he refers only briefly to the contribution made by Minerals Separation Ltd. to lead zinc flotation and the flotation of other sulphides, and he gives few details of the transfer of the technology overseas after the early development in Broken Hill. The papers of the Melbourne office of Minerals Separation Ltd., now available in the University of Melbourne Archives, give much additional information on how this technology was developed for copper and transferred overseas and this aspect is covered in this thesis.²⁹ Mouatt does not discuss the details of the machinery developed to implement the flotation process.

In recent years historical archaeologists have excavated old mining sites around Australia. Several authors including B. Connah, I. Jack and A. Cremin and Michael

Pearson have analysed the results of such excavations to provide information of equipment and processes, the details of which have been largely forgotten, and which were not adequately recorded in the literature in the period in which they were in use.30

In a recent paper ‘Innovation or Imitation? Technological Dependency in the American Nonferrous Industry’, Roger Burt discussed the concepts of macro and micro technological changes in the American nonferrous mining industry in the nineteenth century. He looked at seven macro technological changes, one of which, hydraulic placer mining was a local development, dredging was mainly a New Zealand innovation, while five others were developed outside the United States and only slowly introduced there. He concluded:

It is surprising that the American metalliferous mining industry is found to have had a longer lasting and more complete dependence on imported technology than has usually been suggested and ordinary in that the suggested causes of that performance fit well within existing explanations of relative rates of technological change on either side of the Atlantic ---though here the position is reversed with the American industry displaying characteristics more commonly associated with British enterprise.

Burt’s ideas can be usefully applied in an analysis of technology transfer in Australian mining although he mentions only once the introduction of machine drills in Australia as being rapid.31

In essence Australian mining has been seen by historians and by miners themselves as taking place in isolated pockets where one type of mining is carried out, for example, base metal mining at Broken Hill, coal mining in the Hunter Valley, gold mining in Victoria and at Kalgoorlie. The transfer of technology between mining areas in Australia is a subset of the overall development of Australian mining which has never been adequately assessed. There is a need for a study of the technological development of the minerals industry in Australia as one industry, not as several fragmented groupings. This thesis will attempt such an assessment.

Chapter 1

Muscles and Steam - 1801 to 1851

Introduction

When Adam Smith, the Scottish economist, published his famous book *The Wealth of Nations*, in 1777, he did not refer to steam power as a motive force. However by the time the first fleet left England for Botany Bay in 1787, with soldiers and convicts to form the first settlement in New South Wales, the industrial revolution was well underway in Great Britain. James Watt had patented his low pressure atmospheric steam engine with a surface condenser in 1769, and after years of work with the industrialist Matthew Boulton, during which he had developed the technology to produce the machine in quantity, was selling them to mines and mills. Henry Cort had recently patented a process for making wrought iron by puddling in a reverberatory furnace, a process which increased the supply of iron for the manufacture of steam engines. The arrival of the fleet in Sydney Cove and the annexation of New South Wales meant the mining laws of Great Britain would be automatically applied to any mining in the colony; these laid down that gold and silver ores belonged to the Crown but all other minerals belonged to the landowner.

The sailors, soldiers and convicts of the first fleet brought few mining skills when they landed at Sydney Cove in 1788. However most of them would have had some experience in using coal for cooking and heating. It is not surprising then that the first mineral reported in the new colony was coal; it was prominent in distinctive bands or seams in the cliffs along the coast north and south of Sydney. The most accessible of these seams was at Coal Harbour, later to be called Newcastle after the coal town in the north of England. This seam, discovered in 1797, outcropped along the banks of the river and could be easily extracted by pick and shovel. Organised mining began in 1801 when Governor King despatched a small party of soldiers in charge of several convicts to dig the coal for use in Sydney for heating and to process cast iron in local foundries and perhaps for export to India and the Cape of Good Hope.

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When the colony of South Australia was established in 1836 by a combination of government and private enterprise, the South Australian Company (which had recently been established in London to found a colony in South Australia) sent a German mineralogist and four German miners to develop water supplies and a mining industry. Such proposed company mining did not develop immediately but private individuals in the newly settled colony soon began mining small deposits of lead and silver on alienated land and in the 1840s substantial copper orebodies were found at various places in the hills around Adelaide.

In the same decade the mining and treatment of copper ores and iron ores began in New South Wales. During the first sixty years of the Australian colonies pig iron for foundry work was imported, the first attempt to produce pig iron from local iron ore being made at Mittagong in New South Wales in 1848 by Sydney business men with local capital.

During this early colonial period the extraction and treatment of the minerals depended mainly on human and animal muscle power, with a gradually increasing number of steam engines of British manufacture being introduced from the 1830s for winding and pumping

This chapter will review the establishment of mining in New South Wales with the mining of coal at Newcastle from 1801, followed by the mining and smelting of silver lead and copper ores in South Australia, and copper ores in New South Wales, from the 1840s, and the mining and processing of iron ore at Mittagong in New South Wales from 1848, until the beginning of the gold rushes in eastern Australia in 1851. The aim will be to show how the gradual introduction of British steam technology assisted and replaced some of the muscle power used initially in coal mining and metalliferous mining during the first fifty years of the nineteenth century

**Coal Mining in Australia – 1801 to 1851**

Coal mining had been carried out in England by the Romans who heated their villas with coal dug from near the surface. Over succeeding centuries the surface outcrops were mined out and deeper seams were exploited. Until the eighteenth century iron ore had been smelted using charcoal obtained by burning timber in kilns but after Abraham
Darby developed a process to smelt iron ore using coke in 1709 the coal and iron industries developed more rapidly in Great Britain in the eighteenth century. As the deeper seams were developed by sinking a shaft to the seam, mine water became a problem and was removed by hauling buckets up the shaft by hand windlass and later by horse whim. In the middle ages pumps made of an endless belt with plates drawn up through a pipe, by horses, to lift the water had been developed but this device had a practical limitation of about 300 feet below the surface and a mining radius of about 600 feet around the bottom of the shaft. In 1712 Thomas Newcomen developed a steam driven pump, the first of which was installed in a coal mine near Dudley Castle at Bromsgrove. Subsequently many of these pumps were installed for pumping at coal mines in Great Britain and elsewhere in Europe. This engine was very inefficient because the cylinder was cooled by the water spray and had to be reheated by the next injection of steam.

James Watt modified Newcomen’s engine by allowing the steam to flow from the cylinder to a separate condenser at the end of the up cycle, the injection of water formed a vacuum in the condenser and the cylinder but kept the cylinder hot during its down cycle. This increased the efficiency substantially. Watt patented this engine in 1769. He later improved the efficiency further by making it double acting, with steam injected above and below the piston on successive cycles so the piston was pushed then pulled. This enabled him to develop a rotative drive with a crank from the beam to drive a winding engine or rock crusher. Many of these machines were installed at coal mines for pumping and winding and at Cornish copper and tin mines for pumping, winding and crushing. Coal was dear in Cornwall and the more efficient Watt engines were economical for pumping large quantities of water from below the water line. Watt opposed the development of steam engines working at high pressures because he feared boiler explosions. Richard Trevithick, a Cornish engineer, and others had no such inhibitions and by 1802 Trevithick had installed a machine working at the high pressure of 145 p.s.i.g. at Coalbrookdale. Because of their higher efficiency many of these

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34 Cardwell, The Fontana History of Technology, p. 110.
36 Cardwell, The Fontana History of Technology, p. 121.
37 Ibid., p. 130.
38 Ibid., pp. 161-3.
39 Ibid., pp. 166-7.
vertical cylinder machines were installed for pumping in Cornish mines and exported worldwide, and Cornwall became the major centre for the manufacture of engines and large horizontal boilers made of rivetted iron plates for the remainder of the nineteenth century.  

While English and Scottish and Cornish engineers were developing an efficient steam technology for use in mines, coal was found in the infant colony of New South Wales. The first discovery was in March 1791 when a party of escaping convicts, led by William Bryant, sheltered overnight at what was later called Port Macquarie, north of Sydney. Other deposits were found near Port Stephens in July 1796 by fishermen and in August 1797 at Coalcliff, south of Sydney by shipwrecked convicts. Another party of convicts who escaped by sea from Sydney were pursued unsuccessfully by Lieutenant John Shortland, who during the chase entered a harbour and river which he named the Hunter after the governor. On 9 September 1797 he found loose coal there on the river banks and coal seams in the cliffs on the coast. Philip Gidley King took office as the third governor of New South Wales in September 1800. As the British government had instructed him to develop an export trade in coal to India and the Cape of Good Hope to relieve the expenses of the colony, one of King’s early decisions was to send John Platt, the only convict in Australia with coal mining experience, to bore for coal at the head of the Georges River, west of Sydney, where small coal had been found on the surface. With the assistance of eleven other convicts Platt bored a hole to a depth of 96 feet but found only thin bands of coal which were not worth exploiting. He used hand boring tools already in use in Great Britain for boring to locates coal seams, the tools having been selected in London by Sir Joseph Banks and despatched to King in Sydney. In May 1801 a vessel owned by the government, returned from the Hunter River with a cargo of 150 tons of coal, which was sold for £2 5s per ton to the captain of the Earl of Cornwallis for sale in India. On 11 June 1801 King sent Lieutenant Grant with two ships to the Hunter, then called Coal Harbour, to establish a coal mining and timber cutting settlement. A corporal named Wixted with five soldiers and sixteen
convicts, including Platt, were to form a permanent establishment. Wixted was unable to control the soldiers and convicts effectively and after conducting an enquiry a magistrate Martin Mason took charge, but his management was so harsh the convicts rebelled and only the intervention of Wixted and the soldiers saved Mason’s life. King closed the remote establishment early in 1802 because of this lack of control. On 5 March 1804 Irish convicts around Sydney rebelled, but they were suppressed by the army at Castle Hill. The leaders were hanged. Lieutenant Menzies of the Marines, who had led a detachment during the rebellion, offered to take charge of a new settlement at Coal Harbour where the most incorrigible of the remaining rebels were to be sent. With several officials, eleven military personnel and 34 convicts, Menzies arrived on 30 March 1804. In May he put down an uprising by the convicts. He subsequently developed efficient manual mining procedures and was commended by King. The coal produced was used mainly for heating in Sydney.

After Lachlan Macquarie was appointed governor in 1813 a small coal export trade was commenced with India. The first steam engine was imported into the colony from England in 1815 for grinding wheat and sawing timber, and Newcastle coal was soon being used to heat the boiler. The mining of coal from an adit near the shore continued until a shaft was dug to give better access to the coal. In 1819 John Bigge was appointed by the British Government to inquire into the operation of the convict system in New South Wales. He arrived in Sydney in June of that year. His first report was printed in 1822 and the second and third in the following year. The first report contained a succinct account of the Newcastle coal mine:

Until the year 1817, coal was obtained at this settlement by a drift made on the sea shore, and level with it, penetrating a seam of coal that showed itself under a large mass of superincumbent sandstone that forms the south headland of the

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46 *Australian Dictionary of Biography*, ed. D. Pike (Carlton: Melbourne University Press), vol. 2, p. 213. This appears to be the first occurrence of bad industrial relations at Coal Harbour (later called Newcastle).
47 *Historical Records of New South Wales*, King to Under-Secretary King at the Colonial Office, 5 June, 1802, p. 782.
48 *Australian Dictionary of Biography*, vol. 2, pp. 222-3.
50 *Historical Records of New South Wales*, vol. 4, General Order, 29 Oct. 1801, p. 600. In this Order King set out a daily allowance of coal for household use by public servants, officers and other ranks.
51 *Historical Records of Australia*, 1, vol. 8, Macquarie to Bathurst, p. 159. The Governor of Bengal requisitioned 154 tons of coal each year for use in the government forge in Calcutta. The bill was paid in rum.
entrance to the Hunter’s river. The depth of the seam is three feet and one inch, and it is the same that is now worked by a perpendicular shaft of 111 feet, and a common windlass turned by convicts. The water found in the present coal is carried off by the old drift to the sea shore. Twenty seven men are employed in the working of the mine, and the mouth of the shaft immediately adjoins the offices of the commandant’s house. Twenty tons of coal can be raised in one day by the number of men there employed; and I observed that several could perform their task before the ordinary labour of the convicts ceased, but they were detained at the mouth of the pit, under a shed, to prevent them taking advantage of the absence of other convicts from their houses and plundering them. Eight of the miners employed, who hew the coals, are allowed an extra half ration; and as it is found necessary to employ those men who are expert in this labour, convicts who have been accustomed to it in England are frequently sent up to the Coal River, direct from Sydney, upon their first disembarkation from the ships. The height of the pit, in which the coal is worked, is four feet and a half; and the coals are conveyed in barrows. From the point at which they are hew, a distance which in the month of February 1820 was not less than a hundred yards, to the bottom the shaft. The labour in the coal mines at Newcastle is found to be prejudicial to the health of the convicts, on account of the bad air of the mine that they breathe, and the difficulty that is experienced of clearing it of water. Asthmas, pulmonary and rheumatic complaints, are those from which the miners most suffer.\(^{54}\)

Bigge also reported that he believed the food ration to all convicts at Newcastle was inadequate and he had recommended to the commandant, Major Morrisset, that he apply to the governor for an allowance of the meal of maize at breakfast.\(^{55}\) The evidence that Bigge collected was not published, but was deposited in the Public Records Office in London, where James Bonwick copied sections in the late nineteenth century. Extracts from these have been published and they provide additional information on the workings of the early mine.\(^{56}\) William Evans, assistant surgeon, told Bigge there were several accidents in the mine, generally severe contusions. Dislocations were frequent, but had been reduced by increased care in the propping of the mine.\(^{57}\) Benjamin Grainger, who had trained as a coal miner in Staffordshire in England, said he had been superintendent of the Newcastle mine for over seven years. He had supervised the shaft sinking in 1817 to the Yard Seam (so called because of the thickness of three feet one inch). Each of the eight hewers were required to dig two and one half tons of coal a day. By hard work they could do this by noon. These hewers were allowed an extra half ration. The health of the miners suffered because they remained in their wet clothes

\(^{54}\) Ibid., p. 115.
\(^{55}\) Ibid., p. 116.
\(^{57}\) Ibid., pp. 104-5.
after they came up from the pit and did not have other clothes to change into. After 1818 ships were loaded by a special gang, for which a fee of 2s. 6p. per ton was charged. As a result fewer ships were loading coal. The sinking of the shaft was commenced in 1814 but it was a difficult task which required a large expenditure of iron, powder and labour. Coal production was 2,375 tons in 1819 and 4,065 tons in 1820.

The British Government had appointed John Bigge to report on conditions in New South Wales because of concerns about the cost of running the colony. After considering Bigge’s report the government opened negotiations in 1826 with the Court of Directors of the Australian Agricultural Company for them to take over the coal mine at Newcastle. Governor Darling was instructed to immediately grant the company 500 acres of coal land at Newcastle and another 1500 acres to be chosen later.

The Company appointed Robert Dawson as its Australian agent. He arrived in Sydney late in 1825 and worked with a Colonial Committee, appointed from London, to select suitable land for the agricultural part of the enterprise. John Henderson was appointed principal colliery manager. He was to supervise a mining establishment of an overman engineer or blacksmith, a brakeman or engine driver, a corver (basketmaker), a colliery blacksmith and four hewers for shaft sinking, boring and coal hewing. The Court also approved the purchase of two 24 horsepower steam engines which were the first used for mining in Australia. Henderson was given written instructions to which he agreed.

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58 Ibid., pp. 138-42.
59 Ibid., pp. 19, 215. From this comment we can deduce that the expenditure of iron was for star bits used for hand drilling and black powder (gun powder) used for blasting the rock which was probably a hard sandstone. The stores supplied in 1820 (p. 215) included 180 lbs of gunpowder but whether all this was used for mining is not known.
60 Ibid., p. 278.
61 The Australian Agricultural Company was incorporated in London by Act of Parliament in 1824 with a paid up capital of £1M. the objectives of growing wool, cattle, corn and at a more distant time olive oil, hemp, flax, silk and other agricultural products. The Company was to receive a grant of one million acres of land in New South Wales. See First Annual Report of the Australian Agricultural Company held at the Butlin Archives, ANU, Canberra.
63 Minutes of the sub-committee for coal mines 21 October 1825, A.A.Co. Minute Book A 160/89. The selection criteria for the steam engines are interesting. The Company Secretary had been sent to Newcastle in England to gather information on coal mining and to interview applicants for the position of colliery manager. He said that low pressure Boulton and Watt steam engines were not as efficient as the newer high pressure machines then being manufactured by several firms and recommended two machines of 24 H.P. working at 25 p.s.i.g. made by R. & W. Hawthorne of Newcastle. Each machine had accessories for concurrent pumping and winding. The total cost of the machines on board ship was £1282. A marginal note in the minutes states the steam cylinder was 16 inches. The machines would have been of the beam type with cast iron columns to support the beam and the vertical cylinder. John Henderson was 43 years old, with 4 children residing at Milesmark near Dumferline, Scotland, and was acting manager.
in writing. 64 He was also authorised to purchase a 5 H.P. steam engine and a cupello to smelt iron ore. 65 He sailed with his establishment on 27 July 1826 and there was no further mention of the colliery in the annual reports until the fifth report in January 1829, when it was stated that the British Government had given a grant in fee simple of 2000 acres of coal lands in one or two allotments. 66

On 7 July 1829 Henderson attended a meeting of the Court of Directors in London and reported he had been discharged by the Colonial Committee on 1 June 1828 with no reason given and that the colliery establishment had also been disbanded. He said the coal fields at Newcastle were very extensive, coal was abundant and dirty but could easily be cleaned, and the steam engines were in good order in store. The Court asked Henderson if he was willing to return to Newcastle on the same terms as his original contract to which he agreed. 67 In the interim the Colonial Committee had criticised the selection of land by Dawson at Port Stephens and had suspended him. 68 It had also refused to support Henderson in his application to Governor Darling for the formal transfer of the coal mines at Newcastle. Governor Darling has been accused of procrastinating in granting the land at Port Stephens and handing over the coal mines because he was opposed to such monopoly grants to a company, as were many businessmen in Sydney who saw their own interests threatened. 69 However Darling had not opposed the allocation of the land and the problem was caused by poor communication between successive Secretaries of State and Darling and between the Colonial Committee and Darling, who was never given clear instructions about the transfer of the land. He refused to do so until he received such clear instructions. 70 The Court of Directors in London put pressure on the Colonial Office, which wrote to Darling that he was to negotiate with Sir W. E. Parry, Dawson’s replacement, who would soon arrive in

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64 A.A.Co. Minutes A 160/89 14 July 1826, p. 287.
65 Ibid. p. 247.
66 Fifth Annual Report of A.A.Co., January 1829. This confirmed a previous verbal agreement.
69 Ibid., p. 49. Ellis, A Saga of Coal, p. 23. Both Gregson and Ellis were wrong in making this accusation which was probably circulated by members of the local committee for their own purposes.
70 B. H. Fletcher, Ralph Darling - a Governor Maligned (Melbourne: Oxford University Press, 1984), p. 163. The references given by Fletcher to various despatches in the H.R.A. prove conclusively that Darling was not inimical to the requests of the A.A.Co. and he was exonerated of such charges later by Murray.
Sydney as the manager of the Company, to grant him 500 acres at Newcastle within the boundaries he asked as well as another 1500 acres of coal lands nearby. He was also to be granted 200 yards of waterfront to erect a coal wharf and a further 300 yards with the larger grant when that area was decided.\textsuperscript{71}

Sir William Edward Parry, recently knighted for his polar explorations, was offered the position of manager in Australia for a period of four years with the power to negotiate with Darling the site of the one million acres of agricultural land and the 2000 acres of coal lands. He was also authorised to make all decisions on coal mining including expenditure on Henderson’s advice.\textsuperscript{72} The Colonial Committee was sacked by the Court of Directors.\textsuperscript{73} Parry arrived in Sydney in December 1829 and was followed by Henderson who arrived on 20 April 1830 after a harrowing eight month voyage. On the 30\textsuperscript{th} he reported to Parry that the steam engines were in good repair except that one of the upright fluted columns had been broken but could be easily repaired. The boilers were in good condition.\textsuperscript{74} On 20 May, Parry requested the permission of the Colonial Secretary for Henderson to be given five convicts to bore for new seams at Newcastle and on 18 August he asked for approval for Henderson to sink a pit a half mile east of the existing workings and that six more convicts be supplied.\textsuperscript{75} By 10 September he reported to London that Henderson had sunk the pit seven yards with five men on one and a half rations using hand methods. He employed these convicts after they had finished their allocated daily hours at 1s. 6p. per day. He had also contracted for 100,000 bricks made of Newcastle clay at 23s. per thousand, part for lining the pit and part for the engine house.\textsuperscript{76} In his next despatch he reported the shaft was down to the seam at 11 yards but water had stopped the work while Henderson was installing a small pump to drain the works. The convicts would not work extra for 1s. 6p. so he had reduced the rations to normal.\textsuperscript{77} In February 1831 Parry was told by the Government he could sink an engine shaft 100 yards from the western boundary of the town, that he could mine coal under the town at depths greater than 100 feet and that water frontage

\textsuperscript{71} Historical Records of Australia, 1, vol 15, Sir George Murray to Darling, Despatch No. 73, 20 August 1830, p. 714.
\textsuperscript{72} Minutes A.A.Co. B, 160/90, p.42.
\textsuperscript{73} Sixth Annual Report of A.A.Co. January 1830.
\textsuperscript{74} Despatches, Parry to London, Folio 78/1/9, 1830, p. 365. The comment about the fluted columns confirms the engines were vertical cylinder types. This was a common design in the early 1800s.
\textsuperscript{75} Despatches, Folio 78/1/9. Copies of letters Parry to Colonial Secretary 20 May and 18 August 1830. This pit was to inspect a seam Henderson had located 11 yards from the surface.
\textsuperscript{76} Ibid., 10 September 1830.
\textsuperscript{77} Ibid., Folio 78/1/10, 20 September 1830.
for staiths (coal wharfs) would be granted abreast of the engine shaft. A contract was let to a Mr Moore to sink the engine shaft, internal diameter 9 feet 6 inches with an airtight central partition. The contractor was to supply all the tools and materials except gunpowder (apparently the convicts for this work were those already supplied and the contract rate of £3 10s. per yard did not include labour). Two shifts of 8 hours were to be worked.  

In June Parry wrote to London that Henderson was making good progress and his work was founded on sound scientific principles. The shaft with air partition in the centre was almost down to the working seam and would be completed as soon as the engine could pump out the water. A second shaft of smaller diameter for ventilation was completed. From the bottom of this shaft a tunnel would be dug two ways, one to the main shaft and the other leading out the side of the hill near the sea, all water would be discharged through this adit. One steam engine was being erected and would commence working in August. The boiler was being set on stone foundations brought from Sydney. The blacksmith shop was completed. A pile engine had been made locally and several piles driven eleven feet above high tide as the first stage of developing a staith (a wharf for loading coal). The inclined plane and level from the pit mouth to the wharf area was making rapid progress, one quarter of the length was inclined. He had agreed to take over all convicts from the government mine and would need to build company barracks, solidly walled, to house them. The first coal would be raised in about three months. 

In December 1831, Henderson wrote to Parry saying he intended to excavate the first twelve inches of foul coal at the top of the seam and throw it aside, then quarry the good coal in large pieces by wedges or gunpowder with no waste in small coal. He wished to instal the engine immediately. A drain would be arched with brick from the flat to enter the shaft somewhere below the upper seam to save pumping height. An inclined plane with tramway would be 4320 yards from the pit mouth to the shipping site on the river and the pit would work 213 acres dry, the coal available would be 2000 tons per acre allowing for pillars. This was called the ‘A’ Pit. It was the first mine in Australia to use the steam technology arising from the Industrial Revolution in Great Britain.

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78 Report by Parry and copy of letter from the Colonial Secretary in Despatch No. 33, 78/1/10
79 Despatch 46 in 78/1/11, 28 June 1831, p. 84
80 Letter Henderson to Parry, copy in Despatches 78/1/10, 17 December 1830. It is unclear whether this A Pit drained through the adit. Henderson indicated some pumping was required and Henderson said it was
During 1832 the company sold 6812 tons of coal from the A Pit. During the next twenty years the B Pit, C Pit and D Pits were dug and brought into production in 1838, 1846 and 1850 respectively without any major change in the technology being used. The cessation of the transportation of convicts after 1840 forced a changeover to the more expensive employment of free labour. In 1840 in anticipation of this change 100 Irish labourers and 40 Welsh miners were sent to Newcastle. In 1850 45,084 tons of coal were sold but by this time the equipment in use was obsolete, as working steam pressures had increased in new equipment. A major upgrade of equipment was made in the following years.

During the early negotiations in 1828 regarding the company taking over the coal mine, the Court had interviewed Sir George Murray, the Secretary of State, who told the members that the idea of the company working the mine had originated on the recommendations of the Bigge report and that a grant of land in fee simple would be made as the Charter of the company prevented the leasing of the mines. He said he was not placing a monopoly in the hands of the company, that there was a large amount of coal available and other grants could be made. Davis, one of the Directors, said the company understood the Government would not compete by mining coal nor would it grant coal mining rights to any other company, but the company did not oppose private individuals working coal on their own lands. However on 31 July 1828 Murray sent instructions to Darling that for the next 31 years no Governor was to grant any coal mine or lands containing any coal mine, without specific exception of the coal in such a grant. Several small coal mines began operating on private land in the 1840s but were tolerated until 1845 when the company took J. and A. Brown, who had developed a small coal mine near Maitland, to court for selling coal to the Hunter River Steam Navigation Company. The case went to the Supreme Court in Sydney which found the

unlikely the adit reached the sea because the town intervened. Perhaps the small engine was used to pump from the bottom of the pit to the drain which entered the shaft higher up.


I am indebted to Dr. P. Pemberton for access to her notes on the minutes on the A.A.Co. and for discussions on the company history.


Minutes of A.A.Co. B, 13 June 1828, pp. 148-50. It was later presumed by others that this meant that coal could be mined on lands alienated before this agreement without infringing any monopoly.

Historical Records of Australia, 1, XIV, p. 272-4.
Browns guilty of intruding on the reserves of the Crown and awarded damages of one shilling against them. Their mine was closed. This decision gave certainty to the question of whether the company had a monopoly, but the monopoly was unpopular and the company negotiated changes to the agreement which were announced in Sydney on 17 August 1847. The company gave up its monopoly rights to coal mining in return for a fee simple tenure on 500,000 acres of pastoral grant. The uncertainty about the rights of the company had inhibited others mining coal until the agreement of 1847, even though several, besides the Browns, chanced their luck. The perceived coal monopoly had never been popular in New South Wales; the company had opposed coal mining at Port Phillip (later Victoria) early in La Trobe’s superintendence, opposed immigration to Morton Bay (later Queensland) where coal had been found, and opposed the formation of the Australian Gaslight Company in Sydney. The small coal companies founded in New South Wales in the 1840s cut the price of coal and when the Australian Agricultural Company won the case against the Brown brothers it was seen by the public in the colony as a monopolist organisation, interested in raising prices and in profits for English investors and not interested in local community advancement.

The company managed to avoid major labour problems in the first years of the goldrushes by sending out miners from Great Britain; 29 arrived in 1851 and a further 50 in 1853 and the coal mines continued to work during this period with only a small reduction in output which soon recovered. In 1851 the company’s production was 45,600 tons of a total coal production of 67,600 tons in the colony.

A small coal mine was started in 1833 at Coal Mines Station in Tasmania under the control of the Port Arthur penal settlement. An adit was dug by convicts, into the seam from the beach to access the coal and a shaft soon replaced the adit. A steam engine made at the Derwent Foundry in Hobart was installed in 1841 on this shaft for pumping and winding the coal. A new shaft, about 100 feet deep, was dug in 1842 to give better

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91 Ibid., pp. 32, 39.
92 A.A.Co. Annual Reports, 1849-53 passim.
93 Ellis, *A Saga of Coal*, p. 39. Coal exports to the Americas were developed in the late 1840s but declined during the 1850s as labour problems disrupted the mining industry. Exports were negligible by 1860. See Gregson, p. 240.
access to the seam and the steam engine was transferred to the new shaft. A circular shaft lined with stone was dug for ventilation. The convicts were withdrawn in 1848 and a series of private lessees continued intermittent mining until the 1860s.

Coal was the first mineral mined at Coal Harbour (Newcastle) in Australia, commencing in 1801 using convict labour under the management of military officers. The small colony had no local sources of capital and hand methods were used. After 1826, when the Australian Agricultural Company, a joint stock company registered in London by act of parliament, took over the mine, experienced management staff was sent from Britain and adequate British capital became available to provide steam engines for pumping the mine and erecting staiths (wharfs) for shipping the coal. Convict labour was phased out in the 1840s and replaced with skilled miners from Britain.

### Metalliferous Mining In South Australia and New South Wales 1836 – 1852

In 1834 a bill to establish a colony in South Australia was passed by the British Parliament. This bill required the appointment of a Board of Commissioners to share the administration with appointed government officials. George Fyfe Angus was appointed a Commissioner in May 1835. Difficulty was experienced in selling the land granted to the Commissioners at the required £1 per acre and Angus made an offer of 12s. per acre which was accepted and he then formed a joint stock company, the South Australian Company, which purchased 13,700 acres at the agreed price and was granted the pastoral rights to a further 220,000 at 10s. a square mile. At this time the purchaser of land in South Australia had exclusive rights to any minerals on that land.

The South Australian Company appointed Johannes Menge, a German mineralogist, as ‘Mine and Quarry agent and Geologist’ on 1 July 1836, and engaged four German miners to assist him and ‘work the quarries of stone and lime and procure additional supplies of water from artesian wells’ on company land. Menge had an argument with the manager of the company and was sacked in June 1838. He was not particularly interested in opening mines but was very interested in publicising the presence of

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95 *The Australian Encyclopaedia, 5th Ed.*, pp. 139, 2667 - 73.
minerals, and in 1841 published a booklet *The Mineral Kingdom of South Australia* as well as publishing a list of local minerals in *The South Australian Almanac of 1841.*[^97] He predicted gold would be found in South Australia and that the colony would have the greatest copper mines in the world.[^98] He explored the south east of South Australia and no doubt told shepherds and others he met how to identify minerals.

A small silver, lead orebody was discovered at Glen Osmond, in hilly country, a few miles east of Adelaide in 1840. Three small mines were developed on this orebody by the South Australian Mining Association, Osmond Gillies and Mr Peachey respectively to work this deposit from adits and shafts with stoping at several levels; Wheal Gawler in 1841, Glen Osmond Mine 1842 and Wheal Watkins in 1843. German and Cornish miners were employed. About 2500 tons of hand sorted ore averaging 70 percent lead and 20 ounces of silver per ton was produced from the three mines. At first the ores were shipped to London. A small reverberatory furnace was erected in 1849 by the Glen Osmond Union Mining Company but it produced only a small amount of metal before all three mines closed when the miners left in 1851 for the goldrushes in New South Wales and Victoria. ‘Wheal’ was the Cornish name for a mine.[^99] Also during the 1840s several copper mines were developed; at Kapunda in 1842, Montecute 1843, Burra Burra 1846, South Rhine 1846, Kanmantoo 1847 and others. All were closed by 1852 as miners left for the eastern goldfields. Short lived small alluvial goldfields were opened at Onkarparinga and Echunga in 1850 and 1852 respectively.[^100]

In this period the copper and lead mines were shallow, entirely within the oxidised zone and worked on the Cornish system of tut work, tun work and tribute. Tut work consisted of shaft sinking and excavating development drives on wages, at this time an average weekly rate of 30s. per man. Tun work was piece work where a miner dug and selected higher grade ore underground, the rate was 18s. per ton. One man could grade about 2 tons per week. Tribute was where a party of miners tendered for a section of the orebody and received a tenth of the value of the high grade ore they raised and a varying scale for lower grades. If a tribute party was lucky and struck a rich patch their wages were high but if the patch was low grade they would not make expenses. The company

would then pay a subsistence of 15s. a week which was refunded if that party later had a better patch.¹⁰¹

Only the Kapunda and Burra Burra mines reached substantial size in this period. Both were controlled by South Australians; Kapunda by the owners of the land, Francis Dutton and Charles Bagot, and Burra by Adelaide businessmen who had registered the South Australian Mining Association (a different company to the now defunct company at Glen Osmond) with a company structure similar to that of the English cost book company.¹⁰² Both German and Cornish miners had been migrating to South Australia since the early 1840s; the Germans were assisted to emigrate by the Hanoverian Government because the lead mines in the Harz Mountains in Hanover were closing, and other miners came from Cornwall which was in depression because the rich South Australian mines and new mines in Chile were competing with the Cornish mines.¹⁰³

The Kapunda owners employed Cornish miners with Bagot supervising, but a surveyor, William Oldham, was later appointed mine captain (the Cornish title for mine manager) and the mine developed on Cornish practice.¹⁰⁴ At the Burra Burra mine, Ferdinand Ey, an ex Harz miner was appointed superintendent, but he was soon in trouble for drinking and absenting himself to Adelaide without the permission of the company secretary, Henry Ayres, and was sacked. Captain Roberts, a Cornishman, was appointed for a short time and after Captain Roach was appointed in 1847 Cornish methods were used to develop the mine.¹⁰⁵

The copper ore from the surface to the waterline was oxidised to copper carbonates and copper oxides and could be dug with a pick in the stopes, loaded into low wheelbarrows, wheeled to the shaft where it was shovelled into metal kibbles (buckets), and raised to the surface with a windlass using hemp ropes. At greater depths in harder ground hand drills and hammers were used to drill holes between one and two inches diameter which were then charged with gunpowder, tamped with a wooden rod and

¹⁰¹ These rates were quoted by a visiting reporter to the Burra Burra mine in the *Sydney Morning Herald* 3 May, 1851. The other metalliferous mines in South Australia would have paid similar rates.

¹⁰² M. Davies, "The South Australian Mining Association: An Early Australian Cost-Book Company," *Australasian Mining History* 1, no. 1 (2003): pp. 31-50. This was the second South Australian Mining Association, the first having collapsed. The new company was floated on 5 April 1845 with a paid up capital of £12,320 of which £10,000 was paid to the Government for the land, leaving £2320 as working capital. The surface ore was very rich and within 12 months some 1200 men and boys were employed.


¹⁰⁵ Auhl, *The Story of the Monster Mine*, pp. 70-1 and 86.
fired using a fuse of gunpowder wrapped in greased paper. When the shaft reached around 100 feet the windlass was replaced by a horse driven whim with two buckets in balance moving up and down the shaft, which was usually rectangular to accommodate the two buckets. A whim boy guided the horse alternately in one direction then the other to raise and lower the full and empty buckets. The ore was found in narrow veins in the country rock and the miners used the barren material enclosing the veins (attle) in the stopes and from the development drives to backfill the stopes so as to prevent the walls collapsing. The richer ore from each party was sent to the surface where it was graded by hand methods, stacked in heaps depending on grade, and the heaps were then assayed so payments to each party could be calculated. Two independent assays were made. The ore was then bagged for shipment overseas.\textsuperscript{106} As can be seen from illustrations of Cornish practice in the late 1700s this technology was a direct transfer of Cornish copper mining technology.\textsuperscript{107}

At regular distances down the shafts, plats or open areas were excavated from where drives were dug horizontally to develop the orebody. When the shaft reached the waterline around 100 feet, buckets were used to bail the water from a sump by whim. By 1849 both mines were making water in such quantities that several whims were unable to cope and the Kapunda mine installed a pump driven by a second hand imported beam engine with a double acting vertical cylinder 30 inches diameter producing about 35 H.P., while the Burra mine installed a similar machine with a 50 inch cylinder producing 83 H.P. both built in Cornwall. At each mine the engine houses were made of local stone, with the cylinder rod moving the inside end of the beam up and down about a solidly supported pin at the centre, while the other end raised and lowered the pump rod at a rate between 4 and 12 strokes per minute and with a stroke of 8 to 10 feet. The wooden pump rod went down the shaft to a bottom lift with a plunger and moved a piston on the up stroke so water was lifted by air pressure to about 20 feet above sump level, a valve in the sump closed at the top of the stroke and on the down

\textsuperscript{106} Charlton, The History of Kapunda, Sketch opposite p. 18. The sketch shows the surface workings at Kapunda about 1844. A whim drives two ropes passing over headsheaves on a small headframe, down the shaft. Two men stand at the shaft mouth to empty the buckets. The ore is being sorted at a table by boys and then bagged. At this early stage of development attle is stacked on the surface.

\textsuperscript{107} W. Pryce, Mineralogia Cornubiensis (London: James Phillips, 1778). See the several illustrations of mines.
stroke water in the pipe was forced past a second valve into a rising main and to the
surface.\textsuperscript{108}

The harder ore from below the water line could not be easily broken into small lumps by
hand for transport in bags or for smelting and was better crushed by rolls. These were
called Cornish rolls as they were used extensively in Cornwall at this time to crush
copper ores. They consisted of two parallel rotating steel cylinders, each about 12
inches diameter, spaced a few inches apart so the ore was nipped as it entered the rolls
and reduced in size. Beam engines with rotative mechanisms drove the rolls. The
machine with a 30 inch cylinder which was installed at Kapunda in 1848 for pumping
was also used to drive a set of rolls, and a similar installation was in use at Burra in
1850 for crushing. However the machine at Kapunda was soon overloaded and a Bull
pumping engine with the piston rod connected directly to the pump rods was installed
for pumping only, leaving the other machine free for crushing.\textsuperscript{109}

The high grade oxidised copper ores found near the surface at the South Australian
mines were bagged and sent to Wales for smelting. Bagot had approached the
Australian Agricultural Company about smelting Kapunda ores at Newcastle in 1845,
but the company was at that time involved in litigation about its monopoly and was
uncertain of its future and nothing eventuated from the enquiry.\textsuperscript{110} George Dreyer and
his two sons, with smelting experience at Clausthal in the Harz, arrived in Adelaide in
1845 on the same ship, Patet, as Ey. Ayers employed them to erect a smelter at Burra,
using wood and charcoal as fuel. The smelter began operating in 1847 and was
successful technically but the expenses of smelting were greater than the costs of
sending the ore overseas and the smelters were abandoned soon after.\textsuperscript{111} Ayers then
arranged for the Patent Copper Company of London to construct a smelter at its own
expense at Burra on the agreement that ore from the mine would be sold to the smelter
for processing. The first superintendent, Thomas Williams, arrived in Burra in 1848
with 30 Welsh smeltermen and constructed a smelting house containing 16 wood

\textsuperscript{108} G. J. Drew and J. E. Connell, \textit{Cornish Beam Engines in South Australian Mines} (Adelaide: S. A.
\textsuperscript{110} J. W. Turner, \textit{Manufacturing in Newcastle, 1801 - 1900} (Newcastle: Council of the City of Newcastle,
1980), p. 35.
\textsuperscript{111} Auhl, \textit{The Story of the Monster Mine}, pp. 18, 166.
burning reverberatory furnaces which began operating in 1849. These operated successfully and were later expanded. The company was named after a patent taken out in England by Napier. Full details have not been located but from information in a book on metallurgy published in 1854 the process was still new in 1854. Auhl states the patent was held by Schneider & Co. in Wales in 1848 so it was probably patented after 1845. It reduced the stages in smelting copper from 10 to 5, and was much cheaper than Welsh smelting techniques but had not completely replaced these by 1854. If this is correct the transfer of the technology to Australia was very rapid. In a smelting mania other smelters were erected by various companies at Callington, Port Adelaide, Apoinga, Kanmantoo and Kapunda in 1849 and a lead smelter was erected at Glen Osmond, but all except the Burra works were closed by the end of 1851 as the workers left South Australia for the gold rushes in New South Wales and Victoria.

The first copper mines in New South Wales were opened at Copper Hill near Molong, not far from Bathurst, and near Canowindra in 1844–1845, and in December 1848 the prospectus was issued in Sydney for the Bathurst Copper-mining Company, seeking to raise capital of £900 in 30 shares. The mine was then being worked at Summerhill, 25 miles from Bathurst, on an estate of 1500 acres belonging John Clements, and the company secured the right of mining for 21 years from the owner. Smelters were erected at both mines. In his 1908 report on these mines J. Carne noted that in 1846 the Mining Journal of London was advocating the use of the coal resources of New South Wales to reduce the metals from the ores instead of shipping them abroad. He also noted that Governor Sir Charles Fitzroy in 1849 urged the expediency of a geological and mineralogical survey of New South Wales following the success of copper mining in South Australia.


116 Ibid., p. 7.
The Production of Pig Iron

Richard Dawson established what was probably the first iron foundry in Australia in Sydney in 1833, working with pig iron imported from England. The Australian Agricultural Company had imported a small furnace to melt pig iron for maintenance of equipment at their coal mine in 1828 but it was probably not installed until 1832. The first attempt to produce pig iron from iron ore on a commercial scale in Australia was made at Nattai near Mittagong in New South Wales in 1848, when a local businessman, John Neale joined with Sydney business men Thomas Holmes, and Thomas and William Tipple Smith to form the Fitzroy Iron Mining Company. William Smith had a lapidiary and jewellery business and his brother was a builder. It was intended to exploit a local limonite iron ore deposit averaging 48 percent iron, charcoal was to be made from local timber for fuel and a suitable limestone for flux was found on the property. Mr Povey, an ironworks expert, was engaged in England to manage the works and thirty experienced ironworkers were brought from England. The optimistic promoters called the settlement ‘New Sheffield’. The initial capital was raised in Sydney. The works, 50 miles from Paramatta, which were opened by Governor Brisbane in 1850, consisted of a small Cataline blast furnace and a foundry to process the pig iron. There must have been a puddling furnace as a tilt hammer was purchased at this time for making forgings and this would have been necessary if the pig iron was being converted to wrought iron by puddling and hammering. A rotative beam engine drove a fan for the cylindrical blast furnace and a smaller steam engine provided the blast for the cupola used to melt the pig iron for use in the foundry. The partnership was reorganised in 1851 and new capital was raised.

Conclusions

The first organised mining in Australia was for coal at Coal Harbour, later called Newcastle, in 1801 when Governor King sent a small party of soldiers and convicts.

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118 See p.8.  
121 Silver, A Fool's Gold, p. 26. Hughes, The Australian Iron and Steel Industry, 1848-1962, pp. 2-7. Hughes said an old puddling furnace was reconditioned in the early 1860s which is further evidence that it was built in the first development.
there to dig coal for use in Sydney and possibly for export. The getting of this coal was by manual methods with picks, shovels and baskets with access to the coal seam through an adit. By 1820 access to the working area was from a shaft with the coal being raised to the surface with a windlass. Gunpowder was used to sink the shaft. Working conditions underground were bad as a result of poor ventilation in the working area.

The Australian Agricultural Company, a joint stock company incorporated by an act of the British Parliament, was established to exploit the agricultural resources of New South Wales. In an attempt to reduce the running costs of the penal settlement the British government induced the company to take over the coal mine and in return was granted monopoly rights to all coal mining in New South Wales in 1828. Current British technology was introduced with the bord and pillar system of extraction, low pressure steam engines for mine winding and pumping, coal wagons moving by gravity from pithead to the wharf, and the mechanical loading of the coal into ships. Working conditions were improved with an air shaft adjacent to each pit to provide natural ventilation. In 1847 the company relinquished its monopoly rights, which had inhibited but not entirely prevented other small coal companies from mining, and so removed any restrictions on their expansion. By this time the actions of the company in opposing new coal mines and court action against a small competitor had made it very unpopular in Sydney and Newcastle, and it was seen as monopolistic and benefiting the British shareholders to the detriment of local development.

When the settlement of South Australia began in 1836 the South Australian Company, also a British joint stock company and a large landholder in the colony, employed a German mineralogist, Johannes Menge, to advise on possible mining development, quarrying and artesian water supplies. Over the next few years Menge published much information about minerals in local newspapers and journals. As a result several lead, silver and copper orebodies were found in the colony and by 1845 several mines were in production. The largest and most remunerative orebodies were at Kapunda and Burra Burra. Both contained large amounts of high grade oxidised copper ore, exposed at the surface, the orebodies being so soft they could be dug from the surface by pick and shovel, graded by hand and the rich ore sent to Wales for smelting. The Kapunda mine was financed by the landowners, Bagot and Dutton, who employed miners from
Cornwall who introduced Cornish mining techniques. The Burra mine initially employed a German miner Ey, trained in the lead mines of the Harz Mountains, as manager, but soon replaced him by Cornish managers. It is likely that this decision was due to personal differences not technical efficiency, as Ey was later employed by another company to manage a mine nearby. German smelter technicians were employed to build a copper smelter at Burra using charcoal as fuel but this proved uneconomical and was abandoned. An agreement was then made with a London joint stock company to build a smelter at Burra using Welsh technology and wood, coal or charcoal as the fuel. The smelter bought ore from the mine. The transfer of this latest Welsh smelting technology was quick probably because the firm concerned, Schneider & Co., owned a recently granted improved smelting patent and believed it could make substantial profits by smelting the rich Burra ores at the mine. This smelting at the mine was a departure from British practice where Cornish ore was shipped to Welsh coalfields for smelting. High land transport costs in Australia at this time made it more economical to smelt at the mine and cart the refined ore to the coast for shipping. By 1849 additional smelters were operating at Kapunda, Port Adelaide and several other places in South Australia close to other producing mines. Some small copper mines were started in New South Wales in the late 1840s by individuals and small local companies on private land. Smelting was done locally using Welsh technology. As copper mining developed, more Cornish and German hard rock miners and German and Welsh smeltermen migrated to South Australia and New South Wales. The mines soon reached the groundwater line and bailing the water with buckets proved inadequate and was replaced by medium pressure beam steam engines driving Cornish pumps to dewater the mines.

In 1848 the first attempts to establish an iron industry were made at Mittagong in New South Wales. The venture was financed with Sydney capital and staff experienced in iron smelting were imported to operate the plant which was built to British designs.

In this period all mines, coal or metalliferous, in New South Wales and South Australia operated under laws derived from British practice which gave the landowner control of any minerals other than gold or silver, which remained the property of the Crown. Once the land had been alienated by grant or purchase the owner could mine or not mine minerals as he wished and mining was not controlled in any way by governments. The discovery of gold in California in 1848 focussed attention worldwide on gold, and
within a few months of the end of this period similar discoveries in New South Wales and Victoria ushered in a time of upheaval in which large numbers of people migrated to the colonies, and mining laws were changed and adapted to meet the changed circumstances as democratic ideas forced changes in the ways governments operated. This period will be considered in Chapter 2.
Chapter 2

The Australian Goldrushes – 1851 to 1855

Introduction

Europe in 1848 was a hotbed of political ferment with democratic movements attempting to wrest power from autocratic governments. These movements were unsuccessful, and many people sought to migrate to the United States where cheap land was attractive to those who wished to escape political or religious persecution. Many more had been badly affected by the famines of the 1840s, particularly in Ireland and saw migration as a solution to their problems. Cornish and German mines were facing increasing competition from overseas mines and many of the miners saw migration as likely to lead to a more prosperous future. These multiple pressures to migrate from Europe were to profoundly effect the development of mining in Australia during the 1850s.

News of the gold rushes to California from 1848 was received with great interest in Australia and many left Sydney for San Francisco. The alluvial mining technology in use in California had come from Europe via the eastern United States and from South America. Not all the Australians were successful in finding gold and many returned during 1850 after having learned the methods of prospecting and digging for alluvial gold. Some returned with the belief that they would find gold in Australia. One of them, Edward Hammond Hargraves, started on a prospecting trip to the Bathurst area west of Sydney soon after he returned to Sydney, found a small amount of gold in early 1851 and embarked on a one-man campaign to force the government of New South Wales to change British based mining laws, so as to allow a miner or a small group of miners to peg a claim and extract and keep any gold on that claim as had been the practice in California.

124 Cornish and German miners were already migrating to New South Wales and South Australia to work in the copper mines as discussed in the previous chapter.
This chapter will look at the way Hargraves achieved this objective, how his actions resulted in a flood of miners (experienced and new chums alike) from the Australian colonies and overseas and the effect of this influx on mining law in New South Wales and in Victoria (which became a separate colony on 1 July that year). The technologies used in alluvial and reef mining for gold, which were introduced in the rush will be discussed. Chinese miners began to arrive in large numbers in 1854 and brought skills in alluvial mining, gained from mining tin in Malaya, which were similar to the technologies already imported from California. They brought few skills in reef mining and very few were involved in this type of gold mining. Their contribution to technology development will be discussed briefly in this chapter. Finally consideration will be given to the growing resistance to the licence fee, the way in which the goldfields were administered, and government support for a return to company mining (which resulted in the Eureka uprising and which was followed by widesweeping changes in the mining law).

**Edward Hargraves as entrepreneur**

When the first news of the finding of gold in California reached Sydney in 1848, followed by the arrival there of a ship carrying 1200 ounces of Californian gold, many Australians, including Edward Hammond Hargraves, took passage to San Francisco in the hope of amassing a quick fortune. After some eighteen months mining for alluvial gold with moderate success, Hargraves returned to Sydney in January 1851 with the firm belief that gold also existed in New South Wales. In earlier years others had reported the existence of gold in Australia. Paul Strzelecki found gold in quartz in 1839 and showed his specimens to Sir Roderick Murchison, a prominent geologist, when he returned to England. From his knowledge of gold bearing ores, Murchison predicted gold in quantity would be found in New South Wales and published his prediction in 1844. Later the Reverend William Clarke, who knew of this prediction, also claimed to have found gold and reported his find to the Government, but did not publicise his

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127 Ibid. In Chapter III Hargraves described his Californian experiences, how he learned the techniques of mining alluvial gold and of his and others realization that the physical appearance of the Californian goldfields was similar to areas west of Sydney.

128 Ibid., p. 111.
find.\textsuperscript{129} In 1846 William Tippet Smith offered to show the government where he had found gold and shepherds were selling gold to jewellers in Sydney and Melbourne but none of them made any move to start a goldrush.\textsuperscript{130} In late 1848 the sale of gold by a shepherd to a Melbourne jeweller led to a small number of people digging at Daisy Hill in the Pyrenees region of central Victoria. Charles La Trobe, the Superintendent of the Port Phillip district, sent a party of police to disperse the diggers because they did not have authority to dig for gold which belonged to the Crown.\textsuperscript{131} La Trobe did not consider changing the law to allow them to dig.

Hargraves made it clear in his book, published in 1855, that he had no intention to dig for gold in Australia but to start a rush and then claim a reward from the government.\textsuperscript{132} Soon after arriving in Sydney in late January 1851 he set out for the Bathurst district where he believed he would find gold because the appearance of the country was similar to California, but on the way stopped at the Guyong Hotel where he met the owner Mrs Lister, who arranged for her son to act as a guide. On 12 February, Hargraves and John Lister went to the Summerhill Creek, north west of Bathurst, where Hargraves showed Lister how to fossick for gold and collect the soil and wash it in a dish to separate the gold. They had a trowel, a pick and a light steel dish and found several specks of gold. Hargraves, Lister and James Tom, a friend of Lister, prospected along the Macquarie River and found traces of gold all the way. Hargraves then showed them how to make a cradle and how to use it to wash the soil for gold.\textsuperscript{133} Although several isolated finds of gold - both alluvial and in a quartz matrix - had been made previously in Australia, there


\textsuperscript{130} Hargraves, Australia and Its Goldfields, Ch. IV. Hargraves discussed all these claims of discovery but disparaged Clarke’s claim to any reward because his find had not been publicized. It is likely he was worried about the validity of Clarke’s claim.

\textsuperscript{131} J. Flett, The History of Gold Discovery in Victoria (Melbourne: The Hawthorn Press, 1970), p. 254. British Parliamentary Papers, (Shannon: Irish University Press, 1969), No. 14, Despatch No. 1, La Trobe to Grey, 25 Aug.1851, p. 70. Documents in these despatches from Sir Charles Fitzroy and Charles La Trobe contain much information about the first discoveries and confirm Hargrave’s statements about his dealings with the government. In a despatch No. 4 of 11 June 1851, p. 8 Fitzroy said he had been wary when Smith reported his find because he had been concerned for years that the finding of gold in the colony would agitate the public mind and divert the attention of persons engaged in industrial pursuits from their proper avocations. Events had proved him right.

\textsuperscript{132} Hargraves, Australia and Its Goldfields, p. 122. S. Davison, The Discovery and Geognosy of Gold Deposits (London: Longmans, Green, 1860), p. 52. Davison was a partner with Hargraves in California. Hargraves told him of his plans to return to Australia, find a goldfield and become a Gold Commissioner.

\textsuperscript{133} Hargraves, Australia and Its Goldfields, pp. 114-21.
was no understanding of where and how to search for gold in a systematic way using hand tools and a cradle (called a rocker in California).  

Hargraves returned to Sydney, reported his find to the Colonial Secretary, Deas Thomson, and claimed a reward. In the meantime Lister, James Tom and his brother William had cradled four ounces of gold and told Hargraves of this by letter. Hargraves arranged for a letter to be written to the *Sydney Morning Herald* (published on 29 April) implying that he had found this gold, then went to Summerhill Creek where he purchased three ounces from the others. They had previously formed a partnership of four to share the finds. He then continued to the town of Bathurst and called a public meeting, announced the discovery as his own and showed the gold. This meeting was reported in the *Bathurst Free Press* on 10 May. On that day, Hargraves and a party of 37 horsemen met the Government Geologist, David Stutchbury, by previous arrangement at Summerhill Creek, where the Tom brothers were cradling and after an inspection of the area Stutchbury wrote to his superiors that he had seen ‘sufficient to prove to me the existence of grain gold’. Hargraves was granted a £500 reward on the grounds that the finding of gold would lead to the cessation of convict transportation and stop migration to California.

This illegal mining of gold was unprecedented in British mining law. The government was also afraid the miners would take charge of the goldfields. The response was to appoint John Hardy, then a magistrate in Paramatta, to be the first gold commissioner with the powers of a Commissioner of Crown Lands to take control of the diggings with the assistance of a small detachment of troopers. After receiving a further letter from Stutchbury that there were now large numbers digging along the

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136 *Report of Royal Commission on Conditions and Prospects of the Goldfields*, (Melbourne: Government Printer, 1863), Appendix A. The Commission sought legal opinion and were advised that all mines of gold and silver were Royal mines, that is the gold and silver belonged to the Crown. Mining without permission was illegal.
creek, the government issued a proclamation on 22 May, stating that gold in its natural state on lands of the Queen, or subjects of the Queen, belonged to the Crown and that any unauthorised person digging for gold would be prosecuted. Hargraves claimed that he had advised the government about a licensing system that had been proposed in California. However Deas Thomson had also discussed developments in California with another ex-Californian, Alfred Bush, during an interview on 17 May when the proposed Californian $5 licence fee was mentioned. On 23 May, after consultation with Hardy, a second proclamation was issued setting the licence fee to dig for gold at 30 shillings a month. This fee was similar to that proposed for introduction in California but which was not implemented. In a further letter dated 22 May Stutchbury advised that Ophir, at the junction of the Lewis Ponds and Summerhill Creek, had a population of 1000 digging for gold and that lumps of gold between one ounce and four pounds had been obtained. In his first report from Summerhill Creek, dated 3 June, Hardy advised he had issued 102 licences on the first day and estimated there were 1500 digging along the creek. Hargraves had now achieved his aim of having sufficient people digging for gold that there was no possibility of the government halting the flood of people to the goldfields and refusing to give him the larger reward he was claiming.

This was a rush in which any person, able to acquire a few simple tools and prepared to work hard, could participate. As in California the miners soon realised it was more efficient to work in small groups, one to dig the soil, one to cart it to the washing area and one to wash the dirt, or some variation of this division of work. A welcome

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138 British Parliamentary Papers. No. 14, Despatch no. 3, enclosure 1, Proclamation 22 May 1851, Despatch No. 4. p. 17.
139 Hargraves, Australia and Its Goldfields, p. 122.
140 E. D. Potts and Potts, A., Young America and Australian Gold (St. Lucia: University of Queensland Press, 1974), p. 171. U.S.$5 would have been a little over £1 in sterling currency at this time but the duration of the licence was not mentioned. U.S. $5 was then worth about 25s. sterling.
141 British Parliamentary Papers, No. 14, Copies of letter Stutchbury to Thomson 22 May, p. 20, copy of minute of the Legislative Council 51/22 and 51/23 p. 28.. G. Blainey, The Rush That Never Ended (Carlton: Melbourne University Press, 1963), p. 23. Blainey said the wage of a labourer was 20s. per week at this time so the licence fee was substantial, particularly as finding gold was a gamble.
142 Higgins, Gold and Water - a History of Sofala and the Taron Goldfield, p. 12. The name Ophir was suggested by the father of James Thom.
143 British Parliamentary Papers, No. 14, copies of letters, Stutchbury to Thomson 22 May, Hardy to Thomson in minute 53/27, p. 31.
144 A. Smith, The Wealth of Nations, ed. M Adler, vol. 36, Great Books of the Western World (Chicago: The University of Chicago, 1990), Book 1 Chapter 1, Book 3 Chapter 1. This was a cooperative system not the capitalist system discussed by Smith but the same arguments of efficiency of labour apply.
145 J Pettit, "Letter to His Parents," (1853). Copy in author’s possession. Pettit’s party of 9 was formed in England before embarking on the Great Britain. They arrived in Castlemaine late January but by the end
extension of this principle of division of labour was to add a cook to the party so the remaining members could extend their working time each day. To relieve the monotony and to share the dangers the jobs were often rotated on a weekly basis.

At Ophir Hardy laid out the area of each claim, based on what he believed to be the likely return. The gravel and sand containing the gold was confined to a narrow strip on each side of the creek, with steeply rising hills on each side. His discussions with those mining when he arrived would have given him an estimate of the likely returns from areas along the creek. In July, after advice from Hardy, the government adopted the following claim sizes which became the norm on other New South Wales goldfields:

- 15 feet frontage to a stream for a party of three.
- 24 feet frontage to a stream for a party of six.
- Where there was no frontage to a stream 20 feet square for a party of three.\(^{145}\)

For further efficiency, parties soon acquired a cradle or made one themselves as the Tom brothers had done.

In a despatch on 11 June Fitzroy wrote to the Colonial Office that he trusted the licensing system would meet with approval, that licences would apply only to digging for gold and that whenever the gold may have to be extracted from the matrix by mining in the future, and probably no distant future period, capital, machinery and skill as well as labour would be required and employed to advantage by companies or individuals possessing the former. When that period arrived the mines could be leased or placed on such a footing as may be deemed most advantageous to Crown and Colony. In the meantime he was convinced the licensing system was the best and only system in the emergency of the moment.\(^{146}\) The government regarded the licence as a temporary device to cope with the flood of miners to the goldfields and they expected the rushes would be short lived and that conditions would return to normal, that is to a pastoral life of March the original party was down to three and they added an additional member. H Stacpoole, J., *Gold at Ballarat* (Kilmore: Lowden Publishing, 1971), pp. 28-9.  
\(^{145}\) *British Parliamentary Papers*, No. 14 Despatch No. 6, p. 65, Instructions to Assistant Commissioners, July 1851.  
\(^{146}\) Ibid., No. 14, Despatch Fitzroy to Earl Grey, No. 101, 11 June 1851. The reference to matrix mining was related to the British experience of forming companies to mine in South America where substantial profits were made and repatriated to London. One such company was the St. John d’el Ray Mining Company, then mining in Brazil and making substantial profits using slave labour. See J. Woodland, *Sixteen Tons of Clunes Gold* (Clunes: Clunes Museum, 2001), pp. 13-14. This dispatch shows that Fitzroy and Thomson had lost control of the rushes and had been forced by events to adopt an expedient which they hoped would be shortlived. The finding of several large goldfields in Victoria destroyed that hope.
economy with low wages and where every person knew his place in an ordered society. It was not to be.

As the number of miners increased at Ophir after the initial find was publicised and the available auriferous area was taken up, the newcomers and those whose claims were worked out moved down the creek to the Macquarie River and up the Turon River. From these areas they moved north, east and west, finding new alluvial fields at Tambaroora, Hill End, Braidwood, Stuart Town and further afield.\(^{147}\)

The *London Mining Journal* first reported the finds in New South Wales on 13 September 1851, with the news that £20,000 of gold had been found, and suggested that this find would give impetus to emigration which would populate the South Pacific with Anglo Saxons. It also advised that Thomas Arbruthnot had arrived in London with £4000 of Australian gold. While cautioning mining companies that such large finds may cause the price of gold to fall, it suggested the field could be remunerative. In December the *Mining Journal* contained the prospectuses of several gold mining companies raising funds to mine for gold in Australia. On 7 February the Port Phillip and Colonial Gold Mining Company advertised its prospectus and the intention to raise £150,000.\(^{148}\) On 6 March the *Mining Journal* discussed the merits of emigrating to either Australia or California and favoured the former because the colonies were dependents of Great Britain where British law applied.

Hargraves was famous, he was acknowledged as the discoverer of gold in Australia, was later given a further reward of £9500 by the New South Wales government for his contribution to the development of the economy, appointed to the new position of Exploration Commissioner of Crown Lands (with a roving commission to find more goldfields in that colony at substantial remuneration) and was later appointed to similar positions in Victoria, Tasmania, South Australia and Western Australia (where he was singularly unsuccessful in finding new fields).\(^{149}\) Some derided his ability as a

\(^{147}\) Higgins, *Gold and Water - a History of Sofala and the Turon Goldfield*, pp. 27, 32.

\(^{148}\) *The Mining Journal, London* and *The Mining Journal, Railway and Commercial Gazette*. This Journal, first published in 1834, provided information to the investing public on mining shares and mining company profits, both local and overseas as well as developments in mining technology.

geologist, a defect he freely admitted.\textsuperscript{150} He was also accused of duping Lister and the Tom brothers of their rewards for being the first to find gold in commercial quantity.\textsuperscript{151} However these criticisms should not detract from Hargrave’s role in the initial development of gold mining in Australia.

During his stay in California Hargraves had observed how a gold rush could be started by careful publicity.\textsuperscript{152} His actions at Bathurst show he had planned how he would publicise the existence of gold at Ophir and how he would attract miners to the field in sufficient numbers that the government would be powerless to stop the rush. He played on the democratic spirit of the age and the desire of many to be their own masters, in order to convince sufficient numbers to desert their low paid jobs hoping to gain a fortune from gold. His aim was to make his own fortune from government rewards. He achieved his aim in the first five months of 1851 and in doing so completely destroyed the ability of the government to enforce the mining laws existing at the start of the rush. For the first time in New South Wales mining for gold by individuals and small parties became legal after the payment of a licence fee. As will be shown later in this and succeeding chapters this apparently small change (which Fitzroy believed would be rescinded when the rush subsided), led to major changes in mining law in the colony of Victoria; changes which the miners themselves helped to draft. This complete revolution in British mining law in Australia was not fully achieved until the passing of the Mining Statute in Victoria in 1865, which set the pattern for gold mining law in the other Australian colonies. Further revisions to the Mining Statute resulted in all minerals being classed as royal minerals, a concept now accepted in all Australian states. The Australian economy was also changed from a low-wage pastoral economy to a high-wage mixed economy with a much enlarged population.

In later years some writers have presented the view that Hargraves was a bright and greedy, but rather ignorant individual who saw an opening to make money and exploited it successfully but whose activities were rather disreputable.\textsuperscript{153} This

\textsuperscript{150} Roberts, \textit{The Role of Government in the Development of the Tasmanian Metal Mining Industry 1803 - 1883}, p. 57. Davison, \textit{The Discovery and Geognosy of Gold Deposits}, p. 69. Davison wrote that he met Hargraves at Bendigo in 1852 and they joked about the title as Hargraves had no ability as a prospector.


\textsuperscript{152} Davison, \textit{The Discovery and Geognosy of Gold Deposits}, p. 52.

\textsuperscript{153} Roberts, \textit{The Role of Government in the Development of the Tasmanian Metal Mining Industry 1803 - 1883}, pp. 56-8. Hargraves was invited by the Tasmanian government to search for gold on the island.
description agrees with the comment made by Israel Kirzner that there is a widespread view in Australia that entrepreneurs have these characteristics. In a lecture in Adelaide in 1984 Kirzner presented a rather different view of entrepreneurs:

To repeat, I do not claim that that entrepreneurs are moral heroes. I claim instead that the remarkable set of institutions that make up the entrepreneurial market system is able to harness important human characteristics, important human attributes, to the benefit of society.\textsuperscript{154}

Hargrave’s actions in 1851 should be considered from this viewpoint in that he had a profound effect, not only on the economic development of Australia but also on the development of mining technology. Deas Thomson took this view as he argued very strongly in the New South Wales Legislative Council that the total reward of £10,000 be given to Hargraves.\textsuperscript{155}

In June 1851, when the upheaval of the licence system was at its peak, three aboriginal shepherds called Daniel, Jimmy Irvin and Tommy showed their employer Dr Kerr a large nugget they had found on the surface, on his station near Louisa Creek (now called Hargraves in the NSW central tablelands).\textsuperscript{156} The doctor appropriated the nugget and rewarded his employees with two flocks of sheep, a dray and bullock team.\textsuperscript{157} The Great Nugget Quartz Vein Mining Company was formed in Sydney in September to develop the reef which had shed the Kerr nugget, and in November Gideon Scott Lang (the manager of the company) wrote to the government suggesting modifications to the additional set of regulations published on 7 October. He said the leases should be 160 acres in area, the security for the lease should be £500 not £2000, and that 18 months be allowed to erect machinery not six months. On 19 March the regulations were amended to suit Lang’s requests.\textsuperscript{158} Later in 1852 the Great Nugget Quartz Vein Mining Company, with local capital, was incorporated in Sydney by Act of the New South Wales Parliament.\textsuperscript{159}

\textsuperscript{155}Davison, \textit{The Discovery and Geognosy of Gold Deposits}, p. 113.
\textsuperscript{158}British Parliamentary Papers, No. 14, Despatch No. 5, 1 Jan. 1852, enclosure no. 7, appendix no. 4, 10 Nov. 1851, Despatch No. 9, 8 July 1852; Consolidated and Amended Regulations of 29 March 1852.
\textsuperscript{159}S. Salsbury and K. Sweeney, \textit{The Bull, the Bear and the Kangaroo} (Sydney: Allen and Unwin, 1988), p. 26. The Great Nugget Co. had an authorised capital of £200,000 in shares of £2 each but it is not known how much was paid up at incorporation.
The Early Rushes in Victoria

Victoria became a separate colony on 1 July 1851. The discovery of gold at Clunes and at Anderson’s Creek was announced on 5 July, at Buninyong on 9 August. Following the precedent of New South Wales, the Victorian government issued a proclamation on 15 August stating that regulations for gold mining in Victoria were being prepared, and that licences to mine would be required. On 18 August a second proclamation stated the licence fee would be 30 shillings per month. The government appointed Francis Doveton as Gold Commissioner to this area, and accompanied by a small detachment of police he arrived at Ballarat late in September to find that some miners had already pegged claims at Golden Point, each claim being roughly one quarter acre for a party of four, about 100 feet square, similar to Californian practice. To the consternation of the miners concerned, Doveton forced them to repeg each claim to eight feet square per man. The Golden Point miners accepted because the area was rich in gold and the return was high from even this small area. It became the norm in Victoria. Also at this early period when a claim was worked out the party could move nearby to another claim with a good chance of a high return. Further goldfields were discovered at Mt. Alexander, Bendigo and Beechworth later in the year. At Clunes there was little alluvial gold, but the exposed quartz reef contained visible gold. A few miners went to Clunes but because they had little knowledge of how to extract gold from quartz they soon left for the Ballarat area north of Buninyong where the digging was easier. On all these fields, except Clunes, there was a small stream running through the area of alluvial gold, but there was also much eluvial gold on the surface of the hills well away from the watercourses, particularly at Ballarat and Bendigo. In the latter part of 1851 and the first four months of 1852 nearly all the new arrivals on the goldfields were from the neighbouring colonies. Meanwhile two young men Baker and Strickland, who had mined in California, asked David Reid, who had a pastoral lease at Mayday Hills,
later called Beechworth, for permission to prospect on the lease. Reid allowed his shepherd, Howell, to act as guide and the party soon dug 14 pounds weight of gold from shallow holes along Spring Creek in an area of high average rainfall.\textsuperscript{166} As this area was close to the road from Sydney to the major Victorian fields, many other miners from California who landed at Sydney were attracted to it as a place where they could use their sluicing skills. A rush took place from the Turon and from the central Victorian fields late in 1852, and by the following January mining was centred on rich ground along Spring Creek which was waterlogged down the washdirt at about 12 feet.\textsuperscript{167}

The first brief mention of Buninyong in the \textit{Mining Journal} was on 17 January 1852 and it was not until 10 April that the Forest Creek field was mentioned. Before this on 20 March there was a report that Mr. Richards, late of Devon and Courtenay Mine, had left Tavistock with 50 picked miners to go to one of the newly projected gold mining ventures in Australia. From these reports it appears that miners and others were being encouraged to emigrate to New South Wales before the Victorian fields were well known. A large number of Europeans left for Australia after mid 1852 but most of these would have been attracted to Victoria because of the publicity given to the Victorian fields. As the gold was easily dug from the surface soil and required little capital outlay, many of the early arrivals were young able bodied men and some women who wished to try their luck on one or more fields. During and after 1853, the character of those migrating became more purposeful as more and more, especially family men, decided to migrate permanently.\textsuperscript{168}

\textbf{Early Goldfields Technology}

Brough Smyth, who was secretary of the Mines Department in Victoria from 1863, when reviewing mining in Victoria, divided the early types of gold mining into six categories. They were:

Surfacing – the washing of the thin covering of earth resting on the tops and sides of hills in the close neighbourhood of auriferous quartz veins (now called eluvial mining).

\begin{footnotes}
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Shallow sinking – the obtaining of the washdirt from off the surface of the old claystones, sandstones and slates by sinking pits and making excavations in the valleys and creeks.

Sluicing and hydraulic mining – the washing of auriferous earths by streams of water in the gullies and valleys where recent deposits of auriferous clays and gravels occur.

Deep sinking – the obtaining of auriferous earths by penetrating the deeper tertiaries.

Tunnelling – the obtaining of auriferous earths and veinstones by adits.

Quartz mining – the obtaining of gold from the mineral veins intersecting the older sedimentary rocks.  

The early goldfields along the Macquarie River tributaries in New South Wales and in Victoria had surface claims with creek or river frontages, and here the washdirt was collected from the surface and cradled at the creek. The miners soon realised that away from the creek, where the soil and gravel was more than two or three feet deep, very few areas warranted removing all the soil and washing it as the gold was relatively sparse until just above the bedrock where they often found rich deposits of gold and sometimes gold and tin oxide, in a thin layer of white or blue clay. Removing all the soil (also called paddocking) was abandoned and a round or oblong hole, a few feet in diameter, was dug from the surface to the clay (shallow sinking). Sometimes small nuggets were visible in the clay and were extracted with a pocket knife and placed in a matchbox.  

The early Victorian fields soon eclipsed those of New South Wales in the production of alluvial and eluvial gold. Ballarat was mainly shallow alluvial with some eluvial ground on the hills and not all claims had a creek frontage. Castlemaine had shallow alluvial ground along recent creeks together with older alluvial deposits at depths of 10 feet or so at the bottom of ancient river beds, which now stood up as a series of low hills parallel to the recent creeks. Bendigo had shallow alluvial ground along the recent creeks and eluvial ground, from the decomposition of the quartz reefs in situ, over a

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171 Ibid., Plate 80, Zealous Gold Diggers. This water colour shows a digger, his wife and child working on shallow diggings. The man is pouring water from a dipper into the hopper of the cradle, the child is carrying washdirt from a barrow to the cradle while the wife is rocking the cradle. A full tub and puddling stick are shown in the foreground with a spare tin dipper and dish to be used in the final wash of the cradle contents. Another member of the party is digging a round hole with a pick.
wide area.\textsuperscript{172} Beechworth was a smaller, mainly alluvial field, situated in a hilly area with high rainfall. From late 1852 this field attracted miners who had experience in tomming and sluicing techniques in California, some of whom had initially gone to the Turon area on the Macquarie goldfields. In both places, using experience from California, they built water races to direct water to where it was needed for washing the gold.\textsuperscript{173} Parties of eight or more bailed the water from the combined claim by bucket or a Californian pump and the ground was paddocked down to the washdirt, which yielded up to 12 ounces to the cubic foot, with lower values in the intervening soil. William Howitt reported in January 1853 that the miners were using a belt pump which the Chinese had taken to California and which Californian miners had brought to Australia (where it was called the Californian pump).\textsuperscript{174} To improve efficiency over hand washing some ex-Californians and others who copied them, began to use long toms and sluices to recover the gold; some diverted the creek water for sluicing to their claim, while others built small waterwheels to drive pumps to lift the water from the bottom of the claim into the toms or sluices. As parties moved up and down Spring Creek and adjacent creeks they built long water races to bring water to their claims.\textsuperscript{175} Ground sluicing, box sluicing and tomming were soon in use on all the eastern Australian fields where sufficient water was available from natural rainfall for most of the year.\textsuperscript{176} Details of the several methods of sluicing are given in Appendix 5.

When shallow sinking the early miners first pegged the claim with pegs at each corner, and dug their hole at the centre of the claim with a pick and shovel, to a depth of a few feet. Leaving a ledge of half the hole, the other half was sunk deeper and the soil was thrown to the ledge and from there to the surface. The soil was tipped on the claim; if necessary a stone or timber wall was placed around the shaft to prevent the soil falling down again, and soil could be tipped outside the claim if there were no adjacent claims.\textsuperscript{177} If the depth was 10 feet or more a windlass was erected and the soil was raised in a bucket at the end of a hemp rope. When the shaft was bottomed on the

\begin{itemize}
  \item\textsuperscript{172} Finlay and Douglas, \textit{Ballarat Mines and Deep Leads}. Willman and Wilkinson, \textit{Bendigo Goldfield}. Willman, \textit{Castlemaine Goldfield}.
  \item\textsuperscript{174} Howitt, \textit{Land, Labour and Gold}, p. 99.
  \item\textsuperscript{176} Brough Smyth, \textit{The Goldfields and Mineral Districts of Victoria}, pp. 135-7.
  \item\textsuperscript{177} Pettit, ‘Letter to His Parents’. January 1853.
\end{itemize}
bedrock the clay washdirt was removed by tunnelling to the claim boundary, leaving small pillars of earth or by inserting wooden props to prevent the earth caving in. If the miner was inexperienced this method was dangerous, particularly in wet ground when the soil was likely to collapse. Such new chums had difficulty in making the sides of the shaft vertical and often finished with corkscrew sides or with a decreasing diameter from six feet to one foot at the bottom.\textsuperscript{178}

On most goldfields the miners soon exhausted the rich washdirt above the bedrock and again turned their attention to removing all the soil to the bedrock as this material contained gold, often several pennyweights to the load of soil, but it required a method which would wash large quantities economically (a rough measure was to consider a dray load to weigh one ton). Many miners who had acquired some capital by shallow sinking invested in a puddling machine, an annular hole in the ground, lined on the inside, outside and bottom with wood planks. At the centre stood a vertical pole supported by a wooden framework so the pole could rotate. A horizontal pole was bolted to the vertical one about five feet above the ground. Rakes were attached to this pole so they dragged in the annulus, which was partly filled with dirt that was carried there in barrows or drays from the claim. A horse was harnessed to the end of the horizontal pole so it walked just outside the annulus, dragging the rakes through the soil to break up the clay. Water was then run into the annulus, the mixture was stirred by the rakes and the clay formed a sludge which was drained off through a trapdoor, leaving gold and sand at the bottom. This was then shovelled out and washed in a cradle to separate the gold. Puddling machines could treat up to 60 drayloads a day and recover fine gold economically down to about two pennyweights per ton (about 3 grams per 2000 kilograms or 1.5 parts per million). This compared with a grade of about 20 pennyweights required to make the cradle economical for a party. A puddling machine could be built for about £200 and the cost the two horses needed for continuous work was substantial in the early 1850s, so parties were usually needed to raise the capital required.\textsuperscript{179}

What were the origins of this machine? No evidence has been found that it was used in California, where water was plentiful and sluices were dominant. Hargraves mentioned that puddling machines were in use at Bendigo in July 1852. Two possible sources have been found. In 1850 E. Dobson published a book in England which had an illustration of a clay puddling mill which is identical in construction to the Victorian puddling machine except the diameter was about 40 feet compared with 20 feet. The same illustration appears in a later edition and Birmingham and her co-authors reproduce it on page 84 with the comment that it was similar to a mill at the Irrawang Pottery, owned by James King, in the Hunter Valley in 1836 for puddling clay to make pottery. King lost his earthenware thrower and glazer to the gold rush in 1851. It is a reasonable deduction that one of King’s employees or someone familiar with Irrawang did some lateral thinking at Louisa Creek, initially a small eluvial gold field north of Bathurst, and reversed the function of the machine to save the gold and sand and drain off the sludge. The large diameter of the machine is supporting evidence that this occurred. More details of this field will be given later in this chapter.

William Kelly wrote that puddling machines were first used at Castlemaine. Davey and McCarthy quote Kelly to support the claim that the machine was first developed in Victoria. This claim is not correct as Angus Mackay wrote that he had visited the site of the Great Nugget Vein Mining Company at Louisa Creek in October 1852 and seen a machine for puddling the clay and separating the gold which was four feet deep around the reef. This machine had a channel three feet wide, two feet six inches deep and 50 to 60 feet in circumference, cut in the ground, paved with wood standing on end and boarded at the sides. Soil was put in the channel, a constant stream of water was fed in by pumps, and a heavy harrow dragged through it by a horse attached to the beam of an upright windlass fixed in the centre of the space. This separated and dissolved the clay which was run off and the gravel and sand conveyed in barrows to a cradle rocked by action of the windlass and supplied by pumped water. It was called a pug mill, and 100

180 Hargraves, *Australia and Its Goldfields*, p. 150.
loads a day could be washed for 100 ounces of gold.\textsuperscript{186} At that time the regulations in New South Wales allowed a considerable area around the reef for mining the eluvial gold shed from the reef.\textsuperscript{187}

Early in 1858 James Henderson presented a paper at a meeting of the Institute of Civil Engineers in London, during which he described a circular baffle with a diameter of 18 feet, which was almost identical to the Australian puddling machine. Henderson referred to an earlier paper of 1828 by W. Henwood and said that since Henwood’s paper a few new machines had been introduced in Cornwall and he was including them in his paper. Henwood described only rectangular baffles which Henderson said were old fashioned and he then described the circular baffle and included a diagram in his paper. These remarks can be interpreted to mean that the circular baffle was introduced in Cornwall between 1828 and 1858.\textsuperscript{188} Conclusive evidence on the development of this machine has been given by Marilyn Palmer and Peter Neaverson who wrote in 1989 that the round (circular) baffle was beginning to replace the common (rectangular) baffle by the mid nineteenth century. It was probably developed in Cornwall and then used at Mendip for concentrating crushed slags. An archaeological survey has shown that there were 42 round baffles at Mendip in 1848, probably powered by horses or donkeys. These baffles were 15 to 20 feet in diameter and about 20 inches deep.\textsuperscript{189}

The evidence suggests that gold puddling machines were introduced to Australia in 1852 from two sources: the first in New South Wales, as an adaptation of the pug machine that had been used for many years in Britain and Australia for preparing clay for making pots; and the second quite independently in central Victoria, as a transfer of technology from the tin mines of Cornwall or the lead mines of Mendip.\textsuperscript{190} The available evidence does not indicate which was the first. By 1855 at least two Victorian

\textsuperscript{186} Mackay, \textit{The Great Goldfield}, pp. 16-23.
\textsuperscript{187} Ibid., p. 16.
\textsuperscript{189} M. Palmer and P Neaverson, "Nineteenth Century Tin and Lead Dressing: A Comparative Study of the Field Evidence.," \textit{Industrial Archaeological Review} XII(1) (1989): p. 25. The introduction of the round baffle around 1848 in Cornwall and at Mendip explains why it was unknown to Kelly who was in South America and California in this period. Hargraves, \textit{Australia and Its Goldfields}, p. 150. Hargraves wrote that puddling machines were operating at Bendigo in mid 1852.
\textsuperscript{190} Great confusion has resulted from the use of the word puddling for the process preparing wrought iron in Britain and the use in Australia for separating gold from clayey earth.
foundries were manufacturing and selling steam engine driven puddling machines, which consisted of a rotating trommel into which washdirt was discharged down an inclined plane, the sand fell through the holes in the trommel onto a box sluice, which collected most of the gold behind cross cleats while the sludge was discharged into a creek or dam. These machines required up to 15 men to cart the washdirt and operate the machine but they could treat over 100 tons per day. They used large amounts of water and were often idle in the summer months unless a large dam was built. They were a direct copy of a horse driven washing machine in use on the goldfields of the Ural Mountains in Russia, with the horse drive replaced by a small steam engine. Because the capital cost was several times that of a horse driven puddler only a small number were used in Victoria. The Port Phillip and Colonial Gold Mining Company was sluicing for gold at Beechworth during that year on a small alluvial claim but also recovered 15 tons of tin oxide from the sluice boxes which was sent to England for smelting.

George Mackay, the son of Angus who wrote about Louisa Creek in 1852, claimed that at one time there were upwards of 3000 machines on the Bendigo goldfield, but by 1869 the numbers had fallen to less than 2000 in Victoria. The low grade eluvial gold was nearly worked out by this time.

The miners built small dams on the hillsides to collect the winter rainfall and as this water supply was limited they did not use running water but supplied only enough to make a sludge with each fill of surface soil. After thorough stirring the sludge was run off down the creek. By 1859 there were complaints of sludge building up down the valleys, which became impassable after heavy rain. The problem existed on most goldfields but was worst at Bendigo, Ballarat and Castlemaine. In 1859 a Royal Commission was appointed to investigate the problem. It consisted mainly of Bendigo people and concentrated on the Bendigo Creek. Early in 1860 the Commission recommended the construction of an elevated timber drain along the valley from

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Kangaroo Flat to a swamp at Huntly, some fifteen miles away, with intake drains feeding into it from each gully. The drain was built with government financial assistance; operating and maintenance costs were paid from a levy on each puddling machine under the control of a local committee. Little was done at other fields to alleviate the problem. By the early 1870s the number of machines at Bendigo had decreased substantially and the drain fell into disrepair and was abandoned. The numbers on all Victorian fields decreased gradually as the eluvial gold was exhausted.

As the early alluvial miners dug their shallow shafts they encountered layers of conglomerate rock which was often so hard it had to be drilled with a hand drill and hammer and blasted with gunpowder. It consisted of sand and gravel which had been cemented together by the precipitation of iron oxides and silica from the waters percolating through the alluvial ground, and was also found in the low residual hills which were remnants of tertiary river beds left when the surrounding areas were eroded. It was found on all alluvial goldfields. This was called cement by the early miners; it occurred as conglomerate boulders scattered through the washdirt and just above the bedrock, and often contained considerable gold. Hargraves described in his book how the miners at the White Hills near Bendigo were sinking through the cement into the clay and then the bedrock, so the underside of the cement was five feet above them, and then tunnelling so they could work the cement roof with gads and hammer, raise the separated material to the surface in a bucket, and then crush it with a crude hand crusher and wash out the gold. There were 50 buckets to the load; Hargraves said some loads yielded sixty ounces of gold. The white mudstone raised to the surface from the tunnels was spread over the ground around the shaft. When viewed from Bendigo the area appeared to be white as distinct from the brown to orange of the denuded river bed, hence the name (White Hills) given to the area. In the early years the cement boulders were dumped on the surface, from where they were later (from 1859) collected and crushed with stampers and the gold amalgamated. Cement was found at varying depths in shallow and deep leads at Bendigo, Ballarat, Castlemaine, Beechworth and

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197 Register of Leases, (Melbourne: Government Printer). Lease No. 2 was issued to Thomas Britt in October 1859 to crush tailings (cement) as a special case at Epsom, near Bendigo. There was no reef on the site.
Ararat. It also occurred in the placers in California where it was blasted and sluiced and from 1858 crushed in stampers.

The development of alluvial and eluvial gold mining was similar in New South Wales and Victoria as miners moved between the fields. The Victorian fields were the more extensive and attracted the majority of miners, both of Caucasian origin and from China.

**Processing the Gold Ores**

The first documentation of a quartz processing plant comes from Louisa Creek north of Ophir. Angus Mackay reported in October 1852 that the Great Vein Nugget Company had previously been surfacing the ground around the reef but was then quarrying on two veins which were six feet wide and seven feet apart. Two adits were being driven towards the reef further down the hill, and three shafts were being dug 900 feet apart to 60 feet deep to test the veins. Two hundred and fifty tons of ore in which gold was visible had been blasted out. The crushing plant consisted of a single heavy iron headed stamp (like a pile driver) lifted by a six H.P. steam engine, and let to fall into a strong iron box with a bottom of iron bars. The ore was crushed to marble size and shovelled into an iron basin with two vertical iron wheels revolving to crush the ore finer. Mackay said he believed this plan was used in some parts of South America. The crushed material was then shovelled through an aperture to a Jacobs ladder (like a Californian pump), and conveyed into screens above so as to separate the coarse sand, which was returned for further grinding. The fines from the screens were sent to a cradle for washing. The steam engine also drove a force pump to supply water to the cradle and the boilers. Mercury was used for amalgamation in the cradle. Experiments were being conducted with the plant at the rate of one ton of ore crushed each day, but Mackay felt the operators did not understand the process. An ore grade of one ounce per ton was needed for a profit; selected ore varied from 13 pennyweights to 25 ounces per ton. The establishment consisted of the engine house, machinery house, carpenters and

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199 Meyerriecks, *Drills and Mills*, pp. 11-12.
200 This machine was Nasmyth’s direct action steam hammer for forging wrought iron shafts, first reported in the *Mining Journal* of 11 September 1843. It was sold in London in the early 1850s as suitable for crushing gold ores apparently without ever being trialled. There were similar machines in use at Bendigo in the 1850s. They were said to be useless. See H. Brown, *Victoria as I Found It* (London: T Coutley Newby, 1862), p. 263.
blacksmiths shops, the manager’s house of timber and huts for 60 men, some bark and some peeza (wattle and daub). Thirty men were then employed.\textsuperscript{201} Michael Pearson considers that this was the first plant treating matrix gold in Australia.\textsuperscript{202}

In 1852, with the exception of the crusher, this was a sophisticated plant with two stage crushing and a hydraulic classifier. The manager was Gideon S. Lang, and his staff were James S. Mitchell, Jackson and Atking. Lang was a pastoralist who had driven cattle to the goldrush from Queensland, with no experience in mining.\textsuperscript{203} Nothing is known about the designer of the plant or the staff but some must have had mining experience. Mackay mentions in a footnote that this company sold out to the Colonial Gold Company early in 1853. More will be said about this company later.

As distinct from New South Wales, Victorian legislation between 1851 and 1855 did not mention mining on private property as very little goldfields land had been alienated before 1851, and with the exception of Melbourne and Geelong most occupied areas were divided into annual pastoral licences.\textsuperscript{204} The miners were free to peg their claims where they wished on unalienated land except on pre-emptive rights, areas which had already been sold to the holders of pastoral licences. Near the claim they erected their tents or bark huts. When the ground was worked out they pegged claims on other areas, but after 1853 increasing attention was paid to the quartz reefs which the miners soon realised were the sources of the gold they had been mining. As the reefs were often exposed on the hills, small satellite settlements grew up around those already established along the valleys.\textsuperscript{205} As the mines on the reefs were in harder ground than the shallow sinking in the valleys, more equipment, such as picks, hand drills and hammers, whims, crushing plant and steam engines, was needed so blacksmiths had an essential role in these settlements.\textsuperscript{206}

\textsuperscript{201} Mackay, \textit{The Great Goldfield}, pp. 16-19.
\textsuperscript{202} M. Pearson, "Seen through Different Eyes - Changing Land Use and Settlement" (Australian National University, 1981), p. 301.
\textsuperscript{204} Serle, \textit{The Golden Age}, pp. 131-2.
\textsuperscript{206} R. Annear, D. Bannear, and P. Ingamells, \textit{Discovering the Mount Alexander Diggings} (Mount Alexander Diggings Committee, 1999), p. 80. There were a number of blacksmiths shops at Lisles Reef settlement near Maldon each with a small forge.
As well as the Naysmyth steam stamp already mentioned, the first crushers used by the parties that pegged these reef claims (originally 12 feet by 12 feet per man after 1853) in Victoria were primitive and labour intensive and only economical on very rich ore.

Joseph Panton, the Commissioner at Bendigo, described one of these machines in use in 1853 on a hill top at the head of Ironbark Gully, just outside the town area:

On the top of a stump of an ironbark tree, about eight pieces of iron about six inches long were sunk in the wood about one eighth of an inch apart. On top of this was fastened an iron bucket with the bottom removed. Above this, hanging from the end of a spring pole, was suspended a block of ironbark wood shod with iron as a stamper with handles. The spring pole had its butt fixed to the ground, resting on a fork of a branch sunk in the ground within a foot or two of its base. The blocks of quartz were placed in the bucket and the stamper or dolly was pulled down by the handles onto the quartz. The spring of the pole lifted it back, and once set going when the operator pulled it down it formed a very effective crusher.²⁰⁷

Latham and Watson had a 12 feet by 12 feet claim on Hustler’s Reef next to Thomas Hustler’s claim, a short distance from Ironbark Gully. They co-operated with Hustler to build an improvement of the dolly, which Hustler patented in 1854. Together they used this machine to crush very rich ore on their claims and made substantial fortunes. Brough Smyth said this was the first stamping machine built in the colony, but it is a copy of Cornish stamping machine illustrated as the frontispiece in a book published in 1852 by J. Arthur Phillips, which was distinct in being hand driven, while Hustler’s machine was belt driven by a steam engine. A similar machine, driven by a water wheel, but of more robust appearance, was illustrated in Mineralogia Cornubiensis, published in 1778. Hustler’s machine appears fragile, the rods were wood with iron shoes and the lifting mechanism looks inadequate.²⁰⁸

Hammers were used to separate the gold from a rich vein opened on Black Hill at Ballarat early in 1853 by a party of Frenchmen, and in April of that year Dr William Otway, an American chemist, erected a windmill driven crusher of four wooden stamps

²⁰⁷ J. A. Panton, Memoirs (Melbourne: Unpublished), pp. 62-3. Brough Smyth, The Goldfields and Mineral Districts of Victoria, p. 328. A sketch on this page shows the machine, a dolly, described by Panton, which was also used in 1853 on a 12 feet by 12 feet claim belonging to Latham and Watson on Hustler’s Reef not far from the Ironbark Gully.

shod with iron. It was not a success. Johannes Menge, the German mineralogist who joined the rush from South Australia, was mining a quartz reef at Chewton before November 1852 but no details survive of his methods. Jacob Brache, a German engineer with mining experience in South America, failed in an endeavour to erect a crusher in Castlemaine in 1854 because of opposition from alluvial miners to machinery and the refusal of the authorities to grant him the lease he wanted. He was an advocate of the German system of co-operation between miners and capitalists, a system out of favour in Victoria in 1853 and 1854.

Not all those who moved early into the crushing business were novices. Kelly mentions Messrs Nicholas and Bassett who were sent to Bendigo with capital and machinery in 1852 by the Colonial Gold Company. According to Kelly this company was assigned an indefinite length of quartz reef near Eaglehawk, a settlement near Bendigo, but the management was incompetent and deferred the opportunity until public feeling would no longer tolerate such a semblance of monopoly. The staff was sacked and Nicholas and Bassett took out a claim on the reef and obtained 30 ounces of gold to the ton of quartz. They erected the horse driven stamper with a slanting board in front of the stamps, across which the surging water carried the crushings into a pool of quicksilver which caught the gold. Nicholas invited Kelly to lunch in his tent and showed him cake after cake of solid amalgamated gold like so many Dutch cheeses.

By the end of 1854 the rich eluvial and alluvial gold was depleted on Bendigo and several parties were working the reefs. A few public crushers using Chilean wheels and

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210 W. A. Cawthorne, *Menge the Mineralogist* (Adelaide: 1859). Menge died at Castlemaine in November 1852. His burial place is not recorded but it is likely he was buried at Graveyard Gully, Chewton near the Argus Reef.
212 Kelly, *Life in Victoria*, vol. 2, pp. 198–201. The Colonial Gold Company was incorporated in London early in 1852 and two groups of miners were sent to Australia, one to the Turon under Alfred Spence, the other to Victoria under Thomas Comer. Spence developed mines at Rotherhyde, Tambaroora and Louisa Creek, the latter being purchased from the Great Nugget Company. The equipment included Cornish rolls and stampers. The rolls wore out in 8 weeks, the stampers yielded only 32 ounces from 200 tons. By 1855 Spence decided the operations would not be profitable, sold the equipment and went to Bendigo to take over from Comer. In the meantime Comer had applied for leases under the April 1853 regulations, both for quartz at Eaglehawk and alluvial at White Hills, but was frustrated when alluvial miners invaded the White Hills area and Panton refused to issue a lease. Comer had already erected machinery sheds on the ten acres, but he was able to purchase the land for £200 when the area was put up for sale. He then sold the land in small allotments late in 1854 as well as some of the equipment. Spence arrived and sacked Comer but was forced to reinstate him as Comer held all the details of the companies transactions. The company was liquidated in 1856. See *The Mining Journal*, 9, 30 April 1853, 22 September, 27 October, 24 November 1855, 12 April, 29 November, 27 December 1856.
Berdan pans were erected at this time to crush stone for the reefers who did not have the capital to build their own machine. By doing so they gained public support to resist the anti-monopolists and did not have to spend money on reef mining themselves. The *Bendigo Advertiser* was running an editorial campaign late in 1854 advocating reef mining and this would have helped to reduce opposition to machinery. Also at this time Christopher Ballerstedt and his son Theodore, with both German and Californian mining experience, erected a horse driven stamper, crushing dry, on Victoria Hill at the top of Ironbark Gully. They were soon reputed to be wealthy and others began to copy their example.

While alluvial and eluvial mining boomed and peaked using technologies known for centuries, with some micro-innovations such as the adaptation of tin or pottery equipment to produce the gold puddling machine in 1852, quartz reef gold mining grew from small beginnings. As there were only a few iron foundries in Australia at this time almost all equipment was imported from Britain. It was not always suitable for local conditions. Also during this period of trial and error adjustment of equipment, problems were encountered with the introduction of small claims and the licence fee. These problems were aggravated by government attempts to re-introduce company mining, resulting in resistance by the miners to the way the laws were being implemented.

**Chinese Miners**

The Chinese had been mining alluvial tin in Malaya since the early eighteenth century by paddocking large pits with groups of up to 30 men after testing the ground by boring. They carried the washdirt in baskets suspended on a lever over the shoulder, and washed it in ground sluices. The pit was drained by a chain pump driven by a water wheel or a treadmill which could be made on site with local timbers. When a site was stripped they could move rapidly to another. This system was not easily adapted to machine mining.

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213 Berdan invented the pan to fine crush quartz tailings remaining from earlier mining in Virginia U.S.A. (See "The Mining Journal, London." 30 July 1853). The machines were made in London from 1853. Chilean mills were used in English potteries for fine grinding of clays.


Chinese miners began to arrive in Victoria in large numbers in 1854. They concentrated their efforts on shallow alluvial mining and moved onto abandoned ground when European miners left the fields to rush to a new area. The Chinese paddocked an area, working in large groups and left nothing for other miners. This created resentment and led to governments both in Victoria and New South Wales introducing punitive taxes in attempts to restrict the entry of newcomers and drive out those already in the colonies. These measures were partly successful in restricting new entries after 1860, but in later years around one third of the alluvial miners in Victoria were Chinese, and they formed a larger proportion on some Queensland and Northern Territory fields. They were allowed to peg claims but very few were granted leases for deep lead mining or quartz reef mining. In the late 1850s and during the 1860s they were mainly operating horse puddling machines and ground sluicing in areas of higher rainfall such as the Buckland River in north east Victoria. As gold returns diminished in later years many became market gardeners, agricultural labourers or furniture makers. The newspapers of the day wrote little about their mining methods, and much of the areas they worked have been rehabilitated or dredged and little evidence remains. Recently more research is being done on this neglected group. In the 1870s labour shortages in the Northern Territory led to co-operative ventures between European leaseholders and Chinese merchants, particularly Ping Que who worked the quartz reefs with Chinese miners on tribute. Little local evidence remains about the methods used by the Chinese but it is unlikely that they contributed much to the development of mining technology in Australia.

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218 Mount Alexander Mail, 10 July 1858.
220 “Reports of Mining Surveyors and Surveyors, Victoria,” (Melbourne: Mines Department), 1969. For the quarter ending 31 December there were: alluvial miners 31,499 Europeans and 15,706 Chinese; quartz miners 16, 513 Europeans, 69 Chinese.
221 Register of Claims, (Melbourne: Victorian Mines Department). Most of the puddling claims registered in the Bendigo district in the 1860s were by Chinese parties, see Birrell, Staking a Claim, pp. 80-3.
222 A conference Active Voices - Hidden Histories, was conducted by the History Department of the University of Melbourne on 21-22 June 2003. See Journal of Colonial History, University of New England, vol. 6, 2004.
223 T. G. Jones, Pegging the Northern Territory (Darwin: Department of Mines, Northern Territory, 1987), p. 49.
Miner Resistance

In 1851 large numbers of men left the coal mining areas of the Hunter Valley around Newcastle and Maitland and commenced mining for gold along the Turon River at Maitland Point and around Sofala. They would have included many coal miners who had been involved with the Australian Agricultural Company and other small coal companies, who resented the way those companies had tried to maintain monopoly positions in coal trading. Others from Sydney would have read newspaper accounts or heard about the attempts to prevent new people entering the coal trade. New regulations were promulgated in New South Wales on 21 October setting out the areas for alluvial claims and introducing rules for matrix mining, with each applicant being required to enter a bond to pay a royalty of 10 percent on gold mined on Crown land and 5 percent on private land with an area of one half mile along the vein and 50 yards on each side of the vein. Persons who wanted to drain waterholes along the river had to employ 40 men and take out licences for each man. The government had not understood the political thinking of the miners and still believed that large leases for company mining could be implemented alongside the newly introduced system of claims and licences to mine. A public meeting was held at Sofala on 8 November to protest against these new rules, which would tie up large areas of auriferous land and prevent these areas being mined by small parties.

In Victoria, La Trobe issued a proclamation on 1 December which doubled the licence fee to £3 per month from 1 January 1852. A mass meeting of diggers estimated to be between 10,000 and 15,000 assembled at Castlemaine on 15 December to protest this increase in the licence, which they saw as an attempt to drive them from the goldfields. The Victorian government withdrew the regulation.

The winter of 1852 was wet in New South Wales, there were floods along the Turon and many of the miners moved to the hills at Tambaroora where shallow alluvial mining was still possible. There they formed the Tambaroora Association of Alluvial Miners with James McEachorn, a prominent agitator for democracy, as secretary. This association published two memorials, one rejecting monopoly mining by companies, the other asking for the franchise for miners, Parliament to be elected by ballot, and the

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224 Higgins, Gold and Water - a History of Sofala and the Turon Goldfield, pp. 17-21.
225 Hodge, Valleys of Gold, pp. 52-3.
226 Higgins, Gold and Water - a History of Sofala and the Turon Goldfield, pp. 31-2.
removal of property requirements for members of the Legislative Council.\textsuperscript{228} In November when the floods subsided, the miners returned to the Turon. Several companies requested groupings of up to 176 riverside claims, some of these companies being associations of miners. Angus Mackay wrote at this time that monopoly must be resisted as the jobbing of claims was allowing individuals to gain control of many claims.\textsuperscript{229} In September 1852 the British government handed over control of the goldfields revenue to the two colonial governments pursuant to its policies of reducing costs and devolving power. Each government set up a committee to advise on a new act for the goldfields and on 23 December the New South Wales Goldfields Management Act was passed which required everyone on a goldfield to have a licence, non-British miners had to pay a double fee and companies could obtain 21 year leases after auction. Protest meetings were held at Sofala in January and February, which so alarmed the government that half of the 11\textsuperscript{th} Regiment was sent from Sydney. The miners did not resist the soldiers and order was restored but hundreds of miners left for Victoria and probably stopped at Beechworth, the nearest field.\textsuperscript{230} William Howitt was in Beechworth for some months early in 1853 and soon after sent an article to London in which he discussed the resistance of the miners to companies, capital and machinery, which could monopolise larger claims than ordinary. Howitt concluded the era of gold mining companies had not yet arrived.\textsuperscript{231}

In October 1852 the Victorian government published regulations for the granting of leases on worked out alluvial ground. Each lease was to have an upset price of £360 for each half acre, would be between one half acre and ten acres in area and would be auctioned to the highest bidder annually.\textsuperscript{232} This proved unworkable because as soon as the area was advertised the miners returned to the ground on the premise that if it was worth leasing it still contained gold. As it was no longer abandoned the commissioner was powerless to proceed with the issue of the lease. In April 1853 new gold regulations were tacked on trees around Victorian goldfields which increased the claim size to 12

\textsuperscript{229} Mackay, \textit{The Great Goldfield}, p. 50.
\textsuperscript{230} Higgins, \textit{Gold and Water - a History of Sofala and the Turon Goldfield}, pp. 37-8. Many went to Beechworth which was nearest.
\textsuperscript{231} Howitt, \textit{Land, Labour and Gold}, pp. 145, 207. Howitt wrote that as long as the digger could obtain a living by washing for gold he was jealous of any interference of capital, of machinery and of companies which would ‘monopolise’ as one of them said, he would resist all such movements for any claims larger than the ordinary.
feet square, and allowed five year company leases of up to 160 acres on alluvial ground or one half mile long on a reef with one hundred yards on each side of the reef. Cooperative companies could get leases up to 160 acres. This was probably the first time that a miner could read for himself that the Victorian government had not abandoned the idea of company mining. The first reaction was on 25 April when a meeting of miners at Snake Gully near Beechworth, many of whom had probably come from California and the Turon, decided to write to La Trobe, objecting to the leases on the grounds that companies could prospect quickly and take up large areas and poor miners could not compete. Monster meetings were held at Bendigo in August protesting the licence fee and monopoly, after which the government reduced the licence fee to £2 for three months and the agitation subsided. In October 1853 the New South Wales Act was amended to reduce the licence fee to ten shillings a month and the double fee for aliens was removed. At Fryerstown near Castlemaine the miners again showed their resistance to large leases and company mining when 854 signed a petition objecting to the issue of a proposed large alluvial lease to the Port Phillip Company. Further troubles arose at Ballarat in 1854 when the new governor, Charles Hotham, sought to enforce the collection of the licence fee by police. This led to an armed rebellion at the Eureka Stockade on 3 December 1854 during which some thirty miners and five soldiers were killed.

When compared with the great European battles of the nineteenth and twentieth centuries, the Eureka clash was a minor skirmish and the reasons were complex. However the political fallout was considerable and the events which followed greatly influenced mining law in the Australian colonies which in turn influenced the development of mining technology. A Royal Commission to investigate the management of the goldfields had been set up in November 1854 and became very active after Eureka. It heard evidence from a wide range of people and reported at the

233 Gold Regulations, 5 April 1853. The 160 acre lease size was copied from the New South Wales regulation of March 1852. See p. 7.
234 V.P.R.S. 1184/84, letter from Snake Gully miners to La Trobe, 14 May 1853. Howitt, Land, Labour and Gold, p. 145. Howitt said many miners in this area came from the Turon and California.
235 V.P.R.S. 1189/87, report by Chief Commissioner W. Wright, 3 September 1853, on meeting at Bendigo, 28 August. J. Panton Memoirs, p. 85.
236 Higgins, Gold and Water - a History of Sofala and the Turon Goldfield, p. 42.
237 V.P.R.S. 1189/88, letter from J. Bull, Commissioner as Castlemaine, 12 November 1853.
239 Ibid., pp. 180-87. Serle discusses the reasons in detail.
end of March 1855. The recommendations included the abolition of the licence fee and its replacement by a miner’s right to cost £1 per year which entitled a miner to a claim 12 feet square. The Commissioners also recommended an export duty on gold, and that alluvial leases be a maximum of five acres on old ground or 80 acres on new ground while quartz leases should be a maximum of 220 yards along a reef. Entrepreneurs were to be encouraged to provide quartz crushing plants at central locations to crush for the small miner, and Courts (chaired by a person appointed by the government and having members elected by the miners) should be set up on each major field to control claims and adjudicate on disputes over claims. An Act for the Better Management of the Goldfields was passed on 12 June 1855 and the next day new general regulations were promulgated including the recommendations of the Commission. Local Courts were to be set up on each mining field, consisting of nine elected miners with the warden of the district as chairman. Claims for both alluvial and quartz mining were 12 feet by 12 feet and quartz leases could be up to 220 yards along the reef and 50 yards across the reef. Other Acts were passed to allow the gold export tax, and for holders of miners rights to vote in Parliamentary elections. The latter Act increased the number of members of the Legislative Council by 12, eight were to be elected from the mining districts and four were to be nominees. On the same day in June 1855 the Victorian Legislative passed the Act for the Better Management of the Goldfields it also passed an Act for the Better Regulation of Mining Companies, 18 Vict. 42, which was a copy of an English law, commonly called the cost book system, which allowed expenditure only when funds were available to pay the accounts, dividends could only be paid from profits, and calls could be made on shares to pay losses. Few companies were registered under this act which was commonly called Haines’ act.

The Royal Commission did not discuss the sources of ideas on which their recommendations were based but there were precedents going back to the Middle Ages in Europe. As there were many German and Cornish miners in Victoria in the early

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241 Victorian Act 18 Vict 37, Mining Regulations of 13 June 1855, p. 1419 Victorian Government Gazette 1855.
243 Ibid., p. 67. All members had to sign the memorandum of association and had to meet regularly to authorize expenditure and calls. This proved difficult to arrange as many miners were moving from field to field.
rushes, it is likely that German models of self governing mining communities, as well as the model of the English Stannary laws influenced the Commission.  

**Conclusion**

The gold rushes in Australia were initiated by Edward Hargraves who developed his ideas on how to disrupt the English system of mining law applicable in New South Wales at the time he went to the gold rush in California in 1849. From his experiences there he planned to force the government of New South Wales to abandon the restrictive British mining laws which allowed only company mining on large areas, and to introduce the granting of small claims to individual miners similar to Californian practice. His aim was to generate a rush so large that it could not be prevented by the government, and then ask for a reward on the grounds that the discovery of gold stopped transportation of convicts to Australia and emigration of Australians to California. He achieved this aim in 1851 when the government was forced to implement a licensing system in a belated attempt to control the large numbers of gold miners already working at Ophir and the surrounding area as a result of a publicity campaign he conducted in the Sydney and Bathurst newspapers.  

Paradoxically the government believed the issuing of licences was only a temporary measure and awarded Hargraves a substantial reward for invigorating the economy.

The New South Wales and Victorian governments expected to resume large scale company mining when the rush subsided but the miners agitated and demonstrated against the price of the licence fee and the re-introduction of company mining. The culmination of these protests was the armed uprising at Eureka. A Royal Commission appointed in Victoria to investigate the causes of the unrest recommended the abolition of the administrative structure of goldfield commissioners with a large supporting police force and its replacement by Wardens on each goldfield. The miners were to decide on byelaws for each field and to adjudicate on disputes between members of mining parties.

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244 J. Gimpel, *The Medieval Machine*, 2 ed. (London: Pimlico, 1992), Ch. 3. Miners were the highest paid workers in Central Europe in the 13th century. They were allowed to cut timber from the woods for use in mines, to prospect anywhere except churchyards, gardens and highways, to divert streams, to run their own mines and administer a mining area under a Burgmeister and to conduct their own courts with a dozen or so miners acting as judges. A similar system was in operation in medieval England. See J. Temple, *Mining: an International History* (London: 1972), p. 30.

245 Hargraves is considered by some historians to have been a charlatan who manipulated the media to forward his claims for a reward to the detriment of others. However in my opinion there is no doubt he was the first to introduce Californian methods of washing gold to Australia and that he was an entrepreneur of great importance to the development of mining in Australia.
through elected local courts. The licence system was to be replaced by an annual fee for a miners right. These recommendations were implemented by Act of the Victorian Parliament in June 1855. New South Wales (and subsequently the other colonies) later adopted a similar system.

All but one of the joint stock companies formed in Britain to mine gold in Australia in 1851 and 1852 failed because of the remoteness of the mines, and because the managers they sent to Australia could not adjust to a system which favoured the individual miner or a small party working a small claim. In the confusion of the rushes governments were unable to grant large leases which would support the large overheads of the joint stock companies. Alluvial and eluvial mining produced a boom in gold production and population in these early years but not in share prices on the London market. Rather the failures of the early joint stock companies reduced the flow of capital from London to finance Australian gold mines to a negligible amount for the next forty years.

The manual technologies used in alluvial and eluvial mining in these years were imported from Europe, South America or California. The introduction of the gold puddling machine, which was an adaptation of Cornish tin mining technology or English clay technology, was the only micro-innovation of consequence and there were no macro-innovations. A Chinese pump, originally used for irrigation and later in tin mines in Malaya, was introduced to Australia via California where it had been adapted for alluvial gold mining. The extraction of the gold ores from surface reefs was manual, and most of the crushing and processing equipment was based on European designs centuries old. In the first years of the rushes most of it was imported from Britain. Although the Chinese miners later made up a large fraction of alluvial miners, the early arrivals do not appear to have introduced any new methods, and as few of them participated in reef mining in later years their contribution to the development of mining technology in Australia appears to have been minimal.

The next chapter will discuss how the Victorian miners implemented the recommendations of the Royal Commission of 1855 and effectively took control of the development of mining law in Victoria. The innovations which occurred in extractive and processing technologies of gold ores as these were modified to suit Australian conditions will also be considered.
Chapter 3

The Emergence of a New Type of Mining Company

1855 - 1870

Introduction

As discussed in Chapter 2 one outcome of the Eureka uprising was the passing of an Act by the Victorian Legislative Council which followed European precedents and gave the miners power through the local courts to develop bye-laws for the governance of mining on the goldfields and to settle minor partnership disputes. This chapter will investigate how the Victorian miners accepted this opportunity to become involved in the making of new laws for the gold mining industry, and how they used the local courts and their elected representatives in parliament to do this. In parallel, new technologies were being developed for deep lead alluvial mining and the mining of gold ores below the waterline, and these changes required further changes to the mining laws from the simple concept of small parties mining small claims that had been introduced during the first rushes. The increased costs and capital needed as the mines increased in depth below the water line influenced the miners, through their representatives, to gradually extend the sizes of claims and leases beyond the areas set in 1851 and 1853. Until the mid 1860s conservative Victorian governments again sought to re-introduce company mining. The period up to 1871 was one of continuous conflict between the miners and conservative governments to develop new mining laws to suit Australian conditions or to return to the British system of large company mining. The unanticipated result was the emergence of a new type of gold mining company, different in scale and management philosophy to the joint stock mining companies which had been evolved in Britain in the 1840s. The changes in technology and the differences between the aims and structures of the British joint stock company and the emerging no-liability type company will be discussed in this chapter.
The Miners Seek Control in Victoria

The Local Courts authorised by the Act for the Better Management of the Goldfields (18 Vict. 37) in 1855 had limited jurisdiction. They could develop bye-laws covering the size of claims, the working of claims and the use of machinery as well as deciding partnership disputes involving less than £200. The declaration of districts for each local court and the appointment of a chairman for each court was authorised. The government produced a set of regulations for the guidance of the local courts which set the annual fee for a Miners Right at £1 per year; the claim size on alluvial ground was unchanged at 12 feet square for one miner or 24 feet square for four miners. For reef mining the claim size was 12 feet square for each holder of a miner’s right. Alluvial leases on new ground could be up to 40 acres but on worked ground were not to exceed 10 acres. An annual rent of £10 per acre was payable in both cases. Quartz leases were to be a maximum of 220 yards along the reef and 50 yards across the reef with a lease rent of £1 per yard of length.

On the same day in June that the Victorian Legislative Council passed 18 Vict. 37 it also passed an Act for the Better Regulation of Mining Companies (18 Vict. 42) which was a copy of a British law (commonly called the cost book system for mining companies), which allowed expenditure only when funds were available to pay the accounts, dividends could only be paid from profits and calls could be made on shares to pay losses. Few companies were registered under this Act, commonly called Haines’ Act, because it did not address Victorian conditions. The continuing tensions resulting from the actions of Victoria in legislating for increased miner participation in the control of mining laws, but at the same time passing laws to assist in the formation of mining companies based on the British pattern, were not removed until the bye-laws of the local courts and the later mining boards were consolidated in the Mining Statute of 1865, and miners and investors had succeeded in pushing through parliament the so-called no-liability company act of 1871. As will be explained in succeeding sections, the Mining Statute provided a solid legal basis for Australian gold mining companies. British mining law, designed for mining minerals such as coal, copper, tin and lead

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246 Act 18 Vict. 37 clauses 16 and 17.
247 Victorian Government Gazette, 13 June 1855, pp. 1419-22, clauses 1, 6, 12 and 13. Claims could be pegged by the holder of a miner’s right but applications to the Warden for leases had to be in writing and approved by the Warden.
under entirely different circumstances, was rejected as unsuitable by Australian gold miners.

The government appointed the more capable gold commissioners to the positions of wardens who were to chair the local courts and adjudicate in disputes over claims and encroachment. The initial districts and chairmen were: Avoca, William Templeton; Ballarat, Charles Sherrard; Bendigo, Joseph Panton; Castlemaine, John Bull; Ovens (Beechworth), William Turner. In addition to the chairman each court was to have nine members elected by the holders of miner’s rights. The first election was at Ballarat on 13 July, the second at Bendigo on 21 July and the remainder were completed by 25 August. The wardens who had been senior gold commissioners had difficulty adjusting to a position in which they were subject to and had to implement the decisions of the court. Sherard wrote to Hotham suggesting that James Daly, his assistant, be appointed chairman of the Ballarat court so as to enable Sherard sufficient time to set up the other courts in the district.

The Victorian Act 18 Vict. 34 had made provision for the election of eight additional members of the Legislative Council and four additional government nominees. The enlarged Council met in November and the eight elected from the mining districts and the one miner nominee soon exerted their influence by moving that three Select Committees be appointed: one to investigate the best method of developing the colony, one to report on goldmining on private property, and the third to investigate the operation of the local courts. These committees (on which the newly elected miner members were prominent) reported early in 1856, but the reports did not result in legislation as the Council was prorogued in March 1856. However the findings influenced later legislation.

248 Ibid., 29 June 1855, p. 1542.
249 Act 18 Vict 37, clause 17. Other local courts were established later at Ararat, Buninyong, Creswick, Heathcote, Dunolly, Fryers Creek, Maldon, Taradale, Hepburn, Caledonia, Mount Egerton, Mount Blackwood and Waranga.
251 V.P.R.S 1189/99 letter 55/9686, 1 August 1855.
252 See Chapter 2.
253 Report of Select Committee on Mining on Private Property, reported 1 February 1856, Report of Select Committee on the Operation of the Local Courts, reported 19 February 1856, Report of Select Committee on Development of the Colony, reported 11 March 1856.
The motion setting up the Select Committee on the operation of the local courts was moved by Thomas Benson, who was also a member of the Bendigo local court, and the members appointed were mainly the newly elected goldfields members. The only witness called was Joseph Panton, which makes it probable that the Bendigo local court wished to control Panton’s actions in granting leases as the control of leases was not clearly spelt out in 18 Vict 37. When questioned Panton made it clear that he opposed the court having judicial powers, which he said should only be exercised by a justice of the peace or a judge. He added that the court was wasting its time on partnership disputes, and that it should be limited to recommending bye-laws for its area, including the size of leases. He said he had received 804 applications for leases at Bendigo, but not all had been approved. The quartz leases he had approved had averaged 17 yards along the reef, similar in size to the quartz claims approved by the local court which were 20 yards along the reef to a party of four. Panton snubbed the court by failing to attend several meetings without prior notice. This upset the members and they petitioned the Governor to have him replaced as chairman. Panton said the duties of warden prevented him giving sufficient time to the court. On 6 October, Francis Jones the subwarden replaced Panton as chairman but Panton remained as warden. From early 1856 all applications for alluvial and quartz leases at Bendigo were processed by the local court so it seems Benson won that battle for control.

The Select Committee on developing the colony recommended typographical, geological and natural history surveys of the colony and stressed the need for a central supervisory organisation to supervise mining. The Select Committee on gold mining on private property split equally (pastoralists versus miners) on most decisions, with the chairman Vincent Pyke (a miner) often exercising his casting vote. The committee decided all auriferous land should be worked but could not agree about regulations to control mining on private property.

The bye-laws submitted by the local courts were vetted for legality by the Solicitor-General and if accepted were published in the Government Gazette. If not approved they

255 Bendigo Advertiser, 10 October 1855.
256 The Bendigo Advertiser. See reports of the local court proceedings to late 1857 passim.
257 These arguments foreshadowed the many parliamentary debates until this matter was resolved in 1884.
were referred back to the court for reconsideration.\textsuperscript{258} The warden’s powers in settling disputes over claim boundaries were reduced in 1855 by allowing the appointment of local assessors when requested by the disputing parties, to assist him in making a decision.\textsuperscript{259} In September 1855 the government allowed each court to pay the elected members for each dispute decided, the money being raised from costs of £2 10s charged to the party losing the case, each member present on a case sharing the money.\textsuperscript{260} This established the concept that elected officials should be paid, a concept that was later extended to pay elected members of parliament.\textsuperscript{261}

After six months the tenure of all members of the initial courts expired and fresh elections were held early in 1856. Later that year statistics on the partnership disputes decided by the local courts were collected from the districts. These showed that up to the middle of August the Ballarat court had decided 502 disputes, Bendigo 150, Avoca 36, Beechworth 32 and the others less than 20 each. Returns from some districts in June 1856 show the adult male populations were Ballarat 41,790, Bendigo 7000, Ovens 9030, Avoca 26,950, Castlemaine not given.\textsuperscript{262}

The bye-laws recommended by the local courts were closely related to the type of mining which developed in each district, which in turn depended on the geology of the ore deposit. The shallow alluvial and eluvial deposits of the central Ballarat field were soon depleted and the miners were faced with extracting alluvial gold buried more than 100 feet below the surface. To understand how the miners responded to this challenge and the resulting changes in the bye-laws, it is necessary to investigate the changes that were taking place in the technology required to extract washdirt from these deep leads at Ballarat, and those required for mining the quartz reefs at Bendigo and elsewhere.\textsuperscript{263}

\textsuperscript{258} Reports of the Solicitor-General Robert Molesworth were attached to all draft bye-laws.
\textsuperscript{259} V.P.R.S. 1189/101, letter 55/11552, 1 September 1855.
\textsuperscript{260} Mount Alexander Mail, 17 August 1855.
\textsuperscript{262} V.P.R.S. 1189/457 letters 56/4473, 4474, 4475 and 1189/460 letter 56/7260. The figures have been extracted from the reports from the districts. The Bendigo district was depleted at this time by rushes to other districts.
\textsuperscript{263} The term ‘deep lead’ is believed to have been in use from the late 1850s but was not defined legally until the Mining Development Act was passed in Victoria in 1896. In Clause 2 of that Act it was defined as any watercourse or gutter below the surface of the earth containing alluvial deposits at a depth of not less than 100 feet.
Deep Alluvial Mining

As the alluvial miners at East Ballarat followed the gutters down the hillsides from the shallow sinking the gutters became deeper and the ground wetter, requiring a macro-innovation in technology which was first developed at Ballarat. By the end of 1853 the depth to bedrock was about 150 feet and the gutters were being given individual names such as Canadian Gully and Prince Regent Gully. These gutters generally followed a similar line to the surface drainage and were very rich in coarse gold and nuggets.  

As the depth to the gutter and the inflow of water increased the size of the parties increased to cope with the increased workload of digging and bailing by bucket and windlass. When very wet drifts were encountered the round or oblong shafts were made rectangular, four slabs slightly less than the size of the shaft were fastened together and placed in the centre of the shaft and driven down into the drift, the walls of the shaft were cut away a foot or so and long slabs fitted in. The long slabs were notched to hold the shorter end slabs in position, or holes were drilled in the long slabs to hold pegs behind which the end slabs were inserted. This process was called ‘opening out’. The box in the centre was excavated so it was always below the shaft slabs. Puddled clay was rammed behind the shaft slabs to keep the shaft as dry as possible. This process was continued until drier ground was reached. The miners then dug the shaft to the larger size for a further nine feet or so, then slabbed up from the bottom, ramming clay behind the slabs where necessary. This was repeated till the washdirt was reached. If the ground continued wet the laborious method of the inner box had to be continued.  

Timber companies were soon established to supply cut timber for shaft slabbing, which was usually supplied to give shaft internal dimensions of four feet by two feet ten inches, each slab being six inches by two inches cross section. Parties of 12 were common as this allowed four men per shift, for three shifts per day, and gave a total claim size of 36 feet by 48 feet serviced by one shaft. The shaft was sunk at the centre of the claim to bedrock, drives were put in from opposite sides in the washdirt to the end of the claim boundaries, and from these crosscuts were driven to the side boundaries. Spiling or driving pointed laths into the soil at the bottom of the shaft, removing the shaft soil,

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265 Ibid., p. 449. It is likely that this slabbing technique was developed at Ballarat as buried leads in California were elevated and dry and were accessed by adits.
opening out and slabbing was an alternative way of sinking. At bedrock, legs and caps were erected to form the entrance to the drives, the legs and caps being round or sawn and six inches outside dimensions. The legs were about six feet apart and laths (each six inches wide by two inches thick) were driven between caps to hold up the roof. The sides of the drives and crosscuts were slabbed or lathed if necessary to prevent the wet ground collapsing. When the crosscuts had been completed to the claim boundary, the miners would commence removing the washdirt between the crosscuts, starting from the boundary and working towards the shaft, the roof being allowed to collapse behind them. Cement was being blasted out as early as 1853 in these Ballarat leads. Shallow sinking was a direct transfer of technology from California, where it was called ‘coyoting’. However it was much older than this as the use of the process is mentioned by Herodotus in *The Histories* written about 430 B.C. Mining the deep leads to depths of 500 feet was new technology developed at Ballarat.

Before starting to excavate the drives the miners dug a sump at one end of the shaft to collect the water, which was tipped into a bucket and hauled to the surface with windlass by members of the party. The windlass usually had a wooden barrel with a handle at each end to raise and lower two buckets with hemp ropes, so one ascended as the other descended. Washdirt was raised similarly. As the shaft deepened the windlass was replaced with a horse-whip, which consisted of a pulley wheel on an inclined post or frame, over which passed a hemp rope to raise or lower a bucket in the shaft. The top end of the rope was connected to the horse collar while the other end was passed over the wheel and hooked to the bucket. The horse was guided by the whip-boy along a track towards the shaft so the bucket was lowered to the bottom. While it was being filled the rope was disconnected from the collar and hooked to the swingle-tree. The horse was led away from the shaft and the bucket raised and emptied into a barrow at the surface. Underground the washdirt was carried to the shaft in barrows or in small wooden or iron trucks running on light rails. To turn the trucks at the shaft a sheet of iron was placed at the end of the rails and the truck turned by sliding. Horse operated

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whims were introduced in 1854 and were suitable for shafts several hundred feet deep with two buckets or light cages in balance. Whims for haulage were a direct transfer of Cornish technology in use in the eighteenth century.\textsuperscript{271} The first use in Victoria of a cage carrying trucks to the surface was at Ballarat in 1857.\textsuperscript{272} By 1859 horses were used underground to pull trucks on wooden rails to the shaft for haulage to the surface.\textsuperscript{273}

Whims had already been used at the South Australian copper mines in the 1840s, with small headframes of four wooden legs with pulleys at the top to allow the change in direction of the rope from near horizontal to vertical so as to raise and lower the buckets in the shaft. When cages were introduced the height of the pulleys had to be raised to accommodate the cage and the bailing tank so they could be emptied at the surface. This in turn required longer legs and the introduction of a skyshaft which extended the shaft guides or runners above the surface plat. Fortunately the taller trees required for these legs were readily available in the local forests. The skyshaft was extended sufficiently to allow the trucks to be wheeled out of the cage along rails, to be tipped directly into a puddling machine which separated the gold. The puddling machine was made of cast iron with steam engines driving the rakes through gears, and was usually above the surface so the sand could be washed out of the bottom and not shovelled.\textsuperscript{274}

The first rod pump installation driven by a small rotative steam engine, with flat rods driven from the crank to transmit power to the pump rods, was at the Gravel Pits Lead in Ballarat in 1854. It was used to remove water from the mine. This was a cheaper development of the beam pump already in use in South Australia, as it did not require a substantial engine house to support a beam. It was a Cornish innovation allowing winding and pumping with the one engine. The installation was opposed by many miners who considered it an example of monopoly and a threat to the small miner.\textsuperscript{275}

The earliest method of ventilating underground workings was by a calico windsail and

\textsuperscript{271} Whims were in use in Cornish copper and tin mines in the eighteenth century for raising ore. See W. Pryce, \textit{Mineralogia Cornubiensis} (London: James Phillips, 1778), Plate VI.
\textsuperscript{273} Davey and McCarthy, "The Development of Victorian Gold Mining Technology," p. 74.
\textsuperscript{274} Dicker's \textit{Mining Record}. An illustration on the 29 October 1867 shows the brace 40 feet above the surface with a small truck in the cage which is suspended on multistrand hemp rope while another truck is being swivelled onto a railway running to the puddling mill. The poppet legs are clad in timber to keep out the cold winds of the Ballarat region. Flat rod pumps were in use in South Australia in the late 1840s and were a variation of the beam pump for use with rotative drives.
duct down the shaft, similar to the method used to ventilate the holds of ships, and this was supplemented on still days with a hand driven fanner; neither method was very effective. Connecting two shafts underground to give natural circulation down one and up the other, similar to coal mines, was found to be effective in providing ventilation.

Not every shaft sunk in this period was remunerative if it did not hit the gutter. As the miners moved down the lead they would peg a claim where they thought the lead would be in relation to the last successful claims. As the gutter wandered like a present day creek or river only a few shafts hit near the gutter. An informal system developed where parties ahead of successful claims would “shepherd” their claim by doing the minimum allowable two hours’ work each day, hoping that adjacent parties would energetically work their claim down to bedrock. If one claim produced gold all claims nearby would be worked while others further away would be abandoned. As the several leads were followed from the higher ground to what is now the Bridge Street area of central Ballarat, the width of the washdirt increased to cover a wide area which is believed to have been the bottom of a lake caused by a lava flow. This central area was intensively mined between 1853 and 1858 using the methods described. By October 1855 the lead leaving the Gravel Pits, into which all the leads from east Ballarat had fed, was traced under the basalt flows near the junction of Bridge and Sturt streets. The first co-operative party, called Bath’s party because it was mining on land owned by Thomas Bath, took 18 months to sink through the basalt to a depth of 250 feet in wet ground. They used a Cornish pump with a six inch rising main driven by ten H.P. steam engine, which was increased in power when working the washdirt which was up to 200 feet wide. They worked the lead for 650 feet along its length.

Up to this time the early claims in Victoria and New South Wales were block claims, usually square or rectangular, marked by corner pegs on the surface with the boundaries descending into the earth vertically from the lines between the pegs. Problems with this

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277 I. S. Finlay and P. M. Douglas, *Ballarat Mines and Deep Leads* (Melbourne: Department of Manufacturing and Industry Development, 1992), pp. 6-8, 16-19. These lava flows have been dated between 4.5Ma. and 60,000 years old and cover part of an earlier drainage pattern established between 30 Ma. and 20 Ma.

type of claim became apparent at Ballarat early in 1856 when shafts were being sunk on the basalt plateau by cooperative parties and companies searching for the lead under the basalt. Shepherding became rife as most parties sought to avoid heavy labour costs and other expenditure while others located the lead. The Ballarat local court sought to force all claimholders to sink the shaft but did not have the power to enforce this instruction. On 7 March 1856 the Victorian government, at the request of the court, published what was called the frontage regulation. Briefly this regulation required the claim holder/s deemed most likely to hit the extension of the lead to sink the first shaft (the prospecting claim). Adjacent claims were allowed to wait until this shaft was bottomed and the position of the extended lead established. The position of the lead was marked on the surface by a line of flags and the prospecting claim was then marked out on the surface by the mining surveyor for a distance depending on the depth of the gutter, for example for a depth of 400 feet a party of eight was allowed 225 feet along the gutter with a maximum claim width of 200 feet. Adjacent claims were then moved relative to the prospecting claim and these claim holders could then decide whether to sink their shaft or abandon their claim. At the April 1856 election the supporters of bigger frontage claims won a majority on the Ballarat local court and began a campaign for larger claim areas. This is a good example of how a Local Court was able to draft regulations to suit the characteristics of a particular goldfield. Such an innovation would not have been possible before Eureka.

The first prospecting claim (No. 1) under these regulations was on the plateau on the Frenchman’s Lead about 3 miles south of the Gravel Pits. This distinction was given by general agreement to a party of 12 Newcastle men who had been very active sinking their shaft through basalt to a depth of 130 feet while other parties shepherded. Under the new frontage regulations they then sunk the shaft to 240 feet and tunnelled 170 feet to reach the washdirt after eight months work. The width of the gutter varied between 8 feet and 400 feet. The mine returned a dividend of £4,185 which was not a wonderful return for the labour involved. The evidence available indicates this was a party who

279 Ibid., p. 459.
280 Ibid., pp. 460-1.
282 Brough Smyth, The Goldfields and Mineral Districts of Victoria, pp. 176-7, 496-7. Brough Smyth does not clarify if the men were from Newcastle, Australia, or Newcastle England but in either case they were most likely experienced coal miners. The Ballarat Times of 15 April reported that Giles and Party who were digging the No. 1 hole on Sebastopol Hill were North Country Boys so they may have come
had previous coal mining experience. The sinking was through two layers of basalt with a total thickness of 160 feet as well as layers of clay and sandy soil. Both layers of basalt required drilling holes by hand, filling them with gunpowder and blasting to smash the rock, techniques in which experience in coal mining and shaft sinking would have been of assistance. The second layer of basalt was very wet. The *Ballarat Times* of 24 March 1856 described a successful experiment in this No.1 shaft, where a new method of stemming the gunpowder charge was introduced to ensure the charge fired in very wet conditions. The method was developed by Karoly Nyulasi, a Hungarian who was working with a party in a nearby shaft. It is not known if this was an original invention or an adaption of a previous method, but it was so important to the Ballarat miners that they formed a committee to consider the best method of rewarding Nyulasi.  

It is likely this Newcastle party introduced the bord and pillar system of coal mining to deep lead mining in which a layer of washdirt several feet deep, extending over a wide area, is very similar to a thin coal seam. Later diagrams of drives and crosscuts in deep lead mines are very similar to the layouts of coal mines. See Appendix 5.

In these early years the miners did not know where to dig the shaft to hit the gutter, so they tried the coal mining technique of boring to obtain an understanding of underground conditions. Although no details are available they would have used a heavy bit, repeatedly raised and dropped on a rope attached to a spring pole, to pulverise the rock at the bottom of the hole. A series of bores were put down in a line across the expected path of the lead, and deep enough to pass through the washdirt to the bedrock. The depth of the washdirt in each bore was plotted on a sectional drawing and the location and depth of the gutter determined. Further down Frenchman’s Lead the Albion Company which held claims 115 to 122 on this lead, put down the first series of bores on the Ballarat tableland in 1856, and by mid 1858 had determined where to sink the

direct from England. Many parties at that time were naming themselves after the ship on which they migrated but a search of shipping records shows there were no ships named Newcastle operating in Australian waters or as migrant ships in the 1850s.

283 E. F. Kunz, *Blood and Gold* (Melbourne: F. W. Cheshire, 1969), pp. 97-9. Kunz gives an account of Nyulasi’s life in Australia. He was one of the group of Polish and Hungarian soldiers who took part in the uprising against Austria in 1848 and migrated to Australia in 1852 to join the goldrush. Some of them made considerable contributions to Australian society.


285 This method had been used to bore for water for centuries in China, India and Europe. See C. P. Chugh, *Manual of Drilling Technology* (Rotterdam: A. A. Balkema, 1985), pp. 3-5.
shaft. The depth of the shaft was 475 feet, the washdirt was between one and six feet deep, and varied in width from 70 feet to 400 feet.\footnote{Brough Smyth, \textit{The Goldfields and Mineral Districts of Victoria}, p. 499.}

Because of the ancient drainage system at Ballarat the miners moved from shallow to deep sinking within two years, and the technology of deep sinking in very wet ground was developed there. Another type of deep lead mining in ancient river beds buried at depth was being carried out on the western slopes of the Sierra Nevada Range in California, but the leads there were between 500 and 7000 feet above sea level and present day rivers crossed the old drainage pattern at right angles, so the leads were drained naturally and could be worked by adits.\footnote{C. G. W Lock, \textit{Gold - Its Occurrence and Extraction} (London: E. & F. N. Spon, 1882), p. 936.} There were some elevated deep leads in eastern Australia which were worked by adit but most leads were at low elevations and were very wet and so were more difficult and costly to work because the wet ground turned into sludge unless the water was pumped out before driving commenced.\footnote{Hunter, \textit{The Deep Leads of Victoria}, pp. 5, 15.} In the period before 1870 the pumps used at Ballarat were usually driven by horizontal steam engines up to 40 H.P.\footnote{P. Milner, \textit{On the Significance of Extant Machinery Sites on the Berry Deep Lead System- Tech. Note Tn-87/18} (Melbourne: 1987), p. 10.}

As well as being innovative in developing deep lead technology the Ballarat miners also influenced the development of mining companies. Shaft sinking through basalt, the need to slab the shaft and timber the drives and crosscuts, the need for pumps and other stores and the need to live for months and even years until gold was produced and dividends were paid, meant capital was required to start a mine. Co-operative parties of up to 80 miners formed and additional partners were admitted for supplying goods and services. Partners who could not survive the period until gold was found began to sell all or part of their share and an informal stock exchange developed at the ‘Corner’ where Lydiard and Sturt streets met where such sales were taking place from the mid 1850s. The Ballarat Stock Exchange was established near there in the early 1860s.\footnote{W. B. Withers, \textit{The History of Ballarat}, Facsimile Edition 1980 ed. (Ballarat: F. W. Niven & Co., 1870), pp. 236-7.}

The Ballarat deep lead system was the first in Australia to be opened under basalt as part of a drainage system flowing south. Other south flowing leads were found near Smythesdale and Scarsdale. By 1857 deep leads in an old drainage system flowing north...
from Ballarat were being worked under an extensive basalt plain at Creswick and Clunes, Maryborough and Avoca. These leads joined further north to become the Loddon deep leads, which were very rich in places and were worked until the 1930s. Less extensive leads were found at Bendigo, Ararat, Stawell and other gold fields. Narrow, very wet deep leads, confined by precipitous valley walls were found along Morse’s Creek and other tributaries of the Ovens River in north east Victoria, and an extensive north flowing system was found north from Chiltern to under the present Murray River.\(^{291}\) The Chiltern deep lead system was worked from 1860 and the deepest mine in 1869 was the Extended Sons of Freedom at 235 feet, where the washdirt was up to four feet thick and very wet. There was no basalt cover in this area, with consequent greater pressures at depth and in some places there was more than one lead, each successively deeper, with no bedrock below each washdirt. The cost of boring to locate the washdirt and sinking the shaft was often less in the alluvial covering than in the basalt at Ballarat. The ground was usually wet and the northern miners developed slightly different technology to what they called the ‘down country system’.\(^{292}\) The differences between the two methods are described in Appendix 5.

Deep leads were worked for gold in New South Wales at Uralla from 1856, Forbes 1862 and Gulgong 1871.\(^{293}\) Quartz veins rich in gold were sometimes found in the bedrock where the deep lead crossed the quartz reef. These veins were then worked by the usual quartz mining methods. Some mines (particularly at Ballarat which began as deep lead mines) continued for many years as quartz mines after quartz reefs were found in the bedrock below the lead.\(^{294}\)

Innovations in deep lead gold mining were rapid at Ballarat in the mid 1850s including the use of horizontal steam engines for pumping, the transfer of coal mining technology, improvements in blasting in wet ground and boring to locate the leads. Larger parties were formed to meet the increased labour needed and a new type of mining claim was introduced to allow for the deeper sinking. When combined these changes can be considered to be a macro-innovation in gold mining technology.

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Quartz Reef Mining

As the shallow alluvial gold was depleted the miners began to introduce overseas methods of mining the quartz reefs exposed at the surface. This section will investigate innovations in the imported machinery and the introduction of chemical methods to meet Australian conditions.

The first local court at Bendigo had five members who were strongly in favour of the small alluvial miner and three who were sympathetic to quartz mining and its decisions were castigated in the local newspaper for causing the suspension of quartz mining. From mid 1856 the court was dominated by quartz interests and most applications for quartz claims were approved.

Development of crushing machinery in eastern Australia was rapid. Langlands Foundry in Melbourne was involved in manufacturing stampers and other mining machinery from the early 1850s. Probably these were copied from Cornish designs. Robert Fulton, who had earlier been in partnership with Langlands, made a cam which rotated the shank and stamp a few degrees each lift and gave more even wear on the bottom of the stamp. Fulton did not patent the design. This design required cylindrical stamps.

On 27 October 1855 the Mining Journal reported that at Bendigo it was difficult to predict future developments in crushing but the best machine there was a steam driven stamper in New Chum Gully with a 16 H.P. steam engine geared to a horizontal shaft 16 feet long, and 20 inches in diameter, operating 12 stamps in units of four. Each stamp weighed five hundredweight, with a lift of 12 inches, giving 780 stamps per minute. The discharge ran into an amalgamator. This machine was designed by Thomas Carpenter, a Cornish mining engineer who migrated to New South Wales in 1851 as an employee of the Australasian Gold Mining company. The Mining Journal’s report indicates that by 1855 a consensus was developing that stampers of Cornish design but with heavier...

295 The Bendigo Advertiser, 1 August, 18 December 1855.
296 Ibid., Reports of the meetings of the local court mid 1856 to 57 passim.
298 J. G. Burnell, "Selected Papers from the Journal," Journal of the Institution of Engineers Australia Vol. 1 (1929): p. 407. Fulton did not patent this invention and no proof has been found that it was a first and it may have been a copy of an overseas development.
299 "The Mining Journal, London," 27 October 1855, p. 701. The description is similar to the machine in Agricola, p. 284, and Pryce, Plate V except the Carpenter’s machine would have had iron rods to lift the stamps not square wooden rods. G. Serle, Biographical Register of Victorian Parliament (Melbourne), p. 32.
individual stamps were the best machines for the primary crushing of hard quartz ores. Berdan pans and rolls of United States and European design were discarded due to excessive wear and Chilean mills were better used for fine grinding and amalgamating.\(^{300}\)

Competition between the public crushers, which were established to crush for the many small parties, led to rapid improvements in crushing technology and the prices charged fell quickly. From an initial charge of £8 per ton in early 1855, rates fell to between £2 and £4 per ton at the end of the year.\(^{301}\) At these rates, with gold worth about £4 an ounce, only rich oxidised ore from near the surface with grades over 1 ounce per ton would pay for crushing, but as soon as the water level was reached the average grades on most fields fell below 12 pennyweights per ton. Fortunately the price of crushing continued to fall as experience was gained.\(^{302}\)

In the first years the quartz was separated from the country rock by quarrying, using hand drills to produce a cylindrical hole about one inch in diameter a few feet in depth, which was filled with gunpowder, tamped or stemmed with clay, through which a fuse of gunpowder rolled in paper was inserted, the fuse was lit, and the explosion shattered the rock. Guncotton, an explosive developed in Europe for military purposes, was introduced as an explosive in Victoria in 1869.\(^{303}\) When the veins were narrow, quarrying down to about 30 feet was the maximum for safety, as without removing a large amount of rock from the sides the quarry was likely to collapse. Where the veins were wide (in some cases up to 40 feet) deeper quarrying was safe and economical.\(^{304}\) The miners could then see the veins continuing beneath the quarry floor, so they dug shafts to follow the vein down. Initially these shafts were worked by whip or whim,

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\(^{301}\) Kelly, *Life in Victoria*, vol. 2, p. 210. "Advertisement," *Bendigo Advertiser*, 15 September 1855. Ensor offered 1 ton £6, 2 tons £5, 3 tons £4, 4 tons £2 per ton. On the same page Bassett, Nicholson and Wellington were offering 5 tons £6, 10 tons £5 and larger quantities £4 per ton. "Ensors Quartz Mill," *Bendigo Advertiser*, 21 July 1857. Ensor was crushing with Berdan pans but by June 1857 had upgraded this plant to primary crushing with stampers at the rate of one ton per hour followed by a Berdan pan amalgamator. The horse driven plant of Nicholas and Bassett was then steam driven. See Kelly p. 201.


\(^{303}\) "Reports of Mining Surveyors and Registrars, Victoria," (Melbourne: Mines Department). Sandhurst Division, 1st Quarter 1869. It was used at the Catherine Reef United mine.

\(^{304}\) Brough Smyth, *The Goldfields and Mineral Districts of Victoria*, p. 287-8. Black Hill at Ballarat and the United Claimholders mine at Eaglehawk near Bendigo had networks of spurs at the surface which were quarried to near the waterline.
water was bailed and ore lifted in buckets. In the early years the shafts were usually vertical, plats were cut at suitable depths and levels (called crosscuts) were driven to cut the reef or vein, which was then stoped.

In eastern Australia most gold reefs were narrow but sometimes opened up to larger saddle reefs and lenses, from one sixteenth of an inch to a few feet in width. In narrow stopes the walls were prevented from closing by props of timber as the ore and mullock was removed. In wider stopes the roof was supported where necessary with timber props or pigstyes of stacked timber. From the crosscut a drive was made along the reef, usually six feet high and five feet wide, timbered with legs and caps as with deep sinking, and laths were placed on the tops of the caps and outside the legs to prevent rocks falling into the drive. Rises were then put up above the drive into the orebody, the stope was opened up along the reef, and the broken ore dropped down through timbered orepasses to the drive into barrows or small trucks on rails and carried to the shaft. Here it was shovelled into buckets and raised to the surface. When cages came into use in the late 1850s the truck was pushed into the cage, raised to the surface, and then run on rails to the crusher.³⁰⁵ By 1860 the reefs were being mined below the waterline and rod and beam pumps were being installed, driven by steam engines with either vertical or horizontal cylinders at pressures around 50 p.s.i.g. By the end of the 1860s shafts on the major goldfields were down to 600 feet or more, with single or double drum winders raising and lowering cages in the shafts.³⁰⁶ The advent of cages carrying ore required the division of the shaft into compartments so falling rocks would not injure miners using ladderways or other equipment such as pumps in the shaft. Usually shafts had three or four compartments lined with sawn timber, the internal dimensions of the shaft being from ten to fourteen feet long and six feet wide. For example the Catherine Reef United shaft at Bendigo had two cage compartments, each six feet by three feet, and a ladder and pump compartment six feet by six feet. The partitions were of sawn timber and each stage of the ladderway was 30 feet.³⁰⁷ Steam engines up to 100 H.P. were being installed.³⁰⁸ Where water was plentiful waterwheels were common (for example,

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³⁰⁵ Ibid., pp. 296-8.
³⁰⁶ Ibid., pp. 279-80.
³⁰⁷ "Reports of Mining Surveyors and Registrars, Victoria," Sandhurst Division, Dec. 1861.
in the Beechworth and Gippsland districts in Victoria and at Adelong in New South Wales) for driving crushers and pumps.\textsuperscript{309}

In Cornwall in the eighteenth century miners usually roasted or calcined the tin ores before crushing as they believed this would make the ore more friable and easier to crush. The process also drove off any sulphur and arsenic minerals in the ore.\textsuperscript{310} The early reef miners in Australia repeated this practice in the belief it would assist crushing gold ores with the primitive equipment then available. The ore was heaped in stacks intermixed with wood, or thrown into bottle kilns intermixed with wood; the wood was burnt and the calcined ore was then taken to the crusher. The softening effect of calcining gold ores from the oxidised zone is doubtful, but the practice was widespread in eastern Australia in the 1850s and refractory ores from below the water line were still being calcined in the 1880s.\textsuperscript{311}

There was continuous development of stampers in California and Australia from the early 1850s.\textsuperscript{312} In each country Cornish rolls and Berdan pans were found to wear rapidly on the hard quartz ores. Chilean mills were effective for fine grinding but were slow and costly. By the 1860s the stamper dominated primary grinding in both countries because it was a continuous process as distinct from the batch processing of the Chilean mill and hence used less labour. Developments in each country were reported in the other and comparisons were made of machine efficiencies.\textsuperscript{313} At this time both public crushers and plants at individual mines were common, but the cost of transport by dray to a public plant gradually forced a change to the ore being crushed at each mine. The efficiency of a battery of stampers depended on several variables: the type of ore, the weight of the stamp, the rate of stamping, the distance the stamp dropped, the size of holes in the screens, and the position of the screen relative to the dies. If the ore was free milling and there was no pyrites in the ore, the time in the mortar box had to be kept

\textsuperscript{309} "Reports of Mining Surveyors and Registrars, Victoria," 1st Quarter 1869. At that time 243 were in use in Victoria and 75 in N.S.W.


\textsuperscript{312} S. Davison, \textit{The Discovery and Geognosy of Gold Deposits} (London: Longmans, Green, 1860), pp. 55-60. Davison indicated that the use of stampers for crushing gold ore began in California in 1852.

\textsuperscript{313} W Meyerriecks, \textit{Drills and Mills} (Tampa: W. Meyerriecks, 2001), p. 195. The first stamp mill in the United States was in Georgia in 1829 and possibly the first in California was at Coulterville in 1850.

\textsuperscript{314} W. P. Blake, \textit{Mining Machinery} (New Haven: Charles Clasfield & Co., 1871). Blake included excerpts from the Reports of Mining Surveyors and Registrars of the Victorian Mines Department and compared them with Californian practice (see pp. 201, 207).
short or energy was wasted. If the screen holes were too large, the pulp passing through
the screen would have particles in which the gold had not been separated from the
quartz and which would not be collected by amalgamation. If the screen holes were too
small the slurry particles would remain in the mortar box and be crushed too fine,
resulting in slimes from which it was difficult to separate the fine gold, which floated
off in the current of water and was lost. Heavy stamps gave rapid crushing but power
was wasted if they were raised too high. Despite the number of variables, millmen in
California and Australia reached similar conclusions on best practice by 1871. In that
year W. Raymond, an American writer, published a book which included a table giving
comparisons of Californian and Australian practice.\textsuperscript{314}

<table>
<thead>
<tr>
<th>Goldfield</th>
<th>Wt. of stamp lb</th>
<th>Drops / minute</th>
<th>Drop inches</th>
<th>Tons daily/H.P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>District</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuolumne</td>
<td>500</td>
<td>40-80</td>
<td>6-10</td>
<td>1.26-2.2</td>
</tr>
<tr>
<td>Amador</td>
<td>600</td>
<td>70-79</td>
<td>9-11</td>
<td>1.07-1.9</td>
</tr>
<tr>
<td>Eldorado</td>
<td>300-650</td>
<td>65-80</td>
<td>7-10</td>
<td>1.24-3.93</td>
</tr>
<tr>
<td>Placer</td>
<td>600-800</td>
<td>60-75</td>
<td>7-12</td>
<td>1.24-1.53</td>
</tr>
<tr>
<td>Plumas</td>
<td>400-850</td>
<td>35-70</td>
<td>7-11</td>
<td>1.15-2.83</td>
</tr>
<tr>
<td>Shasta</td>
<td>300-600</td>
<td>60</td>
<td>6</td>
<td>1.83-2.75</td>
</tr>
<tr>
<td>Victoria</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>District</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ballarat</td>
<td>400-850</td>
<td>50-85</td>
<td>7-10</td>
<td>1.66</td>
</tr>
<tr>
<td>Beechworth</td>
<td>442-775</td>
<td>40-90</td>
<td>5-14</td>
<td>2.13</td>
</tr>
<tr>
<td>Bendigo</td>
<td>500-800</td>
<td>25-75</td>
<td>6-18</td>
<td>1.5</td>
</tr>
<tr>
<td>Maryborough</td>
<td>450-800</td>
<td>50-75</td>
<td>6-22</td>
<td>1.33</td>
</tr>
<tr>
<td>Castlemaine</td>
<td>450-800</td>
<td>35-75</td>
<td>6-15</td>
<td>1.7</td>
</tr>
<tr>
<td>Ararat</td>
<td>500-675</td>
<td>60-72</td>
<td>7.5-10</td>
<td>1.83</td>
</tr>
<tr>
<td>Gippsland</td>
<td>600-750</td>
<td>60-80</td>
<td>7-10</td>
<td>1.58</td>
</tr>
<tr>
<td>Pt. Phillip Co.</td>
<td>600-800</td>
<td>60-80</td>
<td>7-10</td>
<td>2.42-3.3</td>
</tr>
</tbody>
</table>

The final column may be considered a measure of the efficiency of crushing. As
weighing was not very accurate at most mines in the 1870s and there is no guarantee
that a ton measured in California was the same as in Victoria the second decimal place
in this column can be ignored. The Shasta and Port Phillip figures are for individual
mines the others are averages for several mines. The figures show the average
efficiencies in the early 1870s were equal if not better at Victorian mines when
compared with the Californian results and the results at the Port Phillip Company were
better than most.

\textsuperscript{314} R. W. Raymond, \textit{Mines, Mills and Furnaces of the Pacific States and Territories} (New York: J. B.
Ford & Co., 1871).
There was one attempt in the early 1860s to break the domination by stampers when James Hart, the maker of a steam puddler already mentioned in Chapter 2, and the miners of Raywood, a small goldfield north of Bendigo, agreed on a fixed rate for crushing ore. Hart then designed and built at his North Melbourne works, an entirely novel rotating crusher which appears to be the first concept of an autogenous grinder. However only eight pennyweights of gold were extracted from a ton of ore containing one ounce to the ton. The miners declared the machine ‘a complete failure’ and Hart did not have sufficient funds to further develop his invention. Further details of the machine are given in Appendix 5. Autogenous grinding was finally developed successfully in the 1950s but not in Australia.

After crushing wet in the stamper box the fine particles were washed over tables covered with blankets on which the particles of gold were collected, or forced through troughs of mercury or passed over copper plates coated with mercury which amalgamated the gold. Gold from the blankets or amalgam were collected and placed in an amalgamating barrel and mixed with more mercury. The final amalgam was then distilled in a retort to drive off the mercury, and the remaining gold cake was sold to a bank for final refining. This process had been used for centuries and few changes to the process were made in Australia.

The Port Phillip and Colonial Gold Mining Company has been mentioned in the table above for the efficiency of its processing plant. The company was formed as a joint stock company in London in 1852 by a group of men who owned other companies mining for gold in South America, and some were also shareholders in the Patent Copper Company at Burra. After several years searching for a suitable mine in Victoria the resident director, Rivett Bland, leased 160 acres of private land at Clunes in 1857 and established a successful quartz mine. In an attempt to avoid the popular resistance to company mining Bland formed a separate locally registered co-operative company, the Clunes Quartz Mining Company comprising 100 Clunes miners (each of the 100 shares being £15) to work the mine. This company was paid £3 per ton by the Port

315 W Perry, Tales of the Whipstick (Eaglehawk: W. Perry, 1975), pp. 125-9. In 1866 the township of Raywood was surrounded by eucalyptus scrub called the Whipstick. A model of this machine is held at the Science Museum at Spotswood in Melbourne.

Phillip Company for crushing the ore. The Port Phillip Company later took over the mining company when some of the shareholders failed to work effectively.\(^{317}\)

Some of the technical staff of the Port Phillip Company had had experience treating gold ores with 15 percent pyrites in South America and although the Clunes ores contained less than one percent pyrites the company included a calcining kiln as part of the first plant in 1857. This was a large bottle-shaped kiln with work platforms top and bottom. Ore and timber were trucked to the top and thrown into the kiln in alternate layers till full. The timber was then ignited at the bottom and as the burnt quartz settled down to the hearth it was quenched with water and shovelled into trucks, which were then wheeled to the stampers.\(^{318}\) Similar kilns were erected by the Colonial Gold Company at its mines on the Turon in 1855. This type of kiln had been used for many years for calcining sea shells to make lime.\(^{319}\)

As the output of the mine increased it became more difficult to continue this process due to the volume of ore and cost. It was replaced, after tests, with a primary rock crusher made by Enoch Chambers in Melbourne. A similar swinging jaw crusher had been patented in 1858 in the United States by Eli Blake for crushing rock for roads.\(^{320}\) Few managers of gold mines in Australia used jaw crushers during the nineteenth century and persisted with the stamper as the primary crusher.\(^{321}\)

By 1856 most of the English joint stock market companies set up to mine for gold in California and eastern Australia had collapsed because of management problems and low grade ores, but the small quartz reef mines at Bendigo, Castlemaine, Ballarat and Clunes prospered and were extracting ores from below the waterline by 1861.\(^{322}\) Most of the gold was being separated cleanly from the quartz gangue using stampers and was


\(^{319}\) *Hill End Historic Site- Quartz Roasting Pits Complex*, N.S.W. National Parks and Wildlife Service.

\(^{320}\) W. P. Blake, *The Blake Stone and Ore Breaker*, vol. XXXIII, *Transactions of the American Institute of Mining Engineers* (New York: 1903), pp. 988-1031. Blake invented his machine to reduce the cost of producing road making material, which had previously produced by hand. The transfer of this technology from road construction to mining plus the transfer from the United States to Australia in four years was rapid. A possible explanation is that the machine was described in the January 1861 edition of the *Mining Magazine and Journal of Geology*. Enoch Chambers was the proprietor of the Melbourne foundry which made the machine apparently for crushing rocks for roads. *Dickers Mining Record*, 3 October 1865, said the machine had been available for three years and two were in use at Clunes.


collected by mercury troughs, copper plates and canvas strakes. The Port Phillip Company was one of the few which regularly tested their tailings, and therefore knew they were losing gold in the tailings. In 1861 the works manager Henry Thompson and the works chemist George Latta confirmed the tailings contained about six percent of the gold and that most of this was in the pyrites which could be collected on strakes, roasted, fine crushed and the gold amalgamated.\textsuperscript{323} Thomas Carpenter was also experimenting with pyritic ores at Bendigo in 1862 using revolving canvas strakes to separate the pyrites, calcining the pyrites in a reverberatory furnace and amalgamating the roasted material.\textsuperscript{324}

The Port Phillip Company altered their flowsheet, the initial calcining was abandoned, and a jaw crushe reduced the variable sized ore from the mine to a uniform size. The ore was then fed to the mortar box of the stampers, the pulp exited from the screens, passed through mercury troughs for amalgamation, across blanket strakes to collect the pyrites, through a final mercury trough to catch any free gold remaining, and the tailings were discharged into the creek. The small amount of pyrites mixed with sand from the blankets was separated in a Borlase buddle, the sand was discharged to the tailings and the pyrites (about one percent of the original ore) was roasted in a small reverberatory furnace.\textsuperscript{325} The Borlase buddle, a Cornish development of the 1840s, was modified by a member of the staff, John Munday, who patented his modification. The arsenic oxide and sulphur dioxide were removed from the gases leaving the furnace by water sprays before the gases were vented up the chimney. The Company completed these experiments and built the reverberatory furnace in 1865.\textsuperscript{326} The pyrites contained up to four ounces of gold per ton and the recovery of this gold could mean the difference between a profit or a loss for companies mining low grade ores less than five pennyweights per ton overall.

These experiments had been watched closely by other mine managers. The Superintendent, Rivett Bland, welcomed inspection by other companies and published the results widely, leading to the adoption of similar methods by other mines in

\textsuperscript{323} Woodland, \textit{Sixteen Tons of Clunes Gold}, p. 71.
\textsuperscript{324} J. A. Lerk, \textit{Bendigo's Mining History 1851-1954} (Bendigo: Bendigo Trust, 1991), p. 26. As discussed later this was apparently an early version of the vanner.
\textsuperscript{325} Woodland, \textit{Sixteen Tons of Clunes Gold}, p. 74.
\textsuperscript{326} Ibid., p. 73.
Unfortunately the results did not solve the problems of all these mines, such as those in St. Arnaud with highly refractory ores containing pyrites with small amounts of the sulphides of silver, copper and lead, and at Daylesford and Stawell, or those at Costerfield containing antimony sulphide. These mines continued to experiment with gravity methods or chemical methods of separating the components in their ores, and with smelting. The Port Phillip Company began treating pyrites concentrates from other companies in Victoria and New South Wales for a fee.

In the 1860s a few people trained in the emerging science of industrial chemistry began to contribute ideas for treating refractory ores. Dr Ottway, an American chemist, tried to adapt a process used at Freiberg in Germany and roasted the silver ores of the Alpha Company at St Arnaud with salt in a reverberatory furnace. This produced hydrochloric acid which reacted with the silver to give silver chloride, which could then be dissolved out and the silver precipitated. He failed to develop a commercial process. Dr Percy of London suggested the silver could better be removed from gold ores by first amalgamating the gold, then concentrating the pyrites by gravity methods, and then treating the tailings with sodium hyposulphate solution to dissolve the silver. This method was proposed by George Foord, a Melbourne chemist, to the Freiberg Company, the successor to the Alpha Company, as suitable for the treatment of a high silver content ore from the oxidised zone. After calcining, crushing and amalgamation the tailings were placed in large vats with filters at the bottom, a hot solution of sodium hyposulphate was poured in, allowed to stand for several hours, and then drained off into casks. The process was called lixiviation (the modern term is leaching). Sodium polysulphide was added to precipitate the silver as silver sulphide, which was dried and roasted in a reverberatory furnace to give silver which was cast into ingots. The sodium hyposulphate was regenerated and used again. A government geologist, George Ulrich, commended the process when he inspected the mine in 1864 and saw the method being used.

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327 Ibid., Chapter 14. In 1868 several mine managers from Bendigo inspected the Port Phillip plant and soon afterwards requested the permission of the Sandhurst City Council to erect treatment plants to roast pyrites (see Bendigo Advertiser 6 June 1868).
328 Report of the Royal Commission on Mining. Several managers and owners who appeared reported on experiments with vanners and other devices being tested. Satisfactory methods of treating these refractory ores were not developed till the 1890s.
329 Woodland, Sixteen Tons of Clunes Gold, p. 76. Pyrites from the Amelia reef in the Blue Mountains of New South Wales were sent to the Port Phillip Company in 1867.
330 The Scottish chemical industry developed in the late seventeenth and early eighteenth century and was active in developing metallurgical processes in the 1860s. Other chemists were trained in Germany.
trialled, and said it was the first successful use of the process world wide.\footnote{G.H.F Ulrich, “Gold and Silver Bearing Reefs of St. Arnaud,” (Melbourne: Victorian Geological Survey, 1864), pp. 10-12. Ulrich was a graduate of the Berg-Akademie at Clausthal.} However he wrote that he did not expect the high grades of the chloro-bromide of silver ore to persist below the water line.\footnote{Ibid., p. 10.} Several thousand ounces of silver were produced in the next few years by the Freiberg Company, but dubious share manipulations, the death of the major shareholder, and the murder of the mine manager led to the demise of the company. In the following years only small quantities of silver were produced by other St Arnaud mines because the grades of the silver chloro-bromide ores decreased rapidly as the mines approached the water line at depth.\footnote{Y. S. Palmer, Track of the Years (Melbourne: Melbourne University Press, 1955), pp. 166-7.}

In 1869 the Port Phillip Company, the largest in eastern Australia with a lease area of 160 acres and several wide reefs, crushed 5500 tons of ore a month. Smaller companies, financed by local capital and with areas less than 30 acres, were crushing around one third of this or less. For example in 1869 the Catherine Reef United Company was averaging 2000 tons a month.\footnote{Woodland, Sixteen Tons of Clunes Gold, p. 105. “Reports of Mining Surveyors and Registrars, Victoria,” Sandhurst, 2nd Quarter 1869.}

Innovations in crushing machinery were rapid in this period as equipment designed overseas was adapted and improved to meet Australian conditions. The stamper emerged as the most efficient machine to crush the hard gold ores. Chemical methods, based on untried theories from overseas were introduced to extract gold and silver from refractory ores rich in silver with varying success.

**The Development of a New Type of Mining Company**

The management structure of the British joint stock mining company proved to be unsuitable for Australian gold mines with their small narrow vein orebodies, and most of these companies failed within a few years. As mines deepened more capital was required to establish a mine and mining parties gradually gave way to a different type of gold mining company. This section will consider the reasons for this change.

After their initial establishment in 1855 the local courts strongly resisted any increase in claim or lease size, particularly on alluvial ground, but from mid 1856 each court
adapted its bye-laws to suit local conditions, such as the deep leads at Ballarat, and the peculiarities of the saddle reefs at Bendigo and allowed larger areas.

Operating experience had led to the criticism that courts were adjudicating on disputes under their own bye-laws. The local courts were abolished at the end of 1857 by a revised Act, the Goldfields Amendment Act, 21 Vict. 32, which set up six Mining Boards to control mining in the colony. Each board of ten members was elected by the holders of miners rights and each Board elected a chairman from the members. The new boards drafted bye-laws based on those of the local court bye-laws and developed new rules for the conduct of business. These were published in the Government Gazette, comments were invited from the law officers and others interested and unless the proposed bye-laws were withdrawn within one month, they became law. The judicial functions of the local courts were given to Courts of Mines in each mining district with judges appointed from the judiciary.\(^\text{335}\)

The Haines’ government was replaced in March 1858 and a new more conservative government led by John O’Shanassy was formed with Richard Ireland as the Solicitor General. Pursuant to the aim of this government to return to the earlier system of company mining, Ireland exerted pressure on the new mining boards in 1858 to agree to larger claims and leases for both alluvial and reef mining. He was assisted by the support of the Ballarat board as the development there of the deep leads was showing the need for larger areas to justify the expenditure needed to develop new mines. Ireland was also active in supporting company mining as the need for more capital to develop reef mining was becoming apparent. He travelled around the goldfields pressing the case for larger leases. Gradually the attitudes of the opposing miners shifted and meetings of miners were more favourable on most fields as the alluvial diggings were depleted. Late in 1858 Ireland wrote to each mining board asking it to pass a bye-law to prevent owners of miner’s rights from occupying, mining, or interfering with land on which a lease had been applied for.\(^\text{336}\) All six boards eventually did this but some were reluctant. Ballarat led the way in February 1859, followed by Castlemaine and Maryborough in May and Bendigo in July but Ararat and Beechworth resisted and the


\(^{336}\) Ibid., p. 69.
government proceeded without their support. The regulations were altered to enable the boards to set the maximum size of alluvial and quartz leases but the government took complete control of the approval and issue of the lease and set up a register for each district.

Victoria was now the innovator for changes in mining law to suit Australian conditions. As the shallow alluvial workings were depleted, miners moved to new fields in New South Wales taking with them the ideas driving these innovations. New South Wales amended the Goldfields Regulations in 1858 to allow 20 feet square for an alluvial claim and 20 feet along the reef for a miner’s right claim, and 400 yards along the reef for a lease at a rental of £5 per 100 yards. Alluvial leases were a maximum of eight acres at £5 per acre rental. Local courts were elected at Kiandra, Adelong, Young, Forbes and Araluen but their influence was less than in Victoria, probably because these fields were smaller and more transient than in Victoria. In 1866 an act abolished the positions of gold commissioners and authorised any justice of the peace to exercise these powers. In 1874 all previous acts relating to gold mines were repealed and replaced by a new act which followed closely the clauses of the Mining Statute of 1865 with the exception that Courts of Mines were replaced by Warden’s Courts with appeals to the District Court sitting as a Mining Appeal Court. Five mining districts were established with a mining board in each.

The cost book system which limited liability of the shareholders (Haines’ 1855 Act) had not been popular in Victoria because of the need for all members to sign the memorandum of association and the need for regular meetings of members to authorise expenditure or the making of calls. These requirements created difficulties as people were still on the move in 1858 in large numbers. In June of that year the Mining Associations Act (21 Vict. 56), commonly called Ireland’s Act, was passed to overcome these problems. This Act was based on the Joint Stock Companies Act that had been

337 Register of Leases, (Melbourne: Government Printer). The first application for a quartz lease at Bendigo was Latham and Watson for 84 yards along Hustlers Reef in March 1859. In 1867 the Mining Record questioned whether Ararat and Beechworth Boards had ever agreed.
passed by the British parliament in 1856.\textsuperscript{342} It allowed the manager to sign documents on behalf of members and the liability was limited to the amount of the shares. It had 81 clauses and was criticised as too complicated by Vincent Pyke, a miner who had been elected to the Victorian Parliament. In 1860 he introduced a bill of 18 clauses in simple language which was passed after much debate. The clause limiting liability was succinct:

\begin{quote}
Any shareholder in any mining company shall be liable only for any debts incurred on behalf of such company to the amount of shares for which the shareholder has agreed to subscribe or of which he has become the holder by share transfer.\textsuperscript{343}
\end{quote}

Pyke’s Act (24 Vict. 109) was immediately popular and some 539 companies were registered by 1864.\textsuperscript{344} There was however one major difference from English mining law, as the small miner still had the right to stake a claim and work either individually or in a small party, but the company was limited to holding relatively small claims or leases. Up to this time the New South Wales government had taken little interest in limiting the liability of companies. In May 1861 it passed an act which was an almost word for word copy of Pyke’s Act.\textsuperscript{345}

Although the size of claims and leases increased slowly the maximum allowable by the end of the century was still only about 40 acres in New South Wales and 30 acres in Victoria. As the mining laws were extended to cover metalliferous mining other than gold, these area limits were applied to all types of mines, such was the strength of public feeling against monopolies in mining in Australia, and no individual company was allowed to peg the whole of a new field.\textsuperscript{346}

The Catherine Reef United Claimholder’s Company is a representative example of a company registered in Victoria under Pyke’s Act. In the 1850s miners at Eaglehawk near Bendigo pegged small claims along the Catherine reef where the ground was an area of rich surface spurs and deeper reefs. Each party put down a shaft with a windlass

\begin{footnotes}
\textsuperscript{343} Victorian Act 24 Vict. 109, Clause II.
\textsuperscript{344} R. Ashley, \textit{Mining Companies Applying for Registration in Victoria, 1860-64} (Ballarat: R. A. Research, 2004), Microfiche. The locations of the companies registered were Ballarat 325, Castlemaine 158, Ararat 22, Maryborough 17, Bendigo 9, Beechworth 8.
\textsuperscript{345} An act to Limit the Liability of Mining Companies, 9 May 1861, 24 Vict. No. 21.
\textsuperscript{346} Blainey, \textit{The Rush That Never Ended}, p. 144. Charles Rasp pegged seven leases each of forty acres at Broken Hill in 1883, one for each syndicate member, but there were parts of the orebody not pegged until later by others.
\end{footnotes}
or whim and mined the spurs in small stopes. They soon realised this was not economical and they combined to form a company to work the area as one mine. Each of the original claim holders received a share allotment depending on the size of his claim, and additional shares were sold to provide capital. The company was registered in April 1861 under Pyke’s Act with 67,600 shares of £1 each fully paid up and with 156 shareholders. Of the initial capital £52,728 was subscribed by Bendigo shareholders, £13,520 by Melbourne shareholders, and £1352 from elsewhere in Victoria. 347 This was quite fictitious. There were 13 original claimholders each of whom was allotted shares to the value of £100 for each yard along the reef, totalling £50,000. Another 1000 £1 shares were sold to the public so the actual paid up capital was £1000 for developing the mine. Most development and equipment was paid for out of profits. 348 In 1859 the claimholders had applied for a lease and final approval was given in 1862 for a length of 501 yards along the reef. The area was extended by amalgamation of leases and claims in later years; by 1880 it was 38 acres. 349 An illustration of the mine drawn in 1866 shows the spurs being extracted by open cut with trucks, connected to a continuous rope, carrying the ore up a tramway to the crusher. Several of the original claims were being worked by shafts with windlass and whim, but the main reef was being worked with a simple headframe by a double drum winder with chains to raise and lower the cages. Steam engines were used to drive the stampers and the winding engine, and by this time a Cornish pump was in operation (but is not shown in the drawing). 350 The successful development of this and similar gold mining companies after the passing of Pyke’s Act in 1860 culminated in the passing of the no-liability act in 1871, to be discussed in Chapter 5.

John O’Shanassy’s conservative ministry was defeated in October 1859 and was out of office until November 1861, when it again took office. 351 By 1862 sufficient experience had been gained in the operation of the Goldfields Amendment Act to show that developments in mining technology were making changes necessary, and the new O’Shanassy ministry appointed a Royal Commission on the Conditions and Prospects of

347 This company information was kindly supplied to me by Robert Ashley from his ongoing research into mining company formation. The slight discrepancy in the totals is due to rounding off.
348 Dicker’s Mining Record, 11 December 1866, p. 372. Many companies probably inflated their capital in this way.
349 Register of Leases. Lease application No. 235 of 15 August 1859 on the Star Reef, Sailors Gully.
the Goldfields. The Commission reported in 1863 and recommended the need for a uniform code of mining law, the abolition of the mining boards, increase of the powers of wardens so as to reduce the number of cases in the Courts of Mines, rules for mining on private property and the establishment of a Department of Mines.\textsuperscript{352} This latter was established in June 1863, before the report was even presented.\textsuperscript{353}

In 1864, when James McCulloch led the government, the various acts covering limited liability mining companies in Victoria were repealed in an attempt to simplify company law, and mining companies were included in a new Trading Companies Act modelled on British practice.\textsuperscript{354} In a short time this was found to be unworkable for mining companies, pressure was exerted by the mining boards, and William Frazer introduced a bill to limit the liability of mining companies as distinct from other trading companies. This new bill was a slightly modified version of Pyke’s Act, and it defined the powers of a liquidator more clearly and was passed quickly in June (27 Vict. 228). It was commonly called Frazer’s Act.\textsuperscript{355}

Also in 1864 a bill to implement the recommendations of the 1863 Royal Commission was presented, but was rejected because of disagreement over clauses to abolish the boards and to cover mining on private property. These clauses were removed and the revised bill, retaining the mining boards, but omitting any mention of mining on private property, was passed in 1865 (29 Vict. 291). It became popularly known as the Mining Statute of 1865. This Act was very effective and the principles were copied by all other colonies in later years. It still allowed the small miner a substantial influence on legislation through the mining boards.\textsuperscript{356} These political manoeuvrings through the 1860s indicate that the miners were strongly influencing the development of mining and company law.

\textsuperscript{353} Papers Presented to Parliament, 1885, no. 13, part 1, Blue Book.  
\textsuperscript{354} McCulloch had been a member of a Haines’ ministry in 1857-8.  
\textsuperscript{355} Victorian Parliamentary Debates, 1864, pp. 341-463 passim.  
\textsuperscript{356} Birrell, Staking a Claim, pp. 71-4, 156-61.
Conclusion

The Eureka rebellion led to major reforms in Victorian mining law. The 1855 act for the management of the goldfields gave miners the opportunity to contribute to these reforms through the local courts, by making bye-laws for each mining district. The miners seized this opportunity and developed bye-laws to suit the mining requirements for the different geology of the orebodies in each district.

Major innovations were introduced at Ballarat and Bendigo. The deep leads at Ballarat required new technologies to mine at depths of 500 feet or more, with the waterlogged washdirt being only a few feet deep but spread over a wide area. Miners experienced in coal mining introduced innovative methods which were based on coal mining technology to mining for gold in the deep leads.

At Bendigo and other quartz reef mining districts such as Stawell when the miners pushed their shafts below the waterline after 1860 they used Cornish pumping methods to keep the mines dry. They used European technologies to roast and then crush the freemilling ores and recover the gold by amalgamation with mercury. Pyrites minerals containing gold in refractory ores from below the waterline were treated to separate the pyrites, which were then crushed finer, roasted, and some of the gold separated by amalgamation. This technology was borrowed from South America. As experience was gained stampers dominated crushing technology and innovation led to greater efficiency and reliability of these machines. Communication between miners in Australia and California ensured a continuous exchange of information, so crushing technology improved at a similar rate in each country. Continuous changes were made in the bye-laws in Victoria to adjust to the changing technologies. These changes were consolidated in a new Mining Act in 1865, commonly called the Mining Statute, which was so successful that it was later copied in all Australian colonies.

Mining at depth in wet ground required capital investment beyond that available to small parties of miners, and conservative governments continued their efforts to re-introduce company mining. However the miners used the influence of the mining boards, which replaced the local courts, together with their parliamentary representatives to introduce and pass mining company laws in the 1860s which better
suited Australian conditions than the British type of joint stock company law. This culminated in the passing of the no-liability company Act in 1871, which allowed a different type of mining company, and allowed a shareholder to forfeit his shares to avoid payment of calls and thereby cease to have any liability for any company debts. A comparison of the productivity of a joint stock company and an emerging small Australian gold mining company indicates they were equally efficient but that the joint stock company required larger areas to pay for the higher overheads caused by the employment of more supervising staff. This will be further discussed in Chapter 5. Chapter 4 will discuss developments in mining other than gold between 1850 and 1870.
Chapter 4

Coal and Metalliferous Mining – 1850 to 1870

Introduction

When the coal monopoly of the Australian Agricultural Company was surrendered to the British government in 1847, the company realised that competition for the Australian coal market would increase and new companies would begin mining coal at Newcastle. In the early goldrushes of 1851 labour problems arose at Newcastle as many coal miners left for the Turon, taking with them a negative attitude to company monopoly. Coal prices rose and problems occurred in staffing the mines. This chapter will discuss the steps taken by the company to develop long term planning and to update the technology, now twenty years old, so as to meet the challenges ahead.

The effect of the goldrushes was more drastic in South Australia, where all the copper mines closed as the miners left for the goldfields and smelting was reduced. The reopening of some of these mines and the discovery and development of new mines led to a recovery of copper mining and smelting in South Australia. New copper mines opened in New South Wales. Changing transport costs affected the location of smelters for these mines. This chapter will investigate company structures and financing, and changes in the mining and smelting of copper ores up to 1870, as well as investigating several attempts to establish a viable iron industry in eastern Australia.

Developments in Coal Mining to 1870

When the Australian Agricultural Company surrendered its monopoly rights to coal in 1847 in return for the right to sell 500,000 acres of its land grant in New South Wales, the Court of directors of the company realised they would face severe competition from other companies developing coal mines in the Hunter Valley. In 1850 a proclamation in the New South Wales Government Gazette cancelled the reservation of coal in all land grants previously issued, and no further such reservations were issued.357 The company had difficulties staffing the mine when miners left for the goldfields on the Turon River from 1851, but this problem was reduced when a colliery overman, Mr Beaumont, was

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357 J. Gregson, The Australian Agricultural Company (Sydney: Angus and Robertson, 1907), pp. 121-2.
employed in England and arrived with 50 miners at Newcastle late in 1852. The
directors in London realised they needed to plan ahead to develop their mine, and as
they had no mining experience, they appointed Frederic Ordenheimer, who had been
Director of Mines in the Duchy of Nassau (one of the then independent German states)
to make a mineralogical and geological survey of the company’s pastoral and mining
estates. He sailed for Newcastle in August 1853. In his report on the colliery,
delivered in 1855, he recommended the development of new pits, new engines for
underground hauling, and the use of locomotives on the surface. In February 1854 the
Governor of the Company, Mr Ravenshaw, apparently with information from
Ordenheimer, expressed concern at the high price of Newcastle coal as a result of
goldrush inflation, and foresaw the need to reduce costs when the boom inevitably
collapsed. In an 1854 report to the Court of Directors he recommended separating the
colliery management from the pastoral section and modernising the colliery
equipment. William Wood, a colliery engineer who had spent some time in Australia,
was appointed in England to order the necessary equipment to upgrade the colliery and
provide self contained workshops. He was then to manage the colliery for five years at a
salary of £500 per year (about the same as that of a warden of the goldfields at that
time). Wood travelled around England and Scotland ordering equipment. Unfortunately
for all this careful planning by the Court, Wood then demanded better conditions and
resigned when these were refused. Robert Whytte was appointed to the position.
The equipment, with an invoice value of £15,380, was loaded on the ship Edmund
which departed Liverpool on 6 June 1856. In a bid to improve the management of

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358 Ibid., p. 150.
359 Ibid., p.149.
360 Minutes of the A.A. Company, 16 November 1855.
361 Ibid, 17 February 1854.
362 Ibid., 16 March 1855.
363 Ibid., 20 June 1856.
364 Ibid., 6 June 1856. Details of the equipment were: see minutes of A.A. Co.1/27 DHI-26, 1856;
160/83N)

- Perran Foundry – Horizontal steam engines, one 25 inch cylinders, one 20 inch.
- J. Buckton – punching and shearing machine, planing machine.
- Smith, Peacock & Tannette – self acting lathe, drilling machine, shaper, screwing machine.
- Forrest & Barr – circular saw bench and 50 saws, 4 ton derrick crane, 3 ton derrick crane.
- Haggie Bros. – ropes of steel wire which were in use in England at this time for underground
haulage and shaft haulage.
- New British Iron Co. – boilers, one 8 feet by 30 feet, one 4 feet by 30 feet, 20 hopper wagons, 2
side tipping wagons, 100 coal hutches, rails.
- W. Fairburn & Sons – 2 locomotives.
the pastoral activities, Arthur Hodgson (who had managed a pastoral lease on the Condamine River in southern Queensland for seventeen years) was appointed general superintendent. He also made final decisions about the colliery. The *Edmund* arrived at Newcastle on 3 January 1857 after a stormy passage during which some of the equipment suffered water damage, on which insurance of £3,478 was claimed but the damage was soon remedied.

This new equipment indicates the advances in coal mining technology that had been made in England since the first machinery had been installed in the company’s mines at Newcastle in the 1830s. The company’s original steam engines, with vertical cylinders operated at low pressures about 10 p.s.i.g., were replaced by so-called high pressure engines with horizontal cylinders working around 50 p.s.i.g., and a fully equipped workshop was set up to handle on-going repairs. When Mr Hamilton, the new governor of the company, visited Newcastle in October 1858 to inspect the agricultural and mining properties, he reported to the directors that the workshops were operating and employing 18 mechanics. However he said the workshops were costly and should be closed and the work contracted out. This would suggest that jobbing foundries were then operating in Newcastle which could adequately service the colliery. However the only foundry in Newcastle at this time was that of Archibald Rogers, which was reported in 1856 to be making windlasses, winches, iron blocks, cranes, crabs and axles and wheels for wagons. Perhaps Hamilton was hoping the sacked mechanics would set up another foundry to provide competition, or perhaps he was aware of developments in Sydney and Melbourne as well as on inland goldfields, where blacksmiths and engineers were developing foundries to service the gold mines. He most likely based his comments on a knowledge that British foundries provided such a service, but a similar situation probably did not exist in Newcastle at that time.

After the Australian Agricultural Company had won the court case upholding its monopoly in 1845, J & A Brown had been forced by the government to close their mine.

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366 Ibid., p. 195.
367 Ibid., p. 209-10.
near Maitland. They soon recommenced coal mining at Burwood, south of the Newcastle mine, on land which had been alienated to John Eales prior to the monopoly and proceeded to develop a new mine. In partnership with Eales they also developed a coal mine at Minmi, about 10 miles west of Newcastle, over which the Browns took complete control in 1859.

Robert Whytte took control of the Australian Agricultural Company’s mine late in 1856 and soon installed the new equipment, which led to a reduction in both production and shipping costs from ten shillings to seven shillings ten pence per ton. This new installation included an underground haulage system, driven by a steam engine on the surface, and comprising a loop of one inch steel rope which ran down the shaft and along the main haulage to near the working face, where the wagons were clipped to the moving rope and hauled to the shaft where they were loaded into the cages. Whytte also installed a new shaft haulage system with two cages in balance each lifting two skips with a total of one ton of coal. However when he later decided to sink a new shaft, called the No. 2 Pit, some 1500 feet south east of the D Pit, he used an iron drum to sink through wet sand but when he struck clay at 50 feet the drum jammed and the Superintendent, Hodgson, suspended the sinking and sacked Whytte in January 1860. The Court of Directors realised how haphazardly the mine had been developed under successive managers and appointed an English coal mining engineer, Matthew Liddell, who never left England but relied on reports from the mine staff to produce a long-term development plan. He selected the next colliery manager, James Winship, who was given written instructions on how the mine was to be developed and how the No. 2 Pit was to be completed. In the meantime the coal reserves were becoming depleted and rather than run out of coal (without referring the matter to Liddell) Hodgson decided to sink another shaft, the G Pit, near the west boundary on land leased from the government. These failures in management show how difficult it was for a joint stock company to develop a mine in Australia with directors and mining engineer in England,

369 See Chapter 1.
372 Australian Agricultural Company, Machinery Despatches No. 11, 17 April 1862. Each cage was 8 feet 6 inches long, 4 feet wide and five feet high and was covered with sheet iron. Kauri timber was used for the runners in the shaft. Winship reported in this dispatch that the equipment had been in use for several years making the probable installation date as 1857 the same year cages were first used at Ballarat.
373 Gregson, The Australian Agricultural Company, p. 221.
with less qualified staff some 12,000 miles away and communications via sailing ship.  

Alexander Brown (not related to the two brothers) who had been overman at the Australian Agricultural Company mine since 1837, left the company during the mid 1850s shake-up and together with a group of Sydney shipping and financial men formed the Newcastle Wallsend Coal Company which was incorporated by Act of Parliament in November 1858 with a capital of £100,000, raised in Sydney. Brown sold 500 acres of coal land on the outskirts of Newcastle to this company. It was a joint stock company.  

At the end of the 1850s there were thus four substantial coal companies ready to compete for local and export markets. Three of these were equipped with the latest British equipment for working on the bord and pillar system (the coal was still extracted from the seam entirely by hand methods). Apparently the Australian Agricultural Company considered introducing the longwall system which was becoming common in Britain, where a long continuous face was worked with all the coal being extracted along the face and the roof allowed to collapse as the working face advanced, but Hamilton advised the Court that Whytte had told him it was impossible to change from the existing system in the present workings.

Winship arrived in January 1861 and soon completed and equipped the No. 2 Pit without difficulty to develop a seam nine feet thick. He later equipped the G Pit. In 1860 the Australian Agricultural Company produced 135,000 tons of the total of 369,000 tons of coal produced in the colony. In the same year the Newcastle miners began to form unions to put pressure on the mining companies for improved wages and conditions, and in response the four companies combined in August 1861, at Winship’s suggestion, in an effort to destroy the unions. The first move by the companies was to

374 C. C. Spence, *British Investments and the American Mining Frontier* (Moscow, Idaho: C. C. Spence, 1995), Ch. 6., discusses the problems of British companies controlling mines and managers in the western areas of the United States.


376 They were the Australian Agricultural Co., the Newcastle Wallsend Co, J & A Brown and the Newcastle Coal and Copper Co. controlled by Dr James Mitchell, a Sydney businessman, mining on the Burwood estate south of Newcastle.


378 Ibid., pp. 227.

379 R Gollan, *The Coalminers of New South Wales* (Melbourne: Melbourne University Press, 1963), p. 40. Gollan quotes a recommendation from Liddell to Winship that before precipitating a collision with the men he should come to an understanding with the other proprietors that they should jointly resist the combination of the men, in which all should agree to put down the system of tyranny to which well disposed men must now be subjected by the Unionists and break up the latter. The quote is from the A.A. Co. papers ‘Colliery Memo A11’.
reduce wages and the miners struck on 17 August, but in October agreement was reached by the union and J & A Brown to pay the old wage. During the strike Winship travelled to Victoria and South Australia recruiting gold and copper miners for work in Newcastle, and he paid the fares of those who accepted. On arrival many refused to become strike breakers but others started work. By the end of 1862 all the mines were back in production with many of the Newcastle miners accepting re-employment on the owners’ terms. The strike crippled the union for some years.

The importance of this episode to the present thesis is that it reinforced previously existing bitterness between miners and management of the Australian Agricultural Company, which was now carried into bitterness between unions and managements of all the coal mines and resulted in continual industrial disputation and a resistance by the miners to any innovation in working practices. In the 1890s the mine owners began to consider mechanisation as an answer to their workers’ restrictive work practices.

The new mines opened in the 1860s increased competition in the coal industry. These included a mine at Lambton by the Scottish Australian Company formed in London in 1861, the Waratah Company of Sydney in 1863 with Sydney capital, the Co-Operative Company formed by a group of miners with their labour as capital and an additional mine developed by J & A Brown, the New Lambton, adjacent to the Agricultural Company’s ground. No information has been found of coal miners in England starting their own colliery so it is likely the strike induced the Newcastle miners to follow the practice developed in Ballarat of forming co-operative companies to which they each provided labour. With the exception of the Co-Operative Company the new mines were equipped with machinery and workshops similar to that of the Australian Agricultural Company. The Co-Operative Company was in the hands of the mortgagees in 1867 and was sold in 1869.

382 Ibid., p. 114.
384 See unpublished notes on New South Wales coal mines by Dr. Penny Pemberton, 2002.
Copper Mining and Smelting

Prior to the gold rushes the South Australian Mining Association had signed a contract with the Patent Copper Company to smelt the Burra ores for seven years but the Association reserved the right to sell the richer ores to other smelters.\(^\text{385}\) The Patent Copper Company was a subsidiary in Swansea in Wales of John Schneider & Company of London, and that company provided the capital and despatched most of the materials and equipment required, together with Gregory Walters as manager and Thomas Williams the smelter superintendent, and a party of Welsh smeltermen to South Australia.\(^\text{386}\) In January 1851 the company employed 1050 men at the Burra smelter, including 400 teamsters with 4000 bullocks to move copper to the coast and coal to the smelter.\(^\text{387}\) This smelter continued to operate on a reduced output during the rushes, using ore already mined, while all other smelters in South Australia closed as the miners left the colony. In 1851, in a restructuring, the English and Australian Copper Company of London took over the Patent Copper Company.\(^\text{388}\) The new smelters that the company now built at Burra, were designed for a process patented in England by an English chemist, Napier, which simplified a nine stage process for sulphide ores used in Welsh smelters for dealing with a variable range of copper ores from many countries.\(^\text{389}\) The high grade Burra ores were free of sulphur, except in the deepest levels, and could be reduced to copper in two stages.\(^\text{390}\) The first stage was to heat the oxidised ores in a reverberatory furnace with a siliceous flux to give a fluid slag at a relatively low temperature. The slag was tapped off first, and then the copper regulus was tapped into moulds and allowed to cool until each ingot solidified, when it was thrown into a tank of water and crumbled into a fine powder. This powder was dried and fed into a melting furnace, coke or charcoal was added and the mixture heated till it fused to give a clean


\(^{386}\) Ibid., pp. 170-1. The cargo of the ship ‘Richardson’ which arrived in Adelaide on 3 October 1848 included 48,000 firebricks, 40 tons of fireclay, 300 furnace slabs, 200 furnace doors, 120 furnace bearers, 10 tons of sand, 45 tons of castings, 12 tons of wrought iron bars, 1 ton shovels, 1.5 tons pig and sheet lead, 30 barrows, 4 dozen brooms, 6 cases laboratory equipment, 1 case scale beams, 1 copying machine, 1 cask crucibles and ironmongery.

\(^{387}\) Ibid., p. 175.

\(^{388}\) Ibid., p. 173. J. Woodland, *Sixteen Tons of Clunes Gold* (Clunes: Clunes Museum, 2001), p 14. Some of the directors of both the Patent Copper Co. and the English & Australian Copper Company were also on the board of the Port Phillip Co.


slag, containing little copper, which was tapped off. The remaining copper was tapped off into moulds and solidified into ingots.\textsuperscript{391}

By mid 1851 the number of men and boys employed at the Burra mine was 1013.\textsuperscript{392} During 1851 and 1852 so many miners left for Victoria that the copper mines were effectively closed and mining did not resume until 1855, when sufficient men returned and more immigrants became available.\textsuperscript{393} The Burra smelter continued production at a reduced rate during this period but in 1861 the smelting company erected a new smelter at Port Adelaide and by 1864 most Burra ores were smelted at this plant and the Burra smelters were wound down.\textsuperscript{394}

In 1861 a refinery stage was added to the Kapunda smelter to produce high grade copper but the grade of ore was declining and in 1865 the Scottish Company, a Glasgow chemical firm controlled by Sir Charles Tennant, took over the lease on agreeing to pay a royalty of one eighth of the copper produced and the new manager, Captain Osborne, installed at the mine a new wet leaching process, the Henderson process, developed in Scotland. The sulphide ores were roasted and the sulphur dioxide gases produced were passed through lead-lined chambers to produce sulphuric acid, which was in turn mixed with salt from Yorke Peninsular salt lakes to produce hydrochloric acid. The lower grade ore, about one half percent copper (not suitable for smelting), was concentrated by gravity methods and leached by the acid to produce copper chloride, which was stored in large tanks. Scrap iron was thrown into the tanks, where the iron atoms were replaced by copper atoms to give a smeltble product. The plant commenced operation in 1867 but the low grade ore made this process marginal and the mine was closed in 1878.\textsuperscript{395} This appears to be the second successful leaching process, after St Arnaud, of minerals in Australia. It was due to the development of the Scottish chemical industry.\textsuperscript{396}

\textsuperscript{391} Phillips, \textit{A Manual of Metallurgy}, pp. 366-7. Phillips describes in detail the several stages to smelt sulphide ores from all over the world as well as the simpler process patented by Napier.
\textsuperscript{392} Auhl, \textit{The Story of the Monster Mine}, p. 19. No record has been found that women and girls were employed in either coal or copper mines in Australia in the eighteenth century as was practice in Britain.
\textsuperscript{393} Ibid., pp. 232-6.
\textsuperscript{394} Ibid., pp. 191-3.
In 1859 copper ore was discovered by shepherds near Kadina on Yorke Peninsula, about 80 miles west of Burra Burra, and two years later further copper deposits were found at Moonta, about 10 miles south of Kadina. Substantial copper mines were developed at these sites, both producing high grade ore, with hand sorted grades being over 30 percent copper. Local capital financed the development of the mines and the Wallaroo Mining Company erected a smelting works on the coast nearby in 1861, roughly equidistant from each mine. It seems there was then sufficient smelting expertise in South Australian that this smelter was designed by G & E Hamilton, civil engineers of Adelaide, and the erection was supervised by Leyshon Jones who had worked at the Kapunda and Burra smelters. The Welsh method of small reverberatory furnaces was used to smelt ores with 10 percent copper. Smelting began in 1861 and remained unchanged for 30 years. In 1868 there were 15 calciners, 22 reducers, 10 roasters, and four refining furnaces with a production of 100 tons of copper a week.397 This large number of units indicates that 1840s smelting technology was being used unchanged in 1868 and that fresh ideas were not coming from outside. That the technology was still in use in 1890 tends to confirm this.

The South Australian copper smelters inland at Kapunda and Burra and elsewhere had to bear the additional costs for the delivery of smelted copper to the coast for export, as well as the costs of transporting Newcastle coal to the smelter. In the first few years the Patent Copper Company and its successor used bullock wagons to carry copper to Port Wakefield, and then ship it to Port Adelaide. In the goldrush period the English and Australian Copper Company was forced to import some 500 mules and their handlers from Monte Video to replace bullocks and drivers who had left for the goldfields. When the railway from Port Adelaide to Gawler was completed in 1857 the Port Wakefield route was abandoned, and the copper was taken to Gawler by two-wheel drays pulled by mules or horses and loaded onto rail, with coal being backloaded from there.398 In 1860 the rail was extended to Kapunda and road transport from Burra was switched to that town. The smelter company was able to obtain concession rates from the railways by threatening to use the mules to carry the 10,000 tons of coal. Mules or horses continued to be used from Burra to Kapunda until the Burra smelters were closed in 1868. Mel Davies has analysed the costs of the different routes and concludes that road transport

costs in South Australia were competitive with rail charges in the 1860s. However inland transport of coal by either method was an additional cost for the smelters.

In 1866 falling copper prices forced the English and Australian Copper Company at Port Adelaide and the Wallaroo Smelters to examine their costs. Small coal landed at Port Adelaide or Port Wallaroo cost about two shillings and sixpence per ton, with freight to the mine about 20 shillings per ton while copper ore could be back loaded to Newcastle for about 2 shillings and sixpence per ton. Both companies decided to build additional smelters at Newcastle, the first on leased land near the New Lambton Pit, and the latter at Port Waratah at Newcastle. This allowed savings by backloading at cheap rates of ore to Newcastle in the ships which carried coal to South Australia. In addition a smelter owned at Newcastle by Dr James Mitchell was reorganised, and smelted ores from other South Australian mines and from Queensland. The Wallaroo Company plant at Newcastle was the largest, and all used Welsh technology. The ores were crushed, sampled, weighed, and sorted, and selected mixtures calcined in the first furnace to reduce the sulphur content. After cooling the roast was reduced in a second furnace to produce regulus, which was transferred to a roasting furnace to produce a 90 percent copper matte. Finally a refining furnace produced a bright copper of 99.5 percent purity, which was cast into ingots of one hundredweight.

To meet the increasing water flow as the Burra mine deepened, the pumping capacity was augmented in 1860 by the installation of Morphett’s engine house with an 80 inch vertical cylinder, but otherwise no changes in technology were made. The mine became uneconomical and was closed in 1867. Pumping continued and tributers worked the mine, a policy which reduced costs but still gave some income while alternatives were sought. The company sought advice from John Darlington, an English mining engineer with experience in open cut mining using machinery developed in Germany for the economical mining of low grade ores. He recommended that the winding engines be converted to hauling ore up a railway incline from the open cut, and that mine water be used for processing the ore, which was to be crushed by stampers and concentrated by jigs. The aim was to concentrate two percent ore to eighteen percent for smelting.

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400 Turner, Manufacturing in Newcastle, 1801 - 1900, pp. 69-76.
Unfortunately the Cornish miners had left little high grade ore, and the jigs were not suitable. They were replaced by manual concentration of selected ore dug out by tributers. The new methods were not tested before installation and the reduction in costs expected by removing the low grade ore in bulk was not achieved. The small profits were mainly spent on modifying the open cut machinery and the mine was finally closed in 1877. This experience with overseas consultants contrasts with successful developments of open cuts at Black Hill in Ballarat and at the Catherine United Claimholders mine at Bendigo earlier, where open cut methods were developed to extract quartz spurs, and the gold ores were crushed with stampers.

**Developments in New South Wales and South Australia**

By 1865 the number of copper mines in New South Wales in the Bathurst-Yass area of the Lachlan Fold Belt had increased to sixteen, with seven of them smelting their ores at the mine. These were small mines on private property financed locally by the property owner or a group of land owners and Sydney capital, and unprotected by specific title (as the New South Wales mining acts of 1852, 1855 and 1857 which related to the goldfields did not mention claims or leases for copper mining). However the Crown Lands Act of 1861 made provision for mineral leases and the first such lease was registered by the New South Wales Mines Department in 1864. In 1851 Stutchbury reported on copper lodes at Cadia near Orange. In 1860 the Scottish Australian Mining Company purchased the land and sent a rotative 25 inch diameter beam engine from Great Britain to Sydney for a mine near Yass but the following year they installed it in a stone engine house at the Cadiangullong mine at Cadia. In July 1862 the company sent smeltermen from Wales to construct a smelter on the site. By 1865 the shaft was 232 feet deep, the beam engine was hauling ore to the surface, driving a seven inch pump to dewater the mine and driving a crushing plant, concentrating jigs and sawing machinery. After producing 2000 tons of ore averaging 12.5 percent copper the mine

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402 Ibid., pp 359-71.
403 W. Bate, *Lucky City* (Carlton: Melbourne University Press, 1978), p. 90. An illustration of the Catherine United mine at Bendigo published in 1866 shows an inclined plane haulage system from the open cut similar to that later installed at Burra. This may have been a copy of Newcastle underground haulage technology transferred to open cut mining.
405 J. P. McCarthy and J. E. Connell, *Cadia Conservation Study* (Parkville: Australasian Institute of Mining and Metallurgy, 1989), pp. 14-16. The engine was 15 H.P., built by J & R Mitchell of Charlestown in Cornwall. The mine manager was Cornishman, Captain Holman who had mining
was offered for sale in 1868 but was not sold and was worked intermittently by Captain Holman for the next ten years.\textsuperscript{406}

In the late 1850s pastoralists were moving their sheep into the remote parts of South Australia and western New South Wales. As on the Yorke Peninsula, where shepherds made the early major discoveries, Robert Blinman, also a shepherd, found copper deposits in the northern Flinders Ranges at a site named after him in 1859 and Bolla Bollana, further north near Arkaroola, was discovered in 1862. Reverberatory furnaces using wood and charcoal as fuel were erected at Blinman in 1863 and later at Bolla Bollana to produce high grade copper ingots.\textsuperscript{407}

The examples given in the above sections indicate there was little innovation in the metalliferous mines in South Australia and New South Wales in this period. Attempts to introduce overseas methods in chemical leaching of copper ores and mechanised open cut mining were not successful and Welsh reverberatory technology of the 1840s continued to be used for smelting copper ores.

\textbf{Iron Production}

In this period efforts were made to further develop an Australian iron industry to service the foundries which were by then servicing the mining industry. They were not successful. This section discusses the reasons for the failures.

As mentioned in Chapter 1 the first cast iron foundry was opened in 1833 in Sydney. P. N. Russell opened an engineering works with foundry in the 1840s and Morts Dock and Engineering commenced operations in 1852. Langland’s iron foundry was established in Melbourne in 1842.\textsuperscript{408} Soon after the commencement of the goldrushes blacksmiths set up operations on the goldfields to service and sharpen mining tools and also along

experience in the Phillipines, Brazil, Canada, South Africa, Malacca and New Zealand. The engine house and chimney was restored by Newcrest in the 1990s and as far as is known is the only one remaining in New South Wales. Only a few components of the engine remain including a boiler end, crankshaft, brake band and pump rods.

\textsuperscript{406} Ibid.


the main roads to repair transport vehicles and to shoe horses. As the towns
developed near the goldfields some blacksmiths moved into the towns and established
foundries to service the machines on the mines. The Phoenix Foundry was opened in
Ballarat in 1855, Horwood and Sons Foundry was operating in Bendigo in 1856 and
Vivians Foundry in Castlemaine soon after. They were soon followed by others in
Sydney, Melbourne and on various goldfields. Some of these developed into
manufacturers of mining equipment and locomotives for the rapidly developing railway
systems. The pig iron used was imported from Great Britain.

Several companies tried successively to develop the Nattai site near Mittagong, to
produce pig iron on a commercial basis, but all failed and the smelting plant was finally
abandoned in 1877. The largest furnace built on the site in this period was of
Hawkesbury sandstone, 79 feet high with a bosh diameter of 14 feet, using a hot blast
and a mixture of coke and coal as fuel. This plant smelted 4000 tons of ore in 1865.
The various companies were undercapitalised and transport of the iron ore and fluxes
from various quarries was expensive. Three attempts to establish an iron industry in
Tasmania in the 1860s and 1870s also failed due to unsuitable ore and inability to
compete with English iron. Sailing ships used pig iron as ballast on the journey to
Australia and the local firms could not compete with the landed price of English iron.

In 1874, James Rutherford and others formed the Esbank Iron Works to smelt iron ore
on the Lithgow coal field. The company built a blast furnace capable of producing 115
tons of iron per week. The plant was a financial failure and was closed in 1882. In

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411 The proprietors of these foundries were usually skilled artisans, trained in English foundries in pattern
making, casting of iron and often machine design.
412 J. C. Fahey, “Wealth and Social Mobility” (Melbourne, 1981), p. 29. A. Roberts and Sons, J. Horwood
and A. Harkness specialised in the manufacture of mining machinery at Bendigo. Bate, Lucky City, p. 212-
14. The Union Foundry at Ballarat made mining machinery and later one of the partners opened Walkers
Foundry in Maryborough, Queensland to service the Gympie goldfields. The Phoenix factory specialised
in building locomotives.
413 H. Hughes, The Australian Iron and Steel Industry, 1848-1962 (Parkville: Melbourne University Press,
414 Ibid., p. 79.
415 Ibid., p. 8.
416 G. Roberts, The Role of Government in the Development of the Tasmanian Metal Mining Industry
frustration Rutherford later blew up the furnace so he would not be tempted to recommence smelting.418

Conclusions

While the period between 1850 and 1870 was one of considerable innovation in gold mining technology, innovation in coal mining was limited to replacing outdated steam machinery with more modern equipment imported from Britain. Efforts were also made to solve weaknesses in mine management. In the copper industry Welsh copper smelting technology of the 1840s continued to be used, and new methods of leaching low grade copper ores using Scottish technology and open cut extraction of copper ores using German technology were unsuccessful.

At Newcastle the monopoly of coal mining held by the Australian Agricultural Company ended in 1847. The company had foreseen the competition which was likely to eventuate, and upgraded its plant to current British practice in the 1850s. It also strengthened its mine management in an attempt to provide continuity of mine development. These problems were caused by the difficulty of having directors inexperienced in coal mining located in London with their mine at Newcastle and three months time interval in communications between the two. A coal mining consulting engineer was appointed to oversee capital expenditure and new development and to advise on the appointment of colliery managers to be sent to the colony.

By 1870 there were three other coal mining companies, in New South Wales, financed by Sydney capital, each with well equipped workshops to support the separate mines. Three copper smelters had been built at Newcastle to process copper ores from South Australia and New South Wales. These followed the Cornish practice of shipping the ore from a mine to a smelter on a coalfield for processing but the mines in South Australia continued to use Newcastle coal and local firewood to smelt at the mines and in Adelaide.

By 1870 the rich copper mines at Burra and Kapunda in South Australia were in decline as their high grade ores were exhausted. Experiments with chemical leaching at

Kapunda and open cut mining at Burra to treat lower grade ores were unsuccessful. New mines had been discovered at Kadina and Moonta but had not been fully developed. South Australian capital financed these mines as well as the smelter built at Wallaroo on the coast nearby to the mines, to process their ores. The economics of shipping coal from Newcastle to a smelter on the coast and backloading ore concentrates to smelters in Newcastle was becoming apparent. Several copper mines were operating in New South Wales financed both by the local owners and London capital but they were small. Some built smelters at the mine to upgrade their ores before transporting the unrefined metal to Newcastle for refining. The smelters in New South Wales and at Wallaroo were erected by smeltermen from Wales or South Australia but the technology was effectively that of Wales in the 1840s using small reverberatory furnaces. Those on the coast were using Newcastle coal and coke for their furnaces while those inland were using wood and charcoal.

Several attempts were made to develop the Fitzroy Iron Works at Nattai, using Sydney capital. A larger circular blast furnace of stone was built but the plant was undercapitalised and found difficulty competing with imported cast iron and was eventually closed down in the 1870s. Attempts to start an iron industry in Tasmania also failed as did an attempt at Lithgow in the 1880s. The iron orebodies associated with these attempts were inadequate in size for the development of a large scale industry, the Australian based companies were undercapitalised and the landed costs in Australia of British pig iron, brought as ballast in empty wool ships was less than Australian production costs.\footnote{Hughes, \textit{The Australian Iron and Steel Industry, 1848-1962}, pp. 4-17.}
Chapter 5

**Government Policy and the Growth of Mining Infrastructure**

**1870 - 1900**

Introduction

The goldrushes of the 1850s and 1860s widened the range of mining in Australia from a small number of coal and copper mining companies using technologies mostly introduced from Great Britain and Germany, to include a large number of small parties working small claims for eluvial and alluvial gold on a co-operative basis. These new conditions produced a climate more conducive to experimentation, adaptation and innovation. In the 1860s several attempts had been made to modify developments in British company law to suit Australian conditions, but the liquidation of a failed mining company was still a difficult process. Further expansion of mining took place in Australia in the period from 1870 to 1900. First there was geographical expansion of mining to all the colonies; second the types of minerals mined expanded to include tin, silver lead and zinc, and fine grained and refractory gold ores which could not be amalgamated; and third more large copper sulphide ore bodies were discovered and developed. New technologies were required to extract and process the ores of these deposits. By the end of the period most of the new technologies needed to extract and process these ores had been developed and final solutions were achieved by 1914.

As a continuation of its previous policy of encouraging and simultaneously controlling mining, the Victorian legislature passed additional legislation in this period to remove the difficulties of establishing and winding up mining companies, acts to control industrial health and safety and mine drainage, acts to bring all minerals under the direct control of the Crown, and acts to control the practice of tributing. Similar acts were later passed in the other colonies during this period to give a fairly uniform set of mining law Australia wide. Surprisingly the various legislatures took little interest in simultaneously developing technical education for the mining industry. Attempts were made by various groups in each colony to develop a satisfactory system of education for the mining industry, with varying degrees of success.

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420 While Pyke’s Act used simple language it did not clearly define the liability of a shareholder for payments to creditors of the company.

This chapter will firstly discuss the geographical expansion of mining in Australia in the period 1870 to 1900 and the widening of the types of minerals mined from coal, high grade copper and free milling gold ores to include low grade copper, tin, silver lead and zinc and very refractory gold ores. The chapter will next consider the development of a legal and financial infrastructure to provide an adequate base for continued mining development and attempts to establish technical education to supply the increasing need for trained technologists to adapt new developments in the sciences to the mining industry. Finally the chapter will argue the new scientific discoveries of electricity and magnetism including telegraphy and telephony were rapidly adopted by the mining industry in Australia. This will set the scene for a discussion in the following chapters of how this infrastructure development assisted the introduction of a more scientific based mining industry in the final thirty years of the nineteenth century, a process called ‘out of the hands of the rule of thumb men’ by Jan Todd when she was commenting on an earlier statement by Geoffrey Blainey about mine managers of the period before 1880; ‘the thumb was their ruler’.422

Expansion of Mining 1870-1900

Victoria was dominant in gold production in the Australian colonies in the years after 1851.423 However a small alluvial gold field was discovered by Keeling Richardson, a shepherd, at Fingal in Tasmania in 1858 and in 1867 James Nash opened an alluvial field at Gympie in southern Queensland which soon developed into a large reef mining area with free milling gold.424 Coal had been discovered along the Brisbane River in 1828 but mining did not commence until 1852 and then on a small scale and only intermittently. By 1870 some 20,000 tons of coal was being mined annually around Ipswich and Maryborough in Queensland, but this was only three percent of the current

423 G. Serle, The Golden Age (Carlton: Melbourne University Press, 1963). Serle p. 390 lists estimates of production up to 1861 showing Victorian production was more than four times that of New South Wales in those years.
New South Wales production. Manual mining methods continued to be used.\(^1\) By the end of the period the annual production from these mines was about 490,000 tons.\(^2\)

By 1869 pastoralists were moving into the arid areas of central western New South Wales and two Danes, Thomas Hartman and Charles Campbell, who had previously mined for gold at Bendigo, were employed to bore for water on the site of the later named town of Cobar. They noticed blue and green stains around a native well and the following year secured the land as a mineral conditional purchase lease (a type of lease peculiar to New South Wales at that time). The development of the Cobar copper and gold fields followed, and will be discussed in more detail Chapter 6.\(^3\) Further expansion by pastoralists along the Darling River in western New South Wales resulted in the discovery in 1876 of silver veins by two well sinkers, Julius Nickel and McLean, on Thackaringa Station, on the western slopes of the Barrier Ranges. There was little interest in the small veins.\(^4\) However in 1881 the discovery of alluvial gold at Mt. Browne, further north, near the Queensland border, led to a rush to the area, but the climate was harsh and dry, the returns from the alluvial and the adjacent reefs was generally small, and many miners retreated south from the drought conditions again renewing interest in the Thackaringa area. The drought broke in 1884 and an article on the silverfields of south western New South Wales in the *South Australian Advertiser* directed further interest in the area with an increase in population around Silverton, on the road from Burra to the pastoral stations to the north, and the Apollyon Valley nearby. By this time several small narrow vein silver mines were being worked in the area and Charles Rasp and fellow pastoral workers had pegged seven leases, each around 40 acres, on a broken hill some twenty miles away.\(^5\) The introduction of new technologies to deal with these new types of orebodies will be discussed in later chapters.

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\(^{1}\) R. L. Whitmore, *Coal in Queensland, the First Fifty Years* (Brisbane: Queensland University Press, 1981), pp. 13, 19, 156.


\(^{5}\) Ibid., pp. 135-44.
An improved method of cooking meat, vegetables and fruit at lower temperatures and at reduced cost led to an increasing demand in the 1860s for tin to plate steel cans to preserve the food. A large deposit of lode tin (tin oxide) was discovered by James Smith (a Tasmanian farmer/prospector who had gained mining experience in the rush to Castlemaine in 1851) at Mt. Bischoff in north west Tasmania in December 1871. Lode tin and alluvial tin oxide was found in the north east of that colony some years later. Alluvial tin oxide was also found in January 1872 near the site of Stanthorpe, in southern Queensland by Mr. Horton and soon after across the border in northern New South Wales. A rich deposit of copper had been found at Peak Downs, inland from Rockhampton in Queensland, in 1862 and by 1872 several mines were operating there and the Peak Downs Copper Mining Company was paying high dividends. Gold was discovered at Ravenswood and Charters Towers, inland from Townsville, in 1871. By 1873 both European and Chinese miners were working alluvial fields, discovered by James Mulligan, on the Palmer River west of Cooktown, and by 1875 on the Hodgkinson River west of Cairns. Other prospectors had moved northwest and located the Etheridge goldfield in the Proterozoic rocks of the Australian Craton in 1869. In 1876 alluvial tin oxide was found west of Townsville and lode tin oxide was found at Herberton west of Cairns in 1878.

Prospectors from Queensland moved into the Northern Territory after 1870, when gold was found at Pine Creek by workers on the overland telegraph line being constructed between Adelaide and Darwin. Later rushes took place in Western Australia at Hall’s Creek in 1886, at Roebourne inland from Geraldton on the Murchison River, and at Southern Cross in 1888 and culminated in 1892 when Arthur Bayley and William Ford discovered gold at Coolgardie and Paddy Hannan, Tom Flanagan and Dan Shea opened

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431 J. Harslett and R. Royle, *They Came to a Plateau (the Stanthorpe Saga)* (Stanthorpe: International Color Productions, 1972), pp. 29-33. In his book *The Rush that Never Ended*, Geoffrey Blainey credits C. S. Mc Glew with the first discovery in the Stanthorpe area but Haslett and Royle show the presence of tin oxide in the area was first reported in 1856.
433 The details of the discoveries of the various gold fields in Queensland are taken from the four volumes *Gold Occurrences in South Eastern, Central, Northern and Far-North Queensland* (Brisbane: Queensland Department of Mines and Energy, 1996).
the North Kalgoorlie field. While this geographical expansion of mining was taking place considerable changes were occurring in government involvement in mining practices. These will be discussed in the following sections.

**The Limiting of Shareholder Liability**

The Mining Statute passed by the Victorian Government in 1865 was the distillation of experience gained by the Local Courts from 1855 and the Mining Boards from 1858 in developing effective rules for mining alluvial and reef gold. This Statute was copied with minor variations by the other Australian colonies as the geographical expansion of mining forced each of them to upgrade their mining law from the inadequate British law they had each inherited. However neither the Victorian Pyke’s Act of 1860 nor its successor Frazer’s Act of 1864 had solved the problem of defining the liability of shareholders in a mining company for debts incurred by the company. In the late 1860s mining companies in Victoria were being formed with a high nominal capital, of which only a small amount was initially called on each share, for example one shilling on a £1 share (5 percent). The company then made calls on the shareholders or borrowed money from a bank to finance initial development on the expectation that gold would be found to finance further development. If insufficient gold was found to pay expenses the company was wound up by the local Court of Mines and a liquidator was appointed. He sought to collect unpaid calls and if unsuccessful sued shareholders for unpaid calls. He often found the shares had been dummied and the shares were listed as being held by someone other than the real owner, usually someone with no assets to pay the calls. The liquidator would then sue any wealthy shareholders for the total liability. Such procedures often took years and the costs took most of the funds collected. The mining industry, miners and investors sought a better system and the Victorian government set up a Select Committee on the proposed Mining Companies Law

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437 Blainey, *The Rush That Never Ended*, Ch. 7. Geoffrey Blainey appears to be the first writer to discuss the anti-clockwise progression of gold discoveries.


439 Some companies, e.g. the Endeavour Company in Bendigo preferred to borrow as this had less effect on the share price than calls.

440 *Report of Select Committee on Mining Companies Law Amendment Bill, Victorian Parliamentary Papers* (Melbourne: 1871). The *Minutes of Evidence* attached to this report give a fascinating picture of how brokers and investors were operating Frazer’s Act in a way the Parliament had not envisaged when the Act was passed in 1864.
Amendment Bill, which reported in October 1871. After receiving the report of the Select Committee the Parliament debated the bill and passed the Act, 35 Vict. 409, commonly called the No-Liability Act, which allowed three types of mining company structure: an updated Haines’ Act for a cost book type company, an updated Frazer’s Act for a company with limited liability and a new type, the no-liability company - a concept unique to Victoria - which allowed a shareholder to forfeit his shares on non-payment of a call and then have no further liability. Within a few years most mining companies registered in Victoria were of this third type. A no-liability company could be registered with only five percent of the nominal capital called up. New South Wales passed a similar act in 1874. Within twenty years other Australian colonies and New Zealand passed laws permitting no-liability companies. Some members of the legal professions did not support this legislation because they felt that it did not give sufficient protection to creditors of the company.

The development of the no-liability company in Victoria was the final step in the search for a company structure that was suitable for Australian gold mining. Changes in legislation from the British concept of the cost book company of 1855, to Pyke’s act in 1860 which was based on the needs of the gold miners, to Frazer’s act, with only small variations from Pyke’s act, and the no-liability act of 1871 which was driven by both miners and investors, resulted in companies suited to deep lead mining where the lead, when found, was often too poor to be worth mining, and also to narrow vein mining in reefs in which the gold content varied continuously and often fell below economical grades. The legislation permitted the rapid formation of a company with a small paid up capital of a few thousand pounds, sufficient to purchase and erect machinery and to pay wages to a small number of miners to begin prospecting. If the mine was payable, calls were made or money was borrowed from a bank to finance development. Alternatively tribute parties were used for prospecting. As the shareholder could forfeit his shares at

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441 Ibid. The Report had only two clauses: that the Committee had taken evidence and amended the original bill and as a result recommended the original bill be withdrawn and the amended bill be introduced.
442 A study of the Victorian Government Gazette from 1872 shows initial registrations were mainly type two i.e. limited liability but there was an increasing number of no-liability companies registered in succeeding years.
443 Act 35 Vict. 409 Clause 118(1)
444 Salsbury and Sweeney, The Bull, the Bear and the Kangaroo, p. 37.
446 Report of Select Committee on Mining Companies Law Amendment Bill. See evidence given by Judge Rogers.
any time his liability was limited to the value of his shares. If payable ore was not found the company could be wound up quickly and resources devoted to other companies to explore new reefs. This new type of company was peculiarly suited to small gold mining companies, working on small claims or leases of less than 30 acres, where gold grades were variable, directors were mainly experienced miners and shareholders mainly resided in the local area.\textsuperscript{447}

The Movement to Company Employment

After 1855 there was tension between Victorian governments and miners as the former sought to develop British mining company structures while the miners sought for structures more suitable for Australian conditions. As already discussed in Chapter 3 this tension had commenced with the cost book company legislation of 1855 (Haines’ act). It was finally resolved by the no-liability act of 1871, which allowed cost book type companies, limited liability companies and no-liability companies. The first of these was of British origin while the latter was distinctly Australian. During this period deep lead alluvial gold mines boomed for a short time and then declined in importance, while quartz reef mining steadily increased. The large numbers of miners working in small partnerships in shallow alluvial mining had started to decline in the late 1850s and while many left mining for agriculture or industry, many others sought employment with mining companies. Some historians have assumed that the passing of Ireland’s act in 1858 and changes to the regulations allowing larger leases in 1859 led to an immediate and rapid increase in company employment in Victoria.\textsuperscript{448} As will be shown the change to company employment was gradual and was not predominant until well into the 1880s.

As the early companies were not registered there is considerable difficulty in determining the number operating between 1855 and 1859. Lease records from 1859 indicate the number was probably less than 100, mainly at Ballarat and Castlemaine, but most were short lived and most probably employed few miners. At Ballarat a few co-operative partnerships were employing 30 to 90 working partners from 1857 on deep

\textsuperscript{447} Weaknesses appeared in this structure at the turn of the century when overseas capital was again invested in Australian mines. No-liability company law allowed calls not paid within fourteen days of the notice of the call to be forfeited to the company. Overseas shareholders sometimes did not receive their call notice until after their shares had been forfeited.

lead mining. The importance of Pyke’s act is indicated by the fact that some 539 limited liability companies registered under this act between 1860 and 1864, the majority at Ballarat and Daylesford, for both alluvial and quartz mines. Larger numbers were registered under Frazer’s act after 1864 and during the quartz boom of the 1870s at Bendigo larger numbers again after the 1871 act.

The statistics of the number of miners in Victoria was not reliable until 1863 when a separate mines department was established. From 1864 to 1888 numbers were reported quarterly and these are consistent enough to be used for analysing the number of miners moving from partnerships to company employment. The following table summarises the estimated company employment in 1864, 1868 and 1884 from an analysis of the number of goldminers and the probable pattern of employment on the several goldfields. The figures are subjective, particularly for 1864. They do not include Chinese miners who came to the goldfields as indentured labourers in parties financed and controlled by Chinese capitalists. After paying off the indenture Chinese miners worked in small parties shallow sinking, puddling and sluicing. A few were employed on deep lead mines puddling the washdirt and a maximum of 200 were employed in quartz mines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Alluvial miners</th>
<th>No. on Wages</th>
<th>Percent</th>
<th>Quartz</th>
<th>No. on Wages</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1864</td>
<td>45,040</td>
<td>3,250</td>
<td>7</td>
<td>15,089</td>
<td>4,200</td>
<td>28</td>
</tr>
<tr>
<td>1868</td>
<td>33,200</td>
<td>15,900</td>
<td>48</td>
<td>14,500</td>
<td>9,500</td>
<td>67</td>
</tr>
<tr>
<td>1884</td>
<td>14,000</td>
<td>10,000</td>
<td>71</td>
<td>13,200</td>
<td>12,300</td>
<td>95</td>
</tr>
</tbody>
</table>

It is of interest to compare the attitudes of the governments in New South Wales and Victoria towards the mining industry in each colony in this period. The New South Wales government was less involved in the detail of industrial relations and mining regulations than the government in Victoria. The coal industry at Newcastle had been dogged by intermittency for many years when the miners were not called for work when

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449 F. Strahan, "The Growth and Extent of Company Mining on the Victorian Goldfield in the 1850s" (B.A. Hons., Melbourne, 1955), p. 19. British Parliamentary Papers, (Shannon: Irish University Press, 1969). Vol. 24, Session 1862-3, p. 157. Governor Barkly reported many of the companies registered in Melbourne at this period were unprofitable and could not meet expenses as employing secretaries, consulting engineers, clerks etc. This indicates they were structured similar to British practice.

450 Victorian Government Gazette, (Melbourne: Government Printer). Some 72 companies were registered in January 1872.

451 "Reports of Mining Surveyors and Registrars, Victoria," (Melbourne: Mines Department), 1864 to 88.

452 Birrell, Staking a Claim, ch. 6.

453 Graphs of the number of miners, discussion of the types of mining on each goldfield and estimates of employment are given in Appendix 4.
trade was slack and the coal available could not be sold. This led to fluctuating wages as the miners were paid for the coal they produced. After the destruction of the early union movement in the early 1860s (discussed in Chapter 4) by the combination of colliery owners, the unions did not recover until the early 1870s when coal miners from Britain, who were experienced in industrial negotiation, applied these skills and organised a general strike in 1873. The miners won a higher hewing rate early and a reduction in working hours to ten per shift. This forced the companies to raise coal prices.\footnote{H. M. Ellis, A Saga of Coal (Sydney: Angus and Robertson, 1969), pp. 105-22.}

Another major strike occurred at Newcastle in 1888 as part of general industrial unrest in New South Wales. The government appointed a Royal Commission on the best method of preventing strikes but little was achieved when the commission accused the miners of seeking to secure a monopoly of labour and excluding non unionists. The strike failed but in the following years there were strikes at Newcastle almost yearly.\footnote{Ibid., pp. 155-6.}

In contrast the Victorian government became involved when a group of gold mining companies in Bendigo decided to reduce the miners’ wages from 45 to 42 shillings per week in 1879. Some 300 miners struck and sent a deputation to interview George Lansell, who was then a large shareholder in many Bendigo mines. Lansell refused the request for a return to the higher rate. The minister of mines threatened to withdraw the lease approvals of companies with men on strike, on the grounds that they were not fulfilling the labour covenants of the lease. The higher wage was reinstated. A gold miners union, the Amalgamated Miners Association, had been organised by William Spence in 1878 but it was more a benevolent society than a militant union.\footnote{J. C. Fahey, “Wealth and Social Mobility” (Melbourne, 1981), p. 129.}

The Development of Colonial Stock Exchanges

The small co-operative parties of the early 1850s needed only sufficient funds for food and a few tools before commencing mining, but the mining of the deep leads from 1853 by large co-operative parties soon led to trading in the shares held by individual members of these parties. Similar trading in shares held in reef mines in Bendigo soon followed, as has been described in earlier chapters.\footnote{See Ch. 2 and Ch. 3. The Bendigo brokers moved into a permanent home in 1871 in the Mining Exchange Building. See The Bendigo Advertiser, 20 September 1871.} Edward Khull, Melbourne’s first share broker, published the first list of stocks and shares of 14 companies, some of them
mining for gold, in the *Argus* newspaper in 1852. The list grew in size gradually and by end of the decade was published by a group of brokers.\(^{458}\) After the issue of mining leases was placed on a sound legal basis by the *Goldfields Act* of 1857 mining companies were registered in increasing numbers and from 1859 broking firms became a more prominent feature of the economic landscape on the goldfields and in Melbourne. In March 1860 the Melbourne Brokers’ Association was formed.\(^ {459}\) An exchange, first known as the Stock Exchange of Melbourne and then the Melbourne Stock Exchange, was formed in 1865, during a period of increased speculation in mining shares, but it was in direct competition with the existing exchanges at Ballarat and Bendigo and later with other smaller exchanges at Walhalla, Wood’s Point, Stawell and elsewhere in Victoria.\(^ {460}\) In March 1869 there was a minor speculative boom, led by investment of local and Melbourne capital in Bendigo mines as companies which had been registered under Frazer’s Act began to pay dividends.\(^ {461}\) At the end of that year the Great Extended Hustlers Company announced the finding of a very rich reef, leading to a boom in shares in the Bendigo mines. The boom was fed by further rich finds in the next two years.\(^ {462}\) Melbourne sharebrokers set up offices in Bendigo, there was a reduction in charges for inland telegrams in January 1870, and after 1871 the completion of the telegraph connection to London enabled rapid transmission of market information, including London metal prices, to and from the world’s financial centre. The Melbourne Stock Exchange became more involved in capital formation for the Victorian gold mining industry.\(^ {463}\) No figures are available for the amount of British capital flowing into Victorian mines during this boom. J. N. Macartney, a Bendigo sharebroker of the period, wrote that the inflow to Bendigo was immense but no evidence has been found to support this claim.\(^ {464}\) Harvey and Press list six British


\(^{459}\) Ibid., pp. 22-4.

\(^{460}\) Ibid. pp. 48, 59-60. There was much debate between 1860 and 1865 on whether brokers should be allowed to ‘job’ i.e. buy and sell shares themselves as well as on behalf of clients or only to buy and sell on instructions from clients.

\(^{461}\) Ibid., p. 79.


\(^{464}\) Cusack, *Bendigo a History*, p. 152. J. N. Macartney, *The Bendigo Goldfield Registry, 2nd Ed.* (Melbourne: 1872), p. 5. Macartney did not quantify the inflow and he may have been attempting to attract British capital to Bendigo mines. The listings of companies in the Government Gazette in this period indicate clearly that most investors lived on the adjacent goldfield or in Melbourne.
companies with a total £680,000 invested in Australian non-ferrous mining companies in 1875, but this would have included copper, and tin mines as well as gold mines.\(^{465}\)

The Melbourne Stock Exchange was disrupted by a dispute over advertising by members in 1884, and a rival, the Stock Exchange of Melbourne, emerged but the two reunited under the latter name within two years.\(^{466}\) The exchange was involved in capital raising for the Broken Hill mines and the speculations in Broken Hill shares in the late 1880s and other mines in Queensland, Tasmania, South Australia and New South Wales.\(^{467}\)

Sydney stockbrokers had been involved in the floating of the Great Nugget Gold Mining Company in 1851, but only the prospectuses of six locally sponsored gold mining companies were listed in the *Sydney Morning Herald* in the 1850s.\(^{468}\) In 1861 the New South Wales government passed an act for mining companies similar to the 1860 Victorian act.\(^{469}\) There is some evidence that a Sydney Stock Exchange was formed in May 1871 and there is documentary evidence of this from October 1872.\(^{470}\)

As mentioned above there was a flurry in speculation in mining shares in Sydney when the Peak Downs copper mine in Queensland was paying high dividends, more copper mines were discovered in New South Wales, and tin mines were opening in both colonies. The boom collapsed in 1873 and reduced the number of active brokers but the pause allowed the Sydney Stock Exchange time to develop a set of rules which provided a legal framework for share-trading in New South Wales.\(^{471}\) Other capital city stock exchanges were opened in Hobart in 1882, Brisbane in 1885, Adelaide in 1887 and Perth in 1889 as mining developed in the other colonies.\(^{472}\)

By the early 1880s the mines at Charters Towers were prosperous and in 1885 a group of mining agents (the equivalent of the legal managers in Victoria) formed themselves into a ‘Mining Exchange’ to trade in mining shares. In 1886 samples of gold ore and a


\(^{467}\) Ibid., p. 121-2.

\(^{468}\) Salsbury and Sweeney, *The Bull, the Bear and the Kangaroo*, p. 26. The Sydney industrialist T. S. Mort was the guiding figure.

\(^{469}\) Ibid., p. 35. This was Pyke’s Act, 24 Vict. 109.

\(^{470}\) Ibid., p. 101.

\(^{471}\) Ibid., p. 117-8. This enabled the Stock Exchange to circumvent an attempt by the government to pass an act to control stockbrokers.

\(^{472}\) *The Australian Encyclopaedia, 5th Ed.*, vol. 7, p. 2727.
display of methods used to extract the gold were sent to the Colonial and Indian Exhibition held in London. English capital was attracted to the Charters Towers mines, new companies were formed locally and the shares sold in London at inflated prices, leading to a boom which collapsed in 1888. This forced the fragmented groups of stockbrokers to form the Charters Towers Stock Exchange in 1890, with a set of rules to control the previous excesses in share trading. Short lived stock exchanges operated at Broken Hill, Silverton and Hillgrove and Gympie in the 1880s. In the 1890s stockbrokers dealing in mining shares combined to form small stock exchanges in towns adjacent to new mines at Launceston, Zeehan and Queenstown in Tasmania, and Coolgardie, Kalgoorlie and Kanowna in Western Australia.

The Mines Inspection Acts

In the first sixty years of mining in Australia there were few concerns about the accident rates in mines. Common law principles in Great Britain and the United States placed the cost of industrial accidents on the injured worker, and legislation there frequently removed any liability from the employer. The first attempt to supervise the use of machinery in mines in Australia was made in 1860 when Thomas Carpenter, then member for Mandurang, introduced a bill (based on a British law of 1855, amended in 1860) in the Victorian Legislative Assembly to provide for the inspection of mines and the appointment of inspectors to ensure safe working practices. The bill passed the first reading but during the second reading members accused Carpenter of over legislation and the bill was voted out by 30 votes to 18. By the 1870s accidental deaths and injuries in Victorian mines had become a public scandal; in the four years from 1870 to 1873 there were 332 fatal accidents, of which falls of earth and rock caused nearly half. Angus Mackay, member for Bendigo and Minister of Mines,
introduced a bill in October 1873 for the regulation and inspection of mines, again based on British coal mining legislation. The bill was assented to on 25 November (37 Vict. 480) and came into operation on 1 January 1874. Under the Act, adequate ventilation had to be provided in all parts of the mine; the storage of explosives underground was limited; shafts and drives had to be timbered where necessary; ladderways were to be provided with landings at regular intervals; signalling systems were required if winding equipment was installed; machines were to be adequately guarded and boilers inspected and tested regularly. No boy under the age of fourteen years and no girl or woman of any age was to be employed underground. The most significant clause was that any accident occurring in a mine was to be taken as *prima facie* evidence that the accident occurred through some negligence on the part of the owner (manager) or some defect in the management, ventilation or machinery. In practice this meant that the manager had to prove to a Coroner that the death had not been caused by negligence on his part. This clause was revolutionary in British mining law.480

Similar Acts were passed in 1876 in New South Wales for coal mines and metalliferous mines, and in 1881 both Tasmania and Queensland passed mines inspection acts similar to the Victorian act.481

**The Changing Concept of Royal Minerals**

In the first proclamation of 22 May 1851 covering the mining of gold, the government of New South Wales specified that all gold in its natural place, whether on lands of the Queen or of her subjects, belonged to the Crown.482 Similarly in his proclamation of 15 August 1851 on the mining of gold in Victoria, Charles La Trobe specified that gold in its natural place, whether on the lands of the Queen or any of her subjects, belonged to the Crown.483 However the Victorian Act 15 Vict. 15 of 6 January 1852 mentioned only digging for ore upon Waste Lands of the Crown.484 This omission of mining for gold on

480 Act 37 Vict. 480, Clause 3.
481 See Ch. 1.
482 Victorian Government Gazette, 1851, p. 362.
483 Act 15 Vict. 15, Clause 1. Although no record of any discussion on this omission has been found it seems likely that private property was excluded from the Act because of opposition in the newly established Legislative Council which met for the first time on 11 November 1851.
private property bedevilled the Victorian legislature for many years. Towards the end of the 1850s, when miners working leads on crown land found the leads entered private property, they were forced to negotiate with the owner of the property about royalties for mining the land. Wardens refused to adjudicate on disputes between miners and land owners, saying the regulations did not apply. An attempt had been made to solve this problem in 1857 when a bill was introduced in the Legislative Assembly to cover mining on private property. It was rejected on the second reading.

Between then and 1882 a similar bill was submitted to one House or the other no fewer than 26 times. Depending on which parliamentary grouping introduced the bill, it was opposed by the landholders or the miners or by both. The landholders argued they owned the minerals on their land, the miners argued they should have equal access to the gold on crown land or private property since the gold belonged to the Crown.

The highest law body in the British Empire, the Privy Council in England, decided in 1877 that contracts between the owner of a property and anyone mining gold on that property were void and could not be enforced. This decision compounded a local problem in Victoria where a person selecting land under the local Lands Acts could be deprived of the land, without redress, if the Mines Department declared it auriferous. Because landholders and miners now had an urgent reason to solve this problem a bill was introduced into the Legislative Council, passed and received royal assent on 25 November 1884. The act allowed a miner to prospect on private property and then to mine, but he had to compensate the owner for any damage to buildings on the surface. In 1890 the Victorian government decided to rationalise the various acts relating to mining and a consolidated act was passed.

The most publicized of these disputes was on the private property leased by the Port Phillip Co. at Clunes when in 1858, miners traced an alluvial lead to the company’s boundary. The Clunes Quartz Mining Company, a co-operative company set up by the Port Phillip Company, sponsored another co-operative, the Clunes Alluvial Gold Mining Company to mine the lead at a depth of ninety feet under basalt. The outsiders were refused entry to the lease so they dug shafts along the boundary and tunneled into the lead, resulting in pitched battles underground between the factions. The dispute was never resolved legally but later in 1858 another lead was found on crown land south of the lease which diverted the trespassing miners to this area and the dispute fizzled out. See J. Woodland, *Sixteen Tons of Clunes Gold* (Clunes: Clunes Museum, 2001), p.41.

Victorian Parliamentary Debates, 16 April 1857, p.585.
Ibid., 23 April 1857., p. 1007.
Ibid. 1858 to 1882, passim.
The owners had no legal base for their argument in British law.
Act 48 Vict. 796. 25 November 1884.
Act 54 Vict. 1120, 10 July 1890. It was divided into three parts:
By 1889 Victorian gold mining was declining in output. In an attempt to find ways of regenerating the industry the Victorian government established a Royal Commission on Mining in that year. It comprised twenty members, all with expertise in the various aspects of mining. The Commission reported in September 1891. The report of 1911 pages was a comprehensive summary of gold mining technology of that time. It was presented during a period of severe financial depression in Victoria and had little impact. As the severe effects of the depression abated the government again turned its attention to updating the mining legislation and introduced an amending bill in September 1896. After more than 12 months of political manoeuvring amendments to the 1890 act were passed. The amendments updated the act to make it more suitable to the economics of the late 1890s.

The financial depression of the late 1880s and early 1890s had been particularly severe in Victoria, and other colonies, particularly New South Wales at Broken Hill, were developing new mining fields and did not feel the need for such a searching inquiry. The recovery of the Victorian economy, together with the introduction of the cyanide process for treating gold tailings and the development of dredging in the 1890s, led to a partial recovery in the value of gold production and the decline of political interest in Victoria in the problems of the industry.

**Tributing**

Although the Cornish practice of tributing was introduced in the South Australian copper mines in the 1840s, it became important in gold mining as well and because it gave the miner employed by a company the chance of a rich find it may have helped to reduce strikes in the gold mining industry when company mining became the norm.

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493 Birrell, *Staking a Claim*. A discussion of the report and the recommendations can be found in Ch. 9
494 Act 61 Vict. 1514. Holders of Miner’s Rights were given authority to mine for all minerals and the fee was reduced to 2 s. 6 p. a year. Lease rents were reduced to 2s. 6p. per acre a year and any miner could ask for an enquiry if he believed the labour requirements for a lease were not being met. If the complaint was proved the miner was given the lease. In this way the law on labour covenants did not require a team of bureaucrats to police it. The ownership of tailings dumps reverted to the Crown if a lease was declared void. Engine drivers were now required to sit for an examination to prove their competency.
The Cornish practices of tut work, tun work and tribute were first used in Australia in the copper mines at Kapunda and Burra.\textsuperscript{496} This system had been developed in Cornwall in the eighteenth century when pumping allowed the deeper lodes to be developed.\textsuperscript{497} Tributers in copper mines usually worked in groups or ‘pares’- often family groups - who were paid a percentage of the value of the ore they extracted. At Burra in 1846 the percentage was 3s. 6p. of each £1 of ore, but this was reduced the following year to 2s. 6p. and then to 1s. 3p. for very rich ore. At the end of each two months a Letting-Day was held at which underground blocks or ‘pitches’ were given a number and the tribute amount. The mine captain then called the pitch number and the rate, and the first party to accept the rate obtained the tribute. If no party accepted, the rate or ‘take’ could be raised and bids called again. After two months the process was repeated. On ‘settlement day’ the mine captain would read out the return to each party, calculated on the basis of assays made on the ore extracted by the party, to determine the value of the contained copper.\textsuperscript{498} Tributing was popular with Cornish miners because there was always the chance of striking a rich patch of ore during the period of the tribute to give a high return.\textsuperscript{499} This may have been a reason for the rarity of strikes in mines working on tribute. The only strike at the Burra mine was in 1848 when the directors reduced wages and the tributing rate.\textsuperscript{500}

When other copper mines were opened around Australia similar practices were continued and were extended to gold mining in eastern Australia when miners began working for companies in the late 1850s.\textsuperscript{501} The tut and tun work payments which had been used in the South Australian copper mines came to be regarded as working for contract or wages in the Victorian gold mines, and the words tut and tun disappeared from the language of the gold miners. Tributing remained as a contract between mining parties and mine management, and because most agreements were verbal there is little information available on the agreements made by the parties. Tributing was in use in

\textsuperscript{496} See chap. 1.
\textsuperscript{499} Pryce, \textit{Mineralogia Cornubiensis}, p. 192.
\textsuperscript{500} Auhl, \textit{The Story of the Monster Mine}, pp. 90-1.
\textsuperscript{501} G. J. Drew, \textit{Discovering Historic Moonta} (Adelaide: Department of Mines and Energy, 1991), pp. 64-5. At Moonta tutwork pitches were quoted at so much per fathom and tribute pitches at so much in the pound sterling. There a party had first right of acceptance when a pitch on which they were working was called on a succeeding letting-day. Tributing ceased at Moonta in 1910 owing to falling ore grades. Woodland, \textit{Sixteen Tons of Clunes Gold}, p. 36b. The Clunes Quartz Mining Co. abandoned the cooperative system in 1859 because some of the partners were loafing and introduced a tributing system but no details are available of the take.
Victorian gold mines as early as 1861. Sir Henry Barkly, the Victorian governor, described the use of tributers in the Bolivia Reef Company, registered under Haines’ act, which had failed due to poor management. It was then sold and the new owners let the mine on a tribute of 25 percent to the miners who had worked for the earlier company. When Barkly visited the mine, probably in 1861, the miners had extracted £10,000 worth of gold. At Bendigo tributing companies were registered to take over a mine and work it on tribute for periods up to five years. Macartney said there were 170 listed tribute companies working on the Bendigo goldfield in 1871. Some paid substantial dividends from working the rich ores in the oxidised zone and at this time were providing a service to companies, set up in a boom period, which did not have the expertise or the capital to develop their own mine.

Information on tributing in gold mines in the other colonies is hard to find although T. Jones describes how Ping Que, a Chinese merchant in the Northern Territory, organised Chinese miners to work quartz mines on tribute in 1875 and later in the 1880s took over the mines when the South Australian owned companies failed due to bad management, and the isolated and the remote location of the mines. A tribute company was working the Phoenix mine at Gympie in Queensland in the early 1890s. J. W. McCarty mentions that Northern Territory quartz mines were being worked by Chinese on tribute in 1897.

During the depression of the 1890s the Victorian Parliament appointed a Select Committee to inquire into and report on the present system of tributing in gold mines in Victoria. Unfortunately the report of the committee did not include details of the evidence of the various witnesses who appeared before it and the only details of the takes are in Clause 5. At Bendigo the practice at this time was to let a tribute for six months on a sliding scale, the agreement being verbal. At Eaglehawk, near Bendigo,

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502 Surveyors Reports, Victorian Mines Department, August 1862. The tribute system was in use in Castlemaine at the Argus Mine (quartz) and other mines.
506 T. Jones, Pegging the Northern Territory, pp. 49,53.
agreements were similar but for 12 months. In both places some mines operated the half system, where the tributer broke the stone and carried it to the plat from where the company raised and crushed it, the yield being divided equally. Any gold recovered from the pyrites or copper plates was usually kept by the company. Some other mines paid the tributer all the gold recovered up to three or four pennyweights per ton, but took a percentage of any higher yield. At Stawell the tributers tendered for the blocks the company was offering for tribute, the tenderer setting the percentage. At Ballarat most companies first took the cost of carting and crushing the stone from any return, and the balance was divided equally between company and tributer. Some evidence on tributing was given to the Royal Commission on Mining in 1891 and Charles Fahey has provided further information on the way the system worked. When this information is considered it is clear the report of the Select Committee gave a concise summary of the way the tributing system worked in the Victorian gold mines.

The Committee found that at this time in the midst of a depression, tributes were never let until the directors were certain the ground would not pay if worked by wages miners. The earnings of the tributers varied considerably but most did not average more than £1 per week (compared with the average wage of £2 5s.), from which they often had to pay working expenses. The exploring work done by tributers had frequently discovered rich reefs. The companies then worked the rich stone with wages men and from the profits paid large dividends to shareholders. Tributing in Victorian gold mines was a more secretive arrangement between a party and the mine management than the system used in South Australia. There was no open bidding as was the practice in the copper mines, and the managers of the gold mines took a much harder bargaining position when offering tributes. The practices of the 1870s, where tributing parties and tributing companies developed rich mines at relatively shallow depths and made substantial profits, had changed in the 1890s to a more exploitive system where companies used tributers as a cheaper method of developing deeper low grade orebodies, rather than

510 Report of the Royal Commission on Mining, (Melbourne: Government Printer, 1891). See evidence by Peter Phillips, paras, 4999 to 5056; James Caisley para. 6197 stated he had made £30 to £40 per week when tributing but this appears to have been exceptional. C. Fahey, "Cornish Miners in Bendigo - an Examination of Their Standard of Living," Cornish Association of Bendigo, pp. 4-11.
511 "Report of Select Committee on Tributing in Gold Mines," Clauses 6, 7, 8.
developing the mine themselves. The depression of the 1890s and a plentiful supply of labour would have made this possible.

In an attempt to control abuses of the system, which seem to have been introduced in Victoria, the Consolidated Mines Act of 1890 had required tribute agreements to be in writing, approved by the directors of the company and submitted to the mining registrar of the district. The Select Committee recommended that each tributer be given a copy of the tribute agreement written in the directors’ minute book, and that the tributer should be entitled to take his working expenses and half wages out of the gross yield. In addition where the tribute agreement was on halves, the copper plates and pyrites should also be divided and the percentages calculated on the net yield. When the Consolidated Mines Act was amended in 1897 the section on tributing required that the agreement be in writing, that the location of the block be specified, that subsistence money be paid, that the number of tributers be given, and a separate copy of the agreement to be held by the owner, the tributer and the warden of the mining district. However the intention of this Act was not realised as the owners refused to pay half wages when paying all crushing costs. The miners had to accept individual terms outside the provisions of the Act. In 1902 the Minister of Mines met miners and mine owners in conferences at Ballarat and Bendigo, where it was agreed that effectively all tributing agreements would be between mine owners and the tributing party and that the restrictive legislation would be repealed. The amended Mines Act of 1904 removed the clauses specifying conditions and left these to the parties involved, but the agreed terms had to be entered in the company books. In the twentieth century, with lower grade metalliferous orebodies being mined, tributing was replaced by the contract system where each party was paid so much per ton of clean ore mined, the ore produced by each party being weighed separately. Development work was contracted as so much per foot for shaft sinking or driving levels. The rate was set by management but a party could relinquish a contract if returns were too low.

512 54 Vict. 1120, Clauses 73-4.
514 61 Vict. 1514, Part III, Div. 3.
515 Reports to the Minister of Mines, Victoria, 1903.
Tributing was not common in the high grade gold mines at Kalgoorlie until World War I, when labour was in short supply and gold grades were falling. Rather than spend money on development the companies employed tributing parties and when the price of gold rose in the 1930s some parties made small fortunes. As the price rose tributing decreased and by 1936 most miners were again employed on wages.\textsuperscript{518}

Although the details of tributing in gold mines were not well documented except in Victoria it is clear the practice was widespread in Australia until the late 1930s as a method of developing lower grade orebodies at low cost. When higher grade ores were opened up by the tributers the companies preferred to use wages miners to extract the richer ores.

**Education for the Mining Industry**

The need for trained personnel to work in the mining industry was appreciated in Europe by the eighteenth century. This could only be achieved by the development of a system of primary and secondary schools to educate students to a standard sufficient to undertake the study of the mathematics and sciences needed to commence the higher level training. The development of suitable schools in Europe and later the introduction of similar systems in the United States and Australia, will be considered in this section.

The Ecole des Ponts and Chasseurs had been established in Paris in 1747 and a School of Mines was added in 1794 to make the Ecole Polytechnique. The courses were University standard, applied research was conducted and graduates were trained for careers in the public service.\textsuperscript{519} During the nineteenth century France developed a system of compulsory primary education, leading to the secondary level lycees for those who intended University studies, and ecoles superieures up to the age of 16 for those entering business.\textsuperscript{520} In 1765 a Bergschule (Mining Academy) was established by the German State of Saxony at Freiberg and another at Clausthal, in Hanover, in 1775.\textsuperscript{521} The University of Berlin, a technical University, was founded by Kaiser Wilhelm Henry of Prussia in 1809, with geology as one of its subjects, and at the same time the Bergschulen were upgraded to University status. The graduates were employed by both

the mining companies and the public service which supervised the activities of the companies.\textsuperscript{522} By the 1870s the German states had a comprehensive education system of education to secondary level.\textsuperscript{523}

A School of Mines was established in London in 1851, with University status and Government financial support, with the aim of supplying trained men for the Geological Survey.\textsuperscript{524} England adopted a laissez-faire attitude to education till 1870 when compulsory primary education under local boards was introduced. Secondary education was left to voluntary organisations running fee-paying grammar schools.\textsuperscript{525} In the early nineteenth century the major English universities, Oxford and Cambridge, were in decline; religious tests on entry excluded Dissenters, Roman Catholics and Jews; the Colleges were monopolised by the upper and middle classes and the nobility, and the very wealthy formed a disproportionately large element in the student population. The emphasis was on teaching the classics. Oxford and Cambridge compared unfavourably with the Scottish universities, which were more democratic and open and provided a better scientific education.\textsuperscript{526} Professional studies had no place at Oxford and Cambridge. Law was studied at the Inns of Court, medicine at the London hospitals and engineers were trained as apprentices in the offices of practising engineers.\textsuperscript{527} In England research in the sciences was in the hands of amateurs such as Dalton, Faraday and Darwin, and the drive for technical education came mainly from the Mechanics Institutes which developed after 1823 and the Society of Arts after 1851.\textsuperscript{528} The University of London, which had been established as University College in 1826, free of religious restrictions, taught the applied sciences as well as the classics.\textsuperscript{529}

By 1866 five technical schools in the United States were providing teaching in mining engineering. Ten years later there were 15 teaching at University level.\textsuperscript{530} Public benefactors of higher education financed new tertiary institutions. Primary and

\textsuperscript{522} Lawson, "Development of National Systems of Education," vol. 6, p. 363.
\textsuperscript{524} Lawson, "Development of National Systems of Education," vol. 6, p.364.
\textsuperscript{525} Ibid., pp. 14.
\textsuperscript{526} Ibid., pp. 34, 45.
\textsuperscript{527} Ibid., pp. 29-31, 61-5.
\textsuperscript{528} Ibid., p. 34.
secondary education in the United States was very diverse and it was not until after 1870 that the states became involved in both primary and secondary education.\textsuperscript{531}

In 1861 the University of Melbourne allowed students who had completed a three year B.A. to study an additional one year to complete a Certificate of Civil Engineering. In 1875 this was modified to include mining and metallurgy subjects, and in 1900 separate degree courses in mining engineering and metallurgy were commenced.\textsuperscript{532} By 1869 deep lead mining was declining in Ballarat and the mines were moving to exploit the quartz reefs which had been discovered in the bedrock below the leads. A motion was passed by the Ballarat Mining Board that a School of Mines be established in the city. The mover pointed out there was a scarcity of mining managers and no means of training young managers.\textsuperscript{533} The Ballarat School of Mines opened in 1871 and was followed by the Sandhurst (Bendigo) School of Mines in 1873.\textsuperscript{534} Both taught assaying, mining engineering, metallurgy, chemistry, arithmetic and technical drawing, and the curriculum appears to be derived from that of the London School of Mines. From the beginning both schools were underfinanced and had difficulty surviving.\textsuperscript{535} In the prosperous 1880s both slowly expanded and trained a number of capable and successful managers.\textsuperscript{536} The Ballarat school affiliated with the University of Melbourne in 1887 but the relationship was not supported by the University Council and the school withdrew from the relationship in 1894.\textsuperscript{537} The Working Men’s College was established

\textsuperscript{533} W Perry, The School of Mines and Industries Ballarat (Ballarat: The School of Mines and Industries Ballarat, Ltd., 1984), p. 4.
\textsuperscript{534} F. Cusack, Canvas to Campus (Melbourne: The Hawthorn Press, 1973), pp. 45-9. Both schools were controlled by Governing Councils, elected by subscribers. Finance to erect buildings was raised by public subscription and additional funds were provided by the Department of Mines. Classes were financed by student fees. The drive for the establishment of the Sandhurst school came from the local Mechanics Institute but several mining men were members of the first Council and the chairman of the Mining Board was the first Registrar. However as Cusack points out on p. 46 the most prominent mining men of Bendigo were not members, but Angus Mackay (the reporter at Louisa Creek in 1852) and by then the owner of The Bendigo Advertiser and the Minister of Mines in Victoria supported the school from its inception.
\textsuperscript{535} Ibid., p. 55. Perry, The School of Mines and Industries Ballarat, p. 39.
\textsuperscript{536} As there were no formal awards for the subjects passed and only some of the early records have survived it is impossible to estimate the numbers trained. However the standards must have been high as several of those trained in this period achieved esteem within the mining industry. Among them were David Avery, later chemical consultant to the Collins House Group, and William Corbould, an assayer who later managed several copper mines, from Ballarat, and William Hamilton, for many years manager at Great Boulder at Kalgoorlie and James Hebbard, later manager of the Central Mine at Broken Hill and an active participant in the development of the flotation process, both trained at Bendigo.
\textsuperscript{537} Perry, The School of Mines and Industries Ballarat, pp. 81, 100-19.
in Melbourne in 1887 with the support of the industrial trade unions in that city after a grant of £5000 by Francis Ormond, a local philanthropist, matched by an equal amount raised by public subscription. In the early years this school was more interested in training artisans for industries in the city. Later in 1899 full time diploma courses in mining engineering and metallurgy were introduced.\footnote{S. Murray-Smith and A. J. Dare, The Tech (Melbourne: Hyland House, 1987), pp. 3-6, 53.}

During the prosperous years from 1870 to 1890 every mining field in Victoria aspired to sponsor a school of mines so boys could obtain tuition in mining subjects locally, as travel to a central school from these isolated towns was almost impossible. Several witnesses who appeared before the Royal Commission on Mining in 1890-1 spoke of the need for technical training, and of the difficulties faced by young men travelling to adjacent towns for training while earning a living at the more remote mines. By 1891 there were some 12 additional schools of mines in Victoria, and one at Moonta, but most were small, few subjects were taught, the lecturers often gave their time free and most were changed to technical schools when the mines in the district closed.\footnote{Those in Victoria were Castlemaine 1887, Kyneton 1888, Bairnsdale, Maryborough, Sale, Creswick 1889, Daylesford, Stawell, Harrietville 1890, St Arnaud 1891 and the Gordon Technical College in Geelong 1887.}

A School of Mines was established in Adelaide in 1889 and reciprocal arrangements were made with the University of Adelaide for B. Sc. students to study assaying at the School and then complete an additional year for a Diploma.\footnote{“Report of the Royal Commission on Technical Education,” (Melbourne: Victorian Parliament, 1901), p. 134.}

The University of Sydney set up a School of Mines within the Engineering Department in 1893, which awarded an Engineering Degree in Mining and Metallurgy.\footnote{Reports to Minister of Mines, New South Wales, 1893, p. 16. In this report Harrie Wood, the secretary of the department, who had been secretary of the Ballarat Mining Board in 1869 claimed to be the projector of the Ballarat School of Mines and said the degree course would soon in every aspect equal the Ballarat diploma course.}

Technical colleges at Broken Hill and Newcastle were offering subjects in mining engineering, the latter including coal mining in the 1890s. Technical schools were opened at Hobart and Launceston in Tasmania in 1888, and small schools of mines were sponsored by local groups at Zeehan and Beaconsfield in 1894 and 1901.\footnote{“Report of the Royal Commission on Technical Education,” p. 125. S. Murray-Smith, "A History of Technical Education in Australia" (Melbourne, 1966), p. 482.}

In the 1890s the Victorian Education Department assumed control of the courses in the Victorian schools of mines, and adapted the Ballarat associate diploma course as suitable for external examinations which were controlled by the Department. The first associate diplomas were awarded by
the Ballarat school in 1896, the Bendigo school in 1902 and the Working Men’s College in 1903.  

Stephen Murray-Smith has documented the development of these mining schools up to 1914 in his unpublished thesis ‘A History of Technical Education in Australia’. He argued that although schools of mines and technical colleges were established in the Australian colonies from 1870 because well meaning members of the middle classes desired to educate youth for moral reasons. However industry, including mining, needed trained personnel, and the major initial emphasis was on continuing education because of the lack of any organised secondary education in Australia before 1910. The supervisors of the independent schools of mines and the government-controlled technical colleges wished to provide vocational education at both tertiary and trade level, but the initial demand was small in both areas; at tertiary level because existing private secondary schools were dominated by the University controlled curriculum, and at trade level because industry preferred to train its operatives in the factories. To survive on small government grants and class fees the mining schools had to open their doors to students wanting continuing education for their work. To provide a route for those entering diploma courses they were forced to develop secondary technical schools, with financial support from governments. Because the schools of mines and technical colleges were financed by governments at a much lower level than the Universities, they were held in lower esteem by the general populace (predominately of British origin) than the Universities, even though the standard of diploma course was at tertiary level but with a less rigorous mathematical content than the University degree. Further contributions to the development of mining technology in Australia will be discussed in later chapters. In their book The Tech, Stephen Murray-Smith and Antony Dare make the following comment about the actions of Francis Ormond and his speech at Scotch College when offering to fund the Working Men’s College:

In many ways it was appropriate that the prime move towards a working men’s college should have been made at the speech day of one of the elite public schools of the colony. Technical education did not grow, to any significant

543 Perry, The School of Mines and Industries Ballarat, p. 1584. Bendigo School of Mines Archives, Box 41. Murray-Smith and Dare, The Tech, p. 55.
544 Murray-Smith, “A History of Technical Education in Australia”.
545 The support in the Australian community in the 1970s for Universities in preference to the more technical oriented Colleges of Advanced Education showed that this attitude was strong. The Dawkins reforms of the 1980s moved the Colleges into the Universities but did not solve the problems of technical education for the mining industry in Australia.
extent, from the needs of industry and agriculture. Members of the ‘trades’ and some of the early unions, were certainly interested in the technical aspects of their work,……., but interest by the labor movement in technical education was not the major factor in its development. Technical education grew above all, from a conviction from ‘above’, from the firmly based, confident and increasingly prosperous middle classes, that the ignorance of the working man, and his lack of opportunity, struck at the roots of the social order. Technical education, in British and Australian history, is a product between a ‘well-born’ father and a humble mother. To this day, many of its problems of nurture and domestic harmony may be traced to this uneasy harmony.\textsuperscript{546}

The statement above that technical education did not grow from the needs of industry, is not justified for technical education for the mining industry in Australia. The drive for the first mining school in Ballarat came from the Mining Board composed of miners elected by miners. At Bendigo, the school was sponsored by the Mechanics Institute Council. The thirteen members of the first school Council contained eight miners and mining investors. There were few philanthropists in the dozen or so mining towns which succeeded in establishing schools; the drive had to come from the local miners. Many of the mine managers who appeared before the Royal Commission on Mining in 1890-1 supported the schools when asked their opinion. Murray-Smith and Dare also unfairly discount the considerable contribution of the union movement in Melbourne to the development of technical education.\textsuperscript{547} However it seems clear that the populace, other than those directly engaged in mining, had little interest in supporting technical education for the mining industry during the first one hundred years of mining in Australia.\textsuperscript{548}

At a conference in Ballarat in 1892 of the Amalgamated Mining Managers’ Association of Australasia, Uriah Dudley, an American mining engineer managing a mine near Broken Hill, moved to establish a professional society of those working in the mining industry. Called the Australasian Institute of Mining Engineers, its objects were to promote the arts and sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings and the discussion of professional papers and

\textsuperscript{546} Murray-Smith and Dare, \textit{The Tech}, pp. 5-6.  
\textsuperscript{548} J. Mokyr, "Technological Inertia in Economic History," \textit{Journal of Economic History} LII (1992): pp. 332-5. Mokyr considers that intellectuals have generally opposed technological change because, among other things, the manipulation of nature is sinful. Technical education would have been seen as promoting technological change, an attitude which is still current.
to circulate by means of publications among its member the information thus obtained.

The Institute held its inaugural meeting in Adelaide in 1893 with Sir Henry Ayers as President and Uriah Dudley secretary. Its rules were based on those of the American Institute of Mining Engineers.\[549\] The Institute has been active in holding seminars and publishing information on current mining practices ever since then and has been very important in educating mining engineers and metallurgists.

**The Emerging Science of Electricity**

A series of scientific discoveries in the nineteenth century in Europe were important in the later development of mining technology in Australia. The industrial revolution was well underway when in 1800 Alessandro Volta, professor of physics at the University of Pavia, announced his invention of the electric battery. Within a few years Humphry Davy, at the Royal Institution in London, used the battery to isolate a series of new chemical elements, including sodium, potassium and the rare earth elements, and to invent the carbon arc lamp. In 1809 Professor Sommering demonstrated his electric telegraph at Kassel, using the battery as the source of energy.\[550\] Further improvements by S. C. Schweiger, Baron Schilling, J. Gauss and W. Weber C. von Steinheil led to a practical system of a battery-operated single wire earth return signalling system in 1838. The developing railway system in England required a fast means of communication along the lines. This was solved when W. Cooke and Professor C. Wheatstone of King’s College in London used Schilling’s ideas to develop a multiwire system by which pointers to 20 letters could be used to send messages along the line.\[551\] In 1843 Samuel Morse in the United States perfected a better system of signalling, using code of dots and dashes to send the signal along a single-wire earth return system to a manual recorder at the end of lines up to 200 miles long.\[552\] These basic principles were used to develop shaft signalling systems which were used in Australia from the late 1850s to control the movement of cages. The telegraph was further developed to the telephone by


\[551\] Ibid., pp. 250-2.

Graham Bell in the United States in 1873. Telephones were installed in several gold mines at Bendigo and Ballarat during 1880 for communication between the engine room and the underground levels. As considerable effort would have been required by overseas companies to make Bell’s invention suitable for use in a mine, this was a very rapid transfer of this technology to Australia.

Michael Faraday, Humphry’s successor at the Royal Institution, discovered the principle of magnetic induction in 1831 and this led almost immediately to the invention of the magneto by Hippolyte Pixii when he spun a permanent magnet close to a coil of wire. Further improvements resulted in the direct current generator and motor. Several firms including Thomas Edison in the United States and Joseph Swan in England developed direct current generators, motors and lighting systems from the early 1880s but the machines were bulky and required continual maintenance. Electric lighting was in use at the Ellenborough gold mine in Bendigo in October 1882, both on the surface and underground. The plant was installed by the Australian Electric Light Company and used both arc lamps and incandescent lamps made in England. The plant was driven by a three H.P. steam engine. Electric power for underground haulage was installed at the Great Southern No. 1 and the Chiltern Valley No. 2 deep lead mines in north eastern Victoria in 1900 and this use developed rapidly in succeeding years. Again this was a very rapid transfer of technology.

The final invention of major importance in the use of electrical energy was the system of three phase generators, motors and transformers by Nikola Tesla of Hungary who sold his patents to George Westinghouse, a United States industrialist who developed the inventions into a practical system of three phase long range high voltage energy transmission, using alternating generators, transformers and robust induction motors suitable for industrial use. The Hungarian firm of Ganz & Co. was active in Australia.

554 The Bendigo Advertiser, p. 2, 24 Jan., p.2, 30 Jan., and p.2, 7 Feb. 1880. Thomas Eyre, until recently the manager of the Catherine Reef United mine, was the Australian representative of Mather and Barker of England who supervised the installation.
556 Ibid., p. 350.
557 The Bendigo Advertiser, 3, 10 and 13 October 1882.
selling lighting plants from the mid 1880s and later three phase machinery. In 1888 the
Austral Otis Engineering Company of Melbourne became sole agents. They sold many
lighting plants to Australian mines.\footnote{E. F. Kunz, \textit{Blood and Gold} (Melbourne: F. W. Cheshire, 1969), pp. 131-4.} The Brush Electrical Machinery Company of
England was also a major supplier of three phase machinery.\footnote{D. Clark, \textit{Australian Mining and Metallurgy} (Melbourne: Critchley Parker, 1904), p. LXII.}

\section*{Conclusion}

Victoria was the largest gold producer of the Australian colonies in the last thirty years
of the nineteenth century. Because of the importance of the industry to the economy the
government actively supported the small mining companies. This was a continuation of
the practices commenced in the previous twenty years when the small miners greatly
influenced legislation through the Local Courts and then the Mining Boards. As has
been discussed this was a direct result of the granting of miners licences to individuals
during the first rushes of 1851, a legacy of Hargraves' skill in forcing changes British
mining law in Australia.

Victoria was the innovator in developing legislation for the mining industry because the
local courts, mining boards and election of miners to the Victorian Parliament gave the
miners direct access to the parliamentary process. As Victorian miners followed new
gold discoveries around Australia they carried these new concepts to other colonies
where they were able to influence the passing of similar mining legislation. The most
important ways in which the governments, led by Victoria, legislated to assist mining
were:

1. laws permitting the easy formation and liquidation of mining companies.
2. laws aimed at reducing the accident rates in mines and promoting the safety of
   miners, and supporting research into ways of reducing accidents in mines such
   as safety cages. Such research could not be financed by small companies
   because of inadequate technical resources or insufficient funds after the payment
   of dividends. As will be seen in Chapter 6 small mines cooperated in financing
   research into rockdrills and other machines not directly related to safety.
3. laws which increased government control over an increasing range of minerals
   on both crown land and private property, with the eventual result that all
   minerals belonged to the crown and mining for any mineral required a licence.
This widened the range of minerals which could be prospected for and mined by the individual miner.

4. In the later years of the period the Victorian government sought to reduce the competitive nature of the tributing system and provide a minimum wage for tributers. Unlike the legislation on mining on private property and the regulation of mines, this was seen by the owners and managers as a direct attack on their management of a mine and was successfully resisted by them. Tributing extended from the copper mines in South Australia in the 1840s to the gold mines in Victoria, and from there to the other colonies. It was still in use in Western Australia in the late 1930s.

Technical education for industry, which was first introduced in Victoria in 1870 and spread to other colonies, was one aspect in which colonial governments were lukewarm in providing funds to set up comprehensive training to meet developing needs. Although some courses were established in mining engineering and metallurgy in universities, the major developments came from the more far-sighted people working in the industry. The results were generally less successful than the development of technical education in Europe and the United States. This is not surprising as there was a similar failure to develop an adequate system of secondary education in Australia in this period. However trained men were produced for the mining industry, which was entering a period where developments in science began to impact strongly on mining technology. Because of the lack of adequate documentation from this period it is difficult to determine the numbers trained. This lack of a comprehensive plan by colonial governments for the development of technical education in the nineteenth century was not improved in the twentieth century and as will be shown in later chapters there is still no overall plan for education for the mining industry in Australia. It also had the unfortunate result that there were few trained technologists capable of transferring the new and more efficient methods of power generation by electricity, then being developed overseas, to Australian mining.

This will be detailed in following chapters together with innovative methods in the chemical extraction of minerals which became more important towards the end of this period including the extraction of gold by chlorination and cyaniding.
Chapter 6

Innovation in Ore Extraction Technologies 1870 – 1900

Introduction

Until the final years of the 1860s coal mining, copper mining and quartz gold mining in Australia followed relatively discrete technologies. Coal and copper miners used practices which had been developed in Europe over centuries and these were little changed in Australia up to this time. Gold mining had introduced new problems in the deep leads and narrow quartz veins found in eastern Australia, but these problems had been tackled and mainly solved by 1870. Scientists had discovered new minerals in the late eighteenth and first half of the nineteenth and as industry developed in the second half of the century so did the demand for a wider range of metals. This in turn led to the discovery in Australia of new types of orebodies such as alluvial and lode tin, and silver-lead-zinc. Mines had been sunk to depths of more than 600 feet in the 1860s but during the next thirty years reached much greater depths. This chapter will discuss the changes in shaft sinking technologies as the depth increased to mine ore at deeper levels, as well as the need to develop more efficient drilling techniques and explosives for extracting the harder rocks encountered at the deeper levels. New stoping techniques needed for the safe mining of the wider and more friable metalliferous orebodies will be examined. Mining at greater depths and the requirements of the mines inspection acts in coal, metalliferous and gold mines needed new approaches to mine ventilation and drainage and safe working practices with machinery. The introduction of new methods to meet these needs will be discussed.

Shaft sinking

The gold miners who pegged claims and leases in the 1850s and 1860s in the Lachlan Fold Belt in eastern Australia had little understanding of the geology of the reefs they were mining. Cornish practice had been to keep sinking if a reef thinned out or became barren in the expectation that further mineralisation would be found lower down. This had often worked in Cornwall but there the copper and tin mineralisation occurred in veins in granite batholiths or in metamorphosed sedimentary rocks adjacent to the
granite where quartz veins and dykes of quartz-porphyry were common. This practice of sinking deeper was followed in eastern Australia with success but the early miners did not know how deep they could follow the reef down and still extract gold economically. In order to keep initial expenses low they kept the shaft dimensions to a minimum cross-section to allow a single cage or two cages in balance and a compartment for a ladderway and pump column. Most shafts were sunk vertically, in the reef, with levels about one hundred feet apart to mine the ore. If the reef was at a small incline to the vertical, crosscuts were driven from the shaft to find the reef. On low pitching reefs inclined shafts were sometimes dug with cages running on rails. At Stawell horizontal reefs occasionally extended between near vertical reefs and at Bendigo the anticlinal saddle reefs, sometimes up to 100 feet across and 30 feet high, occurred one below the other with mineralisation following down the leg of the anticline, sometimes only a few inches thick. The quartz reefs in Gippsland were often found as flat horizontal bands in a near vertical granitic dyke, several feet wide, while at Ballarat the thin vertical reefs in sandstone often opened out as flat horizontal lenses where the quartz crossed a near vertical band of carbonaceous slate (called the indicator by the miners). Sinking the shaft and developing the levels was done by drilling holes with hand drills, charging the hole with gunpowder and firing with a safety fuse. Initial sinking of a shaft was by windlass or whim and surface facilities such as buildings were simple and cheap. As the shafts deepened the sinkers were protected from falling objects by a penthouse, a rough decking of slabs, which was built in the shaft below the lowest plat. Air winches on this plat raised the blasted rock through a trapdoor to the plat from where it was raised to the surface. An alternative was to use a rope below the cage to lift a bucket through the trapdoor and raise it to the surface, with signals to the winder driver on the surface.

In the 1870s the Stawell miners pushed their shafts deeper and kept finding gold as they went down. The Bendigo miners dug from one saddle reef down to the next (each being about 100 feet or more below the previous reef) but they neglected the narrower legs of

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564 Buildings were timber framed and clad with galvanized iron.

the anticline because money had to be spent developing the crosscuts to access them, the location and mineralization of the legs being initially unknown. By 1874 the deepest shafts in Australia were the Magdala (1408 feet), the Newington (1281 feet) and the South Scotchmans (1196 feet), all at Stawell. On other fields the deepest shafts were the New North Clunes (1012 feet), the Great Extended Hustlers at Bendigo (830 feet) and the Temperance at Ballarat (750 feet).566 By 1890 the deepest mine was Lansell’s 180 at Bendigo with a depth of 2640 feet, and there were nine others over 2000 feet in Victoria.567 Unfortunately almost no technical information has survived from the Victorian foundries of this period and how winding engines were strengthened to cope with the increasing depths is therefore unknown, but increasing drum diameter and length to hold more rope would have been an incremental process. When a drum failed due to crushing because of the additional weight of the ropes, the foundries would have increased the thickness of the flanges and the timber of the barrel of the drum. The design of winding engine drums must have been a problem in this period as round and flat manila hemp ropes were in use in shallower mines (particularly deep lead mines at Ballarat) and flat and round steel wire ropes gradually replaced hemp ropes and chains from the early 1870s.568 Both single drum and double drum winders were in use.569 Chains and ropes had first been introduced in Europe for winding in the 1840s and became common in Australian coal mines in the 1850s and gold mines in the 1870s.570

In the 1870s many mines increased the cross section of the shaft to cope with the increased depths. The Ellesmere at Bendigo was at 480 feet when rich reefs were discovered deeper in adjacent mines, so the company increased the shaft dimensions from five feet by three feet to nine feet by three feet six inches, with two cage compartments and one pump and ladder compartment to mine the deeper orebody.571 By the early 1880s the increasing depths of the shafts had resulted in the replacement of most horse driven whims by headframes about 60 feet high to the sheaves with steam

566 “Reports of Mining Surveyors and Registrars, Victoria,” (Melbourne: Mines Department), 2nd Quarter 1874.
567 Ibid., 3rd Quarter 1891.
568 The Bendigo Advertiser, 7 June 1879, p. 5. The Garden Gully mine had been using steel wire ropes for years. Flat steel wire rope of 2.5 inches by 0.5 inches, 1200 feet long cost about £300 while round wire rope from 0.75 inches to 1.25 inches diameter of the same length cost about £200. Rusting of the steel was a problem in wet shafts and they were coated with a mixture of tar and castor oil to keep rusting to a minimum. "Report of the Safety Mining Cages Board," in Papers Presented to Parliament, 1890, Vol. 2 (Melbourne: Parliament of Victoria, 1890), Appendix B.
569 The Bendigo Advertiser, 22 July 1881, p. 3.
570 The Mining Journal, Railway and Commercial Gazette: 12 February 1842.
571 The Bendigo Advertiser, 3 December 1879, p. 3.
driven winding engines.\footnote{Ibid., 22 July 1881} In 1881 George Lansell erected a very tall headframe at his 222 mine in Bendigo, 128 feet from the surface plat to the bearings of the headsheaves with the unloading plat at 80 feet. This was exceptionally high to allow for the ore trucks to be unloaded at the 80 foot plat, tipped into a hopper and loaded into trucks, which were wheeled along a tramway to the crushing battery on the side of a nearby hill.\footnote{Ibid., 20 July 1881. The headframe was the eastern Australian pattern with each leg being two lengths of stringy bark from the Bullerook forest near Ballarat, mortised and bound together with iron bands.}

After the initial development of these gold mines the ore broken from the reefs was hand sorted underground, the quartz containing the gold was hand loaded into small trucks, pushed on rails to the shaft and raised to the surface in cages for processing while the mullock was stacked in the stopes.\footnote{Brough Smyth, The Goldfields and Mineral Districts of Victoria, p. 297.} As the stopes were usually small and narrow the amount of ore to be raised up the shaft daily was small and cage speeds were slow.

Technology development on two tunnelling projects in the northern hemisphere in the 1860s had considerable influence on mining in eastern Australia. The first was the Hoosac railway tunnel west of Boston in the United States commenced in 1851; the second the Mont Cenis railway tunnel through the Alps between Italy and France, commenced in 1857 and financed by the Italian government, to connect the developing European rail system via shipping to the Suez Canal. Each was about 12 kilometres long.\footnote{Engineering, Vol. 6, 17 July 1868, p. 47. T. Sopwith, "The Actual State of the Works on the Mont Cenis Tunnel," The Institute of Civil Engineers XXIII (1863): p. 258.} Initially hand drilling and gunpowder was used in both tunnels and major efforts were made to develop faster methods. Machine drills and nitroglycerine explosives with electric firing were invented to meet these demands.

**Mechanical Extraction of Ores**

In 1861 Germain Sommeiller, the Italian engineer in charge at Mont Cenis, introduced a machine drill with a solid boring bar that was driven by compressed air. Ten machines were mounted on a trolley which was moved on rails to the face, ten holes were bored simultaneously to a depth of about one metre, the carriage was retracted, the holes charged and fired. Water sprays were directed at the face during boring to settle the
dust. At the Hoosac tunnel a practical machine drill was developed by Charles Burleigh in 1868, based on a very heavy compressed air percussion machine patented by Joseph Fowle. Simon Ingersoll later developed a lighter machine at this tunnel and patented it in 1871.

At the Paris Exhibition of 1867 MM. de la Roche, Today and Peres exhibited a rockborer driven by compressed air which incorporated a hollow cylindrical bit tipped with eight diamonds, designed by M. Leschot and tested at Mont Cenis, which could extract a continuous core of the rock as the hole was bored. The hole could then be charged with gunpowder and fired.

The news of the Mont Cenis Tunnel and the Suez Canal developments attracted much interest in Australia. In 1866 the St. Arnaud Mercury reprinted an article from The Bendigo Independent deploiring the fact that such drilling machines were not in use in Australia. Soon after the Mt. Tarrengower Tunnelling Company, which was digging a tunnel through Mt. Tarrengower at Maldon in search of reefs at depth, sent a man to Great Britain to investigate the use of a machine drill to speed the rate of tunnelling. He returned the next year with drills and a compressor, produced in Ipswich, Scotland, by George Low. The company failed to find any productive reefs and was liquidated.

In February 1867 Robert Ford of Bendigo applied successfully for a Victorian patent for a rockdrill driven by compressed air. Vivian’s Foundry, at Castlemaine, manufactured this machine which was demonstrated before a group of mine managers and owners from Castlemaine, Bendigo and Maldon in April 1868. As the mines had a small capital base and paid most profits as dividends they were not prepared to spend money on independent research but some mines were prepared to fund co-operative research with others. A public meeting was held in Bendigo to raise funds to purchase a compressor and rockdrill, for testing. The money was raised from several companies and a machine was trialled at the Hustlers Reef Gold Mine in November. The trial was

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579 Ibid., 4 October 1867, p. 239.
580 St. Arnaud Mercury, 21 July 1866.
581 “Reports of Mining Surveyors and Registrars, Victoria,” First Quarter 1867.
583 Victorian Patent 989 and 989a of 22 February 1867 and 1197 and 1197a of 11 December 1868.
successful, the manager James Millin estimating the drilling time was reduced to 60 percent of that for hand drilling.\textsuperscript{584} The source of Ford’s design is unknown; the patent drawings do not appear to be similar to an overseas design. However his air compressor was a direct copy of the one imported by the Mt. Tarrangower company, made by Low, which itself was a copy of a machine used at Mont Cenis.\textsuperscript{585} The Victorian Mines Department began publishing statistics on rock drill usage in 1869 and reported that six machines were in use in mines, three of Ford, one of Low, a Hunt of unknown origin and a sixth of unidentified make.\textsuperscript{586} In 1876 John Mitchell patented an improved drill which was manufactured by the Harkness foundry in Bendigo.\textsuperscript{587}

Although a few mines in Victoria had investigated the use of percussive rock drills in the late 1860s and a suitable locally manufactured machine was available, the uptake of the technology was slow. George Lansell, who was becoming the dominant figure in mining in Bendigo, went on a world tour in 1876 during which he visited California and observed that mining companies there were developing new techniques in the use of percussion rock drills.\textsuperscript{588} On his return he imported an Ingersoll percussion drill for testing.\textsuperscript{589} He also convinced the Council of the Bendigo School of Mines to raise two thirds of the cost of sending a delegate to the western United States to report on these developments if he supplied one third. Again the mining industry used co-operative research and the money needed was raised by public subscription. Gustav Thureau, then a lecturer in practical mining at the school, was chosen from 19 applicants on the basis of an article he wrote about the mines at Clunes and Stawell. He left Victoria in March 1877.\textsuperscript{590} On his return after five months he wrote a comprehensive report, a synopsis of which was belatedly published by the Mines Department. This synopsis contains details

\textsuperscript{584} The Bendigo Advertiser, 4 April, 30 May, 5 October 1868, Mount Alexander Mail, 6 November 1868.
\textsuperscript{585} Engineering, vol. 1, 2 February, p. 120, 20 April, 1866, p. 254, vol. 13, 9 February 1872, p. 86. Ford was an English blacksmith who migrated to Victoria in 1854, was employed by the Victorian Railways Dept. in 1860 and had been promoted to engineer for construction by the time his drill was tested. The Dept. allowed his private practice. He would have worked on the railway tunnels at Castlemaine and Big Hill. A comparison of the machine shown in the patent and later machines indicate Ford reduced the weight considerably as experience was gained.
\textsuperscript{586} “Reports of Mining Surveyors and Registrars, Victoria,” Fourth Quarter 1869.
\textsuperscript{587} Victorian Patent No. 2587 of 1876.
\textsuperscript{588} G Thureau, Synopsis of a Report on Mining (Melbourne: Government Printer, 1878), p. 3.
\textsuperscript{589} “Reports of Mining Surveyors and Registrars, Victoria,” 2nd Quarter 1877.
\textsuperscript{590} Thureau, Synopsis of a Report on Mining, p.3, 18-19. See also R. Vollmer, “From the Harz Mountains to Adelaide: Government Sponsored Emigration 1848-54,” (University of Osnabruck: 1993), p. 30. Gustav and his brother Julius were technician level graduates of the Clausthal BergAkademie. They arrived in Adelaide on the George Washington in 1849. A copy of this manuscript is held by the German Heritage Society in Bendigo.
of comparative tests between Ingersoll and National rockdrills, air compressors, diamond drills and a wide range of mining machinery in use in California and Nevada at that time. The report is discussed in detail in the Appendix.

However some development occurred when the Rocky Mountain Extended Gold Sluicing Company acquired and consolidated alluvial gold mining leases at Beechworth but could not exploit the lower washdirt because a granite intrusion blocked the drainage. The company dug a tunnel which discharged into a gorge, through the hard granite below the town. The tunnel was commenced in June 1876; five Ford drills and associated compressors were purchased to drive 2600 feet through hard granite. An average rate of advance of 63 feet a month was achieved to complete the tunnel in 1879, a result that impressed the mining community. Three Ford drills were used to drive a tunnel 865 feet long in 75 weeks for the Stawell Waterworks Trust without difficulty.

Also by the late 1870s the Bendigo and Stawell miners had a better understanding of the nature of their respective reefs and wished to drive long exploratory drives from the shaft, often in hard sandstone, seeking the legs of saddle reefs and spurs respectively and they needed to reduce the costs of these explorations.

These developments - Lansell’s conversion to rockdrills; Thureau’s report and his advocacy of rockdrills; the success and low cost of driving the Rocky Mountain and Stawell tunnels; the need for low cost exploratory drives and the knowledge of the few managers who had used Ford drills - all focussed the attention of mine managers and directors on the need to adopt the new technology. The number of machines on Bendigo jumped from two in 1877 to 103 in 1884. The Stawell miners ordered National air compressors and seven National rockdrills on Thureau’s recommendation and by 1884, 31 drills were in use there. The National air compressor was more advanced than Ford’s machine in that it used water jackets around the cylinders for cooling rather than water inside the cylinders, a modification that improved the efficiency considerably.

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591 Thureau, Synopsis of a Report on Mining. See also G. Blainey, The Rush That Never Ended (Carlton: Melbourne University Press, 1963), p. 78. Blainey said few miners read the report and implied it had little effect. However a reading of mining articles in The Bendigo Advertiser between 1878 and 1880 gives a different picture. Thureau had been appointed the Australian agent for National drills and compressors and he was constantly reported commenting on the merits and costs of importing the drills. He certainly influenced the Stawell miners to buy these drills.
592 “Reports of Mining Surveyors and Registrars, Victoria,” 1879 passim.
594 “Reports of Mining Surveyors and Registrars, Victoria,” 1879 passim.
numbers of drills in use around Castlemaine and Maryborough were 10 and 11 respectively in 1884 and five were then in use at Clunes. The Ballarat mines were not large users of rockdrills in the nineteenth century, apparently because of the softer rock there.

By 1891 217 drills were reported in use in Victoria.596 Bendigo, Stawell and Maldon became centres for the manufacture of machine drills. Naylor and Thornton made both a light machine for stoping and a heavy machine for shaft sinking at Stawell from the early 1880s. Oswald, the owner of the North British mine at Maldon, developed a well regarded drill in the 1880s and this machine was still being sold in 1918.597 Taylor Horsfield, who had been a foreman at Robert’s foundry in Bendigo, started his own foundry where he manufactured air compressors and rockdrills as well as agricultural machinery.598 His rockdrill was said to be the best available in Australia by a Western Australian mine manager in 1908.599 Henry Hancock purchased the first rockdrill for the Moonta mine in 1879, a British Darlington machine and imported a diamond drill from the United States.600 From the 1870s rockdrills of overseas manufacture were imported and were competitive with locally made machines. Four English-made Burleigh machines were on the Adelong goldfield in 1880 and three Ford machines were in use at the Great Cobar Copper Mine in the same year.601 During the 1880s machine drills replaced hand drilling and dynamite type explosives, fired by electricity, replaced gunpowder in most mines in Australia.602

Gunpowder was probably invented by the Chinese and used in fireworks in the tenth century. It was later used by the Arabs and Europeans in war machines and by 1627 was in use at Schemnitz in Hungary for breaking rocks in mines.603 As discussed earlier

596 “Reports of Mining Surveyors and Registrars, Victoria,” 1879-91 passim.
597 Victorian Patent No. 2587 of 1876. Reports to the Minister of Mines, Victoria, (Melbourne: Mines Department Victoria), 1885. Mine Managers Reports, Oswald Mine, 1918
598 T. Horsfield, Rockdrill and Air Compressor Catalogue (Bendigo: 1912).
601 Reports to Minister of Mines, New South Wales, (Sydney: Government Printer), 1880.
602 Report of the Royal Commission on Mining, (Melbourne: Government Printer, 1891). The evidence shows a few managers were still using black powder in 1890 and were not convinced of the economies of dynamite.
603 Encyclopaedia Britannica, 15th ed., 1974, vol. 7, p. 83. Because of the dangers of storing gunpowder the Victorian government built 59 powder magazines at ports of entry, military depots and on the larger goldfields, the first in Melbourne in 1847. Other colonies placed the responsibility of storing powder
gunpowder was used at Newcastle for shaft sinking in 1815 and was in use in Victorian gold mines in 1854. Nitroglycerine was invented in Paris in 1847 by Asconio Sobrero.

It was too unstable for general use but in 1866 Alfred Nobel mixed nitroglycerine with kieselguhr, a naturally occurring diatomaceous mineral, to form a stable explosive which he called dynamite. It had twice the explosive force of gunpowder and could be used in deeper drill holes to fracture more rock with one firing. The percussive rock drill and dynamite were complementary as the drill enabled holes several feet deep to be dug in one shift and these deeper holes required a stronger explosive than gunpowder to shatter the rocks.

Nobel also invented the blasting cap or detonator in 1865 by placing small amount of mercury fulminate, an explosive compound, in a small copper tube and combining it with a safety fuse. The tube was placed in the gelatine, inserted in the drill hole and fired. It was soon adapted for firing by an electric current. He made further improvement to dynamite by mixing the nitroglycerine with guncotton in 1875 to produce gelatine dynamite. An alternative high explosive was invented by Hermann Sprengel in England in 1871 by mixing potassium chlorate with a combustible material such as benzene. Both materials were relatively inert, and were transported separately and mixed just before firing. The ingredients were sold commercially as rack-a-rock.

Australian miners were slow in adopting dynamite explosives. By 1873 the Australian Lithofracture Company was manufacturing lithofracture, the local version of Nobel’s 1866 invention, but a survey conducted in 1882 showed a large majority thought the fumes from dynamite injurious. But that time many were using it in wet ground where it was superior to gunpowder. Even in 1890 some miners were using gelignite for shaft

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604 Anon, Annals of Bendigo (Bendigo: 1854), p. 27.
605 Encyclopaedia Britannica, vol. 17, p. 84. The safety fuse was invented by William Bickford in 1831 in Cornwall for use with gunpowder. It was made by rolling a core of powder in jute yarn and waterproofing it with asphalt.
606 Ibid, p. 84.
607 Ibid, p. 86. The modern version is ammonial, produced by mixing ammonium nitrate and fuel oil. It has entirely replaced gelatins in mining on safety grounds as the components are mixed, charged into the hole and fired.
608 The Bendigo Advertiser, 31 August 1875, 4 October 1882.
sinking and gunpowder for blasting ore in the stopes.\textsuperscript{609} This appears to be personal prejudice but the reason may have been that the locally manufactured gunpowder was cheaper than the imported gelignite.

This apparent slow adoption of the percussive rock drill and dynamite explosive in Australia has been criticised but the United States and British experience was very similar.\textsuperscript{610} Burt considers that their use was still limited in the eastern United States and England until 1883 and they were not widely used in the western United States until the late 1880s. They were already widely distributed in Australia by the mid 1880s, so it appears this criticism is unwarranted.\textsuperscript{611}

While the percussion rock drill was developed for drilling holes of one to two inches in diameter, to depths of several feet, for filling with explosive to blast the rock, the diamond drill was found to be better for geological exploration. Leschot’s invention of the diamond drill bit in 1867 (mentioned above) was initially used in England and the United States for drilling holes for blasting ore and shaft sinking.\textsuperscript{612} However by the mid 1870s percussion drills were seen to be more efficient for drilling holes of short depth for blasting and the best use of the diamond drill was for holes of hundreds of feet, for prospecting the geology of the ground penetrated. As miners at Stawell and Bendigo began to understand the geology of their fields and continued to find economic grades at depth, the small claim and lease sizes forced them into deeper sinking which required a better knowledge of the orebody so shafts were not sunk until the ground below was investigated by diamond drills and it was known that deeper quartz orebodies existed.

The Victorian Mines Department and the government were now prepared to become involved in co-operative research to explore for new orebodies, as it was realised that deep mining was crucial to the continuation of the industry. The department imported

\textsuperscript{609} Report of the Royal Commission on Mining. See comments on explosives by various witnesses in the evidence (refer to index).

\textsuperscript{610} Blainey, \textit{The Rush That Never Ended}, p. 78. Blainey wrote that after Thureau returned in 1877 the miners learned how backward the Australian mines were but this statement is not supported by the evidence available elsewhere. Thureau was appointed Australian agent for National drills and had a vested interest in criticising Victorian practice.


four steam driven diamond drills from the United States for prospecting from the surface for deep leads and coal seams in Gippsland, and one compressed air machine for boring for quartz reefs from the lower levels of quartz mines in 1878.613 Tenders were then called for the local manufacture of another six surface machines and four for underground.614 Henry Hancock ordered two drills from the United States in 1880.615 At Stawell, where the near vertical reefs were more or less continuous the Magdala shaft was at 2333 feet early in 1880 while at Bendigo, where the anticlinal reefs repeated at increasing depths, but at unknown distances apart, Lansell’s 180 shaft was the deepest at 1478 feet.616 Various companies on both fields and elsewhere hired the government diamond drill rigs and sank drill holes from the lower levels, others imported their own rigs and some bought rigs made by Australian foundries.617 Managers at Stawell and Bendigo competed to sink the deepest shaft; in 1885 the Magdala was stalled at 2409 feet with Lansell’s 180 not far behind at 2041 feet.618 The Magdala did not find payable ore at that depth and the company was wound up and taken over by the Moonlight Company.619 The Bendigo companies kept sinking; late in 1889 Lansell’s 180 was at 2640 feet and there were seven other Bendigo mines deeper than 2000 feet.620 The emphasis was on sinking to find anticlinal reefs and the companies did little to explore the synclines even though gold was mined in some synclinal reefs that were found by accident.621

By the end of the nineteenth century experience had shown that diamond drilling to explore for deep lead alluvial systems below hard basalt was cost effective compared with hand boring, that diamond drilling to locate seams of coal was effective but not necessarily the cheapest in softer ground, while diamond drilling in Victorian gold mines was effective in locating the position of quartz reefs. It was necessary to drive to

613 Black coal deposits had been found at Cape Patterson in south Gippsland in the 1850s but the deposits near the surface were thin and fractured by faults. It was hoped that thicker seams would be found at depth.
614 Reports to the Minister of Mines, Victoria, 1885, p. 1. It is not certain what influence Thureau had on the purchase of these machines.
615 Robinson, Cap’n Hancock, p. 110.
616 “Reports of Mining Surveyors and Registrars, Victoria,” First Quarter 1880.
617 The Bendigo Advertiser, 13 August 1878, 12 December 1881. Fultons Foundry in Melbourne was selling diamond drill rig under licence from the Australian Drilling Company and in 1881 Morts Dock and Engineering of Sydney was selling a locally made diamond drill rig.
618 “Reports of Mining Surveyors and Registrars, Victoria,” First Quarter 1885.
619 Ibid., Third Quarter 1888.
620 Ibid., Third Quarter 1889.
the reef and determine the gold content by sampling. Assessing the cores for gold did not give a true picture where the gold was shotty. However, as will be discussed later, use of the diamond drill was by then widespread on the southern end of the Kalgoorlie field to indicate the width of the lode and the grade as the ore there contained fine gold distributed throughout the ore. The development of the calyx drill in Australia by Francis Davis in the 1890s provided a cheaper alternative to the diamond drill. Other colonial mines departments purchased diamond drills and hired them for exploration. The real value of the diamond drill became apparent towards the end of the nineteenth century when it was used to locate and delineate metalliferous orebodies which did not outcrop at the surface. Determining the depth and boundaries of the orebody, together with a knowledge of the grade of the ore from the cores, enabled the expected mine life and mineral content of the orebody to be evaluated before any expenditure was undertaken on development of the mine.

New Technologies in Metalliferous and Coal Mines

While the gold miners in eastern Australia were developing new technologies for mining narrow vein orebodies at depth, miners in other colonies were developing new methods for mining the sulphide ores of other types of minerals from below the water line.

The managers of the copper mines at Kapunda and Burra had followed Cornish methods of extraction of the ore, timbering where necessary to support the roof and walls of the stopes and the processing of the mostly high grade oxidised ores. The discovery of large, high grade metalliferous orebodies at Wallaroo and Moonta in South Australia

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622 S. Hunter, *The Deep Leads of Victoria, Memoirs of the Geological Survey of Victoria. No. 7.* (Melbourne: Victorian Department of Mines, 1909), p. 43. Diamond drill boring was used in many valleys in Victoria and elsewhere to determine the contour of the bedrock and roughly determine the position of the lead. Closely spaced bores were then used to plot the boundaries and the main shaft was sunk so it was in solid rock to avoid the problems of sinking through wet sand. The bottom level could then be driven under the wash which could be drained before attempting to mine the washdirt.


625 S Hunter, "Diamond Drill, Calyx and Hand Boring," pp. 46-7, 59. The cost of boring for deep leads covered with basalt was from 7s. 6p. to 12 s. per foot and boring the coal measures in Gippsland with the calyx drill cost 5s. per foot down to 1000 feet.


and Peak Downs in Queensland in the 1860s, and at Cobar in 1871 and Broken Hill in 1883 (both in New South Wales), required new technologies. The quartz reefs of the gold mines of eastern Australia were generally a few inches to a few feet wide and sometimes blowing out to 30 feet deep and 100 feet wide in anticlinal reefs. The hanging and footwalls of the stopes were generally strong and well defined, and weak sections could be supported by individual props or by pig stydes of stacked timber until the empty stopes could be backfilled with waste. In the bord and pillar coal mines operating in Australia the roof was seldom more than 20 feet above the floor and was supported by leaving pillars of coal and using timber props where necessary in the wide roadways. Both pillars and timbers were later removed and the roof allowed to collapse.

The orebodies of metalliferous mines were often wide (occasionally up to hundreds of feet wide) and extended downwards, from sloping to near-vertical for hundreds and sometimes thousands of feet. The hanging and footwalls were often not clearly defined but graded into country rock so continuous sampling and analysis of the ore was required to avoid extracting material of too low grade to be economical. In the oxidised zone the ore was often very friable and soft and as soon as stoping began the walls pressed in on the ore remaining, leading to ground creep and damage to the surface plant erected near the shafts.

The copper lodes at Cobar will be discussed as an example of lodes of medium width in metalliferous orebodies mined after 1870. At the Great Cobar Copper Mine the walls of slate were strong, the ore itself was strong and occurred in bunches up to 70 feet wide with country rock in between. The bunches were from 200 to 300 feet long and continued to depth. When a level was started in ore from the shaft it was advanced to leave a pillar ten feet long. A face of the ore was opened across the orebody, from wall to wall, and stoping commenced by working away the ground forward and upward to a height of 20 feet or so above the level. A leading cut was carried along from the level upwards and the whole face of the stope was worked from the cut so the ore rolled to the level, where it was loaded by hand to trucks and pushed on rails to the shaft. Overhand stoping was used but the local timber, Lachlan pine, was not suitable for

stulls or sets so it was built up as continuous pig-styes which were filled with clay or mullock brought into the stope by mullock passes. The level was timbered over within the pig-styes to leave access to the working face. When the stope had been extended the length of the bunch, the pig-styes were built upwards and filled with mullock to within a few feet of the back of the stope to form a flat surface from which the miners could start the next slice, the broken ore was scraped into orepasses left within the pig-styes, from where it was loaded into the trucks on the level. This excavation was about 12 feet high, the stope was advanced and the filling process repeated. The diagrams in Appendix 5 illustrate the method. Similar stoping methods were in use at the copper mines at Moonta in South Australia and elsewhere from the 1860s, so the Cobar developments were probably based on Cornish practice but adapted to suit local conditions.

While this method of extracting copper ores was being developed, other methods were being tried in lode tin deposits. James Smith discovered stream tin (tin oxide) in north-west Tasmania on 1 December 1871 and the following day traced the source to porphyry dykes in a granite outcrop on Mt. Bischoff. In 1873 he sold the mine to the Mt. Bischoff Tin Mining Company of Launceston, a limited liability company with local capital, for £1500 and 37 percent of the shares. Ferdinand Kayser was appointed manager of the mine in 1875 and after considerable discussion with the Directors convinced them to instal adequate machinery and work the mine as a long term investment. Several quarries were opened on the side of Mt. Bischoff, the miners worked on the face, the broken ore rolled to the bottom and was loaded into trucks and carried to the treatment plant a mile away. The ore was a mixture of tin oxide (averaging 2.75 percent) and iron pyrites. In softer ground a miner could dig out 12 tons per day but in the harder ground four tons per day was average. Other deposits of stream tin in Tasmania, northern New South Wales and Queensland were worked by sluicing along the valleys of creeks and rivers and by deep lead mining methods when

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632 “Mount Bischoff,” Australian Mining Standard, no. 1 July (1898): p. 42. There was increasing demand at this time for tin to make tin plate for cans in which to preserve meat, fruit and vegetables. Kayser had trained in Germany.  
buried by basalt flows. The discovery of more complex and very wide silver lead and zinc orebodies at Broken Hill in 1883 required different methods to extract the soft oxidised silver lead ores above the waterline, and further changes again as the stronger silver lead zinc sulphide ores were mined below the waterline. Near the surface overhand and underhand stopes were dug with picks, generally without filling and relying on stulls to hold the walls and backs. Locally grown mulga or red gum from the Darling River was used but this method was soon found to be unsuitable for the wider friable oxidised ore bodies as the depth increased. The major mine at the time was the Broken Hill Proprietary Company, which had been registered in Victoria in 1885 as a limited liability company with Australian capital, with its directors predominately from the pastoral industry. They sought to solve their lack of mining knowledge by employing Americans H.H. Schlapp as chief of smelting and W. H. Patten as manager in 1887. This was a reversion to the managerial system of the British mining companies of the 1840s where the company employed expert mining engineers to manage the mine.

Patton was paid an annual salary of £4000 per annum, compared with a salary of around £300 per annum for a mine manager at Bendigo at that time. He had had experience in similar orebodies in the western United States and brought with him miners experienced in square set timbering, an interlocking system of sawn oregon timbers which fitted together in a three dimensional lattice to support both the walls and the back. The next year the system was in use at the Block 14, British Broken Hill and Block 10 mines (which had been floated off as separate companies with Australian and British capital), on several of the original leases that had been pegged on the hill by Rasp and his friends. When the stopes reached the level above, the square sets were extended to the upper level. Filling was not used as it was believed the lattice would withstand the pressure but by 1890 severe ground creep was experienced at the British mine above the 200 foot level and the friction generated as the timber moved caused

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fires underground from 1895.\textsuperscript{638} John Howell, also from the United States, replaced Patton in 1890 and began mining the outcrop in the B.H.P. ground by open cut to relieve the pressure on the upper levels. Howell was replaced in turn in 1894 by Alec Stewart, who had open cut experience on a large scale at the Tharsis copper mine in Spain.\textsuperscript{639} Between 1890 and 1905 some 1.4 million tons of oxidised ore was removed as well as mullock which was used for underground filling of the square set system to reduce creep.\textsuperscript{640}

The directors of the B.H.P. Co. realised that more efficient methods of mining the orebody were necessary and in 1899 appointed a new manager, Guillaume Delprat, a Dutchman with mining experience in Spain and elsewhere on the basis of a paper he had published in 1893 on the extraction of ores from wide veins in copper mines in Spain and Portugal.\textsuperscript{641} Delprat implemented what he called the ‘Crosscut’ system in 1903, outside the period being covered in this chapter but it is sensible to discuss it now. Delprat’s method was to develop a level by a longitudinal drive, central to the walls of the orebody for its entire length and timbered. At each 60 feet along this drive, crosscuts were driven at right angles to both the footwall and the hanging wall and timbered. Timbered ore chutes and ladderways, offset to the crosscut were raised from the central drive and vertical connections for filling purposes were raised to the level above. All crosscuts were then timbered, paddocked and filled with mullock. The timbering differed from square sets in that the legs were smaller in cross-section and tapered and a corbel was placed under the cap piece and the cross pieces rested on top of the caps to receive the top lagging. This allowed most of the timber to be withdrawn before the stope above was excavated. It was hoped this would reduce the number of underground fires by leaving a minimum of timber in the filled stopes. Stoping operations were conducted from each side of each crosscut to both walls to excavate a strip eight feet wide to the height of the crosscut, timbered, paddocked and filled. This was repeated until the whole floor had been stoped and filled. The mining of the second floor was then commenced similarly and as each crosscut was excavated the timber in the first floor was withdrawn and used again. The ore from this floor was passed down the

\begin{itemize}
\item \textsuperscript{638} Ibid.: p. 213.
\item \textsuperscript{639} L. S. Curtis, The History of Broken Hill (Adelaide: Fearsons Printing house, 1908), p. 16.
\item \textsuperscript{641} G. D. Delprat, "Extraction of Ore from Wide Veins or Masses," American Institute of Mining Engineers XVI (1893): pp. 89-101.
\end{itemize}
chutes to the level as before. The system was very safe but high cost. While the friable upper levels were being mined in this way underground development opened up the deeper sulphide ore body which was stronger and could be mined by open stoping with flat backs and filling close to the back and face. Pig-styres were used where necessary to support any weak backs.

While these developments were taking place in metalliferous mines most coal mines in Australia made no advances in the introduction of mechanisation for coal extraction. Both miners and managements resisted overseas developments, the miners because they feared reduced employment, and the managements because they considered the capital costs of machines would not be economical in the bord and pillar system in use in their mines. The introduction of new coal mining technology came from an unexpected quarter. Shale deposits containing oil were known to exist in New South Wales for many years but it was not until the Australian Kerosene Oil and Mineral Company Limited was registered in Sydney in October 1878, with a capital of £50,000 in 5000 shares of £10, each that mining on a commercial scale began at Joadja Creek in the Blue Mountains south west of Sydney. The deposits mined were about two feet thick and were interbedded with thin coal seams which were mined to provide coal to heat the retorts used to distil the oil. Alexander Russell was recruited in Scotland as a foreman for the mine as shale oil mines were already producing in that country. Scottish companies were using the long wall system of mining in which the seam was extracted along a face of several hundred feet. As the face moved forward the pit props were extracted and the roof allowed to collapse. This type of mining suited coal cutting machines which undercut the coal or shale layer in a slot of three feet or so, and the coal or shale above the slot was picked down. At Russell’s suggestion a Gartsherrie coal cutter was imported for use in the mine in 1880 and the long wall system was used. This was the first use of coal cutting machinery in Australia. It preceded the use of

644 L. Knapman, Joadja Creek (Sydney: Hale and Iremonger, 1998), p. 32-5.
645 Ibid., pp. 32-3.
647 Knapman, Joadja Creek, p. 36.
similar machines in the Hunter Valley coal mines by more than 20 years (see chapter 8).  

While these developments in the use of machinery in hard rock mining were occurring there was one significant development in mechanising alluvial sluicing practices. This was a transfer of United States technology for high pressure sluicing and New Zealand technology for dredging with barges. This development took place at Yackandandah in the north east of Victoria where sluicing had been common since the early 1850s. In 1887 John Wallace, a mining investor and his foreman John Hedley, began to use the monitor, a high pressure water gun, which had been developed in California in the 1850s for sluicing down banks of alluvial gold deposits. Although there is evidence the monitor was tried in Victoria earlier than 1887 it was not common, probably because the terrain there was not suitable for the construction of high flumes to give the necessary water pressure. Hedley used a steam-driven centrifugal pump to provide water at a high pressure for a monitor to wash alluvial ground into a sump, from where the slurry was pumped by a steam-driven gravel pump to a higher level and then run through a box sluice to extract the free gold. The gravel pump was carried on a barge, which normally sat on the ground at the bottom of the sump, but when required the sump could be filled with water and the barge floated to another location closer to the working area. Gravel pumps were made with very robust impellers to withstand the wear of pumping gravel and stones. The experiments were completed successfully by 1892 and the design was copied elsewhere in Australia for gold and tin recovery. It was called ‘hydraulic dredging’ but it is better called ‘hydraulic sluicing and pumping’.

**The Impact of Mines Inspection Legislation**

Following the passing of the act for the regulation and Inspection of Mines in Victoria in 1873, discussed in Chapter 5, R. Brough-Smyth, the secretary of the Mines Department, was appointed chief inspector and William Grainger and Henry Nicholas, both experienced mine managers, were given temporary appointments to investigate and report immediate problems. Conferences were held at various mining towns to advise

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649 Reports to the Minister of Mines, Victoria. See Report on Dredge Mining.
650 Reports of Mining Surveyors, Victoria. See Ballarat report of 18 August 1859 of sluicing at Humbug Hill and Beechworth report of 19 September 1859 of sluicing at Snake Gully.
owners, managers and miners on the requirements of the act. Two mines surveyors were appointed to check that all boilers were being inspected regularly.\textsuperscript{652} All serious accidents had to be reported immediately and the cause of each was investigated by the inspector and a report on the cause published.\textsuperscript{653} Additional inspectors were appointed and they worked with mine managers to ensure more adequate timbering was used to reduce rock falls underground which was a major cause of deaths. The overall yearly accident rate fell from 1.93 to 1.08 per 1000 miners by 1878 (comparable to overseas rates) and attention was then turned to accidents in shafts involving cages and ropes. A Board of Enquiry on Safety Mining Cages was set up in May 1878 to ‘examine the several inventions for safety cages brought under the notice of the Mining Department and to report as to those which appeared the most effective for the purpose intended.’ In its report the Board noted that for years eminent engineers in Great Britain, Europe and America had endeavoured to reduce the dangers inherent in ascending and descending the shaft, and that with increasing depths of mines the liability to accidents had increased. They concluded that human ingenuity had failed to produce a device which gave complete immunity from accident.\textsuperscript{654}

After wide consultation in the mining industry the Board advised there was a need for a safety cage, that many in use were defective, and that tests had been conducted on six types of safety devices. Additional tests were carried out during 1879 at Bendigo by inspectors under the supervision of the Board, and a final report in December recommended the use of the safest devices and implied the less safe types should not be used.\textsuperscript{655} The choice was left to the mine management, but this was a bad decision and few improvements were made.

That the problems had not been solved was shown ten years later when the Board was re-established but with different membership and under the chairmanship of an experienced mines inspector. The Board was given the additional task of reporting on a uniform code of signals for all mines in Victoria. The terms were more specific in that the Board was to investigate the relative merits of different patterns of safety mining

\textsuperscript{652} Report by the Inspector of Mines, Victoria, 1874.
\textsuperscript{653} Ibid., p. 10. In 1874 with 46,500 miners working the death rate was 90 or 1.93 per thousand compared with a rate of 1.3 to 1.5 in mines in overseas countries.
This Board held 65 sittings and examined and tested safety cages on 29 goldfields in Victoria. Much more rigorous tests were conducted. Tests were made by freeing the rope from the cage at the surface and at some distance down the shaft and checking whether the safety grippers operated when the cage was empty, when it contained an empty truck, and then when it contained a full truck. Tests were also conducted on safety hooks which released the cage if an overwind occurred at the top of the headframe. The Board reported that safety cages made by four manufacturers were safe, four others would act in favourable circumstances and that the other cages tested were unreliable and should not be used. A uniform code of signals to be used on all mines in Victoria, was also recommended for communicating with the winder driver from the various levels in the mine. The recommendations were included in regulations and implemented by the inspectors.

However a variation of this industrial health and safety theme occurred in 1876 when the coal mines’ regulation and inspection act in New South Wales had an immediate effect at the coal mine of the Australian Agricultural Company. The new ventilation requirement, for 100 cubic feet per minute at a working face for each man or horse employed underground, had to be implemented. In practice any mine not reaching this standard was given time to implement the changes necessary. James Winship, who had earlier resisted the introduction of fans when this was suggested from London, because he said he knew nothing of the new technology, retired as manager in January 1876. He was replaced by William Turnbull, who had had British experience in meeting new regulations for improved ventilation as concern rose over the high rates of respiratory diseases in British mines. In March, Turnbull submitted a report and recommendations to Jesse Gregson, the Superintendent, saying the existing furnace-assisted ventilation would not meet the new requirement and recommending the installation of a fan on the basis of his British experience. A Guibal fan, of Belgian design and English manufacture, was imported and installed at the top of the D Pit, tested at various speeds.

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658 Ibid., pp. vii-ix.
659 Australian Agricultural Company, Colliery Correspondence File 1/86/7. Letter W. Turnbull to J. Gregson, 14 March 1876. The estimated cost of repairing the furnace was £612, the annual cost of the furnace was £1528, the installation cost of fan and engine was £3109 but the annual cost was £212. Turnbull said Winship had costed small coal used in furnaces as 2s. 6p. per ton but he Turnbull was selling it for 7s. 6p. per ton and used that price for costing.
and found adequate for the 600 men, boys and horses employed underground. As far as can be determined this was the first exhaust fan installed in a mine in Australia. It was 30 feet diameter and 10 feet wide.660 In 1880 Turnbull installed small fans underground, driven by compressed air, with ducts to carry the air to miners in isolated areas.661 These developments copied British technology. By 1900 the following fans had been installed in New South Wales collieries: 6 Guibal; 9 Schiele (a smaller faster version of the Guibal); 5 Waddle and 5 Walker, the latter two being of different design. Four collieries were still using furnace-assisted ventilation in 1900.662

The ventilation problems of the deep quartz mines in Victoria were different to the coal mines, which generally had extensive workings at shallow depths between the downcast main shaft and upcast airshaft, which were usually some distance apart. The quartz mines were located on small leases on which there was often only one shaft to depths of 2000 feet or more in the late 1880s. Where more than one shaft was dug, the two could be connected at the lower levels to produce natural ventilation, with one shaft as downcast and the other as upcast. When the Port Phillip mine at Clunes reached a depth of 1800 feet in 1878 the ventilation was poor at the lower levels and a Root’s blower was installed at the surface on one shaft to force air underground, where brattices directed the air to the working drives and stopes before it was exhausted to the surface up another shaft.663 Where only a single shaft was available a solution was found by connecting the drives on adjacent leases by agreement, sometimes pressed by the mines inspectors, so both downcast and upcast shafts were available. Very deep isolated shafts were a problem not easily solved. Where a shaft had been closely timbered from the surface, air could be driven down one or more compartments by Root’s blowers, the lower levels brarticled to direct the air to the stopes, and then returned up the remaining compartments of the shaft. Alternatively the air could be sent down the shaft in large diameter sheet iron pipes but this required down cast compartments of sufficient size for the pipes. Shafts of small dimensions, originally started as shallow shafts but which had been continued to great depth as gold was found, with open spaced timbers which

660 Australian Agricultural Company, Colliery Correspondence File, 1/86/7, 6 March 1879, p. 303.
allowed leakage between compartments, were a special problem. There were several of these shafts at Bendigo and Stawell.664

In March 1888 the Victorian government set up a Board to investigate the ventilation of mines. Evidence was taken in Bendigo but Board members inspected mines at Eaglehawk, Ballarat, Stawell, Clunes and Creswick as well as in Bendigo. In its report later in the year the Board found that temperatures at the working areas were high in several mines at Bendigo, although it recommended that action be taken against only one mine, the Great Extended Hustler’s Tribute Company, to force it to improve the ventilation in stopes where the temperature was 86° F. It also recommended that winzes, with smaller dimensions than shafts be dug parallel to the shafts to allow natural ventilation, and that where necessary blowers be used in long crosscuts to assist air flow in such situations. New shafts should be close timbered and of sufficient cross-section to allow large air pipes down the shaft.665 Root’s blowers were installed in nine of the fourteen mines inspected.666

During the next decade some of the Bendigo quartz mines reached depths of over 3000 feet, said to be the world’s deepest at that time, and underground workings of some of the deep lead mines north of Creswick became very extensive. That the report of the first Board on mine ventilation in 1888 had not been effective was shown by the decision of the Government to award a bonus of £1000 for the best method of ventilating a mine. A Board was established to assess the applications, but decided against any award and had its terms of reference extended to use the money to investigate the problem of poor ventilation underground. It reported in 1900.667 The approach of this Board, chaired by the Secretary of Mines (Alfred Howitt, who had trained in science at a German University), was quite different to previous boards in Victoria. The professional officers and inspectors of the Department were co-opted to work on the investigation and advice was sought from Dr. Godfrey, the Assistant Government Medical Officer, and Professor Kernot of the University of Melbourne.

664 Moore, “The Bendigo Goldfield,” p. 189. At Bendigo the temperature underground increased 1°F. for 90 feet increase in depth (1°C. for about 200 feet). The Victoria Quartz mine at Bendigo later reached a depth of 4200 feet and high working temperatures in the stopes were a problem.
666 Ibid., pp. 92-4.
Information on current practice at Moonta, Broken Hill and New South Wales coal mines was sought.\textsuperscript{668} Investigations were made in quartz mines, deep lead alluvial mines and in several small black coal mines which had started in Gippsland during the decade.\textsuperscript{669} Temperatures in various parts of the mines were measured as well as the amount of carbon dioxide in the air and the quantity of air flowing in the working areas. Dr. Godfrey examined miners at Bendigo and Walhalla and found a large number of them were suffering from bronchial and pulmonary catarrh and he and the Government Metallurgist, Henry Jenkins, recommended standards of air quality.\textsuperscript{670} This Board was more definite than its predecessor on the actions needed to be taken to improve mine ventilation. These included the recommendation that no mining lease be granted unless a ventilation system was proposed that could meet the requirements of the \textit{Mines Act 1897}.\textsuperscript{671} Each inspector should be required to report regularly on the ventilation of each mine using an anemometer to measure the airflow, and taking samples to be laboratory tested for air quality. The use of water sprays should be compulsory to lay the dust in mines where rockdrills were used.\textsuperscript{672}

At the same time as strenuous efforts were being made to improve underground ventilation considerable efforts were being made to improve underground drainage, particularly in deep lead mines where inflows of water or mixtures of water and sand were causing serious loss of life. Cornish pumps of the same design as those first used in South Australia in the late 1840s but of larger capacity, were still in use in the Moonta mines and in gold, copper and coal mines of eastern Australia in the 1870s. During this and following decades imported and locally made pumps of this design were still being installed in wet deep lead mines with large water flows such as those in the Loddon Valley. An 80 inch diameter beam pump of 270 H.P., with steam at 15 p.s.i.g., made by Harvey & Co. of Cornwall, was installed at the Duke and Timor Mine near Maryborough in 1874.\textsuperscript{673} In 1884 two beam pumps made by John Hickman at the Union Foundry in Ballarat were installed at the Berry No. 1 mine and the Hepburn

\textsuperscript{668} Ibid., p. 18. The Wallaroo mines were 2400 feet deep at this time with surface fans for ventilation.
\textsuperscript{669} Ibid., See Appendices A to N.
\textsuperscript{670} Ibid., Appendix H, K.
\textsuperscript{671} Ibid., p. 17. This Act, 61 Vict. 1514, Clause 135, required 100 c.f.m for each man and boy and 150 c.f.m. for each horse underground. If noxious gases were present the flow required was 500 c.f.m.
\textsuperscript{672} Ibid.
\textsuperscript{673} \textit{Maryborough and Dunolly Advertiser}, 22 April 1874. It could pump 2.8 million gallons per day.
Estate mine, both near Smeaton. They had single acting cylinders of 70 inch diameter and could pump from 600 feet. Peter Milner lists some 38 beam engines installed in Victoria between 1855 and 1904, almost all of them in gold mines.\textsuperscript{674} The largest Cornish pump installation in Australia was at the Tasmanian Gold Mine at Beaconsfield which was subject to flooding. This installation consisted of three compounded in line steam engines each with a high pressure, 150 p.s.i.g. cylinder of 48 inches diameter and a low pressure cylinder of 108 inches driving a set of pumps through rockers. The first pumped from 1500 feet with a lift of 500 feet, the second from 1000 feet and the third from 500 feet to the surface. The total capacity was eight million gallons per day. The pumps and motors were made by Hathorn Davey of Cornwall.\textsuperscript{675}

Even before the latter two installations were made the Cornish pump was being superseded by more efficient plunger pumps of United States design, in which steam engines drove cylinders to lift the water from the bottom of the shaft. The losses due to the rods in the shaft were avoided. William Turnbull installed a large steam driven pump, of 720,000 gallons per day capacity, of this type at the Australian Agricultural Company’s mine in 1880, with three smaller pumps of the same type but driven by compressed air to feed water from remote parts of the mine to the large pumps at the shaft bottoms. With this installation in place he reduced the labour force underground by 26 men, 4 boys, 4 horses and 4 ponies.\textsuperscript{676}

Cornish pumps were still dominant at the end of the nineteenth century but were being replaced by plunger pumps made by various manufacturers.\textsuperscript{677} In 1888 the South Belle Vue mine at Bendigo installed a double acting plunger pump of capacity 192,000 gallons per day for shaft sinking.\textsuperscript{678} Steam driven centrifugal pumps were manufactured from the early 1870s but were not competitive with Cornish or plunger pumps in large


\textsuperscript{675} The details of the installation were supplied by the Grubb Shaft Museum of Beaconsfield.

\textsuperscript{676} Australian Agricultural Company, Colliery Correspondence File, 1/86/8, 12 Dec. 1880, p. 576. See also Shipping Invoice, File 117/1/24, No. 425-7(1879).


\textsuperscript{678} \textit{The Bendigo Advertiser}, 30 May 1888, p. 5.
capacities, until the availability of three phase induction electrical motors in the twentieth century. This development will be discussed in Chapter 8.

Conclusions

The last thirty years of the nineteenth century was a period of considerable technological advance in ore extraction methods in Australia. Gold mines were pushed down to over three thousand feet, requiring the use of steel wire ropes, a development imported from Europe, and the use of larger and stronger winding engines. As the mines were now the deepest in the world there were no overseas precedents to follow and local foundries used empirical and incremental methods to gradually increase the capacities of steam winding engines to haul from great depths. The small size of Victorian gold mining companies, and the lack of managers with adequate technical training, forced them to undertake co-operative research between companies in developing the use of percussive rock drills for ore extraction and co-operative research with the government in the use of diamond drills for exploring for minerals at depth.

The discovery of new types of orebodies in the other colonies led to the development of new techniques for extracting ores by open cut mining and new types of stoping in wide orebodies with weak walls. In the Cobar copper and gold mines, managers with Australian experience developed these new techniques for stoping in orebodies with strong walls but the wide silver lead orebodies of the oxidised zone at Broken Hill with weak walls required radically different methods. Managers with experience in similar orebodies in Colorado in the United States and in Spain were hired at high salaries to solve the problems using square set stoping and very large open cuts. There was a return to the management structures of the earlier British joint stock companies with expert managers and large numbers of employees.

This period was notable for the number of new technologies introduced for ore extraction, including dynamite explosives, percussive rock drills, diamond drills for exploration, safety mine cages, mechanical methods of mine ventilation and coal cutting machinery and plunger pumps and gravel pumps. Dynamite had its origin in the developing science of chemistry but the other innovations were incremental.

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improvements of older technologies. All of these originated from overseas but there was considerable micro-innovation in adapting them to Australian conditions.

Early in this period, colonial governments began to enact legislation to control the use of machinery in mines in response to public concern about the number of accidents in mines. Inspectors were appointed to ensure proper maintenance of surface equipment and safe working in underground mining methods. The accident rate fell to be comparable with rates in mines in Europe.

The next chapter will consider developments in ore processing technologies in the last thirty years of the nineteenth century.
Chapter 7

Developments in Ore Processing Technologies  1870 – 1900

Introduction

This period was one of rapid developments in ore extraction technologies but these were mainly successive small innovations of technologies already developed overseas. However as new orebodies were discovered and the mines were deepened below water level more complex refractory ores were extracted and the successful processing of these ores required new methods. The processing of the oxidised silver lead ores at Broken Hill on a very large scale and the extraction of gold from the fine grained ores in the oxidised zone at Kalgoorlie, introduced problems which had not previously been encountered in Australia. Later in the period, at Broken Hill when sulphide ore was extracted from below the water line, the separation of the zinc sulphide from the lead and silver sulphides became a major problem. The sulpho-telluride gold ores from below the water line at Kalgoorlie presented further difficult problems in processing of the gold. Millions of tons of the tailings and slimes from which the zinc could not be extracted were stored in dumps which dominated the skyline at Broken Hill, and similar dumps containing unrecoverable gold were stored at Kalgoorlie by the turn of the century. The fortunes to be made, if a solution could be found, attracted many engineers, chemists, metallurgists and financiers to both mining towns.

On a smaller scale the refractory gold ores found on some eastern Australian gold fields required the use of more scientifically based chemical methods using chlorination and cyaniding to separate the gold from the many minerals in the ores. These experiments relied on German and British technologies. When the industrial demand for tin increased in the early 1870s, due to improvements in preserving food in tin-plated steel cans, new tinfields were opened up in Tasmania, New South Wales and Queensland. Tin ores occurred naturally as tin oxide which could be easily separated from the gangue by gravity methods, and the concentrate was smelted using technology previously developed in Germany and Cornwall.

680 There was a substantial market for zinc metal in Europe for galvanizing steel to prevent rust.
This chapter will investigate the problems encountered in processing the new and often more complex ores using chemical methods and gravity concentration. The metals were then separated by more advanced methods of smelting using blast furnaces, pyrite smelting and electrolytic smelting. However, final solutions to some of these problems were not completely achieved until early in the twentieth century. These final solutions will be discussed in Chapter 8.

**Crushing and Concentrating the Ores**

Considerable changes occurred in treating gold and metalliferous ores as more sophisticated machinery was designed and chemical processing with a more scientific base was developed. This section will consider developments in crushing and concentrating ores before final treatment to recover the metals.

Stampers continued to dominate the crushing of the hard quartz in gold mines in this period but the generally softer ores of the metalliferous mines were first crushed in rockbreakers to about two inches size and then crushed in rolls and concentrated in jigs to a grade which could be smelted. There were many variations to this general process to suit the type and grade of the ore.

At the Wallaroo and Moonta copper mines, the grade of copper ore from underground varied from 30 percent to a few percent copper. It was tipped onto a sorting belt from where the higher grade ore was hand sorted onto a second belt, crushed in a rockbreaker, trommelled into several sizes and handsorted to remove low grade material, the fines and the higher grade going to the smelter. The low grade material was combined with that remaining from the first handsorting, crushed to road-metal size and trommelled to produce three sizes 0.5 inch, 1.5 inch and over 1.5 inch. This latter size was again hand picked to separate the ore and the attle (country rock). The ore went to the smelter, the attle to the tip while the remainder, about two percent copper, went to the concentrator. Here it was crushed in rolls to 0.5 inch size and sent to a Hancock jig.\(^{683}\)

The Hancock jig was patented in 1870 by Captain Richard Hancock, the manager of the Moonta mine. It was a development of the German-designed Harz jig. Hancock’s

machine could separate the 0.5 inch maximum feed into the following parts: a high grade concentrate for the smelters and middlings (material containing both ore and gangue), coarse tailings, fine tailings and slimes. The middlings were reground and returned to the jig, the fine tailings were used for underground filling and the coarse tailings which contained some copper were placed in dumps. This copper was recovered many years later using the flotation process. The slimes were spread over a large area and allowed to oxidise, after which the copper oxide was dissolved in acid and the copper precipitated on iron.

Gravity methods were also used to concentrate lode tin for smelting. When he was appointed manager of the Mount Bischoff mine in 1875, Ferdinand Kayser, originally trained as an ore sorter in Clausthal School of Mines and with gold mining experience in Victoria, convinced the Launceston directors to spend enough money to instal an efficient plant and to work the mine for the long term return and not just make large short term profits by selecting the high grade ore. He installed a plant based on German technology, with each section driven by a waterwheel, the plant descending in a river valley so the water was re-used at each section of the plant. The ore from the quarries on Mt. Bischoff was first handpicked on a revolving picking table to remove the high grade ore for smelting. The remainder was first crushed in a stonebreaker then fine crushed in rolls and trommelled to separate four sizes. The three coarsest went to Harz type jigs of three compartments each, the first compartment produced clean ore for smelting, the second produced middlings (tin, copper, iron etc.) and the third middlings of tin and gangue. The final output from the trommel was a mixture of sand and slimes which was sent to spitzlutten to separate the coarse sand (which was rejigged) from the fine sand and slimes, which were allowed to settle, the slimes being run off and treated in buddles. Some tin was lost in the slimes leaving the buddles. The middlings were recrushed in rolls and again jigged. Cornish tin mining technology was later used on

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685 The flotation process is discussed in Chapter 8.
687 H. W. F. Kayser, "Good Management and Ore-Dressing by Automatic Machinery," *Transactions of the Australasian Institute of Mining Engineers* II (1894): pp. 98-101. The term ore sorter is a misnomer. The training was at technician level in mineral technology.
688 Ibid. Kayser did not give a figure for the amount of tin lost in the slimes but this question was raised during the subsequent discussion by the two members who spoke. Kayser was not present for comment.
tin lodes in north east Tasmania when a 50 stamp mill was imported from England and was duplicated by a Launceston foundry.  

The oxidised ore that was extracted in the early years from the Broken Hill mines contained lead carbonate and lead cerussite as well as silver chloride. This ore was suitable for smelting but as lower grade oxidised ores, with gangues that made smelting uneconomical, were mined from 1889 alternative methods were developed to extract the silver. The B.H.P. Co. used a process of lixiviation with sodium hyposulphite to remove the silver from low grade silver ores.  This plant operated from May 1890. From 1892 the company operated a large crushing and silver amalgamating plant concurrently with the lixiviation plant. This plant was closed in 1896 but the lixiviation plant continued for some years while oxidised low grade ore was available.

Also in 1889 the B.H.P. Co. built a gravity concentration plant to upgrade the lower grade oxidised lead ores for smelting. It was equipped with jigs, Cornish buddles and Frue vanners. By 1891 it was clear to all companies mining at Broken Hill that the oxidised ores would soon be mined out. The B.H.P. Co. employed Dr. Schnabel, a German metallurgist, to advise the best method of treating the enormous tonnages of zinciferous ore which would soon be developed at the lower levels. His report gave a comprehensive description of the various methods then available to treat the complex Broken Hill ores. He recommended the best of these was to leach out the zinc using sulphuric acid before smelting the remaining lead ore. Schnabel was assisted in preparing the report by Edgar Ashcroft, a young English electrical engineer who had installed an electric lighting plant at the mine and who was then managing the plant. Schnabel’s recommended solution was not adopted by the company but it led Ashcroft

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691 See Chapter 3. The lixiviation process for extracting silver from gold ores had been used at St. Arnaud in the 1860s. This use from 1890 was important as it led to the development of a flotation process some ten years later.
692 L. S. Curtis, *The History of Broken Hill* (Adelaide: Fearsons Printing house, 1908), pp. 46-9. The reason for the two plants is not clear in the literature. Perhaps it was to allow comparative costs of the two methods to be determined and the lixiviation proved the most economical. A sulphuric acid plant was built in Broken Hill to provide acid to make the sodium hyposulphite needed for lixiviation.
to propose an electrolytic method of smelting to separate the zinc.694 Ashcroft’s attempt to solve this problem will be discussed below in the section on smelting.

The problem of refining the zinc ore to metal was a double problem. The lead and silver sulphides had to be separated from the zinc sulphide by gravity methods and then the zinc sulphide separated from the gangue. Unfortunately the three minerals were so finely intermixed that the best fine grinding machines could not completely separate them. The amount of slimes produced by fine grinding with rolls contained large amounts of middlings.695 Also the specific gravity of any zinc sulphide particles was close to that of the gangue and the two could not be separated by gravity methods.

After rejecting the proposal to leach the ores the six companies then operating at Broken Hill decided to erect gravity concentration plants for the sulphide ores and to produce a lead concentrate containing silver and some zinc which could be smelted for the lead and silver but the zinc was lost in the slag. By 1900 these plants contained various combinations of rockbreakers, crushing rolls, spitzkasten, Hancock jigs, disc grinders buddles and vanners. A typical recovery rate for the minerals in the concentrate as a percentage of the mineral content of the ore was 69 percent of the lead, 50 percent of the silver and 13 percent of the zinc. The remaining mineral content was sent to separate dumps of tailings and slimes in the hope that at a future date new methods would be devised to recover the minerals.696

**Developments in the chemical treatment of ores**

The theory of chemical reactions was developed by British, German, French and Scandinavian scientists during the final decades of the eighteenth century and the first half of the nineteenth century.697 By the 1840s chemical methods were being introduced for mineral separation. The use of water containing dissolved chlorine gas as a solvent to dissolve gold from ores was first suggested in 1846 by Dr. John Percy of London. His proposal was developed into an industrial process by Professor Plattner and his staff at the Royal Freiberg Smelting Works in Saxony in 1848. Gold was dissolved from pyrites

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at ordinary air pressures in earthenware pots, the liquid was run off into other earthenware jars and the gold precipitated from solution by hydrogen sulphide gas. Plattner later suggested the method would work on a larger scale using wooden vats coated with pitch. Plattner’s method was introduced into California in 1857 by C. Deetkin and was used extensively there in following years.\textsuperscript{698}

In 1864 Alan De Lacey, a civil engineer living in Melbourne, was granted Victorian Patent V 748. As well as describing crushing plant the patent covered the use of a solution of chlorine in water for extracting gold, presumably copying Plattner. Pressures above atmosphere were obtained by generating excess chlorine, the crushed pyrites was placed in a barrel, dampened with water, the chlorine gas was injected and the barrel rotated to speed up the processing. The liquid was removed from the barrel and the gold precipitated by adding iron sulphide.\textsuperscript{699} This was not the first barrel process for chlorination as Duflos had used this method in Breslau in 1848.\textsuperscript{700}

By 1865 the Port Phillip Co. at Clunes was extracting gold from pyrites from their own mine and elsewhere in eastern Australia using amalgamation with mercury.\textsuperscript{701} In the late 1860s mine managers from other goldfields inspected the plant and moved to set up similar plants to treat ores from their own mines.\textsuperscript{702} In the 1870s millmen who had worked at Clunes and others began to erect pyrites treatment plants on other goldfields to treat parcels of pyrites concentrates by amalgamation.\textsuperscript{703}

De Lacey’s plant may not have been used immediately in Victoria because it was a batch process treating 4 tons of pyrites per batch and would have been expensive. De Lacey was living in Bendigo in 1871 and in 1876 the United Pyrites Company at Pinchgut Gully replaced an amalgamation plant with a chlorination plant with 4 ton vats,

\textsuperscript{698} T. K. Rose, \textit{The Metallurgy of Gold} (London: Charles Griffin & Co., 1906), Ch. XIII.
\textsuperscript{700} Rose, \textit{The Metallurgy of Gold}, p. 257, said De Lacey’s patent was tried then forgotten but did not give further details.
\textsuperscript{701} J. Woodland, \textit{Sixteen Tons of Clunes Gold} (Clunes: Clunes Museum, 2001), p. 76. Pyrites from the Amelia reef in the Blue Mountains of New South Wales were sent to the Port Phillip Co. for treatment in 1867.
\textsuperscript{702} The Bendigo Advertiser, 6 June 1868, reported that several local managers had visited the Port Phillip mine and requested the permission of local council to erect treatment plants to roast pyrites.
\textsuperscript{703} Claims were granted for the erection of pyrites plants in 1872 near Bendigo: No. 4416 to L. Samuels, 3 acres in April; No 4602 to the United Pyrites Co. - Joel Deeble, Thomas Edwards and others in July; No. 4684 to Hugh McColl. See Register of Claims, Victorian Mines Department. A lease, No. 3218, of 4 acres for a pyrites plant was issued to John Spargo in August 1872. See Register of Leases, Victorian Mines Department.
earthenware gas generators heated by steam, and with a large number of earthenware vessels to hold the auriferous solution. Although no documentation has been found to prove that this installation used De Lacey’s patent it seems likely it did so. It is a good example of the early efforts made to adapt an overseas invention to ore processing in Australia. In 1880 Victorian patent cover was granted to James Mears of Philadelphia in the United States, for a chlorination process in which the chlorine was injected above atmospheric pressure. James Cosmo Newbery and Claude Vautin were granted Victorian patent No. 4484 in 1886, which was similar to those of De Lacy and Mears except the pressure of injection of the chlorine was four times atmospheric, obtained by using compressed air. The solution was heated to speed the process and charcoal was used as the precipitating medium.

Chlorination plants were built at Ballarat, Melbourne, Daylesford, Casillis, Granya and Bethanga in the late nineteenth century and early twentieth century (at the latter two places to treat very refractory gold ores containing copper). The Oswald and South German mines at Maldon were operating chlorination plants up to World War I. There were chlorination plants in NSW at Harden, Wellington, Adelong and two at West Wyalong in 1899. In Queensland, the pyrites works of Curtis and Company was established in Gympie to treat pyritic ores using the Plattner process. The Charters Towers goldfield was discovered in 1871, the ore being found in quartz veins in fault fissures in grano-diorite. The ore contained lead, copper, zinc and iron minerals, the oxides of which caused no difficulties with amalgamation. When the water level was reached problems were experienced with sliming when attempts were made to fine grind the ore for amalgamation. D. A. Brown introduced a process at Charters Towers

706 See Victorian patent application No. 2814 by E. Waters, Patent Attorney, 14 April 1880. The patent was allowed under a law which allowed overseas inventors to be protected without a full submission if the process was already patented in the country of residence. It was the same as De Lacey’s patent which was then void due to effluxion of time.
708 Clark, *Australian Mining and Metallurgy*, p. 269. Clark said the patent was not sound scientifically as the amount of chlorine dissolved was only increased by increasing the partial pressure of the chlorine, not by increasing the total pressure
by which the pyrites concentrates were fine ground in Wheeler’s pans, the sand and slimes were allowed to settle in a tank, reground in Berdan pans, again settled in tanks then roasted with salt to oxidise the pyrites and convert any zinc to zinc chloride. This last stage took place in a spectacular reverberatory furnace built in steps up a hillside. The roasted sand was then fed into wooden vats with a filter of glass at the bottom and dampened with water. Chlorine gas was forced in from below and a weak solution of chlorine gas in water added at the top. The solution containing the gold was run down a vertical column against a counter current of high pressure steam to drive off the chlorine gas for reuse. The gold was precipitated with ferrous sulphate onto beds of charcoal and sawdust, which were burnt and the residue smelted. The method was a technical success but the process was expensive and was replaced by the cyanide process after 1892.\footnote{D. Menghetti, “Extraction Practices and Technology on the Charters Towers Goldfield,” North Australia Research Bulletin, no. September (1982). The cyanide process is discussed below.}

The \textit{Summary of Gold Mines Statistics} printed by the Queensland Mines Department in 1892 listed 6 chlorination vats at Cloncurry, 49 at Charters Towers, 48 at Ravenswood and 132 at Rockhampton (Mt. Morgan).

The Mount Morgan goldfield had been discovered in central Queensland in 1882. The ore was unusual, being very fine grained gold in ironstone.\footnote{Rose, \textit{The Metallurgy of Gold}, p. 281.} Even in the oxidised zone the gold particles were so fine that amalgamation recovered only about 40 percent of the gold, the rest being washed over the plates without being caught. A Plattner process, installed by A. Lymburner of Gympie, was tried in 1884 but did not recover more than 75 percent of the gold. The Newbery-Vautin process was installed in 1885 but was fragile for the amount of ore to be handled and was partly discarded in 1885 when a plant designed by Henry Trenear, who had experience in Mexico, was installed and gave 98 percent recovery. Some of the Newbery-Vautin components were incorporated in this revised plant, called the Lower Works, which was later enlarged to a capacity of 500 tons of ore per week. It was then realised that the orebody was larger than expected and a new plant, the Upper Works, of 1000 tons per week was erected in 1887. The peak production in one year was 325,600 ounces of gold in 1889 when gold grades were five ounces per ton.\footnote{\textit{Annual Report of the Queensland Dept. of Mines for 1889}, p. 61.} After further improvements which reduced costs a final plant, the West Works, was built in four sections during 1896-7 to a total capacity of 10,000 tons per month. This plant was closed in 1911 when the ore for which it had been built was
worked out. The cost of treating the ore to extract the gold had been reduced by then to just over 11 shillings per ton.\textsuperscript{714}

**Sliming Problems with Gold Ores**

The more refractory gold ores of eastern Australia, such as those at Bethanga and St. Arnaud, which contained minerals such as copper and lead, presented many difficulties to the metallurgist in the late nineteenth century. Fine grinding the pyrites led to the formation of slimes from which the gold was not easily recovered by gravity processes, because the fine particles of gold floated off with the water and did not amalgamate. The presence of copper resulted in excessive use of chlorine or cyanide. At Bethanga the mine manager, Thomas Martin, and his son (a trained metallurgist) watched as a succession of metallurgists and smeltermen brought to the mine by the owner, John Wallace, failed to find a solution. By the mid 1890s they developed a successful commercial process using fine grinding in ball mills, roasting in reverberatory furnaces, chlorination in vats and precipitating the gold on sawdust. The liquor was then passed to another vat, heated with steam and scrap iron added to precipitate the copper.\textsuperscript{715}

At St. Arnaud, Fred Stahl (a technician trained at the Clausthal School of Mines and with extensive experience in gold mines in Victoria) experimented before 1890 with gold and native silver ores, looking for a method to separate the gold and silver from the pyrites by fine crushing, and to treat the slimes produced with Wheelers pans followed by amalgamation. The results were disappointing.\textsuperscript{716} At a nearby mine John Frew also experimented with fine grinding the pyrites to slimes, followed by amalgamation. Stahl and Frew combined their resources in this research.\textsuperscript{717} Neither mine was rich enough or large enough to finance this research and both mines failed without finding a solution and were wound up. However the Lord Nelson mine nearby was rich enough both in the grade of ore and profits and the manager Zebina Lane Snr., a Canadian with extensive deep lead mining experience in Victoria, developed a process in which he used fine


\textsuperscript{715} Clark, *Australian Mining and Metallurgy*, pp. 306-12.


\textsuperscript{717} Ibid., para 12213. Frew managed the New Bendigo Gold Mining Co.
grinding of the pyrites to slimes in Wheeler’s pans followed by amalgamation to extract some of the gold and silver. He sent the treated pyrites to Bendigo for further treatment by chlorination. As will be discussed in the next chapter, by the turn of the century he had developed a successful chlorination process at the mine, but he was one of the few managers who refused to divulge their solutions to others and the details are unknown. The North Cornish and Devonshire mines at Daylesford were using Frue vanners to successfully separate the slimes from the sandy tailings before 1890. The slimes were then treated by chlorination.

Cyaniding

The early chlorination processes were expensive and cheaper alternative methods were sought. One development was the cyanide process for the extraction of gold from ores, which was devised by John MacArthur and two brothers, Robert and William Forrest, in Glasgow in 1886. MacArthur was a chemist employed by the Tharsis Company, which owned a copper pyrites mine in Spain, and the Forrests were medical men with an interest in science. The three, together with George Morton, a Glasgow business man who supplied the necessary funds, formed a syndicate to investigate the development of new chemical processes including the extraction of gold from ores. They experimented after normal working hours and made a close study of a chlorination process using electricity. An American, Henry Cassel, had sold this process to the Cassel Gold Extracting Company, which was owned up by the directors of the Tharsis Company. The process was a failure and Cassel absconded with the firm’s assets. After a systematic series of tests using a range of solvents the syndicate reached the conclusion that the use of electricity was not necessary and that gold would dissolve in a weak solution of potassium cyanide in water due to a difference in the electric potential of the atoms involved. MacArthur published an article in the journal Industries in 1886 on the conclusions of the syndicate, as a result of which Sir Charles Tennant, the chairman of the Tharsis Company, offered him the job of technical manager of the Cassel Company, with the responsibility of solving the problems of the defective process. In February 1886 while Cassel was in charge the company sent a plant and two operators to

718 Ibid., paras. 12038-41.
Ravenswood in Queensland and another to Central City in Colorado. In March 1887 another group was sent to the St. John d’el Ray Mine in Brazil with apparatus and chemicals on the assumption the Cassel process could be made to work.

By May 1887 however, MacArthur had decided the Cassel process was unsatisfactory. Overseas staff members were recalled and Macarthur was authorised to extend the syndicate’s work using potassium cyanide as a solvent. Cassel’s earlier method was abandoned in December 1887. Provisional British patents were taken out after October 1887 (No. 14174 of 19 October 1887) for the process of dissolving gold in potassium cyanide solutions and after further work an additional patent was applied for (No. 10223 of 14 July 18880) for the precipitation of gold from solution using zinc shavings. During 1888 applications for patents covering the process were lodged in over twenty countries and colonies.\(^2\)

Potassium cyanide is a very toxic chemical but surprisingly there are few reports of serious accidents due to its use. Alan Lougheed reported that cyanide spills in 2001 in New Guinea and Romania were exceptional and the low rate of accidents was due to the caution with which the poison was treated.\(^2\) In his doctoral thesis ‘A History of Technological Change in Kalgoorlie Gold Metallurgy’, Richard Hartley stated that non fatal accidents due to cyanide fumes were common in Western Australian mines before 1905 and were due to the production of hydrocyanic acid gas during the chemical reactions taking place. In poorly ventilated areas these gases caused dizziness and sometimes collapse but rapid removal from the area would prevent death.\(^3\) James Park reported on two deaths, early in the twentieth century, at the North Pole mine in South Africa where the mill superintendent and foreman both died by inhaling arsniuretted hydrogen formed when gold was being precipitated in the zinc box when treating a gold ore containing arsenic.\(^4\) In Australia most cyanide plants were in the open air and any poisonous gases generated were dissipated before lethal concentrations occurred.\(^5\)

\(^3\) Ibid., Preface (v).
\(^5\) At the Venus mill in Charters Towers the cyanide vats were erected outside the mill buildings. In Victoria many small operators erected one or two vats of galvanized iron painted inside with tar in the open air with a small, well ventilated, galvanized iron shed containing the zinc boxes to protect them from theft.
The Cassel Company adopted a policy of setting up subsidiary companies in gold mining countries in which local interests provided the capital. Cash and/or shares were issued to the Cassel Company and in return the subsidiary received the right to training and the use of the patents (e.g. African Gold Recovery Company and the Australian Gold Recovery Company). In addition a variable royalty was payable. About thirty employees were trained in the process and sent to the goldfields to give technical support. Peter McIntyre and his brother Duncan were sent to Ravenswood in 1888 to rebuild the old plant. The first gold produced on any goldfield by the cyanide process was produced there in late 1888. The process was in use in South Africa at several mines on the Rand by 1891, in New Zealand at the Crown Company by 1889 and in the United States by mid 1892. The Australian Gold Recovery Company was registered in London in 1892 and the Australian office was opened in Adelaide in the same year. This company took over the Ravenswood plant, which had been successful technically but was located on a small goldfield. The plant was transferred to the much bigger Charters Towers field.\footnote{Lougheed, \textit{Cyanide and Gold}, p. 11. Hartley, "A History of Technical Change in Kalgoorlie Gold Metallurgy 1895 - 1915", p. 25.}

Australian gold mines offered some special problems for a company registered in London that wished to promote the global use of a process. Most gold mining companies in eastern Australia were small and had a small capital base, so Cassel staff had to negotiate with many owners and mine managers. Moreover each colony had a different patent system, with different public servants and judges dealing with patent applications and infringements. The biggest difficulty however, was that most ores were free milling with lumpy gold in which the large gold particles took a long time to dissolve in the potassium cyanide. Refractory ores which contained copper used large amounts of cyanide and were often uneconomical to treat with this process. Large amounts of silver sulphide did not cause problems as it did with the chlorination process. At this early period cyaniding was a batch process and hence relatively costly.

The apparatus developed in the field in the late 1880s by the staff of the Cassel Company drew on the methods used for amalgamation and the chlorination processes. Lumpy free milling ores were crushed with stampers sufficiently fine to liberate the gold and silver particles from the gangue, and the coarse gold and silver was collected
by amalgamation on mercury plates. The tailings were then fine ground, and placed in circular leaching vats. These were made with a wood bottom morticed into vertical wood staves, and held together with threaded steel rings and turnbuckles. In Victoria and New South Wales corrugated iron vats were preferred because the cost was half that of timber vats. In South Africa and New Zealand steel vats were preferred. Initially a filter bed of gravel was placed in the tank, but these were later replaced with light wooden frames over which was placed a filter cloth of strong Hessian, canvas, cocoa-matting or burlap. The tailings were placed in the vat and a weak cyanide solution was run onto the top and allowed to percolate down through the filter and then through a pipe to the extractor tank in which the gold deposited onto zinc shavings. The cyanide solution, free of gold, was drained to a sump where it was made up to the required strength and pumped back to the leaching vats as required. The zinc boxes were usually long and rectangular, made of timber and divided into compartments which contained the zinc shavings. At the periodical clean-up the zinc, with deposited gold, was removed and heated in a small tilting furnace to volatilise the zinc as zinc oxide, and the melted gold was cast into ingots.\footnote{Park, \textit{The Cyanide Process of Gold Extraction}, Ch. VI.}

At Charters Towers, where the local ores with low copper content caused few problems, the Australian Gold Recovery Company negotiated a royalty agreement with the Day Dawn Mine late in 1892 to use the patent at its Excelsior Mill for a royalty of five per cent of the gross product. The flowsheet at this time was rock breaker, stamper, amalgamating table, concentration to remove the pyrites which were sent elsewhere for treatment by chlorination, the tailings were ground in a Wheelers pan and then separated in a concentrator into sand and slimes. The sand was treated in a cyanide plant and the slimes were sent to a pan amalgamator.\footnote{Menghetti, "Extraction Practices and Technology on the Charters Towers Goldfield," p. 12 and Fig. 9.} The Australian Gold Recovery Company representative at Charters Towers in 1895, experienced great difficulty in getting the managers of other mining companies, mainly British owned, to instal cyanide plants as the company directors in London who authorised expenditure on new plant wished to use profits to pay dividends on the inflated capital. As an alternative he encouraged small groups of miners and local investors to spend up to £1000 on small plants. They were charged a royalty of five per cent on gold recovered from current tailings and seven per cent on tailings recovered from old dumps. These groups negotiated with the
mining companies for both their current and dump tailings. By 1897 there were 70 small
groups operating in this way and a minor boom in gold production occurred in the
city.\footnote{Lougheed, *Cyanide and Gold*, p. 33.} Many of the huge dumps of tailings stored by Victorian and New South gold
mines were treated once or twice between early 1895 and the late 1930s by small
groups and some larger companies.\footnote{Reports to the Minister of Mines, *Victoria*, 1895, 43. The Duncan brothers were operating a cyanide
plant at Tarnagulla in central Victoria on old tailings from the Poverty Mine. A dump of some 40 000 tons was being treated after the removal of slimes. R. W. Birrell and J. A. Lerk, *Bendigo’s Gold Story* (Bendigo: J. A. & E. Lerk, 2001). Photographs on pages 118 to 120 show various cyanide plants
operating on old dumps in the 1930s at Bendigo. It is interesting to compare these plants with the more automated carbon in pulp plants common in the 1980s illustrated on pp. 138-9.}

The free milling gold ores at Gympie, Ballarat, Castlemaine and Bendigo made the use
of the cyanide process with its high royalty a marginal proposition, and there was little
interest in setting up plants to treat current tailings except where the tailings were very
refractive. At the South German mine at Maldon, with a refractory ore, the crushed ore
was first amalgamated in mercury wells and then on copper plates, the pyrites were
collected on blanket tables and any sand was removed on a Wilfley table, the pyrites
then being chlorinated and the gold precipitated on charcoal. The sands from the
blankets and the Wilfley table were then cyanided and the gold precipitated on
charcoal.\footnote{Clark, *Australian Mining and Metallurgy*, pp. 327-31.} It is probable that this flowsheet was used at the Oswald Mine (successor to
the North British) in Maldon and at the Lord Nelson Mine in St. Arnaud.

At Kalgoorlie, first discovered in 1893, the gold is found in Archean rocks but the Mt
Charlotte deposit at the north end of the field is different to the Golden Mile deposit to
the south at Boulder. The northern deposit is a gabbro hosted quartz vein type of
mineralisation, the southern deposits are hydrothermal replacement bodies formed in
shear zones, faults and tension cracks.\footnote{A. F. Trendal, *Geology and Mineral Resources of Western Australia* (Perth: Department of Mines,
Western Australia, 1990), pp. 660-2.} In the northern oxidised zone the gold could be
extracted by methods similar to those used in eastern Australia but the sulphide ores in
this zone were more difficult. In the southern zone considerable difficulties were
encountered in extracting the gold from both the oxidised and sulphide ores. The
Australian Gold Recovery appointed McBean Bowder & Co. local merchants as its
Perth agents in 1894 and by the end of 1895 three companies at or near Kalgoorlie had
operating cyanide plants.\textsuperscript{733} Donald Clark wrote in 1904 that the Boulder ores were not specially refractory and could not be compared with the ores at Bethanga and Casillis or with many ores from Central and North Queensland. The difficulties were caused by the presence of tellurides and the fineness of the gold which could only be completely liberated by grinding all the ore to slimes.\textsuperscript{734}

After mid 1894 the Western Australian goldfields, particularly Kalgoorlie, attracted a large and sustained influx of British capital, as money was plentiful and interest rates were low.\textsuperscript{735} In 1895 around thirty Western Australian companies were floated in London each month, a total of 342 for the year.\textsuperscript{736} Many of these floats were worthless and some were fraudulent but some mines proved to be very rich in the oxidised zone (for example the London financed Great Boulder mine paid a forty percent dividend on capital in 1895). Between 1897 and 1904 London company promoters drove speculation in Kalgoorlie shares.\textsuperscript{737} Neither the London boards or the shareholders of many of these companies had much knowledge of mine management and they appointed a London-based mine management company, Bewick Moreing, to manage their Australian mines. Bewick Moreing employed engineers trained in mining schools in Australia, Britain and the United States.\textsuperscript{738}

While the London promoters were speculating in Kalgoorlie mine shares, engineers employed in Kalgoorlie by Bewick Moreing and by independently managed mines, were experimenting to solve the problems of the sulphide ores, some containing tellurides. In his excellent thesis ‘A History of Technological Change in Kalgoorlie Gold Metallurgy 1895-1915’, Richard Hartley has described how the metallurgy on that goldfield developed differently from other goldfields because of the peculiar characteristics of the environment and geology. With the author’s permission his conclusions are summarised here.

\textsuperscript{734} Clark, Australian Mining and Metallurgy, p. 14.  
\textsuperscript{736} Ibid.: p. 11.  
\textsuperscript{737} Ibid.: p. 13.  
The first cyanide plant on the Golden Mile was at Hannan’s Brownhill Mine, opened in 1895, used dry crushing with stampers and oil engines rather than steam engines to avoid the scarcity of water, due to the low rainfall. A barrel amalgamator, designed by John MacArthur and Cassel staff, was trialled in London. The amalgamator added salt water and cyanide to the crushed ore in the barrel, which was rotated and the amalgam collected on copper plates inside the barrel. The remaining crushed ore then passed to cyanide vats for leaching. The Cassel-designed plant failed to operate satisfactorily when started in March 1896 because the clays and slimes clogged the crushers and amalgamators and much of the fine gold was lost in the tailings. The Brownhill company then contracted with the Anglo-Continental Gold Syndicate to provide additional capital, for which payment was made by the issue of shares, and the Syndicate was to erect a dry crushing plant. This contract was taken over by the London and Hamburg Gold Recovery Company financed by British and German capital. The company built a plant in which the dry crushed ore was separated by a fan classifier into coarse, medium and fine. The coarse material was further ground and pan amalgamated, the medium was cyanided in percolation vats and the fines including slimes, were agitated in other vats with a mixture of potassium cyanide and bromocyanide and the slurry was dewatered in a filter press. The material held in the filter press was washed and the total liquid passed over zinc shavings to precipitate the gold. The combination of cyanide and bromocyanide was a patented process of the British firm of Sulman and Teed. It was a more powerful solvent than cyanide alone, but in 1898 the patents were acquired by the London and Hamburg Gold Recovery Company. The chief chemist Dr. Diehl introduced tube mills to fine grind the ore after amalgamation.

The presence of gold telluride in mines on the Golden Mile was identified in 1896 and explained one reason why the use of cyanide was not very effective in extracting the gold since the compound was not soluble in potassium cyanide solutions. Some mine managers, including Richard Hamilton at Great Boulder, had Victorian experience with the calcining of refractory concentrates to oxidise the sulphides before amalgamation. During 1897 small scale tests were carried by J. Sutherland at the Lake View Consols Mine in a reverberatory furnace, and in late 1897 the directors of Great Boulder in London contracted with William Koneman to build a plant to treat both oxidised tailings

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740 Ibid., pp. 34, 186.
741 Ibid., pp. 124-6.
and current sulphide ore production by roasting followed by fine crushing and barrel amalgamation plus cyanidation and pressure filtering. The plant was built but by January 1899 it had been proved a failure. In 1899 the Lake View Consols Company installed a Brown straight line reverberatory furnace of American design followed by dry fine grinding in ball mills and cyanide leaching, but difficulties in using wood in a furnace designed for coal led to inconsistent roasting which in turn caused problems in the leaching with cyanide. This plant was not a complete success but by the end of 1900 another roasting process had been developed by J. T. Marriner of the Great Boulder Main Reef into the first successful sulphide treatment plant in Kalgoorlie. This solution involved grinding the roasted ore to all slimes, agitation with cyanide and filter pressing. These examples, which indicate the amount of development work carried out by several companies in Kalgoorlie, will be discussed further in the next chapter.

**Smelting**

There were many developments in blast furnace smelting technology in Europe and the United States after 1850. These were introduced to Australia in the 1880s, mainly by men trained in the United States. This section will discuss the introduction of American designed blast furnaces after 1880. However not all these were successful due to the absence of suitable fluxes and some new reverberatory furnaces were built.

In the early years of this period the Wallaroo smelters treated the concentrates being produced at the mines at Wallaroo and Moonta mines with little change to the plant except the original reverberatory furnaces were enlarged in 1890 when the number of chimneys was reduced and the flue system was modified. Gold ores from Western Australia and silver ores from Broken Hill and Tasmania were smelted there after 1891. Rich Kalgoorlie ores, containing about 10 ounces of gold per ton, were smelted at Fremantle or shipped to South Australian and New South Wales smelters between 1897 and 1904. A small smelter also operated at Kalgoorlie in this period.

At Cobar the original discoverers of copper formed the Cobar Copper Mine and Joseph Becker opened the South Cobar Mine on an adjacent lease in 1871. High grade copper oxide ores were mined on both leases. The Cobar Copper Mine commenced smelting in

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742 Ibid., pp. 130-8.
743 More details are given in the appendix.
1875 with two reverberatory smelters and sent the product by bullock dray to Bourke on the Darling River for transport by boat and rail to Adelaide for final smelting. This mine and the South Cobar Mine were floated as the Great Cobar Copper Company Limited, with Sydney capital in 1876, and by 1881 the company was smelting its copper ores at Cobar in 14 reverberatory furnaces. The railway from Sydney reached Orange in 1877 and the copper matte was then carried to that terminus by dray and railed to Sydney for smelting.\textsuperscript{746} Droughts in the Cobar district in the 1880s caused periodical shortages of wood for the smelters as the woodcarters could not maintain water for their horses. By 1892 the railway had been extended to Cobar and the following year a syndicate of William and Thomas Longwirth and Dr. Richard Read, the owner of the Singleton Coal and Coking Company in the Hunter Valley, took a controlling interest in the mine. They installed American designed water jacketed furnaces with hot air blast to replace the reverberatory furnaces.\textsuperscript{747} Four furnaces were erected, each with a capacity of 80 tons of ore, to produce a matte of 35 percent copper which was cast into billets and railed to Lithgow for treatment in the syndicate’s plant of 16 reverberatory furnaces. In 1900 the syndicate purchased Great Cobar for £500,000 and formed the Great Cobar Mining Syndicate in preparation for floating the company on the English market.\textsuperscript{748}

A copper lode, narrow at the surface with little gossan but 18 feet wide a few feet down and containing about 20 percent copper ore, was discovered at Burraga, south of Bathurst, sometime before 1877 by a shepherd named McIntyre. In 1879 it was purchased by Lewis Lloyd who owned smelting works at Lithgow. He built seven reverberatory furnaces at the mine to produce a regulus of 40 percent, which was then transported by dray 40 miles to a railhead and railed to Lithgow. In 1899 a London


\textsuperscript{747} Blast furnaces for smelting metals had been used in Germany for many years but improved techniques were developed in the United States in the 1860s to reduce the smelting time, the number of stages and the labour required. Blast furnaces could smelt sulphide ores without prior calcinations. In the eastern United States copper ores were highly pyretic, contained 2 to 6 percent copper and had varying silicon content. Blast furnaces gave best results when the slag contained less than 40 percent silica. (see E. D. Peters, \textit{Modern American Methods of Copper Smelting} (New York: The Scientific Publishing Co., 1892), pp. 184-6.) Sulphur remaining in the matte was removed in a second stage in a Bessemer converter, a large iron ladle lined with firebrick, where pressurized air was blown through the molten matte, the sulphur was oxidized to sulphur dioxide and the iron was oxidized to iron oxide which combined with silica to form a slag.

\textsuperscript{748} Stegman and Stegman, “The History of Mining in the Cobar Field,” pp. 10-12.
company, Lloyd Copper Company, was floated with a capital of £250,000 of which £100,000 was used to purchase the mine. Henry Bratnoser, a large shareholder, who was a consulting engineer with wide experience, was sent to Burraga to erect a hot blast water jacket furnace at a cost of £15,000 but it was then found that a suitable limestone flux was not available locally and the ore was not suitable for blast furnace smelting.\textsuperscript{749} In 1903 William Corbould was appointed manager. He discarded the existing furnace and built a large reverberatory furnace, designed by Bill Thomas, an experienced Welsh smelterman, which worked successfully.\textsuperscript{750}

When the Mt Bischoff tin mine in Tasmania commenced operation the mine was very isolated with poor tracks through dense bush and the ore was bagged and packed by horses to Burnie for shipment to Melbourne for smelting. A tin smelter was later built at Launceston with small reverberatory furnaces and the ore was carried by dray to Burnie and shipped from there to Launceston. In 1878 a tramway was built from Burnie on land owned by the Van Dieman’s Land Company, with horses pulling the trucks. This line was converted to a railway in 1884 and the concentrates from the mill were transported in trucks.\textsuperscript{751}

Initially the tin ores from around Stanthorpe and the adjacent tin fields in northern New South Wales were bagged and sent by dray and boat to the Australian Tin Smelting Works in Sydney.\textsuperscript{752} By mid 1874 the Mt. Marlay Company had erected tin smelters near Stanthorpe and in the same year Horace Ransome erected two reverberatory furnaces on Quart Pot Creek to smelt ore for the Blue Mountains Company. Both undertook the smelting of ores for the public.\textsuperscript{753} Also that year John Moffat, a storekeeper in Stanthorpe, financed a smelter at Tent Hill, adjacent to the Vegetable Creek tinfield in northern New South Wales but on first firing the furnace cracked and the firebricks fused with the impure tin ore. Moffat then offered a partnership to John Reid, an experienced mining man, if he could fix the smelter problem, which he finally accomplished by copying the design and dimensions of the furnace at Pyrmont that was

\textsuperscript{750} Ibid., pp. 129-30. The furnace was 56 feet long, and 20 feet wide.
\textsuperscript{753} Ibid., p. 27. The reverberatory furnace at the Mt. Marlay Company was 10.5 feet long, 3.5 feet wide and 2.75 feet thick. The erection was supervised by James Duncan, an experienced smelterman.
owned by the Australian Tin Smelting Works. In the early 1880s Moffat moved his business to the Herberton tinfield in north Queensland and with the aid of Sydney capital erected a crushing plant and reverberatory smelter at Irvinebank.

At the same time as Moffat was developing his interests in north Queensland, the small mines around Silverton in western New South Wales began exploiting the narrow veins containing silver and lead in granite dykes in the oxidised zone. At the Daydream mine north of Silverton, the orebody varied between 1.5 and 7 feet wide. A small water jacketed blast furnace was built on an adjacent lease owned by the Hen and Chicken Company by an American, named La Monte in 1885.

These small mines around Broken Hill were soon overshadowed by the results achieved by the B.H.P. Company. The rich silver lead ores from the oxidised zone on the hill were discovered in 1884 in shallow prospecting shafts and a sample of 48 tons sent to the Intercolonial Smelting and Refining Company in Melbourne produced 35,600 ounces of silver worth £7500. More ore was smelted at the Day Dream smelter to pay expenses. In 1886 the B.H.P. Co. erected a water jacketed blast furnace on the west side of the hill and by 1891 similar furnaces had been erected by the British Broken Hill, Block 14, Central and South mines at Broken Hill. Later the British Broken Hill and the B.H.P. Co. built blast furnaces at Port Pirie on the coast, Block 14 at Port Adelaide and the Central Mine erected a similar plant near Newcastle. High grade silver lead ores were smelted in these plants to produce a silver-lead bullion which was sold in Europe. Initially transport from Broken Hill was by wagon, but in January 1888 a private company, the Silverton Tramway Company completed a private line from the

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754 Ibid., p. 33. Reid first took advice from Langdon, a Cornish smelterman, employed by Caird Patterson & Co., tin merchants of Sydney but his furnace was not suitable for firewood fuels and charcoal, which rapidly corroded the inside lining of the furnace.

755 Ibid., p.p. 59-70. Before erecting this plant Moffat travelled to Europe and inspected Cornish and German mines. He decided German tin crushing equipment was superior to Cornish and purchased German equipment.


758 “Australia's Silver City,” Australian Mining Standard, no. 20 January 1897 (1897): p. 2. E. Henderson, T., “The History of Ore Treatment Processes in Broken Hill,” Proceedings of the Australasian Institute of Mining and Metallurgy N.S. No. 72 (1928): pp. 98-100. The first two 30 ton furnaces were erected by La Monte on the B.H.P. Co. lease followed by three more to allow a total of 500 tons of ore to be smelted per week. Difficulties with the supply of coke, when drays were used for transport, made smelting intermittent.
South Australian Railways line which ended at the colonial border. All smelters at Broken Hill were closed by 1898 as the oxidised ore was worked out.\textsuperscript{759} It was then more economical to smelt the sulphide ores on the coast at Port Pirie or Adelaide with coal from Newcastle, or to ship the ores to Newcastle for smelting. The cost of raling the ore from the coast to Broken Hill was high.

**Pyrite Smelting**

A new smelting method was developed in Tasmania in the 1890s to process copper ores rich in pyrites. This section will discuss the steps involved in taking a process developed in the United States for partial pyrite smelting and taking it to full pyrite smelting.

In contrast to the discovery of the copper and silver mines on mainland Australia, there were no shepherds in the dense forests along the west coast of Tasmania as prospectors moved into the area around Macquarie Harbour, south of Mt. Bischoff in the late 1870s. Con Lynch and Tom Currie, both with gold mining experience in New Zealand, found alluvial gold in a gully near Mt. Lyell late in 1881. The country was rugged and wet and it was not until January 1883 that Steve Carlson and the McDonough brothers William and Michael pegged a 50 acre lease covering a gossan outcrop on Mt. Lyell which they called the Iron Blow, where they panned fine gold.\textsuperscript{760} James Crotty became a shareholder, the company was restructured as the Mount Lyell Prospecting Company, and the lease was mined for gold with indifferent success. Crotty was also a shareholder in the North Mount Lyell Prospecting Association, which had a lease on the other side of the mountain.\textsuperscript{761} In 1888 Crotty convinced some Launceston financiers to invest in the Mount Lyell company and it was renamed the Mount Lyell Gold Mining Company N.L. The company obtained a geological report from a Sydney geologist, Dr. J. Robertson who reported that the mine was poor in gold and silver but rich in iron pyrites, and also contained a small amount of copper. Robertson recommended that further exploration should be made at depth. However the company, with Crotty as mine manager, continued to work it as a gold mine and lost money.\textsuperscript{762}

In 1891 Bowes Kelly, a shareholder in the B.H.P. Company, and others from Broken Hill visited the mine and arranged for a parcel of pyrites to be sent to Herman Schlapp,

\textsuperscript{759} Blainey, *The Rise of Broken Hill*, p. 89.
\textsuperscript{761} Ibid., pp. 35, 102.
\textsuperscript{762} Ibid., Chapter 5.
then a consulting metallurgist at Broken Hill. His report convinced Kelly and his friends to buy shares in the mine.\textsuperscript{763} On the advice of Schlapp, Dr. Peters, an American expert on copper smelting, was retained to report on the mine. His report, issued in May 1893, recommended thorough prospecting to determine the size and grade of the orebody and that if the orebody was proved sufficient the ore should be roasted in stalls, then smelted in a blast furnace and the matte bessemerised in a converter. However he also suggested that it might be possible to smelt the ore by burning the pyrites.\textsuperscript{764} In March 1892, in preparation for courting the British investor, the old company was liquidated and the Mount Lyell Mining and Railway Company Limited was formed. William Knox, its managing director, went to London in 1893 to sell shares but was unable to convince British investors they should buy. In 1894 a block of ore rich in silver was found, the shares soared in value and sufficient funds for development were raised in Melbourne.\textsuperscript{765} Crotty was embittered because he believed Bowes Kelly and his friends had forced the original shareholders to sell out at a low price in 1891, and had then profited unfairly in 1894 when the shares soared.\textsuperscript{766}

The silver, gold and copper ore was mined cheaply by quarrying the surface orebody, and trucking the broken ore to an orepass, through which it fell to a tunnel below and then trucked to the mill. The west coast of Tasmania was different from most other copper districts in Australia in its high rainfall, which washed away the pyrites exposed at the surface into the rivers, or sank into the surface rocks and the dissolved copper minerals which were redeposited as native copper; there were no surface indications of green and blue stains to indicate copper was present. The pyrites orebody was found near the surface, it was yellowish white in color. Following the policy adopted by B.H.P., the directors sent Knox to the United States where, in 1895, he convinced Robert Sticht to migrate to Tasmania to smelt the pyritic ore.\textsuperscript{767} Sticht and his friends, had experimented with this type of smelting in Montana and Colorado, and when he arrived in Queenstown, the town which had grown up around the mine, he scrapped the plant that was being erected to Peters’ design and instead erected a plant to process the

\textsuperscript{763} Clark, \textit{Australian Mining and Metallurgy}, p. 145.
\textsuperscript{764} Ibid., p. 145-52.
\textsuperscript{765} Ibid., p. 62-6.
\textsuperscript{766} Ibid., p. 68.
\textsuperscript{767} Ibid., p. 74.
ore by pyrite smelting. In pyrite smelting the atmosphere in the furnace is an oxidising one, the sulphides being the fuel, as distinct from pyritic smelting in which the atmosphere was reducing with carbonaceous substances being the fuel. Sticht was successful in operating the plant with a minimum of coal in 1896 and in 1906 claimed his plant - with eleven blast furnaces - was the largest in the world using pyrite smelting. As his ore was deficient in silica to produce a liquid slag he had to supply silica from a nearby quarry. He initially used two stages of smelting with blast pressures of 18 ounces to produce a matte of 45-50 percent copper. After 1903 a cold blast at higher pressure produced matte in one stage followed by bessemerising in a converter to refine the copper to a saleable grade.

In contrast to the success which Sticht was achieving, Crotty set out to do better. He registered the North Mount Lyell Copper Company in 1896 to take over his old company and raised about £70,000 in England. In 1897 a gang of men blasting a road on his lease found a rich orebody of the copper mineral bornite and the shares rocketed in value to about £900,000 He started a railway to the North Lyell mine which duplicated the already built line of the Mount Lyell Company, but he died in 1898 before it was completed. In 1900 John Macarthur, the co-inventor of the cyanide process, and a director of the company, went to Tasmania and recommended the construction of twelve large reverberatory furnaces to be followed by bessemerising. L.C. Trent, an American metallurgist, was appointed general manager to carry out this plan and he erected a concentrating plant which Donald Clark said was totally unsuited to the ore. The reverberatory furnaces were not a success and Trent departed. His successor Mr Lewis erected four small blast furnaces which operated successfully, but the transport costs for the coke they burned were very expensive. In May 1903 the two companies amalgamated, and Sticht took over the two mines. The ores were a good

768 R. C. Sticht, "The Development of Pyritic Smelting," Proceedings of the Australasian Institute of Mining and Metallurgy XI (1906): p. 2-3. Sticht defined pyrite smelting as: "The application of blast furnace smelting to sulphide ores with the definite object of limiting to a minimum or excluding the use of carbonaceous fuels within the furnace and of maintaining an oxidizing atmosphere, the thermal powers of the sulphides being the principle sources of heat."

769 Ibid.: p. 64.

770 Ibid.: p. 68.


772 Clark, Australian Mining and Metallurgy, p. 181.

773 Ibid., p. 182.

774 Blainey, The Peaks of Lyell, p. 158.
mixture for pyrite smelting and Sticht combined them for years. He died in April 1922 as his pyrite smelters were being altered to smelt concentrates produced by the flotation process. The grades had fallen and the pyrite smelting was not economic at the copper prices then being paid. The successes and failures of these developments at Mount Lyell show how internationalised Australian mining had become in the late nineteenth century with United States and British smeltermen contributing to the experiments, some successfully, others less so.

**Electrolytic Smelting**

During the first half of the nineteenth century many scientists in Europe and the United States experimented with electricity, the basic principles of which had been discovered in the previous century. How these simple experiments led to experiments to develop a commercial process for the electrolytic separation of zinc in Australia will be discussed in this section.

The principles of electrolysis were discovered by Michael Faraday in 1835 and were first used industrially to separate copper from its ores by James Elkington at his works at Pembrey near Swansea in 1869. The same principles were applied to separating aluminium from bauxite by the American Charles Hall and the Frenchman P. Heroult, who first made their discoveries independently but combined to develop an industrial process after 1886. Edgar Ashcroft, the British electrical engineer who had worked with Dr. Schnabel in Broken Hill, realised that the separation of zinc from the complex Broken Hill ores by electrolysis was a possibility. Ashcroft was initially financed in Broken Hill by J. Reid (of the Tent Hill smelter, and now a mining financier) and V. Saddler, and they later increased the syndicate to include T. Allan and F. Keating. Keating was a principal of A. Gibbs and Son, London-based merchant bankers with an office in Melbourne. Herman Schlapp, formerly chief metallurgist at B.H.P., was appointed to supervise the Australian development and Dr. Schnabel the work in England. The syndicate was renamed the Sulphide Trust and purchased all the shares of

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the Central Mine at Broken Hill; it also floated two Sulphide Corporations, one in London and one in the United States.\textsuperscript{781} Some 600 tons of Broken Hill ore was sent to the Wylyama Works at Grays in Essex, England, for testing in a pilot plant in which the zinc was leached from the ore by sulphuric acid. Dr. Schnabel supervised the test run at Grays and reported there were no problems in working a full scale process.

A full-scale plant was erected at Cockle Creek, near Newcastle in Australia, in 1897. The dried slimes containing zinc were railed and shipped there and Dehne filter presses from Germany were used to separate the zinc liquor from the leady residues which were then smelted at Cockle Creek. By 1897 the electrolytic plant was producing good zinc but there were occasional problems with a phenomenon called ‘spongy zinc’ and the metal pipes corroded rapidly. The Sulphide Corporation in London had appointed an Advisory Board in Melbourne to control the Australian operations. In a panic that funds were running short the Melbourne Board closed the plant and this effectively prevented the London Board raising further capital to complete the development of the process when the news reached London. The Cockle Creek plant was then developed as a conventional smelter of lead concentrates from Broken Hill. This was the first attempt worldwide to produce zinc metal by electrolysis and its failure caused consternation in mining circles as confidence in its success was high after the pilot plant in England operated without difficulty. The Broken Hill mines continued to dump the zinc residues, both tailings and slimes, from the gravity concentration and to look for other solutions.\textsuperscript{782}

The causes of the failure of the Ashcroft process so near to success are complex but the following problems may have contributed:

1. The promoters of the Sulphide Corporation, both in London and in Australia, were more interested in making a quick profit from share dealing than creating a long term industry. The brother of J. Reid wrote to his wife expressing his thanks to God for being able to amply provide for his wife and children after the Sulphide Corporation was floated in the United States, doubtless with

\textsuperscript{781} J. W. Turner, \textit{Manufacturing in Newcastle, 1801 - 1900} (Newcastle: Council of the City of Newcastle, 1980), pp. 83-4. The capital raised was in 500,000 preference shares and 500,000 ordinary shares of £1 each fully paid. The Sulphide Trust received all the ordinary shares in return for the Ashcroft patent and the Central mine. A further 100,000 shares were sold to pay the Trust for the American patent rights.\textsuperscript{782} G. Blainey, \textit{If I Remember Rightly - the Memoirs of W. S. Robinson}. (Melbourne: Cheshire, 1967), p. 40. Robinson said the zinc tailings framed the horizon at Broken Hill in 1905.
considerable profit to the existing shareholders.\textsuperscript{783} When Ashcroft struck difficulties the Melbourne Board was overly quick to close the plant and stop further losses.

2. The creation of a London Board and an Australian Board, both of which made independent decisions about the project, must have created problems for the operating staff at Cockle Creek. Herman Schlapp was advising the Australian Board while Ashcroft was communicating direct with the London Board. Schlapp was antagonistic to Ashcroft’s conservative development and wanted faster development.\textsuperscript{784}

3. Too much was expected of Ashcroft; he was the inventor-designer of the plant, the project manager and the general manager at the same time. Ashcroft asked to be relieved as general manager early in 1896 but the London Board did nothing.\textsuperscript{785}

4. Ashcroft was developing a new technology on a large scale and had few precedents. Plant operation with good deposition of clean zinc was achieved but suddenly, for unknown reasons, spongy zinc was deposited and the reasons were not isolated. This caused loss of confidence by the directors.\textsuperscript{786}

5. The plant at Cockle Creek was designed by Ashcroft on reported assays that the ore contained 45 ounces of silver, 30 percent lead and 30 percent zinc. No systematic assaying of the orebody was made and it was assumed that those grades would exist for the life of the mine. Unfortunately the grades decreased as the mine deepened. The slimes treated at Cockle Creek at the start of the trials contained 16.5 ounces of silver, 24 percent lead and 26 percent zinc and reduced further during the trials as improvements were made in concentration methods at Broken Hill with less minerals in the slimes. The reduced grade lowered the output of metal at Cockle Creek and made the process barely economical instead of producing the substantial profits predicted in the prospectus. Ashcroft considered this as the major reason the plant was closed.\textsuperscript{787}

The failure of this process caused much discussion in the mining industry and led to better sampling of orebodies and more careful estimates of the amount of minerals in

\textsuperscript{783} Turner, \textit{Manufacturing in Newcastle, 1801 - 1900}, p. 84.
\textsuperscript{784} Ibid., p. 86.
\textsuperscript{785} Ibid., p. 87.
\textsuperscript{786} Ibid., p. 89.
an orebody. Nearly twenty years later the same process was improved and used to refine zinc concentrates from Broken Hill using cheap electric power in Tasmania. 

Conclusions

As mining extended into the sulphide zone below the water line the ores extracted became more complex, with more minerals intermixed and with finer grain size. Methods of fine grinding to separate the minerals, and gravity concentration of particular minerals and to prepare them for smelting, were developed. However by the mid 1890s the grinding was so fine in both metalliferous mines and in some gold mines with refractory ores that sliming became a major problem. In gold mining the fine grinding of pyrites to separate the gold resulted in increased losses as the finer gold particles were washed away in the processing water. Chlorination was being used successfully in eastern Australia to extract some of the gold from ironstones and other refractory ores, but it was proving difficult to percolate the solutions through finely crushed material containing slimes. Cyaniding was successful in extracting fine gold from coarse tailings but again slimed material was proving difficult to treat due to percolation problems. Slimes from the fine crushing of copper sulphide ores could be treated by spreading the slimes on the surface and allowing the sulphides to oxidise but this was a slow and costly process. At Broken Hill tailings and slimes from the gravity concentration processes contained lead, silver and zinc sulphides, and were stacked in separate heaps totalling millions of tons in the hope that a method of treating both would soon be found. A failed attempt to use electrolytic methods to extract zinc metal from slimes dampened the enthusiasm of mining companies to undertake basic research in Australia. Tin ore was believed to be free from the sliming problem although questions about the amount of sliming went unanswered.

The introduction of blast furnaces of United States design for smelting silver lead concentrates and copper concentrates generally proved successful and was usually cheaper than smelting in reverberatory furnaces. However the failure of a blast furnace at the Burraga copper mine and the subsequent use of a reverberatory furnace showed that introduction of new technology without careful assessment of the type of ore could lead to failure.

788 These developments will be discussed in Chapter 8.
The increasing employment from 1890 of engineers, metallurgists and chemists from Britain, Germany, Australia and the United States at mines in Western Australia, New South Wales and Tasmania, together with the introduction of management companies, to develop new processes to treat complex ores is an indication of the increasing internationalisation of mining in Australia in this period. This was due to the investment of British and European capital in Australian mines by companies, registered in London, with directors who had little knowledge of the detail of mining technologies. This international investment showed up a weakness in the no-liability companies when London investors claimed their shares were sold at auction for non payment of calls when they had not yet received notice of the call.\textsuperscript{789} However in the other colonies with smaller overseas investment, the mines were still mainly owned by local investors and managed increasingly by Australian-trained technologists.

When rich gold ores were discovered in Western Australia in the early 1890s the British capital market became interested in investing in mining after mid 1894. Some of the floatations were fraudulent and some of the mines were poor but there were sufficient rich mines to maintain the interest of British and European investors. As these investors were inexperienced in mine management many of the boards of the companies employed the management company Bewick Moreing to manage their mines. Other companies employed their own engineers and metallurgists. The period from 1894 to 1905 was a period of continuous experiment to find a successful method of treating the complex ores with the newly developed cyanide process. This process had been discovered using the methods of science but it still required much adaptation to suit a particular type of ore, and failure could occur when insufficient time and money was spent on thorough testing before the full-scale plant was built. How scientific principles and experimental methods were combined to finally solve the problems of sliming will be discussed in the next chapter.

\textsuperscript{789} Discussion with John Hillman of Canada re complaints by English investors in South East Asian tin dredging no-liability companies registered in Melbourne (email 9 Feb. 2005).
Chapter 8

Solving the Slimes Problem 1890 - 1915

Introduction

In the final three decades of the nineteenth century the efforts of millmen on the Australian mineral fields to solve the problems of separating the finely disseminated minerals in complex ores by fine grinding resulted in the seeming ‘dead end of ‘slimming’. Sliming resulted when some of the finely ground minerals were lost in the processing water and then could not be easily separated from each other when water was removed from the slime. Also the sandy tailings produced in the concentrating process often contained appreciable amounts of minerals in the form of middlings with the minerals locked up in particles with gangue. Chemical methods to selectively remove one mineral often failed because other minerals also reacted with the chemical used.

On many fields across Australia, the waste dumps of slimes and tailings contained great riches but new or modified technologies were needed to realise this wealth. Advances in the use of chlorine and weak solutions of potassium cyanide in water had solved most of the problems with pyritic refractory gold ores in eastern Australia by the late 1890s but disputes persisted on how to best deal with the telluride gold ores at Kalgoorlie. No solution was in sight on how to separate the lead and silver sulphides from the zinc sulphide in Broken Hill ores, and the massive tailings and slimes dumps were a constant reminder of the problem.

The problems with the refractory gold ores of eastern Australia, the telluride gold ores of Kalgoorlie and that of zinc recovery at Broken Hill were largely resolved in the years up to the beginning of World War I in 1914 by two macro-innovations of international importance. The Collins House Group, a loose consortium of Broken Hill companies, revisited the problem of separating zinc metal from zinc concentrates and developed a new Australian industry during and after World War I. How these major developments were achieved is the subject of this chapter.
Chlorination and Cyaniding

Industrial chemistry developed in Britain, France and Germany in the early eighteenth century for the manufacture of alkalies, dyes and sulphuric acid. By the 1840s Professor Plattner at the Freiberg Akademy was testing chemical processes for the extraction of minerals from ores. Chemical methods were first tried in eastern Australia in the mid 1860s when Dr. Ottway experimented unsuccessfully with lixiviation to separate silver from the refractive St. Arnaud ores and he later experimented with the Plattner chlorination process on gold ores at Blackwood in central Victoria. As discussed earlier De Lacy patented a variation of the Plattner process in Victoria in 1864 and it is likely a plant to his design was built at the United Pyrites works in Bendigo in 1876 after it was realised that crushing of the pyrites followed by amalgamation failed to extract more than half the gold in the pyrites. In the mid 1880s, after further experiments at the United Pyrites works in Bendigo, the Newbery-Vautin process was patented but it was a costly batch process. This process was tried on oxidised ironstone gold ore in 1884 at Mt. Morgan, in Queensland, but difficulties were encountered with processing the large amount of ore and some of the equipment was incorporated with success by the company staff in a modified barrel leaching process in 1887. This process was used until the gold orebody was worked out in 1911.

Chlorination plants were distributed in strategic locations on the goldfields of eastern Australia to treat refractory ores. As the amount of pyrites in most ores was of the order of a few percent of the ore crushed, the number of plants did not need to be large to treat all the pyrites available. By 1890 most mines with refractory ores were crushing the pyrites fine enough to be experiencing a sliming problem and were experimenting with very sophisticated mechanical methods such as vanners to separate the slimes and the contained gold from the tailings. These slimes were so fine that they packed in the vats used for chlorination and cyaniding, and the solution could not penetrate the dense mass. Joel Deeble, the metallurgist at the United Pyrites plant in Bendigo, experimented

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in the 1890s with an agitator to stir the slimes in the vat so the chemicals could get to the gold to dissolve it. He later sold some nine of these plants throughout the Australian colonies including two to the mines at Kalgoorlie and two at Maldon, which were fine crushing their ores for cyanide plants, but it is likely he first developed them for chlorination.  

By the 1890s some mines in eastern Australia, with very refractive ores, were installing chlorination plants to replace the system of fine crushing the pyrites followed by amalgamation and then sending the residue still containing gold to the pyrites plants for further treatment. At the same time they installed cyanide plants to treat old oxidised tailings, and later fresh sandy tailings which could be treated more cheaply by the newer cyanide method. On some fields such as Charters Towers cyaniding had replaced chlorination by 1897 because the ore there was suitable for the cyanide process. However very refractory ores elsewhere were still being treated by chlorination until after World War I.

As an example, the Lord Nelson Mine at St. Arnaud began paying dividends in 1888, one year after Zebina Lane (Snr) was appointed manager. The company had previously sent small amounts of pyrites concentrates to Freiberg at a profit but Lane introduced fine grinding using Wheeler’s pans, followed by amalgamation. By 1890 he was sending the residue from this process to Bendigo for further treatment by chlorination. Early statistics of the mine production are not available but the Victorian Mines Department published some figures of the mine’s output between 1905 and 1915 the year the mine closed. These figures have been collated as 75,203 oz. by amalgamation, 13,549 oz. by chlorination, 20,186 oz. by cyaniding old tailing dumps and 572 oz. by pan amalgamation of pyrites. Apparently pan amalgamation was abandoned soon after 1905 and then all pyrites was treated by chlorination at the mine. The percentage of pyrites in the ore was up to 20 per cent. The figures show 18 per cent of mine production in this period was obtained by the chlorination process between 1905 and 1914.

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The chlorination process for the extraction of gold has been mostly ignored by mining historians in recent years as the returns were overshadowed by those from the cyanide process after 1900, but the use of this chemical process was important in the development of gold mining technology in eastern Australia from the early 1870s. Although the tonnages of pyrites treated and the gold recovered was not as large as that recovered by amalgamation of the free gold, the income from chlorination was additional income, not otherwise available to a company mining refractory ores. Often it was the difference between paying a dividend or struggling to survive.

While there were never a large number of chlorination plants from 1876 in eastern Australia compared with the cyanide plants after 1900, the experience gained by metallurgists and mine managers who worked in the chlorination plants, which were located across eastern Australia, would have given them an understanding of how chemistry could be relevant to the efficient extraction of gold from complex refractory ores.

Jan Todd has criticised the slow acceptance of the cyanide process in Australia compared with the short time of introduction in South Africa and New Zealand. She wrote:

> The transfer of cyanide gold extraction benefited from the sharing of common institutions, language and culture and from the ready flow of people. A multitude of colonial connections were able to smooth away early obstacles in the patent system. More difficult was the distance between the practices of Australian goldmining and the leading edge of the technology frontier which this chemical process represented despite some pockets of experiment with chlorination, the vast bulk of the goldmining industry was ignorant of chemical extractive processes and the scientific principles which governed them. These were considered the province of the much maligned ‘theorists’. This is an oversimplification of the situation in eastern Australia in the uptake of chemical processes in the second half of nineteenth century.

Todd concedes that colonial Australia showed an ability to change course, to cross the divide between old and new trajectories and to transfer and adapt technologies. Although there were undoubtedly some mine managers and others who were ignorant of the chemical methods after 1890, it is unlikely they were the majority as Todd suggests.

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798 As discussed in Appendix 3 the adoption of the chlorination process in the United States preceded its use in Australia by some twelve years.
800 Ibid., p. 207.
In fact chlorination and cyaniding were adapted in parallel; chlorination was the earlier process and chlorination plants were distributed widely enough to educate mine managers and their staffs in chemical methods of ore treatment. In the first quarter of the twentieth century some mines with refractory ores operated both chlorination and cyanide plants, the chlorination plant to extract fine gold from pyrites and the cyanide plant to extract fine gold from tailings. Ignorance was not the reason the cyanide process was adopted slowly. More important was the complexity of many gold ores, the cost of the royalty, the uncertainty of the validity of the cyanide patents, the 1890s depression in Victoria (with the squeeze on capital for new developments) and the need for time to adapt the cyanide process to complex ores. The sponsors of the cyanide process had to prove that their system was the cheaper something they did not always succeed in doing so.\textsuperscript{801}

**The All-Slimes Process at Kalgoorlie**

The inflow of European capital and concentration of technologists from Europe, Australia and the United States to the Kalgoorlie field resulted in a relatively rapid solution of the technical problems of adapting the use of weak cyanide solutions to extract the fine gold from the rich gold ores after the discovery of the field in 1893. As mentioned in the previous chapter J. T. Marriner, the manager of the Great Boulder Main Reef mine, built a new plant in 1900. The finely ground roasted ore was mixed with a dilute cyanide solution to form a pulp, which was elevated by a tailings wheel to a spitzkasten. Here some of the soluble sulphates produced by roasting were carried off in the overflow and the underflow was separated in a classifier into coarse sand and slimes. The sand was then ground into slimes in Wheelers pans and any coarse gold amalgamated with mercury, while the rest of the sulphates were carried off in the pan overflow. The slimes from the pans and those from the classifiers were combined and agitated in vats with a weak cyanide solution for eight to twelve hours. The pulp went to filter presses, the gold solution was extracted, clarified in another filter press and the gold precipitated in zinc boxes. The main features of this post-roasting process were adopted by the majority of mines on the Golden Mile, which chose dry crushing and

\textsuperscript{801} Ibid., p. 133.
roasting in preference to wet treatment methods. These features remained virtually unchanged for another thirty years.\textsuperscript{802}

Despite the technical success of the Diehl process discussed in the previous chapter, and its similar cost to the dry process, this process was adopted only by three of the many Kalgoorlie mines. 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 roast and crush process and had ordered machinery for it; secondly, there was strong opposition to the payment of royalties on cyanide or bromocyanide; and thirdly, some mines preferred to continue with MacArthur’s cyanide practice and to add bromocyanide only when it proved necessary.\textsuperscript{803}

The problems of extracting the gold from the sulphide ores at Kalgoorlie by grinding all ore to slimes and then cyaniding had been solved by 1904, but the use of the filter press was labour intensive as the press had to be opened after each batch. Attention then turned to using vacuum filters and automating the cyanide process. As Hartley describes this was achieved by 1907 with a notable contribution in developing a vacuum filter by George Ridgway, the engineer at the Great Boulder mine. Other engineers in South Africa and the United States contributed to this and later vacuum filter developments.\textsuperscript{804} Hartley’s opinion is that gold metallurgy developed rapidly in the years from 1905 to 1915, largely as the result of constructive competition and collaboration between engineers and metallurgists from Great Britain, Australia, New Zealand, South Africa and increasingly from the United States.\textsuperscript{805}

While these developments in gold metallurgy using weak solutions of potassium cyanide were taking place in Kalgoorlie, a completely different approach to solving the separate extraction of the minerals was being developed in Broken Hill to treat the silver-lead zinc ores by flotation. Before this is discussed it is relevant to consider a short-lived electromagnetic method of concentrating and the use of a reducing furnace for smelting the zinciferous residues and the methods of smelting the lead-silver gravity concentrates at Port Pirie.

\textsuperscript{803} Ibid., p. 369.
\textsuperscript{804} Ibid., chap. 6.
\textsuperscript{805} Ibid., p. 247.
Methods of Treating Early Broken Hill Concentrates

By the early 1890s the Broken Hill Proprietary Co. was aware that the oxidised lead and silver ore would soon be worked out, so in 1892 the Port Pirie smelter of the British Broken Hill Company was purchased and from 1897 the gravity concentrates of lead-silver ore were transported by rail and smelted there. The Broken Hill smelter was closed. After the other Broken Hill companies closed their smelters around the same time they sold the gravity lead-silver concentrates to European smelters. Three German firms, working in co-operation with German banks, purchased these concentrates and gained near monopoly control of lead smelting, the Port Pirie smelter being the main opposition in Australia.

The problem of separating the gangue from the zinc sulphide led to a search for other solutions than gravity methods. Faraday had discovered many years earlier that some minerals were attracted by bar magnets, others were repelled and some were neutral. The first type he called para-magnetic the second dia-magnetic. In the 1890s several inventors endeavoured to adapt the science of electromagnetism to the separation of minerals, including the separation of zinc sulphides from the rhodonite and garnet gangue of the Broken Hill ores. The Mechernich Electro-Magnetische Gesellschaft of Germany developed these ideas into a commercial machine in the 1890s. The Australian Metals Company, financed by German interests, installed electro-magnetic separators in a new plant at Broken Hill in 1898 and the Sulphide Corporation followed in 1901. Both plants were later upgraded with improved machines and operated successfully, treating dumped material until 1907, when improvements in the flotation process made them obsolete. Another plant treated material from the Pinnacles mine near Broken Hill for a short period. The material was treated dry and all plants created a

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807 P. Richardson, “The Origins and Development of the Collins House Group, 1915-1951,” Australian Economic History Review: pp. 14-5. The three firms were Metallogesellschaft AG, Beer Sondheimer and Aaron Hirsch und Sohn who had mineral interests in every continent. They were called the ‘Trio’.
great amount of dust. Slimes could not be treated. The Australian Metal Company sent the concentrates to Europe for smelting in distillation plants in Belgium, France and Germany, all controlled by German interests, while the Sulphide Corporation produced zinc metal at Cockle Creek in a small distillation plant from 1902 (see below).

The peculiar problem of zinc, which resulted in the formation of zinc oxide when zinc sulphide was smelted in an oxidising atmosphere, had been resolved by European metallurgists in the nineteenth century. The solution was to mix the roasted sulphide with coke in small clay retorts inside a furnace by a preheated gaseous fuel. Each retort held about one hundredweight of the mixture. The reducing atmosphere inside the retort resulted in the zinc distilling off and then liquefying in the small receivers at the end of each retort. The residue left in the retort was a mixture of coke, lead, silver and about one fifth of the original zinc. This mixture could be smelted in a blast furnace but all the remaining zinc was lost. The use of small retorts made of clay was very labour intensive, working around the furnaces was unpleasant in summer and it was difficult to find labourers to do this work in Australia. Some 50,000 tons of zinc metal were produced in Australia by this method.

B.H.P. did not become involved in electromagnetic concentration of zinciferous residues as it was already experimenting with flotation. In the early years of the twentieth century the B.H.P. mill at Broken Hill was producing four products: slimes (sent to the sintering works for roasting), coarse tailings containing zinc (sent to the dumps after passing over shaking tables to remove as much zinc sulphide as possible), fine tailings (sent to the zinc concentrator), and lead-silver concentrates sent to the Port Pirie smelter. The slimes were settled in large tanks and then spread as a thick sludge about one foot deep alongside the railway. After drying the plastic sludge was cut into blocks, loaded into railway trucks and taken to the sintering area five miles from the town. Here the blocks were stacked in heaps, plastered over with slimes and a small wood fire ignited. The sulphides in the slimes ignited and burnt for 15 days, during which the calcined material formed hard lumps of composition about 14.5 percent lead, 12.5 percent zinc, 7 percent sulphur and 15.8 ounces of silver which were smelted in

812 Clark, Australian Mining and Metallurgy, pp. 434-7.
813 Ibid., pp. 436-7.
814 Woodward, “A Review of the Broken Hill Lead-Silver-Zinc Industry,” pp. 283-4. This was Belgian and German technology.
Port Pirie. The fine tailings and the material from the shaking tables was sent to the zinc flotation plant which was then being developed (described in the next section). Part of the zinc concentrate from the zinc flotation plant was sold overseas and the remainder roasted, the fumes being used to make sulphuric acid for the flotation plant, the residue was sent to Port Pirie where the zinc was recovered in a small zinc distillation plant.\textsuperscript{815}

The lead concentrates delivered at Port Pirie were roasted in Ropp furnaces, the roasted material was sent to cast iron pots where a blast of air oxidised the sulphur.\textsuperscript{816} The residue was fed to a blast furnace, mixed with sintered slimes, ironstone and limestone as flux and smelted. The charge averaged 17 percent lead, the output was about 95 percent of the lead, 98 percent of the silver and nearly all the gold.\textsuperscript{817} This complex system of refining the concentrates was greatly simplified by the development of the flotation process for the production of lead and zinc concentrates. The beginnings of this process for the production of zinc concentrates has already been mentioned but the full development will be discussed in the next section.

A small zinc distillation plant was built by G. Delprat at the Port Pirie smelter about 1905, but this plant was abandoned in 1921 when an electrolytic smelter was operating successfully in Tasmania. The Cockle Creek zinc plant was closed in 1909 and production transferred to Seaton Carew in England where cheaper labour was available.\textsuperscript{818} After 1905, English interests became more involved in the processing of Broken Hill ores. Increasing co-operation between the English group involved with the Zinc Corporation and Broken Hill mining companies led the latter to form a loose grouping, often called the ‘Collins House Group’ (discussed later in the chapter).

**The Development of the Flotation Process**

At the beginning of the twentieth century earlier predictions that the metallurgical problems of separating the minerals in the Broken Hill ores would soon be solved, had


\textsuperscript{816} Delprat, “Ore Treatment at the Broken Hill Proprietary Mine,” p. 19.

\textsuperscript{817} Delprat, “Ore Treatment at the Broken Hill Proprietary Mine,” p. 19.

Gravity separation methods were recovering only part of the lead and silver; most of the zinc (with a considerable proportion of the lead and silver) was being dumped in the hope that some method of separating the three minerals would be found in the future. The problem was solved in the next ten years but the documentation of how this was done is less than complete. Most of the many articles written on this subject have been the work of individuals or small groups who were participants in the process, who did not know the total picture and who unintentionally gave biased accounts of the development. As will be described in this section a significant contribution to the development of the flotation process, as it came to be called, was made by the staff of Minerals Separation Limited working in London, Melbourne and Broken Hill, who published little of their contribution.

In the nineteenth century several observers noted that sulphide minerals collected as a scum at the top of a liquid during experiments with the separation of ores. Early patents were taken out in the United States by Hezekiah Bradford in June 1885 for a surface tension process (U.S. patent No. 345,952), and in August 1885 by Carrie J. Everson (U.S. patent No. 348,157) for an oil flotation process. These patents were never developed commercially and lapsed. The next developments took place in England, where Francis Elmore patented a process using large amounts of oil mixed with crushed ore to separate a sulphide mineral from gangue (British patent No. 21,948 of 1898 and

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819 Sir Henry Ayres, "President's Inaugural Address," Transactions of the Australasian Institute of Mining Engineers Vol. 1 (1893): 23. When seconding the motion of thanks to the President at the inaugural meeting of the Australasian Institute of Mining Engineers in 1893, Zebina Lane Jr. predicted that the sulphide problems at Broken Hill would be solved within a few months.

820 The role of Minerals Separation has been mentioned by several authors but because the company policy was not to publish details of their processes details of the role are incomplete. See G. Blainey, The Rise of Broken Hill (South Melbourne: Macmillan, 1968), p. 72.

821 A series of articles on the flotation process in Australia were published in the Transactions of the Australasian Institute of Mining Engineers between 1913 and 1940 by single and multiple authors most of whom were employees of Broken Hill mining companies. The only published paper by a member of staff of Minerals Separation Ltd. that I have located was by Walter Broadbridge, the chief engineer in London, in the Journal of the Institute of Mining and Metallurgy in 1920. It described the mechanical plant developed to that date.

822 A few years ago the records of the Melbourne office of Minerals Separation Ltd. a company registered in London, were lodged in the University of Melbourne Archives. A study of the contents of these records has enabled a better understanding of how the flotation process was developed. The records are grouped in files, each relating to a member of staff, a customer company or a supplier. Individual references will be made in relation to the file in which the document quoted, is found.
U.S. patent No. 653,340 of April 1899). Alcide Froment, an Italian, patented a process to float sulphides using oils and air (British patent No. 12,778 of June 1902).\textsuperscript{823}

The problem of the millions of tons of sulphide minerals being dumped at Broken Hill exercised many minds at the turn of the century. Vincent Potter, a Melbourne chemist, developed a process where he mixed sulphuric acid with the sulphide tailings from the gravity processing in a hot solution. The gas bubbles produced from other compounds in the tailings floated the sulphide particles to the surface, from where they were collected to give a zinc rich concentrate containing a small amount of lead and silver. Most of this lead and some of the silver could be then removed by jigging. He patented the process (Victorian patent No.18775 of 1901). This process was used to treat 49,000 tons of budle tailings on the B.H.P. Block 14 mine between 1903 and 1905. The zinc concentrate contained 47 percent zinc and the recovery from the ore was 78 percent.

The plant initially used a Goyder-Laughton patented scraper to collect the concentrate, but corrosion was rapid in the hot acid and the inability of this machine to handle large tonnages led to this machine being replaced by Delprat’s cast iron box method in March 1904.\textsuperscript{824}

Towards the end of 1902 G. Delprat, and his chief chemist A. Carmichael, at B.H.P. were experimenting with dissolving the zinc compounds out of tailings, by using the acid cake, sodium hyposulphate, which was left over from the lixiviation process to dissolve silver. As Carmichael had forecast this was a failure, but Delprat noticed a heavy scum on the surface and on checking found it to be zinc sulphide. He realised the importance of this discovery and soon developed a plant to treat 1000 tons of tailings per week using an acid solution at near boiling temperature. His patent (Australian patent No. 8082 of 1902) was effectively the same as Potter’s process.\textsuperscript{825} Potter formed the Potter Sulphide Ore Treatment Company Ltd. and then sued B.H.P. for

\textsuperscript{823} Copies of these patents are included in M.S. Papers, Files 5 and 38. A complete list of flotation patents up to 1914 can be found in T. J. Hoover, Concentrating Ores by Flotation, 2nd ed., The Mining Journal, London, 1914.


infringement. The judge decided that the Potter patent was invalid because the patent application was badly worded, but if it had been valid Delprat would have infringed. The decision was appealed but before it went to court the two companies reached agreement that B.H.P. would have free rights to use both patents on its own tailings while Potter’s company had the right to license both patents worldwide. The process was then called the Delprat – Potter process. Delprat was interested only in treating his own ores and as the method was economical in producing a zinc concentrate which could be smelted he was not very interested in further developing the process. Initially slimes could not be treated but E. J. Horwood, the works manager at B.H.P., soon introduced a pump in the circuit to break the bubbles produced from calcite in the ore to keep them small, which allowed the bubbles to pick up slime particles and float them. Up to 1914 the company treated two million tons of tailings and slimes to produce 459 000 tons of concentrate averaging 46 percent zinc, 8 percent lead and 13 ounces of silver per ton. Later individual staff of B.H.P. made further improvements and were allowed to patent these in their own names. Some of these are discussed later. Potter died in 1908; his process was successful at Block 14 mine but when it was tried by the newly incorporated Zinc Corporation in 1906 in a plant on the British mine lease it was not a success.

Delprat experienced difficulties in maintaining the float in his process and employed Auguste De Bavay, a Melbourne chemist and brewer, to solve the problem. De Bavay found the loss of float was due to organic material in the feed. While working on the problem he noticed that sulphides introduced gently onto the surface of the acid solution would float while the gangue settled to the bottom. After completing his work for Delprat he developed this observation into a workable system of separation of sulphides using the property of surface tension of the liquid to float off the sulphides. He patented this process in 1904 (Aust. Patent No. 6239) and with his brewery contacts (including Montague Cohen and William Baillieu) formed the De Bavay Sulphide Process Company Ltd. and introduced the method to the North Mine in 1906, Cohen and

827 Hoover, Concentrating Ores by Flotation, pp. 109-10.
828 Ibid., p. 110. The Zinc Corporation, recently formed, bought a tailings dump on the British mine lease and built a plant to treat the dump on the lease. D. P. Mitchell, "Flotation at the Zinc Corporation, Ltd.," The Engineering and Mining Journal 92, no. 18 November 1911: p. 994. A lead lined flotation box or spitskasten was used similar to Delprat’s method.
Baillieu being directors of that mine.\textsuperscript{830} The first plant could treat 300 tons of tailings per week and a new plant built later could process 1700 tons per week. The company was later refloated as the Amalgamated Zinc (De Bavay) Company Ltd. which erected a large plant on the North Mine lease to treat the gravity tailings from that mill at the rate of 1800 tons per day in 1910. This plant could not treat slimes which were separated out and dumped.\textsuperscript{831}

Meanwhile in England in November 1902, Arthur Cattermole patented a process in which a large quantity of oil was mixed with crushed ore to cause the sulphide particles to coalesce and sink to the bottom of the container while the gangue of lower specific gravity could be washed out of the top of the container (British patent No. 26, 295). This was not a flotation process as later understood by that term, but attempts to develop this process commercially led directly to froth flotation and for that reason the invention was important.\textsuperscript{832}

Minerals Separation Ltd. was registered in London by John Ballot in 1903. By arrangement with the Sulphide Corporation an experimental plant was erected on their lease at Broken Hill in June 1905 to develop the Cattermole process, Minerals Separation having purchased the patent rights.\textsuperscript{833} A laboratory was erected in England and the company’s chemists and metallurgists at both plants began experiments with Broken Hill ores, concentrates, tailings and slimes. It was soon discovered at both plants that under certain conditions, the sulphides floated to the surface and the gangue settled to the bottom of the Cattermole cell.\textsuperscript{834} In 1903 H. L. Sulman and H. F. Picard, English chemists who were shareholders in Minerals Separation, had invented a process of oil concentration in which they introduced bubbles of air or other gas, and oil in the form of a spray into freely flowing acidulated pulp. When Cattermole’s method failed in 1905 the plant was altered to use Sulman and Picard’s invention which was patented by Ballot, Sulman and Picard (English patent No. 7803 of April 1905).\textsuperscript{835} This modified plant ran for two years, with an average recovery of 72 percent zinc in a high grade

\textsuperscript{831} Hoover, \textit{Concentrating Ores by Flotation}, p. 117. The concentrate assayed 48.5 percent zinc, 6.4 percent lead and 5.9 ounces of silver in 1909.
\textsuperscript{832} Ibid., p. 26.
\textsuperscript{833} Ibid., p. 10.
\textsuperscript{834} Hebbard, "Evolution of Minerals Separation Process on Central Mine," pp. 87-100.
\textsuperscript{835} Hoover, \textit{Concentrating Ores by Flotation}, pp. 10-11.
concentrate. G. A. Chapman was in charge of the experiments at Broken Hill while H. Higgins ran the English laboratory. Both plants were in close contact and the emphasis of the research was changed to floating the sulphides; further work showed that quite small amounts of oil and acid, less than one percent of the ore in each case, would give excellent froths to float the sulphides and that several oils and acids were effective. The first plant could treat 400 tons per day. The Sulphide Corporation then built a second plant to the low-oil design in a new mill, to separate lead and silver by gravity and zinc by flotation from current tailings with a capacity of 900 tons per day. Minerals Separation purchased the remainder of the Central mine’s accumulated zinciferous tailings and erected a third plant, with a capacity of 900 tons per day, to treat this material with the low oil method. The first plant was demolished and a fourth plant erected to treat accumulated slimes containing lead, silver and zinc from Block 10 and the Central mine. The combined concentrate from this plant proved difficult to smelt and the plant was a commercial failure. The last of these plants closed in 1913.

In 1905 Herbert Hoover and a group of English and Australian financiers formed the Zinc Corporation in Melbourne with the aim of treating some of the Broken Hill slime dumps which had been purchased by Hoover as a speculation, and any other dumps they could purchase. As mentioned earlier they tried the Potter process in a plant built on the British mine lease in 1906 with lead lined spitzkasten but the process was a costly failure. The company then modified the plant to use the Ballot low oil process but this also failed to produce a satisfactory concentrate. Finally the company tried an updated version of the Elmore process which had been invented in England by Francis Elmore and improved by his brother Alexander (British patents Nos. 6,519 of March 1901 and 13,578 of June 1904). This process was marketed by the Ore Concentration Syndicate Ltd. It was an elegant engineering design with the bubbles rising under a vacuum to float the sulphides in an oil rich mixture. The oil was then burnt from the concentrate and some lead was removed by vanners and Wilfley tables. The plant on the Zinc Corporation lease at the south end of the lode was a success on the zinc rich tailings and slimes being treated. This plant was phased out in 1911 after comparative trials

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836 Ibid., pp. 34, 11-12.
837 The First Fifty Years - the Zinc Corporation Ltd., (London: Consolidated Zinc Corporation Ltd, 1955), n. p. This group of Australian financiers was later known as 'The Collins House Group' from their adjacent offices in Collins House in Melbourne.
838 Mitchell, "Flotation at the Zinc Corporation, Ltd.,” pp. 994-6. 630 000 tons were treated by the Elmore plant.
against a further improved Minerals Separation plant on slimes containing a lower percentage of zinc. The Ore Concentration Co. believed that mechanical perfection had been achieved in their process well before this contract and made little attempt to improve the performance of their machines while Minerals Separation was constantly improving its methods.

Minerals Separation Ltd. had teams of chemists, metallurgists and engineers at work on improving their processes both in Australia and England. G. Chapman returned to England and Henry Lavers became the senior metallurgist in Australia, reporting to T. J. Hoover the general manager of the company. He was the elder brother of Herbert Hoover and was appointed to this position in 1906. After working at the Sulphide Corporation in Broken Hill for some time he operated from London, receiving monthly reports from Lavers and other staff members who were sent to Broken Hill to gain experience. Henry Howard Greenway opened the company’s Melbourne office in 1909, and supervised a test plant in South Melbourne as well as controlling the work of the company. This work had previously been supervised by the firm of Gibbs, Bright who were Melbourne solicitors. Henry Lavers then corresponded direct to H.H. Greenway. Edward Nutter, an American, was posted to Broken Hill for experience prior to returning to the west coast of the United States to supervise the company’s operations there.

Many metallurgists, chemists and engineers contributed to the development of the flotation process in the early years of the twentieth century in Broken Hill and elsewhere. Several of the most important of them are named in the many published articles about flotation and their contributions will be assessed later in this thesis. Others like Lavers worked for firms who had a policy of secrecy about new developments in an

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841 Henry Lavers had been trained in metallurgy at the Stawell School of Mines. See "The Australian Mining Standard," 7 July 1898, p. 3061.
842 M.S. Papers. File 83b. Lavers first report to T. Hoover was written in January 1909 advising that Harvey and Higgins had arrived from London, Harvey was to take charge of grinding at the M.S. plant while Higgins was to assist James Hebbard the manager of the Sulphide Corporation plant.
843 Ibid. File 35 letter H. Greenway to London office 22 September 1909. H. H. Greenway was a chemist who was an expert in patents who is believed to have previously worked in New Zealand for MacArthur’s cyanide company. He should not be confused with T. J. Greenway, no relation, who worked for the Block 10 mine on flotation matters. H. H. Greenway opened his office in Melbourne next to that of Gibbs Bright the local branch of A. Gibbs & Sons of London, metal buyers.
844 Ibid. File 96 letter H. Greenway to H. Lavers, 4 April 1910.
attempt to gain commercial advantage, and they did not publish any papers. In general the mining companies in Broken Hill did not adopt this policy and allowed their staff to publish relevant papers. The Minerals Separation Papers show that Henry Lavers made a significant contribution, but he has received little recognition for his work.\textsuperscript{845} From early in 1909 he was in the forefront of testing new chemicals as frothing and wetting agents and in experiments on differential flotation, although others solved this problem before him. He also spearheaded the use of neutral and alkaline solutions for lead and zinc ores which consumed large amounts of acid, and the development of the flotation process to concentrate low grade copper and gold ores. He and his assistant metallurgist, A. Lowry, were involved in testing Broken Hill South oxidised slimes in alkaline solutions in 1913. De Bavay had earlier experimented with adding alkaline carbonates but his process could not treat slimes. Lavers was the first to use eucalyptus oil as a frother, an oil which gave a significant improvement in the recovery of sulphides. This was patented by Greenway and Lavers (British patent No. 21,857 of October 1909).\textsuperscript{846}

Lavers’ work involved considerable travel in Australia and he spent almost the whole of 1912 in England and Chile developing the processing of copper ores by flotation. In 1910 he was promoted to chief metallurgist for Australia and was thanked by the shareholders for his contributions to the company. Charles Faul, the company engineer, reported to Greenway in 1912 that T. J. Hoover, who was no longer in the employ of Minerals Separation, was intending to offer inducements to Lavers to leave Minerals Separation and Faul recommended Lavers be made further offers to retain him.\textsuperscript{847} He was later transferred to the London office but no details are known of his work there. One interesting fact in the Papers is that practitioners of the emerging technology of metallurgy were paid much less than industrial chemists or professional engineers at this time. Lavers was paid £750 p.a. with a house provided while Greenway was paid £2500 p.a. and Faul £1800 p.a., even though each man would appear to have been of equal value to the company.\textsuperscript{848}

\textsuperscript{845} Ibid. File 60 which includes his diaries, reports and letters detailing his work.
\textsuperscript{846} Hoover, \textit{Concentrating Ores by Flotation}, 38. Lavers was the discoverer, Greenway’s name appeared on the patent because it was company policy to include two or more employees and to assign the patent to the company.
\textsuperscript{847} M.S. Papers File 86 letter C. Faul to H. Greenway 28 Jan. 1912.
\textsuperscript{848} M.S. Papers File 100 Minutes of meeting of directors of M. S. and De Bavay Processes held on 5 July 1912 list the staff salaries.
The managerial relations between T. J. Hoover, H. H. Greenway, the Broken Hill staff of Minerals Separation and the staff of the Sulphide Corporation do not seem to have been clearly specified. The Sulphide Corporation general manager, C. F. Courtney, together with the manager of the Central Mine, James Hebbard, controlled the operations of the plants on the Central Mine for a management fee, while Henry Lavers and his staff, who were Minerals Separation employees, carried out experimental work and provided technical advice to Courtney and Hebbard. These two built new plants and adapted them to suit new developments and designed equipment to be sold to other mines. After 1910 Charles Faul was employed by Minerals Separation as mechanical engineer and advisor to other mines, but all drafting and construction work was done by Hebbard’s staff. This odd arrangement was a likely source of friction, but in fact it seemed to work well, probably because of the personalities of Courtney, Hebbard, Lavers and Faul, who were production oriented. Greenway was busy on patent litigation and setting royalties and did not interfere in production matters. T. J. Hoover constantly analysed the costs of the several plants at the Central Mine and kept telling Lavers to reduce costs. Lavers wrote several times of the difficulties, saying he could only give advice to Courtney and Hebbard and could in no way tell them to do anything.

It has been suggested elsewhere that secrecy was paramount because developments were likely to be subject to litigation and as a result companies tried methods which had failed elsewhere with sometimes surprising success because conditions were different. While the various managers may have believed this to be the case, the Minerals Separation files indicate that this was not so, except for the short period when the Zinc Corporation was considering the replacement of the Elmore equipment in 1910 and 1911. Francis Govett, the joint managing director of the Zinc Corporation, said in 1911 that Minerals Separation threatened legal action over running their plant side by

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849 Hebbard, "Evolution of Minerals Separation Process on Central Mine." A reading of this paper together with the correspondence in the M.S. Papers makes it clear that Hebbard provided the technical services required by Minerals Separation, under the supervision of Courtney. Hebbard had trained at the Bendigo School of Mines.

850 Greenway conducted the company’s defence in Sydney against a charge of patent infringement by the Ore Concentration Co.

851 M.S. Papers File 70 letter 8 January 1909 T. J. Hoover to Lavers.

852 Ibid. Files 70, 83b, 41.

853 Blainey, The Rise of Broken Hill, p. 76.
side with Elmore plant in 1910. The Zinc Corporation asked Minerals Separation to take their staff off the lease in February 1911. The two companies later reached agreement to conduct a trial comparing the two plants and the staff were allowed back. Faul, who had previously been employed by Bewick Moreing (managers of the Zinc Corporation), wrote to Howard Greenway during this separation period that he had obtained complete drawings and information on the running of this plant. There are no details of whether or not he paid for this information but it seems likely he obtained it through friendships with former workmates and that such information was passed freely between operating staff on the mines. T. J. Hoover never concealed his opposition to the patent system, regarding legal decisions on patents as arbitrary and unscientific, and many of his colleagues probably felt likewise. Faul wrote with full details of tests with magnetic separation equipment on Broken Hill Block 14 ore. When he was leaving Broken Hill in mid 1910 Edward Nutter refused a request from the London office to supply information about developments on other mines. He said he was given much information in confidence and was not prepared to divulge it. These examples show that detailed technical information was circulated informally between operating staff of various companies.

**Differential Flotation**

Development metallurgists working on the early flotation processes soon realised the water used had considerable effects on the results achieved. The minerals dissolved in the mine water could determine whether flotation succeeded or failed. As there was no theoretical understanding of the process at this time, its introduction at a particular mine was somewhat a hit or miss affair.

The sulphide dumps remaining at Broken Hill contained large amounts of zinc minerals and small amounts of lead and silver minerals. The flotation processes available in 1909 first floated most of the lead, zinc and silver sulphides as one concentrate. This was then tabled on straking tables to remove most of the lead and silver sulphides, which was

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854 M.S. Papers File 86, Minutes of Annual Meeting of the Zinc corporation in London 24 November 1911.
855 Ibid. File 6 letter 20 January 1912, Faul to H. Greenway.
856 Ibid. File 112 letter 2 June 1911, Faul to H. Greenway.
857 Ibid. File 72 letter 12 June 1911, Faul to Greenway.
858 Ibid. File 41, letter 5 June 1910, Nutter to H. Greenway.
859 M.S. Papers. When a mine requested a test on its ore Greenway always asked for a sample of mine water to be sent at the same time as the ore sample.
sent to the lead smelters; the remaining zinc concentrate was sent to the zinc distillation smelters. When the process was applied to crushed ore from the mine most of the lead and silver sulphides were separated by jigs and tables. Flotation of the residue produced a concentrate containing zinc sulphide and a small amount of lead and silver sulphide. Most of this lead and silver was then separated by gravity methods and combined with the earlier gravity concentrate for smelting. The remaining zinc concentrate was then smelted. Lavers had worked intermittently on differential flotation. He tried potassium bichromate but could not make it work. In 1910 E. J. Horwood, the works manager of B.H.P. under Delprat, patented a process in which he heated the combined concentrate to a temperature between 400°C. and 500°C to convert the lead sulphide to sulphate which was not floatable. The zinc sulphide was then floated off leaving a lead silver concentrate. This was the first differential flotation process. Early in 1912 James Lyster, a foreman in the Zinc Corporation mill on the South Blocks lease, used mine waters which were neutral or alkaline, in a Minerals Separation plant, to differentially float the lead and then with other additives floated the zinc. He patented the process which was the first differential float using different chemicals to aid or suppress the floating of different sulphides. In May 1912, when Lavers was overseas, A. Lowry developed a another differential process; this used a one percent potassium bichromate solution to condition the combined concentrate slurry, the solution was decanted off, water and eucalyptus added and the zinc sulphides floated.

Leslie Bradford, a chemist at B.H.P., developed a process to float off the zinc sulphide from a combined concentrate using salt and sulphuric acid. He also developed a process in 1913 to differentially float lead and zinc sulphides using copper sulphate and then sulphur dioxide gas. This is regarded by some as one of the most important flotation processes. In 1912 Owen, the mill superintendent of the Junction mine, differentially

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861 M.S. Papers File 73, Australian Patent No. 8594 awarded to Greenwood, Lowry and Lavers, 3 April 1913.
864 M.S. Papers File 63, details of Australian patent No. 8594 of 3 April 1913.
floated lead and zinc slimes, first by agitating in cold water plus eucalyptus, then adding the slimes to the top of a cylindrical tank, agitated again and the lead sulphides floated and removed. Agitation was stopped, sulphuric acid was added and the zinc sulphides floated off. Agitation was achieved with an impeller and an air jet at the bottom of the tank. The problem of oxidised lead in slimes dumps was solved in 1928 by E. T. Henderson of B.H.P by adding lime to precipitate dissolved salts, conditioning the pulp with sulphuric acid, and then passing sulphur dioxide gas through the pulp before agitating.

By 1910 Ballot and his fellow directors had enough confidence in the processes they had developed to sell them to companies outside Broken Hill and for other sulphides than lead and zinc. Bewick Moreing in London applied pressure on the London boards of companies operating in Australia. In July 1910 the London board of Great Fitzroy Mines instructed the Melbourne board to install a Minerals Separation plant to concentrate copper and gold ore, but this was opposed by the mine management as a gravity separation plant had just been installed. Henry Lavers was sent to Queensland to install the plant but D. P. Mitchell, the manager, was hostile and stalled on plant modifications requested by Lavers. Faul was sent to help, the plant was only partially successful and the mill staff spread rumours that the plant was a failure. In retrospect it would seem too much pressure was exerted to get quick results, and that not enough was known about the flotation of copper and gold ores and necessary testing to improve the process was hindered by the mill staff. A more successful application of the process to copper ore was at the Kyloe Mine at Adaminaby in 1911. Here Lavers was strongly supported by the management, the changes he requested were made and the cost of installing the plant was recovered in five months. Another successful installation was at the Cobar Chesney mine in early 1912 where Godfrey installed the plant. However an installation at the Lancefield gold mine in Western Australia in 1911 was not a success; there was a high percentage of calcite in the ore and a neutral solution was

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867 Ibid.: p. 413.
868 M.S. Papers File 60, letter 11 January 1911, H. Lavers to H. Greenway; File 16, letter 27 March 1911, Faul to H. Greenway.
869 Ibid. File 60, letter 26 January 1911, H. Greenway to H. Lavers.
871 M.S. Papers File 31, letter 18 April 1913, C. Faul to H. Greenway.
used. Not much was known about these solutions in 1911; Lavers was not given sufficient time for testing and the Western Australian manager of Bewick Moreing decided the plant was not economic. Again there was pressure to reduce costs quickly and the local mining managers were not interested in a new process with doubtful economic gains because they had just invested a great deal of time and money in developing the use of cyanide with sliming and filtering to extract the gold. After further experiments at the Kalgoorlie School of Mines in the 1920s and 1930s flotation was introduced into the Western Australian goldmines with reductions in mineral dressing costs.

At the start of 1912 Lavers sailed to London on his way to the Braden Copper Mine in Chili. The mine was established by William Braden but was taken over by the Guggenheims who owned large copper mines in the Western United States, so Minerals Separation put much effort into the installation in the hope of further orders. Lavers and Broadbridge, the managing engineer, set up the plant at the mine. At least one foreman was sent from Broken Hill to train local operators. Six units each of 600 tons a day capacity were commissioned by Broadbridge and G. A. Chapman in 1913.

Edward Nutter, who had returned to California after gaining experience at Broken Hill, approached the management of the Inspiration Mine in the town of Miami in the western United States in 1912 and suggested they install a Minerals Separation flotation plant for the low grade copper ore instead of a gravity plant then being designed. A 50 ton test plant was installed successfully and a 600 ton a day plant was operated from 1914. This plant was replaced by a 15,000 ton a day mill designed by Inspiration staff. In 1923 Kellow and Lewis of the San Francisco staff of Minerals Separation

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872 Ibid. File 26, letter 7 October 1911, H. Lavers to H. Greenway; letter 8 September 1911, C. Faul to H. Lavers
874 M.S. Papers File 48, cable 3 January 1912 from H. Greenway to London office said Lavers willing to go to Chili. Cables of 8 August and 13 September 1912 from London office that Braden had ordered plant for 3000 tons per day and the Lavers would leave Chili at the end of October.
875 Ibid. Cable 5 January 1912 to H. Greenway.
North American Corporation obtained a patent for the use of xanthates as collecting agents.\textsuperscript{877} This patent was assigned to Minerals Separation.

In the early years of the company Minerals Separation had three aims:
1. To control all patents relating to flotation.
2. To buy mines and process sulphide ores with flotation.
3. To buy residue dumps of sulphide ores and process them.

The control of patents was pursued vigorously and by 1912 a company called Minerals Separation and De Bavay Processes Pty. Ltd. was established in Melbourne with control of all relevant flotation patents. William Baillieu negotiated the transfer of the Potter-Delprat patent and the de Bavay patents in London in 1911. The purchase of mines was not vigorously pursued although mines near Mt. Lyell in Tasmania and at Ravensthorpe in Western Australia were investigated, probably because Greenway was overloaded with supervising royalty payments and patent litigation.\textsuperscript{878} After some initial purchases of zinciferous dumps at Broken Hill which were treated profitably under the supervision of the Sulphide Corporation staff the third aim was not pursued (probably because all the dumps had been purchased by others at prices the company was not prepared to pay).

During the 1890s there had been a great deal of resistance in Australia to the payment of royalties to the Australian Gold Recovery Company for the use of the cyanide process. The rate of 7.5 percent was regarded as excessive.\textsuperscript{879} Surprisingly in Australia there appears to have been no opposition to paying the royalty charged by Potter or by Minerals Separation either for the lead-zinc ores, the copper ores or the copper-gold ores. At Broken Hill, De Bavay received royalties for lead-zinc ores. Delprat was not involved in licensing. In the early years of the twentieth century, flotation was the only method which could separate zinc sulphides at a good profit and convert low grade copper ores economically into concentrates suitable for smelting. When mine managers realised how much greater the returns were with flotation compared with inefficient


\textsuperscript{878} M.S. Papers File 112 letter 12 March 1911, C. Faul to H. Greenway recommending that the Broken Hill South Extended mine be purchased. This was not done. File 28 letter 29 December 1911, 2 Jan 1912, to Mt. Jukes mine in Tasmania rejecting purchase. Files 76 and 77 letters to and from Phillips River Gold and Copper Co. re installation of treatment plant and processing of ores by Minerals Separation.

\textsuperscript{879} Hartley, "A History of Technical Change in Kalgoorlie Gold Metallurgy 1895 - 1915", Chapter 1.
gravity methods they could not wait to instal flotation. As mentioned above the Kyloe management recovered the total cost of installing a flotation plant in five months.

Minerals Separation charged 2.5 shillings per ton of lead or zinc concentrate produced and for copper mines 3 pence per pound of copper. For mines with gold as well as copper in the ore an additional charge was made of 2.5 percent of the gold recovered. Attitudes were quite different in the United States, where the view was held that the Everson patent of 1886 would void the patents held by Minerals Separation. When a final decision was reached in the United State’s courts that the Minerals Separation patents were valid, the damages, back royalties and continuing royalties paid must have been enormous.880 By 1930 such was the dominance of the Minerals Separation processes that they were used for producing lead concentrates on all Broken Hill mines except B.H.P. and for producing zinc concentrates on all but one mine. Xanthates were used on most mines as the collector for the lead and zinc and differential flotation was obtained with the Bradford method using copper sulphate to separate the zinc in Minerals Separation designed plants.881

There is little doubt that Minerals Separation was the most progressive company in developing empirical research on flotation and by 1913 its technology was superior to that of other companies. After this time competitors in the United States gradually caught up with this technology, but by then it was too late to challenge earlier court decisions and Minerals Separation was able to prosper on the royalties it derived from its patents until the last one expired in the late 1930s. The process was developed to float many other minerals, particularly by companies in the United States.882

Even in Australia the flotation process did not gain immediate acceptance everywhere. The North Mine (with A. Lowry as chief metallurgist), built an all flotation mill in 1928, but reinstalled a lead gravity section in 1938 when oxidised ores from the British

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880 No attempt has been made to assess these United States returns to Minerals Separation as they are not directly relevant to this thesis.
mine were again treated. The Zinc Corporation tested an all flotation plant from 1935 and built a new all flotation mill in 1939. Following successful research conducted at the Kalgoorlie School of Mines the flotation process was used in mines there to produce concentrates of sulpho-telluride gold ores from the local mines followed by cyaniding.

The initial development of the flotation process was based on observation and experiment which were applications of the scientific method, but the affinity of the bubbles to the sulphide particles, was not based on any scientific theories. In this sense it was distinct from other metallurgical processes developed in the same period such as chlorination and cyaniding of gold ores and the electromagnetic separation of zinc ores which were based on scientific theory. A theoretical basis for the process was not developed until the 1930s, when a group associated with A. F. Taggart in the United States published a paper on the collecting properties of bubbles in the flotation process. This theory was further developed by the Australians I. Wark and A. Cox in 1934 but a complete theory has not yet been developed.

The Collins House Group and Its Role in Electrolytic Smelting

As mentioned above an informal group of financiers visited Broken Hill in 1905 to investigate the prospects for investment there, and soon invested in the Zinc Corporation and the North Broken Hill mines. Included in the group were Lionel Robinson, an Australian then working as a stockbroker in London, his brother William (who was then the financial writer for the Melbourne Age newspaper), Francis Govett (a London financier), and William Baillieu (a Melbourne financier). Baillieu was a member of the board of the De Bavay Treatment Company which had the flotation patent, as well as being a director of the North Broken Hill mine. He was also an

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885 R. S. Blaskett, *Ore Treatment at Western Australian Gold Mines* (Melbourne: Tait Publishing, 1952), p. 11. The advantage of flotation was the tailings were removed before cyaniding the concentrates.
investor in the Zinc Corporation. Through his brother’s involvement with the Zinc Corporation, later a London based company, William Robinson became associated with the board of that company, in which the Baillies had invested. In 1912 the three companies, North Broken Hill N.L., Broken Hill South N.L. and the Zinc Corporation Ltd, established their offices at Collins House in Collins Street Melbourne, and from then on worked closely together in establishing an Anglo-Australian mining industry. In 1914 this group was approached by B.H.P. to buy the Port Pirie smelter as B.H.P. wished to raise funds to build an iron and steel plant at Newcastle. The group formed a new company, Broken Hill Associated Smelters, taking 78 percent of the capital with B.H.P. taking the remainder. The initial paid-up capital was £600,000. William (W. S.) Robinson became managing director.

On the outbreak of war in 1914 considerable difficulties arose in selling the products from Broken Hill until the Australian government and the British government signed a contract in 1916 for Britain to purchase the output until 1930 at a fixed price and to assist with development costs of an electrolytic zinc smelter in Tasmania. W. S. Robinson (who was advising W. Hughes, the Australian Prime Minster, on metals policy) was involved in this deal. English smelters were to smelt 60 percent of the zinc concentrates and the rest were to be smelted in Australia.

The successful development of an electrolytic method of producing copper as distinct from smelting in a furnace has been discussed in Chapter 7. The copper produced in the refining stage of smelting copper ores in furnaces contained small percentages of impurities which were detrimental to its use as an electrical conductor, for which purpose most of the copper produced at the end of the nineteenth century was used. In addition the refined furnace copper contained sufficient gold and silver to make their separation worth while. By 1906 there were a dozen or so electrolytic refiners in the

887 Blainey, If I Remember Rightly - the Memoirs of W. S. Robinson., pp. 38-43. The De Bavay Company was later renamed Amalgamated Zinc
890 W. S. Robinson, ”The W. S. Robinson Papers,” in Melbourne University Archives (Melbourne), File 181. The Trio of German firms were prevented from purchasing concentrates by wartime regulations.
891 D. M. Levy, Modern Copper Smelting (London: Charles Griffin & Company, 1912), p. 218. On page 23 Levy tabulates the influence of impurities on the electrical conductivity of copper. Arsenic, nickel and cobalt are the most detrimental.
United States producing very pure copper from smelted material. Little information is available on the early development of this process in Australia, but by 1908 a plant had been erected in Lithgow to refine copper from the Great Cobar Mine and another plant was being erected at Port Kembla to refine copper from Mt. Morgan and Mt. Lyell. The Lithgow plant had six, four pole dynamos each of 72 kilowatt capacity at 60 volts and 1200 amperes and driven by a compound steam engine. Two of these worked 144 tanks each and three worked 128 tanks. The sixth was a spare. The Port Kembla plant had two 550 kilowatt machines and another of 150 kilowatt, providing 250 volts at 600 and 2200 amperes respectively. Each plant was adjacent to a coalfield where electricity could be generated relatively cheaply using steam engines to drive the dynamos.

The success of these copper smelting plants encouraged metallurgists to revisit Ashcroft’s failed process. In 1908 James Gillies, a metallurgist trained at Sydney University, arrived in Tasmania to experiment with ways to treat flotation concentrates and complex zinc ores from west coast mines such as the Hercules near Zeehan. He solved the problems which had dogged Ashcroft ten years earlier and formed Gillies Company, which purchased the rights to water from the Great Lakes for hydroelectric generation from the Tasmanian Government. He commenced the construction of a power station, but lacked capital and sold the unfinished station back to the government in 1913, while still retaining the water rights. He wished to roast the sulphide ores and purchased a site at Risdon near Hobart to erect a plant. Possibly because of the destruction of forest around Queenstown at this time by the fumes from Sticht’s pyrite smelter, the Tasmanian government refused permission.

In 1915 Herbert Gepp, the general manager of Amalgamated Zinc, was in the United States selling zinc concentrates when he heard that the Anaconda Mining Company was making zinc metal by an electrolytic process. W. S. Robinson went to the United States,
met Gepp and Gilbert Rigg of the General Electric Company (who had also been experimenting with electrolysis). Gepp went to Anaconda to study the process and then took over General Electric’s small plant to experiment with Broken Hill concentrates. The experiments were successful. W. L. Baillieu negotiated with Gillies for his water rights and Edward Shackell (the secretary of many of the companies in the Collins House Group) negotiated with the Tasmanian government for permission to erect a plant at Risdon. An election was due in Tasmania and the government was keen to solve the power station problem. When Shackell and Baillieu agreed to calcine the sulphide concentrates in Broken Hill before transport to Hobart, the government seized the opportunity and, in 1916, awarded the hydro rights to Amalgamated Zinc at very favourable rates. Gillies had no option but to agree. Gepp returned to take charge of the plant. A new company, Electrolytic Zinc, financed and controlled by the Collins House Group, was formed and a pilot plant erected at Risdon in late 1916. To avoid the troubles encountered by Edgar Ashcroft, a steady escalation of plant size was planned. First a glass cell plant to produce 6 pounds of zinc a day, then a larger plant to produce 250 pounds a day, then to extend this to 600 pounds a day. If this was successful it was planned to build a larger plant to produce 5 tons a day and finally a 100 ton a day plant. By early 1924 production was 125 tons of zinc metal a day. Problems were encountered with a build up of chloride in the cells, with borers in the wood of the tanks eating through the lead lining to cause leaks and cobalt impurities in the ore, but these were solved one by one as the company made sufficient funds available.

Nearly twenty years after the failure by Ashcroft to produce an economical method of producing zinc metal in Australia the situation was altered. The Collins House group had achieved a vertically integrated lead zinc industry based on Broken Hill ores, and together with a group of companies associated with the Zinc Corporation in England

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895 F Laist et al., "Electrolytic Zinc Plant at Anaconda Copper Mining Co. At Great Falls, Mont.,” American Institute of Mining and Metallurgical Eng. LXIV (1920): pp. 699-763. Mention is made of Gepp’s work on the effect of impurities including cobalt in the liquor (see page 700).
898 Reynolds, "The Establishment of the Electrolytic Zinc Industry in Tasmania." One clause in the agreement with Amalgamated Zinc was that no noxious fumes were to be discharged.
had taken the control of these metals produced in the British Empire and had replaced the German monopoly in controlling these minerals.\textsuperscript{900}

**Conclusions**

The first decade of the twentieth century saw the re-establishment in Australia of large limited liability companies in Australia with overseas capital and overseas directors, which employed locally trained mining engineers and metallurgists to work with technologists from Europe and the United States to solve the problems of separating minerals containing gold, silver, lead and zinc, in complex sulphide ore bodies from below the waterline, and refining these metals from the minerals. Most goldmines continued to operate as no-liability companies.

Attempts to improve the separation by fine grinding had resulted in sliming and the dumping of residues containing valuable minerals. Methods other than gravity concentration followed by furnace smelting were needed. The older process of chlorination for extracting gold was improved. The use of new processes developed for the use weak solutions of cyanide for extracting gold and flotation for extracting silver, lead, zinc and copper, were exported world wide and enabled the exploitation of large low grade orebodies which could not be worked economically by gravity concentration.

The chlorination and cyaniding processes were firmly based in scientific theories developed earlier in the nineteenth century, but the flotation process was a result of observation and continuous experimentation to find more suitable reagents and better mechanical systems.\textsuperscript{901} Theories explaining why the flotation process worked followed years after the practice and are still not completely developed. The electro-magnetic method of concentrating zinc minerals, which was based on scientific theories, proved to be a dead end economically and was replaced by the flotation process.\textsuperscript{902} Electrolytic smelting of zinc minerals to produce zinc metal, again based on science, was finally developed into a commercial process after earlier failure. These examples show that while a new process may be solidly based on scientific theory, its technical and


\textsuperscript{901} The process of continual improvements by experiment has been called microtechnology as distinct from invention of a new process which is a major advance in a short time or a macrotechnology See Burt, “Innovation or Imitation? Technological Dependency in the American Nonferrous Mining Industry,” p. 323.

\textsuperscript{902} Electro-magnetic methods of separating minerals in beach sands were successful after World War II.
commercial success often depends on considerable experimentation in the laboratory and on the mines to adapt it to a particular orebody.

Gold and silver were an immediate source of wealth and directly contributed to the growth of the Australian economy. The ready availability of lead enabled the rapid growth of the motor car industry world wide. The rapid increase in the supply of zinc at lower prices made the prevention of corrosion of steel economic, and enabled the expansion of industrial infrastructure such as bridges and buildings on a scale needed to support the rapid growth of industry and transport of goods. Electrolytic refining of copper made low resistance copper available in sufficient quantities to support the age of electricity. The adaptation of the cyanide process to the sulpho-telluride ores of Kalgoorlie, and the development of the flotation process to separate minerals in complex sulphide ores at Broken Hill, were major advances in mining technology which in turn have made possible the world wide industrial growth of the twentieth century. In the long term the development of the flotation process has been the most important development in mining technology in the history of mining. The first decade of the twentieth century was a period in which a combination of European capital and Australian, European and American technologists made a substantial contribution to the advancement of mineral processing. The next chapter will discuss other developments in the Australian mining industry during the first fifty years of the twentieth century.
Chapter 9  
A Period of both Progress and Decline 1900 – 1945  

Introduction  
Following the success of the Australian mining industry in solving the problems of sliming described in the previous chapter it was reasonable to expect that further advances in mining technology would follow. This expectation was not fulfilled in the period from World War I to the end of World War II, and Australian mining declined in some areas and made small advances in others, with one exception. This exception was the successful development of the iron and steel industry, first by the Hosking brothers and then by the B.H.P. Company, which used its strong financial position and technical management resources to develop an industry in Australia capable of competing with overseas companies. This chapter will investigate the reasons for continuing progress in the development of technology in the Australian mining industry up to the beginning of World War I, followed by only small advances in coal and metalliferous mining during two world wars and a world wide economic depression. During this period of boom and bust the new technologies of electricity and internal combustion engines from overseas replaced steam as the main source of motive power in Australian mining.  

Initial Boom and Subsequent Decline in Mining  
Gold production in Australia increased from the late 1890s as the cyanide process was adapted to extract gold from tailings, both retreatment to extract gold remaining in old sand dumps, and recovery of gold from current production in eastern and western Australia. Unemployment during the 1890s depression in Victoria drove many of the unemployed to rework shallow alluvial deposits and lower wages encouraged quartz mining into the first decade of the twentieth century. The technology of bucket dredging for gold was introduced from New Zealand in 1899 when Garland’s No.1 dredge began operation on the Macquarie River near Stuart Town in western New South Wales. Production from gold dredging and hydraulic sluicing and pumping peaked in 1908 as suitable alluvial deposits were depleted, but dredging at a reduced rate  

903 Reports to Secretary of Mines, Queensland, 1905, p. 113. There were 13,200 European miners in Queensland in 1905 plus 547 Chinese, most would have been mining for gold. Between 5000 and 6000 of these were working on tribute. Another 3800 were employed on the surface in mills, smelters, workshops.  
904 D. S. Clift, Gold Dredging in New South Wales, Mineral Resources No. 41 (Sydney: Geological Survey of N.S.W., 1975), Frontispiece.
continued for the remainder of the century. Dredging was adapted to alluvial tin mining, but both lode and alluvial tin mining declined after 1907 as the tin fields were depleted and the price of tin fell. New technology for extracting coal by cutting machines was introduced in New South Wales coal mines in 1903 but as described later in this chapter the improvement in productivity was poor.

The advent of World War I had serious repercussions for mining in Australia. Many gold mines closed as miners and staff enlisted for war service and the prices of cyanide and general supplies increased. A strike by woodcutters in Kalgoorlie over wage rates in 1916 severely curtailed fuel supplies and mine timber, with a consequent reduction of gold produced. The success of the silver lead zinc industry in developing differential flotation from 1912 was seriously interrupted by the loss of overseas markets for these concentrates and metals in 1914, when the German importers of concentrates lost their access to the Australian suppliers. Recovery was slow until an agreement for the sale of lead and zinc was signed with the British government in 1916. Industrial unrest and a strike of eight weeks at Broken Hill in 1915, followed by another of eighteen months duration from April 1919 over industrial health conditions, caused major disruption of the industry. During and after the war the effects of inflation caused further closures of gold mines as the price of gold was fixed and gold mining became uneconomic in many mines. A fall in the price of copper in 1919 and rising operating costs forced the closure of many copper mines in Queensland, South Australia and South Australia. Only the more efficient mines such as Mt. Lyell and Mt. Morgan survived. A very large silver lead zinc deposit was discovered by a prospector, Campbell Miles, at Mt.Isa

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906 R. S. Kerr, John Moffatt of Irvinebank (Brisbane: J. D. & R. S. Kerr, 2000), p. 221. B. Brown, I Excel, the Life and Times of Sir Henry Jones (Hobart: Libra Books, 1991), pp. 56-64. In the process of developing an alternate supply of tin for the Tasmanian jam industry as tin production in Tasmania declined the IXL Jam Co. exported Australian tin dredging technology to Thailand, through its agent Captain Edward Miles, who organized the first dredging of Tongkah Harbour. Australian companies later dredged for tin in Malaya.
907 Reports to the Minister of Mines, Victoria, 1916.
909 See Chapter 8.
in north west Queensland in 1923. The low grade ores and the remoteness of the deposit required large capital investment, which came initially from British sources and then the United States when the British resources proved insufficient. The company did not pay a dividend until 1947.  

Some relief for gold mining was obtained in the 1930s when the Australian government subsidised the price of gold by £1 per ounce, the exchange rate was cut by 25 percent and the price of gold rose, leading to a rise in gold production after 1930. The commencement of World War II caused further problems in the gold industry, when government policy diverted materials from all mines except those producing essential minerals, and miners were lost to the armed forces or to essential industries. These closures and the loss of skilled personnel had a detrimental effect on the gold industry in this period and gold production fell from 1941.

In contrast to these problems in the gold and silver, lead, zinc, tin and copper sections of the industry in the first half of the twentieth century, the iron and steel industry prospered and grew in Australia and this averted a national disaster as overseas supplies were cut off during the two world wars when a lack of shipping prevented imports of iron and steel. In New South Wales the fortunes of the coal mining industry were closely related to the requirements of iron and steel industry after 1915. Coal output increased only slowly in Victoria, Queensland, Tasmania and Western Australia during the period.

**The Iron and Steel Industry**

The demise of the fledgling iron smelting industry when James Rutherford blew up the blast furnace at Lithgow son after 1882 has been discussed in Chapter 4. However the processing of iron and steel in Australia using imports continued. In 1886 William Sandford, an Englishman from Bristol, installed a steel wire-netting plant at Sydney for John Lysaght, an English company. In 1886 he left his employment with Lysaght and leased the rolling mill associated with Rutherford’s old plant at Eskbank, near Lithgow, 

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912 G. Blainey, *Mines in the Spinifex* (Sydney: Angus and Robertson, 1970), pp. 70, 193. Copper was discovered later at deeper levels. During World War II production was concentrated on copper.


914 Close, *The Great Gold Renaissance*, Fig. 1.

915 H. S. Elford and M. McKeown, *Coal Mining in Australia* (Melbourne: Tait, 1947), pp. 14-16. New South Wales black coal production was 5.5M tons in 1900 and 11.3M tons in 1946.
to roll wrought iron rails, bars and plate using scrap and obsolete rails.\textsuperscript{916} The boom of the 1880s and the availability of cheap scrap iron as the New South Wales Railways replaced iron rails with imported steel rails enabled the plant to remain viable through the 1890s depression.\textsuperscript{917} In 1892 Sandford bought the works and the colliery for £68,260, money he borrowed from Commercial Banking Company of Sydney.\textsuperscript{918} In the late 1890s he bought a four ton open hearth steel furnace from Seimens, an English firm. The first steel made in Australia was smelted in this furnace in April 1900 (two more furnaces were added later).\textsuperscript{919} A company, William Sandford Ltd., was then registered, with a capital of £60,000 in £1 shares of which 55,000 were allotted as fully paid up to Sandford as payment of the land and plant.\textsuperscript{920} The additional working capital of £5000 did little to solve his continual money problems and he borrowed additional funds from the Commercial Banking Company of Sydney.\textsuperscript{921}

In 1905 the New South Wales government accepted a tender from William Sandford Ltd. for the supply of all its iron and steel requirements for the next seven years, and he built a blast furnace at Lithgow.\textsuperscript{922} The furnace, 75 feet high, was based on English practice. It used relatively low grade iron ores and English workmen were imported to do the erection. The pig iron was suitable for foundries and sold readily, 700 tons per week being the maximum production.\textsuperscript{923} In November 1907 the bank foreclosed on its debt and the plant was purchased by G.

\& C. Hoskins, iron founders of Sydney. Charles Hoskins became manager in 1908. This firm built a second blast furnace alongside the existing furnace in 1912 and operated both to produce hot basic metal for the steelworks and sand cast foundry pig iron. The blast furnace capacity was 2,000 tons of pig each week.\textsuperscript{924} The small steel furnaces were replaced by one fifty ton open hearth furnace, with the molten pig iron from the blast furnace being loaded directly to the open hearth.

\begin{itemize}
\item \textsuperscript{916} E. Lewis, "Iron and Steel Industry in Australia," \textit{Journal of the Institution of Engineers, Australia Selected Papers from the Journal (1929)}: p. 83.
\item \textsuperscript{918} Ibid., p. 28.
\item \textsuperscript{919} The principles of operation of open hearth furnaces will be described in more detail when discussing the B.H.P. steelworks.
\item \textsuperscript{920} Lewis, "Iron and Steel Industry in Australia," p. 85.
\item \textsuperscript{921} Hughes, \textit{The Australian Iron and Steel Industry, 1848-1962}, p. 28.
\item \textsuperscript{922} Lewis, "Iron and Steel Industry in Australia," p. 85. Lewis considered this contract to be one of the most important events in the history of the iron and steel industry in Australia.
\item \textsuperscript{923} Ibid.
\end{itemize}
The Hoskins brothers received assistance from the State government in preferential treatment against imports and from the Federal government by bonus from 1914 to enable the firm to compete with imports.\textsuperscript{925}

Meanwhile in 1900 the B.H.P. Company had acquired leases over large deposits of high grade iron ore in the Middleback Ranges in South Australia, across the headwaters of Spencer Gulf from Port Pirie, where it was developing lead and zinc smelting of the gravity concentrates from Broken Hill. This iron ore, containing low percentages of silica and phosphorus and an iron content up 68 percent, was very suitable as a flux in the lead smelter.\textsuperscript{926} The ore could be cheaply mined from the side of the Iron Knob, a hill in the Middleback Ranges, by open cut and the company built a railway to the coast at Whyalla in 1901 from where the flux was shipped to Port Pirie. The directors realised that B.H.P. had a limited life as the ore reserves at Broken Hill were depleted but felt they could ensure the long term future of the company by building an iron and steel plant based on the iron ores of the Middleback Ranges. In 1907 Delprat tested the iron ore in a small blast furnace at Port Pirie and produced a few tons of pig iron which sold readily.\textsuperscript{927} He then visited iron and steel works in England, Europe and the United States and saw that American companies were producing iron and steel from high grade ores from the Mesabi Range, near Lake Superior, which were similar to the South Australian ores, at lower prices than that produced by English companies from their lower grade ores.\textsuperscript{928} The company engaged David Baker, a consulting engineer of Philadelphia, to advise on the feasibility of an Australian plant.\textsuperscript{929} His report recommended the building of an iron and steel works on the coast at Newcastle, using local coal for coke making, iron ore from the Middleback Ranges and limestone from a quarry on Wardang Island in Spencer Gulf. Both the latter two materials could be mined by open cut methods and shipped cheaply to the coalfields at Newcastle.\textsuperscript{930} This was a return to the Cornish practice of shipping the ore to the coalfields for smelting.

Baker was then employed to design the plant, consisting of one 350 ton blast furnace, three 65 ton basic open hearth steel furnaces and sixty six coke ovens. The company

\begin{footnotes}
\item\textsuperscript{925} Hughes, \textit{The Australian Iron and Steel Industry, 1848-1962}, p. 51.
\item\textsuperscript{927} Hughes, \textit{The Australian Iron and Steel Industry, 1848-1962}, p. 60.
\item\textsuperscript{928} Newman, "Blast Furnace Practice in Australia," p. 35.
\item\textsuperscript{929} G. Blainey, \textit{The Steel Master} (Carlton: Melbourne University Press, 1995), p. 44.
\item\textsuperscript{930} Hughes, \textit{The Australian Iron and Steel Industry, 1848-1962}, p. 64.
\end{footnotes}
already owned land in the area and acquired further adjacent land, mainly tidal swamps, on which piles were driven to support the heavy structures. The land was raised above tide level by dredging the sea floor adjacent to the site and dumping the sand on the works area. Construction material was imported from the United States, erection commenced in January 1914 and the blast furnace was “blown in” on 9 March 1915.931

One month later the first steel ingots produced were rolled in the blooming mill and the structural steel mills which had been erected near the furnaces.932 A number of department superintendents had been engaged in the United States and England prior to final commissioning to control this work and to assist them skilled operators from the United States were employed.933

The blast furnace was designed to produce 800 tons of pig per day using technology developed in the Lake Superior area of the United States for high grade iron ores. It was 84 feet high, with a hearth diameter of 17 feet 9 inches and a bosh diameter of 21 feet 6 inches. A hot blast was used. Ships discharged iron ore and limestone alongside the ore docks for direct charging of the furnace.934 The by-product coke ovens were of European Semet-Solvay design, each with a capacity of 7.5 tons of coal, heated for 24 hours to produce 5 tons of coke. The company tried to gain the right to use American designed coke ovens but was unsuccessful and had to purchase the right to use the less efficient English Semet-Selvay design. The first coke was produced in June 1915, the first successful operation of a by-product coke plant in Australia.935 By 1921 the number of Semet-Solvay ovens had been increased to 224.936

The initial plant design at Newcastle was for three 65 ton basic open hearth furnaces, in which molten iron from the blast furnace was mixed with scrap steel and limestone

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932 Lewis, “Iron and Steel Industry in Australia,” pp. 91-3. The land owned by the company was at Port Waratah, the site of the first Wallaroo copper smelter at Newcastle.

933 Ibid.: p. 94.


935 R. L. Carr, “Metallurgical Coke Making Practice,” in Extractive Metallurgy in Australia, ed. J. C. Richards (Melbourne: Australasian Institute of Mining and Metallurgy, 1953), p. 2. The first plant was of Belgium design erected near Newcastle in 1913 but it was not a commercial success and soon closed. By-product coke plants produce organic compounds, hydrogen sulphide gas and ammonia which can be sold separately.

936 Ibid., p. 8.
following United States practice. Scrap was loaded into 20 cubic feet pans and delivered to the charging floor on rail buggies by locomotive. Steel was tapped from the furnaces into 85 ton ladles moved by overhead cranes, and poured into moulds on narrow gauge rail cars which were hauled to the soaking pits by steam locomotives. In the pits the ingots were kept hot before being moved to the rolling mills. These furnaces could operate on producer gas, but later furnaces could also use mixtures of producer gas and coke oven gas or producer, coke oven and blast furnace gas.

Increased demand in 1916 led to the construction of a second blast furnace, additional by-product coke ovens and a mixer of 1000 tons capacity to store molten pig iron prior to its conversion to refined steel. Both the Lithgow works and B.H.P. made good profits during the war but by 1921 rising prices and wages, with a more competitive market and industrial unrest, led to the latter company closing the Newcastle plant for nine months.

The high rail costs of operating the Lithgow plant forced Hoskins to relocate to the seaboard and in 1927 Hoskins Iron and Steel Company Ltd. commenced the erection of a blast furnace at Port Kembla, south of Sydney on 400 acres of land near the southern coalfields. In 1928 this company merged with Dorman Long & Co. Ltd., and Baldwins Ltd. (both English steel companies) and Howard Smith Ltd., an Australian shipping company, to form Australian Iron and Steel Ltd. with a nominal capital of £5 million. The blast furnace at Port Kembla was “blown in” in August 1928. Despite two of the major shareholders being English steel firms, a Chicago firm of consulting engineers, the Freyn Engineering Co., was employed to design the blast furnace. This furnace was 82.5 feet high, hearth diameter 18 feet and bosh diameter 21.5 feet, designed to produce 800 tons of pig iron daily. Two open hearth furnaces, each of 125 tons capacity, were designed by the staff of the Port Kembla company. Blooming and

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937 The terms ‘basic furnace’ or ‘acid furnace’ are derived from the type of slag produced in the furnace. The decision on whether to use an acid or basic slag depends on the level of sulphur and phosphorus contained in the iron ore. If either of these is higher than can be tolerated in the steel a basic slag is used to absorb them. Basic slags contain lime or magnesium oxide; acid slags contain silica or phosphorous pentoxide. The nature of the slag determines the type of refractory lining used in the furnace. An acid slag will attack and dissolve basic linings while a basic slag will dissolve acid linings. Iron ore low in phosphorous or sulphur is smelted with acid fluxes (high in silica) in furnaces with acid linings.


939 Ibid., p. 77.

940 Lewis, “Iron and Steel Industry in Australia,” p. 94.


The company could not locate an iron ore deposit of sufficient size which would allow economical mining and was forced to enter into a ten year contract with B.H.P. for the supply of iron ore. When the financial depression struck in 1929 A.I.S. were beaten by price cutting until B.H.P. was almost the sole supplier of iron and steel on the Australian market. Ordinary dividends were not paid by A.I.S. from 1929 and the company used calls to complete its construction program. By 1931 the Lithgow plant was closed. B.H.P. took over A.I.S. late in 1934.

Helen Hughes wrote that B.H.P. was fortunate in starting production at a time when markets were assured due to wartime restrictions on imports, but its success was also due to its industrial experience, good management and ample financial resources. These three reasons are worth more detailed consideration to fully explain the success of the company over A.I.S. Firstly the board of B.H.P. was experienced in supervising a strong engineering management and making decisions on competing recommendations on engineering matters, as shown when it accepted the recommendation of the deputy general manager Essington Lewis not to use the Duplex Process recommended by Delprat. Secondly, the Board had dealt with many strikes in the history of the company and had a hard attitude to industrial relations which enabled it to shut down the plant when it was not profitable. Both Sandford and the Hoskins appear to have been more benevolent to their workers. The Hoskins brothers had both financial and management control and their financial position was always more precarious than B.H.P., which had little difficulty in raising additional funds required by issuing shares at a premium. In this situation decision making by the Hoskins would have been very difficult. Thirdly, although the Port Kembla blast furnace was American in design the rest of the plant was tied to English practice which was less efficient. Also A.I.S was buying its iron ore from B.H.P. and would have had to pay more than the B.H.P. cost price.

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945 Ibid., pp. 114-5.
946 Ibid., p. 75.
947 G. Blainey, Essington Lewis (Melbourne: Melbourne University Press, 1995), pp. 63-4. Essington Lewis was Delprat’s assistant. The Duplex process involved two stages in turning iron into steel. During a world tour in 1920 Lewis recommended that the Board should not accept Delprat’s advice to build the plant. The Board agreed.
948 Hughes, The Australian Iron and Steel Industry, 1848-1962, p. 114. The Hoskin’s company could not raise sufficient funds to quickly build the new plant at Port Kembla and had to keep the Lithgow plant operating for years.
949 The coke ovens at Wongawilli did not produce by products that could be sold.
By 1951 B.H.P. was operating three blast furnaces at Newcastle, three at Port Kembla and one at Whyalla, the port for Iron Knob, with capacity to produce each year around 1.25 million tons of pig iron at Port Kembla, 800,000 tons at Newcastle and 220,000 tons at Whyalla.\textsuperscript{950} At that date the Newcastle Works had ten 125 ton open hearth furnaces producing 1.1 million tons of steel annually, and Port Kembla had seven furnaces with a capacity up to 800,000 tons.\textsuperscript{951} The successful development of the iron and steel industry by B.H.P. in Australia was a major achievement by an Australian owned and managed company, and its success provided the base for that company becoming one of the world’s largest mining companies by the 1990s.

**New Sources of Motive Power**

New power sources became available towards the end of the nineteenth century with major consequences for mining and its allied industries in the first half of the twentieth century. As discussed in Chapter 3 electricity for lighting surface and underground mining was in use in the Bendigo gold mines in 1882, using English equipment. The first electric railway installed in an Australian mine was at the Tasmanian Gold Mining Company in Beaconsfield in 1897, where a Siemens traction system in a tunnel carried gold ore from the stopes to crushing plant on the surface. Power was generated by a Pelton wheel driven DC generator at 300 volts.\textsuperscript{952} A more comprehensive electrical installation was installed at the Sunlight mine at Hillgrove in New South Wales, where a small electroplating plant was installed in the 1890s to silver plate the amalgamating plates before rubbing in the mercury. This was successful and a lighting plant for the surface and main drives was added. This was followed in 1898 by an electric hoisting plant of 120 volts DC at 150 amps at the end of a tunnel 1000 feet long, the generator being on the surface 200 feet away from the tunnel entrance. A Walker fan driven by a modified electric railway engine of 100 volts 25 b.h.p. was also installed to assist ventilation.\textsuperscript{953}

The first alternating electrical system in an Australian mine appears to be that installed at the Charlotte Plains Proprietary mine on the Loddon deep leads after 1898. This mine

\textsuperscript{950} Newman, "Blast Furnace Practice in Australia," p. 33.
\textsuperscript{951} Knight, "Steel Making Practice," pp. 72-6.
\textsuperscript{953} Ibid.: 12 Jan. 1899, p. 37.
had been developed by local interests to the production stage when an inrush of water in 1892 had closed the mine. The major shareholder, Drysdale Brown, sought fresh capital in London and raised £20,000 there to develop a better pumping system. With these funds the company installed a power station with alternating generators made by the General Electric Company of New York. This plant also supplied power by overhead transmission lines at 6,600 volts 60 hertz to the New Havilah mine and the Junction Deep Leads mine, both some miles away. Three throw double acting plunger pumps each capable of pumping 2.6 million gallons per day were installed in each of the three mines. The winding engines, underground haulage at 240 volts and ventilation fans of 15000 c.f.m. were also electrically driven.

Electric firing of explosives had been introduced in gold mines and in New South Wales coal mines during the 1880s and was in general use by the 1890s. It was accepted by the miners more readily than other electrically operated equipment because it was both safer than the safety fuse and also a misfire could be inspected within five minutes compared with eight hours for safety fuses. However the coal miners were more resistant to the introduction of electric-driven coal cutting machines, particularly in gassy mines, because of the danger of sparks if the cable to an electrically powered machine was accidentally cut, and also because machine cutting was a threat to the skilled miner as his labour was replaced by a more productive machine which could be operated by unskilled labour. Management was slow to push the installation of the new machines because the old established collieries around Newcastle worked the bord and pillar system which was poorly suited to machine mining. By the end of the nineteenth century these mines were nearing the end of economic working. In 1903 the Australian Agricultural Company opened a new pit at Hebburn, near Maitland, and an English manager, Robert Harle, was employed to develop the mine. He planned to mechanise it from the start with entry via two tunnels from the surface, steam driven machine haulage from the face to the surface, and electric pumping and coal cutting with either electric or compressed air machines. At the same time J. & A. Brown and other companies were experimenting with imported cutting machines.

956 Ibid., p. 144.
957 Ibid.
Harle first installed two electric cutters made by the Jeffrey Company of the United States in 1903 and by arrangement employed Mr. Goddard, an experienced technician from the United States, to maintain the machines and train operators. The machines of the chain cutter design operated on 220 volts DC. Compressed air Jeffrey chain machines were installed in June 1904 and comparisons of operating costs for the two types were made. The electric machine proved the better machine. Coal cutters were accepted by the miners in July 1904 after agreement on the rates which gave a miner 12 shillings a day compared with 10 shillings for hand mining. Other coal companies reached similar agreements.

The miners were concerned with the safety of the electric driven machines, particularly with sparks from cable breakages and switchgear causing explosions in gassy mines. A Royal Commission was appointed to investigate but while it was deliberating the miners struck in 1907. The Commission recommended very stringent regulations on the use of fire-proof switchgear and protection of cables. These were accepted by the mining companies and work resumed after 16 weeks. By 1908 Hebburn had 15 machines in use and several other northern collieries were similarly equipped. On the southern field around Port Kembla three out of 12 collieries were then using machines, and on the western field around Lithgow one was using machine cutters. By 1914 27 percent of the 10 million tons of coal mined in New South Wales was machine cut. However due to miner resistance and no clear economic advantage over hand methods, little progress was made on increasing this percentage and in 1939 32 percent of the coal was cut by machine. Coal cutters were first installed in Queensland coal mines in 1905 and by 1913 there were 25 in use, but by 1925 the numbers had declined, particularly in the Ipswich area apparently because the increased productivity did not justify the increased capital cost. The stated opposition of the miners to mechanical equipment was not due to its use to cutting the bords and cut-throughs in the first extraction but the later

958 A.A. Co. Papers, Hebburn Colliery Monthly Reports 1/86/13, June 1903 to June 1908.
959 Ellis, A Saga of Coal, p. 146.
960 A.A. Co. Papers, Hebburn Colliery Reports, January 1908.
961 Ellis, A Saga of Coal, pp. 145, 224-5.
extraction of pillars, which they regarded as extremely dangerous because the noise of the machine drowned out ground movement noises.\footnote{ Joint Coal Board N.S.W., \textit{Report} (Sydney), 1950-1, p. 21}

Several small black coal mines were operating in Victoria from the 1890s, some using the bord and pillar system and some the long wall system with machine cutting, but the seams were between 1 foot 6 inches and 5 feet thick and the ground was faulted. The mines found difficulty competing with New South Wales collieries and production was small.\footnote{ Reports to the Minister of Mines, \textit{Victoria}, 1896, pp. 31-2.} A long strike in the New South Wales collieries forced the Victorian government to open a mine at Wonthaggi in 1909 to supply black coal for steam driven trains, but the main interest in Victoria was on developing the huge deposits of brown coal in Gippsland. In 1921 the government appointed Sir John Monash to establish the State Electricity Commission to undertake the electrification of the state using brown coal.\footnote{ Elford and McKeown, \textit{Coal Mining in Australia}, pp. 14-15. The Longwall system was usually used at Wonthaggi. Output of brown coal was 5.7M tons in 1946. See p. 15.} The brown coal seams, some two hundred feet thick were mined on several levels with bucket chain dredges imported from Germany. The coal heated steam boilers driving turbines connected to alternators which generated electricity for transmission to Melbourne.\footnote{ Ibid., pp. 200-1.} By 1935 a further transmission line was connected to Bendigo, where the Monument Hill Consolidated Mining Company bought electric power to drive the machinery on a gold mine it was developing.\footnote{ J. A. Lerk, \textit{Bendigo's Central Deborah Gold Mine} (Bendigo: J. Lerk, 1993), p. 10.} An early open cut black coal mine was commenced at Blair Athol in Queensland in 1937. The overburden was removed by scoops driven by diesel engines, the coal seam face (some 60 feet deep) was blasted down, and the broken coal loaded by steam driven shovels into five ton capacity motor trucks, which delivered it to the screens.\footnote{ Elford and McKeown, \textit{Coal Mining in Australia}, pp. 177. Queensland production of black coal was 1.57M tons in 1946.}

The Broken Hill mines changed gradually from steam driven plants to electricity in the 1920s but each mine had its own voltage and frequency. Small electric winders were the first changes but electric haulage was not introduced until 1932. Electric locomotives underground were trialled at B.H.P. in 1902 for one year but then abandoned and horses reinstalled because of costs. In 1934 a Central Power Station was...
built using diesel driven alternators to supply 6900 volts at 40 cycles per second and all steam power plants were decommissioned.\(^{969}\)

The blacksmiths and foundrymen who had migrated to Australia in the nineteenth century had brought with them a thorough understanding of the metallurgy of iron and the making of steam machinery using cast iron. Some arrived before the gold rushes but most migrated in the 1850s and they had little knowledge of the properties of steel, this technology being developed in Europe and the United States after 1850.\(^{970}\) As electricity began to replace steam as motive power in the twentieth century, the technology of iron founding to produce steam engines was rendered obsolete with major consequences to several related industries. By the end of the nineteenth century the countries making steel had developed steel alloys with superior strength, hardness and resistance to wear compared with cast iron. These in turn enabled the manufacture of machine components of lighter weight, lower maintenance requirements and longer life.

One of the early casualties of the failure to develop steel technology in Australia before 1900 was the local rockdrill industry, the genesis of which was described in Chapter 6. American and British manufacturers, specialising in rockdrills for export as well as home use, developed alloy steels suited to each component of a drill.\(^{971}\) This enabled the weight of the drill to be reduced to enable operation by one man instead of two, a large saving in extraction costs. Also in 1900 the Leyner Company of Denver, Colorado, marketed a rockdrill with the drill steel containing a central hole through which water could be injected to dampen the silica dust produced during drilling. By the 1920s this design replaced the Australian rockdrills as concern mounted over the prevalence of silicosis in miners caused by rockdust. The Australian foundries could not compete as the development of steel alloys lagged overseas practice and rockdrill manufacture disappeared as an Australian industry.\(^{972}\)


\(^{970}\) R. A. Buchanan, "History of Technology," in *Encyclopaedia Britannica* (Chicago: William Benton, 1974), vol. 18 p.42. Bessemer patented his converter in 1856 and the Siemens-Martin open hearth process was introduced in 1863


The use of electricity as a motive power required the use of special alloy steels with high magnetic properties. Electric motors and transformers used these steels in large quantities. Steam engine power - with its major requirement of line shafting and belt drives to individual machines in mining mills and factories - was replaced with individual electric motors, all supplied by high voltage transmission lines and step down transformers. The generators, driven by water power, large steam turbines or diesel internal combustion engines were grouped in central power stations. Small internal combustion engines, which were introduced gradually in the early twentieth century replaced steam power at isolated mining plants in inland Australia. Australian foundries ceased manufacture of steam engines in the 1920s and as this had been the major business of most of them, the foundries themselves collapsed. A few diversified and survived. Austral Otis Engineering in Melbourne diversified into lift manufacture and Thompsons foundry in Castlemaine specialised in pump manufacture.973 Walkers at Maryborough in Queensland continued to produce a wide range of mining machinery.

Advances in mechanical and electrical technology overseas in the latter part of the nineteenth century were only slowly introduced into the curricula of the tertiary educational institutions. In 1896 the Ballarat School of Mines had somewhat belatedly introduced tertiary-level associate diploma courses in mining and metallurgy as a response to the discovery of new metalliferous mines in Australia. This was followed by similar courses at the South Australian School of Mines. The Victorian Education Department used the Ballarat courses as a basis for examinations and the other Victorian schools then upgraded their courses. Similar courses were developed in other States.974 The University of Melbourne introduced degree courses in mining and metallurgy in 1901.975 This slowness of response was criticised by the mining industry and the mining press. When giving evidence to the Victorian Royal Commission on Technical Education in 1900, William Knox, the president of the Victorian Chamber of Mines, said that while the schools at Ballarat, Bendigo and Bairnsdale were producing assayers, metallurgists and mining engineers up to foreman level, none of them were

973 University of Melbourne Archives, "Austral Otis Engineering Papers," in Accession No. 60/10, Folder 4/1. Most foundries in provincial mining towns also collapsed.
974 Similar diploma courses were developed at Charters Towers (founded 1901), Brisbane technical College (1882), Perth Technical School (1901), Kalgoorlie School of Mines (1904), Zeehan School of Mines (1896) and Launceston Technical College (1888).
filling senior positions.\textsuperscript{976} What was needed, he said, were metallurgists like Mr Schlapp (who had trained at Freiburg and had been chief metallurgist at B.H.P.), along with a gradation of education, in order to make the perfect mining engineer and metallurgist who could deal with mining enterprises of the other colonies.\textsuperscript{977}

There appear to be several weaknesses in Knox’s criticism. Firstly, if Schlapp was such a superior graduate why had he not contributed more to solving the problems of slimes at Broken Hill. Secondly, diploma and degree courses were then being introduced in Victoria. Thirdly, there were senior staff in the mines who had trained in the schools of mines in the 1880s.\textsuperscript{978} His criticism was also unfair to the Victoria taxpayers who were subsidising the local schools, however inadequately that may have been. To expect them to train men to work in other States was unreasonable. As far as is known B.H.P. did not contribute money to assist the schools until much later in the twentieth century, when the company supported research in the universities and actively recruited graduates and diplomats from the schools of mines.\textsuperscript{979}

The responses by most of the mining schools to developments in mechanical and electrical engineering overseas were slow. Sydney University produced the first graduates in a combined mechanical and electrical course in 1895.\textsuperscript{980} Victoria was still suffering the effects of the 1890s depression and little money was available for new courses. Although single subjects in mechanical and electrical technology were taught in the Schools of Mines in Victoria before 1900 it was not until 1908 that the first diplomates in electrical engineering graduated from the Ballarat School of Mines.\textsuperscript{981} Mechanical engineering degree courses commenced at the University of Melbourne in 1907 and electrical engineering in 1912.\textsuperscript{982}


\textsuperscript{977} Knox was also the secretary of B.H.P. which at that time was stacking concentrates and slimes at Broken Hill. He did not mention the School of Mines at Sydney University or the one in Adelaide.

\textsuperscript{978} Some examples were James Hebbard, manager of the Sulphide Corporation at Broken Hill, William Hamilton, at Great Boulder in Kalgoorlie, both Bendigo trained and George Richards, chief metallurgist at Mt. Morgan who was Ballarat trained.


\textsuperscript{981} W Perry, \textit{The School of Mines and Industries Ballarat} (Ballarat: The School of Mines and Industries Ballarat, Ltd., 1984). See list of graduates.

\textsuperscript{982} Blainey, \textit{A Century History of the University of the University of Melbourne}, p. 128.
The Schools of Mines struggled in the first half of the twentieth century as mining declined and government funding was inadequate to keep teaching facilities and laboratories up to date. The development of State financed secondary schools took over the continuing education function and the smaller Schools of Mines closed or were converted to secondary technical schools. The number of diplomates from the Schools of Mines and technical colleges between 1900 and 1939 is estimated to have been an average of 15 mining engineers and 25 metallurgists and the numbers of graduates from the universities was about the same. No total figures are available for electrical and mechanical engineers but it is likely the numbers were less than the mining engineers and metallurgists.

**Conclusions**

The promise of the major advances in processing technology achieved at Broken Hill and Kalgoorlie by Australian technologists working with overseas trained people was not lasting. Two world wars, financial depression and fluctuating metal prices led to the demise of many gold, copper and tin mines. The resultant loss of jobs and the loss of trained personnel to the armed services decimated the skills available to the mining industry. The policy of both the British and Australian governments during World War I was to support those mines which were producing essential minerals for the war effort. During and after this war the lack of financial support either from governments or the mining industries resulted in the Schools of Mines and the Universities failing to provide the more advanced training necessary to meet overseas competition in the new mechanical and electrical industries.

When steam power was replaced by electricity and the internal combustion engine from the 1920s, European and United States companies preferred to invest their funds in innovation in their own countries and there was neither the finance or the skills base in Australia to develop suitable new manufacturing industries to replace the obsolete iron foundries. Australian industry lost the ability to innovate in the new technologies and

985 These figures should be treated with caution. The conferring of a diploma required evidence of one or two years of experience after completion of the course. An unknown number did not bother to produce the evidence needed and the diploma was never conferred.
electrical equipment and the larger internal combustion engines used in mining were imported.

The one exception to this gloomy picture was the development of a strong and competitive iron and steel industry at Newcastle after 1915, based on the iron ore deposits in the Middleback Ranges and dolomite deposits near the coast of South Australia. B.H.P. was able to finance this development from the profits of its Broken Hill mine and a local loan. During World War II additional blast furnace capacity for making iron was built at Whyalla. This enabled back loading of coal by the ships travelling to the area to pick up iron ore.

Also there was improvement in the 1930s when the price of gold increased and the recovery of the world economy led to increases in the demand for metals. These difficult years produced a group of Australian engineers and managers with a solid grounding in mineral technology. A small inflow of British capital in the 1930s, mainly from the efforts of W. S. Robinson was of considerable assistance. After World War II Australians such as George Fisher, Jim Foots, Maurice Mawby and Lindesay Clark were in the forefront of the expansion of Australian mining.\textsuperscript{986}

This chapter concludes the detailed analysis of the development of mining technology in Australia at a time when most mining was at a low ebb due to the worldwide depression of the 1930s.

After World War II measuring instruments developed during the war were soon adapted to mining exploration. This led to a revolution in the science of geology and new theories on the formation of orebodies, leading in turn to the discovery of new orebodies of minerals already mined and the finding of minerals which had not been previously mined in Australia. When coupled with improvements in extractive and processing technologies this led to the mining of lower grade ores in enormous quantities and a mining boom which started in the 1960s and has not finished. Because of space limitations these developments will be only briefly outlined in the epilogue.

\textsuperscript{986} This will be discussed further in the Epilogue.
Chapter 10

Conclusions

The earlier chapters of this thesis have outlined the growth of the Australian mining industry from a humble base of convicts mining coal along the Hunter River in 1801 to the extensive and economically important industry of the twenty-first century. A central feature of all but the first of these chapters has been the many innovations in the various technologies involved in that growth. In analysing the evolving technologies underpinning this growth of Australian mining the following themes have emerged and will be consolidated in this concluding chapter: the changing capital base and management structures of the mining companies; the radically changing methods of extracting, processing and smelting the ores; and the sources and training of the skilled personnel required to convert ores to metals. These themes will be considered further in the following analysis of the development of mining technology in Australia, but before doing so the chronological framework for these developments needs to be restated.

In this chapter I will argue that the first fifty years of mining from 1801 in New South Wales and South Australia was a period during which miners and mining technology were imported mainly from Britain but with a significant contribution from German sources. There was little local innovation in the technologies needed to extract the coal, iron ore and copper lead and silver ores. The next period of about fifty years to 1900 was ushered in by the gold rushes of 1851. It was a time of major innovation, due to the need to adapt overseas machinery to the requirements of Australian orebodies. The wealth produced by gold mining financed new machinery and further mining investment. There was also major innovation in mining law due to the introduction of new political ideas of democracy by the many gold miners who had not been previously involved in mining. The decision of the government of New South Wales, soon followed in Victoria, to allow individual miners to peg a small claim and mine for gold on payment of a licence fee, resulted in a new type of mining company structure emerging in Victoria. This was more suited than the English joint stock company to mining the small claims and leases. By the late 1860s it was clear that mining engineers and metallurgists with a better scientific training were needed to develop the deep lead

987 Most mining historians consider coal mining to be a distinct technology from metalliferous mining, but in this presentation I have argued that coal seams can be considered to be a flat or gently sloping orebody which is mined in a way similar to any other flat orebody.
and deep quartz reef gold mines, and this realisation led to the establishment of schools of mines in the various colonies. The discovery of the silver lead and zinc orebody at Broken Hill in the 1880s and the complex finely disseminated gold ores of Kalgoorlie in the 1890s required improved technologies since finer grinding was needed to separate the minerals. Many small gold mines in eastern Australia were also experiencing problems in fine grinding refractory gold ores to separate the gold. The slimes produced by the fine grinding contained considerable amounts of the desired minerals but these were being lost with the tailings. In the 1890s the richness of the new orebodies again attracted overseas mining companies. These had the large capital resources needed to finance innovative research (based on now well established scientific methods) and to employ technologists from Australia and overseas. However innovations in gravity concentration methods and the new blast furnace technology introduced from overseas failed to completely solve the problems of sliming.

It was only during the third period of Australian mining, the fifty years 1900 – 1945, that these problems were overcome. This chapter will discuss how the problems of sliming were finally solved during the first 15 years of this period. Finally this chapter will consider the remainder of this third period from 1915 to 1945. This included two world wars and a major economic depression, which restricted the development of new technologies. The period nonetheless finished with a mining industry strong in trained and experienced staff, who formed the base from which explosive growth was possible in the years after 1945.

This chapter will consider the development of these changes and, following the ideas of Joel Mokyr and Roger Burt, will attempt to classify them as micro innovations, successive small changes in existing technologies, or as macro innovations, radical new concepts without clear precedent. However it will also extend these concepts to include the combination of several important micro innovations which produced a new technology of major importance.988

Limitations of space prevent a detailed analysis of the enormous expansion of Australian mining and new innovations in mining technologies during the fourth period from 1945 to the present, but a brief discussion of this period has been included in an

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epilogue for completeness, together with an analysis of the most important future needs of the mining industry in Australia.

**Historical Background**

The stage for the first period from 1801 was set in 1788 when the first fleet arrived in Sydney with convicts and their military supervisors to establish a penal colony. They would have brought with them a general knowledge that coal, iron, copper and tin were essential elements in the industrial revolution that was transforming their British homeland but as far as is known there were no experienced miners among them. The early years of the new colony were a struggle to survive, but by 1800 the settlement was well established and coal seams had been found in outcrops along the coast. The British government desired to offset the increasing costs of the settlement by exporting some of that coal but also to use some of it in Sydney for heating and blacksmithing to maintain and sharpen iron tools. Deposits of coal, easily accessible along the Hunter River at Newcastle, were mined from 1801 by convicts using hand methods with convicts experienced in coal mining as underground supervisors and mine planners working under overall military supervision. Due to the lack of specialised mining equipment the hand methods used and drainage by adit lagged far behind current practice in the private enterprise mines of Britain. These British mines used steam engines for pumping and raising coal to the surface and mechanised loading of coal onto ships at the staiths on the wharves. After seventeen years the seam at Newcastle (Australia) had been worked a sufficient distance from the adit entry to require a shaft to be dug, through which the broken coal could be manually hauled to the surface by basket.

After the Bigge report of 1823 on the state of the colony of New South Wales, the British government endeavoured to reduce the costs of the inefficient coal mine and handed control to the Australian Agricultural Company in 1828, with an inducement of 2500 acres of coal lands in the area and a monopoly of coal mining in Australia. This joint stock company had been chartered by an Act of the British parliament in 1824 with a grant of one million acres of land in New South Wales for agriculture and sheep raising. The paid up capital was one million pounds sterling, the directors were financial investors and the head office and secretarial staff were in London. The directors had no experience in coal mining but as similar companies were mining for coal in Britain the government apparently assumed the company would be successful in New South Wales.
if expert staff were employed to operate the mine. Due to management problems the mine was not taken over until 1832, after which experienced staff installed low pressure steam engines for pumping and haulage, and mechanised the loading at the wharves to the current British standards. Competition from other privately owned coal mines began to develop in the 1840s despite the supposed monopoly and when the Australian Agricultural Company successfully sued the owners of one of these mines for infringing the monopoly it became very unpopular with the miners who lost their jobs, and with Sydney capitalists who wished to start other coal mines. The company surrendered the monopoly in 1847 and other coal mines under company control were then developed at Newcastle with capital raised in Sydney and in Britain.

The range of minerals mined in Australia in this initial period was extended soon after the colony of South Australia was formed in 1835 when the British government legislated for control of the new settlement to be shared between government officials appointed from London and a Board of Commissioners. Problems with selling the land granted to the Commissioners led to the formation of the South Australian Company, a joint stock company, in London in the same year, which partly purchased and partly leased a large area of agricultural and grazing land. The purchase of the land gave the company the right to mine any minerals on the land. Among the supervisory staff sent to the colony by the company were a German mineralogist, Johann Menge, and two German miners. Menge explored the country areas for minerals and publicised his finds locally and in Germany but the company managers lost interest in mining ventures. Small silver lead mines were opened in 1840 near Adelaide by others and several copper mines were opened in succeeding years.

One of these copper mines at Kapunda, opened in 1844, was financed and operated by the owners of the land on which it was found, and another mine at Burra, opened the following year, was controlled by a company, the South Australian Mining Association, with capital raised in Adelaide and registered in South Australia as a cost book company under British mining law. In both cases the colonial government followed British precedents and did not interfere with the operation of the mine in any way. The publicity about these mines in Europe led to the migration of both German and Cornish miners and their families in substantial numbers. They brought with them the technologies in use in Germany and Cornwall for mining silver lead ores and copper
and tin ores respectively. As the Cornish miners were the predominant group and they were used to working in a private enterprise system rather than in the more bureaucratic government controlled systems of the German states, they preferred Cornish management and Cornish technology which became dominant in South Australia. Small copper mines were also developed around Bathurst in New South Wales in the 1840s. Capital for development was supplied by the owner of the land on which the mine was located and if needed additional capital was raised in Sydney. Miners and equipment were imported from Britain. Sydney capital was used to establish a small mine and blast furnace near Mittagong in 1848 to produce pig iron from local iron ore, using local coal as the fuel and limestone as the flux. The blast furnace was built of local stone to a British design and British managers and operators were imported.

During the early years of copper mining in the rich metalliferous ores in the oxidised zone picks and shovels were used to extract the ore, which was then transported to the nearest port and shipped to Swansea in Wales, then the major centre for smelting copper and tin ores from Cornwall. This followed current British practice as the availability of cheap coal on the Welsh coalfields made the shipping of Cornish ores, after concentration by hand jigs, to the coal cheaper than shipping the coal to Cornwall for smelting. In Australia when the ore grades fell at deeper levels it was not economical to ship the lower grade ores overseas for smelting. The Australian Agricultural Company was not interested in building a smelter at Newcastle so the South Australian and New South Wales mining companies erected their own smelters at the mines. The largest was at Burra, where the newly formed South Australian Mining Association employed German smelter technologists to build a smelter at the mine using wood and charcoal as fuel. It was uneconomical and was closed in 1847. The company then negotiated with a London-based joint stock company to build a smelter at the mine, based on newly patented technology to smelt ore purchased from the mine. This smelter began operating in 1849. Other companies erected smelters either at the mine they owned, adjacent to a group of mines, or at Adelaide. A mixture of wood, charcoal and Newcastle coal was used as fuel and all the furnaces were of the reverberatory type, designed by Welshmen and operated by imported Welsh smeltermen.

This first fifty years of mining in Australia was a period during which British technology and mining law was predominant but with a substantial contribution from
German miners and smeltermen. The metalliferous mining companies established in the 1840s sought the latest British technology and imported British miners and technologists to operate their mines, so there was little time lag in the introduction of current overseas technology to Australia. This argument is also valid for the Australian Agricultural company mine at Newcastle when it first commenced operations in the early 1830s, but by 1851 the equipment then installed was obsolete and was not competitive with the more up to date technology imported by the smaller coal companies which began operating around Newcastle in the late 1840s. These new coal mines installed new British equipment for pumping and mine haulage, and the increased competition forced the Australian Agricultural Company to update its equipment in the mid 1850s to remain competitive.

This situation in which mining was controlled by British laws and British technology predominated, ended abruptly in 1851 when Edward Hargraves returned from the Californian goldfields with a knowledge of how to mine for alluvial gold a few feet below the surface of the ground. He believed, from earlier knowledge and experience, that he would find alluvial gold deposits near Bathurst and immediately travelled there. With the assistance of several local people he found a small amount of alluvial gold and commenced a publicity campaign through newspapers in Sydney and Bathurst to inform the public of this find. The locals found more gold, using the methods Hargraves had taught them, and Hargraves then used this information to start a rush similar to the rushes which had occurred in California in 1848 and 1849. He achieved this aim when a substantial rush to Ophir occurred in May. The New South Wales government was powerless to prevent this rush but sought to control it by allowing the miners to peg small claims and pay a high licence fee for the right to mine the gold on the claim. The pegging of the claim followed precedents established in California by miners themselves but the individual licence fee was unprecedented. Under British mining law in 1851, dating from the time of Elizabeth I, gold and silver belonged to the crown. British law permitted a mining company to mine any minerals on private property with the agreement of the landowner but any gold and silver recovered had to be sold to the crown at fixed prices. A substantial fee had to be paid to the crown for a mineral lease, before mining land known to contain gold or silver. The mining itself was closely supervised by a resident government official at the mine. Only a small amount of gold was being mined in Britain at this time. However mining lead ores containing silver was
controlled, and there was no doubt mining for gold was still controlled by this law in all
British colonies.

Immediately following the gold rushes, Hargraves was famous among the general
public, as the discoverer of gold in Australia. Some of his close associates found him to
be a liar and a cheat who manipulated circumstances for his own financial gain to the
detriment of others, and some recent historians consider him to be a charlatan.  All of
these views show different aspects of the man, but the public and his associates of the
1850s could not envisage, and historians have ignored, the long term impact of his
actions on British mining law in the Australian colonies. He started a train of events
which overthrew the semi-feudal British mining law and led to its replacement with a
new set of mining laws, more attuned to the democratic ideas of the mid nineteenth
century, which were anchored in the actualities of mining in the early 1850s. These
laws have continued without substantial change into the twentyfirst century. Hargraves’
actions also led to the emergence of a new type of mining company, more suited to the
needs of gold miners. If modern management theories are applied to Hargraves, he can
be considered as an entrepreneur of enormous influence on Australian mining. The
addition of gold to the range of minerals mined introduced a new level of complexity to
mining law and technology in Australia.

As well as macro-innovation in mining law, this 50 year period to 1900 saw micro-
innovation in ore extraction, ore processing and smelting technologies, and the
education of technologists to deal with a wider range of minerals. However the many
innovations resulted in difficulties in sliming as the ores were crushed finer in an
endeavour to separate the minerals in the ores. These problems were solved by some
macro-innovations during the early decades of the third period from about 1900. The
remainder of the period until the end of World War II in 1945 was a period of limited
innovation as depression and world wars had a major effect on the world economy. The
following sections will discuss these minor and macro-innovations in more detail.

990 See Chapter 2, "Edward Hargraves as Entrepreneur".
The Evolution of the No-Liability Mining Company

In order to retain control of the mining for gold during and after the rushes of 1851 the pre-democratic governments of New South Wales and Victoria passed laws and developed regulations to allow goldfields commissioners and an associated police force to supervise small scale gold mining and collect licence fees. The licence fee and the methods used to enforce payment were resented by the miners, who held protest meetings on the Castlemaine, Turon and Bendigo goldfields which culminated in the armed uprising at Eureka on the Ballarat goldfields in December 1854. Behind this resentment over the licence fee was the miners’ concern that both governments were endeavouring to re-impose the British system of company mining by granting leases covering large areas which would squeeze out the individual miner. The earlier experiences of job losses among the coal miners who had worked in the small coal mines in the Hunter Valley in the late 1840s, and who later rushed to the Turon in 1851, greatly fuelled this fear.991

The Victorian governor, Charles Hotham, used the military and police to easily suppress the uprising at Eureka, but the political fallout was far reaching. The Legislative Council surprisingly accepted the major recommendations of a Royal Commission and in June 1855 passed legislation to replace the licence fee with a miners’ right (a subtle use of words for what was still a fee) costing £1 per year, and to set up local courts in each of six mining districts, which were to develop and enforce new byelaws for mining in each district. Other legislation allowed miner representation in Parliament. The miners seized these opportunities; the local courts of miners, elected by miners, soon submitted new byelaws for their districts and the miners who were elected to the new parliamentary seats, together with an additional miner nominee, sought to introduce new laws to cover gold mining. The local courts initially had power to adjudicate on partnership disputes, but this led to concern among miners themselves and those who understood the principle of the ‘separation of powers’ that a body making regulations should not also adjudicate on those regulations, and so the local courts were restructured in 1858 into mining boards without this power. Independent Courts of Mines were set up to adjudicate on mining disputes and to decide cases of mining law.

991 See Chapter 2, "Miner Resistance".
In 1865 the various byelaws of the local courts and mining boards were consolidated by a more democratically elected parliament than the one which had existed in 1855. The resulting Mining Statute continued in operation with only minor changes for 125 years. This Act, based on practical mining experience, was used in the years up to 1900 by all other Australian colonies as the core of their own mining legislation. The result was uniform mining legislation, Australia wide, which has been of immense importance in the development of mining technology in Australia, as mining regulations in all jurisdictions are very similar and equipment made to comply with legislation in one state can be used without modification in others.

The pre-democracy decisions of 1851 to limit the size of claims to a small area (which it was believed would give a liveable return to a single miner or small party, but not make them rich) also had considerable consequences. British mining law had allowed mineral leases of large area sufficient to support the considerable overheads of a joint stock company. The concept of the lease had continued in the new Victorian legislation after Eureka, but the local courts forced a reduction in the area allowed to make it consistent with the size of a claim in an attempt to prevent companies mining for gold. Pressure by miners forced New South Wales to follow suit. Notwithstanding this pressure both governments continued to sponsor company mining. In 1855 Victoria legislated to allow companies, similar to British cost book companies, to be formed to raise capital from shareholders but the mining population was still too fluid to establish companies in large numbers. By 1858 miners at Ballarat had followed the shallow alluvial washdirt into deeper ground, the so-called deep leads, and pressure mounted to allow small parties to amalgamate their claims into larger claims or to convert them to leases and to form co-operative parties so as to cope with the challenges of deeper sinking and the costs of pumping of large amounts of water from the deeper mines. Following a change by the British government to British company law to limit the liability of shareholders in joint stock companies, further legislation was passed in Victoria in 1859 to limit the liability of shareholders in mining companies. However this

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992 A mineral lease was a surveyed area of ground, approved in writing by the governor, from which the lessee was entitled to mine the approved mineral. Holders of leases were required to employ a stated number of men. The area was determined by the governor, in practice this was by an official of the department of mines. A claim was a small area of ground, 12 feet by 12 feet in 1853, pegged by a miner, who had paid a licence fee, without survey, from which he could extract any gold he found. After 1863 claims could be registered with the warden and had better protection from jumping by others.

993 See Chapter 3, “Deep Alluvial Mining”.
legislation, drawn up by the Solicitor General, Richard Ireland, was too complex to be generally popular. By 1859 many miners realised that the deeper mines, both alluvial and quartz, could only be developed with the aid of extra capital and Ballarat miners, through their local court, led the way to agreeing to larger claims and leases. The Victorian government began to register and control leases more tightly, measures aimed to attract outside capital to mining. The joint stock type companies formed before 1860 soon collapsed because of the high overheads inherent in the company structure.  

In 1860 the miners reasserted their influence when Vincent Pyke, a miner member of the Victorian parliament, introduced a simply worded mining company bill with a clause to limit shareholder liability. The resulting Act was popular and several hundred companies were formed in Victoria in the next three years, mainly at Ballarat and Daylesford. In 1864 the government sought to develop a single company law to include all types of companies but the miners quickly forced a return to the spirit of Pyke’s Act when Frazer’s Act was passed. It was similar to Pyke’s Act but simplified the procedure for winding up a failed mining company. As many quartz mines were now below the waterline and needed more capital for pumping and winding machinery many additional companies were formed, particularly at Bendigo and Stawell.

By the late 1860s many deep alluvial mines around Ballarat had extracted their washdirt and many of the quartz mines in all districts did not find payable ore and were wound up by the Courts of Mines. These courts passed the winding up to agents, mainly lawyers, who found that many shares were held by ‘dummies’, people who had signed the share certificate but were not the real owners, and who did not have money to pay any unpaid calls on the shares. Typically when the agent tried to recover the unpaid calls he was unsuccessful, and he then sought to recover money from any wealthy shareholders by suing for all the unpaid amounts on the shares. As many of the companies had started operations on a paid up capital of one shilling for each 20 shilling share, the amounts could be considerable. Capital for new mining ventures dried up as a result, so legal managers stopped forcing the forfeiture of shares when calls were not paid, particularly on Bendigo. Company investors and miners, mainly from Bendigo and Melbourne, combined to have the law changed to allow shareholders to forfeit their shares when they did not wish to pay a call and then have no more liability for any  

994 See Chapter 3, “The Development of a New Type of Mining Company”.
company debt. The so-called No-Liability Act was passed in Victoria in 1871. It allowed three types of mining company, the earlier cost book type, the earlier limited liability type of Pyke and Frazer and the new no-liability type, the first of its type worldwide. The no-liability type became increasingly popular during the 1870s, and from 1880 almost all gold mining companies registered in Victoria were of this type. New South Wales passed similar legislation immediately after Victoria and the other colonies followed. Some silver mines in Broken Hill adopted this company structure in the late 1880s.

The no-liability company was well suited to gold mining on small claims and leases. It could be registered quickly as only five percent of the nominal capital had to be raised before registration, and if the company failed to find payable ore it could be wound up quickly. Shareholders were guaranteed they could relinquish their shares and cease to be liable for any company debts. It was very suitable for close knit communities where local investors provided most of the capital. Overheads were low because companies were formed to take over mines which had been worked successfully as claims. Many of the original partners became directors in the new company and they decided how the mine should be developed. The mine manager was little more than the underground foreman and was paid little more than a miner. The legal manager, really the company secretary, acted in this role for as many as twenty mines and the cost to each mine was small. One weakness was that the law allowed shares to be forfeited within a fortnight of the announcement of a call and a remote shareholder, living at such a distance that notice of a call did not reach him in sufficient time to allow a response, could find his shares had been forfeited before he received notice of a call. There was a possibility that directors could then buy those shares cheaply at the subsequent auction. For this reason shares in no-liability companies were not popular with British investors, who preferred the limited liability company. However subsequent events, including fraudulent share manipulation by Whittaker Wright between 1895 and 1900, showed that limited liability companies registered in London and operating mines in Kalgoorlie were just as susceptible to fraud as any no-liability company.\(^{995}\) The no-liability company was a unique Australian development in the structure of mining companies world wide and was particularly adapted to the uncertainty of gold mining on small areas. While never adopted on a large scale elsewhere, except in New Zealand, it was very popular in

Australia where no-liability gold mining companies have continued into the twentyfirst century. It can be considered as a macro innovation in Australian mining company law.

Many historians have taken the view that the Victorian mining company legislation of 1855 and particularly 1859, together with the depletion of the easily mined shallow alluvial ground, resulted in an immediate shift from independent miners to company employment. This is not borne out by analysis of the statistics produced by the Victorian Mines Department after 1863 together with mining company registrations published in *Government Gazettes*. This analysis shows that substantial numbers of mining companies were not registered in Victoria until the 1860-64 period of Pyke’s Act, followed by further large registrations under Frazer’s Act from 1864 and the No-Liability Act of 1871. Until the late 1860s a substantial fraction of the alluvial gold miners were still participating in the various rushes around the colony and most quartz mining by partnerships did not change to company mining until after 1865, when capital was needed to sink deeper and pump water from below the waterline. While the exact numbers of miners working in partnerships or in company mines is difficult to determine, it is clear that the trend to company employment was gradual after 1860 and that there were still many gold miners working in partnerships during the mid 1880s.

The joint stock company model with a large capital base, external and often remote shareholders and with directors with little technical knowledge of mining, resulted in company structures with high overheads which required large orebodies to generate high returns. The amalgamated claims and small leases of about 30 acres permitted in the eastern Australian colonies in the second half of the nineteenth century would not support them. The only successful one was the Port Phillip Company but it was exceptional in that a loophole in Victorian mining law in the 1850s allowed it to lease 160 acres of private land on which were several reefs. Claims and leases on crown land at that time effectively limited a mine to one reef. The result was that almost every joint stock type gold mining company in eastern Australia had failed by 1860 when the evolution of the no-liability type began with Pyke’s Act. The no-liability type company with a small capital base, directors who managed the mine and with most shareholders living locally, was better suited to claims and small leases restricted to cover one reef.

996 G. Serle implied in his book *The Golden Age* that the change to large company mining was rapid from early 1859 (see p. 224). Other historians including T. Dingle in *The Victorians – Settling* p. 56, have emphasized this argument but as I argue in Appendix 4 the change to company employment was more gradual.
The small area allowed also had implications for innovations in extracting and processing the ore as will be discussed in the next section.

**Innovation in the Extraction, Processing and Smelting of Ores**

**Innovation in Ore Extraction**

The technology of the early gold rushes was a reversion to very old methods from Europe, which had been taken to the north east and south Americas and arrived in eastern Australia through California. An exception was the so-called Californian pump for draining shallow workings, which had originated in China many centuries earlier for irrigation, and was taken by Chinese miners to California in the late 1840s. These early methods of shallow sinking, dishing, and sluicing were improved by the addition of the cradle, apparently invented in the United States in the early 1800s and used in California, all of which were applied without alteration on the Turon in 1851. The major method of gold recovery on the early Australian goldfields was by shallow sinking and cradling the washdirt, but the Californian practice of building dams and water races to supply water for sluicing was soon in use in the Turon area and at Beechworth in north eastern Victoria, where ample water was available in winter. An early micro innovation was the gold puddling machine, which seems to have been a transfer of technology from two sources independent of each other. At Louisa Creek, on the Turon, the source was most likely the pottery industry of the Hunter Valley, and the other at Bendigo and Castlemaine was by Cornish miners adapting an alluvial tin washing buddle first developed in Cornwall in the late 1840s. The evidence available indicates both were 1852 innovations but does not permit a priority to be given to either one.  

An early macro innovation was introduced at Ballarat in the mid 1850s as miners followed the shallow workings into deeper alluvial ground under a thick basalt cap. The ground was very wet, which made mining dangerous when the washdirt turned to sludge which filled the workings. Coal miners, either from England or the Hunter Valley, adapted coal mining methods to pump the washdirt dry by sinking by hand and tunnelling into the washdirt, draining off the water into a sump and pumping it to the surface with Cornish steam pumps. A Hungarian miner with previous military experience developed a method of firing gunpowder in wet ground which solved the

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997 See Chapter 2, "Early Goldfields Technology".
problem of sinking through the wet basalt. The early mining regulations allowing only the pegging of small block claims with fixed boundaries, were altered by the Ballarat local court to allow frontage claims where the boundaries were not fixed until the gutter in the washdirt was located by shaft sinking. The thin horizontal deposit of washdirt was then developed using coal mining techniques similar to bord and pillar to extract the gold bearing dirt. The Ballarat deep lead mines under the basalt were unique in the 1850s and the simultaneous transfer of coal mining technology and innovations in explosive technology and in mining law warrant the classification of an Australian macro innovation. The improved technology was soon used to mine similar gold and tin deep lead alluvial deposits around Australia.998

There was innovation in shaft sinking and ore extraction in hard rock mining for gold but it was a micro innovation based on gradual improvements in older technologies. Cornish and German stoping methods developed for copper and tin ores and for silver lead ores respectively were directly applicable to the generally narrow vein gold ores. Where the orebodies expanded into larger lenses the ground was usually strong and only simple wooden props were needed to support the walls and back. Back filling with barren rock from development drives or from the surface was sufficient to prevent collapse of the workings. As mines were extended below the waterline in the 1860s Cornish pumps were used to dewater the mines and simple cages, already developed in coal mines in Europe and applied in coal mines in New South Wales, were used to haul small trucks containing ore to the surface. Because the claim and lease areas were small, mine managers were forced to develop their mines vertically. They continued to find economic gold at depth in both deep lead mines where they found underlying reefs and in reef mines despite predictions of the opposite by geologists and scientists. As the mines deepened the hemp ropes were replaced by imported steel wire ropes, winding engines were powered by steam instead of horse driven whips and whims, and the engines themselves were made stronger to withstand the increasing stresses due to the longer ropes. No new principles were involved, the innovations were incremental and empirical methods were used in increasing the strength of machines. The local foundries, which had developed from the blacksmith shops of the 1850s, employed immigrant staff trained in British workshops, and mining machinery was made of cast and wrought iron. As the mines deepened, the small dimensions of the initial shafts

998 See Chapter 3, "Deep Alluvial Mining".
were inadequate to allow the installation of larger cages, safety ladders and ventilation pipes. The shafts were stripped to larger cross-sections, larger headframes were erected and from the 1890s scientific methods of stress analysis were used to assess the stresses in the headframes. The foundries in the larger mining centres, Bendigo and Ballarat in Victoria, Gawler in South Australia and Maryborough in Queensland, together with industries in the capital centres of Sydney, Melbourne and Adelaide, were the centres of these micro innovations.

While these gradual improvements in ore extraction were occurring in gold mines in the eastern colonies, the micro innovations driven by gold were also introduced in the copper and silver mines. The Kapunda and Burra mines closed in the 1870s when their orebodies were depleted, but substantial new copper mines were developed at Wallaroo and Moonta in South Australia, at Cobar in New South Wales and at Peak Hill in central Queensland. The expanding Australian economy, arising partly from the gold rushes and partly from pastoral expansion and wheat production, led to the development of new coal mines in New South Wales and Queensland, financed by both British and Australian capital, to supply coal for steam ships, gas works and the expanding iron foundries. However all the coal mines continued to use the bord and pillar system and hand methods for ore extraction. The newer overseas method of extracting coal by the longwall system using machines was ignored, probably because of the capital costs involved in any change but also because price fixing among the coal companies enabled them to continue with older less efficient technologies at a profit. In the 1860s a determined effort by all the major companies, but led by the Australian Agricultural Company, to destroy the union movement then developing in Australia, led to great bitterness between the companies and the coal miners, bitterness which persisted for 100 years. Miner resistance to the introduction of mechanisation in the coal mines was the long term result and the mines were not fully mechanised until the 1960s, many years after overseas mines.999

The small size of the gold mining companies of the 1860s and 1870s in eastern Australia and the policy of quickly paying profits as dividends meant these companies had insufficient resources individually to support research to develop new technologies. However they occasionally combined to support such research. In 1867 a company in

999 See Chapter 4, "Developments in Coal Mining to 1870".
Maldon purchased a new type of machine drill in Scotland and imported it for testing to drive a tunnel under Mt. Tarrengower to search for reefs. The machine was a success but local interest in the overseas development of a machine drill had already led Robert Ford, a Victorian railway engineer, to design such a machine which was manufactured at Vivian’s Foundry in Castlemaine. Several mining companies supplied the money to purchase a machine and its associated air compressor and instal and test the equipment in a Bendigo mine in 1868. The tests showed the drilling rates in hard ground with the machine were about double those for hand drilling. Ford improved his drill and reduced the weight over the years, other drills were imported from England and the United States, but it was not until the early 1880s that machine drills and the associated air compressors were lightened and reduced in cost sufficiently to replace hand drilling in most Australian mines. This apparent slow acceptance has led Geoffrey Blainey to criticise the backwardness of Australian goldmines in the late 1870s but recent research overseas is showing that Australian mines adopted machine drills more quickly than most British and American mines. The manufacture of rockdrills was soon an important part of the business of Australian foundries. Although Australian mines were quick to adopt this technology the basic design ideas came from Europe and the United States and for that reason it is classed as a micro-innovation. Several colonial governments also assisted miners to explore for new deep leads, quartz reefs and coal seams by paying for the import or local manufacture of diamond drills, which they hired to miners at nominal fees. The cores produced from gold reefs with shotty gold were not of great use in determining gold grades, but the cores from large metalliferous orebodies were essential in determining the grades and extent of the deposits. In recent years the mineral content of the ore is calculated from drill cores before mining is commenced and company investors are kept advised as estimates are revised after further drilling.

In Britain in the 1840s and 1850s an increasing death rate among miners in the deep coal mines due to underground gas explosions led to public concern and the belief that these deaths could be avoided by better working practices. In the same period the drive to improve efficiencies by increasing steam boiler pressures resulted in an increasing death rate from boiler explosions. The British parliament passed a series of mines inspection acts from the 1850s which mandated adequate air flows underground to

1000 See Chapter 6, "The Mechanical Extraction of Ores".
prevent the build up of explosive gases and regular boiler inspections to remove corroded boilers from use. This legislation alerted Australians to the fact that although Australian coal mines were shallower and there were fewer gas explosions than in England there was an increasing number of deaths in both coal and metalliferous mines in Australia. These deaths were due to rock falls and the lax use of explosives in the mines during the ore extraction. However it was not until the early 1870s that similar mines inspection acts were passed in Victoria and New South Wales. Other colonies copied this legislation as mining developed. The legislation covered the collecting of accident statistics both on surface and underground, the regular inspection of boilers, safe working practices, control of working hours underground and inspection of underground air flows and mine temperatures, together with a set of mandatory minimum standards. This led rapidly to the installation of large fans and blowers in coal mines and deep gold mines, better practices in the use of explosives and better inspection and prevention of rock falls in underground stotes. Improvements were achieved by micro-innovations in boiler safety devices and fan design but much of the required technology for these improved practices was imported from the United States and Europe. This government involvement in mine safety led to the Victorian mines department becoming directly involved, after the mid 1870s, in research into safety devices on cages and the development of more efficient mine fans.

Further micro-innovation occurred when wider and deeper copper and gold orebodies were discovered at Cobar in the 1870s and existing methods of timbering and backfilling were adapted to use local materials to support the walls and back. However when the very wide and deep silver lead orebody was discovered at Broken Hill in 1883 the soft ore and weak walls in the oxidised zone led to unexpected problems of ground creep and rock falls in the stotes. In this situation the technologies used for stoping gold ores proved inadequate and the directors of the largest mine, the B.H.P. Company (who were mostly pastoralists and investors with no experience in mining such a complex orebody), imported mine managers from the United States and Europe with experience in similar orebodies to solve these problems. They introduced square set timbering and very large open cuts to deal with the pressures on the weak ore and walls of the oxidised zone. When the mine was developed into the sulphide zone

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1002 See Chapter 5, "The Mines Inspection Acts".
1003 See Chapter 5, "Expansion of Mining 1870 -1900" and Chapter 6, "New Technologies in Metalliferous and Coal Mines".
below the waterline in the late 1890s the ore and walls were stronger, open stoping methods were again used.

A further micro innovation in paddock mining of gold took place in north eastern Victoria in the late 1880s, when large areas of alluvial ground was washed down with high pressure hoses and the slurry pumped from a sump with gravel pumps for treatment with box sluices. The ideas came from California but considerable micro-innovation was required by local foundries to develop a satisfactory gravel pump.

However drawings and specifications and manufactured components of bucket dredges were imported from New Zealand in the late 1890s to establish a gold dredging industry along the Macquarie River in New South Wales and the Ovens River in Victoria. While the machines themselves were larger and required much greater power to operate than the earlier puddling machines, the technology of removing the soil above the bedrock and washing it to separate the gold by gravity was similar but larger in scale. The micro-innovations were mostly imported.

Notwithstanding Blainey’s argument about backwardness and the dominance of small company gold mining units, Australian miners were quick to use new macro-innovations arising from advances in the science of electricity in the second half of the nineteenth century but these were all imported. Electric firing of explosives, electric lighting of mines both on the surface and underground and the use of telephones for communication between surface and underground were in use soon after development overseas. However the transfer of technology for the use of electric motors to replace steam power for traction and haulage was much slower. A few mines were using such equipment from around 1900 but it was not until the 1930s that most mines had abandoned steam as the main power source. Coal mines in Australia began to experiment with machine cutting of coal in the early 1900s, many years after it was in general use overseas. The financial depression in Victoria in the 1890s, the slow recovery, the advent of World War I, the financial depression of the late 1920s and poor industrial relations and management conservatism in the coal industry, were all contributory factors.1004

1004 See Chapter 5, “Electricity” and Chapter 9, "New Sources of Motive Power".
The examples of innovation in ore extraction listed above indicate that Australian mining company directors and their managers were not resistant to new technology. Almost all the mine managers and many of the directors had been practical miners who had learned on the job how to adapt earlier technologies to gold mining by trial and error in partnerships. They used similar methods when they became managers and directors. Where necessary they developed innovative solutions to solve the problems of mining new types of orebodies and where suitable technology was already available from overseas they imported it. Australian foundries became very proficient in producing machines made of cast and wrought iron. They copied machines developed overseas but also made important micro-innovations in machine development. Nor were managers resistant to new scientific ideas such as the use of electricity. Rather the speed of technology transfer depended on economic conditions and the involvement of Australia in overseas wars. In the first half of the twentieth century, in difficult economic circumstances, small gold mines were slow to replace steam power with electricity and coal mines were slow to mechanise.

**Innovation in Ore Processing**

When news of the initial gold discoveries in eastern Australia reached London late in 1851 mining investors there sought to share in the expected rewards. They formed joint stock companies which financed the purchase of ore processing equipment to be sent to the goldfields, together with managers and operating staff. It was often inadequate. By 1854 as the shallow alluvial fields were depleted individual miners began to extract the oxidised gold ores from the adjacent exposed reefs. Few of them had previous experience in processing gold ores and experimented with adapting equipment designed for processing copper, tin and silver lead ores to crush the ore to enable amalgamation of the gold, a process used in Europe and South America for centuries. A fifty year period of micro-innovation in gold processing technology followed and there were also micro-innovations in the processing of copper sulphide ores from below the waterline. Towards the end of this period new mineral fields were discovered, containing silver lead zinc ores and sulpho-telluride gold ores, which required new processing technologies. This section will discuss how incremental improvements in crushing technology enabled finer grinding to separate the various minerals in the ores. However these improvements caused the ores to slime and empirical and emerging scientific methods were then used to collect the desired mineral without losses due to sliming.
Several of the joint stock mining companies, formed in London in 1852 to mine in Australia, sent managers and miners and mining equipment to Australia. They expected to develop alluvial and reef mines. Also at least one joint stock company was formed in Sydney expecting to obtain a large lease to develop a quartz reef in the Turon district, and imported miners and ore processing equipment from Britain. The British equipment was often inadequate for the hard and abrasive Australian ores, the companies incurred high overhead costs due to the number of inexperienced supervisors and the inability of the managements to obtain the large leases they expected. All but one of these companies failed. The exception was the Port Phillip and Colonial Gold Mining Company mentioned above.\textsuperscript{1005}

From 1853 miners with hard rock experience overseas began to investigate the surface outcrops of the quartz reefs which had provided the eluvial and shallow alluvial gold which was then being depleted. In 1854 they began to blast these outcrops and crush the ore with simple hand operated dollies and separate the gold by amalgamation with mercury, a process in use from the sixteenth century in Europe. In at least one case the miners who had been employed by a joint stock company took over the imported stampers when the company failed and worked them on a small claim to crush and amalgamate the ore. Other partnerships operated imported crushing equipment such as rolls, stampers, chilean mills or Berdan pans to crush the rock at public crushing mills where any miner could take his ore to be crushed and amalgamated for a fee. The Port Phillip Co. began to crush its own ore with stampers and chilean mills in 1857, and as other partnerships and local mining partnerships and companies began to make profits they invested in crushing machinery to save the costs of carting the ore to public crushers. Experience soon showed that stampers were the most efficient for crushing the hard and abrasive quartz and sandstones of the reefs. The imported stampers were machines based on German and Cornish designs that had been in use for centuries. They were not very robust and the maintenance to keep them operating was high. A long process of micro innovation of stamper design continued for the next 20 years, during which the early stampers (largely made of wood) were converted into more robust equipment mostly made of wrought and cast iron. During this period there was continual exchange of ideas on the design and best operation of stampers between

\textsuperscript{1005} See Chapter 2, Quartz Reef Mining.
Miners and foundries in eastern Australia, California and Britain where many stampers were made. By 1875 best practice in crushing was very similar on the eastern Australian and Californian goldfields. By this time many foundries in eastern Australia were building stampers to the same basic design but with individual variations to suit local ores.\footnote{1006}{See Chapter 3, "Quartz Reef Mining".}

Many immigrant miners brought with them the idea that quartz ores could be softened for crushing by roasting and that amalgamation was improved if the ore was calcined or roasted by heating it in stacks or in ovens with wood as the fuel, and for several years most miners calcined their ore before crushing. However staff of the Port Phillip Company, with experience of mining pyritic ores in South America, analysed the tailings of the mine and found they contained substantial amounts of gold after amalgamation. This was fine gold in the iron pyrites in the ore. The company changed its operating procedure to separate out the pyrites from the crushed sand using blanket tables, then roasted only the pyrites, crushed it finer using a Chilean mill and recovered most of the fine gold by amalgamation. They also introduced a jaw crusher as a primary crusher before the stampers. The jaw crusher was invented in the United States for crushing rocks for roads but was soon adapted to mining and was made by a Melbourne foundry from the early 1860s. Other mining engineers in Victoria experimented with treating pyritic gold ores, but few used jaw crushers and preferred to use boys to prepare the ore for the stampers. They considered this to be part of the training of mining apprentices. From the early 1870s pyrites treatment plants began to buy the small amounts of pyrites produced by the mines and separate the gold by roasting, fine crushing and amalgamation.\footnote{1007}{Ibid.}

Although the science of chemistry was still in its infancy in the mid nineteenth century chemical methods of ore processing were tried quite early in eastern Australia to extract silver from gold ores at St. Arnaud before 1864. Initially they failed, but success but in that year success was achieved in the lixiviation of silver using sodium hyposulphite solution, on advice from Mr Foord a Melbourne consulting industrial chemist. This micro-innovation was based on work done at the Freiberg Akademy. Unfortunately for
the company concerned, the Freiberg Company, the ore with the high silver content did not persist below the waterline and the company failed.

As the copper mines in Australia began to mine the sulphide ores below the waterline in the 1860s the grade decreased and the ore had to be concentrated before smelting. This was done with hand jigs using Cornish technology, which itself had been derived from German technology. An improved system was devised by Richard Hancock, the manager of the Moonta mine in South Australia in the late 1860s, which could separate several grades of ore and middlings from the gangue by gravity in one operation. The middlings were ground finer and rejigged and the final concentrate was smelted. This jig was an important micro-innovation extensively used in many countries well into the twentieth century. Also in the late 1860s a Scottish process of leaching low grade copper ores with sulphuric acid was introduced at the Kapunda and the copper in the leach was precipitated on iron, but the process was not economic.

Jan Todd has given the impression that below the waterline free gold ‘often disappeared completely’ and the gold was intimately bound up in the pyrites in the ore.\textsuperscript{1008} This is not completely correct. Even in the 1890s most eastern Australian pyritic gold ores were freemilling and up to 90 percent of the gold could be recovered by amalgamation.\textsuperscript{1009} A few very refractory ores, such as at Bethanga in Victoria, met her definition but in most ores less than 20 percent of the gold was in the pyrites and could be separated by fine grinding. The problem was to recover the finely ground gold from the slimes produced from the pyrites. Recovering this gold could ensure a good profit. The Plattner process for extracting gold from pyrites by dissolving in chlorine was first used in eastern Australia at Bendigo from the mid 1870s. The important micro-innovation of precipitating the gold on charcoal was developed at the United Pyrites in Bendigo by Cosmo Newbery in mid 1884. Development in using the process was slow until the 1880s when suitable methods were developed locally to extract gold from the pyritic ores at Gympie and Charters Towers. The process was also used to separate fine gold from ironstone at Mt. Morgan.\textsuperscript{1010}

\textsuperscript{1008} J. Todd, \textit{Colonial Technology} (Hong Kong: Cambridge Press, 1995), p. 112.
\textsuperscript{1010} G. Thureau said in his 1877 report that Bendigo lagged 12 years behind similar plants in the western USA.
At Broken Hill after 1883 the rich silver lead ores in the oxidised zone were smelted to a bullion of lead and silver. When lower grades of silver lead oxides were mined in this zone the silver was leached using methods similar to those used at St. Arnaud in the 1860s. However when lead and silver sulphide ores mixed with zinc sulphides were mined in the late 1890s it was found that most of the silver lead ore containing some zinc could be separated by gravity methods, but most of the zinc containing some silver lead could not be separated from the gangue by gravity. Attempts to fine grind the ores resulted in excessive sliming of the zinc ores, which were dumped as untreatable. Because of the possible profits to be made if a suitable method of extracting zinc from the ores could be developed, British capital was attracted to Broken Hill in the 1890s to solve the sliming problem of zinc residues, using electrolytic methods which had been successful on copper ores in Europe and the United States. However unknown impurities resulted in failure and insufficient capital was available to solve the problem. After the discovery of the Kalgoorlie goldfield in 1893 attempts to use the amalgamation methods successful in eastern Australia failed to recover much of the gold, which was very fine and mixed with tellurides. Chlorination would not work because the chlorine reacted with other minerals in the ores. Fine grinding resulted in excessive slimes which were stored in large dumps awaiting a solution. British and European capital was also attracted to Kalgoorlie because of the richness of the gold ores. The overseas capital funded experienced managers and technologists from other mining areas in Australia, and from Britain and the United States to work at Broken Hill, and others from Britain, Germany and the United States to work at Kalgoorlie on these problems.

Solutions to the problems of sliming with sulphide ores came from two directions, cyaniding and flotation. In Scotland in the 1880s John Macarthur and his co-workers used science based research to develop the process of dissolving gold in a weak solution of potassium cyanide and then precipitating the gold on metallic zinc. This process was introduced in eastern Australia in the 1890s, but uptake was generally slow due to high royalties charged by the patentors and uncertainty whether the patents were valid. On some goldfields such as Charters Towers the switch from chlorination to cyaniding was rapid because cyaniding was much cheaper for the ore, but at Mt. Morgan chlorination costs had been reduced sufficiently that savings were less clear and

1011 See Chapter 8, "Chlorination and Cyaniding" and "The Development of the Flotation Process".
cyaniding did not replace chlorination. On fields with refractory gold ores experience in the 1890s showed cyaniding was cheaper than amalgamating in treating sandy tailings, while chlorination was often the cheapest way of treating refractory pyritic slimes to extract the gold not recovered by amalgamation. At Kalgoorlie several companies experimented with wet and dry crushing of the ores, roasting to oxidise the sulpho-telluride ores and cyaniding. By the early years of the twentieth century it was clear the best method was to dry crush the ores very fine, roast and then mix the crushed ore with cyanide solution, and finally separate the solution by filtering off the solids in filter presses adapted from German sugar technology. The gold could then be precipitated on metallic zinc without problems caused by other minerals. The process was called the all sliming, roasting, cyaniding and filtering process. This combination of several micro-innovations can be considered a macro-innovation.

At Broken Hill a completely different and more empirical approach combined with the scientific methods of testing and analysis, was taken. Several observers in several countries had noticed in earlier years that sulphide ores mixed with acids produced bubbles which floated to the surface carrying the sulphides with them, from where the sulphides could be skimmed off. Oiling the sulphide particles improved the process. Here also several mines tried different combinations of chemical reagents and agitation methods to produce bubbles to float off the sulphides. Several patented processes resulted, including the Potter-Delprat process and the Minerals Separation process, which used mechanical agitation to drive the bubbles to the surface. The De Bavay process (which floated the sulphides by surface tension) was also developed, but this method could not treat slimes. In each process after washing the silver lead sulphides were separated from the zinc sulphides by gravity jigs.

Careful observation by a mill foreman at the Zinc Corporation led to the understanding that different reagents could selectively float different metal sulphides, and other metallurgists refined this discovery. By 1912 the Minerals Separation process of mechanical agitation (using selective reagents) became dominant because it was the most effective in treating all the crushed ore, including the slimes. This process was applied to concentrating copper ores, first in Australia and then in South America from where it spread to the western United States. From there it spread world wide and was further developed to float a wide range of metal sulphides and other non metals.
Both the dry crush, roast and cyanide process for fine gold ores and the flotation process for sulphide ores were macro inventions. They were developed by joint stock type companies operating in Australia, using local and overseas capital and local and overseas trained technologists. The processes were used world wide to develop large low grade orebodies.

An early Australian attempt by Edgar Ashcroft to extract zinc from concentrates electrolytically failed in the 1890s, but the use of overseas electrolytic methods of separating copper from leached ores expanded in Australia in the early years of the twentieth century. By 1914 the electrolytic method of depositing zinc from solution had been solved in Australia by James Gillies, an Australian metallurgist, but a lack of capital prevented him developing both a hydro electric power system and a zinc production facility in Tasmania. The Collins House Group, a loose consortium of Broken Hill companies which had become wealthy from using the flotation process, took over the development in conjunction with the Tasmanian government. This group used an improvement of the 1890s failed process, bought from a United States company, which had further improved the technology. They heeded the lessons of the previous failure and built several pilot plants of increasing capacity to test the process and eliminate problems at each stage.

**Innovation in Smelting**

During the period of local micro-innovations before 1900, in ore processing technology to reduce the costs of concentrating lower grade ores before smelting, there were also improvements in smelting technology. Most of these were developed overseas and imported and adapted for smelting Australian ores and concentrates. These changes in smelting technology and the rapidly changing economics of transporting ores by ship, which caused continuing reconsideration of the most economic sites to build smelters, will be considered in this section.

Following Cornish practice the copper and silver lead miners in South Australia in the 1840s sent their rich oxidised ores to Swansea in Wales for smelting. However they soon realised that higher profits could be made by concentrating lower grade ores by

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1012 See Chapter 7, “Electrolytic Smelting”.
1013 See Chapter 8, “The Collins House Group and its Role in Electrolytic Smelting”.
handpicking and jigging and then smelting at the mine, using wood as the fuel, and reverberatory furnaces were built at several inland mines and at Adelaide. In the 1860s copper smelters were built at Wallaroo on the coast near the Moonta mines and the concentrates carried by rail to the smelter. As the trees near the inland mines were denuded it became cheaper to concentrate smelting on the coast and to ship Newcastle coal there for smelting, rather than incur the high transport costs of carting the coal to the mine. The early inland copper mines in New South Wales built their own smelters on site but in the 1870s the large copper mines at Cobar experienced fuel problems when the nearby trees were cut down and droughts caused problems as the woodcarters could not water their horses. The cost of moving the coal to the mine was reduced when a railway was extended from the coast through Lithgow to the town by the government. Similar transport problems arose in the 1870s when tin was found inland in Tasmania and northern New South Wales, although wood was plentiful in both places. Furnaces were built at Launceston for the Mt. Bischoff tin mines, and in Sydney for the tin mines in New South Wales. All these mines built reverberatory furnaces using Welsh technology developed in the 1840s.

In the 1880s the richness of the oxidised ores of the silver lead mines around Broken Hill warranted the building of smelters at the mines, but by this time water cooled blast furnaces were available. These were developed in the United States from earlier German designs and their higher efficiency and high grades of the Broken Hill ores made the transport of coal from Newcastle economic. At Broken Hill when the rich oxidised ores were depleted in the 1890s and lower grade sulphide ores were mined below the waterline and concentrated by gravity it was no longer economic to smelt locally. The smelters at the mines were closed and the silver lead concentrate was sent by rail to new smelters at Port Pirie or to Adelaide for smelting. Port Pirie was the port preferred by B.H.P. as there was no break of rail gauge but other smaller mines incurred higher rail costs due to changes in rail gauges to Adelaide. This problem of transporting coal inland was well understood by directors of B.H.P. Some became directors of the Mount Lyell Mining and Railway Co. in the remote west of Tasmania in the 1890s and they appointed Robert Sticht, an American metallurgist with experience in smelting copper ores with a high percentage of pyrites, to manage their mine in the hope that he would develop a smelter using a minimum of coal as fuel and using pyrites as the fuel. He was successful but the remoteness of the mine and lack of a market for sulphuric
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acid prevented the conversion of the gases produced into acid. The gases were discharged into the moist air and there produced acid which destroyed the local vegetation. A similar problem arose in north Queensland in the 1920s at the Mount Isa silver lead mine but the air was dry and the company built high chimneys to allow the gases to disperse without obvious effects on the sparse vegetation. The discovery of a phosphate ore body in the area warranted the building of a sulphuric acid plant to convert the gases from both the lead and copper smelters in operation at Mt. Isa in the 1990s. This mine was fortunate that a government railway was in existence near the mine when the orebody was found and coal could be carried to the smelter economically by rail from the coal fields near the coast. In recent years partial smelting to a matte at the mine and final refining by electrolysis at Townsville has reduced the amount of coal transported to the mine.

The initial site chosen for the production of cast iron at Mittagong had small deposits of iron ore, coal and limestone available locally. The availability of large deposits of several minerals in the one location is rare, and a viable iron and steel industry was only established in Australia after 1915 when high grade iron ore and limestone from South Australia could be combined with local coal at Newcastle and Wollongong, using large ships to reduce transport costs. This was later combined with backloading coal to Whyalla in the ships carrying iron ore to New South Wales, to warrant the establishment of a marginal iron smelter in South Australia. The failure to establish a viable iron and steel industry in Australia in the nineteenth century had severe consequences in the twentieth century. In the early twentieth century when steam was replaced by electricity as the major source of power for the operation of mines and factories, many of the Australian foundries supplying the mining industry disappeared. They were not replaced by industries manufacturing electrical machines as there was little knowledge in Australia of the special iron and steel alloys needed for these machines. Almost all the electrical equipment needed in mining had to be imported.

As most mines are in inland Australia but most coalfields are near the coast the final refining of ores is a continuing problem. The invention of the flotation process for concentrating low grade ores has reduced the bulk of the minerals but the problem of where to refine remains. The individual decision must be made on whether to transport...

1014 See Chapter 7, “Pyrite Smelting”.
the concentrated ore to the coast by rail or slurry pipeline and then ship around Australia or overseas, or carry coal to the mine by rail and smelt locally. The final choice depends on the location of the mine, the economics of the various methods of transporting different materials and the availability of cheap electricity. In more recent years there has been an increasing move to search for hydrometallurgical methods of refining at the mine rather than transport bulky concentrates or coal.

**Education for the Mining Industry**

During the first fifty years of mining in Australia the mines were managed and operated by men who had learned to mine by on the job experience, either in coal mines in England and Scotland or metalliferous mines in Cornwall and Germany. The goldrushes of the 1850s saw an influx of men of wider experience from Europe, North America and South America who had gained practical experience in gold mining in California or elsewhere in the Americas, many from Britain who had no mining experience and a few trained in mining technology in England and Germany. Almost all of them learnt the simple methods of mining for alluvial gold brought to Australia by the Californians. By the late 1860s many of this group had become mining investors and were controlling the development of new technologies in wet deep lead mining and deep quartz reef gold mining for which there were few precedents. This section will discuss the attempts that were made by the mining industry and by governments to provide trained personnel for the industry and the successes and failures of these efforts.

The more forward thinking mining investors and mine managers of the late 1860s realised that managers were needed with training in the new science of geology, the emerging methods of machine drilling, new explosives and chemical processing of ores. The Ballarat mines were in crisis at this time, because the deep lead mines there were nearing depletion and the quartz reefs found below them required different technologies. This group considered overseas methods of training such managers in Schools of Mines, and established a similar school in Ballarat in 1870 using the School of Mines in London as a model. They received little support from the Victorian government which was at that time preoccupied with the introduction of universal primary education. In 1873 a similar school was established in Bendigo by the local Mechanics Institute. In the following thirty years mining and metallurgy courses were

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1015 See Chapter 5, "Education for the Mining Industry".
commenced at the universities of Sydney, Melbourne and Adelaide, Schools of Mines were started at various locations in Victoria, South Australia, Tasmania and Western Australia and sub-tertiary courses were developed in a range of courses for the mining industry in all the colonies. In this period the university courses were oriented to training for the professions rather than doing basic research, the schools of mines concentrated on teaching about existing technologies and the technical schools and colleges trained artisans in a wide range of skills not directly related to the mining industry. Artisans in the mining industry learned on the job. The Australasian Institute of Mining and Metallurgy, first formed in 1893, has also been important in educating those working in the mining industry by disseminating papers on current practice in its journals and in books as well as arranging visits to mines during annual meetings and seminars.

Although the numbers in training in the first 50 years in the twentieth century, were not large, the Australian mining schools and technical colleges produced a group of adequately trained Australian mine managers and technical support staff who gained solid experience in difficult economic conditions in the 1930s. Those who completed their training in the 1930s provided the core of the expert management required for the expansion of the mining industry after World War II.

A Final Analysis

The conclusions of this thesis are that while innovations in mining technology in Australia were largely micro-innovations of technology imported from overseas, there were four macro-innovations, two of which were important in the development of mining in Australia and two which had major impacts on mining worldwide. Although the first fifty year period of Australian mining was one using mainly British technology and operating under British mining laws, a period of many micro-innovations and two macro-innovations followed the gold rushes of the 1850s. Control of coal and copper mining by a few large joint stock type companies was complemented in the 1860s by many small gold mining companies, each with a small capital base financed by the

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1016 C. Rasmussen, *Increasing Momentum* (Melbourne: Melbourne University Press, 2004), pp. 81, 126. The University of Melbourne conducted research in metallurgy from 1926 but it was not until 1947 that a professor of metallurgical research was appointed.

profits of the early gold rushes and with shareholders who could renounce any liability for company debts by forfeiting their shares. This development of the no-liability type company was a macro-innovation in Australian mining law. The combination of micro-innovations in several technologies to meet the problems of the unique gold deep leads in Victoria was also a macro-innovation. Many micro-innovations were introduced in ore extraction, mineral processing and smelting during the fifty years after the gold rushes, some imported from overseas but many developed in Australia to meet the requirements of new types of orebodies and the increasing complexities of the ores from below the waterline. The more important of these were micro-innovations in ore crushing with stampers, rock drilling, sinking to great depths and gravity concentration.

The lure of the very rich and complex ores of Broken Hill and Kalgoorlie again attracted overseas capital in the 1890s. The difficulties of mining and processing the new types of orebodies led to the inflow of a small number of overseas technologists who worked with locally trained men on macro-innovations which solved the problems of sliming, as the ores were crushed finer to separate the minerals. By the commencement of World War I in 1914 the macro-innovation of dry crush, roast cyaniding and filtering of sulpho-telluride gold ores from Kalgoorlie had been developed. The macro-innovation of flotation was also developed in this period to separate and concentrate silver lead sulphides from zinc sulphides in Broken Hill ores and to concentrate copper sulphides in copper ores from mines elsewhere in Australia. This latter innovation was the most important innovation in the history of mining technology. Both innovations were later used worldwide and made possible the development of very large low-grade orebodies which underpinned world wide industrialisation in later years.
Introduction

Although Australian mining was generally run down by the end of World War II the increasing world demand for minerals after the war soon led to a rejuvenation. There was springboard for this development in the substantial munitions industry and its supporting industrial base which had been developed in Australia during World War II. Existing mining companies seized the opportunity to expand their operations and to search for new minerals, with the Australian and State governments supporting this growth by the expansion of tertiary and sub-tertiary education. There was both a rejuvenation of earlier mining (including coal, iron, copper and gold) and the exploitation of minerals (such as nickel, uranium oil and natural gas) which had previously not been mined in Australia. This epilogue will briefly discuss the changes in company structures, the rejuvenation of the coal mining industry, advances in mineral exploration methods and methods of extracting and processing of ores since 1945. Further consideration will be given to the failure to develop an overall policy for technical education for the mining industry, and finally the current state of the Australian mining industry will be discussed.

Changes in Company Structure

The capital structure and management control of Australian mines has varied considerably over the last two hundred years. From 1801 to 1851 capital was raised both in Britain and Australia but the mine managers were British with Cornishmen predominant. Australian resident managers trained in Cornwall were then dominant in the gold mines but most capital was locally raised. After 1890 British and European capital flowed into Australia and brought with it numbers of British, American and German managers and technologists, who worked with Australian trained technologists to solve the problems of complex ores. These inflows were reduced after the beginning of World War I and with the exception of a few mines like Mt. Isa did not resume to any extent until after 1945. In this period management control reverted to Australian born and trained technologists.\footnote{Sir G. Fisher, "Overseas Investment in the Australian Mining Industry," \textit{Proceedings of the Australasian Institute of Mining and Metallurgy} 223, no. September (1967): pp. 1-7.}
At the end of World War II most Australian mining companies operated as local or regional entities or occasionally had mines and processing plants in several states.

Since 1945 companies operating worldwide have taken over smaller companies operating within national boundaries, resulting in a few very large international companies and fewer small national companies. B.H.P. Billiton is now one of the world’s largest mining companies with boards of directors in Australia and London but effective control is still in Australia. Mt. Isa Mines is now controlled by Xstrata, a Swiss company. K.C.G.M., an amalgamation of the major mines in Kalgoorlie, is now owned by Newmont which is domiciled in the United States. B.H.P. Billiton distributes profits produced in other countries to its Australian shareholders, but as it is less easy for Australians to purchase shares in overseas companies they are less likely to participate in the dividends of the Australian mines owned by overseas companies.

These international limited liability companies operate similarly to the joint stock companies of the mid-nineteenth century. They have a large capital base, the directors are usually not experts in mining and they employ skilled managers to control the mines. However the number of operating personnel at the mine is quite small compared to the numbers employed in the 1840s because large machines now do the work earlier done by muscle power. The operating personnel must be highly trained to control the machines, hence a continuing need for technical education. Companies such as B.H.P. Billiton no longer provide such training in-house and expect educational institutions either public or private to do so. Whether the Australian taxpayer should fund such training for people to work in mines owned by companies domiciled overseas is debatable.\textsuperscript{1019}

The large international companies owned overseas are usually not interested in small or developing mines in Australia and sell any such companies they obtained in takeovers. However there are still opportunities for investment in Australian mines, as quite often these small companies are sold cheaply on the understanding that if the small company develops a profitable mine the large company can repurchase a substantial shareholding. Also new orebodies are still being discovered in Australia and new mines are being floated on the local stock exchange.

\textsuperscript{1019} This argument is a globalised version of the debates which occurred around 1900 that States such as Victoria should train people for mines in other States of Australia.
The Rejuvenation of Coal Mining

The immediate post war years after 1945 was a period of major industrial disputes in the coal mines of New South Wales, where union officials affiliated with the Communist party sought to disrupt the industry for political reasons. The Australian government appointed a Royal Commission to investigate the conditions on the various coalfields around Australia, predominately in New south Wales and Queensland. The report was tabled in March 1946. In it the Commissioner reported:

The (coal) miners are influenced by a tradition of bitterness towards the employers but most of the evils that previously existed have vanished. It can not be contended that living and working conditions in areas devoted to metalliferous mining are so superior to those on the coalfields as to make comparisons between the two industries irrelevant. …. The miners have a propensity to brood over and magnify their own troubles.  

The backwardness of the coal industry in New South Wales particularly was due to 150 years of bitterness between management and miners, the smallness and varying demand of the local market and the isolation of the industry from overseas competition. After considering the report the Australian and New South Wales governments set up the Joint Coal Board to improve the living conditions of the coal miners and their families and to mechanise the coal mines. Money was provided to enable the provision of amenities such as civic centres and swimming pools in the coal mining towns, and to assist the coal companies to mechanise operations underground (with electric boring machines, coal cutters, shuttle cars and machine loaders to feed the cut coal to trucks or conveyor belts for transport to the surface, and electric and diesel locomotives). Roughly half of this equipment had to be imported because the design skills needed for its manufacture were not available in Australia and local industry was already stretched in providing materials for general post war reconstruction.

After a disastrous strike of 5 months in 1949, during which the federal Australian Labour government sent the army to work the coal mines, conditions settled down and

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1020 Mr. Justice Davidson, Report of the Commissioner Appointed to Enquire into the Coal Mining Industry (Sydney: 1946), p.12. The other States declined the the offer to participate because of State and Australian government rivalries.

1021 The acts authorizing the Board were the Coal Industry Act No. 40 of 1946 by the Australian government and the Coal Industry Act No. 44 of 1946 of N.S.W. Other States were invited to participate but declined.

1022 Joint Coal Board, Annual Report (Sydney), No. 1, 1947-8.
The Board worked with the mining companies to show the pillars could be safely extracted by machines and this was finally accepted by the miners. In 1963 the Board reported that for all practical purposes the New South Wales coal mines were fully mechanised. Longwall and shortwall methods were introduced in the 1970s with self advancing roof supports and continuous miners and shuttlecars for extracting the coal, using equipment of overseas design but made in Australia. Most equipment was electrically operated. Intermittency, the ceasing of production when there was no immediate demand for coal, was abandoned. Output per man shift for all employees rose from 2.98 tons underground and 8.69 tons open cut in 1951 to 15.37 and 35.47 tons respectively in 1989.

**Mining New Minerals**

The tungsten minerals, wolfram and scheelite, had been mined in Tasmania before and during the war and production increased after the war ended. Titanium and zirconium had also been mined prewar from beach sands in northern New South Wales and postwar production was increased to meet demands for a non-toxic paint filler, for a strong light metal for aviation and for alloying of steels. During the war the Australian government had moved to establish an aluminium industry, using hydroelectric power in Tasmania and imported bauxite. The first aluminium was produced at Bell Bay in 1953. In the same year large deposits of bauxite were discovered in Queensland and soon after in the Northern Territory and Western Australia, and alumina and aluminium production commenced in several States. Uranium was now in demand overseas for electric power generation and atomic bombs, and modern methods of exploration soon enabled the discovery of substantial deposits at Rum Jungle, south of Darwin, and at Mary Kathleen in north Queensland. Nickel was in demand as an alloying mineral for steel in the 1960s and the high prices soon led to the discovery of large nickel orebodies at Kambalda, south of Kalgoorlie. After the Australian government lifted the embargo on the export of iron ore in 1960 enormous deposits of high grade iron ore were rediscovered in the Pilbara region of Western Australia and these were soon exploited for export to Japan and Europe. Phosphate rock was discovered near Cloncurry in

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1023 Ibid., No. 3, 1949-50.
1024 Ibid., No. 5, 1951-2.
1025 Ibid., No. 16, 1962-3.
1026 Ibid., No. 26, 1972-3.
1027 Ibid., Statistics sheet.
Queensland in the 1960s but exploitation was delayed for many years until Pacific island deposits were depleted. Manganese for alloy steels was discovered on Groote Eylandt in 1960 and was soon exploited. The first commercial oil field was discovered in Queensland at Moonie in 1960, another off shore in Western Australia at Barrow Island and another, producing both oil and gas in Bass Strait, off the Victorian coast in 1964.1028 Diamonds were discovered in the Kimberley Region of Western Australia in the mid 1970s and large scale mining began in 1985. In 1986 Australian diamond production was one third of the world’s output.1029

The price of gold was deregulated in 1971 and rose from US$35 an ounce to US$186 after the first oil shock in 1973, fluctuated and again rose in 1980 to US$850 during the second oil shock, but fell to US$300 in 1982 and later fluctuated around this price. This enormous price increase led to a spectacular increase in Australian gold production after 1983 from about 500,000 ounces per year to over 10 million ounces (320 tonnes) in 1997.1030 In 2001 Australia produced 285 tonnes of the world gold production of about 2500 tonnes.1031

**Advances in Technology**

**Extraction methods**

An understanding of the geology of the rocks that make up the earth’s crust gradually improved during the late nineteenth and first half of the twentieth centuries but very few mines in Australia employed geologists in this period. A study of a mine manager’s report of gold mine operations in the 1860s, and a geologist’s report of mine development in the late 1930s, gives an indication of how little change there had been in the understanding of gold orebodies during those years.1032 In both reports underground exploration of a gold orebody was to dig a crosscut and sample the ore to see if the

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1029 *The Australian Encyclopaedia, 5th Ed.*, (Terrey Hills: Australian Geographic Pty Ltd, 1988), pp. 1003-4. Five percent of the diamonds are first class gem quality, 45 percent are cheap gems and 55 percent are industrial grade.
1031 Ibid., p. 52.
1032 The mine manager’s reports of the Victoria Reef G. M. Co at Bendigo for 1861 and the geologist’s reports of the mine development at Bendigo Mines Ltd. for 1935 use similar wording when describing the development of crosscuts when exploring for economic grades of gold underground. See University of Melbourne Archives, "Western Mining Corporation Papers," (Melbourne), Technical Committee Reports 7/3/1 of 1935.
grade was economic. If the grade was too low that area of the mine was abandoned and exploration moved elsewhere in the mine. The only difference was that in the 1930s diamond drilling was used to locate the quartz reef. There was no real understanding of how orebodies were formed and no adequate theories of the structures of orebodies to guide mining engineers. In the 1960s theories of the earth’s structure based on the new science of plate tectonics gave geologists a better understanding of where to look for new orebodies and how to interpret the structures of the bodies they found. This understanding, combined with the availability of new scientific instruments which had been developed during World War II, gave the Australian and international mining industry a set of very valuable tools for mineral exploration and major finds followed. Rapid analysis of drill cores enabled ore bodies to be modelled using computers. The discovery and delineation of the buried copper, gold and uranium deposit at Olympic Dam in South Australia and oilfields off the Australian coast were made possible using the new tools.

The lower grade ores mined after 1945 required the use of much larger machines to mine the orebody economically, and more stringent industrial health and safety requirements have forced mining companies to automate and to control this equipment remotely where possible to remove the operator from dangerous operating situations.

Stoping methods developed in earlier periods are still in use but open stopes and block caving is now also being used in suitable underground metalliferous mines to break the ore without miners being required to work in the stopes. Remotely controlled shuttle cars are used to remove the broken rock from the stope access points. Sub-level block caving is used in deeper orebodies. The drilling of blast holes is by hydraulic-operated drilling jumbos drilling several holes at once. The scientific study of rock mechanics has enabled the use of rockbolting to support newly exposed rock faces and substantially

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1034 The instruments include aerial cameras, magnetometers, gravity meters, Geiger counters, scintillometers, and remote scanning from satellites using infra-red and radar techniques. Spectrometers are used for the chemical analysis analysis of soil and rock samples


reduce rock falls underground. Access to these orebodies is usually through declines of large dimensions which enable diesel trucks to carry materials and men underground and to bring the broken ore to the surface. In mines using shaft haulage the winding engines are automated with large skips carrying the ore to the surface.

Surface outcropping orebodies and near surface orebodies are usually mined by open cuts. Blast holes are dug with jumbo drills and explosives are produced on site or nearby by mixing suitable chemicals. Specialist firms often supply and load these into the blast holes. The location of the blast holes is plotted by a geologist to ensure only economic ore is processed. Special drilling rigs are used to sample the orebody for analysis before locating the blast holes. Uneconomic ore and rock is tipped on the dump. The ore for processing is loaded into large diesel trucks using diesel or electric driven scoops, graders, shovels and draglines. Much of this equipment is of overseas design, made overseas and imported, but some is made locally by branches of the overseas firm or licensees and by Australian companies.

**Processing**

Post war innovations in mineral processing have mainly been in the size and capacity of the equipment. At the mill metalliferous ores are first reduced in a primary crusher, ground to size in an autogenous grinder, ball mill or rod mill and concentrated by flotation (using flotation cells similar to prewar designs but much larger). A more recent development is the column flotation cell of Canadian and Australian design. Coal is cleaned by jigging or by separating in heavy liquids in which the coal rises to the surface while the gangue sinks. Free milling gold ores are crushed and ground similarly to metalliferous ores, but are then treated in a carbon in pulp plant in which the ground ore is mixed with a weak cyanide solution and circulated through activated charcoal. The gold is deposited on the surface of the charcoal, from where it is later stripped and then deposited electrolytically on iron filings, which are burnt and the gold

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1038 Ibid., p. 8.
1041 Stampers were obsolete by the 1930s and except in small gold mines were replaced by ball and rod mills which were more efficient.
1043 Ibid., pp. 221-42.
smelted. Refractory sulphide gold ores are roasted to drive off minerals such as
tellurides or the ore is oxidised by bacteria before cyaniding. Dump leaching with
cyanide solutions is used with low grade gold ores to dissolve the gold before separating
it in the carbon in pulp plant. 1044 Aluminium ores are crushed and converted to alumina
before the aluminium is deposited electrolytically. Crude petroleum oil is carried by
pipeline to the refinery where distillation processes are used to separate the petrol and
oil products.


The vulnerability of Australia to attack from overseas became an issue in the 1930s and
the Australian government moved to establish a defence industry through the Munitions
Supply Board and existing local industry. The major local companies with sufficient
capital and the technical resources required were B.H.P., the Collins House group (who
developed a number of companies processing metals and aircraft manufacture), and
Imperial Chemical Industries (a British firm with an Australian subsidiary which
manufactured chemicals and explosives). The Munitions Supply Board set up factories
to make explosives, armaments, radio components and essential industrial chemicals. 1045

At the end of World War II the Australian government sponsored returning servicemen
to study tertiary courses at the schools of mines, senior technical colleges and
universities, resulting in an increase in trained people entering the mining industry.
However this group diminished in the early 1950s. As a result of the wartime
experience in supporting and developing basic industries such as B.H.P., the Australian
government realised that considerable effort was needed to make Australian industry
competitive on a world scale. Exports needed be expanded to earn foreign currencies.
Higher education in Australia was lagging that of overseas countries and only federal
government funding could provide the necessary stimulus. In 1957 the Murray
Committee, which investigated the state of the universities at the request of the
Australian liberal government, recommended that government take a more substantial
interest in tertiary education and provide funding for universities. 1046 The government
then established the Committee on the future of Tertiary Education in Australia in 1961.

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1044 Close, The Great Gold Renaissance, facing p. 27.
1045 A. Ross, Armed and Ready (Sydney: Turton and Armstrong, 1995), pp. 70-1.
Its report, presented in 1964, recognised that primary, secondary and tertiary education were interdependent, and that education in the humanities and social sciences as well as the physical and biological sciences and technologies were important and yielded direct and significant economic benefits. It recommended that any conflict between individual aspiration and community needs in education should be resolved by the operation of supply and demand.\footnote{Sir Leslie Martin, “Tertiary Education in Australia,” (Canberra: Commonwealth of Australia, 1965), p. 1.}

As a result of this report the Australian government provided funds to develop what were called the Colleges of Advanced Education, based on the larger technical colleges and schools of mines, which were to upgrade their courses to a standard equal to similar courses in the universities but of a more applied nature (later called the binary system).\footnote{Ibid., Clause 5, p. 165.} Teachers Colleges were incorporated into the system in 1973.\footnote{Connell, \textit{Reshaping Australian Education} 1960-1985, p. 378.} The schools of mines were absorbed into the College of Advanced Education system and became a minor component as the colleges expanded into the new fields of arts, business studies and information processing. The aim of similar but different was not achieved, the Colleges moved away from an initial concern with applied science and engineering to a greater involvement in business and liberal arts courses, and the employment of lecturing staff who had been trained in the universities led to increasing pressures to turn the colleges into universities.\footnote{Ibid., pp. 376-85. Connell quotes the Chairman of the CACAE that this was happening by 1975.} The earlier debate on a liberal versus a vocational education was renewed but was transformed into a debate on the human capital theory that a higher level of education enabled a person to adapt better to technological change. This theory was combined with arguments for the market reform of education by a Labour government in 1987 to justify the amalgamation of the Colleges of Advanced Education into the University system.\footnote{S. Marginson, \textit{Education and Public Policy in Australia} (Melbourne: Cambridge University Press, 1993), p. 45-50. This was called the Dawkin reforms after the Minister involved, a policy decision which has been hotly debated since.} Rather than remaining equal but different they were absorbed and although not accepted by many university academics initially they were gradually transformed into traditional style universities. The one attempt by a Liberal Australian government to provide a solid base for the development of a vocational education system in Australia, distinct from that provided by the traditional universities, failed as had an earlier attempt by the Victorian
government seventy years before. The philosophy of a liberal education based on the ideals of the traditional universities prevailed.

By the end of the twentieth century courses in mining engineering and metallurgy which attracted relatively small numbers of students, became subsumed in the process of economic rationalisation which swept the Australian economy and education in the 1990s. In 1960 six universities and six technical colleges were offering such courses but by 1997 only six universities were offering mining courses at tertiary level. This was not just an Australian phenomena as student interest in mining courses occurred in other countries when a similar rationalisation occurred in economically advanced countries overseas. Certificate and diploma courses in mining were offered at sub-tertiary level by Technical and Further Education institutions.

The Australian mining industry was lax in shedding experienced staff at each economic downturn and these people were mostly lost to the industry. The amalgamation of secondary technical schools and high schools in the 1980s has been one of the reasons leading to a reduction of apprentices and technicians with a result that there is a shortage of skilled people each time the economy booms. The mining industry has responded by developing teams of mining consultants and mining suppliers offering turnkey arrangements to design and supply new mining plants. Large contracting firms provide teams to extract ores. There have been spectacular failures of this system, particularly with small start-up mining firms seeking to introduce new untried

1052 Martin, "Tertiary Education in Australia," p. 136. T. Golosinski, "Mining Education in Australia," CIM Bulletin 93, no. 1039: pp. 60-3, Martin, "Tertiary Education in Australia." The Universities are Queensland, 45 graduates in 1997; Wollongong, 7; New South Wales, 32; Ballarat, 15; South Australia, 15 and Curtin (Kalgoorlie), 25. Ballarat later abandoned the mining course. The courses are accredited by the Institution of Engineers, Australia and the Australasian Institute of Mining and Metallurgy.
1053 H. Phillips, "Mining Engineering Education," Mining Magazine (2004): November, p. 10. By 2004 Australia had three mining schools, North America 15 and Britain two. South Africa was an exception with an increasing enrolment in mining courses in recent years (a web search in 2005 showed there were four universities offering four year mining courses, Queensland U.T., Univ. New South Wales, Univ. Wollongong and Curtin (Kalgoorlie School of Mines).
1054 See for example the list of certificate and diploma courses in mining available at the Bendigo Regional Institute of TAFE. These courses are accredited by the National Mining Industry Training Advisory Board.
1056 During the 2004 Federal election campaign the Liberal Party criticised the States for failing to provide sufficient trained people at this level and said it would fund new technical colleges to eliminate the shortages. See the Bendigo Advertiser, 22 November 2004.
1057 Mining journals currently contain advertisements for consultants and contract teams who operate world wide. For example see Mining Magazine, Oct. 2004.
technologies. However B.H.P. has had a similar failure when using its own staff to design and erect an iron ore enhancement plant. While consultants have been a feature of the mining industry since the nineteenth century, the complexity of plant design - involving chemical, metallurgical and automation processes - is much greater than one hundred years ago. It will take years to show which system, consultants or in-house design is the better one in the more complex present day environment.

In the calendar year 2004 Australia exported $A58.3 billion of minerals, which was 38 percent of all exports. For the last three financial years expenditure on exploration by mining companies in Australia has been on average of $A1.73 billion p.a.. The latest statistics for research was for the 2002-3 financial year, when $A5.45 million dollars was spent by mining companies (compared with a gross mineral production of $A32.5 billion for that year). An unknown additional amount was spent by universities and government agencies for research and training. In addition the export of computer software, designed in Australia, is said to be used in 60 percent of the world’s mines. The software covers delineation of orebodies and mine design, control and analysis of mineral processing, remote control of machines, control of blasting and mine accounting. Australian suppliers are also strong in supplying mineral processing equipment for niche markets overseas.

**Future Requirements**

As Australian mining moves into its third century it is dominated by several very large international mining companies, the largest being B.H.P. Billiton, an expansion of the first Broken Hill company of 1883. These limited liability companies mine a range of minerals with large mines in several countries and operate similarly to the British joint stock companies of the mid-nineteenth century. Below these giants are a large number of small Australian-owned companies mining one or two minerals, mostly in Australia, but a few are also mining overseas. Although registered as no-liability or limited liability mining companies, they operate similarly to the no-liability gold mining

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1058 An example is the Murrin Murrin laterite nickel plant in Western Australia which took years to solve the technical problems involved with a new plant designed by consultants. The original company was bankrupted and was taken over by overseas interests.
companies of the late nineteenth and twentieth centuries, with a relatively small capital base and concentrate on finding and developing new orebodies. When they have proved the size and value of a new mine it will almost certainly be taken over by an international company more interested in certain future profits than the more speculative searching for new mines.

While the present bottlenecks in transporting coal to the ships for export should be solved by more co-operation between the companies involved and a relatively small expenditure on infrastructure, there are three long term weaknesses inherent in this system. The first is that the international companies are concentrating on increasing production while the local companies do not have sufficient funds to spend on developing new technologies for exploration and processing. The second is that the annual expenditure on exploration has remained steady in the last three years, even though the value of mineral exports has almost doubled in the same period, and more will need to be spent in the future or mining will decline as existing orebodies ore depleted more rapidly in the present boom. The third is that neither governments nor the mining industry has an overall policy to attract young people to mining or to train them in sufficient numbers to meet future the requirements of an increasingly automated industry. Governments and the mining industry will need to co-operate in planning a system of taxation which will encourage mining companies to invest funds in solving these weaknesses.1063

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Appendix 1

Goldfields and Mining Sites in Australia

Goldfield Discoveries

Prior to the goldrushes in 1851 the exposed coal seams at Newcastle and elsewhere in New South Wales were discovered by convicts, shipwrecked sailors, and naval officers, because they were located along the shoreline, and easily seen from ships or people walking along the shore. The copper mines of inland South Australia were noticed on the surface by shepherds and pastoralists due to the colours of the oxidised minerals. Gold outcrops in reefs exposed at the surface had been seen in several places by explorers and geologists and by shepherds and pastoralists, and a small amount of gold had been sold in Sydney and Melbourne by shepherds who found it during their daily work. It is uncertain whether this gold was from reef outcrops or from alluvial or eluvial deposits. It seems likely it was only from outcrops or eluvial deposits on the surface near outcrops. Geoffrey Blainey has argued that the claim that Australia did not have the necessary knowledge to mine gold until Hargraves returned with his Californian skills ignores an earlier influx of mining skills. He considers the Burra miners and the Cornish miners living around Bathurst who would have had experience of washing alluvial tin, and would have been far more experienced than Hargraves. However experience in washing alluvial tin did not ensure that tin washing technology would be automatically transferred to washing for gold. When questioned John Lister admitted he had no knowledge of washing for gold until shown how to do so by Hargraves. As Lister lived near the Cornish miners around Bathurst, and had searched for gold previously, it is likely that any local knowledge of washing for gold would have soon spread widely. Hargraves must have realised this lack of local knowledge and was eager to get back to the Bathurst area before any one else from California did so.

The techniques of locating the buried washdirt and separating the gold were easily understood once seen and the correct method of washing in a dish or cradle was soon mastered. When the goldfields became crowded after the early rushes, experienced alluvial miners spread over the country looking for new fields. As discussed earlier they moved to Tasmania and northwards through New South Wales to Queensland, the Northern Territory, northern Western Australia and south to the Murchison and the Yilgarn to finish at Kalgoorlie. Geoffrey Blainey called this the Indian Ocean Gold Trail. One result of the early gold rushes was a hardy breed of gold prospectors who kept moving on as new fields were developed. As they tramped they spotted surface outcrops containing silver and copper and lead minerals, and the claims they pegged on these outcrops were sold to companies. The genuine prospector then moved on to search for new fields.

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1065 B. Hodge, Major Controversies of the Australian Goldrush (Tambaroora: Cambaroora Star Pubs., 2003), p. 78. In Appendix 1 Hodge includes evidence that Lister gave to a Select Committee in 1853 in which he said that he had never seen anything of the kind before he was shown by Hargraves, when asked if he knew anything about washing for gold.
The more important goldfields in New South Wales and the dates of discovery were: Ophir 1851, Hill End 1851, Sofala 1851, Stuart Town 1851, Tuena and the Abercrombie area 1851, Louisa Creek 1851, Lucknow 1851, Rocky River 1851, Young 1860, Forbes 1861, Parkes 1862, Grenfell 1866, Gulgong 1866.  

In Victoria the larger fields were: Clunes 1851, Ballarat 1851, Castlemaine 1851, Bendigo 1851, Daylesford 1851, Creswick 1851, Omeo 1851, Wedderburn 1852, Heathcote 1852, Harrietville 1852, Steiglitz, 1853, Maldon 1853, Maryborough 1853, Avoca 1853, Buckland 1853, Stawell – Pleasant Creek 1853, Dunolly 1854, Ararat 1854, Beaufort 1854, Blackwood, 1855, St Arnaud 1855, Inglewood 1859, Gaffneys Creek 1860, Crooked River 1860, Walhalla 1863, Landsborough 1864, Woods Point 1865, Bethanga 1875, Casillls 1885.


Queensland: Lucky Valley near Stanthorpe 1852, Canoona 1858, Peak Downs 1861, Morinish 1866, Gympie 1867, Mount Perry 1867, Marodian 1867, Cawarral 1868, Ravenswood 1868, Etheridge 1869, Charters Towers 1871, Palmer 1873, Hodgkinson 1875, Mount Morgan 1882, Croydon 1886, Eidsvold 1887.

Northern Territory: Yam Creek 1870, Pine Creek 1872.

Western Australia: Halls Creek 1886 (Kimberley), Marble Bar 1888 (Pilbara), Nannine 1890 (Murchison), Southern Cross 1888, Coolgardie 1892, Kalgoorlie 1893 (Yilgarn).

The Growth of Mining Towns

Many of the mineral deposits found by the early shepherds, pastoral workers and prospectors were of sufficient size and wealth to attract many miners who settled in the areas adjacent to the mines. Townships and a few cities developed from some of these settlements but the smaller mineral fields were soon worked out, and if the settlement was in a region suitable only for grazing, the miners left the area and the settlements

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1071 T. G. Jones, *Pegging the Northern Territory* (Darwin: Department of Mines, Northern Territory, 1987).
became ghost towns. The map below shows some of the settlements which were founded on minerals and later grew into towns and cities as well as some which became ghost towns.\textsuperscript{1073}

**Major Mining Centres in Australia 1990**

Appendix 2  

Glossary of Mining Terms

Activated Carbon – granulated carbon, often made from coconut shells, heated between 800°C and 1000°C in a current of steam to remove hydrocarbons. Each granule has an enormous surface area.

Adit – a horizontal passage leading into a mine used as an entrance or for drainage or ventilation.

Agitation – stirring up a suspension of mineral particles in a liquid or in air by a mechanical stirrer or compressed air.

Aerial Tramway – device to carry ore from a mine to a processing plant in buckets suspended from an endless steel rope supported on towers, also called a Flying Fox.

Air Compressor – machine to compress atmospheric air to a pressure sufficient to drive other machines such as rockdrills.

Airleg – device operated by compressed air or hydraulic fluid to hold up a rockdrill while drilling.

Alluvium – deposits of gravels, sand and soils deposited in river and creek valleys by running water hence Alluvial Gold is gold deposited in alluvium.

Amalgam – gold and/or silver dissolved in mercury.

Amalgamated Claim – adjacent mining claims worked together by one party.

Amalgamating Barrel – a wooden or iron barrel with an axle passing through the longer axis. It is charged through a square hole in the side, with minerals caught by blanket tables and mercury, and rotated for several hours. The amalgam of gold, silver and mercury is then collected.

Amalgamating Plates – copper plates coated with mercury which collect gold or silver by amalgamation from the slurry produced by crushing the ore.

ANFO – explosive made by mixing ammonium nitrate and fuel oil, each of which is not an explosive by itself. The mixture is placed in the borehole and fired by detonator.

Arrastre – Fixed round iron pan about twelve feet in diameter, with a vertical central pole from which extends a horizontal beam to which granite blocks are hung by chains or alternatively on which granite rollers rotate. When the axle is rotated by a horse or steam engine, the blocks or wheels move around the pan grinding the ore within to a fine sand.

Assay – the determination of the grade of a mineral in a sample.

Attle – worthless rock material produced in mining.

Auriferous – gold bearing.

Autogenous grinding – the grinding of ore in a rotary mill without balls or rods, the ore is self grinding.

Back – roof of a drive, stope or the hanging wall side of a reef. The ground between the working area and the surface.

Ball-mill – rotating steel cylinder with a hardened steel or rubber lining and containing iron or steel balls. Water and ore from the mine is fed into one end, the ore is crushed to a smaller size by the balls as the mill rotates. The reduced material leaves the mill at the other end as a slurry. Alternatively the ore is crushed dry but coverings must then be provided to contain the dust.

Battery – one or more stampers used to crush ore; alternatively the total of the stamps and the engine driving them e.g. a one hundred head battery had one hundred stamps. In common usage in the nineteenth century the word stamp as well as the word stamper
could mean one or many. In this thesis for clarity I have used stamp for one, and
stamper for the total of stamps in a mortar box.

**Beam Pump** – pump with a vertical steam cylinder to move a beam up and down to lift
and lower rods in the shaft, so as to lift water from the mine to the surface. The
development of this pump in Cornwall in the late eighteenth and early nineteenth
century increased the depths to which mines could be sunk. Later improvements
replaced the heavy beam and vertical cylinder with horizontal steam cylinders to raise
and lower the shaft rods through an eccentric drive and linkage at the mouth of the
shaft.

**Bedrock** – geological strata on which the alluvium lies.

**Berdan Pan** – fine crusher using heavy steel balls to reduce coarse sand particles,
containing gold, fine enough to separate the gold from the quartz, so the gold would
amalgamate with mercury in the pan.

**Bessemer process** – method of removing impurities from iron or copper by blowing air
through the molten metal to burn off the impurities such as sulphur.

**Blanket Table** – an inclined surface or table covered with a woollen blanket to catch
fine gold or other minerals coming from the crusher.

**Blast furnace** – a steel furnace using a forced blast of air to produce molten metal.

**Bonanza** – (Spanish) prosperity, fine weather. A mine in bonanza was prosperous. Now
used to describe a rich orebody.

**Bosh** – the lower part of a blast furnace above the hearth.

**Bord and Pillar system** – parallel bords or headings are driven into the coal seam and
then cross drives excavate the coal, leaving pillars to support the roof. The pillars are
later removed and the roof is allowed to collapse. Room and Pillar is an alternative
name.

**Bottom** – in alluvial mining when a shaft is dug to the bedrock the gold obtained from
the washdirt is said to be off the bottom.

**Brace** – mouth of a shaft.

**Buddle** – fixed longitudinal devices or rotating circular devices which separated
minerals on the basis of the specific gravity.

**Bustle pipes** – large air pipes to carry pressurised air to near a blast furnace. Smaller
pipes then carried the air into the tuyeres from where it was blasted into the melting ore.

**Cage** – structure of wood, steel or aluminium for moving men, ore or materials in the
shaft.

**Calcinining** – the oxidation of ores by heating.

**Californian pump** – a long wooden pipe about six inches square, at the upper end of
which a wheel turns a long band of canvas, stitched to form a circle, on which are fixed
upright pieces of board at regular intervals. As the wheel turns the pieces of board enter
the tube and carry water with them until it is discharged at the upper end.

**Call** – payment on a share which has not been fully paid to its nominal value.

**Captain** – the chief superintendent of a mine (Cornish).

**Cataline furnace** – an early design of blast furnace, using charcoal, in which iron ore
was smelted to produce pig iron.

**Cavil** – the drawing of lots by contract miners to determine the working place in the
coal mine, usually for a period of three months.

**Cavil out** – paid off in order of seniority i.e. last on first off, during a period of
retrenchment.

**Cement** – a conglomerate material formed in alluvial ground when sand and quartz
pebbles are bound into a solid mass by iron and silica compounds.
Chilean mill – an annular steel dish in which rolls one or two heavy wheels of cast iron or granite, rotating on a common shaft driven by horse or steam power. The heavy wheels crush the ore to a fine powder.

Chlorination – chemical process to extract fine gold by dissolving it in a chlorine solution in water.

Churn Drill – machine that raises and then drops a chisel into the rock at the bottom of the drill hole so the rock is pulverised and can be washed to the surface.

Claim – a small area of ground, descending vertically into the earth, which is pegged at the corners by the holder of a miners right, who is then the legal owner of minerals found in the claim.

Classifier – a device to separate minerals after crushing by size e.g. separating particles of small diameter from those of large diameter by passing the small particles through a screen while the large particles remain on the screen. The larger particles are then returned to the crusher for further reduction in size. Other types of classifier separate on particle weight or specific gravity.

Clipper – the operator who connected full skips or wagons to the haulage rope with a clip and disconnected empties from the rope.

Coal Seam – horizontal or near horizontal layer of coal varying in thickness from a few centimetres to many metres.

Coke – solid residue left after distilling coal in a closed retort.

Colour – minute particle of gold indicating there may be more gold in the vicinity.

Comminution – crushing or grinding into smaller particles.

Concentrates – valuable minerals separated from the gangue.

Condenser – a metal container in which steam is cooled and converted to water.

Copper plate – sheet of copper with mercury rubbed into the surface, placed at the outflow from a battery so the mixture of sand, gold and water flows over it and the gold amalgamates with the mercury.

Costean – prospecting trench dug on the surface to locate a reef.

Coyoting – the Californian term for digging a shaft to the washdirt then tunnelling out to the claim boundaries to remove the washdirt.

Cradle – wooden box for washing alluvial sands and gravels.

Crosscut – level driven from the shaft to locate a reef.

Crusher or Crushing Plant or Crushing Mill - a group of stampers arranged side by side, with a common drive shaft to lift and drop the stamps. A plant or mill includes the equipment to collect the mineral after crushing, e.g. amalgamation tables or blanket tables.

Cupola – cylindrical vertical furnace for melting metals especially iron, the metal being mixed with coke or coal and fired.

Cyanide – common usage for potassium or sodium cyanide, a chemical used to dissolve gold from crushed ore.

Cyaniding or Cyanidisation – the process of recovering gold by dissolving in cyanide.

Darg – an agreed quota of coal to be hewed by a contract miner per shift.

Decline – a tunnel sloping down from the surface to the orebody, of sufficient dimensions to enable large trucks or conveyors to carry ore to the surface and other vehicles to carry men and materials to the stopes. Declines are also dug from a level underground to stopes deeper in the mine.

Deep lead – in Victoria a legal term for an ancient river bed now covered with soil or basalt rock, which may contain alluvial gold or tin oxide. If the depth of the river bed is less than 100 feet below the surface it is legally a shallow lead or a lead.

Deep sinking – the obtaining of washdirt from deep leads.
Deputy – an assistant manager, qualified in safety procedures, responsible for ensuring the safe working of a section of a coal mine.

Development – the work of driving to and in a proven orebody so the ore can be removed by systematic mining.

Diamond Drill – machine which extracts a cylindrical core of rock by drilling with a bit studded with diamonds.

Dip – the angle from the horizontal by which a reef descends into the earth.

Dish – sheetmetal or plastic container about 400 millimetre diameter and 150 millimetres deep with a recess just below the lip. Washdirt is placed in the dish, which is swilled in water to gradually wash off the clay and gravel leaving the heavier gold in the bottom.

Dolly – simple quartz crusher consisting of a wooden block shod with iron suspended from a flexible pole which moves the block up and down to impact on quartz placed on an iron grating.

Dolly pot – a cylindrical iron pot about 6 inches diameter by 12 inches long in which quartz samples are placed and ground with an iron pestle. The crushed quartz is then washed in a dish to separate any gold. Used by gold prospectors.

Dredge – a floating pontoon with a chain of buckets to lift alluvial ground to sluices to separate the gold or tin oxide from the soil.

Drive – level driven along a reef to develop stopes above and as a roadway to remove the ore.

Dyke – intrusive rock or vein formed when a liquid rises from deep in the earth to fill faults and cracks and then solidifies.

Dynamo – rotating machine by which mechanical energy is converted to electrical energy. Modern usage is restricted to a machine which produces large currents at medium voltages.

Electrolysis – the decomposition of a chemical compound by an electric current.

Electrolyte – the fluid which conducts the electric current.

Electrolytic deposition – the deposition of metal on the cathode or negative terminal when a current is passed from anode to cathode.

Eluval – a mineral remaining near the site from which it eroded from an orebody.

Elvan – applied to felspathic rocks found in dykes, a quartz porphyry.

Eyesight – the location in a coal mine where the miner paused to allow his eyes to adjust to the darkness.

Face – the wall side or cheek of a reef on which mining is being carried out. Sometimes the end of a drive or level or any vertical cutting in rock.

Filter – machine to remove water from a mineral slurry or air from dust particles. Pressure may be used externally to force the water through a filter cloth or a vacuum may be used internally to suck the water through. In a filter press the mineral remains inside the press after the water is removed. In a vacuum filter the mineral remains on the outside of the filter from where it is scraped into a collecting bin. Air filters usually force the contaminated air into bags in which the particles are retained while clean air passes through. This type of air filter is sometimes called a BAG-STACK. The process is called filtration.

Fill or Backfill – waste rock or sand placed in the excavated part of a stope to support the walls while mining proceeds upwards.

Fines – graded black coal less than 10 mm in size.

Firedamp – a mixture of methane in air which can cause an explosion if ignited.

Flame Proofed Machinery – electric motors and switchgear enclosed in such a way to prevent sparks igniting gases in the mine.
**Flotation** – method of concentrating minerals where the particles of the minerals to be concentrated attach to bubbles of air or gases and float to the surface of the water borne pulp from where the mineral is skimmed off.

**Flowsheet** – a diagram showing the successive processes used at a mine to separate a mineral from an ore and convert it to a metal.

**Flume** – timber or metal trough on trestles to carry water in a race across a gully.

**Flying Fox** – see aerial tramway.

**Footwall** – country rock beneath or on the lower side of a reef or orebody.

**Frothing agent** – chemical which promotes the production of gas bubbles.

**Fuze or Fuse** – small cylindrical cord filled with gunpowder used for igniting the gunpowder in a borehole.

**Gad** – small steel wedge used for splitting large rocks.

**Gangue** – stony, earthy minerals associated with metallic minerals in the ore in a vein or orebody.

**Gas Engine** – an internal combustion engine with one or more cylinders, using a fuel called water gas produced by passing steam over heated charcoal or coke.

**Gate End Box** – a cast iron box containing electrical switches for controlling the operation of electrical machinery in use underground in a coal mine. The box was sealed to make it explosion proof. It was normally situated at the end of the gate or access drive nearest the machine.

**Goaf** – the area left after pillars of coal have been extracted and any supporting timbers have been removed to allow the roof to collapse.

**Gossan** – rocks, commonly outcropping, composed of hydrated iron oxides covering rocks containing sulphides of iron and/or other metals.

**Gravel pump** – a centrifugal pump with robust vanes, heat treated to withstand heavy abrasion from sand and gravel. It can pump to heads of about 100 feet.

**Grunching** – using explosives to blast down coal or stone without boring a hole.

**Guides** – continuous lengths of squared timber or steel about 150 mm by 75 mm, which run down the side of the skip or cage compartment in a shaft. Each side of the skip or cage has attached steel plates which slide along the guides to keep the vehicle centered in the shaft compartment. Timber is preferred if safety grippers are used. An alternative name on Australian fields is Runners.

**Gutter** – the original bed of a stream now buried by soil or basalt.

**Hand Drilling** – one man holds and rotates the drill steel while another hits the head of the steel with a hammer.

**Hand Picking** – grading ore by selecting by sight and removing the richest ore to be sent to the smelter. Also Hand Sorting.

**Hanging Wall** – country rock above or on the high side of a reef or orebody.

**Haulage** – movement of coal from the underground working face to the pit bottom before hoisting to the surface, or the movement from the working face to the surface via an adit. The wagons or skips, running on rails, were first pulled or pushed by men or women, then several wagons were pulled by horses, then the wagons were clipped to an endless steel wire rope driven by a steam engine. Locomotives powered by steam, electric batteries, overhead electric wires or diesel engines are now used to haul the wagons.

**Headframe** – timber or metal structure at the top of a mineshaft with headsheaves to convert the direction of the rope to vertical to enable cages to be raised or lowered in the shaft.

**Headsheave** – see pulley.
Hearth – the lower part of a blast furnace where the molten metal collected before being tapped off.
Hewing rate – price per ton paid to a miner for extracting coal.
Hopper – a wooden or steel box to hold ore before crushing.
Hydraulic Filling – a method of filling a stope after the ore is removed to support the walls and back. Sand from the mill tailings is mixed with water on the surface and the slurry piped into the stope. The water drains out of the slurry to the level below and is pumped to the surface.
Hydraulic sluicing – using a jet of high pressure water to wash down a face of alluvial ground. The resulting slurry is passed through a tom or box sluice to remove the mineral such as gold or tin oxide.
Hydraulic sluicing and pumping – using a jet of high pressure water to wash down a face of alluvial ground and collecting the slurry in a sump from where it is pumped by a gravel pump to a sluice.
Hydrometallurgy – separation of a metal from a mineral using water in the processing.
Jaw crusher – primary crusher to reduce ore to about 25 mm. particle size between a fixed plate and a moving plate. Also called rockbreaker.
Jig – an apparatus for separating ore from gangue usually with water as the liquid medium.
Kibble – bucket used for raising ore or rock when sinking a shaft.
Kiln – container in which clays and minerals are heated to change the chemical composition.
Labour Covenant – the number of men required to be employed on a lease.
Laterite – rock-like iron rich surface residual deposit resulting from a long period of weathering.
Leach – to remove a soluble component from an ore by percolation of water, a solvent or an acid.
Lead – layer of washdirt containing alluvial gold or tin, usually found just above the bedrock with a thickness of a few centimetres to several metres.
Lease – an area of ground, granted by the governor after written application, which entitles the owner to mine the ground for the minerals named in the lease approval.
Level – horizontal excavation made in country rock or an orebody, often two metres high by two metres wide, supported by timber, along which the ore is trucked to the shaft.
Lixiviation – to treat ore with a solvent; to leach.
Long Tom – a gold washing machine up to twenty feet long, about two feet wide and with six inch sides, mounted on trestles to give it a slight slope. A stream of water enters at the top and washdirt is shovelled into the tom near the top, stirred with forks to break up any clay, and carried down to a hopper at the bottom end. Here the finer particles pass through a sieve onto a ripple board and often then to blankets where the gold is collected. Coarse particles collect in the hopper and, unless they were nuggets, are discarded.
Longwall system – where coal or other ore is extracted in a long continuous face and the roof is allowed to collapse as the working face advances.
Matrix – rock in which a crystallised mineral is embedded.
Matrix mining – extracting the matrix and embedded minerals from the country rock; usually applied to mining quartz containing gold.
Matt or Matte – an unrefined metallic product of smelting of ores especially copper; material with a dull surface, not metallic.
Middlings – material intermediate between the concentrate and the tailings produced by jigs and concentrating tables. The particles contain both minerals and gangue and require further crushing to separate the mineral from the gangue.

Mine Manager – chief superintendent of a mine, originally in underground mines but now used for the chief superintendent of an open cut mine.

Miners Right – a document, issued by a State government, available to any adult person on the payment of a fee, valid for a period of one or more years which authorises the person to fossick and dig for gold near the surface on crown lands. Until recently it allowed a person to mine but this now requires a licence to mine.

Mucking – the operation of loading broken rock by hand or machine.

Mullock – what remains after any ore is removed from the rock extracted from a mine, the worthless part.

Mundic – iron pyrites.

Onsetter – the man stationed at the bottom of the shaft to control the movement of men and materials and who operated the shaft signals.

Open Cut – excavation from the surface to allow the removal of the ore from an orebody.

Orebody – a generally continuous mass of minerals which is distinct from surrounding country rock.

Outbye – moving out of a coal mine from underground towards the shaft or portal entrance.

Outcrop – the part of a reef exposed at the surface.

Overburden – unmineralised earth above a buried orebody.

Overwind – an accident due to raising the cage or skip in the skyshaft above the highest safe position.

Oxidise – to convert the sulphides of an element into its oxide or carbonate by percolation of an orebody by water containing dissolved oxygen or carbon dioxide.

Paddocking – Removing all the soil on a claim down to bedrock. Alternatively called surfacing. Deep paddocking is removing the soil to depths over 10 feet. In metalliferous mining at Broken Hill the removal of ore from part of a stope and then building walls of timber covered with hession, the space enclosed being filled with mullock or hydraulic fill, was called paddocking.

Pass – an opening between two points in a mine for the passage of materials; an orepass enables ore to be moved from a stope to a level; an airpass allows air to circulate between two levels.

Percolation – the process of a liquid passing through a porous material.

Percussion drill – machine to drill holes using a bit at the end of a solid rod or a rope. The rock is pulverised by successive blows of the bit.

Pig iron – iron produced in a blast furnace.

Pigstye – a wooden structure to support the roof in a stope. The wooden poles are stacked in a square until the roof of the stope is reached when the top layer is wedged against the roof. Extra stability may be achieved by filling the stye with waste rock during erection.

Pillar – portion of virgin ground left in a mine to support the back or the walls.

Pilot Plant – a small scale plant erected to test the process and economics of refining the ore.

Placers – alluvial gold deposits in the western United States, usually at elevated levels in mountainous country, cut across by more recent river valleys and hence dry.

Plat – intersection of a shaft and a level where men and materials are loaded and unloaded underground.
Poppet Head – a headframe.
Portal – the entrance to an underground mine.
Prill – high grade ore ready for smelting.
Prospect – to search for a mineral.
Prospector – one who makes his living searching for minerals.
Puddling – the conversion of pig iron into wrought iron by heating and stirring the molten metal in a reverberatory furnace with an oxidising agent or the act of making puddle of clay or similar material (English usage). Stirring soil in a tub to allow any gold and quartz to settle to the bottom. The fine material containing clay was then poured out of the tub. The quartz particles and gold was washed to separate the gold (Australian usage).
Puddling mill – an annular space dug in the ground, the sides and bottom being lined with wood or sheet iron, with a vertical shaft driven by horse power or steam engine in the centre. The vertical shaft drives a horizontal beam to which are attached rakes or harrows to break up the mixture of sand and clay in the annular space. Water is added to float off the clay and sand and remaining gold is washed with a cradle.
Pulley or headsheave – wheel at the top of a headframe around which the rope holding the cage or skip changes direction to vertical to raise or lower the cage or skip in the shaft.
Pulp – mixture of finely ground ore and water.
Pyrites – metallic sulphides in orebodies, usually iron disulphide or arsenic sulphide.
Pyrometallurgy – separation of the metal from a mineral by heating.
Rabble – a rake used to spread ore around the floor of a furnace before and during heating or removing the heated material from the furnace. This was initially done by operators but mechanical rabbles were introduced in the nineteenth century. The process is called rabbling.
Race – a man-made water course which carries water from a dam or river to a water wheel or sluicing operation.
Refractory ore – an ore which is difficult to separate into individual minerals or groups of minerals, e.g. gold from ores which also contain arsenic sulphide or iron sulphide.
Regulus – metallic material which forms below the slag in the lower part of a furnace.
Reverberatory furnace – a type of smelter usually constructed of brick, with a firebox at one end and a roof which reflects the hot gases down onto the ore being heated on the floor or sole of the furnace. The fuel is not in direct contact with the ore.
Riffle (ripple) – wooden or metal cleat across a tom or sluice to trap the gold, because of its higher specific gravity, as the slurry was washed down the device towards the exit.
Rise – to excavate ore or rock upwards. A miner working above his head is said to be rising. Also a small shaft excavated upwards from a level for exploring a reef, for ventilation or communication. An alternative is Raise.
Roaster (mechanical) – furnace for roasting ores in which the ore is introduced at the flue end and moved towards the firebox by mechanical means (distinct from older reverberatory furnaces where the ore was moved by hand rakes).
Rockbreaker – see jaw crusher.
Rockdrill – machine driven by compressed air or hydraulic fluid to drive a drill bit into rock to excavate a circular hole which can be filled by explosive which shatters the rock when fired.
Rod-mill – similar in construction and operation to a ball-mill but the balls are replaced with steel rods.
Roots Blower – a type of fan to provide fresh air underground.
Rolls or Roll Crusher – two cylindrical steel rolls between which particles of ore are crushed to smaller size.
Royalty – duty charged by the government on the quantity of mineral produced from a claim or lease.
Safety Grippers – spring loaded devices to operate when the tension of the rope is removed from a cage or skip by rotating to grip the wooden guide in the shaft and prevent the cage or skip falling to the bottom of the shaft.
Safety Hook – safety device connected between the winding rope and the cage which disconnects the cage if an overwind occurs.
Screen – plate of thin sheetmetal in which holes are punched or woven wire. Particles of ore with diameters below the screen size can pass through the holes to the next stage of processing.
Set or Rake – a series of full or empty skips or wagons connected together.
Shaft – a vertical or near vertical entry to a mine either circular or rectangular.
Shaft Pillar – the material of an orebody left around the shaft to provide support for the roof.
Shallow sinking – obtaining washdirt from near the bedrock by sinking shafts less than 100 feet deep.
Shepherd (verb) – to work the minimum daily hours on digging a shaft while neighbouring parties dug their shafts to the washdirt. If the neighbouring shaft(s) found gold the shaft would be rapidly dug to the washdirt otherwise it was abandoned.
Shiftboss – underground supervisor in a mine.
Shot-firer – the man who set and fired explosive charges in a coal mine.
Silicosis – disease of the lungs caused by breathing silica particles in rock dust.
Sinter – (verb) to bring about the agglomeration of particles of a metal by heating, (noun) the material produced.
Skip – rectangular box, open at the top, to hoist ore or coal from the working level to the surface.
Slimes – finely crushed ore which floated off and was lost after crushing while still containing the mineral or minerals the processing was expected to collect.
Sludge – the sediment deposited along creek and river valleys after sluicing the auriferous earth.
Sluice or Box Sluice – a washing device similar to a tom, except it is fitted with ripples or a false bottom, with the top end wider than the bottom so sluices can be joined end to end to give the length required to catch all the gold. If a false bottom is used it is drilled with holes through which the fine washdirt falls into the true bottom which has ripples to catch the gold. The coarse material remaining is discarded.
Sluicing – the washing of auriferous earth by streams of water.
Smelter – devices in which ores are heated to melt the contained metals which are then tapped off.
Smelterman – one who builds smelters or who treats ores in a smelter.
Snig – to drag timber props to position using horses.
Spiling – driving timber laths into the soil at the bottom of the shaft or along a level in deep leads to hold back the loose wet ground while sinking and driving. After removing the soil the miners slabbed inside the laths and packed clay behind the slabs to prevent water entering the shaft.
Spitzkasten – Mineral classifier in which a mineral slurry enters an inverted cone container at the top side, the lighter particles are drawn off with the liquid at the opposite top side and the heavier particles settle to the bottom and are drawn off through the apex of the cone.
Spitzlute – mineral classifier similar to the spitzkasten but with the addition of a jet of water introduced through the bottom of the inverted cone, the flow being adjusted so the lighter particles float over the top lip while the heavier particles settle to the bottom of the cone from where they can be drawn off.

Staith – riverside berth or pier at which ships can load coal.

Stamp – a single rod with a heavy cast iron or steel weight attached to the bottom end which was lifted and dropped onto lumps of a mineral to reduce them to a smaller size.

Stamper – a group of stamps arranged side by side in a supporting frame so they could be lifted and dropped in a regular sequence onto lumps of a mineral held within a cast iron mortar box to reduce the particle size. The number of stamps was eventually standardised at five per stamper.

Stope – an underground space along a reef from which ore has been removed.

Strake – table on which canvas or corduroy or similar rough surfaced material was stretched. When the crushed pulp flowed over it, the heavier particles of gold or pyrites settled in the depressions of the material.

Strike – work stoppage by miners in an industrial dispute. Or the discovery of an orebody. Or the compass direction of horizontal line along a reef.

Stull – a timber or steel support between the footwall and hanging wall of a narrow stope to prevent movement of the stope walls after the ore has been extracted.

Surfacing – the washing of the thin covering of earth on the surface to extract the contained gold.

Syndicate – small number of persons who join together to sponsor the development of a mine and then float it on the stock exchange. The group forms an unincorporated partnership.

Tailings – the remaining material carried away from a crushing machine after some or all of the mineral in the ore has been removed. It is normally stored in a dam or dump on the mine lease.

Tamping – pushing an explosive into a borehole with a wooden rod or tamper to compact it before firing.

Token – a disc of leather or metal, stamped with a miner’s identification number and attached to the filled skip or wagon for recording when the skip is weighed.

Trapper – the person who opens and closes ventilation doors underground to allow traffic through.

Tributer – a miner or party of miners who extract ore for an agreed percentage of the mineral recovered.

Truck – rectangular box of iron or steel with wheels to run on rails to carry ore from the stopes to the surface or to the shaft for raising to the surface in the cage.

Tube mill – a rotating cylindrical tube with a length to diameter of between 3 to 1 and 5 to 1. Nineteenth century models used flint pebbles for fine dry grinding and were called pebble mills. Tube mills were used in Kalgoorlie for grinding the ore to slimes.

Turbidites – sedimentary rocks laid down in deep seas adjacent to continental shelves around continents when the sedimentary material on the shelf becomes unstable and slips down the outer edge of the shelf and is deposited in lenses in the deep seas.

Tuyere – hole through which an airblast is sent into a furnace

Vanner – machine with a moving flat belt for sorting mineral particles from a slurry by weight or size.

Vein – narrow orebody filling a fissure or crack in the earth.

Warden – government official having judicial and regulative powers over mines and mining procedures.
**Water race** – channel dug in the ground at a slight slope to carry water from a river or creek to the area where mining was being conducted.

**Water right** – the right a miner enjoys to divert and use water from a spring, lake, dam, river or reservoir.

**Wetting agent** – chemical which coats the surface of a small particle of a mineral with a layer of liquid to which a bubble of air or gas can adhere to float the particle to the surface.

**Wheal** – mine.

**Wheeler** – The person who moved empty skips from the haulage rope to the working face, manually or with horses, and then returned the full skips to the marshalling area prior to haulage to the surface.

**Whim** – a frame of strong timber supporting a vertical timber pole, to which is fixed a concentric wooden cylinder around which the rope is wound horizontally. Underneath and attached to the cylinder is a long beam, to the end of which the horse is harnessed. As the horse walks around a circular path the rope winds off and onto the cylinder. A bucket or cage is attached to each end of the rope so they move up and down the shaft as the horse moves forward or in reverse.

**Whip** – a timber post about 20 feet long, fixed firmly in the ground at one end and standing at 45 degrees to the horizontal. The thin end is located about ten feet vertically above the centre of the shaft. An iron sheave with a grooved circumference is attached to the thin end of the pole and a rope runs in the groove with a bucket at the shaft end. A horse is attached to the other end to raise or lower the bucket as it moves away from or towards the shaft.

**Wilfley table** – a table about sixteen feet by six feet covered with linoleum, sloping from the upper right hand corner. The pulp flowed from this corner across the table while water was added along the right side. Wooden riffles 12 mm. high by 6 mm. wide were fixed to the table top parallel to the longer side and as the pulp flowed over the riffles the percussive jerks of the table caused the heavier particles to settle and flow along the riffles to the left side along a diagonal while the lighter particles collected on the left side of the table so the heavier particles could be collected separately from the lighter.

**Winder** – machine to hoist or lower the cage or skip in the shaft.

**Windlass** – hand operated device over the mouth of a shaft to raise or lower a bucket in the shaft.

**Winze** – small shaft sunk from a level or between two levels, for exploring the reef, or for ventilation, or for communication between levels.

**Zinc Box** – wooden box in which zinc dust or zinc shavings is placed in the cyanide solution to precipitate the gold.
Appendix 3

Discussion of G Thureau’s Report of 1877

Geoffrey Blainey has written that while Victoria led the continent in trying new mining techniques in the 1870s, most Victorian managers were slow to use them. When George Lansell and the mine owners of Bendigo sent Gustav Thureau to study mining methods in California and Nevada they learned in 1877 how backward were Australian mines. 1074

In the introduction to his report, written on his return, Thureau wrote1075: (see p. 1)

Whilst sojourning in the State of California, Mr Lansell, who, it is needless to say, possesses a very extensive practical mining knowledge, observed many instances connected with mining and the treatment of auriferous ores, which were there very successfully worked, and which, if introduced here would in his opinion, result to the advantage of our miners on Bendigo or elsewhere.

Thureau makes it clear that it is Lansell who is criticising the methods in use. In my opinion he then subtly dissociated himself from this statement when he wrote on page 4:

In describing the various matters connected with mining in America, and submitting my views for adoption here, it is not intended to convey an impression unfavourable to what we may have become accustomed to from actual practice, but rather to give the thinking portion of our mining community an opportunity to read, compare and form their own judgement as to which of the two systems – viz, the Victorian and the Californian – is preferable, and which should be adopted of either, or what should be rejected.

In 1877 George Lansell was becoming one of the most powerful figures in the mining industry in Bendigo, while Gustave Thureau was a lecturer at the School of Mines there and would have been careful not to offend a person who could directly influence his future career. Although he was a technician graduate from the Clausthal School of Mines, Thureau’s Australian gold mining experience was limited to the central and western Victorian gold fields, and the limited number of mines he had inspected in California and Nevada, which had been selected as most up to date by his Californian advisers(see p. 4).

An analysis of the individual sections of the report shows what Thureau was thinking:

1. The deep lead systems on the continents were different to those in Victoria, no drainage was required in the elevated Californian deep leads and the working there was easier(p.15).
2. Shaft sinking was similar and he had no special remarks to make (p.16).
3. Cross-cutting was similar but in some cases in California smaller headers were pushed on ahead of the final drive and rockdrills were used to good effect (17).
4. Pumps were similar in both places (p.17).
5. Air compressors with water in the cylinders were similar (to the local Ford machine) but the National Company had recently introduced compressors with water jacketing for higher efficiency. Thureau was appointed Australian

agent for the National Company, probably while he was in the United States, and he promoted the sale of these drills on his return, so he was not an unbiased reporter (p. 18).

6. The Californian hand boring machines were not effective for overhead work. The use of rockdrills in California would in the future reduce working costs by half (p. 19). James Millin had said much the same thing in Bendigo in 1868.

7. Diamond drills were a novelty in several places in California but he thought they would prove useful in locating water ahead of the working area and in locating new orebodies (p. 21). The Victorian Mines Department imported several diamond drills in 1878 probably before being influenced by the report.

8. Root’s blowers were in use in 1878 at the Port Phillip Company (p. 22).

9. Return tubular boilers were already in use at the Port Phillip Co. as well as in California (p. 23).

10. Winders and poppet heads were similar to those in Bendigo (p. 24).

11. Cables or steel wire ropes were similar to those in Victoria (p. 26).

12. Safety devices were similar. Whims and whips were in use on small goldfields in Victoria as the probably were in California although Thureau did not see any on the larger fields (p. 24).

13. Crushing and amalgamating techniques were matters of debate among millmen and there were many variations in both countries (p. 22 – 37). Comparative tables of crushing efficiencies published in 1873 showed Victorian mills were better than most in the U.S.

14. The use of chlorination for the treatment of pyrites seems to be one area in which California was in advance of Victorian practice. However there was a chlorination plant in operation in Bendigo at this time which Thureau does not mention. He was specific in criticising Bendigo for still using roasting and amalgamating of pyrites, and by implication excludes Clunes where tests had proved conclusively that this method did extract most of the gold from the local pyrites (p. 38).

15. Ball mills for fine grinding and Frue vanners for the separation of tailings were in use in California but not in Australia at this time, but Thureau says the vanner was a prototype which was an improvement of the rotating belt for separating pyrites (p. 39-40). Thomas Carpenter had been using this belt in Bendigo in 1862.

16. Thureau questioned whether Bendigo managers were careful enough in testing losses of gold and mercury in the tailings, and cited the more elaborate and effective Californian methods. Again he criticises the Bendigo mines and does not mention Clunes where careful testing of tailings was undertaken at that time (p. 38).

17. Retorting of amalgam was similar in both countries (p. 41).

18. From Thureau’s description of chlorination this process was better developed in the U.S. than in Victoria in 1877. He said calcination of pyrites followed by amalgamation had been obsolete for 12 years in the U.S. while it was still extensively used in Victoria, and that the best U.S. plants were extracting up to 97 percent of the gold in the pyrites (pp. 41-3). The best Australian practice did not achieve this standard until about 1890 at Charters Towers. Costs of extraction achieved later in Australia appear to be about the same as U.S. costs.

19. Sluicing techniques appear to be similar except pipes were cheaper in the U.S.
However at the few places where wet deep lead mining was carried on in the U.S. the technology lagged well behind Victorian practice. Most deep leads in the U.S. were drained by river valleys at lower levels than the leads (pp. 46-9).

20. The recently established School of Mines at Berkeley was having difficulty attracting students as it was competing against well established schools of mines in Europe and the eastern United States. Graduates from these schools were in ample supply in California and Nevada. The Berkeley school was a part of the State University, and was conducting a two year course in a range of subjects from which the student could select subjects to make up a course in civil or mining engineering, geological surveying, metallurgy, analytical chemistry or mining superintendent. Thureau was a lecturer at the School of Mines in Bendigo which had been opened in 1873, and which was developing similar subjects (p.52).

21. In his Part II Thureau described the Comstock lode which he said was quite different to anything being mined in Australia. The orebody was up to 600 feet wide with lenses of quartz containing mainly gold at the surface and silver at depth. Twenty companies held ground along 20,000 feet of reef so the average length and the width of the reef mined by each company was much larger than for Victorian companies, where the allowable length was about 180 feet and the reefs were generally only a few feet wide. The Comstock orebody was friable and square sets were used in the stopes with timber being used for filling. Cornish pumps, driven in some cases by compounded steam engines, were used for pumping. The ore was crushed in stampers similar to Victorian equipment and amalgamation was used to separate the gold. Chlorination is not mentioned in the report as being used in Nevada.

Thureau said that rockdrills were being accepted more quickly in California than in Victoria, that the use of the chlorination process was well in advance of Bendigo practice, and that Californian managers were more careful in testing losses in the tailings than were Bendigo managers. However Roger Burt has written recently that machine rockdrills were not in general use in the western United States until the 1880s, i.e. about the same time they were being widely adopted in Victoria. Otherwise Thureau indicates that Victorian mining practices were similar to those in use in California at the time of his visit. George Lansell was the critic who implied that Victorian practice lagged overseas practice, but Thureau dissociated himself from this rather vague statement. No doubt Lansell had his reasons for making such a comment but it seems he was prone to making snap judgements. Charles Fahey mentions that Isaac Edward Dyason, Lansell’s senior manager, wrote in his diary in 1893 that Lansell had sacked the manager and miners at his Comet mine when he received information alleging the miners were stealing gold. Without seeking proof he discharged all the men except contractors, an action which Dyason criticised in his diary when he said Lansell acted without proof, something he had done at Gold Mines years before. In my opinion the sweeping statement by Geoffrey Blainey that Thureau’s report showed how backward Australian mines were in the 1870s is not supported by a careful reading of the report.


1077 C. Fahey, "Cornish Miners in Bendigo - an Examination of Their Standard of Living," *Cornish Association of Bendigo*, pp. 5-6.
Appendix 4

The Movement from Individual to Company Employment in Victoria

The First Ten Years 1851 to 1860

As the Victorian gold miners gained experience they began to realise that not only the hastily devised colonial goldfields regulations but also the underlying framework of British mining law were not suitable for Australian conditions. As the bye-laws of the local courts and the mining boards were changing the laws covering the processes of mining, the miners began to understand that changes in the laws covering mining companies were needed. This appendix will investigate how these changes, which resulted in companies of a new and distinctive type, led to increasing employment in company mining.

The first attempt, the passing of legislation to allow partnerships with limited liability in 1853, had been a failure as only some 10 mining partnerships were registered, and all were for the operation of crushing plants which would have employed probably less than twenty men each. The passing of Haines’ Act in 1855 (for companies operating on the English cost book system) and Ireland’s Act (for mining associations with limited liability) appear to have had some success but there is considerable difficulty in determining the numbers of companies. Lease records after 1859 indicate the number of companies was probably less than 100, mainly at Ballarat and Castlemaine, but most were short lived, and most probably employed few miners. At Ballarat a few cooperative partnerships were each employing 80 to 90 men in 1857 on deep lead mining.

Company Growth after 1860

The importance of the passing of Pyke’s act in 1860, with its relevance to Australian conditions, is indicated by the fact that some 539 companies were registered under this act between 1860 and 1864, the great majority at Ballarat and Daylesford for both alluvial and quartz mines. Larger numbers were registered under Frazer’s Act after 1864 and during the quartz boom at Bendigo larger numbers again under the 1871 act.

1078 Victoria: Act 17 Vict. 4, I December 1853. A. Bolt, Diary (Bendigo: Copy of original diary held by the German Heritage Society, Bendigo., 1854). Bolt obtained work with Christopher Ballerstedt who was operating a private crusher at Bendigo in 1854 employing 12 men. He was paid £1 per day. No records of these private crushers have been found.

1079 F. Strahan, "The Growth and Extent of Company Mining on the Victorian Goldfield in the 1850s" (B.A. Hons., Melbourne, 1955), p. 31. British Parliamentary Papers, vol. 24, Session 1862-3, p. 157. Governor Barkly reported many of the companies registered in Melbourne at this early period were unprofitable or could not meet current expenses such as secretaries, consulting engineers, clerks etc. These companies were clearly structured similarly to British practice.

1080 R. Ashley, Mining Companies Applying for Registration in Victoria, 1860-64 (Ballarat: R. A. Research, 2004), Microfiche.

1081 Victorian Government Gazette, (Melbourne: Government Printer). Some 72 companies were registered in January 1872 of which 62 were limited liability and 10 were no-liability.
The statistics of the number of miners in Victoria were not very reliable until 1863 when a separate Mines Department was established. From 1864 to 1888 the numbers were published quarterly, and these are consistent enough to be used for analysing the number of miners moving from partnerships on claims to company employment.\textsuperscript{1082}

An analysis of these figures shows that in January 1864 some 10,000 alluvial miners were working in the Ballarat mining district (which included Smythesdale, Creswick and Clunes), with 4,500 of these in central Ballarat. Some 325 companies were registered in the Ballarat mining district from 1860 to 1864, and by 1864 some of these were becoming productive. From 1864 to 1868 the number of alluvial miners in central Ballarat increased from 4,500 to 9,000 as these companies employed more men, either on wages or on a cooperative basis, with another 2,000 in the outlying divisions. However this employment collapsed in 1868 as the mines in central Ballarat were worked out and fell linearly to less than 1100 in 1876. In the outlying divisions employment fell to less than 1500 in 1868, but then increased gradually to 3000 by 1882 as the Creswick and Springhill deep lead mines expanded. The Ballarat district quartz mines in which most employees would have been wages men, gradually increased their employees from 2000 in 1864 to 5000 in 1882 when many mines became uneconomical, and employment collapsed to 2800.

At Castlemaine the number of alluvial miners rose from 7300 in 1864 to 7500 in 1866, an increase most likely due to company employment, but then fell rapidly to 2400 in 1874. Castlemaine district quartz mining, mainly at Daylesford, in 1864 involved 2600 men, most of whom were probably on wages, but this employment fell steadily to 1500 in 1884.

Alluvial miners at Bendigo, perhaps a few hundred of whom would have been employed in the deep lead mines at Huntly, fell precipitously from 7,700 in 1864 to 2,200 in 1872 and then to 1000 in 1884. However quartz miners at Bendigo, starting from 3,300 in 1864 (most of whom would have been in partnerships), rose to 4,100 in 1866 as the few companies there developed, remained steady to 1869 as the companies registered under Frazer’s act developed, and rose another 1000 to 5700 until 1872. The numbers, mainly wages men, then dropped slowly to 4400 in 1884.

In the Ararat district the number of alluvial miners, probably mostly self employed in 1864 fell precipitously from 3,500 to 1300 in 1868 and then remained reasonably steady as the deep lead mines in the district prospered. In this district Stawell was the most prominent quartz mining division, but only one company was registered under Pyke’s act so it is likely little transfer to company employment took place until companies registered under Frazer’s act became profitable after 1865. The number of quartz miners in this district fluctuated around 1000 from 1864 until the late 1880s.

The Beechworth district had 5400 alluvial miners in 1864, and this dropped with some fluctuations to about 2000 in 1882. Probably half of these were self employed. Beechworth district quartz mines, mainly in the Woods Point area, employed 4300

\textsuperscript{1082} Report of Royal Commission on Conditions and Prospects of the Goldfields, (Melbourne: Government Printer, 1863), 1963, p. 403. When giving evidence in late 1862 Brough Smyth said there were 100,000 miners who had settled and another 50,000 to 60,000 who were still following rushes from field to field. However the statistics of January 1864 give a total of 80,000 miners.
miners in 1866 (more than Bendigo’s 4100) but after this the number declined rapidly to 2000 in 1876.

After 1864 Maryborough district self-employed alluvial miners fluctuated from 11000 due to rushes at Korong and Berlin but held up between 6500 and 4500 until 1876 due to employment at the deep lead mines in the Loddon valley. It then dropped to 2500. Maryborough quartz mining fell from 3200 to 1800 in the four years from 1864 then fluctuated around 2000 wages men until 1884.

Company development did not start in Gippsland until 1865 and employment in the mines there peaked at 1200 in 1872 and settled to about 600 in the 1880s.  

The following table summarises the estimated company employment in 1864, 1868 and 1884 from an analysis of the number of goldminers, and the changing pattern of the changeover from alluvial mining to quartz mining on the several fields in Victoria.

<table>
<thead>
<tr>
<th>District</th>
<th>1864 Alluv.</th>
<th>1864 Quartz</th>
<th>1868 Alluv.</th>
<th>1868 Quartz</th>
<th>1884 Alluv.</th>
<th>1884 Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballarat</td>
<td>4000</td>
<td>500</td>
<td>9000</td>
<td>2000</td>
<td>2500</td>
<td>2300</td>
</tr>
<tr>
<td>Bendigo</td>
<td>1000</td>
<td>1000</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
<td>4500</td>
</tr>
<tr>
<td>Ararat</td>
<td>500</td>
<td>200</td>
<td>1000</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Beechworth</td>
<td>500</td>
<td>1000</td>
<td>1000</td>
<td>2700</td>
<td>2000</td>
<td>1500</td>
</tr>
<tr>
<td>Maryborough</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>1000</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Castlemaine</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>1200</td>
<td>1500</td>
<td>1000</td>
</tr>
<tr>
<td>Gippsland</td>
<td>—</td>
<td>—</td>
<td>400</td>
<td>800</td>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>Totals</td>
<td>7000</td>
<td>4200</td>
<td>15900</td>
<td>9500</td>
<td>10400</td>
<td>12100</td>
</tr>
</tbody>
</table>

These figures can be quoted as percentages of the total numbers of alluvial and quartz miners:

<table>
<thead>
<tr>
<th>Year</th>
<th>Alluvial miners</th>
<th>No. on Wages</th>
<th>Percent</th>
<th>Quartz</th>
<th>No. on Wages</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1864</td>
<td>45,040</td>
<td>7,000</td>
<td>16</td>
<td>15,089</td>
<td>4,200</td>
<td>28</td>
</tr>
<tr>
<td>1868</td>
<td>33,200</td>
<td>15,900</td>
<td>48</td>
<td>14,500</td>
<td>9,500</td>
<td>67</td>
</tr>
<tr>
<td>1884</td>
<td>14,000</td>
<td>10,400</td>
<td>74</td>
<td>13,200</td>
<td>12,300</td>
<td>95</td>
</tr>
</tbody>
</table>

The figures for 1864 are more subjective than for the other years, but the overall employment pattern is clear. The changeover to company employment was not immediate after 1859, but was progressive with around half of all miners working for companies in 1868, and the changeover to company employment of quartz miners was almost complete by 1884.


1084 "Reports of Mining Surveyors and Registrars, Victoria," (Melbourne: Mines Department), 1863 -84.

1085 During the depression of the 1890s many unemployed were assisted by the government to take up shallow alluvial mining but no reliable figures of the increase of these numbers is available.
These figures are subjective estimates based on a knowledge of what was happening in each mining district at each of the years given. They do not include the numbers of Chinese miners who came to the goldfields as indentured labourers in parties financed and controlled by Chinese capitalists. After paying off the indenture they worked in small parties on shallow sinking, puddling and sluicing. A few were employed on deep lead mines puddling the washdirt and a maximum of 200 were employed in quartz mines.\footnote{R. W. Birrell, \textit{Staking a Claim} (Carlton: Melbourne University Press, 1998), ch. 6. “Reports of Mining Surveyors and Registrars, Victoria,” 1864-84. \textit{Dicker’s Mining Record}. 28 November, 1867, p. 206.}

It is difficult to estimate the total of mining companies working at any one time. Most were short lived, and raised little capital initially, almost entirely from funds generated in mines in the district and from merchants in Melbourne. Almost no English funds were involved before 1890.\footnote{Ibid , October 1864, p. 187 and 27 May 67, p. 244. The Victoria (London) Gold Mining Company was a British company holding shares in 13 Victorian companies in 1864. Richard Kitto, of Fryer’s Creek went to London in 1867 and raised sufficient capital to develop the Duke of Cornwall mine, but generally British investors ignored Victorian gold mines in this period.} A few early claimholders became rich on the gold produced from the claim and a few long term investors made money.\footnote{J. C. Fahey, “Wealth and Social Mobility” (Melbourne, 1981), p. 18. Barnet Lazarus and J. B. Watson were mine owners, and G. Lansell, also a mine owner and a substantial investor in other mines, made substantial fortunes.} Some speculators made money but the most widespread profits were made by claim holders who were lucky enough to peg rich claims. They sold their claims to companies and received shares and money in payment and then benefited from the share dividends. A few, like George Lansell in Bendigo, bought shares in partnerships and small companies which were profitable in the early 1860s and later privatised these mines and converted the claims to leases. With his extensive shareholdings and leases Lansell began to dominate mining in Bendigo in the 1870s.\footnote{The \textit{Claims Register} for the Sandhurst District shows Lansell taking shares in claims in the 1860s. For example he bought into Rigby & Co’s claim No. 746 on the Garden Gully line in December 1864. The first lease in which he was involved was No. 2649 for the Ada Company in New Chum Gully, with G. Lansell, John Hasker and Edward Hunt as co-lessees, applied for on 21 November 1871. \textit{See Lease Register, Sandhurst District}} Victorian gold mining companies remained small in size with few employing over 100 men. Most were controlled by directors who had themselves been mining in partnerships in the 1850s, and they employed managers who were almost always practical men and operated as foremen.\footnote{The minutes of the Endeavour Company, a quartz mine, show that tight control over the mine was kept by the ten original partners who were given shares when the company was formed in 1865. They became directors of the mine. The mine manager referred all decisions on mine development to the directors.} The directors made the important decisions, and to keep share prices high they paid dividends at short intervals, often fortnightly, if the mine was profitable. After 1900, as the old miners died, this company structure altered and became controlled almost entirely by outside investors employing specialist managers. An attempt was made at Bendigo in the 1920s to amalgamate the small mines into a larger unit but this failed because of postwar inflation and high costs while the price of gold remained steady at prewar values.
Miners in the Bendigo District

Miners in the Ballarat District
Appendix 5

Ore Extraction

Washing for Gold and Tin

Alluvial and eluvial gold sometimes mixed with tin was found on or a few feet below the surface on the early gold diggings. Extraction of the minerals using simple gravity methods required little capital to commence work, and if the ground was rich fortunes could be quickly made.

This scene was sketched by C. Rudstone Read in 1851 during the early Turon rushes. The various techniques of shallow sinking, driving tunnels into the bank to follow the washdirt, dishing, cradling and carting the soil in barrows, are shown. The small claim size in New South Wales of 20 feet square meant the tents had to be erected away from the pegged area. The heavy gold was usually deposited on the inside curve of the river as the water velocity was slowest there. Read later became a gold commissioner on a small goldfield near Bendigo.1091

Simple Gold Washing Technology

The washdirt was placed in the dish which was then dipped into the water and the mixture was swilled around and the lighter particles allowed to escape over the lip. In a few minutes only the heavy gold and tin remained in a little sand. The gold was placed in a small bottle or matchbox.1092

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Dishing

In clayey ground the soil was shovelled into a tub, water was added and the mixture was stirred with a puddling stick. The clayey sludge was poured off and the sandy residue was washed in a dish to recover the gold.

Cradling

The washdirt was shovelled into the hopper of the cradle which was rocked from side to side with the handle while water was poured from the dipper onto the washdirt. Stones were removed from the hopper by hand, and the sand washed across the cleats behind which the gold collected.
Edward Hargraves instructed the Tom brothers how to make a cradle similar to this one out of boards. It was normally positioned near a creek or river to provide plenty of water to be scooped up with the dipper for pouring onto the soil in the hopper. Mercury was often placed between the cleats on the bottom to amalgamate the small gold particles. The cradle was rocked by hand to give a swirling motion to the water.

Sketch of a Cradle

Sluicing technologies were brought from California in the early period of the goldruses in 1851, and were used in eastern Australia where sufficient water was available, particularly around Beechworth where the method was used to recover alluvial gold and tin. Later when dams were built by companies or governments, sluicing became widespread. Several variations of sluicing are shown here.

1093 I. Idriess, Prospecting for Gold (Sydney: Angus & Robertson, 1931), I. Idriess, Prospecting for Gold (Sydney: Angus & Robertson, 1930).
Tomming

The tom could be used with a small head of water. It was made of two inclined sections, one above the other. The upper box had a grating at the lower end with a riffle box placed at the exit end of the grating box. With water flowing into the tom washdirt was shovelled into the upper box, the stones washed over the grating, while the smaller particles fell into the grating box, from where they were washed into the riffle box leaving any heavy particles in the grating box. Finer gold and tin particles collected behind the riffles from where they were regularly removed. A long tom was about 14 feet long with a width of 18 inches. A broad tom was about 7 feet long, 12 inches wide at the top and 3 feet wide at the bottom. One operator broke up lumps and raked the soil to keep it moving. The waste soil was washed away into a creek or river.

Ground Sluicing

Here the sluice channel was dug in sloping ground, water entered at the top and flowed down the sluice. The washdirt was shovelled into the sluice, and the gold or tin settled onto the rough bottom, from where it was regularly removed. The ground sluice required more water than the tom but less labour was required.

Box Sluicing
This sluice performed the same function as a ground sluice but was portable, and the angle of flow could be adjusted to suit the quantity of water available. The boxes were made of boards each about 12 feet long, and slightly wider at the bottom than at the top so lengths could be fitted together end to end. The boxes were set to the required slope on trestles. Cross riffles were fitted to collect the gold or tin.

The Puddling Machine

This machine, first used for washing alluvial gold in central Victoria in 1852, was a direct adaptation of the Cornish circular buddle for washing alluvial tin, first used in Cornwall about 1848. This was a very rapid transfer of new Cornish technology to Victoria. The earth was carried in drays from surfacing areas nearby, and tipped into the annulus. Water from a dam or race was run in and the slurry thoroughly mixed by the rakes as the horse walked around the circular path pulling the horizontal bar. When thoroughly mixed, the slurry was run off through the covered duct at the front of the picture. Any heavy pebbles were thrown out, and the remaining sand was washed in a cradle or dish. As there were thousands of these machines in use on goldfields, such as Bendigo and Castlemaine, the slurry or sludge ran down the creeks and filled the valleys to depths of many feet.

Hydraulic Ground Sluicing

Hydraulic Ground Sluicing

If sufficient water was available hydraulic ground sluicing was used to wash down the alluvial ground into a ground sluice. Water was normally carried in a water race and flume from a higher altitude to the wash site to give a head of water over 100 feet. It was then carried in a hose to a monitor or water gun which gave a water jet of sufficient force to break up the washdirt and carry it to the sluice. Two men could wash up to 100 cubic yards of washdirt a shift with this method. This method also filled the creek and river valleys with sludge to depths of many feet.

**The Water Gun or Monitor**

![Photograph by the author](image)

The monitor was invented in California in the early 1850s but no evidence has been found of its use in eastern Australia until the late 1870s. The erection of fluming to give a sufficient head of water for the monitor was expensive, and it was not until suitable pumps became available to provide the required water pressure that the monitor was used extensively in Australia. The gun barrel was connected to the incoming water pipe through a swivel joint. The balance box was loaded with stones to balance the backward thrust of the water, so the operator could stand at the side of the gun and direct the jet of water by moving the lever on the top of the barrel. Ground that was too hard for the jet was drilled and blasted to loosen it before washing down.

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1097 Photograph by the author
Hydraulic Pumping and Sluicing

The alluvial sands were sluiced with a hose into the lowest point of the sump shown in the photo (the low point was to the left). A gravel pump with a strengthened impeller for pumping sand and stones, lifted the sludge from the sump to the box sluice which collected the gold and tin, the waste water being stored in an adjacent dam until it was required for further sluicing. The barge rested on the floor of the sump until the area was worked out. The sump was then filled with water, the barge was floated to a new location, and the sluice trestle was relocated. The barge carried the steam plant to drive the pumps.

Bucket Dredges

The above photograph shows the rear end of an early gold bucket dredge working at Jembaicumbene in central New South Wales. The dredge floated in the dam and the alluvial ground was excavated by buckets on an endless chain and tipped into a box

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1098 J. E. Carne, *The Tin Mining Industry of New South Wales* (Sydney: Geological Survey N.S.W., 1911). Plate XXI
sluice to extract the gold. This early machine (1901) discharged the tailings back into the dam, and no attempt was made to return the ground to its original state with the fine material at the top. In Victoria, legislation was passed in the early 1900s requiring the top soil to be stored, the coarse stones in the tailings were deposited first, then the fine tailings on top and finally the top soil was replaced on the surface, so the land could be re-used for agricultural purposes.

The Harrietville Dredge

![Design Drawings of the Harrietville Dredge](image)

The Harrietville bucket dredge located in north east Victoria was designed by the New Zealand/British firm, F. W. Payne and Sons in the 1930s, and was the largest built in Australia. The overall length was 550 feet, weight 4,891 tons, digging depth to 130 feet with 20 cubic feet buckets. The speed of the bucket line could be controlled by an electric motor with a Ward-Leonard drive. Other motors were also electric. Electric power was drawn from the state electricity grid. Double stacker belts on the rear boom allowed the stones to be dumped behind the pond and then covered with sand. Finally the original top soil was spread over the sand. The structural framework of steel is shown in the drawing. It was clad with galvanised iron sheets. The bucket chain is drawn in the retracted position. The machine was built by Thompsons Foundry of Castlemaine

Deep Lead Mining

Deep leads were found in several different geological formations in Australia containing gold or tin minerals or both together. The first was where the washdirt was covered with one or more layers of basalt but rivers running on each side of the hard basalt had eroded into the softer reef rock so the valleys were below the level of the washdirt.

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In this situation the washdirt could be accessed by driving an adit from the side of the valley at a level below the washdirt so the drift could be drained through the adit. When dry the washdirt could be extracted through the adit without continuous pumping to remove the water.

The second type occurred where the basalt layer extended across the valley floor but little erosion had occurred.

Here the washdirt could only be drained by continuous pumping of the water from the bottom level. For safety in case of pump failure the washdirt was removed through the leading wash drive. The plan of the mine workings for a relatively narrow washdirt of this type is shown below. The workings follow the old river bed with the drives and crosscuts being laid out roughly in a bord and pillar system.
This type was common in the Ballarat area. After some preliminary boring, usually by diamond drill through the basalt, to locate the gutter, the main shaft was sunk in reef rock to sufficient depth to drain the whole lease. At the bottom a plat was cut, and the reef or main drive dug along the supposed lead with short bores being put up into the washdirt to drain off the water. An intermediate drive was made above the level of the main drive, from which rises were put up into the washdirt and wash drives opened up the washdirt. Branch drives were made off the intermediate drive to prospect the ground and payable areas were cut up into irregular blocks and panelled to extract the washdirt. Commencing along one edge of a block a drive about 6 feet wide and high was cut partly into the bedrock perpendicular to the wash drive with laths driven to secure the roof while the panel was excavated. At the end of the panel about 16 feet long, the miner returned to the washdrive and commenced another panel along the edge of the block, repeating the process until the block was removed. In this system the reef or intermediate drive is ahead of the workings but it was difficult to ensure it was always below the gutter. The third type had only clay and sand above the washdirt level. Here the width of the washdirt was often wider allowing a more extensive development of a bord and pillar like system.

The plan of a deep lead mine in north east Victoria shows an extensive underground area laid out in this way.
The Chiltern system was slightly different to the Ballarat or down-country system described above. In this case the main shaft was sunk through the alluvium to a depth some 60 feet below the wash dirt level and the reef or main drive cut under the washdirt. Drainage bores were extended up into the washdirt which was drained of water into a sump at the bottom of the main shaft and pumped to the surface. The leading wash drive was then dug at a level slightly below the deepest washdirt at the boundary of the lease so all the washdirt could be drained to this level, and from it to the reef drive. Cross drives were dug at right angles to the leading wash drive to both boundaries of the washdirt, and the leading wash drive was connected to the reef drive with a vertical shoot with ladderway. As the face workings were extended back towards the main shaft a timber and upcast airway was dug on the same level as the leading wash drive, but outside the washdirt and in solid ground. The ground was allowed to subside as the washdirt was extracted.

This illustration with longitudinal and cross sectional views shows a method of timbering a leading wash drive with the washdirt being extracted from the left end. The side laths were removed to allow the development of blocking drives. The floor of the drive was normally in bedrock below the level of the washdirt to allow sufficient height for men to work while still allowing all the washdirt containing economic gold values to be extracted.
Headframes

The early goldfields in eastern Australia were located in areas with substantial trees which could be used for the construction of surface buildings, headframes and underground timbering. For shallow alluvial gold mining a round or rectangular shaft was sunk with a windlass turned by hand being used to lower and raise miners and buckets to bring the washdirt to the surface. At first hemp ropes were used but these were replaced later by wire ropes. As the size of claim allowed was small the waste soil raised had to be stacked around the shaft so it did not encroach on a neighbouring claim. Timbering was used to contain the soil.

For shafts up to two or three hundred feet deep the manual labour of the windlass could be reduced by using a whip with a horse to raise and lower the bucket. A whip boy guided the horse to walk to and from the shaft as required. A pulley built into the top of the whip pole changed the direction of the rope from near horizontal to vertical.

For depths of several hundred feet the whim was a simple and effective method for hauling rock and ore up the shaft. The whim was a drum of vertical wooden slats around which several turns of rope were wound with the ends passing over pulleys to move the
buckets up and down the shaft. The timber headframes to carry the pulleys were small and made of tree trunks. The drum was turned by attaching a horizontal pole to the vertical support with a horse walking a circular path backwards and forwards to raise and lower the buckets. A whim boy guided the horse.\textsuperscript{1101}

As the shafts went deeper steam winding engines were installed to provide more power to raise and lower the cages installed to carry trucks of ore up the shaft and to handle the greater weight of steel wire rope in the shaft. The use of cages and safety gear to prevent the cage falling down the shaft if the rope broke, required higher headframes to accommodate the cage at the surface. The runners or guides which ensured the cages did not strike the shaft timbering, required extension above the surface into the skyshaft and safety catches extended this upwards.

\textsuperscript{1101} These three illustrations are from Hunter, \textit{The Deep Leads of Victoria}. 
The illustration above is the headframe of Lansells 222 mine at Bendigo. Each leg was made of two tree trunks joined end to end to provide sufficient height for the cages, safety gear and ore storage bin so the ore from the bin could be dumped into trucks which were pushed along rails on the gantry to the crusher plant outside the photo on the right. The steam winder was housed in the building at the left with idler pulleys halfway to the headframe to prevent excess slap of the rope. This installation was built in the 1870s.

By the end of the 1890s the local forests had been denuded of tall trees and the increasing shaft depths were placing extra stresses on timber headframes which were replaced gradually by steel structures. The eastern Australian headframe with four timber legs at equal angles became too weak to withstand the greater weight of the rope, larger cages and bigger ore trucks and the resultant greater rope stress required additional legs on the rope side to take the stress and prevent the larger overturning forces overstretching the legs on the rope side. This led to headframes on the goldfields similar to that in the above figures, approaching the design of those used for many years in coal mines which had been designed on a more scientific basis to cater for the stresses involved. The skyshaft timbers, the safety gates at the surface plat and the unloading plat for ore trucks on the first level can be seen. It is interesting that the legs of this headframe which was built by A. Roberts and Sons foundry in Bendigo, were of rivetted steel plates tapered to simulate tree trunks, perhaps for aesthetic reasons, although there was no structural need to do so.

At the same time as this headframe was erected at the Garden Gully United mine in Bendigo, one of the largest gold fields in eastern Australia, a headframe of quite different design was being erected on the Birthday coal mine in central Sydney on a very deep shaft built to exploit a deep coal seam below that city. This structure was designed taking the actual stresses involved into account with the steel girders and beams being of lattice construction to save steel while still retaining strength and

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1102 Photograph courtesy James Lerk.
1103 Reports to the Minister of Mines, Victoria, (Melbourne: Mines Department Victoria), 1899.
making the angles of the beams a better fit to the direction of the stresses involved. The main shaft and airshaft followed British tradition by being of large diameter, circular and lined to reduce air resistance and assist ventilation.  

A somewhat different type of headframe for an inclined shaft is shown in the diagram below. This was built at Mt. Morgan in Queensland to access the gold copper orebody in 1905. The winding engine installed at the same time was electrically driven. A photograph of the engine room is shown below.

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1104 Reports to Minister of Mines, New South Wales, (Sydney: Government Printer), 1900.
This winder had a DC motor at each end each of 200 H.P. with a maximum speed of 200 r.p.m. each geared to one of the two 10 feet diameter drums. The winder was made by Walkers foundry at Maryborough, Queensland. Skips running on wheels on rails down the incline were of 93 cubic feet capacity to carry 2500 tons of ore per day at speeds up to 800 feet per minute.

**Steam Winders**

Steam driven winding engines were in use in Australian coal mines at Newcastle, and gold mines at Ballarat in the mid 1850s. The horizontal steam cylinders were positioned on each side of the machine so each drum could be uncoupled by a clutch and driven independently through a crank on each side, or the clutch could be engaged and both drums driven together. The illustration above is of a double drum winder installed at the Derby mine at Bendigo in the mid 1930s by the Derby (Bendigo Mines Ltd.) Mining Co. N.L. This company was one of several operated by Bendigo Mines Ltd. with British
capital, but this was the only steam plant the company installed, probably to enable a comparison of costs compared with the electrical drives at their other mines. Although electrical drives had generally replaced steam by the 1930s many second hand engines were still available from defunct mines at little cost. The photograph shows the light timber frame and galvanised cladding of the winder house, the chair on which the winder driver sat while operating the lever controls, and the steam driven air compressor plant in the foreground which was controlled and maintained by the winder driver. 1106

Cages

Cages were in use in British coal mines early in the nineteenth century and were first used in the Newcastle coal mines in Australia in the early 1950s, and in Ballarat deep lead mines in 1857. Early cages were little more than a platform, raised and lowered in the shaft by a rope with runners or guides to control the position of the cage in the shaft, so it did not rotate and strike the timbering of the shaft. At this early period the miners did not ride in these cages but used the ladders or adits to get to the working face and return to the surface. The illustration below shows an early cage containing an ore truck in the Catherine Reef United gold mine at Bendigo in the 1860s. 1107 The truck similar to those then in use in coal mines had one pair of wheels about centre, for easy rotation on a steel plate on the plat at the entrance to the cage. As the mines deepened, climbing ladders meant loss of working time, so the miners were transported through the shaft to the face. For safety reasons the framework of the cage was improved, and eventually by the end of the nineteenth century larger mines were using cages clad in sheetmetal to prevent any part of a miner protruding into the shaft. In large mines fully enclosed cages carrying up to 80 men became common in the twentieth century, each cage having two decks with loading of each at the same time from two level plats. The Victorian Mines Department sponsored the development of safety devices on cages to prevent the cage falling to the bottom of the shaft if the rope broke and better cage design to protect miners in the cages from falling objects in the shaft. Illustrations from the report of 1890 of the Safety Cages Board showing improved protection and better safety catches are shown in the succeeding diagrams. 1108

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1106 Photograph courtesy James Lerk.
The left diagram below shows Clarke’s cage with stronger construction of the frame and one of the two top flaps which protected miners from falling stones in the retracted position. The right diagram is a line drawing of Chessell’s safety catch after operation with the grippers dug into the wooden runners. In normal operation the grippers were held away from the runners by the upward pull of the rope.\textsuperscript{1109}

Many designs of safety grippers were made, but the Safety Cages Board of 1890 reported that after extensive tests the Board was satisfied that Chessell’s design was the most effective. It was designed and made in Kyneton in Victoria. Another design, tested but found ineffective, was White’s gripper which forced wheels against the runners. The illustration of this design includes a drawing of a safety catch to protect against overwind in the skyshaft, and the consequent rope breakage as the cage was forced into the top deck of the headframe. A thimble opened the safety catch so that when the free cage started to fall down the shaft it was stopped by the thimble.

\textsuperscript{1109} Ibid.
The safety catch is shown approaching the thimble. After passing through the rope and hook was detached without breaking the rope and the opened catch settled back on the thimble to prevent the cage falling. Details of the position of the safety catch after operation are shown in the next diagram. These catches were developed in British collieries in the 1860s and they were in use in Nevada mines by 1870.\[^{110}\] The date of the first use of this device in Australia is uncertain.

**Shaft Haulage\[^{111}\]**

The illustration, which is believed to have been taken at either the Moonta or Wallaroo copper mine in the 1890s, shows end tipping trucks of broken ore being tipped through grizzly bars to sort out the oversize lumps into the loading station adjacent to the shaft. With the skip in position in the shaft, the long lever was pulled down to lift the chute door and allow the ore to fall into the skip for haulage to the surface. The large lumps were reduced in size with a heavy spaller (hammer). The trucks have a pair of wheels centrally to allow easy tipping. The heavy upright timbers of the level can be seen together with the much smaller local mallee used as laths to hold back the filling. The shaft timbering was sawn timber fitted together in the shaft to prevent excessive leakage of ventilation air.


\[^{111}\] Photograph courtesy of James Lerk.
Stoping

No two ore bodies were exactly the same, and mine managers had to devise suitable methods to extract the ore safely. The basic method was to drive a level from the shaft into the orebody, erect the timbers to protect the level, then break the ore above the level so it fell on the timbering and could be withdrawn from orepasses to trucks on the level for transport to the shaft for hauling to the surface.

Narrow Vein Stoping

These diagrams illustrate two methods of extracting ore from narrow veins. On the left the stope is being developed from a lower level upwards and waste rock has been used to backfill the empty stope and support the walls. To develop a new level a drive was put in at A in ore and timbered with struts B supporting the walls. The ore at B, called the crown pillar, was then removed and backfilled to provide a floor for the new drive A and the ore above A was then removed. The diagram on the right shows a drive put in on solid ore and timbered. Stoping was then developed upwards using pigstyes to support a weak roof as work proceeded. In each case an ore pass above the drive was built upwards with a door allowing broken ore to emptied into trucks in the drive for transport to the shaft.

Wider Stopes in Copper Orebodies at Cobar

The illustrations show a plan and two elevations of a wider copper orebody at Cobar in western New South Wales, in an arid area where the pine trees were small diameter and not as strong as the eucalypts available in higher rainfall areas.\footnote{J. R. Godfrey, “Some Methods of Timbering and Working Wide Lodes in New South Wales,” \textit{Transactions of the Australasian Institute of Mining Engineers} vol. 7 (1901).} The walls and orebody were strong enough to be left unsupported for a short time while the first cut of the stope was extracted. The timber was then built up as continuous pigstyes, with the level and orepasses being timbered as required. Passes for backfill were dug from the level above and waste rock and clay from the surface was run through these into the stope to fill the pigstyes. The stope was excavated for its full length and the next layer was then excavated upwards using the filling as the working floor. This was a local adaptation for mining a wider orebody with fairly strong walls and roof but which required strong support in the long term.
The rich and wide silver-lead orebody at Broken Hill had weak walls and soft ore in the oxidised zone. In this zone problems were experienced in the stopes as rock falls from the roof were common, and the walls pinched inwards as the working depth increased. William Patton, a mine manager with experience with mining similar ores in the western United States, was imported to solve the problem. He brought with him a knowledge of square set stoping and miners experienced in the method. \textsuperscript{1114} He also imported Oregon pine timber which was light, easily sawn and manipulated underground to build the sets. It was not until World War II when Oregon timber was in short supply that it was replaced by heavier eucalypt timbers. The illustrations show how the sets were built into a rigid structure to support both walls and roof as stoping proceeded. The miners worked from inside the set at the face as the stope was developed, and built new sets as sufficient space was excavated. At first the sets were left unfilled as it was believed that

\textsuperscript{1114} D. Clark, \textit{Australian Mining and Metallurgy} (Melbourne: Critchley Parker, 1904), p. 358.
they were sufficiently strong to withstand the pressure, but it was soon found the surface ground creep occurred as the walls crushed the sets, and surface equipment such as winding engines and workshops had to be rebuilt with new shafts outside the creep area. To supply fill material and the relieve the pressures in the oxidised zone, an open cut was commenced at the surface outcrop of the orebody. Low grade ore from the open cut was sent to the mill and the waste was sent through backfill passes to fill the square sets. In the oxidised zone the timber was prone to catch fire with disastrous results. Methods were devised to seal off and flood the burning areas. A new manager, Guillaume Delprat with experience in mining wide orebodies in weak ground was imported to solve this problem.

Delprat introduced the crosscut system of stoping by developing a level with a longitudinal drive traversing the orebody along its length midway between the walls. At 60 foot intervals along the drive crosscuts were driven to the footwall and hanging wall. Orepasses and backfill passes were connected to the level above but offset from the main drive. The crosscuts were then filled. Side stopes 7 feet wide were excavated on
each side of the first crosscut from the main drive, timbered and backfilled. The length of the orebody was then stoped similarly. The square set timbers were tapered so they could be pulled up out of the initial stopes as the upper crosscut was started and used again so little timber remained in the fill to catch fire. The whole orebody was then stoped by crosscuts up to the next level.

The illustrations above show a modified Delprat procedure for harder ground as mining went below the oxidised zone and the walls and backs were stronger. The central longitudinal drive was now excavated along the footwall, and the crosscuts dug from there to the hanging wall. Crosscuts were then dug leaving blocks to support the walls and roof. The first block was then extracted, timbered and stoped at the first level, then stoped at the second level, removing the timbers from the first level and so on until the block was extracted. The second block was then extracted and so on for each odd block. The even blocks were extracted after the backfill had consolidated. This method was an intermediate stage until solid ground was developed in the silver lead zinc sulphide zone at deeper levels. Here open stopes using sand tailings from the flotation process were suitable for the stronger walls and roof, and the use of timber was discontinued except for square sets when removing the crown pillar before developing the next level above.

**Open Stopes**

![Diagram of a crosscut and stoping method](image)

In this method only the main drive was timbered on the first extraction. It was then backfilled with orepasses being offset, and backfill sand passes being dug to the level above. The second extraction was then made using the first backfill as the working floor, and so on to the level above when the crown pillar was timbered. Open stopes are used for many metalliferous orebodies where the walls and backs are strong enough. They are often called cut and fill stopes.

In the second half of the twentieth century a general mining system has developed worldwide where a surface outcropping orebody is first mined by open cut methods. When the open cut has reached the maximum depth for the economic removal of waste rock without creating unstable walls to the open cut, underground mining is commenced. Entry for miners and equipment and removal of ore and waste can be by decline from the bottom of the open cut and/or by shafts with cages for miners and equipment and

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1115 Ibid., pp. 362-6.
1116 Ibid., pp. 362-3.
skips for removal of ore and waste. Trackless vehicles such as drilling jumbos, load haul drive transporters (LHD transporters) to remove ore and dump trucks are used to reduce the underground labour force to a minimum. These vehicles are now being increasingly remotely controlled so the operator can remain outside the stopes isolated from dangerous areas of the mine. In coal mines longwall faces are used with coal cutting machinery but the overall systems of mining are very similar in all types of mines. The following illustrations are taken from *Guide to Underground Mining* produced by the Atlas Copco Company.  

**A Modern Mine**

Within the orebody itself various methods of stoping are used depending on the type of orebody.

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Room and Pillar Stoping

This is used for flat or bedded orebodies of limited thickness such as coal seams.

Vein Mining – Cement Consolidated Fill

This is a development of the crosscut system used at Broken Hill in the early 1900s. Primary stopes are mined first then backfilled with deslimed tailings mixed with fast setting cement or crushed rock mixed with cement slurry.

Longwall Stoping

This method is used in thin bedded deposits of large horizontal dimensions and uniform thickness. In Australia the main use is in coal mines where the roof adjacent to the face is held up with pneumatic props which are moved forward as the face is extracted. Coal cutting machines extract the coal to conveyors or LHD transporters. The roof of the worked out area is allowed to collapse. Overseas soft rocks such as potash seams are mined by this method, the roof being supported by timber or concrete props. Hard gold
conglomerates are mined in South Africa by this method using hand held pneumatic rockdrills

**Sublevel Stoping and Bighole Stoping**

Open stopes are developed with longhole drilling between one or more levels. The blastholes are filled with explosives and large amounts of ore are broken on one firing. The broken ore is extracted through draw points by LHD transporters. Crown pillars are left to support the hanging wall as well as vertical pillars. The dimensions of the stope depend on the strength of the walls. The empty stope is backfilled.

Bighole stoping is a larger version of sublevel stoping. Longer blastholes up to 165 mm diameter and 100 metres long are common. This method was used at the Mt Charlotte mine at Kalgoorlie.
This method is used for large orebodies, dipping steeply and continuing to large depths. The hanging wall must fracture and collapse and the mine must be in an isolated location where the ground surface around the mine can be left to subside. The mine is not backfilled. The orepasses are located outside the orebody in solid ground.
Blockcaving is suitable for low grade massive orebodies with large dimensions both horizontally and vertically, and rock that breaks into manageable sized blocks and which occur in isolated locations where the surface can be allowed to subside. Drilling and blasting is minimal, and the volume developed is massive, but development takes considerable time before production. Caving of the rock mass is started by undercutting the block and gravity forces break up the overlying mass. LHD transporters remove the broken rock from the drawpoints.

**Rockdrills**

Drilling holes in rocks for the insertion of explosives to break the rock when fired has been in use since the early seventeenth century in Europe. Drilling and gunpowder explosive was first used in the coal mines at Newcastle in New South Wales in the early nineteenth century. Until the 1860s all holes were hand drilled using steel bits hammered into the rock.

This illustration is from Europe but the methods used were universal with one man holding the drill and turning it after each stroke, with one or two strikers wielding heavy hammers (spallers) to drive the drill into the rock. The dust produced in the hole was removed with a spoon like tool before inserting the gunpowder. The Mont Cenis railway tunnel in Europe and the Hoosac railway tunnel in the United States were built in the mid nineteenth century but slow progress by hand drilling led to attempts to develop machine drills to speed up the tunnelling rate at both sites. When a British built drill was imported to Maldon in 1867 the publicity stimulated Australian blacksmiths to produce a local product. Robert Ford of Bendigo, a railway engineer, designed a workable machine, a prototype of which was built and tested at Vivian’s Foundry in Castlemaine in 1868.

The illustrations show a posed photograph of Robert Ford with one of his drills and the other of an air compressor designed by Ford to provide power for his drills. It was also made in Victorian foundries. Machine drills and air compressors made overseas were imported into Australia in this period in competition with Australian made machines.

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1118 Simonen, *The Underground Life of Mines and Miners*.

1119 Drill photo courtesy of the Bourke Museum Beechworth and the compressor photo is from the author’s collection
The next four illustrations show a Burleigh drill and air compressor and an Ingersoll drill from the United States but all machines were made in the United States and in Britain before being imported into Australia.\textsuperscript{1120}

Until the 1950s machine drills were supported on tripods as shown or were bolted to horizontal or vertical bars and required two miners to move and operate them. The Atlas Copco Company of Sweden then invented a lighter drill on a pneumatic air leg which could be moved and operated by one man.\textsuperscript{1121}

Diamond Drills

The drill bit with embedded diamonds which enabled fast drilling in very hard rock was invented in France by M. Leschot and first exhibited at the Paris Exhibition of 1867. The bit was simple in design but very effective. The drawing shows the essential features of the drill bit. 1122

The four diamonds on the inner and outer surfaces were inserted in holes drilled in the steel casing, and the steel was punched in to hold the crystals firmly. The bit was socketed to pins on the end of a hollow steel rod, with the other end having a screw joint to another rod which could be screwed on in sequence to give deep drilling. To collect the core the rods had to be raised at regular intervals. Later inventions allowed the cores to be lifted to the surface without withdrawing the rods and this greatly speeded the rate of drilling deep holes. In the early years the holes were used for blasting but it was soon realised that pneumatic machines were better for drilling short holes for blasting and diamond drills were more suitable for exploring the geology of the underground rock formations.

Diamond drilling machines were first imported into Australia from the United States in the 1878 by the Victorian Mines Department and were being manufactured by Melbourne and Sydney foundries soon after that. The illustration shows an American machine very similar in design to the early imports. 1123

1122 The Engineer, 4 October 1867, p. 293.
1123 Engineering, 26 August 1892, p. 249.
The drilling machine was driven by a portable steam engine and a derrick was erected above the drill to allow easy raising and lowering of the rods.

**Pumping Engines**

When mining went below the waterline it became necessary to pump the water out before mining could proceed. The Chinese had used a simple pump for irrigation and alluvial mining for centuries.

**The Chinese Pump**

The Chinese originally used this pump for irrigation and took it to the Californian gold rush in 1849. It was then brought to Australia in the early 1850s and called the Californian pump. It was used to pump water from the alluvial workings or paddocks so the soil could be dug out. As well as being driven by a waterwheel as shown the

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The machine could be driven by hand or foot cranks. The belt was canvas and the remaining fittings were wood.

**Newcomen’s Engine**

For the deeper mines in Europe waterwheel driven pumps were in use in the Middle Ages, but by the eighteenth century deep mines required more powerful engines. Thomas Newcombe installed the first engine at Coneygree coal mine near Bromsgrove in Britain in 1712. Steam at low pressure was injected to the lower end of the cylinder and assisted the weight of the pump rods to tilt the beam so the rods were lowered in the shaft. At the top of the stroke of the piston, steam was cut off and cold water sprayed into the cylinder to condense the steam and form a partial vacuum below the piston. Air pressure then forced the piston down, the beam was tilted to raise the pump rods so that a plunger in the pump at the bottom of the shaft lifted water to the surface. A system of valves automatically reinjected steam and the cycle repeated.

**Watt’s Engine – single acting**

The first improvement James Watt made to the Newcomen machine was to add a separate condenser. Steam entered below the piston and lifted it so the rods moved

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down. At the top of the stroke a valve opened to allow the steam to flow to the separate condenser where it was condensed. Air pressure then forced the piston down, the beam raised the rods to loft the water. Efficiency was improved as the cylinder remained hot for the next injection of steam.

Watt’s engine – double acting

![Diagram of Watt’s engine - double acting](image)

The double acting design further improved efficiency by producing a power output on both up and down strokes of the piston. In this design the top of the cylinder was covered, and the piston rod passed through the cover via a gland. When the steam was injected below the piston the volume above was connected to the condenser, the piston moved up and lowered the rods. At the top of the stroke, both top and bottom halves of the cylinder were connected to the condenser, the top was then disconnected from the condenser and steam injected to force the piston down and raise the rods. The cycle was then repeated. The chains of the previous design were replaced by rods to allow power to be applied to the beam at both ends. This design also allowed a rotary motion to be produced by a flywheel to drive a pump and/or a winder drum.
Complete Beam Pump Installation

This illustration shows a complete Cornish beam pump in a mine. There were many installations of this design, with cylinders up to 80 inches diameter, in eastern Australia from the 1840s to 1900. The bottom lift of about 25 feet on the right of the shaft was by atmospheric air pressure forcing the water up to the tank as the air pressure was reduced in the first rising main by the piston operated by the lower rod. This was called the suction lift. From the tank the piston in the upper rising main lifted the water to the surface. The rod operated clacker valves to close and open as required. The men working on the pump installation in the shaft were called pitmen.
Steam Pumping and Winding

In this machine the vertical cylinder and beam of Watt’s double acting machine is replaced by a double acting horizontal cylinder driving the shaft via a connecting rod and crank. The boiler is not shown here. The machine used Trevithick’s design of a higher pressure steam cylinder (25 to 100+ p.s.i.g.) and clutches on the shaft allowed a winder drum or a flat rod to a pump rod, shown on the right, or a crusher to be operated at the one time, if sufficient power was available, or any combination of these three. The design was developed into a practical machine in the first half of the nineteenth century. The low horse power pumps and winding engines at early Ballarat mines were of this design.

Plunger Pumps

In the 1860s plunger pumps were developed in the United States and Europe, but the date of the first installation in Australia is unknown. These steam driven pumps used reciprocating pistons to force the water up the rising main. This illustration is from an advertisement of 1871 and does not state a maximum pumping height but claims the pump will force to any height (an overstatement). Elsewhere the same advertisement says the long stroke pumps should be used for heights over 100 feet. The boiler to drive the pump engine was normally placed on the mine surface and steam piped down the shaft to the pump. The bulbous fitting was filled with air to absorb pressure surges in the rising main.1126

The Cornish Boiler

The boiler consisted of a central heater flue inside the outer boiler shell with water partly filling the space between the two. A sight gauge on the front allowed a check on the water level. When in operation a water feed pump forced water into the space to replace the water turned to steam. The heated air from the burning coal or wood in the grate moved down the central flue to heat the water, and was then exhausted to the chimney. A pressure relief valve was connected through the outer case and blew if the steam pressure exceeded the set amount. To conserve heat in the boiler it was encased in brickwork.1127

The Water Tube Boiler

1127 Drew and Connell, *Cornish Beam Engines in South Australian Mines*, Fig. 34.
The Babcock and Wilcox Company manufactured this type of boiler in Britain from the 1880s. Mud from impure water settled in the mudtank at the bottom right and the steam collected above the water in the top tank. This boiler was more efficient than the Cornish boiler because the water tubes were directly exposed to the fire. The boiler was built into enclosing brickwork on the mine site.\textsuperscript{1128}

**An Early Centrifugal Pump\textsuperscript{1129}**

This centrifugal pump driven by a vertical steam engine was manufactured by Gwynne and Co. in London in 1871 for providing cooling water for condensers in large steam engines. The top half of the pump casing could be unbolted and lifted up to give access to the impeller.

**Three Stage Centrifugal Pump\textsuperscript{1130}**

This pump was manufactured in 1915 with three impellers in series to give a higher head of water in deeper mines. In very deep mines several stages of pumping may be used e.g. pumps may be installed at the lowest level to pump the water up the rising main to a sump at an intermediate level. From this sump another set of pumps will pump the water up another rising main to the surface. Pumps driven by electricity can be switched on automatically when the level in the sump rises to set height, and switched off when the water level falls to a lower set level by float switches in the sump.

\textsuperscript{1128} *The Engineer*, 7 September 1888, p. 199.

\textsuperscript{1129} *Ibid.*, 17 March 1871.

\textsuperscript{1130} R. Daugherty, *Centrifugal Pumps* (New York: McGraw Hill, 1915). Fig. 92.
Gas Engines

Internal combustion engines using petrol, kerosene or diesel fuel, became available for driving mining machinery late in the nineteenth century. The technology was developed mainly in Europe and most larger machines used in Australian mining were imported from there although some foundries such as Ronaldson & Tippetts in Ballarat made small engines. English firms such as Tangyes and Crossley made a range of engines between fractions of one H.P. up to several hundred H.P. Having one or two cylinders the machines were easy to maintain and they would run on several fuels including producer gas made from burning charcoal in air. Charcoal was cheap and readily available in outback Australia and this type of engine was used on many small mines to drive crushers, pumps for hydraulic sluicing, small electric generators and conveyors during the first half of the twentieth century. The illustration below is a copy of a 1904 advertisement for a Crossley engine for driving an electric generator with the associated gas producer.\(^{1131}\)

\(^{1131}\) Clark, *Australian Mining and Metallurgy*. 
Ventilation

Underground Furnace

The diagram shows the method of ventilating the underground workings of a coal mine by heating the air so it rose in the air shaft, and drew air from the working face. The method was most common in coal mines because it was considered the small coal used was cheap at the time when most sales were for coarse coal. Later when small coal fetched higher prices this method of ventilation was replaced by fans. The method was dangerous in gassy coal mines where it could cause explosions. A chimney was built at the top of the air shaft to carry the exhaust air away from the surface workings of the mine. This method was also used in metalliferous mines with wood as the fuel.

Windsocks
This photograph was taken on Victoria Hill at Bendigo in 1857.\textsuperscript{1132} The miner’s dress indicates it was taken on a public holiday and one of the windsocks is furled. The other, which shows the calico tube to carry the air down the shaft, is open. At this early date the shafts would have been shallow.

**Mine Fans – the Guibal Fan**

The Guibal fan was first used in European coal mines in the 1840s.\textsuperscript{1133} The air was drawn up the mineshaft and entered the fan through a duct at the centre of the fan shafting (duct not shown). The rotating blades increased the velocity of the air and forced it up the vertical chimney. Alternatively the valve at the top of the chimney could be closed and the valve leading to the duct at the right of the diagram could be opened and fresh air forced down the shaft. The suction system of exhausting the used air from the mine was usually used. With this setting the fresh air flowed down the main shaft, also used for haulage, and then to the working face from where it was exhausted via the air shaft to the atmosphere. Brattice doors underground were opened or closed to route the air to the face, and then to the air shaft. In nineteenth century coal mines in Europe women and children were employed to open and close the doors as coal was moved from the face to the main shaft. These fans were built up to 30 feet in diameter capable of displacing 3500 cubic feet of air per second.

The photograph below shows a similar fan being installed in a coal mine in Sydney in 1900.\textsuperscript{1134} The blades are being enclosed with brickwork with the inlet duct entering at the centre right. The size of the blades can be assessed from the man standing at centre left of the picture.

\textsuperscript{1132} Photo courtesy Bendigo Historical Society.
\textsuperscript{1133} Blake, *Mining Machinery*, p. 156.
\textsuperscript{1134} *Annual Report of the Minister of Mines, New South Wales*, 1900.
The Root’s Blower

This blower was in use on the Comstock lode in the western United States in 1868 and was also later used in eastern Australian metalliferous mines to force air from the surface through ducts to the working face.\textsuperscript{1135} Made in several sizes, pressures of up to five p.s.i.g. could be produced at speeds around 250 r.p.m. In mines with a single shaft with partitions between compartments air was forced down one compartment and a second compartment used as a return airway. Brattices were built underground or ducts were used to direct the air from the down compartment to the face and return it to the up compartment. Partitions in the shaft had to be made airtight or leakage would be excessive.

\textsuperscript{1135} Blake, \textit{Mining Machinery}, pp. 154-5.
The layout of a more modern exhaust fan system, constructed to provide exhaust ventilation at the mines of the Zinc Corporation and New Broken Hill Consolidated mines in the early 1950s is shown in the following diagrams.\textsuperscript{1136}

The photo shows the fan of this installation partly removed from the casing. The fan could exhaust 900,000 cubic feet of air per minute from the underground workings.\textsuperscript{1137}


\textsuperscript{1137} Anon, The Fabulous Hill (1955).
The illustration above shows a chain type coal cutting machine driven by compressed air, made by the Gartsherrie Company in Scotland in 1880. It was the first such machine installed in Australia at a shale oil mine at Joadja Creek, west of Sydney in 1881. The coal mining companies in Australia did not begin to use this type of machine until the early 1900s when trials were conducted on machines driven by compressed air or by electricity. The tests showed that the electrically driven machines were the best, but government regulations required they be made explosion proof. They were then made with totally enclosed fan-cooled alternating current motors, and the controlling switchgear was enclosed in cast iron boxes, called gate end boxes, because they were placed near the machine at the end of the access drive ‘the gate end’. Cables to the machine were armoured to prevent sparking if they were damaged.

Appendix 6

Ore Processing

Rock Crushing

The first step in extracting the desired mineral from the ore was to crush the ore sufficiently fine to allow the mineral to be separated from the gangue or unwanted material. From the sixteenth century the Germans and Cornish miners used stampers as the primary crusher, but the large rocks were broken down by hand to a uniform size before crushing. After 1862 a jaw crusher was often used in eastern Australia and in the United States as the primary crushing stage to reduce the broken ore from the stope to about two inches diameter for feeding to the stampers, which then became the secondary crusher. Eli Blake invented the jaw crusher in the United States in the 1850s for crushing rocks for road making and it was first used as a primary crusher in gold mines in California in 1861. Enoch Chambers was making a jaw crusher in Melbourne by the 1860s and one was installed at the Port Phillip gold mine at Clunes in 1862.

Primary Crushers

This sectioned illustration of a modified Blake machine made in France shows an adjustable oscillating jaw driven by toggles from an eccentric on the main shaft. The rocks were cracked to a small size as the jaw moved in and pinched them against the fixed plate. Only one of the two flywheels is shown here. The machines were made in various sizes with early machines crushing up to six cubic yards per hour.1139

The Gyratory Jaw Crusher

The movable jaw in this design is in the form of a cone suspended at the top, which gyrated within a cylinder which was the fixed jaw. The space between the jaws was convergent downwards, but was annular and the swinging jaw in its path around the walls of the cavity was constantly approaching the fixed jaw on one side, while receding

from it on the other side. The jaw was thus acting on and breaking the rock continuously. The crusher illustrated was patented in Chicago in 1895.\textsuperscript{1140}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{crusher_diagram.png}
\caption{Diagram of a secondary crusher.}
\end{figure}

\textbf{Secondary Crushers - Stampers}

In Germany and Cornwall stampers were used as primary crushers after some hand breaking of ore with hammers had reduced the size of the ore sufficiently small to be fed beneath the stampers. This procedure was followed in small eastern Australian gold mines until the end of the nineteenth century, but from the 1860s larger and more progressive mines installed jaw crushers as primary machines which fed the rock crushed to a uniform size through automatic feeders into the mortar boxes of the stampers.

\textbf{The Stamp}

In 1873 the South Clunes United mill had 60 stamps in 6 sections of two mortar boxes each containing 5 stamps. The total weight of the stamp was 8 hundred

weights (896 lbs). The diagram shows a section of one stamp.\textsuperscript{1141}

\begin{itemize}
  \item \textbf{H} is the lower end of the chute leading from the ore bin. Attached to it was \textbf{G} the lower end of the iron rod \textbf{F} which had at its top the disc \textbf{E} which was keyed to the rod and projected under the extra tappet \textbf{D}. When the feed was low the stamp fell further than normal so \textbf{D} struck \textbf{E}, and \textbf{G} struck \textbf{H} and ore moved down the chute to the feed hole \textbf{N} into the mortar box \textbf{M}. \textbf{D} and \textbf{E} were kept in place by keys. With five stamps in the mortar box the order of drop was 3, 5, 2, 4, 1. The shoes \textbf{K} were made of cast iron 10 inches diameter and 10 inches high and weighed 196 lbs. The dies or false bottoms \textbf{L} were hexagonal in section, of wrought iron with a diameter of 10 inches and a depth of 6 inches. A shoe would crush 90 tons before it was worn out. The stamp was raised by the rotating cam \textbf{A} lifting the tappet \textbf{B} which the stamp fell under gravity.

  The mortar box had a double discharge, front and back, with the distance from the bottom of the screen to the top of the die about 4.5 inches. No mercury was used in the mortar box. The front grating frame \textbf{P} was 5 feet long by 13 inches wide, the rear grating \textbf{O} was 5 feet by 12 inches. Both gratings were vertical and covered by a splash board which sloped forward. The pulp issuing at the back passed over the lip \textbf{Q} and was conducted by the launder \textbf{U} to the front of the battery where it united with the front discharge passing over \textbf{V}. \textbf{R} was a perforated plate which spread the pulp evenly over the width of the wells and blanket which followed. This plate was 1 foot across and 3/16 inch thick with 5/16 inch diameter holes, patterned at the four corners of a square inch. The pulp fell onto the apron \textbf{S}, a wooden table 20 inches across, 2 inches thick, from which the pulp dropped successively into two wells \textbf{T} and \textbf{W}, the first having a drop of 10 inches and a depth of 4 inches, the second having a drop of 8 inches and a depth of 4 inches. Each well held 50 lb. of mercury. The boards \textbf{X} forced the pulp to pass through the mercury. These wells, including the lip, were of cast iron; they had a curved inside contour and were sunk into the wooden frame. The wells had a slight slope to one end, where a tap hole allowed the easy removal of the amalgam at clean up. The wells were covered by a locked grating to prevent theft of the amalgam.

  The pulp then passed over the blanket tables at \textbf{Y}. The blankets were spread over tables covering the width equal to both of the two mortar boxes forming a section. This width was divided into seven partitions each 18 inches wide and 12 feet long on a slope of 3/4 inch per foot. Then followed Cornish buddles (Munday’s patent) and finally tyes, box sluices each 20 feet long, which collected heavy pyrites and any remaining amalgam. At clean up of the mortar boxes once a fortnight, the grating frames were removed from the mortar box and the gold between and around the dies was scooped up into buckets, sieved and put in an amalgamation barrel. The amalgam was drained from the wells weekly and squeezed through canvas to separate the mercury. Some of the pyrites collected on top of the mercury in the wells and was skimmed off as required and further crushed and amalgamated in three Berdan pans each of three feet diameter. The pyrites collected on the blankets was washed off in tubs and amalgamated in a barrel with the mixture of pyrites and amalgam collected in the tyes. The tailings from all the barrels went to a buddle to separate the pyrites from the sand, the pyrites were then roasted in a reverberatory furnace, and ground in a Chilian mill with mercury to form an amalgam.
\end{itemize}

\footnotesize
Five amalgamating barrels were used, each of 54 gallons capacity, rotating at 16 revolutions per minute for about 10 hours per charge. Seventy five pounds of mercury was used per charge as well as a bucket of wood ash to make the mixture alkaline. After each treatment the contents were discharged over a perforated iron plate to catch coarse matter, and the amalgam ran through three successive wells to separate the amalgam. In one month 2,973 tons of ore were crushed and the gold collected from each section was:

<table>
<thead>
<tr>
<th>Gold Source</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free gold from the mortar box</td>
<td>376.7 oz.</td>
</tr>
<tr>
<td>Gold from amalgam in the wells</td>
<td>254 oz.</td>
</tr>
<tr>
<td>Gold from amalgam from blanket material</td>
<td>143.8 oz.</td>
</tr>
<tr>
<td>Gold from skimmings from the wells</td>
<td>66.5 oz.</td>
</tr>
<tr>
<td>Gold from tailings of tyes and barrels</td>
<td>7 oz.</td>
</tr>
<tr>
<td>Gold from pyrites concentrates (17 tons)</td>
<td>80.7 oz.</td>
</tr>
</tbody>
</table>

The loss of mercury was 5.5 grains per ton of ore crushed, due mainly to a small amount of copper in the ore, which combined with the copper and was lost in the tailings. This mill was similar to that of the Port Phillip Company nearby.

Stamps were usually assembled in groups of 5 to one mortar box, these groups of 5 were assembled in line and the cams were driven by a single line shaft through pulleys or gears by a steam engine. For wet crushing water was supplied to the mortar box by gravity or a pump. The illustration shows an assembly of 10 stamps each with replaceable discs screwed to the bottom of the stamp. The disc could be replaced when it wore down without replacing the whole stamp.1142

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Iron Framed Stamper of the 1890s

By the 1890s, after more than thirty years of development by local foundries the stampers were more robust, and required less maintenance, than those used in the 1850s. This machine, produced in Bendigo, was built into an iron frame with substantial baseplate for mounting on a solid timber or granite foundation. A single screen was used on the mortar box, which was enclosed to prevent theft. The ball bearings on the drive shafts were mounted in bearing housings for easy adjustment and replacement. A walkway was provided so tappets and cams could be replaced and adjusted quickly.  

Berdan Pan

This machine was invented by Mr Berdan of New York. It consisted of a cast iron basin up to 7 feet diameter in which rolled one or more steel balls of weight up to 1700 pounds. The mercury collected near the contact point of the ball with the container so crushing and amalgamation occurred at the same time. It was made in New York for use on the Californian goldfields, and a London company was formed to manufacture and sell the machine in the British empire as tariffs were charged on foreign manufactures.

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1144 Illustration courtesy of the German Heritage Society, Bendigo.
Mr Earl was appointed Melbourne agent in 1854. He sold a large model of 7 feet diameter and a small model, 3 feet 9 inches diameter. Two small machines were in operation in Maldon in October 1854 and a large imported machine was operating at Edward Ensor’s mill in Bendigo by mid 1855 driven by a steam engine. The machine was a failure for crushing hard quartz as the balls wore unevenly and it was soon replaced with stampers for primary crushing and was relegated to amalgamating only. This use as an amalgamating pan continued well into the twentieth century. The illustration shows two pans back to back, a large and small ball was used in each pan with a fire below the pans heated the mercury to improve amalgamation. Bevel gears on the shaft of each pan connected each pan to the horizontal shafts driven by the pulley wheels shown at the side. Complete machines were made by Australian foundries.\footnote{The Mining Journal, Railway and Commercial Gazette." 5 April 1853, 2 December 1854.}

The above illustration shows a small Berdan pan in use at the Tennant Creek Government Battery in 1990 for fine grinding pyrites.\footnote{Photo by the author.}

**The Chilean Mill**

This illustration shows an original Chili mill for crushing ores in Chili in the eighteenth century.\footnote{Simonin, *Underground Life of Mines and Miners.*}
A modern version of the Chilean mill is shown in this illustration. It consists of a steel bowl with two steel or granite wheels rotated by gearing from a driving motor. Machines similar to this were used in eastern Australia from the mid 1850s to fine grind gold ores prior to amalgamation. They were not successful for coarse grinding of gold ores as the wear was excessive and the crushing rate was slow.\textsuperscript{1148}

**Rolls**

Rolls were more suitable for crushing softer ores, such as copper and silver lead zinc than the hard quartz which was better crushed by stampers. Rolls were used in the Australian copper mines and at the silver lead zinc mines at Broken Hill. One roll was spring loaded so it could move away from the other to allow a hard rock or metal object to pass through. The ore was fed between the top of the rolls which contra-rotated to carry it down between them pinching and breaking it on the way.\textsuperscript{1149}

\textsuperscript{1148} Richards, *Ore Dressing*, p. 270.
\textsuperscript{1149} Blake, *Mining Machinery*, p. 182.
The Huntington Centrifugal Roller Mill

This machine was used for crushing gold ores particularly for fine grinding jig middlings. It was designed on the principle of the Cornish rolls, with a tighter nip as one roll was replaced by the inner steel ring of the machine. As the speed of rotation was increased the pressure between the several rollers and the ring increased as the roll shaft swung outward from the top pivot. The machine was fed by an automatic feeder through a hopper on the side. It produced less slimes than the stamper. The illustrations show a perspective and a section of the machine.\textsuperscript{1150} It was an American design with a maximum feed size of 0.75 inches and gave good results wet crushing clayey material.

\textsuperscript{1150} Richards, \textit{Ore Dressing}, pp. 276-82.
The Griffin Roller Mill

This machine had a single roller on a vertical axis. At speed the ore was crushed between the roller and the ring. The maximum feed size was 1.5 inches and the machine was suitable for wet or dry crushing.\textsuperscript{1151}

\textsuperscript{1151} Ibid., pp. 282-4.
Tube mills with flint pebbles as the grinding medium were used to fine crush the sulpho-telluride gold ores at Kalgoorlie before roasting. From the primary crusher the ore entered the machine through the hopper at the left, through the hollow trunnion into the mill which rotated to tumble the flint particles, and the ore which was ground fine. The fine particles passed through the hollow trunnion on the right, through the screen, and were sucked out by a fan. With dry crushing the inside of the machine was a lower pressure than the air so air entered through any perforations and dust did not escape. An alternative was to use cast steel balls as the grinding medium.\footnote{H. Fischer, "The Operation of a Tube Mill," in \textit{Notes on Metallurgical Mill Construction}, ed. W. Ingalls (New York: The Engineering and Mining Journal, 1904), pp. 137–44.}

\textbf{The Ball Mill}

The Krupp ball mill was made in several sizes from O, diameter 26 inches to 8, diameter 107 inches. The inside of the cylindrical steel shell was lined with hardened steel plates, and the fine crushing was done as hardened steel balls from 3 to 5 inches diameter tumbled with the ore as the mill rotated on a horizontal axis. The finely ground material passed through perforations in the grinding plates and then through a coarse and fine screen surrounding the plates. The whole machine was encased in a dustproof steel casing. The finely ground material was sucked from the inside of the casing with a
fan. An alternative design allowed wet crushing. A no. 5 machine crushed between 20 and 40 tons a day depending on the hardness of the ore.

The first illustration is from Ore Dressing, 1903 edition, of the Gruson ball mill made by Krupp in Germany. The author stated that this machine was a later improved form of the Krupp mill but does not give a date for its construction. The second is from the 1892 Report to the Minister of Mines, Victoria illustrating a crusher made by the Austral Otis Engineering Company of South Melbourne. Either Otis made the machine under licence from Krupp of which there is no acknowledgement or the machine was copied without permission. A great deal of such re-engineering occurred worldwide and Australian engineers were involved in such practices from the nineteenth century. For this reason care should be taken in quoting the number of patents taken out in a country as a measure of the industrial capability of that country. Early patent law in Victoria did not require the patentee to prove originality and it is clear from a study of early patent
documents and overseas journals from the 1850s and 1860s that many machines patented in Victoria were direct copies of overseas designs.\textsuperscript{1153}

**Hart’s Crusher\textsuperscript{1154}**

James Hart trained as an engineer in Britain before migrating to Australia in the 1850s. He patented a steam driven gold puddling machine in Victoria in the 1850s, which was very similar to a horse driven gold washing machine in use in Siberia at that time. In the 1860s he patented the quartz crusher illustrated above, and formed a company to crush rock at Raywood, a small goldfield near Bendigo. His firm in Melbourne manufactured the machine in 1866, railed it to Bendigo and then rolled the components over the bush tracks to Raywood. The machine was christened with considerable pomp but it failed to crush the gold ore fine enough for satisfactory amalgamation and was abandoned.\textsuperscript{1155} It was the first autogenous grinder. It was not until the 1960s that a successful design of this type was produced, but the major development was in Brazil, not in Australia.

\textsuperscript{1153} Richards, *Ore Dressing*, p. 261. *Reports to the Minister of Mines, Victoria*, (Melbourne: Mines Department Victoria), 1892, Fig. 8.
Jigs

After the ore was crushed the mineral particles were separated from the lighter gangue in a jig. The hand jig shown in the illustration was in use in the Harz mountains in Germany and Cornwall in the early nineteenth century. It was used in the early copper mines in South Australia but it is unlikely that women were employed as operators there.

More details of the operation of this type of jig are shown in the diagram below.  

\[\text{Richards, Ore Dressing, p. 496.}\]
The jig box G was loaded with ore of the proper size and depth. A downward push on the lever D released the bed of material in the box as the box was forced down into the water. The return movement brought the water back through the screen, and suction drew the fine concentrates down to the bottom of the box. After repeated jigging the box was lifted out of the water and the top layer skimmed off with a short handled hoe and thrown on its heap. The middle layer was then removed onto its heap as middlings and the bottom layer collected as concentrate. The middlings were returned to the box and further crushed ore added and the process repeated.

The hutch product which had passed through the screen was then treated with a finer screened jig and the hutch product from the second jigging was added to the first concentrate and sent to the smelter. In some plants the middlings were crushed finer before rejigging to separate the contained minerals. A jig of this type could concentrate about 40 tons of ore in 24 hours.

The Harz Jig

![Harz Jig Illustration]

The illustration shows the side elevation and end elevation of a four screen Harz type jig with two jigs back to back. This design was first developed in Germany in the early nineteenth century and then used worldwide. The plunger U was reciprocated by the eccentric drive to pulse water through the screens. Crushed ore was fed to the jig through S, the ore moved along the screens L with concentrate being discharged through spouts l. Tailings continued down the screens to the discharge at T.

The Hancock Jig

This jig was developed at Moonta in the 1860s by Captain Hancock and his staff. It was driven by a steam engine through an eccentric shaft and could separate ores into concentrates, middlings, tailings and slimes. The crushed ore feed containing up to 4 percent copper was fed into the left of the machine shown in the side elevation below into the jig box S. The jig box extended almost the length of the machine and was moved by levers and cams so the ore moved in a series of jumping motions along the box as it moved in an oblong reciprocating motion through the water. The concentrates

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1157 Ibid., pp. 507-9.
1158 Ibid., p. 504-5.
passed through the screens which were of increasing fineness to produce coarse concentrate middlings, and fine concentrates in successive compartments. The tailings were collected in the last compartment with the slimes collecting at the extreme end from where they were drawn off. The middlings were crushed finer and re-jigged. One machine could treat from 300 to 600 tons of low grade ores per 24 hours. Hancock patented the jig in 1870. They were used extensively in Australian copper mines and at Broken Hill in the 1890s for concentrating silver lead zinc ores and world wide for separating many other minerals from low grade ores not suited to flotation methods well into the twentieth century.\textsuperscript{1159}

![Diagram of a jig](image1)

**Fine Sand and Slime Concentrators**

During the 1880s and 1890s ores were crushed finer in an attempt to better separate the minerals from each other. It then became necessary to separate the sandy coarse tailings from the slimes, as the tailings were often easier to treat by chemical means using percolation to extract the small amount of contained minerals. The slimes tended to pack and make percolation methods difficult to use. Various types of vanners were developed using belts with a shaking action to separate the pulp into layers and to collect the heavy minerals at one end and the lighter minerals at the other end.

**The Vanner**

Various types of vanner were developed in the 1880s, the most famous being the Frue vanner developed in the United States. The Union vanner shown in the illustration was a slightly modified Frue machine.

![Diagram of a vanner](image2)

The upper surface of the belt moved upwards from right to left while at the same time being given a shaking motion from left to right. Water was fed onto the belt at the left and the pulp was fed through the distributor adjacent to the water spray. As the belt moved upwards to the left the concentrates passed under the water spray and were carried by the belt to a tank below the machine where they were scraped off. The tailings were carried down the slope by the water current and collected by a launder.

**Shaking Tables**

Shaking tables were an alternative to the vanner for separating minerals from sands and slimes. The Wilfley table was such a table developed in the United States in the 1890s and was used particularly for separating gold from tailings and slimes.

The Wilfley table separated the heavy and light particles into layers by agitation, and then by a jerking motion, threw them towards the head end 69, while the lighter particles were washed down the slope towards the tailings side 68 by the surface water, which flowed at right angles across the table. The slurry was fed from a trough along the feed side 65. The concentrates settled in the riffles from where they were moved to the head end. The lighter gangue rolled over the riffles to the tailings side. The various grades of concentrate were collected from the head end.

Each vanner could treat about 10 tons of slurry each 24 hours while the Wilfley table could handle about twice that amount so most larger concentrating mills operated several machines in parallel.

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Chemical Processing

Chemical extraction of gold from crushed ores using chlorine solutions to dissolve the gold began in eastern Australia in the 1870s, and cyanidation of gold ores began in the late 1880s. Chlorination was used on a large scale to extract fine gold from ironstones at Mt. Morgan in Queensland and in smaller plants spread over the Lachlan fold belt in eastern Australia to treat more refractory gold ores, particularly those containing small amounts of other minerals such as copper. The adoption of cyanidation was slow in Australia in the 1890s due to uncertainty over the legitimacy of the patents, but its use for extracting gold from coarse tailings became common after 1900. On some mines with large amounts of refractory pyrites in the ore, chlorination was used to extract gold from the crushed pyrites, while at the same time, a cyanide plant was in use to treat old oxidised tailings and new tailings from sulphide ores after roasting.

Chlorination

A large scale chlorination plant was developed at Mt. Morgan by the mine staff in the 1880s and extended in the 1890s. The process was finally discarded in 1911 when all the ironstone gold ore was extracted.

The sectioned layout of the Mt. Morgan plant is illustrated. The legend explains the function of each section. The vats O, at bottom left, where the chlorine solution percolated through the roasted crushed ore were rectangular and lined with cement.

Other plants treating finely ground refractory pyritic gold ores used circular vats for percolation.

C. H. Humphreys, "West Works - Mount Morgan (Queensland) Chlorination," Proceedings of the Australasian Institute of Mining Engineers XV (2) (1911): Plate LXIII.
Cyaniding

A weak solution of potassium cyanide was percolated through the tailings of finely crushed gold ores in large tanks, and the gold taken into solution, was precipitated on charcoal or zinc shavings held in an adjacent small tank. The charcoal was burnt and the residue containing the gold was smelted in a small furnace. The zinc shavings were also smelted to recover the gold. At Charters Towers the tanks were often rectangular and lined with cement. The tailings and weak cyanide solution were agitated in the tanks with mechanical stirrers to improve the rate of leaching. In Victoria the leaching tanks were fabricated from corrugated galvanised iron into circular vats, and leaching was by percolation without stirring as the tailings did not pack so tightly in the vats. Old tailings dumps, remaining from the nineteenth century were retreated, sometimes several times in the twentieth century as well as tailings from current crushings.

The illustration shows a mechanical loader dumping old tailings into a rear dumping horse dray for carting to cyanide vats where it was dumped into the vat before percolation. This photo and the next were taken in Bendigo in the 1930s.1162

1162 Photographs by courtesy of James Lerk.
This photograph shows several galvanised steel vats at ground level. The weak cyanide solution was pumped into and out of the vats with pumps in the adjacent shed, which also contained the zinc boxes for precipitating the gold from solution. The vats were in the open air, and the zinc boxes inside the shed to prevent stealing of the gold were well ventilated to prevent the build up of dangerous fumes.

The Filter Press

This press was used at Kalgoorlie to separate the weak cyanide solution containing dissolved gold from the slurry after the slimed ore had been mixed with the nascent cyanide solution. The gold was then precipitated on zinc shavings in the zinc boxes.

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**Flotation**

In the late 1890s the mines at Broken Hill began to extract ore from the sulphide zone containing the sulphides of lead, silver and zinc. Most of the lead and silver minerals could be separated by gravity methods, but the zinc minerals could not be separated easily from the gangue, and the residue contained an appreciable amount of lead and silver sulphides. Efforts to crush the ore finer to achieve better separation resulted in sandy tailings containing large amounts of zinc sulphide and some lead and silver sulphides, as well as large quantities of slimes containing all three minerals. The tailings and slimes were dumped until a method of separation of the minerals could be found. Considerable research was conducted by various groups in Europe and Australia to find solutions to enable the extraction of the minerals. The first successful method was discovered by Charles Potter, a Melbourne chemist who added sulphuric acid to tailings. The acid reacted with minerals in the tailings to produce carbon dioxide gas which gave buoyancy to the sulphide mineral particles, and lifted them to the surface, from where the bubbles could be skimmed off. Guillaume Delprat, the manager of the B.H.P. mine at Broken Hill, developed a process using a solution of sodium hyposulphate in water to produce the carbon dioxide gas, but otherwise the Potter and Delprat processes were similar. After some litigation the two inventors combined the processes, Delprat having sole rights to use it at B.H.P. while Potter retained the right to licence the process elsewhere. It was then called the Potter-Delprat Process.

**The Potter-Delprat Process**

At the B.H.P. mine the tailings including slimes from the lead concentrating mill, containing about 20 per cent zinc, 6 percent lead and 6 ounces of silver plus the gangue of quartz, rhodonite and calcium and iron carbonates, was crushed fine and fed to the top of the spitzkasten of wood lined with lead. The sulphuric acid was fed down the two pipes. On the left the acid mixed with the tailings which slid down the spitzkasten. Here the carbon dioxide bubbles produced lifted the sulphide particles to the surface while any stones, bolts or nuts fell into the left partition from where they were removed regularly. Some tailings and gangue passed over the partition into D where it reacted with more acid to form gas to lift the sulphides to the surface where they floated into the launder H, and were carried off to the washer, and then drained and loaded into railway trucks. Any gangue carried up by the bubbles dropped again on the right of the baffle for return to D. The gangue and excess acid was removed from the outlet D onto a uphill sloping belt so the acid solution drained into a sump for reuse, and the tailings fell off the end of the belt. They were used for underground backfilling of stopes. The
spitzkasten were heated to 80° C. by injected steam. One unit could treat about 100 tons per day of tailings and slimes. \textsuperscript{1164}

The Elmore Process

This machine was invented in England by the Elmore brothers. It was an elegant engineering design, being simple and easy to operate automatically. The pulp from regrinding the tailings was fed into a mixer in which oil and acid were mixed by the beaters, and fed to an inlet pipe into the separator by the suction of a vacuum pump which removed most of the air from the top of the separator. Rakes at the bottom of the separator revolved slowly, driven by a worm gear M. The gas bubbles lift the sulphides to the top of the liquid and they flowed off the surface down the concentrate pipe. The tailings circulated at the bottom and flowed down the tailings pipe. The feed pipe was up to 30 feet high with the two outlet pipes being a few feet longer so the system formed a syphon and no additional pumping power was required. An inspection window at the top allowed a visual check of correct operation. One machine could treat up to 50 tons per day, the power required being about 2 H.P. Machines were operated in parallel as required.

The De Bavay Process

Auguste De Bavay, a Belgian chemist, was working as a brewer in Melbourne when he invented his process in the early 1900s. The De Bavay machine was not effective with slimes, as it depended on surface tension of water to allow the oiled sulphides to float while the gangue sank into the water. The tailings from the mill or dumps was first deslimed and the slimes discarded. The cleaned tailings were then fine ground and mixed with sulphuric acid in water in an agitator. They were then mixed with oil and stored in a tank from which they flowed under gravity through a feeder to the top of a stepped cone, and ran over corrugations to the water level in a spitzkasten. The sulphides floated on the surface and ran into a launder. The gangue sank through the surface and was drawn off at the bottom. This process was repeated over several cones to remove most of the sulphides.

The Minerals Separation Process

Minerals Separation Ltd. was a British firm with laboratories in London and Melbourne. Experiments on pilot plants were conducted at Broken Hill on the lease of the Sulphide Corporation mine, that company also providing management and engineering support to Minerals Separation metallurgists working on pilot plant development. Patents were applied for by several of Minerals Separation staff but the company owned the patents. Licences were sold to other companies to operate the patents. After years of experiments and tests, by 1910 the company had developed a very effective process for treating all combinations of slimes and tailings from dumps and from freshly processed ores. For the next 25 years or so the company dominated the use of the flotation process worldwide until its patents expired in the 1930s. The illustration below describes the machine patented by Theodore Hoover, then chief engineer of Minerals Separation, in 1909.
This machine had the advantage of being able to treat tailings containing a considerable percentage of slimes, the slimes improving the frothing of the mixtures. After wet crushing most of the lead and silver sulphides were separated by gravity and smelted. The remaining pulp, containing mostly zinc sulphides but also some lead and silver sulphides, was dewatered to give a pulp with three parts of water to one of ore. The mixing tank was separated into three compartments by partitions with an interconnecting gap between. The pulp was fed into the left compartment through C. Acid and a small quantity of oil were fed through D and E respectively. Steam was fed into this compartment to raise the temperature to 70°C and the mixture was agitated by the impeller B so large amounts of air were added to the mixture. The mixture was forced through the aperture at the bottom into the centre compartment, agitated more, and then into the third compartment. From there it was forced into the spitzkasten where the bubbles with the sulphide particles attached floated to the top and were skimmed off into the launder. The gangue was removed at the bottom. If necessary units were placed in series to collect all the sulphides. The bubbles were washed, drained and fed to further gravity separators to remove some of the lead and silver sulphides and the remaining concentrate fed to railway trucks for despatch to the zinc smelters. After differential flotation was developed in 1912 the pulp was first treated to float off the lead and silver sulphides, other chemicals were then added to the remaining pulp and the zinc sulphides floated off.

The illustration shows a set of flotation cells in use at Broken Hill in the early 1950s. In each cell, an impeller with electric motor drive, agitated the slurry, and then added reagents to form bubbles which lifted the particles of the sulphide minerals to the surface of the water in the cell from where they drained into the launder. By adding one set of reagents lead minerals could be floated off, then adding a new set of reagents zinc minerals could be floated off.

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Appendix G

Smelting

Reverberatory Furnaces

Calcining

Swansea in Wales was the principal centre for smelting lead- silver, tin and copper ores in the nineteenth century.\textsuperscript{1167} Ores from England, Chili, Peru and Cuba were mixed and smelted. Rich copper ores were sent from South Australia from the mid 1840s. The various copper ores had the following components:

1. Large amounts of copper pyrites, iron pyrites, 3 to 16 percent copper, small amounts of oxides and carbonates, earthy and silicious gangues.
2. Richer in copper pyrites with 15 to 25 percent copper, high in iron pyrites.
3. Copper pyrites, low iron pyrites, large amounts of oxides and carbonates.
4. Copper oxides and carbonates and copper sulphides, 20 to 30 per cent copper.
5. Oxidised minerals, no sulphur, up to 80 percent copper, silicious gangue, mainly from South Australia and Chili.

The calcining furnace shown was used for the treatment of the sulphides of type 1 with an ore hearth 16 feet long by 13.5 feet wide, formed of refractory bricks firmly bedded in fireclay. The lower diagram is a plan of the upper along a line AB. The arch descended rapidly from the firebox, the furnace height half way along was 2 feet and there were two cone hoppers in the roof each with a sliding door at the bottom through which the ore was dropped into the furnace. A current of cold air, controlled by a damper could be admitted through d. The roasted ore was raked out through four side ports onto the floor of the arched chamber below the furnace. In Swansea, anthracite mixed with bituminous coal was shovelled onto grate F, heated air was blown into the mixture which burnt and fused to provide many passages for the air while the fuel remained in the grate. Carbon monoxide plus nitrogen from the air passed into the furnace where air from d and from holes in the side ports mixed to burn the carbon monoxide evenly over the ore. This furnace had a capacity of 3 to 3.5 tons of ore. After 12 hours roasting the side ports were opened, the ore was raked out onto the basement floor, allowed to cool and then transferred to the melting furnace.

Melting

In the melting furnace shown Welsh practice was to mix two thirds anthracite and one third small coal. In Australia wood or Hunter Valley coal or coke was usually mixed.
The carbon monoxide burnt above the calcined ore spread over the hearth but higher temperatures were achieved by a greater draught of air. The sole S was a vitreous slag in which a depression B was scraped. Ores of the third class, copper rich slags from earlier melts, and roasted ore together with fluor spar to give a liquid slag were mixed and levelled. On heating the copper and sulphur combined, oxides then combined with the sulphur to form sulphur dioxide which escaped up the flue and iron, silica and oxides formed an iron silicate slag. After four hours the slag was liquid enough to be raked out through a door in the end of the furnace, opposite the grate, into moulds to form slag bricks. At the same time a tap hole was opened and matte flowed out into the circular vessel filled with water, where it shattered into fragments which were collected in a metal pan. This was called coarse metal and averaged about 35 percent copper.

The fragmented matte in batches of three tons was then calcined for 36 hours in a calcining furnace to oxidise any iron, the granules being raked at regular intervals, and finally drawn out the side ports to the chamber. This material was then mixed in a melting furnace with a smooth floor, with ores low in iron pyrites and rich in oxides and carbonates, type 4 above, at a higher temperature than the first melt. All the iron sulphide combined with the oxide to give a siliceous slag and the fused copper sulphide was tapped off after 5 hours as white metal with about 70 percent copper. Various ores were then mixed with the white metal to produce a melt with a higher percentage of copper which was tapped off and solidified into ingots called regulus. By further roasting the regulus the small amount of sulphur remaining was driven off as sulphur dioxide and impurities such as iron, cobalt, nickel, arsenic, antimony and tin combined in the slag. Further heating in the same furnace produced a crude copper called blister copper from its appearance. Cakes of blister copper were placed on the sole of a longer and higher reverberatory furnace to give a charge of about ten tons and heated for 20 hours. The sand adhering to the cakes and the reaction of the melt with the siliceous lining gave a slag which was raked off, and finely powdered coal or charcoal was spread over the surface of the molten copper to reduce any oxides remaining. A long pole of green wood was then plunged into the copper. This caused the copper to boil and after 20 minutes a copper sample was taken on the end of an iron bar. This sample was removed with a chisel, hammered flat on an anvil and repeatedly bent backwards and forwards in a vice. If the flexibility was satisfactory the last slag was scraped off and the copper tapped into moulds by large iron ladles as quickly as possible.

Napier’s process was developed in the late 1840s and used at Burra for the rich copper carbonates and oxides which were first roasted and then transferred to a second furnace, mixed with a siliceous flux and melted to produce blister copper.

**Blast Furnaces**

The mining of pyritic sulphide ores led to the development of the blast furnace, in which a blast of hot or cold air was forced by a fan into the bottom of a vertical cylindrical furnace, where the sulphide ore was oxidised with a fuel and fluxes to produce the metal and a slag. The early stages of this development took place in Europe, particularly in Germany where the charge was initially enclosed in a small vertical shaft, a blast of air was forced by bellows through tuyeres near the bottom of the shaft, and the molten ore tapped off at the bottom. By 1850 a rectangular firebrick shaft enclosed in stonework was in use, the size being about 4 feet by 2.5 feet at the tuyere level. In 1875 the Plitz water jacketed blast furnace was developed for smelting lead ores. The furnace was
circular in section with the boshes made of two concentric shells with water circulating between them. The Americans quickly developed this design for copper smelting with rectangular water jackets, leading to enormous improvement in smelting practice. By the 1880s American technicians were installing these furnaces in Australia for smelting copper and silver–lead ores. 

This photograph shows the way in which a rectangular blast furnace was built up by bolting sections together. Air was blown in through the tuyeres, the larger holes in the sides while water for cooling entered and left the jacket through the smaller holes. The jacket was supported by external I beams as can be seen in the photograph on the next page which shows a complete furnace in section. The furnace was built up on a solid foundation. Initially the air was preheated and fed to the tuyeres through large diameter bustle pipes, but preheating was found to be unnecessary if there were sufficient pyrites in the air and cold air was used. The water pipe connections are not shown but the water

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entered each jacket section through a bottom entry and left when heated through a top exit. The connections for entry and exit are shown as nipples. The liquid metal collected on the hearth which was made of firebrick and was tapped off. Only the slag tap is shown with the liquid metal tap at the end of the furnace.
This furnace was erected at the Sunny Corner copper and silver mine in New South Wales in the 1880s.\textsuperscript{1169}

**The Bessemer Converter**

William Kelly of Pittsburgh in the United States developed a converter for refining pig iron in the 1840s. Henry Bessemer of Birmingham in England independently developed and patented a similar process in 1856. It has since been called the Bessemer process. The molten pig iron was transferred to the Bessemer converter in a semi-horizontal position. The converter was then tilted upright and a blast of air blown through the molten metal to burn off impurities. It was not successful for iron containing phosphorus.

In Australia the process was adapted for purifying blister copper after smelting in reverberatory or blast furnaces in the first decade of the twentieth century. Converters were in use at Mt. Lyell in 1904, at Blayney in 1907 and Wallaroo in 1910.

![Converter - Side View](image)

The converter, shown in the vertical position, was filled with molten copper matte from the blast furnace or melting furnace (at Mt. Lyell about 45 percent copper) when in the horizontal position. It was then tilted slowly to the vertical and a blast of air at about 8 p.s.i.g. was forced through the matte. When no more slag was being produced as shown by a blue flame, the slag was poured off by tilting the converter. Further tilting allowed the blister copper to be poured off, cast into moulds and later purified by electrolysis. Converters were mounted on railway trucks and filled by ladles operated by an overhead crane. The illustration on the next page shows a converter in use at the Bayney Mines and Smelter Works circa 1907. Instead of being tilted on trunnions like the Mt. Lyell machine this installation used gears to rotate the tilting mechanism.\textsuperscript{1170}


\textsuperscript{1170} Ibid.
Prefabrcicated Furnaces

In the late nineteenth century it was expensive to employ expert furnacemen in remote areas to erect custom built smelters. Thomas Edwards was a partner with Joel Deeble in the United Pyrites Company at Bendigo in 1872, when they began treating pyritic gold ores sent on consignment from other mines in Australia. He later erected and operated a similar plant at Ballarat. In the 1890s he designed, built and sold a prefabricated furnace which could be shipped to the mine in parts and rebuilt by inexperienced workmen under the supervision of a factory expert. Mechanical rabbles moved the heated ore through the furnace from the exhaust or chimney end to the firebox end. The flues, chimney and firebox were built of brick on site.

The internal brick reverberatory section was constructed inside the steel framework after the framework was in position. Richard Hamilton installed Edwards furnaces at the Great Boulder mine in Kalgoorlie in the 1890s and by 1906 there were 39 operating in Western Australia including 12 at Great Boulder and 15 at the Kalgurlie mine.\(^{1171}\)

Blast Furnaces for Pig Iron

Blast furnaces were built at Lithgow, Port Kembla and Newcastle in the first half of the twentieth century. By 1953 there were 6 at Newcastle, and 1 at Whyalla all operated by B.H.P., and 6 at Port Kembla operated by Australian Iron and Steel. Earlier furnaces of English design had been erected at Lithgow by William Sandford in 1900 and by G. & C. Hoskins to a similar design in 1912 after they bought the plant. All the later plants were based on United States designs.\textsuperscript{1172}

All of the 13 plants mentioned above, which were operating in 1953 were of similar construction to that shown in the above illustration but of slightly differing heights.

Open Hearth Steelmaking Furnaces

The Bessemer process of using converters for steel making was not used in Australia. Australian iron ores with high iron content had low sulphur and phosphorus contents and were suited to smelting in reverberatory furnaces with basic refractory linings. These were called open hearth furnaces. In 1953 the Newcastle plant of B.H.P. was operating ten 125 ton and four 135 open hearth furnaces with an annual capacity of 1.2 million tons of steel, while Australian Iron and Steel was operating seven 230 ton open hearth furnaces. One 240 ton furnace was being constructed with a total annual capacity of 1.325 million tons of steel. These furnaces were of varying designs all based on

United States designs and all operated on identical practice. The illustration below shows the design of the 240 ton open hearth furnace at Port Kembla.  

Appendix 8

*Australian Mineral Statistics*

Production Summary 2002-03 and 2003-04\(^{1174}\)

<table>
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<th>Mineral</th>
<th>Unit</th>
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<td>Zircon conc.</td>
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6. Theses

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