La Trobe University, Bendigo

Bendigo Gold:
Past, Present and Future

Part 1 **History and Geology**

by Howard K Worner

Part 2 **Refractory Gold Ores**

by R Findlay Johnston

Worner Research Lecture 1997

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Part 1

History and Geology
by Howard K. Worner

Introduction

My two brothers, Neil and Hill, and I are both deeply appreciative and feel greatly honoured by the University in the creation of the Worner Research Lectures.

Immediately after the inaugural Lecture by Dr Seviour in 1995 and as Dr Findlay Johnston drove me back to Tullamarine Airport, I raised the thought that Findlay and I might contribute to the series with a lecture on "Bendigo Gold : Past, Present and Future". Findlay concurred so when I was back in my office in the University of Wollongong I faxed Bendigo's Pro-Vice-Chancellor conveying the suggestion for the 1997 Lecture. Professor Kilmartin responded promptly and enthusiastically.

There are a number of reasons for selecting the topic. Firstly, research on Victorian gold is going on at both the Bundoora campus and here in Bendigo. (Findlay will talk about the work in his department on extraction of gold from "refractory" ores and concentrates.) Secondly, the Worner brothers paternal grandfather worked on the Bendigo goldfield in the exciting years of early 1852 to 1854, but without great financial success. Thirdly, I still have vivid recollections of gold mining here when as a primary school boy and later as a student at the Bendigo School of Mines our family lived in Bendigo. The fourth reason is that C.J. La Trobe was the new Lieutenant Governor of the infant Colony of Victoria in 1851 when gold was discovered here and mining commenced. We pay honour to La Trobe in this Lecture.

La Trobe University, Bendigo had its roots in gold. Its oldest predecessor, the Bendigo School of Mines, was founded in 1873 to supply trained personnel for the rapidly expanding reef mining operations with problems peculiar to the mode of occurrence of the gold and also to the presence of some of the gold within the minerals, pyrite (FeS_2 - "fools gold") and arsenopyrite (FeAsS).

In the brief review of the history of Bendigo gold I have drawn on my own recollections and also on the considerable number of books written on the subject. I have found four texts to be particularly helpful. In his 1963 volume, "The Rush that Never Ended - A History of Australian Mining", Professor Geoffrey Blainey devotes many pages to gold in Bendigo. Frank Cusack, one of the local historians, devotes much space in his "Bendigo, A History" to gold and its importance to the city. The other author who has contributed considerably to the subject is James A. Lerk both in his "Bendigo's Mining History 1851 - 1954" published in 1991 and his "Bendigo's Central Deborah Gold Mine and Its Era" published in 1993.

Early History

The discovery of gold in California in 1849 was the catalyst that stimulated gold search in Australia. Two geologists, The Reverend W.B. Clarke and Samuel Stutchbury both reported that several rocks were suitable to host gold. The authorities in Sydney and later in Melbourne were anything but enthusiastic fearing troubles among the ex convicts now spread throughout the community. In the event, gold was discovered west of the Blue Mountains in New South Wales early in 1851. The gold fever generated was contagious and quickly spread to Victoria. Payable gold was found and mined in quick succession in places like Clunes area, Warrandyte (near Melbourne), Ballarat and surrounding districts, Mount Alexander (near Castlemaine) and a few weeks later the wives of two shepherds were to find gold in the rapidly drying pools of the creek given the name "Bendigo".

By Christmas 1851, Lerk (1991) reports that there were 600 people searching the bed of the creek and adjacent gullies. Six months later over 20,000 diggers were eagerly searching for alluvial gold in the district.

The production during 1852 and 1853 exceeded most other rich Australian alluvial fields and the wealth generated encouraged the erection of permanent buildings in a rapidly growing town, soon to become a city. While the Bendigo Creek became the most densely populated, gold discoveries extended many kilometers in all directions, to White Hills in the north east, Kangaroo Flat in the South and Eaglehawk to the north west. There were many other rich gullies such as Long Gully, New Chum Gully, Golden Gully, Derwent Gully, California Gully, Sailors Gully, Peg Leg Gully to mention just a few. Apart from the surface gullies and creeks it was soon discovered that gold existed in buried streams, the so called "deep leads". These extended to Epsom and Huntly in the north, Bagshot in the north east and Marong in the west. Severe flooding in some of the deep leads provided an impediment to the successful mining of gold.

There were many challenges which were to encourage many inventions or adaptations of developments in other alluvial fields. Special windlasses were erected above the shafts, puddling machines were developed to break up the gold-bearing clay; dredges and sluicing techniques were evolved to aid the recovery of gold from the deeper banks of auriferous soils and gravels.

As can be seen from Figure 1 (a geological map of what geologists call the "Lachlan Fold Belt" in central Victoria), Bendigo is one of the most northerly of the several gold fields discovered in that "belt". Within a few years of the discovery it became evident that the alluvial gold was derived by the weathering, over geological time, of quartz reefs. Interestingly, these reefs were generally parallel to each other and trend in approximately north-south direction (see Figure 2). The big problem was how to get the gold out of the hard quartz. Various crushing techniques were tried but in the end the so called stamp battery became the preferred technology. The iron stampers were built in units of five stamps. Within a few decades batteries were being erected with over one hundred stamps.

Figure 1 *Gold deposits in the Lachlan Fold-Belt in Central Victoria. Bendigo is the most northerly and also is the largest. There is no direct relationship between the quartz vein hosted gold and the granitic masses (from Cox et al 1991).*

Figure 2 *Map of the anticlinal axial lines in the Bendigo Goldfield. The heavy black indicates the more productive sections of the lines (from D.E. Thomas 1953).*

Bendigo a Rich Field

Unlike Mount Alexander and most of the gold fields in the Lachlan Fold Belt, it became apparent that although the alluvial gold in Bendigo was very rich, there was even more gold to be won from the quartz reefs and spurs underground. Quartz reef mining became a feature of gold mining in Bendigo.

The data published in different papers and books varied considerably but relying principally on information collected and published in 1991 by Professor Stephen F. Cox (then at the Australian National University but now at The University of Newcastle) it seems that the production at Bendigo, particularly underground, was many times greater than that from other major Victorian gold fields. The alluvial production from the surface and the deep leads was somewhat less than that recovered from the Ballarat district but still substantial. Bendigo production area was also the largest. From an area of about 25 km^2 Bendigo produced nearly 900,000 kg of gold. Ballarat produced about 600,000 kg - mostly alluvial and the Castlemaine-Chewton region a little over 100,000 kg.

Using the older non-metric system it has been claimed that the Bendigo urban area, including Eaglehawk, White Hills and Kangaroo Flat, produced over 20 million ounces. The total production for the Bendigo-Ballarat zone (often abbreviated to BBZ) produced over 2000 tons of good quality gold.

Before the reef systems at Bendigo and Ballarat were mined there were several geologists in the world, led by Sir Roderick Murchison, who believed that gold only occurred in the rocks within a few hundred feet of the surface. Bendigo was to prove this theory completely wrong. When my brothers and I were students at the Bendigo School of Mines there were local mines producing gold from operations almost a mile underground (in the metric system, 1.5 km deep).

Geology

As has already been mentioned, the Bendigo gold field occurs in the Lachlan Fold Belt. Most of the basal rocks in this Belt are very old. The shales and sandstones (now called "turbidites") were originally laid under oceans or great lakes in what geologists call the Ordovician period, the sedimentation extending over millions of years. As a general rule the basal rocks on the western side of the Lachlan Fold Belt were several million years older than those on the eastern side. They were formed somewhere in the period 500 million to 450 million years ago.

Towards the latter period and extending for about another 100 million years enormous lateral pressures, as well as the weight of the sediments still being deposited, caused extensive folding and faulting. The folding in the Bendigo region had a remarkable regularity about it; some have likened it to a stack of corrugated iron though for many of the folds there is more angularity about them and the description "chevron" folds has been applied. The crests of the folds were given the name "saddles" and the quartz reefs that were injected into them became known as "saddle reefs". Types of saddle reefs with associated faults in B & C are shown in Figure 3, A, B & C (taken from the 1991 paper by Professor Stephen Cox and colleagues).

The quartz reefs which formed were not always as simple as shown in Figure 3. One illustration of such complexity, kindly supplied to me by Mr Douglas Buerger, Managing Director of Bendigo Mining NL's extensive drilling program, is shown in Figure 4. Much faulting and fracturing of the host shales and turbidities was a feature of many areas and gave the quartz reefs some odd shapes. The same comment can be applied to the "spurs" which were fed with quartz solutions (sometimes bearing gold) from the major fault systems. One example taken from James Lerk's 1993 book is shown in Figure 5.

Figure 3 *Schematic illustration of the geometry and mechanics of formation of saddle reefs. (A) Simple crescendic saddles formed by lateral pressure and flexural slip. (B) More complex saddle geometry in which a through-going fault breaks across the fold "hinge". (C) Saddles with several associated faults. Some are concordant with the bedding and others discordant (from Cox et al 1991).*

Figure 4 *Massive quartz near a saddle in North Deborah mine as demonstrated by detailed drilling by Bendigo Mining NL. Such quartz masses are sometimes continuous for over a kilometre (courtesy of Douglas Buerger, Bendigo Mining NL).*

Figure 5 *Typical "spurs" of quartz in the North Deborah Mine. Some of the spurs contained gold and others did not (from Lerk, 1993).*

The nature of the wall rocks often played a significant role in the precipitation of the gold within the quartz. For example, the presence of carbon (mostly as graphite) was a potent precipitant. Other factors were pressure changes and an increase in oxygen in the system.

At this point it is appropriate to refer briefly to the modern theories regarding the form in which the gold was transported in what was equivalent to an enormous pressure cooker system. Before I go into chemical detail I should mention that in addition to consulting several geologists working in this field, Dr Findlay Johnston kindly arranged that one of his honours students, Stacey Contini, should spend some months working with a silica lined high pressure autoclave. Stacey's conclusions generally support the results of other researchers, particularly Dr T. M. Seward and Dr K.L. Brown and colleagues working in New Zealand. I am also indebted to Associate Professor Philip K. Seccombe of the University of Newcastle. The following is a summary of Philip's theories about gold transport mechanisms and factors contributing to precipitation.

The hydrothermal fluids, often carrying silica (SiO_2) as well, were highly pressurised and contained gases like methane (CH_4), carbon dioxide CO_2), carbon monoxide (CO) and sulphureted hydrogen (H_2S) all derived from hot rocks. The gold (in trace amounts) was leached out and transported in solution as gold bisulphide complex with chemical composition $AuHS^o$ or $Au(HS)_2^-$. Gold can be precipitated from such solutions by pressure release in the veins (triggered by faulting) which helps to drive off H_2S and so destabilises the gold-bearing complexes. Other mechanisms include:

(i) sulphidisation reactions with iron in wall rocks by which pyrite (FeS_2) or pyrrhotite (FeS) is formed;

(ii) reaction with organic matter or methane in the wall rocks reducing the gold to the elemental state (Au);

(iii) mixing of upwelling ore fluids-with colder near-surface groundwater.

Of course all of these can operate together.

This highly technical discussion leads me to say that I can now understand why gold, which is such a heavy metal, was preferentially found in the saddle reefs and spurs running off from them or associated faults. This concept is further supported by the Figure 6A & B which is taken from the valuable 1991 paper by Cox and colleagues.

Figure 6 *(A) Schematic fluid circulation pattern around saddle reefs and related fault zones. Supralithostatic fluid pressures develop in the stippled regions when fluid supply rate from fault feeder zones locally exceeds the rate at which fluid escapes from these areas by infiltration of low permeability wall rocks.*
(B) Variation of fluid pressure with depth along profile A-B. Growth of hydraulic fractures takes place in regions of supralithostatic fluid pressure (stippled) (from Cox et al 1991).

There is time to address briefly only one other puzzling question. It is, by what mechanism did the gold get concentrated into such a geological small region as Bendigo? Once again I call upon a diagram used by Professor Stephen Cox and his colleagues in their 1991 paper in "Ore Geology Reviews". Figure 7 is a schematic diagram illustrating fluid flow paths and possible volumes between fluid source rocks and gold-silica source rocks.

Figure 7 *Schematic diagram illustrating fluid flow paths and possible volumetric relationships between fluid source rocks, gold source rocks, and gold-quartz deposits in a gold field like Bendigo. Note the enormous tonnages of both rock and fluid involved (from Cox et al 1991).*

Large Literature on Subject

As this audience includes relatively few people knowledgeable in the earth sciences I have been highly selective in the aspects discussed. I apologise to our own Dr Tom Fowler whose important work on folding and flexural slip I have not discussed. Equally, apologies are extended to Drs David Foster and T.A.P. Kwak of La Trobe University, Bundoora, for not dealing with their detailed work on the timing of gold mineralisation in Victoria. This and related researches have been made possible by the great advances made in the last decade or two in what are known as isotope dating techniques. It is now possible to make fresh examinations of important geological events including the quantz-gold injection in the older host rocks of places like Bendigo.

The Future

All Bendigonians are aware that a great deal of gold exploration continues in this area. Bendigo Mining NL has spent and continues to spend large sums on their detailed drilling search. In the company's Quarterly Report for April-June of this year the statement is made, "Interpreted new ore positions in unmined ribbons provide at least 10 million ounce potential termed the New Bendigo". The Report goes on to say, "Additional drilling and reinterpretation increases resource/reserve base to 460,000 ounces of gold".

Whether the people of Bendigo will assent to Bendigo Mining NL engaging in actual mining is a question which I am not able to answer. The future remains uncertain but of this we can be sure, there is still much gold in the old rocks of Bendigo and district.

Acknowledgements

I am indebted to many people for help and information used in this lecture. My sincere thanks to Cheryle Parker who gave advice on several matters,to Irene Kline who typed the lecture, Anne Cooper for production of lecture slides and booklet and to Associate Professor Joe Petrolito for his assistance in proof reading this publication. My brother Neil obtained for me copies of Lerk's books and Lynley Graham kept me posted with Reports issued by Bendigo Mining NL and relevant extracts from the Bendigo Advertiser. Many geological friends have supplied me with technical papers. I am especially grateful to Dr Tom Fowler who sent me copies not only of his own papers but those of other Australian geologists. Associate Professor Philip Seccombe of Newcastle has done the same and has shared his theories with me.

I have quoted extensively from the comprehensive paper by Professor Stephen Cox written when he was at the Australian National University but more recently at The University of Newcastle. I have had frequent valuable discussions with my geological colleagues Drs Paul Carr and Chris Ferguson at the University of Wollongong. Finally, it has been a pleasure to work with Dr Findlay Johnston on this project and also with Honours Student, Stacey Contini in the experimental research.

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Part 2

Refractory Gold Ores

by R Findlay Johnston

Introduction

In Part 1 of this lecture, Professor Worner has outlined the history and has speculated on the forces which have combined to form the Bendigo Gold Field. In this second part, I would like to draw your attention to some of the more recent developments in the Bendigo region and to discuss the nature of the gold in some of the surrounding areas. In so doing I will also give you some idea of the research which has been and is being carried out at La Trobe University, Bendigo.

As outlined above, gold mining in the Bendigo region has passed through several phases, the first two of these being the mining of alluvial gold, followed by reef gold mining.

i. **Alluvial gold,** is loose and free, readily amenable to the techniques available in the past such as simple gravity separation.

ii. The **reef gold** can also be easily freed from the surrounding rock by simple crushing operations. It too is successfully treated by traditional methods.

iii. Much of the attention of researchers at La Trobe University focussed, and still focuses on the so called **refractory gold** found in the region. This gold is termed refractory because it is difficult to extract and it is almost impossible to see on examination of the ore itself. The gold is in fact often actually dissolved in sulfide minerals common in the region, minerals such as pyrite and arsenopyrite. These minerals do not reveal their gold content readily even when

they are analysed under the powerful scanning electron microscope. The chemical analysis of these gold bearing minerals shows that they can have quite significant gold content but the gold must be 'liberated' before it can be extracted. To liberate this gold it is not sufficient to simply crush and grind the host minerals.

The necessity to treat refractory gold ores and to do so in a way that is environmentally acceptable has really driven the development of entirely new methods of gold recovery. These new technologies have been combined into totally different types of gold treatment plants. Students and staff at Bendigo have been involved in and have contributed to these new developments through their researches. To explain the context of much of the research that is being carried out at La Trobe University I will very briefly describe the main features of a typical modern gold extraction plant (see Figure 1).

Figure 1 *Schematic Diagram of a typical modern Extraction Plant for Refractory Gold.*

A modern plant would be likely to use bacteria to break up the sulfide minerals so liberating the gold (Johnston 1994). These so called litho-trophic bacteria occur naturally with the gold bearing sulfides and can be encouraged to grow by presenting the right conditions. They oxidise the ore and use the energy of the oxidation process to metabolise. The gold exposed by this process of bacterial oxidation can then be leached out using a dilute solution of sodium cyanide which forms a complex with the gold and allows it to be taken up into solution. The solution produced will not, of course, be very pure and will have other, unwanted, species along with the valuable gold. Selectivity for the gold is provided by adsorbing it in the form of the sodium gold cyanide complex onto the surface of activated carbon. This carbon is of high purity and one commonly used source is charred coconut husks. Carbon in this form has a very extensive surface area and so it is able to adsorb a large quantity of complexed gold. This carbon, now with gold attached, can be easily removed from the solution and transferred to a clean vessel in which the gold is desorbed. The carbon is recycled and the gold is removed in a relatively pure form by electroplating. The gold has then to be refined by a separate operation before it is gold bullion.

Oxidation of Refractory Sulfide Ore

In terms of gold metallurgy a refractory ore is one that has to be persuaded rather strongly to yield its store of gold. This is usually because the gold is dissolved in the sulfide and consequently it is well disseminated through-out the sulfide crystals. When you consider that gold is normally present in parts per million quantities in these ores (that is in quantities as low as 0.0001%) the task of finding and extracting the gold makes finding the needle in the haystack look a trivial problem. To make this easier the sulfide ore can be oxidised (burned) to an oxide which has the dual effect of opening up the crystals within the ore to allow chemicals to penetrate into their interior, and at the same time of encouraging the gold to migrate together into agglomerated particles. The problem with the traditional roasting technique is that it is environmentally unacceptable to current

day standards regulating emissions to air and ground water. As a result alternative ways of achieving the same ends have been explored. Together with onetime member of staff at Bendigo, Dr Sam Swaminathan we have examined various means of oxidising refractory gold bearing ores and one of the first post graduate students from this campus, Colin Williams, took this for his research topic and thesis (Williams, 1991). It is generally accepted now that the use of bacteria to oxidise the refractory ore is the cleanest and the most economic way to treat the ore. These so called lithotrophic bacteria use the energy of oxidation of the sulfide to grow and in so doing they perform the task of opening up the sulfide grains a little as if they were popcorn swelling in a pan of hot oil.

The resultant exposure of the gold from within the grains allows it to be contacted by suitable chemicals for subsequent dissolution, concentration and extraction.

Leaching of Weathered Ore

Of course, sometimes, if the ore is near the surface, natural weathering achieves the same end of oxidising the ore. This, however takes place over a very long period of time and it only occurs on or near the surface of a mineral deposit. My colleague Ross Anderson together with final year students B. Loechel and T. Griffin have been studying the leaching of weathered ore in open air heap leaching pads. The heap leaching process allows the leaching solution to percolate through the heaped up oxidised ore and in the process to dissolve the gold as a cyanide complex. The heaps need to be open to allow both the leachant and oxygen to permeate and this in turn requires the relatively fine ore to be agglomerated into open balls bound together for stability. Mr Anderson and his students have been examining various alternatives to the conventional cement used for this purpose and in particular they have been studying the effectiveness of various forms of gypsum in this context (Anderson, 1997).

As well as studying the use of gypsum in the heap leaching process, Ross Anderson, Associate Professor Joe Petrolito and PhD student Scott

Pigdon have been examining the effectiveness of gypsum as a substitute for cement in mine backfill. Thus,when the waste from the gold extraction operation is repaced back into the mine it requires some addition to stabilise it. Traditionally cement has been used but Pigdon's investigations have shown that some forms of gypsum can be substituted successfully giving a corresponding saving in energy and cost (Pigdon, 1997).

Gold Adsorption onto Activated Carbon

Once the gold has been dissolved out of the gold ore and is in solution, the question of how to concentrate this arises. To do this it has been found that the gold complex will adsorb onto carbon. Any carbon will adsorb the gold complex but the most efficient is a form of carbon which has a very large surface area. The carbon most commonly used is a carbon char made from coconut husks and this is because it has a structure similar to that of a sponge. The surface is activated by heating it and this drives off any gases that may have been adsorbed onto its surface leaving it in a suitable state to adsorb the gold aurocyanate complex. Of course the cleaner the surface of the carbon the greater its ability to absorb gold and so if the carbon becomes fouled by any contaminant the ability of the carbon to perform properly is compromised. One particularly difficult contaminant which can act in this way is lime which is an important addition to the gold winning process. The late Professor John Miller and Dr Rob Glaisher have successfully demonstrated the contamination effect of lime in some of the local gold recovery operations using the scanning electron microscope at La Trobe University in Bendigo.

The Kinetics of Gold Desorption from Carbon

Once this gold complex has been adsorbed onto its surface, the carbon can then be removed from the solution and the gold, now in a pure form, can be desorbed from it.

This desorption of gold is one of the slowest processes in the winning of gold and the work of masters degree student Paul Pyke (Pyke, P, 1994)

in this department has made a significant contribution to speeding up this step using thiourea. Commercially operational stripping processes such as the Zadra or the AARL rely on heat and/or high pressure to speed up the process and are expensive to run. Other developments require costly or highly toxic volatile chemicals. Thus this aspect of gold winning is most expensive and inefficient. Pyke determined that by using thiourea together with a small amount of cyanide for this dissolution step the desorption of the gold could be speeded up by a factor of up to ten times and the process could be carried out at atmospheric pressure (Pyke, Swaminathan and Johnston, 1997). This process is now being used in industrial gold extraction operations (Pyke, Johnston and Swaminathan, 1997).

Natural Carbon in the Ore

Many gold ores contain naturally occurring carbon in various forms. The gold ores of the Bendigo region are no exception to this and Dr Peter Brooks, with honours student Brendan Pyke (Pyke, B, 1997), as part of his honours year project is currently looking at the various forms this carbon takes and the effect these various types of carbon have on the extraction of the gold. Essentially this work is aimed at devising ways of identifying, and then eliminating, the harmful forms of carbon so that the coconut char can be left to adsorb gold without interference. Carbon in gold ores seems to be in four main forms.

Carbonates of Various Types

These mineral carbonates occur in almost all gold bearing ores and they appear to have little affect on the gold recovery. Thus once they have been identified and their levels established they can be ignored.

Native Carbon

This is thought to be predominantly elemental carbon and it appears to behave like activated carbon such as coconut char. It therefore adsorbs complexed gold or gold chloride from the solution. Unlike coconut char, however, it is very fine in nature and so it is not easily removed from the solution. It is therefore lost to the tailings dam and represents a corresponding loss of gold recovery.

Heavy Hydrocarbon Oils

This group of high molecular weight hydrocarbons are present in minute quantities and appear to be associated with the native graphite surfaces. They seem not to interfere with the extraction of the gold.

Organic Acids

Part of the organic carbon content of ores is a group of acidic substances known collectively as humic acid (see Figure 2). This humic acid, commonly found in soil samples, is a product of the biological degradation of plants and other organisms. The presence of humic acid is detrimental to the recovery of gold and it has been suggested that at least some of the components of humic acid can complex gold and then strongly bind it to carbonaceous material in competition with the cyanide complex. The binding is much stronger, however, and the gold bound in this way is not removed under standard stripping conditions. This therefore represents further loss of gold.

Figure 2 *Proposed Structure of Humic Acid (after Radtke and Scheiner (1970)).*

Conclusion

Despite its ancient origins and the very long time over which it has been practiced, gold metallurgy is still able to present some intriguing problems and La Trobe University is active in pursuing solutions. There are two main thrusts to encouraging new developments in the industry. There is the constant striving to exploit leaner ores and ores which are more complex therefore more difficult to handle. Refractory ores such as have just been discussed are examples of these. This has led to the development of new technologies to handle the complex and refractory nature of the ores themselves. Early studies by my colleagues at La Trobe University indicated that for one group of ores in the Bendigo region which contained antimony as well as gold, it is possible to recover both metals using high pressure techniques (Williams, 1991). The antimony, recoverable as an oxide, could then be useful in the manufacture of some polymer materials. A second feature that is fuelling the effort to produce new technologies is the increasing awareness that we have for our environment and the desire to leave the planet to our children in as good condition or better than we ourselves inherited it. Gold extraction processes have come a long way from the days of noisy stamp batteries pounding the ore 24 hours a day, week in week out, and the sulfide roasters sending toxic sulfur dioxide gas far and wide. The use of mercury, also highly toxic, to amalgamate the gold and the subsequent distillation of the mercury to regenerate it is no longer an acceptable practice. The pioneering of the use of alternatives to cyanide including thiourea for complexing gold has been carried out by my colleagues and me (Swaminathan, Pyke and Johnston, 1990).

As economic necessity and social pressures are generating the need for newer, cleaner technologies, this, in turn, requires a better and deeper understanding of the processes involved in the winning of the gold and of the characteristics of the gold bearing ores themselves. This involves fundamental studies into the nature of the minerals using powerful tools such as the GCMS (gas chromatography, mass spectroscopy) and scanning electron microscopy to identify tiny quantities of components in the ore which could interfere with the extraction process. La Trobe University, Bendigo is an active participant in these studies.

Acknowledgments

I would like to thank the many people who have helped me in the preparation of this lecture. In particular I would like to pay a tribute to my colleagues of the Department of Metallurgy, a department which dates back to the very beginning of tertiary education in Bendigo. Unfortunately this department no longer exists, but my colleague Ross Anderson is still active in research in metallurgy. Particular thanks too to Dr Sam Swaminathan, now at RMIT and to the support which Dr Rob Glaisher has given to research in metallurgy through his expertise in scanning electron microscopy.

I would also like to extend my gratitude to Cheryle Parker, Anne Forden, Chris Meurer, Ivan Burge and Anne Cooper for assisting in the preparation of this lecture, a particularly difficult job since I was in Toronto at the time and communication was by e-mail and fax.

Thanks also to La Trobe University for granting me OSP leave which I spent at the University of Toronto, Canada. Part of that leave was spent in preparation of this lecture.

Thank you also to Professor Les Kilmartin and the Research Committee at La Trobe University, Bendigo for providing funds to cover costs in the preparation of this lecture.

Finally I would like to thank my wife, Maureen, for her constant support and encouragement, not only throughout my career in research and teaching but in particular over these last months while I was in Toronto, Canada and she was in Bendigo, Australia.

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The Worner Research Lecture Series

The annual Worner Research Lecture form a series of public lectures at La Trobe University, Bendigo. The aim of the series is to publicise research carried out at La Trobe University, Bendigo.

The University is proud to be associated with the Worner brothers, Howard, Neil and Hill, who were students at Bendigo School of Mines, a forerunner of La Trobe University, Bendigo. The three brothers were raised on a farm in the Mallee. In the early 1930s, they studied at Bendigo School of Mines: Howard and Hill for a Diploma of Industrial Chemistry and Neil for a Diploma of Civil Engineering. All three brothers later won prestigious scholarships to Melbourne University.

Howard Worner's distinguished career in academia and industry led him to his present honorary professorship at the University of Wollongong, where he has been Director of the Microwave Applications Institute since 1989. In 1994, La Trobe University conferred on him the degree of Doctor of Science (honoris causa).

Neil Worner pursued a career in civil engineering, including the position of Chief Civil Engineer with the Snowy Mountains Hydro-Electric Authority. His career continued in senior and advisory capacities in Australia and over-seas on projects such as the design and construction of major dams.

Hill Worner's career included several years on the Executive of the CSIRO, and 22 years as Professor of Metallurgy and three as Dean of Engineering at The University of Melbourne, where he is now Professor Emeritus in Engineering.

Lecturers in the series so far have been the following:

1995: R. J. Seviour, Micro-organisms: the Good, the Bad and the Ugly

1996: T. M. Mills, Join the Dots and See the World

1997: Howard K. Worner and R. Findlay Johnston,
Bendigo Gold: Past Present and Future

Biographical Sketches

Professor Howard Worner was born in 1913 and began his formal tertiary education in his chosen fields of chemistry, metallurgy and geology at the Bendigo School of Mines where he graduated 65 years ago. He progressed to the University of Melbourne where he earned the first of the degrees and awards that were to distinguish his long and active career. He graduated from Melbourne with a Bachelor of Science with First Class Honours in 1934. His Master of Science was awarded, again with First Class Honours, in 1936 and in 1942 he was awarded the degree of Doctor of Science from the University for published work. Howard Worner was then only 28 years old, and he is still probably the youngest DSc from The University of Melbourne. From 1939 to 1946, Professor Worner was the only non-medical Fellow of the National Health Medical Research Council. In the decade after World War II he was a Professor of Metallurgy and then Dean of Engineering at Melbourne University. In 1963 Professor Worner left Australia to act as an inter-national consultant and returned later that year to become the Director of New Process Development with CRA Limited, a position held until his "retirement" in 1975. During "retirement" he has continued to work at the University of Wollongong and on numerous government committees.

Dr Findlay Johnston is a graduate of Glasgow University and Strathclyde University, Scotland. After graduation he spent some time at the Technical University of Norway and the University of Paris before accepting a position at the Bendigo Institute of Technology, a precursor of La Trobe University, Bendigo. Dr Johnston has held various positions at La Trobe University including Head of Metallurgy and Head of Division,Physical Sciences and Engineering. Dr Johnston's research interests are in studying the chemical reactions involved in extraction processes for metals. In gold metallurgy he is particularly interested in refractory gold ores and has consulted to a number of companies in this. His other main research interest is the chemistry of transition metal extraction.