Seeking Hidden Millions - Metallurgists and the Broken Hill Lode

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Mining still continues on the enormous Broken Hill orebody that has produced ore for almost 120 years. Production started by the mining of an astonishingly rich oxidised zone - lead as the carbonate (cerussite) and silver as a chloride (cerargyrite) that could be treated by grinding, gravity separation and smelting.[1] However, even in the early phase there were indications from the variety of the oxidised minerals of the problems to come.

As mining reached below the oxidised zone, sulphide ores proved difficult to treat by conventional methods. Companies constructed new concentrating mills to produce lead (67 per cent recovery) and silver (45 per cent recovery) concentrates, but the significant zinc content could not be separated from the gangue and was passed into the tailings with the unrecovered lead and silver. Millions of pounds worth of ore thus went to waste. As is recorded in numerous publications,[2] the solution came largely from the discovery and development of flotation. But this discovery and development was by no means simple, and numerous metallurgists in various companies, were involved, for many years.

Even when geological knowledge of the orebody was limited it was recognised that there were variations in the orebody from (mine) north to south (actually northeast to southwest), and even across the deposit.[3] Over the years it became recognised that there were in fact a number of separate 'orebodies' each with its own mineralogy.[4] Consequently, although the Broken Hill ore consists dominantly of silver-lead-zinc sulphides, each mine along the line of lode has had to face differences in relative abundance of the various sulphides and changes in gangue minerals. These factors affected how the ore material in each mine was treated to separate the various sulphides, and later to produce the metals from the sulphides. As early as 1892, C. Schnabel made the point that 'the future existence of the Broken Hill mining industry will depend on the metallurgical treatment of the sulphides [consisting of] a silver-bearing mixture of galena and zinc blende intimately intermixed.'[5]

This paper briefly looks at the more publicised efforts made to resolve Broken Hill's technical problems but the main thrust will relate to the interconnected lives of three lesser known metallurgists who worked from 1900 in Broken South Mine (BHS) and its partial offshoot Broken Hill Associated Smelters (BHAS). Each contributed to the continued improvement in the processing of Broken Hill ore over a period of fifty years, with methods that were taken up by mines in every part of the globe. Their contributions relate not only to their contribution in the realm of technological change but to their educational role in helping to disseminate their ideas through the medium of the written word and in sponsoring and encouraging younger cohorts of engineers. It might also be suggested that with few exceptions, co-operation with fellow engineers, rather than competition, was the basis of their contributions to the mining and processing industries.

The role of the metallurgists

Over the years, perhaps by force of self-publicity and the emphasis upon success of their early mining and treatment developments, has tended to promote the Broken Hill Proprietary Company (BHP) as the industry leader. Thus the celebrated discovery of the flotation process and its development has been attributed to G.D. Delprat, who, after graduation from study in Amsterdam, began his mining career as metallurgist at the Tharsis copper mine in Spain in 1879 before going to Broken Hill in 1898.[6] As Brian Kennedy has suggested, he was 'not without a touch of ruthlessness',[7] while W.S. Robinson believed he was not above exaggerating his own technical efficiency.[8] The work in this area by Leslie Bradford[9] and E.J. Horwood, also of the BHP, is also known, albeit with acknowledgement of a little help from the outsiders Charles V. Potter and Auguste De Bavay.[10]

Examining the literature, both Geoffrey Blainey and Robert Solomon add a little to the story, commenting on the work of T.M. Owen (at Junction North mine) and F.J. Lyster (Zinc Corporation (ZC). Blainey indeed nominates 'forty Broken Hill men, and eleven Broken Hill companies' who made 'important innovations in the technique of flotation by the year 1915',[11] but does not identify them further. Alan Trengrove provides additional information, mentioning A.D. Carmichael's collaboration with Delprat.[12]. Albeit briefly, O.H. Woodward's *Review of the Broken Hill Lead-Silver-Zinc Industry* gives something of the material in this present paper,[13] as do Worner and Newnham.[14] Worner and Mitchell also indicate a little of the complexity of the story,

paying tribute in particular to Lyster at the Zinc Corporation, for introducing the first true differential flotation process for the selective flotation of ore minerals,[15] particularly zinc sulphide. This he did in 1912, although as early as October 1909, geologist J.E. Carne was already talking about how the Broken Hill orebody treatment had been 'revolutionised by the Zinc process success'.[16] Other relevant papers expanding the story of Broken Hill ore treatment and flotation are by Poole, Henderson (who mentions the metallurgists, but does not identify them individually), and particularly Mouat, who gives details of earlier flotation experiments.[17] Mouat points out that Potter worked on chemical methods of treating Broken Hill tailings as early as 1899.[18]

In a recent interesting and informative paper Ralph Birrell develops the story of the contribution of the Minerals Separation Ltd Company to Broken Hill flotation developments, and indeed to the wider-world.[19]. He points out the unjustified neglect that the Australian metallurgist Henry Lavers has suffered, despite his considerable research undertaken at Broken Hill and elsewhere for the company between 1905 and 1913.[20] The availability of the historical records of the Australian arm of Minerals Separation, which Birrell has examined, will help to broaden the picture of the history of Australian metallurgical research.[21] As Birrell points out, release of the extensive records held in the company offices in London and New York should enable a more complete picture to emerge.[22] In the context of the present paper it is interesting that the South Broken Hill Mine seems to have maintained its independence in its pursuit of mineral treatment. After having a sample treated by Minerals Separation the company went ahead with its own processing.[23]

Three other contributing metallurgists

Broken Hill South Mine was the major supplier of zinc tailings to the Zinc Corporation between 1906 and 1912 during its experimental phase. It also had strong links with North Broken Hill and Baillieu interests through De Bavay's [Amalgamated Zinc (AZ)] in taking over De Bavay's treatment company in Melbourne.[24] Broken Hill South, North Broken Hill and Zinc Corporation through BHAS essentially took over from BHP at Port Pirie in 1915.[25] Together with AZ between 1916 and 1921, they developed commercial zinc smelting by electrolysis at Risdon.[26] BHS, NBH and ZC were also closely involved in the development of zinc smelting at Avonmouth in England from 1923 to 1929.[27]

Involved in the developments were three metallurgists who are the subject of this paper - William John McBride, Thomas Andrew Read and George Kenneth Williams. Naturally enough they were all young when they started, but two of them, McBride and Williams, were only just out of University when they were given enormous responsibility: McBride at the 'coal face' so to speak, Williams as a backroom boffin (though he didn't stay at the back for long), and Read who was the odd man out, learning on the job, but getting Technical College qualifications as he went along. Of the three, McBride had the most varied life, but he vanished from the metallurgical scene in the 1930s, and only luck revealed something of his last 35 years of obscurity in England.[28]

McBride

William John McBride (1879-1970) who graduated from Adelaide University in metallurgy and geology in 1898 was appointed metallurgist to the short-lived company that re-opened the Reedy Creek Gold-Copper deposit operating 75km north east of Adelaide.[29] In 1900, following the resignation of metallurgist T.J. Greenway, McBride joined Broken Hill South Company as metallurgist, chief assayer and mill superintendent under W.E. Wainwright (1873-1959), a very capable mine manager, and himself with metallurgical skills which he first applied in Kalgoorlie before taking over at the South Mine in 1898.[30] In his first 18-months McBride enlarged and modified the milling plant, increasing its efficiency. The consequent cost reduction helped the company ride out the following four-year decline in metal prices.[31]

As metal prices recovered in 1905 McBride planned & constructed a new and considerably enlarged mill, containing many technical modifications. It was completed in 1908 and provided a high-grade lead concentrate during its first year of operation. In the next ten years there was an economic need to separate the particular metals from the ore, to which McBride applied himself, carrying out experiments and plant trials on selective lead and zinc flotation methods, apparatus and reagents.[32] During this period McBride was training Read, who soon took over much of the assaying work.

L.S. Curtis commented on the South Mine mill experiments and felt that the appointment of McBride and other similar trained people meant 'the cessation of operation by purely practical men – rather solving problems and making decisions through sound reasoning and technical knowledge rather than rule of thumb'.[33]

Following this statement, there is some irony in the success of mill foreman F.J. Lyster's selective zinc flotation discovery a year or two later.

There were several diversions from metallurgical work for McBride. In 1908 a controversy arose about the possible harmful effects of new explosives being introduced underground. The 'new' explosives problem came about through the attempt by various British explosives companies to form a cartel and raise prices. The Broken Hill mines (South Mine was represented by F.C. Howard), together with Mount Morgan (which R.G. Casey represented) in association with other Australian companies, and some South African mines, grouped together and set up a South African explosives company (The Cape Explosives Company) operated by De Beers. The British groups backed down, but too late, as from then on a considerable proportion of the explosive material for the main Australian mines came from South Africa. McBride supervised much of the analytical work and design of apparatus for testing for underground air quality, dust and alleged greater toxicity of the South African sourced explosives in use at Broken Hill, ultimately vindicating the product and allaying the concerns of some hard liners in the labour force.[34]

Perhaps more important for the mining community was McBride's design and construction of equipment to measure suspended dust levels in the underground mine air, this problem being the subject of a number of health surveys over many years.[35]

Up to 1914 McBride's methods in the treatment plant continued to increase both the grade and recovery of metals produced by Broken Hill South. Of particular significance, McBride, with John C. Cunningham (company engineer) designed, in 1913, a sub-aeration flotation cell for T.M. Owen's mineral separation process in order to commercially treat slime dump material containing high values of lead, silver and zinc. This patented cell design (Patent No. 3361/1917), the 'first working machine of the sub-aeration type built in Broken Hill', was adopted by other Broken Hill mines and remained in use into the 1970s.[36]

The outbreak of World War 1 in 1914 interrupted the export of metals to Germany for final treatment and sale (or use!) making replacement plant essential for the war effort. Consequently, McBride was sent to Port Pirie (South Australia) where he represented the combined Broken Hill mining companies in formation of a new joint company, Broken Hill Associated Smelters (formally established on 7 May 1915), to carry out full treatment of Broken Hill ores. McBride had more than a hand in the

design and construction of the new treatment plant, which had to be built in a very short time.[37]

W.E Wainwright was one of the managers who felt the mining industry could not afford to lose key people during the war. However, he probably didn't have much say in McBride's case, and after a brief return to Broken Hill, McBride who was a skilled rifle shot,[38] enlisted. Joining Edgeworth David's Tunnellers he served in France for the duration of the war and earned himself an M.C. for astonishing bravery underground on the Messines Ridge.[39] But his skills were not forgotten by the Collins House Group involved in BHAS,[40] for on McBride's discharge in England, Colin Fraser (1875–1944) and H.W. Gepp (1877–1954, himself a metallurgist of considerable ability), sent him off in 1919 to visit as many mines and treatment works as possible in North America. This was at company expense on his way back to Australia.[41] The next five years were very busy. In late 1920 he was sent off to advise the Burma Corporation on the treatment of the ore at the remote Bawdwin Mine at Namtu in Northeast Burma (close to the Chinese border). This was some three years before W.S. Robinson and his associates took control of that company, and Robinson and Colin Fraser undoubtedly had a good look at its potential. Although he is not named, McBride almost certainly designed the 'small experimental mill' at Namtu and also the final gravity and flotation concentration mill there.[42] However, John Moule expressed some doubts on whether the new mill would come up to expectations as 'some oxidized ore had been used in the tests'.[43] The rest of the time to 1925 McBride acted as liaison officer for the treatment activities at Broken Hill, and at Port Pirie, and for the newly developing zinc roasting operations at Risdon (Tasmania).[44] The main tasks undertaken were the construction and operation of blende roasters at Broken Hill, Port Pirie, Wallaroo and Risdon, as well as an acid plant at Cockle Creek near Newcastle. He also worked again on the gravity and flotation concentration of lead, silver and zinc.[45]

In 1925 McBride was sent off as consulting metallurgist to the National Smelting Company (Swansea, Wales and Avonmouth, near Bristol), in which the Collins House Group had just made a substantial investment.[46] He remained there until about 1935, when he apparently resigned and returned to Adelaide where he consulted for a brief period (including to the Wallaroo and Moonta mines). Things didn't go well and McBride returned to the UK a few years later, thus severing his connections with Australian mining. We leave off McBride's life here. He died aged 91 at Eastbourne in 1970.[47]

Read

Thomas Andrew Read (1886-1972) began work with Broken Hill South Mine's general store in 1901. Noted by mine manager Wainwright, for his enthusiasm and intelligence, he was transferred to the assay office as assayer's boy in 1905. He quickly became McBride's assistant, and having completed his diploma at Broken Hill Technical College was appointed chief assayer when McBride's metallurgical chores became more than enough to cope with.[48]

In 1915, when McBride moved to Port Pirie, returned, and then enlisted, Read took over McBride's duties as metallurgist, and in the ensuing five years continued laboratory and plant experimentation. In particular he worked on selective lead and zinc flotation methods, including the use of compressed air and the improvement of apparatus and reagents. Read put into operation the first De Spirlet zinc concentrate roaster to produce sulphuric acid for the flotation process. In 1917 he had his first major success with the successful use of ferric salts in the differential flotation process, tests which had begun with McBride.

Like McBride, Read was also diverted to the underground dust problem, and between late 1917 and early 1918 he experimented with mechanical methods of dust allaying, continuing this work episodically during the 1920s.[49]

For some reason, Read had to wait until 1922 before being named chief metallurgist, and despite attempts by various companies to lure him away, it was a position he was happy to retain until his retirement in 1955. In this period he became involved in the activities of the Broken Hill Branch of the Australasian Institute of Mining and Metallurgy (AustIMM), being Chairman for a period in the 1930s. He was also quite prolific in his publications.[50]

In 1926, Read and underground superintendent H.H. (Bert) Carroll, spent nine months visiting mines and mills in South Africa, Europe and North America.[51] On his return Read became largely responsible for the design and construction of a new Broken Hill South concentrating plant, the first in Broken Hill to use concrete and steel. The gravity section opened in 1929, and the flotation section came into operation in 1934. The plant incorporated a sub-aeration flotation machine developed by Read and G.B. Game.[52]

In addition, Read made significant additions to the chemistry of flotation processes. In July 1927 he and his assistants had found that before flotation, the addition of potassium ethyl xanthate (rather than the recently introduced sodium ethyl

xanthate for zinc recovery) and frothing oil led to a considerable increase in the recovery of lead and silver. This was a discovery other mines were not slow to take up.[53]

In the late 1930s, probably through the Collins House connection, Read was appointed consultant to Broken Hill North Ltd for the design and erection of its new concentrating plant. His important role as an educator should also be noted, for after completion of the concentration plant, North Broken Hill was happy to employ Read's protégé, L.G. (George) Wilkins, as metallurgist. Numerous others were trained by Read and came to occupy important assay and metallurgical positions on various Australian mining fields.[54]

Williams

The work of George Kenneth Williams (1896-1974)[55] is perhaps better known than that of McBride and Read, possibly because it remains in the memory of a recently retired body of metallurgists. Williams graduated as a Bachelor of Mining Engineering with Honours from the University of Melbourne in 1919, and immediately joined the research centre of Broken Hill Associated Smelters, South Melbourne. This Centre had been set up the previous year by the English metallurgist, Gilbert Rigg to improve the treatment of lead at the Port Pirie smelting works, which Rigg had visited in July 1916. He had been brought to Australia from New Jersey through the efforts of H.W. Gepp and appointed Technical Director of the Research Station in Melbourne.[56] The necessity for research had been highlighted by the perceived need for Australia to become self-sufficient in production of strategic materials following its experience during the First World War.

Williams examined the behaviour of mixtures of silver and lead during cooling in the commonly used, but inefficient, seventy year old Parkes Refining Process, in which zinc was used to help separate gold and silver from the main lead content. The process involved a series of separate heating and cooling operations, which required great skill and timing by the smelter workmen, a very large labour force and considerable waste of fuel. In 1921 Williams was transferred to Port Pirie to apply the laboratory results on a pilot plant scale and then, hopefully, at full scale.[57] He worked under O.H. Woodward (1885-1966), then Plant Superintendent (who had been recommended to Gepp by McBride, who had been associated with Woodward in the Australian Tunnellers),[58] and the following year was named superintendent of the

research department. Williams' new Crust Enrichment Process led to a great decrease in the cost of producing silver and was patented and put into operation in 1923.

Figure 1: *Photograph labelled 'Dr. George Kenneth Williams Recipient of Institute Medal for 1942'.*

Source: Courtesy AustIMM

Stimulated by Rigg's ideas, Williams then set out to change the plant operation from the 48 episodic batch operations involving large operating and maintenance crews, working in a big space, to a continuous flow process. Although Williams's experimental work showed that a greatly improved, faster and more economical process of refining was possible, it still had to be tried on a commercial scale. Following successful trials in late 1925, building of a semi-commercial plant was strongly supported by Woodward, Colin Fraser and other Directors of BHAS after being recommended by Williams. The tests from August 1927 to the end of 1928 indicated an even larger, but still semi-commercial plant was needed, with bigger kettles to give greater operational space to allow the de-silvering crusts to form and be removed. The new tests began on 2nd January 1929. Consistent commercial grades were finally attained by August 1930 when a large 3-section kettle was built and successfully operated. An even larger 4-section kettle came into operation in October 1930. Fortunately it was completed before the depression affected the company's business, and cut down funding for expensive research.[59] The continuous flow refinery went ahead quickly and came into operation in 1932. During the preparations for commercial operations the Sydney firm, Bradford & Kendall, founded by Leslie Bradford, former BHP metallurgist, built the high-quality iron and steel castings. The specially cordial relations established between Williams and managing director Jim Kendall of Bradford's, strengthened by their mutual love of horse-racing, ensured full co-operation. [60]

Williams's work, to prove the viability of the new methods so they could be quickly applied at the commercial level, went on at a 'frantic' pace. This effort was spurred by Williams's enthusiasm and his rapport with the foremen and labouring staff, who became both practically and emotionally involved in the task. Williams discussed plant problems freely with them, explained the steps he was trying to achieve, and always listened to their ideas and suggestions. He could be a hard taskmaster, but the technical men received an unforgettable lesson in concentrated analytical thinking, persistence in the face of reverses and, above all, the will to succeed. His success in research and operations was due to his ability to identify his targets correctly, to avoid being diverted to peripheral issues and to do only the work needed to achieve results.

Williams recognised the importance of teamwork based on the presence of a small core team. Completion took six years of pilot plant work, long and irregular

hours that involved numerous trials and tribulations, including two fires, but which resulted in a strong bond of comradeship between Williams, his fellow researchers and loyal workers. The big kettle proved the vital unit in the continuous refining train. It is 'a monument to the genius' of G.K. Williams and 'one of the great achievements in modern non-ferrous metallurgy'.[61]

In these developing years Williams also went ahead on other fronts: in 1930 he made improvements to the lead blast-furnace design; in 1934 he carried out radical, successful experiments with his assistant J.L. Sampson (c.1892-1935) when making significant improvements to the sintering process. That same year the University of Melbourne awarded him a Doctorate in Engineering.[62] Appointed Chief Metallurgist in 1933, Williams then went through a number of promotions: Assistant General Superintendent of BHAS (1935); General Superintendent (1942); and Works Manager (1942-48).[63]

In these latter years Williams continued to experiment, and in 1947 introduced up draught rather than downdraft sintering to prepare lead concentrates for blast furnace smelting. This process allowed the collection of gases for acid production and overcame the problem of lead-fall in the windboxes. The up-draft sintering method remains the standard today.[64]

In 1948 Williams followed McBride's steps, moving to Imperial Smelting Corporation, Avonmouth, near Bristol, as consultant for the development of furnace production of zinc.[65] In 1957 he returned to his roots as Metallurgical Consultant to Consolidated Zinc in Melbourne, continuing as Consultant to Conzinc Riotinto when the companies merged in 1962. Williams retired to Adelaide in 1966.[66]

The links and some conclusions

The McBride-Read connection is clear. McBride was the chief inspiration and teacher of Read, who continued at Broken Hill South on the paths set out by his mentor. McBride and Williams are connected as separate steps in the BHAS story at Port Pirie and at Avonmouth, and they almost certainly met at Port Pirie and discussed metallurgical matters. They might have met again in England in the 1950s. The Read - Williams connection is tenuous. They might have met through meetings of the Australasian Institute of Mining and Metallurgy (AustIMM), particularly at Port Pirie in 1921.

All three published in the Institute's (or its forerunner's) proceedings. The regular Broken Hill Australasian Institute of Mining Engineers meetings provided a fruitful field for the promulgation of ideas and results of research in metallurgy across company boundaries, and ensured that the Broken Hill field remained at the forefront of technological development in metallurgy. In this, Read played an important part, for between 1921 and 1935 he published in the Institute's Proceedings, a number of papers on the operations of the company, the first in association with Wainwright being an important paper on the concentration practices of Broken Hill South. Others were joint papers with colleagues.[67]

McBride published one paper only (with W.E. Wainwright) on fine grinding, but in the light of what he had seen in North American mills in 1919, he contributed to AustIMM discussions on visits to Broken Hill in 1919 and the early 1920s.[68] Being too much on the move, and a minion (albeit appreciated) of his Collins House bosses, his contributions to Australian metallurgy have remained largely forgotten.

While the Institute meetings at Broken Hill probably helped the spread of information by bringing together metallurgists from different companies, it is interesting that Williams argued he was better off at Port Pirie, the isolation helping to keep him focussed on the problems at hand without having to worry about what other researchers were doing.[69] As listed, Williams published a few papers and one influential book.

All three secured Patents. Williams's Crust Enrichment Process that led to a greatly decreased cost of producing silver was patented and put into operation in 1923. The Continuous flow refining process of 1930 brought considerable royalties to the BHAS at Port Pirie. Linked to this, the human side of Williams is illustrated by his consideration that ensured all the workers involved in the work benefitted, with payments to families being continued after the original workers had died.[70]

Williams received more tangible recognition for his work[71] than did McBride or Read, but each helped in the recovery of the hidden wealth of Broken Hill and all deserve to be remembered for their invaluable contributions.[72]

Acknowledgement

I have to thank Mel Davies, University of W.A. for presenting an earlier version of this paper on my behalf at the Mining History Conference in Kalgoorlie, 2001. Thanks are also due to the late Kathy Bennett, and her successor at the Broken Hill Archives, Brian Tonkin, and to several un-named referees for their positive suggestions for improving the paper.

Endnotes

[1] See for instance H. Watson, 'Notes on Smelting at Broken Hill', *Transactions of the Institution of Mining and Metallurgy*, December 1897, 4 pp. [Reprint in the author's possession].
[2] Roy Bridges, *From Silver to Steel: The Romance of the Broken Hill Proprietary*, George Robertson, Melbourne, 1920; O.H. Woodward, *A Review of the Broken Hill Lead-Silver-Zinc Industry,* Australasian Institute of Mining & Metallurgy*,* 2nd edn, 1965, 520 pp; Geoffrey Blainey, *The Rise of Broken Hill.* Macmillan of Australia, 1968; Alan Trengrove, *What's Good for Australia ... ! The Story of BHP*, Cassell Australia, Stanmore, NSW, 1975; R.J. Solomon, *The Richest Lode*, *Broken Hill 1883-1988*, Hale & Iremonger, Sydney, 1988; W.C. Lacy and John C. Lacy, 'History of Mining and Metallurgy along the Pacific Rim', *Proceedings of the Pacific Rim Congress*, vol. II, 1990, pp. 427-34; W.J.R. Rankin, 'Metallurgy', in Susan Bambrick (ed.), *The Cambridge Encyclopedia of Australia,* Cambridge UP, Cambridge, 1994, pp. 279-80; D.F. Branagan, 'The Broken Hill Orebody, New South Wales, Australia - the first ten geological years', in R.A. Facer & D.F. Branagan (eds), *Mineral Search in the South West Pacific Region. A Memorial to Ken Glasson,* The Eighth Edgeworth David Day Symposium, September 1995, pp. 65-82.
[3] See for instance D. Bergeat, 'On Stelzner's view of the systematic relationship of the garnet-galena deposits at Broken Hill' [in German]. *Zeitschrift Praktische Geologie*, 1897, pp. 314-16; R. Beck, 'Contributions to our knowledge of Broken Hill', *Records of the Geological Survey of New South Wales* [translation from German], vol. VII, 1900, pp. 20-29; Geological Sub-Committee, Geology of the Broken Hill Lode, *Transactions of the Australasian Institute of Mining Engineers*, 15, 1911, pp. 161-236.
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[5] C. Schnabel, *Report on the Metallurgy Treatment of the sulphides of the Barrier Ranges*, Sands and McDougall, Melbourne, 1892.
[6] Bridges, *Silver to Steel*, pp. 197, 200-204; Graeme Osborne, 'Delprat, Guillaume Daniel (1856-1937)', in Bede Nairn and Geoffrey Serle (general eds), *Australian Dictionary of Biography*, vol. 8 (1891 – 1939), Melbourne UP, 1981, pp. 274-76.
[7] Brian Kennedy, *Silver, Sin, and Sixpenny Ale: A Social History of Broken Hill 1883-1921*, Melbourne UP, Melbourne, 1978, p. 95.
[8] W.S. Robinson (edited Geoffrey Blainey), *If I remember rightly*: *The Memoirs of W.S. Robinson 1876-1963*, Cheshire, Melbourne, 1967, p. 89.
[9] 'Alban Lynch', (ed. John Burns), *Leslie Bradford Golden Jubilee Oration*, The Australasian Institute of Mining and Metallurgy, Melbourne, 1987.
[10] See for instance Blainey, *Rise of Broken Hill*, pp. 68-77; Solomon, *Richest Lode*, pp. 69-76; 'Treatment of Zinc Sulphides: an interesting case', in *The Australian Mining Standard,* 26 November, 1903. p. 734.
[11] Blainey, *Rise of Broken Hill*, p. 75.
[12] Trengrove, *What's Good for Australia*, pp. 67-68.
[13] O.H. Woodward, *A Review of the Broken Hill.* See sections on South Broken Hill Mine, pp, 92, 95-6, and papers by W.J. McBride, T.A. Read and G.K. Williams referred to in later sections.
[14] H.W. Worner and I. Newnham, Keynote Address, Annual Conference, the Australasian Institute of Mining and Metallurgy, Broken Hill, 1983, published as 'Advances in Techniques and Technology stemming from Broken Hill', *Bulletin of the Australasian Institute of Mining and Metallurgy* no. 478, September 1983, pp. 15-19. Simon Scott in " 'Supplementary Notes' to Alban Lynch", *Leslie Bradford Golden Jubilee Oration*, p. 52, incorrectly quotes the date of this paper as 1933
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[17] W. Poole, 'Treatment of Broken Hill ores', *Journal and Abstracts 1908-09 Session University of Sydney Engineering Society*, vol. 13, 1908-09, pp. 83-121; E.T. Henderson, 'The History of Ore Treatment in Broken Hill', *Proceedings of the Australasian Institute of Mining and Metallurgy*, New Series [hereafter NS] 72, 1928, pp. 99-112; J. Mouat, 'The development of the flotation process:

technological change and genesis of modern mining, 1898-1911', *Australian Economic History Review,* vol. 36, no. 1, March 1996, pp. 3-31.

[18] For some details of the Delprat versus Potter court case see 'Treatment of Zinc Sulphides: an interesting case', *The Australian Mining Standard,* 26 November 1903. p. 734.

[19] Ralph W. Birrell. *The Role of Mineral Separation Ltd. in the Development of the Flotation Process. Australian Mining Monographs Number 7*, Zlota Press, Strathfieldsaye, Victoria, 2000.

[20] *Ibid*., pp. 15-16.

[21] The 114 files of the Melbourne office of the Minerals Separation Company for the period 1905 to 1913 are now housed in the Archives section of the University of Melbourne and have been examined in some detail by Ralph Birrell, *The Role of Mineral Separation Ltd*. Some basic information about the company archives is available on the Austech Web, April 2004; and 'Minerals Separation', Guide to Records. Notes on the Minerals Separation Collection by Peter Crabb for the Minerals Separation & De Bavay's Processes Australia Pty. Ltd.

[22] Birrell, *The Role of Mineral Separation Ltd*, p. 1.

[23] *Ibid.,* p. 27.

[24] Brian Carroll, *Built on Silver: A History of Broken Hill South,* Hill of Content, Melbourne, 1986, p. 41; see also Robinson, *If I remember rightly*, pp. 40-43.

[25] *Ibid*., pp. 45-46; Woodward, *A Review of the Broken Hill*, pp. 250-51, 460-63.

[26] *Ibid.,* pp. 252-53, Carroll, *Built on Silver,* particularly pp. 47, 52.

[27] E. Cocks and B. Walters, *A History of Zinc Smelting in Britain*. George Harrap, London, 1968, chs 4 to 8, particularly ch. 7.

[28] D.F. Branagan, 'McBride, William John (1879-1970),' in John Ritchie (general ed.) *Australian Dictionary of Biography*, vol. 15, 1940-1980, Melbourne UP, Melbourne, 2000, pp. 159-60. I have only located two photos of McBride, both in-group photos of Officers of the Australian Mining Corps. One group photo is published in D.F. Branagan, 'The Australian Mining Corps in World War 1', *Bulletin and Proceedings of the Australasian Institute of Mining and Metallurgy,* vol. 292, no. 9, December 1987, pp. 40-44.

[29] For this company see H.Y.L Brown, *Record of the Mines of South Australia,* 4th edn, Government Printer, Adelaide, 1908, pp. 9, 70-75.

[30] D.F. Fairweather, 'Wainwright, William (1873-1959)', in John Ritchie *Australian Dictionary of Biography*, vol. 12, Smy-Z, Melbourne UP, Melbourne, 1990, p. 348.

[31] William Hodder, *History of the South Mines,* Broken Hill Archives, Charles Rasp Library, A622.34 HOD, n.d. (c.1965); Carroll, *Built on Silver*, p. x, pays tribute to Hodder, and says Hodder died before his (Hodder's) manuscript was ready for publication. However, while the Broken Hill Archives gives his death as 1979, a pencilled annotation to the manuscript says 1965. This was possibly the date when Hodder began his writing; see also *Ibid*., p. 41.

[32] *Ibid.,* pp. 48-50, 53-54.

[33] L.S. Curtis, *History of Broken Hill: Its rise and Progress*, Frearson's Printing House, Adelaide, 1908, p. 51.

[34] For this section see Hodder, *History of the South Mines*, pp. 66-67, and Bridges, *From Silver to Steel*, ch. 35.

[35] Hodder, *History of the South Mines*, pp. 66-67.

[36] Carroll, *Built on Silver*, p. 41.

[37] Hodder, *History of the South Mines*, p. 78; Broken Hill Associated Smelters, *A Survey of the Lead Smelting and Refining Industry at Port Pirie,* 6th edn, Melbourne, 1963; 'Beginning of Associated Smelters', *Barrier Miner*, 28 July 1915, p. 1, located in Sir Colin Fraser Papers, Baillieu Library, University of Melbourne.

[38] 'Annual meeting of the Broken Hill Rifle Club and McBride's return from Port Pirie (sent there in August 1914)', *Barrier Miner*, 24 July 1915, p. 4.

[39] 'Captain W.J. McBride, M.C.', *Barrier Miner*, 20 June 1917; Alexander Barrie, *War Underground*, Fred Muller, London, 1962, p. 249 (also quoted in Branagan, *Australian Dictionary of Biography,* 2005, p. 589); Branagan, *Australian Dictionary of Biography,* 2000, pp. 159-60; Australian War Memorial (AWM) 28, Collection 2, Box 14 (17), R.A.E. 1st Tunnelling Company, 8 April-13 April, 1917, Recommendation files for Honours and Awards.

[40] The various Broken Hill mining companies, with other associated companies, often with similar directorships, had offices in a single building, Collins House in Collins Street, Melbourne, and for many years important decisions on combined activities were made there, either formally or informally. See Gilbert M. Ralph, MBE, 'The Broken Hill - Collins House Connection: Mining Personalities', *Journal of Australasian Mining History*, vol. 2, September 2004, pp. 198-221.

[41] Branagan, *Australian Dictionary of Biography*, 2000, p. 159.
[42] For aspects of McBride's visit to Burma, see, *Proceedings of the Australasian Institute of Mining and Metallurgy,* NS 39, 30 September 1920, p. lii, and John W. Moule, 'Burma Corporation Ltd: A Description and Review of Early Chinese and Present Day Operations', in *Ibid.,* NS 46, 30 July 1922, pp. 59-101, and figures.
[43] *Ibid.,* pp. 78, 85.
[44] For some aspects of this development see Robinson, *If I remember rightly*, pp. 96-7, 100, 132-35.
[45] Branagan, *Australian Dictionary of Biography*, p. 159.
[46] For some aspects of this company's formation and varying fortunes see Robinson, *Australian Dictionary of Biography*, pp. 100, 121-23, 124, 132, 160; See also Cocks and Walters, *A History of Zinc Smelting in Britain*, ch. 5.
[47] Branagan, *Australian Dictionary of Biography*, 2000, p. 160; (British) Institute of Mining and Metallurgy records, McBride's application for membership (1920s).
[48] Hodder, *History of the South Mines*, p. 37; Branagan, 'Read, Thomas Andrew (1886-1972)', *Australian Dictionary of Biography*, 2002, pp. 65-66. I have not located a photo of Read, although he almost certainly appears in photos taken at Australasian Institute of Mining and Metallurgy conferences, particularly at the Broken Hill Meeting of 1925, photo at Umberumberka Dam, in *Proceedings of the Australasian Institute of Mining and Metallurgy*, No. 59, p. xli. He is also possibly in the Port Pirie Meeting photo, in *Proceedings of the Australasian Institute of Mining and Metallurgy,* NS 47, Sept. 1922, p. xl.
[49] Hodder, *History of the South Mines*, pp. 37-38; P.H. Warren, 'Mechanical Methods of allaying dust,' *Proceedings of the Australasian Institute of Mining and Metallurgy,* NS 42, 1921, pp. 31-100, particularly pp. 31, 69-70; P.H. Warren and T.A. Read, 'Methods and apparatus for the determination of dust suspended in air', *Ibid.*, NS 47, 1922, pp. 297-342; For further information on this topic see, *Further Reports of the Technical Commission of inquiry appointed to investigate the occurrence of industrial diseases in and about the metalliferous mines at Broken Hill*, Department of Labour and Industry, NSW, 1922.
[50] 'Informal presentation by T.A. Read on the milling plants he had visited in South Africa and North America, Broken Hill Branch Notes', in *Proceedings of the Australasian Institute of Mining and Metallurgy*, NS 67, September 1927, p. lxxxi; 'T.A. Read re Taylor sieves, Broken Hill Branch Notes', in *Proceedings of the Australasian Institute of Mining and Metallurg*y, no. 68, December 1927, p. lxxxviii; 'T.A. Read, presiding, opened the discussion on Grinding media for Ball Mills, Broken Hill Branch Notes', in *Ibid.*, NS 89, 18 April 1933, p. xlii. 'T.A. Read's paper on Rotating Impellers presented, Broken Hill Branch Notes', in *Ibid.*, NS 89, 1933, 20 June 1933, p. xliii.
[51] Carroll, *Built on Silver*, p. 70; 'Informal presentation by T.A. Read on the milling plants he had visited in South Africa and North America, Broken Hill Branch Notes'. *Proceedings of the Australasian Institute of Mining and Metallurgy*, NS 67, September 1927, p. lxxxi.
[52] Hodder, *History of the South Mines*; Branagan, *Australian Dictionary of Biography,* 2002, p. 66; Woodward, *Review of the Broken Hill*, p, 131.
[53] Branagan, *Australian Dictionary of Biography,* 2002, p. 66; Woodward, *Review of the Broken Hill*, p. 134
[54] Hodder, *History of the South Mines*; Branagan, *Australian Dictionary of Biography,* 2002, p. 66.
[55] Branagan, 'Williams, Kenneth George (1896-1974)', *Australian Dictionary of Biography,* 2002, pp. 551-52. For a photo of Williams see 'Award of the Institute Medal for 1942 to G. Williams', *Proceedings of the Australasian Institute of Mining and Metallurgy*, no. 129, 31 March 1943, pp. ix-x.
[56] Branagan, *Australian Dictionary of Biography,* 2002, pp 551; Robinson, *If I remember rightly*, pp. 96-97, 100.
[57] Frank A. Green, *The Port Pirie Smelters*, BHAS, Melbourne, 1977. G.K. Williams, 'The determination of certain curves and their application to the Parkes Process', *Proceedings of the Australasian Institute of Mining and Metallurgy*, vol. 58, 1925. p. 47**.** Also see, p. 91, 'Application for Australian patent No. 5681, Improvements in the treatment of silver &/or gold-bearing "crusts" obtained in the refining of lead by the 'Parkes Process' in operation at Port Pirie for the last two years [with an explanation why it is satisfactory]'.
[58] Branagan, *Australian Dictionary of Biography,* 2005, pp. 299-300, 589.
[59] G.K. Williams, 'Description of Continuous Lead Refining at the works of the Broken Hill Associated Smelters Proprietary Limited, Port Pirie, South Australia', *Proceedings of the Australasian Institute of Mining and Metallurgy,* NS 87, 1932, pp. 75-133 (with many figures). A footnote p. 97 in this paper refers to the 1932 patent; G.K. Williams, *The development and application of the continuous lead refining process*, McCarron Bird, Melbourne, n.d. (? 1933).

[60] Branagan, *Australian Dictionary of Biography,* 2002, pp 551-52; Green, *The Port Pirie Smelters*; See also 'Alban Lynch'.
[61] Green, *The Port Pirie Smelters,* pp. 51, 65.
[62] Branagan, *Australian Dictionary of Biography,* 2002, p. 152; 'Congratulations to G.W. Williams', *Proceedings of the Australasian Institute of Mining and Metallurgy,* NS 93, 1934, p. iv.
[63] Branagan, *Australian Dictionary of Biography*, 2002, p. 152.
[64] Rankin, 'Metallurgy', p. 280.
[65] Imperial Smelting Corporation was established in 1929 to take over the assets of the National Smelting Company, see for instance Robinson, *If I remember rightly*, pp. 124-5, and Cocks & Walters, *History of Zinc Smelting in Britain*, chs 3 to 8, particularly ch. 7.
[66] Branagan, *Australian Dictionary of Biography,* 2002, p. 152.
[67] T.A. Read, 'A mechanical disintegrator for slime samples', *Proceedings of the Australasian Institute of Mining and Metallurgy*, NS 47, 1922, pp. 289-90; T.A. Read, 'Concentrating Practice at the South Mine, Broken Hill', *Ibid.*, NS 88, 1932, pp. 247-340; T.A. Read, 'Rotating Impellers for Machines working the (Froth) Flotation Process', *Ibid.*, NS 91, 30 September 1933, pp. 377-96; T.A. Read, 'The new lead and zinc flotation sections of the concentrator of South Broken Hill Limited', *Ibid.*, NS 98, 1935, pp. 305-48. A further paper, listed by Woodward, *Review of the Broken Hill*, p. 508, is credited to J.A. Read, C.W. Thomas, and K.P.W Parsons, 'The development of flotation for the treatment of lead - silver - zinc ores at Broken Hill', in *Quarterly of the Colorado School of Mines*, 56 (3), p. 417. [n.d. or full pagination given]. This is almost certainly by T.A. Read and his associates, but I have been unable to access this paper. W.E. Wainwright, and T.A Read, 'Concentrating Practice at the Broken Hill South Ltd', *Proceedings of the Australasian Institute of Mining Engineers,* NS 44, 1921, pp. 225-94; P.H. Warren, and T.A. Read, 'Methods and apparatus for the determination of dust suspended in air', *Ibid.*, NS 47, 1922, pp. 297-342; See also W.E. Wainwright and J.C. Cunningham, 'Description of New Plant at South Mine, Broken Hill', *Ibid.,* NS 43, 1921, pp. 201-18.
[68] W.E. Wainwright, and W.J. McBride, 'Fine Grinding Tests: Tube Milling and Grinding Pans, Broken Hill South Mine', *Ibid.*, IV, February 1909, pp. 1-21, plus seven folding plates; See also, 'Broken Hill Branch Notes', *Ibid.,* NS 36, 31 December 1919, pp. 108-109.
[69] D.F. Branagan, *Australian Dictionary of Biography*, 2002, p. 152.
[70] Green, *Port Pirie Smelters,* p. 51, Branagan, *Australian Dictionary of Biography*, 2002, p. 151.
[71] Doctor of Engineering, the Institute Medal of the AustIMM (1942), and in 1951 the gold medal of the (London) Institution of Mining and Metallurgy, see, 'Award of the Institute Medal for 1942 to G. Williams', *Proceedings of the Australasian Institute of Mining and Metallurgy,* no. 129, 31 March 1943, pp. ix-x, with photo; Australasian Institute of Mining & Metallurgy, *G.K. Williams Memorial Volume*. Symposia Series, no. 43, Melbourne, 1985.
[72] Apart from the papers listed in endnotes for the introductory section, there is much useful information in C.C. Freeman, 'Froth Flotation at Broken Hill', *Proceedings of the Australasian Institute of Mining and Metallurgy*, NS 36, 31 December 1919, pp. 89-105; I.W. Wark, 'The Chemical Basis of Flotation', *Ibid.,* 90, 1933, pp. 83-124 [first given as a lecture at Broken Hill, 30 Nov. 1932]. The Centenary of Flotation Symposium, held in Brisbane in June 2005 focussed mostly on recent developments, although the paper by Alban Lynch and others (A.J. Lynch, J.S. Watt, J.A. Finch and G.J. Harbort, 'A History of Flotation Technology', Keynote Address, Century of Flotation Symposium, Brisbane, Australasian Institute of Mining and Metallurgy, June, 2005) presented accounts of major steps in the Australian story, particularly showing diagrams of the changing designs of flotation cells. The paper, and others from the symposium, can be viewed on the AustIMM website.