A difficult challenge: Processing complex ore at Bethanga

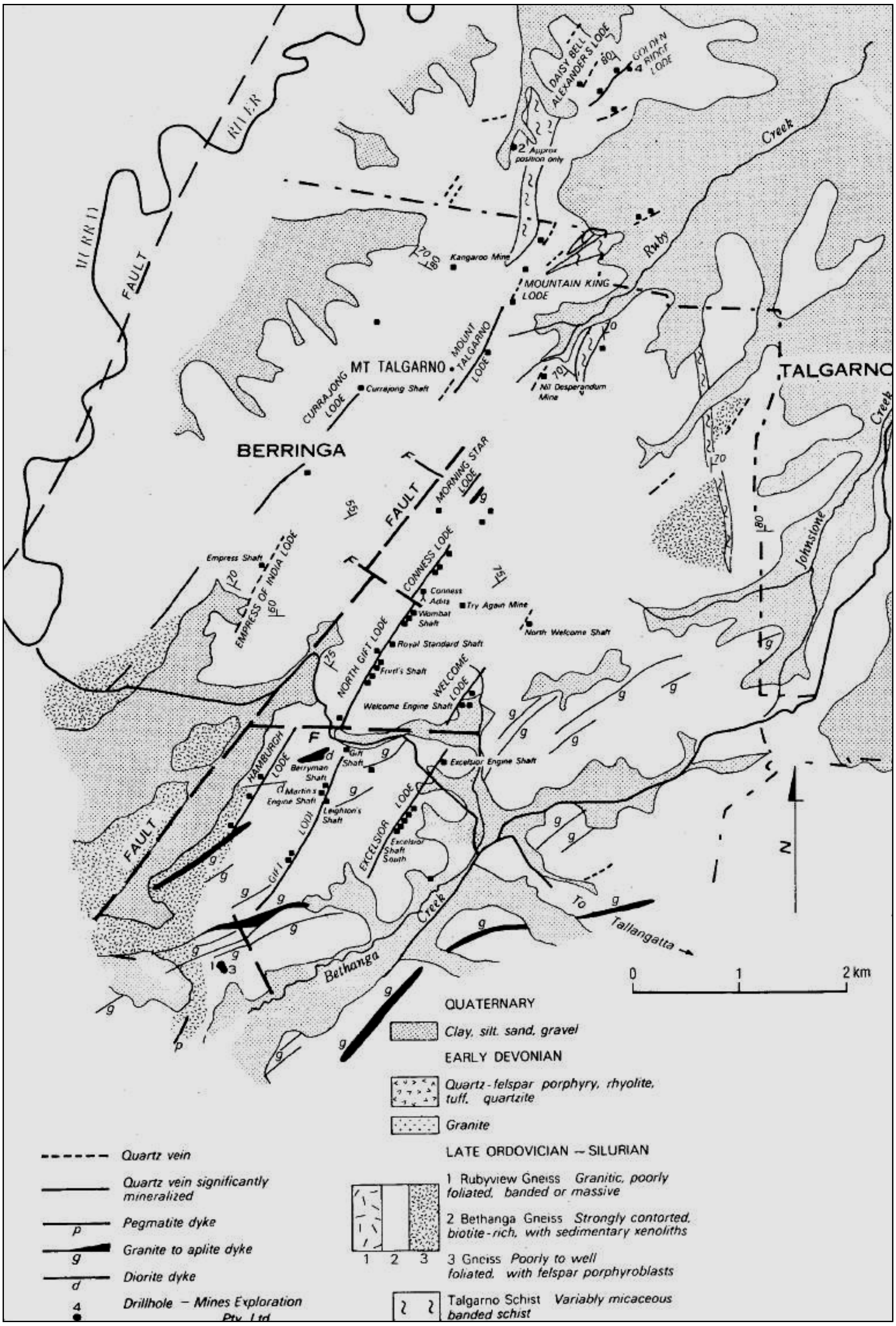
By JIM ENEVER

Gold was discovered in the gossans of several mineral lodes in the Bethanga area of Victoria's upper Murray valley in September 1875.[1] By August 1876, a number of relatively thin, parallel, near vertical ore bodies (Fig.1) had been defined, and small claims were being worked along the strike of these lodes by parties of miners recovering gold from the near surface oxidised zones, using the simple free gold recovery techniques common of the time.[2] By 1877, most of the claims had reached a depth of around 20 metres and entered the primary sulphide mineralisation (locally termed 'Black Jack') from which the gold could not be readily recovered using the previous techniques.[3] The September 1877 report by the mine surveyor suggested that copper ore had been discovered beneath the oxidised zone of almost all claims and that exploitation of this ore might 'provide an alternative for miners disappointed by dwindling gold returns'.[4] During 1877 and early 1878, a total of 43 applications were made for mineral leases to mine copper, predominantly by small parties of resident miners who had been previously working for gold,[5] and by early 1878, 450 miners were reported to be at work.[6] During this early phase of copper mining, stockpiles of ore were amassed pending the emergence of a viable means of processing the ore but appeals for the erection of a centralised treatment works, along the lines of the Government gold batteries that had been set up throughout the State, fell on deaf ears.[7] Attempts to provide such a service privately were short lived, effectively bringing to an end Bethanga's period as a 'Poor Man's Diggings'.[8] The search for a solution to the processing of the highly refractory ore was ultimately to rest with capital interests established to mine and process their own ore, but it took 15 years and required a degree of tenacity unimaginable at the time to eventually achieve a viable treatment. In those 15 years, Bethanga became a veritable test bed for the trial of nearly all contemporary developments in the processing of complex sulphide ores. Failure followed failure and vast amounts of capital were expended until success was finally achieved.

Early attempts at ore treatment

Tests by the government analyst revealed the ore to be a complex mixture of iron, copper and arsenic sulphides, together with gold, silver and minor amounts of other materials.[9] From 1877, reports describe parcels of ore being sent by different mining parties to established processing centres in Australia and overseas for treatment, generally at a loss.[10] Among the interested parties at this time was John Wallace (Fig. 2), a major figure in north-east Victorian mining and future member of the Victorian Parliament, who was to become the persistent, if somewhat erratic, driving force behind mining at Bethanga. In July 1877, Wallace was reported to be erecting a purpose built smelting works in Footscray (Melbourne) specifically to test the Bethanga ore.[11] Several parcels of ore amounting to around 200 tons were apparently sent off to be tested in these works. Details of the process employed and the results of the trial smelts do not appear to have been openly published. Assays of the ore were, however, encouraging, revealing a copper content up to 14 per cent, 'comparing favourably with South Australian experience'.[12] In addition, the ore was found to contain over an ounce of gold per ton, a significant bonus.

Figure 1: *The geology of the Bethanga Mineral Field.*



Source: G.W. Cochrane, *Copper, Lead, Zinc and Barium Deposits of Victoria,* Bulletin, No. 6, Geological Survey of Victoria, 1982.

Figure 2: *John Alston Wallace.*

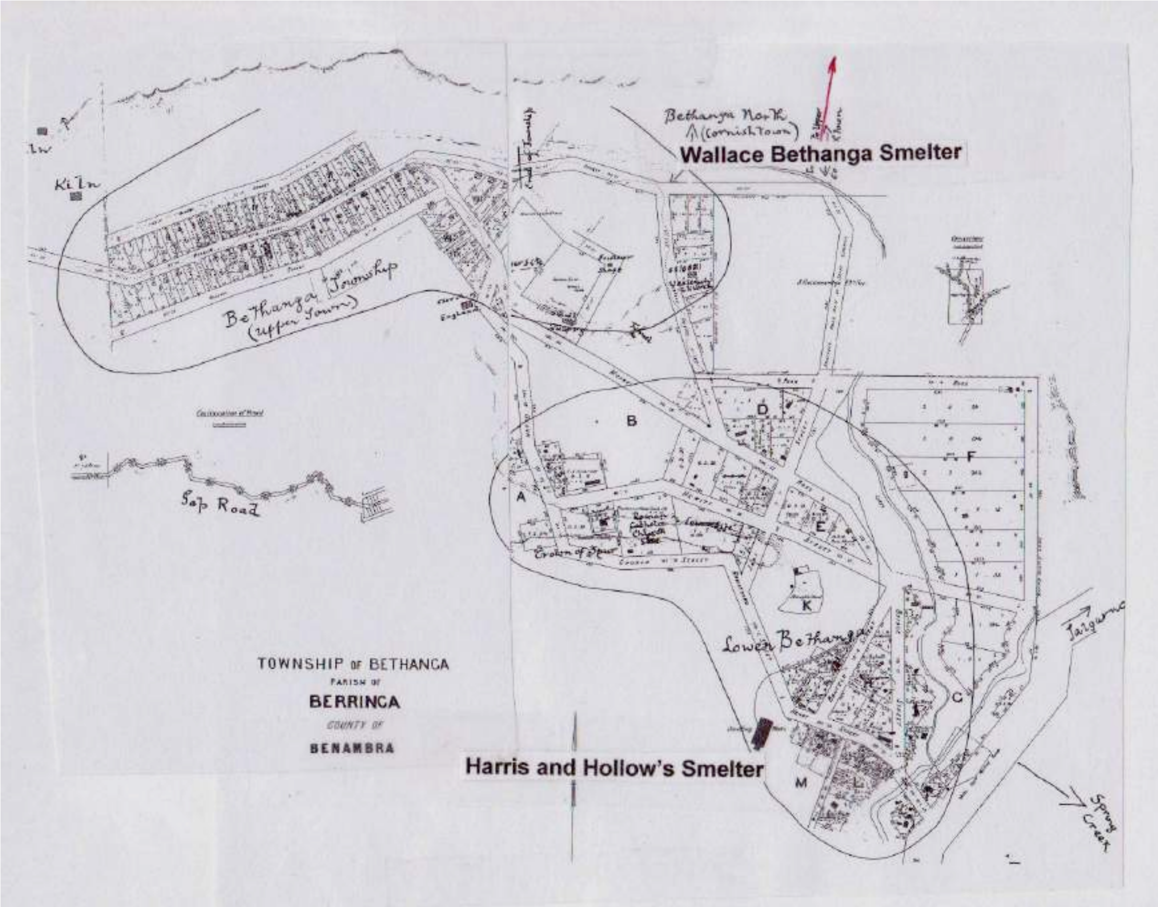
Source: *Cyclopedia of Victoria*, *Vol 1,* The Cyclopedia Company, Melbourne, 1903.

The first to make a serious attempt to treat the ore locally were Harris and Hollow, a gold mining partnership from Rutherglen. In October 1877, they applied for a mineral lease away from the main ore bodies, in what was to become the township of Lower Bethanga (Fig. 3).[13] It was on this lease that they established the Great Eastern Copper Smelting works to conduct a direct smelting operation employing the 'Welsh Process'. By January 1878, the first of three reverberatory furnaces was in operation, producing regulus for export.[14] Two further reverberatory furnaces were in operation by mid 1878, followed by an additional calcining furnace to pre-treat the ore prior to smelting.

At first, Harris and Hollow were apparently prepared to treat ore from the independent lease holders, but by late 1878 they were reported to be working the Gift lode in their own right and treating the ore in their works, to the exclusion of other parties.[15] By this time they were reported to have invested £10,000 in the smelting plant and to be employing 71 men in the works, producing six tons of regulus per week.[16]

In early 1878, another mining partnership, Redelin and Davies, acquired a mineral lease adjacent to the Welcome lode in what was to become Upper Bethanga (Wallace Bethanga Smelter site, Fig. 3), with a view to erecting smelters to process their ore. Reports describe three reverberatory furnaces being erected, with regulus being produced by April 1878.[17] The Bethanga Copper Mining and Smelting Company was registered that same month and absorbed the interests of Redelin and Davies,[18] major shareholders in this company being John and Peter Wallace. By late 1878, this company was reported to be producing regulus from ore mined from their own leases, while employing around 75 men and investing some £13,000.[19]

Figure 3: *Plan of Township of Bethanga, circa 1880, showing major smelting sites.*



Source: June Philipp, *A Poor Man's Diggings-Mining and Community at Bethanga, Victoria, 1875-1911,* Hyland House, Melbourne, 1987.

After a promising start, smelting activities at Bethanga were to come to a crisis point very quickly. The mine surveyor reported in March 1879 that Harris and Hollow's works were at a standstill and that Wallace's works had been let to a tributer.[20] In fact, both operations had effectively gone into hibernation by the end of 1878. Loss of gold into the slag produced during smelting was a major issue. On top of this, a relatively low copper content in the regulus being produced, and the lack of full credit for the assayed gold and silver content of the regulus during overseas refinement, was reported to have made treatment using the 'Welsh Process' unprofitable.[21]

From 1879 to 1883, Harris and Hollow's works operated sporadically, apparently with a progressive transition from direct smelting to the use of the 'wet process'.[22] Reasonable smelting results were apparently obtained if the ore was carefully selected, presumably to be somewhat oxidised.[23] From the end of 1881, however, reports talk only of the use of the 'wet process' by Harris and Hollow, now operating as the Bethanga Mining Company NL.[24] It is not clear from the contemporary accounts exactly what the 'wet process' as pursued by Harris and Hollow might be, although Victorian Government analyst, Cosmo Newbery, was at this time promoting a 'wet process' based on roasting of the ore followed by leaching out of the copper and silver content, leaving the gold to be recovered.[25] Reports by the Bethanga Mining

Company for June 1882, December 1882 and June 1883 show income from gold sales, but not copper.[26] Other contemporary reports talk of on-going loss of gold in the tailings emanating from the plant.[27] By the end of 1883, Wallace had managed to acquire and merge many of the independent leases under his control, and by absorbing Harris and Hollow's interests - with the 'wet process put aside - he became the undisputed driver of all mining activities at Bethanga.

In pursuit of a direct smelting solution

Wallace was convinced that Bethanga should be primarily a copper producer, with gold as a by-product, and that the necessary processing would have to be based on direct smelting and conducted on site. During the late 1870's, advances had been made in the smelting of copper ores that held out promise for treating the Bethanga ore. From 1878 on, the *Mining Journal* reported on experiments with the Bessemer process applied to the smelting of copper sulphides, most notably conducted by Hollway in the UK.[28] In essence, the process as patented by Hollway involved:

> a method of treating both iron and cupreous iron pyrites in such a manner at to utilise [oxidation of] the sulphides a fuel … [obtaining] in separate groups the metals originally contained in the pyrites … in the metallic state, or in the form of sulphides or oxides … The furnace [used being] a modification of the Bessemer converter … so closed at the top as to prevent the escape of [the various components in the vaporous state] … [Air is driven in] at or near the bottom of the furnace, and by increasing or decreasing the quantity [the] temperature of the operation [is regulated]. Sulphide of iron being oxidised in preference to sulphide of copper, the latter always accumulates, [and can be withdraw as a] regulus whenever sufficiently rich in copper.[29]

Claims were made that this process could handle complex refractory ores such as Bethanga's, with a much reduced fuel bill, whilst allowing the minor metallic components to be collected and subsequently refined from the copper regulus or matte produced.

This was the cue for Wallace to be galvanised into action. From 1880, reports appeared of various items of machinery arriving at Wallace's works and a frenzy of activity taking place on the site as experiments were made around Hollway's process, apparently with limited success.[30] To finance these activities, Wallace floated the Wallace Bethanga Mining Company in 1882, with a nominal capital of £80,000 and a predominant shareholding by Wallace himself.[31] In 1884, it was reported that 'three expert smelters from Swansea' had been procured to work at Bethanga, and the services of 'Mr Vautin, metallurgist to the Cobar Copper Company', retained to supervise operations.[32] Vautin had successfully demonstrated his version of Hollway's process at the Great Cobar mine by this time, and had been engaged to erect a smelting works based on this principle at Cobar.[33] It is not clear how much of Vautin's version of the process was translated to Bethanga, but he undoubtedly had impact on the progress of events.

In February 1885, the *Ovens and Murray Advertiser* carried an advertisement for carters to carry ore from the Gift, Leightons and Conness Mines to the smelter works at the rate of 40 tons per day.[34] In March 1885, full scale smelting commenced with a fanfare,[35] the process that had finally evolved from the years of experimentation being described by a number of reporters:[36] in essence, the process involved first breaking and calcining the run of mine ore in heaps in the open air near to the mine openings to remove most of the arsenic; this was followed by treatment in a blast furnace at the works to produce a matte containing copper, iron, gold, silver and a small amount of sulphur; the molten matte was then run into the centrepiece of the operation, 'The Wallace Patent Converter', where a high-pressure blast of air was passed through the molten matte to dispel the sulphur as a gas and oxidise the iron to allow it to form a slag, with silica added to the converter as a flux. The remaining copper, gold and silver was collected as a 'rich copper regulus' from which the gold and silver could be separated from the copper. In the words of Cosmo Newbery,

> Though only a few words are necessary to give an outline of this process, failure has followed failure in overcoming practical details, but now success seems to have been achieved, and a fairly cheap process provided for treating poor refractory ores.[37]

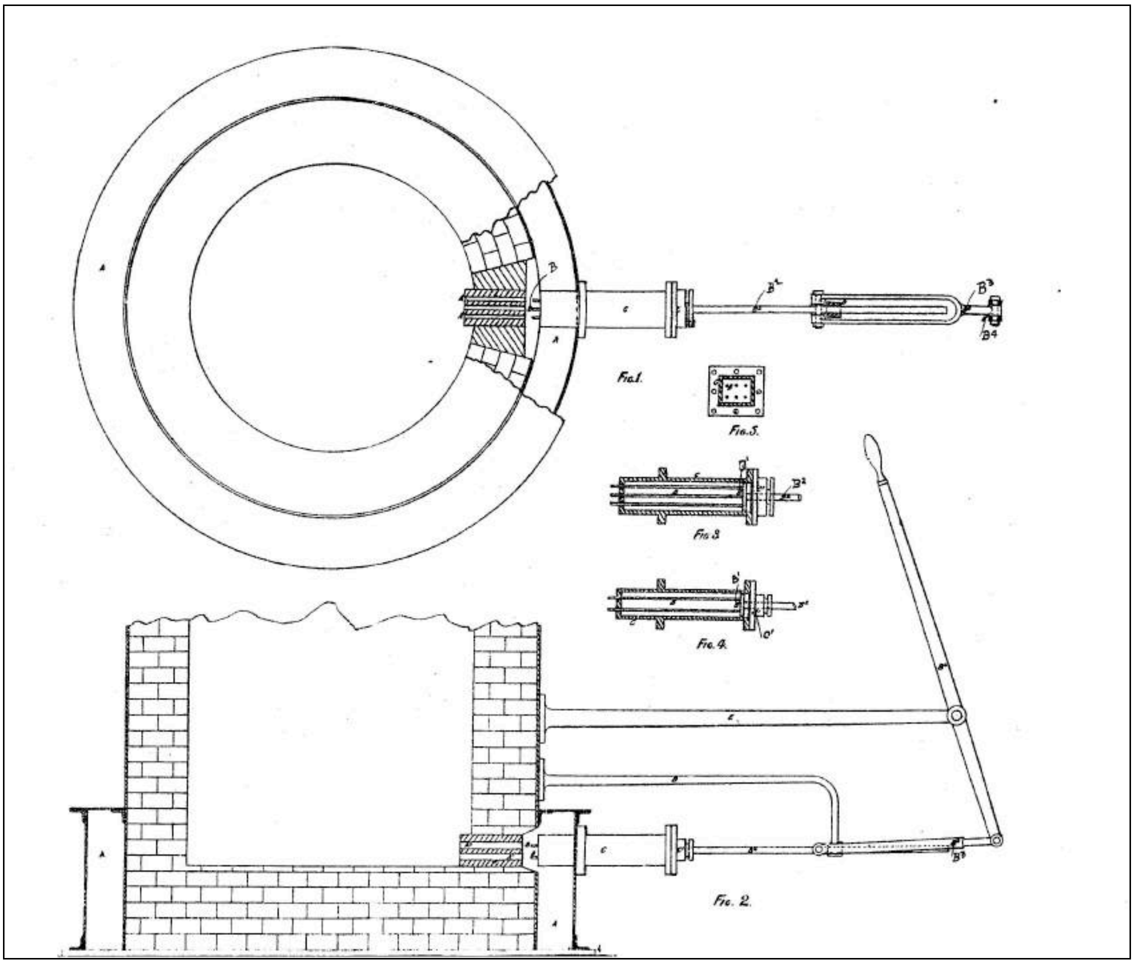
These were to prove prophetic words in the years to come.

The novel idea incorporated in the converter and subject to patent applications appears to have revolved around an arrangement to ensure that air blast holes (tuyeres) did not become blocked by molten and/or semi solidified material during operation.[38] In 1881, an application for a patent covering this idea was granted in Victoria to Thomas Martin, Wallace's works manager, with Wallace as assignee.[39] Figure 4 is a simplified sketch of the apparatus as attached to the patent application. At the centre of the invention was a system of push rods designed to be moved in and out through the tuyeres to keep them clear, operating through stuffing boxes so as to allow a positive air pressure to be maintained.

In his March 1885 report, the mine surveyor described the successful results of the first trial of the system, in which 117 tons of ore were treated in a week. The *Ovens and Murray Advertiser* claimed that up to 600 tons of ore, valued at £3 per ton (presumably including the gold and silver value) could be treated per week at a treatment cost of £1 per ton.[40] If achievable, this would have certainly marked Bethanga as a viable producer. In mid 1885, it was reported that 79 men were employed and that the works were running smoothly, albeit with on-going alterations to the plant.[41] In his account attached to the annual report of the Mines Department for 1885, Cosmo Newbery noted that upward of 3,000 tons of raw ore had been concentrated into regulus by this time, at a cost around £1 per ton, all of which had been shipped to Germany for refining to recover the gold and silver content.[42] The realisation of the full value of the precious metals (particularly gold) contained in the regulus was by this time emerging as being central to the viability of the smelting operation.

During 1886 and 1887, continuous changes were made to the regulus smelting process, whilst experiments were conducted to develop an on-site refining method that would avoid the critical costs of shipping regulus overseas for refining.

Figure 4: *Wallace's patent mechanism for keeping air blast holes clear.*



Source: Victorian Patent No 3126, Patent Records, State Library of Victoria, 1881.

Throughout 1886 and 1887, there were reports of further smelt runs, with the regulus in each case being sent to Germany for refining, despite attempts to develop on-site refining.[43] There is no direct evidence of the results of the further processing in Germany, but only a hope that if the results were satisfactory, a dividend might be paid.[44] It can only be assumed that this did not happen, there being no reports revealing the financial position of the company for this period. By December 1887, the mine surveyor reported that the works manager, Thomas Martin, who had set about altering the configuration of the smelting furnaces, had made great improvements to the process. He had largely overcame previous problems with production of regulus, particularly the unwanted creation of large furnace blocking lumps of iron containing much of the gold, locally referred to as 'bears'.[45] Despite all the improvements that had been made to the smelting furnaces by the end of 1887, the achievement of a viable on-site refining method remained elusive.

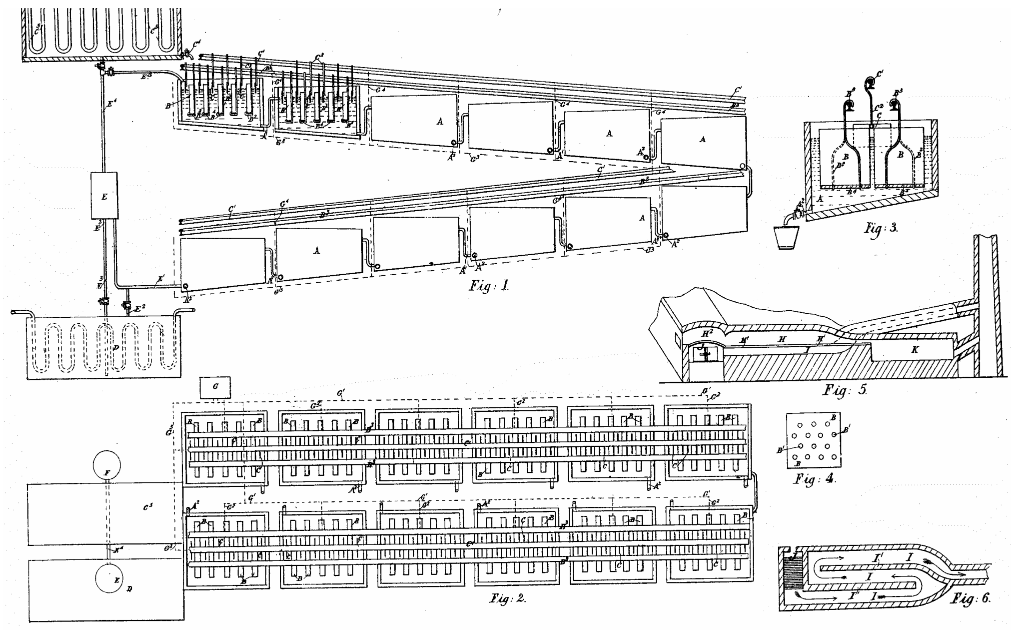
Toward a refining process

Reports from early 1886 describe attempts at refining being conducted on site by Vautin.[46] There is no clear evidence of exactly what was trialled, nor of the success or otherwise of this activity, except in the on-going search for alternative refining solutions. Wallace showed himself open to approaches from promoters, taking a personal interest in a series of generally unsuccessful trials and seemingly having an open cheque book. Some trials involved sending parcels of ore or regulus away, while others, such as those described below, were conducted on site. Details of the trials conducted off site were not generally published, but all proved to be ultimately uneconomic.[47]

An early example of Wallace's willingness to countenance speculative ideas occurred during a trial refining of a parcel of regulus using cupellation.[48] After making changes to the smelting plant to accommodate the trial, approximately eight tons of regulus was treated. This consumed about the same amount of metallic lead that had been brought to site from Melbourne at considerable expense to provide the necessary medium to extract the gold from the molten regulus. The lead/gold mixture produced by bringing the lead into contact with the molten regulus was subsequently cupelled to liberate the gold. The result of this was five to six ounces of gold recovered against an assay value of the regulus treated of around 96 ozs. The changes made to the smelting plant were quickly reversed and the idea put to bed.[49]

The mine surveyor reported in December 1886 that Dr Franz Wunderlich was at Bethanga and experimenting with an electrolytic process for refining the regulus to separate the various components.[50] Wunderlich apparently had a parcel of regulus that had previously been sent away and returned, and re-smelted into thin slabs to act as electrodes.[51] These slabs were subject to his patented electrolytic process (Fig. 5).

Figure 5: *Wunderlich's patent electrolytic refining apparatus.*



<u>Source</u>: Queensland patent application by Franz Wunderlich, A13127/236. National Archives of Australia.

In essence, the apparatus consisted of a series of wooden troughs lined with sheet lead arranged to allow the electrolyte (a dilute solution of copper sulphate mixed with sulphuric acid) to move progressively from one chamber to another, leaving any sludge containing the valuable by-products in the bottoms of the chambers from whence it could be periodically removed. Suspended in the solution were interleaving anodes made from plates of regulus (approximately 50mm thick by 500mm square) and cathodes in the form of a light copper framework upon which the copper in solution would precipitate. Steam to heat the solution was supplied through pipes and a dynamo provided electricity.[52] The process was claimed to take from a half to two days.

After expenditure of around £2,500, the day finally arrived when the results of the first trial were to be demonstrated to the assembled directors:

> The expectant directors waited for their cake of gold-for the matte used to run 56 per cent of copper and 32 oz. per ton of gold - from this parcel. The doctor came to his final smelt, poured his cake and turned it over. His exclamation, "Got dam", and his hurried departure left the onlookers in no doubt as to this process being before its time.[53]

The net result of the trial was about 12 pounds of refined copper, but no gold.[54] In the mine surveyor's view, failure of this trial was due to an inadequate electricity supply, given that a battery rather than a dynamo appears to have been used. This failure brought a premature end to experimentation with what was eventually to become the electrolytic refining process for copper.

Although, apparently, attempts to arrive at a viable refining process continued throughout 1887, by 1888 the focus had changed from the simultaneous production of copper and precious metals by direct smelting, to concentration on recovery of the gold content of the ore as the primary objective. Most effort in this direction went into the more or less systematic development of the chlorination process.

The chlorination process

Chlorination seems to have been attempted on Bethanga ore as early as 1884.[55] Sketchy reports talk about trials of the chlorination process using chlorine gas being conducted, apparently without success.[56] At about this time, Cosmo Newbery and Claude Vautin, both of whom had connections to Bethanga, were experimenting toward the 'Newbery-Vautin' process (patented 1886) when utilising a closed reactor with chlorine gas under pressure.[57] Although there is no clear evidence that the early trials of chlorination at Bethanga involved the use of this technique, it is a distinct possibility.

In 1889, Wallace entered into an arrangement with the Metals Extraction Company of London to implement their patented process for the treatment of refractory ores. The process, based on progressive leaching and precipitation of the base metal constituents, followed by chlorination in vats to recover any gold remaining, was originally developed at the well known Fahlun works in Sweden.[58] The chlorination component of the process was attributed to Henrik Munktell, and formed the basis for the eventual on-going development of chlorination at Bethanga.[59] The Metals Extraction Company acquired the patent to the Fahlun process and had a plant commissioned at Llanelly in Wales, where they successfully demonstrated the process on a range of refractory ores. The arrangement struck between the Company and Wallace involved a commitment by Wallace to finance construction of the necessary plant for a trial of the process at Bethanga and to pay for the various reagents, and for the Company to provide experts to supervise the trial.

NSW Chief Mining Surveyor, E.F. Pittman, who witnessed the operation, provided a detailed account of the trial:

> calcining of the ore in heaps in the open air, crushing in a rock breaker, pulverising in the dry state, roasting with or without salt, leaching in closed vats with hot water, collection of the water containing the copper in solution and precipitation of the copper by means of scrap-iron, treatment of the ore in the same vats with dilute sulphuric acid to remove the suboxides of iron, etc., treatment in the vats with chlorine under pressure and collection of the liquor containing the gold in solution, precipitation of the gold with sulphate of iron, collection of the precipitated gold, smelting with litharge and cupelling.'[60]

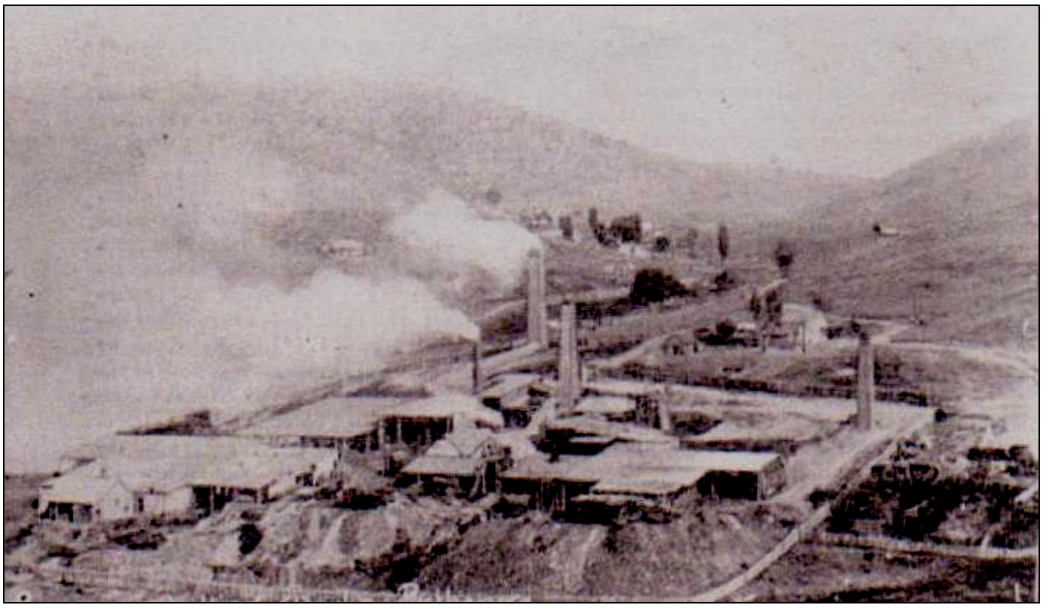
Calcining was continued until 'combustion of the sulphur and arsenic ceased'. Crushing and grinding of the calcined ore was aimed to produce a product that would pass a screen of '144 holes per square inch'. Roasting was conducted in a reverberatory furnace with a 'inclined hearth', and was continued until testing revealed that the material contained no more sulphides of copper or iron. The roasted material was subsequently treated in lead-lined, circular wooden vats of about 'half a ton capacity'. The vats were charged with ore from the top before a sealed lid was put in place. Liquid reagents entered the vats from the bottom at a positive pressure of about 'half an atmosphere', and exited through the lids. The vats were arranged in banks such that the various stages of the treatment process could be carried out sequentially, the liquors exiting the first vat in a bank being connected to the inlet of the second vat and so on. This arrangement was designed to ensure optimum use of the reagents. The first stage of the leaching process involved the circulation of hot water to recover soluble copper, the copper being precipitated on to scrap iron in tanks. Following this, dilute sulphuric acid was circulated until all iron was removed from the material being treated. The final chlorination stage was then initiated by the introduction of a mixture of sulphuric acid and chloride of lime solution to the vats to produce the active chlorine required for the recovery of the remaining gold. Chlorination typically took about three days during the trial. The pregnant liquor derived from chlorination was collected in a lead lined vat, heated to about 150° F, and the gold precipitated by the addition of iron sulphate solution saved from the copper precipitation stage.[61]

In testimony given to the 'Royal Commission on Gold Mining in Victoria' being held at the time of the trial, the Metals Extraction Company experts claimed that their process could recover 80 per cent of the gold remaining after the base metals were removed, with a cost for the reagents of from two to 15 shillings per ton.[62] If achievable, this would make the processing of the ore by this method an attractive proposition.[63] Pittman gave figures that suggested 20 per cent of the gold in one trial had been lost in the tailings, but could not comment on the overall gold recovery efficiency due to a mishap that occurred during final processing of the gold concentrate. Pittman attributed what he considered to be an excessive loss of gold in the tailings to poor quality reagents.[64] Although Pittman saw merit in the process, in Wallace's view the outcome was not a commercial success.[65] This appears to have brought to an end Wallace's relationship with the Metals Extraction Company, but by no means his interest in the Munktell process.

Apart from brief flirtations with other versions of the chlorination process under the supervision of visiting experts, further development of the technique at Bethanga during the early 1890s focused on refinement of the Munktell process, primarily by resident works manager Thomas Martin.[66]

By 1894, calcining in the open air had been discontinued, in recognition of the negative impact of arsenic fumes on health.[67] The raw ore was now sent directly to a rock crusher, followed by grinding in a ball mill to a much finer size than in earlier times, prior to roasting. Alterations had been made to the configuration of the roasting furnaces to overcome the inadequate roasting thought to lead to loss of gold encountered in earlier times. The roasted ore was sent directly to the chlorination vats. By this time the size of the chlorination vats had been increased to about three-and-a-half tons capacity. The vats were left open at the top to facilitate charging with the roasted ore. The reagents were also introduced from the top and left to percolate down and to be eventually removed from the bottom (usually after about three days). The vats were arranged in banks on two levels, with the pregnant liquor from the vats on the top level being fed into the lower level vats. Gold and silver were recovered from the lower vats by the addition of sulphur dioxide before the liquor was finally fed into large precipitation tanks where the copper was recovered using scrap iron.[68]

Figure 6: *Wallace Bethanga Chlorination Works, circa 1897.*



Source: *The Town and Country Journal*, 20 March 1897.

In 1894 Wallace floated the Wallace Bethanga Copper and Gold Mining Company Ltd. Half yearly reports of this company during 1894, 1895 and 1896 showed continued investment and income from gold sales (but not copper).[69] During 1894 and

1895, investment was made in the 'Nicholas Process' being developed at Bethanga by James Nicholas.[70] A patent was applied for in Victoria in 1894 for this process, with Nicholas as the inventor and Wallace as his assignee.[71] In essence, the process revolved around the use of nitro hydrochloric acid as a reagent during chlorination. The advantages of this were not clearly set out in the application. The application was refused and there is no clear evidence that the Nicholas process was ever applied routinely at Bethanga.

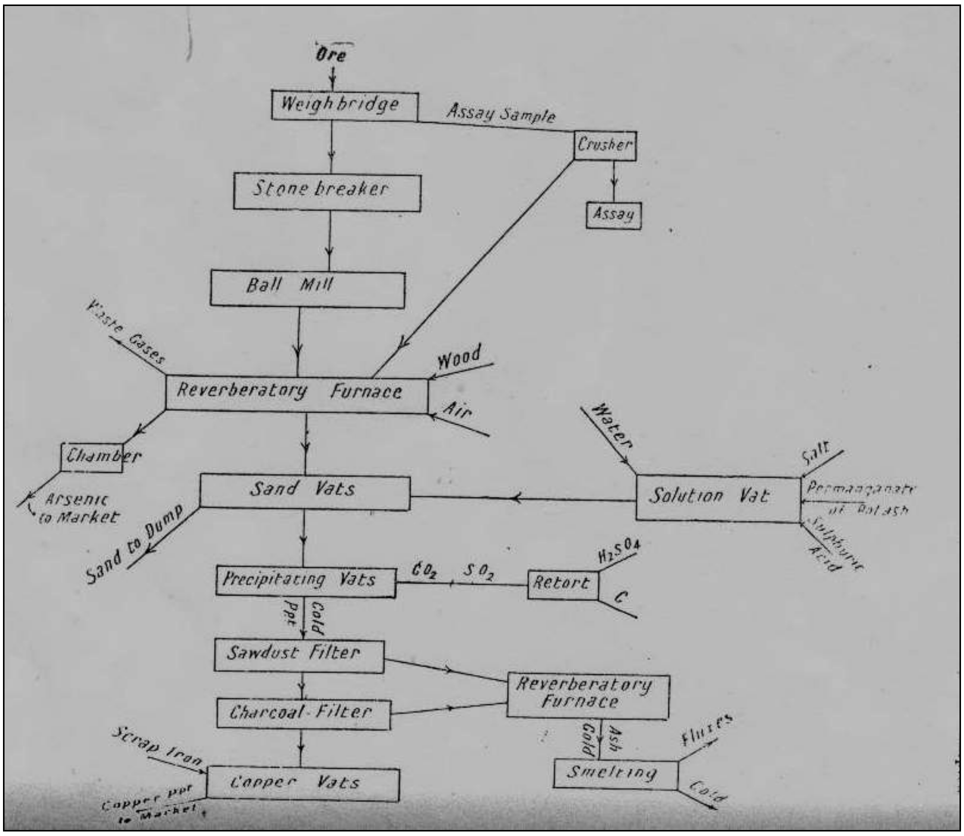
By 1895, the treatment process was developed enough for Wallace to see an opportunity to recover his investment by promoting a company in the UK during a boom period for Australian mining shares.[72] Bethanga Goldfields was registered in 1895 and all assets of the Wallace Bethanga Copper and Gold Mining Company had been transferred to the new company by the end of 1896. Wallace became a local representative of this company, and Martin remained as works manager. Martin continued to make progressive refinements to the treatment process that improved its efficiency and reduced costs. In 1897, a NZ promoter patented the Etard chlorination process in Victoria.[73] The central features of the Etard process were progressively introduced into the Bethanga treatment scheme, including the use of relatively shallow leaching vats fitted with agitators, and pebble/sand filter beds on false bottoms.[74] After a leaching period, typically of around three days' duration, the pregnant liquor could be drawn off from below the sand filters and sent off to precipitation tanks to remove the gold and subsequently copper, from solution.[75]

Another feature pioneered in the Etard process was the use of permanganate of potash as a component of the leaching solution.[76] It is not clear at what point this might have been trialled at Bethanga, but eventually a formulation developed by Professor Black of Otago University that was claimed to overcome the problems encountered when treating copper bearing ores was introduced.[77] The formulation in question was a mixture of common salt, sulphuric acid and permanganate of potash. The advantages claimed for this formulation were that the filters did not become clogged as they often did with other reagents; that chlorine gas was not liberated to the detriment of the work force; and that the addition of the permanganate allowed the progress of the leaching process to be continuously monitored by the colour of the solution.[78] The introduction of this formulation appears to have been the last significant refinement to the chlorination process at Bethanga during Wallace's time. In the early 1900s, Clark published a detailed description of the process ultimately developed there. This is summarised in diagrammatic form in Figure 7. At this stage the plant (Fig. 6) included six hand rabbled roasting furnaces constructed to allow for progressive increase of the roasting temperature as the ore was moved forward during the roasting process, and 11 shallow leaching vats of varying capacity (7, 13 and 16 tons). In its final format, the treatment process was claimed to recover from 93 to 96 per cent of the gold present in the ore, as well as copper and arsenic as saleable by-products.[79]

On the look out for alternatives

Interspersed with the sometimes stop/start development of chlorination throughout the 1890s, Wallace was always on the look out for alternative treatment schemes that might fill any holes in the path of progress. Any new process that might offer promise was usually given a go.

Figure 7: *Diagrammatic summary of the treatment process, circa 1900.*



Source: Donald Clark, *Australian Mining and Metallurgy*, Critchley Parker, Melbourne, 1904.

In 1891, a new development of the well established amalgamation method for gold recovery was given a trial. The new system, patented in Victoria by Johnson, Field and Beeman in 1890, promised to overcome the problem of the 'sickening' of mercury amalgam common when treating refractory ores by amalgamation, a problem that had been encountered previously when attempting to treat the Bethanga primary ore.[80] 'Sickening' was the term used to describe a change in the surface chemistry of mercury particles such that gold would not form a stable amalgam with it. The new patent involved the addition of metal salts (usually zinc) to the pulp being treated, and then generating hydrogen gas in close association with the mercury particles by adding an acid or caustic solution to act on the free metallic component. By this means, a stable gold-mercury amalgam could be formed, even in the presence of the interfering constituents in the ore. According to the inventors, the patent could be applied in any type of amalgamating device.

The Johnson, Field and Beeman process was apparently successful in an early trial at Bethanga, returning 83 per cent of the gold assay value of the ore.[81] It is not, however, clear from reports, exactly what type of ore had been treated in this case. By mid 1891, preparations were underway for trials of the process on the primary ore.[82] The lack of further reports on these trials suggests that the modified amalgamation process was not going to be a viable alternative. The process does not appear to have gained wide usage for the treatment of complex ores elsewhere in Australia, chemical treatments such as chlorination and cyaniding coming to dominate from the 1890s.

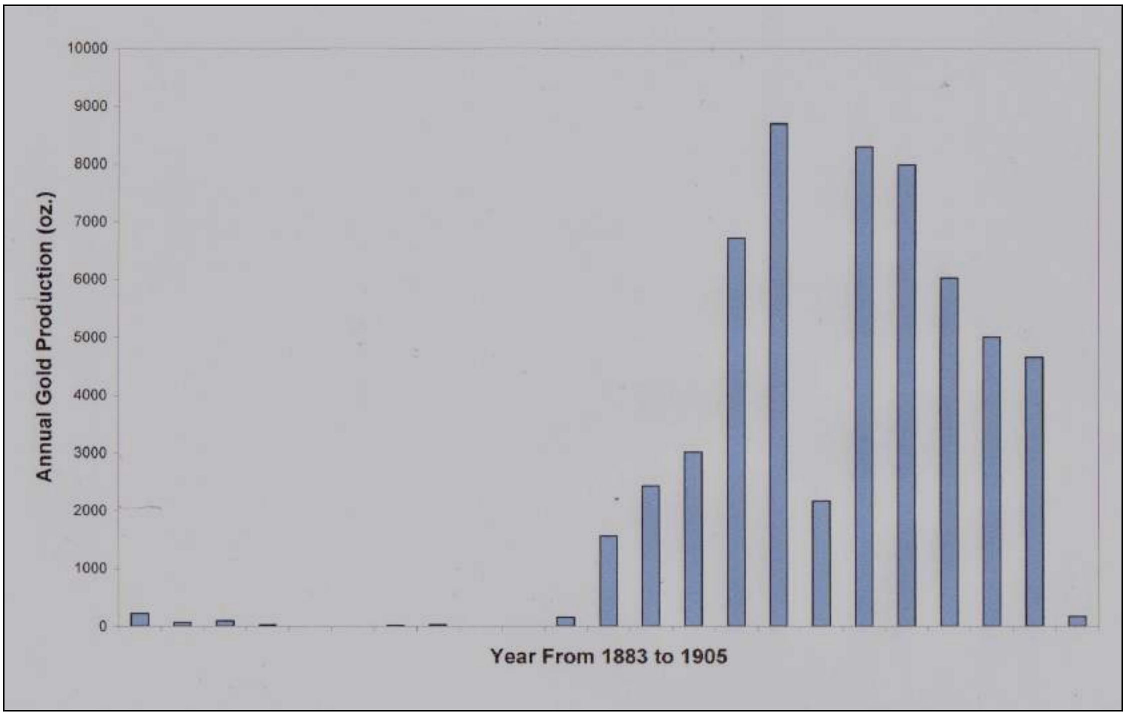
By the early 1890s, the cyanide process for gold recovery from refractory ores was gaining popularity in Australia and New Zealand. By the mid 1890s, the bromo-cyanide process that greatly increased the rate of dissolution of gold in a cyanide solution had been patented and was being introduced into Victoria. Different versions of this process were being trialled at a number of locations in Victoria, with some promise.[83] There is contemporary reference to a trial of the bromo-cyanide process being undertaken at Bethanga, but no details of exactly what version of the technique might have been trialled.[84] The archaeological evidence from the site today confirms that a cyaniding trial did take place, but does not give any further insight into the details.[85] Whatever the case, the trial was considered unsuccessful.[86] The lack of success of the trial is consistent with experience elsewhere with refractory copper bearing ores during the same period.[87]

Conclusion.

Throughout Wallace's tenure, Bethanga suffered from an identity crisis, starting as a gold field, attempting to become primarily a copper producer, and then reverting to be essentially a gold producer. From the start of attempts to produce copper in 1878 it became evident that to be profitable the gold content of the ore would have to be realised. Much of the subsequent history of the development of mineral processing at Bethanga was driven by the search for a cost effective means of recovering all or most of the gold content, either in conjunction with copper production or in its own right. From 1880 to 1894, Mines Department records show that gold production from the primary ore was minimal and that the production of copper metal and regulus was sporadic. From 1894, when the chlorination process was finally rendered effective, gold production increased dramatically (Fig. 8). Mines Department records for the same period do not give any details regarding the copper produced as a by-product, except for a mention in the 1903 annual report where copper was described as a 'profitable by product'.[88] By 1904, the Bethanga mines were reported as having been worked to a standstill, and Bethanga Goldfields had ceased operations. Wallace had by this time died, having seen his enterprise and persistence finally rewarded after the investment of a vast amount of capital by the standards of the time.[89]

At various points in time, activities at Bethanga intersected with the development paths of several of the major mineral processing techniques emerging in Australia and elsewhere during the last quarter of the nineteenth century. The wide range of schemes trialled unsuccessfully at Bethanga, from pyritic copper smelting, with electrolytic refining to cyaniding for gold recovery, contributed to the body of understanding surrounding these techniques that helped to ensure their eventual successful development at other mining centres. By the time that chlorination had been perfected at Bethanga, large-scale chlorination works had been installed at several Australian mining centres, notably Mt Morgan and Charters Towers in Queensland. Sites like these had arrived at their own versions of the chlorination process by trial and error to match the peculiarities of the ores in question. The scope for direct translation of the Bethanga version of the chlorination process to other centres was limited.[90]

Figure 8: *Record of gold production at Bethanga, 1883 to 1905.*



Source: Victorian Department of Mines, unpublished statistics.

Epilogue

There was a short-lived resurgence of activities at Bethanga when New Bethanga Gold Mines NL took over the leases and re-commenced operations in 1906. This company instituted a re-evaluation of the ore reserves and made the decision to try to recover the complete value of all the constituents present in the ore, rather than continue with the chlorination process that was reported to have led to the previous loss of most of the copper and all the silver in the ore.[91] A roasting kiln and thirty-ton water jacket blast furnace were installed and smelting commenced in 1907 to produce copper matte that was sent to Swansea for further treatment. Mines Department records summarise the results for 1907 and 1908, with the combined matte produced containing 72 tons of copper, 4,400 ounces of silver and 1,061 ounces of gold.[92] Smelting operations were suspended after this, and a new chlorination plant erected to concentrate once again on gold production. From 1909 to 1911, 3,500 ounces of gold were produced.[93]

New Bethanga Gold Mines ceased operations in 1911. Another attempt at smelting was made in 1915/16 when the price of copper was high.[94] A new water jacket blast furnace was installed and smelting for matte resumed, but it was reported that this operation was interrupted by a coal strike. A number of small-scale operations to mine copper ore occurred in the district during the early part of the twentieth century.[95] The potential for Bethanga to become a major copper producer has been revisited at various times since then,[96] and in recent times Bethanga has once again become the focus for explorers, attracted by the extensive system of ore bodies.

Endnotes

[1] Tony Convey, *The Days of Gold - Mining in the Tallangatta District*, Thompsons Printing, Albury, 1980.
[2] June Philipp, *The Making of a Mining Community: Bethanga, Victoria 1875-1885*, Latrobe University Studies in History, Latrobe University Press, 1990.
[3] *Ibid.*
[4] *Quarterly Reports of Mine Surveyors and Registrars, Mitta Mitta North Subdivision*, Victorian Government Printer, September 1877 (hereafter *QR Mitta Mitta*)
[5] Mineral Lease Files, VPRS 7843, Public Records Office of Victoria [hereafter PROV].
[6] *QR Mitta Mitta,* March 1878.
[7] Evidence by John Rowley to the *Board established to advise the Government as to the best mode of developing the Auriferous and Mineral Resources of the Colony*, Victorian Government Printer, 1880.
[8] In her history of Bethanga, *A Poor Man's Diggings-Mining and Community at Bethanga, Victoria, 1875-1911,* Hyland House, Melbourne, 1987, June Philipp describes Bethanga in the 1870s as often being referred to as a 'Poor Man's Diggings' in recognition of the modest living offered to small independent claim holders at a time when the mining industry elsewhere in Victoria was becoming progressively dominated by capital companies. The failure to be able to readily process the complex primary ore by the small independent miners led ultimately to the abandonment of their independent activities and the consolidation of leases under control of a few capital interests. Many of the independent miners gained employment as paid employees or tribute workers for these capital interests, leaving behind a lingering feeling of resentment.
[9] Cosmo Newbery, 'Laboratory Report', *Geological Survey of Victoria Progress Report No. 4*, Victorian Government Printer, 1877.
[10] See for example, *Annual Report of the Victorian Mines Department*, Victorian Government Printer, December 1877, and Report by proprietors of Mineral Lease 450, Mineral Lease Files, VPRS 7843, PROV.
[11] *The Sydney Morning Herald*, 11 July 1877.
[12] *Annual Report of the Victorian Mines Department*, Victorian Government Printer, December 1877.
[13] Mineral Lease Files, VPRS 7843, PROV.
[14] *Launceston Examiner,* 14 January 1878.
[15] *QR Mitta Mitta*, September 1878.
[16] *Ibid.*
[17] See for example*, The Sydney Morning Herald*, 17 April 1878.
[18] Articles of Association, Bethanga Copper Mining and Smelting Company Ltd, Company Registration Files, VPRS 932/28/436, PROV.
[19] *QR Mitta Mitta*, September 1878.
[20] *Ibid.,* March 1879.
[21] Evidence by John Wallace and T. Harris to the *Board established to advise the Government as to the best mode of developing the Auriferous and Mineral Resources of the Colony*, Victorian Government Printer, 1880.
[22] Quarterly *Reports of Mine Surveyors and Registrars, Bethanga Subdivision*, Victorian Government Printer, September 1881, December 1881, June 1882, December 1882, March 1883, June 1883, and December 1883 (hereafter *QR Bethanga*)
[23] *Ibid.*, September 1881.
[24] *Ibid.*
[25] Evidence by Cosmo Newbery to the *Board established to advise the Government as to the best mode of developing the Auriferous and Mineral Resources of the Colony*, and Cosmo Newberry, 'Laboratory Report', *Geological Survey of Victoria Progress Report No6*, Victorian Government Printer, 1880.
[26] *Half Yearly Reports of the Bethanga Mining Company, June 1882, December 1882 and June 1883,* Company Registration Files, VPRS 932, PROV.
[27] See for example*, QR Bethanga*, March 1883.
[28] See for example, *The Mining Journal*, 30 November 1878.
[29] Supplement to *The Mining Journal*, 26 October 1878.
[30] See for example, *Ovens and Murray Advertiser*, 19 June 1880, and *Annual Reports of the Victorian Mines Department*, Victorian Government Printer, 1880, 1881, 1882 and 1883.
[31] Articles of Association, Wallace Bethanga Mining Company, Company Registration Files, VPRS932/45/717, PROV.
[32] *QR Bethanga*, December 1884. Claude Vautin was a London based consultant metallurgist and mining adventurer.

[33] Neville Burgess, *The Great Cobar,* Published by The Great Cobar Heritage Centre*,* Cobar, 1995.
[34] *Ovens and Murray Advertiser*, 28 February 1885.
[35] *Ibid.,* 28 March 1885.
[36] See for example, *Ovens and Murray Advertiser*, 28 March 1885.
[37] Cosmo Newbery, 'Laboratory Report*', Geological Survey of Victoria Progress Report No. 7*, Victorian Government Printer, 1884.
[38] *Ovens and Murray Advertiser*, 28 March 1885.
[39] Victorian Patent No. 3126, Patent Records, State Library of Victoria, 1881.
[40] *Ovens and Murray Advertiser*, 28 March 1885.
[41] *QR Bethanga*, June 1885 and September 1885.
[42] Cosmo Newbery, *Appendix C to Annual Report of the Victorian Mines Department*, Victorian Government Printer, December 1885.
[43] *QR Bethanga* June 1886, December 1886, March 1887, and June 1887.
[44] *Ibid.,* June 1886.
[45] *Ibid.*, December 1887.
[46] *The Argus*, 5 April 1886; Thomas Martin described Vautin initiating the installation of a gas fired furnace and a water jacketed blast furnace to further his experiments with the treatment process, including refining of regulus. See, Thomas Martin, witness statement to the *Royal Commission to enquire into and report as to the best mode in which assistance can be rendered to develop the auriferous resources of the colony*, Victorian Government Printer, 1890 [hereafter, Thomas Martin, RC 1890].
[47] *Ibid*.
[48] Cupellation is the name given to a common process used in fire assaying of gold ores to isolate the gold and silver content of an ore by heating the ore in the presence of lead and subsequently absorbing the lead into the porous cupell used for the treatment. The use of cupellation on a large scale was a novel idea.
[49] Witness statement by Thomas Martin, RC 1890.
[50] *QR Bethanga*, December 1886.
[51] Donald Clark, *Australian Mining and Metallurgy*, Critchley Parker, Melbourne, 1904.
[52] Queensland patent application by Franz Wunderlich, A13127/236, National Archives of Australia [hereafter NAA]
[53] Clark, *Australian Mining and Metallurgy*.
[54] Witness statement by Thomas Martin, RC 1890; *Wodonga and Towong Sentinel*, 25 January 1895.
[55] *QR Bethanga*, March 1884, and June 1884.
[56] Supplement to the *Australian Mining Standard*, June 1899; *Australian Town and Country Journal*, 28 June 1890.
[57] Ken McQueen, 'Early Developments in Treating Pyritic and Refractory Gold Ores in Australia', *Journal of Australasian Mining History*, vol. 10, October 2012, pp. 88-102.
[58] The Stora Kopparberg (Great Copper Mountain) mine at Falun in central Sweden was for a millennium up to 1992, one of the most important mining centers in the world, producing as much as two-thirds of Europe's copper needs and underpinning Sweden's economy. Technological developments at the mine had a profound influence on mining globally throughout the eighteenth and nineteenth centuries.
[59] Joseph Guinchard (ed.), *Sweden historical and statistical handbook, Part 2: industries,* 1914, Project Runeberg.
[60] E.F. Pittman, 'Notes on Experiments with the Munktell Chlorination Process at Bethanga Vic', *Records of the Geological Survey of NSW*, vol. ii, part 4, NSW Government Printer, 1892.
[61] *Ibid.*
[62.] Witness statement by Leslie Probyn to *Royal Commission to enquire into and report as to the best mode in which assistance can be rendered to develop the auriferous resources of the colony*, Victorian Government Printer, 1890.
[63] Pittman, 'Notes on Experiments with the Munktell Chlorination Process…'.
[64] *Ibid.*
[65.]Witness statement by John Wallace to *Royal Commission to enquire into and report as to the best mode in which assistance can be rendered to develop the auriferous resources of the colony*, Victorian Government Printer, 1890.
[66] Donald Clark in *Australian Mining and Metallurgy*, mentions a Mr French from Glasgow and a Mr Hazelton from Melbourne as experimenting with the original Plattner chlorination process at Bethanga. The details of these experiments remain obscure.
[67] The practice of open air roasting that produced injurious arsenic fumes over the town was an on-going source of contention between Wallace and Bethanga's residents that added to the often fractious relationship between Wallace and his work force at Bethanga.

[68] *Wodonga and Towong Sentinel*, 1 February 1895.
[69] *Half Yearly Reports of Wallace Bethanga Copper and Gold Mining Co. December 1894, June 1895 and December 1896*, Company Registration Files, 567/502/5264, PROV.
[70] *Ibid.*
[71] Victorian patent application by James Nicholas and John Wallace, A13150/11818, NAA.
[72] See for example, A.R. Hall, *The London Capital Market and Australia, 1870-1914,* Australian National University, Canberra, 1963, and Alan Lougheed, 'The London Stock Exchange boom in Kalgoorlie shares, 1895-1901', *Australian Economic History Review*, Vol. 35, No. 1, March 1995.
[73] Victorian patent application by Thomas Dennison, A13150/14122, NAA.
[74] Donald Clark, *Australian Mining and Metallurgy*, Critchley Parker.
[75] *Ibid.*
[76] Victorian patent application by Thomas Dennison, A13150/14122, NAA.
[77] *The Colonist*, vol. XL1, issue 9007, October 1897; Clark, *Australian Mining and Metallurgy*.
[78] *Ibid.*
[79]*The Town and Country Journal*, 20 March 1897.
[80] Victorian patent application by Johnson, Field and Beeman, A13136/221, NAA.
[81] *Wodonga and Towong Sentinel*, 7 November 1890.
[82] See for example, *The* Argus 12 June 1891.
[83] Jan Todd, *Colonial Technology-Science and the Transfer of Innovation to Australia*, Cambridge University Press, 1995.
[84] *Albury Banner and Wodonga Express*, 12 February 1897.
[85] David Bannear, Heritage Notes on the Wallace Smelter Site, Department of Sustainability and Environment, Victoria, 1995.
[86] *Albury Banner and Wodonga Express*, 12 February 1897.
[87] Ralph Birrell, 'The extraction of Gold by Amalgamation and Chlorination', *Journal of Australasian Mining History*, vol. 2, September 2004, pp. 17-34.
[88] *Annual Report of the Victorian Mines Department*, Victorian Government Printer*,* 1903.
[89] Various reports describe expenditure of amounts up to £100,000 at different times during the period from 1878.
[90] The Munktel/Etard process found application elsewhere in Australia, invariably with local refinement. At the Cassillis Gold Mining Company's works at Cassillis in East Gippsland, Victoria, a process similar to that pioneered at Bethanga was introduced at around the same time as the process was nearing its ultimate form at Bethanga.
[91] *Half Yearly Report of New Bethanga Gold Mines NL., January1907,* Company Registration Files, VPRS 567/692/7886, PROV.
[92] *Annual Reports of the Victorian Mines Department*, Victorian Government Printer*,* 1907 and 1908.
[93] Victorian Department of Mines, unpublished statistics.
[94] *Annual Reports of the Victorian Mines Department*, Victorian Government Printer, 1915 and 1916.
[95] P.L. Kenny, 'Notes on the Bethanga District', *Geological Survey of Victoria Record no. 3, part 1*, Victorian Government Printer, 1909.
[96] An interesting example of this is provided by an attempt to re-commence mining at Bethanga to provide work for migrants. To this end, an unpublished consulting report on the status of the Bethanga mines was prepared by the Geological Survey of Victoria for the 'Development and Migration Commission' in the 1930s.