Copper under the stars: The history of discovery and mining at Girilambone, northwest New South Wales

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Copper was discovered at Girilambone in 1875, shortly after the initial discovery of copper in the region at Cobar and by one of the same discoverers. Early mining from 1881 to 1885, with hand sorting of oxidised ore and direct smelting or shipment for custom smelting, was a technical failure and financial fiasco. Failure was largely due to metallurgical difficulties with the smelting and lack of ore concentrating machinery. Redevelopment by another company from 1896 introduced gravity concentration of the ores, with both on-site smelting and shipment of concentrates. This group was more successful, but unable to repay its capital investment, again due to the difficult metallurgy of the ores. By the early 1900s the company had resorted to small-scale chemical leaching of low-grade ores and tailings, with copper recovery by the cementation process. This phase of mining ceased in 1907.

The Girilambone mine with its low-grade oxide-carbonate resource languished until 1990, when it was realised that a new two-stage, hydrometallurgical process of bulk heap leaching followed by solvent extraction and electrowinning could efficiently and profitably extract large amounts of high quality copper from the near surface parts of the deposit. Successful mining and processing commenced in 1992, pioneering the introduction of the new technology to Australia. Near-mine and regional exploration during the same period also discovered significant primary copper mineralisation at depth, which has extended mining in the area until the present.

Girilambone is an outstanding example of a copper deposit that had to wait for new technology to become a significant and economically workable resource. It provides a striking case for the more sustainable use of a low-grade mineral deposit through modern, high efficiency extraction technology.

Place of falling stars

The locality of Girilambone has special significance to the local indigenous Weilwan people of northwest NSW (Fig. 1). In their language the name means ‘place of falling stars’ and relates to a dreamtime story in which Gambil Gambil, a troublesome spirit woman, had an encounter with a Wirrigan or wise elder, sent to remove her from the land. A version of this story was published in 2001, as retold with permission by June E. Barker, an indigenous storyteller and Elder.[1] The story is a complex one with deep meaning, and the reader is referred to the published version for the full details. In essence, it explains two natural phenomena created when the wily Wirrigan tied himself to the back of Gambil Gambil to prevent her escaping or destroying him as he attempted to kill her with his spear. His attempt was unsuccessful and Gambil Gambil changed to her spirit form and plunged into Cuddie Springs to dislodge him. The violent struggle

turned the once beautiful clear spring into ugly soda water. When this did not remove the Wirrigan she flew up high into the sky to the path of the falling stars (meteors), which knocked the old man off her back. He fell with the stars to where Girilambone is now. The story goes on to state that:

> The Weilwan people also said the biggest star they ever saw fell at Girilambone, and it lit up all the land around. Even the Murrawarri, Barkinji, Weilwan, Ngemba, the Narran tribes, Kamilroi, Wongaibon and the rest of the Bogan tribes saw it.[2]

Falling stars are still described by the Weilwan people as Gambil Gambil flying across the night sky trying to shake the old Wirrigan off her back.

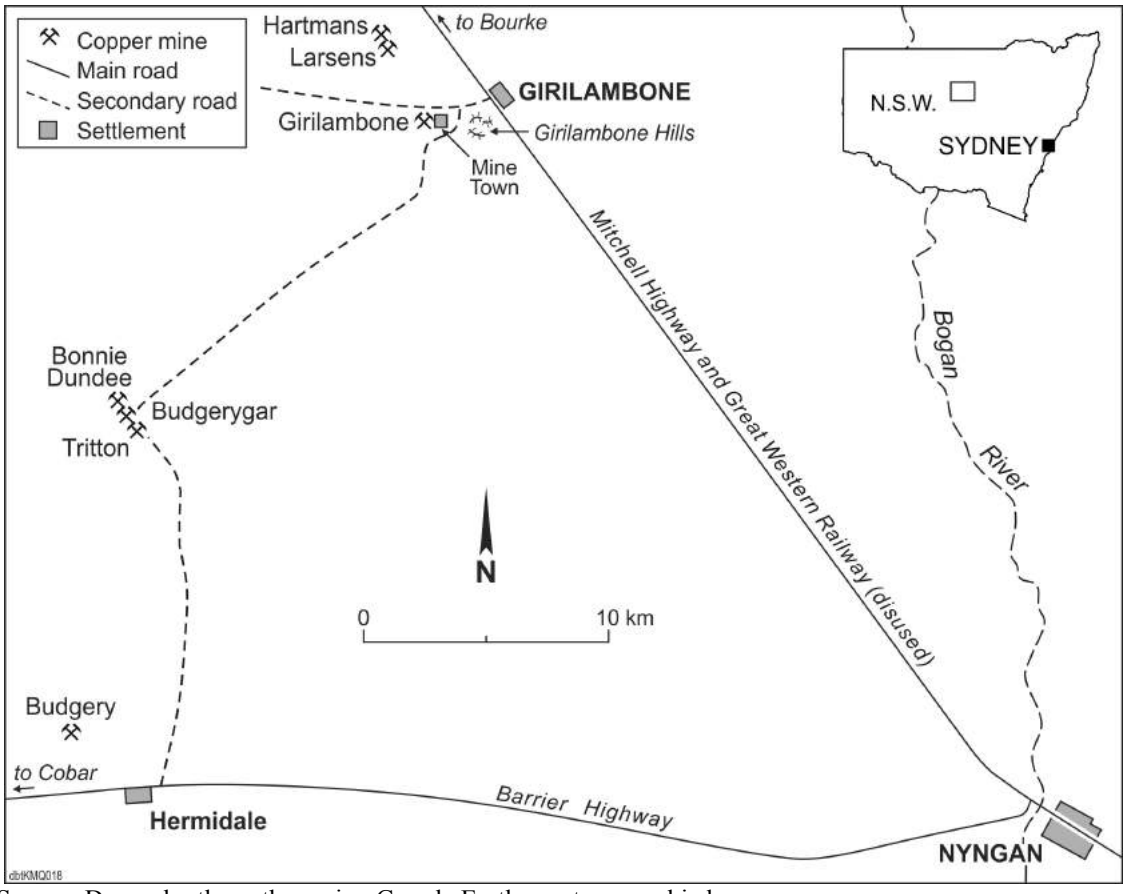
The Girilambone story is likely based on an astronomical event, such as a meteorite or comet strike, observed by the Weilwan ancestors. This would have been well in the past and certainly prior to European settlement, as no such event has been observed in the area since Europeans arrived. There is no known physical evidence of an impact at Girilambone, however the presence of a cluster of prominent and distinctive, quartzite hills could give the impression to later generations of Weilwan that the ground has been disturbed and thus later ascribed as the place where the 'star' fell. The nearest evidence of a meteorite fall is a 32 kg chondritic, stony meteorite found in 1909 at Hermitage Plains, 70 km southwest of Girilambone.[3] This meteorite has a weathering crust indicating that it landed a significant time ago. A meteorite of this size seems a little small to create a fireball visible over such a large area (from Cuddie Springs to the Darling River, ca. 700 km), but it may have been part of a larger body that broke up in the atmosphere, possibly the reference to multiple stars. Interestingly, the locations of the Hermitage Plains meteorite find (31º 44′ S, 146º 24′ E), Girilambone and Cuddie Springs are closely aligned on a southwest trajectory, consistent with the area of observation described, although this does not prove it was the 'star' observed by the Weilwan ancestors.[4]

The current Weilwan story is also interesting in that it shows how aboriginal myths may be modified or updated with new information. The published version ends with the following description of events after the fall, and even introduces some 'ore genesis theory'.

> After a few moons had passed, the elders of all these tribes knew the big star would be cool, so they all went to have a look at it. But when they arrived, it had disappeared. They said it made a big hole and melted. It ran away underground to where Cobar is today and even farther out, in a straight line, to Broken Hill. That's why copper, silver and gold are found there today, because of that big, bright star that fell at Girilambone – way back in the Dreamtime.[5]

Clearly, this section of the story has been influenced by European knowledge and ideas on meteorite impacts, as well as the discoveries of copper-gold at Cobar in 1870 and silver-lead at Broken Hill in 1883.

Figure 1: *Map of the Girilambone area showing the location of the mine, mine town and the present village of Girilambone. Also shown are the locations of some other copper mines referred to in the text.*



Source: Drawn by the author using Google Earth as a topographic base.

Discovery of copper at Girilambone

In 1875, Thomas Hartman, one of the discoverers of copper at Cobar in 1870, was travelling from the Bogan River to Cobar and camped under the stars at some 'gilgai' water holes near Girilambone Hill. He observed a small outcrop with copper carbonate stains and although not initially impressed by the find, he collected a sample to take to Cobar.[6]

In 1879, accompanied by Charles Campbell, (a co-discoverer of Cobar) and two others, possibly including George Hunter, Hartman revisited the Girilambone site and pegged out four 40-acre Mineral Conditional Purchase claims.[7] The group commenced mining surface 'bunches' of red copper oxide, but their title was disputed by brothers William and Tottenham Richardson, who occupied the surrounding pastoral run of Murrawombie (No. 5 West Bogan Block). They claimed prior right by volunteer land orders. Tottenham Richardson also claimed that he had been separately alerted to the presence of the copper mineralisation about 1880 by a stockman on the run, who had been attracted by the coloured rocks. Hartman and company, not overly impressed with the apparent shallowness of the deposit, relinquished their claim rather than engage in litigation.[8]

The deposit was inspected by NSW Geological Surveyors Lamont Young and Joseph Carne in 1880. Young described an eastward dipping, lode exposed in a small trench over a width of 18 feet (5.5 m) and composed of quartz veins and extremely rich 'bunches' of red copper oxide coated with green copper carbonate. This was on the summit of a small hill and signs of the lode could also be seen 100 m and 130 m northeast of the trench.[9]

Early mining (1881-1885)

After Hartman and his associates withdrew their claim over the Girilambone discovery, William Richardson registered two 40-acre Mineral Conditional Purchase claims in June 1880 and three additional 100-acre claims in July and September, in preparation for setting up a mine.[10] In December 1880 surveyor Charles King prepared a subdivision plan for a private town near the mine (Fig. 1). The new town of Girilambone was to feature well laid out streets with exotic, as well as mineralogical names, including Rue D'Enfer, Great Northern Road, Australia Parade and Malachite, Oxide, Carbonate and Sulphate streets.[11]

On the 24 March 1881 the Girilambone Copper Mining Company Ltd was formed with nominal capital of £75,000 in £100 shares. The directors were Russell Barton M.L.A., William Richardson, W. Clarke, Captain J. Broomfield and Thomas Gillespie.[12] Mine development soon started under the direction of Captain William Datson, and by the end of the year 650 tons of ore, grading about 20% copper had been raised from the development shafts and drives. Three shafts had been sunk on the main mineralisation; No. 1 (South) shaft to 156 feet; No. 2 (Middle) to 192 feet; and No. 3 (North) to 198 feet. The No. 2 and No. 3 shafts were connected by drives at two levels, both through good ore. Two trial shafts had also been commenced on outcrops of ore some distance from the main deposit. Furnace construction for on-site smelting was well under way. Total expenditure to the 31st of December was £11,788.[13]

By early 1882 the township of Girilambone had quickly grown to a booming centre, with a population of about 500, largely funded by mine development expenditure. A Girilambone correspondent to the *Sydney Mail and New South Wales Advertiser* observed, 'I have seen many towns in their infancy in this and other colonies, but I never saw one with more signs of healthy vitality'.[14] There were two banks, the Mercantile and the Australian Joint Stock Bank, two hotels, the Girilambone and the Royal, a large store operated by S. Sullivan and W.N. Willis, postal service, several other stores and a school with between 52 and 91 students.[15] The only 'drawbacks' seemed to be a lack of water and police presence, the local correspondent noting that:

> The early (hotel) closing law does not affect us much, as there are no police stationed here, although no doubt before long we shall boast our trooper, or perhaps two. What we want more than police and more than a parson even, is rain… Pay-day is a great day here, and the amount of liquor imbibed per male adult (and in some cases you may fairly throw in a female or two) must entitle Girilambone to be ranked as a good revenue producing township.[16]

The monthly wages bill at the mine was £1,000-1,200. Drinking water had to be brought 18 miles (29 km) from the Bogan River and was retailing at 8s 6d per cask.[17]

Development work and mining of irregular zones of copper carbonates and oxides continued throughout 1882, although 70 men, mostly miners, were laid off before August.[18] In December, the first smelting trials were conducted, using two of the completed reverberatory furnaces, to produce a small amount of 94% copper.[19] From the outset there were metallurgical problems with smelting the Girilambone ore on-site. The near surface, mostly carbonate-oxide ore, was very low in iron, but had abundant associated quartz (i.e. siliceous ore). This meant that it was almost impossible to form sufficient iron-silicate slag to remove the quartz and other silicates from the molten copper matte. Ironstone flux had to be separately mined from some nearby gossans and transported 6 km to the smelters. Access to primary, iron sulphide rich ore for blending would be the ideal solution, but at this stage no such ore had been discovered at the mine. By the end of the year, 2,650 tons of ore had been raised from a lode, 6-25 feet (2-7.6 m) wide, the bulk being sent to the English and Australian Copper Smelting Co. works at Waratah near Newcastle. General expenditure on the mine for the six months to the 31 December had totalled £21,552.[20]

Mines Inspector, William Slee, visited the Girilambone operations at the end of January 1883. He reported three shafts on the main deposit, with two being used to work the mine: Middle shaft, down to 252 feet; and South Shaft, at 156 feet. Exploratory drives on two levels extended east and west from the Middle shaft and southerly along a lode from the South shaft. This work and surface exploration also indicated mineralisation towards the east. The smelting plant consisted of four wood-fired reverberatory reducing furnaces and one refining furnace, but at the time of the visit only one furnace was operating.[21] All work was now under the management of Captain William Vaudrey.[22] Slee also noted that Girilambone had five well-furnished hotels, four large stores and several other business places. The population was still around 500, with 90 employed by the mine. The Great Western Railway to Bourke was about to arrive at Girilambone, building hopes for a bright future. A telegraph office was opened in April 1883 and in the same month, bore water was found near the town by the Mines Department.[23] Things were looking shining.

Up to the end of April 1883 the mine employed 130 men and boys, but a decision was then made to further explore the deposit by sinking a new main shaft, and all except 22 men were laid off. Only about 450 tons of ore were mined during the year to produce just over 32 tons of fine copper, worth £1,655.[24] Total ore raised by the company since the start of mining to December 1883 was 3,100 tons.[25] The advancing railway finally reached Girilambone at the end of 1883 and the town became the railhead for the next stage of construction, with a temporary workers' camp adding to the population. Early 1884 witnessed a very hot summer, with much sickness and six deaths before the end of January. A large number of women and children were ill with fevers, possibly typhoid brought by the railway workers.[26] At the mine, deepening of the main shaft continued and at the beginning of May there were signs of a significant 'permanent' lode containing the much sought-after sulphides, needed for successful smelting. It was reported that 'the residents of Girilambone are in ecstasy'.[27]

By July 1884, the main shaft at the mine had reached 325 feet and brackish water was struck, making about 300 gallons per hour. Several 'bunches' of mineralisation had been intersected during the development, including a 14-foot section of gossan and carbonates at 86 feet from the surface, a 7 foot thick band of ironstone at 100 feet, carbonate and black oxide ore at 122 feet and, in a westward drive at the 300 foot level, black ore with minor sulphides. The deepest part of the shaft had exposed yellow sulphide ore (pyrite-chalcopyrite), thought by the manager to be the cap of a well-defined sulphide lode.[28] Optimistic reports from the mine continued until September 1884, but the only production was from the development work.[29] The copper price was hovering around a low of £43 per ton and copper mining in the district was generally depressed. The Girilambone Copper Mining Co. Ltd was now rapidly running out of capital, with little likelihood of raising more. At the eighth half-yearly meeting of the company, held in February 1885 it was revealed that general expenditure for the previous year had been £44,910 with income from copper sales a mere £1,741. It was resolved that the company be voluntarily wound up.[30] Girilambone's 'ecstasy' with hopes for a profitable mine had evaporated.

After the railway to Girilambone had been officially opened for business in May 1884 a new Government village was gazetted near the railway station, 3.5 km east of the mine. The first land sales were in June and over time the new village drew all settlement away from the private town at the mine.[31] Business premises were also removed, some more rapidly than others. In the early hours of the 7th of January 1885, a disastrous fire in the mine town destroyed Willis and Co.'s store, as well as the Mercantile Bank. Buist's Royal Hotel, the Post and Telegraph offices and the Australian Joint Stock Bank narrowly escaped, thanks to the strenuous efforts of the townspeople.[32]

The Girilambone copper mine, including 200 acres of surrounding land, was put up for public auction in June 1886, but failed to sell.[33] A sustained rebound in the copper price would be needed to spark any interest in a mine that had been so unprofitable and this did not happen until the late 1890s. Liquidation of the Girilambone Copper Mining Company was finalised in April 1891, ownership of the property apparently reverting to the Australian Joint Stock Bank.[34] In 1893 the Richardson brothers worked the mine on tribute, selectively mining high-grade pockets and sending hand-picked ore away for smelting. During the year copper to the value of £957 was produced, representing about 23 tons.[35] In 1894 tributers mined ore sufficient to produce 36.5 tons of copper valued at £1,180.[36] The mine then lay idle for almost two years, before again being offered for sale in December 1895.[37] By this time the copper price had improved and there was some interest. The mine, including 357 acres of surrounding land, the plant and copper ore at grass, was finally purchased in June 1896 through mining agent Leonard Dodds, by a syndicate of Sydney investors, including George and Frederick Richards, Thomas Graves, Edgar Phillips, Alexander Goodsir, John Skelton and G.H. Lukin.[38] The sale did not include the mine manager's house and office, as these had burnt down the previous March, the former manager and his family, apparently still in residence, only 'escaping in their nightdresses'.[39]

During this early phase of mining several other exposures of copper carbonate, as well as gossans, were found in the Girilambone area and tested by prospectors and small groups including Thomas Hartman, George Hunter, Christiansen and Co. and Laars Larsen. At Hartman's workings a shaft was sunk 150 feet and a 200 foot drive put into gossanous material with copper carbonate veining, which proved unpayable to mine at the time.[40]

The Girilambone Copper Mining Company NL (1896-1902)

In October 1896 the Girilambone Syndicate floated the Girilambone Copper Mining Company NL with nominal capital of £50,000 in 50,000 £1 shares.[41] William Blakemore was appointed mine manager and the plan was to work the mine on a larger scale with more efficient ore processing. Blakemore had previously been the manager of the Nymagee copper mine, which was closed and liquidated in October 1896.[42] Rapid improvements were made at the Girilambone mine and by November, the Main (engine) shaft had been dewatered and timbered to a depth of 325 feet and a new poppet head installed (Fig. 2). To increase the grade of the smelter feed a new concentrating plant, capable of treating 100 tons of ore per day, was constructed. This consisted of a rock breaker, Krom rolls, a Hancock jigger, new 20 hp steam engine and 29 hp boiler, as well as two Worthington pumps to supply the jigger and boiler with water. At the existing smelting works, the old furnaces were pulled down to be replaced by new reverberatory furnaces with a much larger capacity.[43] Underground exploration by cross-cutting had revealed a significant body of ore with an average grade of almost 9% copper over 200 feet (61 m) and deemed suitable for concentrating. Other bodies of oxidised ore were observed, including copper-bearing ironstones (gossan) in the southern workings assaying 1.5-19% copper with traces of gold. This was the first inkling that the ore contained trace amounts of gold. Blakemore, in a report to the press, optimistically stated that 'in fact, the whole (Girilambone) hill is nothing but a massive lode body running east and west, intersected by another lode running north and south'.[44] By the end of the year the concentrating plant was operating 16 hours a day, but due to a lack of sufficient iron-rich flux, smelting had not commenced and the concentrates were shipped for treatment.[45] With all this activity the total workforce soon grew to 200.[46]

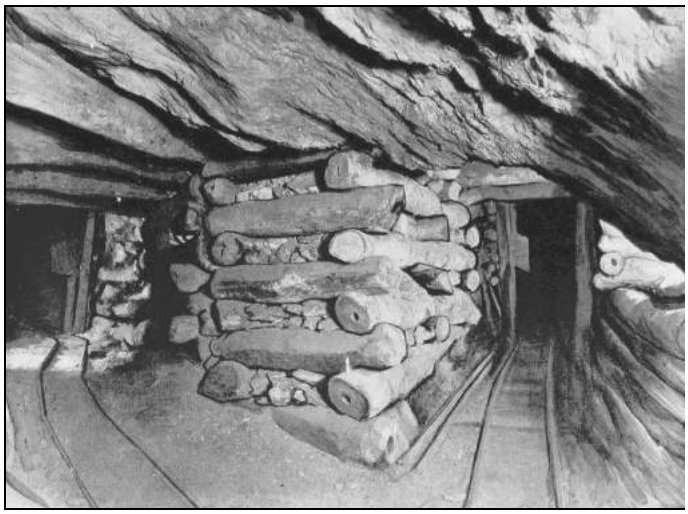
Figure 2: *View of the Girilambone copper mine with new poppet head, looking northeast ca. 1896. Houses in the mine town can be seen in the far background.*

Source: State Library of New South Wales collection.

In June 1897 the company issued 125 debentures of £100 each to fund the purchase of a larger winding engine, deepen the main shaft and make improvements to the concentrating plant.[47] The following month, Randolph Adams, recent general manager of the Central mine at Broken Hill, inspected the Girilambone mine and made a very favourable report, concluding that 'the mine is a mineral deposit of very great value and extent'. This appears to have been a successful attempt by the company to boost investor interest as three days later the share price surged from 16s to 30s, with many buyers.[48]

In the first six months of 1897, 7,792 tons of ore were raised and concentrated, with 583 tons sent to the Great Cobar Syndicate smelting works at Lithgow. The first smelting on site commenced in August, following completion of two of the new reverberatory furnaces.[49] At the third half yearly meeting of the company held in March 1898 it was reported that an additional 9,362 tons of ore had been mined and treated, with 1,748 tons smelted on site to produce 190 tons of copper (i.e. a grade of 10.9%). The new winding equipment had been installed and improvements made to the concentrating plant, although it was indicated that some final adjustments would be needed. The board of directors noted their regret that the output of copper had not been up to expectation, owing to the lack of a proper mixture of ores for smelting. As a remedy they recommended that the main shaft should be deepened to much lower levels to reach the primary sulphide zone. To enable this work, as well as install water jacket blast furnaces, it was also recommended and resolved at a subsequent extraordinary meeting that more capital be sought through an issue of 50,000 new share, initially offered to shareholders, proportional to their existing holding and paid up to 7s 6d.[50]

Figure 3: *Girilambone mine main drive on Level 1. Note 'pigstye' method of roof support.*

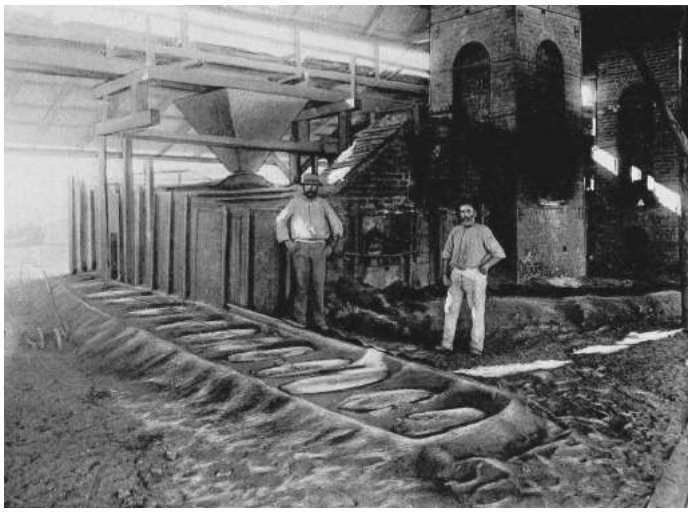


Source: J.E. Carne, *The Copper Mining Industry and the Distribution of Copper Ores in New South Wales.* 1899.

Over the course of 1898 the main shaft was deepened to 544 feet and a chamber cut at the 522-foot level in preparation for driving on the sulphide ore. Total ore mined was 14,435 tons.[51] A new concentrating plant was completed, but due to drought conditions it could not be fully utilised and by the end of the year operations had virtually ceased. Mine manager, William Blakemore, conducted some experiments with a small Oxford-type blast furnace and considered the trials satisfactory, after producing 8 tons of 37% copper matte, at half the usual cost. Smelting continued with the reverberatory furnaces and during the last half of the year about £10,000 was received from copper sales. Despite this income, the company booked a £1,327 loss after capital expenditure and running costs.[52]

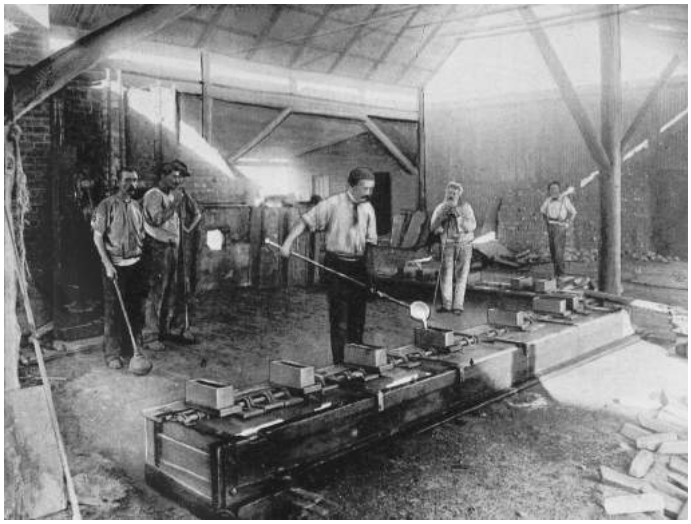
Geological Surveyor Joseph Carne inspected and reported on the Girilambone mine during 1898 (Figs 3, 4, 5 and 6). He provided a detailed geological description of the deposit and the different ores, noting that the carbonate ores were rarely homogenous or solid, but rather earthy and 'pulverulent'. He also described the ore treatment at this time, which began with dividing the raised ore into three classes of: 'carbonates' with some red oxides from the upper levels of the mine; 'sulphides' from the 240 and 300 foot levels; and 'oxides' from the transitional zone. The 'carbonates' averaged about 4.6% copper and about 40% of this material was sent directly to the smelters after hand picking and screening to a grade of about 13%. Most of the remainder was sent to the rock breaker, crushers (Cornish and Krom rolls) and concentrating jigs, with the concentrate sent to the smelter. The tailings still contained significant copper due to the difficulty of gravity separation of the thin earthy carbonate coatings. The 'sulphides' and 'oxides' went direct to the crushing and concentrating plant to be treated separately, with the first concentrates going to the charge bins of the smelters (Fig. 6). The seconds were stacked for possible further treatment and the residue sent to the waste dumps. Carne calculate that only about 50% of the contained copper was extracted due to losses in the concentration and smelting.[53]

Figure 4: *Pouring copper matte from reverberatory furnace into sand moulds, Girilambone mine 1898.*



Source: J.E. Carne, *The Copper Mining Industry and the Distribution of Copper Ores in New South Wales,*1899.

Figure 5: *Pouring refined copper into ingot moulds, Girilambone mine 1898.*



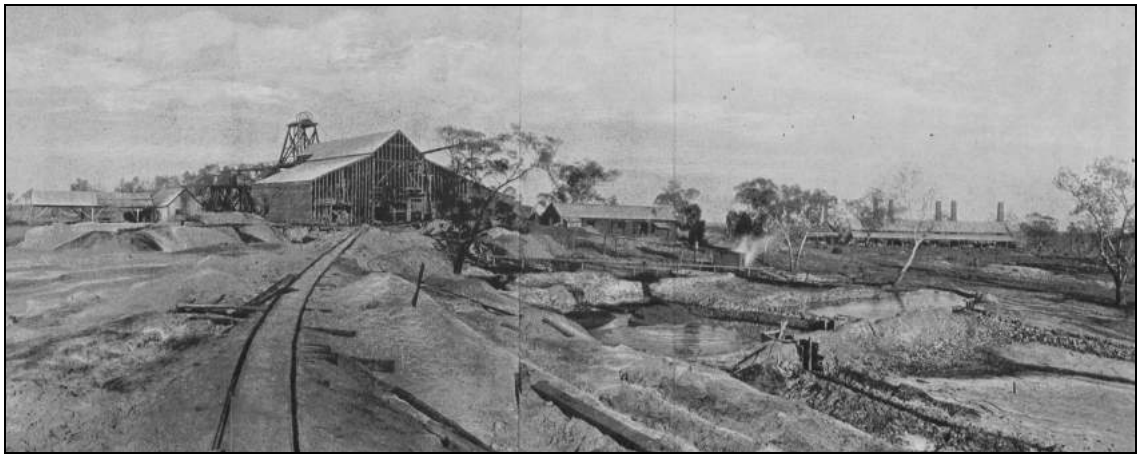
Source: J.E. Carne, *The Copper Mining Industry and the Distribution of Copper Ores in New South Wales,* 1899.

The rapid expansion in worldwide electrification around the turn of the twentieth century resulted in higher demand for copper and increased prices. By September 1899 the local price had risen to about £70 per ton. British investors were also starting to take greater notice of potential mining projects in Australia, and Girilambone generated a twinkle of interest.

In November 1899 a proposal was put to an extraordinary general meeting of the Girilambone Copper Mining Company to sell the mine to a group of London investors, who had offered £45,000 cash and 55,000 fully paid £1 shares in a new company with nominal capital of £250,000 and working capital of £50,000. The shareholders were reluctant to sell at this price and a committee was set up to investigate a better deal.[54] Nine days later the shareholders agreed they would sell for £65,000 plus a 25% interest in the new company.[55] Negotiations continued, with some additional conditions proposed, but in early February the following year negotiations for the sale fell through.[56] Given how things had developed over the intervening months and would transpire in the near future, the London investors had a lucky escape.

Over the course of 1900, activity at the mine was focussed on exploring and developing two of the deeper levels, with the aim of mining more of the sulphide zone to provide ore to blend with the large reserves of siliceous oxidised ore. William Blakemore resigned as mine manager in July and was replaced by Thomas Hosking. Small amounts of ore were raised during development work, concentrated and sent to Cockle Creek for custom smelting.[57] This activity continued into 1901 when L.G. Hancock from Moonta was employed to improve the concentrating plant with the addition of Wifley tables. Magnetic separation was also unsuccessfully trialled.[58] Experiments were conducted to see if the large accumulation of tailings and the oxide ores could be treated by leaching.[59] Following successful laboratory trials, a small test plant was constructed. The general manager of the mine, now F. Stanley Low, reported that deeper exploration had revealed some good quality sulphide material suitable for concentration, but no defined body of the much desired pyritic ore. However, he was certain that 'further exploration both in the present workings and below those of the south shaft would disclose an amount of sulphide ore which would give the mine a great and prosperous future'.[60]

Figure 6: *View looking southwest of the Girilambone copper mine and works at the time of J.E. Carne's inspection in 1998. Concentration plant at centre in front of main shaft head frame and smelting plant far right*



Source: J.E. Carne, *The Copper Mining Industry and the Distribution of Copper Ores in New South Wales*, 1899.

From April 1901 the world copper price had started to decline and by the end of the year it had slumped to £48 15s, close to the production cost of most mines in Australia.[61] At the end of February 1902 an extraordinary general meeting of the Girilambone Copper Mining Company NL was held at which it was proposed that the company be liquidated and reconstructed as the Girilambone Mining Company NL.[62] In part, this was a scheme to pay out the existing bondholders and remove the interest payments and encumbrance on the freehold title for the shareholders. The plan was agreed to at a subsequent meeting on the 18th of March, with the provisional directors being George Pauton, Neville D. Cohen, W. Wark and Leonard Dodds.[63]

The Girilambone Mining Company NL (1902-1908)

Restructuring to form the Girilambone Mining Company was completed in July 1902.[64] The new company then further investigated the possibility of producing copper by leaching the 30,000 tons of tailings at the mine. A six-ton parcel of tailings grading 2.6% copper was sent to the NSW Government Metallurgical Works at Clyde for trial treatment by the Payne-Gillies process. This involved treating the crushed tailings with a ferrous sulphate solution and then heating them in a furnace at a low temperature to convert the copper oxides and carbonates to soluble sulphates. The sulphates were then leached while still hot and the copper precipitated out of solution by scrap iron, in the process producing a ferrous sulphate solution, which could be recycled as the mother-liquor. The trial proved disappointing, as although cost effective, about half of the copper remained in the residues.[65]

In September, the company arranged with a Mr Pechey to leach the tailings on tribute. His approach was to use the standard cementation process, involving leaching of the tailings in vats with a sulphuric acid solution and precipitation of copper out of the solution with scrap iron. The plant, probably modified from the earlier test plant built by Hosking, was set up in August, and in December Pechey predicted that once the process was fully running he could produce 25 tons of copper per week and deliver the first parcel of refined copper the following February.[66] The company appears to have taken over the leaching plant in April 1903 and further experiments resulted in the installation of a larger plant. Through the latter part of the year and into 1904 about 200-250 tons of tailings were treated per week to produce between 2 and 3 tons of copper by leaching, smelting and refining on site. In September 1904 a pulveriser was added, to improve production.[67] During 1904 a total of 2,478 tons of carbonate tailings were treated to yield 26 tons of copper, worth £1,752.[68] Although a technical success this was hardly a stellar financial result.

By 1905 the copper price had improved significantly, and the Girilambone Mining Company successfully tested some of the oxidised ore from the mine by leaching. This suggested that the ore itself could be treated profitably by this process. The board decided to recommence mining following dewatering of the workings. In the first six months of the year 7,241 tons of tailings were leached to produce £5,642 worth of copper. However, the company's debit balance had increased to £5,283.[69] Mining, both in a small open cut and underground, commenced in the latter part of the year as the dewatering progressed, and in November the company decided to completely renovate

the ore concentrating plant under the direction of engineer, R. Gregory.. The high price of copper, £72 5s per ton, had reignited inquiries for copper properties and the board began negotiations for the sale of the mine in London.[70]

Dewatering of the mine was completed in February 1906 and development on the No. 5 level (deepest level) had finally revealed a solid body of sulphide ore. The upper levels of the mine were providing a good supply of payable ore for resumed concentration and smelting. To further assist the smelting, some sulphide ore was procured from Cobar, however unprecedented wet weather meant that smelting was intermittent because of the difficulty in supplying wood fuel to the three furnaces. Over the year 6,035 tons of ore were treated for 132 tons of copper (a recovered grade of 2.2%).[71]

At the end of 1906 the global copper price had risen to £105 per ton and the Girilambone Mining Company finished the year with a £5,670 profit. [72] The new year beckoned brightly and in February the company sold 15 tons of copper in Sydney at £106 15s per ton.[73] The directors proposed issuing 50,000 reserve shares to establish a 'sinking fund' to redeem the £12,400 worth of debentures and provide capital for more mine development. However, applications for the new shares were not sufficient for the issue to proceed.[74] Mining continued apace with ore processing by concentration and smelting, assisted by sulphide fluxing-ore from Cobar and the Mount Boppy Copper Mining Company. Up to 28 drays were employed carting wood for the furnaces, but there were still periodic stoppages due to lack of fuel. Leaching of historic and new tailings also continued. In the first half of 1907 the company sold £6,848 worth of copper and held stocks worth £2,894.[75] The high copper price encouraged further prospecting in the region and nearby discoveries included the Bonnie Dundee (originally prospected for gold in 1882), Budgerygar and Budgery deposits (Figure 1).[76]

In September 1907 the copper price took a dive, quickly descending to £63 per ton. This was due to uncertainty about the boom in electrification and copper demand, exacerbated by. and partly linked to, financial panic in the United States.[77] Operations continued at Girilambone, despite the low price and great uncertainty, but at the half yearly meeting of the company in February 1908 the directors announced that, except for mine dewatering and maintenance of the plant and machinery, all expenditure and work would cease.[78] Conditions for copper mining did not improve over the next few years. There was some minor leaching of tailings in early 1910, but the mine was not re-opened.[79] Thus ended, the second phase of mining at the place of 'falling stars'.

From the start of mining in 1881 until 1907 the total recorded ore mined from the Girilambone deposit was 58,408 tons for a production of 1,141 tons of copper.[80]

A languishing resource with sporadic flashes of interest (1910-1990)

The Girilambone mine still held a significant copper resource, but it was clear that the type and grade of ore could not be profitably worked with existing technology, unless the copper price was very favourable. The copper price did improve, particularly during WWI, but then collapsed shortly after. Interest in Girilambone waned until late 1920, when the New South Wales Copper Recovery Co. NL selected the site for a new copper

leaching plant. This company, with £25,000 in capital, was set up by Sydney mining expert and company director F.B. Brown. The plan was to use a similar vat leaching process to that previously employed, but on a larger scale, circulating 500 tons of dilute acid solution daily and producing 10 to 14 tons of copper precipitate per month. Up to early 1921 the operation treated 1,000 tons of ore to produce 108 tons of copper worth £8,000, but then fizzled out, probably due to lack of ore and capital to expand.[81]

Over the next 38 years there was scant activity at the now derelict Girilambone mine. Several individuals and groups, including Joseph Whyte, Thomas Kelly, W.R. Roche and W.D. Moreland, set up small cementation plants to extract copper from mine water pumped and circulated from the old underground workings. The results were mostly marginal.[82] In 1958, Dr M.D. Garrety who held a lease over the old mine area, initiated through Mining and Prospecting Services Pty Ltd, the first diamond drilling at Girilambone. A single hole was drilled northeast of the main lode on a magnetic geophysical anomaly detected by the Ministry of National Development in 1948. The 725-foot (220 m) deep hole intersected sheared slates, quartzite and a zone of chloritic schists and serpentinite, but no mineralisation.[83] Attention shifted to the slag dumps as a source of railway ballast and these were quarried, and a crushing plant set up by J. Bennett. Minor extraction of copper from the mine waters continued until 1970.[84]

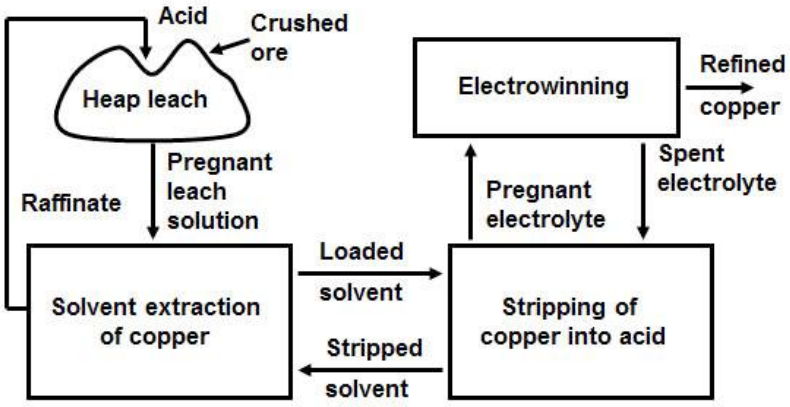
In 1960, the Bureau of Mineral Resources conducted an airborne geophysical survey over the Girilambone area and this rekindled interest, coincident with the 1960's boom in base metal exploration. Utah Development Corporation commenced an intensive, ten-year exploration program over the mine site and surrounds in 1963. This work included geophysical surveys (airborne and ground EM, IP), regional mapping and auger drilling for geochemical sampling, followed by drilling of more than 64 combined percussion/diamond drill holes. The work outlined a resource of 3.315 Mt of 2.12% copper, too small for Utah's requirements and the prospect was relinquished.[85]

The Girilambone tenements were taken up in 1974 by Australian Selection Pty Ltd (Seltrust Mining Corporation). Further prospecting was followed up with a 362 m deep drill hole designed to test the depth potential of the sulphide mineralisation northeast of the mine. The drilling intersected semi-massive pyrite with low-grade copper (<1.6% Cu) between 292 and 335.3 m. Seltrust relinquished the property in 1983 and the following year it was acquired by Sanidine Exploration, later in joint venture with Hunter Resources Ltd. This group undertook additional exploration, including a magnetic induced polarisation survey, which indicated a significant conductor in the immediate mine area. The latter was interpreted as a shear zone and not followed up.[86] Hunter Resources retained the prospect and then combined with Nord Australex Nominees Pty Ltd (Nord) to continue exploration. During 1989, Nord conducted a drilling program around the old Girilambone mine and re-evaluated the previous exploration data believing the extent and grade of mineralisation had been underestimated. Results were sufficiently encouraging for the company to exercise an option with Hunter Resources to purchase 100% of the Girilambone project in December 1990.

New technology creates a rising star

An extensive drilling program by Nord during 1990-1992 defined a mineral resource at Girilambone of 8 Mt of 1.4% copper, as copper carbonates, minor copper oxides, native copper and secondary chalcocite.[87] Metallurgical testing showed that this material was amenable to new leaching technology, initially developed at the Bluebird Mine in Arizona in 1968 and refined around the world over the next two decades. This new technology, described as Solvent Extraction Electrowinning (SX-EW), involved heap leaching of carbonate-oxide copper ore with sulphuric acid, selective extraction of the copper in solution by an organic solvent, followed by stripping back into solution and recovery of the copper by electrolysis (Fig. 7).[88]

Figure 7: *Simplified flow chart of the heap leach, solvent extraction, electrowinning (HL, SX-EW) hydrometallurgical process introduced at Girilambone in 1992.*



Source: Modified from G.A. Kordosky, *Journal of the South African Institute of Mining and Metallurgy,* November/December 2002, p. 446.

The Girilambone Copper Company was formed in 1991 as a joint venture between Nord (40%) and Straits Resources Ltd (60%) to develop and operate a new mine on the Girilambone resource, estimated at 83,700 tonnes of recoverable copper. Development included an open pit mine into the oxide zone around the old Girilambone mine and construction of heap leach pads east of the pit, over the area of the original Girilambone town site.[89] Mining started at the Murrawombie open pit (Fig. 8) in October 1992 at a rate of 1 Mt per year. By February 1993 stacking of the heap leach pads had begun and in May a SX-EW plant was completed and high-quality copper cathode (99.999% Cu) production commenced.[90] Carbonate/oxide ore was processed over the first 12 months followed by transition to the underlying secondary chalcocite zone (Fig. 9). This heap leach SX-EW operation was the first in Australia and produced around 14,000 tonnes of direct marketable copper per year, a dramatic contrast to the early mining, which produced little more than 1,140 tonnes over 15 years.[91]

Exploration around the old workings at Hartmans and Larsens, 4 km north of Girilambone (Fig. 1), discovered exploitable copper mineralisation, including a new blind deposit (North East) nearby. Open pit mining of these three small deposits began in June 1996.[92] Mining in all four open pits terminated by 1997, when non-leachable

sulphide ores were reached at depths near the water table (131 m in the Murrawombie pit). Heap leaching of the existing pads and copper production by SX-EW continued until 2003. Regional exploration by the joint venture partners near the historic Bonnie Dundee and Budgerygar mines, southwest of Girilambone, also discovered a new sulphide-rich deposit at Tritton in 1995 (Fig. 1). This 20 Mt deposit was developed by Tritton Resources Ltd (later a 100% owned subsidiary of Straits Resources) into a mine in 2004, with a mill employing concentration by conventional selective flotation. A 570,000-tonne parcel of sulphide ore from the bottom of the Murrawombie pit was used to help commission the Tritton processing plant. Sulphide ores were also mined from underground extensions of the North East and Larsen's mines.[93]

Figure 8: *View of the Murrawombie open pit at Girilambone in 1995, looking east. The pit incorporated many of the old underground workings. Note brown, leached oxidised zone at the top of the pit.*

Source: Photo by the author, August 1995.

In early 2008 it was decided to develop an underground mine at Girilambone, by decline access from the bottom of the Murrawombie pit. This would access the newly defined copper sulphide resource for treatment at the Tritton plant. After initial development this project was put on hold in November 2008 due to the global financial crisis (GFC) and a lack of capital funding. However, underground mining recommenced in December 2015 to provide ore to the Tritton mill following closure of the North East and Larsens underground mines. Also in 2008, a copper cementation plant was installed at Girilambone to cheaply extract the low-level residual copper in the heap leach pads. Up to 400 tonnes of copper per year were produced at a gradually declining rate.[94]

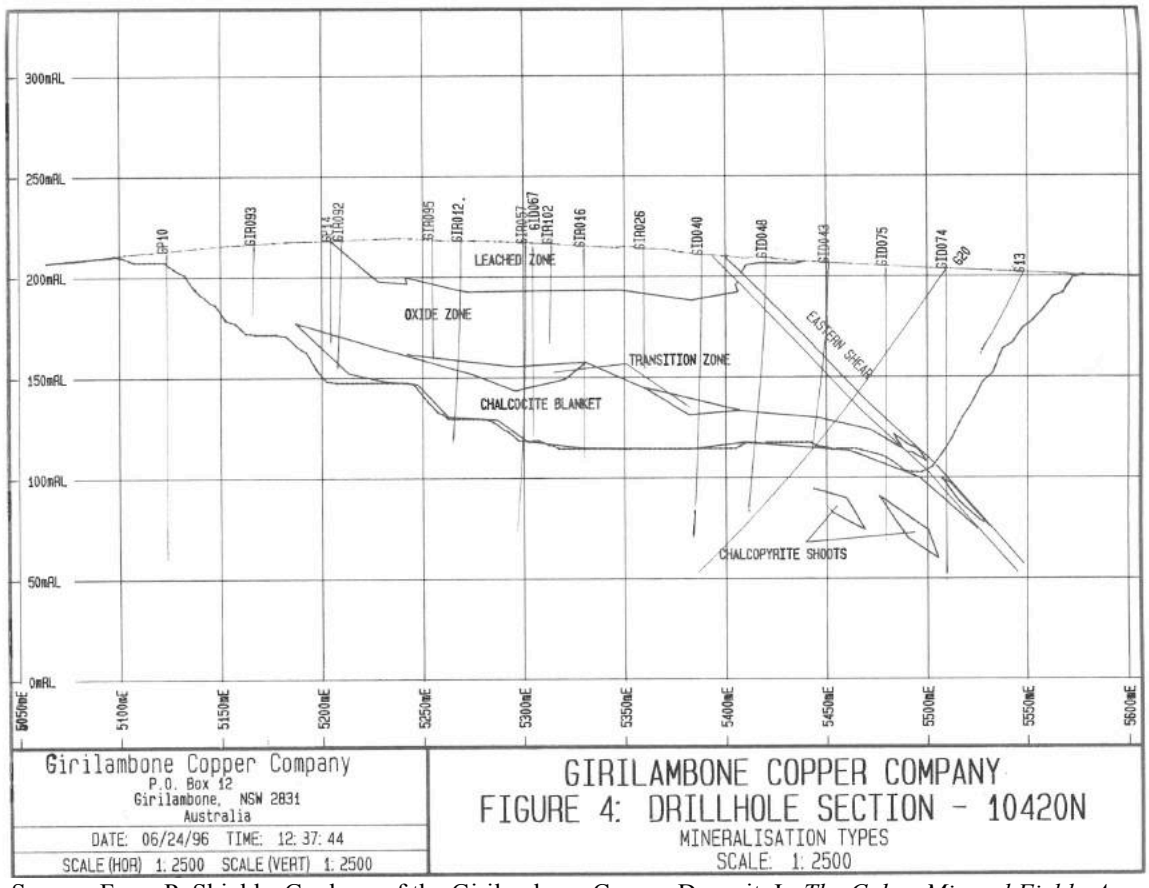
The Girilambone-Tritton operation became fully owned by Straits Resources after Nord withdrew from the joint venture in late 2005. Ownership subsequently passed to Aeris Resources Ltd through a corporate restructure.

Total copper metal production from the combined Girilambone-Tritton area mines from 1993 to 2017 is 429,630 tonnes.[95] By-product gold and silver have also been recovered from the sulphide ores.

Discussion and conclusions

The Girilambone copper mine has clearly had a very chequered history. Two early phases of mining were largely thwarted by the difficult geological and metallurgical features of the copper deposit. Intense chemical weathering to a depth of 100 m had leached the upper part of a series of irregular lenses and disseminated zones of sulphide mineralisation and produced secondary copper carbonates, oxides and native copper and a lower zone of enriched chalcocite (Fig. 9). The low iron content of the dispersed, oxidised material and the high silica content made direct smelting in reverberatory furnaces very difficult, without concentration of the copper minerals and addition of separate iron-rich flux.

Figure 9: *Cross section through the Murrawombie open pit (outlined) in 1996, showing the distribution of the different ore types in the east dipping Girilambone deposit.*



Source: From P. Shields, Geology of the Girilambone Copper Deposit, In *The Cobar Mineral Field –A 1996 Perspective*.

Gravity concentration, introduced by the Girilambone Copper Mining Company NL in 1896, had difficulty in separating the copper carbonates because of their fine dispersion and coating on the silicate gangue, which reduced the relative difference in specific gravity. Much of the copper was lost to the tailings. The low sulphur content of

the ores also resulted in the formation of magnetite during matte roasting and the development of viscous 'black slag', which trapped small prills of the copper matte, further adding to the copper loss.[96] The ore type also defied economic treatment by blast furnace, due to the limited availability of iron sulphides in the mine to promote pyritic smelting. Ironically, the introduction of blast furnace technology that revolutionised copper smelting in the Cobar region in the late 1890s was a failure at Girilambone. Resort had to be made to continuing with reverberatory furnaces. Selection of the Oxford-type blast furnace, rather than water jacket furnaces, was probably also a factor in this failure.

Other problems for early mining at Girilambone included the lack of a reliable water supply. This was a major problem for gravity separation during drought periods and until the mine workings reached the water table, which could provide a sufficient supply for the plant. The use of wood fuel and horse teams to collect it was also a drawback in periods of wet weather. Girilambone did have the advantage of a nearby railway to cheaply transport equipment and product.

Early success with leaching of the tailings and mined ore was an indication of how the oxidised Girilambone ores might eventually be effectively processed. The earthy and dispersed nature of the fine-grained copper minerals gave them a large surface area, ideal for chemical leaching. However, the scale and methods of leaching and extraction available at the time were not sufficient to make this approach economically significant. Modern open pit mining and introduction of the two-stage hydrometallurgical process of large-scale heap leaching and solvent extraction-electrowinning (SX-EW) was a breakthrough for Girilambone and a pioneering step-up for the copper mining industry in Australia.[97]

Important improvements and refinements to the SX-EW technology were developed at Girilambone to address local conditions, including the deleterious effects of high manganese and the precipitation of silica gels related to the high silica content of the leach solutions.[98] These improvements have been adopted in other deeply weathered environments in Australia and around the world. Another feature of the leaching at Girilambone was improved extraction from the rich chalcocite material in the lower part of the deposit. It was found that the chalcocite could be oxidised by ferric iron in solution to release copper and form covellite and then the covellite broken down by naturally occurring bacteria to release the remaining copper, for example:

$$Cu_2S + 2Fe^{3+} = Cu^{2+} + 2\,Fe^{2+} + CuS$$
$$CuS + 1/2O_2 + 2H^{+} + \text{bacteria} = Cu^{2+} + S^{0} + H_2O$$

Techniques to increase aeration of the heap leach pads, such as leach/rest cycles, coarser crushing sizes and forced aeration were developed to improve the reaction rates.[99] Worldwide, the SX-EW process has now developed to the point where about 20% of global copper production is by this method.[100]

The renaissance of Girilambone also benefited from convenient location for connection to the high voltage state power grid and to rail transport from Nyngan, 35 km away. The copper produced by the improved SX-EW method developed was found

to be consistently of very high purity (better than LME Grade A, with less than 10 ppm impurities), commanding a premium on the market.[101]

In parallel with this novel project to successfully work a regolith-hosted oxidised copper resource, exploration using modern geophysical and deep drilling techniques located extensions of the deeper sulphide ore bodies and discovered new copper sulphide deposits in the Girilambone area, notably the Tritton deposit. These discoveries now support ongoing underground mining.

Girilambone is a striking example of a copper resource that had to wait for new technology to convert what was once considered a minor, low-grade, unprofitable mining proposition into a 'rising star' of copper production.

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Glossary of some terms used in the text
Chalcocite – an enriched copper sulphide (Cu_2S) commonly formed at the base of the oxidised zone by replacement of primary sulphides during natural chemical weathering.
Covellite – another secondary copper sulphide (CuS) commonly formed by natural chemical weathering.
EM – abbreviation for electromagnetic geophysical methods used to detect conductive bodies of mineralisation.
Gilgai – hollows or lumpy ground formed in soils rich in shrink-swell clays, common on the black soil plains of western NSW.
IP – abbreviation for induced polarisation geophysical methods.
Jigs – devices of various design used to concentrate ore minerals by gravity separation in a water matrix, according to the different densities or specific gravity of the various ore and gangue (waste) minerals.
'Ore at grass' – refers to ore mined and stacked at the surface.
Regolith – everything between fresh rock and fresh air.
Raffinate – a liquid remaining after a dissolved component has been removed by solvent extraction.
Supergene – formed by descending waters during surface weathering.

Units
1 inch = 25.4 mm, 1 foot = 0.3048 m, 1 mile = 1.609 km, 1 acre = 0.4047 hectares.
1 troy oz (the standard measure of gold and silver) = 20 dwt = 31.10348 g; 1 dwt = 1.555 g.
1 pound (lb) = 0.454 kg, 1 ton (long) = 2,240 pounds (lbs) = 1.01604 tonnes.
1 (imperial) gallon = 4.4561 litres.

Pre-decimal currency
£1 (pound) = 20s (shillings) and 1 shilling = 12d (pence)

Endnotes

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[2] *Ibid*. The tribal groups mentioned as observing the event occupied areas around Narrabri, Brewarrina, Nyngan, Cobar and as far as Wilcannia on the Darling River a total distance of about 700 km.
[3] *Meteorological Bulletin*, Data Base: https://www.lpi.usra.edu/meteor/metbull.php?code=11877
[4] Cuddie Springs, 80 km southeast of Brewarrina, is the campsite from which the Weilwan claimed to have observed the event. There is also a recorded chondritic, stony meteorite of 8 pieces discovered in 1889 and 1920 on Gilgoin Station. This is 11 km due west of Cuddie Springs, but 100 km northeast of

Girilambone, the suggested site of the fall. *Meteorological Bulletin* Data Base. Cuddie Springs is a site with numerous extinct mega-fauna fossils and the indigenous people were well aware of these. The large fossil bones might also be interpreted as a sign of primaeval struggle.

[5] Barker, 'Girilambone, Place of Falling Stars,' pp. 112-114.

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[7] *Ibid*.; Records show that four claims (CP80-46,-47,-48,-49) were registered to Thomas Hartman, R. Green and P. Murray on the 22nd April 1880. *Mineral Conditional Purchases made since January 1 1870*, Legislative Assembly New South Wales 1884, p. 26.

[8] Carne, *The Copper Mining Industry and the Distribution of Copper Ores ....* pp. 217-225.

[9] *Ibid*.; *Annual Report of the New South Wales Department of Mines* (hereafter *ARNSWDM*) for 1880, p. 262.

[10] These were claims CP80-72, -73, -103, -142, -144, *Mineral Conditional Purchases made since January 1 1870*, Legislative Assembly New South Wales 1884, p. 26.

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[12] 'Girilambone Copper Mining Co.', *Maitland Mercury and Hunter River General Advertiser*, 29 March 1881, p. 5.

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[19] 'Mining Items', *Sydney Morning Herald*, 23 December 1882, p. 1146.

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[31] Terry Kass, *A Thematic History of Bogan Shire*, Draft Report to Bogan Shire Council, 2011, p. 40.

[31] 'Girilambone Copper Mining Co.', *Maitland Mercury and Hunter River General Advertiser*, 29 March 1881, p. 5.

[32] 'New South Wales', *Evening Journal*, 8 January 1885, p. 3.

[33] 'Auction Sales – The Girilambone Copper Mine', *Sydney Morning Herald*, 29 May 1886, p. 17.

[34] 'Girilambone Copper Mining Company (Limited)', *New South Wales Government Gazette,* 13 March 1891, p. 2006.

[35] *ARNSWDM* for 1893, pp. 44-45.

[36] Carne, *The Copper Mining Industry and the Distribution of Copper Ores …,* p. 218.

[37] 'Auction Sales – Valuable Copper Mining Property', *Barrier Miner*, 2 November 1895, p. 3; 'Auction', *Australian Town and Country Journal*, 11 November 1895, p. 5.

[38] 'Memorandum for the Registration of the Girilambone Copper-Mining Company (No Liability)', *New South Wales Government Gazette*, 30 October 1896, p. 7818.

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[83] *Ibid*., for 1956, p. 17; *Ibid*. for 1958, p. 18.
[84] Girilambone, Geological Survey of N.S.W., Report File MR 0517.
[85] P. Shields, 'Geology of the Girilambone copper deposit', *in* W.G. Cook, A.J. Ford, J.J. McDermont, P.N. Standish, C.J. Stegman and T.M. Stegman, (eds), *The Cobar Mineral Field:A 1996 Perspective*, The Australasian Institute of Mining and Metallurgy, Melbourne, Spectrum Series No. 3/96, 1996, pp. 293-303.
[86] *Ibid.*
[87] *Ibid.*, pp. 293-303.
[88] G.A. Kordosky, 'Copper recovery using leach/solvent extraction/electrowinning technology: Forty years of innovation, 2.2 million tonnes of copper annually, *Journal of the South African Institute of Mining and Metallurgy*, November/December, 2002, pp. 445-450.
[89] At the time of construction of the heap leach pads there was only one surviving building on the old town site, the mine managers house. Philip Shields pers. comm. 2018.
[90] 'Mineral Resource and Ore Reserve Estimate Statement 30th June 2017', Aeris Resources Ltd, 12 pp.
[91] Shields, 'Geology of the Girilambone copper deposit', p. 224.
[92] 'Mineral Resource and Ore Reserve Estimate Statement 30th June 2017', Aeris Resources Ltd, 12 pp.
[93] *Ibid*.
[94] *Ibid*.; 'History of the Tritton Copper Operations', Aeris Resources Ltd website.
[95] Brad Cox, Geology Manager Aeris Resources Ltd, pers. com., 2018.
[96] Carne, *The Copper Mining Industry and the Distribution of Copper Ores,* p. 222.
[97] Whim Creek in Western Australia appears to have been the second site in Australia where the HL, SX-EW technology was introduced in 1994. Other sites that followed included Mt Cuthbert and Selwyn in Queensland, Kanmantoo in South Australia and numerous others to the present time, https://www.altamet.com.au/consulting/projects/copper-projects/
[98] G.M. Miller, D.J. Readett and P. Hutchinson, 'Experience in operating the Girilambone SE-EW plant in changing chemical environments', *Mineral Engineering*, vol. 10, 1997, pp. 467-481.
[99] H. Holle and M. Braaksma, 'Girilambone Copper Company – heap leach operations', *in* W.G. Cook, A.J. Ford, J.J. McDermont, P.N. Standish, C.J. Stegman and T.M. Stegman, (eds), *The Cobar Mineral Field: A 1996 Perspective*, The Australasian Institute of Mining and Metallurgy, Melbourne, Spectrum Series No. 3/96, 1996, pp. 425-429.
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[101] K. Dudley, 'Production of high purity copper cathode by solvent extraction and electrowinning: Optimisation and process control at Girilambone Copper Company', *in* W.G. Cook, A.J. Ford, J.J. McDermont, P.N. Standish, C.J. Stegman and T.M. Stegman, (eds), *The Cobar Mineral Field: A 1996 Perspective*, The Australasian Institute of Mining and Metallurgy, Melbourne, Spectrum Series No. 3/96, 1996, pp. 431-438.