Copper mining and treatment in South Australia

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South Australia — 'The Copper Kingdom'

Copper was first discovered in South Australia near Montacute in the Mount Lofty Ranges, 16 km east-northeast of Adelaide, in 1842. This had been preceded by the discovery and development of Australia's first metal mines (silver–lead) at nearby Glen Osmond in 1840–41. The small Montacute discovery was followed in rapid succession by much more substantial finds at Kapunda (1843), Burra (1845) and Callington–Kanmantoo (1846). The Bremer Smelting Works, erected near Callington in 1848, was Australia's earliest commercial smelter.

By 1851, prior to the Victorian gold rush, Burra was the largest inland population centre in Australia. It was producing 10% of the world's copper and had become known as the 'Monster Mine', with South Australia known as the 'Copper Kingdom'. Mining of the Wallaroo and Moonta fields on northern Yorke Peninsula commenced in 1860, and a myriad of smaller copper mining ventures proliferated in the Flinders Ranges up to the turn of the century. Burra closed in 1877 and Kapunda the following year, but Moonta–Wallaroo continued mining until 1923 and smelting to 1926.

South Australian copper production effectively ceased at the end of World War II but was revived from 1969 with reopening of Burra, Kanmantoo and Mount Gunson. These had again closed or were in decline by the mid-1980s. In its second mining life of 12 years (1969–81), Burra produced ~40 000 t of contained copper, much the same as for its first 32-year episode (1845–77). Kanmantoo output was similar, while Mount Gunson produced a more substantial 130 000 t of contained copper. Nevertheless, Moonta–Wallaroo's record of 340 000 t of copper (plus 1.7 t of gold and 17 t of silver) remained unchallenged and still constituted half of the State's total output to that time. Then, in 1988, production commenced at Olympic Dam. It took only seven years to eclipse Moonta–Wallaroo's total, and a further four years to exceed all prior production in the state. This will now be replicated every three years — it seems that the Copper Kingdom has a new Monster Mine.

Figure 1 summarises South Australian copper production statistics as recorded by PIRSA (and the former MESA). It very clearly illustrates two distinct periods of copper production, roughly corresponding with the latter halves of the 19th and 20th centuries. Cumulative value, in dollars-of-the-day (£1=$2), is $2.5 billion. Cumulated tonnage from these data is 2 Mt but includes some concentrates. Contained copper, obtained by summing recorded output of the major producers (see below), is 1.5 Mt.

Review of SA copper deposits

Following its early dominance, South Australia has slipped to being Australia's second-ranked copper producing region. There are over 800 named, previously worked deposits in the state; the Adelaide Geosyncline – Stuart Shelf, covering ~150 000 km², hosts 80% of these. Current production is 200 000 t/y, essentially from a single operation — Olympic Dam. This compares to 1500 deposits over 80 000 km² in Queensland's Mount Isa Block, with 350 000 t/y current production from six operations.

In resource terms, South Australia again became the pre-eminent Australian copper province following discovery of Olympic Dam. Table 1 summarises the state's more significant copper deposits and fields, based on an identified resources of at least 20 000 t contained metal; locations are provided on Figure 2. In production terms, Olympic Dam is by far the largest producer. Sub-economic Olympic Dam style Cu–U–Au mineralisation is known at Acropolis, Wirrda Well and Emmie Bluff to the south of Olympic Dam, but resources are not published. This is also the case for smaller but more encouraging Cu–Au finds at Benagerie and White Dam on the Curnamona Craton to the east of the Adelaide Geosyncline.

Past and present copper operations

Table 2 lists the 20 mines in South Australia that have produced 200 t or more of contained copper.

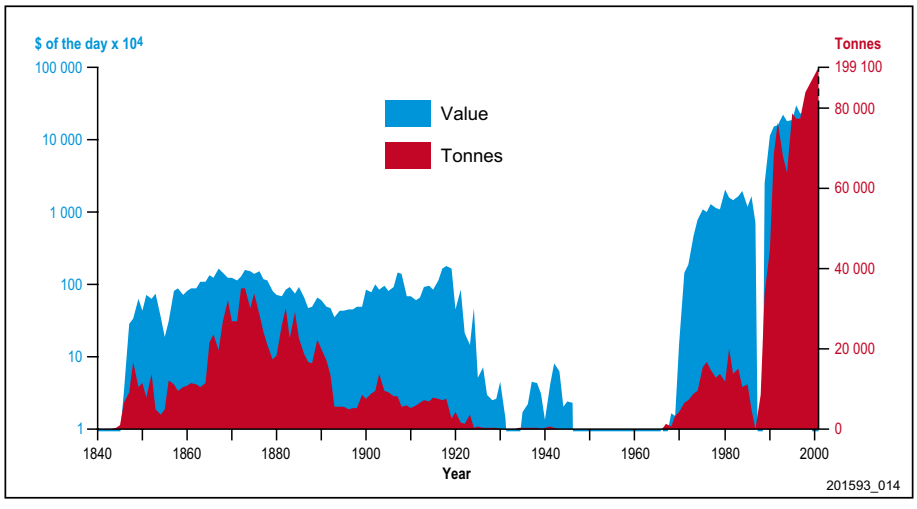

***Fig. 1** South Australian copper production, 1840–2000.*

Table 1 *Identified South Australian copper resources.*

Deposit	Ore (t)	Cu (%)	Cu (t)	Co (%), Other	Au (ppm)	Ag (ppm)	Pb–Zn (%)	Strip ratio	Resource class	Copper minerals	Past prod.	Status
OLYMPIC DAM												
	2 700 000 000	1.2	32 000 000	0.4 kg/t U	0.5	3	–	u/g	M+Ind+Inf	Cc, Bn, Cpy	1 200 000	200 000 t/y mine, refinery
MOUNT GUNSON												
Shale hosted												
Emmie Bluff	25 000 000	1.3	325 000	?	–	?	?		Inferred		0	Prospect, 400 m depth, Adelaidean only
Windabout	19 000 000	0.96	180 000	0.05	–	10	–/0.2		Indicated	Cc, Bn, Cpy	0	Prospect, at 70 m depth
MG 14	1 100 000	1.7	19 000	0.039	–	17	0.05/0.1		Indicated	Cc, Bn, Cpy*	0	Prospect, at 20 m depth
Gully	900 000	0.9	8 100	0.01	–	5	–/0.2		Inferred	Cc*, Bn, Cpy	0	Prospect, at 15 m depth
Sweet Nell	350 000	1.2	4 200	?	–	?	–		Inferred	Atac, Cc*, Bn, Cpy	20	Prospect, at 10 m depth
Sandstone hosted												
Cattlegrid	15 000 000	0.67	100 000	0.01	–	2	–		Indicated	Cc, Bn, Cpy	140 000	200 t/y in-pit leach, cementation
Main Open Cut	3 300 000	0.51	17 000	–	–	1	–		Indicated	Atac*, Cc	16 000	Remnants with in-pit leach potential
MUTOOROO												
	8 700 000	1.7	150 000	–	–	–	–		Indicated	Nat, Cc, Bn, Cpy*	240	Prospect; drill intercepts only
KANMANTOO												
	8 000 000	1.1	88 000	–	–	–	–		Inferred	Cpy	38 000	Below-pit remnants
Oxide stockpile	370 000	0.95	3 500	–	–	–	–		Measured	Mal*, Az, Cc, Cpy	1 000	Feasibility for leach, EMEW
WALLAROO–MOONTA												
West Doora	2 700 000	2.1	57 000	–	?	–	–		Inferred	Cpy	0	Prospect; drill intercepts only
Moonta	1 900 000	2.4	45 000	–	0.2	–	–		Inferred	Cpy*, Py, Po	150 000	U/G remnants; flooded
Wallaroo	3 100 000	1.4	43 000	–	0.1	–	–		Inferred	Cpy*, Py, Po	190 000	U/G remnants; flooded
Wheal Hughes	74 000	3.4	2 700	–	?	–	–		Indicated	Cpy*, Py, Po	9 000	Pillars and unmined remnants
Alford	60 000	2	1 200	–	?	–	–		Inferred	Atac, Mal	0	Prospect; drill intercepts only
KAPUNDA	4 300 000	1.1	47 000	–	Tr	Tr	–		Indicated	Mal, Az, Cc*, Bn, Cpy	14 000	Resource 0.5% cut-off to 90 m
KALKAROO	3 000 000	1.4	42 000	–	0.38	?	–		Inferred	Mal, Az, Nat, Cc	0	Prospect
PARABARANA	3 500 000	0.85	30 000	–	?	?	–	1	Inferred	Mal, Az, Chr, Cup, Cv	20	Prospect
ANABAMA	4 000 000	0.66	26 000	Tr Mo	?	?	–/Tr	2.9	Indicated	Mal*, Cc, Bn, Cpy	21	Prospect
DOME ROCK	2 500 000	0.85	21 000	0.03	Tr	?	–	2.2	Indicated	Mal, FeO, Chr, Cc	130	Prospect
LEIGH CREEK												
Lorna Doone	1 800 000	0.73	13 000	–	–	–	–		Measured	Mal*, Az, Chr, FeO	350	Feasibility for heap leach, cementation
Mountain of Light	1 200 000	0.82	10 000	–	–	–	–		Measured	Mal*, Az, Nat, Cc	600	Feasibility for heap leach, cementation
Total	**2 800 000 000**	**1.2**	**33 000 000**									
Excluding Olympic Dam	**110 000 000**	**1.1**	**1 200 000**									

Due to varying sources, resources are not necessarily strictly in accordance with JORC classifications eg quotation of strip ratio indicates that the figure is 'in-pit' (and possibly diluted), constraints and criteria generally applicable to reserves

* dominant species

Twelve of the mines in Table 2 exceeded 1000 t of contained copper, eight exceeded 10 000 t and four exceeded 100 000 t. Except for the modern Poona–Wheal Hughes operation, all down to Kitticoola (350 t) plus many smaller mines, had site smelters. In general, these were reverberatory type furnaces for non-sulphide ores. Many were not very successful due to either lack of anticipated feed or lack of sufficient timber fuel. Not only did site smelters obviate the cost of overland haul to Port Adelaide and shipping to Wales for smelting, but allowed much lower grade materials to be treated. Custom copper smelters also operated at Port Adelaide, Dry Creek, Scott's Creek and Apoinga. The mines with production of more than 10 000 t contained copper are reviewed below.

Table 2 *South Australian mines with recorded production exceeding 200 t of contained copper.*

	Tonnes	Principal production periods
Olympic Dam	800 000	1988–
Wallaroo	190 000	1860–1923
Moonta	150 000	1861–1923
Mount Gunson	150 000	1970–
Burra	86 000	1845–77, 1969–82
Kanmantoo	39 000	1970–76
Kapunda	14 000	1844–78
Blinman	9 700	1862–1907
Poona	9 000	1988–91
Wheal Hughes	9 000	1991–93
Bremer	3 200	1850–1907
Prince Alfred	2 000	1866–1908
Sliding Rock	1 000	1871–87
Mountain of Light	600	1890–1918
Yudnamutana Group	370	1862–67
Kitticoola (Tungkillo)	350	1846–52, 1890–1938 (Au)
Lorna Doone	350	1902–10
Clara St Dora	300	1895–1900
Montacute	300	1843–51
Mutooroo	240	1888–1908
Total	**1 465 410**	

Kapunda

Developed by graziers Dutton and Bagot in 1844, Kapunda boasts numerous firsts in Australian mining. It was the first commercially successful copper mine and Australia's first mining town. The first Cornish Beam Engine was erected here in 1848. Later, it had the dubious privilege of hosting one of only two 'Buhl' engines to leave Britain — in an attempt to circumvent James Watt's patent, the cylinders of these engines were inverted directly over the shaft but were soon disallowed by the patent courts. The other was installed at the North Rhine Mine near Keyneton, northeast of Adelaide.

Smelting furnaces were erected in 1849 and a refinery unit was added in 1861. From 1867, the site hosted Australia's first large-scale open cut in conjunction with its first hydrometallurgical plant. The Scottish Henderson Process consisted of leaching jig-concentrated carbonate ore with hydrochloric acid, followed by cementation on scrap iron. The hydrochloric acid was manufactured on site with salt from Port Adelaide and sulphuric acid made by burning pyrite from the mine. Although technically successful, the 1600 t of 75% Cu cement produced failed to repay the £60 000 capital investment. The principal reason was said to be the 0.5% (recovered?) ore grade being only 10% of that predicted.

The deposit comprised 28 discordant quartz–sulphide-filled fractures averaging 0.45 m in width and a bedding-parallel main lode, which was a pyritic horizon, partly replaced by copper in the supergene zone. Host silty sediments are heavily kaolinised, allowing mining to be carried out mostly by pick and shovel without the need for blasting. Copper mineralogy included the full oxidation sequence from malachite and azurite near surface through supergene native copper and chalcocite to chalcopyrite at depth. Deepest development was to 145 m in Harris Shaft. The remnant resource to 90 m is dominated by chalcocite but with ~20% mixed carbonate in <300 mm wide fractures and a dissemination halo.

Henderson Plant at the Kapunda Mine, 1875. *(Photo N024003)*

Burra

More than any other deposit, Burra symbolises 'Australia's Earliest Mining Era' — the title of the book by Auhl and Marfleet (1975). With three engine houses, two chimneys, a concentrating tower, powder magazine, Paxton Square cottages, dugouts and brewery cellars, the site is a living museum. The early mine was so successful that its operator, the South Australian Mining Association (SAMA or 'Sammie') never

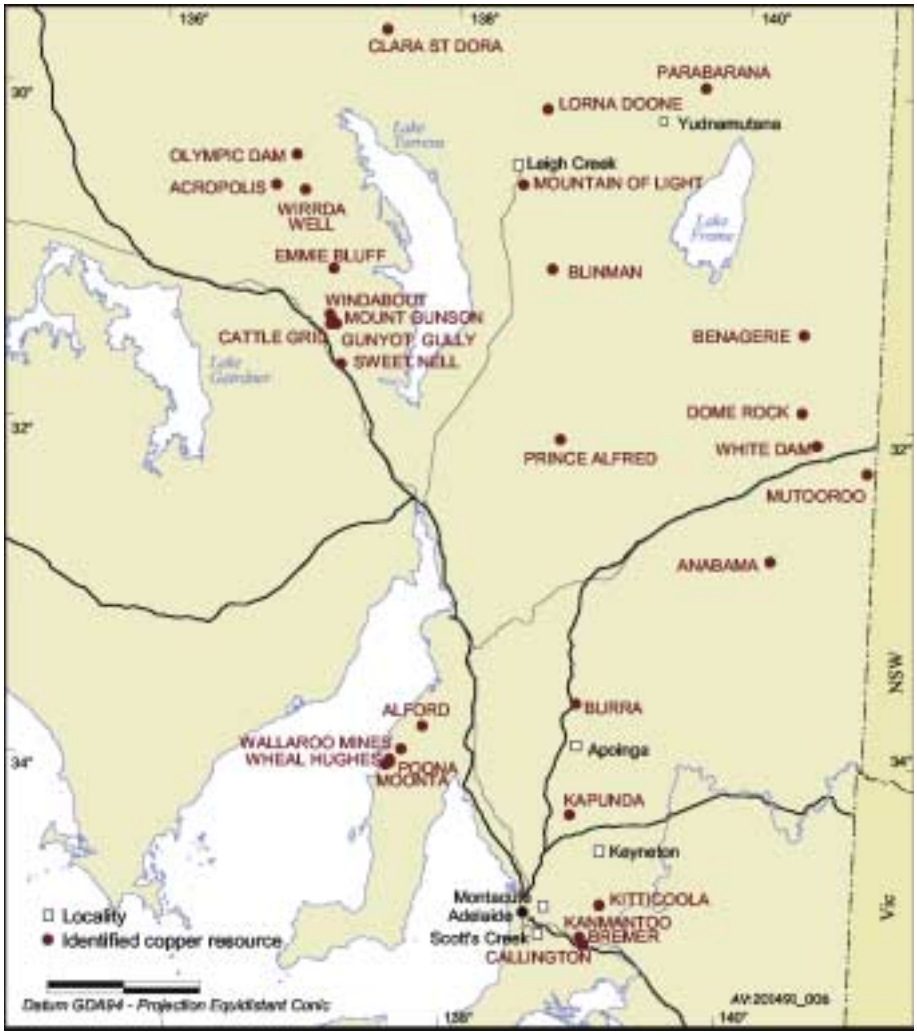

Fig. 2 *Location of principal South Australian copper deposits.*

made a subsequent capital raising and paid average dividends of 339% for 18 consecutive years. The mine was the major contributor to Australia's earliest mining boom, which revived the then struggling South Australian economy that had been founded on short-lived land speculation.

Although the sulphides bornite and chalcopyrite were exposed in the deepest workings at Morphett Shaft (600 feet), the vast majority of production was from carbonate ore and Burra is famous for its specimen (but rarely gem grade) malachite and other oxidised copper minerals. During the 19th century mining phase, Burra employed large numbers of 'picky boys' to hand sort ore from mullock as the primary concentration method. This was increasingly augmented by various forms of washing, including buddles and sluicing. Following an aborted early attempt by SAMA, smelting was carried out across Burra Creek by the Patent Copper Company.

The ammonia-leach cupric oxide plant, which was established in 1970, continues to operate on non-sulphide feed from elsewhere (see MESA Journal 26, pp.28–31). Retro-addition of a pre-leach reduction roast (Herreschoff, multi-hearth, vertical shaft, gas-fired kiln) overcame early recovery problems due the presence of clay and the copper silicate, chrysocolla.

Greater than 50 m width and extension of fully oxidised ore to more than 100 m below surface (and 50 m below water level) were exceptional features of the Burra ore. Host rocks were leached, brecciated, carbonate sediments and rhyolitic porphyry. Geological interpretation remains controversial. It is my belief that the host rocks are Callanna Group diapiric material. The alternative view is that the sediments are part of the surrounding Burra Group country rock and the small amounts of igneous materials are Jurassic volcanics. Drilling beneath the open pit in 1981 yielded a maximum intercept of only 3 m (2 m true width) at 1.06% Cu as chalcopyrite, in and disseminated around carbonate veins associated with the Kingston Fault. There are no known remaining resources.

Morphetts Pumphouse and Windinghouse, Burra, ~1906. (Photo 032148)

Moonta–Wallaroo

To date, this field maintains its status as the longest lived in the state, with 64 years of continuous production. The initially separate Wallaroo Mining & Smelting Company and Moonta Mining Company merged in 1889. The mines at Kadina (Wallaroo Mines) and Moonta, served by a smelter and port at Wallaroo, constituted the colloquially known 'Copper Triangle'. Between 1867 and 1872, >300 000 t of 'low grade' (10–15%) ore were backloaded to Hunter River Smelting Works, New South Wales, on ships bringing coal to the Wallaroo boilers. The Wallaroo Smelter also treated custom ores (not just copper) from elsewhere in South Australia, Western Australia, Tasmania, Queensland and Broken Hill. Acid produced from smelter gas spawned a superphosphate industry, which continues to the present.

At Moonta, multiple parallel lodes occur in fractures in rhyolitic Moonta Porphyry. A swing in strike from northerly to northeasterly essentially describes a pattern of concentric shells. Lodes are steeply northwest dipping, with very steeply pitching ore shoots typically much greater in vertical than horizontal extent. The similarly steeply dipping Wallaroo lodes constitute an east–west-striking en echelon series of stacked lenses. They are hosted by Doora Schist, comprising mafic volcanics and clastic and chemical metasediments. Ore mineralogy in both cases is dominantly chalcopyrite–pyrite–pyrrhotite. Wallaroo ore carries minor sphalerite, galena and molybdenite. Moonta ore is typically coarser grained with a gangue of quartz, tourmaline, K-feldspar and chlorite.

The field made a particularly significant metallurgical advance with development of the Hancock Jig. Large-scale paddock and heap leaching of slimes and jig tailings was undertaken using acidified seawater, with copper recovery by cementation. Cementation boxes were also deployed in drains underground. In later years, following its development at Broken Hill, froth flotation was also practised.

Drilling blast holes with jackhammers in a stope at Wallaroo Mines, ~1916–18. (Photo N010765)

Office ore sorting plant at Wallaroo Mines in 1916. (Photo N007169)

Wheal Hughes Tourist Mine, 1998. (Photo 046546)

The Poona and Wheal Hughes deposits on the northern margin of the Moonta field were reworked during 1988–93. Moonta Mining Joint Venture extracted 450 000 t averaging 4% Cu and 1 g/t Au ore by both open cut and underground methods. The ore was treated by flotation in a now dismantled plant located at the old Wallaroo Mine site at Kadina. About 17 000 t of copper were recovered as chalcocite-rich concentrates, typically grading 30% Cu and 7 g/t Au. The product was sold to Australian and Japanese smelters. The Wheal Hughes decline and mine have been converted into an excellent 'tourist mine' operated by the District Council of the Copper Coast.

Kanmantoo

In the 19th century era, Kanmantoo was one of many deposits in the Callington field, of which the Bremer Mine was the main producer. Host rocks to the mineralisation are garnet–andalusite–biotite schist of the Cambrian Kanmantoo Group.

The 1970s operation by BH South Ltd was an open pit with flotation to produce a chalcopyrite concentrate, which was railed to ER&S, Port Kembla, for smelting. Four million tonnes of 0.88% Cu primary ore were treated, and an unmined resource of 8 Mt at 1% remains below the pit floor. Decline access was developed off the pit haul road for trial underground mining but no production ensued. Approximately 25% of a 0.5 Mt stockpile of 1% oxide ore was treated in a sulphidising circuit just prior to closure of the mine in 1976. However, recovery did not meet expectations and a remnant stockpile remains at the site. This has recently been subject to a study for leaching with copper recovery by the Electrometals electrowinning (EMEW) process.

Mount Gunson

Ore was discovered at Mount Gunson in 1875 and first recorded production was from 1899. A smelter was erected in the Main Open Cut (MOC) area in 1904. A leach and cementation plant was operating on the shores of Gunyah Lake in 1915 (immediately northwest of the current tailings dam) possibly using ore from the nearby Gunyot and Bornite (West Lagoon) Workings. Rio Tinto Southern mined 32 000 t of 3.5% Cu and 14 g/t Ag ore from the MOC during 1941–43.

In 1970–71, CSR Ltd subsidiary Pacminex mined 234 000 t of chalcocite ore, principally from the East Lagoon Workings in Gunyah Lake, with a small contribution from West Lagoon. Concentration was by flotation, with recovered grades of 0.79% Cu and 12 g/t Ag. Utilising the same plant, the Cattlegrid deposit was developed from 1974 and, to 1986, 7.2 Mt of 1.9% Cu ore were mined. Together with 270 000 t of MOC ore, this yielded 127 000 t of copper and 62 t of silver in concentrates.

From 1987, current operator Adchem has produced 14 000 t of copper in cement for feed to the Burra cupric oxide plant. This was principally from heap leaching of 1.2 Mt of 1.3% Cu oxide ore from the MOC area, Gunyot, House and Core Shed deposits. However, it also includes 2000 t from in-place leaching (after blasting) of low-grade (0.4% Cu) chalcocite remnants in the northeastern Cattlegrid Mine pit floor.

Mount Gunson is located on the Stuart Shelf, comprising an undeformed cover sequence of flat-lying, late Adelaidean platform sediments on Gawler Craton crystalline basement. Both sandstone-hosted and shale-hosted mineralisation types occur at Mount Gunson.

Only the former have been mined and occur as undulating blankets comprising networks of fracture-filling veins in a breccia formed by periglacial reworking of a quartzite – aeolian sand disconformity. The quartzite is the locally silicified upper part of the Pandurra Formation, a thick (~1000 m) pre-Adelaidean fluviatile sandstone unit. The hummocky breccia surface incorporates descending sand wedges of the overlying Adelaidean Whyalla Sandstone. The principal ore mineral is chalcocite but significant bornite and chalcopyrite occur locally along with accessory carrollite, galena and sphalerite. Due to the salina-dotted surface environment, the hydroxy chloride atacamite is the principal oxide mineral.

The shale-hosted mineralisation occurs in the Adelaidean Tapley Hill Formation where this unit is present between the Pandurra and Whyalla units. Sulphide mineralogy is similar but much finer grained and not necessarily breccia hosted. Although many examples are known, with resources containing 0.5 Mt of metal, all have so far proved too thin, deep and/or low grade to exploit. Flotation recovery is poor at marketable grade but leaching of low-grade concentrates has shown some promise.

Mount Gunson pit-floor copper leaching, 1999. (Photo 049054)

Aerial view of Kanmantoo Mine in 1982, six years after closure. (Photo 036406)

Aerial view of the Cattlegrid Mine, 1982. (Photo T023076)

Olympic Dam Mine and refinery, 1999. (Photo 047242, courtesy Western Mining Corp.)

South Australia's surviving Cornish enginehouses

Hughes Shaft, Moonta. (Photo 39633)

Harvey's Shaft, Wallaroo. (Photo 40200)

North Rhine Mine, Keyneton. (Photo 40197)

Graves Shaft, Burra. (Photo 40198)

Morphetts Enginehouse and Windinghouse, Burra. (Photo 40199)

Richman's Enginehouse and plant, Moonta. (Photo 40201)

Worthing Mine, Hallett Cove. (Photo 37810)

Olympic Dam

Olympic Dam was discovered by WMC in 1975, following two decades of exploration in the Moonta–Wallaroo area and, in part, using Mount Gunson as a model. It is hosted by brecciated Mesoproterozoic Hiltaba Suite granite of the Gawler Craton, beneath the Stuart Shelf. Covered by 300 m of younger sediments, the deposit was poorly understood until underground mining provided significant exposure. The environment of deposition was an explosive volcanic crater. Chemically, the ore is characterised by sulphur deficiency, massive amounts of iron oxide, and high barium and rare earths.

Olympic Dam is the world's fourth largest copper resource (8th on reserves), the world's largest uranium resource and Australia's largest gold (and silver) resource. It has already undergone two expansions from 38 000 to 200 000 t/y copper output and has environmental consents to go to 350 000 t/y. At the end of 2001, proved and probable reserves were 717 Mt at 1.5% Cu, 0.5 kg/t U_3O_8 and 0.6 g/t Au. The operation is unique in Australia in that it incorporates mine, concentrator (copper and uranium hydrometallurgy), smelter and electrolytic refinery on the one site.

Possible future developments

With Olympic Dam having the capacity for further major expansion of production whilst still maintaining a likely century of life, South Australia is in no danger of losing its current copper production ranking in the foreseeable future. However, there are no projects in the pipeline by which it might re-establish its former pre-eminence in the near term. Clearly, there is potential for more major deposits to be found (see 'update' below) and, in addition to Olympic Dam style mineralisation on the Gawler Craton – Stuart Shelf, the Curnamona Province appears to offer significant promise.

The Burra cupric oxide plant sells a specialty product into a niche market and has maintained an average 5000 t/y output for three decades, with higher figures in recent years. It presently uses largely non-mine feed, a significant portion of which is imported. There is potential to redress this situation by boosting the dwindling contribution from Mount Gunson with further innovative development of low-grade resources at that site. Oxide deposits at Leigh Creek were proved up in the early 1980s for planned heap leaching and cementation to supply Burra. However, development was deferred in favour of higher grade deposits at Gunson. Subsequently, the copper price has not been conducive to their development either on this basis or for stand-alone solvent extraction and electrowinning, for which the resource base is also minimal.

The Pasminco Port Pirie lead smelter's immediate future has been secured with feed from the Cannington Mine in Queensland. However, its present 4000 t/y copper output, being a by-product from Broken Hill concentrates, is possibly limited to shortly after the closure of Broken Hill, currently scheduled for 2006.

In conclusion, South Australia's history of 19th century copper mining has left a legacy of 'little Cornwalls' throughout its rural landscape. There are ubiquitous pepper trees, miner's cottages and a colloquial taste for Cornish pasties. Stone and brick chimneys — round for the Cornish miners, square for the Welsh smelters — abound in conjunction with the largest number of surviving enginehouses (eight of 33) outside of Cornwall.

Copper mining is synonymous with South Australia's past and will unquestionably feature prominently in its future.

Acknowledgement and update

This article was originally part of a background presentation given at the ALTA2000 Copper-6 Hydrometallurgical Conference, Adelaide, October 2000. Since this article was written:

- Optimisation 3 at Olympic Dam is scheduled to bring potential production capacity to 235 000 t/y Cu by the fourth quarter of 2002. Achievement of this rate is not expected until 2004 due to rebuilding of the solvent extraction circuits following a fire and planned relining of the smelter in 2003. A scoping study has been completed and pre-feasibility commenced for subsequent major expansion, possibly to as high as 600 000 t/y Cu and incorporating new mining methods and mineral processing technologies.
- The flagged potential of the Gawler Craton for further Olympic Dam style mineralisation has been emphasised with recent, very promising drill intercepts by Minotaur Resources at Prominent Hill, and a consequent ground rush in the region by other explorers.

For further information contact Ken Bampton (ph. 08 8264 7745).

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