

Early History of Graphite Mining in South Australia

By BRIAN R. HILL

South Australia's Eyre Peninsula is well-endowed with large deposits of graphite mineralisation. From several of these deposits graphite products can be recovered that are suitable for most of the uses of this essential industrial mineral. However, all early attempts over the past 100 years to establish a graphite mining industry failed, as the cost of producing graphite in a marketable form proved to be uneconomic. Today, however, with an enhanced market price for graphite stimulated by the withdrawal of much of China's production from the world market and the development of new uses for graphite, the local industry is on the cusp of resurgence with one of the mines reopening this year and several others on the drawing board.

The early endeavours to establish the industry in the first half of the 20th century were triggered by war-time exigencies in both world wars, and the U boat menace to shipping that prevented the importation of graphite from Australia's traditional supplies in Ceylon (today Sri Lanka) and Madagascar (today Malagasy). These shortages led to sharp price increases for graphite which resulted in exploration activity and mine development with the latter often supported by government subvention. However, prices collapsed when cheaper imports were once again readily available, thus rendering the production of Australian graphite unviable.

A subsequent venture attempted to take advantage of improved overseas market prices some 25 years ago, resulting from China then withdrawing from export markets and an increased overseas demand for graphite, mainly for steel furnace lining bricks, but this project was moth-balled in 1993 after considerable expenditure when China re-entered the export market again, severely depressing prices.

Graphite and diamonds are both carbon

Surprisingly, both graphite and diamonds are mineral forms of the same non-metallic element, carbon: but unlike the sparkling gem which is the hardest natural mineral, graphite is soft, black, and unctuous, or greasy-feeling.¹ Graphite has a metallic lustre, and it marks paper, hence not only its use in lead pencils, but also the derivation of its name from the Greek word *graphon*, to write.

Graphite occurs in disseminated flakes in the Eyre Peninsula deposits, but also as scaly compact masses in some overseas orebodies. All naturally occurring graphite is crystalline, but in the industry the term 'crystalline' or 'flake' graphite is reserved for varieties that occur in crystals large enough to be visible to the unaided eye. Finer graphite is usually termed 'amorphous' graphite.² Geological science is undecided on the origin of graphite, which is found in beds or veins in sedimentary and metamorphic rocks where it possibly resulted from the alteration of carbonaceous matter, or more probably was introduced in the form of carbon-bearing gases. The deposits on Eyre Peninsula occur in graphitic beds of Lower Proterozoic age in schists and gneisses

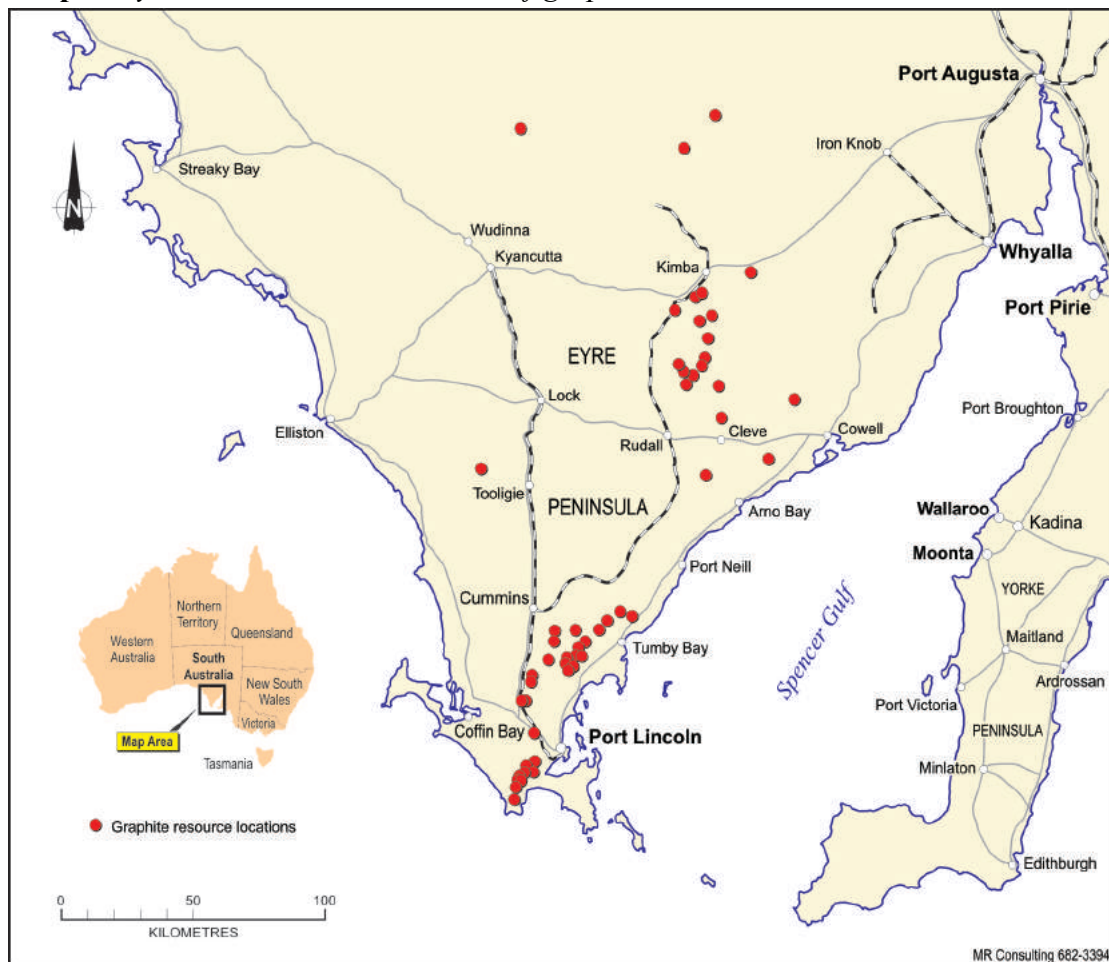
within the Cleve Metamorphics near the base of the Hutchison Group. They are traceable discontinuously, because of poor outcrop conditions, from the southern coast to Uley, and Koppio, and over a wide area between Darke Peak and Cowell.³

In the early years of the 20th century Ceylon was the main producer of graphite, followed by Madagascar. Other countries producing some graphite were Austria, Russia, Korea, Czechoslovakia, Germany and Mexico. The main uses for graphite at that time were - in decreasing order of magnitude: foundry facings and crucibles; paints and pigments; pencils and crayons; dry cell batteries; commutator brushes for electric motors; stove polish and lubricants. Total world consumption was some 100,000 tons a year. Later in the 20th century annual consumption grew to some 180,000 tons a year and China emerged as a major supplier.⁴

Eyre Peninsula 'the Pilbara of graphite'

South Australia contains the majority of the graphite deposits in Australia, and the only commercially exploited deposits are to be found on Eyre Peninsula.⁵ The extent of these deposits has drawn imaginative parallels with the iron ore deposits of the Pilbara region of Western Australia, and recently Eyre Peninsula has been excitedly described as the 'Pilbara of graphite'.⁶

Map 1: Eyre Peninsula - 'The Pilbara of graphite'



Source: Map based on DMITRE plan 204436-029.

Settlers on Eyre Peninsula observed evidence of graphite deposits as they cleared their farms for agricultural production. It is reported that graphite was first produced in South Australia in the 19th century when 11 tons were exported to London in 1866.⁷

In 1907 the first graphite company, The South Australian Graphite Company Ltd, was launched with a nominal capital of £3,750 in 150 shares of £25 each, to 'acquire and work and turn to account the graphite grounds or mines' near Tumbly Bay, about 50kms north of Port Lincoln. This first graphite company seems to have done more 'acquiring' than 'working and turning to account', and despite the rather grandiose ambitions, as detailed in its objects, 'to acquire ... to improve maintain manage and work any roads, ways, tramways, piers, wharves, bridges, warehouses, shops, stores, reservoirs, and hydraulic and electrical and other works ...' it sank out of sight without achieving anything, and was wound up in June of 1909.⁸ Others subsequently pegged the company's claims in the Hundred of Hutchison, which had been abandoned, in the 1917 graphite rush on Eyre Peninsula. The Assistant Government Geologist, R. Lockhart Jack, inspected them in 1917 and 1918 and reported that in view of the poor prospects, with only low grades of graphite encountered in workings 36 feet deep, that it 'might be advisable for the syndicate controlling the property to transfer its activities to a locality of greater promise'.⁹

World War I supply restrictions

The greatest impetus for the development of graphite mining came in World War I when supply restrictions resulted in sharply increased prices, doubling at one point to £30 a ton. This meant that graphite ore with a grade of 10 percent recoverable graphite was then equivalent in value to gold ore carrying half an ounce of gold to the ton, and on Eyre Peninsula there were several large deposits believed to be of that grade. In an excited flurry of exploration activity, prospecting syndicates were formed, several trends of graphite bearing rocks were soon recognized, and many claims were pegged.¹⁰ Jack made several trips to the Port Lincoln district to inspect the prospects and assess the potential for the establishment of a graphite mining industry. Because of the prospectors' lack of experience with graphite, some understandable mistakes were made in the rush. A number of claims pegged in the Hundred of Louth proved on examination to have been pegged over pegmatized biotite schist, the prospectors having mistaken the dark flakes of mica in the worthless biotite schist for graphite.

Jack pointed out that there was only a limited demand for the low value amorphous graphite, and the £20 per ton price was for graphite flake resting on an 80-mesh sieve and having a minimum carbon analysis of 80 per cent, with a rise of 10 shillings per unit of carbon above 80 per cent.¹¹ This meant that 90 per cent carbon graphite was worth £25 per ton. A method of assaying samples was devised that would reflect the value of the recoverable, marketable flake graphite contained, because chemical analysis of crude ore would show total carbon content including any uneconomic amorphous graphite in the sample. To avoid this problem the material was tested by apparatus designed to give the same treatment as ore underwent when passing through a working plant. It was ground and screened, and the undersize which passed

through an 80-mesh screen, and which contained the amorphous graphite, was discarded, while the oversize was treated by flotation,¹² the proportion of concentrates determined, and the carbon content of these concentrates was ascertained by chemical analysis.¹³

Government graphite bonus

It was apparent from the results of initial prospecting that the occurrence of graphite on Eyre Peninsula was widespread. Two discoveries of significant potential had been made – one on private land at Koppio 36km north of Port Lincoln, and the other at Uley, which was 23km south west of Port Lincoln. The prospects of establishing a payable industry appeared to be promising.¹⁴ This was an exciting potential development for the State, and the government moved swiftly to encourage the establishment of a graphite mining industry by offering a bonus for the production of graphite. Under the Native Industries Encouragement 1872, a bonus of £1 per ton would be paid on all graphite produced in the State and sold prior to 30th June 1919.¹⁵ The bonus, dated 23rd August, 1917, was announced in the same *Mining Review* in which the Assistant Government Geologist warned that the future of the industry would largely depend upon the success or otherwise of the earliest mills, and that treatment plants should not be erected until the best method of treatment had been worked out. Obviously the offer of a bonus for production occurring before 30th June 1919 was in conflict with this recommendation, and the bonus offer was quickly extended to 30th June 1922.¹⁶

However no bonus was paid, although 57 claims had been pegged in addition to the leases on private land at Koppio where the minerals were alienated, and owned by the landholder.¹⁷ Despite the favourable prospects, actual exploration work carried out was rather desultory with only 15 shafts sunk averaging 7m in depth, and three crosscuts driven averaging 10m in length.

The government pointed out that in 1915-16, blacklead plumbago or graphite and foundry facings imported into Australia were removed from bond to the value of £11,363. Duty amounted to £2,777, making a total cost to the local consumer of £14,140. 'The bulk of this market was open to Australian graphite in addition to manufactured graphite products that were also imported'. The government urged more energetic development of the Eyre Peninsula deposits:

On the promise afforded by the deposits in the Port Lincoln district, much more attention than was at present devoted to them should be given, that South Australia might take its place as a producer of this important mineral.¹⁸

However, sensing an imminent end to the war, most claimholders logically stunted any further expenditure waiting to see what the post-war prospects for the industry would be. A notable exception was the Uley Graphite Syndicate, which pressed on with exploration of their claims, encouraged by the size and grade of the graphite orebody being opened up. This syndicate was financed largely by a local landholder, Herbert Wollaston. Operations were in charge of well-known South Australian prospector Thomas Creer who originally pegged the deposit. In January 1918 there was

a fatal accident when miner Elijah Charles slipped from a ladder and fell 12m down a shaft.¹⁹ Graphite was dangerously slippery especially on ladder rungs.

The end of the 1917 graphite rush

As imported graphite once again became freely available after the war and prices fell, prospecting ceased and most of the claims pegged in the Eyre Peninsula 'graphite rush' were allowed to lapse. However because of the potential disclosed at the Uley deposit, work continued there supported by a 'government subsidy of £210/15s/0d. By 1920 a considerable tonnage of good grade ore containing flake graphite of high quality had been proven, and the government rather hopefully anticipated that, 'The coming year should see this important mineral appearing in the list of non-metallic products of the state for the first time'.²⁰

With the production of graphite now appearing to be imminent, the government refined its bonus offer: the maximum amount would be £1 per ton payable on graphite containing not less than 80 per cent carbon. On lesser grades the bonus would be in proportion to the carbon content. However, no bonus was paid, and the achievement of production of graphite at Uley was to take another eight years, and the first sale of any graphite did not occur until five years after that.

By the mid-1920s the five mining leases comprising the Uley mine were all owned by Tully C. Wollaston²¹ who had acquired the land and mining titles from his brother Herbert Wollaston, probably when the latter encountered financial difficulties.²² The Mines Department assisted Wollaston in experimental work on the recovery of the graphite, as well as with proving up the mine ore reserves, carrying out an extensive drilling programme.

Substantial graphite company formed

In March 1927 Wollaston formed a public company Graphite Ltd to take over the project and complete the development of the mine, and to establish a treatment plant to produce graphite for the Australian market. The company had a capital of £40,000 in 40,000 shares of £1 each. Wollaston granted the company a six month option to purchase the 2,719 acres of land he owned at Uley for £3,000, and sold his five mining leases and all plant and equipment at the mine to the company for £19,000, to be satisfied by the allotment to him of 19,000 fully paid vendor shares in the company. Some 77 shareholders (including 15 with Eyre Peninsula addresses) took up the balance of the shares, which were issued for cash.²³

The successful floating of the company was materially assisted by a favourable Mines Department report published in the *SA Department of Mines Mining Review 44*, which said there were 63,200 tons of ore in sight, from which 7,027 tons of graphite flake that could be caught on an 80-mesh sieve could be recovered. In addition there were about 1,500 tons of finely divided graphite. The Department reported:

At £20 per ton for large flake, and £15 per ton for fine graphite, this was worth £173,000 at present prices. There was also an *ad valorem* duty of 10 per cent on graphite entering Australia, which should ensure a ready market. Costs should not

exceed 22s. per ton, leaving a profit from the ore already developed of £100,000 ... There was every reason to believe that additional ore would be disclosed during the mining of the existing reserves.²⁴

This optimistic report, which was to prove to be wildly inaccurate in its assessment of the economic viability of the mine, ensured the raising of the necessary capital by Graphite Ltd. The company immediately proceeded to erect a mill along the lines recommended by the Mines Department and the Bonython Metallurgical Laboratory, which had carried out the experimental work on beneficiating the Uley ore. The main difficulty was to produce as large a flake size as possible while grinding the material sufficiently small to release the flakes of graphite in the ore. Composite particles of graphite and gangue tended to float in the flotation circuit with the flakes of graphite and had to be separated from the concentrate, but not rejected, as the contained graphite had to be recovered if possible to ensure an acceptable percentage recovery. A relatively complicated flow sheet was devised.

Figure 1: *The newly erected plant of Graphite Ltd at the Uley graphite mine in 1928. On the left can be seen the incline rail on which mine trucks were hauled up from the open pit, which is out of sight to the left. The ore bin is to the right of the elevated round water tank. The two tower-like structures were the high level hydraulic classifiers that screened the material. The chimney, partly obscured by the tower on the right, served the drier used to prepare the final product for bagging and shipment.*



Source: South Australian Mines Department, 1928.

Operation of the mine on the other hand would be relatively simple as it was worked as an open cut and the ore delivered to the treatment plant by mine trucks hauled up a decline rail track from the open pit. The ore was ground in a ball mill, and then elevated to pass through a high level hydraulic classifier which screened the material by size with the oversize (which would not pass through a 10-mesh screen) returned to the ball mill for regrinding. The fraction which passed through the 10-mesh screen, but which was too coarse to pass through a 20-mesh screen, went to a Wilfley table to recover coarse flake graphite. The proportion that passed through the 20-mesh screen was dewatered in a thickener to prepare it for flotation in a series of flotation cells.²⁵

The Wilfley table recovered the coarse flake graphite as the sideways-shaking motion of the table separated the lighter graphite from the heavier particles of gangue.

This largest flake size was the premium product. It was dried in a rotary drier, then screened and bagged for marketing. Coarse tailings from the table were discarded, but a 'middling' product that still contained considerable graphite was returned to the ball mill for regrinding to liberate the particles of graphite that were mixed with gangue.

In the flotation circuit the tailings from the first or rougher flotation cell were rejected to the dump, and a 'middling' was returned to the ball mill for regrinding. The concentrates from the rougher flotation cell passed to a cleaner flotation cell, and the concentrate from this was further concentrated on a Wilfley table to produce a fine flake for marketing. The tailings from both this Wilfley table and also from the 'cleaner' flotation cell were returned to the ball mill for regrinding, and a second run through the plant. As all these functions were taking place continuously and simultaneously it can be imagined how complicated the treatment was, and the expertise required to run the plant properly. The company appointed A.W. Wincey, formerly of Broken Hill, as manager.

The mill commenced operation at its designed rate of six tons of ore an hour on 14th September 1928. There must have been cost over-runs because on the 17th of that month, the company held an extraordinary general meeting to increase the nominal capital by half to £60,000. The notice of meeting advised that it was proposed to offer 12,000 of the new shares to shareholders, 'the issue having been underwritten'.²⁶

Disaster

It was soon apparent that something was very wrong, as the market would not accept the company's product. Within a few months, having failed to sell even one ton of graphite, the new mill shut down and the mine closed. In February 1929 the shareholders of Graphite Ltd resolved to sell the undertaking. However, there were no buyers.

The Department of Mines blamed the failure on a 'great change in the nature of products most in demand', but this does not satisfactorily explain the failure to sell any graphite at all, which was probably due to the Uley product not meeting the standards and specifications of local consumers. The Department reported that:

Originally high grade flake graphite was the most in demand, the manufacture of graphite crucibles requiring about 55 per cent of total production, but now, due to the increased use of electric furnaces, the manufacture of crucibles had dwindled and at present consumed but 13 per cent of the product.²⁷

Ironically the Uley graphite mine had been selected as the location to try out new geophysical and electrical methods of prospecting by the Imperial Experimental Survey. When undertaken in 1930 the work proved eminently successful, and a new wide zone of graphite was indicated which was confirmed by underground work undertaken by the government.²⁸

By early 1933 the despairing shareholders resolved that the company be voluntarily wound up, and a liquidator was appointed. Later that year the liquidator was able to sell some of the graphite the company had produced nearly five years before. Over the next four years he marketed 124 tons in small lots for a total of £1,875. Sales

of plant were similarly laggardly and it was not until 1941 that he was able to finalise the liquidation. Asset sales could raise only £3,328, and after the expenses of the liquidation there was only £1,615/17s/11d left for the hapless shareholders as a first and final return of capital, a derisory 7.458pence per £1 share – not even sevenpence-halfpenny!

In a further ironic twist, as the shareholders were receiving this paltry and belated return from their investment made with such optimism 14 years before, wartime problems with the supply of graphite from Australia's overseas suppliers were again leading to shortages and the price of graphite was rising, once again stirring interest in the possibilities of producing graphite from the Eyre Peninsula deposits.

Second World War supply restrictions

During 1940 and 1941, both the Uley mine and the Koppio prospect were taken up again, Uley being pegged by F.R.M. Drummond and E. Hambour, and Koppio being taken up by H. Harcourt Cribb.²⁹ The Koppio prospect that had appeared so interesting in 1918 had had no further work done on it until Cribb took out a lease in November 1941. Fourteen months later the energetic Cribb was able to place graphite on the market, and it found a ready acceptance by industry, commanding a premium price, selling for £60 a ton. The graphite produced by Cribb's enterprise, styled the 'Western Carbon Company', was of a large flake size, assaying 90 per cent carbon.³⁰ However, this quality of product was achieved at the cost of excessive losses of graphite in the treatment process.

Despite CSIR metallurgical reports recommending the installation of flotation cells, Cribb's plant design eschewed flotation and relied on a Wilfley table to concentrate the graphite, which was screened and re-cleaned on a vibrating screen.³¹ The plant was installed at Port Lincoln and it produced 97 tons of graphite in 1943 and 1944, which sold for £6,494.³² The Koppio mine closed early in 1944, but the Port Lincoln plant continued treating a stockpile of ore until the end of that year.

Declaring that 'if the mine could be made to pay now, there would be a good chance of establishing a permanent industry in South Australia' the Mines Department reported extensively on the mine.³³ In 1945 the Industries Development Commission advanced funds for the exploration of the deposit by driving and crosscutting, the Mines Department undertaking the work, as well as drilling a diamond drill hole to furnish confidence that the ore body persisted at depth. Although this programme expanded the mine's ore reserves to 3,900 tons of proven and 14,000 tons of probable ore, the Department had to conclude that with the future price of graphite then so uncertain, the outlay of £5,000 required for the addition of flotation to the plant to improve recoveries was 'to some extent speculative'.³⁴ No further work was undertaken and the mine was eventually abandoned.

Meanwhile the Uley mine was also re-opened, the claimholders Drummond and Hambour forming a private £2,500 company, South Australian Graphites Pty Ltd, in December 1940.³⁵ One thousand of the shares were issued as vendor shares to acquire their claims, several other modest cash issues were also made in 1941 and 1942, and the company had some two-dozen shareholders. Initially the ore was shipped to Port

Adelaide for treatment in a newly erected flotation plant at Birkenhead, and this plant produced 158 tons of graphite over three years from 1941.³⁶ Although this was sold for £30 a ton, it is highly likely that the government subsidized this production, which must have been quite costly because of the cost of shipping raw ore to Adelaide.

Government finance

The wartime exigency necessitated that a serious attempt be made to produce Australia's industrial requirements of graphite, and the Commonwealth government provided financial assistance for the installation of a treatment plant at the Uley mine. The CSIR and Melbourne University undertook detailed test work on the Uley ore, and a treatment plant was designed and erected with government assistance. It commenced operation in 1944, producing 207 tons of graphite in 1944 and 37 tons in 1945, but shut down when supplies of imported graphite became available in 1945. The flow sheet was not dissimilar to the 1928 Graphite Ltd plant discussed above.³⁷ The product was of a lower grade than the Koppio graphite and the flake size smaller, mainly because of the amount of grinding needed to free the graphite in the composite particles of ore to achieve a reasonable rate of recovery and avoid losses. As the ore contained calcite, the installation of additional plant for acid treatment of the table concentrates to reduce calcium carbonate content of the final product to the minimum required by battery manufacturers was contemplated, but did not proceed.

Some of the ore treated was from the old Graphite Ltd open cut, but a new shaft was sunk and ore was stoped underground from the 66ft. and 115ft [20.2m to 35.1m]. levels. Gouging by hand from the open cut was resorted to when explosives were not available. Underground ore extraction was by square set stoping which is a relatively high-cost method requiring large quantities of timber. It was not only the safest system for the ground conditions encountered at Uley, but its flexibility allowed the mining of irregular patches of ore with minimum dilution by waste or low grade ore. This could be left in place or sorted out and used for filling the stopes.

In late 1944 the Mines Department was able to report that 70 per cent of local consumption could be satisfied by South Australian graphite which had found a ready market in the foundry industry, and as a lubricant.³⁸ At that time the consumption of graphite in Australia was divided as 40 per cent for foundry and 20 per cent for dry battery manufacture, with crucible manufacture 10 percent and sundry uses, including mainly lubricants but also electrodes, paint and stove polish taking up 30 per cent. Little effort had been made to produce the high grade flake required for crucible manufacture, but the SA industry could supply 90 per cent of trade requirements. Although the Uley deposit had disclosed sufficient ore for continuous production for years, the report concluded that the future of the industry was problematic because the cost of production was high compared with graphite from Ceylon and Madagascar which was won by cheap labour and refined at low cost.

When imported graphite became more readily available in 1945, consumers showed a preference for the better-known and standardized grades of their traditional suppliers, and Uley joined Koppio in closing down.³⁹

Syndicate effort

Over the next five years a syndicate, which included some of the former directors of South Australian Graphites Pty Ltd, attempted to reopen the Uley mine. This resulted in the intermittent production of about 200 tons of graphite that was sold for £30 a ton.

In 1952 the Mines Department published a study of the cost of producing South Australian graphite.⁴⁰ Based on Uley manning levels and costs, which were thought to be typical for any operation in the region, the Department estimated mining costs at £4/3s/0d per ton of ore, treatment at £3/6s/3d, management and general costs at £1/9s/0d, and indirect and head office costs at 13s/0d, making a total cost of £9/8s/6d per ton of ore. As the head grade of the ore was 15.7 per cent, and in producing a 75 per cent graphite concentrate there would be a only a 65 per cent recovery of the graphite in the ore, 7.35 tons of ore would have to be mined and treated to produce a ton of graphite. At a cost of £9/8s/6d a ton, the estimated cost of producing a ton of South Australian graphite would therefore be £69/5s/6d. This estimate did not include any allowance for depreciation, nor interest on, nor amortization of the capital investment required. As graphite could then be readily imported for much less than £69 a ton, the dream of a South Australian industry slipped away, and nothing further was heard of graphite for another 30 years.

The third treatment plant at Uley

In the early 1980s, while exploring southern Eyre Peninsula for base metals, Australian mining giant CRA Ltd intersected high grade graphite while drilling a geophysical anomaly near the abandoned Uley mine. Although their work indicated a substantial graphite orebody, CRA offered the property for sale because of a 'stated lack of synergy with its portfolio'.⁴¹ Because of the recent development of a new use for graphite in improving the durability of furnace bricks used in the steel industry in high-wear areas of furnaces, CRA would have anticipated some interest in its acquisition, and would have been pleasantly surprised to have received an offer of \$3,000,000 and a royalty of 5 per cent. This bold offer was made by a private Perth company, Solution Mining Pty Ltd, which had made considerable profit mining a rich gold deposit at Tennant Creek, and apparently believed it could repeat its good fortune mining graphite. Solution Mining acquired the tenements in November 1988. Sharply increasing prices for graphite seemed to provide justification for their optimism, and a subsidiary, Graphite Mines of Australia Pty Ltd, was established to operate the project.

After carrying out test work, this company proceeded to erect a treatment plant at the mine – the third to be built there. Running out of funds before the plant had produced any graphite for sale, Solution Mining sold out to a listed gold mining company, being partially taken over by Tarcoola Gold Ltd, later to be renamed Eagle Bay Resources NL.⁴² Tarcoola Gold completed a small plant which produced a limited amount of 'saleable product' prior to suspending operations in August, 1990, 'due to sub-economic scale.'⁴³ The outlook for the successful establishment of the local industry was then gloomy, except for the continuing increases in graphite prices.

Enter overseas capital

In October 1990, US coal mining conglomerate, The Pittston Company, which was seeking mining ventures in Australia, acquired an option over the Uley project, conducted test work and market studies during 1990/91, and committed to establish a new project. In September 1991, a joint venture agreement was announced between subsidiaries of Eagle Bay Resources (formerly Tarcoola Gold) and The Pittston Company, whereby Pittston would earn a 75 per cent interest in Uley.⁴⁴ The joint venture provided that Pittston would pay out the current bank overdraft of \$1,250,000, and fund a redevelopment to a rated capacity of 14,000 tonnes of graphite per annum. Pittston would have 100 per cent of the net cash flow from the project until they recovered the amounts expended, and thereafter the joint venturers would participate in proportion to their respective interests.⁴⁵ Pittston undertook a drilling programme which indicated a resource of some 400,000 tonnes, grading 12.5 per cent carbon at the open pit site, with a waste to ore ratio of less than three-to-one. It was expected that further drilling would readily and substantially expand this resource estimate. The project had had some \$6 million invested in it before the arrangement with Pittston, which invested an additional \$8 million.

Subsequently an Australian specialist mining company, Mining Project Investors Pty Ltd [MPI], formed mainly by previous executives of the Australian Consolidated Minerals group after that group was taken over, acquired an interest from Pittston on the following terms: MPI to manage the project, and Pittston to assist with technical work and marketing, as well as fund completion of the project to agreed specifications, and provide a \$2.5 million working capital credit line. MPI bought 25 per cent of Pittston's interest for \$2 million, but wisely arranged an 18-month put option to be able to sell it back to Pittston at cost at MPI's election. In addition MPI had a 3-year call option to buy another 25 per cent at Pittston's cost plus 10 per cent.

Ore was mined by contractors from the open pit during the summer months, and stockpiled at the treatment plant for year-round milling. The modified treatment plant had a capacity of 35 tonnes per hour. The graphite was concentrated by flotation, and gravity tabling rejected silicate minerals, and wet high intensity magnetic separation rejected iron oxide. Products of different flake size and carbon content were made. However, although graphite supplied to customers in Japan and elsewhere for commercial trials confirmed the acceptability of the Uley products, the project was unable to establish viable contracts at economic prices. The cost of producing Uley graphite was then some \$780 per tonne and prices fell below this level [Table 1] as China re-entered the export market. In 1993 the Uley mine closed yet again.

Market analysis

It now seems that the 1988-1993 period of activity at Uley, when more than \$14 million was invested in the project, occurred during a period of price aberration, with several factors restricting the usual supply of graphite to the market, which forced up prices. China, which then supplied nearly half the world graphite market, restricted output because of a severe drought, with scarcity and rationing of process water reducing mine

output. The price increases in this period were not the result of increased consumption but were only transitory, being the logical market response to reduction in supply (which turned out to be only temporary). What may have obscured the real position to the local industry was that there was concurrent but only ephemeral increased demand from traders and some consumers who were temporarily building up stocks because of their recognition of the supply restriction. Prices increased by about 30 per cent from 1988 to 1990, followed by a slide back to pre-1988 prices as China re-entered the market and discounted prices to regain market share.

Table 1: *Graphite prices C & F Japanese ports, in \$US per tonne, from 1988 to 1993*

Grade	Fixed Carbon %	Flake Size	1988 \$	1989 \$	1990 \$	1991 \$	1992 \$	1993 \$
594	94	+50 mesh	1119	1412	1331	1441	1283	1064
590	90	+50 mesh	846	1064	1105	1117	898	833
894	94	+80 mesh	969	1115	1261	1066	893	740
890	90	+100 mesh	719	915	947	811	572	555
194	94	+100 mesh	365	642	575	550	410	369
190	90	+100 mesh	505	717	755	687	510	444
-190	90	-100mesh	256	367	467	516	419	291

Source: PMI, *personal communication*

Uley always suffered a location disadvantage in selling into the Japanese market. Having to take its product 700km by road transport to Adelaide and then 20 days sailing to Japan resulted in transport costs much higher than those of Chinese or Canadian producers.

The main problem preventing the successful development of a graphite mining industry in Australia has always been the market for the product. This now appears to be changing, with attractive price increases as China restricts its exports, and exciting developments taking place with new uses for graphite.⁴⁶ Traditional demand for graphite in the steel and automotive industries is growing at about 5 per cent annually, and prices have tripled in recent years. New applications are also big consumers of graphite. These include lithium-ion batteries, fuel cells and heat sinks in computers. China has dominated graphite production for the last 20 years, producing about 70 per cent of annual world production. However, in mid-December 2013 it was announced that operations at Pingdu, Shandong Province, had been ordered closed by government authorities on environmental grounds, and these operations represent about 20 per cent of China's flake graphite production.⁴⁷ China is also limiting its graphite exports with quotas – imposing a 20 per cent export tariff and a 17 per cent value added tax.

Equity markets are still somewhat wary, so financing the development of a new graphite mine will not be easy, but most graphite hopefuls will seek off-take commitments with end-users, and seek to borrow mine development funds against these agreements.⁴⁸ The market will be very competitive because the number of graphite companies world-wide has more than doubled in the last two years to 73 companies with 176 graphite projects.⁴⁹

New company floated on Uley

After the closure of Uley in 1993, MPI exercised its put option and left the joint venture, and Pittston also withdrew. This left Tarcoola Gold, which held on to the Uley graphite mine for some 20 years, mainly because of the pertinacity of its managing director Tony Rechner. His faith is now being vindicated by the announcement of Tarcoola Gold's descendant Valence Industries that they are re-opening the mine this year.

Figure 2: *The 1988-1993 treatment plant at the Uley mine which has been mothballed for 20 years and which is now being refurbished and expanded by Valence Industries Ltd for resumption of production in 2014. The open pit is behind the photographer who stood upon a stockpile of ore at the mine.*



Source: Photograph courtesy Valence Industries Ltd, 2014.

There has been a tortuous trail to this point. Tarcoola Gold (or Eagle Bay Resources, and later Strategic Graphite, then Valence Industries) was taken over by Strategic Energy Resources [SER], and renamed Strategic Graphite Ltd [SGL]. In May 2011 SER proposed listing Strategic Graphite on the Toronto Stock Exchange *via* a sale to Canadian graphite company Mega Graphite Inc. at a value of \$70 million. In April 2012, SER demerged SGL distributing 80 per cent of its SGL shares pro-rata to some 3,600 existing SER shareholders. In addition to its then 20 per cent interest in SGL, SER retained a 1.5 per cent royalty over graphite sales from Uley. In November 2012 SER terminated the deal with MGI due to Mega's non-performance. Strategic Graphite then changed its name to Valence Industries, and in January 2014 raised \$6.74 million in a prospectus issue and listed on the Australian Stock Exchange.⁵⁰ This was the first company float in Australia for the year. Subsequently Valence placed 17,024,543 shortfall shares plus options from the float raising an additional \$3.4 million.

Valence Industries has commenced work refurbishing and reconstructing the old plant at Uley that has been mothballed for 20 years. The company expects to ramp production up to 50,000 tonnes of graphite a year. A scoping study indicates costs of less than \$600 per tonne at that output, with average product pricing of \$1,400 per tonne. According to managing director Christopher Darby the company expected to finalise sales agreements prior to commencing production this year (2014).⁵¹

The company has announced an indicated resource estimate of 4.3 million tonnes and an inferred resource of 3.3 million tonnes with a grade of 8.7 per cent at a

3.8 per cent cut-off. The company's consultants, Coffey Mining, estimate that the Uley leases have a potential 25-150 million tonnes at 6-9 per cent total carbon.⁵² Depending upon the market for graphite, as always, Uley at last seems assured of a very long life.

Other companies rush to Eyre Peninsula

Besides Valence Industries with their Uley mine project, there are now several other companies active to varying degrees in graphite exploration on Eyre Peninsula. They include Lincoln Minerals, Archer Exploration, Monax Mining, and Lithex Resources.

Lincoln Minerals took up the old Koppio graphite mine, and also the nearby graphite discovery of Kookaburra Gully made by Pancontinental Mining in 1980.⁵³ In 2013, Lincoln Minerals drilled the Kookaburra prospect, defining a maiden resource of 2.25 million tonnes grading 15 per cent total graphitic carbon (TGC), with 338,000 tonnes of contained graphite at a cut-off grade of 5 per cent TGC. The potential could be much greater as Lincoln has drilled only 500 metres of a 4-5km long electromagnetic anomaly indicating underlying graphite mineralisation. According to Lincoln Minerals managing director John Parker, 'This is one of the best graphite deposits in the world'.⁵⁴ Lincoln Minerals hopes to construct a \$1.94 million pilot plant this year so as to have trial processed graphite samples ready for customer qualifications.⁵⁵

Archer Exploration has defined a resource at its Campoona prospect near Cleve on Eyre Peninsula of 2.527 million tonnes at an average grade of 12.3 per cent graphite for a total resource of 310,800 tonnes of graphite. The company hopes to start production in 2015. Archer Exploration's coffers received a welcome boost in May 2013, when the company sold its base metal exploration tenements 90km from BHP's Olympic Dam mine to BHP Billiton for \$8 million.⁵⁶ However according to Archer's managing director Gerard Anderson, the company's work is now geared around identifying graphite off-take agreements to provide the impetus for mine construction and commissioning of the Campoona prospect.⁵⁷

Monax Mining has been exploring a graphite prospect at Waddikee on Eyre Peninsula. In November 2013, the company announced an inferred mineral resource of 6.38 million tonnes grading 8.8 per cent total graphitic carbon (TGC). This indicates some 550,000 tonnes of contained graphite using a 5 per cent TGC cut-off.⁵⁸

There is ten times more graphite in a lithium-ion battery than there is lithium. Recognising this, Lithex Resources, whose portfolio included lithium projects, has expanded into graphite, recently picking up graphite prospects on Eyre Peninsula as well as in Western Australia, New South Wales and Queensland.

In addition to these companies exploring prospects on Eyre Peninsula, a plethora of Australian companies seeking graphite have sprung up or converted from other activities.⁵⁹ They include Lamboo Resources, Montezuma Mining, and Buxton Resources active in Western Australia, but other Australian companies exploring for graphite have gone overseas. Included in their number are the sensationally successful Syrah Resources⁶⁰ and Triton Resources in Mozambique, Talga Gold in Sweden, MRL Corporation and Bora Bora Resources in Sri Lanka, Malagasy Minerals in Malagasy, Global Metals Exploration, Uranex, and Kilbaran Resources in Tanzania, Castle Minerals in Ghana, and Discovery Africa in Namibia and Uganda.⁶¹

Graphene - the world's next wonder material

The new uses of graphite including electrification of vehicles and energy storage have resulted in it being called the 'new silicon'.⁶² The world is said to be entering a new era of carbon-based materials technology.⁶³ Graphite's criticality and potential scarcity have been recognised by the EU and USA, with both declaring graphite a supply-critical mineral. However it is the wonder material graphene made from graphite that is generating most excitement.

Graphene is a one atom thick layer of graphite. It has startling properties, being stronger than steel and tougher than diamonds, making it the strongest substance on earth. It has many attributes that give rise to multiple applications that can be applied across a range of commercial areas. The unique structure of graphene, with a thin layer of carbon atoms arranged in a honeycomb lattice, allows electric currents to move through it faster than through any known material. It will be used in solar cells and communication devices, and every kind of material that needs to be this strong or to conduct electricity. Graphene has been known since the 1940s, but it was not until 1994 that researchers from the University of Manchester were able to isolate graphene from graphite.⁶⁴

Appreciating the boundless potential of this wonder material made from graphite, and the possibilities of instituting vertical-integration, the companies exploring for graphite on Eyre Peninsula have moved with alacrity to forge connections with universities researching graphene. In May 2013 Strategic Energy Resources [SER], which then owned Uley, announced positive findings from Monash University's research into Uley graphite's suitability for graphene. Along with the Australian Research Council, SER has been funding a three-year graphene research project with Monash University. SER's successor at the Uley mine, Valence Industries, has announced an \$800,000 investment to establish a graphene research centre at the University of Adelaide.⁶⁵ Archer Exploration has announced that in collaboration with the University of Adelaide it has successfully produced a number of graphene and intercalated graphite products from raw Campoonna graphite. Archer Exploration managing director Gerard Anderson is of the opinion that if Australia does not take leadership with efforts to commercialise value-adding opportunities around its high-grade graphite deposits, 'it will be beaten to the punch by other countries striving to achieve early development and first mover position in these emerging markets'.⁶⁶

After a century of sporadic attempts to establish a graphite mining industry in South Australia which all failed, it now appears with the recently improved market conditions and increased prices, plus the possible potential of wondrous new applications through the development of graphene, that the industry might finally be on the cusp of profitable development and permanent establishment.

(Note: the information in this paper was up to date at the time of submission in March 2014).

Acknowledgements

The author thanks and gratefully acknowledges the assistance of Mr Keith Johns, former Director of the SA Mines Department; Mr Christopher Darby, managing director Valence Industries Ltd; Dr John Parker, managing director Lincoln Minerals, Mr Dwayne Povey, Chief Geologist, Lincoln Minerals; and landowners Messrs. R. & C. Calderwood and R. & L. Cullen of Koppio for allowing the author to visit the Koppio graphite mine and the Kookaburra prospect site respectively; and Mr Darby and his Valence Industries team for showing the author over the Uley mine project; and Mr Michael Ross of MR Consulting for preparing the map accompanying this paper. Any errors and omissions in this paper are the responsibility of the author.

Endnotes

¹ As both graphite and diamond are mineral forms of carbon they are both designated by the chemical element symbol C, but they differ markedly in their crystalline structures which impart their physical characteristics. Graphite is in the rhombohedral division of the hexagonal crystal system, and diamond is in the octahedral form of the cubic crystal system. Graphite rates 1, the lowest measure on Moh's scale of hardness, and diamond 10, the highest. Graphite has a specific gravity of 2.2 and diamond 3.4. See, H.H. Rutley, *Rutley's Mineralogy*, London, 1927, p. 38.

² New series No. 138 C.S.I.R. No. 124, 'Notes on Graphite', in *SA Department of Mines Mining Review* [hereafter *SADM Mining Review*], 76, 1943, p. 47.

³ R.K. Johns, 'Graphite – South Australia', in *Economic Geology of Australia and Papua New Guinea*, AIMM 1976, p. 157; and R.K. Johns, *Geology and Mineral Resources of Southern Eyre Peninsula*, Geological Survey of South Australia Bulletin 37, 1961.

⁴ C. Pettinos, *Graphite: Marketing of Metals and Minerals*, London, 1925.

⁵ Some graphite has been produced in Queensland, but it is amorphous graphite. Deposits of flake graphite have been recognized in other states, mainly in Western Australia but none has yet been developed for production.

⁶ This claim was made by the managing director of Lincoln Minerals, Dr John Parker, at the South Australian Resources and Energy Investment Conference in Adelaide on 1 May 2013. He said there would be several world class deposits developed on Eyre Peninsula. See, 'No. 1 for graphite', *Port Lincoln Times*, Port Lincoln, 2 May 2013; Monax Mining managing director Gary Ferris echoed the 'Pilbara of graphite' comment at a Mining SA presentation and in a Monax Mining ASX report dated 27 November 2013.

⁷ R.K. Johns, 'Mining and Mineral Resources', *Natural History of Eyre Peninsula*, Royal Society of SA, 1985, p. 52. This report assumes that the ore was from the subsequent site of the Uley graphite mine, but a local farmer, Jack Casanova, in his book *Fading Footprints. Pioneers, Runs and Settlement of Lower Eyre Peninsula*, Port Lincoln, 1992, p. 244, claims that this first production came from 'the Murninnie copper mine, then working near Moonaby [sic]'. Murninnie Copper mine is located 240 km north of Port Lincoln.

⁸ £1,000 in 50 free vendor shares deemed to be paid up to £20 each were issued to the predecessor The South Australian Graphite Syndicate as full consideration for the transfer to the company of the interests of the Syndicate. See The South Australian Graphite Company Ltd *Returns* located at State Records, Adelaide.

⁹ R. Lockhart Jack, *SADM Mining Review* 27, 1918, p. 64.

¹⁰ Only one of these early syndicates, which were prospecting partnerships, was formed into a company. This was Port Lincoln Plumbago Syndicate NL, formed in March 1918. See Port Lincoln Plumbago Syndicate NL *Returns* in State Records, Adelaide. This company acquired claims in the Hundred of Lincoln some three km east of the Uley graphite mine, but results of shafts sunk were quite unpayable, and prospects looked very poor and unpromising according to Jack, Jack, *SADM Mining Review* 27, 1918, p. 61, and *SADM Mining Review* 30, 1919, p. 35.

¹¹ R. Lockhart Jack, *SADM Mining Review* 26, 1917, p. 48.

¹² The flotation process separates minerals by discriminating between their 'wettability', or different surface tension properties. Bubbles of compressed air are blown through a tank in which the material is agitated in water to which a frothing agent, usually pine oil, is added. The particles of graphite cling to the surface of the bubbles and rise to the surface where the froth is scraped off, and the graphite is recovered by filtering, and dried. The gangue, or valueless minerals in the ore, sink in the flotation tank and are drained off and discarded.

¹³ R. Lockhart Jack, *SADM Mining Review* 26, 1917, p. 51.

¹⁴ *Ibid.*, p. 62.

¹⁵ 'Notice of the offer of a bonus for the production of graphite.' *SADM Mining Review* 27, 1917, p 15.

¹⁶ *Ibid.*, 29, 1918, pp. 13, 16.

¹⁷ In the earliest years of the colony buyers of land also acquired by that purchase the mineral rights of that land, and the minerals were alienated from the Crown. After the 1870s minerals were excluded from subsequent land sales and no minerals were thereafter alienated from the Crown by the sale of land, and they were available for pegging and claiming by a holder of a Miner's Right. The great majority of the graphite deposits on Eyre Peninsula were in this latter category, and only the deposits at Koppio, which were on land that had been bought from the Crown in the early days, were alienated from the Crown and privately owned.

¹⁸ R. Lockhart Jack, *SADM Mining Review* 27, 1918, p. 24.

¹⁹ Jack Casanova, *Fading Footprints. Pioneers, Runs and Settlement of Lower Eyre Peninsula*, Port Lincoln, 1992, p. 244.

²⁰ *SADM Mining Review* 31, 1920, p. 5.

²¹ Tully Wollaston had earlier played a role of some note in the development of the Australian opal mining industry.

²² Jack Casanova, *Fading Footprints. Pioneers, Runs and Settlement of Lower Eyre Peninsula*, Port Lincoln, 1992, p. 244.

²³ *Graphite Limited Returns*, State Records, Adelaide.

²⁴ *SADM Mining Review* 44, 1926, p. 33.

²⁵ The thickener at Uley was a large tank in which the concentrates settled to the bottom where revolving strakes raked them to an exit portal leading to the flotation cells. Meanwhile the water from which the concentrates had been separated overflowed into a launder and was re-used in the treatment process.

²⁶ *Graphite Limited Annual Returns*, State Records, Adelaide.

²⁷ 'General Notes', *Mining Review* 51, 1930, pp. 33, 35.

²⁸ L. Keith Ward, 'Preface', *SADM Mining Review* 51, 1930, p. 3.

²⁹ Drummond was a practical mining man, and Hambour an accountant in Kapunda. Cribb was something of an inventor, having developed an egg-pulping machine for producing powdered eggs.

³⁰ E. Broadhurst and A.T. Armstrong, 'Koppio Graphite Mine', *SADM Mining Review* 82, 1946, pp. 107, 108.

³¹ A.T. Armstrong, 'Koppio Graphite Mine', *SADM Mining Review* 80, 1945, p. 113.

³² F.N. Betheras, 'Graphite Resources of South Australia', *SADM Mining Review* 92, 1950, p. 152.

³³ Broadhurst and Armstrong, 'Koppio Graphite Mine', *SADM Mining Review* 82, 1946, p. 109.

³⁴ *SADM Mining Review* 82, 1946, p. 110.

³⁵ See 'South Australian Graphites Pty Ltd Returns, State Records, Adelaide.

³⁶ F.N. Betheras, 'Graphite Resources of South Australia', *SADM Mining Review* 92, 1950, p. 152.

³⁷ A.T. Armstrong (Chief Inspector of Mines), 'Uley Graphite Mine', *SADM Mining Review* 81, 1945, pp. 92-111.

³⁸ *SADM Mining Review* 79, 1944, p. 6.

³⁹ *Port Lincoln Times*, April 1990, interview with former Uley mine manager Harry Feist, then aged 76. Mr Feist said the mine shut on 25th February 1945 'when the Department of Defence withdrew its financial assistance'. Mr Feist, who kept a daily diary of his involvement in the project was manager of the treatment plant from June 1944, and again managed the Uley venture for the syndicate from March 1947 to 1950.

⁴⁰ F.N. Betheras, 'Production of Graphite in South Australia', *SADM Mining Review* 97, 1952, pp. 136-140.

⁴¹ International Carbon (Aust.) Pty Ltd, *Uley Graphite Mine*, pamphlet, 1992.

⁴² In March 1990, Tarcoola Gold (in a 'scrip deal valued at about \$1.5 million') acquired a 92.8 per cent interest in Solution Mining. See, *The Advertiser*, Adelaide, 13 March 1990.

⁴³ *Port Lincoln Times*, Port Lincoln, 24 September 1991.

⁴⁴ *Eagle Bay Resources NL Annual Report*, 1991.

⁴⁵ *Ibid.*

⁴⁶ After a prolonged period of very low prices, from a few hundred dollars a tonne several years ago, graphite prices have increased to \$2,200-\$2,700 a tonne for large + 80 mesh flake of 94-97% carbon, and \$1,900-\$2,300 for 90% carbon, and \$1,875-2,200 for -80 + 100 mesh medium flake of 94-97% carbon, and \$1,500-\$2,000 for 90% carbon, and \$1,300-\$1,800 for 85-87% carbon. See, Lithex Resources brochure, 'Why Graphite?', 2013.

⁴⁷ Lincoln Minerals ASX announcement, 6 January 2014.

⁴⁸ See London market analyst Roskill Information Services' 413 page report on graphite, 'Natural & Synthetic Graphite: Global Industry Markets and Outlook', 8th Edition 2012. Web reference: <http://www.roskill.com/natural-graphite> , accessed January 2014.

⁴⁹ Kiril Mugeran, 'Graphite investors should look for large flakes, small resources', *The Mining Report*, 4 March 2014.

⁵⁰ The float was intended to raise more. There was a non-renounceable rights offer of 43,200,000 shares of 20c per share on the basis of 3 shares for every 8 held with one free 25c option for every share subscribed up to approximately \$8,640,000, and a public offer of shortfall shares at 20c with a free option for every shortfall share issued, as well as a placement of up to 7,500,000 shares at 20c per share up to \$1.5M also with a free attaching option. The rights issue and placement was underwritten by Patersons Securities to the minimum subscription amount of \$6.5 million.

⁵¹ Valence Industries ASX announcement, 30 January 2014.

⁵² Strategic Energy ASX announcement, 16 December 2012.

⁵³ See the DMITRE SARIG [SA Department of Manufacturing, Innovation, Trade, Resources and Energy] website: www.dmitre.sa.gov.au/minerals DMITRE open file report book RB2100087 for Koppio Mine facts and drill hole, and DMITRE open envelope 5233 for Pancontinental Mining's work on Kookaburra Gully in the 1980s. Website visited January 2014.

⁵⁴ 'Local graphite export options under review', *Port Lincoln Times*, 28 January 2014.

⁵⁵ 'Lincoln closer to Eyre graphite pilot plant', *Port Lincoln Times*, 9 April 2013.

⁵⁶ 'Tenement sale boost lets Archer expand', *The Advertiser* [Adelaide], p. 44.

⁵⁷ 'Archer wants to fund its Eyre Peninsula graphite project within a year', *The Advertiser* [Adelaide], 4 November 2013.

⁵⁸ Monax Mining managing director Gary Ferris at the SA Mining and Exploration Conference, Adelaide, 28 November, 2013.

⁵⁹ One conversion earned the company involved the 'Lazarus Award' in 'Pierponts's Dubious Distinction Awards 2012'. This was Fluortechnics Ltd, which had been languishing on the Stock Exchange at 1.5c when it bought a graphite deposit near Wyndham in Western Australia. The shares shot up to 45c enabling Fluortechnics to raise \$7 million by issuing 35 million shares at 20c each. The \$7 million bought Fluortechnics, now named Lamboo Resources, the graphite deposit. See, Trevor Sykes, 'Pierpont's Dubious Distinction Awards 2012', *The Weekend Australian Financial Review*, 21 December 2012, p. 22.

⁶⁰ Syrah Resources' market capitalization has ballooned to \$620 million from \$10 million in 2011 when it took up its graphite exploration interests in Mozambique. The company has a memorandum of understanding with a subsidiary of China's state-owned Chinalco, which it expects to lead to a binding off-take agreement for a third of the initial planned annual production of 220,000 tonnes of graphite from Syrah's Balama mine.

⁶¹ Details of these companies and their exploration projects are to be found on the ASX website: www.asx.com.au

⁶² Robin Brumby, 'Prices put lead in graphite's pencil', *The Australian*, 6 December 2012, p. 27.

⁶³ 'New technologies give future of graphite a fillip', *The Australian*, 25 March 2014, p. 18.

⁶⁴ Profs. Andre Geim and Konstantin Noroselov were awarded the 2010 Nobel Prize in Physics for their discovery.

⁶⁵ 'On the Valence of probabilities, uni's a winner', *The Advertiser* [Adelaide], 29 March 2014, p. 73.

⁶⁶ 'New technologies give future of graphite a fillip', *The Australian*, 25 March 2014, p. 18.