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Mining and the Lake Eyre Basin environment – past, present and possible futures

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Introduction

The extraction of mineral and energy resources has a varied history across the Lake Eyre Basin, especially on its fringes, growing considerably since the 1960s. Given the recent mining and energy boom, especially coal, coal seam gas (CSG) and base metals, resource extraction will grow around and within the Lake Eyre Basin. This brings benefits in minerals, metals or energy resources and economic activity, but it also brings substantial environmental risks, if not managed well. This has always been the heart of the mining debate – balancing risks and benefits – ideally within the ecological resilience of the local, regional and global environment. Georgius Agricola, one of the earliest scholars of metal mining, recognised this in the 16th century in his treatise *De Re Metallica* (Agricola 1556, p. 8):

> [T]he strongest argument of the detractors is that the fields are devastated by mining operations … Also they argue that the woods and groves are cut down, for there is need of an endless amount of wood for timbers, machines, and the smelting of metals. And when the woods and groves are felled, then are exterminated the beasts and birds, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life … Thus it is said, it is clear to all that there is greater detriment from mining than the value of the metals which the mining produces.

Agricola, a firm supporter of mining and its products for society, clearly understood the significant environmental and social risks. His warnings are just as relevant today to the management of the Lake Eyre Basin: balancing the benefits of economic development against the social and environmental risks. Sustainable management of the Lake Eyre Basin is at stake. I review the status of mineral and energy resources within and adjacent to the Lake Eyre Basin, key production trends, potential environmental impacts and risks, illustrated by case studies from important sectors or accidents. Finally, I consider the implications for the future sustainability of the Lake Eyre Basin.

Mineral and energy resources and the Lake Eyre Basin

Mining within and around the margins of the Lake Eyre Basin has focused mainly on petroleum, base metals (copper, lead and zinc) and some gold mining. These remain the commodities for future developments, along with substantial coal, CSG and, potentially, shale gas and tight gas projects (e.g. Geoscience Australia and Australian Bureau of Agricultural and Resource Economics 2010). Mineral deposits and energy resources are associated with the major geological provinces, including the Mount Isa Block and Galilee Basin, the Arckaringa Basin and Stuart Shelf, the Pedirka Basin and the Willyama (Broken Hill) Block (Fig. 19.1). Water remains one of the most critical resources, potentially constraining or affected by these developments (see Chapter 20). This includes changes to flood waters which periodically flow through the Lake Eyre Basin rivers and the underlying groundwater resources in the Great Artesian Basin (see Chapter 1).

There are substantial mineral and energy commodities available for production, compared to annual production in and around the Lake Eyre Basin (Table 19.1). For the

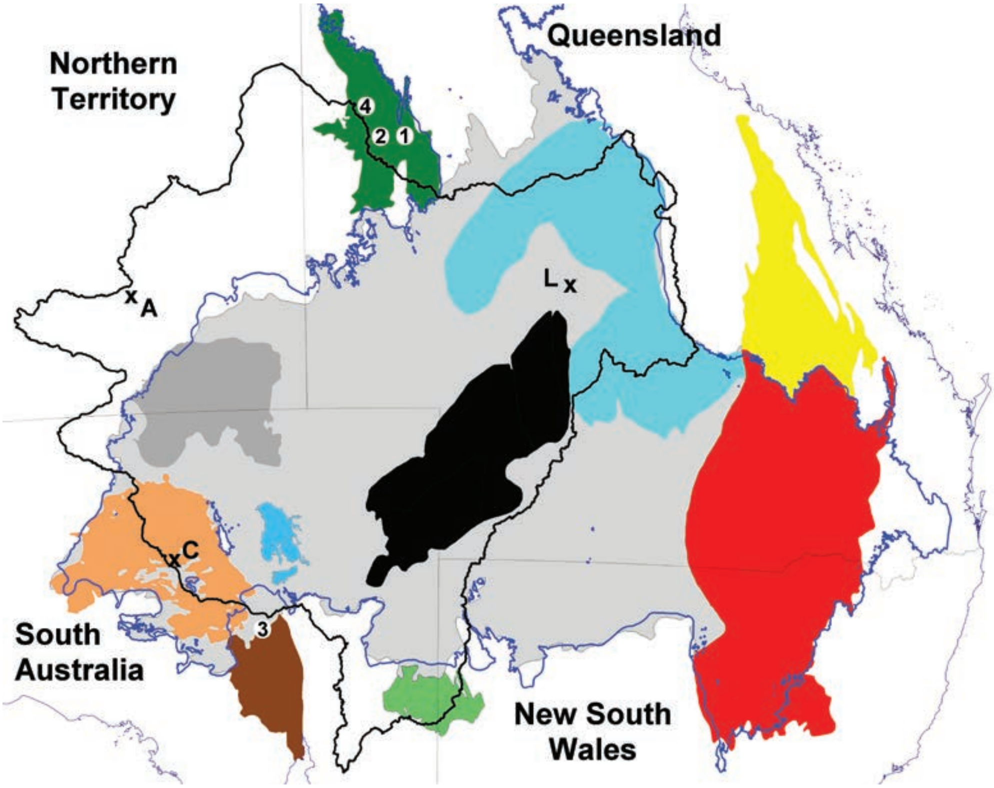

Fig. 19.1. Eastern Australia showing the location of the Lake Eyre Basin (black outline), Great Artesian Basin (blue outline), major geological basins or blocks (Ackaringa Basin (orange), Bowen Basin (yellow), Cooper Basin (black), Eromanga Basin (light grey), Galilee Basin (light blue), Mount Isa Block (dark green), Pedrika Basin (dark grey), Surat Basin (red), Willyama (Broken Hill) Block (light green), major towns (marked x, Alice Springs – A, Coober Pedy – C, Longreach – L, 2 – Mt Isa) and the locations of four case studies (filled circles, 1 – Mary Kathleen uranium mine; 2 – Mount Isa lead-zinc-silver-copper mining complex; 3 – Olympic Dam copper-uranium-gold-silver mining complex; 4 – Lady Annie copper mine).

Table 19.1. Volumes of available resources and production of mineral and energy commodities in 2013, within and adjacent to the Lake Eyre Basin, including the proportions relative to available Australian resources and annual production in parentheses.

Units include tonnes (t), thousand tonnes (kt), million tonnes (Mt), million litres (ML), and peta (10^{15}) joules (PJ) for energy.

Major geological province	Commodity	Available Resources	Production in 2013
Mount Isa Block	Copper (Cu)	16.11 Mt (11.6%)	248.4 kt (24.9%)
	Lead (Pb)	29.60 Mt (50.4%)	431.1 kt (60.6%)
	Zinc (Zn)	46.52 Mt (79.2%)	956.7 kt (62.8%)
	Gold (Au)	418.6 t (2.8%)	6.88 t (2.6%)
	Uranium oxide (U_3O_8)	103.9 kt (3.0%)	0
	Rare earth oxides (REOs)	0.90 Mt (1.5%)	0
	Iron (Fe) ore	328 Mt (0.2%)	0
Galilee Basin	Black coal	35 300 Mt (20.8%)	0
Arckaringa Basin	Brown coal	11 131 Mt (4.9%)	0
Eromanga Basin	Black coal	5941 Mt (3.5%)	0
Cooper-Eromanga Basin	Conventional gas	1906 PJ (1.7%)	109 PJ (4.9%)
	Liquefied petroleum gas (LPG)	503 ML (0.3%)	353 ML (3.2%)
	Condensate	5243 ML (1.7%)	250 ML (3.5%)
	Crude oil	16 014 ML (11.8%)	1916 ML (17.6%)
Leigh Creek Field	Black coal	546 Mt (0.3%)	3.2 Mt (0.5%)
Willyama (Broken Hill) Block	Copper (Cu)	0.47 Mt (0.3%)	4.0 kt (0.4%)
	Lead (Pb)	2.37 Mt (4.0%)	51.4 kt (7.2)
	Zinc (Zn)	3.09 Mt (5.3%)	64.2 kt (4.2%)
	Gold (Au)	30.5 t (0.2%)	2.05 t (0.8%)
	Uranium oxide (U_3O_8)	90.3 kt (2.6%)	~300 t (4.7%)
	Rare earth oxides (REOs)	0.05 Mt (0.1%)	0
	Iron (Fe) ore	1985 Mt (1.5%)	0
Stuart Shelf (and nearby)	Copper (Cu)	85.08 Mt (61.2%)	252.0 kt (25.2%)
	Lead (Pb)	0.21 Mt (0.4%)	0
	Zinc (Zn)	0.21 Mt (0.4%)	0
	Gold (Au)	3566.9 t (24.2%)	7.71 t (2.9%)
	Uranium oxide (U_3O_8)	2654 kt (77.0%)	4024 t (62.6%)
	Rare earth oxides (REOs)	52.67 Mt (90.5%)	0
	Iron (Fe) ore	586 Mt (0.4%)	0
Pedirka Basin (and nearby)	Copper (Cu)	0.35 Mt (0.3%)	0
	Lead (Pb)	0.026 Mt (0.04%)	0
	Zinc (Zn)	0.022 Mt (0.04%)	0
	Gold (Au)	3.2 t (0.02%)	0
	Uranium oxide (U_3O_8)	23.5 kt (0.4%)	0
	Rare earth oxides (REOs)	1.22 Mt (2.1%)	0

All mineral resources estimates compiled from company reporting; production data compiled from Australian Bureau of Resource and Energy Economics (2014); Geoscience Australia (2014); Mudd (2014); Office of the Chief Economist (2014); Australian Petroleum Production and Exploration Association (2015); United States Geological Survey (2015).

Fig. 19.2. Typical oil and gas production facility in the Cooper–Eromanga Basin of the Lake Eyre Basin, south of Innamincka (photo, R.T. Kingsford).

conventional petroleum industry in the Lake Eyre Basin, the Cooper–Eromanga Basin (Figs 19.1 and 19.2) continues to be a strategic national resource, making up ~12% of Australia's crude oil resources and represents almost one-fifth of Australian annual production (Table 19.1). Production of conventional gas is still relatively minor, compared to national production (under 2%; Table 19.1), but it remains a critical supply for the eastern gas market (~14.3%). There were no formally reported reserves of unconventional gas (CSG, shale gas and tight gas) in 2013 in the Lake Eyre Basin (specifically the Galilee, Cooper, Pedirka and Arckaringa Basins), but exploration licences are extensive across South Australia and Queensland (Queensland Department of Natural Resources and Mines 2015; Queensland Department of Natural Resources and Mines 2017). There is little coal production, apart from Leigh Creek field, north of Port Augusta in South Australia, just outside the Lake Eyre Basin, which closed in late 2015, but giant projects are under various stages of development in the Arckaringa, Galilee and Pedirka Basins. The Galilee Basin projects are the most advanced, such as Alpha and Kevin's Corner by the GVK Hancock Coal partnership led by Gina Rinehart, China First/Galilee led by Clive Palmer's Waratah Coal, and Carmichael led by India's Adani Mining Group. These massive projects will dwarf existing mines in the Bowen Basin or Hunter Valley if they proceed. One mine could potentially produce up to 60 Mt coal per year (e.g. the Alpha open pits will reach up to 6 km wide by ~24 km long, with about an equal area for infrastructure, tailings dams and overburden dumps).

Mines also produce metals in and around the Lake Eyre Basin, with the Mount Isa and Stuart Shelf (central South Australia) regions accounting for half of Australia's annual production of copper with nearly three-quarters of the nation's remaining copper resources, dominated by the Olympic Dam mine (78.7 Mt copper , Cu). The Mount Isa Block also has most of Australia's lead–zinc (Pb–Zn) resources (Table 19.1), dominated by the Mount Isa mining complex (20.3 Mt Pb, 32.5 Mt Zn). Most of Australia's uranium resources (uranium oxide, U_3O_8) are in central South Australia, dominated by Olympic Dam mine (2.5 Mt U_3O_8), with some uranium from the Mount Isa Block (albeit mostly refractory ores which effectively remain uneconomic). Relatively minor deposits of gold are also mined with other metals, contributing considerably to the economic viability of projects (e.g. Prominent Hill, Olympic Dam, Ernest Henry, Osborne; Table 19.1). Minor metals (silver, cobalt, molybdenum and the rare earth oxides), often found in copper deposits in or near the Lake Eyre Basin, also contribute to production.

There are also rare earth projects around the margins of the Lake Eyre Basin, particularly Olympic Dam (~52.5 Mt). Using 2013 prices for metals – copper $7572/t, uranium ~$95 000/t U_3O_8, gold $46 755/kg, silver $785.6/kg, rare earths (assuming a light-dominant rare earth mix) ~$30/kg (adapted from OCE 2014; United States Geological Survey 2015) – makes the rare earths at the Olympic Dam site worth about $1274 billion, more than the combined worth of copper, uranium, gold and silver ($1004 billion).

'Frontier' areas for mineral and energy exploration (e.g. the Pedirka, Arckaringa and southern Galilee basins) are portrayed as regions for significant hope of discovery and potential development, especially unconventional gas (either CSG, tight gas or underground coal gasification), and although there are some reported coal resources (e.g. Alpha, Carmichael), there are no formal estimates of gas reserves (as of 2013). There is also potential in these basins for underground coal gasification or coal-to-liquids projects, although these methods remain arguably uneconomic and are deeply controversial for their environmental impacts (e.g. Linc Energy near Chinchilla in Queensland). Other relatively minor commodities (e.g. mineral sands or potash) may also prove economically viable, if exploration is successful, though the balance between economic value and environmental and social risks and benefits remains largely untested.

Megatrends and their environmental implications

I now review the history and future for mining developments in the Lake Eyre Basin and immediate surrounds by examining the current understanding of base metal, petroleum and gas and rare earth mining.

Base metals

Australia's production of base metals (copper, lead and zinc) is increasing gradually, dominated by big projects around the margins of the Lake Eyre Basin (e.g. Mount Isa, Cannington, Olympic Dam and Century mines). Megatrends affecting modern mining include declining ore grades; increasing tailings' volumes; increasing use of megapits; increasing project scales; increasing waste rock movements; more environmental scrutiny during assessment and approvals; more stringent regulatory oversight (at least in theory); more complex ores (especially mineralogy) requiring increased grinding and use of processing technology; and more demanding expectations from local communities and interested

Fig. 19.3. Former open cut mine at the Mary Kathleen uranium project, showing active weathering (i.e. sulfide oxidation) of the side walls and the lack of any rehabilitation of the former pit where water quality remains poor (photo, G. M. Mudd).

stakeholders (e.g. investors, shareholders and non-government organisations) (e.g. Mudd 2009; Mudd 2010). As a result, managing and rehabilitating mine wastes is increasingly difficult using standard approaches. I examine these challenges for four mining case studies: Mary Kathleen, Mount Isa, Olympic Dam and Lady Annie. The first three are just outside the margins of the Lake Eyre Basin, but Lady Annie sits across the catchment boundary, with some infrastructure extending into the headwaters of the Lake Eyre Basin. The technical issues and environmental challenges posed by these projects are all symptomatic of the challenges facing the future of mining projects inside or around the Lake Eyre Basin.

Mary Kathleen uranium mine

The former Mary Kathleen uranium mine (Figs 19.1 and 19.3) operated over 1958–63 and 1976–82. It was rehabilitated during 1982–85, winning a national environmental excellence award in 1986 from Engineers Australia, based on three key claims: minimal seepage from the tailings dam; no acid mine drainage; and minimal risks of water quality affecting human health or grazing animals – but each claim has proven incorrect (Lottermoser *et al.* 2005; Lottermoser and Ashley 2008; Lottermoser 2011; Mudd 2014). Further rehabilitation is widely expected to be required, given the exposure of grazing cattle to heavy metals and radionuclides. A challenge, or opportunity, is that the tailings still contain a modest amount of rare earth oxides – opening up the possibility of reprocessing the tailings to extract these and potentially fund further site rehabilitation to a modern standard.

Mount Isa mining complex

The Mount Isa mining complex (Figs 19.1 and 19.4) is among the larger base metal mines in the world. Discovered in February 1923 and brought into production by 1931, it has produced considerable lead–zinc–silver and copper (Table 19.2). The grades of ore milled and remaining resources have declined for lead and silver but remain similar for zinc, while

Fig. 19.4. Mount Isa mining complex, one of the world's largest mines for production of base metals, showing the extent of industrial infrastructure, including the copper and lead smelters, and an open cut mine in the background (photo, R. T. Kingsford).

copper grades have also declined, even though steady until 2003 (Fig. 19.5). The Mount Isa field has had significant historical pollution problems with lead and heavy metals, particularly via airborne dispersion of smelter emissions and dusts. There are ongoing issues affecting public health, especially blood lead levels in children (Munksgaard *et al.* 2010; Taylor *et al.* 2010). Although the lead and copper smelters were to close in 2016, they were recently extended to ~2020, with expansion plans involving two major open cut mines (lead–zinc–silver and copper). These would require the relocation of all milling and smelting plants and

Table 19.2. Cumulative production (1931–2014) and available mineral resource (2014) from the Mount Isa field (updated from Mudd 2009).

Resources	Ore mass (Mt)	Metal	Ore grade	Metal mass
Cumulative production	218.7	Lead	5.4%	8.72 Mt
		Zinc	6.6%	9.88 Mt
		Silver	129 g/t	20.3 kt
	269.9	Copper[a]	3.2%	8.09 Mt
Available resource	704.3	Lead	3.0%	21.4 Mt
		Zinc	5.2%	36.7 Mt
		Silver	59 g/t	41.4 kt
	352.2	Copper	1.4%	4.87 Mt

[a] Includes at least 41.4 t silver

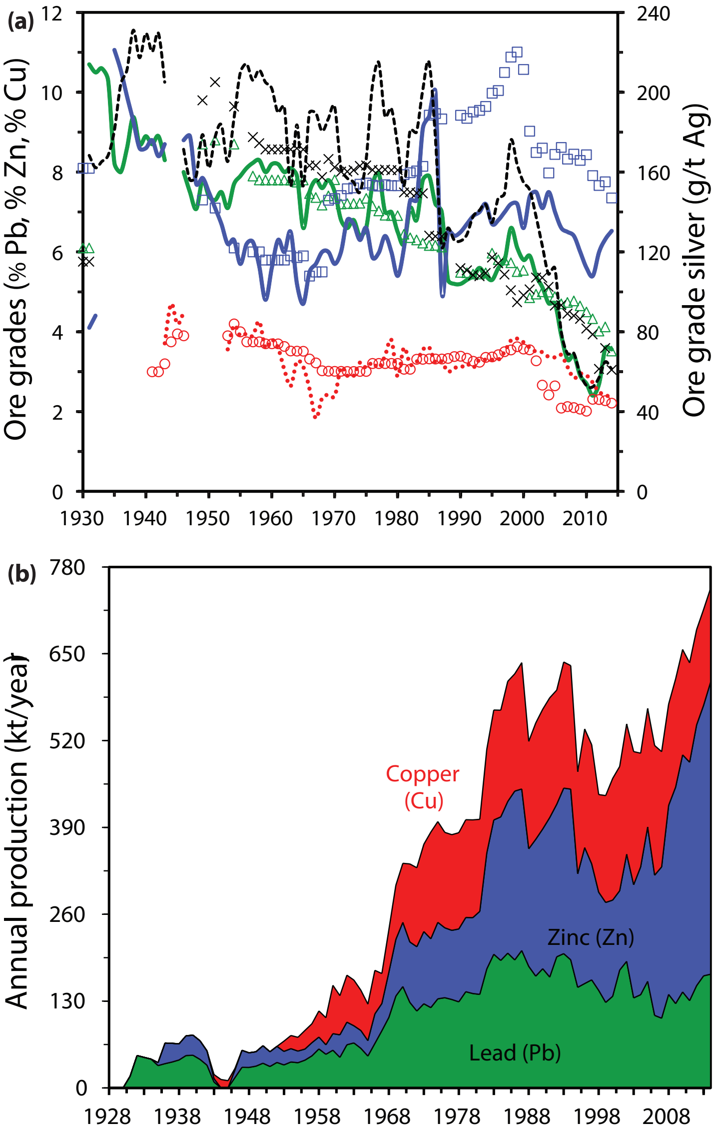

Fig. 19.5. Long-term annual trends (1931–2014) in (a) lead (% Pb) in ore milled (green line) or mineral resources (open green triangles); zinc (% Zn) in ore milled (blue line) or mineral resources (open blue squares); silver (g/t Ag) in ore milled (dashed black line) or mineral resources (diagonal black crosses); and copper (% Cu) in ore milled (dotted red line) or mineral resources (open red circles); and (b) production of lead, zinc and copper from the Mount Isa mining complex (data updated from Mudd 2009).

infrastructure. Plans are yet to be publicly released. Mount Isa still holds substantial mineral resources and could continue for decades. Potential environmental, health and social impacts could increase if the open cut developments proceed, without rigorous baseline assessments and environmental management. Risks to the flows and water quality of the Leichardt River provide significant lessons for the free-flowing rivers of the Lake Eyre Basin.

Fig. 19.6. Olympic Dam, near Roxby Downs in South Australia, is one of the largest copper, uranium, gold and silver projects in the world, and includes an underground mine, ore processing mill, copper smelter, refinery, hydrometallurgical facility and massive above-ground tailings dam (photo, B. Parkhurst).

Olympic Dam

The Olympic Dam (Figs 19.1 and 19.6) copper, uranium, gold and silver project is one of the larger base metal–uranium deposits in the world (Table 19.3), particularly including the potential value of rare earth oxides (Mudd *et al.* 2013; Weng *et al.* 2015). Despite considerable environmental and political controversy, production began in August 1988, with a large underground mine, flotation mill, copper smelter and refinery, and a copper and uranium hydrometallurgical plant. There were plans to develop a megapit, substantially increasing capacity (costing ~$25 billion), but the Fukushima nuclear accident, combined with low commodity prices, forced BHP Billiton to investigate more economical methods to expand the project and extract value. Despite the large quantity and economic value of rare earths (Tables 19.1 and 19.3), used in beneficial modern environmental and consumer technologies

Table 19.3. Olympic Dam cumulative production (1988–2014) and mineral resources (2014).

Data updated from Mudd (2009); Mudd (2014).

Resources	Ore mass (Mt)	Metal	Grade	Metal mass
Cumulative production	168.5	Copper	2.27%	3.53 Mt
		Uranium oxide	0.065%	~74.8 kt
		Gold	~0.6 g/t	54.2 t
		Silver	~6 g/t	494.5 t
Available resource	9550.0	Copper	0.81%	78.47 Mt
		Uranium oxide	0.026%	2498 kt
		Gold	0.29 g/t	2,975 t
		Silver	1.6 g/t	11 040 t
		Rare earth oxides[a]	~0.55%[a]	~52.5 Mt[a]
Available resource (gold only)	283.0	Gold	0.75 g/t	273 t

[a] Not Joint Ore Reserves Committee (JORC)-compliant and represents an estimate only (see Weng *et al.* 2015)

Table 19.4. Production, energy, water and greenhouse gas emissions for Olympic Dam (mean ± standard deviation, 2009–2013), based on each metal's proportional financial value, in parentheses, and average annual inputs divided by outputs.

Data updated from Mudd (2009); Mudd (2014).

Measure	Production	Water	Energy[a]	Greenhouse gases[b]
Copper (75.27%)	170 ± 39 kt/year	47.1 ± 5.5 kL/t	21.8 ± 4.6 GJ/t	3.8 ± 0.1 t CO_2/t
Uranium oxide (17.54%)	3650 ± 775 t/year	528 ± 43 kL/t	249 ± 39 GJ/t	44.0 ± 2.9 t CO_2/t
Gold (6.25%)	3.21 ± 0.66 t/year	271 ± 17 ML/t	125 ± 17 PJ/t	22.6 ± 1.1 kt CO_2/t
Silver (0.94%)	29.16 ± 6.05 t/year	4.4 ± 0.4 ML/t	2.0 ± 0.4 PJ/t	0.36 ± 0.006 kt CO_2/t
Average inputs/outputs[c]		11 100 ± 1750 ML/year	5.63 ± 0.93 PJ/year	951 ± 53 kt CO_2/year

[a] giga (10^9) joules (GJ)
[b] Greenhouse gas emissions are carbon dioxide (CO_2) equivalent.
[c] Average inputs divided by outputs refers to taking inputs (e.g. water) divided by outputs such as copper, based on the proportional financial value of that output (e.g. 75.27% of total input water is allocated to producing copper).

(Weng *et al.* 2013), these resources continue to be ignored for the more controversial and lower value uranium.

Olympic Dam has significant environmental costs in energy, water and greenhouse gas emissions (Table 19.4). Total energy, water consumption and greenhouse gas emissions have increased over time (Fig. 19.7). The overall efficiency of water and energy use and greenhouse gas emissions improved over the first decade of operations, but stabilised after ~2002. With respect to production of metals, the energy and greenhouse gas emissions intensities per tonne of metal (e.g. GJ/t Cu, t CO_2/t U_3O_8) are gradually increasing, due to declining, albeit variable ore grades, while water use remains stable. Major accidents can increase environmental costs significantly. For example, the October 2009 Clark Shaft failure limited production from the underground mine for several months until mid-2010. This reduced total energy and water needs but still drove up environmental metrics in 2009–10, despite reduced activity (Fig. 19.7b). As ore grades decline, significant pressure will drive up energy–water–greenhouse gas metrics, with fewer metals produced from lower grade ore for the same inputs and outputs. Although the former Western Mining Corporation used to report such data regularly in corporate sustainability reports, these data are increasingly difficult to obtain. Transparency and good public reporting on environmental performance are essential for assessing long-term environmental and socio-economic costs and benefits of the major Olympic Dam mining project.

Lady Annie copper mine

In early 2009, there was a very large environmental accident at the Lady Annie copper mine, ~200 km north-west of Mount Isa (Fig. 19.1). While the open cut mines are just outside the Lake Eyre Basin, the main processing infrastructure was just inside, consisting of a heap leach which uses acid solutions passing through piles (or heaps) of copper ore to dissolve and

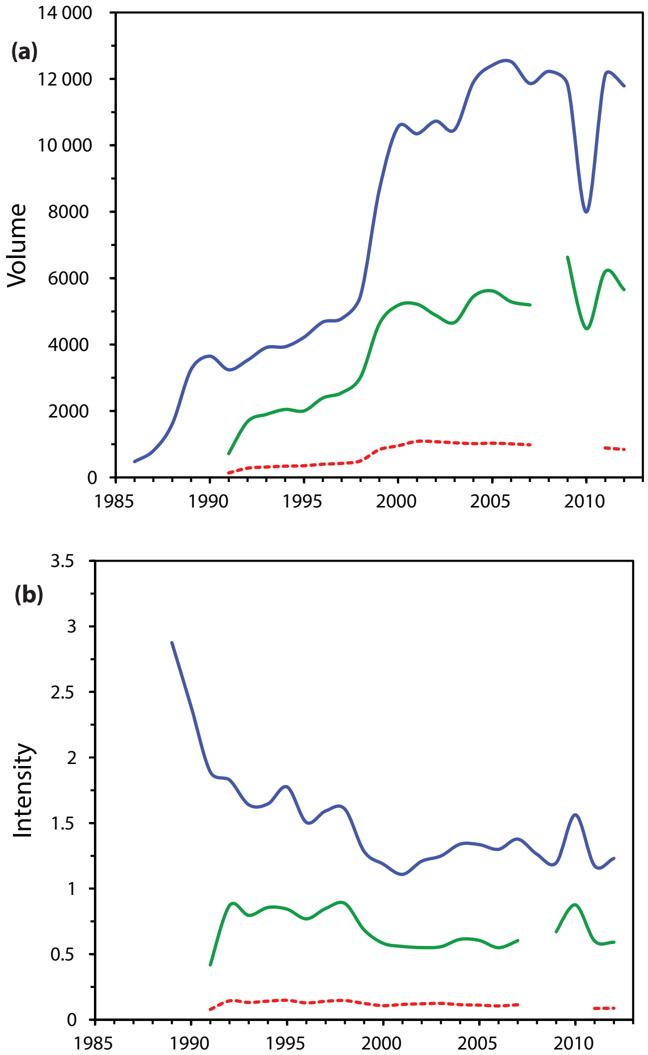

Fig. 19.7. (a) Annual water consumption (ML/year, blue line), energy use (TJ/year, green line) and greenhouse gas emissions (kt CO_2/year, dashed red line) for Olympic Dam (1985–2013; gaps due to lack of reporting); (b) water consumption (kL/t of ore, blue line), energy use (GJ/t of ore, green line) and greenhouse gas emissions (t CO_2/t of ore, dashed red line) (data updated from Mudd 2014).

extract the copper to be purified in a chemical refinery. Commercial operations started in October 2007, at the height of the mining boom. By late 2008, global metals prices had crashed, due to the evolving global financial crisis, and the project became uneconomic, followed by bankruptcy placement for the operating company (CopperCo). Unfortunately, cumulative rainfall was high in early 2009, producing considerable local flooding onsite. This eventually caused a structural failure of the solution ponds, sending highly acidic and metal-rich solutions into Saga and Inca Creeks, part of the headwaters for the Buckley River, one of the Lake Eyre Basin's major western river systems.

At least 447 ML of mining waste water was accidentally released into the Saga and Inca Creeks in the headwaters of the Buckley River, one of the Lake Eyre Basin's western rivers, during two periods in early 2009 (Queensland Department of Environment and Heritage Protection 2012). It severely degraded water quality, biodiversity and pastoral grazing, as well as recreational and traditional values for the streams (Taylor and Little 2013). In particular, the downstream river became highly acidic and rich in heavy metals. This killed fish and had severe impacts on other biodiversity and cattle. It even dissolved star pickets used in fencing. The mining company was convicted of serious environmental harm and fined half a million dollars, with the additional responsibility and costs of remediation and engineering costs of almost $11 million (Queensland Department of Environment and Heritage Protection 2012). The mining company had been explicitly alerted to this risk by the regulator before the accident. There was only a modest 'rehabilitation' bond held for the project, inadequate for the environmental and economic cost of the accident. This serious flaw in the environmental regulatory system for mining remains unresolved throughout Australia: rehabilitation bonds do not currently cover the costs of accidents. The Lady Annie case stands as a rare but stark example of the challenges in achieving strong environmental protection from the risks of mining impacts in the Lake Eyre Basin and Australia.

Petroleum and gas

The Cooper–Eromanga Basin is an important oil and gas field for Australia, supplying gas to eastern Australia as well as a critical source of crude oil. Primary operations are centred around Moomba in north-eastern South Australia in the Lake Eyre Basin, operated by Santos, with smaller companies recently developing modest size oil fields (or wells) (Fig. 19.2).

Australia's crude oil production, with 17.6% from the Cooper–Eromanga Basin, peaked at 34.0 GL in 2000, but has rapidly dropped to 12.6 GL in 2014 (Fig. 19.8). Conventional

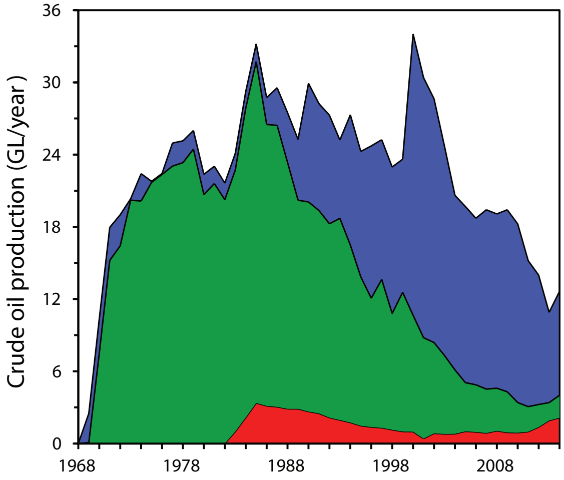

Fig. 19.8. Annual crude oil production in Australia, showing the proportion from Cooper–Eromanga Basin (red) of Queensland and South Australia, relative to the Gippsland Basin (green) and the rest of Australia (blue) (data from Australian Petroleum Production and Exploration Association (2015); GL – billion litres).

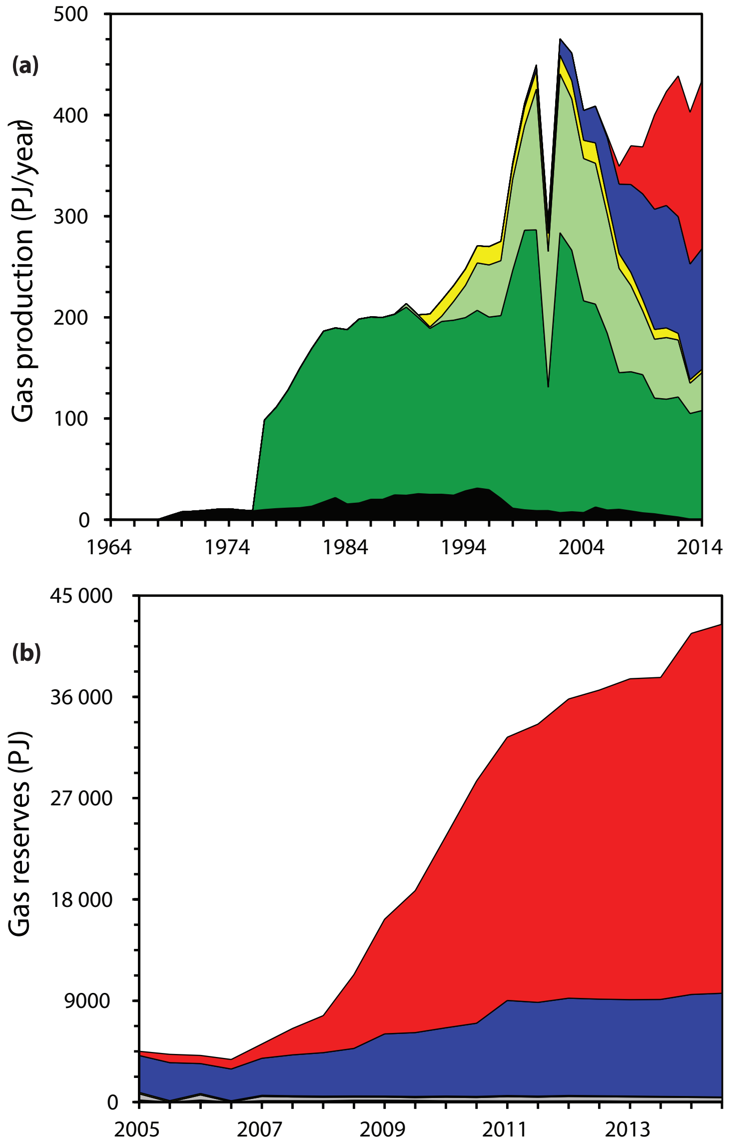

Fig. 19.9. (a) Annual conventional gas production in the Bowen–Surat Basin (black), Cooper–Eromanga Basin (South Australia, dark green; Queensland, light green) and Denison Basin (yellow) and CSG in the Surat (red) and Bowen (blue) basins; (b) six-monthly reporting of Queensland reserves of conventional gas in the Bowen–Surat Basin, Cooper–Eromanga and Denison basins (grey and black) and CSG in the Surat (red) and Bowen (blue) basins (equivalent data unavailable for South Australia) (data combined from Queensland Department of Natural Resources and Mines, 2004–2014; Australian Petroleum Production and Exploration Association 2015).

gas from the Cooper–Eromanga Basin in South Australia and Queensland peaked in 2002, leading to a significant increase in production of unconventional gas from CSG fields (Fig. 19.9). This explains why the Queensland Government has increasingly supported CSG as a major gas supply (Queensland Department of Natural Resources and Mines 2015), rather than investigating other technologies that might reduce gas demand – such as switching electricity and domestic heating or cooking away from gas to more sustainable technologies such as solar thermal electricity or solar hot water.

The recent trends in conventional and CSG reserves in Queensland (Fig. 19.9) show a downward trend for conventional gas and a relatively modest total of 474 PJ at the end of 2013. In addition, Santos, Beach Energy and Drillsearch all report 1570 PJ of gas in their SA operations in the Cooper-Eromanga Basin (current gas production is 109 PJ/year; Table 19.1). There has been extraordinary growth in CSG reserves in the Surat and Bowen Basins in Queensland, with the Surat Basin rising from 374 PJ in December 2004 to 32 795 PJ in June 2014. This makes CSG reserves comparable in scale to those off the northern coast of Australia (e.g. the Carnarvon, Browse and Bonaparte basins), underpinning three major liquefied natural gas export projects on Curtis Island near Gladstone in Queensland. While there are no formally reported CSG or shale gas reserves within the Lake Eyre Basin yet (as of 2013), companies are exploring the Galilee and other basins. Given the extensive exploration licences issued by the Queensland Government (e.g. Western Rivers Alliance 2016), there is a good probability that the CSG history from the Bowen and Surat Basins could be repeated inside the Lake Eyre Basin (especially the Galilee Basin), leading to new frontiers for CSG and potentially shale gas developments and associated environmental risks for the Lake Eyre Basin.

Coal seam gas (CSG) in Queensland

The CSG industry remains highly controversial, with major environmental, economic and social risks and impacts. This relates to its exploration and development, which can have impacts on groundwater levels (i.e. heads or pressures) and groundwater quality (especially, salts, metals, organics and radionuclides), as well as the potentially greater release of methane to the environment due to groundwater impacts (Drinkwater *et al.* 2014). CSG is produced underground, where it is trapped in coal seams. To release this gas, wells need to be established, sometimes close to each other (~0.6–1 km), involving a platform and a road and pipe network to service the well and take away the gas and water produced (Fig. 19.10). To extract the gas from deep underground, groundwater invariably needs to be extracted first to reduce water pressure and allow the flow of the gas to a well from where it is extracted. This groundwater needs to be stored or managed above ground. Average groundwater extraction produced for the past 10 years (2004–2014) is respectively 50.0 and 121.6 ML/PJ for CSG in the Bowen and Surat basins. Water extraction is higher in the earlier phase of CSG development and then declines over time (Drinkwater 2015).

Occasionally where the coal has low permeability, water with small quantities of sand and a wide array of chemicals (e.g. various salts, heavy metals, organics and biocides, depending on the biogeochemistry involved) is injected under extremely high pressure to hydrologically fracture and control the behaviour of the coal and allow the gas to escape to a nearby well – a process commonly known as 'fracking'. This water also needs to be removed and managed (e.g. treated, discharged to surface water and sold to local users such as farmers), but invariably contains residual contamination from the complex mix of chemicals. There are inevitable environmental and social risks in these developments, which remain poorly

Fig. 19.10. The patchwork of CSG wells near Chinchilla in Queensland, showing the potential network of roads and cleared platforms that may serious affect river flows of the Lake Eyre Basin if established in the Channel Country (photo, R. T. Kingsford).

studied and quantified. These include effects on groundwater (water level declines and pollution), fugitive emissions (especially methane and volatile hydrocarbons), surface water (methane gas bubbling, and treated waters discharged to rivers), land values, infrastructure (pipelines, roads, ponds and process plants), social impacts, economic issues (especially availability and cost of labour), greenhouse gas footprint and climate change risks (Drinkwater *et al.* 2014).

Existing domestic CSG projects in Queensland were approved under petroleum legislation, with no traditional environmental impact assessment (EIA) process. There were no systematic baseline studies before development to track environmental impacts on groundwater, surface water, flow paths, air quality, water quality, health or demographics. Furthermore, monitoring is historically minimal, with key aspects such as methane still missing in statutory requirements. The domestic CSG projects meet domestic supply obligations but increasingly compete with large CSG export projects, which have undergone normal EIA approvals. Considerable difficulties remain for adequate scientific assessment of environmental and public health impacts from CSG operations (Drinkwater 2015). For the Lake Eyre Basin and its potential CSG developments, there is a need to clearly identify potential impacts on the rivers, groundwater and socio-economic values.

Shale gas

The rise of unconventional gas extraction from shales, as well as hydrocarbon liquids used to manufacture some petroleum products, has been substantial in the United States (Rao 2012).

Although some call the emergence of shale gas an 'energy revolution' or even a 'game changer', critiqued by Hughes (2013), potential environmental and public health impacts make it highly controversial (e.g. Jackson *et al.* 2013; Small *et al.* 2014). This also uses hydraulic fracturing ('fracking') of the shale to increase permeability and allow water, gas and petroleum liquids to flow from where they are trapped. Given the vast size of shale rocks across continental platforms, such as the Marcellus Shale in the eastern United States, this represents an enormous energy resource. The hydrocarbon liquids produced by shale gas activities attract the oil price, and this value is deducted from the costs of gas extraction. A high oil price makes gas cheaper to produce, although the recent decline in the oil price has reduced this effective subsidy and now makes some shale gas operations marginally economic to uneconomic. There are significant environmental and health risks and potential impacts, although there are relatively few scientific studies (Drinkwater *et al.* 2014).

First, shale gas and fracking may increase methane (and possibly other contamination) into shallow groundwater resources, sometimes important for drinking water. The most infamous example is the lighting of methane from a kitchen tap in Colorado, burning continuously due to the high methane content of the water (popularised by the documentary movie *Gaslands* by Josh Fox). The two common ways which could explain this outcome are either faulty construction of wells, allowing methane to migrate along this pathway to shallow (less than 100 m) groundwater (Osborn *et al.* 2011; Jackson *et al.* 2013) or fracking causing connection of vertical fractures between shale gas and overlying groundwater systems. This is not widely accepted for deep shales (2–3 km) but may be a problem for shallow shale gas operations. Second, some chemicals used in fracking are highly toxic, such as biocides used to control unwanted bacterial growth, which can seal the fracture and reduce permeability. These chemicals have seldom been subjected to rigorous environmental risk assessments for use in fracking. This is especially relevant for CSG, which is often much shallower, 0.5–1 km, than shale gas. Third, there are increased risks of seismic activity (i.e. earthquakes) from fracking, often relating to low intensity but increased frequency, although this may be more related to deep injection of wastewaters (Small *et al.* 2014). Fourth, concerns over or competition for water and land between gas companies and agriculture can be significant (Drinkwater *et al.* 2014). Fifth, increases in air pollution, especially volatile hydrocarbons and noise, could explain impacts raised by local communities near shale gas activities, although still poorly understood (Drinkwater *et al.* 2014). Sixth, formation waters extracted from shale gas operations are often saline and may be rich in hydrocarbons and/or heavy metals, including sometimes radioactive elements such as radium or uranium (Barbot *et al.* 2013), leading to major wastewater management issues. Finally, discussion about the relative merits of investment in renewable energy, compared to shale gas development, is seldom debated. Shale gas production remains a deeply contentious industry. Despite high profile claims of a potential shale gas bonanza in the Arckaringa Basin (Fig. 19.1), there remain no reported shale gas reserves yet in or near the Lake Eyre Basin.

Rare earths

The rare earth group of elements, often called rare earth oxides, their typical form in nature, are increasingly critical for a range of modern technologies. They are essential for computers, renewable energy, phosphors, consumer electronics, speciality alloys and chemicals as well as various military technologies. There are light rare earth oxides such as lanthanum and cerium, or heavy rare earth oxides such as dysprosium, terbium and neodymium. The heavy ones are much higher value, but are also found in low concentrations in rare earth deposits. The main minerals hosting rare earths, such as monazite or bastnäsite, often have a widely variable mixture of light and heavy rare earth oxides and constituent elements. Most of the world's deposits are dominated by light rare earth oxides (Weng *et al.* 2015).

This makes rare earth mining projects inherently difficult, with each deposit needing a unique approach for separation of different rare earth oxides to saleable products, along with substantial chemical and energy inputs. Rare earth mining often includes substantial thorium and some uranium, resulting in radioactive wastes following processing and refining of rare earths. If the refinery and various gaseous, liquid and solid wastes are poorly managed, this can lead to significant risks for workers and the surrounding environment and communities. This explains concerns raised by Malaysian and Chinese communities about these impacts from their historic or current rare earth mining projects and refineries. If a project proposes to extract and sell the thorium and/or uranium, this also raises significant public concerns given that both are nuclear source materials and subject to international treaties for nuclear power or weapons.

Conclusion

The Lake Eyre Basin has extensive mineral and energy resources, some critical for Australia's energy supplies or export-focused metal industries. The mining and petroleum industries have grown substantially in recent decades, with considerable opportunity to expand. The gradual depletion of conventional petroleum is driving a switch to unconventional sources, including CSG and shale gas. These mining and petroleum projects may have profound impacts on water resources and their associated natural resources (see Chapters 20 and 21). They may affect groundwater, surface water and flood flows across the landscape, as well as altering water quality. Mining developments in the Lake Eyre Basin are commonly growing in size and generating more waste. The cost–benefit analyses for such developments are rarely comprehensive, seldom including economic values of the environment (see Chapter 18). If the experience of the United States or even CSG in Queensland is repeated and the dreams of petroleum geologists come to fruition, developments of CSG and shale gas will impose considerable risks to the Lake Eyre Basin and its unique water resources, ecosystems and cultural heritage. There is an increasing environmental assessment burden, requiring extensive monitoring followed by rehabilitation, sometimes already poorly managed at potentially great public cost (e.g. Lady Annie mine). As Agricola (1556) acknowledged, mining can bring economic and material benefits, but it also comes with environmental, social and economic risks. This remains the heart of the sustainability debate for the mineral and energy sectors operating in or around the Lake Eyre Basin.

Acknowledgements

I would like to acknowledge the many individuals and local and Indigenous communities around Australia, and especially those in and near the Lake Eyre Basin, which have

contributed to my understanding and knowledge of the environmental impacts of mining and resource extraction. Your efforts to protect your local and global environments are a continuing source of inspiration. Thanks also to John Polglase, Tim Werner and Stephen Northey for help with the Lake Eyre Basin map.

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