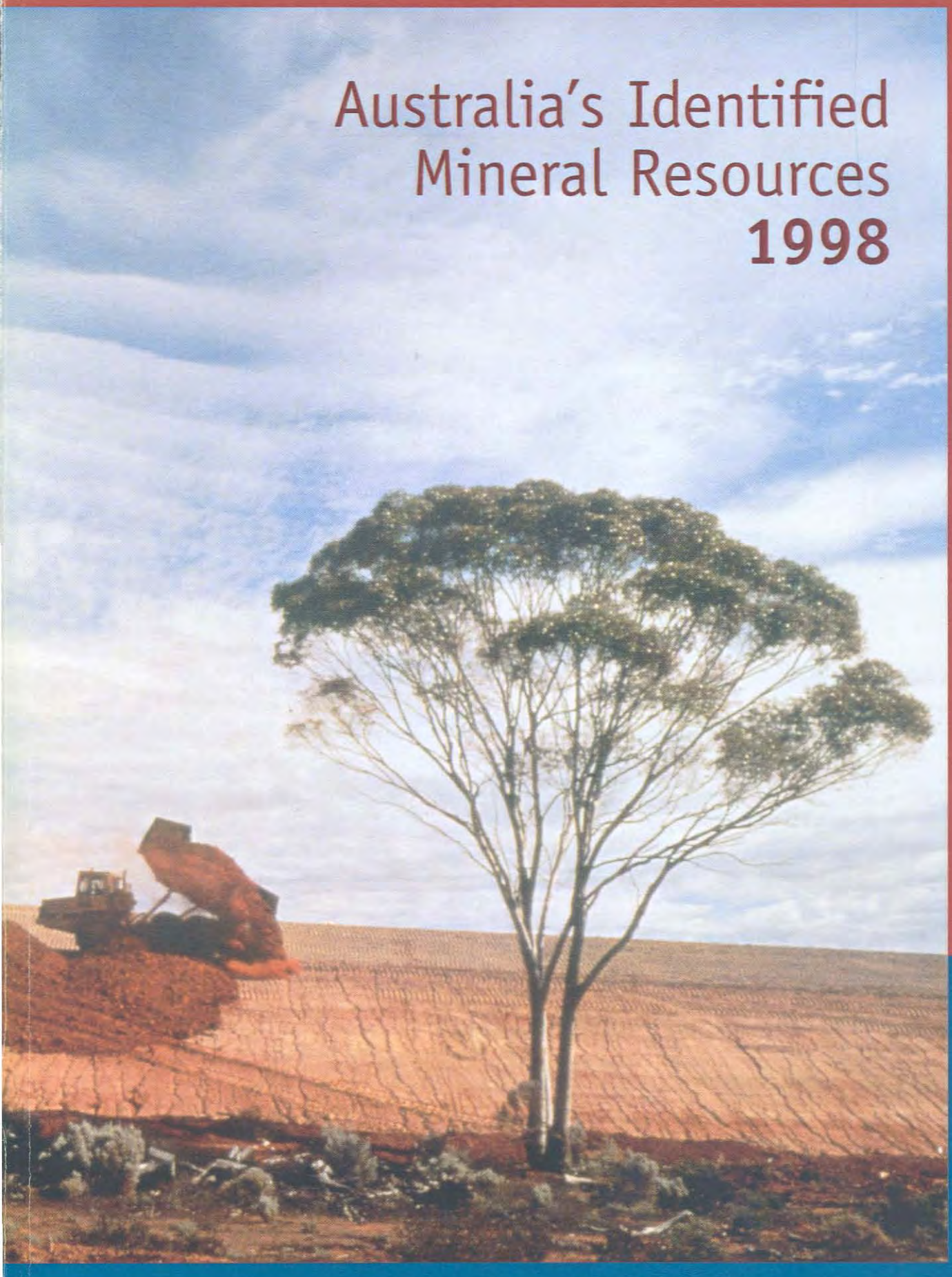
Australia's Identified Mineral Resources 1998



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The Bureau of Resource Sciences is a professionally independent scientific bureau within the Department of Primary Industries and Energy (DPIE). Its mission is to provide first-class scientific assessments, analysis and advice to enable DPIE to achieve its vision — rising national prosperity and quality of life through competitive and sustainable mining, agricultural, fisheries, forest, energy and processing industries.

Cover photograph: Rehabilitation operations at the Kanowna Belle gold mine, Western Australia — photograph courtesy of North Limited.

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Foreword

The Bureau of Resource Sciences (BRS) is a professionally independent scientific bureau within the Department of Primary Industries and Energy (DPIE). Its mission is to provide first-class scientific assessments, analysis and advice to enable DPIE to achieve its vision — rising national prosperity and quality of life through competitive and sustainable mining, agricultural, fisheries, forest, energy and processing industries.

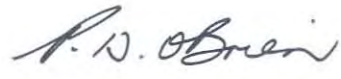
BRS provides independent advice and analysis on Australia's inventory of identified mineral resources, their rate of development and the level of exploration activity. To ensure that policy makers, the mining industry, the investment sector and the general community are well informed on these matters, BRS produces *Australia's Identified Mineral Resources* annually, drawing on data and information from mineral exploration and mining companies.

The MINRES database underpins the resource assessment work of BRS. MINRES contains information on the location of and resource tonnage, grade and elements present in over 2700 mineral deposits; a commercially available version contains non-confidential entries for over 1500 of these deposits. MINRES is currently being re-developed with the dual aims of improving both the efficiency of maintaining a high quality dataset and the ease of use of the system. It is anticipated that the re-developed system will be in use within BRS by mid-1998. Issues associated with granting easier and wider public access to MINRES are currently being considered. In addition to MINRES, BRS also maintains the commercially available national mineral occurrence database, MINLOC, which contains detailed locations for over 56 000 mineral occurrences across Australia.

As well as by its resource assessment work, BRS underpins government policy and management decisions by: appraising the mineral resource potential of areas being considered for restricted land use; advising on environmental issues in relation to exploration, mining, rehabilitation and mineral processing; and providing advice on offshore exploration and mining issues.

BRS undertakes work for external clients that is consistent with its role as a professionally independent government agency. This work includes:

- development of innovative geographic information systems to assist resource and environment management and land use decisions;
- appraising mineral resource potential;
- undertaking independent audits of mineral resources;
- advising on sustainable development of mineral resources; and
- advising on best practice mining sector development.



Peter O'Brien
Executive Director
Bureau of Resource Sciences

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QNI Limited's cobalt plant at Yalumba, Queensland.
Photograph courtesy of QNI Limited

Gold in quartz veins from Gympie, Queensland.
Photograph courtesy of Gympie Gold Limited

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Summary

In 1997, Australia's Economic Demonstrated Resources (EDR) of bauxite, black coal, cobalt, magnesite, mineral sands, nickel, tantalum and vanadium rose. Reduced EDR were recorded for antimony, cadmium, copper, gold, industrial and gem and near gem diamond, iron ore, lead, lithium, manganese ore, platinum group metals, silver, tin, uranium and zinc. The falls in EDR were due mainly to ongoing high levels of production. EDR of all other mineral commodities remained unchanged.

Among the major commodities, EDR of nickel, ilmenite, rutile and zircon reached record levels in 1997. Bauxite continued the slow growth started in 1993 and although black coal EDR rose it remained in the range that has existed since 1987. Gold EDR fell in 1997, breaking the long term growth trend that started in 1982. EDR of iron ore has fallen since 1994 and in 1997 was at its lowest level since 1990. Lead and zinc EDR both continued on a downward trend reaching the lowest levels since 1992. Following a small fall in 1996 copper EDR fell again in 1997.

Australia continues to rank highly as one of the world's leading mineral resource nations. It has the world's largest EDR of bauxite, industrial diamond, lead, mineral sands (ilmenite, rutile and zircon), nickel, silver, tantalum, uranium and zinc. In addition, its EDR is in the top six world-wide for black coal, brown coal, cobalt, copper, gem and near gem diamond, gold, iron ore, lithium, manganese ore, rare earth oxides, gem and near gem diamond, and vanadium.

Mineral exploration expenditure rose by 20% from $960.2 million in the previous year to $1148.5 million in 1996–97. Increases were recorded in all States except Queensland where a reduction of 11% occurred. A fall of 5% was recorded for expenditure in the Northern Territory. Gold was again the main target, and increased its share of total expenditure from 57% to 63%. Of the total expenditure about 73% was spent in greenfields leases. Despite the continued growth, in constant dollar terms, expenditure in 1996–97 was still below the peak of 1987–88.

Australia's mineral resources sector continued to underpin the standard of living of all Australians in 1997. As the nation's largest export earner, the minerals industry is vital to the well-being of the economy. In addition to its nationally important export performance, mining contributes significantly to the regional economies and the social well-being of communities in many parts of Australia.

In 1996–97 mineral resources exports increased to $36 495 million, a rise of 5% over the previous fiscal year. The Australian Bureau of Agricultural and Resource Economics (ABARE) forecast export earnings to rise to $44 530 million in 2002–03. The so called Asian financial crisis may impact adversely on Australia's ability to achieve the projected level of exports.

Introduction

This report presents the sixth annual assessment of Australia's identified mineral resources by BRS.

The assessment is undertaken as an input into government policy decisions relating to the sustainable development of mineral resources and environmental management. The report examines trends in resources of all major and some minor mineral commodities, and comments on Australia's world ranking as a resource nation. In addition, it comments on exploration expenditure (in current dollars) in 1996-97 and the previous four fiscal years. The current level of expenditure is put into perspective by comparing it in real terms to expenditure over the preceding 27 years.

Estimates of Australia's identified resources of all major and several minor mineral commodities are reported for 1997 (Table 1). The estimates, prepared by the Mineral Resources and Energy Branch (MREB) of BRS, are based on published and unpublished data relevant to the 1997 calendar year available to BRS. Data on petroleum resources were provided by the Petroleum Resources Branch of BRS. World data have been obtained or calculated from various sources but mainly in publications of the United States Geological Survey (USGS).

The mineral resource classification used in this report reflects both the geological certainty of existence of the mineral resource and the economic feasibility of its extraction (see *The BRS classification system for identified mineral resources*). The term EDR is used instead of 'reserves' for national totals of economic resources because the term 'reserve' has specific meanings under the terms of the Joint Ore Reserves Committee code used by industry for reporting reserves and resources. EDR also allows meaningful international comparisons of the economic resources of other nations. With few exceptions, ore is mined from resources in the EDR category. EDR are reduced by mining and increased by new discoveries and technical and economic changes that allow formerly subeconomic deposits to be reclassified as economic.

BRS has prepared estimates of Australia's uranium resources within categories defined by the OECD Nuclear Energy Agency (OECD/NEA) and the International Atomic Energy Agency (IAEA) (OECD/NEA & IAEA 1998). In this publication these estimates are reported under the corresponding resource categories of the BRS classification scheme. A correlation of the BRS and OECD/NEA schemes is given in the review of uranium resources.

Long-term trends in EDR for bauxite, black coal, iron ore, gold, copper, lead, zinc, nickel, and mineral sands are shown in Figure 1. EDR for these commodities have mostly increased or been maintained since 1975 despite substantial levels of production. Much of the success in maintaining EDR can be attributed to the sustained exploration activity that Australia has enjoyed over that period and to the highly prospective nature of the continent.

Table 1 Australia's identified resources of major minerals and fuels, and world figures for 1997

COMMODITY	UNITS	AUSTRALIA							WORLD	
		Demonstrated			Inferred			Mine production (f)	Economic demonstrated resources (l)	Mine (a) production
		Eco-nomic	Subeconomic: Para-marginal	Subeconomic: Sub-marginal	Economic	Sub-economic	Undifferent-iated			
Antimony	kb Sb	87.2	36.2	35.6	8.5	17.7	30.3	1.9	2400	124
Asbestos										
Chrysotile ore	Mt	-	46.24	-	-	-	75.18	-	large	} 2.3 (k)
Crocidolite fibre	Mt	-	0.37	-	-	-	2.12	-	large	
Bauxite	Mt	3187	3795	1729	-	-	1598	44.5	23300	115 (b)
Black coal										
In situ	Gt	71.2	0.7	5.6	-	-	very large			
Recoverable	Gt	51.4	0.4	3.4	-	-	very large	0.27 (c)	702 (o)	3.7 (d)(o)
Brown coal										
In situ	Gt	46	1	2	-	-	184			
Recoverable	Gt	41	1	2	-	-	166	0.061	311	0.9
Cadmium	kt Cd	119.9	11.3	22.7	24.4	2.5	-	na	530	19.5
Chromium	kt Cr	-	55.5	207.8	-	1635.8	-	-	3600000	12000
Cobalt	kt Co	434.8	81.3	326.2	-	-	514.1	na	4000	27
Copper	Mt Cu	21.4	19.4	2.0	0.8	3.1	10.4	0.55	334	11.3
Diamond										
Gem & near gem	10^6 c	70.3	194.0	4.4	29.6	1.1	6.2	} 40.2	-	56
Industrial	10^6 c	71.6	201.6	3.2	28.2	0.7	20.8		980	62
Fluorine	Mt F	-	24.34	9.84	-	-	2.04	-	106.34 (i)	2.01
Gold	t Au	4352	1184	124	-	-	2376	311	45000	2315
Iron ore	Gt	16.6	14.2	0.2	-	-	18.8	0.158	167.0	1.04
Lead	Mt Pb	17.5	6.1	9.0	5.3	15.5	1.2	0.53	65.0	2.9
Lithium	kt Li	162	79	3	-	-	7	na	3700	11 (b)
Magnesite	Mt-$MgCO_3$	190.8	6.7	343.7	-	-	107.5	0.25	8600	9.2 (b)
Manganese ore	Mt	112.9	27.0	167.0	70.2	94.0	-	2.1	1970	22.1
Mineral sands										
Ilmenite	Mt	143.5	66.5	0.7	-	-	97.7	2.2	594	6.4 (b)
Rutile	Mt	17.5	36.3	0.6	-	-	30.2	0.23	41.98	0.39 (b)
Zircon	Mt	23.3	26.7	0.5	-	-	24.3	0.42	62.8	0.87 (b)
Molybdenum	kt Mo	-	6.3	3.2	-	-	859.5	-	5500	131
Nickel	Mt Ni	6.7	2.1	5.1	-	-	10.0	0.12	43	1.08
Niobium	kt Nb	9	31	-	-	-	1848	-	3500	16.5
Petroleum (recoverable) (e)										
Crude oil	GL	240	-	30	-	-	-	25.1	161984	3678
Natural (sales) gas	10^9m^3	1360	-	984	-	-	-	30.0		
Condensate	GL	193	-	54	-	-	-	7.8	} 140036	2361
LPG naturally occur.	GL	174	-	77	-	-	-	4.1		
Phosphate rock	Mt	103	2758	-	-	-	1947	-	11000	136
PGM (Pt, Pd, Os, Ir, Ru, Rh)	t metal	18.7	10.8	36.3	3.5	83.0	2.4	na	70600	264 (j)
Rare earths										
REO and Y_2O_3	Mt	1	3.5	10.7	-	-	4.2	-	100	0.08
Shale oil	GL	-	461	3158	-	-	41552	-	na	na
Silver	kt Ag	41.5	12.8	14.3	9.9	11.3	2.3	1.1	280	15.3
Tantalum	kt Ta	11.40	6.02	0.17	-	-	63.06		20.79	0.41
Tin	kt Sn	102.7	45.1	185.5	0.6	302.9	5.3	10.2	7700	201
Tungsten	kt W	0.98	34.22	27.99	2.47	177.61	-	-	2100	32
Uranium (g)	kt U	615	-	93	136	45	-	6.5 (n)	2333 (h)	36.003(m)
Vanadium	kt V	151	1483	8425	-	2202	-	-	10000	35.0 (b)
Zinc	Mt Zn	36.3	14.1	14.5	10.5	9.7	1.1	1.04	190	7.8

Abbreviations: t = tonne; c = carat; m^3 = cubic metre; L = litre; kt = 10^3t; Mt = 10^6t; Gt = 10^9t; GL = 10^9L; na = not available

(a) 1997 World production figures are mostly USGS estimates.
(b) Excludes USA.
(c) Raw coal.
(d) Saleable coal.
(e) Source: Petroleum Resources Branch, BRS (as at 31 December 1996).
(f) Source: ABARE.
(g) Refer to text for comparison of resource categories in the BRS scheme with those of the international scheme for classifying uranium resources.
(h) Source: Most recent OECD/NEA and IAEA data.
(i) Excludes Morocco and Brazil.
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COMMODITY	UNITS	AUSTRALIA							WORLD	
		Demonstrated			Inferred			Mine		
		Economic	Subeconomic Para-marginal	Subeconomic Sub-marginal	Economic	Sub-economic	Undifferentiated	Production[f]	Economic Demonstrated Resources [g]	Mine production[a]
Antimony	kt Sb	87.2	36.2	35.6	8.5	17.7	30.3	1.9	2,400	124
Asbestos										
Chrysotile ore	Mt	-	46.24	-	-	-	75.18	-	large	2.3[k]
Crocidolite fibre	Mt	-	0.37	-	-	-	2.12	-	large	
Bauxite	Mt	3187	3795	1729	-	-	1598	44.5	23300	115[b]
Black coal										
in situ	Gt	71.2	0.7	5.6	-	-	very large			
recoverable	Gt	51.4	0.4	3.4	-	-	very large	0.27[c]	702[e]	3.7[d][e]
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Copper	Mt Cu	21.4	19.4	2.0	0.8	3.1	10.4	0.55	334	11.3
Diamond										
gem & near gem	Mc	70.3	194.0	4.4	29.6	1.1	6.2	40.2	-	56
industrial	Mc	71.6	201.6	3.2	28.2	0.7	20.8		980	62
Fluorine	Mt F	-	24.34	9.84	-	-	2.04	-	106.34[i]	2.01
Gold	t Au	4,352	1,184	124	-	-	2,376	311	45,000	2,315
Iron ore	Gt	16.6	14.2	0.2	-	-	18.8	0.158	167.0	1.04
Lead	Mt Pb	17.5	6.1	9.0	5.3	15.5	1.2	0.53	65.0	2.9
Lithium	kt Li	162	79	3	-	-	7	na	3,700	11[b]
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Niobium	kt Nb	9	31	-	-	-	1,848	-	3,500	16.5
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Crude oil	GL	240	-	30	-	-	-	25.1	161,984	3678
Natural (sales) gas	10^9m^3	1360	-	984	-	-	-	30.0		
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LPG naturally occur.	GL	174	-	77	-	-	-	4.1		
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Silver	kt Ag	41.5	12.8	14.3	9.9	11.3	2.3	1.1	280	15.3
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Vanadium	kt V	151	1483	8425	-	2202	-	-	10,000	35.0[b]
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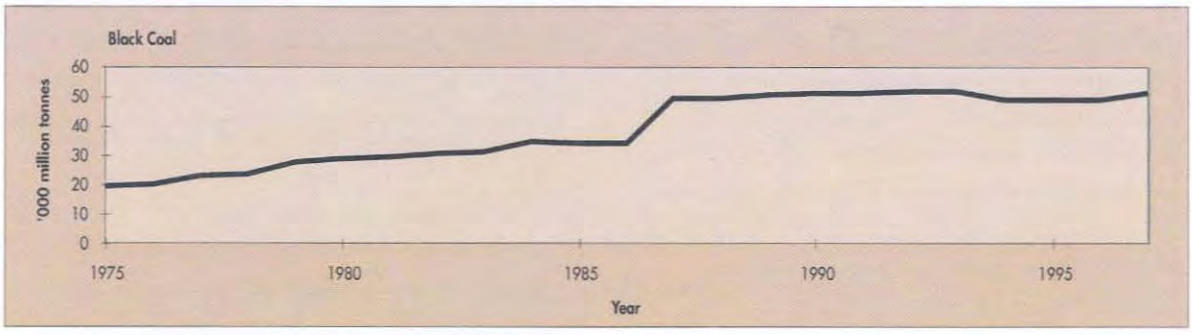
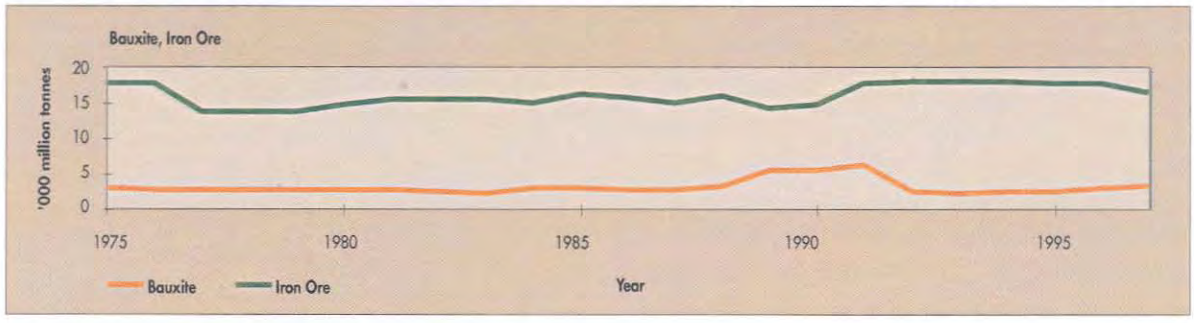
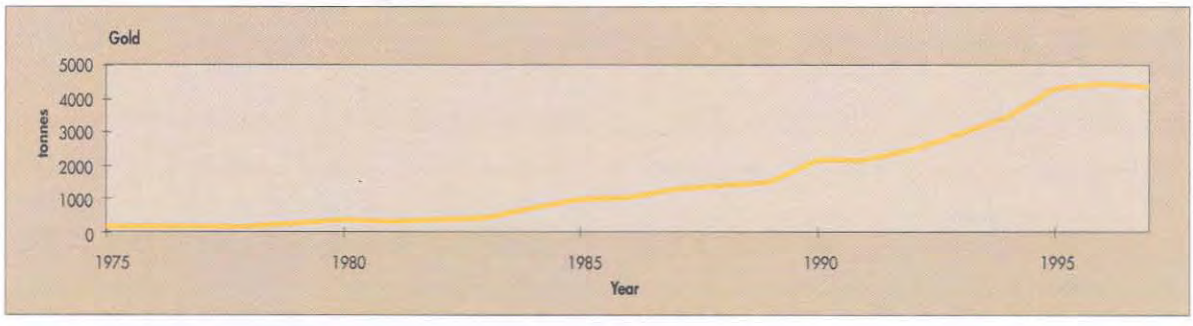
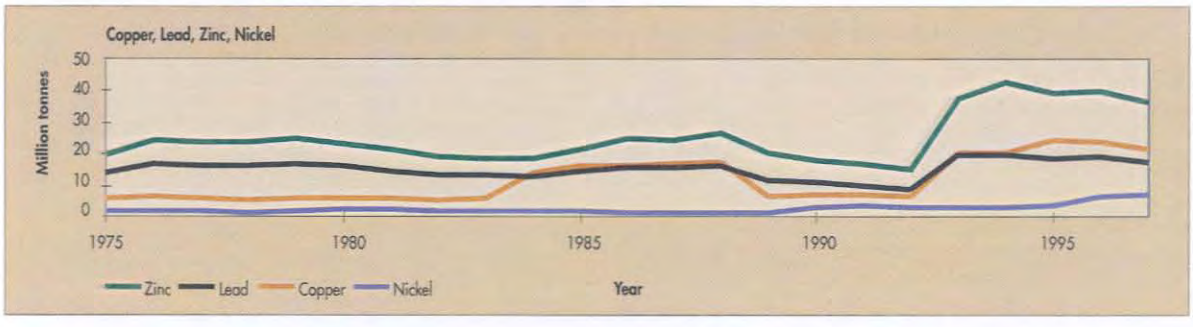
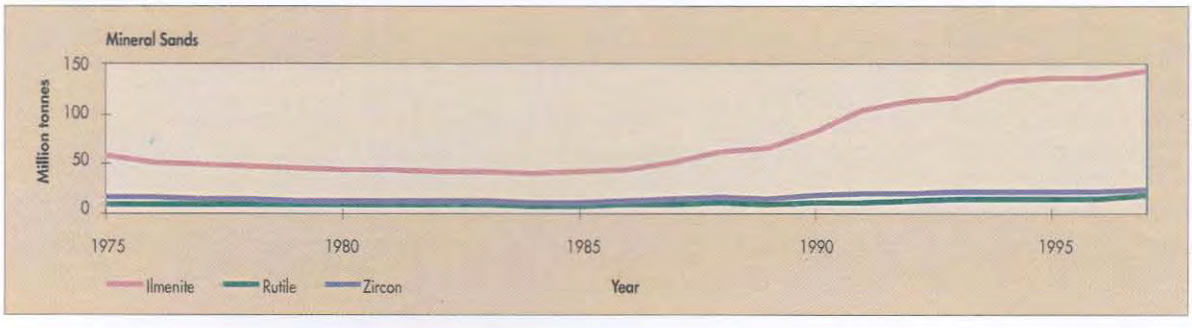
Figure 1 Trends in Economic Demonstrated Resources (EDR) for major commodities since 1975











Commodity Review

Bauxite

Collectively, the bauxite-alumina-aluminium industries employ over 90 000 people at mines, refineries, smelters and semi-fabrication plants These industries are particularly important in regions such as north Queensland, the Hunter Valley, New South Wales, southwest Victoria, southwest Western Australia, the Northern Territory and north Tasmania.

Resources

Australia's vast resources of bauxite, located in the Weipa and Gove regions on the Gulf of Carpentaria and in the Darling Ranges south of Perth, underpin the long-term future of its world class alumina and aluminium industries. Deposits in these regions continue to rank among the world's largest identified resources in terms of extractable alumina content. The development of bauxite deposits at Mitchell Plateau and Cape Bougainville in the north of Western Australia is currently uneconomic but they are a significant potentially viable future resource.

EDR increased by 5% in 1997 to represent just over 30% of identified resources. The increase resulted from successful exploration programs and upgrading of some resources previously classified as subeconomic.

Subeconomic demonstrated resources increased by 4% in 1997 as a consequence of exploration activity. Inferred resources remained unchanged.

Production

In 1996–97, Australia produced 43 Mt of bauxite, 13.3 Mt of alumina and 1.4 Mt of primary aluminium.

World ranking

Australia's demonstrated bauxite resources of 8.7 Gt rank number one in the world ahead of Guinea, Brazil, Jamaica and India. Australia is the world's largest refiner of bauxite and fourth largest producer of primary aluminium.

Industry developments

In February 1998, Alcan South Pacific Pty Ltd and Comalco signed an agreement providing for the future development of the Alcan-owned Ely bauxite resource with Comalco's Weipa operations in western Cape York Peninsula. The Ely resource is 25 km north of Weipa.

The agreement involves consecutive mining of both deposits, which provides important economies of scale. The long-term integrated approach also eliminates complexities of simultaneous processing of two bauxites at Queensland Alumina Ltd's refinery. In addition, regional bauxite mining and shipping infrastructure will be optimised and will enable integrated management of environmental and community impacts.

During 1997, Comalco continued to study the feasibility of a greenfield refinery based on Weipa bauxite. The company has announced that two sites are being evaluated — Gladstone in Queensland and Bintulu in Sarawak, Malaysia.

Black Coal

Black coal occurs in most Australian States (Map 1). Most deposits are of Permian age (about 250 million years old), but lower rank, younger deposits of Triassic, Jurassic and Cretaceous ages are also important. Large quantities of black coal are mined in New South Wales and Queensland (Plate 1) for both domestic and overseas consumption. Although production in Western Australia, South Australia and Tasmania is relatively small it is an important contributor in each of those economies. The major use of black coal in Australia is for electricity generation; other uses include coke making for the iron and steel industry and as a source of heat in cement manufacturing.

Resources

Australia's in situ EDR of black coal increased by 3 billion tonnes to 71 billion tonnes in 1997 largely due to increased exploration and reclassification of resources. EDR of black coal occur in most Australian States, but Queensland with 50% of the in situ EDR and New South Wales with another 47% are dominant.

Subeconomic resources of black coal occur mainly in South Australia (89%) and most of those (94%) are in the Arckaringa Basin.

Inferred resources are very large but are not quantified for Queensland or New South Wales. An in situ total of about 20 billion tonnes occurs in Western Australia and South Australia alone.

In 1997 there were 98 projects in Australia that had coal mining activities (31 in Queensland and 62 in New South Wales). Fourteen billion tonnes of recoverable EDR were located at these projects, representing 27% of the total recoverable EDR of 51 billion tonnes. New South Wales had 4 Gt or 16% of its recoverable EDR located at presently operating mines and Queensland had 10 Gt or 37%. Black coal amenable to open-cut mining was about 40% of Australia's in situ black coal EDR. However, in the Bowen Basin, Queensland, only about 23% of the in situ EDR can be mined by open-cut methods.

Exploration

Coal exploration expenditure in Australia in 1996–97 was $70.5 million, up from $52.6 million in 1995–96. Two thirds of the 1996–97 expenditure was in Queensland and a further 28% in New South Wales. Expenditure on coal exploration has increased by 150% from $27.7 million in 1993–94 to its current level due mainly to the Queensland and New South Wales governments lifting restrictions on tendering for prospective coal areas.

Production

In 1997, Australia produced 271 Mt of raw coal which yielded 217 Mt of saleable coal, increases of 7.5% and 8.5%, respectively, over 1996. Exports of black coal during 1997 were 83 Mt of metallurgical coal and 74 Mt of steaming coal. The Electricity Supply Association of Australia reported that in 1995–96 total black coal consumed in power stations in Australia was 44 Mt (containing 986 petajoules of energy) up from 42 Mt in 1994–95. In 1997, 72% of Australia's raw coal production came from open-cut mines.

ABARE projects that Australian saleable black coal production will rise to 241 Mt in 2003 and total Australian exports are projected to rise to 182 Mt in the same year. Thermal coal exports are projected to

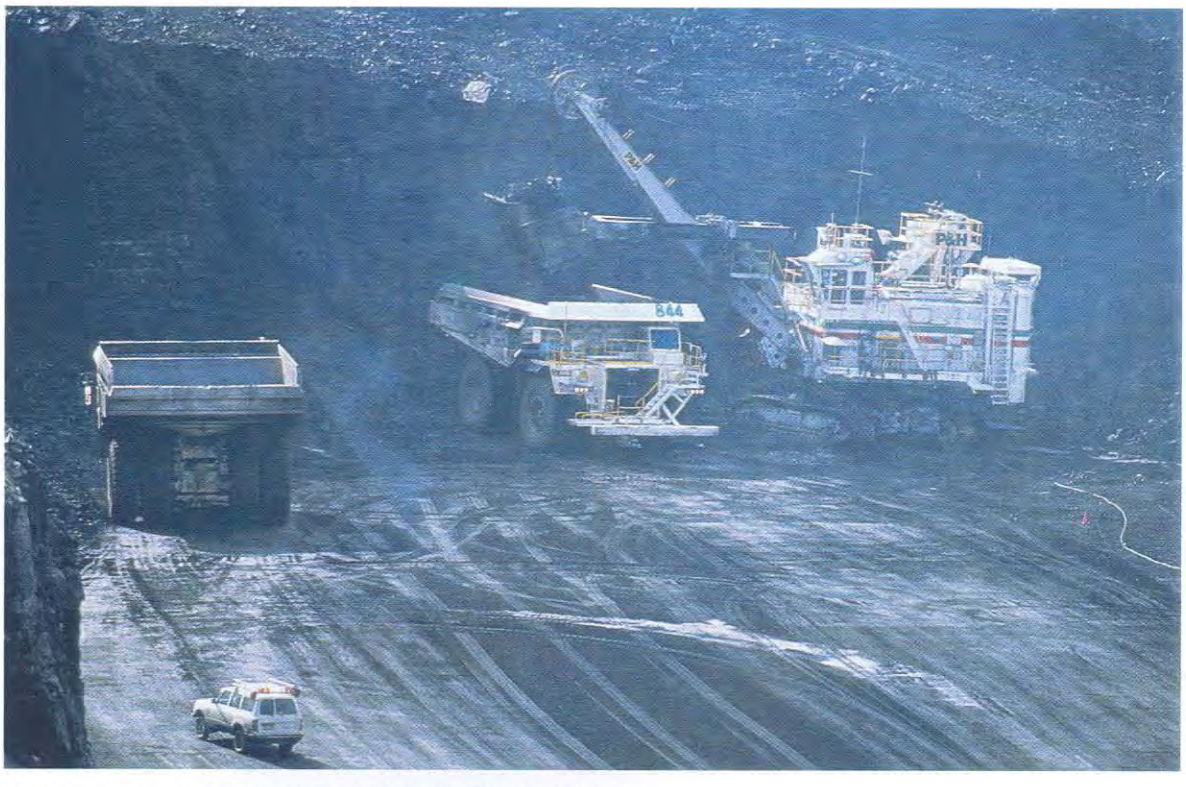


Plate 1 Open-cut mining operations at Blair Athol, Queensland
Photograph courtesy of Pacific Coal Pty Ltd

Map 1 General distribution of Australia's coal & iron ore resources

grow faster than those of metallurgical coal. This projected growth in exports is expected to come mainly from demand in Asian markets for both thermal and metallurgical coal. The projected rise in Australian production can be supported by substantial resources of high quality metallurgical and thermal coals.

World ranking

Recoverable EDR of black coal occur in over 60 countries. At current production levels these are estimated to last about 200 years. The top six countries have about 86% of the total recoverable EDR. In 1997, Australia accounted for about 7% of the world's recoverable EDR of black coal and was ranked sixth behind the USA (29%), the former USSR (20%), China (13%), India (10%) and South Africa (8%). Australia produced about 6% of the world's saleable black coal output in 1997 and was ranked fifth after China (35%), the USA (22%), the former USSR (8%) and India (8%).

Industry developments

Developments in Queensland during the year included: stage 3 at the Ensham open cut; development of longwall operations at Moranbah North, Oaky North and Newlands, and planned expansion at the Peak Downs and Saraji mines; feasibility studies are being undertaken at other projects including the possible doubling of

production at the Burton Coal Joint Venture; staged development at the Theodore and Dawson coal mines; longwall mining at Togara North; development of Hail Creek; and development of Suttor Creek in association with the Newlands mine. There are also proposals for mine mouth power stations including those at the Millmerran and Wandoan coal deposits.

In New South Wales, developments include: commissioning of a longwall at Moonee and a continuous haulage operation at United; construction at the Bengalla mine; approvals being sought for Duralie, Kayuga and Ravensworth West projects; extensions being sought to the Cooranbong and Newstan mines; and Bayswater No 3 is being developed to replace Bayswater No 2. Feasibility studies continued on the Mount Pleasant, Glendell and Howick expansions.

In Western Australia the new Collie power station will be supplied with coal from the new Premier open-cut mine. An Ausmelt demonstration plant to be built at Whyalla, South Australia, will use coal from the Arckaringa Basin.

BHP Coal introduced a highwall mining system to mine seams dipping at up to 12° at its Moura mine in Queensland. Highwall mining can be used where traditional open-cut mining methods have reached their limits. Many mines in Australia have used this technique including Ulan, New South Wales, and German Creek, Oaky Creek, South Blackwater, Newlands, Jellinbah and Yarrabee, Queensland. The Thiess/Namoi Joint Venture at Oaky Creek has developed a longwall punch mining operation where a longwall is developed from exposed an highwall. Some bord and pillar underground operations have introduced the cut and flit (or place changing) mining method to improve productivity.

Brown Coal

Significant brown coal deposits occur in Victoria, South Australia, Western Australia and Tasmania (Map 1). It is mined only in Victoria where it is used predominantly for electricity generation. Another important use is for the production of briquettes which are used for industrial and domestic heating in Australia and overseas.

Resources

Brown coal resources remained virtually unchanged in 1997. Victoria accounted for 94% of Australia's in situ brown coal EDR which totalled 46 Gt. Of this total EDR, 86% is located in the La Trobe Valley, Victoria. Australia has 184 Gt of in situ inferred resources of brown coal, 99% of which are in Victoria.

Production

In 1997, Australian brown coal production was about 61 Mt, up from 54 Mt in 1996. The Electricity Supply Association of Australia reported that in 1995–96 total brown coal consumed in power stations in Victoria was 50 Mt (containing 398 petajoules of energy) an increase of 2 Mt from 1994–95.

World ranking

Recoverable brown coal occurs in over 30 countries. At current production levels these resources are estimated to last about 350 years. The three leading countries have about 60% of the recoverable EDR. In 1997, Australia had almost 14% of the world's recoverable EDR and was ranked third behind the former USSR (32%) and Germany (14%). Australia produced about 7% of the world's brown coal output in 1997 and, as a producer, ranked sixth after Germany (21%), the USA (17%), the former USSR (10%), the Czech Republic (7%) and Poland (7%).

Industry developments

Yallourn Energy plans to spend $200 million to develop a brown coal mine at Maryvale in the La Trobe Valley, Victoria's first new coal mine in almost two decades. The mine is to supply the Yallourn W power station with 18 Mtpa until 2030. It will replace Yallourn Energy's East Field mine, which has sufficient reserves to last until 2004, and its almost depleted Township Field mine. Planning and design work for the new mine will take about two and a half years and construction another four years, with the first coal expected to be mined in 2004.

During 1997 Loy Yang Power Management Ltd (a consortium of companies led by CMS Energy) purchased the Loy Yang A power station and the Loy Yang mine. This mine also provides brown coal to the Loy Yang B power station which was bought by Edison Mission Energy in early 1997. Some 28.5 Mt of brown coal are won from the Loy Yang mine each year. It is the largest open-cut coal mine in the southern hemisphere.

Copper

Established copper provinces, such as northwest Queensland, and other areas of the country are continuing to support new discoveries as well as extensions of resources at known deposits. As a consequence, Australia has developed over the last decade into a world-ranking copper-producing nation. The general distribution of Australia's resources of copper is shown in Map 2.

Resources

In 1997, EDR for copper fell by 9% to 21.4 Mt compared with the previous year. The reduction is attributed to the reclassification of some resources and depletion through mining. Total identified resources of copper increased by 2% to 57.1 Mt as a result of the delineation of both inferred and demonstrated paramarginal resources, particularly in north Queensland, central western New South Wales and Western Australia.

Map 2 General distribution of Australia's copper resources

Exploration

Exploration expenditure for copper is not recorded separately but is combined with results of spending on exploration for base metals and cannot be disaggregated from the total. The base metals category includes expenditure on zinc, lead, nickel and other base metals as well as copper.

Although increasing slowly in dollar terms, over the past six years, base metal exploration expenditure has varied between 30% and 20% of total exploration expenditure while gold has made up most of the remainder. In percentage terms, base metal exploration expenditure in the last three years has drifted downwards into the low twenties as against the high twenties some five to six years ago. Quarterly data for the end of the 1997 calendar year show, however, that expenditure on base metals exploration has increased at the relative expense of gold.

Notable copper discoveries during the year have been mainly in the relatively greenfields area west of Broken Hill, New South Wales, particularly the border area and further west into South Australia. The style of mineralisation has, in places, an affinity with the copper–gold style encountered in northwest Queensland. Some of the more notable discoveries include Portia, North Portia, and White Dam.

Production

The bulk of Australian production is from the six largest producers: the Mount Isa, Olympic Dam, Northparkes, Osborne, Selwyn, and Mount Lyell mines. In 1997, Australia's mine production was 545 000 t of contained copper, 4% higher than in 1996. However, during the year, two significant base metal mine closures in New South Wales – the CSA mine at Cobar and the Woodlawn mine, east of Canberra – resulted in some loss of copper output.

World ranking

Australia has the world's third largest EDR of copper (6%), after Chile (26%) and the USA (14%). As a copper producer, Australia ranks fifth in the world after Chile, the USA, Canada, and Peru.

Industry developments

Mine production in Australia is expected to rise by about 5% in 1998. Further, it may reach 600 000 tpa in 1999 when full production is achieved from the Mount Isa Mines Limited/Savage Resources Limited Ernest Henry project (95 000 tpa capacity) near Cloncurry, Queensland, which began production in October 1997. Concentrates from the Ernest Henry mine are being treated at MIM's copper smelter at Mount Isa.

Expanded production is expected from Aberfoyle Limited's Gunpowder mine, north of Mount Isa, which will increase capacity from 7000 tpa to 44 000 tpa in the form of copper cathodes produced by solvent extraction/electrowinning (SX/EW).

The Cadia Hill copper–gold mine, near Orange in New South Wales, owned by Newcrest Limited, is also expected to commence production in late 1998, with a capacity of 23 000 tpa copper in concentrate.

Olympic Dam will supplant Mount Isa as Australia's largest copper mine when current expansion to 200 000 tpa is completed in 2000.

Copper exports contribute just over $1 billion annually to the Australian economy and represent about 3% of total export earnings from minerals.

Diamond

Resources

In 1997 EDR fell by 14.7 Mc (17%) to 70.3 Mc for gem/near gem diamond and by 18.4 Mc (20%) to 71.6 Mc for industrial diamond. Total identified resources for gem/near gem diamond fell by 36.3 Mc (11%) to 305.7 Mc and by 55.4 Mc (15%) to 326.1 Mc for industrial diamond.

Production at the Argyle mine, Western Australia accounted for most of the reduction in EDR in 1997, while the lower grades of measured and indicated resources at the Argyle AK1 pipe mine caused most of the remaining reduction in total identified resources.

World ranking

Australia's EDR for industrial diamond is the world's third largest after the Republic of Congo and

Botswana. Detailed data are not available on world resources of gem/near gem diamond but Australia has one of the largest stocks of EDR for that category. Australia's diamond production is the largest in the world for both gem/near gem and natural industrial diamond categories, with most production from the Argyle open pit and a minor contribution from the nearby Argyle Alluvials operation. Mining and processing at the alluvial operation were hampered by the wetter than normal 1996–97 wet season.

Industry developments

Evaluation of a 9.5 to 10 Mtpa underground, block caving operation to mine resources below the current open pit at Argyle was completed in 1997. As an alternative, the feasibility of accessing deeper ore by expanding the open pit is being investigated, with geotechnical investigations of the west wall of the Argyle pit under way. An underground sub-level stoping mining option of 3 to 4 Mtpa, to run in parallel with open-pit mining, is also being examined.

Development at Merlin, in the Northern Territory, is under way. Stage One involves open-pit mining and further bulk sampling of several diamond-bearing kimberlite pipes. Production at about 550,000 tpa of ore is expected in January 1999 increasing later to 710,000 tpa at an average grade of about 0.43 carat/t.

At Copeton, in New South Wales, small scale open-pit mining and bulk sampling of resources at workings dating back to the turn of the century have yielded a significant number of diamonds. Mining at the Streak of Luck workings, just south of Mount Ross, commenced in early 1997. Almost 422 diamonds were recovered at an average size of about 0.25 carat and with one yellow diamond of 1.1 carat. Nearby, diamonds have also been recovered from open-pit bulk sampling of the old Round Mount workings. Late in 1997, open-cut mining started on the western side of Mount Ross near the old Star of the South mine, last worked in 1904. One hundred and one diamonds were recovered. Their average size was 0.4 carat, the largest being a 1.91 carat yellow diamond and a 1.45 carat white diamond.

North of the Copeton Dam, bulk samples from the old Wonderland workings yielded over 391 diamonds weighing 90.3 carat, the largest being 2.13 carat. At Staggy Creek, 180 diamonds totalling 34.1 carat were recovered from bulk trench samples.

Gold

Resources

Total identified resources of gold increased by 432 t (5.7%) in 1997. This growth was achieved despite production of 311 t. However, EDR and paramarginal demonstrated resources fell, and the two lower categories of submarginal demonstrated resources and inferred resources rose. Gold resources occur in all Australian States and the Northern Territory (Map 3).

Australia's EDR of gold fell by 102 t (just over 2%) to 4352 t in 1997, 54% of total identified resources. This fall, the first since 1982, can be attributed largely to the low gold prices that prevailed throughout most of the year. Of the total EDR, 58% is from the JORC Code reserves categories (proven, probable or proven plus probable). The remainder is that part of resources reported under the JORC Code as measured, indicated or measured plus indicated resources, which BRS has assessed as EDR.

EDR fell in the Northern Territory and all States except South Australia, where a significant increase was recorded. Despite a fall of 11% in its EDR, Western Australia remained the leading gold state with 55% of total Australian EDR. The rise in EDR in South Australia resulted from the publication of comprehensive data for the Olympic Dam by WMC Limited, which reported reserve tonnage totalling 566 Mt compared with 0.3 Mt in 1996. Consequently, South Australia became the State with the second largest EDR holdings. It was followed, in order, by New South Wales, the Northern Territory, Queensland, Victoria and Tasmania. The Australian Capital Territory is the only jurisdiction with no EDR.

Subeconomic demonstrated resources, which accounted for 16% of total identified resources, rose by 46 t during the year. Paramarginal demonstrated resources fell by 22 t because an increase of 354 t in

Map 3 General distribution of Australia's gold resources

Western Australia was more than offset by reductions in New South Wales and South Australia. Minor increases were recorded in other States.

Submarginal demonstrated resources increased in the Northern Territory and all States except South Australia, which was unchanged. Of the total increase of 68 t, 39 t was recorded for Western Australia and 11 t for the Northern Territory.

Inferred resources rose by 26% to the record level of 2376 t in 1997. Western Australia recorded strong growth with an increase of 220 t (15%) over its 1996 level. Although substantial increases were recorded in New South Wales and South Australia as the result of discoveries, Western Australia remained the main holder of inferred resources with 62% of the Australian total. New South Wales with 11% has the second largest inferred resource and all other States and the Northern Territory each had less than 10% of the total.

The solid growth in inferred resources is important to the long term future of the industry because, with ongoing exploration, much of the resource is likely to be upgraded to the demonstrated category, from where it might support a mining operation.

Exploration

ABS reported that expenditure on the exploration for gold continued to grow strongly, rising by 33% in 1996–97 to $728.2 million. This was 63% of all

Plate 2 Open-cut gold mining operations at the Kanowna Belle mine near Kalgoorlie, Western Australia
Photograph courtesy of North Limited

Australian mineral exploration expenditure. Reliable data are not available on a State-by-State basis for exploration expenditure. Although ABS publishes quarterly figures for each State the sum of those figures exceeds the annual figure of $728.2 million by some $15 million. ABS does not publish annual figures, or revised quarterly figures, on a State basis.

For calendar year 1997, ABS figures show an increase of 18% in the expenditure on the search for gold compared with 1996. Based on published quarterly expenditure, gold exploration accounted for $736.6 million (63%) of a total mineral exploration expenditure of $1166.6 million. Base metal exploration expenditure was the next highest with 19% of the total.

Despite strong spending in 1997 there was a substantial (12%) reduction in December quarter spending compared with the December quarter 1996. This was significant because it reverses an established trend for increases in successive December quarters. The significance of the reduction is not clear but spending levels during 1998 will be important for the future maintenance of Australia's resource stock. While the December quarter reduction is of concern it should be noted that it was offset by strong growth (19%) in the September quarter spending compared to the September quarter 1996.

Production

Preliminary figures published by ABARE for 1997 show an 8% increase in production to 311.36 t. Western Australia dominated with 237.76 t, just over 76% of total output (Plate 2). Ranking of the other States remained the same as in 1996 and was: Queensland 28.94 t (9.3% of total Australian production), Northern Territory 23.79 t (7.6%), New South Wales 11.2 t (3.8%), Victoria 4.65 t (1.5%), Tasmania 3.6 t (1.2%) and South Australia 0.88 t (0.3%). The growth in Australian production was dominated by increased production in Western Australia where output rose by 18.4 t, just over 82% of the total growth for the country as a whole. ABARE has made a substantial reduction in the projected production in 1999–2000, from 336 t to 312 t. The current ABARE projection for production in 2002–2003 is 291.5 t.

World ranking

Based on BRS estimates and the USGS world resource data, the world's three largest stocks of gold EDR in 1997 were held by South Africa (41% of world total), USA (12%) and Australia (10%). The rankings were unchanged from 1996, as were shares of EDR. The estimates were based on world data which do not include China because the USGS report that reliable data on the level of Chinese resources are not available, even though China is a significant gold producer.

Using Australian production and the USGS estimates for other countries, world production for 1997 was 2315 t, an increase of 65 t on the previous year. South Africa was again the leading producer with 490 t (41% of world output), followed by the USA with 325 t (14%) and Australia with 311 t (13.6%). The fourth largest producer was Canada with an output of 150 t (6.5%).

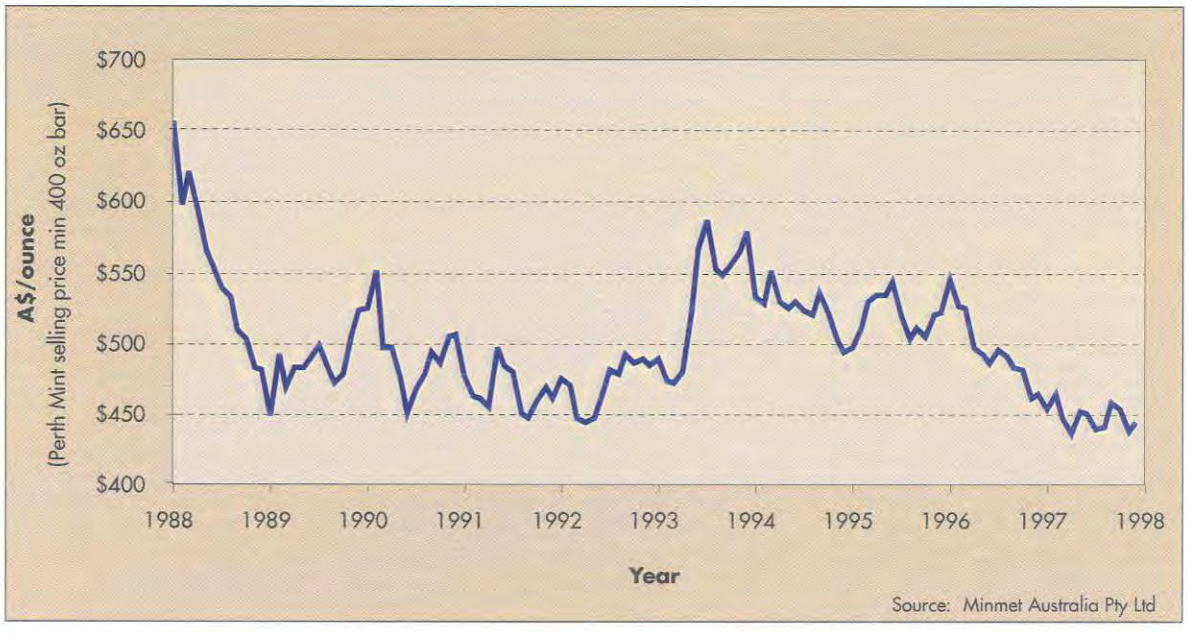
Industry developments

The low gold prices prevailing throughout most of the year (Figure 2) dominated industry operations and planning. Although many producers are protected to a greater or lesser extent by their hedge book, the low prices have caused some closures, the most notable of which was the Mount Todd operation in the Northern Territory. Two aspects of the prevailing low prices of concern relate to the question of maintenance of Australia's stock of resources. These are, any moves to reduce operating costs by mining only higher grade ore, and any reduction in exploration expenditure that may occur in an effort to contain costs.

Preferential mining of higher grade zones can potentially sterilise lower grade zones in a deposit that might otherwise have been mined, thereby effectively reducing EDR. A reduction in exploration spending, especially if it extends over a number of years, is likely to result in reduced numbers of discoveries and ultimately in reduced EDR. Should EDR fall significantly, maintenance of current and projected levels of production will not be feasible in the medium to long term. At the 1997 production level, 311 t of new EDR must be discovered annually just to maintain EDR stocks.

During the year, initial resources were announced for a number of deposits throughout the country. Included in these were the first resources – for the Challenger and Golf Bore deposits in the Gawler Craton – which can be attributed to the provision of high quality geoscientific data by the South Australian Government. In New South Wales, resource estimates were released for the Ridgeway deposit at the Cadia project near Orange, and in Western Australia resources were announced for the

Figure 2 Variation in gold price since 1988



White Foil (near Kalgoorlie) and Whisper/Innuendo (near Laverton) deposits.

Iron ore

Resources of iron ore occur in all Australian States and the Northern Territory (Map 1). Western Australia is the premier iron ore State but important resources are present in South Australia and Tasmania. Activity in all three States was strong in 1997, with Tasmania, in particular, receiving a major boost with the redevelopment of the Savage River operation.

Resources

Australia's EDR fell by 7% to 16.6 Gt in 1997. Approximately 13% of the reduction was due to the loss of resources to production. The remainder of the fall resulted from new resource data for deposits in both Western Australia and South Australia. A substantial increase was recorded in Tasmanian EDR following the publication of new data for Savage River by Mineral Resources Tasmania in its Annual Review for 1996–97.

Despite the reduction in Western Australian EDR, that State remained the dominant iron ore region with over 99% of Australian EDR. Within Western Australia, the Pilbara is the dominant iron ore region, holding almost 98% of Australia's total EDR. Tasmanian and South Australian EDR occur at Savage River and in the Middleback Ranges, respectively.

In terms of contained iron, Australia's EDR stood at 9.8 Gt.

National subeconomic demonstrated resources rose by just over 1% to 14.4 Gt, mainly as the result of an increase of 0.3 Gt in paramarginal demonstrated resources in Western Australia. Of the national subeconomic demonstrated resources, over 96% occurs in Western Australia.

Submarginal demonstrated resources fell by almost 0.2 Gt following the publication of new resource estimates for a deposit in South Australia which downgraded the classification to inferred and reported lower tonnage and grade. Subeconomic resources in other States were unchanged in 1997.

In terms of contained iron, Australia's subeconomic demonstrated resources stood at 7.9 Gt.

Inferred resources rose by 8% to 18.8 Gt in 1997. Significant growth was recorded in inferred resources in Western Australia, South Australia and Tasmania, but Western Australia remained dominant with 85% of Australia's total.

Exploration

On the basis of quarterly exploration expenditure published by ABS, Australian expenditure on iron ore in 1997 was $26.2 million, an increase of 46% over the previous year. Comprehensive State data are not available in the ABS published data but it is reasonable to assume that most expenditure was incurred in Western Australia.

Production

Preliminary figures published by ABARE put Australia's iron ore production in 1997 at 157.8 Mt. This was composed of 154.5 Mt from Western Australia, 3.08 Mt from South Australia and 0.18 Mt from Tasmania. The relatively small output from Tasmania was a result of the temporary closure of the Savage River mine. Tasmanian output began again in the December quarter as the Savage River mine came back on stream under new ownership.

World ranking

On the basis of estimates published by the USGS, Australia has about 10% of the world's EDR of iron ore. It has the fourth largest tonnage of EDR after Russia, the Ukraine and China. The USGS reported figure for China rose from 9 Gt of iron ore EDR in 1996 to 25 Gt in 1997, on the basis of new information becoming available. In terms of contained iron, Australia, with 14% of world total, had the second largest EDR after Russia. The Ukraine was ranked third and China fourth.

China was again the world's largest producer with 25% of world ore production, according to USGS estimates. Brazil, with 18%, was the second largest producer and Australia was third with 15%.

Industry developments

Important developments took place in each of the three iron ore producing States in 1997. In Western

Australia, Rio Tinto Limited announced that it would proceed with the development of its Yandicoogina mine in the Pilbara at a reported cost of $722 million. All environmental and government approvals have been obtained. Initial production is expected to be 5 Mtpa with capacity to increase to 15 Mtpa should market conditions warrant.

The Western Australian Government announced in October that environmental approval had been given for the steel plant component of the An Feng Kingstream Steel Limited's Mid West Iron & Steel project to be located at Oakajee, 23 km north of Geraldton. The plant is designed to produce 2.4 Mtpa of steel slab which will be further processed in Taiwan. Included in the proposal is a plant for the production of 2.8 Mtpa of iron ore pellets. Ore for the project will be drawn from the Tallering peak, Weld Range, Koolanooka and Blue Hills deposits.

The Savage River mine and Port Latta facility in Tasmania were on care and maintenance in the first part of 1997 before Australian Bulk Minerals took over the operation on 26 March. Production recommenced toward the end of the year. Contract mining is to be by conventional blasting and trucking methods. As part of the re-established operation a study is in progress to examine the feasibility of producing pig iron, and potentially, steel at the Port Latta site.

In South Australia, the government announced in May that resources had been defined in eight deposits that would form part of the South Australian Steel and Energy Project (SASE). Deposits were reported in the Hawks Nest and Giffen Well areas 120 km south of Coober Pedy. They have a mixture of indicated and inferred resources totalling 850 Mt of magnetic ore with an average grade of 35% Fe. Tests have indicated that it will be possible to produce a concentrate with a grade of between 65% and 70% Fe from the ores.

A further boost to the SASE project came toward the end of 1997 when it was announced that funding support had been received for the construction of a 2 tonnes per hour iron ore smelting demonstration plant. The Industry Research and Demonstration Board granted $6.5 million toward the plant which will be built at Whyalla. The objective is to provide more accurate measurement of operating parameters than can be obtained from the existing pilot plant.

Lithium

Resources

All of Australia's resources of lithium occur in Western Australia and all EDR occur in the Greenbushes deposit in the southwest of Western Australia at the town of Greenbushes. At the end of 1997, EDR stood at 162 000 t, some 2.4% less than the previous year. Over half this reduction was due to loss of resource to production, and the remainder resulted from revised resource and reserve estimates published by Gwalia Consolidated Limited.

Subeconomic demonstrated resources and inferred resources were unchanged in 1997.

Production

Gwalia Consolidated Limited is the world's largest producer of spodumene ($Li_2O.Al_2O_3.4SiO_2$). Production is from the Greenbushes deposit which is the world's largest and highest grade spodumene deposit. Production fell by about 25% to 88 399 t in 1997 in response to a significant drop in demand.

World ranking

On the basis of BRS work and estimates published by the USGS, Australia has just over 4% of the world's EDR of lithium. This places it behind Chile (80% of world EDR), the USA (9%) and Canada (5%). Although production figures for the USA are withheld by the USGS, it reported that, for the first time, the USA was surpassed by Chile as the world's biggest producer of lithium. Assuming then that the USA was the second largest producer, Australia would have been the fourth largest after Chile, the USA and China. Based on USGS figures for world (excluding the USA) production, Chile accounted for 41% of output, China 23% and Australia 18%.

Industry developments

Re-commissioning of the lithium carbonate plant at Gwalia's Greenbushes operation progressed at a slower than expected rate before the company announced in June that it was placing the plant on care and maintenance. A reduction of 30% – 40% in

the price of lithium carbonate caused by a new Chilean entrant into the market contributed to the company's decision.

Also at Greenbushes, Gwalia is to mine and stockpile a zone of high grade potassium feldspar. Testing has indicated that processing the ore through the lithium plant's heavy media circuit could yield a high grade product suitable for use in the ceramics industry. Sample product is being tested by potential users. The company is continuing work to develop a suitable process to recover mica using the flotation section of the lithium plant.

Magnesite

Resources

Australia's EDR of magnesite increased by about 6 % to 191 Mt in 1997. The bulk of this increase was in Tasmania, where a resource of 29 Mt with a grade of 42.8% MgO has been identified at Arthur River, approximately 53 km southwest of Burnie.

The largest Australian EDR of magnesite occurs at Kunwarara, 70 km northwest of Rockhampton, Queensland. This deposit, which is being mined, contains substantial accumulations of very high density "bone-type" magnesite with low iron, nodular, cryptocrystalline characteristics.

Australia's other major magnesite mine, which is currently not operating, is at Thuddungra, 23 km northwest of Young in New South Wales. Magnesite from this mine, which typically contains 98–99% $MgCO_3$, is processed at Young.

More than 340 Mt of subeconomic demonstrated resources of magnesite occur in the Kunwarara deposit. The bulk of the Australia's inferred resources of magnesite are located in the Yaamba / Herbert Creek area close to the Kunwarara deposits.

Production

During 1997, Queensland Metals Corporation Limited mined some 2.5 Mt of crude magnesite ore at Kunwarara, which was beneficiated to produce about 250 000 t of magnesite. This material was used to produce about 86 000 t of deadburned and 21 000 t of electrofused magnesia; for the manufacture of high quality refractory bricks, used for lining heat containment vessels in the steel, cement, non-ferrous metals and chemical industries.

A small quantity of magnesite ore was mined in the Myrtle Springs area of South Australia in 1997.

World ranking

By world standards, Australia's resources and production of magnesite are small, accounting for only 2% of the world's EDR, and about 3% of the world's production in 1997. However, the Kunwarara deposit is the world's largest known resource of cryptocrystalline, nodular magnesite, a high quality ore by world standards.

Industry developments

The Arthur River magnesite project in Tasmania is currently the subject of engineering and financial studies by Crest Resources Australia N.L. The company plans to mine 300 000 tpa of raw magnesite ore which will be upgraded to 45% MgO through rejection of silica by single-stage beneficiation. The second stage of this project is to produce some 60 000 tpa of magnesium metal using Alcan International's electrolytic cell and dehydration technology.

The Australian Magnesium Corporation, jointly owned by Normandy Mining Limited and Queensland Metals Corporation, was formed in January 1997 to build a magnesium smelter with a capacity of 90 000 tpa at Gladstone, Queensland. A 1000 tpa demonstration plant is expected to commence operation by mid-1998. Production of magnesium metal from a commercial plant is expected to begin in late 2002, with full production by late 2004. The Ford Motor Company has signed a long term supply agreement to purchase 45 000 tpa of magnesium alloy from the plant.

Manganese ore

Australia's resources of manganese ore are the basis of a major mineral export industry as well as a significant domestic ferromanganese, silicomanganese and manganese dioxide processing industry. The principal manganese resource and major operating manganese mine is on Groote Eylandt, Northern Territory. The deposit is a world-class resource from

which high grade manganese ore is being won. The Groote Eylandt manganese deposit was discovered in 1961 and the first ore was produced in 1966. To date the mine has produced over 45 Mt of high grade (49% Mn) ore.

Resources

In 1997, Australia's EDR of manganese ore fell by about 4% from 118 Mt to 112.9 Mt as a result of depletion of resources through mining at Groote Eylandt and a reclassification of resources in the east Pilbara, Western Australia. There were no significant changes to either subeconomic demonstrated resources or inferred resources.

Resources of manganese ore in the Woodie Woodie area of the east Pilbara were downgraded following the closure Valiant Consolidated Limited's processing plant and associated mining operations in October 1997. The known resources in this province are relatively small compared with those on Groote Eylandt.

Production

Despite a 50% reduction in manganese ore production from the east Pilbara, Australian manganese ore production increased slightly to more than 2.1 Mt. This followed a 9% increase in output at Groote Eylandt, where Groote Eylandt Mining Company produced over 1.96 Mt of high grade manganese ore (49% Mn).

Before the operations at Woodie Woodie ceased, the east Pilbara district had produced about 174 000 t of high grade manganese ore for the year, 45% less than in 1996. Reasons given for the closure were: record cyclonic rains in early 1997 which affected the mining of ore and its transport to Port Hedland; falls in demand and stagnant markets for the product; and trading losses. The closure followed the sale of the beneficiation plant and other assets at Woodie Woodie by Portman Mining Limited to Valiant in 1996. All manganese mining in the district has ceased.

World ranking

Based on a combination of USGS and BRS data, Australia has an estimated 11% of world EDR. When EDR is estimated in terms of contained manganese in ore, Australia is ranked third after South Africa and the Ukraine. Using the same measure, Australia is the world's third largest producer of manganese ore, after South Africa and China. In 1997, Australia contributed an estimated 13% of world production.

Mineral sands

The principal components of mineral sands are rutile, ilmenite, and zircon. Rutile and ilmenite are titanium minerals used mainly in the production of titanium dioxide pigment, with a small portion (less than 4% of total titanium mineral production), typically rutile, used in making titanium sponge metal. Zircon is used as an opacifier for glazes on ceramic tiles, in refractories and in the foundry industry.

Resources

The EDR of rutile, ilmenite and zircon all increased substantially in 1997. EDR of *rutile* increased by more than 17% to 17.53 Mt, *ilmenite* by about 5.5% to 143.5 Mt, and *zircon* by 8.6% to 23.26 Mt. These increases, which more than offset depletion by mining, resulted from a combination of new discoveries and reclassification of resources by companies.

RGC Limited published new resource information for deposits on North Stradbroke Island, the first since 1987. RGC acquired the resources from Consolidated Rutile Limited in late 1996. The resources present on the island are more substantial than was previously thought. The new data put the reserves for rutile, ilmenite, and zircon for all the deposits on North Stradbroke Island at 2.2 Mt, 6.95 Mt, and 1.84 Mt, respectively.

Infill drilling by current mineral sand producers in Western Australia resulted in a small increase in the EDR of rutile, ilmenite and zircon in that State

Some 22%, 26% and 31% of Australia's EDR of ilmenite, rutile and zircon, respectively, are unavailable for mining. A slight fall from 1996 levels reflects an increase in new resources located in areas less sensitive to mining. Areas quarantined from mining and now largely incorporated into national parks include: Moreton, Bribie and Fraser Islands;

the Cooloola sand mass north of Noosa; Byfield sand mass and Shoalwater Bay area in Queensland; and Yuraygir, Bundjalung, Hat Head and Myall Lakes national parks in New South Wales.

Australia's subeconomic demonstrated resources of ilmenite declined by 3% to 66.5 Mt in 1997, whereas subeconomic demonstrated resources of rutile and zircon increased, respectively, by 7% to 36.9 Mt, and by 8.5% to 27.2 Mt. The rutile and zircon increases occurred mainly in the southwest portion of the Murray Basin in New South Wales following successful exploration.

Continuing exploration in the Victorian area of the Murray Basin increased Australia's inferred resources of ilmenite, rutile and zircon by about 10%, 19% and 16%, respectively, in 1997.

Exploration

During 1997, BeMax Resources N.L. discovered a number of strandlines at Plain Tank, and Nanya, 120 km south southwest of Broken Hill, New South Wales. Many of these strandlines are very long and consist of clean, well sorted, coarse-grained sands, rich in rutile and zircon. No resource estimates for these deposits are yet available.

In Victoria, RGC Limited discovered a number of high grade deposits, known as Kulwin, Woornack and Rownack, east of Ouyen, with heavy minerals grades in the range of 9–25%. The deposits have grain sizes similar to conventional beach sand deposits and are, therefore, amenable to standard dredging and dry plant separation techniques. The company has initiated mining and metallurgical studies with the aim of developing these resources which are which are readily accessible and close to power. These discoveries follow those by Aberfoyle Resources Limited at Spring Hill and Twelve Mile in New South Wales, and Wemen in Victoria. RZM Ltd has formed a joint venture with Aberfoyle to develop a mining and dry plant operation in the region.

Following these successes, a large portion of the Murray Basin in New South Wales, Victoria and South Australia is now under application for exploration licences

Production

In 1997, Australia produced 2.23 Mt of ilmenite, 226 000 t of rutile and 424 000 t of zircon. Although the bulk of Australia's rutile and zircon production is exported only about 50% of the ilmenite output is shipped overseas. The ilmenite that is not exported is upgraded to synthetic rutile containing 92-93% TiO2.

World ranking

From USGS and BRS data, BRS estimates that at the end of 1997 Australia had 24%, 42%, and 37% of the world's EDR of ilmenite, rutile and zircon, respectively, and produced about 35%, 58% and 49%, respectively, of world output of these minerals. South Africa and Canada mine similar quantities of ilmenite to Australia, the former from dune sands and the latter from hard-rock deposits. Both these countries upgrade their ilmenite to titanium slag before export. Australia is the world's leading producer and largest exporter of all three minerals.

Industry developments

In early 1997, Australia's biggest sand mining dredge, over 93 m long and weighing 3500 t, was commissioned at the Beenup project in Western Australia. The dredging and mineral separation operation is expected to produce 600 000 tpa of ilmenite and 20 000 tpa of zircon for at least the next 50 years. About 50% of the Beenup's production of ilmenite is to be processed at BHP's Tyssedal smelter in Norway.

In Queensland, RGC Limited began dredging the Ibis Deposit in January 1997 following the closure of its Bayside mine in mid-1996, and the subsequent relocation of the dredge.

Westralian Sands Ltd commissioned its second synthetic rutile kiln at Capel, Western Australia, in late 1997, thereby doubling its capacity to 230 000 tpa.

Molybdenum

Resources

All of Australia's molybdenum resources are subeconomic and no molybdenum is produced here.

In Queensland, subeconomic resources occur at Wolfram Camp (75 km southwest of Cairns), Ben Lomond (60 km southwest of Townsville) and Maureen (40 km northwest of Georgetown), the last two being associated with uranium.

Australia's largest resources occur in the inferred category and are located at Yetholme (20 km east of Bathurst) in New South Wales and, with tungsten (scheelite) mineralisation, at Mount Mulgine (230 km east-southeast of Geraldton in Western Australia).

Exploration by Newcrest Mining Limited in 1996 at Cadia East (adjacent to Cadia Hill near Orange) in New South Wales identified an inferred resource of 150 Mt containing 179 ppm molybdenum associated with gold and copper.

Production

There was no production of molybdenum in Australia in 1997.

World ranking

Australia's identified resources of molybdenum comprise about 7% of the world's total identified resources of 12 Mt.

Nickel

Resources

Australia's EDR of nickel increased by 5.4% in 1997, from 6.37 Mt to a record 6.72 Mt. All of this increase occurred in Western Australia, and was mainly an outcome of company reassessment of resources at either existing mines or new deposits nearing production. A substantial increase in resources was reported for the Mount Keith nickel operations and minor increases occurred at the Kambalda and Leinster mines. Company reassessment of the massive and disseminated sulphides at Yakabindie, and of laterites at Cawse and Murrin Murrin, also contributed to the increase.

Subeconomic demonstrated resources of nickel increased by nearly 30% to 7.22 Mt in 1997, as a result of further drilling at Eucalyptus Bore, Ravensthorpe, and the Emily Ann prospect near the Maggie Hays deposit, as well as discoveries at the Abednego and Waite Kauri deposits in Western Australia. At Syerston in New South Wales and in the Marlborough district in Queensland, company reassessment aided by additional drilling resulted in increased subeconomic demonstrated resources.

Company reassessment of earlier data, and additional drilling, resulted in inferred resources of nickel increasing by about 51%. Most of the increase was at deposits in the Marlborough district in Queensland. Increased inferred resources were also located at Beaconsfield in Tasmania, and at the Eucalyptus Bore, Mertondale, and Pinnacle deposits in Western Australia.

Production

In 1997, 814 000 t of nickel concentrate, containing an estimated 124 000 t of nickel, was produced. All the production was from Western Australia.

World ranking

Based on a combination of USGS and BRS data, world EDR of nickel fell from 51.2 Mt in 1996 to 43 Mt in 1997 as a result of a sharp decline in EDR in Cuba. Australia's share of world EDR increased to 15.6% in 1997, up from 12.5% in 1996. Australia is now the world's largest holder of EDR, followed by Russia, Cuba, and Canada with 15.4%, 12.8% and 12.3%, respectively.

Australia accounted for about 11.5% of the estimated world nickel output of 1.08 Mt in 1997, and was the fourth largest producer after Russia, Canada and New Caledonia.

Industry developments

Mining continued at Kambalda, Leinster and Forrestania in Western Australia. Production from Outokumpu Mining Australia Pty Ltd–Mining Project Investors Pty Ltd's rich massive sulphide deposit, Silver Swan, began in May 1997.

Developments at three laterite deposits in Western Australia — Anaconda Nickel Ltd's Murrin Murrin deposit, Centaur Mining & Exploration Ltd's Cawse deposit, and Resolute Ltd's Bulong deposit — were all on schedule. Production from these mines is expected to start in the latter part of 1998. When fully operational, they will produce, initially, about 63 000 t of nickel metal.

One nickel smelter operates at Kalgoorlie, Western Australia, and there are two refineries, one at Yabulu, Queensland and the other at Kwinana, Western Australia. The Yabulu refinery processes ore imported from New Caledonia.

Phosphate

Currently, no phosphate rock mined in Australia is used in the manufacture of phosphoric acid for making high analysis fertilisers. However, by late 1999 this will change with the start of the Queensland Fertiliser Project at Mount Isa, Queensland.

Resources

Australia's EDR of phosphate rock totalled 103 Mt in 1997, all at Phosphate Hill, 70 km south of Duchess, in northwest Queensland. The Phosphate Hill resources are a sedimentary rock (phosphorite), with an average grade of 23.4% P_2O_5, at the southeastern margin of the Georgina Basin.

Most of Australia's demonstrated resources of phosphate are in the Georgina Basin and are classified as paramarginal. The exception is the carbonatite deposit at Mount Weld, 26 km southeast of Laverton, Western Australia.

All of Australia's inferred phosphate resources are phosphorites in the Georgina Basin, and these are approximately evenly distributed between Queensland and the Northern Territory.

Production

Less than 5000 t of phosphate is mined annually in Australia, mainly from small deposits in South Australia. This material is high in aluminium and iron and is not suitable for manufacturing superphosphate. It is used as a direct-application fertiliser or for making organic fertiliser for horticultural applications.

World ranking

Australia's EDR of phosphate rock comprises about 1% of the world's total EDR of 11 000 Mt which occurs principally as sedimentary marine phosphorites.

Industry developments

In late 1996, WMC Limited announced that it would proceed with the development of mining and processing facilities at Phosphate Hill at a cost of $750 million. The Phosphate Hill operation has been on care-and-maintenance since 1983. Future developments at the site will include phosphate rock mining, ammonia production, phosphoric acid production and fertiliser granulation. Natural gas for ammonia production is to be supplied by Santos Limited from the Cooper Basin, and sulphur dioxide gas for the production of sulphuric acid by MIM Holdings Limited. Construction of the major chemical plants at Phosphate Hill and Mt Isa began in early 1998.

Shale oil

Resources

BRS assesses that Australia currently has no shale oil resources in the EDR category. In the short term, this assessment will be significantly influenced by results from the demonstration plant under construction at the Stuart project near Gladstone, Queensland.

Subeconomic demonstrated resources are some 35% lower than in the previous assessment due to application by Southern Pacific Petroleum N.L. (SPP) and Central Pacific Minerals N.L (CPM) of the JORC Code to their resource estimates. Application of the Code resulted in substantial resources in the Condor, Duaringa, Lowmead, Nagoorin, Nagoorin South and Stuart deposits being reclassified as inferred resources. Minor resources in New South Wales and Tasmania and other resources in Queensland were unchanged in 1997.

Resources in the Stuart deposit are classified as subeconomic paramarginal by BRS. Should the demonstration plant prove that extraction of oil from the Stuart oil shales is commercially feasible, it is expected that resources in the deposit, and possibly others, will be upgraded to the EDR category.

As a result of the reclassification of resources in the Queensland deposits, Australia's inferred resources of shale oil rose by 25%. Minor inferred resources in New South Wales and Tasmania were unchanged.

Exploration

As expected, there was little exploration of oil shale deposits in 1997 reflecting the fact that deposits had been well explored in earlier years. SPP/CPM undertook a limited drilling program on the Duaringa deposit as part of the process of converting the tenements from Exploration Permits to Mineral Development Licences. Esperance Minerals N.L. and Greenvale Mining N.L. undertook an assessment of the additional geological studies that would be required to optimise mine development plans for the Alpha deposit.

Production

There was no production of shale oil in Australia in 1997.

World ranking

Information on world resources and production of shale oil is not available.

Industry developments

The major development during 1997 was the commitment given by the project partners, SPP/CPM and Suncor Energy Inc., to commence work on Stage 1 of the Stuart shale oil project. Stage 1 is the first of a proposed three stage project and will result in the construction and operation of a 4500 barrels per day demonstration plant which will aim to prove that the Alberta Taciuk Process is a viable processing option and to provide data that will allow for optimal operation of Stages 2 and 3. Stage 2 is planned to be a single full commercial module and Stage 3 a full commercial plant consisting of five additional processing units and downstream facilities for production of a full range of light sweet crude products. SPP reported that site clearing commenced at Stuart in August and that by year's end over than a quarter of the project had been completed by the contractor Bechtel Australia.

Tantalum

Australia is an important source of tantalum, and Gwalia Consolidated Limited is the world's largest supplier of tantalum concentrates. The main use of tantalum is in the electronics industry, particularly in the manufacture of tantalum capacitors. Other uses include applications in the chemical industry, and in jet engines, optical glass and cutting tools.

Resources

Tantalum EDR increased by 41% in 1997. This increase was mostly due to an almost eight times increase in tantalum in the resources reported by Gwalia for the Wodgina project in Western Australia. In addition, the start of production at the Bynoe property in the Northern Territory saw a small tonnage upgraded to EDR. Greenstone Resources N.L. has lodged with the Department of Minerals and Energy a Notice of Intent to commence mining at the Cattlin Creek deposit in Western Australia. The small Cattlin Creek resource has been upgraded to EDR.

A 10% increase in paramarginal demonstrated resources was due to increased resources at Wodgina more than offsetting the small reduction caused by the upgrading of the Bynoe resource. The one-third reduction in resources in the submarginal demonstrated resource category was due entirely to the upgrading of the Cattlin Creek resources.

The 3% reduction in inferred resources resulted from the reported resources at Wodgina being insufficient to offset the loss of inferred resources at Greenbushes. Gwalia Consolidated reported no inferred resources at Greenbushes in its 1997 annual report.

Production

Gwalia Consolidated reported production of 665 995 lbs of Ta_2O_5 from its Greenbushes plant in 1997 and 147 857 lbs, from Wodgina. Gwalia also reported that its Bynoe project was being mined under a tribute agreement which calls for annual production of about 30 000 lbs of Ta_2O_5. The ore is purchased from the miner and treated at Greenbushes.

World ranking

Australia remained the world's premier holder of tantalum EDR. Based on the USGS estimates for other countries and the BRS estimate of Australia's EDR, Australia has about 54% of world EDR. This represents a substantial increase from the 43% held in 1996 and can be attributed mainly to the increased EDR at Wodgina. Nigeria has the second

largest holding with about 15%, followed by Canada and Congo (formerly Zaire) each with just under 9%.

Australia is the world's largest producer of tantalum with an output of about 302 t of contained tantalum in 1997. This is approximately 74% of total world output of 407 t. Brazil and Canada were the second largest producers, each with 50 t.

Uranium

Resources

BRS has prepared estimates of Australia's uranium resources within categories defined by the OECD Nuclear Energy Agency (OECD/NEA) and the International Atomic Energy Agency (IAEA) (OECD/NEA & IAEA 1998). In Table 1, these estimates are reported under the corresponding resource categories of the BRS classification scheme. Comparisons of the resource categories within both these schemes show the following approximate correlations:

BRS Scheme	OECD/NEA & IAEA Scheme
Economic Demonstrated Resources	Reasonably Assured Resources (RAR) recoverable at less than US$80/kg U (commonly referred to as low cost resources)
Subeconomic Demonstrated Resources	RAR recoverable at US$80-130/kg U
Economic Inferred Resources	Estimated Additional Resources Category 1 (EAR-1) recoverable at less than US$80/kg U
Subeconomic Inferred Resources	EAR-1 recoverable at US$80-130/kg U

Australia has the world's largest resources of uranium in the low cost RAR category, with 26% of world resources in this category. Other countries which have large low-cost resources include Kazakhstan (19%), Canada (14%), South Africa (9%), Namibia (7%), Brazil (7%), the Russian Federation (6%), and the USA (5%).

Approximately 95% of Australia's total uranium resources in the low cost RAR category are within the following six deposits (Figure 3): Olympic Dam, South Australia; Ranger, Jabiluka, and Koongarra in the Alligator Rivers Region, Northern Territory; and Kintyre and Yeelirrie, Western Australia.

Production

Uranium oxide is currently produced at two mining/milling operations: Ranger and Olympic Dam. Australia's total production for 1997 was a record high of 5489 t U (6473 t U_3O_8) [U = 0.848 x U_3O_8], 10% greater than in 1996, of which Ranger produced 4063 t U and Olympic Dam produced 1426 t U.

Industry developments

Ranger — Energy Resources of Australia Ltd (ERA) completed mining of Ranger No. 1 orebody in December 1994 and since August 1996 the open cut has been used as a repository for mill tailings.

In May 1996, ERA received approval from the Northern Territory Government to commence the development of its second orebody at Ranger (referred to as Ranger No 3) located approximately 1 km north of the mined-out No 1 open cut. Full-scale mining commenced in July 1997 at the No 3 Orebody which has proven plus probable reserves of 18.8 Mt ore with average grade 0.28% U_3O_8, containing 53 400 t U_3O_8 (as at June 1997). The orebody is within the Ranger Project Area and was included in the original Environmental Impact Statement (EIS) for the Ranger Project which was completed in the late 1970s.

Expansion of the Ranger mill to a capacity of 5000 tpa U_3O_8 was completed by mid -1997. In the event that the company's proposal to mill ore from Jabiluka, also owned by ERA, at Ranger is approved, then the capacity of the mill would be increased further to 6000 tpa U_3O_8.

Figure 3 Uranium deposits and prospects in Australia

Olympic Dam — The Olympic Dam copper-uranium-gold-silver deposit is the world's largest deposit of low-cost uranium. Total proved plus probable reserves amount to 347 800 t of contained U_3O_8, as at 30 June 1997 (WMC 1997).

The orebody occurs within the hematite-rich Olympic Dam Breccia Complex, which is a large Mesoproterozoic hydrothermal breccia complex within the Roxby Downs Granite. The deposit is unconformably overlain by approximately 300 metres of undeformed Neoproterozoic and Cambrian aged marine sedimentary rocks. There is a variety of breccia types which range from granite breccias through hematite-granite breccias to hematite-rich breccias.

The Olympic Dam operation has an annual production rate of 85 000 t copper, 1700 t U_3O_8 and associated gold and silver. WMC Limited proposes to undertake a two-phase expansion of production at Olympic Dam. The first phase, to be completed by the end of 1999, will increase production to a nominal rate of 200 000 tpa copper, approximately 4600 tpa U_3O_8, 2050 kg per annum gold and 23,000 kg per annum silver. For the processing plant to achieve a sustained production rate of 200 000 tpa copper, the mine would need to supply, depending on the grade, 8.7–9.2 Mtpa of ore (Kinhill 1997).

The second phase of the expansion, which is subject to WMC Board approval, would further increase production to 350 000 tpa copper, 7700 tpa U_3O_8 and associated gold and silver.

The final EIS for the expansion was assessed jointly by both Commonwealth and South Australian governments. The major issues raised (Kinhill 1997) relate to:

- the sustainable supply of water for mining, processing, and the township from borefields within the Great Artesian Basin;
- containment of tailings and
- management of radiation exposures.

Following consideration of the final EIS for the expansion project, the Commonwealth Environment

Minister advised the Minister for Resources and Energy in December that, on the available evidence, the expansion appeared to be environmentally acceptable. The Environment Minister also recommended that the existing environmental controls be augmented by additional conditions relating to the management of the Great Artesian Basin water resources, future assessments of the tailing management system, and impacts of future changes to technology and mining practices at the mine.

The **Olympic Dam** expansion is South Australia's largest development project. Some statistics which indicate the size of the expansion include: cost of the expansion is $1.48 billion, 1000 new construction jobs on site, 3000 jobs off-site and another 200 full-time jobs.

Following removal of the 'three mines' policy in March 1996, the Government has received formal proposals to develop four new uranium mines: Jabiluka deposit, Beverley deposit, Honeymoon deposit and Kintyre deposit.

Jabiluka — The EIS for development of Jabiluka considered two milling options. ERA's preferred option is to mill the Jabiluka ore at Ranger, which would ensure there is minimal environmental impact. Ore would be trucked by a haul road located entirely within the ERA leases and would not enter the adjoining Kakadu National Park. Tailings would be placed in the Ranger open pits. ERA's alternative milling option involves above ground processing and tailings storage facilities on the Jabiluka lease.

The final EIS for the Jabiluka Project was submitted to the Commonwealth and Northern Territory governments in June 1997. In August, the Minister for the Environment completed his assessment of the EIS and recommended to the Minister for Resources and Energy that there did not appear to be any environmental issue which would prevent the preferred Jabiluka proposal from proceeding. However, the Environment Minister recommended that stringent regulatory and operating conditions be applied to ensure the protection of World Heritage values, flora and fauna and cultural heritage (including Aboriginal sacred sites). Best practice environmental management will be required at all stages of the project including water management and rehabilitation.

In October 1997, the Minister for Resources and Energy, formally advised ERA of his endorsement of the recommendations of the Minister for the Environment, and cleared the way for the Jabiluka project to proceed. He required the company to undertake further relevant baseline environmental studies. The Minister noted that ERA had an excellent record on environmental management at its nearby Ranger operation. The Office of the Supervising Scientist (now the Supervising Scientist Group) has monitored the environmental impact of this operation over 16 years, and has consistently reported that there have been no significant environmental impacts on the surrounding areas of the National Park.

ERA is negotiating with the Traditional Aboriginal Owners for consent to develop Jabiluka according to the company's preferred option. It is estimated that the Aboriginal community will receive approximately $210 million (1996 dollars) in royalties over the life of the mine, in addition to royalties already being received from the Ranger Project (Davies 1997).

ERA plans to develop Jabiluka by 1999, and initially 300 000 t of Jabiluka ore will be processed annually to produce approximately 1800 tpa of U_3O_8. The capacity of the operation will expand to 900 000 t ore annually to produce approximately 4000 tpa of U_3O_8 in the 14th year.

Beverley — is located near Lake Frome, 530 km north-northeast of Adelaide, South Australia. Mineralisation occurs at depths of 110 to 140 m within partly consolidated and uncemented sands and clays of the Tertiary aged Namba Formation. Uranium is present as coffinite which coats sand grains and also occurs within the interbedded clay horizons (Heathgate Resources Pty Ltd 1997). Beverley has in situ resources of 21 000 t contained U_3O_8 at an average grade of 0.18% U_3O_8.

Uranium mineralisation is within a semi-isolated aquifer zone that resembles a concealed stream. This aquifer appears to be isolated from other

groundwater aquifers in the area. Impermeable plastic clays and silts, over 100 m thick, separate the Beverley aquifer from the underlying Great Artesian Basin aquifers (Heathgate Resources Pty Ltd 1997).

In November, the South Australian government gave approval for Heathgate Resources to conduct in situ leach trials at Beverley to collect information for the EIS, which is currently being prepared. These trials began in early January 1998 and the company reported that chemistry and water flow results were in line with predictions, while uranium recoveries were much better than expected.

In the trial, oxygen and a weak acid solution are being injected into the highly saline Beverley aquifer to dissolve the uranium. The trials involve a series of well patterns comprising: injection wells, a single recovery well, and a series of monitoring bores (Plate 3). A small ion-exchange processing plant was constructed to recover uranium from the solutions.

Heathgate proposes to develop a commercial in situ leach (ISL) operation capable of producing 900 tpa U_3O_8 with production commencing in the year 2000.

Honeymoon — The Honeymoon deposit is in the Lake Frome region of South Australia, 80 km northwest of Broken Hill. The deposit has a roll-front shape and occurs at an oxidation–reduction interface along the lateral margins of a palaeochannel. The deposit is within Tertiary aged sands of the Eyre Formation and is 110 m below the surface.

During the late 1970s, testwork showed that the most efficient method of recovering uranium is leaching with sulphuric acid, ferrous sulphate and hydrogen peroxide. A small commercial plant with a flow capacity of 25 litres/second was constructed. In March 1983, the South Australian Government announced that, in accordance with the then Commonwealth Government's 'three mines' uranium policy, it would not grant a production licence for the project. Subsequently the site was placed on care and maintenance.

In 1996, the project was acquired by Southern Cross Resources Inc., a Canadian-based company. Southern Cross recently announced plans to develop the Honeymoon project by refurbishing the existing ISL plant and associated facilities. The company proposes

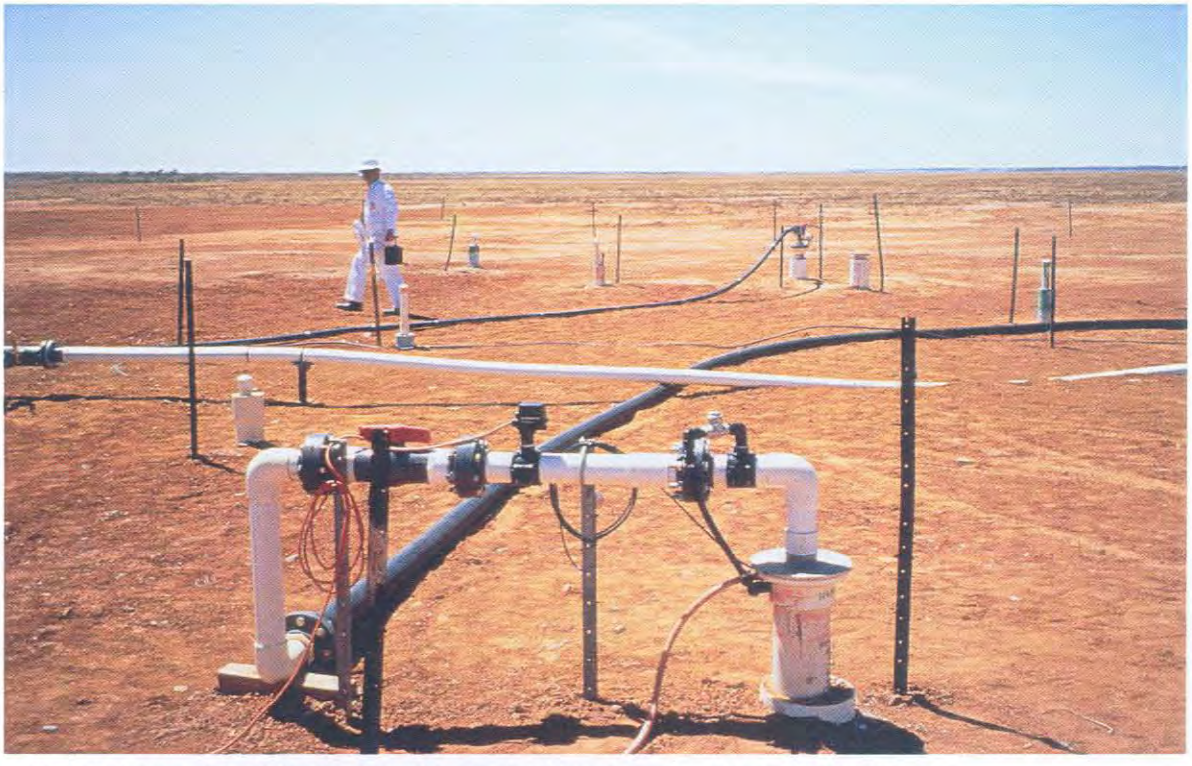


Plate 3 Injection wells for in situ leach trials at the Beverley uranium project, South Australia
Photograph courtesy of Aden McKay, BRS; published with permission of Heathgate Resources Pty Ltd

to operate the plant at a rate of 25 litres/second for approximately 18 months as an initial phase of the development. Refurbishment commenced during 1997 and it was planned to commission the plant in February 1998. A Declaration of Environmental Factors was lodged with the South Australian Department of Mines and Energy Resources in November 1997 to obtain government approval to carry out field leach trials. Final approval for these trials was expected in early 1998. A draft EIS for the project is currently being prepared.

The proposed commercial operation will produce approximately 460 tpa U_3O_8 using a flow rate of approximately 100 litres/second. Subject to the necessary approvals being obtained, production is scheduled to start in 2000 (Bush 1998).

The resources recoverable by ISL methods for Honeymoon and nearby deposits owned by Southern Cross are shown in Table 2.

In situ leach mining for uranium

Although in situ leach mining has been used to mine uranium in Europe, Asia and North America for over 25 years, there are currently no commercial ISL mines in Australia.

ISL is a closed-loop mining system where groundwater from the aquifer within the ore zone (uranium-bearing sands) is used as the transport medium. Uranium is dissolved in situ within the sandstone units, generally using oxygen as an oxidant, and with either an alkaline or acid leaching agent, depending on the chemistry of the ore and the groundwater (Brunt 1998). Patterns of boreholes (called injection wells) are used to deliver the reagent stream to the ore horizon, enabling it to dissolve the uranium mineralisation whilst passing through the aquifer (Figure 4). Similarly, patterns of recovery or extraction wells fitted with submersible pumps deliver the uranium-carrying fluid to the surface for processing to recover the dissolved uranium. After processing, the fluid is returned to the wellfield to continue the leach cycle.

The reagent stream is confined to the mineralised sandstone mainly by the impervious layers of mudstone above and below the ore zone, by careful wellfield planning, and by excess pumping of extraction over injection to create a zone of depression centred on the mining activity. ISL mining is able to recover 60 to 80% of the total uranium resources within a deposit, depending upon the geology, resource calculation method and the leaching chemistry.

From an environmental viewpoint, ISL has a number of advantages over conventional mining including: no open pits, shafts or tunnels; no grinding and crushing plants; no waste rock dumps; no tailings disposal areas.

Long-term restoration and rehabilitation requirements are significantly less than for conventional mining. Because the ore is left in situ, radon release is reduced and dust generation is insignificant. Reduced dust and absence of exposure to the ore greatly reduce radiation exposures.

Senate Inquiry into uranium mining and milling

During 1996 and part of 1997, the uranium mining sector was the subject of a review by the Senate Select Committee on Uranium Mining and Milling. The committee tabled its report in May 1997. The majority report (Coalition/Labor) concluded:

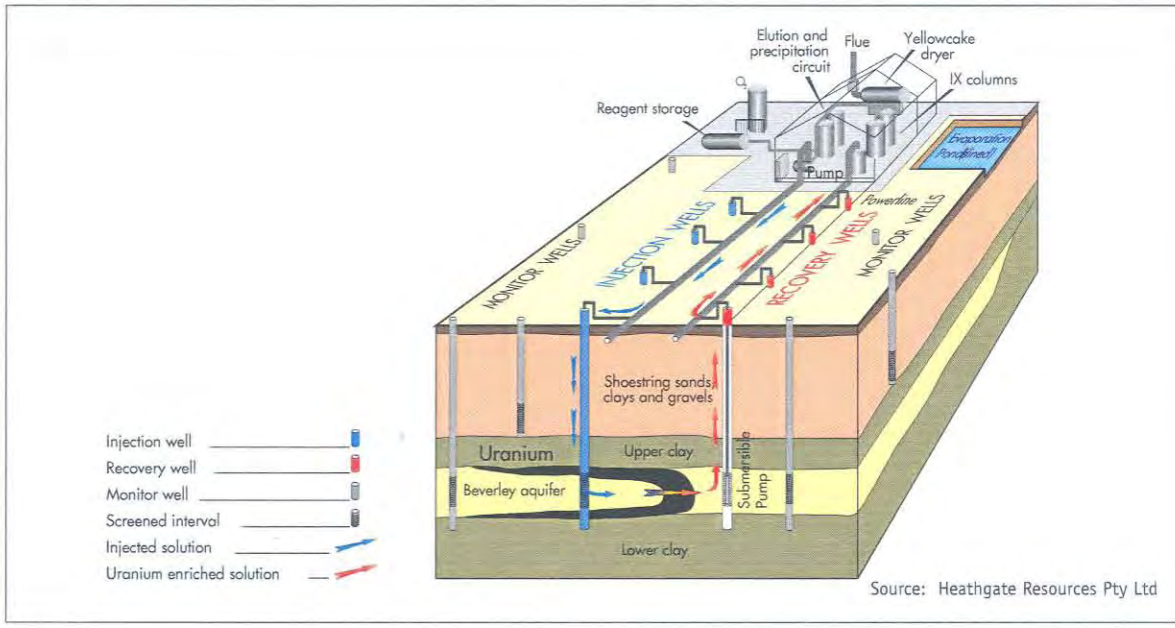
> '.... that the principal findings of the Ranger Uranium Environmental Inquiry (the Fox Report) has [sic] been vindicated by two decades' experience. Fox stated that: 'The hazards of mining and milling uranium, if those activities are properly regulated and controlled, are not such as to justify a decision not to develop

Table 2 Resources recoverable by in situ leach methods at Honeymoon and nearby deposits

Deposit or prospect	Resource category	Resources (t U_3O_8)	Grade (% U_3O_8)
Honeymoon (including Honeymoon Extension)	measured	3700	0.156
East Kalkaroo	indicated	900	0.14
Goulds Dam	inferred	2300	0.14

Source: Ackland 1997

Figure 4 Schematic diagram of an in situ leach uranium mining operation



Australian uranium mines'. The majority report contained 31 conclusions and recommendations. The minority report (Democrats/Greens) preferred that the industry be closed down but, failing this, provided 33 recommendations 'aimed at ameliorating the harm done to Australia by continuing this deadly trade'.

Exploration

Uranium exploration in Australia has increased since 1994 — the first sustained increase in exploration since 1980. Uranium exploration expenditure in Australia declined from 1980 to a low of $6.67 million in 1994. This decline was driven by many factors including a progressive fall in both spot market and contract prices for uranium during this period, and the effects of the 'three mines' policy. However, from 1994 onwards, uranium exploration expenditure has increased progressively, to $14.92 million in 1996, and is estimated to have exceeded $20 million in 1997.

The main areas of uranium exploration during 1997 included:

- Arnhem Land (Northern Territory) — exploration for unconformity-related deposits in Palaeoproterozoic metasediments below a thick cover of Kombolgie Sandstone;
- Paterson Province (Western Australia) — exploration for unconformity-related deposits in Palaeoproterozoic metasediments of the Rudall Metamorphic Complex which hosts the Kintyre orebody;
- Westmoreland area (northwest Queensland) — exploration for sandstone type deposits in Proterozoic sediments of the McArthur Basin;
- Olympic Dam area — exploration drilling along the southern margins of the deposit.

Vanadium

Vanadium is used in metal alloys, principally to strengthen steel.

Resources

During 1997, Australia's EDR of vanadium increased by 136.4 kt owing to the announcement of the proposed commercial development of the Windimurra deposit, located 80 km east of Mount Magnet, Western Australia.

Industry developments

Precious Metals Australia Ltd (PMA) and Glencore International AG announced that they are jointly committed to the fast-track development of the Windimurra Vanadium Project. Glencore will also enter into a marketing agreement for production from Windimurra.

PMA reported that commissioning is planned for the third quarter of 1999. It expects the Windimurra project to become the world's largest low cost vanadium producer with planned annual production of 15.8 million pounds of vanadium pentoxide. This would be approximately 12% of world production.

Zinc, lead, silver

Resources

EDR estimates for zinc (36.3 Mt), lead (17.5 Mt) and silver (41.5 kt) fell in 1997 by 9%, 6% and 4% respectively compared with 1996 as a result of production and reassessment of resources at major mines. Australia's total identified resource stocks of zinc (86.3 Mt) remained steady and those of lead (54.6 Mt) and silver (92 kt) each fell by 1%.

Production

Production is mainly from mines at Cannington, which commenced in October 1997 (Plates 4 and 5), Hilton and Mount Isa in Queensland; McArthur River in the Northern Territory; Broken Hill and Elura in New South Wales; Hellyer and Rosebery in Tasmania; and Scuddles in Western Australia. Australia's gold mines are significant contributors to silver production.

World ranking

Australia has the world's largest EDR of zinc (19%), lead (27%) and silver (15%). As a producer, Australia ranks first in the world for lead, second for zinc and fifth for silver.

Industry developments

Reserves have been delineated at Century, Queensland, and mine development is continuing after resolution of Native Title issues through the Gulf Communities Agreement. Fine ore grinding technology will be used to liberate fine grained deleterious silica for removal during zinc recovery.

At Mount Isa, zinc-lead-silver reserves will be depleted by mid–2000. In 1997, reserves fell by 4.2 Mt compared with 1996 because of production and mine design changes. Measured and indicated resources fell as a result of a mining plan review and removal from the resources inventory of resources that are uneconomic for metallurgical reasons.

Plate 4 Underground drilling of blast holes at the Cannington project, Queensland
Photograph courtesy of BHP Minerals

Plate 5 Then Cannington ICON (Innovative Combination of the North) is a 233 combination used to transport Cannington concentrates to the Yurbi rail loading facility
Photograph courtesy of BHP Minerals

At the nearby Hilton deposit, reserves fell by 4.5 Mt compared with 1996 because of production, geological interpretation and drilling. A review by the company, removed metallurgically unfavourable mineralisation from reserves and resources. Indicated resources were reduced by revised economic parameters applied in peripheral areas of mineralisation and by downgrading of resources to the inferred category.

The future of lead smelting and zinc concentrate production at Mount Isa will depend on the feasibility of the George Fisher zinc-lead-silver deposit (formerly Hilton North). Total resources at George Fisher increased in 1997 by 27 Mt to 108 Mt at a slightly reduced zinc grade as a result of diamond drilling, structural geology reinterpretation, geostatistical resource estimation, cut-off grade changes and better than expected metal recoveries from ore processing. It is expected that a decision to proceed with development at George Fisher will be made in early 1998.

Sulphur dioxide emissions from the Mount Isa smelters will be reduced by 80% when sulphuric acid production begins in two years. The acid is to be used in fertiliser manufacture based on the Duchess phosphate deposits, southeast of Mount Isa. Carbon dioxide emissions will be reduced by 40% principally because of the conversion of the local Mica Creek power station from coal to natural gas near the end of 1997–98.

A company audit of mineable zinc-lead-silver resources at Broken Hill, New South Wales, resulted in the exclusion of 2.4 Mt of high grade, inaccessible remnant mineralisation from reserves. This was partially offset by the addition of 1 Mt of medium grade resources. A further 1.2 Mt of inferred resources and 1.4 Mt of new resources were added through diamond drilling, while mining depleted reserves by 2.5 Mt of ore. The Potosi open-pit mine completed its first full year of operation during which 100,000 t of ore was mined.

Development of the deeper part of the Elura main ore body in New South Wales, continued, and

mining of the Northern ore bodies is to commence. Mining and pillar support failure caused a 1.4 Mt reduction in resources in 1997.

Reserves at Rosebery, Tasmania increased by 12% (0.5 Mt) while overall measured, indicated and inferred resources (including reserves) rose by 24%. Exploration for new resources and the upgrading of resources to reserves status through drilling is continuing. The nearby Hercules mine has been recommissioned.

At the Browns lead-copper-cobalt nickel deposit, Northern Territory, a pre-feasibility study resulted in a resource increase and indicates that the deposit could sustain a 16 year mine life. Successfully completed metallurgical studies involved bacterial oxidation treatment of Browns sulphide concentrate, solvent extraction and electrowinning of copper and cobalt, then chloride leaching of residues to recover lead and silver.

Although mining has ceased at the Cadjebut deposit, Western Australia, ore from the nearby Kapok and Goongewa mines is being treated at the Cadjebut processing plant. Drilling at these deposits and the new Kutarta (Prices Creek) deposit suggests good potential for resource extension. Fifty kilometres away, underground development of the Pillara deposit (formerly Blendevale) and construction of a processing plant commenced in mid-1997. Commissioning of a 1.5 Mtpa ore capacity mining operation at Pillara is expected in mid-1998.

Deep drilling beneath the Scuddles deposit in Western Australia intersected significant zinc and copper mineralisation and further drilling is planned for 1998. Development of the zinc orebody at the nearby Gossan Hill deposit started in late 1997.

Mine closures are due at the Thalanga deposit, Queensland in 1998, and the Hellyer deposit, Tasmania in mid-2000. However, the Thalanga processing plant will continue to process ore from the Reward-Highway deposit 50 km to the east.

The $85 million co-treatment program to transport zinc refinery residues from Risdon, Tasmania to Port Pirie, South Australia for further processing was implemented in late 1997. Ocean dumping of jarosite from Risdon will therefore cease.

Mineral industry performance and outlook

The Minerals Council of Australia's (MCA 1997) annual industry survey showed that production (Plate 6) by respondents rose by 4% in 1996–97, compared with a 6% increase in the previous year. The report also noted that industry profitability declined substantially compared with 1995–96 as a result of the combined impact of costs associated with increased production, lower commodity prices and increased wage and salary expenses.

Australian mine production statistics for various commodities in 1997, provided by ABARE, are reported in Table 1. ABARE (Waring & Hogan 1998) reported that the gross nominal value of mine production in 1996–97 was $35 035 million, an increase of 5% over 1995–96. In real (1997–98 dollars) terms, however, the increase was substantially less at 1.6%. Looking to the future, ABARE forecasts continuing increase in mine production, with output projected to increase by about 18% between 1997–98 and 2002–03 despite the fact that some mines will close.

The nominal value of Australian mineral and energy exports in 1996–97 rose by over 5% to $36 495 million. In real (1997–98 dollars) terms the increase was 1.7%. ABARE's projections for export earnings to 2002–03 show an increase in nominal terms to $44 530 million. In real terms (1997–98 dollars) a small decrease over 1997–98 is projected for 2002–03, with earnings reaching $ 38 575 million compared with the 1997–98 forecast level of $39 239 million.

Details of production and exports of selected mineral commodities for 1996–97 are given in Table 3.

There are many projects currently under construction or consideration (Waring & Hogan 1998). However, the uncertainty caused by low commodity prices and the general world economic climate adds a significant

degree of uncertainty as to which of these will proceed. The Minerals Council of Australia (MCA 1997) note that Access Economics reported that, as at June 1997, projects under construction or committed in the minerals sector had a value of $17 000 million. Further, projects under consideration or possible had a value of $41 000 million.

Plate 6 Nickel roundels at the QNI Resources Pty Ltd's nickel refinery at Yabulu, Queensland
Photograph courtesy QNI Resources Pty Ltd

Table 3 Australian production and exports of selected mineral products 1996-97

Commodity	Production	Exports	Export value $ million
Aluminium			
Bauxite (Mt)	42.990		104
Alumina (Mt)	13.252	11.011	2,604
Aluminium (Mt)	1.395	1.060	2,088
Coal			
Black raw (Mt)	260.98		
Black saleable (Mt)	207.49	146.27	7,960
Brown	60.70		
Copper			
Ores and concentrates (kt)	1,738	890	655
Refined primary (kt)	305	128	352
Diamond (kc)	37,120	36,208	568
Gold			
Mine production (t)	299.23		
Refined (t) [a]	326.48	315.3	4706
Iron & Steel			
Ore & Pellets (Mt)	154.376	137.557	3,155
Iron and steel (Mt) [b]	15.972	3.212	1,384
Lead			
Ores and concentrates (kt)	785	178	55
Refined (kt)	202	177	205
Bullion (kt)	191	164	207
Manganese			
Ores and concentrates (Mt)	2,297	1,797	231
Mineral sands			
Ilmenite concentrates (kt)	2,100	1,147	114
Rutile concentrates (kt)	186	186	136
Synthetic rutile (kt)	544	361	190
Titanium dioxide pigment (kt)	159	130	256
Zircon concentrates (kt)	425	382	230
Nickel			
Concnetrate (kt)	795		
Refined (kt)	73[c]	na	1,072[d]
Uranium (t U_3O_8)	5,995	5,701	245
Zinc			
Ores and concentrates (kt)	1,985	1554	491
Refined (kt)	319	228	353

na = not available; t = tonnes; kt = 10^3t; Mt = 10^6t; kc = 10^3 carats

Source: *Australian Commodity Statistics*, ABARE, December 1997

(a) Includes gold of Australian and overseas origin
(b) Includes 7.545 Mt pig iron and 8.427 Mt raw steel
(c) Sum of products in the <99% Ni and >99% Ni categories
(d) Sum of all nickel product export values

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Geologists logging drill core at the Cannington project, Queensland.
Photograph courtesy of BHP Minerals

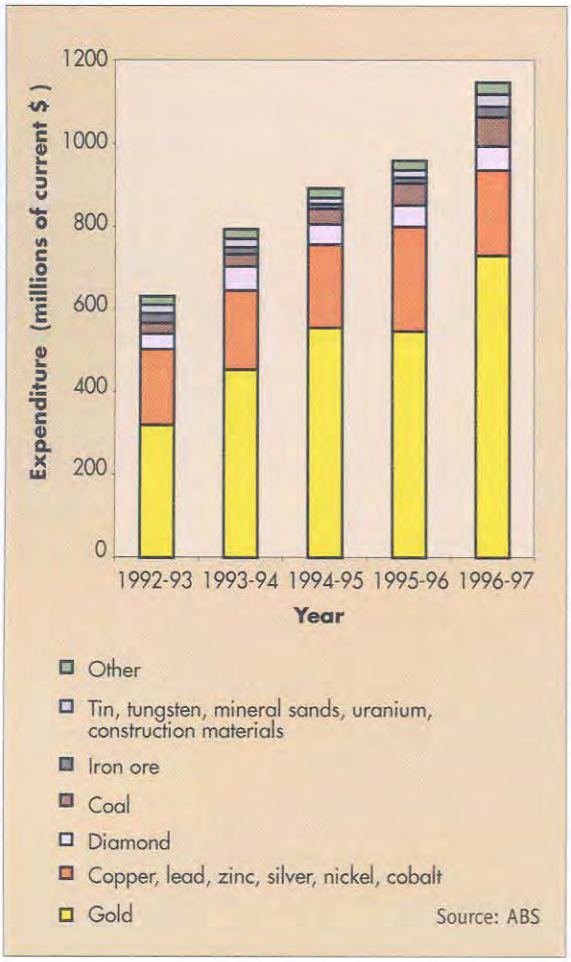
Mineral Exploration in Australia

Exploration expenditure

Mineral exploration expenditure for a range of commodity groups is monitored by ABS on a quarterly basis and the following discussion and statistics are based on survey data for 1996–97. The differentiation of commodity groups before 1980 is based largely on a breakdown of ABS totals by BRS.

Mineral exploration expenditure in Australia in 1996–97 rose by about $188 million or 20%, from $960.2 million in 1996–97 to $1148.5 million (Figure 5). This increase, was in line with the upward trend conspicuous since the low expenditure year of 1991–92. Gold (up by $181 million) was responsible for the bulk of the growth, but increases were also recorded by coal ($18 million), uranium ($13 million), mineral sands ($14 million), iron ore ($12 million) and diamond ($6 million). Expenditure on base metals went against the trend, falling $45 million or 18% and there continued to be little interest in tin or tungsten exploration.

Figure 5 Australian exploration expenditure since 1992–93



Exploration expenditure increased in most States, the exceptions being Queensland (down by $20 million, 11%) and the Northern Territory (down by $5 million, 5%). Western Australia, with 60% of the total, was again responsible for most of the expenditure, followed by Queensland with 14%, New South Wales with 8.2% and the Northern Territory with almost 8%.

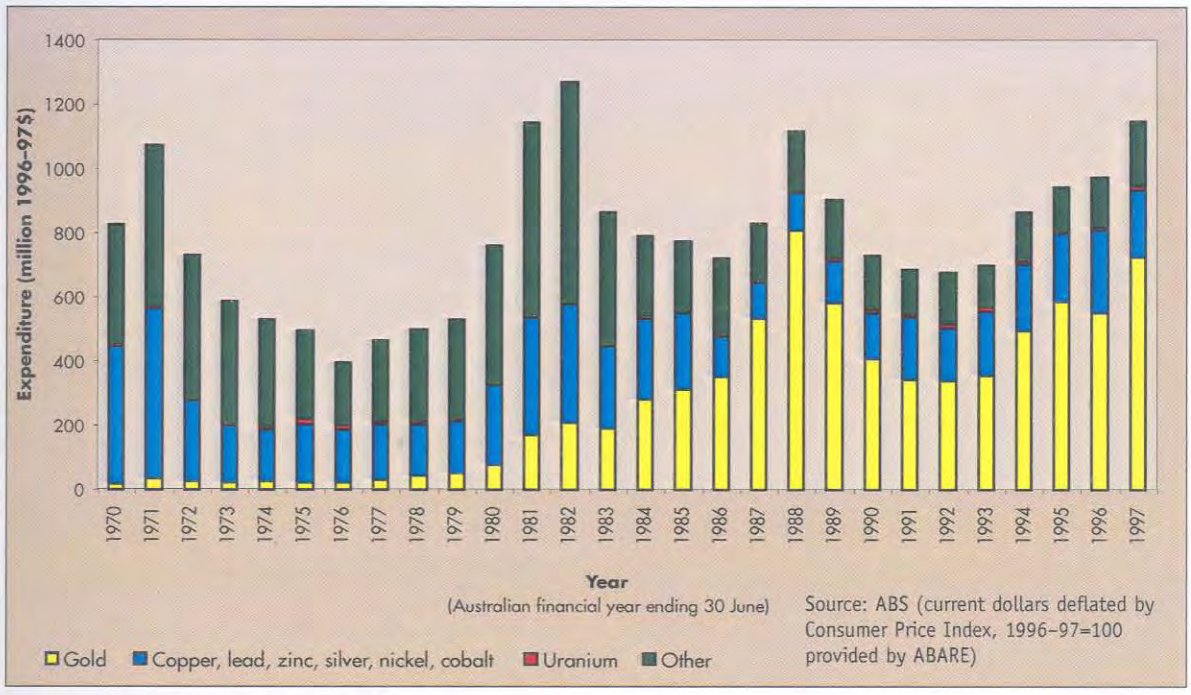
Gold accounted for 63% of total Australian exploration expenditure by commodity group, up from 57% in the previous year. It was followed by a group made up of the base metals (copper-lead-zinc) plus silver, nickel and cobalt (18%), coal (6%), diamond (5%), and mineral sands and uranium accounting for 1% each of the total exploration expenditure.

Expenditure on 'production leases' exploration rose by about $100 million or 47% in 1996–97. Exploration expenditure in 'greenfields' areas (areas outside production leases) increased by $90 million, or about 12%. Overall, about 27% or $306 million was spent on 'production leases' in 1996–97 while 73% or $842 million was spent on 'greenfields' leases.

In constant 1996–97 dollar terms, the rise in exploration expenditure which began in 1992–93 continued unabated through to the present 1996–97 period (Figure 6). Despite the continued growth, the level of expenditure has still not reached the all time high attained in 1981–82.

Exploration expenditure figures published by ABS for the first half of 1997–98 show a 3% increase in overall exploration expenditure, compared with the corresponding period for 1996–97. States, other than Victoria, Queensland and the Northern Territory, recorded modest percentage increases in expenditure over this period. However, the fall in exploration expenditure over the September and December quarters of 1997 is the first occasion a decrease in these two successive periods has occurred for over six years.

Figure 6 Australian exploration expenditure since 1969–70 expressed in 1996–97 dollars



Exploration drilling

In 1997, BRS again commissioned ABS to undertake a survey of exploration and mining companies to ascertain the amount and type of exploration drilling carried out in Australia in 1996–97. The survey was undertaken on behalf of the Conference of Chief Government Geologists to enable a State-by-State comparison to be made of expenditure and metres drilled by type of drilling. A summary of the data was released by ABS on 22 December 1997 (ABS Catalogue No. 8412.0).

Of the $1148.5 million expended on exploration in Australia as a whole in 1996–97, about $481.2 million (42%), was spent on drilling, well up on the 34% of the previous year. A State-by-State breakdown of drilling expenditure is presented in Table 4. The highest and lowest proportions of exploration expenditure directed to drilling within the total recorded expenditure for each State in 1996–97 were 52% in Tasmania and 17% in Victoria (Figure 7).

About 13.4 million metres of exploration drilling was undertaken in 1996–97 (Table 5), of which 34% was in production areas, a similar proportion to that reported last year. Drilling in Western Australia

Table 4 Exploration expenditure and exploration drilling, 1996-97

State	Total exploration expenditure ($ million)	Exploration drilling	
		$ million[a]	'000 Metres[a]
New South Wales	94.1	43.022	782.9
Victoria	51.9	8.829	193.0
Queensland	160.8	65.672	1097.7
South Australia	35.1	9.260	434.9
Western Australia	691.7	322.528	9979.5
Tasmania	26.1	13.473	130.8
Northern Territory	88.9	18.387	741.9
Australia	1148.5	481.171	13360.6

Note: Totals and sums of components may vary because of rounding.
(a) Statistics collected by ABS for Bureau of Resource Sciences, on behalf of the Conference of Chief Government Geologists.

Figure 7 Proportion of Australian exploration expenditure spent on drilling in each State in 1996–97

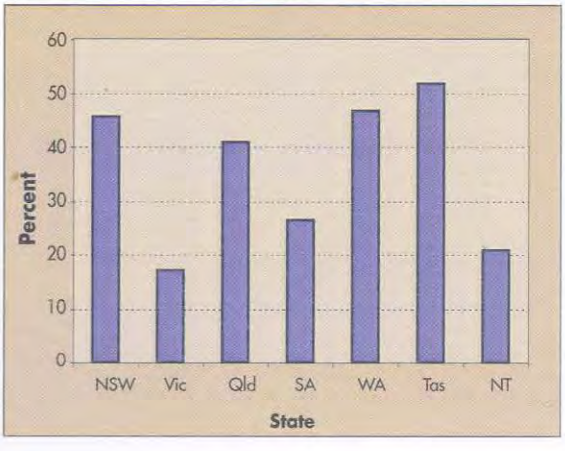
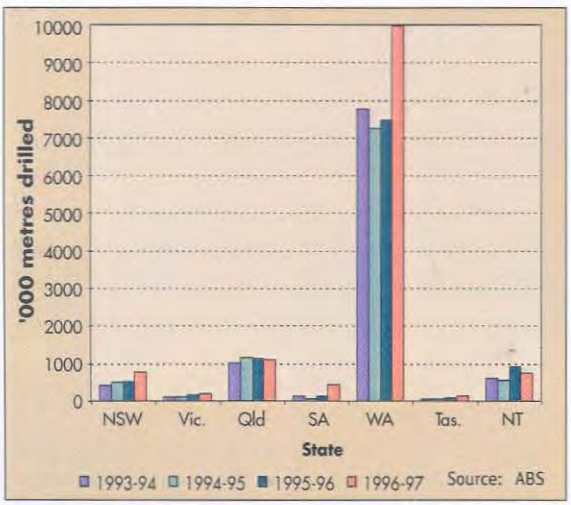


Table 5 Methods of exploration drilling in Australia, by type of area drilled, 1996-97

Drilling Method	Production Areas			Other Areas			Total		
	'000 metres[a]	'000 $[a]	Average $/m	'000 metres[a]	'000 $[a]	Average $/m	'000 metres[a]	'000 $[a]	Average $/m
Diamond	1,025.8	102,997	100.41	575.5	64,462	112.01	1,601.3	167,459	104.58
Reverse Circulation	2,275.9	84,916	37.31	2,886.1	118,616	41.10	5,162.0	203,532	39.43
Percussion	151.6	5,738	37.85	758.5	11,602	15.30	910.2	17,340	19.05
Rotary Air Blast	1,074.7	11,370	10.58	3,538.5	62,862	17.77	4,613.1	74,232	16.09
Others	58.0	1,633	28.16	1,016.0	16,975	16.71	1,074.1	18,608	17.32
Total	4,586.0	206,654	45.06	8,774.6	274,517	31.29	13,360.6	481,171	36.01

(a) Statistics collected by ABS for Bureau of Resource Sciences, on behalf of the Conference of Chief Government Geologists.

Figure 8 Australian exploration metres drilled in each State from 1993–94 to 1996–97



accounted for just under 10 million metres or 75% of total metres drilled (Figure 8). In terms of drilling expenditure, Western Australia was responsible for 67% of the Australian total. South Australia, Tasmania and Victoria were each below 3% in terms of proportion of total metres drilled in stralia and proportion of the total expenditure spent on drilling.

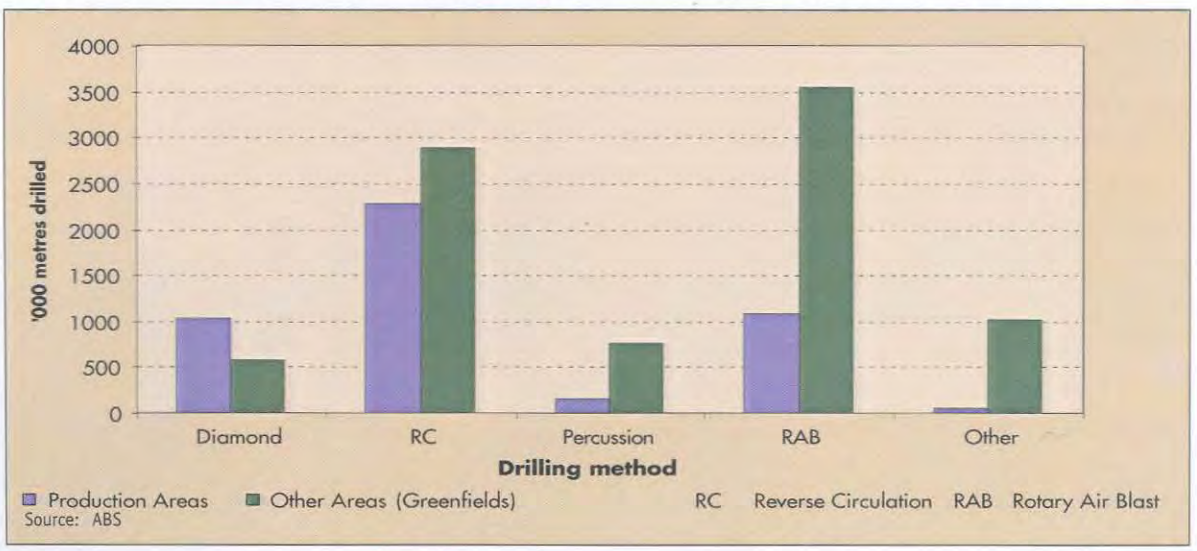
Exploration drilling on greenfield areas was 66% of all exploration metres drilled and involved 8.775 million metres at a cost of $274.5 million. Drilling statistics by method of drilling and type of area are summarised in Table 5 and Figure 9.

Overall expenditure on drilling rose by 46% to $481.2 million in 1996–97, while metres drilled increased by 29% over 1995–96, from 10.388 million metres to 13.361 million metres.

Compared with 1995–96 average RAB drilling costs rose by 38% to $16/m for all areas, while the average cost of diamond drilling ($104.6/m) increased by 2%. Average percussion drilling costs fell to $19/m, while average drilling costs for reverse circulation rose 31% to $39. "Other" drilling (including aircore/vacuum drilling) costs increased by 20% to $17/m over the period.

The 29% increase in total metres drilled in 1996–97 reflected major increases in percussion drilling on production leases and reverse circulation drilling and "other" drilling on greenfields areas (other areas).

Figure 9 Australian exploration drilling by drilling method and by type of exploration area during 1996–97



Offshore mineral exploration in Commonwealth waters

The Commonwealth *Offshore Minerals Act 1994* regulates exploration for and mining of minerals, other than petroleum, over the continental shelf three nautical miles beyond the territorial baseline (generally the low water mark) of the States and territories.

Applications for a mineral exploration licence (MEL) are made to the Designated Authority (usually the relevant State or Territory Minister responsible for mining) with an application fee of $3000. The application must be made in the approved manner and must specify details such as:

- block numbers (each block being approximately 2 km by 2 km and no more than 500 blocks can be applied for with each application);
- amount of money allocated to each part of the program;
- technical qualifications of the applicant and employees; and
- financial resources.

The initial term of a licence is four years and it may be renewed for three, two year periods subject to the satisfactory performance of licence conditions. There is a mandatory reduction of 50% of the licence area on renewal of an MEL. However, it is possible to apply for an extension of term if activities have been significantly interrupted or stopped by circumstances beyond the control of the licence holder.

As at 1 May 1998, a total of 64 offshore MEL applications had been received since February 1990. Twenty one licences have been granted and 11 are active (six offshore Western Australia, four offshore Northern Territory, and one offshore Tasmania) (Table 6). There are also two MEL's pending in Commonwealth waters offshore from Queensland. Nine of the active MELs are in the Joseph Bonaparte Gulf in the northwest of Australia. This exploration is directed at the search for alluvial diamonds in offshore palaeochannels. To date, only Cambridge Gulf Exploration NL has undertaken exploration drilling in Commonwealth waters. In 1993 this company discovered gem quality macrodiamonds in Western Australian waters near WA-1-MEL which is offshore from the Ord River. In 1994 the company discovered more gem quality macrodiamonds offshore from the Berkeley River in Western Australian waters. To date no diamonds have been discovered in Commonwealth waters.

To the end of 1997, over $17 million had been spent on exploration in Commonwealth waters, most of it in the Joseph Bonaparte Gulf. Over 2000 km of reconnaissance and detailed seismic surveys aimed at locating potential diamondiferous palaeochannels have so far been undertaken.

Deposits potentially economic in the short to medium term are likely to be in relatively shallow waters of the continental shelf close to the coast. Commodities forming such deposits include diamond, gold, heavy mineral sands, tin and placer deposits of other commodities. Construction materials (sand and gravel) may also be important near large population centres. Most of the offshore mineral exploration for diamond, heavy mineral sands and tin is based on known distributions of these minerals on adjacent onshore areas.

Offshore accumulations of tin are known to occur in Ringarooma Bay, off Cape Barren Island, Tasmania, and around the Bynoe Harbour area, Northern Territory. In Ringarooma Bay 138 holes were drilled from 1966 to 1968 and an inferred resource of 23 million cubic metres at a grade of 149 g tin metal per cubic metre was identified.

Table 6 Active offshore exploration licences in Commonwealth waters

MEL	Date Granted	Location
WA-1	29-Jul-90	120 km north of Wyndham, WA (Ord Prospect)
WA-4	22-Jun-92	120 km northeast of Wyndham, WA (Victoria Prospect)
WA-7	10-May-94	140 Km north northwest of Wyndham, WA (Berkeley Prospect)
WA-9	18-Aug-94	100 km north of Wyndham, WA
WA-12	22-Nov-94	Nickol Bay near Dampier, WA
WA-13	22-Nov-94	130 km north of Wyndham, WA
NT-1	17-Jan-92	170 km northeast of Wyndham, WA (Victoria Prospect)
NT-2	17-Jan-92	140 km northeast of Wyndham, WA (Victoria Prospect)
NT-3	16-Apr-95	300 km northeast of Wyndham, WA
NT-4	16-Apr-95	200 km northeast of Wyndam, WA
T-2	30-Mar-98	Ringarooma Bay, Tas

Abbreviations and acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
BRS	Bureau of Resource Sciences
CSIRO	Commonwealth Scientific & Industrial Research Organisation
EAR-1	estimated additional resources — category 1
EDR	economic demonstrated resources
GL	gigalitre
Gt	gigatonne
IAEA	International Atomic Energy Agency
ISL	in situ leach
kg	kilogram
km	kilometre
kt	kilotonne
L	Litre
lbs	pounds
m	metre
m^3	cubic metre
Mc	million carats
MEL	mineral exploration licence
mm	millimetre
MREB	Mineral Resources and Energy Branch
Mt	million tonnes
Mtpa	million tonnes per annum
MW	megawatt
na	not available
NSW	New South Wales
NT	Northern Territory
OECD/NEA	Organisation for Economic Cooperation and Development/Nuclear Energy Agency
PGM	platinum group metals
Qld	Queensland
RAB	rotary air blast
RAR	reasonably assured resources
RC	reverse circulation
$	dollar
SA	South Australia
t	tonne
Tas	Tasmania
tpa	tonnes per annum
U	uranium
U_3O_8	uranium oxide
USA	United States of America
USGS	United States Geological Survey
US$	United States of America dollar
Vic	Victoria
WA	Western Australia

The BRS classification system for identified mineral resources

Introduction

Australia's mineral resources are an important component of its wealth, and knowledge of the location, quantity and quality of such resources, is essential for formulating sound policies on their use and conservation. Results of resource assessment can be used also to set priorities for mineral exploration and research to indicate mineral potential where alternative land uses are being considered.

In 1975, the then Bureau of Mineral Resources, Geology and Geophysics (BMR) adopted, with minor changes (BMR 1976), the McKelvey resource classification system used by the US Bureau of Mines and US Geological Survey (USBM/USGS 1976). Subsequently informal guidelines for using the system's definitions were developed and used by BMR for several years, until the whole system and its application were reviewed in the light of accumulated experience. The results of that review were published (BMR 1984) as the refined BMR mineral resource classification system for national resource assessment.

The principles of the McKelvey system were retained, as were most of the definitions used by BMR in its original system, although relatively minor changes were made to some. Guidelines on applying the system were established and adopted. It was decided that the term 'reserves' would not be used for regional or national aggregates of resources, so as to avoid the confusion arising from its use with different meanings in other contexts.

The Bureau of Resource Sciences (BRS) was formed in 1992 by combining the Mineral and Petroleum Resource Assessment Branches of the BMR with the Bureau of Rural Resources. BRS has continued using the modified McKelvey system in preparing its annual national assessments of Australia's identified mineral resources. This has ensured that estimates prepared by BRS are consistent with earlier estimates prepared by BMR, thereby allowing analysis of trends in consistent datasets.

Several editions of an industry code for reporting resources in individual deposits have been published, the most recent being the 1996 edition entitled *Australasian Code for Reporting Identified Mineral Resources and Ore Reserves,* commonly referred to as the JORC code. This was a report of a Joint Committee of the Australasian Institute of Mining and Metallurgy, the Australian Institute of Geoscientists and the Minerals Council of Australia.

The BRS and industry codes are compatible, and data reported for individual deposits under the industry code are used by BRS in the preparation of its assessments of Australia's mineral resources.

Classification principles

BRS classifies known (identified) mineral resources according to two parameters: degree of assurance of occurrence (degree of geological assurance) and degree of economic feasibility of exploitation. The former takes account of information on quantity (tonnage) and chemical composition (grade); the latter takes account of changing economic factors such as commodity prices, operating costs, capital costs, and discount rates.

Resources are classified in accordance with circumstances at the time of classification. Resources which are not available for development at the time of classification because of legal and/or land-use factors are classified without regard to such factors; however, the amount of resource thus affected will, wherever possible, be stated for each classification category.

The classification framework is designed to accommodate all naturally-occurring metals, non-metals, and fossil fuels, and to provide a means of comparing data on different resources which may have a similar end use (e.g. petroleum, coal and uranium as energy sources).

Terminology and definitions

RESOURCE — A concentration of naturally-occurring solid, liquid, or gaseous materials in or on the earth's crust and in such form that its economic extraction is presently or potentially (within a 20-25 year time frame) feasible (see guideline i).

Categories of resources based on degree of assurance of occurrence

IDENTIFIED RESOURCES — Specific bodies of mineral-bearing material whose location, quantity, and quality are known from specific measurements or estimates from geological evidence. Identified resources include economic and subeconomic components. To reflect degrees of geological assurance, identified resources can be subdivided into the following categories:

MEASURED — Resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes, and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling and measurement are spaced so closely, and the geological character is so well defined that size, shape, and mineral content are well established.

INDICATED — Resources for which tonnage and grade are computed from information similar to that used for measured resources, but the sites for inspection, sampling and measurement are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than for resources in the measured category, is high enough to assume continuity between points of observation.

DEMONSTRATED — A collective term for the sum of measured and indicated resources.

INFERRED — Resources for which quantitative estimates are based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geological evidence. This evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geological evidence of their presence. Estimates of inferred resources should be stated separately and not combined in a single total with measured or indicated resources (see guideline ii).

Categories of resources based on economic considerations

ECONOMIC — This term implies that, at the time of determination, profitable extraction or production under defined investment assumptions has been established, analytically demonstrated or assumed with reasonable certainty (see guideline iii).

SUBECONOMIC — This term refers to those resources which do not meet the criteria of economic; subeconomic resources include paramarginal and submarginal categories.

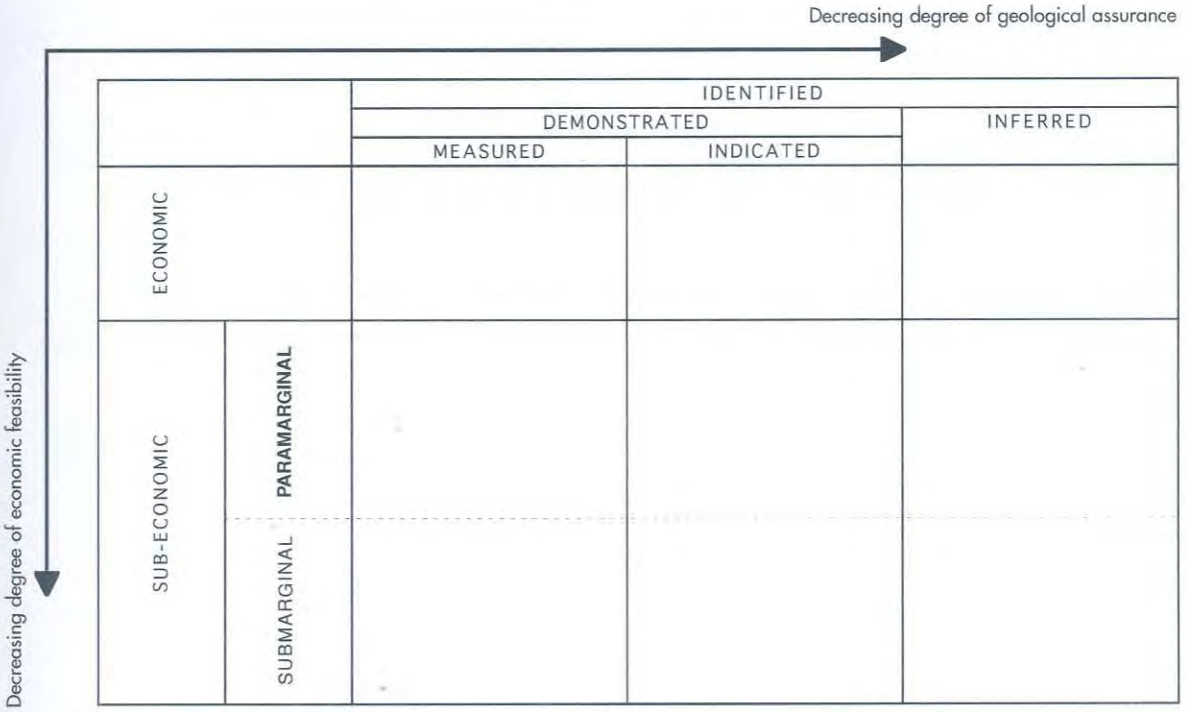
PARAMARGINAL — That part of subeconomic resources which, at the time of determination, almost satisfies the criteria for economic. The main characteristics of this category are economic uncertainty and/or failure (albeit just) to meet the criteria which define economic. Included are resources which would be producible given postulated changes in economic or technical factors.

SUBMARGINAL — That part of subeconomic resources that would require a substantially higher commodity price or some major cost-reducing advance in technology, to render them economic.

BRS guidelines for classifying mineral resources

(i) Use of the term 'resources' is restricted to material the extraction of which is generally judged to be potentially economically viable in an arbitrary time frame of about 20 to 25 years. The term includes, where appropriate, material such as tailings and slags. The definition does not intend to imply that exploitation of any such material will take place in that time span, but only that its possibility might reasonably be considered. This guideline attempts to establish a lower limit to what is worth assessing. It should be applied on a commodity by commodity basis to take account of prevailing

The BRS system for classifying identified mineral resources



and prospective technologies. Material falling outside the category of resource should be referred to as 'occurrences'.

(ii) By definition, inferred resources are classified as such for want of adequate knowledge and therefore it may not be feasible to differentiate between economic and subeconomic inferred resources. Where inferred resources are shown as 'undifferentiated', the amount known or judged to be economic may be indicated. Such judgments must take careful account of the commodity being assessed and its mode of occurrence, as these factors will have a bearing on the reliability of estimates made. Specifically, grade estimates can be more reliably made for concordant sedimentary deposits than for discordant epigenetic deposits (King et al 1982, p.8).

(iii) The definition of 'economic' is based on the important assumption that markets exist for the commodity concerned. All deposits which are judged to be exploitable economically at the time of assessment, whether or not exploitation is commercially practical, are included in the economic resources category. It is also assumed that producers or potential producers will receive the 'going market price' for their production. The classification is therefore based on the concept of what is judged to be economic rather than what is considered to be commercial at any particular time.

The information required to make detailed assessments of economic viability of a particular deposit is commercially sensitive (e.g. a company's costs and required internal rate of return), and these data may not be available to organisations such as BRS. Furthermore, as corporate strategies are likely to be different, individual companies will have different criteria for what is considered to be 'economic'. Thus, to standardise the approach for national or regional resource assessments, the following mineral deposits/situations are accepted by BRS, as a general guide, to be economic:

(a) the resources (published or unpublished) of operating enterprises, whether or not such operations are sustained by long or short term, direct or indirect, government subsidies;

(b) resources in a deposit which is being developed for production (i.e. where there is a corporate commitment to production):

(c) undeveloped resources which are judged to be economic on the basis of a financial analysis using actual, estimated or assumed variables, viz: the tax rate, capital and operating costs, discount rate (such as reflects the long-term bond rate), commodity prices, and depreciation schedules; the values for the economic variables used in an assessment must be realistic for the circumstances prevailing at the time of the assessment;

(d) resources at mines on care-and-maintenance meeting the criteria outlined in (c) above.

(iv) The term 'recoverable' is considered to make allowance for mining as well as processing losses. Where a finer distinction needs to be made, *mineable* is used to take account of mining losses and *metallurgically recoverable (saleable* for coal) is used to take account of processing losses.

(v) Some minerals derive their economic viability from their co-product or by-product relationships with other minerals. Such relationships and assumptions must be clearly explained in footnotes or in accompanying text.

(vi) National aggregates of resource estimates should be rounded to the appropriate last significant digit so as not to create false impressions of accuracy.

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Mineral Resources and Energy Branch Staff

Director	Phone	Email
Ian Lambert	6272 3042	ian.lambert@brs.gov.au
Personal Assistant		
Suzy Obsivac	6272 4391	suzy.obsivac@brs.gov.au

Mineral and Energy Resources and Mining

Bill McKay (Manager) Bauxite	6272 4020	bill.mckay@brs.gov.au
Mike Huleatt Gold, iron ore, tantalum, lithium, oil shale, niobium	6272 3245	mike.huleatt@brs.gov.au
Lloyd David Lead, zinc, silver, gem and semi-precious stones, antimony, arsenic, bismuth, cadmium, selenium, tellurium	6272 4127	lloyd.david@brs.gov.au
Roy Towner Titanium, zirconium, nickel, rare earths, clays, magnesite, fertiliser minerals, cobalt, talc, dolomite, peat, limestone, gypsum, silica, chemical industry minerals and specialty minerals, molybdenum	6272 4369	roy.towner@brs.gov.au

National Mineral & Energy Databases

Brian Elliott (Manager) Mineral databases	6272 4433	brian.elliott@brs.gov.au
Stuart Girvan Tin, platinum-group metals, tungsten, chromium; mineral databases; potential mineral resources	6272 3243	stuart.girvan@brs.gov.au
Neal Evans Computer geologist	6272 5896	neal.evans@brs.gov.au
Maria Fisher Mineral databases	6272 5423	maria.fisher@brs.gov.au

Mineral Resources Potential and Exploration

Yanis Miezitis (Manager) Potential mineral resources	6272 5939	yanis.miezitis@brs.gov.au
Subhash Jaireth Potential mineral resources	6272 5173	subhash.jaireth@brs.gov.au

Don Perkin Exploration analysis, manganese, copper; potential mineral resources	6272 5815	don.perkin@.brs.gov.au
Keith Porritt GIS	6272 3044	keith.porritt@.brs.gov.au
Aden McKay Uranium, vanadium; potential mineral resources	6272 3045	aden.mckay@.brs.gov.au

Energy and Greenhouse

David Rossiter (Manager) Energy and greenhouse gases technical issues	6272 5374	david.rossiter@brs.gov.au
Leyden Deer Commercial buildings energy efficiency	6272 3204	leyden.deer@brs.gov.au
John Pollock Commercial buildings energy efficiency databases	6272 3111	john.pollock@brs.gov.au
Ron Sait Coal, offshore mineral exploration, carbon dioxide capture and disposal	6272 5875	ron.sait@brs.gov.au

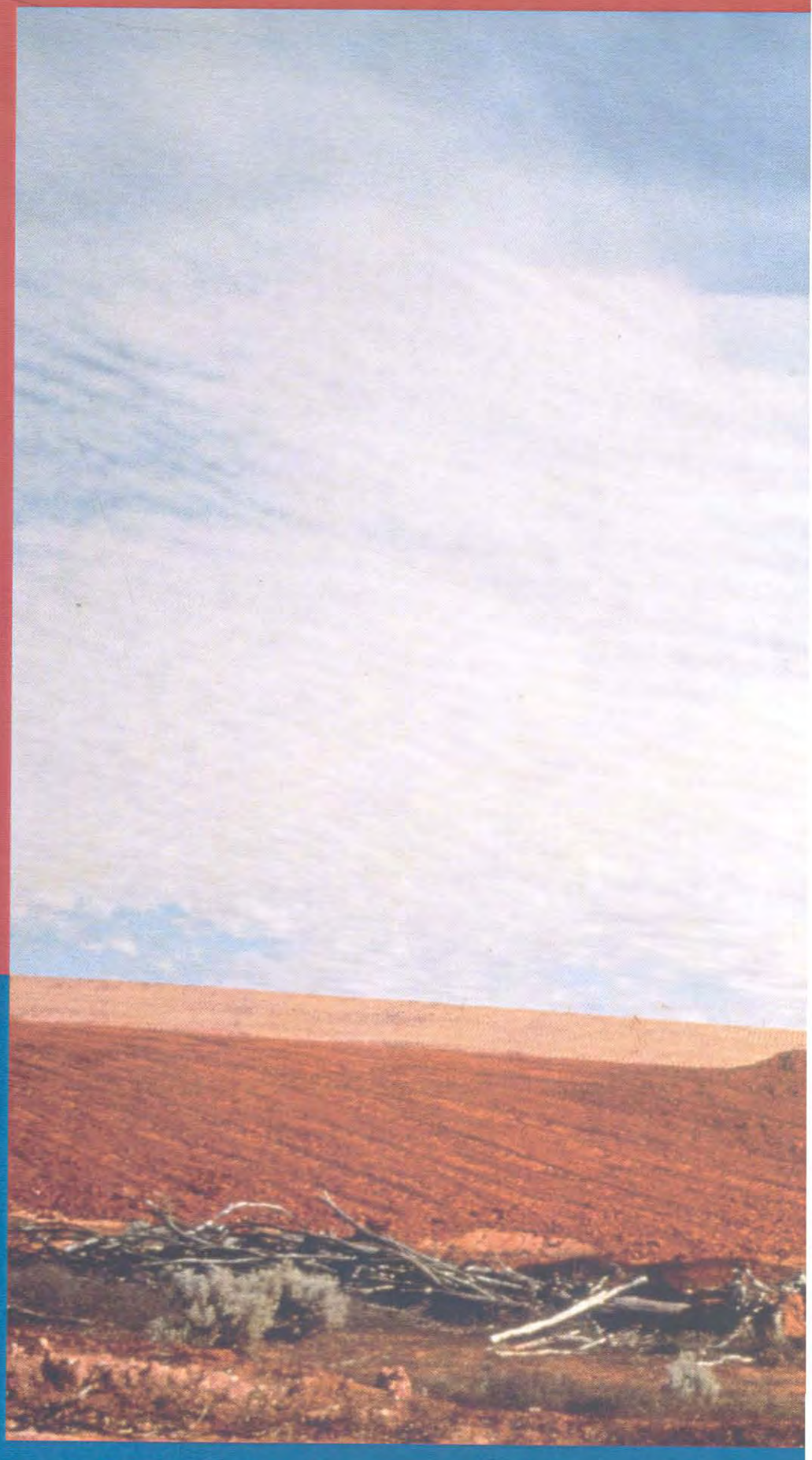
Computing, Geographic Information Systems

Andrew Lucas	6272 5371	andrew.lucas@brs.gov.au
Tim Johns	6271 6428	tim.johns@brs.gov.au
David Kershaw	6272 6622	david.kershaw@brs.gov.au

Facsimile No: (02) 6272 4161

Location:
Postal Address:
Bureau of Resource Sciences
PO Box E11
Department of Primary Industries & Energy
KINGSTON ACT 2604
Core 4, Level 3, Wing 1
Edmund Barton Building
Kings Avenue, Barton, Canberra
ACT 2600 AUSTRALIA

Internet: http://www.brs.gov.au



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