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APPENDICES

APPENDIX 1. GLOSSARY

(modified from Cassidy et al., 1997; Neuendorf et al., 2005).

aeolian–sand sized material picked up, transported, and deposited by wind.

airborne geophysical data–geophysical information (e.g., gravity, gamma-ray spectrometric, and magnetic data) collected by instruments specially fitted to and being transported by an aircraft.

alkaline–said of an igneous rock that contains more sodium and/or potassium than is required to form feldspar with the available silica.

alkaline igneous complex–igneous body consisting of several alkaline rock types (e.g., phonolite, syenite, loparite, nepheline syenite, sövite, alkaline basalt).

alluvial sediments–sediments deposited, usually in stream channels, by flowing water.

aplite–a light-coloured igneous rock characterised by a fine-grained granular texture and consisting predominantly of quartz, potassium feldspar, and sodium-calcium feldspar.

Archean–the term, meaning ancient, has been generally applied to the oldest rocks of the Precambrian (older than 2500 million years).

base metal–generally referring to the elements, copper, lead, zinc and sometimes nickel.

basement–the lowest mappable rocks, generally with complex structure, that underlies other major rock sequences of a region.

breccia–a coarse-grained clastic rock, composed of angular broken rock fragments held together by a mineral cement or in a fine-grained matrix.

Cambrian–see Paleozoic.

carbonaceous–said of a rock or sediment that is rich in carbon or organic matter.

carbonatite–a carbonate rock of apparent magmatic origin, generally associated with kimberlites and alkaline rocks. Carbonatites may be calcitic (sövite) or dolomitic (rauhaugite).

Cenozoic–the era of geological time from 65.5 million years to present; divided into three Periods: Paleogene, Neogene, and Quaternary, which in turn are divided into seven Epochs: Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and Holocene (present). See Figure 5.2 for details of the geological time scale.

concordant–structurally conformable; said of strata displaying parallelism of bedding or structure.

conglomerate–a coarse-grained clastic sedimentary rock, composed of rounded to subangular fragments larger than 2 mm in diameter set in a fine-grained matrix of sand or silt.

craton–a part of the Earth's crust that has attained stability and has been little deformed for a prolonged period, and generally restricted to continents.

discordant–structurally unconformable; said of strata lacking conformity or parallelism of bedding or structure.

dyke–a tabular igneous intrusion that cuts across the bedding or foliation of the country rock.

element–one of a class of substances which consist entirely of atoms of the same atomic number.

exploration–phase in which a company or organisation searches for mineral resources by carrying out geological and geophysical surveys, followed up where appropriate by drilling and other evaluation of the most prospective sites.

felsic–a descriptive term applied to the composition of an igneous rock containing abundant light coloured and few dark coloured minerals.

fenite–a quartzofeldspathic rock that has been altered by alkali metasomatism at the contact of a carbonatite intrusive complex. The process is called fenitisation.

gneiss–a foliated rock formed by regional metamorphism, in which bands or lenticles of granular minerals alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits. Varieties include augen gneiss, granite gneiss, feldspar gneiss, and aplitic gneiss.

granite, granitic–broadly applied, any holocrystalline, quartz–bearing plutonic (intrusive) igneous rock.

greenstone–a field term applied to any compact dark-green altered or metamorphosed mafic igneous rock (e.g., basalt, gabbro, diorite) that owes its colour to the presence of chlorite, amphibole or epidote.

Heavy-Mineral (HM) sands–a concentration of heavy minerals (rutile, zircon, ilmenite, monazite) on a contemporary or ancient beach, or along a coastline.

Holocene–see Cenozoic.

holocrystalline–texture of an igneous rock composed entirely of crystals.

hydrothermal–of or pertaining to hot water, to the action of hot water or to the products of this action, such as a mineral deposit precipitated from a hot aqueous solution, with or without demonstrable association with igneous processes.

hydrothermal deposit–a mineral deposit formed by precipitation of ore and gangue minerals in fractures, faults, breccia openings, or other spaces, by replacement or open-space filling, from fluids generally ranging in temperature from 50 to 700 degrees Celsius and ranging in pressure from less than 4 kilobars.

igneous complex–an assemblage of intimately associated and roughly contemporaneous igneous rocks differing in form or in petrographic type; it may consist of plutonic rocks, volcanic rocks, or both.

igneous rocks–said of a rock or mineral that solidified from molten or partly molten material, i.e., from a magma; also, applied to processes leading to, related to, or resulting from, the formation of such rocks. Igneous rocks constitute one of the three main classes into which rocks are divided, the others being metamorphic and sedimentary.

inlier–an area or group of rocks surrounded by rocks of younger age.

intermediate–said of an igneous rock that is transitional between felsic and mafic, generally having a silica content of 54 to 65%.

JORC Code–The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves, prepared by the Joint Ore Reserves Committee. This is a principal-based code, which sets out recommended minimum standards and guidelines on classification and public reporting. Companies listed on the Australian Securities Exchange are required to report exploration outcomes, resources, and reserves in accordance with the JORC Code standards and guidelines.

lacustrine sediments–sediments that accumulated in a lake-like environment.

laterite–a term for a highly weathered red subsoil or material rich in secondary oxides of iron and/or aluminium. It develops in a tropical or forested warm to temperate climate, and is a residual product of weathering.

LCT–Lithium–Cesium–Tantalum-bearing pegmatite.

lignite–a brownish-black coal that is intermediate in qualification (maturity) between peat and subbituminous coal.

limonite–a general field term for a group of brown, amorphous, naturally occurring hydrous ferric oxides whose real identities are unknown. Common secondary material formed by oxidation (weathering) of iron or iron-bearing minerals.

Ma–million years.

mafic–a descriptive term applied to the composition of an igneous rock containing abundant dark coloured minerals, such as pyroxene and olivine.

magma–naturally occurring mobile 'rock' material, generated within the Earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.

Mesozoic–the era of geological time from the end of the Paleozoic (251 million years) to the beginning of the Cainozoic (65.5 million years). The Mesozoic is divided into the Triassic, Jurassic, and Cretaceous time Periods.

metamorphic grade–the intensity or rank of metamorphism, measured by the amount or degree of difference between the original parent rock and the metamorphic rock. It indicates in a general way the pressure-temperature environment or facies in which the metamorphism took place. For example, conversion of shale to slate or phyllite would be low-grade metamorphism, whereas continued transformation to a garnet-sillimanite schist would be very high-grade metamorphism.

metamorphic rocks–any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shear stress, and chemical environment, generally at depth in the Earth's crust.

metasomatic–pertaining to the process of metasomatism and to its results. The term is especially used in connection with the origin of ore deposits.

metasomatism–the processes by which one mineral is replaced by another of different chemical composition owing to reactions set up by the introduction of material from external sources.

migmatite–a composite rock composed of igneous or igneous–appearing and/or metamorphic materials, which are generally distinguishable megascopically.

Mt–million tonnes.

NYF–Niobium–Yttrium–Fluorine-bearing pegmatite.

Paleozoic–the era of geological time from the end of the Precambrian (542 million years) to the beginning of the Mesozoic (251 million years). The Paleozoic is divided into Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian time Periods.

paludal sediments–sediments that accumulated in a marsh-like environment.

pegmatite–an exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dykes, lenses, or veins, especially at the margins of large granitic igneous bodies. Pegmatites have gross compositions generally similar to that of granite.

(per)alkaline–said of an igneous rock in which the molecular proportion of aluminium oxide is less than that of sodium and potassium oxides combined; a general chemical class of igneous rocks.

PGEs–platinum-group elements comprising the six metallic elements: platinum (Pt), palladium (Pd), rhodium (Rh), iridium (Ir), osmium (Os), and ruthenium (Ru).

phosphorite–a sedimentary rock with a high enough content of phosphate minerals to be of economic interest. Most commonly it is a bedded primary or reworked secondary marine rock composed of carbonate fluorapatite in the form of laminae, nodules, oolites, and shell and skeletal fragments.

placer–a surficial mineral deposit formed by mechanical concentration of mineral particles from weathered debris. The common types are beach placers and alluvial placers. The mineral concentrated is usually a heavy mineral, such as gold, cassiterite, magnetite, zircon, rutile, and monazite.

Pleistocene–see Cenozoic.

Pliocene–see Cenozoic.

Precambrian–all geological time, and its corresponding rocks, before the beginning of the Paleozoic; it is equivalent to about 90% of geological time and includes the Proterozoic and Archean Eons.

Precambrian basement–basement rocks belonging to the Precambrian.

production–the phase at which operations produce mined product.

prospect–a potential accumulation of minerals that is sufficiently well defined to represent a viable drilling target.

Proterozoic–the era of geological time from the end of the Archean (about 2500 million years) to the beginning of the Phanerozoic (542 million years).

pyroclastic–pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also, pertaining to rock texture of explosive origin.

Quaternary–see Cenozoic.

regolith–the unconsolidated material, both weathered in place and transported, which overlies consolidated rocks (bedrock).

resources–a concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form and amount that its economic exploitation is currently or potentially feasible.

rift, rift basins–a long, narrow continental trough that is bounded by normal faults; a graben of regional extent that marks a zone along which the entire thickness of the lithosphere has ruptured under extension.

sedimentary rocks–a rock resulting from the consolidation of loose sediment that has accumulated in layers; e.g., a clastic rock (such as conglomerate or sandstone) consisting of mechanically formed fragments of older rock transported from its source and deposited in water or from air or ice; or a chemical rock (such as rock salt or gypsum) formed by precipitation from solution; or an organic rock (such as certain limestones) consisting of the remains or secretions of plants and animals.

shale–a fine-grained detrital sedimentary rock, formed by the consolidation (especially by compression) of clay, silt, or mud. It is characterised by finely laminated structure, which imparts a fissility approximately parallel to the bedding, along which the rock breaks readily into thin layers and that is commonly most conspicuous on weathered surfaces.

sill–a tabular igneous intrusion that parallels the planar structure of the surrounding rock.

skarn–a general term for silicate gangue (amphibole, pyroxene, garnet, etc.) of certain iron–ore and sulphide deposits, particularly those that have replaced limestone and dolomite, and experienced introduction of large amounts of silicon, aluminium, iron, and magnesium by hydrothermal fluids.

slate–a compact, fine-grained metamorphic rock that possesses slaty cleavage and hence can be split into slabs and thin plates.

strandline–a former shoreline now elevated above the present water level.

supergene–said of a mineral deposit or enrichment formed near the surface, commonly by descending solutions.

tectonic–said of, or pertaining to, the rock structure and external forms resulting from the deformation of the Earth's crust; broad architecture of the outer part of the Earth.

tuff–a general term for all consolidated pyroclastic rocks associated with a volcano.

volcanic–pertaining to the activities, structures, or rock types of a volcano.

volcanic rocks–a generally finely crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface, either ejected explosively or extruded as lava (e.g., basalt, andesite, dacite, rhyolite).

weathered rock–bedrock which has had its composition and appearance changed by weathering.

weathering–the destructive process or group of processes by which earthy and rocky materials on exposure to atmospheric agents at or near the Earth's surface are changed in colour, texture, composition, firmness, or form, with little or no transport of the loosened or altered material; specifically the physical disintegration and chemical decomposition of rock that produce an in situ mantle of waste and prepare sediments for transportation.

APPENDIX 2. ALPHABETICAL LISTING OF CHEMICAL ELEMENTS

Symbol	Element	Atomic Number	Symbol	Element	Atomic Number
Ac	Actinium	89	Md	Mendelevium	101
Al	Aluminum	13	Hg	Mercury	80
Am	Americium	95	Mo	Molybdenum	42
Ar	Argon	18	**Nd**	**Neodymium**	**60**
As	Arsenic	33	Ne	Neon	10
At	Astatine	85	Np	Neptunium	93
Ba	Barium	56	Ni	Nickel	28
Bk	Berkelium	97	Nb	Niobium	41
Be	Beryllium	4	N	Nitrogen	7
Bi	Bismuth	83	No	Nobelium	102
Bh	Bohrium	107	Os	Osmium	76
B	Boron	5	O	Oxygen	8
Br	Bromine	35	Pd	Palladium	46
Cd	Cadmium	48	P	Phosphorus	15
Ca	Calcium	20	Pt	Platinum	78
Cf	Californium	98	Pu	Plutonium	94
C	Carbon	6	Po	Polonium	84
Ce	**Cerium**	**58**	K	Potassium	19
Cs	Cesium	55	**Pr**	**Praseodymium**	**59**
Cl	Chlorine	17	**Pm**	**Promethium**	**61**
Cr	Chromium	24	Pa	Protactinium	91
Co	Cobalt	27	Ra	Radium	88
Cn	Copernicium	112	Rn	Radon	86
Cu	Copper	29	Re	Rhenium	75
Cm	Curium	96	Rh	Rhodium	45
Ds	Darmstadtium	110	Rg	Roentgenium	111
Db	Dubnium	105	Rb	Rubidium	37
Dy	**Dysprosium**	**66**	Ru	Ruthenium	44
Es	Einsteinium	99	Rf	Rutherfordium	104
Er	**Erbium**	**68**	**Sm**	**Samarium**	**62**
Eu	**Europium**	**63**	**Sc**	**Scandium**	**21**
Fm	Fermium	100	Sg	Seaborgium	106
F	Fluorine	9	Se	Selenium	34
Fr	Francium	87	Si	Silicon	14
Gd	**Gadolinium**	**64**	Ag	Silver	47
Ga	Gallium	31	Na	Sodium	11
Ge	Germanium	32	Sr	Strontium	38
Au	Gold	79	S	Sulfur	16
Hf	Hafnium	72	Ta	Tantalum	73
Hs	Hassium	108	Tc	Technetium	43
He	Helium	2	Te	Tellurium	52
Ho	**Holmium**	**67**	**Tb**	**Terbium**	**65**
H	Hydrogen	1	Tl	Thallium	81
In	Indium	49	Th	Thorium	90
I	Iodine	53	**Tm**	**Thulium**	**69**
Ir	Iridium	77	Sn	Tin	50
Fe	Iron	26	Ti	Titanium	22
Kr	Krypton	36	W	Tungsten	74
La	**Lanthanum**	**57**	U	Uranium	92
Lr	Lawrencium	103	V	Vanadium	23
Pb	Lead	82	Xe	Xenon	54
Li	Lithium	3	**Yb**	**Ytterbium**	**70**
Lu	**Lutetium**	**71**	**Y**	**Yttrium**	**39**
Mg	Magnesium	12	Zn	Zinc	30
Mn	Manganese	25	Zr	Zirconium	40
Mt	Meitnerium	109			

Source: modified from http://periodic.lanl.gov/list.shtml. Rare-earth elements are shown in **blue** font.

APPENDIX 3. ESTIMATED MINE PRODUCTION OF RARE-EARTH ELEMENTS BY COUNTRY (TONNES OF REO EQUIVALENT)

Country	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010
Australia	6050	3300	3300	0	0	0	0	0	0	0	0
Brazil	911	396	400	200	1400	200	0	402	730	650	550
China	16 500	21 300	30 600	55 000	65 000	73 000	88 000	95 000	119 000	120 000	130 000
India	2500	2200	2500	2700	2700	2700	2700	2700	2700	2700	2700
Malaysia	1830	427	234	340	350	450	450	250	200	380	350
Republic of South Africa	724	400	400	0	0	0	0	0	0	0	0
USA	22 700	20 700	20 700	20 400	5000	5000	5000	0	0	0	0
Commonwealth of Independent States[1]	8500	8000	6000	6000	2000	2000	2000	2000	NA	NA	NA
Others	409	237	303	130	120	120	120	2200	NA	NA	NA
Total	60 124	56 960	64 437	84 770	76 570	83 470	98 270	102 552	122 630	123 730	134 000

[1] Former members of Soviet Union.

Source of data: United States Geological Survey Mineral Commodity Summaries for 1990 to 2011—Rare Earths (http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/).

Others = Other countries include Congo (Kinshasa), Madagascar, Sri Lanka, Thailand, and Zaire.

NA = Not Available.

APPENDIX 4. COMPOSITIONS[1] OF THE MAJOR RARE-EARTH-ELEMENT DEPOSITS IN THE WORLD

	Mount Weld Australia Monazite[2]	Nolans Bore Australia Apatite	Brockman Australia Bastnäsite	Bayan Obo China Bastnäsite	Guang-dong China Monazite	Guangdong China Ion-adsorption clays	Mountain Pass USA Bastnäsite	Lovozersky Russia Loparite
LREO								
Lanthanum	25.5	19.74	5.8	25	24	30.4	33.2	28
Cerium	46.74	47.53	16.8	50	42.7	1.9	49.1	57.5
Praseodymium	5.32	5.82	0.1	5.1	4.1	6.6	4.3	3.8
Neodymium	18.5	21.20	0.4	16.7	17	24.4	12	8.8
Samarium	2.27	2.37	0.03	1.2	3	5.2	0.8	0.96
HREO								
Europium	0.44	0.40	0	0.2	0.1	0.7	0.12	0.13
Gadolinium	Trace	1.00	0.4	0.7	2	4.8	0.17	0.21
Terbium	0.07	0.08	0.1	Trace	0.7	0.6	Trace	0.07
Dysprosium	0.12	0.33	10.4	Trace	0.8	3.6	Trace	0.09
Holmium	Trace	0.05	0.2	Trace	Trace	Trace	Trace	0.03
Erbium	0.03	0.09	7.7	Trace	0.3	1.8	Trace	0.07
Thulium	Trace	0.01	0.1	Trace	NA	Trace	Trace	Trace
Ytterbium	0.06	0.05	5.0	Trace	2.7	Trace	Trace	0.29
Lutetium	Trace	0.01	0.1	Trace	NA	Trace	Trace	0.05
Yttrium	0.35	1.32	52.4	0.2	2.4	20	2.6	Trace

Source of data: modified from Hastings Rare Metals Limited (2011: http://www.hastingsraremetals.com/userfiles/file/Hastings%20Investors%20Presentation.pdf), the United States Geological Survey, Arafura Resources Limited (http://www.arafuraresources.com.au/nol_reo_dist.html), and company reports.

[1] Percentage of total rare-earth oxides.

[2] Dominant mineralogy/style of deposit.

NA = Not Available.

APPENDIX 5. RESOURCE CLASSIFICATIONS AND DEFINITIONS

Mineral resource classification

Estimated resources of minerals and elements (e.g., the REE) are geologically-based and their classification is largely based on the McKelvey resource classification system.

The McKelvey resource classification system classifies known (identified) resources according to the certainty or degree of (geological) assurance of occurrence and the degree of economic feasibility of exploitation either now or in the future. The first takes account of information on the size and quality of the resource, whereas the economic feasibility considers the changing economic factors such as commodity prices, operating costs, capital costs, and discount rates.

The assessments of **Identified Resources**—resources for which the location, quantity, and quality are known from specific measurements or estimates from geological evidence—are based on and compiled from resource data reported for individual mineral deposits by companies. The Australian Securities Exchange mandates standards for the public reporting of mineral resources by Australian-listed companies. Listed exploration and mining companies must follow the Joint Ore Reserves Committee (JORC) Code. This is a principal-based code which sets out recommended minimum standards and guidelines on classification and public reporting in Australasia. Companies listed on the Australian Securities Exchange are required to report exploration outcomes, resources, and reserves in accordance with the JORC Code standards and guidelines.

Data from company reports on specific projects are aggregated into categories in the national classification scheme to provide estimates of the national resource base.

In the national system used by Geoscience Australia, **Demonstrated Resources** are resources that can be recovered from an identified resource and whose existence and quality have been established with a high degree of geological certainty, based on drilling, analysis, and other geological data and projections.

Economic Demonstrated Resources (EDR) are resources with the highest levels of geological and economic certainty. For petroleum these include remaining proved plus probable commercial reserves. For minerals, these include JORC Code proved and probable ore reserves and measured and indicated mineral resources. For these categories, profitable extraction or production has been established, analytically demonstrated or assumed with reasonable certainty using defined investment assumptions.

Sub-Economic Demonstrated Resources (SDR) are resources for which, at the time of determination, profitable extraction or production under defined investment assumptions has not been established, analytically demonstrated, or cannot be assumed with reasonable certainty (this includes contingent petroleum resources).

Inferred Resources (INF) are those with a lower level of confidence that have been inferred from more limited geological evidence and assumed but not

DECREASING GEOLOGICAL ASSURANCE →				
DECREASING ECONOMIC FEASIBILITY ↓	**Identified resources**			**Undiscovered resources**
	Demonstrated resources		***Inferred resources***	
	Economic Demonstrated Resources	JORC mineral reserves	JORC inferred mineral resources Possible petroleum resources	Quantitative mineral potential assessments Undiscovered petroleum resource assessments
		Proved petroleum reserves		
		Proved and probable petroleum reserves		
		JORC measured and indicated mineral resources		
	Subeconomic Resources	Subeconomic mineral resources	Contingent possible resources	
		Contingent proved and probable petroleum resources		

Figure Appendix 5.1. Australia's national energy resources classification scheme (based on the McKelvery resource classification scheme). See text for explanation of terms.
Source: Geoscience Australia.

verified. Where probabilistic methods are used there should be at least a 10% probability that recovered quantities will equal or exceed the sum of proved, probable and possible reserves.

Undiscovered or potential resources are unspecified resources that may exist based on certain geological assumptions and models, and be discovered through future exploration. Undiscovered resource assessments have inbuilt uncertainties, and are dynamic and change as knowledge improves and uncertainties are resolved.

Uranium resources (including REE in some deposits) at the national level are commonly reported under the Nuclear Energy Agency/International Atomic Energy Agency (IAEA) uranium resources classification system. Economic Demonstrated Resources correlate with **Reasonably Assured Resources** recoverable at <US$80/kg U, and Inferred Resources are the same in both systems.

APPENDIX 6. AUSTRALIAN PRODUCTION (TONNES) OF MONAZITE, 1980 TO 1995

Year	New South Wales	Queensland	Western Australia	Total
1980	261	457	12 357	13 075
1981	639	-	12 643	13 282
1982	198	-	9364	9562
1983	36	14	14 629	14 679
1984	668	-	15 592	16 260
1985	980	-	17 755	18 735
1986	75	-	14 747	14 822
1987	688	189	11 250	12 127
1988 (e)	<500	<200	11 000	<12 000
1989 (e)	0	<500	11 000	<11 000
1990 (e)	NA	0	7900	7900
1991 (e)	NA	0	6700	6700
1992 (e)	0	0	5600	5600
1993 (e)	0	0	6500	6500
1994 (e)	0	0	2300	2300
1995 (e)	0	0	200	200
Approximate total	<4045	<1360	159 537	<164 942

Source of data: Cassidy et al. (1997).
(e) – estimated annual production.
NA = Not Available.

APPENDIX 7. EXPLORATION HISTORY OF RARE-EARTH ELEMENTS IN AUSTRALIA

The following description (see summary in Section 1.6) of REE exploration in Australia is largely from Barrie (1965), Cassidy et al. (1997), Miezitis (2010), various REE reviews relating to Western Australia (Fetherston et al., 1997; Fetherston and Abeysinghe, 2000; Fetherston, 2002, 2008), Queensland (Cooper 1990), the Northern Territory (Eupene Exploration Enterprises Proprietary Limited, 1989; Hussey, 2003), and from mining company websites. This section is not a complete compilation of REE exploration activities in Australia, but it describes the major discoveries and events. For further details on these occurrences, and the most recent developments in the REE industry, it is recommended that the interactive online databases (e.g., DIGS, MINEDEX, STRIKE, TIGER) managed by the various State/Territory geological surveys are interrogated (http://www.geoscience.gov.au/), and such information can also be found in annual National mining compilations, such as the 2011/12 Register of Australian Mining (http://www.riu.com.au/Register/AustralianMining/).

The names of those deposits described in this appendix, or their general locations, are indicated in bold font for quick reference.

Exploration history

Pre-1950:

Precambrian[6] albite-rich pegmatites and veins in the Pilbara Craton of Western Australia have attracted considerable exploration interest since tin was first mined in the Pilbara in 1889. The Mount Cassiterite vein deposit was considered the most important deposit since it represented the largest underground tin mine in Western Australia. Other commodities, such as REE, tantalum, beryllium, niobium, together with non-metallic industrial minerals (mica, feldspar) have been produced from pegmatites, associated hydrothermal veins, and secondary alluvial/eluvial deposits (Sweetapple, 2000). The REE-bearing minerals manganotantalite, manganocolumbite, microlite, fergusonite, tanteuxenite, 'calciosamarskyite', and 'tapiolite' occur at **Cooglegong, Wodgina, Moolyella, and Mount Francisco**. Barrie (1965) reported that a pegmatite deposit at Cooglegong Crossing, ~55 km south-southwest of Marble Bar, was worked in 1913 and 1920 and yielded about 2 tonnes of gadolinite (yttrium iron beryllium silicate: $(Ce,La,Nd,Y)_2FeBe_2Si_2O_{10}$). An analysis of the Cooglegong gadolinite yielded 45.78% of Y_2O_3 and 4.81% of other REO (note that gadolinite does not contain more than trace amounts of gadolinium). Associated REE minerals in the concentrates include allanite, yttrotantalite, monazite, 'tantalopolycrase', and tanteuxenite (Barrie, 1965). Some of the concentrate samples contained more than 70% of REE minerals. Tantalite-bearing dykes in the Wodgina area, ~95 km south of Port Hedland, contain thorogummite, 'makintoshite', and manganotantalite (Barrie, 1965). Quantities of REE as rare-earth silicates, and complex Nb-Ta-bearing species, have been identified in alluvial deposits from Cooglegong, and the Shaw River–Pinga Creek tin fields.

Minerals documented from the **Shaw River** Tinfield (see references in Sweetapple, 2000) include:
Major minerals: cassiterite (SnO_2); columbite–tantalite mineral series $[(Fe,Mn)(Ta,Nb)_2O_6]$; yttrotantalite $[(Y,U,Fe)(Ta > Nb)O_4]$; tanteuxenite $[(Y,REE > U,Th)(Ta > Nb,Ti)_2O_6]$; monazite $[(Ce,La,Y,Th)(PO_4,SiO_4)]$; microlite $[(Na,Ca)_{2-m}(Ta+Nb > 2Ti)_2O_6(F,OH,O)_{1-n} \cdot pH_2O]$; xenotime ($YPO_4$, includes HREE); and zircon ($ZrSiO_4$).
Minor minerals: gadolinite $(Be_2Fe(Ce,Y,Nd,La)_2Si_2O_{10})$; thorite $[Th(SiO_4)]$; euxenite $[(Y,REE > U,Th)(Nb > Ta,Ti)_2O_6]$; fergusonite $[(REE,Fe)(Nb,Ta,Ti)O_4]$; cheralite $[(Ce,Ca,Th,U)(P,Si)O_4]$; samarskite $[(Y,Fe,U,REE)(Nb,Ta)O_4]$; and wodginite (probably $MnSnTa_2O_8$).

Minerals documented in the **Pinga Creek** Tinfield (including Abydos and Woodstock: see references in Sweetapple, 2000) include:
Major minerals: cassiterite (SnO_2); gadolinite $(Be_2Fe(Ce,Y,Nd,La)_2Si_2O_{10})$; 'tantaliferous polycrase' (probably tanteuxenite $[(Y,REE > U,Th)(Ta > Nb,Ti)_2O_6]$; and allanite $[(Ce,Ca,Y)(AI,Fe)_3(SiO_4)_3(OH)]$.
Minor minerals: monazite $[(Ce,La,Y,Th)(PO_4,SiO_4)]$; and manganocolumbite (ideally $MnNb_2O_6$).

Other REE occurrences in Western Australia (Barrie, 1965) found during exploration for mainly tin and uranium include: gadolinite near **Bullock Well**, ~130 km south-southeast of Port Hedland; yttrotantalite in tin-bearing gravels at **Eleys Well** on Split Rock station, ~40 km southwest of Marble Bar, and also with calciosamarskyite and cassiterite at **Hillside station**, ~70 km south-southwest of Marble Bar; and tanteuxenite in tin concentrate at **Francisco Well**,

[6] The geological timescale is shown in Figure 5.2, and the technical terms are explained in the Glossary (Appendix 1).

~150 km south of Port Hedland, and also with allanite in pegmatite on the western side of the **Yule River**, ~90 km southwest of Marble Bar; xenotime grains up to 5 mm in diameter from **Nullagine**, ~90 km southeast of Marble Bar; monazite in tin placers near Moolyella; euxenite from **Mount Dale**, ~45 km southeast of Perth; detrital thorogummite coated with hydrothorite at **Saunders Creek** in the East Kimberleys; and gadolinite from **Payne's Find**, ~140 km southeast of Yalgoo.

Proterozoic sedimentary units ~150 km southeast of Halls Creek in the Proterozoic Birrindudu Basin near the Western Australian–Northern Territory border have been explored for REE, uranium, and gold. Canadian Energy Resources (CER) discovered uranium mineralisation in the 1980s at the **Mount Mansbridge** prospect (http://www.qur.com.au/gardnerrange/). A significant uranium geochemical anomaly (up to 980 ppm U in pits) with a 300 m strike length was found from the testing of an airborne geophysical target. The only REE assayed by CER was yttrium. Follow-up sampling by Quantum Resources Limited (http://www.qur.com.au/CompanyAnnoucements/) indicated that the uranium had associated REE abundances of up to 7%, with the mineralisation described as a xenotime-rich alteration zone. Uraniferous xenotime and xenotime-rich in HREE have been discovered in several localities in the region. The uranium-REE mineralisation appears to be associated with the unconformity between the Paleoproterozoic Killi Killi Formation and the overlying Mesoproterozoic Gardner Sandstone. Orion Metals Limited has described HREE mineralisation in unconformity and basement rocks at the nearby **Killi Killi Hills** prospects (http://www.orionmetals.com.au/documents/MarchHK2011.pdf). These prospects were tested for uranium in 1969. No systematic analysis for the REE was conducted because of the focus for uranium. Two radiometric anomalies 1 km apart were tested in 1969, and results confirmed significant levels of HREE, including dysprosium, ytterbium, and erbium. Maximum yttrium and uranium abundances of 2.06% and 326 ppm, respectively, were recorded, and the average yttrium value for 45 samples was 1327 ppm. Anomalous strontium is also associated with the REE-uranium mineralisation. REE-bearing minerals xenotime and florencite of possible hydrothermal origin have been reported. Mineralisation is not hosted in veins, but it occurs pervasively throughout the conglomerate and sandstone units (http://www.mining-reporter.com/index.php/component/content/article/811-metallica-minerals/5146-high-grade-heavy-rare-earth-element-hree-uranium-and-gold-discovery).

Pegmatites in the Mount Isa–Cloncurry region of Queensland have been a source of REE-bearing monazite, mica, beryl, feldspar, tourmaline, tin, tantalite, and bismuth-bearing minerals (Cooper, 1990). Brooks and Shipway (1960) indicated that the **Mica Creek** pegmatites, ~20 km southwest of Mount Isa, crop out over 15 km along the eastern margin of the Sybella Granite. These pegmatites were discovered in 1914, with intermittent mining of mica and beryl occurring from 1922 to 1927 and after 1943. Monazite concentrations were found in four locations in the pegmatites, with Th contents ranging from 5.73 to 7.1%, but no REE abundances were reported. Barrie (1965) described REE occurrences associated with felsic dykes in the Mount Isa–Cloncurry region, including allanite at **Spear Creek**, **Elaine Dorothy**, **Hidden Valley**, and davidite [$(La,Ce,Ca)(Y,U)(Ti,Fe^{3+})_{20}O_{38}$]-like minerals at **Cameron River–Ballara**, **Six Kangaroos**, and 'absite' (thorium brannerite) at **west Cloncurry** and **Ballara**.

Several minor occurrences of REE associated with monazite have been documented from Tasmania. Monazite was reported in tin-tungsten-bismuth mines in the **Moina** district and with wolframite in the **Mount Bischoff** tin deposit of Tasmania. Monazite was also found with alluvial tin deposits north of **Zeehan** and on **King Island**. The only commercial production (~30 t of concentrates) of monazite from Tasmania was in 1943 from the **Endurance** alluvial tin mine near South Mount Cameron in the northeast of the state (Barrie, 1965).

1950 to 1980:

Australia exported large quantities of monazite from heavy-mineral sands mined in **Western Australia, New South Wales, and Queensland**, for the extraction of both REE and thorium. Much of the historical production in eastern Australia has been derived from North Stradbroke Island and the beaches from Southport south to the New South Wales border. The monazite content of the heavy-mineral fraction of the Queensland and New South Wales deposits ranges up to 2% (Barrie, 1965). Between 1952 and 1995, Australia exported 265 000 tonnes of monazite with an export value (in 2008 dollars) of $284 million (Australian Bureau of Statistics, 2009). However, since production ceased in 1995 it is believed no significant quantities of REE or thorium associated with the mineral sands have been imported or exported by Australia. Details of exploration activities related to monazite by-products of heavy-mineral sand mining in Australia can be found in Barrie (1965), Cooper (1990), Williams (1990), Towner et al. (1996), Cassidy et al. (1997), Mason et al. (1998), and Miezitis (2010).

In the 1950s, Zircon Rutile Limited at **Byron Bay**, New South Wales, processed a small quantity of monazite to produce Ce oxide for use in glass polishing.

Many deposits containing REE were discovered as a result of uranium prospecting in the Mount Isa–Cloncurry region of northwest Queensland. The presence of REO in the Proterozoic **Mary Kathleen** uranium deposit was recognised soon after its discovery in 1954 (Hawkins, 1975). Prospectors found boulders of radioactive rock in a creek draining from a hill on which the deposit occurs, and then tracked them back to their source. The Rio Tinto Group carried out regional and detailed geological mapping, radiometric prospecting, diamond drilling, and costeaning (Matheson and Searl, 1956). Mary Kathleen is a major hard-rock occurrence of uranium-REE in Queensland. Mining was carried out from 1956 to 1963, and from 1975 to 1982. The major occurrences of uranium-REE mineralisation in the Mary Kathleen orebody, the Rita-Rary and Elaine prospects are steeply dipping uraniferous lenses in garnet skarns. Mary Kathleen originally contained around 10 000 tonnes of uranium oxide at a grade of 1.2 kg/t and 200 000 tonnes of mixed REO. The ratio of REO to uranium is about 20:1 (Cooper, 1990). Some 9.5 million tonnes of ore with 4.5% rare earths were mined, processed, and retained in the tailings dam. The REE are hosted by allanite (orthite) and stillwellite (lanthanum boro-silicate), which are the main uranium-bearing components of the orebody. Local concentrations of REE also occur in fluorapatite and sulphides. Yttrium occurs within the garnet lattice and is largely unrecoverable. Allanite comprised about 35% of the ore at outcrop. The REE are broadly distributed with the uranium mineralisation, but the relationship between them is not clear. Isolated areas of non-uraniferous allanite are present in remobilised zones. Ceric and lanthanum oxides constitute approximately 85% of the REE. Hawkins (1975) noted that the TREO concentrations are: scandium oxide (0.006%), yttrium oxide (0.3%), lanthanum oxide (33.5%), ceric oxide (51.5%), praseodymium oxide (4.0%), neodymium oxide (9.1%), samarium oxide (1.1%), europium oxide (0.05%), gadolinium oxide (<0.06%), terbium oxide (<0.02%), dysprosium oxide (0.05%), holmium oxide (<0.02%), erbium oxide (0.06%), thulium oxide (<0.02%), ytterbium oxide (0.01%), and lutetium oxide (<0.01%). The LREE subgroup constitutes about 99% of the TREO content.

Several REE-bearing minerals, including 'absite', allanite, betafite, brannerite, davidite, euxenite, fergusonite, florencite, monazite, orthite, polycrase, samarskite, thorite, xenotime, and yttrocrastite have been documented in pegmatites, in fissure-fillings within granitic rocks, and in hematitic breccias in the Olary and Mount Painter districts of the Curnamona Province of South Australia (Cassidy et al., 1997). These minerals were found throughout the state during uranium and base-metal exploration, but no primary commercial production of the REE took place. The REE-bearing minerals are generally associated with uranium minerals, occurring in uraniferous titanium-rich minerals at **Radium Hill, Crockers Well,** and **Mount Victoria** (Barrie, 1965). Davidite is an important component of lodes in high-grade metamorphic rocks at Radium Hill, whereas the major uranium and REE mineral in the Crockers Well deposits is 'absite'. Samarskite and monazite are associated with hematite and brown feldspar in quartz veins at **Mount Painter**, monazite in rutile-bearing pegmatite veins near **Myponga**, and davidite-type minerals have been recorded at **Houghton**, near Adelaide (Barrie, 1965).

Davidite concentrates produced from the uranium tailings of the **Radium Hill** uranium mine were treated between 1954 and 1961 at Port Pirie. The tailings contained an estimated 1500 tonnes of REO comprising the oxides: scandium (3%); yttrium (16%); lanthanum (38%); cerium (24%); praseodymium (0.7%); neodymium (1.8%); samarium (0.2%); europium (0.07%); gadolinium (0.4%); terbium (0.5%); dysprosium (3.3%); holmium (0.7%); erbium (3.8%); thulium (0.7%); ytterbium (6.5%); and lutetium (0.6%). About 136 kg of high-purity scandium was produced as a by-product of the uranium mining at Radium Hill (Towner et al., 1987). In 1969, the Rare Earth Corporation of Australia Limited, operating at Port Pirie in South Australia, began producing Ce, La, Y, and Th compounds from locally produced monazite. However, the plant ceased operations in mid-1972 because of a lack of working capital and the difficulty of breaking into world markets for processed REE.

The first significant exploration of the **Brockman** multi-element prospect, 18 km southeast of Halls Creek in the Halls Creek Orogen of Western Australia, was carried out by Rio Tinto in 1954 when they detected anomalous radiation in the area during regional radiometric surveys. In the 1960s, the Geological Survey of Western Australia conducted regional geological mapping of the region as part of the Gordon Downs 1:250 000 Geological Sheet. In 1973, Trend Exploration Proprietary Limited recorded high levels of niobium in stream-sediment samples during follow up of radiometric anomalies originally identified in regional surveys by the Bureau of Mineral Resources. Several sources of niobium mineralisation with anomalous yttrium, fluorine, zirconium, tantalum, and zinc values were associated with Paleoproterozoic alkaline volcanic rocks. In 1983–84, Union Oil Development Corporation completed detailed geological mapping, reconnaissance stream sediment, and soil and rock-chip geochemistry. Maximum REO abundances in rock chips were 2820 ppm Y_2O_3, 830 ppm La_2O_3, and 1040 ppm Ce_2O_3. Nineteen trenches across the mineralised formation, called the 'Niobium Tuff', returned grades of up to 0.45% Nb and 0.23% Ta. In 1985, the Union Oil Development Corporation commissioned mineralogical studies at the CSIRO which identified the fine-grained nature of the monazite-dominated mineralisation, with an average grain size of less than 10 microns. Major REE minerals include bastnäsite, calcian-bastnäsite, parisite, and synchysite (see Table 1.2). Drilling programs by West Coast Holdings in the mid-1980s confirmed the findings of earlier trench sampling with the target commodities confined to the 'Niobium Tuff'. In mid-2004, Brockman Minerals Proprietary Limited released a measured, indicated, and inferred resource totalling 50 million tonnes grading 0.09% REO, 1.04% ZrO_2, 0.44% Nb_2O_5, and 0.027% Ta_2O_5 (Aztec Resources, 2003). Metallurgical test work involving heavy liquid mineral separation commenced in late 2005. Initial development plans for the Brockman multi-element deposit involved the production of high purity oxides of zirconium, hafnium, yttrium, niobium, tantalum, aluminium, selected REO, beryllium, scandium, and gallium metal. In December 2010, Augustus Minerals Limited released a JORC-compliant resource for the Brockman (alternate name Hastings deposit) REE deposit as over 22 million tonnes (0.79% ZrO_2, 0.31% Nb_2O_5, 0.023% Ta_2O_5, and 0.10% Y_2O_3) comprising 8.83 million tonnes in the Indicated category and 13.25 million tonnes in the Inferred category. The REE (except Y) were not included in this resource, but the relative abundances of individual REE in the Brockman deposit are shown in Appendix 4. Historically, the exploitation of this resource was hindered by the fine-grained (<20 um), hydrous nature of the ore minerals, which requires a specialised chemical leaching process to achieve high degrees of recovery of rare metals (Ramsden et al., 1993; Taylor et al., 1995a,b). The Brockman deposit is described in detail in Section 3.3.1.

The nickeliferous laterites associated with ultramafic-mafic complexes in the **Greenvale** area of northern Queensland were discovered in 1957 during the regional mapping programs carried out by the Bureau of Mineral Resources and the Queensland Geological Survey (Fletcher and Couper, 1975). Limited sampling of the upper ferruginous zone of the Greenvale laterite defined nickel concentrations of over 1%. In 1966, Metals Exploration NL located a nickel-enriched silicate zone beneath the ferruginous cap with nickel concentrations in excess of 3%. Metals Exploration NL with Freeport Minerals Company undertook drilling programs and by 1969 a rsource of 40 million tonnes of ore averaging 1.57% Ni and 0.12% Co had been established. The two companies decided to proceed in December 1971 with a mining operation that would produce 25 000 tonnes of nickel and 1000 t of cobalt annually (Fletcher and Couper, 1975). The scandium credits of the laterites in the Greenvale region are currently being assessed by Metallica Minerals Limited (http://www.metallicaminerals.com.au/). Ni-Co-Sc resources have been determined at the Lucknow (comprising Red Fort, Grant's Gully, and Lady Agnes), Kokomo, and Greenvale (comprising Power Line, Powder Magazine, Moonscape, Area 15, Edge, and Edge South) deposits that are associated with the Boiler Gully and Gray Creek ultramafic complexes.

One of the most significant REE deposits in Australia is **Mount Weld**, 35 km south-southeast of Laverton in the Yilgarn Craton of Western Australia. This polymetallic deposit is associated with a Paleoproterozoic carbonatite pipe-like body that has REE grades ranging from 4 to 13.8%. It is one of the richest REE deposits in the world and one of the few commercial viable operations outside China. The deposit has been subjected to a number of operational changes since it was first drilled in the late 1960s. The mining operational phase is currently being managed by Lynas Corporation Limited, with the first ore planned for processing in the concentration plant in 2011. The Mount Weld deposit features on the cover of this publication. The presence of a prominent circular magnetic anomaly high (see Inset of Fig. 5.5) was highlighted from a regional aeromagnetic survey carried out by the Bureau of Mineral Resources in 1966. Interpretation of aeromagnetic data by Utah Development Company and modelling of gravity data collected by Union Oil Development Corporation indicated a vertical cylindrical body comprising a high-density core 3 to 4 km in diameter, surrounded by a 0.5 km-wide annulus of lower density rock. The presence of carbonatite was confirmed in 1967 by core drilling by the Utah Development Company (Duncan and Willett, 1990). The carbonatite pipe has no surface expression due to Quaternary alluvium cover. Drilling programs by Union Oil Development Corporation from 1981 to

1984 outlined polymetallic REE, niobium, tantalum, zirconium, and phosphorous mineralisation in the regolith above the carbonatite. A number of feasibility studies from 1980 to 2002 have investigated the potential of phosphate-rich mineralisation derived from apatite concentrations as a source for fertilizer. Lynas Corporation Limited undertook further REE resource assessments from October 2001 when it obtained 100% acquisition of the Mount Weld project from Anaconda Industries Limited. Feasibility studies completed in 2005 showed that the open-cut mine had 2.8 million tonnes of proved and probable reserves at 15.5% REO ore during the first 14 years of mine life. Inclusion of low-grade ores and further metallurgical tests will result in a mine life in excess of 20 years. Lynas Corporation Limited announced in December 2006 that a proposed $220 million plant to carry out final separation and product enhancement would be built at Gebeng on the east coast of Malaysia (Fetherston, 2008). In late 2007, mining operations had commenced and plans were in place to build a concentration plant at Mount Weld. By March 2008, over 2.0 Mm^3 of overburden had been removed from the open-pit, and 0.32 Mm^3 of ore had been mined, graded, and stockpiled. The mining initially focused on a central high-grade secondary monazite zone. In September 2010, Lynas Corporation Limited announced that the Central lanthanide deposit had a Measured, Indicated, and Inferred Resource of 9.88 million tonnes with total lanthanide rare-earth oxides (TLnREO) at 10.6% and 990 ppm Y_2O_3 (HREO), and the Duncan HREE deposit had a Measured, Indicated, and Inferred Resource totalling 7.62 Mt @ 4.5% TLnREO and 2570 ppm Y_2O_3. Forge Resources in March 2011 acquired the niobium-tantalum (Crown) and phosphate (Swan) resources from Lynas Corporation Limited. Further descriptions of the Mount Weld REE deposit are provided in Section 3.3.1.

Other prominent magnetic anomalies similar to the anomaly at Mount Weld have been explored for REE deposits in the eastern Yilgarn Craton. Preliminary geophysical modelling by Southern Geoscience Consultants (unpublished SGC Report 2148, 25-01-2010) suggests that the **Mount Barrett** magnetic anomaly, ~150 km northeast of Laverton, may be prospective for Mount Weld-style REE mineralisation. 3D inversion modelling of the undrilled Mount Barrett anomaly indicates a ~1.5 km-wide body with the depth to the top of the body ranging from 300 to 500 m (Carew and Craven, 2010).

Geophysical comparisons to Mount Weld have also been made for the coeval **Ponton Creek** (previously called Cundeelee) carbonatite plug near Cundeelee Mission, 180 km east-northeast of Kalgoorlie, Western Australia (Lewis, 1990). Exploration commenced in the Cundeelee Mission region in the 1970s targeting sandstone-hosted uranium mineralisation. In 1986, a hole drilled by Union Oil intersected serpentinised pyroxenite at 557 m. In 1994, aerial and ground magnetic and radiometric surveys undertaken by Herald Resources Limited outlined a strong radiometric anomaly in addition to several magnetic anomalies. Surface sampling and small pits dug over the radiometric anomaly in 1995 produced strongly anomalous results up to 23% REO (Cassidy et al., 1997). Galaxy Resources Limited reported in 2011 (http://www.galaxyresources.com.au/projects_ponton.shtml) that Herald Resources completed an air-core drilling program with the best drill intersections being: 16 m @ 14.48% REO (all lanthanide elements plus Y), and 28 m @ 10.50% REO, including 8 m @ 13.12% REO. Further drilling identified a 10 km-wide central core of alkaline ultramafic cumulates (mostly olivine pyroxenite). In contrast to the Mount Weld Carbonatite, there is no development of a paleo-regolith profile due to the scouring of the complex by Permian glaciation (Lewis, 1990).

Exploration in the Kimberley region of Western Australia has also defined several carbonatite bodies with associated REE mineralisation. The **Cummins Range Carbonatite** is a sub-vertical, zoned stock, located near the junction of the Halls Creek and King Leopold orogens (Andrew, 1990). CRA Exploration Proprietary Limited (CRAE) discovered the carbonatite complex in 1978 when they ground tested a 4900 nT (nT: nanotesla is a unit of magnetic field) aeromagnetic anomaly that extended over ~1.8 km. The carbonatite is also associated with a radiometric anomaly (Dentith et al., 1994). Uranium enrichment in the regolith is believed to be the source of this anomaly. Subsequent ground magnetics revealed internal curvilinear patterns which were to be confirmed by drilling to be concentric lithological zones within a roughly circular carbonatite complex. The carbonatite is deeply weathered and covered by a thin layer of aeolian soil. A central core of carbonatite is enclosed by carbonated, mica-rich pyroxenite, passing outwards into an outer zone of unaltered pyroxenite that constitutes about 60% of the intrusion. Coarse magnetite and exfoliating flakes of mica were found at surface, and a few small isolated outcrops of silicified breccia occurred near the centre of the intrusive. High cerium concentrations were recorded in a drill hole near the margin of the body, and the exploration program changed from the initial focus of kimberlites and diamonds to regolith-hosted

REE. From 1978 to 1984, CRAE explored the area drilling 3240 m of auger, rotary air blast, air core, and percussion drilling in 187 holes in addition to 804 m of diamond drilling in two holes. The widely spaced shallow drilling program confirmed the deposit consisted primarily of apatite and monazite, and it had a resource of 3 to 4 million tonnes grading 2 to 4% REO (Fetherston, 2008). Between 2002 and 2006, Navigator Resources Limited carried out surveying and reviewed all historical data. Navigator Resources in 2007 completed 464 m of air-core drilling in 21 holes and 9293 m of RC drilling in 93 holes within the central carbonatite zone. In September 2009, the company reported an Inferred Resource of 4.17 Mt @ 1.72% TREO, 11.0% P_2O_5, 187 ppm U_3O_8, and 41 ppm Th at a cut-off grade of 1% TREO. Economically important abundances of Nb, Ta, Zr, and Ti have also been reported. The deposit is similar to that at Mount Weld with an indicative mix of predominantly LREE from CeO_2 (47.5%), La_2O_3 (27.6%), Nd_2O_3 (16.2%), Pr_6O_{11} (5.0%), Sm_2O_3 (1.7%), to Gd_2O_3 (1.0%) (Navigator Resources, 2007). Figure 3.32 shows a schematic section of the mineralised regolith profile and significant drill-hole intersections at Cummins Range (http://www.navigatorresources.com.au/files/files/742_Investor_Mining_2010_Brisbane _PPR_v1.pdf).

The **Yungul** carbonatite dykes in the East Kimberley of Western Australia are massive calcite carbonatites that host very coarse, pegmatitic veins and pods of calcite (Gwalani et al., 2010). The dykes have carbonatised and fenitised the ~1790 Ma Hart Dolerite country rocks. The Yungul carbonatites are spatially associated with epithermal fluorite deposits that contain resources of 6.7 Mt @ 24.6% CaF_2. In contrast to other calcite-dominant carbonatites, the TREE contents of the Yungul carbonatite are low (174.0–492.8 ppm; La/Yb 2.28–10.74: Gwalani et al., 2010).

The **Mordor** Complex (Langworthy and Black, 1978; Barnes et al., 2008) in the eastern Arunta Region of the Northern Territory is a composite plug-like alkaline-ultramafic body that has been explored for REE, PGEs, Ni, Cu, Cr, diamonds, vermiculite-phlogopite, and uranium. The alkaline felsic rocks and discordant carbonate-rich dykes have been a focus for REE exploration over several decades. Barnes et al. (2008) reported maximum REE concentrations in alkaline syenite and apatite pyroxenite of 175.2 ppm La, 374.3 ppm Ce, 48.2 ppm Pr, 188.7 ppm Nd, 36.0 ppm Sm, and 25.5 ppm Gd. Stratabound PGE mineralisation (8 m @ 0.67 ppm Pt+Pd+Au) hosted by cyclic sequences of ultramafic rocks (Barnes et al., 2008), and base-precious mineralisation (1 m @ 1.4% Cu, 0.3% Ni, 0.4 ppm Pt+Pd, and 0.1 ppm Au) at the Braveheart ironstone on the southeast margin of the intrusion highlight the polymetallic character of the complex.

Other minor carbonatite bodies (Table 3.14) throughout the Precambrian Australian Shield have created various levels of exploration interest (Jaques, 2008). However, for most of these occurrences the carbonatite complexes are generally small in size, and TREE abundances are low or have not been reported. Such examples include the 1821 Ma Copperhead alkaline intrusion (Halls Creek Orogen, WA), **Walloway** suite of Jurassic dykes and plugs (Gawler Craton, SA), 732 Ma **Mud Tank Carbonatite** (Arunta Region, NT), and carbonatite veins from the **Granny Smith** and **Wallaby** gold mines (Yilgarn Craton, WA).

1980 to 1990:

In the 1980s, Lachlan Resources NL explored for PGE mineralisation in the **Gilgai intrusion**, 20 km west-southwest of Nyngan in central New South Wales. The Gilgai intrusion is one of several 'Alaskan'-type mafic-ultramafic bodies which intrude Cambrian-Ordovician metasedimentary rocks of the Girilambone Group. The intrusion is covered by up to 50 m of Cenozoic alluvial material. Airborne and ground magnetic surveys were used to delineate the poorly exposed intrusion and rotary-air blast (134 holes) and diamond (2 holes) drilling defined a range of 'alkaline' rock types including monzonite, hornblendite, pyroxenite, olivine pyroxenite, dunite, and peridotite. Jervois Mining Limited obtained the sample pulps from a drilling program undertaken for nickel in 1999–2001 and showed that there was significant enrichment of scandium in the laterite above the Gilgai intrusion. Jervois Mining Limited is currently targeting the scandium resources at the Nyngan Gilgai laterite deposit that was previously explored by Platsearch NL. The laterite zone is locally up to 40-m thick, layered, and comprises hematitic clay at the surface, followed downwards by limonitic clay, saprolitic clay, weathered bedrock, and finally fresh mafic-ultramafic rocks. Scandium is concentrated in the hematitic, limonitic, and saprolitic zones, with values attaining 350 ppm. Further drilling (69 holes) in 2006 determined a JORC-compliant resource (as of 2nd of August 2010), using a 100 ppm Sc cut-off, consisting of a: Measured Resource of 2.718 Mt @ 274 ppm Sc; Indicated Resource of 9.294 Mt @ 258 ppm Sc; and a Total Resource of 12.012 Mt @ 261 ppm Sc (http://www.resourceinvestor.com/News/2010/2/Pages/EMC-Metals-will-develop-Rare-Earth-Scandium-Deposit.aspx).

In similar geological settings to the Gilgai intrusion, high grades of scandium have been found in a number of 'Alaskan'-type mafic-ultramafic bodies in the Nyngan–Fifield district. It was reported (Financial Review, 31st July 1998) that Uranium Australia found scandium grades ranging from 19.8 g/t to 370 g/t in the **Syerston** nickel-cobalt laterite project near Fifield. The project contains 76.8 Mt @ 0.73% Ni and 0.13% Co, with significant PGE credits. The laterite is developed over the Tout intrusion, an ultramafic-mafic complex comprising a serpentinised dunite core surrounded by pyroxenite, gabbro, and diorite. The laterite profile is best developed over the dunite core, where it averages 35 m in thickness. Laterite overlying the pyroxenite is thinner and has elevated cobalt, but relatively low nickel grades. Platina Resources Limited in late 2010 reported that the surficial laterite above the **Owendale intrusion**, 10 km north of Fifield, contains elevated cobalt, nickel, copper, and scandium. Best drill intersection in the laterite was 9 m @ 0.3% Co, 0.3% Ni, and 514 g/t Sc (http://new.platinaresources.com.au/projects/fifield/).

Four nickel-cobalt laterite deposits extending over a strike length of 30 km have been explored by Jervois Mining Limited at **Thuddungra**, about 25 km northwest of Young, New South Wales. Regionally the host serpentinite rocks extend from at least Grenfell in the north to Tumut in the south, a distance of ~150 km. Airborne and ground magnetics and local serpentinite outcrops led to the discovery of the laterites virtually concealed by alluvium. Since the underlying serpentinite source rocks are strongly magnetic, the exploration procedure was to locate the magnetic anomalies and pattern drill them. A combined resource for the deposits amounts to 168 Mt @ 0.72% Ni and 0.07% Co, with additional significant scandium credits (~40 g/t in representative mineralised bulk samples). The source of the Ni-Co-Sc mineralisation is the Cambrian Wambidgee Serpentinite. The serpentinites (harzburgite protoliths) have intruded the Jindalee Beds as north-trending elongated bodies associated with faulting. In the Young–Cootamundra area, the ultramafic rocks are flanked on the eastern side by the Silurian Young Granodiorite. This felsic body is interpreted to have played an important role in the formation of the mineralised laterites. Water run-off in the region is from east to west (away from the Great Dividing Range) and the acid-rich ground water chemically leached the mafic components of the serpentinites, removing silica, magnesium, and other soluble elements, and leaving a laterite enriched in iron, aluminium, nickel, cobalt, and scandium. The mineralised laterites formed from the weathering of the serpentinite during the Cenozoic. The laterite profile is zoned downwards from hematitic (pisolitic) clay at the surface, to limonitic clay, saprolite (smectitic clay), with weathered serpentinite at the base. Scandium is enriched in the upper parts of the profile, cobalt in the middle, and nickel in the weathered serpentinite and saprolite zones. (http://www.jervoismining.com.au/index.cfm?siteaction=tenement&tenementid=1 and http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/316838/Nickel.pdf).

Exploration activities have defined nickel, cobalt, and scandium resources in laterites at **Lake Innes**, near Port Macquarie, New South Wales (Douglas McKenna and Partners Proprietary Limited, 2003). Serpentinite complexes occur in a Permian fault zone in Silurian–Devonian country rocks. Locally, over the serpentinite complexes, laterites containing weathered serpentinite, saprolite, limonitic clay, and hematitic clay, range in thickness from 10 m to 30 m. Scandium is enriched in the upper part of the lateritic profile, whereas cobalt and nickel are found in the middle and lower parts of the profile. The deposits contain 15.7 million tonnes of Ni at 1.46% Ni, 0.09% Co, and 41 ppm scandium (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0016/238201/RareEarth.pdf).

Between 1986 and 1988, twelve REE prospects were evaluated by reconnaissance drilling at **Yangibana**, 280 km east-northeast of Carnarvon, in the Gascoyne Complex of Western Australia (Fetherston, 2008). REE were associated with anomalous base-metal concentrations in a tightly folded ironstone-dyke sequence. The dykes crop out over an area of 500 km^2 and were later explored in the early 1990s by Grenfell Resources NL. The Yangibana prospect has a recorded resource of 3.5 Mt @ 1.7% REO. The REE are in coarse-grained monazite containing up to 20% Nd_2O_5 and 1600 ppm Eu_2O_3. Artemis Resources Limited reported in its December 2009 quarterly report that it had acquired the Yangibana REE prospect.

In January 1987, it was announced that the French chemical company Rhone-Poulenc would build a two-stage monazite processing plant at **Pinjarra** in Western Australia to produce REE from monazite, but the project was suspended. Deckhand Proprietary Limited, a wholly owned subsidiary of Currumbin Minerals, was blocked in 1988 on environmental grounds from establishing a REE processing plant at **Lismore**, New South Wales. SX Holdings Limited of South Australia was planning to establish a plant at **Port Pirie** to process monazite with a 2000 tonnes per annum cracking and separation plant but the project did not proceed.

The **John Galt** and adjacent **Corkwood Yard** REE deposits are located near the western end of the Osmond Range, about 120 km north-northeast of

Halls Creek in the East Kimberley. REE mineralisation at John Galt consists of disseminations of xenotime in lithic quartz sandstone of the Proterozoic Red Rock Formation. Inferred resources at the Corkwood Yard deposit, which is an alluvial occurrence, are 0.359 Mt @ 0.001% REO (Ceplecha, 1988). Limited exploration activities have occurred at these deposits since these resource estimates.

A review of REE in the Northern Territory by Eupene Exploration Enterprises Proprietary Limited in 1989 provides an insight into the search for REE prior to the discovery of the Nolans Bore REE-P-U-Th deposit in 1995. The company reported that no significant occurrences or deposits of REE (and Y) were identified in the Northern Territory. Elevated levels of REE were recorded in six geological provinces, namely the **Pine Creek Orogen, Davenport Province, Southern McArthur Basin–Murphy Inlier, Arunta Region, Birrindudu Basin**, and the **Musgrave Block**.

1990 to present:

The **Nolans Bore** REE-P-U-Th deposit in the Reynolds Range of the Arunta Region, Northern Territory, is one of Australia's most important and advanced REE developments. Mineralisation at Nolans Bore was discovered in 1995 when PNC Exploration (Australia) Proprietary Limited followed up an airborne radiometric anomaly as part of a uranium exploration program (Thevissen, 1995). A literature review in 1999 of exploration results in the area highlighted the polymetallic potential of the prospect. Surface sampling by Arafura Resources Limited indicated high REE abundances (averaging about 7% TREE) were associated with massive fluorapatite, which occurs as veins and forms 53–93% of the rock (Hussey, 2003). A ground radiometric response coincided with the apatite that cropped out sporadically over an area of ~800 by 1700 m. Drilling in 2001 outlined an Inferred Resource of REE-bearing fluorapatite mineralisation of 3.8 million tonnes at a grade of 3.8% acid-soluble REE within 100 m of the surface. Arafura Resources Limited is conducting a definitive feasibility study on the Nolans Bore project and, in July 2010, reported that it is on track to commence production in 2013.

The development of the Nolans Bore REE-P-U-Th deposit in the Northern Territory has stimulated recent exploration interest in the REE prospectivity of the central Australia region. Uranium explorers found numerous pegmatite, breccia, vein, and alteration-hosted REE occurrences in the **Harts Range** and **Plenty River** mica fields and over large areas near Arltunga. Hussey (2003) describes the different styles of REE mineralisation and the potential of the Arunta Region to host major REE deposits. Some of the more important REE occurrences he describes include: **Blueys Folley, Origin Hill,** and **Entia** pegmatite group (pegmatite-related); **Mount Finniss** (leucosome or metasomatic pod); **Hosteins** and **Mary River** (hydrothermal veins); and **Quartz Hill** (metasomatic). Most of the several hundred occurrences of REE compiled by Hussey (2003) for the eastern Arunta Region appear to be small and uneconomic, however, only a few of them have been fully evaluated.

Capital Mining Limited have undertaken geological mapping, surface sampling, ground radiometric surveying, bulk sampling, and metallurgical analysis at the **Narraburra** REE deposit near Temora in central New South Wales. In 2006, RC drill testing of a deeply weathered granitic intrusive with relatively high Zr, Hf, Nb, Th, and REE in a 1500 m by 800 m zone generated interest. Follow up air-core drilling in 2008 closed off the main mineralised zone. An Inferred JORC compliant oxide resource of 55 Mt @ 1500 g/t Zr, Y, Nb, Th, Li, and REO, containing 55 000 tonnes zirconium oxide and 16 000 tonnes REO has been estimated as of 18 January 2011 (http://www.capitalmining.com.au/narraburra.html; http://www.capitalmining.com.au/Announcements/CMY_145_Notice_18Jan2011.pdf).

Resampling of historical drill core by Alligator Energy Limited (AGE) defined a REE-bearing alteration halo peripheral to the uranium mineralisation at the **Caramel** uranium prospect, 20 km south of the Nabarlek uranium deposit in the Pine Creek Orogen, Northern Territory. The uranium potential of the region was initially highlighted by regional rock geochemical programs undertaken by Uranerz in the mid-1980s. Best drill-hole intersections reported by AGE were 4 m @ 5094 ppm TREE and 5 m @ 7351 ppm TREE, including 2 m @ 1.16% TREE. The mineralisation is dominated by the LREE La, Ce, and Nd. In 1987, Uranerz also defined TREE abundances of 2.48%, 3.27%, 2.08%, and 1.59% from 2 km east of the Two Rocks prospect. Mineralisation is dominantly La, Ce, Nd, and Pr, with lesser Y, Gd, and Sm (http://www.asx.com.au/asxpdf/20110309/pdf/41xb5z56bnxm3k.pdf).

Crossland Uranium Mines Limited has obtained anomalous REE concentrations in a stream sediment and drilling program at their **Charley Creek** Project near Mount Chapple in the Arunta Region, Northern Territory. Stream-sediment concentrates from the Cattle Creek prospect consisted of 3 samples >32% TREO (maximum value of 38.4% TREO); 12 samples >16% TREO; 25 samples >8% TREO, 45 samples >4% TREO, and 74 samples exceeded 2% TREO. Re-assaying of unweathered bedrock in drill core returned a 5 m intersection of 1.03% TREO and 0.103% Y_2O_3, with the HREO representing 8.3% of the TREO (http://www.crosslanduranium.com.au/LinkClick.aspx?fileticket=AemQBpNli3I%3d&tabid=3280&mid=5687).

The Territory Uranium Company (TUC) has recently identified fluorite- and sulphide-bearing shales enriched in REE at the **Quantum** uranium-REE prospect south of the Rum Jungle uranium field in the Pine Creek Orogen of the Northern Territory (http://www.territoryuranium.com.au/images/stories/PDFs/tuc_asx_110321_qtm%20second%20phase%20results.pdf). The following description of this uranium-REE prospect is mostly from Bamborough (2011). Interest in the area was initiated in early 2010, when a review of historical company data and an interpretation of open-file aeromagnetic and radiometric data by TUC identified several potential exploration targets. The prospective stratigraphy of the region comprises the Paleoproterozoic Finniss River Group and older Proterozoic sedimentary rocks of the Mount Partridge Group. Both groups are known to host unconformity-related vein-type uranium ± gold mineralisation. Historic mines in the area have produced 19.7 tonnes of U_3O_8. The mineralisation is associated with gossanous outcrops and faults within folded sedimentary rocks. Gamma-ray spectrometer examination of historic drill core in the Northern Territory Geological Survey core library by TUC led to the identification of several zones of uranium mineralisation. Geochemical analysis of the core returned an intersection of 0.5 m @ 4224 ppm U_3O_8. Zinc-bismuth mineralisation was also identified, with an intersection of 3.4 m @ 4.84% Zn, including 0.9 m @ 15.6% Zn and 1.4 m @ 0.07% Bi. The historic drilling confirmed the presence of fertile rocks under 40 to 120 m of Cambrian basinal sedimentary rocks. The first hole of a drill program in September 2010 tested a weak, 4.5 km-long, airborne radiometric anomaly near the historic mineralised hole and intersected 50 m of quartz/fluorite veining and sulphide mineralisation in a black carbonaceous shale unit, correlated with the Gerowie Tuff. The co-existence of fluorite, pegmatite vein systems, low-level radioactive anomalies, and unusual sulphide mineral assemblages refocused the exploration programs towards REE. A high-grade zone of 9.2 m @ 3.78% TREO was intersected within a 21.9 m-wide zone assaying 2.55% TREO. Average proportions of 11% neodymium, 4%, praseodymium, and 0.2% dysprosium plus europium, collectively totalled about 15%. The REE-bearing mineral allanite, hosts the secondary REE-bearing minerals bastnäsite and synchysite, which occur within veins and fissures, or as rims to allanite crystals in a hydrothermal vein and alteration system. These minerals have been documented in other well-known REE deposits, such as Mountain Pass, USA, and Hoidas Lake, Canada. Gold, uranium, zinc, silver, and bismuth are also associated with the REE highlighting the potential of the Quantum region for polymetallic hydrothermal mineralisation. Mineralogical studies suggest a granitic association for the mineralising fluids with gravity gradient data under the Daly Basin indicating a possible deep-seated ?Archean granite beneath the Quantum prospect. (http://www.territoryuranium.com.au/images/stories/PDFs/quarterly%20report%20tuc%20dec%202010_final.pdf).

In late 2009, TUC also discovered the **Energy** prospect, ~70 km south of the Quantum uranium-REE prospect, Northern Territory. A significant zone of yttrium mineralisation was found to be associated with uranium and minor REE in a shallow dipping weathered sandstone unit. A best intersection of 7 m @ 1% Y + TREO (72% Y) was reported for this sandstone-hosted uranium-REE occurrence (http://www.territoryuranium.com.au/images/stories/PDFs/quarterly%20report%20tuc%20dec%202010_final.pdf).

The Northern Territory Geological Survey discovered in 2006 a group of dykes hosting anomalous REE in the **Hale River** region in the southeastern corner of the Northern Territory. The Hale River area is underlain by the Casey Inlier, which is composed of Proterozoic mafic and felsic gneiss, and deformed ultramafic and mafic rocks. A rock sampling program (~174 samples) by Kidman Resources identified 8 zones of REE mineralisation, with 16 samples exceeding 0.32% TREE + Y_2O_3, and the maximum value attaining 1.66% REE + Y_2O_3. Secondary copper mineralisation (up to 27% Cu) occurs in 1 to 3 m-wide carbonate-rich veins at the Arthur Popes prospect (http://www.kidmanresources.com.au/hale_river.html).

Xenotime (REE-Y-bearing phosphate mineral) was first identified in the western Brown Range Dome in the Northern Territory in the1980s by the Japanese nuclear energy organisation PNC Exploration while exploring for uranium. The **Browns Range** Project is located in the Tanami region on the Western Australia–Northern Territory border, 150 km southeast of Halls Creek in Western Australia. The Paleoproterozoic dome consists of a granitic core intruding the Archean–Paleoproterozoic Browns Range Metamorphics (meta-arkose, feldspathic metasandstone, and schist). The dome and its aureole of metamorphics are surrounded by the Mesoproterozoic Gardiner Sandstone of the Victoria–Birrindudu Basin. Xenotime mineralisation (up to 16% Y, 0.2% U, 0.5% LREE, and 12% HREE) at the Area 5 Prospect is hosted by 10 to 30 cm-wide, 15 m-long quartz veins. Unusually high concentrations of HREE have recently been reported by Northern Minerals, 4 km to the north-northeast of the Area 5 prospect. Xenotime concentrations up to 4% occur in a hydrothermal quartz stockwork mineralising system. Hymap hyperspectral airborne mapping and airborne radiometrics the quartz stockworks and associated alteration clay signature. Based on anomalous uranium radiometrics have identified the REE target zone is open in several directions and extends over some 9 km (http://www.northernuranium.com.au/index.php/rare_earths/browns-range).

A group of prospects (**Green Valley, Florence Bore, Sterling, QMH**) managed by ActivEx Limited, located about 55 km southeast of the Mary Kathleen REE prospects, Queensland (described above), have elevated concentrations of HREO/TREO. Highest concentrations of TREO in rock samples occur in the Green Valley and Sterling prospects, and the highest proportion of HREO occur at Florence Bore. Rock samples from Florence Bore North returned 4538 g/t TREO with a 64% HREO/TREO ratio. The HREO are associated with copper-gold-cobalt mineralisation, with hydrothermal fluids possibly transporting the HREO by the formation of halide (chloride and fluoride) and hydroxide complexes (http://www.activex.com.au/reports/2010-11/AIV_20110301_ASX_Announ_Cloncurry_REO.pdf).

Callabonna Uranium Limited located anomalous REO in rock chips at the **Gilbert River** REE prospect in the Georgetown Inlier of northern Queensland. Reconnaissance follow up of radiometric anomalies found the radiometric response was due to heavy-mineral concentrates in basal Jurassic sandstones. Samples of these often ferruginous sandstones returned high TREO (1.93%) with moderate uranium values up to 311 ppm U_3O_8 (http://www.callabonna.com.au/?LinkServID=BCF6EC46-D481-6E25-5828A4FA6343647D&showMeta=0).

Spectrometer surveys by Jervois Mining Limited over **Lake Barlee** in southwest Western Australia indicate the area is anomalous in uranium, potassium, and thorium, and iron-rich laterites (48% Fe) were identified. The Geological Survey of Western Australia reported that a ferruginous sample from the Lake Barlee region, as part of a regional laterite geochemical survey over the western Yilgarn Craton, obtained 2640 ppm Ce, with anomalous europium, lanthanum, thallium, lead, barium, and cobalt. Consequently, Jervois Mining Limited has recently changed their exploration focus to include REE, iron, and base metals (http://www.jervoismining.com.au/uploaditems/reports/20110131%20Quarterly%20Report%20to%2031%20December%202010.pdf).

Ground truthing of prospective areas with high uranium signatures identified in ground spectrometer surveys in the northern Gawler Craton, South Australia, has defined elevated REE abundances associated with other metals. Mineralised ferruginised mafic dykes, quartz veins, and zones of silicification traverse Early Proterozoic metamorphic rocks that are overlain by Late Proterozoic (Adelaidean) rocks. Reedy Lagoon Corporation Limited has located weathered rocks with up to 3.92% TREE + Y at the **Victory** uranium-REE prospect near Edward Creek, northern Gawler Craton. The samples are enriched in uranium (up to 412 ppm) and are described as fine-grained, intensely weathered kaolinised rocks. The presence of mineralisation (0.56% TREE + Y, 1320 ppm Cu, 60.3 ppm U, 1250 ppm Co, 361 ppm Zn, 7.87% Mn) in weathered metamorphic rocks at the Victory prospect, which represents secondary enrichment near the surface due to weathering effects, may indicate a primary mineralised source at depth http://www.reedylagoon.com.au/downloads/ASX_10-10-12_Edward%20Creek.pdf.

The **Carrapateena** copper-gold project is located 100 km southeast of the world-class Olympic Dam deposit on the eastern margin of the Gawler Craton, South Australia (http://www.ozminerals.com/Media/docs/ASX_20110309_OZAcquiresCCP-b7c5f474-aba2-4272-a397-619d68a286de-0.pdf). This iron-oxide copper-gold deposit has many geological similarities to the Olympic Dam and Prominent Hill deposits. Carrapateena was discovered in 2005 by Rudy Gomez (RMG Services), whose exploration program was funded in collaboration with the South Australian Government's 'Plan for Accelerating Exploration' (PACE) incentive program. Geophysical (gravity and aeromagnetics) and structural lineament studies played important roles in the discovery of these deposits. Carrapateena is hosted in a Proterozoic brecciated sequence comprising conglomeratic sediments with clasts and fragments of granite, gneiss and vein quartz, and altered dolerite and felsic dykes. Copper is mostly chalcopyrite in veins and as blebs and bornite forms a discrete high-grade zone. Mineralisation has been intersected over a vertical height of approximately 1000 m, the deposit is roughly cylindrical and its top is located 470 m below barren sedimentary rock. Copper, gold, silver are the dominant metals, with significant quantities of uranium, iron (hematite), and REE. The mineralisation is interpreted to be controlled by the intersection of north-northwest–south-southeast-trending structures and east-west-trending structures.

One of the early drill-hole intersections that created much interest was 905 m @ 2.17% Cu, 0.9 g/t Au, 11.5 g/t Ag, 255 ppm U and 38.8% Fe, including 82 m @ 4.78% Cu and 1.1 g/t Au. LREE abundances in DDH CAR002 are 178.2 m @ 0.21% Ce and 0.13% La, with the major components being 1.83% Cu and 0.64 g/t Au. An inferred resource (calculated from 33 drill holes totalling 45 504 m on the southern part of the deposit), stands at 203 Mt @ 1.31% Cu, 0.56 g/t Au, 270 ppm U_3O_8, and 6 g/t Ag, for a contained 2.7 million tonnes of Cu, 3.7 Moz Au, 120.9 million pounds of U_3O_8, and 39.2 Moz of Ag, based on a 0.7% copper cut-off grade (http://www.ozminerals.com/Media/docs/ASX_20110414_March2011_Quarterly-Report-9ef5527d-ae2d-4486-9c02-a1acac16f1f2-0.pdf).

APPENDIX 8. RARE-EARTH-ELEMENT DEPOSITS AND PROSPECTS IN AUSTRALIA (SOURCE OF DATA OZMIN[1])

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Alice Springs	NT	Mineral deposit	133.8679383	-23.695682	Rare-earth oxides	Magmatic	Magmatic-hydrothermal	Apatite and/or fluorite vein
Ambergate	WA	Mineral deposit	115.340088	-33.701553	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Beach)
Angourie	NSW	Unknown	153.268	-29.815	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (Beach)
Atlas	NSW	Mineral deposit	143.35	-33.883333	Rutile, zircon, ilmenite, leucoxene, uranium	Basinal	Placer	Heavy-mineral sands (Beach)
Avonbank	VIC	Mineral deposit	142.32	-36.62	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
Barda	NSW	Mineral deposit	142.836	-33.54	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Beenup	WA	Historic mine	115.2643219	-34.235112	Ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine?)
Benbow	NSW	Mineral deposit	142.7342827	-33.829501	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Bidaminna	WA	Mineral deposit	115.6033936	-31.100482	Ilmenite, leucoxene, rutile, zircon	Basinal	Placer	Heavy-mineral sands (Beach)
Birthday Gift	NSW	Mineral deposit	142.9166899	-33.480284	Zircon, rutile, ilmenite, mineral sands, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Blind Pew	NSW	Mineral deposit	142.67565	-33.711064	Zircon, ilmenite, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Boambee	NSW	Unknown	153.11553	-30.3341	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (Beach)
Bribie Island N.P.	QLD	Mineral deposit	153.1699798	-27.04681	Rutile, zircon, ilmenite, monazite, mineral sands	Basinal	Placer	Heavy-mineral sands (High dune)
Brigantine	NSW	Mineral deposit	142.8	-33.65	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Broadwater N.P.	NSW	Unknown	153.432392	-29.024825	Ilmenite, rutile, zircon, magnetite, (monazite)	Basinal	Placer	Heavy-mineral sands (High dune)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Brockman	WA	Mineral deposit	127.7820325	-18.319196	Rare-earth oxides	Magmatic	Orthomagmatic	(Per)alkaline rocks
Brooks Bore	SA	Mineral deposit	140.75	-32.9	Ilmenite, rutile, zircon, xenotime	Basinal	Placer	Heavy-mineral sands (Beach)
Bullant–Karridale	WA	Mineral deposit	115.148163	-34.150181	Ilmenite, zircon, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Bundjalung N.P.	NSW	Unknown	153.322287	-29.428164	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (High dune)
Bunker Bay	WA	Mineral deposit	115.043976	-33.545716	Ilmenite, zircon, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Byfield	QLD	Mineral deposit	150.6999876	-22.796865	Rutile, zircon, ilmenite, monazite, mineral sands	Basinal	Placer	Heavy-mineral sands (High dune)
Byrnes Tank	NSW	Mineral deposit	142.8	-33.64	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Calypso	WA	Mineral deposit	115.3423167	-30.550886	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Channel)
Campaspe	NSW	Mineral deposit	143.34	-33.79	Zircon, rutile, ilmenite	Basinal	Placer	Heavy-mineral sands (Beach)
Capel North	WA	Mineral deposit	115.585724	-33.520386	Ilmenite, zircon, (rutile, leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Cavalier	NSW	Mineral deposit	142.72	-33.83	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Coburn	WA	Mineral deposit	114.126953	-26.70377	Ilmenite, zircon, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Coliban	NSW	Mineral deposit	143.08	-33.93	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Cooglegong	WA	Mineral deposit	119.4167	-21.5834	Ti, Nb, rare-earth elements	Magmatic	Orthomagmatic	Pegmatite
Cooljarloo	WA	Operating mine	115.413696	-30.625429	Ilmenite, zircon, rutile, leucoxene, mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Cooljarloo JV (Atlas, Telesto, Titan)	WA	Mineral deposit	115.42978	-30.62985	Zircon, ilmenite, rutile, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Cooljarloo North	WA	Mineral deposit	115.2333333	-30.533333	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Beach)
Cooloola N.P.	QLD	Mineral deposit	152.9999814	-26.126816	Rutile, zircon, ilmenite, monazite, mineral sands	Basinal	Placer	Heavy-mineral sands (High dune)
Coolup	WA	Mineral deposit	115.93924	-32.769043	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Beach)
Coombah 1	NSW	Mineral deposit	141.7499891	-32.907005	Zircon, ilmenite, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Crayfish	NSW	Mineral deposit	142.3299771	-33.397007	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Crowdy Bay N.P.	NSW	Unknown	152.711	-31.838866	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (High dune?)
Cummins Range	WA	Mineral deposit	127.1760141	-19.285821	Rare-earth oxides, uranium, (thorium, phosphorous oxide, rare-earth elements, uranium oxide)	Magmatic	Orthomagmatic	Carbonatite
Cyclone	WA	Mineral deposit	128.1	-28.4333	Zircon, rutile, (ilmenite, leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Cylinder	NSW	Unknown	143.067	-34.15	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Dardanup	WA	Mineral deposit	115.789497	-33.43029	Ilmenite, zircon, leucoxene, rutile, (monazite, rare-earth oxides, thorium)	Basinal	Placer	Heavy-mineral sands (Beach)
Dardanup (Doral)	WA	Operating mine	115.805012	-33.353732	Ilmenite, zircon, leucoxene, rutile, (monazite, rare-earth oxides, thorium)	Basinal	Placer	Heavy-mineral sands (Beach)
Dongara Project	WA	Mineral deposit	115.1665914	-29.459703	Ilmenite, zircon, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Doubloon North	NSW	Mineral deposit	142.693932	-33.746904	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Douglas (Iluka Murray Basin)	VIC	Operating mine	141.77835	-37.104525	Zircon, rutile, ilmenite, mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)
Elaine Dorothy	QLD	Mineral deposit	140.0166667	-20.8	Rare-earth oxides, uranium, uranium oxide	Magmatic	Magmatic hydrothermal	Skarn
Eneabba area (Iluka Mid West)	WA	Historic mine	115.3017944	-29.835537	Ilmenite, zircon, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Fingal-Box Beach	NSW	Unknown	152.182473	-32.738664	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (Beach)
Finigans Tank	NSW	Unknown	143.067	-34.15	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Fouracres	WA	Mineral deposit	115.577	-34.309696	Zircon, ilmenite, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Fraser Island N.P.	QLD	Mineral deposit	152.9999841	-25.516816	Rutile, zircon, ilmenite, monazite, Mineral sands	Basinal	Placer	Heavy-mineral sands (High dune)
Frasers REE	WA	Mineral deposit	116.3119	-23.95093	Rare-earth oxides, thorium, rare-earth elements	Magmatic	Orthomagmatic	Carbonatite
Galileo	VIC	Mineral deposit	142.4125	-34.9575	Rutile, zircon, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Gallipoli	NSW	Mineral deposit	142.3299779	-33.457007	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Ginkgo	NSW	Operating mine	142.2159283	-33.371548	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Gladstone–Eurimbula	QLD	Mineral deposit	151.2676818	-23.845292	Rutile, zircon, ilmenite	Basinal	Placer	Heavy-mineral sands (Unknown)
Goliath	NSW	Mineral deposit	142.97	-34.27	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Gordon Inlet	WA	Mineral deposit	119.500366	-34.295395	Ilmenite, zircon, rutile	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Gray Bridge	VIC	Mineral deposit	142.962	-36.612	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
Gwindinup North	WA	Operating mine	115.725235	-33.543156	Zircon, ilmenite, (leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Gwindinup South	WA	Mineral deposit	115.692871	-33.562393	Ilmenite, zircon, (leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Happy Valley North	WA	Mineral deposit	115.716217	-33.549896	Zircon, ilmenite, (leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Happy Valley South	WA	Mineral deposit	115.582321	-33.697113	Zircon, ilmenite, (leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Hassell Beach	WA	Mineral deposit	118.396225	-34.835159	Zircon, ilmenite, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Hat Head N.P.	NSW	Unknown	153.047296	-31.055851	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (High dune)
Hopelands	WA	Mineral deposit	115.906189	-32.396255	Zircon, ilmenite, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Inskip Point	QLD	Mineral deposit	152.9999867	-25.816815	Rutile, zircon, ilmenite, monazite, Mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)
Israelite Bay	WA	Mineral deposit	123.869217	-33.600922	Ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Jacinth–Ambrosia	SA	Operating mine	132.228669	-30.861125	Zircon, (rutile, ilmenite)	Basinal	Placer	Heavy-mineral sands (Beach)
Jacks Tank (Spring Hill)	NSW	Mineral deposit	143.2999796	-33.15528	Zircon, rutile, ilmenite, mineral sands, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Jangardup	WA	Historic mine	115.6287362	-34.359577	Ilmenite, zircon, rutile, leucoxene, Mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)
Jangardup South	WA	Mineral deposit	115.656784	-34.400177	Ilmenite, rutile, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
John Galt	WA	Mineral deposit	128.2012906	-17.345804	Rare-earth oxides	Magmatic	Magmatic-hydrothermal	Apatite and/or fluorite vein

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Jurien	WA	Historic mine	115.0811824	-30.271872	Ilmenite, zircon, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Karra	NSW	Mineral deposit	143.067	-34.15	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Kemerton	WA	Mineral deposit	115.7441	-33.1781	Ilmenite, zircon, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Keysbrook	WA	Mineral deposit	115.926491	-32.431545	Ilmenite, zircon, leucoxene, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Killi Killi Hills No.1	WA	Mineral deposit	128.9741218	-19.774964	Uranium, rare-earth elements	Basinal	Diagenetic hydrothermal	Unconformity-related
Killi Killi Hills No.2	WA	Mineral deposit	128.8750222	-19.728015	Uranium, rare-earth elements	Basinal	Diagenetic hydrothermal	Unconformity-related
King Sound–Fitzroy River	WA	Mineral deposit	123.5513	-17.45626	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
Kokomo	QLD	Mineral deposit	145.171214	-18.552506	Nickel, cobalt, (scandium, platinum)	Regolith	Residual lateritic	Ultramafic/mafic–associated
Korella	QLD	Mineral deposit	139.9667	-21.95	Y_2O_3, P_2O_5	Basinal	Sedimentary	Phosphorite
Kulwin	VIC	Mineral deposit	142.5697	-34.9886	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Laburnum	NSW	Mineral deposit	142.2799769	-33.337007	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Lake Innes	NSW	Mineral deposit	152.8708758	-31.476212	Nickel, scandium, chromium, iron, cobalt, talc	Regolith	Residual lateritic	Ultramafic/mafic associated
Limeburners Creek N.P.	NSW	Unknown	152.972724	-31.317698	Ilmenite, rutile, zircon, (monazite)	Basinal	Placer	Heavy-mineral sands (Unknown)
Lucknow	QLD	Mineral deposit	144.9554727	-19.025366	Nickel, cobalt, scandium	Regolith	Residual lateritic	Ultramafic/mafic–associated
Magic	NSW	Mineral deposit	141.35	-32.883333	Zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Mary Kathleen	QLD	Historic mine	140.0130208	-20.746033	Rare-earth oxides, uranium, uranium oxide	Magmatic	Magmatic hydrothermal	Skarn
Mercury	VIC	Mineral deposit	142.3522222	-34.898889	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Mindarie	SA	Historic mine	140.2075	-34.795	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Mindarra Springs	WA	Mineral deposit	115.970398	-31.08153	Ilmenite, zircon, (rutile, monazite, leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Minervah	NSW	Mineral deposit	142.12	-33.39	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Moreton Island N.P.	QLD	Mineral deposit	153.3999761	-27.076808	Rutile, zircon, ilmenite, monazite, mineral sands	Basinal	Placer	Heavy-mineral sands (High dune)
Mount Gee	SA	Mineral deposit	139.3391	-30.2224	Uranium, uranium oxide, rare-earth oxides, rare-earth elements	Magmatic	Magmatic-hydrothermal	Iron-oxide breccia complex
Mount Painter	SA	Historic mine	139.3699731	-30.227049	Uranium, uranium oxide, rare-earth elements	Magmatic	Magmatic-hydrothermal	Iron-oxide breccia complex
Mount Weld	WA	Operating mine	122.5475227	-28.859949	Rare-earth oxides, (many components: yttrium oxide, thorium, tantalum pentoxide, zirconia, niobium pentoxide, phosphate, phosphorous, niobium, tantalum, rare-earth elements, phosphorous oxide)	Regolith	Residual lateritic	Carbonatite-associated
Mulga Rock	WA	Mineral deposit	123.592004	-29.904345	Uranium, rare-earth elements	Basinal	Sedimentary	Lignite
Myall Lakes N.P.	NSW	Historic mine	152.392487	-32.459314	Ilmenite, corundum - ruby, zircon, rutile	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Narraburra	NSW	Mineral deposit	147.5667	-34.325	Rare-earth oxides, (thorium, zirconia, yttrium oxide, hafnium, niobium)	Magmatic	Orthomagmatic	(Per)alkaline rocks
Nepean HMS	NSW	Mineral deposit	143.36	-34.07	Zircon, rutile, ilmenite	Basinal	Placer	Heavy-mineral sands (Beach)
Nolans Bore	NT	Mineral deposit	133.238557	-22.59385	Rare-earth oxides, (uranium, phosphate, phosphorous oxide, uranium oxide, rare-earth elements, thorium)	Magmatic	Magmatic-hydrothermal	Apatite and/or fluorite vein
North Dandalup	WA	Mineral deposit	115.948945	-32.583286	Ilmenite, zircon, rutile, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
North Entrance	NSW	Unknown	151.518538	-33.320618	Ilmenite, rutile, zircon	Basinal	Placer	Heavy-mineral sands (Beach)
North Stradbroke Island	QLD	Operating mine	153.4435	-27.476791	Zircon, rutile, ilmenite	Basinal	Placer	Heavy-mineral sands (High dune)
Nyngan	NSW	Mineral deposit	146.983333	-31.633333	Scandium, nickel, cobalt, (platinum, gold)	Regolith	Residual lateritic	Ultramafic/mafic–associated
Olympic Dam	SA	Operating mine	136.889293	-30.437444	Copper, uranium, gold, (silver)	Magmatic	Magmatic hydrothermal	Iron-oxidised breccia complex
Phoenix	NSW	Mineral deposit	143.3072839	-34.468497	Zircon, ilmenite, rutile, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Pinga Creek	WA	Mineral deposit	119.00008	-21.75	Sn, Nb, rare-earth elements	Magmatic	Orthomagmatic	Pegmatite
Port Gregory	WA	Operating mine	114.281448	-28.178205	Garnet, ilmenite	Basinal	Placer	Heavy-mineral sands (Beach)
Puwanapi	NT	Mineral deposit	130.065651	-11.72027	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Beach)
Rocky Point	QLD	Mineral deposit	151.9499792	-24.276837	Rutile, zircon, ilmenite, monazite	Basinal	Placer	Heavy-mineral sands (Unknown)
Rodds Peninsula N.P.	QLD	Mineral deposit	151.6999813	-24.02684	Rutile, zircon, ilmenite, monazite	Basinal	Placer	Heavy-mineral sands (Unknown)
Round Hill Head–Deepwater	QLD	Mineral deposit	151.891464	-24.183744	Rutile, zircon, ilmenite, monazite	Basinal	Placer	Heavy-mineral sands (Unknown)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Rover Range–Glenarty Creek	WA	Mineral deposit	115.186218	-34.199345	Ilmenite, (leucoxene, rutile, zircon)	Basinal	Placer	Heavy-mineral sands (Beach)
Scott River	WA	Mineral deposit	115.3332222	-34.260112	Ilmenite, zircon, rutile, leucoxene, mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)
Shamrock	NSW	Mineral deposit	142.52	-33.51	Rutile, zircon, (ilmenite, leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Shoalwater Bay Training Area	QLD	Mineral deposit	150.802439	-22.67014	Rutile, zircon, ilmenite, monazite	Basinal	Placer	Heavy-mineral sands (Beach)
Snapper	NSW	Mineral deposit	142.11998	-33.397009	Rutile, zircon, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
Somme	NSW	Mineral deposit	142.32	-33.35	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Sunshine Coast N.P.	QLD	Mineral deposit	153.101331	-26.416506	Rutile, zircon, ilmenite, monazite	Basinal	Placer	Heavy-mineral sands (Unknown)
Swan Lake	WA	Mineral deposit	115.178482	-34.305012	Ilmenite, zircon, rutile, leucoxene, monazite	Basinal	Placer	Heavy-mineral sands (Unknown)
Tarawi North	NSW	Mineral deposit	141.16804	-33.42866	Zircon, ilmenite, rutile, (leucoxene, Thorium)	Basinal	Placer	Heavy-mineral sands (Beach)
Tarawi South	NSW	Mineral deposit	141.18427	-33.473733	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Beach)
The Loop	WA	Mineral deposit	115.941566	-32.656712	Zircon, leucoxene, ilmenite, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Titan	VIC	Mineral deposit	142.4130556	-34.968889	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Tiwi	NT	Operating mine	131.026301	-11.36257	Zircon, rutile, leucoxene, ilmenite	Basinal	Placer	Heavy-mineral sands (Beach)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Toongi	NSW	Mineral deposit	148.6181783	-32.445319	Rare-earth oxides, uranium, (zirconia, niobium pentoxide, tantalum pentoxide, yttrium oxide, uranium oxide, niobium, tantalum, yttrium)	Magmatic	Orthomagmatic	(Per)alkaline rocks
Trelawney	NSW	Mineral deposit	142.71	-33.65	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Triangle	NSW	Mineral deposit	142.92	-33.46	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Tutunup	WA	Mineral deposit	115.5647222	-33.681111	Ilmenite, rutile, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Tyrrell Ridge	VIC	Mineral deposit	142.7533333	-35.735556	Rutile, ilmenite, zircon	Basinal	Placer	Heavy-mineral sands (Beach)
Urquhart	QLD	Mineral deposit	141.8	-12.75	Ilmenite, rutile, leucoxene, zircon	Basinal	Placer	Heavy-mineral sands (Beach)
Wakool	NSW	Mineral deposit	143.2	-33.93	Zircon, rutile, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Warner Glen	WA	Mineral deposit	115.213165	-34.180729	Ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Watchem 'A' Strand	VIC	Mineral deposit	142.8955556	-36.071111	Rutile, ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Watchem 'B' Strand	VIC	Mineral deposit	142.8955556	-36.071111	Rutile, ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Wedderburn	VIC	Mineral deposit	143.2666667	-36.616667	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
Wemen	VIC	Historic mine	142.7000132	-34.813696	Rutile, zircon, ilmenite, mineral sands	Basinal	Placer	Heavy-mineral sands (Beach)
Western Strands	NSW	Mineral deposit	142.85	-33.49	Zircon, rutile, ilmenite, (leucoxene)	Basinal	Placer	Heavy-mineral sands (Unknown)

Name	State	Operating status	Longitude	Latitude	Commodities	Mineral-system association	Mineral system group	Deposit type
Whicher Scarp	WA	Mineral deposit	115.49828	-33.74525	Zircon, ilmenite, rutile	Basinal	Placer	Heavy-mineral sands (Beach)
Wild Cattle Island	QLD	Mineral deposit	151.3999727	-23.976851	Rutile, zircon, ilmenite, monazite, mineral sands	Basinal	Placer	Heavy-mineral sands (Unknown)
WIM 50	VIC	Mineral deposit	141.8846887	-37.062241	Ilmenite, rutile, zircon, xenotime, leucoxene, (monazite)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
WIM 100	VIC	Mineral deposit	141.6013771	-36.96224	Ilmenite, rutile, zircon, leucoxene, xenotime, (monazite)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
WIM 150	VIC	Mineral deposit	142.3400494	-36.806155	Leucoxene, rutile, zircon, xenotime, ilmenite, (mineral sands)	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
WIM 200 (Jackson)	VIC	Mineral deposit	142.6346869	-36.678866	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
WIM 250 (Donald)	VIC	Mineral deposit	142.768011	-36.512196	Ilmenite, rutile, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Offshore shallow marine)
Winchester	NSW	Mineral deposit	142.31	-33.34	Rutile, ilmenite, zircon, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Witchcliffe	WA	Mineral deposit	115.128998	-34.027115	Ilmenite, zircon, (garnet, leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Wonnerup	WA	Mineral deposit	115.4506	-33.653782	Zircon, ilmenite, (leucoxene, rutile)	Basinal	Placer	Heavy-mineral sands (Beach)
Yabbie	NSW	Mineral deposit	142.5	-33.52	Rutile, zircon, ilmenite, leucoxene	Basinal	Placer	Heavy-mineral sands (Beach)
Yalyalup	WA	Mineral deposit	115.472298	-33.689709	Rare-earth elements	Basinal	Placer	Heavy-mineral sands (Beach)
Yangibana	WA	Mineral deposit	116.1972149	-23.890331	Rare-earth oxides	Magmatic	Orthomagmatic	Carbonatite
Yuraygir N.P.	NSW	Mineral deposit	153.2690624	-29.813401	Ilmenite, rutile, zircon	Basinal	Placer	Heavy-mineral sands (Unknown)

[1] The REE resource data used in this review for Australia's deposits and prospects are from OZMIN (2011: Ewers and Ryburn, 1977)—Geoscience Australia's national database of Mineral deposits andf resources.

N.P.= National Parks and other reserves.

APPENDIX 9. SUMMARY OF AUSTRALIAN GOVERNMENT AND RARE-EARTH-ELEMENT MINING INDUSTRY DEVELOPMENTS

Australian Government developments

Geoscience Australia (www.ga.gov.au)

Very few reviews on the distribution and geology of REE deposits in Australia have been published by the Australian Government. Two exceptions include reports ('Commercial-In-Confidence' at the time of release) by Towner et al. (1996) and Cassidy et al. (1997) of the Australian Geological Survey Organisation (predecessor to Geoscience Australia). The report by Towner et al. (1996) focuses on resources, exploration, and processing of mineral-sand deposits, whereas the latter report by Cassidy et al. (1997) discusses the geology and potential of primary hard-rock and mineral-sand deposits. This particular publication represents the first national review that describes the geological setting and exploration of REE since Cassidy et al. (1997). Other digital map and database products with potential applications for REE exploration produced by Geoscience Australia since 2008 are summarised in Section 5.3 and Appendix 10.

Commonwealth Scientific and Industrial Research Organisation (http://www.csiro.au/csiro/channel/_ca_dch2t.html)

The Minerals Down Under National Research Flagship (http://www.csiro.au/org/MDU-Overview--ci_pageNo-1.html) is a collaborative program between the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the minerals industry, and various government organisations to create new knowledge and transform technologies for the mineral sector. Within this and previous research frameworks, the CSIRO has carried out a number of scientific projects involving the REE. The wide variety of research projects highlights the diverse applications of these strategically important elements. Such projects include:

- mineralogical and metallurgical investigations of REE deposits (e.g., Cummins Range Carbonatite-hosted deposit in the East Kimberley, WA: Andrew, 1990) and scandium-bearing Ni-Co laterites (Gilgai intrusion, Nyngan project, NSW: http://www.jervoismining.com.au/uploaditems/reports/20110211%20Nyngan%20Scandium%20Report%20from%20CSIRO.pdf);
- aquatic geochemistry of REE in geological materials associated with river catchments (e.g., Pioneer River, central Qld: Lawrence et al., 2006); and
- CSIRO has applied advanced techniques in design incorporating the use of REE permanent magnets to develop high-efficiency electric motors.

Australian Nuclear Science and Technology Organisation Minerals (http://www.ansto.gov.au/home)

ANSTO Minerals is a business unit of the Australian Nuclear Science and Technology Organisation, located at Lucas Heights near Sydney.

The focus of ANSTO Minerals is on the processing of ores containing naturally occurring radioactivity, specifically ores containing uranium and thorium, which are often associated with the REE. ANSTO Minerals undertake innovative process development for the mining industry, from evaluation of drill-hole samples through to operation of pilot plants and demonstration plants at our own facilities, or if required, at the clients mine site.

Since 1990, ANSTO Minerals have been involved in commercial process development projects targeting the recovery of rare earths from Australian ores and concentrates and have gained expertise in areas specific to rare-earth processing including caustic conversion of rare-earth phosphate type minerals, sulphuric acid bake/water leach processes and purification of rare earths by solvent extraction techniques which requires operation of multiple circuits containing many mixer-settler units.

An example of this recovery-processing service involves the Toongi deposit (Dubbo Zirconia Project), New South Wales, that is managed by Alkane Resources Limited. ANSTO Minerals has used a demonstration pilot plant to process an initial 100 tonnes of ore from the deposit and has recovered 1300 kg of zirconium chemicals and nearly 300 kg of saleable niobium concentrate containing approximately 70% Nb_2O_5. The demonstration plant also has produced zirconia concentrate and yttrium-REE concentrate from the deposit.

Rare-earth-element mining industry developments in Australia

Lynas Corporation Limited: The Mount Weld deposit in Western Australia occurs in the lateritic profile over an alkaline carbonatite complex. In September 2010, Lynas announced resource figures for the Central lanthanide deposit of Measured, Indicated and Inferred Resources of 9.88 million tonnes with total lanthanide oxides (TLnO) at 10.6% and 990 ppm Y_2O_3 ('heavy' REO) and the newly named 'Duncan' ‘heavy’ REO deposit with Measured, Indicated and Inferred resources totalling 7.62 Mt @ 4.5% TLnO (4.8% TREO) and 2570 ppm Y_2O_3. In another part of the carbonatite complex called the Crown Polymetallic deposit, there are Indicated (1.5 Mt) and Inferred (36.2 Mt) Resources totalling 37.7 million tonnes, which include total lanthanides at 1.16% and 0.09% Y_2O_3. The company completed the first stage of mining activities in 2008 and commenced construction of a concentration plant at Mount Weld and an advanced materials plant in Malaysia. Both of these activities were suspended in the first quarter of 2009 because of uncertainty concerning the financing arrangements for the project. In September 2009, Lynas announced a fully underwritten share issue in Lynas to raise $450 million, which will be used to complete phase 1 of the Lynas REE project. Lynas reported in its 2009 annual report that it had signed long-term contracts with four customers to supply REE and signed letters of intent with another two customers. Lynas Corporation Limited has announced that it plans to commence production of rare-earth mineral concentrate, followed by further processing to rare-earth concentrates and separated products in Malaysia, in 2011. This is a milestone for the REE industry as most of the new production capacity in the last 15 years has been in China. ANSTO Minerals has been associated with this project through various companies owning the deposit, Carr Boyd Minerals, Ashton Mining, and Lynas Corporation. The ANSTO facilities in Sydney tested a caustic conversion route in the early 1990s and later carried out test work on an acid bake processing route. Test work included operation of continuous solvent extraction mini-plant to achieve separation of middle, light, and rare-earth fractions as well as production of separated rare-earth products, mainly cerium and neodymium. As part of these studies, ANSTO Minerals has developed a solvent extraction process specifically for cerium based on extraction from sulphate liquor.

Arafura Resources Limited: Nolans Bore REE-phosphate-uranium-thorium deposit is located 135 km northwest of Alice Springs in the Northern Territory. It has Measured, Indicated and Inferred Resources totalling 30.3 million tonnes to a depth of 130 m with grades at 2.8% REO, 12.9% P_2O_5, 0.44 pounds per tonne U_3O_8, and 0.27% Th. According to Arafura, the distribution of the LREE currently being considered for extraction, (La, Ce, Pr, and Nd) amount to 95%, whereas other REE (Sm, Eu, Gd, Tb, Dy) amount to 4.23%. Since 2006, ANSTO has been involved in the development of a process route for the recovery of rare earths from this deposit, with phosphoric acid and uranium as by-products. ANSTO Minerals has tested various stages of the process to pilot scale and a demonstration plant is currently being planned. The test work has also included the application of solvent extraction technology for further purification of a mixed rare-earth solution into separate rare-earth products. In February 2009, Arafura announced it had executed a letter of intent with the Jiangsu Eastern China Non-Ferrous Metals Investment Holding Co Limited (JEC) a subsidiary of the East China Mineral Exploration and Development Bureau (ECE) for ECE to acquire up to 25% for the issued capital of Arafura through two share placements. The proposal was approved by the Foreign Investment Review Board in May 2009 and accepted by the shareholders in September 2009. The company is conducting a definitive feasibility study on the Nolans Bore project and, in July 2010, reported that it is on track to commence production in 2013 (http://www.arafuraresources.com.au/documents/July2010AdvertorialFINAL.PDF accessed September 2010).

Alkane Resources Limited: A Demonstration Pilot Plant (DPP) was constructed and commissioned in May 2008 at (ANSTO). Alkane reported that the DPP completed two trial runs in 2008 and one more in the first quarter of 2009, producing high quality zirconium and niobium products. In November 2009, Alkane reported that the plant had produced the first LREE and Y-HREE products and stressed the importance of the rare earths as a revenue earner, particularly the HREE. The current plans are to make a decision on development during the second half of 2010 with production to commence in 2011–12 if development goes ahead.

Navigator Resources Limited: The company’s Cummins Range Carbonatite deposit occurs in the Kimberley region of Western Australia. In September 2009, it reported Inferred Resources of 4.17 Mt @ 1.72% TREO, 11.0% P_2O_5, 187 ppm U_3O_8 and 41 ppm Th, at a cut-off grade of 1% TREO. The TREO was subdivided into 95.6% LREE (La, Ce, Pr, Nd), 4.1% MREE (Sm, Eu, Gd, Tb, Dy) and 0.3% HREE (Ho, Er, Tm, Yb, Lu). A mineralogical investigation of the Cummins Range deposit by the CSIRO Minerals Down Under Flagship was completed during the March 2010 quarter with the principal REE-bearing minerals being primary apatite and monazite and only subordinate amounts of secondary REE-bearing minerals are present.

Capital Mining Limited: Similarly, the (per)alkaline granitic intrusions of the Narraburra complex, near Temora in central New South Wales, contain anomalous amounts of zirconium, REO, and low concentrations of thorium. The ThO_2 content amounts to 2750 tonnes (2420 tonnes Th). In the March Quarterly Report in 2010, the owners of the project, Capital Mining Limited reported that it was conducting metallurgical tests to recover Hf, Th, Ta, Nb, Nd, and Ce.

During the last couple of years **scandium-bearing lateritic nickel-cobalt deposits** have attracted increasing attention in response to anticipated global rise in demand for scandium. Scandium-stabilised zirconia rather than yttrium-stabilised zirconia as an electrolyte for Solid Oxide Fuel Cells (SOFC) reduces the operating temperature of the fuel cell significantly, thereby providing a much longer life. SOFCs are expected to play a major role in the developing battery powered electric transportation industry (cars, trucks, trains, etc) as well as in stationary applications, using SOFCs as electricity generators in substitution of coal fired power plants or directly in the home (EMC Metals Corporation of Canada, 2010).

Metallica Minerals Limited: During 2010 Metallica announced scandium resources located within their Kokomo and Lucknow lateritic nickel-cobalt deposits in northern Queensland. At the Kokomo deposit, about 175 km northwest of Townsville, the company used a cut-off of 70 g/t Sc to delineate a scandium-rich Measured, Indicated and Inferred Resource of 9.0 Mt @ 109 g/t Sc, 0.24% Ni, and 0.03% Co, which is located within a larger lateritic nickel-cobalt deposit of 16.3 Mt @ 0.67% Ni, 0.12% Co, and 36 g/t Sc.

Jervois Mining Limited: A scandium-rich portion of Nyngan lateritic nickel-cobalt-scandium-platinum deposit in central New South Wales was updated in June 2009 as Measured Resources of 2.718 Mt @ 274 ppm Sc and Indicated Resources of 9.294 Mt @ 258 ppm Sc. Jervois in a joint venture agreement with EMC Metals Corporation of Canada are currently engaged in scoping studies to provide data for a prefeasibility study of the Nyngan scandium joint venture project in 2011.

APPENDIX 10. USEFUL WWW LINKS FOR INFORMATION ABOUT RARE-EARTH ELEMENTS

Australian information, maps, and statistical data relating to rare-earth elements from Geoscience Australia:

Australia's Identified Mineral Resources 2010:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71584

Australian Mineral Exploration a review of exploration for the year 2010:
https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=71503

Rare-Earth Elements:
http://www.ga.gov.au/minerals/mineral-resources/rare-earth-elements.html

Australian Mines Atlas:
http://www.australianminesatlas.gov.au/index.jsp

General issues and international statistical data of rare-earth elements:

Wikipedia, the free encyclopedia about rare-earth elements:
http://en.wikipedia.org/wiki/Rare_earth_element

United States Geological Survey
Annual rare-earth-element statistics and information:
http://minerals.er.usgs.gov/minerals/pubs/commodity/rare_earths/

United States Geological Survey
Scientific Investigations Report 2010–5220:
http://pubs.usgs.gov/sir/2010/5220/

British Geological Survey
Rare-earth elements: a beginner's guide from the BGS:
http://www.bgs.ac.uk/research/highlights/rare_earth_elements.html

British Geological Survey
Map of rare-earth-element deposits in the world:
http://www.bgs.ac.uk/research/highlights/documents/Global_REE_Deposits.pdf

About.com Chemistry
Multiple articles about the rare-earth elements:
http://chemistry.about.com/lr/rare_earths/239403/2/

Baotou National Rare-Earth Hi-Tech Industrial Development Zone
Overview of China's rare-earth element industry:
http://www.rev.cn/en/int.htm

Australian Shares: Database of Australian mining and energy shares. Searchable by what they mine or explore for, how much of any given resource they have:
http://www.australian-shares.com

AustralianRareEarths.com:
http://www.australianrareearths.com/current-issues.html

National Nuclear Data Centre, Brookhaven, USA:
http://www.nndc.bnl.gov/

International Union of Pure and Applied Chemistry (IUPAC):
http://old.iupac.org/dhtml_home.html

Thomas Jefferson National Accelerator Facility: Periodic Table of Elements:
http://education.jlab.org/itselemental/

Elementymology & Elements Multidict:
http://elements.vanderkrogt.net/index.php

Tasman Metals Limited:
http://www.tasmanmetals.com/s/Home.asp

Naming rare-earth elements and rare-earth-element-bearing minerals:

http://www.nndc.bnl.gov/nndc/history/origindc.pdf

http://elements.vanderkrogt.net/rareearths.php

http://www.tasmanmetals.com/s/OresMinerals.asp

http://www.mindat.org/index.php

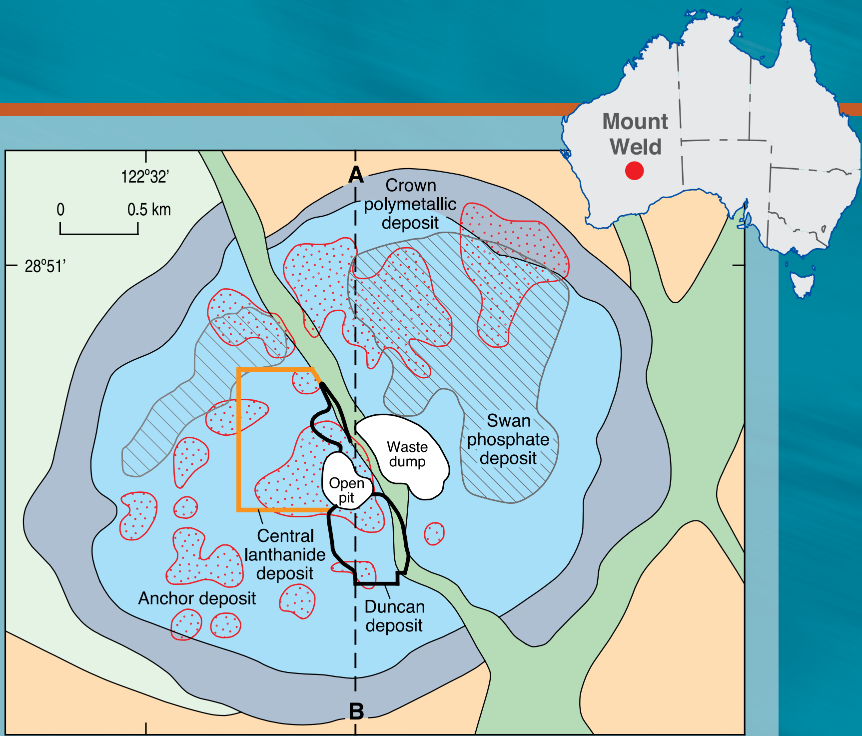
http://www.angelo.edu/faculty/kboudrea/periodic/trans_lanthanides.htm

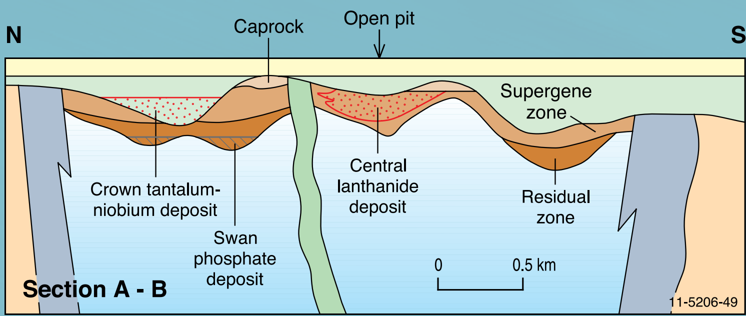
Government organisations involved with research into rare-earth elements:

Geoscience Australia (GA):
www.ga.gov.au

Commonwealth Scientific and Industrial Research Organisation (CSIRO):
http://www.csiro.au/csiro/channel/_ca_dch2t.html

Australian Nuclear Science and Technology Organisation Minerals (ANSTO):
http://www.ansto.gov.au/home





Rare-earth elements (REE: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium) have unique chemical, magnetic, and luminescent properties that make them critical to several high-technology industries. Their applications in many emerging technologies associated with the transport, information, environment, energy, defence, nuclear, and aerospace industries have gained rapid momentum in recent years. This, together with a narrow global supply base, has led to price increases for the REE, and so they are becoming an increasingly attractive commodity for the minerals industry.

This report produced by Geoscience Australia describes the distribution, geological characteristics, and resources of Australia's major REE deposits as a stimulus for further research into their geological characteristics. The information and main messages presented are intended to inform the public, students, and professionals.