REE
Rare Earth
Elements

RARE EARTH ELEMENTS

Critical mineral potential of South Australia

Diana Zivak, Peter Keller, Mitchell Bockmann,
Alicia Caruso, Carmen Krapf, Adrian Fabris
and Alexander Corrick

SOUTH
AUSTRALIA

Government
of South Australia
Department for
Energy and Mining

Department for Energy and Mining
Level 4, 11 Waymouth Street, Adelaide
GPO Box 320, Adelaide SA 5001
Phone +61 8 8463 3000
Email dem.minerals@sa.gov.au
dem.petroleum@sa.gov.au
www.energymining.sa.gov.au

South Australian Resources Information Gateway (SARIG)
SARIG provides up-to-date views of mineral, petroleum and geothermal tenements and other geoscientific data. You can search, view and download information relating to minerals and mining in South Australia including tenement details, mines and mineral deposits, geological and geophysical data, publications and reports (including company reports).
map.sarig.sa.gov.au

Acknowledgement of Country
As guests on Aboriginal land, the Department for Energy and Mining (DEM) acknowledges everything this department does impacts on Aboriginal country, the sea, the sky, its people, and the spiritual and cultural connections which have existed since the first sunrise. Our responsibility is to share our collective knowledge, recognise a difficult history, respect the relationships made over time, and create a stronger future. We are ready to walk, learn and work together.

Preferred way to cite this publication
Zivak D, Keller P, Bockmann M, Caruso A, Krapf C, Fabris A and Corrick A 2024. *Rare Earth Elements. Critical Mineral potential of South Australia*, Report Book 2024/00028. Department for Energy and Mining, South Australia, Adelaide.

Rare Earth Elements

Critical Mineral potential of South Australia

Diana Zivak, Peter Keller, Mitchell Bockmann, Alicia Caruso, Carmen Krapf, Adrian Fabris and Alexander Corrick

Geological Survey of South Australia,
Department for Energy and Mining

August 2024

Report Book 2024/00028

CONTENTS

TABLES

FIGURES

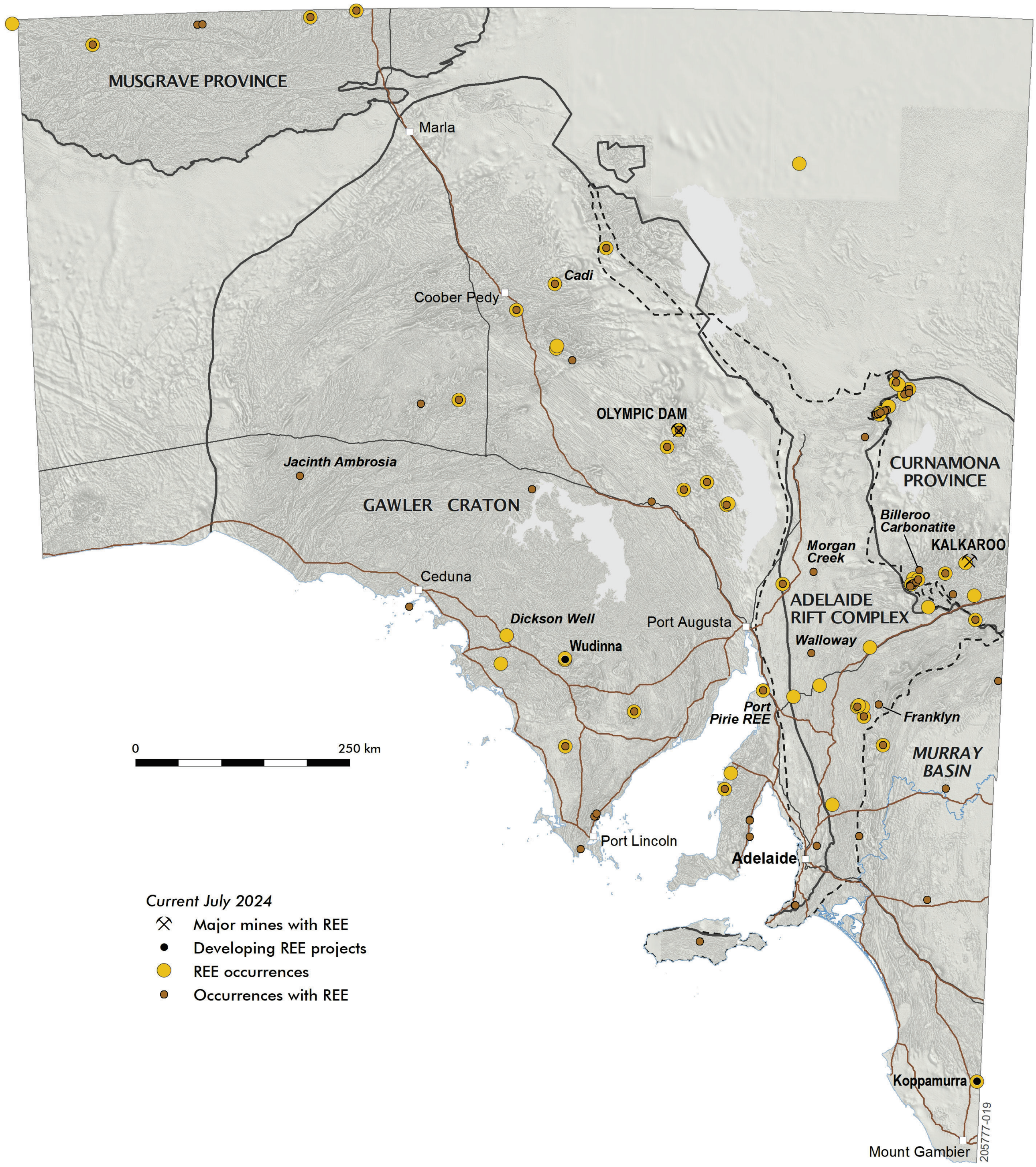

Figure 1. Rare Earths occurrences and REE-bearing minerals in South Australia. (205777-019 PDF 4.7 MB)

Rare Earth Elements

Diana Zivak, Peter Keller, Mitchell Bockmann, Alicia Caruso, Carmen Krapf, Adrian Fabris and Alexander Corrick

The Rare Earth Elements (REE) are a group of 16 naturally occurring elements — the 15 lanthanides in addition to yttrium, which tends to also occur in the same ore deposits and exhibits similar chemical properties (Balaram 2019). Although scandium is commonly included in this list, its behaviour during physicochemical processes that lead to REE enrichment is somewhat different owing to its smaller ionic radius compared to the lanthanides and yttrium, therefore it is not included in this report.

REE do not occur naturally as metals, rather they are found in a wide range of mineral compounds including halides, carbonates, oxides, phosphates and silicates (Walters and Lusty 2011). The term ‘rare earth’ is misleading as it implies scarce crustal abundance, and yet in fact, REE are relatively plentiful in the Earth’s crust having an overall upper crustal abundance of 117.14 ppm (Rudnick and Gao 2004). The crustal abundance of individual REE varies widely, from cerium at 43 ppm to 0.28 ppm for thulium (Taylor and McLennan 1995). Rare earths are often categorised by their atomic weight into two groups (Table 1). Lanthanum to europium represent the light rare earth elements (LREE) while gadolinium to lutetium represent the heavy rare earth elements (HREE). When companies report REE assays, they may use the term ‘REO’ which refers to the rare earth oxide content, or ‘TREO’ which refers to total rare earth oxide content in a given sample.

The global production of REE in 2023 was 350,000 t REO. Of this, China produced 240,000 t REO giving it a dominant share of the market. The United States of America (43,000 t), Burma (38,000 t), Australia (18,000 t) and Thailand (7,300 t) were the other significant producers. World mine reserves are estimated to be around 110 Mt of REO (United States Geological Survey 2023). Production from Australia was primarily from Mt Weld in Western Australia. Concentrates from Mt Weld are processed at a processing facility in Malaysia to produce REO products (Geoscience Australia 2023).

USES

Rare earth elements are used for and in a wide variety of materials and applications that have become essential in modern society. A summary of common uses for the 16 rare earth elements are summarised in Table 1. The use of neodymium-iron-boron magnets for electric vehicles and wind turbines has increased substantially in recent years and will continue as global decarbonisation takes place (Arafura Rare Earths Ltd). These new uses for magnet metals are driving increased exploration for REE. Emerging technologies will most likely find new uses for REE which will only add to the demand for these resources.

Table 1. Summary of common uses for different rare earth elements after Weng et al. (2015).

Element	Symbol	Heavy/light REE	Uses
Lanthanum	La	Light	Optics, batteries, catalysis, hydrogen storage
Cerium	Ce	Light	Chemical applications, colouring, polishing glass, catalysis, hybrid vehicles
Praseodymium	Pr	Light	Magnets, lighting, optics
Neodymium	Nd	Light	Magnets, lighting, lasers, optics, hybrid vehicle batteries
Promethium	Pm	Light	Limited uses due to radioactivity, used in luminous paint and atomic batteries; very rare in nature due to its short half-life
Samarium	Sm	Light	Magnets (SmCo), lasers, masers, lightweight magnets
Europium	Eu	Light	Lasers, lighting, medical applications
Gadolinium	Gd	Heavy	Magnets, glassware, lasers, X-ray contrast agent, computer applications, medical applications
Terbium	Tb	Heavy	Lasers, lighting, lightweight magnets
Dysprosium	Dy	Heavy	Magnets, lasers, hybrid vehicle batteries
Holmium	Ho	Heavy	Lasers
Erbium	Er	Heavy	Lasers, medical applications, neutron-absorbing control rods in nuclear industry
Thulium	Tm	Heavy	X-ray generation
Ytterbium	Yb	Heavy	Lasers, chemical industry applications
Lutetium	Lu	Heavy	Medical applications, chemical industry applications
Yttrium	Y	Heavy	Lasers, superconductors, microwave filters, lighting, ceramic

ECONOMIC DEPOSIT TYPES

Around 200 minerals are known to contain REE, but almost all REE production has come from less than 10 of these (Castor and Hendrick 2006). Important minerals associated with REE mineralisation are listed in Table 2. Three of these minerals, bastnäsite, monazite and xenotime, have traditionally been the major source of REE (Walters and Lusty 2011). Bastnäsite and monazite are the primary source of the LREE, mainly cerium, lanthanum, and neodymium. Monazite has a different balance as it contains less lanthanum and more neodymium and HREE. It is also worth noting that monazite contains the radioactive element thorium, which can present problems during processing and post mining. Xenotime is dominated by the heavier REE including yttrium, dysprosium, erbium and holmium. As many of the rare earth elements have a close chemical similarity, they often substitute for each other in a mineral’s crystal lattice, which can lead to many varietal forms. It can also complicate the metallurgical refinement to metal process (Walters and Lusty 2011).

Table 2. REE-bearing minerals which commonly host the REE mineralisation. Modified after Dostal (2017).

Mineral	Formula[1]	Estimated TREO[2] (wt %)	REE associations
Eudialyte	$Na_4(Ca,REE)_2(Fe^{2+},Mn^{2+},Y)ZrSi_8O_{22}(OH,Cl)_2$	9	
Allanite	$(REE,Ca,Y)_2(Al,Fe^{3+})_3(SiO_4)_3(OH)$	37.5	Light REE > Heavy REE
Stillwellite	$(REE,Ca)BSiO_5$	27	Light REE > Heavy REE
Loparite	$(REE,Na,Ca)(Ti,Nb)O_3$	30	
Fergusonite	$YNbO_4$	46	
Monazite	$(REE,Th)PO_4$	65	Light REE > Heavy REE
Bastnäsite	$(REE,Y)(CO_3)F$	75	Light REE > Heavy REE
Florencite	$LREEAl_3(PO_4)_2(OH)_6$	32	Light REE > Heavy REE
Parisite	$Ca(REE)_2(CO_3)_3F_2$	61	
Synchysite	$Ca(REE)(CO_3)_2F$	51	
Xenotime	YPO_4	61	Heavy REE + Y > Light REE
Apatite	$Ca_5(PO_4)_3(OH,F,Cl)$	<1	Light REE > Heavy REE
Carbonate fluorapatite	$(Ca, Na, Sr, Mg, REE)_{10}(PO_4, CO_3, SO_4)_6F_2$	0.5-1	Light REE > Heavy REE

1 REE – Rare Earth Elements (lanthanide group).

2 TREO – Total rare earth oxides, the sum of the oxides of lanthanides and yttrium (Y). Estimates of TREO content based on average mineral composition.

Global REE deposits and occurrences (not currently mined) can be subdivided based on their mineral systems into the following five categories:

- Magmatic-related REE deposits
  - Carbonatites (e.g., Mt Weld, WA; Bayan Obo, China)
  - Peralkaline/alkaline igneous rocks (e.g., Toongi volcanics, NSW)
  - Pegmatites (Strange Lake, Canada)

- Hydrothermal REE deposits (with or without magmatic-hydrothermal input)
  - Unconformity-related REE deposits (e.g., Browns Range, NT)
  - Vein, skarn and breccia hosted REE deposits (e.g., Nolans Bore, NT; Olympic Dam, SA)

- Placer deposits
  - Heavy mineral sand deposits (e.g., Jacinth-Ambrosia, SA)
  - Channel and alluvial placer deposits

- Sedimentary deposits (currently not produced)
  - REE-rich phosphorites (e.g., Georgina Basin phosphorite, QLD)
  - Coal and coal ash REE deposits

- Surficial (including deep weathering) deposits
  - In-Situ clay-hosted REE deposits (e.g., ionic-clays in China)
  - Residual deposits (laterite, e.g., Mt Weld, WA)
  - Transported clay-hosted REE deposits (e.g., Koppamurra, SA)

Deposits may also be considered in terms of whether they contain predominantly heavy or light rare earth elements. The majority of LREE are currently produced from carbonatites, while HREE are largely produced from ion-adsorption clay deposits in south China (Verplanck et al. 2014; Dostal 2017).

Historically, REE (particularly LREE) were produced from monazite and xenotime concentrates from heavy mineral sand deposits. Australia was one of the largest producers of REE from heavy mineral sands until the process became uneconomic in the mid-1990s, associated with the increased production of rare earth oxides (REO) from China (Mudd and Jowitt 2016). In 2023, Australia was ranked sixth in the world for REE resources with estimated economically demonstrated resources of REO + Y_2O_3 of 5.70 Mt, constituting approximately 4% of known global REE resources (Hughes et al. 2023). Australia also ranked third in the world for REE production in 2023, with 16 kt of REO + Y_2O_3, which constituted approximately 5% of global production (Hughes et al. 2023). Currently, the majority of REE in Australia is mined and processed in Western Australia. The Mt Weld carbonatite deposit is expected to deliver 12,000 t Nd/Pr products in 2024. The Eneabba Rare Earth's refinery is forecasting production of up to 23 kt of REO concentrate per annum with first production scheduled for 2025 (Australian Trade and Investment Commission 2022).

MAGMATIC-RELATED REE DEPOSITS

This class of REE deposits are typically associated (and hosted in) magmatic rocks, with or without large hydrothermal inputs. Often, carbonatites, alkaline igneous rocks and pegmatites are temporally and spatially related and occur in similar tectonic settings associated with large crustal-scale structures and peripheral to orogenic belts, associated with links to orogenic events and rifting events (Jones et al. 2013; Chandler and González-Álvarez 2022). In Australia, a majority of the magmatic-related REE deposits occur in intraplate tectonic settings associated with crustal-scale structures (Spandler et al. 2020). Though spatially, and sometimes temporally related, carbonatites, alkaline igneous rocks and pegmatites are each geochemically and mineralogically distinct and are here considered separately. A majority of the global REE supply comes from these types of deposits.

Many of the magmatic-related REE deposits are also associated with significant resources of high field strength elements (HFSE) (Nb, Zr, Hf and Ta) as well as Fe in some carbonatite complexes such as the Bayan Obo Nb-Fe-REE deposit (Huleatt 2019; Hou et al. 2020). Minor amounts of REE are also sourced from the recycling of permanent magnets (Jowitt et al. 2018).

Carbonatites

Carbonatites are mantle-derived igneous rocks with >50 wt% carbonate content and <20 wt% SiO_2 (Wang et al. 2020). They can be further subdivided into calciocarbonatite, magnesiocarbonatite, ferrocarbonatite, natrocarbonatite and silicocarbonatite based on the relative proportions of CaO, MgO, FeO_T, Na_2O (including K and Ca) and SiO_2 respectively (Wang et al. 2020; Chandler and González-Álvarez 2022). Most carbonatites are plutonic to subvolcanic in nature and occur largely at cratonic margins and in association with crustal-scale lithospheric faults (Wang et al. 2020; Chandler and González-Álvarez 2022).

Key REE-bearing minerals in carbonatites include monazite, xenotime, apatite and REE-carbonates (bastnäsite, synchysite and parasite; Table 2). Except for xenotime, these minerals are generally more enriched in LREE compared to HREE. Carbonatite-hosted REE deposits provide the majority of the world's LREE (Verplanck 2017). A majority of economical carbonatite REE deposits occur in China, Brazil, Australia, United States, Russia, India, South Africa, Vietnam, Burundi and Malawi (Wang et al. 2020). The Bayan Obo REE carbonatite complex in China is currently one of the largest global suppliers of REE (Wang et al. 2020). Economic viability of many carbonatite deposits is typically achieved through secondary hydrothermal and supergene processes that remobilise and concentrate REE as secondary mineral phases such as monazite, rhabdophane or gorceixite (Verplanck 2017; Wang et al. 2020; Slezak et al. 2021).

Ore grades in carbonatites are typically highest of all global REE deposits (Jaireth et al. 2014; Spandler et al. 2020), with grades of up to 20% TREO (REE_2O_3) reported in calcic carbonatite dykes associated with the Bayan Obo carbonatite complex in China (Wang et al. 2020). The Mt Weld deposit in Western Australia's Yilgarn Craton contains over 54.3 Mt @ 5.2% TREO (Lynas Rare Earths Ltd 2023), while the Gifford Creek Carbonatite Complex in Western Australia's

Gascoyne Province is also emerging as a prominent REE district, with 29.93 Mt @ 0.93% TREO contained in the Yangibana Project (Hastings Technology Metals Ltd 2023) and a further 20.06 Mt @ 1.03% TREO currently defined in the Mangaroon Project (Dreadnought Resources Ltd 2023).

Peralkaline/alkaline igneous rocks

Peralkaline/alkaline igneous rocks typically form by low-degree partial melting of enriched mantle sources in rift-related settings, with REE and HFSE endowment reached by extensive fractionation of primary magmas to largely felsic endmembers, for both intrusive (alkaline/peralkaline granites and syenites) and extrusive (trachytes and rhyolites) rocks (Spandler et al. 2020). However, many REE-bearing alkaline igneous rocks also form in syn- to- post-collisional tectonic settings, akin to those of the Miannin-Dechang Belt in China (Goodenough et al. 2021). Hydrothermal alteration in these types of rocks is typically minor and redistributes REE at a local scale (Spandler et al. 2020). The typical REE grades in these types of deposits in Australia are typically much less than that of carbonatites (<1 wt%), with the economic viability of these deposits substantially improved by the occurrence of significant HFSE (Nb, Zr, Ta and Hf) mineralisation in addition to REE.

The main REE-bearing phases in these types of deposits are bastnäsite, eudialyte, loparite, xenotime, monazite, and fergusonite (Dostal 2017). In Australia, the most prospective rocks for this type of deposit are the Toongi Volcanics near Dubbo (NSW) and Paleoproterozoic volcanic rocks in the Halls Creek Orogen (e.g., Brockman deposit, WA). The Toongi deposit (also known as the Dubbo Zirconia Project) has a total Mineral Resource of 75.18 Mt @ 0.88 % TREO (including Y_2O_3), with significant grades also noted for ZrO_2 (1.89 %), and Nb_2O_5 (0.44 %) (Australian Strategic Materials Ltd 2023). The Brockman deposit in Western Australia is hosted by alkaline volcanics (known as Niobium Tuff) that erupted into a rift-related shallow marine environment (Spandler et al. 2020). The deposit contains an Inferred Mineral Resource of 41.6 Mt @ 0.20% TREO (0.17% HREO), along with 0.86% ZrO_2 and 0.35% Nb_2O_5 (Hastings Technology Metals Ltd 2023). Although a number of alkaline rock-hosted REE deposits are in advanced stages of exploration, the only REE deposits that are actively mined at present are those on the Kola Peninsula in Russia (Dostal 2017).

Pegmatites

Pegmatites with potentially economic concentrations of REE are typically grouped based on their chemical associations into two categories:

- Lithium-Caesium-Tantalum (LCT) granitic pegmatites, typically enriched in Li, Cs, Ta, Be, B, F, P, Mn, Ga, Rb, Nb, Sn and Hf
- Niobium-Yttrium-Fluorine (NYF) pegmatites, typically enriched in Be, Sn, B, Nb, Ta, Ti, Y, REE, Zr, Th, U, Sc and F, but depleted in Li, Cs and Rb

LCT pegmatites typically do not yield high concentrations of REE metals and are considered uneconomic for REE production. However, the NYF class of pegmatites are typically associated with REE mineralisation and are spatially and temporally related to their A-type metaluminous- to-alkaline (locally peralkaline) parental melts and granitic bodies from which they evolve by extensive fractionation (Goodenough et al. 2019). Most of the worldwide NYF occurrences are in Mongolia (Khan Bogd), Canada (Strange Lake) and Namibia (Amis Complex) showing close spatial associations between them and large granitic intrusions (Goodenough et al. 2019). Many of the pegmatites are found within the roof zones of the large granitic bodies (Goodenough et al. 2019; Duuring 2020). Structures, fabrics and bedding in surrounding country rocks typically control their emplacement (Duuring 2020).

Most REE-bearing NYF pegmatites are uneconomic due to their relatively small size, highly variable grades, spatially disseminated nature and complex mineralogy that is not amenable to easy extraction and processing. Most of the production of REE from pegmatites took place in the first half of the 1900s, but these operations were small and short lived (Chakhmouradian and Zaitsev 2012). There are currently no operating REE pegmatite mines.

HYDROTHERMAL REE DEPOSITS (MAGMATIC-RELATED AND UNRELATED)

This class of REE deposits typically forms due to significant hydrothermal activity that is commonly associated with magmatic activity, though in many cases evidence for magmatic precursors is lacking or highly debated, e.g., Nolans Bore, NT (Huston et al. 2016; Anenburg et al. 2020). Diversity in the styles of mineralisation that fall under this category impedes simplistic mineral systems model or separation into their respective categories, therefore, an attempt is made here to categorise these deposits based on their relationship with magmatic activity including no magmatic hydrothermal input (unconformity-related deposits) and magmatic-hydrothermal vein, skarn and breccia-hosted deposits.

Unconformity-related REE deposits

Unconformity-related REE deposits are a relatively newly recognised class of deposit with two main REE occurrences of economic interest that includes significant mineralisation: Browns Range Dome in the Tanami Region of northern Australia (Nazari-Dehkordi et al. 2020) and the Maw Zone in the Athabasca Basin in Canada (Rabiei et al. 2017). The principal REE bearing mineral in these deposits is xenotime, with minor florencite (Table 1). The xenotime is highly attractive due to its higher HREE concentrations, compared to higher LREE concentrations in florencite (Walsh and Spandler 2023).

Total REE grades between the seven deposits along the Browns Range Dome vary between 0.21–2.33% TREO, with a total Mineral Resource of 10.81 Mt @ 0.76% TREO. Wolverine, the largest deposit has a resource of 6.44 Mt @ 0.9% TREO (Northern Minerals Ltd 2023). Economic viability of this type of mineralisation is high due to the shallow depth of the mineralisation and simplistic REE mineralogy that allows for easy processing of the ore.

Vein-, skarn- and breccia-hosted REE deposits

Vein- and breccia-hosted REE deposits are commonly associated with magmatic-hydrothermal intrusions, with both direct (observed magmatic intrusions) and indirect (magmatic intrusions at depth) evidence for involvement of fertile magmas. These types of deposits typically develop due to melting of metasomatised, enriched mantle, with crustal-scale structures providing conduits for melt and fluid migration (Groves et al. 2010; Skirrow et al. 2018). In some instances, the presence of magmatic activity is inferred based on chemistry and alteration associated with this style of mineralisation, with direct evidence of magmatic intrusion often lacking (e.g., carbonatitic magmatic affinity for REE mineralisation at Nolans Bore, NT (Anenburg et al. 2020). Other examples of vein-hosted REE mineralisation suggest mixing of basinal brines and magmatic fluids that concentrate along structural corridors, e.g., Lemhi Pass and Diamond Creek REE-Th district, USA.

Due to the diversity in mineralisation styles that are encompassed by this classification, the deposit types can be further subdivided into:

- Iron oxide – phosphate (e.g., apatite, monazite) ± REE vein-hosted deposits
- Iron oxide-copper-gold (IOCG) ± U-REE deposits
- Iron oxide-apatite deposits (IOA)
- Skarn REE deposits

Reflective of the diversity of these deposits is the variation in REE grades, thus some magmatic-hydrothermal deposits are more prospective than others. For example, iron oxide-apatite deposits are generally more prospective for REE mineralisation due to potentially higher grades and simpler REE mineralogy (Kumar et al. 2022; Slack et al. 2016), whereas the world’s largest IOCG deposit, Olympic Dam, contains an estimated Mineral Resource (not an official Mineral Resource according to JORC code 2012) of 10,400 Mt @ 0.37% TREO (Cook et al. 2023).

At present, beneficiation and extraction of this vast resource of REE as a by-product of Cu and Au extraction is challenging due to the fine particle size and variety of the REE minerals (bastnäsite, florencite, synchysite, monazite, plumbogummite-group minerals, fluorapatite and xenotime). The Nolans Bore deposit contains a total Mineral Resource of 56 Mt @ 2.6% TREO (Arafura Rare Earths Ltd 2023) and has a relatively simple mineralogy in fluorapatite, allowing for a more streamlined metallurgical approach. Iron oxide-apatite deposits such as those found in the Mineville district and Pea Ridge in the USA, have mine tailings that contain Mineral Resources of 15.7 Mt @ 1.04% TREO and 0.6 Mt @ 12% TREO respectively (Orris and Grauch 2002). The majority of the REE here is contained within apatite. Skarn REE deposits, such as Mary Kathleen in Queensland, are formed by metasomatism of calc-silicate host rocks, which can reach grades of up to 4% total REE, with allanite and stillwellite as the primary REE bearing minerals.

In many of these systems, uranium is often transported in REE bearing fluids responsible for mineralisation, which presents environmental and metallurgical challenges for REE extraction (Parker 2022). Currently, there are no operating mines that produce REE from these types of deposits.

PLACER DEPOSITS

Heavy mineral sand (HMS) deposits – coastal

Historically, heavy mineral sand (HMS) deposits have been one of the most significant sources of REE, with a great proportion of global REE supplied from HMS deposits in Australia in the early 1900s. These deposits form by weathering and erosion of igneous and metamorphic terranes and subsequent accumulation of eroded materials in coastal areas where they are mechanically concentrated and sorted by their density by a combination of processes such as tidal action, longshore currents, waves, wind, and natural traps (Jackson and Christiansen 1993). The main REE-bearing minerals in HMS deposits are monazite, xenotime and, to a lesser extent, bastnäsite. They are typically found along paleo-beaches (and to a lesser extent near modern beaches) and/or shorelines, forming strandlines that are easily mined by dry and wet (dredging below water table) mining methods (Iluka Resources Ltd 2009).

The principal commodities targeted are zirconium and titanium (ilmenite, rutile, leucoxene), with REE-bearing minerals, monazite and xenotime, typically treated as a by-product of zircon and titanium production. Typical grades are reported as a percentage of total heavy mineral component in the sand, with individual minerals reported in percentages of the total HMS assemblage. For example, Iluka Resources reported a total resource of 325 Mt, including measured, indicated and inferred resources, grading at 4.9% HM from the Eucla Basin in South Australia. Of that, REE minerals (monazite and xenotime) make up a total of 0.3% of the Mineral Resource, equivalent to 975,000 t of REE mineral concentrate (Iluka Resources Reserve Inventory 2022). Production of REE concentrate from HMS is currently lacking, however, the first REE refinery at Eneabba is being established in Western Australia that will be fed by REE mineral concentrate from HMS. The first production is expected to commence in late 2025, producing up to 23,000 t per annum of REO concentrate (Australian Trade and Investment Commission 2024).

Production of REE from HMS deposits poses some transportation and environmental challenges due to high concentrations of uranium and thorium in monazite. Some mitigation strategies include blending monazite with silt and waste sands, and/or ilmenite ore to allow for easier transportation, while some countries such as India, China, France, Norway and Brazil support storage and extraction of thorium for potential use in nuclear reactors (McNulty et al. 2022).

Channel and alluvial placer deposits

Channel and alluvial placer deposits are represented by thin to thick (metre to tens of metres) accumulations of heavy minerals (rutile, ilmenite, zircon, monazite, xenotime etc.) in alluvial fans and fluvial channels. Monazite and xenotime are the main host minerals for REE mineralisation. These types of deposits often face similar handling and environmental issues as heavy mineral sands when dealing with the uranium and thorium content in monazite.

Fluvial channel HMS deposits are typically smaller than the coastal HMS accumulations but can also contain significant resources of monazite. The Calypso deposit in Western Australia is a fluvial channel placer deposit thought to have formed as part of a braided fluvial system that was active during the Mesozoic (Jaireth et al. 2014). It contains a resource of 51.5 Mt @ 1.7% heavy minerals, with close to 16,000 t of monazite with inferred average REE content of 45–60% (Jaireth et al. 2014). In Central Australia, alluvial outwash fans, which formed from the weathering, erosion and subsequent deposition of older Proterozoic metasedimentary and igneous rocks, can also host significant concentrations of REE-bearing HMS, such as the Charley Creek deposit in the Northern Territory. The REE grades at Charley Creek are typically low, with an Indicated Mineral Resource of 387 Mt @ 295 ppm total REE (Enova Mining Ltd 2022). However, the lower costs involved with mining these deposits can make them economically viable.

SEDIMENTARY DEPOSITS

REE-rich phosphorites

Phosphorites are phosphate-rich sedimentary rocks, with greater than 18–20 wt.% P_2O_5 and mined as a phosphate fertiliser. The primary mineral (and host to the REE mineralisation) is carbonate fluorapatite (Table 1), hosting up to 0.5–1 wt% REE (Valetich et al. 2022). Phosphorites are typically deposited in shallow marine basins and are primarily younger than the Neoproterozoic, with only a handful of Paleoproterozoic occurrences known worldwide (Dar et al. 2015; Hiatt et al. 2015). Post-depositional modification due to weathering can significantly enhance the concentration of REE in phosphorites, through formation of plumbogummite-group minerals in areas where phosphorite is interbedded or overlain by aluminium-rich sedimentary rocks, such as clays and shales, for example, the Korella and Ardmore deposits in Queensland (Jaireth et al. 2014).

Worldwide, large phosphorite deposits occur along the margins of northern Africa, Europe, Russia, China, Brazil, USA and Australia (Emsbo et al. 2015). In Australia, the greatest accumulations of REE-rich phosphorites can be found along the SE margin of the Georgina Basin in Queensland. (Valetich et al. 2022). In particular, the Ardmore deposit contains Total Ore Reserves of 10.1 Mt @ 30.2 wt.% P_2O_5 with an average grade of 0.16 % TREO (Centrex Metals Ltd 2021; Valetich et al. 2022) and the Phosphate Hill mine contains an unofficial estimated Mineral Resource (not according to JORC code 2012) calculated from the average REE concentrations in the phosphorites at the Phosphate Hill mine by Valetich et al (2023) of 127.6 Mt @ 0.06% TREO. Though total REO grades in phosphorites are typically <1%, these deposits are often associated with large tonnages (>100 Mt), simple mineralogy, and rocks of a shallow and friable nature that allow for the cheap extraction of REE as a by-product of fertiliser production. These deposits are therefore desirable exploration targets. Assessment on the extraction of REE as a by-product of phosphate fertiliser production is currently being carried out by many companies exploring and mining phosphate in the Georgina Basin and globally (Emsbo et al. 2016).

Coal and coal ash REE deposits

Many authors and mining companies have recognised that coal deposits contain considerable concentrations of REE (>0.1%), with some considering extraction of REE from coal ash combustion products (Seredin and Dai 2012). The mechanisms of REE enrichment in coals are highly debated and varied, with Seredin and Dai (2012) subdividing them into four genetic types:

- Terrigeneous – REE input by surface waters
- Tuffaceous – REE enrichment due to falling and leaching of acid and alkaline volcanic ash
- Infiltrational – REE enrichment driven by meteoric water and deep fluids
- Hydrothermal – REE enrichment due to ascending hydrothermal and deep fluids

In most instances, REE are hosted in fine-grained authigenic phosphates, aluminophates, carbonates and sulphates as well as organic compounds (Seredin and Dei 2012). Many studies have also demonstrated the potential for extraction of REE as by-products of coal mining and combustion, with REE grades in coal ash for many deposits worldwide as high as 1% REO (Seredin et al. 2013). There are currently no REE produced from these types of deposits.

SURFICIAL (DEEP WEATHERING) DEPOSITS

Clay-hosted REE deposits

Much of the global REE supply is produced from ion-adsorption clay deposits (Rezaei et al. 2022) in southern China (Yin and Song 2022) with new discoveries also recently reported from Madagascar (Borst et al. 2020). Ionic clay-hosted REE deposits form through intense weathering, typically of igneous rocks such as granites. Grades in these deposits are typically low (>100 ppm), however, they are often enriched in HREE relative to LREE. The ease of extraction of REE from these types of deposits through heap leach processes or in-situ leaching using ammonium sulphate makes them an attractive exploration target (Borst et al. 2020).

There have been several recent discoveries of REE-rich clays along the southern margin of Australia, extending from near Esperance on the south coast of Western Australia to the Gawler Craton, Flinders Ranges and southeast of South Australia. However, many companies have reported poor recoveries of REE from these clays, suggesting that REE are likely to be hosted in secondary minerals such as rhabdophane, cerite or bastnäsite. For this reason, they are referred to as ‘clay-hosted’ rather than ‘ionic adsorption’ (Rezaei et al. 2022) clay deposits that typify the deposits exploited in China. Recent industry evaluation of recovery rates from clay-hosted REE deposits in South Australia are relatively low, with some recoveries as low as 28–65% for neodymium, praseodymium, dysprosium and terbium (iTech Minerals 2022a). Others are slightly better at 63–82% for the same elements, albeit at highly acidic conditions using an aqua regia mixed acid digest (Taruga Minerals Ltd 2022).

The recovery rates of REE from clay-hosted deposits are significantly lower than the ~80–90% recoveries obtained from ionic adsorption clays in China (Moldoveanu and Papangelakis 2013). Extensive work is currently underway to understand the mineralogical composition of these types of deposits to development of metallurgical flowsheets to liberate REE from secondary minerals in the clays. Recently, Australian Rare Earths produced REE carbonate from their Koppamurra prospect in South Australia and are on track to establish the first metallurgical flowsheet for extraction of REE from clay-hosted REE deposits (Australian Rare Earths Ltd 2023).

Residual (laterite) deposits

Residual laterite REE deposits typically develop due to extensive weathering of primary igneous rocks enriched in REE, e.g., alkaline rocks and carbonatites (Cocker 2012). Remobilisation and subsequent re-precipitation of REE as secondary minerals along with the removal of primary igneous minerals can result in REE enrichments between 3 to 10 times (even up to 100 times) higher compared to primary source rocks. Laterite deposits are considered separately here from clay-hosted REE deposits as clay minerals can be both present or absent in laterite deposits, with the mineralisation hosted solely in secondary REE-bearing minerals such as monazite, rhabdophane, apatite, xenotime, plumbogummite-group minerals, carianite and chruchite.

The Mt Weld deposit in WA, though described as a carbonatite, is actually an example of a laterite deposit where a thick lateritic profile developed in the upper part of the carbonatite rock due to deep and intense weathering. Grades in these types of rocks can be quite high, for example, <45% TREO at Mt Weld (Weng et al. 2015). Other examples of upgrading REE enrichment through extensive weathering and laterite development include deposits such as Bear Lodge in the USA, Araxa in Brazil (5% TREO), Chuktukon in Russia (6% TREO), and Yangibana in Western Australia (~1% TREO), the latter hosted within phosphatic ironstones from the weathering of primary ferro-carbonatite (Spandler et al. 2020; Zhukova et al. 2021). Operating mines include the Mt Weld mine in Western Australia and the Ngualla mine in Tanzania, currently on track to become the next largest laterite REE deposit outside of Australia and China, with production expected to reach 37.2 kt per annum of 45% TREO concentrate (Peak Rare Earths Ltd 2022).

MINE WASTE

Although not a mineralisation style, it is important to recognise the potential to produce REE and other critical minerals as by-products from mine waste of previous operations of the deposit types listed above. Waste materials from the processing of mine ores includes waste rock, tailings and pyrometallurgical waste (slag). It is estimated that approximately 4 Bt of coarse waste rock and fine tailings are produced globally per annum (Lèbre et al. 2017). Increasing interest in the potential economic benefits of deriving critical metals from mine waste is forcing governments and the private sector to re-evaluate many abandoned mine sites and processing facilities, as well as current operations where critical metal concentrations had not been investigated. This comes at a time when the demand for critical metals is rapidly growing to satisfy clean energy technologies. Many agencies are now examining ways to create a green/circular economy for efficient use, conservation and recovery of scarce resources (Jackson et al. 2023). Historic mine tailings and smelter slags are now being reprocessed to recover minerals that were previously uneconomic or unattainable due to technological constraints at the time. For example, since 2002, copper and cobalt has been recovered from mining centres in the Republic of Congo, helping to improve both environment and productivity (Lutandula and Maloba 2013).

OCCURRENCES IN SOUTH AUSTRALIA

In South Australia, REE mineralisation has traditionally been associated with vein-, skarn- and breccia-hosted deposits where REE are listed as a secondary commodity after copper, gold or iron ore. Olympic Dam contains one of the largest resources of REE globally, with an unofficial Mineral Resource estimate of 10,400 Mt grading at 0.37% TREO (Cook et al. 2023). Overall, the vein and breccia hosted REE deposits make up 56% of the total occurrences in South Australia (Fig. 2a). This is in stark contrast to other global occurrences, which are often restricted to carbonatites, alkaline igneous and heavy mineral sands (Fig. 2b). Heavy mineral sand operations in South Australia have been focused on the production of zirconium and titanium, with REE minerals from HMS operations in the Eucla Basin, such as Jacinth-Ambrosia, currently stockpiled at Eneabba in Western Australia. Deep weathering processes associated with development of lateritic profiles and clay-hosted REE deposits are the second leading contributor to overall REE occurrences in South Australia (Fig. 2a).

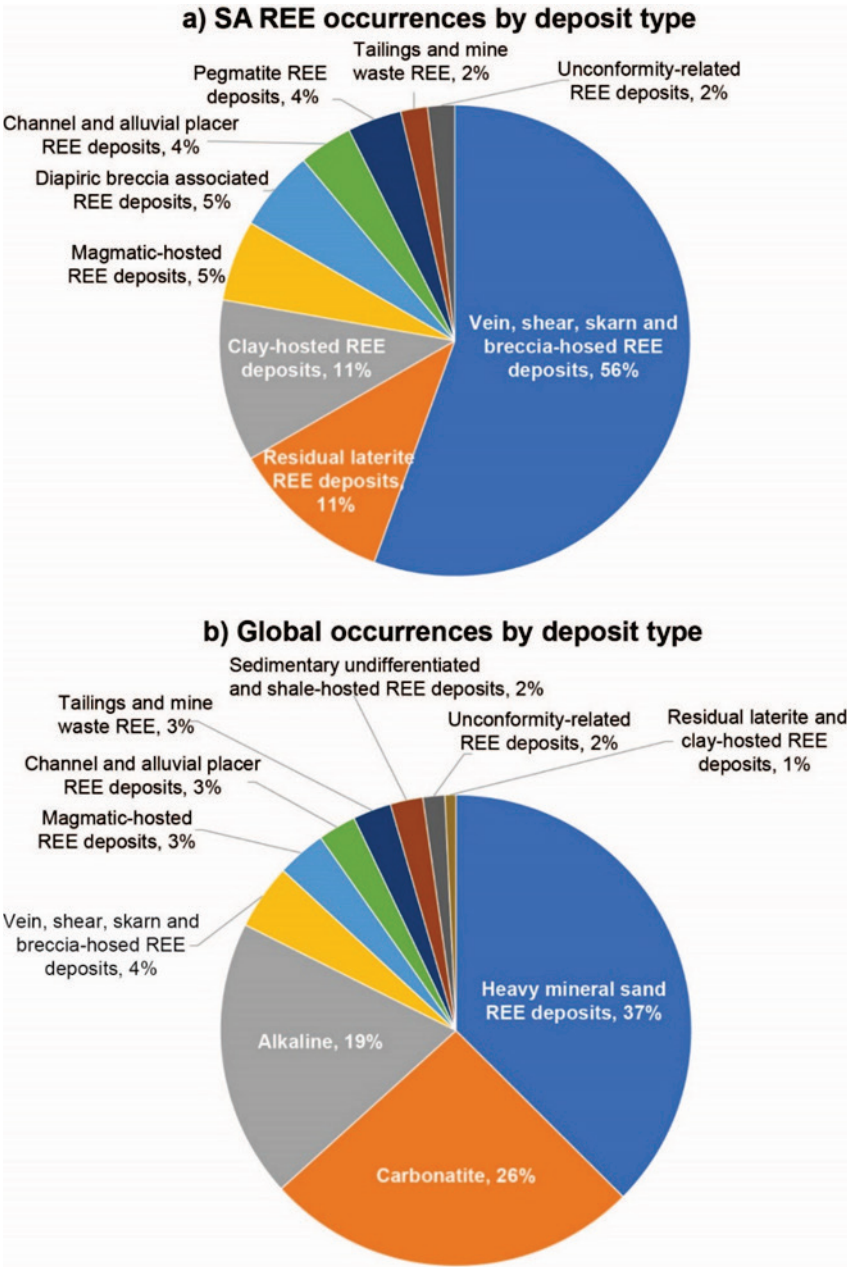

Figure 2. **Relative proportions of different rare earth element (REE) occurrences by deposit type in (a) South Australia (SA Geodata MINDEP Database, Department for Energy and Mining, South Australia) and (b) globally (Weng et al. 2015).**

SURFICIAL (DEEP WEATHERING) DEPOSITS

Over the past few years, there has been significant interest across South Australia for clay-hosted REE deposits. As previously mentioned, the mineralisation in majority of Australian clay REE deposits is hosted within secondary minerals, which presents challenges for REE extraction compared to ion-adsorption clay deposits. An exception to this is the Boland project which is an ionic clay-hosted REE prospect that occurs in paleochannel sediments on the Eyre Peninsula. There have been multiple intersections >1,000 ppm TREO, with the proportion of HREE representing up to 40% of TREO (Cobra Minerals PLC 2024a). The footprint of mineralisation is currently >33 km^2 and remains open in multiple directions. Metallurgical test work results from a sample of 2,688 ppm TREO returned recoveries of 41% TREO, with a high proportion of MREO and HREO (532 ppm Nd_2O_3 + Pr_6O_{11} and 83 ppm Dy_2O_3 + Tb_2O_3). Importantly, these results were achieved ambient temperature conditions and a pH of 3 (Cobra Minerals PLC 2024b). Work is continuing assessing the viability of REE extraction via in-situ leaching in the paleochannel, similar to methods used for uranium mining in other parts of South Australia.

There are other noteworthy clay-hosted occurrences across South Australia, these are spread across various geological provinces and basins.

The Koppamurra deposit (MinDep no. 11871) contains a Total Mineral Resource of 186 Mt @ 712 ppm TREO and has significant potential for growth with work underway on a pilot plant for REE carbonate processing (Australian Rare Earths Ltd 2023).

In the Gawler Craton, recent assay results from drilling at Minos (MinDep no. 11182), returned best results of 4.67% TREO and 2.23% MREO from a 1 m interval (Indiana Resources Ltd 2023). Multiple near-surface intersections of >1000 ppm TREO over 4+ m have been reported at Target 21, located east of Aurora Tank, in intensely weathered Mulgathing Complex (Marmota Ltd 2024). Slightly higher grades and thicknesses have been reported from the nearby Comet project, predominantly within intensely weathered mafic units (Petratherm 2024).

On the Eyre Peninsula, Caralue Bluff (MinDep no. 9323), a prospect containing thick intervals of kaolin close to the surface with elevated REE mineralisation over an extended area of 10x9 km. This project has an exploration target of 110–220 Mt @ 635–832 ppm TREO and 19–22% Al_2O_3 (iTech Minerals Ltd 2022b). Recent exploration activity targeting halloysite at Dickson Well (MinDep no. 11899) on the Eyre Peninsula, has identified some significant REE mineralisation, with multiple intersections averaging >0.5% TREO, including 1 m at 1.4% TREO in one drillhole (Power Minerals Ltd 2024). Exploration at the Franklyn prospect (MinDep no. 10098), 15 km east of Terowie in the mid-north of the state, has identified halloysite-kaolinite mineralisation with numerous assays reporting >1,000 ppm TREO over 3–4 m in kaolin-rich intervals over a large area (iTECH Minerals Ltd 2024; iTECH Minerals 2022a, b).

At Morgan’s Creek (MinDep no. 11900) in the Adelaide Rift Complex, drilling has outlined a clay-hosted REE occurrence formed above the Yednalue Quartzite where REE occurs from depths <20 m. The best intercept recorded was 1m @ 9,082 ppm TREO (Taruga Minerals Ltd 2022). Other significant anomalous intercepts of REE have also been found in the weathered sedimentary rocks of the Callanna Group in the Flinders Ranges that are largely spatially related to diapiric breccias that occur throughout the Adelaide Rift Complex.

Cobra Resources Plc have also announced an Inferred Mineral Resource of 41.6 Mt @ 699 ppm TREO from the clay-hosted Wudinna REE project (Cobra Resources PLC 2023).

MAGMATIC-RELATED REE DEPOSITS

Carbonatites are globally the most significant sources of REE. At present, no carbonatite-related REE deposits have been discovered in South Australia due to the lack of carbonatite complexes identified in South Australia (Chandler and González-Álvarez 2022). However, there are multiple regions with carbonatite potential across the State. In the Adelaide Rift Complex, carbonatite-rich lamprophyric intrusions associated with Jurassic-aged kimberlites from the Walloway Diapir have enriched concentrations of lanthanum, cerium, niobium, barium and strontium that have been interpreted to be of carbonatitic origin (Tucker and Collerson 1972). The potential for associated economic REE and niobium mineralisation is currently undetermined as the scale of the carbonatite system in this region is poorly understood. Recent assay results of a kimberlite sample contained 1.02% TREO and 0.082% Nb, reaffirming exploration for carbonatite mineralisation in this area (Olympio Metals 2023).

The Billeroo North Alkaline Magmatic Complex in the Curnamona Province is also prospective for carbonatites. Carbonatites are commonly associated with highly alkaline magmatic rocks, as both rock types form in highly fractionated magmatic systems that have undergone low-degree partial melting (Yaxley et al. 2022). Elevated concentrations of phosphorus (up to 1.24%) and europium (up to 0.14%) have been found in samples of lampophyre and ijolite rocks from the Billeroo carbonatite (MinDep no. 10599). A carbonate-rich breccia of possible carbonatitic origin has been mapped but requires more work to better understand the potential of this alkaline complex. The Oolgelima Intrusive Complex (OIC) in the northern Gawler Craton may also have potential to host cabonatites, having a circular geometry in magnetic imagery reminiscent of the ring dykes and cone sheets that are often seen in carbonatite complexes (Simandl and Paradis 2018, Swain 2022). In addition, a two-metre intersection of 2.55% La+Ce from a depth of 150 m, was found at Cadi (MinDep no. 8437), near the margin of the OIC. These enriched LREE values have enhanced speculation on the carbonatitic affinities of the OIC (Swain 2022).

Pegmatite-hosted REE mineralisation are very limited and are largely restricted to the Musgrave Province and northern Gawler Craton (Fig. 1).

HYDROTHERMAL REE DEPOSITS (WITH OR WITHOUT MAGMATIC-HYDROTHERMAL INPUT)

The largest, most significant deposit in this category is the Olympic Dam IOCG deposit in the Gawler Craton region of South Australia. Olympic Dam is world class deposit of copper and uranium with significant gold, silver, REE and other critical minerals. The Olympic Dam deposit has a Total Mineral Resource of 11.38 Gt (BHP 2023). REE-bearing minerals are also noted in South Australia’s other IOCG mines at Prominent Hill and Carrapateena (Sawyer et al. 2017; Porter 2020), as well as occurrences in the Curnamona Province, which are largely restricted to the Olary, Mulyungarie and Moolawatana domains, including deposits such as Kalkaroo, Radium Hill, Mount Victoria and Gunsight. However, further work needs to be done to understand the viability of REE production as a by-product of current mining operations.

Extraction of REE is not seen as economically recoverable through current flotation and smelter/refinery operations. The ore at Olympic Dam is a hematite-dominant breccia containing various REE minerals such as bastnäsite, synchysite, florencite, monazite and xenotime (Cook et al. 2021). These minerals end up in flotation tailings and wastes at the mine site.

PLACER DEPOSITS

The Jacinth-Ambrosia heavy minerals deposit (MinDep no. 8344) is the world’s largest producer of zircon, with rutile, ilmenite, monazite and xenotime also mined. A Total Mineral Resource for the Eucla Basin deposits stands at 322 Mt @ 4.9% HM (Iluka Resources Ltd 2023). Monazite and xenotime collectively constitute approximately 0.3% of the heavy mineral content in these deposits, however, they are not being processed for REE currently. Total production for 2023 from Jacinth-Ambrosia was ~326 kt of heavy mineral concentrate, which is shipped to the Narngulu mineral separation plant in Western Australia (Iluka Resources Ltd 2023).

Coal ash from coal fired power generation has emerged as a potential source of REE and is appealing as reprocessing would assist removing millions of tonnes of toxic dust from the environment while being a source of various critical minerals (Creamer 2023). South Australia’s only coal fired power stations at Port Augusta have been demolished since they ceased operation in 2016. The site has since been undergoing rehabilitation. The ash from this site was causing a serious public health risk as it was becoming airborne (Flinders Power 2019). Fly ash at Port Augusta has previously been targeted for use as an additive to produce ‘green’ cement (Hallet Group 2022) and therefore the REE potential of this coal ash has not been explored.

Channel and alluvial placer REE occurrences are very limited in South Australia and are largely restricted to the Musgrave Province and northern Gawler Craton.

MINE WASTE

From 1954–1962 the South Australian Government operated the Radium Hill Uranium mine close to the SA-NSW border in the Curnamona Province, processing the ore in Port Pirie. The davidite ore mined at Radium Hill was enriched in REE, however, at the time of operation only uranium was extracted and the REE remained in the tailings dams. These dams are estimated to contain around 172,365 t of material with approximately 1,500 t of REE residing within these tailings as oxides of 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%), ytterbium (6.5%) and lutetium (0.6%) (Jackson et al. 2023).

Tailings at Olympic Dam is known to have dominantly LREE minerals present within the ore but are currently not considered viable to recover. An estimated 180 Mt of tailings have been produced there to date and reside in on-site tailings storage facilities. These tailings have potential to recover REE in the future (Jackson et al. 2023).

PROSPECTIVITY IN SOUTH AUSTRALIA

There are opportunities to establish a rare earth industry in South Australia, producing not only rare earth concentrates but value adding through further processing (The South Australian Centre for Economic Studies 2024). A summary of the most prospective REE deposit types and mineral provinces in South Australia is provided in Table 3.

Globally, the majority of REE resources are hosted in carbonatites, alkaline rocks and heavy mineral sands (Fig. 2b), though this does not necessarily reflect the production of REE, which comes primarily from carbonatite and ionic adsorption clay REE deposits in China (Weng et al. 2015). At present, Australia produces REE from a single mine, Mt Weld in Western Australia, with the Eneabba Rare Earths refinery in Western Australia expected to come into production in 2025 (Iluka Resources Ltd 2022). The Eneabba refinery is being designed to liberate REE from monazite and xenotime derived from heavy mineral sands, such as from Jacinth-Ambrosia in South Australia, as well as xenotime from unconformity-related REE deposits, such as Browns Range in Western Australia.

The economic viability of REE deposits in Australia is likely to be higher for deposits that contain monazite and/or xenotime as the primary REE-bearing minerals due to their relative simplicity in processing. For this reason, the Murray and Eucla Basins in South Australia are highly prospective for REE related to heavy mineral sand deposits.

The most prospective domains for vein, skarn and breccia hosted REE deposits in South Australia include the eastern margin of the Gawler Craton (Olympic Domain) and the Curnamona Province. Deposits include e.g., Olympic Dam, Carrapateena and Kalkaroo. However, extraction of REE from these types of deposits as a by-product of Cu and/or Au production is technologically challenging at present due to complex mineralogy and fine grain size of REE minerals. The viability of these types of deposits may improve with future technological advances and the discovery of large deposits with relatively simple mineralogy, such as at Nolans Bore in the Northern Territory.

Clay-hosted REE deposits are the focus of many companies operating in South Australia. While it is difficult to predict where these might occur, the most prospective domains appear to be in areas with deep weathering profiles, such as in-situ saprolite and regolith clays present in many parts of the Gawler Craton, and in transported clay-hosted deposits such as Koppamurra. Sediments of the Neoproterozoic Callanna Group associated with diapirs and diapiric breccias in the Adelaide Rift Complex, the Blanchetown Clay in the Murray Basin and clay-rich zones developed over existing Cu and/or Au mineralisation are also prospective. The recent discovery of ion adsorption clay REE mineralisation within paleochannel sediments at the Boland prospect indicates additional prospectivity for REE mineralisation in paleochannel systems. More research is required to understand the controls on this style of REE mineralisation, however, South Australia’s extensive paleochannel systems present significant exploration opportunities (Hou et al. 2012; Hou et al. 2021). The potential for low-cost extraction and low environmental impact of in-situ recovery mining add to the appeal of this mineralisation style.

The link between REE mineralisation and diapirism in the Adelaide Rift Complex remains uncertain and more work is needed to characterise this style of mineralisation. Neoproterozoic- to Cambrian-aged marine sediments of the Adelaide Rift Complex may also be prospective for the phosphorite-style REE mineralisation similar to the Georgina Basin phosphorites in Queensland. Exploration for carbonatite-related REE mineralisation is challenging, however, increasing their prospectivity will result from understanding and defining their geodynamic drivers that have shaped the Archean and Proterozoic cratonic domains in South Australia (Bockmann et al. 2023). These processes have formed a large area of metasomatised, continental lithospheric mantle as the potential source for carbonatitic melts to form and numerous mantle-tapping structures that can act as conduits for mantle melts to reach the upper crust. These essential features, combined with a protracted history and punctuated by numerous thermal events, provides significant potential for many carbonatite-forming events and associated REE deposits in South Australia.

Secondary REE sources like extraction of REE from mine waste have an emerging REE source potential.

Table 3. Summary of deposit types which may contain economic concentrations of rare earth elements and regions of South Australia.

Key deposit types	Regions of interest in South Australia
Major deposit types:	
Vein, skarn and breccia hosted REE deposits	• IOCG and iron oxide-phosphate type deposits typically associated with Cu and Au mineralisation (e.g. Eastern Gawler Craton, Curnamona Province and Adelaide Rift Complex)
Clay-hosted REE deposits	• Areas of deep weathering, saprolitic profiles and transported clays, typically along the southern coast of South Australia and the Murray Basin (e.g. Koppamurra)
Heavy Mineral Sand REE	• Paleochannels and shorelines (e.g. Murray and Eucla Basins)
Minor deposits:	
Diapiric breccia associated REE deposits*	• Adelaide Rift Complex (e.g. Morgans Creek)
Residual (laterite) REE deposits	• Deep weathering and formation of manganese oxide deposits with REE (e.g. Curnamona Province, Musgrave Province, Adelaide Rift Complex)
Channel and alluvial placer REE deposits	• Quaternary outwash fans and fluvial channels associated with weathering of metamorphic and igneous rocks (e.g. Musgrave Province)
Pegmatite and magmatic hosted REE deposits	• Allanite-rich pegmatites (e.g. Musgrave Province) • Gawler Craton • Curnamona Province • Adelaide Rift Complex
Coal and coal ash REE deposits	• Adelaide Rift Complex • Ash dams at Port Augusta (coal mined from Leigh Creek)
Secondary resources:	
Mine waste	• Olympic Dam mine tailings • Port Pirie tailings

*Deposit style newly recognised in South Australia and not well defined. Association with diapirism inferred based on spatial proximity.

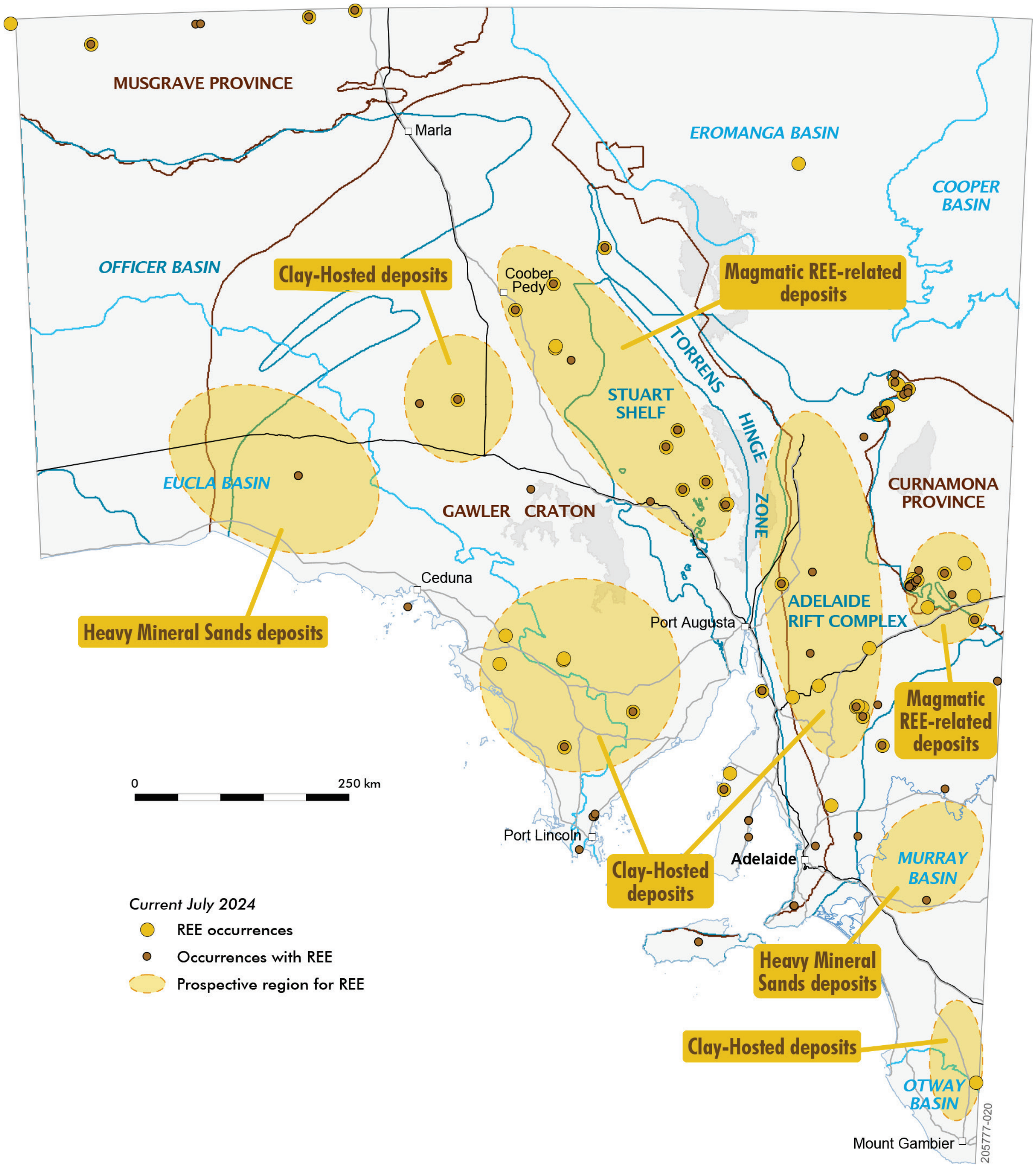

Figure 3. Rare Earths occurrences and REE-bearing minerals in South Australia with provinces, basins and rare earths regions. (205777-020 PDF 197 KB)

REFERENCES

Anenburg M, Mavrogenes JA & Bennett VC 2020. The fluorapatite P–REE–Th vein deposit at Nolans Bore: genesis by carbonatite metasomatism. *Journal of Petrology* 61 (1). https://doi.org/10.1093/petrology/egaa003

Arafura Rare Earths Ltd 2023 Annual Report. https://www.arultd.com/wp-content/uploads/2023/08/CC.02.01-Annual-Report-30-June-2023-Final-Undesigned.pdf

Australian Rare Earths Ltd 2023. AR3 commences major drilling program to expand Koppamurra Rare Earths Province*ASX Announcement*. https://investorhub.ar3.com.au/announcements/4421124

Australian Rare Earths Ltd. 2023. First Koppamurra Mixed Rare Earth Carbonate produced. *ASX Release*. https://ar3.com.au/9-3-23-first-koppamurra-mixed-rare-earth-carbonate-produced/

Australian Strategic Materials Ltd, 2023. Annual Report 2023. https://asmd.irmau.com/site/pdf/49a43eb5-8eec-439e-8733-495e202996fd/Annual-Report-to-shareholders.pdf

Australian Trade and Investment Commission 2022. Australian Critical Minerals Prospectus. https://international.austrade.gov.au/en/news-and-analysis/publications-and-reports/critical-minerals-prospectus

Australian Trade and Investment Commission 2024. Australian Critical Minerals Prospectus https://www.globalaustralia.gov.au/sites/default/files/2024-01/ATIC_Australian_Critical_Minerals_Jan_2024.pdf

BHP 2023. BHP Annual Report 2023. https://www.bhp.com/-/media/documents/investors/annual-reports/2023/230822_bhpannualreport2023.pdf

Bockmann M, Wise T, Fabris A, Krapf C & Camac B 2023. Where are South Australia's carbonatites? Poster at Ctricon 2023, Adelaide. https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/plans/sarig1/image/DDD/205751-002

Borst AM, Smith MP, Finch AA, Estrade G, Villanova-de-kenavent C, Nason P, Marquis E, Horsburgh NJ, Goodenough KM, Xu C, Kynický J & Geraki K 2020. Adsorption of rare earth elements in regolith-hosted clay deposits. *Nature Communications* 11 (4386): 1-15. https://doi.org/10.1038/s41467-020-17801-5

Castor SB & Hendrick JB 2006. Rare earth elements. *Industrial minerals and rocks: commodities, markets and uses.* Society for Mining, Metallurgy, and Exploration, pp. 769-792.

Centrex Metals Ltd. 2021. Ardmore Phosphate Rock Project - August 2021 Updated Definitive Feasibility Study. *ASX Release*. https://company-announcements.afr.com/asx/cxm/eb9b8764-faff-11eb-a6d1-8e68c7d2035e.pdf

Chakhmouradian AR & Zaitsev AN 2012. Rare earth mineralization in igneous rocks: sources and processes. *Elements* 8 (5): 347-353. https://doi.org/10.2113/gselements.8.5.347

Chandler R & González-Álvarez I 2022. Australian carbonatites: insights on geological characteristics, exploration proxies and the national prospectivity for undiscovered carbonatites and associated critical metal mineralisation. In, *Goldschmidt Hawaii 2022 Conference*. Goldschmidt https://conf.goldschmidt.info/goldschmidt/2022/meetingapp.cgi/Paper/10746

Cobra Resources PLC 2023. Wudinna Project Update. Maiden Rare Earth Resource Estimate - Unique and Unconstrained. *ASX Release*. https://polaris.brighterir.com/public/cobra_resources/news/rns/story/xle27gw

Cobra Minerals PLC 2024a. London stock exchange release 30/05/24 Cobra Resources PLC - Boland Re-Assay Results. https://investors.cobraplc.com/announcements/6359009

Cobra Minerals PLC 2024b. London stock exchange release 11/07/24 Cobra Resources PLC - ISR Bench Scale Study Update https://investors.cobraplc.com/announcements/6426673

Cocker MD 2012. Lateritic, supergene rare earth element (REE) deposits. In, *Proceedings of the 48th Annual Forum on the Geology of Industrial Minerals* Scottsdale, Arizona: https://www.researchgate.net/profile/Mark-Cocker-2/publication/299281407_Lateritic_supergene_rare_earth_element_REE_deposits/links/56f02d2c08ae0dcdafd6a42a/Lateritic-supergene-rare-earth-element-REE-deposits.pdf

Cook N, Ciobanu CL & Ehrig KJ 2021. Critical minerals in complex copper cores: realizing the potential of the word-class Olympic Dam Cu-U-Au-Ag deposit, South Australia. In American Geophysical Union (ed.), *AGU Fall Meeting 2021*. New Orleans, Louisiana: https://ui.adsabs.harvard.edu/abs/2021AGUFM.V41B..04C/abstract

Cook N J, Ciobanu C L & Ehrig KL 2023. The critical mineral potential of the Olympic Dam Cu-U-Au-Ag deposit, South Australia. In, *Critcon2023*, https://www.adelaide.edu.au/australian-critical-minerals-research-centre/ua/media/140/critcon2023_abstractvolume66.pdf

Creamer M 2023. Coal, discard seen as potential viable sources of rare earth elements. *Creamer Media's Mining Weekly*. https://www.miningweekly.com/article/coal-seen-as-potential-viable-source-of-rare-earth-elements-2023-04-05

Dar SA, Khan K, Khan SA, Khan S & Masroor Alam M 2015. Petro-mineralogical studies of the Paleoproterozoic phosphorites in the Sonrai basin, Lalitpur District, Uttar Pradesh, India. *Natural Resources Research* 24 339-348. https://doi.org/10.1007/s11053-014-9260-x

Dostal J 2017. Rare earth element deposits of alkaline igneous rocks. *Resources* 6 (34). https://doi.org/10.3390/resources6030034

Dreadnought Resources Ltd 2023. Annual Report to Shareholders. https://investorhub.dreadnoughtresources.com.au/announcements/4410505

Duuring P 2020. Rare-element pegmatites: a mineral systems analysis. 2020/7. Geological Survey of Western Australia. https://geodocsget.dmirs.wa.gov.au/api/GeoDocsGet?filekey=37896d75-0d2c-40c1-a002-65b614587d1c-6jn0xakxzvc3mu6xp7slf9mkvnep50zb31qntmbk

Emsbo P, McLaughlin PI, Breit GN, du Bray EA & Koenig AE 2015. Rare earth elements in sedimentary phosphate deposits: solution to the global REE crisis? *Gondwana Research* 27 (2): 776-785. https://doi.org/10.1016/j.gr.2014.10.008

Emsbo P, McLaughlin PI, Bray EA, Anderson ED, Vandenbroucke TRA, Zielinski RA, Verplanck PL & Hitzman MW 2016. Rare Earth Elements in Sedimentary Phosphorite Deposits: A Global Assessment.In: Verplanck PL &, Hitzman MW (Eds.) *Rare Earth and Critical Elements in Ore Deposits.* Reviews in Economic Geology, Vol. 18. Society of Economic Geologists. https://doi.org/10.5382/Rev.18.05

Flinders Power 2019. Augusta Power Stations Dust Management Plan, Demolition and Site Rehabilitation. pp. 7-8. https://www.epa.sa.gov.au/files/14254_port_augusta_dust_plan_may2019.pdf

Geoscience Australia 2023. *Rare Earth Elements*. Accessed 19/02/2024. https://www.ga.gov.au/scientific-topics/minerals/mineral-resources-and-advice/australian-resource-reviews/rare-earth-elements#:~:text=Australian%20rare%20earths%20production%20is,and%20processing%20at%20Browns%20Range.

Goodenough KM, Shaw RA, Smith M, Estrade G, Marqu E, Bernard C & Nex P 2019. Economic mineralization in pegmatites: Comparing and contrasting NYF and LCT examples. *The Canadian Mineralogist* 57 (5): 753-755. https://doi.org/10.3749/canmin.AB00013

Goodenough KM, Deady EA, Beard CD, Broom-Fendley S, Elliott HA, van den Berg F & Öztürk H 2021. Carbonatites and alkaline igneous rocks in post-collisional settings: storehouses of rare earth elements. *Journal of Earth Science* 32 (6): 1332-1358. https://doi.org/10.1007/s12583-021-1500-5

Groves DI, Bierlein FP, Meinert LD & Hitzman MW 2010. Iron oxide copper-gold (IOCG) deposits through Earth history: Implications for origin, lithospheric setting, and distinction from other epigenetic iron oxide deposits. *Economic Geology* 105 (3): 641-654. https://doi.org/10.2113/gsecongeo.105.3.641

Hastings Technology Metals Ltd 2023. Annual Report 2023. https://www.investi.com.au/api/announcements/has/03c419a2-4d6.pdf

Hallet Group 2022. *Green Cement Transformation Project*. Accessed 17/10/2023. https://hallett.com.au/index.php/green-cement-transformation-2/

Hiatt EE, Pufahl PK & Edwards CT 2015. Sedimentary phosphate and associated fossil bacteria in a Paleoproterozoic tidal flat in the 1.85 Ga Michigamme Formation, Michigan, USA. *Sedimentary Geology* 319 24-39. https://doi.org/10.1016/j.sedgeo.2015.01.006

Hou B, Fabris A, Michaelsen B, Katona L, Keeling J, Stoian L, Wilson T, Fairclough M, Cowley MW & Zang W (compilers) 2012. Geological Survey of South Australia, Department of Manufacturing, Innovation, Trade, Resources and Energy. Palaeodrainage and Cenozoic Coastal Barriers of South Australia. *Digital Geological Map of South Australia, 1:2 000 000 Series* (2nd Edition). https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/DIGIMAP00002.pdf

Hou B, Keeling JL, Reid AJ, Pobjoy R & Wu E 2021. Models, geology and exploration of heavy minerals deposits in South Australia. Report Book, 2021/00011. South Australia, Department for Energy and Mining, South Australia, Adelaide. https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB202100011.pdf

Hou X-z, Yang Z-f & Wang Z-j 2020. The occurrence characteristics and recovery potential of middle-heavy rare earth elements in the Bayan Obo deposit, Northern China. *Ore Geology Reviews* 126 103737. https://doi.org/10.1016/j.oregeorev.2020.103737

Hughes A, Britt AF, Pheeney J, Summerfield D, Senior A, Hitchman AP, Cross AJ, Sexton M, Colclough H & Hill J 2023. Australia's Identified Mineral Resources 2022, Canberra. https://d28rz98at9flks.cloudfront.net/147673/147673_00_1.pdf

Huleatt MB 2019. Australian Resource Reviews: Rare Earth Elements 2019, Canberra, Australia. p. 22 http://dx.doi.org/10.11636/9781925848441

Huston DL, Maas R, Cross A, Hussey KJ, Mernagh TP, Fraser G & Champion DC 2016. The Nolans Bore rare-earth element-phosphorus-uranium mineral system: geology, origin and post-depositional modifications. *Mineralium Deposita* 51 797-822. https://link.springer.com/article/10.1007/s00126-015-0631-y

Iluka Resources Ltd. 2009. Mineral Sands Technical Information. https://www.iluka.com/media/w2klnfof/iluka_technical_brochure_07_12_09.pdf

Iluka Resources Ltd. 2022. Eneabba Rare Earths Refinery – Final Investment Decision. *ASX Release*. https://iluka.com/media/srypf2vr/erer-fid-asx-release-final.pdf

Iluka Resources Ltd. 2023. Iluka Annual Report, Deliver Sustainable Value. https://www.iluka.com/media/e2ne2v0d/2023-annual-report-for-website.pdf

Indiana Resources Ltd. 2023. Bonanza Ree Assay Results At Minos Up To 4.67% TREO & 2.23 % MREO. *ASX Release*. https://indianaresources.com.au/wp-content/uploads/2023/04/IDA-BONANZA-REE-ASSAY-RESULTS-AT-MINOS.pdf

iTech Minerals 2022a. Metallurgy Update: Clay Hosted Ree Projects Progress To Second Round Of Testing. *ASX Release*. https://wcsecure.weblink.com.au/pdf/ITM/02579071.pdf

iTech Minerals 2022b. New Rare Earth Drill Results Expand Caralue Bluff Prospect, Eyre Peninsula Project. *ASX Release*. https://www.itechminerals.com.au/wp-content/uploads/2022/08/20220718-New-REE-Drill-Results-Expand-Caralue-Bluff-Prospect.pdf

iTECH Minerals 2024. *Nackara Arc Project - Overview*. Accessed 19/01/2024. https://www.itechminerals.com.au/projects/nackara-arc-project/

Jackson L, Corrick A, Han Z, Moyo A & Parbhakar-Fox A 2023. Secondary prospectivity of South Australia's mine waste: review. Report Book 2023/00031. Department for Energy and Mining, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB202300031.pdf.

Jackson WD & Christiansen G 1993. International Strategic Minerals Inventory Summary Report--rare-earth oxides. - United States Geological Survey. https://pubs.usgs.gov/circ/1993/0930n/report.pdf

Jaireth S, Hoatson DM & Miezitis Y 2014. Geological setting and resources of the major rare-earth-element deposits in Australia. *Ore Geology Reviews* 62 72-128. https://doi.org/10.1016/j.oregeorev.2014.02.008

Jones AP, Genge M & Carmody L 2013. Carbonate melts and carbonatites. *Reviews in Mineralogy and Geochemistry* 75 (1): 289-322. https://doi.org/10.2138/rmg.2013.75.10

Jowitt SM, Werner TT, Weng Z & Mudd GM 2018. Recycling of the rare earth elements. *Current Opinion in Green and Sustainable Chemistry* 13 1-7. https://doi.org/10.1016/j.cogsc.2018.02.008

Kumar AA, Sanislav IV & Dirks PHGM 2022. The geological setting of the indium-rich Baal Gammon and Isabel Sn-Cu-Zn deposits in the Herberton Mineral Field, Queensland, Australia. *Ore Geology Reviews* 149. https://doi.org/10.1016/j.oregeorev.2022.105095

Lèbre É, Corder G & Golev A 2017. The role of the mining industry in a circular economy: a framework for resource management at the mine site level. *Journal of Industrial Ecology* 21 (3): 662-672. https://doi.org/10.1111/jiec.12596

Lutandula M.S & Maloba B 2013. Recovery of cobalt and copper through reprocessing of tailings from flotation of oxidised ores. *Journal of Environmental Chemical Engineering* 1 (4): 1085-1090. https://doi.org/10.1016/j.jece.2013.08.025.

Lynas Rare Earths Ltd. 2022. 2022 Annual Report. https://wcsecure.weblink.com.au/pdf/LYC/02581455.pdf

McNulty T, Hazen N & Park S 2022. Processing the ores of rare-earth elements. *MRS Bulletin* 47 (3): 258-266. https://doi.org/10.1557/s43577-022-00288-4

Moldoveanu GA & Papangelakis VG 2013. Recovery of rare earth elements adsorbed on clay minerals: II. Leaching with ammonium sulfate. *Hydrometallurgy* 131 158-166. https://doi.org/10.1016/j.hydromet.2012.10.011

Mudd GM & Jowitt SM 2016. Rare earth elements from heavy mineral sands: assessing the potential of a forgotten resource. *Applied Earth Science (Transactions of the Institutions of Mining and Metallurgy: Section B)* 125 107-113. https://doi.org/10.1080/03717453.2016.1194955

Nazari-Dehkordi T, Spandler C, Oliver NH & Wilson R 2020. Age, geological setting, and paragenesis of heavy rare earth element mineralization of the Tanami region, Western Australia. *Mineralium Deposita* 55 107-130. https://doi.org/10.1007/s00126-019-00878-4

Northern Minerals Ltd. 2023. Becoming an important supplier of heavy rare earths – Company Presentation July 2023. https://wcsecure.weblink.com.au/pdf/NTU/02685483.pdf

Olympio Metals 2023. *Euralia Project*. Accessed 22/12/2023. https://olympiometals.com.au/eurelia-project/

Orris GJ & Grauch RI 2002. Rare Earth Element Mines, Deposits, and Occurrences. United States Geological Survey. https://pubs.usgs.gov/of/2002/of02-189/ -

Parker P 2022. *Critical minerals: The challenges that lie ahead*. Australian Mining, Accessed 1/03/24. https://www.australianmining.com.au/critical-minerals-the-challenges-that-lie-ahead/

Peak Rare Earths Ltd. 2022. 2022 Annual Report. https://wcsecure.weblink.com.au/pdf/PEK/02584166.pdf

Porter 2022. Prominent Hill, PorterGeo (webpage accessed 18/07/2024). https://portergeo.com.au/database/mineinfo.asp?mineid=mn951

Power Minerals 2024. Drilling delivers up to 14,152ppm TREO REE at Eyre Peninsula Project. *ASX Release*. https://announcements.asx.com.au/asxpdf/20240202/pdf/0600ssm3g21rh1.pdf

Rabiei M, Chi G, Normand C, Davis WJ, Fayek M & Blamey NJ 2017. Hydrothermal rare earth element (xenotime) mineralization at Maw Zone, Athabasca Basin, Canada, and its relationship to unconformity-related uranium deposits. *Economic Geology* 112 (6): 1483-1507. https://doi.org/10.5382/econgeo.2017.4518

Rezaei H, Shafaeu SZ, Abdollahi H, Shahidi A & Ghassa S 2022. A sustainable method for germanium, vanadium and lithium extraction from coal fly ash: Sodium salts roasting and organic acids leaching. *Fuel* 312. https://doi.org/10.1016/j.fuel.2021.122844

Rudnick, R. L. and Gao, S. 2004. Composition of the continental crust. In The Crust ed. R. L. Rudnick, vol. 3. Treatise on Geochemistry, ed. H. D. Holland and K. K. Turekian. Oxford: Elsevier-Pergamon.

Seredin VV & Dai S 2012. Coal deposits as potential alternative sources for lanthanides and yttrium. *International Journal of Coal Geology* 94 67-93. https://doi.org/10.1016/j.coal.2011.11.001

Seredin VV, Dai S, Sun Y & Chekryzhov IY 2013. Coal deposits as promising sources of rare metals for alternative power and energy-efficient technologies. *Applied Geochemistry* 31 1-11. https://doi.org/10.1016/j.apgeochem.2013.01.009

Simandl GJ & Paradis S 2018. Carbonatites: related ore deposits, resources, footprint, and exploration methods. *Applied Earth Science (Transactions of the Institutions of Mining and Metallurgy: Section B)* 127 (4): 123-152. https://doi.org/10.1080/25726838.2018.1516935

Skirrow R, Van Der Wielen S, Champion D, Czarnota K & Thiel S 2018. Lithospheric architecture and mantle metasomatism linked to iron oxide Cu-Au ore formation: Multidisciplinary evidence from the Olympic Dam region, South Australia. *Geochemistry, Geophysics, Geosystems* 19 (8): 2673-2705

Slack JF, Corriveau L & Hitzman MW 2016. A special issue devoted to Proterozoic iron oxide-apatite (±REE) and iron oxide copper-gold and affiliated deposits of southeast Missouri, USA, and the Great Bear magmatic zone, Northwest Territories, Canada: Preface. *Economic Geology* 111 (8): 1803-1814. https://doi.org/10.2113/econgeo.111.8.1803

Slezak P, Spandler C, Border A & Whittock K 2021. Geology and ore genesis of the carbonatite-associated Yangibana REE district, Gascoyne Province, Western Australia. *Mineralium Deposita* 56 (5): 1007-1026. https://doi.org/10.1007/s00126-020-01026-z

Spandler C, Slezak P & Nazari-Dehkordi T 2020. Tectonic significance of Australian rare earth element deposits. *Earth-Science Reviews* 207. https://doi.org/10.1016/j.earscirev.2020.103219

Swain G 2022. A 'Carbonatite' Model for the Oolgelima Intrusive Complex. Presentation at South Australian Exploration and Mining Conference 2022. https://saemc.com.au/wp-content/uploads/2022/12/Session-1-04-Greg-Swain.pdf

Sawyer M, Whittaker B & de Little J 2017. Carrapateena iron oxide Cu-Au-Ag-U deposit. In Phillips GN (Ed.) Australian Ore Deposits. The Australasian Institute of Mining and Metallurgy, Mono 32, pp. 615-620.

Taruga Minerals Ltd. 2022. Exceptional REE Recoveries Continue at Morgan’s Creek. *ASX Release*. https://app.sharelinktechnologies.com/announcement/asx/2daee83f48fb769fd5eeb83417276c80

Taruga Minerals Ltd. 2022. Exceptional Rare Earth Drill Results At Morgans Creek. *ASX Release*. https://app.sharelinktechnologies.com/announcement/asx/13331178ec31de34f5dbf8ab6a5b8b5c

Taylor S & McLennan SM 1995. The geochemical evolution of the continental crust. *Reviews of geophysics* 33 (2): 241-265. https://doi.org/10.1029/95RG00262

The South Australian Centre for Economic Studies 2024. Economic study for the sustainable development of critical minerals sector and value chain in South Australia, Report Book 2024/00005. Department for Energy and Mining, South Australia, Adelaide. https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB202400005.pdf

Tucker DH & Collerson KD 1972. Lamprophyric intrusions of probable carbonatitic affinity from South Australia. *Journal of the Geological Society of Australia* 19 (3): 387-391. https://doi.org/10.1080/00167617208728808

United States Geological Survey 2023. Rare earths. *Mineral commodity summaries 2023.* United States. Geological Survey, https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-rare-earths.pdf

Valetich M, Zivak D, Spandler C, Degeling H & Grigorescu M 2022. REE enrichment of phosphorites: An example of the Cambrian Georgina Basin of Australia. *Chemical Geology* 588. https://doi.org/10.1016/j.chemgeo.2021.120654

Verplanck PL, Gosen BSV, Seal RR & McCafferty AE 2014. A deposit model for carbonatite and peralkaline intrusion-related rare earth element deposits, Scientific Investigations Report 2010-5070-J https://doi.org/10.3133/sir20105070J

Verplanck PL 2017. The role of fluids in the formation of rare earth element deposits. *Procedia Earth and Planetary Science* 17 758-761. https://doi.org/10.1016/j.proeps.2017.01.014

Walsh JM & Spandler C 2023. The role of zircon in hydrothermal heavy REE mineralisation: The case for unconformity-related ore deposits of north-west Australia. Chemical Geology, 629, 121493. https://www.sciencedirect.com/science/article/pii/S0009254123001936?via%3Dihub

Walters A & Lusty P 2011. Commodity Review: Rare earth elements, United Kingdom. British Geological Survey. https://nora.nerc.ac.uk/id/eprint/17448/1/Rare_Earth_Elements_profile%5B1%5D.pdf -

Wang Z-Y, Fan H-R, Zhou L, Yang K-F & She H-D 2020. Carbonatite-related REE deposits: An overview. *Minerals* 10 (11): 26. https://doi.org/10.3390/min10110965

Weng Z, Jowitt SM, Mudd GM & Haque N 2015. A detailed assessment of global rare earth element resources: opportunities and challenges. *Economic Geology* 110 (8): 1925-1952. https://doi.org/10.2113/econgeo.110.8.1925

Yaxley GM, Anenburg M, Tappe S, Decree S & Guzmics T 2022. Carbonatites: classification, sources, evolution, and emplacement. *Annual Review of Earth and Planetary Sciences* 50 261-293. https://doi.org/10.1146/annurev-earth-032320-104243

Yin J & Song X 2022. A review of major rare earth element and yttrium deposits in China. *Australian Journal of Earth Sciences* 69 (1): 1-25. https://doi.org/10.1080/08120099.2021.1929477

Zhukova IA, Stepanov AS, Jiang S-Y, Murphy D, Mavrogenes J, Allen C, Chen W & Bottrill R 2021. Complex REE systematics of carbonatites and weathering products from uniquely rich Mount Weld REE deposit, Western Australia. *Ore Geology Reviews* 139 104539. https://doi.org/10.1016/j.oregeorev.2021.104539

RELATED LINKS

Rare Earth Elements webpage
https://www.energymining.sa.gov.au/industry/minerals-and-mining/mineral-commodities/rare_earths

South Australian commodity resource information (SARIG)
http://map.sarig.sa.gov.au/MapViewer/StartUp/?siteParams=DashboardWidget%7CcommoditiesIndicators

Critical Minerals South Australia dashboard
https://www.energymining.sa.gov.au/industry/geological-survey/gssa-projects/critical-minerals-south-australia/south-australias-critical-minerals-dashboards

Critical Minerals South Australia project
https://www.energymining.sa.gov.au/industry/geological-survey/gssa-projects/critical-minerals-south-australia

South Australia’s Mineral Deposit (MinDep) database
https://minerals.sarig.sa.gov.au/MineralDepositSearch.aspx

APPENDIX

OCCURRENCE DATA

Combined data available from South Australia’s Mineral Deposit (MinDep) database as displayed in Figure 1 (as at August 2024).
Click to open attachments panel.