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The major rare-earth-element deposits of Australia: geological setting, exploration, and resources

Dean M. Hoatson, Subhash Jaireth & Yanis Miezitis

DEPARTMENT OF RESOURCES, ENERGY AND TOURISM

Minister for Resources and Energy: The Hon. Martin Ferguson, AM MP
Secretary: Mr Drew Clarke PSM

GEOSCIENCE AUSTRALIA

Chief Executive Officer: Dr Chris Pigram

ISBN 978–1–921954–01–6 (hardcopy)

ISBN 978–1–921954–02–3 (webcopy)

GeoCat 71820

Bibliographic Reference

Hoatson, D.M., Jaireth, S. and Miezitis, Y., 2011. The major rare-earth-element deposits of Australia: geological setting, exploration, and resources. Geoscience Australia, 204 pp.

Cover Photograph and Illustrations

Front cover: Mount Weld in Western Australia is one of the richest rare-earth-element deposits in the world, with significant additional resources of niobium, tantalum, and phosphate. This aerial view shows the mine workings, in laterite developed above a ~2025 million year carbonatite intrusion. Lynas Corporation Limited (http://www.lynascorp.com/index.asp) is acknowledged for providing the aerial photograph.

Back cover: geological map and cross-section of the Mount Weld rare-earth-element deposit.

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THE MAJOR RARE-EARTH-ELEMENT DEPOSITS OF AUSTRALIA: GEOLOGICAL SETTING, EXPLORATION, AND RESOURCES

Dean M. Hoatson[1], Subhash Jaireth[1] & Yanis Miezitis[1]

[1.] Onshore Energy and Minerals Division, Geoscience Australia, GPO Box 378, Canberra, ACT 2601

SCOPE AND OBJECTIVES

The rare-earth elements (REE) have unique and diverse chemical, magnetic, and luminescent properties that make them strategically important in a number of high-technology industries. Traditionally they have been used for car engine exhausts, magnets, catalysts, metallic alloys in metallurgy, and for colouring and polishing glass. However, 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. Dramatically increasing prices for the REE reflect this expanding range of applications and the narrow global supply base. Consequently, the REE are increasingly becoming more attractive commodity targets for the minerals industry.

This report produced by Geoscience Australia[1] reviews the distribution, geological characteristics, resources, and potential of Australia's major REE deposits. With the exception of Barrie (1965), Towner et al. (1996), Cassidy et al. (1997), and Miezitis (2010), very few publications have described these deposits and compiled their resources at a national scale. In addition, there is a paucity of published documentation describing the geological features of key REE deposits in Australia similar to Lottermoser's (1988, 1990, 1991, 1994) comprehensive mineralogical-geochemical investigations on carbonatite-associated deposits. This report provides an up-to-date review of such deposits as a stimulus for future research into the geological characteristics of REE in Australia. In a mineral-systems framework, we examine the elements considered important for the formation of REE deposits and provide suggested exploration guidelines relevant to Australia. Also included is a compilation of recent products and national databases produced by Geoscience Australia that have potential applications in the exploration for REE deposits. The information and main messages presented in this review are intended to inform the public, students, and professionals.

The review comprises five chapters that are structured as follows:

Chapter 1 is a general overview of the REE, and provides background information on the discovery, major properties, applications, and production and resource status of the REE from a global and Australian perspective. A brief summary of the major events relating to REE exploration in Australia concludes the chapter.

Chapter 2 is focused on the geochemical behaviour of the REE. Metal abundances in mantle-crustal environments, various host rock types and hydrothermal fluids, partitioning into magmas of different composition, and behaviours in hydrothermal fluids are discussed within a evolutionary geochemical cycle framework.

Chapter 3 summarises the geological settings and main features of the major REE deposits in Australia, including stratigraphy, age and source of REE, resources, economic significance, and the genesis of fourteen type deposits. This information is used to compile a classification scheme for all Australian deposits.

Chapter 4 incorporates the information provided by the type examples described in Chapter 3 and assesses those criteria considered critical for the formation of each particular deposit type. This mineral-system approach differs from description-based classifications in that it can predict potential new areas and types of REE mineralisation.

Chapter 5 summarises exploration techniques for REE in Australia. It also provides information on some recent innovative digital national maps and databases produced by Geoscience Australia that could facilitate exploration.

Appendices 1 to 10 provide national and global REE data, exploration history, useful www links, and glossaries of resource and scientific terms.

The REE resource data used in this review for Australia's deposits are from OZMIN (2011: Ewers and Ryburn, 1997)—Geoscience Australia's national database of mineral deposits and resources.

[1] Geoscience Australia (http://www.ga.gov.au/; formerly the Bureau of Mineral Resources, Geology and Geophysics; and the Australian Geological Survey Organisation) is the Australian Government's geoscience agency which provides geoscientific information and knowledge to enable government and the community to make informed decisions about the exploitation of resources, the management of the environment, and the safety of critical infrastructure.

ACKNOWLEDGEMENTS

This report of the major REE deposits in Australia was undertaken as part of the Mineral Exploration Promotion Project (leaders: Mike Huleatt and Paul Henson) within the Onshore Energy and Minerals Division (OEMD) of Geoscience Australia. The review has compiled public information and data from a range of domestic and international sources, in addition to the latest information held by Geoscience Australia and the State/Territory geological surveys. An important component of this information was derived from various mining companies operating in Australia and elsewhere.

Lynas Corporation Limited (http://www.lynascorp.com/) is acknowledged for the use of the Mount Weld photographs that feature on the cover and in Chapter 3 of this publication. In particular, Georgia Bunn (Communications Manager) is thanked for her assistance. Richard Brescianini (General Manager of Exploration and Development) of Arafura Resources Limited (http://www.arafuraresources.com.au/) is also thanked for providing the images of the Nolans Bore deposit in central Australia. Jim Mason (previously GA) provided some of the landscape photographs.

The following people and organisations are thanked for granting permission for information and photographs relating to the discovery and applications of the REE used in Chapter 1: Stephen Gagnon (Thomas Jefferson National Accelerator Facility, Virginia, USA: http://www.jlab.org/); Dr. Norman Holden (National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York: http://www.nndc.bnl.gov/); Mark Saxon (President and CEO of Tasman Metals Limited: http://www.tasmanmetals.com/s/OresMinerals.asp); Dr. Peter van der Krogt (Elementymology & Elements Multidict: http://elements.vanderkrogt.net/); Tantalus Rare Earths AG (http://tre-ag.com/en/rare-earths_applications.php); Peggy Greb, United States Department of Agriculture, Agricultural Research Service: http://www.ars.usda.gov/is/graphics/photos/jun05/d115-1.htm); and John Veevaert (http://trinityminerals.com/ms2003/day3.shtml). Photographs of chemists used in Chapter 1 have expired copyright status (i.e., in the public domain) and are reproduced from Wikimedia Commons (http://commons.wikimedia.org/wiki/Main_Page).

The following geoscientists from Geoscience Australia (GA) provided summaries in Chapter 5 of how GA's National datasets can be used for the exploration of REE: Patrice de Caritat (National Geochemical Survey of Australia); David Champion (Felsic Igneous Rocks); Lynton Jaques (Kimberlite Map of Australia); Peter Milligan (Gravity and Magnetic Maps of Australia); Oliver Raymond (Surface Geology of Australia Map); Murray Richardson and Brian Minty (Radiometric Map of Australia); and Ian Roach and Marina Costelloe (Airborne Electromagnetic Surveys).

The report was improved from comments received from Leesa Carson, Paul Henson, David Huston, Terry Mernagh (GA), and Lynton Jaques and Alastair Stewart (previously GA). The visual impact of the figures owes much to the cartographic skills of Silvio Mezzomo and Chris Evenden (GA), the two fold-out maps were drawn by Gayle Young (GA), and Alissa Harding and Maria Bentley (GA) were responsible for the design and production of the report.

EXECUTIVE SUMMARY

The rare-earth elements (REE) are a group of seventeen speciality metals that comprise the lanthanide series of elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), in addition to scandium (Sc) and yttrium (Y), which show similar physical and chemical properties to the lanthanides. The REE have unique catalytic, metallurgical, nuclear, electrical, magnetic, and luminescent properties. Their strategic importance is indicated by their use in a number of emerging and diverse technologies that are becoming increasingly significant in today's society. Applications range from routine (e.g., lighter flints, glass polishing mediums, car alternators), to high-technology (lasers, magnets, batteries, fibre-optic telecommunication cables), to those that have futuristic purposes (high-temperature superconductivity, safe storage and transport of hydrogen for a post-hydrocarbon economy, environmental global warming and energy efficiency issues). Over the last two decades, the global demands of REE have significantly increased sympathetically with their dramatic expansion into high-technological, environmental, and economical environments.

REE are relatively abundant in the Earth's crust, but known minable concentrations are less common than for most other exploited metals. Past demand for REE has been met by a small number of producers and mines. Since the mid-1990s, China has dominated the global supply of REE, with most production derived from the very large Bayan Obo iron-niobium-REE deposit (Inner Mongolia, China) and from lateritic clays (southern China). In 1992, China surpassed the United States of America (USA) as the world's largest producer of rare-earth oxides (REO); being responsible for 95.5% of the world's output in 2009. At the end of 2010, China held 55 million tonnes (48.3%) of the world's economic resources of REO, followed by the Commonwealth of Independent States (former members of the Soviet Union) with 19 million tonnes (16.7%) and the USA with 13 million tonnes (11.4%). Australia's global REE impact in 2009 amounted to no recorded production and total Economic Demonstrated Resources in 2010 were 1.65 million tonnes of REO (1.45% of the global inventory).

Small-scale production of REE has taken place in Australia in the past with yttrium-rich minerals (gadolinite) first mined in 1913 from a pegmatite vein in the Cooglegong region near Marble Bar, Western Australia. Australia's REE industry attained an international profile when REE-bearing heavy minerals (monazite and xenotime) were obtained as by-products from beach sand mining activities in Western Australia, New South Wales, and Queensland. During the 1970s and 1980s, Australia's annual production was about 12 000 tonnes of monazite and 50 tonnes of xenotime. Australia became the world's largest producer of monazite when production peaked in 1985 with 18 735 tonnes of monazite. Between 1952 and the 'temporary closure' of the industry in 1995, Australia exported some 265 000 tonnes of monazite with an export value of $284 million (in 2008 dollars). Some beach sand mining projects are currently still operating in Western Australia (e.g., Cooljarloo) and Queensland (North Stradbroke Island). During the past decade there has been increasing industry interest in hard-rock REE deposits as the demand and global prices for these strategic metals have significantly increased. A number of deposits with significant resources (e.g., Mount Weld, WA; Nolans Bore, NT; Toongi, NSW) in different geological settings are now at advanced stages of development. Their planned production contributions (e.g., starting dates of 2011 for Mount Weld, ~2013 for Nolans Bore) are likely to have a discernible impact on the global supply of REE.

REE in Australia are associated with igneous, sedimentary, and metamorphic rocks in a wide range of geological environments. Elevated concentrations of these elements have been documented in various heavy-mineral sand deposits (beach, dune, offshore marine, and channel), carbonatite intrusions, (per)alkaline igneous rocks, iron-oxide breccia complexes, calc-silicate rocks (skarns), fluorapatite veins, pegmatites, phosphorites, fluviatile sandstones, unconformity-related uranium deposits, and lignites. The distribution and concentration of REE in these deposits are influenced by various rock-forming processes, including enrichment in magmatic or hydrothermal fluids, separation into mineral species and precipitation, and subsequent redistribution and concentration through weathering and other surface processes. The lanthanide series of REE (lanthanum to lutetium) and yttrium show a close genetic and spatial association with alkaline felsic igneous rocks, but scandium in laterite is associated with ultramafic-mafic igneous rocks.

A mineral-systems approach has been used in this review to classify the major Australian REE deposits according to various mineralising criteria and/or associated geological events. This hierarchical classification framework has the advantage over more traditional descriptive classifications in that it attemps to understand the geological processes considered critical to the formation of a particular deposit type. It also has a more predictive capacity for identifying potential new areas and types of REE mineralisation. The highest level of the classification comprises four general '*Mineral-system association*' categories—Regolith, Basinal, Metamorphic, and Magmatic—and their sixteen '*Deposit Type*' members, namely:

1. Regolith—carbonatite-associated; ultramafic/mafic rock-associated;
2. Basinal—heavy-mineral sand deposits in beach, high dune, offshore shallow marine tidal, and tidal environments; phosphorite; lignite; unconformity-related;
3. Metamorphic—calc-silicate; and
4. Magmatic—(per)alkaline rocks; carbonatite; pegmatite; skarn; apatite and/or fluorite veins; and iron-oxide breccia complex.

The most commercially important REE deposits in Australia are related to magmatic and weathering processes associated with carbonatites and alkaline igneous rocks, and secondary placer deposits, such as heavy-mineral sand deposits. There is considerable potential for the discovery of high-grade, large tonnage polymetallic REE deposits in residual lateritic profiles of carbonatites and within alkaline igneous rocks in the Precambrian terranes of Australia. Residual laterite deposits associated with carbonatites are typically enriched in other metals, such as zirconium, niobium, and tantalum. They also have the advantage of being easily mined by open-pit methods and they do not require extensive crushing and milling. Mesozoic alkaline volcanic provinces of eastern Australia provide scope for lower-grade, polymetallic deposits in the primary zones of trachytic and associated alkaline rock complexes. The discovery of scandium-bearing nickel-cobalt laterites associated with Phanerozoic ultramafic-mafic rocks, and REE-bearing phosphorites in Cambrian basinal successions have recently created exploration interest throughout eastern Australia. Large iron-oxide breccia complexes (e.g., Olympic Dam, SA) may be an important source of by-product REE that could be exploited in the future. The economic significance of less conventional exploration targets where the REE are hosted by lignite and bauxite accumulations is yet to be established. In addition, ionic-adsorption clay deposits that are mined in southeastern China represent a potential exploration target in Australia.

The complex spatial distribution and concentration of REE in many Australian deposits reflect the subtle differences in physical and chemical behaviours of many elements (17 REE and associated metals) in the primary host rock and in the secondary weathering profile. Each orebody is 'unique' with different geological and metallurgical challenges. The pathway to production is project specific, and involves many intricate processing stages that often need to adapt during the life of the project. Some REE-bearing ores have associated abundances of uranium and thorium, thus environmental and competing land-use issues (e.g., heavy-mineral sand deposits along the coastal zone and National Parks) may also have to be considered. The development of a REE deposit from discovery to production may therefore be a protracted process involving many technical challenges and expensive commitments. Ideally, mining companies need a REE orebody with favourable geological-geochemical-processing parameters, a careful approach to environmental considerations, high levels of different skills, and access to processing technologies and significant amounts of capital.

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