

# Rare Earth Elements

Intertek

Rare earth elements (REE) are relatively abundant in the earth's crust, but discovered economic concentrations are less common than for most other ores. Rare earths can be divided into light rare earth elements (LREE) which include La, Ce, Pr, Nd and Sm, and heavy rare earth elements (HREE) which include Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu plus Y.

World resources of LREE are constrained primarily in carbonatites, LREE-bastnäsite and monazite. Bastnäsite deposits in China and the United States constitute the largest fraction of the world's rare-earth economic resources. Monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand and the United States constitute the second largest segment. The latter are found in paleoplacer and recent placer deposits, sedimentary deposits, veins, pegmatites, carbonatites, and alkaline complexes. Alkali igneous intrusions in the Lovozero and Khibina Massifs in Russia are also highly enriched in REE, Nb and Ta.

A large portion of HREE is found in xenotime and monazite which occur in a wide variety of geologic environments. These include alkaline granites, hydrothermal deposits, laterites, placers, and vein-type deposits. A significant portion of HREE is associated with weathered clay deposits, yttrium-bearing minerals in apatite-magnetite-bearing rocks, deposits of niobium-tantalum minerals, non-placer monazite-bearing deposits, sedimentary phosphate deposits, eudialyte-bearing deposits and some uranium ores. Undiscovered REE resources are thought to be very large relative to the expected demand<sup>1</sup>. Rare earth elements are ranked as the highest mineral raw materials of critical concern, given uncertain future supplies and their importance to advanced industrial economies<sup>2,3</sup>.

The demand for rare earth elements has increased substantially owing to their unique physical, chemical and light-emitting properties. They are exploited in a range of new technologies along with elements such as Y, Nb, Ta, Zr, Hf and Sc with which they are intimately associated in many deposits. **Nd, Dy, Eu, Tb and Y are now considered "critical" rare earths** in terms of their importance to the clean energy economy and the risk of supply disruption.

Demand for the rare-earth materials has grown more rapidly than that for commodity metals such as steel and in the new developing market segments Dy, Nd and Pr account for 85% of rare earths used<sup>4</sup>.

## Rare Earths Application in Clean Energy

Rare earths are becoming vital to some fast growing businesses in clean energy. New generation wind-powered turbines use NdFeB/DyTb permanent magnets. This critical component gives greater magnetic field strength and higher coercivity (resistance to becoming demagnetized) than other magnets. The use of rare earths in permanent magnets considerably reduces the size and the mass of the generator. Similar magnets are also used in motors for hybrid vehicles, hard disk drivers and many other electronic applications. Electric car motors require up to 200g of Nd and 30g of Dy. Wind turbine generators can contain one tonne of Nd per megawatt installed capacity<sup>4</sup>. Nd demand is currently third after Ce and La with an increasing forecast deficit for this element along with Tb and Dy (Fig. 1).

Rare earth permanent magnets are the largest consumer of REE accounting for 39% of the production (Fig. 2). The next largest REE consumers are catalysts (19%) and metal alloys (18%). About 12% of LREE is used for polishing, TV and computer monitors, mirrors and microchips. A total of 10% of the LREE are used in the glass industry. Lanthanum, for example, increases the refractive index of glass and is used in camera lenses.

The phosphorescent properties of rare earths, including Y, are heavily exploited in the production of energy-efficient compact fluorescent lamps (CFL) and light emitting diodes (LED). The new generation of organic light emitting diodes (OLED) uses rare earths (Eu, Tb, Tm) to produce transparent or surface emitting flat panel displays. The colour of the emitted light can be tuned by changing rare earth ion concentration<sup>5,6</sup>.

Rare earths are also added to ceramic glazes for colour control<sup>7</sup>. Barium titanate powder alloyed with REE is used in electronic applications. Yttrium is used to make ferrites for high frequencies and to stabilize zirconia in oxygen sensors<sup>8</sup>. In 2008 7000 t of REOs was used in this category, of which yttrium oxide accounted for 53 % and the remainder being oxides of La, Ce, Nd and Pr.

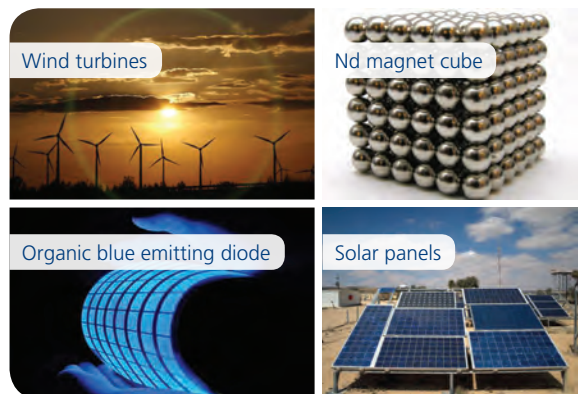
Rare earths are widely used in medical technology. For example, Gd-based compounds are used as a contrast agent to image tumours with MRI (Magnetic Resonance Imaging) and the MRI uses REE magnets<sup>9</sup>. Erbium yttrium aluminum garnet (Er:YAG) lasers are used in dermatology for skin resurfacing to remove wrinkles.

The unique magnetic properties of Gd may be used in future refrigeration technology. These refrigerators do not require ozone-depleting or hazardous substances and reduce electricity consumption by up to 15 per cent due to higher energy efficiency<sup>10</sup>. A thulium-doped lutetium yttrium aluminum garnet (Tm:LuYAG) laser is used in meteorology to measure wind speed and direction, pollution and moisture.

Promethium occurs naturally in minuscule amounts<sup>11</sup>, however, it can be produced by bombarding neodymium-146 with neutrons. Promethium can be used in nuclear powered batteries which use beta particles, emitted by the decay of promethium, to induce a phosphor to emit light. This light is then converted into electricity by a device similar to a solar cell. This type of battery could provide power for up to five years<sup>12</sup>.

Japan and the USA are two of the major countries which import REE for their high-tech industries. Together they imported 34000 tonnes of REE compounds and metals in 2009. These two countries were followed by Germany (8200 tonnes), France (7000 tonnes) and Austria (4500 tonnes) in 2009. China accounted for 97% of the REE supply in 2010. In recent years China has constrained the export of un-beneficiated REE preferring to export finished products<sup>9</sup>. China also plans to reduce illegal mining of REE and introduce stricter environmental regulations concerning REE production. This has boosted the price for REE which has, in turn, made mines outside China more economically viable.

Africa, Australia, Canada<sup>13</sup> and Greenland have the biggest potential for filling the REE deficit. As one of the biggest importer of rare earths Japan had already started to negotiate supplies of rare earths from India and Vietnam<sup>14</sup>. Projects like Steenkampskraal (GWMG, South Africa)<sup>15</sup>, Zandkopsdrift (Frontier Rare Earth, Southern Africa), Mt Pass (Molycorp Inc., USA), Bear Lodge (Rare Elements Resources, USA),



Mt Weld (Lynas Corp, Australia), Kvanefjeld (Greenland Minerals and Energy Ltd, Greenland), Dong Pao (Vimico Rare Earth Co, Vietnam) and other projects will assist to meet the future demand for predominantly light rare earths. Strange Lake (Quest Rare Minerals, Canada)<sup>16</sup>, Nechalacho (Avalon Rare Metals, Canada)<sup>17</sup>, Kvanefjeld (Greenland Minerals and Energy Ltd, Greenland), Tanbreez (Tanbreez Mining Greenland, Greenland)<sup>18</sup>, Nolans (Arafura Resources, Australia)<sup>19</sup>, Browns Range (Northern Minerals<sup>20</sup>) and Dubbo (Alkane Resources, Australia) are promising heavy rare earth projects. The deficits for HREE will however, remain significant.

### Global Demand and Supply of REO for 2014 (+14%)

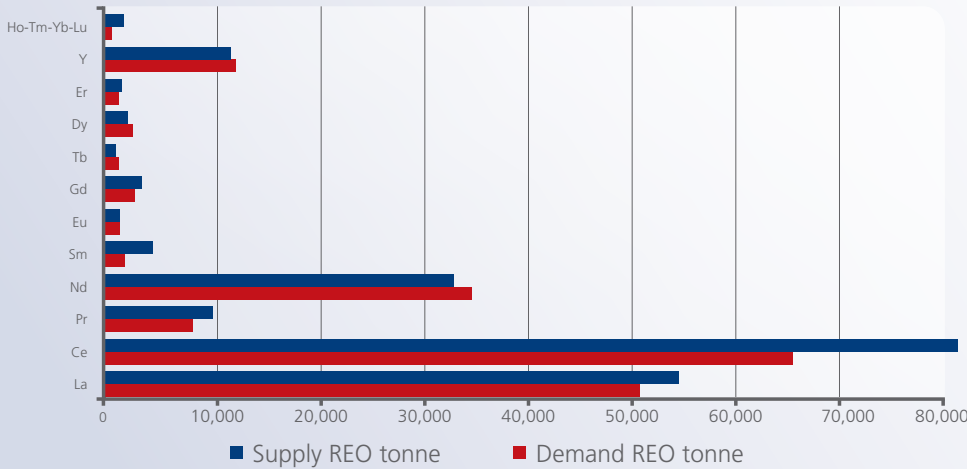


Fig. 1. Global demand and supply of REO for 2014 (± 14%)(IMCOA).

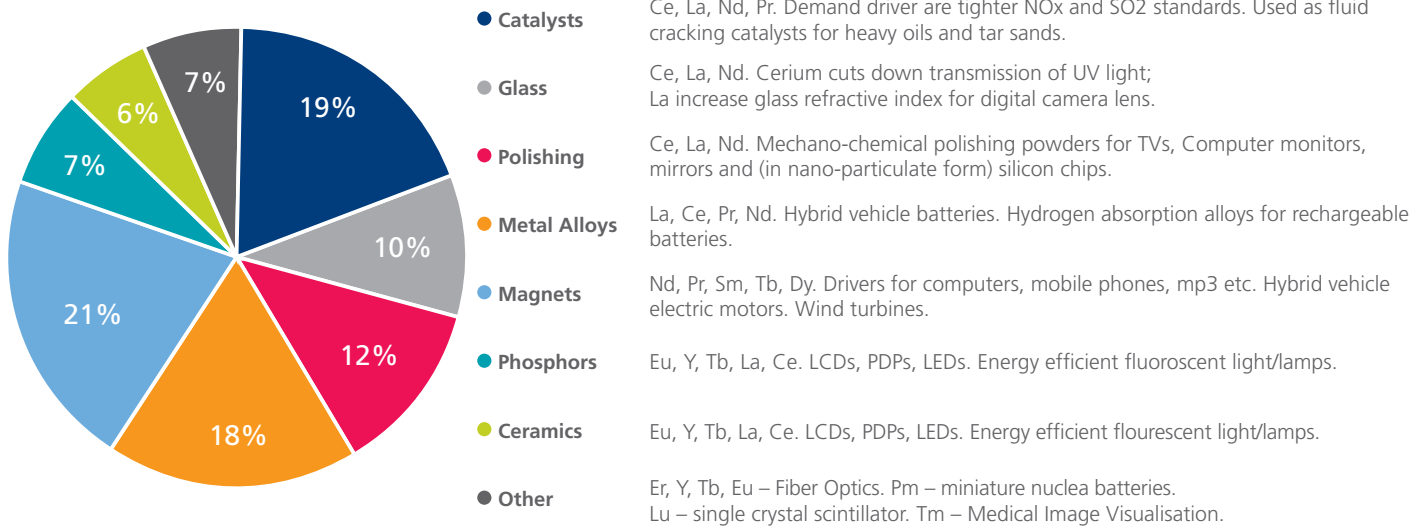


Fig. 2. Pie chart of global rare earth demand in 2008 by application (adapted from USSG Scientific Investigations Report 2011-5094).

### Rare Earths Analysis

For many years chondrite normalised plots of the REE have been used in petrogenesis (Fig.3). A europium anomaly is generally an indication that a rock or the parent from which it was derived has fractionated plagioclase or a mineral into which Eu has partitioned. During magma crystallization in a reducing environment divalent  $\text{Eu}^{2+}$  preferentially incorporates into plagioclase substituting for  $\text{Ca}^{2+}$ . A plagioclase cumulate will have a positive Eu anomaly whereas the residual magma, from which it fractionated, a negative anomaly. Large positive Eu anomalies occur in the most felsic rocks which also have a high Ba content and are severely depleted in HREE. A negative Eu anomaly is a signature of post-Archean sediments<sup>21</sup>. In addition to europium, one can observe cerium in two different states: soluble  $\text{Ce}^{3+}$  can be oxidised by atmospheric oxygen to less soluble  $\text{Ce}^{4+}$ . The presence of a Ce anomaly can be used to determine redox conditions in marine sediments like carbonates and phosphates<sup>22</sup>.

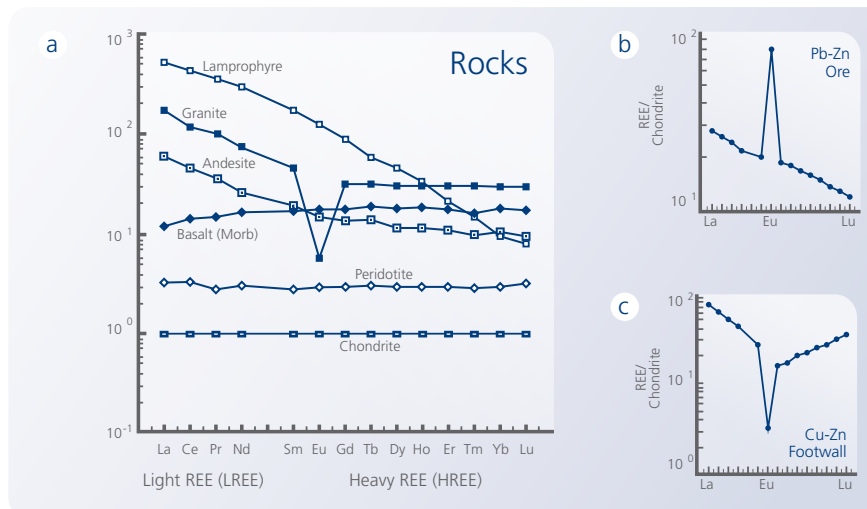


Fig 3. a) REE Chondrite plots of various rocks; b) chondrite plot of Pb-Zn ore with positive Eu anomaly, which is associated with Pb-Zn sulphides, New Brunswick, Canada (Graff<sup>23</sup> et al, 1977); c) chondrite of Cu-Zn of footwall with negative Eu anomaly with enriched heavy REE ("birdwing profile") in rocks below the ore (Schade et al, 1989).<sup>24</sup>

Lanthanum/gadolinium (La/Gd), as a measure of LREEs/HREEs, plotted against Eu/Eu\* (measured europium divided by europium calculated from interpolation between samarium and gadolinium) is also helpful in the classification of REE deposits and the interpretation of their origin (Fig. 4).

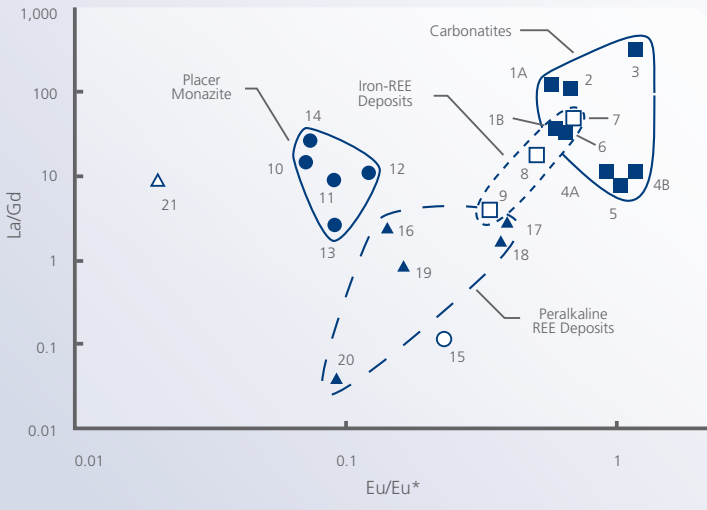


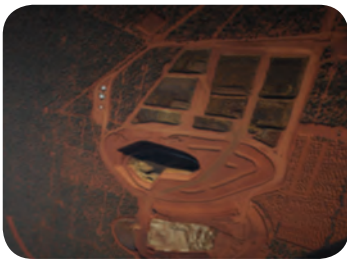
Fig. 4.

- 1A - Mountain Pass Bastnäsite;
- 1B - Mountain Pass monazite;
- 2 - Kangankunde REE-rich carbonatite;
- 3 - Kizilçören REE-rich carbonatite; 4A, 4B - Salitre II perovskite and anatase;
- 5 - Mount Weld carbonatite;
- 6 - Maicuru REE-rich carbonatite;
- 7 - Bayan Obo ore;
- 8 - Pea Ridge breccia;
- 9 - Mineville apatite;
- 10, 11 - Western and Eastern Australiaplacer monazite;
- 12 - South China placer monazite; 13 - Florida placer monazite;
- 14 - Brazil placer monazite;
- 15 - Malaysia placer xenotime;
- 16 - Strange Lake peralkalineigneous HREE deposits;
- 17 - Kipawa Lake eudialyte;
- 18 - Bokan Mountain peralkalineigneous HREE deposits;
- 19, 20 - JabaSa'id and JabaTawlahperalkaline igneous REE deposits;
- 21 - Crescent Peak vein deposit.

## Techniques for Rare Earths Exploration

Most of REE deposits are restricted to areas underlain by Precambrian rocks, which have recognizable features and can be identified by **aerial photography**. However, this approach may not be suitable for complexes, which occur in clusters (Mt Weld, Australia) or linear belts (Araxá-Catalão, Brazil). Owing to the presence of U and Th in REE deposits, **surface or airborne radiometric surveying** can be used quite successfully. Placer deposits however, produce weak radiometric signatures so due care must be exercised. **Geophysical methods** can be used for buried mineralisation, but the effectiveness depends on the anomalous density as well as the magnetic susceptibility of the deposit and the associated rocks. **Geochemical surveys** using stream sediments, water and soil are used widely to identify REE host rocks. **Biogeochemistry** can be useful in identifying REE deposits below cover. **Trenching and pitting** by heavy equipment may also be useful for poorly exposed deposits.

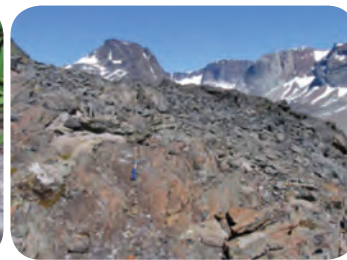
Using several methods of exploration increases confidence in the results and helps data interpretation. A HREE deposit in Strange Lake in Canada was found using regional lake water, a sediment survey and tracing of glacially transported boulders, which were found up to 20 km from the source<sup>22</sup>.



Mt Weld REE Deposit, Western Australia. Photo courtesy of Lynas Corp Ltd



Kanyika Multielement deposit, Malawi. Photo courtesy of Globe Metals and Mining Ltd.



Kvanefjeld REE and Multielement deposit, Southern Greenland. Photo courtesy of Greenland Minerals



## Methods of Analysis

Whether you are using REE as indicators or exploring for REE deposits using soil, rock chips or drill core you need to choose an appropriate analytical method. The HREE, Y, Zr, Hf, Nb and Ta are commonly hosted by refractory minerals that may not be completely digested by an acid digestion. Fusion using Na peroxide or Li borate fluxes may be required to completely digest the sample in cases where a multi-acid attack may only liberate the LREE (Fig. 5).

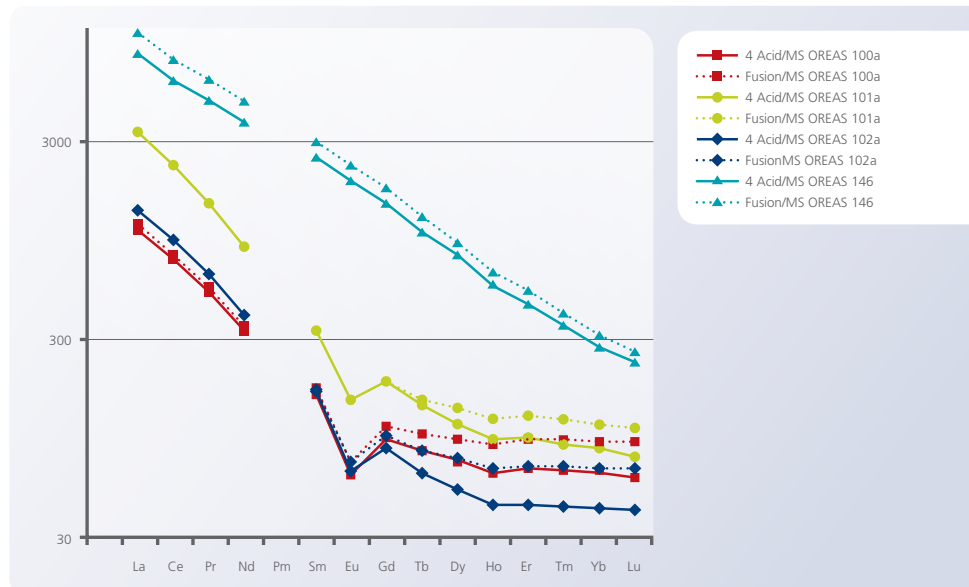


Fig. 5. Recovery of REE from Uranium and REE ores with four acid and sodium peroxide fusion.

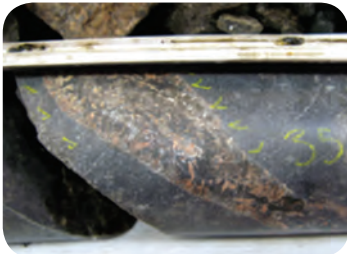
# Techniques for Rare Earths Exploration

The refractory nature of many of the minerals which host rare earth elements (REE) make fusion followed by a combination of ICP-OES and ICP-MS an ideal technique for the accurate characterisation of REE ores along with important major, minor and trace components. Fusions, using either sodium peroxide or lithium borate flux, ensure the complete digestion of all minerals giving total elemental analyses. All data are checked for consistency using chondrite normalised plots.

An extended REE package including the major elements is available on request, as well as a wider selection of elements including Cs, Rb, Ba, Sr, V and Sc. Low level litho geochemistry options are also available, including the combined digest, where a four acid digest is followed by fusion for total heavy rare earths recovery and low detection limits.

If you are exploring in areas of cover, regolith sampling with partial selective digests or vegetation sampling may work in the area of interest.

Anyone is most welcome to contact the laboratory for further information.



Rare earths mineralisation,  
Bokan Mountain.  
© Clint Cox, The Anchor House, Inc. 2009



Bastnäsite ore, Mt Pass  
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Inc. 2009



Red Eudialyte with black Aenigmatite,  
white feldspar and Aegirine  
© Maurice de Graff, Takhtarvumchorr,  
Khibiny massif, Russia, 2009.

## Rare Earths Mineralisation Na Peroxide Fusion ICP-MS Package

Sodium peroxide is a highly effective, oxidising flux which melts at 495°C. It can be used to decompose a diverse array of rocks and ores to determine many elements commonly hosted in refractory minerals, oxides, sulphides, silicates and carbonates. These include galena, sphalerite, pyrite, molybdenite, arsenite, cassiterite, baddeleyite, ilmenite, wolframite, beryl, tourmaline, bismuth ores, manganese and iron ores, chromium ores, niobium and tantalum ores, monazite, euxenite, xenotime, loparite, samarskite, bastnäsite. Rare earths minerals from peralkaline granitic rocks are usually hosted in relatively refractory minerals like eudialyte, fergusonite, allanite, gittinsite and can be fully recovered with fusion.

Element	Range ppm	Element	Range ppm	Element	Range ppm
La	0.2 - 20%	Ho	0.1 - 2%	Ta	0.1 - 50%
Ce	0.5 - 30%	Er	0.1 - 5%	Hf	0.1 - 5%
Pr	0.05 - 10%	Tm	0.05 - 1%	Zr	5 - 50%
Nd	0.1 - 20%	Yb	0.1 - 5%	Sn	2 - 50%
Sm	0.1 - 10%	Lu	0.05 - 1%	W	1 - 50%
Eu	0.1 - 5%	Y	0.5 - 50%	Li	1 - 20%
Gd	0.1 - 5%	Th	0.1 - 2%	Be	1 - 2%
Tb	0.05 - 2%	U	0.1 - 60%	Ga	1 - 5%
Dy	0.1 - 5%	Nb	10 - 30%		

REE Package by Na peroxide fusion Ni crucible / ICP-MS

FP6/MS33

Element	Range ppm	Element	Range ppm	Element	Range ppm
Ag	5 - 4%	Nb	10 - 60%	Y	0.5 - 50%
As	20 - 40%	Nd	0.1 - 40%	Yb	0.1 - 10%
Ba*	1 - 4%	Pb	20 - 70%	Zr	5 - 50%
Be	1 - 4%	Pr	0.05 - 20%	Al	0.01 - 50%
Bi	0.1 - 20%	Rb	0.5 - 10%	B	50 - 10%
Cd	1 - 10%	Re	0.1 - 2%	Ca	0.1 - 70%
Ce	0.5 - 60%	Sb	0.5 - 20%	Fe	0.01 - 75%
Cs	0.05 - 2%	Se	20 - 4%	K	0.05 - 20%
Dy	0.1 - 10%	Sm	0.1 - 20%	Mg	0.01 - 60%
Er	0.1 - 10%	Sn	2 - 50%	P	0.01 - 50%
Eu	0.1 - 10%	Sr	20 - 50%	S	0.05 - 60%
Ga	1 - 10%	Ta	0.1 - 50%	Sc	20 - 5%
Gd	0.1 - 10%	Tb	0.05 - 4%	Si	1 - 50%
Hf	0.1 - 10%	Te	1 - 4%	Ti	0.1 - 60%
Ho	0.1 - 4%	Th	0.1 - 4%	V	50 - 5%
In	0.1 - 10%	Tl	0.5 - 4%	Mn	0.2 - 75%
La	0.2 - 40%	Tm	0.05 - 2%	Cr	20 - 5%
Li	1 - 40%	U	0.1 - 60%		
Lu	0.05 - 2%	W	1 - 50%		

REE Sodium peroxide fusion Ni crucible for metallurgical samples / ICP-MS

FPH6/OM

\*not complete recovery

## Rare Earths Mineralisation Li borate Fusion ICP-MS Package

Lithium borate fusion can be used when elements such as Na and K also need to be determined. The flux is an eutectic mixture of lithium metaborate and lithium tetraborate and is effective for a wide variety of oxide, silicate and carbonate minerals<sup>26</sup>. The fusion is done at higher temperature (1000°C) and potentially leads to the losses of volatiles. This method uses platinum for the crucibles and is not recommended for samples with high sulphide sulphur or copper contents.

Element	Range ppm	Element	Range ppm	Element	Range ppm
La	0.2 - 20%	Ho	0.02 - 2%	Nb	0.1 - 5%
Ce	0.5 - 30%	Er	0.05 - 5%	Ta	0.1 - 5%
Pr	0.05 - 10%	Tm	0.05 - 1%	Hf	0.1 - 5%
Nd	0.1 - 20%	Yb	0.05 - 5%	Zr	1 - 50%
Sm	0.05 - 10%	Lu	0.02 - 1%	Sn	1 - 5%
Eu	0.05 - 5%	Y	0.5 - 50%	W	1 - 5%
Gd	0.05 - 5%	Th	0.05 - 2%	Ga	0.1 - 5%
Tb	0.02 - 2%	Be	0.5 - 2%		
Dy	0.05 - 5%	U	0.05 - 20%		

REE Package by Li borate fusion / ICP-MS FB6/MS34

## Rare Earths Combined Digest Package

The combined digest offers a combination of low detection limits and complete dissolution by fusion the residue of four acid digest with lithium borate and recombining this with the acid digest solution. This package is useful for the lithogeochemical characterisation of ultramafic rocks, where REE and tantalum, in particular, are present in very low concentrations which maybe close to or below the detection limit of the lithium borate fusion method alone.

Element	Range ppm	Element	Range ppm	Element	Range ppm
La	0.02 - 5000	Eu	0.02 - 1000	Er	0.02 - 1000
Ce	0.02 - 5000	Gd	0.02 - 1000	Tm	0.02 - 1000
Pr	0.01 - 5000	Tb	0.01 - 1000	Yb	0.02 - 1000
Nd	0.02 - 5000	Dy	0.02 - 1000	Lu	0.01 - 1000
Sm	0.02 - 5000	Ho	0.02 - 1000		

REE Combined digest / ICP-MS CD/MS68

## High Field Strength Element (HFSE) Combined Digest

Element	Range ppm	Element	Range ppm	Element	Range ppm
Hf	0.1 - 500	Ta	0.02 - 500	Y	0.1 - 500
Nb	0.1 - 500	Th	0.02 - 5000	Zr	1 - 500

HFSE Combined digest / ICP-MS CD/MS70

## X-Ray Diffraction

Powder XRD is used in many areas where the identification of unknown materials is required; these include geological, environmental, material science, biological and industrial applications.

The results given are either qualitative (descriptive of the sample make-up) or quantitative. Quantitative results can include the non-crystalline (amorphous) content.

### XRD Pulverise Package

Description	Code
Crush -2mm, rotary split 800g, pulverise 800g to 60um	XRD13

### Qualitative Analysis

Element	Description	Code
QUALITATIVE	Qualitative analysis for complete mineralogy	XRDQual

### Quantitative Analysis

Element	Description	Code
QUANTITATIVE	Quantitative analysis for complete mineralogy (crystalline content only)	XRDQuant
QUANTITATIVE	Quantitative analysis for complete mineralogy and amorphous content	XRDQuant901
QUANTITATIVE	Quantitative analysis for complete mineralogy and amorphous content (2 x Scan analysis)	XRDQuant902

# Appendix

## Rare earths-Uranium deposit classification<sup>27,28</sup>

Precipitation Conditions	Deposit Type	Example	Associated elements	Minerals
<b>Surface Processes / syndimentary</b>	Surficial deposits	Calcrete uranium deposits, Yeelirrie, Langer Heinrich	U-V (K-CO <sub>2</sub> )	calcium/magnesium carbonate, carnotite
	Quartz-pebble conglomerate deposits	Elliot Lake, Witwatersrand	U, Au, Ag	uranthorite, brannerite, coffinite, pyrophyllite, chloritoid, muscovite, chlorite, quartz, rutile, and pyrite
	Phosphorite deposits	Santa Quiteria and Itataia mines, Florida and Idaho, Mt. Weld	P-REE-Nb±Sr-Ca-Al-K-U-Ti-Ta	fluorite, apatite, phosphorite, fluorapatite
	Lignite	Serres Basin, North and South Dakota, Mulga Rock	U±S-As-Se-Mo-Co-Ni-V-Cu-Zn-Pb-REE-Y (Si-O-C-P), Sc, Au, Ag	clay-rich lignit, carbonaceous sands and clays (kaolinite), coffinite, brannerite, ilmenite, rutile, anatase
	Black shales	Ranstad, Ronneburg, Rudnoye and Zapadno-Kokpatasskaya deposits		marine organic-rich shale or coal-rich pyritic shale, containing syn-sedimentary disseminated uranium adsorbed onto organic material
<b>Diagenetic</b>	Sandstone deposits	The Wyoming basins, Inkai, Niger, Gabon, Karoo Basin	U, Se, Mo, V, Cu, Pb	pitchblende, coffinite
	Heavy mineral sand deposits	Coburne, Murray Basin, Cooljarloo	Ti-Fe-Zr-Th-REE±Cr-Sn	zircon, ilmenite, rutile, leucoxene, chromite, kyanite
<b>Diagenetic – Hydrothermal</b>	Unconformity-related deposits	Alligator River, Coronation Hill, The Athabasca Basin, Saskatchewan	U-Au-Cu-Co-Ni-Ag±Zn-Sn-Pb-Bi, Pt-Pd (Mg)	uraninite, pitchblende
	Vein deposits	Jachymov, Bohemian Massif, Schinkolobwe, Port Radium	U, Mo, Pb, F	uranit, coffinit, brannerite, in shear zone (brannerite, thorite)
	Collapse breccia pipe deposits	Arizona		uraninite, pitchblende, which occur as cavity fills and coatings on quartz grains
<b>Magmatic – Hydrothermal</b>	Breccia complex deposits	Olympic Dam, Ernest Henry	Cu-U-Au-Ag-REE (S-F)	uranit, coffinite, (meta)-torbernite, uranophane
	Volcanic deposits	Streltsovskoye, Dornod, McDermitt	U, Pb, W, Sn	pitchblende, molybdenite
	Metasomatite deposits	Ross Adams, Novokostantynivka, ZhovtaRichka, Valhalla	U, Th, REE	uraninite, brannerite, thorite, allanite, coffinite, uranophane
	Intrusive deposits	Rossing, Ilimaussaq intrusive complex, Palabora	U, REE, Zr, Nb, Be, Sr	agpaiticnepheline, syenite, alaskite, granite, pegmatite, monzonites
<b>Metamorphic – Hydrothermal</b>	Metamorphic deposits	Greenbushes, Wodgina, Mary Kathleen	Sn-Ta-Nb-Li, Be-Li-Cs-Rb±U-Th REE (Si)	uranit, garnet, columbite, tantalite, niobite, spodumene, lepidolite, tourmaline, cassiterite, holtite, turguoise

**Rare earth minerals that occur in economic or potentially economic deposits**

Mineral	Formula <sup>29*</sup>	Environment <sup>26</sup>	REO wt %
aeschnite	(Ce,Ca,Fe)(Ti,Nb)2(O,OH)6	Nephelinesyenite rocks.	36
allanite	Ca(REE,Ca)Al2(Fe <sup>++</sup> ,Fe <sup>+++</sup> )(SiO4)(Si2O7)O(OH)	Found in close association with calcite and barite in barite veins that cut a dolomitic metamorphosed limestone. Epidote group.	30
anatase	TiO2	Usually secondary, derived from other Ti-bearing minerals. Common as a detrital mineral	3
ancylite	Sr(Ce,La)(CO3)2(OH)·(H2O)	In hydrothermal veins in nephelinesyenites.	46
apatite	Ca5(PO4)3(F,Cl,OH)	Phosphorite deposits.	19
bastnäsite	(Ce,La,Y)CO3F	Contact or alteration zones in alkalic rocks.	76
brannerite	(U,Ca,Ce)(Ti,Fe)2O6	Found in the same settings as gold, including placers, quartz veins, and in granite pegmatites. Alteration product of uraninite.	6
britholite	(Ce,Ca,Th,La,Nd)5(-SiO4,PO4)3(OH,F)	In nephelinesyenites, pegmatites and contact deposits related to them.	62
cerianite	(Ce <sup>++++</sup> ,Th)O2	Partially absorbed inclusions of wall-rock in a dikelike zone of carbonate rock cutting nephelinesyenite.	81
cheralite	(REE,Ca,Th)(P,Si)O4	Disseminated in a kaolinized pegmatite dike. Cheralite-(Ce) (1953) is now regarded as Ca-rich monazite-(Ce).	5
churchite	YPO4•2H2O	Scarce rare earth mineral associated with phosphate minerals.	5
eudialyte	Na4(Ca,Ce)2(Fe <sup>++</sup> ,Mn,Y)ZrSi8O22(OH,Cl)2	Nepheline-syenite rocks.	10
euxenite	(REE,Ca,U,Th)(Nb,Ta,Ti)2O6	granitepegmatites and a component of detrital black sands.	<40
fergusonite	(Nd,Ce)(Nb,Ti)O4	Rare earth deposit.	47
florencite	REEAl3(PO4)2(OH)6	Found in placer sands	32
gadolinite	(Ce,La,Nd,Y)2Fe <sup>++</sup> Be2Si2O10	In syenite pegmatite veins along a contact between basalt and monzonite.	52
huanghoite	BaREE(CO3)2F	Hydrothermal veins associated with rare-earth-bearing carbonatite deposits in alkaline igneous complexes.	38
hydroxylbastnäsite	LnCO3(OH,F)	Red karstic bauxites.	75
kainosite	Ca2(Y,Ce)2Si4O12(CO3)•(H2O)	In vugs in pegmatites in granites and alkalic complexes.	38
loparite	(REE,Na,Ca)2(Ti,Nb)2O6	Primary mineral in differentiated nephelinesyenite massifs and alkalicpegmatites, replacing perovskite in carbonatites.	36
monazite	(REE,Th)PO4	Granitic pegmatites.	71
mosandrite	Na(Na,Ca)2(Ca,Ce,Y)4(Ti,Nb,Zr)(Si2O7)2(O,F)2F3	Alteration product of rinkite.	<65
parisite	Ca(Nd,Ce,La)2(CO3)3F2	In calcite veins in hydrothermal deposits.	64
samarskite	(REE,Fe,U)(Nb,Ta)5O4	Accessory mineral in REE-rich granite pegmatites.	12
synchysite	Ca(Ce/Nd/Y)(CO3)2F	Found with parisite in REE-bearing pegmatites and alpine veins.	51
thalenite	Y3Si3O10(OH)	REE-bearing pegmatites	63
xenotime	(Y/Yb)PO4	Minor accessory mineral in both acidic and alkalic igneous rocks and their pegmatites.	61
yttrotantalite	(Y,U,Fe)(Ta,Nb)O4	Accessory mineral in granite pegmatites.	<24

\*The formula is for specific chemical variant of the mineral identified. Note one or more other chemical variants, in which the dominant element varies from the one shown, may exist.

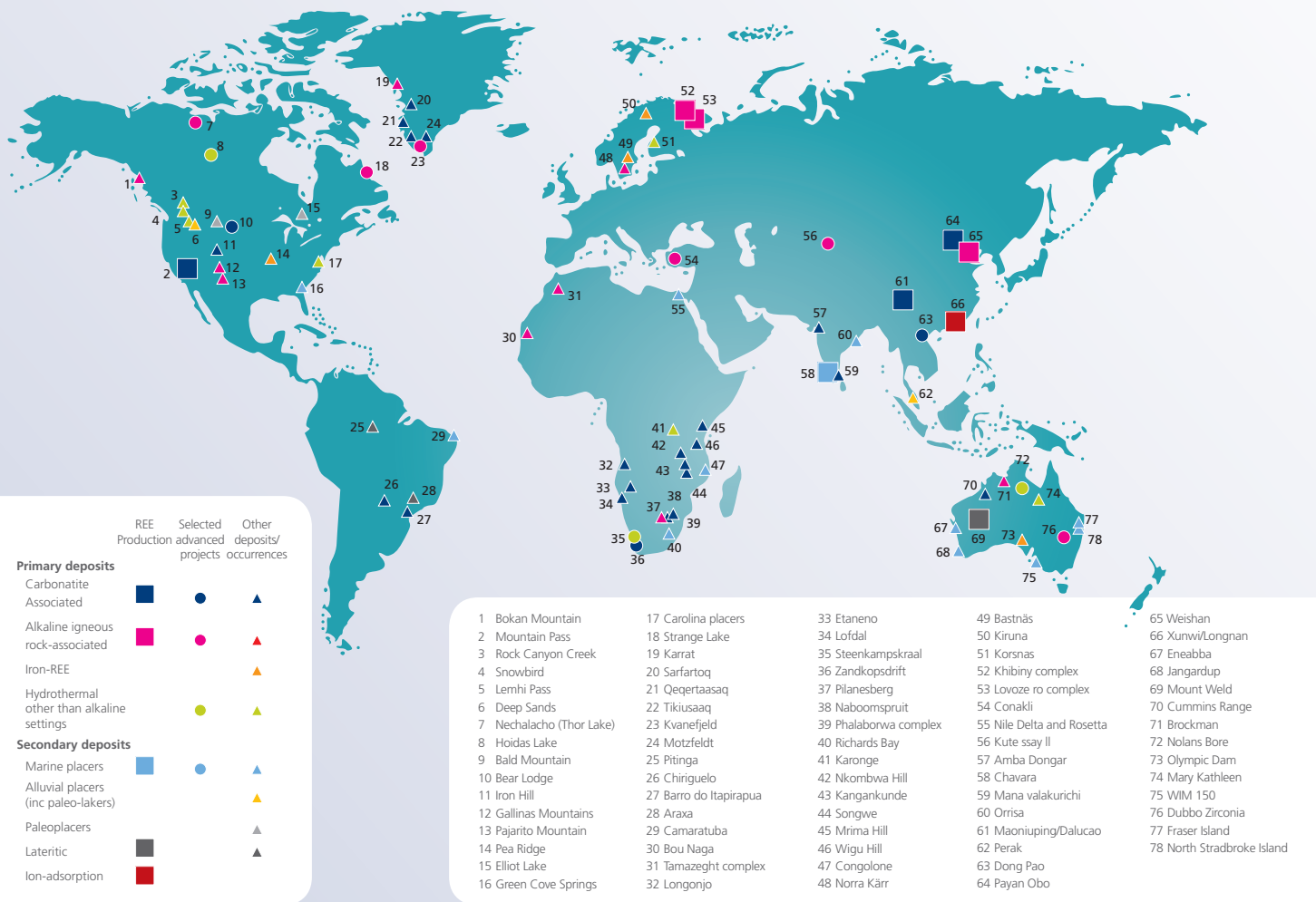


Figure 6. Map showing the global distribution of REE deposits<sup>9</sup>

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