



Technical Bulletin

Rare Earth Elements

By: Shannon Zurevinski, Materials Scientist

Introduction and uses of rare earth elements

Lanthanum to lutetium comprise atomic numbers 51 through to 71, and represent the rare earth elements. Yttrium, (Y, atomic number 39) is also commonly included as a rare earth element because of its similar chemistry (and relatively low toxicity). Each of the elements have very similar chemical and physical properties and are utilized for hundreds of applications, from high technology to environmental applications. Rare earth elements (REEs) are further subdivided into two groups, those with lower atomic numbers and masses- lanthanum (La) to samarium (Sm), are referred to as Light Rare Earth Elements (LREEs) and those with higher atomic numbers and masses- gadolinium (Gd) to lutetium (Lu), are referred to as Heavy Rare Earth Elements (HREEs). LREE are more incompatible (they have much larger ionic radii), therefore are more concentrated in the continental crust than the HREE. This leads lanthanum (La), cerium (Ce), praseodymium (Pr), and neodymium (Nd) to be approximately 90% of the total REE deposits. This also means that the HREE are less abundant and therefore much more valuable. Rare earths are not naturally found as native elements, but reside as compounds within minerals.

It is well known that technological applications of REEs have increased over the last decades, which is sparking a new interest in REE exploration around the world, and particularly in North America. REEs are often referred to as “highly specific,” which simply means that there are no substitutes for the REE. In fact, REEs are more abundant in rocks than industrial metals, however, they are not commonly found in high concentrations in ore deposits, which makes exploration and extraction difficult. The least abundant of the REEs (thulium and lutetium) are nearly 200x more concentrated than gold (Haxel et al. 2002).

The United States Geological Survey (USGS) reports that up to 90% of REE required by the industrial US come from China. Why are they so important? They are used in nuclear, metallurgical, chemical, catalytic, electrical, magnetic and optical practices, and in almost all cases, cannot be substituted for another element. Some important high technology applications are lighter flints, glass polishing, phosphorus, lasers, magnets, batteries, magnetic refrigeration, light bulbs, high definition televisions and electronics, and almost all of the small telecommunication gadgets that we rely on every day, across the world (Haxel et al. 2002).

One of the most important REE high technology industries which rely on a variety of REEs is the magnet industry. Permanent magnets are used in green technologies such as wind turbines, electric hybrid cars and appliances. The most widely used magnets are neodymium-iron-boron

(Nd-Fe-B) magnets and samarium-cobalt (Sm-Co) magnets. These powerful permanent magnets are the strongest in the world. A REE is combined with a transition metal that exhibits magnetism (i.e. Fe or Co), making it possible to “channel” the magnetic output into a single N-S axis, which is what creates the strong magnet. Other REE which are used in the magnet technology are gadolinium and dysprosium, and are used in the production of tiny permanent magnets that are in so many of the electrical components that we use every day, such as mini multi-gigabyte portable disk drives, as well as various communication systems.

Lanthanum produces fluid-cracking catalysts for the petroleum industry, which are used to convert highly viscous hydrocarbons in crude oil to more useful, less viscous hydrocarbons. It is also used in the electric car industry in the Ni-metal-hydride batteries found in hybrid cars.

Cerium's most well-known for use as a polishing agent for glass, but is also used in the catalytic converters of cars and trucks (CeO is combined with the platinum group metals to make these devices work).

A more recent example of the uses of REEs is the colour cathode-ray tubes and liquid crystal displays in computer monitors and televisions. This employs europium (Eu) as the red phosphor to which there is no known substitute. This makes Eu very valuable, ranging from \$250-\$1700.00 per kg for Eu₂O₃ (Haxel et al. 2002). The ever popular energy efficient lamps and light bulbs use yttrium, lanthanum, cerium, europium, gadolinium and terbium in their production.

REE Ore Deposits

In most igneous rocks, REEs are dispersed as minor or trace constituents of phases; not essential components. Minerals with major components of REEs are of most interest to the exploration industry. Highly differentiated magmatic fluids tend to host the REE phases, such as pegmatites, carbonatites, and some peralkaline igneous rocks.

A carbonatite is an intrusive or extrusive igneous rock in which carbonate minerals make up at least half of the total volume of rock. Most occur as plugs within larger zone alkaline intrusive complexes, but can also occur as dikes, sills, breccias and veins (Bell 1989). Exploration of carbonatite complexes across North America is increasing due to the demand of REE for high technology. They are enriched in niobium, REEs, barium, strontium, phosphorus and fluorine, while being depleted in silica, aluminum, iron, magnesium, nickel, titanium and sodium. Carbonatites are not just a source of REEs, in fact, agricultural phosphate used in fertilizer is the most common product of carbonatites. Other igneous rocks that are commonly found occurring with carbonatites are ijolites, melteigites, teschenites, lamprophyres, phonolites, foyaites, shonkinites and nephelene syenites (Bell 1989). A pegmatite is an extremely coarse grained intrusive igneous rock that has the identical mineralogy of a granite (quartz, feldspars, mica etc.). Although REE-enriched minerals are common in pegmatites, the economic concentrations are much smaller than those from carbonatites.

REE Ore Minerals

The main ore minerals of REE are monazite ((REE,Th,Y)PO₄), bastnäsite ((REE(CO₃)F), xenotime ((Y,REE)PO₄), and apatite ((Ca,REE)5[(P,Si)O₄]3(O,F)) (Richardson and Birkett 1996). Monazite and bastnäsite account for almost all of the historical world production of REEs (Neary and Highley 1984). Commercial monazite concentrates commonly contain 55-60% of rare earth oxide (REO) (Neary and Highley 1984). Although this is one of the most common REE minerals, monazite has elevated thorium (with a Radium radioactive daughter product which during processing accumulates in concerning amounts).

Therefore, low thorium minerals like bastnäsite are preferred. Some other minerals that REEs have been recovered from are brannerite $((U,Ca,Ce)(Ti,Fe)_2O_6)$, cerianite $((Ce^{4+},Th)O_2)$, pyrochlore $(A_2B_2O_6(O,OH,F))$ (where A sites are occupied by atoms of Na, Ce, REE, K and U) (Figure 1), and B sites by Nb, Ta, and Ti), and euxenite $((Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6)$. Note the absence of silicate minerals in the economic REE minerals lists, which is due to the feasibility of processing and separation of the REEs. REEs are almost entirely produced from (1) alkaline rocks and carbonatites, and (2) placer deposits (Neary and Highley 1984). It is also well known that REE-enriched apatite is used in production of REEs, because commercial recovery is feasible during the production of phosphoric acid for fertilizers.

The Mountain Pass Carbonatite Complex (California, USA) was discovered in 1949, and determined to be commercially viable as a LREE ore. Most of the LREE were hosted in bastnäsite. This was (and is) a world class deposit, and was mined from 1965 through to the mid 1980s. Since 1985, China has been the lead producer of REEs, mainly from the Bayan Obo iron-niobium REE deposit (Inner Mongolia), which is host to a pseudo-carbonatite. China also mines ion adsorption ores in laterites which are adjacent to granites and syenites and are enriched in HREEs (Haxel et al. 2002).

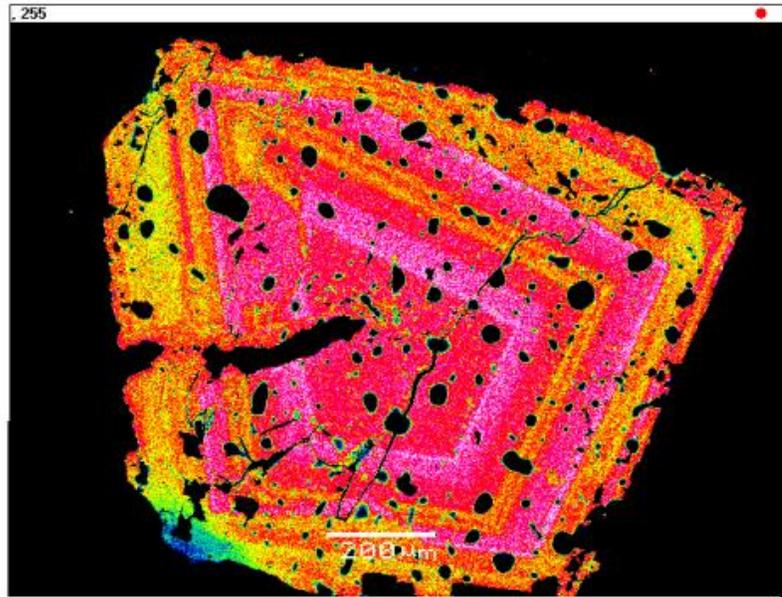


Figure 1. A false-colour Scanning Electron Microscopy (SEM) image of Ce-pyrochlore (see text) from the Oka Carbonatite Complex, Quebec (from Zurevinski and Mitchell 2004)

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Lakehead University's Centre for Analytical Services offers advanced mineral analysis to exploration and mining companies. The right mineralogical information can lead to increased profit.

Specialized REE services that Lakehead University Centre for Analytical Services (LUCAS) can offer geologists, exploration companies and prospectors:

- 1) Thin section preparation**
- 2) Petrography and Scanning Electron Microscope (SEM) analysis of thin sections to identify the minerals which host the REE, all completed by research scientists specializing in carbonatites and REE-hosted rocks (see below). This includes qualitative mineral identification, and if needed, quantitative mineral analysis.**
- 3) Imaging of the REE-host rock, both petrographic and high resolution imaging (using SEM)**
- 4) X-ray diffraction (XRD) analysis of mineral phases in the rocks, including semi-quantitative and quantitative assessments.**

Dr. Shannon Zurevinski holds a PhD in Mineralogy and Geochemistry and masters and bachelors degrees in Geology. She's an expert in the petrology of mantle-derived rocks, kimberlites and experimental mineralogy. Providing technology transfer on a routine basis as well access to the specialized analytical facilities at Lakehead University's Instrumentation Laboratory. Shannon Zurevinski offers consulting services for investigation of solid materials. Her clients include some of North America's leading chemical manufacturers and exploration companies. Materials analysis reports can be generated in days, helping leading edge, forward-looking companies develop new products and stay competitive.

**For more information on this service, contact:
Dr. Francis Appoh, Director
Lakehead University Centre for Analytical Services (LUCAS)
955 Oliver Road, Thunder Bay, ON
P7B 5E1
(807) 343-8853 Fax: (807) 346-7864
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