Critical Metals: Geology of the REE, supply chains & mineral processing
Introduced by Kathryn Goodenough
13th April 2022 at the University Women's Club, Audley Sq.

Kathryn had travelled down from Edinburgh for the Discussion and so it was really special to welcome her to London on such a topical issue. Her own interest in the rare earth elements (REE) began during a PhD at Edinburgh in the 1990s, working on alkaline igneous rocks in Greenland, before joining the BGS as a field geologist in Scotland. At that stage, the REE were of academic interest only, not as part of a strategic resource. In 2010 China began to restrict REE for export, just as their importance to the climate emergency and decarbonisation became recognised worldwide.

What was not recognised then was the extent to which the world would have to vastly increase mining operations to provide these critical elements, particularly for batteries, which require Li, C, Ni, Co & Mn, and REE for the high strength magnets in wind turbines and in motors for electric vehicles. Of the 15 REE (the Lanthanide elements in which Sc and Y are often included), they were termed rare in the 19th century not because they were truly rare in abundance, but because they were chemically so similar to one another that it was very difficult to separate one from another. As far as the modern demand for magnets is concerned, the important REE elements are Pr (atomic number 59), Nd(60), & Dy(66).

The main source of REE is carbonatite, such as the Bayan Obo deposit in China, Mountain Pass in N California, and Mount Weld in Australia, which are highly alkaline igneous rocks with a strange mineralogy. The geology of surface weathered carbonatites is very complicated but they are much easier to mine than the original igneous rocks. Another significant REE deposit are the mineral sands, particularly in India, but in these the REE come from monazite (cerium phosphate) which is derived from granites; since monazite included both U & Th in its lattice, these deposits are radioactive, which has restricted mineral sand mining in many parts of the world. The other important type of deposit is tropical laterite where the REE are not locked up in minerals, but adsorbed onto clay by ion adsorption, from which the REE can be leached out by solvents (e.g. in China).

The other potential source of REE is from the vast lakes of red waste at existing aluminium and phosphate mining plants, reworking of which would potentially be a sound environmentally friendly thing to do; however, this would require expensive reengineering at the plant and this is not economic at present.

Consequently, over 80% of the world's REE are still provided by China and so many governments around the world would like to secure their own supplies of REE, yet this is not really happening. One of the reasons for this is mineralogy: while there are literally hundreds of minerals which contain REE, processing is based on only three carbonatite minerals: bastnaesite (cerium carbonate/fluoride), monazite (cerium phosphate) and xenotime (yttrium phosphate), and most of the world's processing takes place in China. Europe long ago ceased to process these minerals for REE and so it follows that even if a highly enriched granite (for example) was discovered in Europe, it is likely to be sourced in a different mineral (say allanite), for which there is no processing facility available. In addition, the REE market is very small and is controlled by the Chinese, which sets the prices, so it is very difficult for western companies to get into this market. On top of these barriers there are social and environmental aspects of mineral processing to be considered, led by knowledge of the devastating environmental impacts of REE mining and mineral processing reported from China. While a lot is known about the geology of REE deposits around the world, and with the exception of Mt Weld in Australia, all of the world's REE mines are in China which controls the whole supply chain, and which the western world does not seem able to do much to change.

Discussion

Q. Should we be worried about the UK's ability to get the elements it needs for its batteries and REE for its magnets for the energy transition, or is it simply a question of price?
A. There is no evidence that China will cut off the supply of these critical metals to the West, but there is much misinformation in the press about their availability, which is not helpful. Resources and reserves grow as more exploration is done.

Q. Why is it that Pr/Nd/Dy are the main REE used?
A. It's a question of their magnetic properties, and in the case of Dy, it is for higher temperature use. Since every REE mineral contains all the REE elements, albeit in decreasing abundance (and only minor uses have been found for La and Ce) all deposits have an over abundance of La/Ce which cannot be sold. Other middle order elements such as Eu have specific uses in lasers, screens and defence but the biggest demand is for those used in magnets. While separation by ion exchange is one method of separating the REE from one another, that is not to say converting this process from laboratory to large scale commercial use is easy.

Q. Carbonatites are commonly thought of primarily in the context of the rift valley of east Africa, but are they found commonly elsewhere?
A. This is the common perception but they have been explored in many parts of the world; although most occur in a rift environment, many are regarded primarily as Nb and P deposits. In the east African rift type environment, the weathered zone has been depleted in the more soluble carbonate minerals, leaving secondary REE minerals which have been mined. But relatively old carbonatites are also found in post-collisional environments where the source of the REE was the lithospheric mantle. Many other elements have also been very enriched in these rocks. The Alps and Himalaya are probably too young to have developed post-collision carbonatites.

Q. Are we really in trouble in terms of China being so dominant in this market?
A. China does not have a dominant position for the battery minerals such as Li, C & Co. What it has done is focus very well on the whole supply chain and processing, so it's not just a question of the volume of the rare metals. Consequently we should not be too concerned about the supply of these critical elements from other sources eventually, but the issue is the time it takes to develop new sources. It takes many years to open a mine so the bottleneck is not scarcity per se, but that independent sources will not be available in the timescale that governments have defined for the decarbonisation of transport to occur, particularly as western governments are totally relying on the private sector to deliver the resources required. Probably our best hope will be to support British companies to explore overseas and develop an integrated supply chain with offtake agreements, and working together to build a single processing plant. In general, one mine will not support a single processing plant, it needs several. This applies to the battery metals as well as the REE, and many forecasts predict that the overall mineral consumption for all the metals we are going to need will have to increase by a factor of about six between 2020 and 2050.

Q. Getting many small mines in different parts of the world to work together to supply a single processing plant will surely be impossible unless it is driven by a superpower or the EU. Can they perhaps drive this integration?
A. To take the example of Li opportunities in Africa, a recent report concluded that the only option for small producers is to sell their Li output to China for processing. Theoretically the EU could act in the same way, as it had done previously for REE processing plants in La Rochelle and in Estonia, but it seems impossible to open mines or processing plants in Europe in any case.

Q. It seems that to open a mine in many parts of the world requires destruction of forests i.e. carbonising one area to supply materials to help decarbonise other areas.
A. Indeed, but on Madagascar where only 10% of the indigenous forest survives (because the people have not valued the forest in order to grow crops), there is an important Ni mine which has a policy that provides forest elsewhere to compensate for the forest that is damaged by mining, and also compensates people for environmental protection and measures that it puts in place. After 15 years of operation, there has been no net loss of forest. So it is possible to manage natural resources alongside mining operations if suitable environmental measures are in place at the outset.

Q. What about deep sea mining for critical metals?
A. Seabed nodules do have potential for Ni, Co, & Mn, but how well do we know the environment, how much will it cost to recover and process these? While there will be less chance of immediate neighbour protests, there is little knowledge of how it would be managed or what the environmental impacts would be, but predictably bad!

Q. Do tailings waste deposits hold any future for reprocessing to get REE?
A. Mine tailing waste on land can potentially be reprocessed. The vast red mud tailings from a bauxite mine may be a viable source of REE and Sc in the future and in Zimbabwe, the tailings from a former tin mine are rich in Li.

Q. Who in the UK understand all the long-term problems about mining and mineral resources.
A. Government has set up an All-Party Parliamentary Group for Critical Minerals, [https://www.criticalmineral.org/all-parliamentary-group-appg] chaired by Steve Double, in which Alexander Stafford MP is a knowledgeable member. Other branches of Govt. include the Dept. for Business, Energy & Industrial Strategy (BEIS), Dept. for International Trade, and the Dept. for Environment, Food & Rural Affairs. The Faraday Battery Challenge represents a UK Government investment of £330 million between 2017 and 2022. Finally, a Critical Minerals Expert Committee chaired by BEIS Chief Scientific Advisor, Professor Paul Monks has been set up. The Committee has met three times, and the latest meeting was opened by Business Secretary Kwasi Kwarteng on 28 January 2022. But the really critical expertise resides with the BGS, academics, companies and consultants.

Q. Are there any examples of a vertically integrated companies that have a REE source and a processing plant in the UK?
A. Pensana on Humberside and Peak Resources on Teeside both seem to have long term agreements to import carbonatite (from Angola and Tanzania respectively) and are building processing plants in the NE of England, but present estimates of reserves will almost certainly depend upon assays of the easily mined weathered zone, which are enriched in REE compared to the unweathered, hard rock below. Consequently, the vast expenditure of building a processing plant will ultimately require further reliable feedstock to have a sustainable future. Some collaboration between UK companies in future is likely to be required to keep their processing plants running. Morocco, by contrast, has one state-owned processing centre which can accept ores from very different metal mines e.g. copper, lead, zinc and cobalt.

The Chairman thanked Kathryn for stimulating what has probably been our longest and widest ranging Discussion, and to all those who had contributed to a most valuable event.

John Bennett