THE MASTERY OF IRON

David J. Vaughan

Kipling's poem is a powerful reminder that iron, the subject of this issue of *Elements*, is a raw material as essential to industry today as it was three hundred years ago. In 1709, Abraham Darby initiated the industrial revolution by being the first to use coke in iron smelting, which he accomplished at his ironworks on the banks of the River Severn in Shropshire, England. Iron accounts for over 90 percent of all metals consumed annually and, over recent decades, there has been a dramatic increase in the total amount of iron annually extracted from the Earth. In just the fifteen years between 1994 and 2009, global iron production grew from 1000 million to over 2200 million metric tons. Iron is one of the six most abundant metals in the Earth's crust, so there is no danger of running out of minable deposits of iron. However, most of the iron produced for modern industry is only useful when alloyed with one or more of a number of other metals that act to increase its strength, machinability or corrosion resistance, or provide it with special properties, such as those associated with magnetism.

Gold is for the mistress
Silver for the maid
Copper for the craftsman, cunning at his trade
'Good' said the Baron, sitting in his hall,
But iron, cold iron, is master of them all

—Rudyard Kipling
(1835–1936)

Whereas iron is still, as Kipling implies, the 'backbone of industry', it is ironic that geochemically scarce metals, such as chromium, titanium, cobalt, nickel, and tungsten, are essential for using that iron. Furthermore, in addition to metals for alloying with iron, a growing number of scarce and rare metals are essential raw materials for modern technologies. Examples include lithium for batteries, germanium and indium for computers, and tantalum for mobile phones. It is becoming apparent that shortages may soon arise in the supplies of certain of these metals; indeed, they are acquiring the kind of strategic importance previously only associated with reserves of oil and gas. The rare earth elements (REE) are a good example: they are used in small amounts in everything from high-powered magnets to batteries and electronic circuits. The need for these metals is rapidly growing because of their roles in clean-energy technologies (lanthanum for hybrid car batteries, neodymium for permanent magnets in wind turbines, and europium for energy-efficient lighting). At present, China controls 97% of global REE production. In October 2010, China cut its exports of REE by more than 70% over the previous year, disrupting manufacturing in the USA, Europe and Japan and forcing price rises of 40% or more. According to experts, these cuts were related more to the needs of the Chinese to satisfy their own growing internal market than to an attempt to profit from their near monopoly. Such developments raise the spectre of future international economic or even military conflicts arising over the supplies of rare metals.

The role of geoscientists in addressing the issues concerned with the supplies of strategic metals will be obvious to the readers of *Elements* magazine. Our community has been involved since the beginning in the application of science to mineral exploration, mining, mineral processing and metallurgy. These contributions are more important than ever, and are now complemented by the efforts we make towards the 'responsible' exploitation and utilization of Earth resources. In the cycle of mining, ore processing, metal utilization, and either recycling or safe disposal of the end products (and especially also of the wastes associated with mining), geoscientists need to play a central role in ensuring that we do not cause irrevocable damage to our environment. With a world population now approaching seven billion people, and predicted to grow to around nine billion by 2050, demand for metals is bound to further increase. Any return to 'simpler' ways of living that would not require such resources is unrealistic. Without mechanized food production and distribution, for example, there would be mass starvation around the globe.

This is my last editorial as a principal editor of *Elements* magazine, and thinking back over my previous editorials I recognize one central theme. It is that the community of Earth scientists, particularly those whose interests are focused on mineralogy–petrology–geochemistry, should be 'centre stage' in addressing many of the most pressing concerns that threaten the health and even the survival of future generations. These problems include the safe containment or clean-up of hazardous wastes (especially nuclear waste); pollution of the atmosphere impacting on human health; climate change, whether of human or other origins; and, in the context of the present article, secure supplies of many raw materials, including 'rare' metals. In the debates about how best to tackle these concerns, we need to be sure that our arguments are based on rigorous and objective science and, above all, that our voices are heard.

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