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ARTICLE

New age metals: the geology and genesis of ores required for a changing economy and a carbon-constrained world—preface to a thematic issue on critical commodities

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Over the last decade or so, the development of technologies associated with consumer electronics, renewable energy, and specialty steel have sparked demand for a range of "specialty" mineral commodities. These commodities are quite diverse and include, among others, rare earth elements, (REEs: lanthanides, Y, and Sc), Ga, In, W, platinum group elements (PGEs: Ru, Rh, Pd, Os, Ir, Pt), Co, Nb, Mg, Mo, Sb, Li, V, Ni, Ta, Te, Cr, Mn, Se, Ti, Sr, graphite, Sn, Ge, Be, Zr, Bi, F, and Cd. Most of these commodities have small, restricted markets, and, in some cases, supply is restricted—concentrated in either a small group of countries or producing companies. Some elements, such as In, Ga, Cd, Se, and Te, are produced as by-products of the extraction of base metals.

Although the amount of these commodities produced can be quite small (annual global production of Re, for example, was ~50 t in 2012: www.comtrade.un.org/db), they can be highly critical for some manufacturing industries. Consequently, a number of countries, including USA (United States Department of Energy 2010), UK (British Geological Survey 2012), Japan (JOGMEC 2010), Korea (Bae 2010), the European Union (European Commission 2010), and Australia (Skirrow et al. 2013), have commissioned reports on critical commodities. Most of these reports concentrated on economic aspects, with few discussing the geological occurrence of critical commodities. Although the details differed, most of these reports identified REEs (particularly heavy REEs), Ga, In, W, PGEs, Co, Nb, Mg, Mo, Sb, Li, V, Ni, Ta, Te, Cr, and Mn as being highly critical (see Skirrow et al. 2013 for summary). Interestingly, some of these reports identified more traditional commodities, such as Zn, as critical.

This Thematic Issue is the result of a symposium at the 34th International Geological Congress in Brisbane, Australia in August 2012 entitled "New age metals: the geology and genesis of ores required for a changing economy and a carbon constrained world". The purpose of this symposium was to discuss the geology and, to a lesser extent, the economics of critical commodities. This thematic issue presents some of the results of this symposium and related research.

The first paper in this issue (Simandl 2014) presents an overview of the geology and market dependency of REE resources. This analysis indicates that in recent years, changes in Chinese government policy have had a major impact on the supply and price of REEs, and that the production of these elements is highly dependent upon metallurgical characteristics and the ratio of heavy to light REEs in the ores. At present, most REEs are produced from carbonatite and related alkaline rocks. Recycling of these elements is in its infancy.

Geological and geochemical descriptions of the Cummins Range deposit in Australia and of Bastnäs-type deposits in the Bergslagen district in Sweden are presented by Downes et al. (2014) and Holtstam et al. (2014), respectively. Important results from the Cummins Range deposit include recognition of shear zone-hosted, REE-rich apatite-monazite-(Ce) rocks formed by the hydrothermal remobilization of REEs from carbonatites within the complex, and that the carbonatitic melts were derived from a subduction-

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modified mantle source (Downes et al. 2014). Holtstam et al. (2014) found that Bastnäs-type deposits formed when high temperature (>400 °C) magmatic fluids of Svecofennian age (ca. 1,900 Ma) interacted with dolomitic rocks in supracrustal assemblages. These fluids carried Fe, REEs, Cu, Mo, Bi, and Au as ore metals, along with Si, F, Cl, S, and CO_2.

Höhn et al. (2014) describe the geology and geochemistry of clay deposits in the Czech Republic and in Austria. In particular, they assess whether REEs could be recovered as by-products of kaolinite production. Although REE-bearing minerals are enriched in the by-products of kaolinite extraction, the quantities produced are insufficient to justify extraction.

Migdisov and Williams-Jones (2014) consider the hydrothermal geochemistry of REE transport and demonstrate that, under many geological conditions, chloride complexes, rather than fluoride complexes, were the most likely transporting agents for REEs. This has significant implications when considering the mechanisms and environments of REE deposition.

Simandl et al. (2014) document the application and reliability of hand-held X-ray fluorescence (XRF) analysis to exploration for REE deposits. They determined analytical uncertainties and detection limits for a range of REEs and related elements, demonstrating that this technique can be used effectively for REE, particularly light REE, exploration. Horiuchi et al. (2014) also discuss the utility of hand-held XRF spectrometry for REE exploration, in this case for the Blockspruit deposit in South Africa. They show that handheld XRF analysis of termite mounds in the field can effectively map the distribution of both light and heavy REE mineralization where exposure of outcropping rocks is poor.

Finally, Mackay and Simandl (2014) explore the history and uses of Ta and Nb, including the growing demand for "conflict" columbite-tantalite concentrates from Africa. These elements are extracted from a range of geological sources, including pegmatites and related alluvials for Ta, and weathered carbonatites and peralkaline complexes for Nb. An important conclusion of this study is that in the long-term, the supplies of Ta and Nb should be assured.

In addition to this thematic issue, *Mineralium Deposita* has recently published a number of other articles covering critical commodities. Sanematsu et al. (2013) studied a weathering profile with ion-adsorption type REE mineralization over granite in Phuket, Thailand. Luque et al. (2014) described the geology and geological controls on vein graphite, a commodity that has received much interest due to its use in graphene and other high tech applications. Yang et al. (2014) described the geology, geochemistry, and mineralogy of the Baerzhe deposit in China, one of the largest Zr-REE-Nb deposits in Asia. Frenzel et al. (2014) discussed potential geological sources of Ge and the technologies required to extract this critical commodity. Boudreau et al. (2014) discussed alteration in the offset zone of the Lac des Iles Pd deposit in Ontario, and a new model for the formation of the PGE-, Cr-, and V-rich layers of the Bushveld Complex was presented by Maier et al. (2013).

This thematic issue and recent papers in *Mineralium Deposita* have highlighted that many commodities that are considered "critical" by industrialized countries differ not only in economics, but also in their geology, with respect to more broadly traded commodities such as iron ore, Cu, Zn, Pb, Au, Ag, and Ni. Many critical commodities are associated with rocks, such as carbonatites and peralkaline magmatic rocks that have been the topics of highly specialized studies. Perhaps, the current emphasis on critical commodities may spur a better understanding of the metallogeny of these unusual, but important, rocks.

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