Editorial

From “strategic” tungsten to “green” neodymium: A century of critical metals at a glance

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A B S T R A C T

The relative criticality of mineral commodities is evaluated using a wide range of parameters and in different contexts (e.g., from the standpoint of their importance to national security, or to a specific industrial application), which explains the multiplicity of classification schemes and variations in terminology applied to these commodities in the literature, media and government reports. The core group of critical metals, listed alphabetically, includes: antimony, beryllium, chromium, cobalt, gallium, germanium, indium, niobium, platinoids, rare-earth elements (REE, including yttrium), tantalum and tungsten. The present retrospect briefly describes the emergence of critical metals as a distinct resource type and the evolution of society’s perception of these commodities over the past 100 years.

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Those who hold the purse strings of mineral resources, hold power, those who lose them lose power.

[Alan M. Bateman (1961, p. 331)]

The present Special Issue was conceived at the 1st International Workshop on Critical Metals in Beijing in September of 2012 (Fig. 1), which attracted delegates from 10 countries, and provided a great forum for sharing some current ideas on the sources of these metals and processes leading to their concentration in such unique deposits as Bayan Obo (northern China). This type of publication seemed very timely, given the recent upsurge of interest in the exploration community and among the general public in rare earths and other obscure materials that were now inseparable from the notion of technological progress and economic prosperity (telecommunication, electronics, nuclear...
energy, etc.), the above definition was later expanded beyond the defense sector and to include crises other than war (e.g., natural disasters or civil unrest). For example, the US Congress (1983) characterized these materials as those “needed to supply the military, industrial, and civilian needs of the United States during a national defense emergency and whose supplies are dependent on imports” (p. ix), drawing a distinction between “strategic” resources, whose supply was under potential threat, and those “critical” to the US economy (Jones, 1988).

In many other countries, no such distinction is made, and any resource potential threat, and those

 Fig. 1. Participants of the 1st Critical Metals Workshop in Beijing, China (September 2012).

or civil unrest). For example, the US Congress (1983) characterized these materials as those

strategic

or “strategically important” (e.g., Shestakov, 2000; UK House of Commons, 2011). The term “critical” re-emerged in the international business and political lingo with concentration of ~50% of the global production of some rare elements in relatively few countries by the 1990s (e.g., W, rare earths and Sb in China, Nb in Brazil, Be in the US, and Pt in South Africa), which coincided with commercialization of many new technologies dependent on these elements (hybrid and electric vehicles, energy-efficient lighting, solar panels, touch screens, etc.), rapid economic growth of China and several other developing countries, and with increasing pressure on both miners and manufacturers to extract and utilize these metals in a socially and environmentally responsible way (e.g., Chakhmouradian and Wall, 2012). In the past few decades, a variety of new terms have been coined to underscore a specific critical aspect of the commodity: high-tech metals, green metals, etc. Clearly, there is no universally accepted register of such commodities. The criticality of the same element is viewed and assessed differently by each country and even by different government-appointed bodies in the same country (cf. entries 1 and 2 in Table 1). In the long term, these lists are also affected by largely unpredictable changes in the geopolitical situation and market dynamics (cf. entries 3 and 4 in Table 1). It is important to note in this context that not all stockpiled materials are necessarily critical; for instance, Zn was stockpiled in Japan in the 1970s to mitigate overproduction in a weak market (Hewitt and Wall, 2000).

In recent years, a quantitative approach has been increasingly applied to the assessment of criticality, based on such parameters as the scarcity of a commodity, diversity and stability of its available supply, substitutability of the element in various types of end products and its amenability to profitable recycling, as well as various geopolitical, environmental factors and anticipated impact of any supply disruptions on the economy (BCS, 2012; Committee on Critical Mineral Impacts on the US Economy, 2008; European Commission, 2010; Graedel et al., 2012; Skirrow et al., 2013; Speirs et al., 2013; US DoE, 2011). Although there is much variation in quantifiable parameters and individual rankings (see Fig. 2 for some examples), about a dozen symbols appear on several lists (Table 1), with rare earth elements (REE) most consistently identified as critical. The light lanthanide Nd, for instance, is an essential ingredient of permanent magnets used in a wide range of things, from the Patriot missile to the Toyota Prius hybrid and other clean-tech applications. Again, it is not just the importance of REE-based materials for industry or defense, that catapulted this and related metals into the headlines a few years back, but a whole series of changes in the political and economic structure of the world since the 1980s (Chakhmouradian and Wall, 2012; Hatch, 2012), which allowed China to capitalize on its remarkable Bayan Obo and ion-adsorption clay deposits (Kynicky et al., 2012; Smith et al., this issue). Further examples can be found in a recently published compendium covering rare earths, Sb, Be, Co, Ga, Ge, In, Li, Mg, Pt-group metals, Re, Nb, Ta and W (Gunn, 2014).

The core group of critical and strategic elements highlighted in Table 1 and Fig. 2 is not a geochemically coherent group; they range from lithophile alkalis and alkali earths (Li, Be) to siderophile d-metals (Co and the platinoids), chalcophiles (Ga, Ge, In, Sb), high-field-strength lithophiles (Nb, Ta, W), and elements which are difficult to pigeonhole (e.g., Y and lanthanides). For this reason, it would be impracticable to attempt here even a brief overview of their mineral deposits, or processes that control their distribution in the crust. Some of the commodities listed in Table 1 were covered at considerable length in previously published Special Issues of Ore Geology Reviews, including Ni (González-Alvarez et al., 2013), Mn (Polgári and Gutzmer, 2012), W (Mao et al., 2011), Cr and Pt-group metals (Economou-Eliopoulos et al., 2008), Ga, Ge, In and Sc (Schwarz-Schampera, 2006). The economic geology of Sb, Li and Co, at least in the realities of today’s market, was addressed by Wu (1993), Kesler et al. (2012) and Mudd et al. (2013), respectively. The emphasis of the present Special Issue is on the metallurgy of critical metals that have not yet received a global- or continent-wide coverage in this journal, namely REE, Nb and Ta. In addition to papers stemming from oral presentations at the Beijing Workshop, we invited contributions from several leading research groups who were unable to attend this meeting. As a whole, the Issue covers the majority of deposit types currently being explored for REE, Nb and Ta ores, even though the Chinese ion adsorption clays may seem somewhat underrepresented relative to their commercial importance (Chi and Tian, 2008) and the possibility of extraction of valuable heavy REE from similar deposits elsewhere using low environment-
Non-fuel critical and strategic resources: an overview; underlined are the core group of elements appearing on multiple lists.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Classification category: resources</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Department of Defense</td>
<td>Strategic and critical non-proprietary materials (listed in order of decreasing shortfall value)</td>
<td>US DoD (2013)</td>
</tr>
<tr>
<td></td>
<td>Sn, Sb, Al₂O₃ (fused crude), SiC, Y, W, Ta, Bi, Ge, Mn, Tietal (electrolytic), Dy, fluotri (acid grade), Be metal, Er, Cr metal, Ga, Tb, Tm, Sc</td>
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<tr>
<td></td>
<td>Dy, Eu, Nd, Tb, Y</td>
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<td></td>
<td>Near-critical materials, short- or medium-term:</td>
<td></td>
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<tr>
<td></td>
<td>Sb, Be, Co, fluorite, Ga, Ge, graphite, In, Mg, Nb, PGM, REE, Ta, W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sb, Be, borates, Cr, Co, fluorite, Ga, Ge, graphite, In, manganosite, Mg, Nb, PGM,</td>
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<td>phosphate, REE, Si, W</td>
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<tr>
<td></td>
<td>U, Mn, Cr, Ti, bauxite, Cu, Ni, Pb, Mo, W, Sn, Zr, Ta, Nb, Co, Sc, Be, Li, Ge, Re, HREE, Au, Ag,</td>
<td></td>
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<td>PGM, diamondoids, ultra-pure quartz</td>
<td></td>
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<tr>
<td>UK Government</td>
<td>Striategically important metals (listed alphabetically):</td>
<td>UK House of Commons (2011)</td>
</tr>
<tr>
<td></td>
<td>Sb, Be, Cr, Co, Ga, Be, Au, Hf, In, Li, Mg, Ni, Nb, PGM, Rf, RfE, Ta, Ti, W, V</td>
<td></td>
</tr>
<tr>
<td>Geoscience Australia</td>
<td>Critical commodities (listed in order of decreasing criticality):</td>
<td>Skirrow et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>REE, Ga, In, W, PGM, Co, Nb, Mg, Mo, Nb, Sc, Li, V, Ni, Ta, Cr, Ten</td>
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</tr>
</tbody>
</table>

a Listed are the materials whose shortfall value relative to the National Defense Stockpile exceeded US$1 million.
b Platinum-group metals (platinoids), including Ru, Rh, Pd, Os, Ir and Pt.
c Rare-earth elements, including the lanthanides (La–Lu) and Y; in some sources, Sc is also included in this category. Note that some organizations rank each individual REE separately (e.g., US DoD, 2013; US DoE, 2011), rather than collectively as the “rare earth basket”.
d Defined as mineral resources whose export is controlled, restricted or not permitted to prevent harm to the security or economy of the country (Shestakov, 2000).
e Heavy REE (including Y).
f Commodities ranking below 12 (see Fig. 2 for further details) are not listed.

Impact methods. The shortage of papers on “ionic clays” reflects the comparative lack of adequate understanding of these materials, which may drive the next phase of research and technological development in this area in the near future.

The present issue opens with a series of contributions on rare earths, including a review of the genesis of the previously mentioned world-class Bayan Obo deposit by Smith et al., followed by detailed studies of REE mineralization in carbonatic and related rocks from the Kola Peninsula, Russia (Zaitsev et al.), Bear Lodge deposit in Wyoming, USA (Moore et al.), and Wicheeda Lake complex in British Columbia, Canada (Dalsin et al.). The long-debated carbonatite–Bayan–Obo connection is placed under scrutiny again by Zhu et al. based on new isotopic-evidence. The new age constraints on carbonate-hosted REE deposits in southwestern China are discussed by Liu et al., and the REE geochemistry and mineralogy of granites supporting ion-adsorption clays of southern China by Wang et al. The well-known association of REE with Nb is explored in further detail by Graupner et al. and Kempe et al. on the example of complex igneous–hydrothermal systems at Vergenoeg (South Africa) and Khazan Buregte (Mongolia), respectively. The next five papers put the spotlight on Nb, Ta and other “less critical” high-field-strength elements (HFSE). Mitchell’s review of primary and secondary Nb deposits in carbonatites is followed by a detailed account of Nb, Ta and Zr distribution in the Aley carbonatite deposit in British Columbia by Chakhmouradian et al. Melcher et al. present a systematic study of Ta–Nb–Sn mineralization in African pegmatites and rare-metal granites, Badanina et al. describe compositional variations in Columbite-group minerals from pegmatites at Kolmozero (Kola Peninsula), and Aseri et al. examine the effects of F on the solubilities of Ta, Nb, Zr and HF minerals in experimental haplogranitic melts. The Issue concludes with two contributions on geologically remarkable, but little studied systems, namely In-rich epithermal polymetalllic veins (Lopez et al.), and carbonate-hosted Mo deposits (Song et al.).
This project would not have come to fruition without the invaluable help of many referees, who generously shared their expertise and insight with our contributing authors. We would like to express our gratitude to all of them, as well as to Editor-in-Chief Franco M. Pirajno and to the OGR staff, in particular Journal Manager Hemalatha Moorthy and Content Specialist Yanping Hou, for their hard work in bringing this issue together.

In conclusion, we would also like to thank Xu Cheng, Zhengqian Hou, Lifei Zhang and their colleagues and students from Peking University and the Chinese Academy of Geological Sciences for making the Beijing 2012 meeting a success, and invite you to attend Critical Metals 2015 in the Kola Peninsula! For detailed information about this event, please visit http://criticalmetalsmeeting.com/.

References


