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Review

Value of mineral deposits associated with mafic and ultramafic magmatism: Implications for exploration strategies

D.C. Peck [a,*], M.A.E. Huminicki [b]

[a] Peck Geoscience & Exploration Corporation, 738 23rd Street, Brandon, Manitoba R7B 1W3, Canada
[b] Micro Analytical Facility, Department of Geology, Brandon University, 270 18th Street, Brandon, Manitoba R7A 6A9, Canada

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ABSTRACT

Magmatic ore deposits associated with ultramafic and mafic magmatism (MODUM) include nickel sulfide deposits that are locally enriched in copper, cobalt, platinum group elements and gold, a diverse range in platinum group element deposit types, oxide- and silicate-related nickel–cobalt laterite deposits formed by weathering of ultramafic bodies, and massive and stratiform accumulations of chromite, ilmenite and vanadium-bearing magnetite. Magmatic ore deposits associated with ultramafic and mafic rocks span most of earth's history and are well represented on all continents, and in all climatic zones and physiographic regions. Currently, these deposits are estimated to account for approximately 7% of the total value of annual global metal and mineral mining. They include the world's greatest concentration of metals — the Bushveld Complex, which has an estimated total metal endowment value, representing past production and current reserves and resources, of $US 3.6 trillion.

Recent trends in exploration spending for mafic to ultramafic magmatic ore deposits compared to commodity market size and production value indicate a significant under-investment in exploration for magmatic chromite, ilmenite–vanadium and polymetallic disseminated copper–nickel–platinum group element sulfide deposits. Historically, exploration of mafic to ultramafic magmatic belts has commonly involved a narrow range of deposit models, geological environments and exploration methods. A value-based and more holistic approach to exploration for mafic to ultramafic magmatic ore deposits is proposed that captures a larger range of known mineralization styles, settings and commodities. A focus on high-value deposits providing excellent operating margins and long mine life is recommended as a starting point for new programs. However, by recognizing the full range of possible mineralization styles and understanding mineral economic thresholds, future explorers can expand the search area and methodology and increase the probability of discoveries that create value.

Assuming that commodity prices continue to rise with declining average grades, current global resources hosted by mafic to ultramafic magmatic ore deposits are adequate to meet global demand for nickel, platinum group elements (PGE), chromium and vanadium for many decades to come. Despite this, the high net smelter return (NSR) value of many types of MODUM deposits provides ongoing economic motivation for both greenfields and brownfields exploration in these strategically important deposits. Furthermore, the large range in producer costs for key MODUM commodities such as nickel, copper and PGE provides significant opportunities for new projects to displace existing, higher-cost operations on the industry cost curve. The known clustering of high-value deposits within discrete magmatic belts (e.g., nickel sulfide and nickel laterite deposits) is an additional motivation for exploration investment as it allows exploration to focus early in areas of higher mineral potential. Additional incentives for MODUM exploration include the cumulative size and maturity of MODUM commodities that reduce investment risk and thereby appeal to junior explorers, mid-cap explorers and developers and major, multi-national mining companies. The economies of scales that were successfully applied to mining of large porphyry copper deposits for many decades could have a similar positive impact on a large number of advanced MODUM projects, especially polymetallic sulfide deposits capable of generating high value concentrates having significant base metal and precious metal contents.

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* Corresponding author.

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1. Introduction

Magmatic ore deposits associated with ultramafic to mafic magmatism (MODUM) are important contributors to current global mineral production and an essential source of several strategic, industrial metals including copper, nickel, cobalt, platinum-group elements (PGE), chromium, titanium and vanadium (e.g., United States Geological Survey, 2013). Historically, exploration and mining investment into this class of ore deposit has been led by major western producers such as Inco, Western Mining and Falconbridge and large state-owned or state-directed mining groups such as Vale, Noril'sk Nickel and the Jinchuan Group Company. In the early 2000s, hundreds of junior-sector explorers became involved in global MODUM exploration with a specific focus on greenfields projects, advanced projects in emerging mining districts and historical discoveries that were re-assessed in more detail.

For the purpose of this study, MODUM include the following subtypes of ore deposits that formed in mafic to ultramafic magmatic bodies including intrusions and lavas, or by weathering of ultramafic rocks:

- massive to disseminated copper–nickel–PGE sulfide deposits that may also contain recoverable amounts of gold and cobalt;
- massive and stratiform chromite deposits;
- massive and stratiform vanadium-bearing magnetite deposits;
- massive ilmenite deposits; and,
- nickel+/- cobalt +/-PGE laterite deposits, including saprolite, transitional and limonite subtypes, that formed during the weathering of ultramafic magmatic rocks.

This manuscript provides an independent analysis of the current value of MODUM reserves and resources in terms of both the *in situ* value of the contained metals and the estimated net smelter return (NSR) value of the mineralization. The NSR value is a common value metric for metallic mineral deposits and is typically defined as the net revenues a mine receives for its mineral concentrates after deducting transport, smelting and refining charges. An assessment of exploration spending trends is also provided in relation to total market sizes for the ore metals and minerals hosted in MODUM. Finally, a review of the geographic distribution of MODUM emphasizing magmatic provinces hosting multiple styles of MODUM leads into a discussion of optimal exploration strategies.

2. Data sources and assumptions

The reserve, resource and mine production data presented in this study are principally derived from SNL Metals and Mining's online mineral resource database (SNL Metals and Mining, 2014a; www.snl.com/Metals) used here with SNL's permission. Other data sources used include published information given in company annual reports and investor presentations, numerous web-based commodity review papers, and recent global commodity reviews provided by the United States Geological Survey, Natural Resources Canada and the Indian Geological Survey. Where resources are specifically referenced, they are inclusive of any published reserves and capture all resource (measured, indicated and inferred) and reserve (proven and probable) categories (Canadian Institute of Mining, 2010). Less than 5% of the cited resources and reserves are based on historical, non-compliant estimates. All dollar amounts refer to US dollars. All references to ounces are troy ounces. Price assumptions are based on published average metal and mineral prices for the 2013 calendar year (references provided below).

Reviews of this type are unlikely to capture 100% of the actual global mineral resource base or mine production because of the lack of published information for specific countries and certain types of mining operations such as chromite mines that are integrated with steel manufacturing businesses. However, the compiled resources described in the current study compare favorably with other, recent global reviews for the MODUM commodities in terms of total numbers of projects, resources and reserves, average grades and annual production (e.g., United States Geological Survey Minerals Yearbooks and Mineral Commodity Summaries; Indian Minerals Yearbooks; Vanitec website; Roskill Consulting web-based commodity reviews; producer annual report global commodity reviews; Johnson Matthey and CPM Group annual reviews of PGE markets; Cawthorn et al., 2005; Mudd, 2010; Mudd et al., 2013; Mudd and Jowitt, 2014; Laznicka, 2010).

3. Global reserves and resources

Table 1 provides a statistical summary of reserve and resource information for global magmatic nickel–copper–cobalt–PGE (gold) deposits sourced from individual project data that are given in Appendix 1. Table 2 provides a statistical summary for magmatic chromite, vanadium and ilmenite deposits sourced from individual project data provided in Appendix 2. In order to provide an equivalent basis for comparing the grade and value of the MODUM discussed in this study, both the copper equivalent and the nickel equivalent grades were calculated for each project using the factors provided in Table 3. Likewise, an estimate of equivalent NSR value per tonne of resource was calculated using the standard assumptions listed in Table 4. Standard assumptions were necessary to apply to the NSR calculations because of incomplete reporting of specific parameters in the NSR calculation, most notably the transport cost, recovery factors and smelter payability factors that are frequently not reported for non-western world mines and are generally not known for undeveloped resources. The assumed values for these factors are listed in Table 4 and are based on typical or median values estimated from corporate annual reports on production costs. NSR value estimates are highly influenced by metal price assumptions.