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Global platinum group element resources, reserves and mining – A critical assessment

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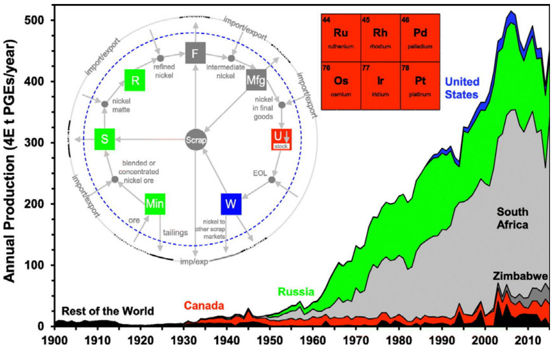
HIGHLIGHTS

- Global platinum group elements (PGEs) resources continue to grow.
- South Africa contains the 2/3rd of reserves and resources followed by Russia (1/6).
- Social, environmental, and economic issues are major constraints on the PGEs sector.
- PGEs are likely to remain as critical metals due to resource location.

GRAPHICAL ABSTRACT



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ABSTRACT

The platinum group elements (PGEs) are used in many technologies and products in modern society, especially auto-catalysts, chemical process catalysts and specialty alloys, yet supply is dominated by South Africa. This leads PGEs to be assessed as 'critical metals', signalling concern about the likelihood and consequences of social, environmental and economic impacts from disruptions to supply. In order to better understand the global PGE situation, this paper presents a comprehensive global assessment of PGE reserves and resources and the key mining trends which can affect supply. The data shows that global PGE resources have increased from 90,733 t PGEs in 2010 to 105,682 t PGEs in 2015, a 16.4% increase – despite global production of 2243 t PGEs over this period. This suggests that the key issues facing the PGE sector are not geological or resource depletion, but clearly social, economic and environmental in nature – as highlighted by recent social issues in South Africa and volatile global economic conditions. Concerns over PGE supply reliability and the implications of any supply disruption will therefore continue to see the PGEs labelled as critical metals – but certainly not due to resource depletion.

1. Introduction and background

The platinum group elements (PGEs) play a crucial role in many modern technologies, such as catalytic converters used in automobiles (or auto-catalysts), chemical process catalysts (critical for oil refineries), hydrogen fuel cells, jewellery, electronics and special medical alloys. Given the critical mega-trends of rising global population and consumption, and the need to address climate change (i.e. greater need for renewable energy technologies), it can reasonably be expected that demand for PGEs will continue to grow for many decades (e.g. UNEP, 2013).

The PGEs formally consist of platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir) and osmium (Os), and are among the

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rarest of the elements in Earth's upper continental crust, ranging from 0.022 ppb for Ir to 0.52 ppb for Pd (see Rudnick and Gao, 2014). Traditionally, given the common geological association with gold (Au) and the very low concentrations of Os present in PGE mineralization, concentrations are often presented as either ‘4E’, consisting of Pt + Pd + Rh + Au (the dominant metals by concentration and value), or as ‘6E’, consisting of Pt + Pd + Rh + Ru + Ir + Au (or sometimes 3E = Pt + Pd + Au). Here, we use the term PGEs to avoid confusion with PGMs being interpreted as metals or minerals, with all data presented in 4E format (unless otherwise specified).

South Africa continues to be the dominant country in mining and supplying PGEs to the world, entirely from the Bushveld Complex, followed by Russia's Noril'sk-Talnakh field (and small amounts elsewhere), and modest but useful contributions from Zimbabwe, Canada and the USA. This means that the PGEs are often labelled as ‘critical metals’ due to the supply dominance of South Africa as well as their fundamental role in important modern technologies, with the supply of PGEs from South Africa vulnerable as a function of potential technological (e.g. depth of mining), infrastructure (e.g., secure supply of energy to mine sites), and social (e.g. recent mine strikes and associated violence) issues, among others. Although concerns over resource supply are known throughout antiquity, the debate has reached a greater prominence in the past decade (Dewulf et al., 2016; Frenzel, 2017; Sykes et al., 2016). The US National Academy of Science (NAS) released a study in 2008 which used importance of use and supply vulnerability to assess whether a metal was critical and at risk of interrupting society in some manner (NRC, 2008) – with PGEs assessed as being highly critical. There are now further studies expanding the methodology to assess criticality (e.g. Graedel et al., 2012) as well as various national or regional assessments of which metals can be considered critical (e.g. BGS, 2015; EC, 2014; Skirrow et al., 2013; USDoD, 2014; USDoE, 2011) – with PGEs invariably labelled as critical in all of these studies.

There are also further considerations when examining the criticality of a metal, namely recyclability, current recycling rate, and the potential for substitution and the effects on product or technological performance (e.g. Gunn, 2014; UNEP, 2013). For the PGEs, it is possible to substitute between Pt and Pd in auto-catalysts, with recycling already practiced extensively in this sector (e.g. Stillwater project, USA; SMC, 2016). The balance of Pt versus Pd use is therefore dominantly economic – although Pt gives superior performance it is typically more expensive, but if the price of Pd becomes sufficiently low, more Pd will be used over Pt. There are similar issues in other PGE uses (e.g. petroleum and chemical industry catalysts), although for some uses the ability to recycle PGEs is quite limited (e.g. medical) or remains uneconomic (e.g. electronics and electrical sectors). This flow of metals through the anthroposphere is studied in the field of industrial ecology and is often represented as a ‘wheel’ (Supplementary Information, Figure SF1). This figure demonstrates that metals are extracted from the lithosphere (sensu lato rather than lithosphere in a mantle/geological sense) and flow through the supply chain to eventual waste disposal or recycling. Given the expected growth in demand for PGEs, this makes understanding the first stage of this wheel of fundamental importance in quantifying both the industrial ecology of PGEs but also their criticality.

In the mining industry, the reporting of mineral deposits is typically governed by an industry or statutory code, with the fundamental concepts of ore reserves and mineral resources being the dominant approach. Examples of codes include Australia's Joint Ore Reserves Committee (JORC) Code, South Africa's SAMREC Code, Canada's National Instrument 43-101 (aka NI43-101) and associated CIM Code, the U.S. Security & Exchange Commission's Industry Guide 7, the European PERC Code, with similar codes in Chile, China, Russia and elsewhere (references provided in Supplementary Information). In normal practice, ore reserves are typically estimated based on short term mining plans and are expected to be economic, whereas mineral resources are less certain in some respects (e.g. economics) but are sufficiently understood in others (e.g. geologically, metallurgy) to be considered to have reasonable prospects for eventual economic extraction (AusIMM, 2014; see also Mudd et al., 2017a) for a detailed review of critical and by-product metals in reserve-resource reporting). Thus it is the distinction between reserves and resources which is important to understand in assessing future supply potential, especially the distinction between short-term (say 5–10 years) and longer time frames of many decades. This has never been assessed and published in detail for the PGEs (nor any other metals), leaving a key gap in the literature and therefore public discourse concerning the availability of PGEs to meet various demands this century.

A key need, therefore, in assessing the ‘criticality’ of the PGEs is a detailed understanding of ore reserves, mineral resources, and key trends in mining and supply, including the often complex factors which may affect all of these aspects. A previous study, Mudd (2012), compiled and presented some of this data on PGEs for and up to the year 2010 (but mineral resources only and not ore reserves), while other studies compiled PGE mineral resources data for 2009 (Glaister and Mudd, 2010), for 2011 from a global Ni mineral resources study (Mudd and Jowitt, 2014) (but not ore reserves), as well as an unpublished compilation for 2012. This paper updates and expands this assessment for and up to the year 2015, including for the first time a split between ore reserves and additional mineral resources, a comparison between current reserves-resources in two different time periods, key mining trends and issues, and a broad discussion of the current state of the PGEs sector of the global mining industry, examining aspects such as governance, human development, economic and other metrics of the countries with PGE resources. Overall, the paper synthesizes a detailed view of global PGE resources, reserves, mining and links to important factors which help understand the criticality of the PGEs.

2. Methods

The approach adopted for this study is to compile detailed data sets on ore reserves and additional mineral resources reported on an individual project basis for the year 2015, as well as mining production data and key trends over time. Almost all reserves and resources are reported on a strict code-basis (e.g. SAMREC, JORC, NI43-101), and are typically sourced from corporate annual (or sometimes quarterly), technical and sustainability reporting. The Fennoscandian Ore Deposit Database (GTK et al., 2015) was also used, with data verified from technical and other literature where possible. This replicates the approach from similar studies for copper (Cu; Mudd et al., 2013a), cobalt (Co; Mudd et al., 2013b), nickel (Ni; Mudd and Jowitt, 2014) and lead zinc (Mudd et al., 2017b). The primary groupings chosen are the Merensky and UG-2 reefs of the Eastern and Western Bushveld Complex, the Platreef of the Northern Bushveld Complex, the Great Dyke of Zimbabwe, miscellaneous PGE resources (where PGEs are >60% of reported metal value), Ni-Cu-PGE resources (where Ni-Cu ± Co are >40% of value) and other miscellaneous resources containing PGEs (based on metal price data from USGS, 2016). Where there are multiple deposit types present, we choose the dominant type (see Jowitt et al., 2013). All data are provided in Supplementary Information.

Following the collation and verification of entries in the database, further analyses of PGE resources are conducted, including assessments of ore grade distributions, and distribution of resources between countries and mineral deposit types. All statistical regressions were completed in Excel, which uses the Pearson method and assumes a normal distribution in a data set (further statistical evaluation is outside the scope of this study). It is also possible to use these country-level PGE distributions to further understand the implications or risks associated with future PGE supply. For example, political instability in various countries hosting PGE resource could affect their supply, but the extent of any supply disruptions depends on the amount of resources present in each country. In Section 5, we compare per-country resources to some country-level socio-economic, political and environmental indices.