Ore Geology Reviews 64 (2015) 253–272

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Controls on disseminated PGE–Cu–Ni sulfide mineralization within the Rietfontein deposit, Eastern Limb, Bushveld Complex, South Africa: Implications for the formation of contact-type magmatic sulfide deposits

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ARTICLE INFO

Article history:
Received 16 February 2014
Received in revised form 4 July 2014
Accepted 6 July 2014
Available online 12 July 2014

Keywords:
Magmatic sulfides
Bushveld Complex
Platreef
Platinum group elements
Layered intrusion

ABSTRACT

The Rietfontein platinum group element (PGE)–Cu–Ni sulfide deposit of the Eastern Limb of the Bushveld Complex hosts disseminated contact-style mineralization that is similar to other economic magmatic sulfide deposits in marginal settings within the complex. The mineralization at Rietfontein consists of disseminated PGE-bearing base metal sulfides that are preferentially located at the contact between a distinct package of marginal norites overlain by a thick heterogeneous unit dominated by gabbronorites with lesser norites and ultramafic rocks. Down-hole composite data and metal scatterplots indicate that the PGE correlate well with Ni, Cu and S and that only minor metal remobilization has taken place within the basal norite sequence. Plots of $(Nb/Th)_{PM}$ vs. $(Th/Yb)_{PM}$ indicate that the melts that formed the Rietfontein intrusive sequence were strongly crustally contaminated prior to emplacement at Rietfontein, whereas inverse relationships between PGE tenors and S/Se ratios indicate that these magmas assimilated crustal S, causing S-saturation and the formation of immiscible sulfides under high R-factor conditions that generated high PGE tenor sulfides. Reverse zoning of cumulus minerals at Rietfontein suggests that fresh primitive melts were introduced to a partially fractionated staging chamber. The introduction of new magmas into the chamber caused overpressure and the forced evacuation of the contents of the chamber, leading to the emplacement of the existing magmas within the staging chamber at Rietfontein in two separate pulses. The first pulse of magma contained late-formed cumulus phases, including low Mg# orthopyroxene and plagioclase, was emplaced between footwall unreactive and S-poor Pretoria Group quartzites and a hangingwall sequence of Rooiberg Group felsites, and was rapidly chilled to form the basal norite sequence at Rietfontein. The second pulse of magma contained early formed cumulus phases, including olivine, chromite, and high Mg# orthopyroxene, and was emplaced above the chilled norite sequence as a crystal mush to form gabbronorites and ultramafic rocks. This second pulse of magma also contained PGE-bearing base metal sulfides that accumulated at the contact between this second batch of magma and the already chilled basal norite sequence. The formation of Platreef-type mineralization outside of the Northern Limb of the Bushveld Complex confirms there are a number of areas within the Bushveld Complex that are prospective for this style of mineralization.

1. Introduction

The Rietfontein platinum group element (PGE)–Cu–Ni deposit is hosted by a series of marginal mafic–ultramafic rocks within the Eastern Limb of the Bushveld Complex (Fig. 1). Mineralization at Rietfontein is similar to the contact-type Platreef deposit of the Northern Limb of the Bushveld Complex of South Africa, the world's third largest PGE resource, in that both deposits have thicker mineralized intercepts than the reef-style UG-2 and Merensky Reef PGE deposits within the complex (Naldrett et al., 2008). This means that mineralization in the Platreef and at Rietfontein are open pittable and therefore highly attractive targets for mineral exploration. However, it is currently unclear how, if at all, the Rietfontein and Platreef styles of mineralization are analogous. In addition, the presence of contact- and Platreef-type mineralization within the Eastern and Western limbs of the Bushveld Complex, such as at Blue Ridge (Cawthorn, 2010) and Sheba's Ridge (Stevens, 2007), as well as elsewhere within the Northern Limb, such as within the Grasvally Norite–Pyroxenite–Anorthosite member (Maier et al., 2008; Smith et al., 2011), means that identification of the processes that formed these highly prospective styles of mineralization is an area worthy of further research.

Here, we present new petrological and geochemical analysis of samples from eight drill holes across the Rietfontein deposit (Fig. 2).

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http://dx.doi.org/10.1016/j.oregeorev.2014.07.006

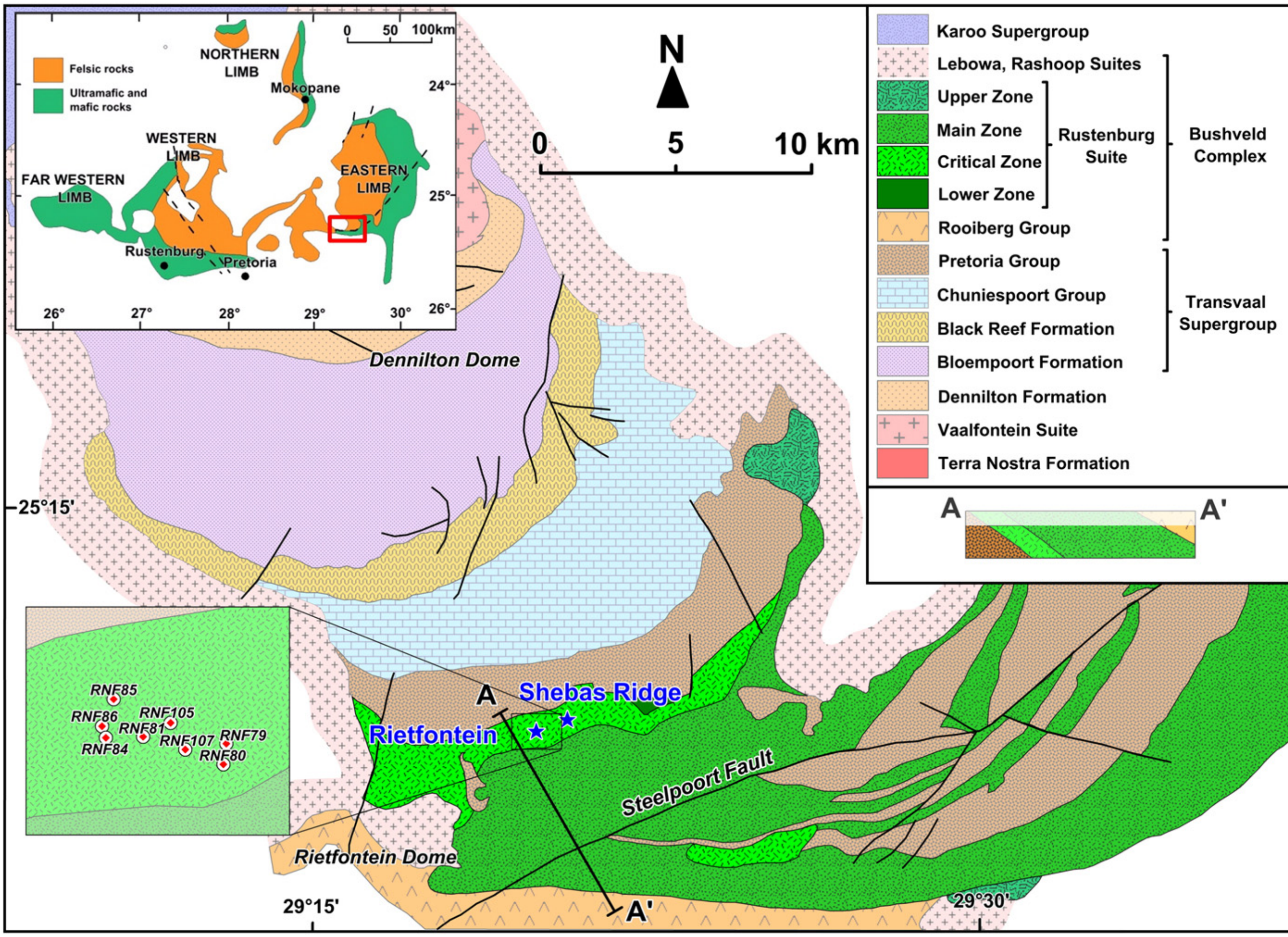

Fig. 1. Map showing the regional geology near the farm Rietfontein 70 JS on the far western periphery of the Bushveld Complex (modified from Hartzer, 1995), including drill hole collar locations for drilling within the Rietfontein intrusion (inset).

These holes were selected to determine the magmatic processes involved in the formation of the basal PGE–Cu–Ni sulfides within the study area. In addition, whole-rock data from three Platreef drill holes (Ihlenfeld and Keays, 2011) are used as a comparator to determine whether the same processes were responsible for the formation of PGE mineralization in both areas. This study presents a summary of the dominant lithologies in the mineralized margins of the intrusive rocks at Rietfontein and their relationship to the PGE–Cu–Ni mineralization in this area, the location and stratigraphic correlation of PGE mineralization across the drill holes, the identification of individual magma pulses and the igneous evolution of the Rietfontein magmas prior to and during emplacement. In addition, we present a model for the causes of sulfide saturation and PGE mineralization at Rietfontein and a comparison of the styles and processes involved in the formation of PGE mineralization with samples taken from the Platreef PGE deposit at Overysel, Tweefontein and Sandsloot.

1.1. Geological background

The Bushveld Complex of the Republic of South Africa consists of mafic and ultramafic rocks of the Rustenburg Layered Series (RLS), the felsic Lebowa granite suite and the Rashoop granophyres (Fig. 1; Eales and Cawthorn, 1996). The RLS is the world's largest known layered mafic–ultramafic igneous intrusion, covers an area of 65,000 km^2 (Eales and Cawthorn, 1996) and was intruded between the 2.4 and 2.5 Ga Paleoproterozoic Transvaal Supergroup sediments that form the footwall rocks to the Bushveld Complex and dacite and rhyodacite lava flows with minor pyroclastic and sedimentary interflow units of the ~2061 ± 2 Ma Rooiberg Felsites (Walraven, 1997). It was emplaced from a series of magmas as a large lopolithic sill and hosts over 70% of the world's known PGE resources and some 26% of the world's magmatic sulfide Ni resources (Mudd and Jowitt, in press; Ernst and Jowitt, 2013; Mudd, 2012) as well as significant amounts of Cu (Mudd et al., 2013). The majority of PGE mineralization within the complex is hosted by three main ore deposits, namely the stratiform UG-2 and Merensky reefs in the Western and Eastern Limbs and the stratabound/contact type mineralization of the Platreef in the Northern Limb (Cawthorn, 1999; McDonald and Holwell, 2011; Naldrett, 2004).

The Rietfontein PGE–Cu–Ni deposit occurs approximately 50 km west of Stoffberg on the farm Rietfontein 70 JS, on the far western periphery of the Eastern Limb of the Bushveld Complex (Fig. 1). The intrusive sequence occurs between the Rietfontein and Dennilton Domes and near the major crustal lineament of the Steelpoort Fault. The mafic–ultramafic succession at Rietfontein dips moderately to the southeast and was intruded between steeply dipping Pretoria Group sediments in the northern footwall and Rooiberg Group volcanics in the southern hangingwall (Crous, 1995; Hartzer, 1995). The relationship between the intrusive sequence in this region and the Bushveld Complex stratigraphy has not been equivocally established and remains controversial (e.g., Hartzer, 1995; Kruger and Behr, 2002).

The marginal intrusive rocks at Rietfontein have been assigned to the Critical Zone by Hartzer (1995) and form the focus of this paper. This sequence strikes approximately 20 km in an east–west direction from Rietfontein to the adjacent farm at Sheba's Ridge and has an undulating relationship with the footwall sequence (Crous, 1995;