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Compositional and lithological variation of the Platreef on the farm Nonnenwerth, northern lobe of the Bushveld Complex: Implications for the origin of Platinum-group elements (PGE) mineralization

By

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ABSTRACT

The present study documents the nature of the Platreef on the farm Nonnenwerth, northern Bushveld Complex and compares the lithologies and composition of the mineralized interval to those on the farm Townlands. The Platreef on Townlands was the subject of a previous study (Manyeruke 2003, MSc thesis, University of Pretoria), but in the course of the present investigation, additional data were collected. Nonnenwerth is located more than 70 km to the north of the well characterized occurrences of the Platreef at Sandsloot, Overysel and Drenthe. At Nonnenwerth, the Platreef rests on Archaean granite gneiss floor rocks whereas at Townlands, the Platreef rests on pelitic rocks of the Transvaal Supergroup.

At Nonnenwerth, the basal rocks of the Bushveld Complex may be sub-divided into two lithologically and compositionally distinct units. At the base is a relatively heterogeneous sequence of gabbronorite with minor amounts of norite, anorthosite and igneous ultramafic rocks containing several calc-silicate xenoliths. It is some 110 m thick and is enriched in Platinum-group element (PGE)-Cu-Ni bearing sulphides (<ca. 3 modal %). Layering is mostly weekly defined and discontinuous. The mineralized interval is overlain by the Main Zone that is made up of some 170 m of relatively homogenous gabbronorite, containing several large dolomite xenoliths. The two units are separated by an up to 25m thick dolomite xenolith. In many aspects, the composition of the Platreef and the Main Zone broadly overlap ($Mg\#_{opx}$ 57 – 72, An_{plag} 40 – 75, $MgO_{whole\ rock}$

7 – 15 wt. %, similar incompatible trace element patterns). However, the Platreef has distinctly higher Cr contents ($Cr_{whole\ rock}$ up to 1813 ppm as opposed to 280 ppm in the Main Zone) as well as concentrations of chalcophile elements (Ni, Cu, PGE) and sulphur.

The Platreef and the Main Zone have relatively unfractionated REE patterns with Ce/Sm between 5.7 and 10.6 (averaging 8). This suggests that the Platreef on Nonnenwerth is genetically related to Bushveld tholeiitic magma (B2/B3 of Sharpe, 1981). In contrast, Platreef rocks on the farm Townlands, south of Mokopane, are more primitive in terms of mineral and whole rock composition (Mg# opx 77, An plag 68, presence of olivine) and have higher and more fractionated REE contents (Ce/Sm 8 – 14.2, averaging 11.6). They show certain similarities to Upper Critical Zone cumulates and appear to have crystallised either from B1 – B2 hybrid magmas, or from B2 magma contaminated with crust upon emplacement. This implies that Platreef PGE mineralization cannot be correlated with specific stratigraphic units or magma types, but that it formed in response to several different processes.

Platinum-group element (PGE) contents of Platreef samples from Nonnenwerth reach 10 ppm, whereas PGE contents in the Platreef at Townlands reach 4.4 ppm. PGE distribution patterns at Nonnenwerth are more fractionated than at Townlands, with Pd/Ir mostly >>100 at Nonnenwerth compared to < 100 at Townlands. At both localities, there is a broad positive correlation between the concentrations of those PGE that could behave in a mobile manner (in particular Pd, Hsu *et al*. 1991) and those that are believed to be immobile under most conditions (e.g., Pt and Ir) and between individual PGE and S (for samples with > 0.1 % S), suggesting that sulphides were the primary PGE collector. At Nonnenwerth, this model is supported by a typical magmatic sulphide assemblage composed mostly of pyrrhotite, chalcopyrite and pentlandite and the close spatial relationship between platinum-group minerals (PGM) and base metal sulphides. However, at Townlands, the presence of pyrite and millerite attests to some secondary mobility of sulphur due to assimilation of floor rock shale.

Pd, Pt and Rh are below the detection limits of the electron microprobe in the sulphides analysed from Nonnenwerth and Townlands except for pentlandite from Nonnenwerth which hosts Pd in solid solution. Pd in pentlandites from Nonnenwerth constantly contain appreciable amounts of Pd (range from ~ 140 – 700 ppm). This finding is in accordance with literature data (e.g. Gervilla et al., 2004) that pentlandite may carry even up to some % of Pd (substituting for Ni) in its crystal lattice. Accordingly, the Pd contents in Nonnenwerth pentlandite probably reflect a primary magmatic signature. The lack of measurable Pd contents in pentlandite on Townlands may be due to (ii) mobilization of Pd-bearing PGM during replacement of 'primary' sulphides by pyrite dominated assemblages into the surrounding silicates (Prichard *et al*., 2001), (iii) syn- to post-magmatic modification of the 'primary' sulphides or (iii) the results may not be representative as Pd in pentlandite was analysed in one sample only.

The platinum-group minerals (PGM) on Nonnenwerth are dominated by Pd-rich followed by Pt-rich bismuthotellurides and rare braggite and sperrylite. In contrast, mineral proportions of the PGM on Townlands are dominated by Pd-rich bismuthotellurides, minor sperrylite, rare stibiopalladinite and isomertieite. One obvious difference, however, is the wide compositional range of Pt-Pd bismuthotellurides and the presence of Pt-rich bismuthotellurides at Nonnenwerth only, whereas at Townlands, only Pd-rich bismuthotellurides are present. The significance of this finding cannot be evaluated conclusively. The variability may be related to local factors like different host rocks; footwall lithologies, down-temperature re-equilibration, activity of fluids, and other possible causes. The PGM at Nonnenwerth occur predominantly at the contact between sulphide (mostly chalcopyrite, minor pyrrhotite and rare pyrite) and secondary silicate (mostly chlorite and albite after plagioclase) or enclosed in sulphides. Importantly, Pd-rich PGM (Pd-bismuthotellurides) are mostly enclosed in silicates. However, even these PGM enclosed in silicates retain a strong spatial relationship with the base metal sulphides, mostly chalcopyrite, and are associated with secondary minerals (mostly chlorite and albite which replace plagioclase, or rarely amphibole which replaces orthopyroxene and base metal sulphides). The above observation may result from dissolution of the base metal sulphides hosting Pd, and leaving isolated insoluble Pd-PGM behind (Barnes *et* *al*., 2007), or Pd may have been remobilized from the sulphides into the surrounding silicates. Based on textural evidence, the latter model is preferred. In contrast, on Townlands the PGM occur predominantly enclosed in sulphides (mostly pyrite and minor chalcopyrite and millerite), or locally at the contact between sulphide and secondary silicate (amphibole after orthopyroxene).

Sulphur isotopic ratios on Nonnenwerth range from $d^{34}S$ 0 to +2 ‰ suggesting that the sulphur in the Platreef is of mantle origin or that any S that may have been assimilated from the floor rocks was unfractionated. A similar value of $d^{34}S$ has been found by previous workers in the Platreef at Overysel which is equally located above granite gneiss. As both the basement granite and the Transvaal dolomites contain little sulphides, these results suggest that most of the S in the Platreef is of primary magmatic derivation. In contrast, Townlands sulphides have $d^{34}S$ between +4 and +8 ‰ suggesting addition of crustal sulphur. These data indicate that the formation of the PGE mineralisation in the Platreef was not controlled by assimilation of external sulphur. Instead, sulphide saturation may have been reached due to assimilation of dolomite, and/or due to differentiation and cooling of the magma upon emplacement. Subsequently, assimilation of S may have merely modified already existing sulphide melt particularly in areas where the floor rocks consisted of sulphidic shales e.g. at Townlands.

The study therefore indicates i) that contact-style PGE mineralization extends along most of the strike length of the northern lobe of the Bushveld Complex despite variable floor rocks of different composition underlying the northern Bushveld Complex from south to north, ii) that contact-style PGE mineralization in the northern lobe of the Bushveld Complex cannot be correlated with specific stratigraphic units i.e. the Upper Critical Zone that hosts the Merensky Reef and the UG2 Reef or magma types, but that it formed due to several different processes, iii) that base metal sulphides were the primary PGE collector, iv) that Pd and Pt occur mostly as PGM with close spatial relationship with base metal sulphides. At Nonnenwerth, Pd additionally occur dissolved in pentlandite, v) that they was minimal S assimilation from floor rocks at Nonnenwerth compared to localities further south i.e. at Townlands, and vi) a dominant Bushveld B2/B3 magma source/lineage for the Platreef at Nonnenwerth.