
Chromite is the Key to PGE

F. Johan Kruger¹, Judith A. Kinnaird¹, Paul A.M. Nex² and R. Grant Cawthorn²

¹Economic Geology Research Institute – Hugh Allsopp Laboratory

²School of Geosciences, University of the Witwatersrand, WITS 2050, South Africa.

Email: 106fjk@cosmos.wits.ac.za

Introduction

Chromitite layers in the Bushveld Complex have long been known to host anomalous concentrations of PGE. Indeed, the first recorded occurrence of PGE is from a chromitite in the area around Mineral Range in 1908. Initially these discoveries did not flourish due to metallurgical constraints, and the discovery in 1924 of the pipe-like (Onverwacht, Mooihoek and Driekop) bodies with payable Pt-Fe alloys, and then the chromite bearing (but S-enriched) Merensky Reef (both metallurgically amenable) suppressed interest in chromitite as a source of PGE (see Cawthorn, 1999 for a historical overview of the discovery of the Merensky Reef), until in the late 1970's and 1980's when metallurgical breakthroughs and increased demand led to mining of the UG2.

In the 1980's the model of Naldrett and co-workers. (see e.g. Naldrett, 1989), in which a very high ratio of magma to an immiscible sulfide liquid (R-factor) associated with magma influx and mixing is invoked, gained favour due to the presence of sulfide in the Merensky Reef. However, this model has recently been discredited for PGE in the Bushveld Complex (Cawthorn, in press).

Mineralogy, Geochemistry and Sr-Isotope Data

The chromitite layers of the Bushveld Complex host platinum group elements as platinum group minerals (PGM) which principally include PGE-sulfide minerals, (laurite, braggite and cooperite), but antimonides (geversite, stibio-paladinite), arsenides (sperrylite), bismuthides (insizwaite), tellurides (merenskyite, moncheite) and alloys (isoferro-platinum) are major contributors (see e.g. Lee, 1996). Base metal (Ni-Cu-Fe) sulfides also occur, but are not sufficiently abundant to be the residue of a PGE enriched immiscible sulfide liquid. Furthermore, many of these minerals occur as euhedral crystals enclosed in chromite grains. The R-factor modelling depends on large sulfide liquid/silicate liquid partition coefficients which obey Henry's Law. The presence of liquidus PGM negates this assumption – which can only be sustained by special pleading (e.g. assumed post-crystallization sulfur loss).

Chromitite is highly enriched in PGM, and chromite compared to most silicate host rocks and potential primary magmas (see e.g. Scoon & Teigler (1994)). The enrichment of chromium in chromitite ($\text{Cr} \pm 20\%$ in UG2) compared to a tholeiitic liquid (± 250 ppm) is about 800, and the enrichment in PGE in chromitite (8 ppm for the UG2) relative to a potential tholeiitic liquid (± 40 ppb (Davies & Tredoux, 1985)) is about 200. These ball-park figures are within a factor of 4 and suggest that the *process* that led to the crystallization of chromite simultaneously led to the crystallization *and* co-concentration of PGM. This requires the processing of a large volume of liquid (some 200-800 times the mass of the precipitated chromitite).

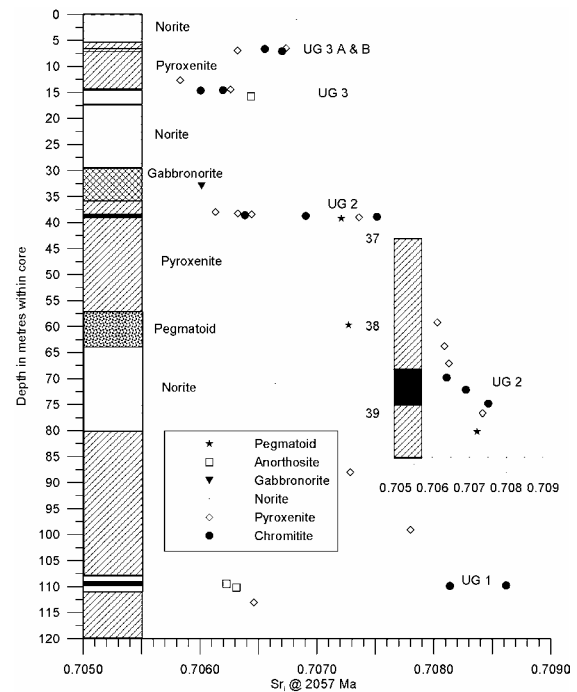


Figure 1. Strontium isotope profile in upper Critical Zone silicates and chromitite-hosted plagioclase from 10m below UG1 to 5m above UG3 in KF17 core, north of the Steelpoort lineament. The expanded inset for isotopic ratios through the UG2 chromitite illustrates the upward decrease in initial ratios from base to top of the chromitite. Source of data, Richardson (2002).

Seminal papers by Irvine (1975 & 1977) showed that chromite crystallization can be induced by felsic (silica) contamination (1975) or by mixing of “parental” magma and more evolved residua (1977); the process of mixing dissimilar magmas forcing the mixture into the chromite phase field.

Recently, Schoenberg *et al.* (1999) showed that chromitite layers have exotic enriched Sr-isotope systematics which are completely different from those of the host silicate rocks, and which imply sudden and major contamination by a ‘granitic’ crustal component. Furthermore, this contamination was only active while the chromitite was forming and ceased once the chromitite stopped forming. These observations have been confirmed and extended by Kinnaird *et al.* (in press) an example of which is shown in Figure 1.

These mineralogical, geochemical and isotopic data suggest a mechanism for chromitite formation that revives Irvine’s (1975) model in combination with his 1977 parental magma mixing model, but negates the later (1981) double diffusive convection model and the Irvine & Sharpe (1986) U- and A-type magma mixing models for these rocks.

A Model for Accumulation of Chromite and PGM

In this model we envisage that influxes of new magma into the Bushveld magma chamber rose up as fountains that interacted with and entrained granophyric roof-rock melt. This process contaminated both the new magma and the resident entrained melt with a SiO_2 rich component that induced crystallization of copious chromite and the concomitant crystallization of PGM. The small PGM crystals are collected and incorporated by the more abundant chromite grains as suggested by Hiemstra (1979). The chromite with adherent PGM and magma was carried to the floor of the chamber by the collapsing fountain to form chromitite layers enriched in PGE. Chromite (and PGM) only crystallize while there is roof-melt interaction or there is sufficient compositional contrast to force the mixture into the chromite phase field. The contamination process ceases when the head of the fountain ceases to impinge on the floating roof-rock melt. Continued magma influx may occur which is uncontaminated by the roof-rock melt. This process is illustrated in Figure 2

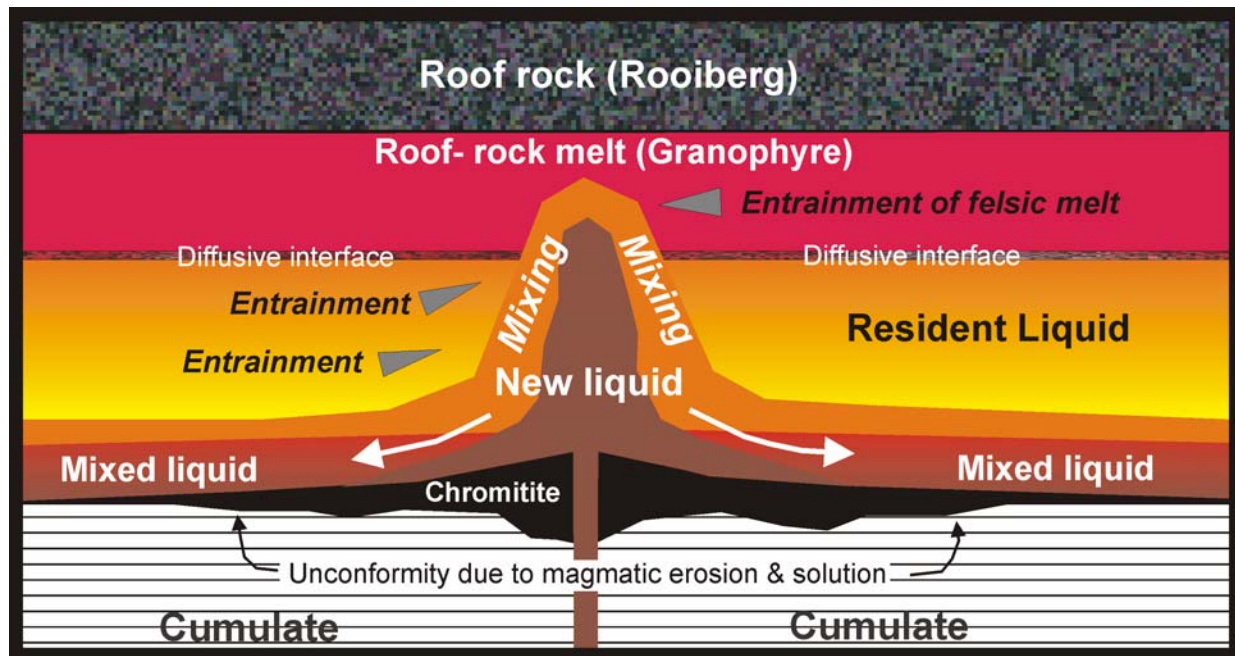


Figure 2. Introduction of a new magma ($Ro = 0.705 - 0.706$) as an active fountain results in entrainment of the resident mafic liquid and if there is sufficient upward momentum roof-rock melt ($Ro > 0.72$) is also entrained. This results in contamination by a silica-rich component with the resulting forced crystallisation of chromite. The mixed liquids are out of equilibrium with the floor cumulates and react and erode to form an unconformity onto which the chromite/PGM ore is deposited.

This process involves mixing three component magmas to produce chromitite. These are the resident (residual) magma, the new influx of magma and the roof-rock (granophytic) melt. The resident magma need not be a derivative of the second new magma as required by some models for PGE mineralisation and chromitite formation such as those of Campbell & Naldrett (1983) or Irvine (1977).

In the Bushveld Complex, the influxing magmas are not a single primitive “parental” magma, but a diverse series of different magmas as shown by Harmer & Sharpe (1985).

Conclusion

The model outlined here provides an explanation for the following features of chromitites and their PGM mineralization:

1. The apparent random stratigraphic positions of chromitites with respect to the evolving layered silicates, which cannot be predicted in the sequence as they are induced by magma addition events and not fractional crystallization.
2. The apparent unconformable relationships to underlying sequences.
3. The co-enrichment of Cr and PGE.
4. The unusual isotopic, mineralogical and chemical properties.

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