

The formation of the PGE bearing Bushveld chromitites and the Merensky Reef by magma mixing: a combined Re-Os and Rb-Sr study

R. Schoenberg

Gruppe Isotopengeologie, Mineralogisch-Petrographisches Institut,
Universität Bern, Erlachstrasse 9a, 3012 Bern, Switzerland

F. J. Kruger

Hugh Allsopp Lab., University of the Witwatersrand, Wits 2050,
South Africa

J. D. Kramers

Gruppe Isotopengeologie, Mineralogisch-Petrographisches Institut,
Universität Bern, Erlachstrasse 9a, 3012 Bern, Switzerland

The Critical Zone of the Bushveld Complex is characterized by repeated cyclic crystallization series (Cyclic Units), each comprising a chromitite layer, enriched in PGE-bearing sulphides and platinum metals, at its base. It is now widely accepted, among workers in the Bushveld Complex, that injections of fresh melt followed by mixing with residual liquid forced the composition of the crystallizing hybrid magmas into the stability field of chromite (Scoon *et al.*, 1994 and references therein) and thus lead to the accumulation of prominent chromitite layers. However, details of this process, like the composition of the magmas involved and the origin of the crustal component displayed by initial isotope ratios (particularly Sr isotopes, Kruger and Marsh, 1982) are still under investigation. From inverse geochemical fractionation trends (e.g. Mg number of whole rocks and pyroxenes, Ni/Ti of pyroxenes) at stratigraphic levels, where new melt was injected, Eales *et al.* (1990) and others concluded that the new influxing magma must be of primitive composition. Based on immediate increases in initial Sr ratios at the same stratigraphic horizons, Kruger & Marsh (1982) and others concluded that the new magmas were derived from a partial crustal source or were crustally contaminated prior to the influx into the magma chamber.

In contrast to chromite accumulation, the PGE enrichment within chromitites is still ascribed variously to (1) the orthomagmatic model: PGE are collected by an immiscible sulphide melt, being formed after magma mixing, (2) the fluid flow model: PGE are transported by upward-migrating hydrothermal fluids into the chromitites and platinum reefs (Ballhaus *et al.*, 1986) and (3) the chromitite control model: PGE are concentrated in sulphide-poor chromitites, probably due to local S saturation (Scoon *et al.*, 1994).

In order to test these hypothesis and to investigate the correlation between magma mixing and crustal contamination, we used combined Re-Os and Rb-Sr data on chromite and gangue (interstitial phases in chromitites) samples from the Critical Zone and the Merensky Reef, as well as pyroxenites from the overlying Merensky Cyclic Unit (Fig. 1).

Os concentrations in gangues exceed those in associated chromites by up to 30 fold, demonstrating the presence of the Pt-alloys as interstitial phases. Chromite concentrations of different dry splits from the same sample may vary as much as 300 %, which is most probably caused by micro-nuggets and/or micro-inclusions of laurites. Initial $^{187}\text{Os}/^{188}\text{Os}$ ratios of chromites as well as gangues of the lower group chromitites lie only slightly above the contemporaneous mantle value (i.e. 0.113 at 2061 Ma). A general increase of initial Os isotopic composition with stratigraphic height culminates in the value of interstitial feldspathic pyroxenite of the Merensky Reef (sample AE-26), which lies within the range of laurites determined by Hart and Kinloch (1989). However, they also measured two erlichmanite grains (OsS_2), which perfectly reproduce the mantle value at that time. Four feldspathic pyroxenites, situated at different levels within the Merensky Cyclic Unit, define a Re-Os isochron (Fig. 2), yielding an age of 2043 ± 11 Ma (MSWD = 0.707), which agrees within error with the generally accepted Rb-Sr age of 2061 ± 27 Ma.

Offsets in initial Os isotopic composition between chromite and gangue samples, as observed throughout the upper Critical Zone may be the result of magma mixing or in situ crustal contamination of a single magma, while crystallization is already in progress. Decreases in initial Os isotopic compositions of the UG1 layer and the Merensky Cyclic Unit samples relative to underlying horizons, contradict bulk in situ crustal contamination of a

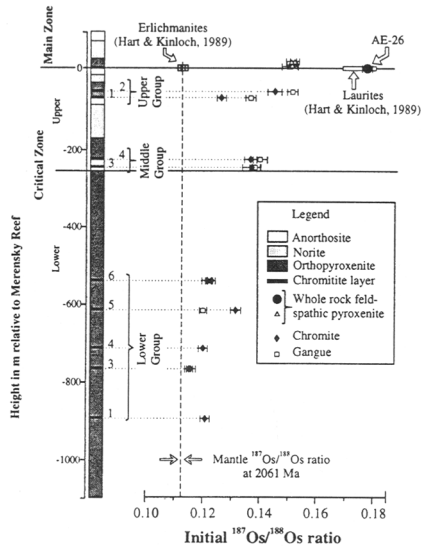


FIG. 1. Initial $^{187}\text{Os}/^{188}\text{Os}$ of chromites and corresponding gangues from the Critical Cyclic Zone as well as pyroxenites of the Merensky Cyclic Unit. Note the erlichmanites and laurites from the Merensky Reef determined by Hart and Kinloch (1989).

single magma, since then initial $^{187}\text{Os}/^{188}\text{Os}$ ratios would always have to increase with increasing height. Therefore we prefer magma mixing being responsible for these offsets, which is also in agreement with chromite crystallization models.

Mavrogenes and O'Neill (1997) found experimentally that ascending S saturated mantle melts can not segregate a sulphide melt unless significant compositional changes via fractionation or assimilation occur. From these results, we conclude that the erlichmanites determined by Hart and Kinloch (1989) were not formed in the source region or during their ascent, but in a primitive milieu within the magma chamber. We regard this, together with the near mantle values of lower group chromites and gangues, as evidence that the new influxing magmas were primitive in composition, which is in agreement with geochemical trends (Eales *et al.*, 1990). Initial Sr signatures of some gangues are much more radiogenic than directly over- and underlying rocks (initial $^{87}\text{Sr}/^{86}\text{Sr}$ of up to 0.720 compared to 0.706, respectively), which points to a local crustal contamination of the magma from which the chromitites crystallized. We suggest that the new magmas intruded the chamber as fountains and that a strong crustal contamination of the resulting hybrid magma occurred through *in situ* roof melting and/or incorporation of the granophyric roof melt by the fountain top.

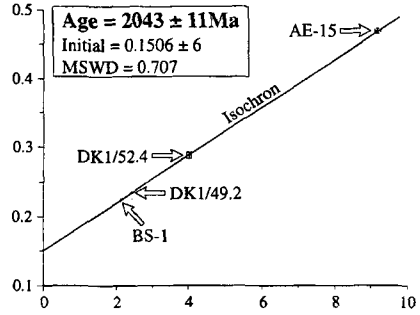


FIG. 2. Re-Os isochron of four pyroxenites of the Merensky Cyclic Unit. Large error on the decay constant of ^{187}Re is not included in error calculations.

Fluid flow emplacement or remobilization of PGE, as proposed by Ballhaus and Stumpfl (1986) and Hart and Kinloch (1989) would likely involve in situ mixing of radiogenic fluid-borne Os and more primitive magmatic Os. This is implied by the hypothesis itself, as fluid flow is made responsible for PGE deposition in the Merensky Reef, which is characterized by a huge range in very radiogenic initial Os isotopic ratios. Thereby a mixing correlation in the $^{187}\text{Os}/^{188}\text{Os}$ vs $1/\text{Os}$ space should be apparent within units transversed by the fluid, a feature which is not observed. Taking the Merensky Reef as an example, whether the fluid migrated upwards or downwards to deposit PGE's, it should have passed horizons with low Os contents (i.e. lower group chromitites or pyroxenites of the Merensky Cyclic Unit, respectively). All these horizons are characterized by less radiogenic Os signatures than the Merensky Reef itself. Particularly the isochron fit of the four pyroxenites above the Merensky Reef, which have very low Os concentrations (0.3–4 ppb), is striking evidence against any fluid flow disturbance of the Re-Os isotope system. Thus fluid flow emplacement of PGE's in chromitites and the Merensky Reef can not be reconciled with our data.

References

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