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The geochemical nature of the Critical/Main Zone boundary, Bushveld Complex

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Although an unconformity exists at the base of the Merensky Reef, Bushveld Complex, it is unclear as to whether the Reef itself forms the base of the Main Zone (MZ) or the top of the Critical Zone (CZ). Geochemical analyses of CZ and MZ rocks show that there are certain parameters that enable the minerals to be confidently classified as belonging to one or the other. These distinctions can also be shown in plagioclase and orthopyroxene separates, enabling further constraints to be placed on the influx of MZ magma at the level of the Merensky Reef, occuring close to the top of the CZ.

We report results of detailed sampling through the uppermost CZ and lowermost MZ in the eastern limb of the Complex. Sr-isotope initial ratios (Sr_i) are used to characterise plagioclase. Sr_i values of around 0.706 and 0.707-0.708 are typical for the CZ and MZ respectively. Cr/MgO ratios in orthopyroxene yield differences between CZ and MZ, approximately 110 and 50 respectively, provided MgO>5wt%. These criteria were then applied to mineral separates from this study, allowing these two minerals to be categorized as originating from either a CZ or MZ magma.

Investigation of the Merensky and Bastard cyclic units reveals that plagioclase and orthopyroxene are sometimes not in equilibrium, with pyroxenes originating from CZ magma and plagioclase originating from MZ magma. The Merensky Reef demonstrates CZ affiliation in both plagioclase and orthopyroxene, with low Sr_i initial ratios and high Cr/MgO. Overlying anorthosites contain plagioclase with MZ Sr_i signatures. The Bastard Reef gives MZ Sr_i values. However, orthopyroxene very clearly has a CZ signature. This disequilibrium can also be observed in the western Bushveld and suggests that crystals collecting in the Reefs have originated from different magmas.

These data indicate that there is no clear geochemical boundary between the CZ and MZ. Although MZ magma influx is recognized at the level of the Merensky Reef, the data here do not support that the Merensky and Bastard Cyclic units were simply formed from one magma or the other or a mixture of the two. A model for the formation of the Merensky Reef is proposed that invokes the accumulation of orthopyroxenes collecting from a suspended CZ magma and in situ crystallisation of MZ interstitial plagioclase. A similar method of orthopyroxene crystal settling through MZ magma results in the formation of the Bastard Reef. Thus, the Merensky and Bastard cyclic units form a “Transition Zone”, the result of *crystal* mixing, between the stratified (and unmixed) CZ and MZ magmas.

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Stratification and crystallization of an initially homogenous magma: The Upper Zone of the Bushveld Complex

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The Upper Zone (UZ) of the Bushveld Complex has isochron Sr-isotope systematics with an initial ratio of 0.7074 over the whole 2.4 km thick stratigraphy in the eastern and western limbs[1]. This implies that the magma which flowed into the chamber to initiate the UZ blended with the resident Main Zone (MZ) magma in the chamber as a single event. The isotopic composition of the resident magma was 0.7084 and that of the new magma 0.7051 as determined in the southern limb of the complex, where no MZ was present. The new and resident magmas thus mixed in a proportion of c. 1:2.3, assuming similar Sr content

Nevertheless, the UZ is a strongly differentiated layered sequence in which there is an overall upsection change in plagioclase An (mol%) from 72 to 43 and augite Mg# (74–5). In the Bierkraal drill cores we have identified 6 cyclic units displaying reversals of up to 10 mol% An and correlated reversals in Mg# of pyroxene across unit boundaries. Such reversals coinside with the termination of apatite crystallization. To test if these features indicate magma addition, we also present further Sr-isotope data on one cyclic unit and its foot-- and hangingwall rocks, which confirms that no further magma addition occurred at this level. We conclude that the cyclicity and layering were generated by reorganisation of the magma from an initially homogenous layer c. 2.4 km thick and >200 km in lateral extent into a multiply diffusive convective system when vertically directed heat and mass flow were reestablished.

The modal and cryptic layering represents a closed system process (only heat loss) and open system differentiation of stacked convecting magma layers due to coupled heat and differential mass diffusion on the smaller 1 to 500 m scale. This m.d.c. stacking became possible when bottom crystallisation of dense magnetite (rejected solute much less dense & mixes upward) and light plagioclase (rejected solute much more dense and may pond at the bottom) modulated the convective behavior of the magma[2].

References

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