Tracing heterogeneous intercumulus processes by rutile: examples from the Bushveld Complex

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Mafic cumulus rocks of the Bushveld Complex (BC) contain rutile of highly variable composition. On hand specimen scale, rutile crystals show enormous inter-grain differences in trace element contents, e.g., Nb (3 to 54.000 ppm), but scarcely any intra-grain zoning. We suggest that these differences mainly result from primary processes during rutile nucleation and growth and can be used to unravel intercumulus processes in detail. Textural relationships, compositions, and modelling results indicate that rutile crystallized during two major magmatic stages. Early rutile (Rt1) was formed together with chromite and orthopyroxene from SiO_2-undersaturated melts at T>1200°C. These grains show relatively low, but variable contents in Nb (3 - 1530 ppm), Zr (48 - 2250ppm), and Zr/Nb ratios (0.2 - 48). The variations can be explained by Rayleigh fractionation during rutile+chromite crystallization in heterogeneous melt batches, which result from incomplete mixing of resident fractionated magma with replenished primitive parental magma. Late rutile (Rt2) was formed from highly fractionated intercumulus melts as indicated by commonly much higher Nb contents (up to 54.0000 ppm) and local intergrowths with zircon and quartz. Enormous compositional variations of Rt2, up to 4 orders of magnitude (!), also suggest Rayleigh-like fractionation. Rt2 mostly yield Zr-in-rutile temperatures between 935°C and 690°C, overlapping with Ti-in-zircon temperatures obtained from co-existing zircon. Higher temperatures up to 1060 °C point to crystallization from SiO_2-undersatured melts, and must be considered as maximum temperatures.