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Metamorphic and thermal evolution of large contact aureoles – lessons from the Bushveld Igneous Complex

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Large igneous intrusions crystallise, cool, and transfer heat out into their host rocks. The thermal structure of the resulting aureole can be mapped as a series of assemblage zones and isograds, and can in principle be modelled on the assumption that heat transfer is dominantly by conduction. The local peak of contact metamorphism occurs later in time with increasing distance from the igneous contact. The importance of fluids as a metamorphic/metasomatic agent or heat transfer mechanism depends on volatile contents of magma and country rock, and on the geometry of the intrusion.

Many of these features are spectacularly illustrated by the aureole beneath the mafic Rustenburg Layered Suite of the Bushveld Complex, which was emplaced at ca. 2060 Ma sub-concordantly into the shale-quartzite succession of the Pretoria Group in the Transvaal Basin. The layered suite reaches a thickness of at least 8 km, and the metamorphic aureole extends 4 km or more downwards into the "floor" of the intrusion. The great extent and relative absence of deformation make this a remarkable natural laboratory for studying the fundamental processes of metamorphism. In quantifying the thermal history, however, a number of second-order factors need to be taken into account. The first relates to the markedly different thermal properties of the major quartzite and shale units, and the second to the importance of endothermic metamorphic reactions in shale units relative to the quartzites.

Further insights into metamorphic processes arise from the exquisite detail of poikiloblast growth microstructures preserved in graphite-poor metapelites of the Timeball Hill and Silverton Formations, 2.5 to 3.5 km beneath the igneous contact. These allow a detailed reconstruction of the time sequence of mineral growth and replacement, revealing a marked overlap of the growth intervals of porphyroblastic staurolite, cordierite, biotite, garnet and andalusite at the expense of muscovite, chlorite and chloritoid. The sequence is grossly inconsistent with the predictions of equilibrium calculations; its formation requires the simultaneous operation of metastable as well as stable reactions at conditions significantly removed from equilibrium, the large overstepping governed largely by delayed nucleation of refractory porphyroblasts such as andalusite (Waters & Lovegrove, 2002). The dramatic conversion of chloritoid-chlorite slate into porphyroblastic andalusite hornfels is compressed into a short interval after the nucleation of the critical phases cordierite (metastable) and andalusite (stable), so that most of the prograde fluid release and endothermic heat drawdown in a given rock volume is predicted to occur in a relatively brief pulse. Since the metamorphic zonation is inverted, the released fluid will pass up into higher-temperature metamorphic zones that have already experienced peak temperature, where it may cause retrograde mineral growth.

Reaction "cascades" of this kind can give rise to a more episodic pattern of metamorphic effects than predicted by equilibrium models, and contribute to a view of metamorphism in which long periods of relative quiescence are punctuated by bursts of fluid-present mineral transformation and mass transfer.

Waters, D.J. & Lovegrove, D.P. (2002). J metamorphic Geol., 20, 135-149.