# Application of a continuum diffusion controlled growth model to metamorphic crystallization

LUKAS P. BAUMGARTNER[1] AND C.T. FOSTER [2]

[1]University of Lausanne, Mineralogy, BFSH-2, 1015 Lausanne, Switzerland (lukas.baumgartner@unil.ch)
[2]University of Iowa, Geology, Iowa City, Iowa 52242, USA (tom-foster@uiowa.edu)

The rate of metamorphic crystallization has been shown to be mainly controlled by diffusion, though other mechanisms have been proposed. The modeling of metamorphic crystal growth has on one hand been advanced using the assumption of local equilibrium and a single controlling component or using coupled diffusion fluxes assuming steady state and local equilibrium throughout the system. Here we present results obtained based on continuum diffusion growth models proposed for igneous crystallization. Equilibrium is maintained on the growing crystal surface, and the matrix buffers the composition to a constant value at a large distance from the porphyroblast.

Simultaneous solution of the coupled diffusion equations and the equilibrium mass action equation at the surface of the growing porphyroblast indicates that concentration ratios between the diffusing species of a factor ten or more (or a variation of the diffusion coefficient of the same order) is enough to allow the system to be controlled by this minor component in the fluid phase. The other concentration profiles show only a small change in concentration towards the porphyroblast surface. A glance at the solubility of typical pelitic assemblages using experimental and thermodynamically estimated values reveals that the chlorine-rich fluids contain Al only as a very minor solute. Hence the common assumption that it is Al diffusion which is limiting diffusional porphyroblast growth in chlorine rich fluids is in agreement with this analysis. Solubility of elements in chlorine poor, alkaline rich fluids is complicated by the complexing of alkalies with Al and Si. Experiments have shown that solubility of Al is similar that of Na, K, and Si. In these solutions no single element is likely to control the diffusional growth of porphyroblasts. The controlling factors are likely one or more of the bivalent cations in the case of e.g. garnet growth. Another interesting consequence of diffusion limiting growth of porphyroblast is that concentration variation in the crystal can also reflect growth velocity variations.

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# Garnet zoning pattern, growth mechansism and the development of Lu-depleted halos in eclogites

S. SKORA[1], N.J. MAHLEN[2], L.P. BAUMGARTNER[1], C.M. JOHNSON[2] AND S. PILET[1]

[1]Institute of Mineralogy and Geochemistry, University of Lausanne, BFSH2, 1015 Lausanne, Switzerland (Susanne.Skora@unil.ch)
[2]Department of Geology and Geophysics, University of Wisconsin, 1215 W. Dayton St. Madison WI 53706, USA

Radius-rate relationships use major element compositional zoning in minerals to identify the rate-limiting growths mechanisms (e.g. Kretz 1973; Carlson 1989). Application of this concept to garnets of the eclogites of the Zermatt-Saas-Fee ophiolite (ZSFOe, Western Alps, Switzerland/Italy) suggests that all garnets precipitated the same amount of radius per time interval. Hence they grow limited by an interface-controlled mechanism.

Understanding of REE zoning in garnets is the key for interpreting age dates (Lapen et al. 2004). Measured HREE zoning pattern in garnets of the ZSFOe display a prominent change from Gd, which is depleted in the cores and enriched close to the rims, to Lu, which forms a narrow spike in the center.

Most of the HREE including Y behave similar to the major elements which mean that concentration profiles for different garnet sizes from a sample approximately plot on top of each other, if their rims are aligned. This suggests that these elements equilibrated throughout the matrix. However, Lu concentrations in the cores of smaller garnets are always enriched relative to Lu contents at the corresponding distance from the rim of larger garnets. This difference in behavior indicates that Lu incorporation is controlled by another mechanism. The fact that Lu concentrations in small garnets are higher in the center than the composition of Lu in the co-precipitated parts of larger garnets indicates that larger garnets have developed depletion halos surrounding them. Hence Lu-incorporation is diffusion-controlled. Note that trace elements are not abundant enough to influence the rate-limiting mechanism and thus will not hinder nucleation in this diffusion-depleted halos. Similarly, Lu matrix-garnet disequilibrium does not necessarily imply Lu-isotopic disequilibrium, which would invalidate Lu/Hf dating.

## References

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