

Thus the modeled chemistry, which has enhanced crystal edge growth, resulting in face re-entrants, differs entirely from the observed chemistry with enhanced crystal face growth and edge re-entrants. The former, as noted by Wilbur and Ague, is consistent with dendritic growth, which would seem to lie at the opposite end of a textural spectrum from textural sector zoning (Fig. 1), the one characterized by rapid edge growth and the other by inhibited edge growth.

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**REPLY:** doi: 10.1130/G23787Y.1

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We thank Rice (2007) for insightful comments on our work (Wilbur and Ague, 2006) and for highlighting important issues in metamorphic crystallization. However, Rice’s comments do not affect our conclusions regarding disequilibrium during garnet growth.

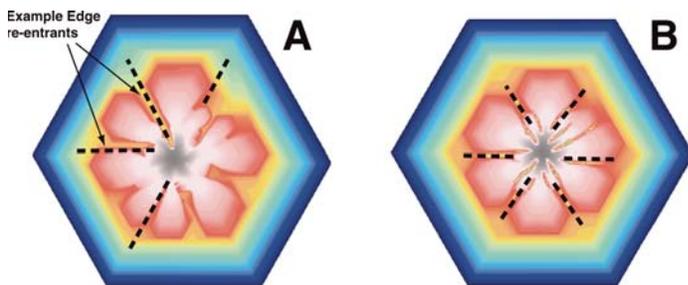
The first issue Rice raises concerns terminology. To many in the community, any term that includes “sector zonation” implies that different crystal faces grew with different chemical compositions. We were simply emphasizing that the term “textural sector zonation” does not refer to such differences (for crystals of any symmetry, cubic or otherwise).

The second set of issues centers on dendrites and crystal growth morphology. Following conventions in solid-state physics, we use the term “dendritic” in a broad sense to describe a crystal that develops with a branching form (cf. Ben-Jacob and Garik, 1990). This would include both of the branched morphologies in Rice’s Figure 1. Rice argues that the branching in our models produces face re-entrants, whereas edge re-entrants are observed in the natural examples. It is true that the natural examples we show have large numbers of edge re-entrants, although face re-entrants are also found. Without detailed crystallographic measurements, we are not convinced that Rice’s interpretations of chemical zonation are diagnostic of growth morphology in all cases. Regardless, it was not our intention to argue that all growth far from chemical equilibrium is characterized by face re-entrants. Rather, our goal was to show in a general way how branching morphologies can develop during such growth. We highlight two points in this regard.

1) Most importantly, the interplay between rates of surface diffusion, bonding, and the propagation of crystallographic perturbations is complex and is a strong function of the saturation state and the transport of nutrients

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**Figure 1. Monte Carlo (MC) crystal growth simulations showing formation of edge re-entrants. A: Transitional case with edge and face re-entrants. Dashed lines trace out positions of edge re-entrants during growth, such that  $\Delta\mu/kT = 9.25$  for first 5% of growth history, decreasing to 5 for the next 20%, and then to  $10^{-2}$  for the remaining 75% ( $\Delta\mu$  = chemical potential difference;  $k$  = Boltzmann’s constant;  $T$  = absolute temperature). Nutrient aqueous species generated at edge of circular source region at some distance from crystal; normalized bond strength = 8; and interaction energy ratio = 0.1. See Wilbur and Ague (2006) for detailed discussion. B: Similar to Figure 1A, but  $\Delta\mu/kT = 9.7$  for first 5% of growth history, decreasing to 5 for the next 20%, and then to  $10^{-2}$  for the remaining 75%. Nutrient aqueous species generated throughout circular source region surrounding crystal.**

to growing crystals. Space did not permit us to show a large number of examples of how these phenomena relate to each other. However, we show in this Reply that at very high initial supersaturation, there is a transition to growth characterized by edge re-entrants (Fig. 1). Here, the bonding rate is fast relative to surface diffusion, and regions of larger surface area (e.g., faces) can propagate rapidly. Given the model simplifications, we emphasize that very detailed comparisons between natural crystals and models should be done with caution. Nonetheless, the models in Figure 1 of this Reply are similar in morphology to garnets in our study, such as the crystal in our original Figures 1B and 2E–2H. We illustrate a transitional case here in Figure 1A to show that edge re-entrants and face re-entrants both can develop during growth relatively far from chemical equilibrium. The directions of dendrite propagation are critically dependent on the dynamics of disequilibrium growth such that growth branches can follow *either* of the general orientations shown in Rice’s Figure 1 (see also Figure 4 in Ben-Jacob and Garik, 1990).

2) Natural garnet is cubic and three-dimensional, whereas our models are based on a two-dimensional, trigonal lattice. There will be unavoidable differences between observed and model morphologies because of the model simplifications. We note that simplifications are not limited to our Monte Carlo models. The qualitative models of Rice’s Figure 1 are also highly simplified and fail to capture some of the characteristic morphological features of the growth branches, particularly the curved or irregular tips that are observed in many specimens (Wilbur and Ague, 2006; Fig. 1C, 1F).

We conclude that edge re-entrants and face re-entrants do not represent opposite ends of a “textural spectrum” as envisioned by Rice, but instead are both manifestations of the same underlying phenomenon: growth relatively far from chemical equilibrium.

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