Oscillatory and stepwise compositional zoning in high pressure–low temperature garnets: records of transient and spatially-variable fluid-fluxing during subduction?

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During subduction, devolatization reactions within the downgoing slab release significant volumes of fluid. Once released, the fate of such fluids remains unclear; they may either stagnate such that local rock systems remain undrained, or fluids may be mobilized over large length scales, draining the dehydrating rock volume. The fact that there is evidence from the metamorphic rock record to support both open- and closed-system fluid behavior demonstrates that permeability in deep crystalline metamorphic rock is both spatially and temporally heterogeneous. Prograde eclogitic veins greater than cm-scale are volumetrically scarce in the high pressure–low temperature (HP–LT) rock record, suggesting that either transient channelized flow is incredibly efficient and thus necessitates negligible grain boundary transfer and a low intact rock permeability, or that a large proportion of fluid migration to the subduction interface may be via more elusive grain boundary mechanisms.

Major element electron microprobe maps of HP–LT garnets from metabasic rocks of the Urals, Russia, As Sifa, Oman, and Syros, Greece, variably reveal short-wavelength and concentric oscillatory zoning in the outer rim region. Oscillatory zoning in most garnets is accompanied by homogeneous core-to-rim aluminum content. However, in samples from As Sifa and Syros, the onset of near-rim major element oscillatory zoning is concomitant with a rimwards step increase in Al content. Secondary ion mass spectrometry (SIMS) O-isotope analyses across rhythmic zoning in samples from each setting are used to assess the hypothesis that this sharp, stepwise change in garnet chemistry reflects a period of localized open system fluid-fluxing behavior, superimposed on a history of an otherwise stagnant fluid within an impermeable grain boundary network. In such a case, coupled oscillatory zoning in major and trace elements—as revealed by laser ablation–inductively coupled plasma–mass spectrometry (LA–ICP–MS) mapping—may point to pulsed $P$–$T$ fluctuations, variable partitioning behavior, local kinetic effects associated with metamorphic reaction/dehydration, or changes in redox state serving as a driver for the development of this characteristic HP–LT geochemical garnet zoning.