What minor phases reveal about the timing of major phase growth

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Accessory minerals occur in all rock types as significant hosts for a wide variety of trace elements. Although the main body of research into the formation of high-temperature metamorphic lithologies is based on the chemical interaction of major mineral phases, there is growing interest in the role of accessory phases in petrogenesis. This change in focus is largely due to advances in microbeam techniques that allow for quantitative analysis and compositional imaging of sub-100 micron mineral grains within thin sections. Whereas radioisotope-bearing minerals such as monazite and zircon are conventionally separated from host samples and analyzed to determine the timing of petrogenesis, recent studies by electron (CHIME-EMP), ion (SHRIMP) and laser-ablation (LAICPMS) analysis of these minerals in petrographic context reveal that, like major metamorphic phases, accessory minerals have complex histories of growth that can be tied to specific processes during the prograde and retrograde stages of a metamorphic episode.

In the first example, monazite in a single thin-section of metapelite from the granulite-grade Higo Terrane of central Kyushu reveals a wealth of associations with metamorphic and deformational textures in the major phases. Monazite occurring with euhedral growth zones enclosed in high-Ca, low-Mg cores of garnet, and as clusters that represent pseudomorphs of allanite, represents growth before and during partial melting at peak metamorphic temperatures. Flattened grains and trails of low Th monazite, aligned with sillimanite and biotite to define an S2 axial planar foliation, represent growth during retrograde metamorphism and deformation. Moderate Th / low Y domains on resorbed monazite grain margins record late-stage retrogression, probably in association with hydrous fluids released by the crystallization of anatectic melt. CHIME ages of the monazite growth stages cannot be resolved; CHIME monazite and zircon and SHRIMP zircon ages from a variety of Higo lithologies restrict the timing of major mineral growth to 110-130Ma. Results from other dating methods which suggest that peak metamorphism occurred at c.250Ma appear to be influenced by isotopic inheritance.

In the second example, zircon grains from metapelite samples of the granulite-grade Lutzow-Holm Complex of east Antarctica show a complex range of textures and ages. Whereas previous SHRIMP ages from zircon grain separates concentrate around 530-550Ma, and were interpreted as timing peak metamorphism, new analyses yield a spread of age estimates from 510 to 610Ma. In-situ analyses of zircon inclusions in garnet porphyroblasts reveal a stage of

U-rich zircon growth at c.600Ma, with flat HREE-MREE profiles indicating prograde growth in the presence of garnet. Zircon preserved in a garnet megacryst grown in association with felsic pegmatite that fills D2 boudin necks in a metapelitic layer show multiple stages of metamorphic growth, with c.600Ma flat H-MREE (garnet-equilibrated) cores, c.570Ma rims with outward steep to flat H-MREE growth zoning, and resorbtion prior to incorporation in the garnet megacryst and crystallization of the felsic pegmatite at c.540Ma. Although the 100Ma spread of zircon ages could be interpreted as recording separate metamorphic events, the textural and chemical associations between zircon, garnet and felsic melt suggests that zircon growth was progressive through a prolonged metamorphic event, and that a large proportion of zircon growth at 530-550Ma occurred during retrograde rather than peak metamorphism.

In both examples, age data cannot be used to constrain the timing of major phase growth without careful examination of the paragenetic relationships between minor and major phases. In metamorphic terranes with complicated histories, petrographically-constrained geochronology through microbeam techniques is essential.