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Monazite petrogenesis and geochronology by electron microprobe: analytical challenges and applications for dating tectonic processes

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The use of monazite for geochronology, thermometry, geochemistry, and petrology has increased dramatically. Reasons include: 1) monazite is observed in a wide variety of igneous, metamorphic, and sedimentary rocks; 2) slow diffusion rates allow monazite to retain a detailed record of previous geologic conditions; 3) the refinement of techniques for trace element analysis and dating of monazite; 4) increased understanding of the conditions under which monazite can crystallize, dissolve, and reprecipitate; and 5) identification of geochemical and petrologic links between silicate assemblages and monazite. Monazite crystals typically contain multiple compositional and age domains which can be linked to silicate textures, fabrics, and reactions. However, very small grains or domains can be too small for in-situ isotopic techniques. The electron microprobe can demonstrably yield precise dates from such micro-volumes, but new analytical techniques are required for accurate trace element analysis. Background characterization is critical because curvature of the spectrum and background interference can lead to systematic errors of 50 m.y. or more. Spectrum modeling and regression allow accurate determination of background and associated uncertainty that must be incorporated into the total error on microprobe monazite age data. Peak interferences are also important and must be calibrated for each instrument. Specimen beam damage and conductivity effects are significant and must be mitigated. Results from the optimized “Ultrachron” electron microprobe at UMass, combined with new analytical software and procedures, indicate that precision can be on the order of several m.y. to tens of m.y. even in very small, chemically-homogeneous domains.

On-going research is aimed at integrating monazite (and xenotime) petrogenesis into metamorphic or hydrothermal reactions that can be linked to tectonic events. Three examples will be presented from the deep crustal Athabasca granulite terrane, Saskatchewan. Penetrative, shallowly-dipping granulite-grade fabrics in a lower crustal granitoid batholith contain monazite crystals that record the syn-kinematic growth of Grt at the expense of Ca-rich plagioclase. High-PT migmatites elsewhere contain monazite that records the evolution of host-rock composition through melting and peritectic garnet growth, plagioclase depletion and reintroduction, and growth of garnet during a second granulite-grade event prior to exhumation of the terrane. Finally, in the terrane-bounding shear zones, monazite records Archean high-grade metamorphism and a detailed record of Proterozoic exhumation and rehydration. The integration of monazite composition, texture, and geochronology, together with silicate petrogenesis, represents a new frontier in constraining P-T paths and tectonic histories in complex tectonites. The partitioning of major and trace elements between monazite and silicate phases during metamorphic reactions and fluid infiltration provides a powerful petrogenetic tool for building realistic petrologic models that can be evaluated with pseudosections for specific bulk compositions. The ultimate goal remains to understand the processes that control growth, dissolution, and reprecipitation of monazite during magmatism, metamorphism, and deformation, thus providing new tools for monitoring the tectonic evolution of complex poly-metamorphic terranes.