U-Th-Pb systematics of monazite, xenotime, and zircon from Pleistocene leucogranites at Nanga Parbat (Pakistan Himalaya)

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U-Pb isotopic data from monazite, xenotime, and zircon from Pleistocene leucogranites in core of the Nanga Parbat massif allow a sequence of accessory mineral crystallization to be documented at the 10,000-year level and have implications for the behavior of Th/U in granitic melts during generation and crystallization. Dates were obtained by isotope dilution thermal ionization mass spectrometry (IDTIMS) from single grains and grain fragments after BSE and CL imaging of internal chemical zoning. Due to initial U-Th disequilibrium, monazite has considerable excess ^{206}Pb, xenotime has a small deficit of ^{206}Pb, and zircon has a moderate deficit. Crystallization ages are therefore estimated from the ^{207}Pb/^{235}U dates, which have small errors due to high U concentrations and little or no common Pb; 2σ errors on xenotime dates are ± 1,500-6,000 years and errors on monazite and zircon dates are ± 7,000-30,000 years. The Th/U of the melt from which the minerals crystallized is modeled by using the amount of excess or deficit of ^{206}Pb, the ^{207}Pb/^{235}U dates, and the Th/U of the mineral (Th estimated from ^{208}Pb).

Monazite in the oldest sample crystallized from 1.65 to 1.40 Ma at constant Th/U[melt] = 0.6. The youngest sample exhibits a sequence of mineral crystallization with steadily decreasing Th/U[melt]. Monazite began growing at 0.76 Ma with Th/U[melt] = 1.1 and ceased growing at 0.68 Ma with Th/U[melt] = 0.4. Six fragments from a single grain with a core-rim relationship evident in BSE images yielded dates of 0.76 Ma from the core to 0.71 Ma from the rim, and Th/U[melt] decreased from 1.1 to 0.7. Early xenotime growth was coeval with the youngest monazite at Th/U[melt] = 0.4, and xenotime growth continued until 0.62 Ma at Th/U[melt] = 0.2. Zircon growth was coeval with xenotime at Th/U[melt] of <0.2. The documented sharp decrease in Th/U[melt] during monazite crystallization is consistent with monazite having removed Th from the melt. Xenotime in two other samples crystallized at <1.0 Ma with low Th/U[melt].

Combining these U-Pb ages with available P-T constraints shows that as much as 15-17 km was eroded off Nanga Parbat since ~1.5 Ma (10 mm/y), possibly by chanellized ductile flow of the lower-middle crust.

He diffusion and (U-Th)/He thermochronometry of monazite and rutile

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Most (U-Th)/He dating work has focused on apatite, zircon, and titanite. However, other U and Th-bearing phases are likely to provide additional tools for establishing thermal histories of rocks. In this study, we present new experimental data constraining the He diffusion kinetics of monazite and rutile and elucidate the implications for (U-Th)/He thermochronometry of these minerals.

Monazite is a REE-rich phosphate that has long been used in U-Th-Pb geochronology due to its high U and Th concentrations. It occurs as an accessory mineral in metaluminous to peraluminous granitoid rocks, pelitic schists, gneisses and migmatites and as detrital grains in sedimentary rocks. Step-heating He diffusion experiments on single crystals of monazite exhibit Arrhenius behavior characterized by activation energies of 45-50 kcal/mol and log(*D0/a2*) of 5.3-6.3 s^{-1}. Variable size experiments indicate that the diffusivity scales with the physical grain size of monazite. For typical monazite (~80-140 μm), these parameters yield closure temperatures of 220-250°C (-dT/dt = 10°C/myr). The data also show that Th incorporation into monazite through huttonite substitution affects monazite diffusion kinetics, resulting in a linear decrease in closure temperature with increasing Th content from ~240°C (~2.5 wt% Th) to ~190°C (~13 wt% Th). Significant Y incorporation might also further lower the closure temperature, since xenotime has a closure temperature of only ~120°C.

Rutile is a primary accessory mineral in many plutonic and metamorphic rocks (e.g., blueschists, eclogites, and granulites). Rutile He diffusion experiments show Arrhenius behavior characterized by activation energies of 48-51 kcal/mol and log(*D0/a2*) of 6.5-7.1 s^{-1}, translating into closure temperature estimates of ~220-235°C (-dT/dt = 10°C/myr). Since rutile occurs in metamorphic rocks that are often prone to excess Ar, rutile (U-Th)/He dating might prove to be a valuable alternative thermochronometer.

In conclusion, monazite and rutile are characterized by distinct He diffusion kinetics and closure temperatures, ranging from ~220ºC to ~250ºC, offering the possibility of constraining different portions of a rock's thermal history.