Monazite age depth profiling: nm-scale thermochronometry

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Significant capabilities of the ion microprobe for thermochronometric investigations of geologic materials remain largely unexploited. While spot analysis allows ~5 μm scale imaging of Th-Pb age profiles in sectioned monazites (Harrison *et al.*, 1997), the spatial resolution offered by depth profiling into the surface region of natural crystals is two orders of magnitude higher. We document here the ability of the ims 1270 ion microprobe to resolve age differences of <1 m.y. with better than 500 Å depth resolution in Tertiary monazites. We apply this approach to reveal natural $^{208}Pb/^{232}Th$ gradients preserved in the outer μm of monazites from the hanging wall of the Himalayan Main Central Thrust (MCT) and use these variations to constrain the displacement history of this fault. This approach offers great potential for revealing near-surface ^{208}Pb distributions within monazite that are inaccessible by ion microprobe spot analysis or thermal ionization mass spectrometry.

Experimental

The ims 1270 ion microprobe is now routinely used for in situ Th-Pb dating of young monazites that have been sectioned and polished (Harrison *et al.*, 1997). We recently developed a method that permits us to perform Th-Pb analyses in depth profiling mode on monazite crystal faces. In experiments discussed below, use of a 20 μm diameter, 4 nA O^-, primary spot yields a sputter rate of 3.9 ± 0.1 Å/sec in monazite. When the secondary ion beam is filtered with a mass resolution of 5500 (which separates all molecular interferences) and collimated with a 100 μm aperture (to mask material sputtered from pit margins), the resulting ion intensities are still sufficient to resolve differences of 1 m.y. in successive measurements separated by <500 Å in Miocene age samples. Final pit dimensions are measured with a surface profilometer with a nominal precision of ± 50 Å. Because ^{204}Pb intensities are near background, corrections for common ^{208}Pb are performed using a ^{207}Pb correction procedure based on measurement of U and Th, and employing the $^{208}Pb/^{207}Pb$ ratio of common Pb (2.50 ± 0.01) measured in Himalayan leucogranites (Schärer *et al.*, 1986).

Results

Sample DH-68-96 was obtained from an undeformed, Early Miocene pegmatite in the Darondi Khola, Nepal, that was exhumed from ~25 km depth along reactivated splays of the MCT between 8–4 Ma (Harrison *et al.*, 1997). The rock is located ~200 m structurally above the mapped position of the MCT. Tabular monazites, 100–250 μm in size and exhibiting morphologies consistent with preservation of primary crystal faces, were pressed into an adhesive substrate together with 554 standard monazite (45 ± 1 Ma). A second set of polished 554 grains was positioned adjacent to the individually mounted grains. Additional epoxy was poured to form a composite mount which was then cleaned and coated with ~50 Å of Au.

Depth profiling of polished 554 or DH-68-96 monazite grains produced no resolvable age variation in profiles up to 0.3 μm deep. Similar procedures using unpolished 554 monazite revealed monotonically increasing ages from 40–45 Ma over the first 1000 Å and uniform ages thereafter, an expected result given the relatively rapid cooling of the host granitoid. In contrast, depth profiling of unpolished DH-68-96 monazites reveal monotonically increasing, convex upward, age gradients within the outer 2000–4000 Å (Fig. 1). Ages obtained at greater depths are within uncertainty of those obtained from the same grains polished to a depth of 5 μm (12.6 ± 0.6 Ma). Interpretation of ^{207}Pb-corrected age profiles in the initial ~500 Å is complicated by the presence of a surface contaminant which is not contributed by Pb from either the epoxy or Au coat as the $^{208}Pb/^{207}Pb$ ratio measured in Au coated epoxy (2.48 ± 0.04) is indistinguishable from that employed to correct for common Pb.

Although the form of the DH-68-96 age gradients are consistent with closure theory (Fig. 1; Dodson, 1973), Th-Pb ages obtained over the first 500 Å yield ages younger than the coexisting $^{40}Ar/^{39}Ar$ mica

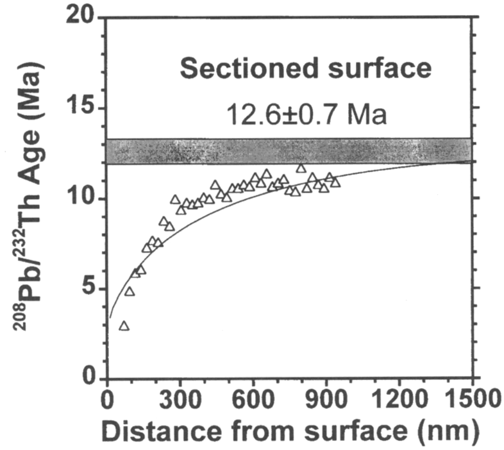

FIG. 1.

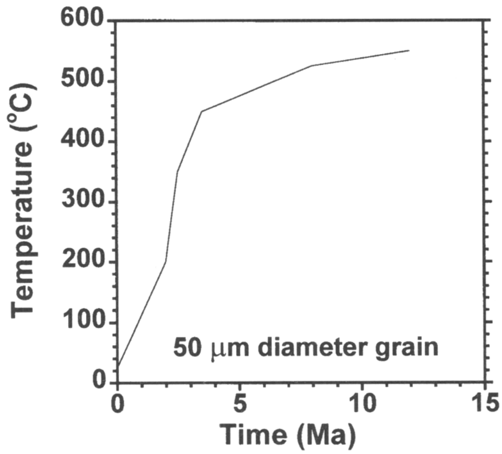

FIG. 2.

ages. Because the closure temperature of Pb in monazite for this length scale (Smith and Giletti, 1997) is equal to or greater than that for Ar in bulk micas, an over correction for $^{208}Pb^*$ has been made, probably due to a small (organic?) surface correlated interference at masses 207 and 204. We have overcome this problem by using the known low temperature history (Copeland *et al.*, 1991) to constrain the composition of the interfering component. Micas from the structural level of DH-68-96 yield $^{40}Ar/^{39}Ar$ ages indicating cooling below 300°C by 3–4 Ma, constraining the outer ~250 Å of the monazite to yield Th-Pb ages at least that old. To produce such an effect requires that the surficial contaminant have a 208/207 ratio of ~2.3. Assuming that the measured intrinsic common Pb content is uniform, we can then scale this correction to reveal the true radiogenic ^{208}Pb gradient (Fig. 1).

Thermal history results

Geochronology from the MCT hanging wall clearly indicates that anatexis and simple shear deformation was occurring at 22 ± 1 Ma, while cooling ages in structurally higher positions suggest that hanging wall deformation had terminated by ~18 Ma (Copeland *et al.*, 1991; Hodges *et al.*, 1996;). In contrast, Th-Pb dating of monazite included in garnets of the prograde assemblages defining the inverted metamorphic zone in the MCT footwall indicate that peak recrystallization occurred at 8–6 Ma (Harrison *et al.*, 1997). Thermo-kinematic modelling of this data suggests that the MCT reactivated at 8 Ma (after ~10 m.y. of inactivity) at a slip rate of ~20 mm/yr. Between 6–3 Ma, activity shifted from the MCT to a broad shear zone in the footwall.

While the post-Early Miocene thermal history of the footwall is recorded by garnet grade monazite forming reactions, earlier Tertiary metamorphism in the hanging wall exhausted the capacity of these gneisses to produce monazite, preventing utilization of this method to constrain the thermal history there. However, age profiles preserved in these older monazites can provide similar insights into the late Neogene thermal evolution of the MCT hanging wall. The form of the age profiles (Fig. 1) place tight bounds on the post-middle Miocene cooling history of DH-68-96. The best-fit temperature-time history which reproduces the observed age profile is shown in Fig. 2. This continuous thermal history from 15–2 Ma is consistent with that calculated by Harrison *et al.* (1997) for the adjacent footwall rocks. This method appears to offer great potential for recovering thermal history data at temperatures not previously accessible by thermochronometry.

References

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