Forum Reply

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Deformed monazite yields high-temperature tectonic ages

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Monazite from granulite facies rocks of the Sandamata Complex, India were shown by us (Erickson et al., 2015) to contain crystal-plastic microstructures that have variably reset the U-Th-Pb systematics. We highlighted a combination of intragranular deformation microstructures, including low-angle grain boundaries, lattice distortion, and deformation twinning that correspond with variable Pb loss. New strain-free granules (neoblasts) of monazite developed within the strained host record a concordant U-Pb age that is significantly younger than the host grain. We interpret the neoblasts to have been produced via dynamic recrystallization processes, and thus record the age of deformation.

Wawrzenitz and Krohe (2015) propose dissolution precipitation creep (DPC) as an alternative mechanism for the development of the neoblasts, which is a fluid-assisted recrystallization mechanism, also known as pressure solution (Wheeler, 1987; Wintsch and Yi, 2002). They speculate that the monazite neoblasts grew as a result of DPC either during or after monazite deformation. Dissolution-precipitation has been inferred as a mechanism for reconstituting monazite within mid-crustal rocks (e.g., Wawrzenitz et al., 2012), and the potential for DPC to produce complex age arrays in monazite is, in general, not disputed. However, this mechanism is not active in the Sandamata monazite because of the following microstructural and petrologic observations:

(1) The granulite host rocks contain an anhydrous mineral assemblage without any textural evidence of fluid-related retrogression (Buick et al., 2010). The lower crustal rocks were dry, and there is no evidence for a fluid phase being present during the deformation of the monazite (Yardley and Valley, 1997). The absence of a fluid phase precludes the possibility of dissolution, which is inconsistent with DPC.

(2) The majority of monazite neoblasts are found within the host grains and are isolated from the matrix of the rock (Erickson et al., 2015, our figure 2). There is no evidence of neoblast growth at phase boundaries between monazite and matrix grains, which are more likely to have been pathways for fluids, if present. Neoblast growth within the grain, and their absence at grain edges, are not consistent with DPC.

(3) The neoblasts have preferentially nucleated and grown along several types of crystal defects, including deformation twins, subgrain boundaries, and high-angle grain boundaries. There is no microstructural evidence that they are associated with brittle fractures, which would act as fluid pathways, as speculated by Wawrzentiz and Krohe.

(4) Our data show that the neoblasts have systematic disorientation relationships with the host grains, and are not randomly oriented. This relationship is consistent with our model. Crystallographic data for monazite DPC microstructures do not exist, but new monazite formed through DPC would most likely be syntaxial with the host grains, which is inconsistent with our observations.

(5) Element mapping shows that the neoblasts locally inherit the original composition of the host monazite. New monazite formed via DPC would differ in composition from that of the host grain and be either uniform in composition or be systematically zoned, reflecting the fluid composition at the time of precipitation (c.f. Harlov et al., 2011).

Wawrzenitz and Krohe argue that a lack of increasing systematic disorientation within the lattice of the host domain bordering the neoblasts precludes grain boundary migration. However, analyses of microstructures demonstrably formed through dynamic recrystallization need not show increasing misorientation into the boundary (e.g., Bestmann and Prior, 2003; Halfpenny et al., 2006). Furthermore, the EBSD data provide evidence for an increase in disorientation adjacent to the domains containing neoblasts (Erickson et al. 2015, our figure 2). Thus, the argument of Wawrzenitz and Krohe has no support.

All lines of evidence are consistent with neoblast formation through dynamic recrystallization processes involving subgrain rotation and grain boundary migration recrystallization. Therefore, we maintain the interpretation proposed in our original manuscript.

We have shown, for the first time, that dislocation creep microstructures in monazite can modify U-Th-Pb compositions and yield the timing of tectonic strain (Erickson et al., 2015). Integrating quantitative microstructural analysis with high-spatial-resolution geochronology, enables crystal-plastic microstructures to be used to deconvolve complex, *in situ* age distributions within monazite. These results are especially relevant to the study of tectonic regimes in the middle and lower crust, in which, hot and dry conditions are ubiquitous.

REFERENCES CITED

Bestmann, M., and Prior, D.J., 2003, Intragranular dynamic recrystallization in naturally deformed calcite marble: diffusion accommodated grain boundary sliding as a result of subgrain rotation recrystallization: Journal of Structural Geology, v. 25, p. 1597–1613, doi:10.1016/S0191-8141(03)00006-3.

Buick, I.S., Clark, C., Rubatto, D., Hermann, J., Pandit, M., and Hand, M., 2010, Constraints on the Proterozoic evolution of the Aravalli–Delhi Orogenic belt (NW India) from monazite geochronology and mineral trace element geochemistry: Lithos, v. 120, p. 511–528, doi:10.1016/j.lithos.2010.09.011.

Erickson, T.M., Pearce, M.A., Taylor, R.J.M., Timms, N.E., Clark, C., Reddy, S.M., and Buick, I.S., 2015, Deformed monazite yields high-temperature tectonic ages: Geology, v. 43, p. 383–386, doi:10.1130/G36533.1.

Halfpenny, A., Prior, D.J., and Wheeler, J., 2006, Analysis of dynamic recrystallization and nucleation in a quartzite mylonite: Tectonophysics, v. 427, p. 3–14, doi:10.1016/j.tecto.2006.05.016.

Harlov, D.E., Wirth, R., and Hetherington, C.J., 2011, Fluid-mediated partial alteration in monazite: The role of coupled dissolution–reprecipitation in element redistribution and mass transfer: Contributions to Mineralogy and Petrology, v. 162, p. 329–348, doi:10.1007/s00410-010-0599-7.

Wawrzenitz, N., Krohe, A., Rhede, D., and Romer, R.L., 2012, Dating rock deformation with monazite: The impact of dissolution precipitation creep: Lithos, v. 134–135, p. 52–74, doi:10.1016/j.lithos.2011.11.025.

Wawrzenitz N. and Krohe A., 2015, Deformed monazite yields high-temperature tectonic ages: Comment: Geology, v. 43, p. exxx, doi:10.1130/G37394C.1

Wheeler, J., 1987, The significance of grain-scale stresses in the kinetics of metamorphism: Contributions to Mineralogy and Petrology, v. 97, p. 397–404, doi:10.1007/BF00372002.

Wintsch, R.P., and Yi, K., 2002, Dissolution and replacement creep: a significant deformation mechanism in mid-crustal rocks: Journal of Structural Geology, v. 24, p. 1179–1193, doi:10.1016/S0191-8141(01)00100-6.

Yardley, B.W.D., and Valley, J.W., 1997, The petrologic case for a dry lower crust: Journal of Geophysical Research. Solid Earth, v. 102, p. 12173–12185, doi:10.1029/97JB00508.