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New constraints on the timescales of continental lower crust formation: a garnet Lu-Hf petrochronological investigation of the Ivrea-Verbano Zone, Italy

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Characterizing the formation and evolution of continental lower crust is vital to understanding the Earth's structure, chemistry, and dynamics. The Ivrea-Verbano Zone, northwestern Italy, is considered an archetypal section of continental lower crust. To better constrain the prograde metamorphic history and timing of peak metamorphism, here we present results of a comprehensive garnet Lu-Hf petrochronological investigation; results are integrated with existing zircon and monazite (U/Th)-Pb petrochronological datasets.

Garnet-whole-rock Lu-Hf dates from six metapelites, collectively spanning the amphibolite-granulite transition, range from 311 to 239 Ma. Dates exhibit a systematic decrease with structural depth in the crustal section. Amphibolite-facies samples yield ages of 311.3 ± 2.8 Ma (all error reported as 2σ; MSWD = 3.6), 292.9 ± 2.7 Ma (MSWD = 27), and 275.9 ± 2.5 Ma (MSWD = 9.4), while granulite-facies samples yield dates of 263.9 ± 2.7 Ma (MSWD = 0.7), 275.4 ± 3.1 Ma (MSWD = 3.9), and 238.6 ± 8.2 Ma (MSWD = 0.3).

Major and trace element zonation in garnet preserving the oldest date is consistent with growth during burial from <5 kbar to ~7 kbar, at 311 Ma. The absence of major element growth zoning and Rayleigh-type trace element zonation in samples with dates spanning 275-263 Ma is interpreted as preserving the timing of garnet growth/recrystallization during Permian decompression from peak temperature conditions. The youngest date is interpreted to record garnet recrystallization due to fluid influx.

Combined with published zircon (e.g., [1]) and monazite (e.g., [2,3]) datasets, our garnet data show that: i) the metamorphic climax was attained at disparate times throughout the section and therefore the observed field PT array cannot represent a true geotherm; ii) evidence for Variscan metamorphism is mostly restricted to the shallowest depths of the section (<6 kbar; <23 km) and the pervasive high-T metamorphic mineralogy formed during Permian decompression; iii) the lowermost crust (>9 kbar; >30 km) remained sufficiently hot to facilitate garnet growth over ~50 Myr.

[1] Ewing et al. (2013), *Contributions to Mineralogy and Petrology*, 4, 757-779

[2] Williams et al. (2022), *Journal of Metamorphic Geology*, 6, 1015-1042

[3] Wyatt et al. (2022), *Tectonics*, 41