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# A multiphase geochronological approach to constrain the thermal evolution of the Himalayan Metamorphic Core, Suru Valley region, Zanskar Himalaya, NW India

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Orogenic belts are characterised by diverse rock compositions and associations, reflecting a complex lithotectonic architecture. The broad range of compositions impacts element availability during metamorphism and thereby the crystallisation potential of accessory phases used to constrain orogenic evolution. This study reconstructs the thermal history of an archetypal orogenic sequence using multiphase U-(Th)-Pb and trace element petrochronology of titanite, allanite, monazite, zircon and rutile across varying rock compositions, structural levels, and metamorphic grades. Each analysed mineral demonstrably (re-)crystallized at different times in different rock compositions, thus recording different portions of the metamorphic cycle at each structural level. These data are integrated with with microscale to macroscale petrographic and structural analysis to determine the spatial and temporal relationship between deformation and metamorphism.

The Suru Valley region, NW India, represents an optimal location to study a near-complete Barrovian metamorphic cycle, preserving extensive kyanite-grade metamorphic assemblages related to the early collision record of the Himalayan orogen, alongside later sillimanite-grade assemblages that equilibrated during exhumation. During the early India-Asia collision, the Indian margin experienced polyphase SW-vergent thrusting and folding ($D_1$ and $D_2$) concomitant with greenschist- to amphibolite-facies metamorphism. Mineral isograd patterns and the relationship between porphyroblast growth and fabric development suggest the thermal peak of metamorphism ($M_1$) outlasted deformation in this part of the Himalayan Metamorphic Core. Deformation and metamorphism propagated to the SW from higher to lower structural levels and increasing metamorphic grade. Prograde conditions (syn-$D_2$) are recorded between 38–30 Ma, with peak $M_1$ conditions between 37–27 Ma (syn- to post-$D_2$). Decompression initiated after 28 Ma towards sillimanite-grade conditions, and peak $M_2$ conditions are recorded across all grades between 25–21 Ma, coincident with the dominant stage of extension on the Zanskar Shear Zone (a regional extension of the South Tibetan Detachment system) at 23 Ma.

From this dataset, allanite and early titanite capture the prograde evolution, while monazite and later titanite record peak metamorphism and decompression. Zircon from leucogranites provides evidence of anatexis, and rutile constrains cooling on the decompression path. These results underscore the necessity of a multiphase petrochronological approach to fully characterize the inherent complexity of collisional orogenic evolution.