

Crustal Melt Presence and Removal Controls Crustal Strength and Influences the Development of Deformation Mode in the Himalayan Orogen

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Understanding how crustal strength varies and interplays with tectonic processes is critical for continental orogenic studies. The Himalayan orogen is an ideal region to investigate this issue. Coeval with widespread crustal melting and leucogranite intrusion during Oligo-Miocene time, the Himalaya experienced crustal shortening with both long thrust sheets and short duplex and imbrication thrust sheets, crustal thickening and high-grade metamorphism, and significant surface elevation gain from <2000 m to >5000 m.

In this study, we combine thermodynamic and rheological calculations with wedge mechanics to investigate how Himalayan Cenozoic leucogranite melting and melt-removal affect crustal strength and thereby influence large-scale tectonism. Integrating the previous studies of Himalayan crustal deformation, tectono-metamorphism, and paleo-elevation reconstruction, our results reveal three key phases: 1) Rising geothermal gradients during ~60-30 Ma crustal thickening weakened the mid-lower crustal strength that potentially triggers the initiation of the Himalayan structural discontinuities since ~40 Ma, replacing the Tethyan fold-thrust belt as the primary convergent strain accommodator along the Himalaya; 2) Early-stage broad leucogranite melting during ~30-20 Ma weakened the mid-lower crustal strength, producing a supercritical wedge that promoted across-strike lengthening of low-elevation (<2000 m) Himalayan taper accommodated by the N-S directed normal faulting along the South Tibetan detachment and the Gangdese rift basins and far-traveled long basal thrust sheets along the Main Central thrust since ~30–25 Ma; 3) Melt-removal and extraction coeval with widespread leucogranite intrusion during ~20-10 Ma substantially strengthened the mid-lower crust, transitioning the wedge from supercritical to subcritical states, thereby maintaining the growing high-elevation taper and shifting deformation mode from long thrust sheets along the Main Central and Ramgarh-Munsiari thrusts to foreland-propagated short imbrication/duplex thrust sheets in Lesser Himalayan rocks. A relatively strong Himalayan mid-lower crust, existing both before broad melting and after melt-removal, rims the softer South Tibet crust at depth, likely influencing far-field tectonism. These observations highlight how the transition from melt-presence to melt-removal significantly affects orogenic crustal strength controlling major tectonism and demonstrate that the vertical rheological structure during melt-removal differs substantially from conventional quartz and feldspar analogs.