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Integrated geochemical and structural constraints on the origin and emplacement of dyke swarms, Chumathang Granitoid Complex, Ladakh (NW Himalaya)

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The Chumathang Granitoid Complex of Ladakh preserves an important record of felsic magmatism linked to Himalayan convergence and post-collisional crustal reorganization within the Trans-Himalayan batholith. This study integrates whole-rock major, trace and rare-earth element geochemistry of granitoids exposed at Zebra Hill with a statistically robust structural dataset of dyke orientations (n = 300) to understand magma evolution and emplacement processes. The granitoids are silica-rich (SiO_2 = 65.8–77.5 wt.%) and span a broad compositional range from clearly metaluminous to peraluminous (ASI = 0.70–1.10), recording progressive melt evolution and increasing crustal involvement. Systematic decreases in MgO, FeO and CaO with increasing SiO_2, together with strongly depleted compatible elements (Cr, Ni, Co and V), indicate advanced fractional crystallization following partial melting of heterogeneous crustal protoliths. Trace element characteristics, including enrichment in Rb, Th and U and depletion in Sr and Ba, point to feldspar-controlled differentiation, while REE patterns show strong LREE enrichment ($(La/Yb)_n$ = 3–20), relative HREE depletion and pronounced negative Eu anomalies (Eu/Eu* = 0.2–0.6), reflecting significant plagioclase fractionation during melt evolution.

Structural analysis reveals that dyke orientations are strongly non-random and dominated by steeply dipping, NW–SE–striking intrusions (~310–340°), indicating magma ascent along a persistent, regionally imposed fracture system. The dominance of subvertical dykes suggests that melt transfer was largely governed by tectonically induced extensional stresses rather than episodic overpressure-driven hydrofracturing. The close association between highly evolved granitoids and structurally focused dyke emplacement implies efficient extraction of fractionated melts from mid- to upper-crustal magma reservoirs during syn- to post-collisional stress reorganization. We interpret the Zebra Hill granitoids as representing a petrogenetic continuum from early I-type metaluminous granodioritic magmas to increasingly peraluminous granites and pegmatites, generated by crustal anatexis, amplified by prolonged fractional crystallization, and locally modified by late-stage fluid–melt interaction. This integrated geochemical–structural framework highlights the fundamental role of regional stress fields in controlling felsic magma evolution and emplacement during Himalayan orogenesis.