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NEWS AND NOTES

Polychronous and Multi-stage Growth History of Ladakh Batholith, Trans-Himalaya, through Mafic-Felsic Magma Mixing and Fractionation

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The granitoids and associated magmatic rocks constitute the bulk of the Ladakh Batholith (LB), which forms an integral part of the Trans-Himalaya magmatic arc system located in the north of Indus Suture Zone (ISZ). The calc-alkaline Andean-type LB formed due to the subduction of north-dipping Neo-Tethyan oceanic crust beneath the southern margin of the Asian plate. The dominant magmatic pulses of LB are recorded between 70 and 45 Ma with some discrete early pulses at ca 100 Ma. The northward continued subduction of oceanic crust and tectonic movement of Indian plate brought the LB arc close to the Karakoram Batholith (KB) along the Shyok Suture Zone (SSZ). In the eastern Ladakh Himalaya, pre-existing lithounits within the Karakoram fault zone experienced multiphase deformations, metamorphism, and melting events during syn- to post-collision regimes and formed the leucogranite-pegmatite network and granitoid plutons.

The LB is an assembly of composite plutons composed of gabbro-diorite-tonalite to granodiorite-granite-leucogranite-pegmatite. The magnetic susceptibility (κ) of LB granitoids represents magnetite (oxidized; $\kappa > 3.0\times10^{-3}$ SI) and ilmenite (reduced; $\kappa < 3.0\times10^{-3}$ SI) series granitoids, broadly corresponding to metaluminous (I-type) and peraluminous (S-type) granitoids respectively. Oxidizing nature of granitoids reduced gradually from northwestern to southeastern parts due to the subducting source materials and crustal contamination.

Fine grained, melanocratic to mesocratic, rounded to elliptical, mafic to hybrid microgranular enclaves and synplutonic dykes/sheets are ubiquitous in the LB granitoids (Fig. 1a, b). The observed field features such as crenulated margins of enclave-felsic host contact caused by viscosity contrast of mafic/hybrid-felsic magma, formation of composite enclaves with variable colour indices, shapes and sizes with sharp contact outlines with the host granitoids, elongation of enclave swarms due to magmatic flowage, irregular geometry, and zone of synplutonic mafic to hybrid dyke injection and their disruption forming brecciated enclave swarm strongly reveal the injection of mafic to hybrid magmas at an early (<35%) to late (>65%) crystallizing stages of host granitoid magmas of the LB. The enclaves and synplutonic dykes bear hbl-bt-pl-Kf-qz-ap-mag-zrn assemblage similar to the host granitoids, but they are modally disequilibrated. The enclaves exhibit fine grained, equigranular, hypidiomorphic to porphyritic textures. The sharp and wavy (pillow-like) contact outline and acicular apatite crystals resulted from the mingling and undercooling of enclave magma globules against relatively cooler host granitoids. The plagioclase phenocrysts in porphyritic enclaves are patchy and oscillatory zoned with resorbed surfaces over which anorthitic rims are grown, which indicate mechanical transfer of crystals into a high-T hybrid melt. Synplutonic mafic to hybrid dykes and sheets show a typical interlocking sub-poikilitic texture. The observed field petrographic features strongly oppose the cumulate, restite, and xenolithic origin for the microgranular enclaves.

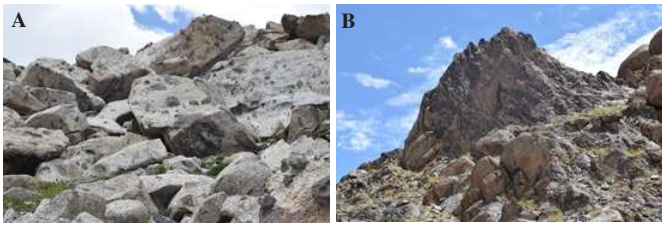

Fig.1. Mafic to hybrid microgranular enclaves of various shapes and sizes (**A**) and synplutonic dykes and sheets (**B**) hosted in the granitoids of Ladakh Batholith.

The biotites in enclaves and host granitoids crystallized and evolved mostly in metaluminous (I-type) magma and a few in peraluminous (S-type) magmas. Al-in-hornblende rim barometers suggest shallow level (2.00-3.25±0.5 kbar) emplacement of enclave and granitoid magmas, and hence mafic to hybrid magma zone must be hidden at or below 8 to10 km. Linear to near-linear whole rock elemental variations on Harker's plots, identical trace, and rare earth element patterns of enclaves and host granitoids can be attributed to mixing, fractionation, and diffusion during the development of mafic-felsic hybrid zone, post-entrapment undercooling, and mingling of enclave globules into partly crystalline host granitoids. However, high silica peraluminous granitoids (SiO_2>73%) with high Rb/Sr and Rb/Ba ratios, more prevalent in the eastern parts of the LB, appear to have formed due to contribution from the crustal source in the collisional environment. U-Pb zircon ages of mafic to hybrid enclaves, syn-plutonic dyke and host granitoid are synchronous that underline their coeval nature. However, coeval mafic-felsic magmas were episodic and polychronous that co-existed in plutonic condition. Positive whole rock εNd^t, zircon εHf^t values and young Hf model ages strongly suggest involvement of juvenile sources in their genesis and mixing between mafic-felsic magmas. Zircon U-Pb-Hf data further mark one of the several India-Asia collisional ages at ca. 50-51 Ma. The integrated evidences suggest that the LB is a product of polychronous pulses of coeval mafic and felsic magmas that experienced multistage growth history of synchronous mixing, fractionation, mingling, and diffusion. A few calc-alkaline granitoid pulses continued to produce after India-Asia collision, which interacted with crust-derived melts producing leucogranite-pegmatite system mostly in the eastern part of LB.