CHAPTER 6:

CONCLUSIONS AND FUTURE PROSPECTIVES
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6.1 CONCLUSIONS

The study area, Ladakh Accretionary Prism (LAP), was developed in two different subduction events, i.e. (i) at the beginning, the Tethys Oceanic plate subducted below Continental Asian plate giving rise to a magmatic arc called Dras and development of an attendant accretionary Prism, called Paleo Accretionary prism (PAP) at the fore arc basin as the Dras arc collided with the Asian Plate (Honegger, 1982, 1989; Thakur, 1981; Mahéo et al., 2004, 2006 and many more). (ii) The continued northward push of the Indian plate caused complete consumption of the Tethyan oceanic plate that ensued Indian and Asian continental plate collision (Figure 2.1). This second phase gave rise to the Ladakh magmatic arc along the Indus–Tsangpo Suture Zone (Honegger, 1989; Mahéo et al., 2004, 2006; Henderson, 2011) and shaped the South Ladakh Accretionary Prism (SLAP). The first phase of the collision began at ~120 Ma while the second phase of the collision took place sometimes at ~65 Ma. Further, the extension of a part of Paleo accretionary prism (PAP) occurs to the NE section of Ladakh Himalaya, which is referred to as Zildat Ophiolitic Mélange (ZOM).
The southern margin of SLAP is dominated by the marine sediments derived from
the Indian plate while at the northern margin; the sediments are deposited under
fluvial condition consisting chiefly of terrestrial sediments derived from Ladakh
magmatic arc (LMA). The PAP and SLAP is jointly referred to as the Ladakh
Accretionary Prism (LAP) which is bounded by deep seated thrusts at the
northern and southern margins namely, the Indus thrust and the Zanskar thrust
respectively. The fault/fracture filling veins comprised of quartz and calcite
minerals are omnipresent in the LAP, which intruded and emplaced during the
Miocene time (Kharya et al., 2014). These cut across all the formations of the
LAP and are therefore much younger than the last phase of the deposition in the
LAP. These veins are the subject matter of this study as it is expected to contain
vital archives of the tectono-magmatic activities during waning phase of
Himalayan orogeny. Following are the salient conclusions that can be drawn from
the present study:

The petrographic study of these mineralized veins indicates that the veins were
formed by quartz and calcite minerals which were present either in the pure form
or in co-existing pair. Fluid inclusion micro-thermometric results predict
minimum temperature of fluid entrapment in the range of 212 to 325 °C. This is
found consistent with the oxygen isotope thermometric results ranging from 152
to 528 °C. We assign these temperatures to be the crystallization temperatures of
the hydrothermal veins of SLAP (Figure 4.26). The re-equilibration textures of
fluid inclusions (Figure 3.8 and 3.13 – 3.17) indicate an enhanced tectonic activity in SLAP (as criteria given by Boullier, 1999).

The fluid inclusion study suggests that the P–T path for the entrapment of fluid inclusions was initially isothermal then become isochoric at the last stage (Figures 3.24 and 3.26). It also indicates that the veins were rapidly exhumed from about 12.6 km and 21.0 km depth in PAP and SLAP, respectively. Re-equilibration textures such as ‘C’ shape ‘L’ shape, implosion and dense CO2 fluid inclusions were noticed during petrography and microthermometry which point toward the deep seated magmatic origin of fluid from the deep part of the earth.

High REE abundance having nearly flat trend (Figure 4.15 and 4.16) with or without positive Eu anomaly (Eu/Eu* ≥1), which are quite unlikely of crustally derived materials, and were probably have mantle or magmatic kinship. High partition coefficient of REEs in coexisting calcite/quartz, high La/Gd ratios (Figure 4.17) and high ΣREEs in calcites are also suggestive of magmatic affinity of the fluids.

The stable isotope geochemistry of calcite suggests strong affinity for mantle or ophicarbonate like fluid source, which was probably fractionated to some extent at the later stage due to various mixing or alteration processes, such as- marine mixing, hydrothermal alteration and meteoric water alteration (Figure 4.21).
Furthermore, the Sr isotopic ratio also suggests that the fluid was initially derived from mantle sources and were fractionated by various processes at later stage as the fluid travelled further southwards. The Pb isotopic compositions are in agreement with other proxies and offers strong evidence of mantle fluid source. The Pb isotopic systematics propose that fluid were derived from the Enrich Mantle II type of deeper sources (upper mantle), that are relatively more radiogenic in nature compared to other mantle sources (Figure 4.23). Low Sr isotopic compositions are also relatively enriched but are within the range of enriched mantle composition (EM II). Sr isotopic ratios together with Pb isotopic signatures suggest derivation of fluid from deeper source in the mantle domain and are more radiogenic than other mantle end members such as normal-MORB, depleted MORB mantle (DMM) etc. The oxygen isotopic ratio of quartz shows affinity very similar to those of the fluids of magmatic origin. Moreover, the oxygen isotopic composition of vein forming fluid $\delta^{18}O_{(\text{fluid})}$ estimated from the $\delta^{18}O$ values of quartz and calcite veins at known temperatures of formation is also fall within the mantle and ophicarbonate field (Figure 4.27).

In the spatial distribution of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the vein carbonates reveal a more pristine enriched mantle value in veins that occur at the northern side of LAP. This is further enriched gradually towards the southern margin (Figure 4.22). It suggests that the vein forming fluids were initially intruded from the northern margin of LAP, but gradually became enriched through mixing and interaction with the crustally derived marine components (with higher $^{87}\text{Sr}/^{86}\text{Sr}$ values) as it
moved further south along the down going slab (Kharya et al., 2014; also see in Figure 5.3). It is notable that the southern margin of SLAP consists of mostly marine sediments.

The mantle related magmatic activity in the Miocene also reported from the Kohistan part of magmatic arc between 30 and 13 Ma from Tibet (Ji et al., 2009). This arguably is an evidence of mantle related fluid activity in the Himalayan orogeny took place until as late as ~13 Ma (Ji et al., 2009). Ji et al (2009) further proposed that the late stage Kohistan arc magmatism is related to few pulses of mantle melting, which is coeval with the break-up of the locked-in Indian plate beneath the Asian plate. Based on the new results from this study, a modified tectonic model of the late stage of the Himalayan orogeny is proposed here. This comfortably explains a rationale for the mechanism of derivation of mantle fluids flux and revival of mantle activity during the Miocene time and attendant tectonic activity (Figure 5.3, Kharya et al., 2014). The proposed break-off of Indian plate during the Miocene epoch (Chemenda et al., 2000; Ji et. al. 2009) resulted in upwelling of asthenospheric mantle promoting partial melting by decompression and exaltation of fluid fluxes that swept all across the LAP. Therefore, it can be concluded that the presence of mantle signature in the fluid for the formation of veins in LAP is a crucial evidence and is one of the manifestations of the breakoff of the Indian plate underneath at the penultimate stage of the Himalayan Orogeny within accretionary complexes (Figure 5.2 and 5.3).