

Geological controls on groundwater chemistry in the Himalayan Indus River basin aquifers, India

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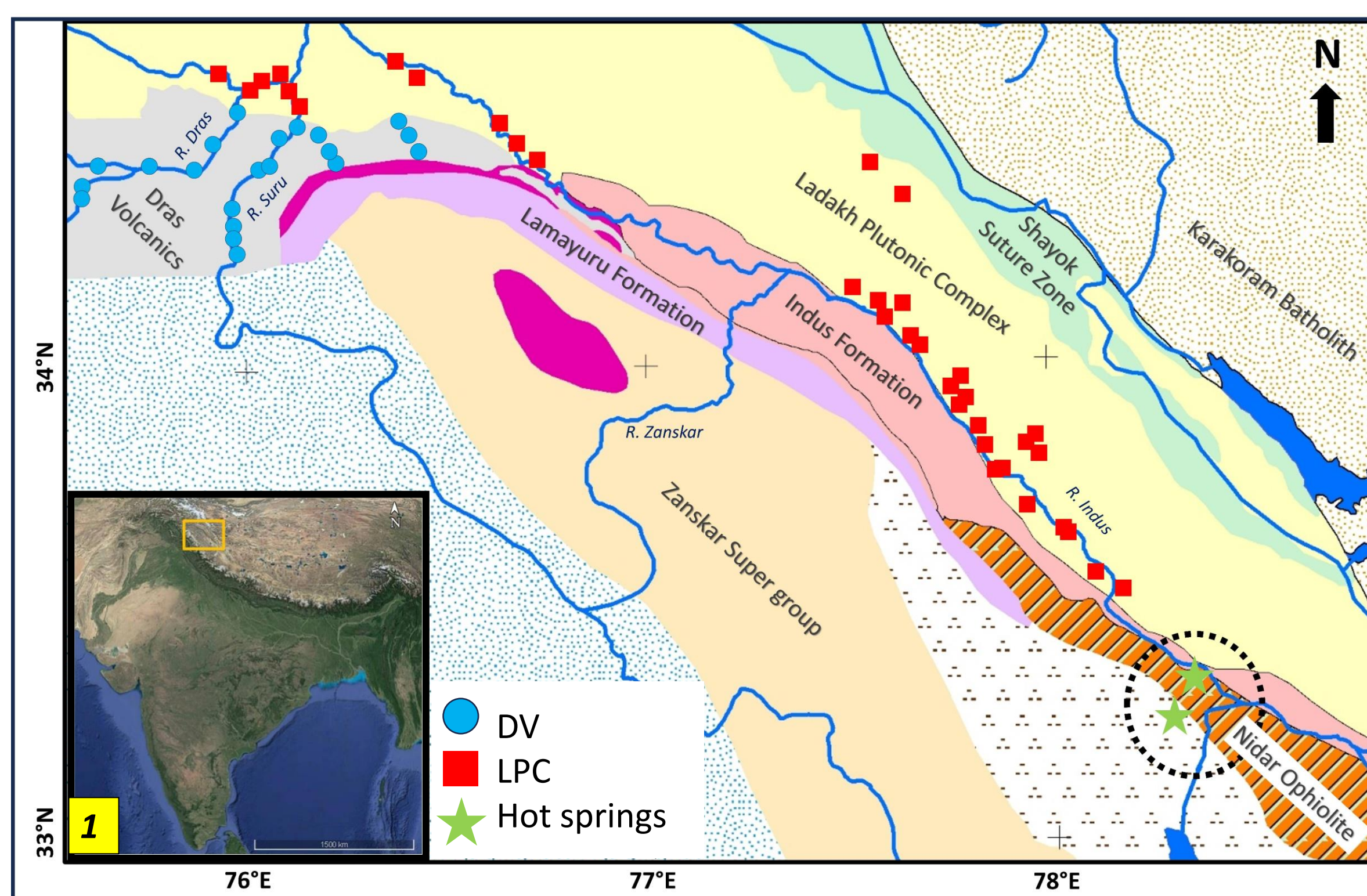
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Introduction

- The trans-boundary Indus River basin aquifers spans 16 million hectares across six countries. Although extensive research on groundwater quality and quantity has been conducted in its middle and lower reaches, the high-altitude aquifers have gone unnoticed until recently (Lone et al., 2020)
- The upper Indus River basin aquifers spanning over the Himalayan, Karakoram, Hindu Kush ranges is a vast water scarce region, which have escaped the notice of the groundwater scientists until recently
- Hence, the primary objective of the present study is to delineate the sources of solutes and processes of groundwater-rock interaction in the shallow Trans-Himalayan Indus River basin aquifers of India

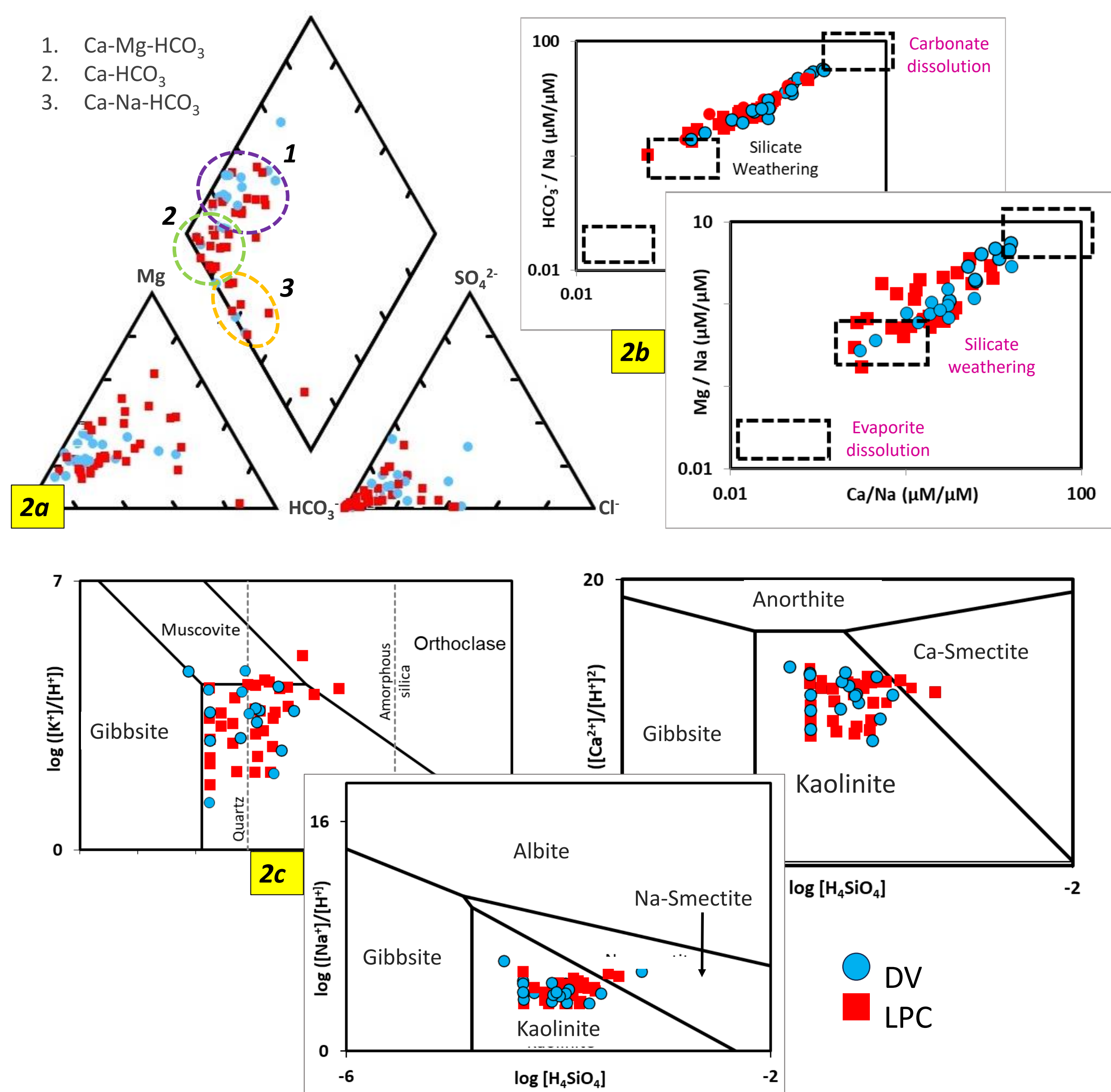
Study area

- The study site is located in the Union Territory of Ladakh, India, covering an area of ~60 x 10³ km². It is bounded by the Himalayan and Karakoram ranges, and has a mean altitude is 4500 m. The region experiences arid to semi-arid climate, receiving an annual precipitation of 115 mm
- Geologically the area is located on the Indus Tsang Po Suture Zone (ITSZ), the zone of amalgamation of the Indian and Eurasian plates. Stratigraphically the ITSZ can be divided into 8 formation, of which groundwater samples collected from the Dras Volcanics (DV) and the Ladakh Plutonic Complex (LPC) are considered for the current study (Fig.1)
- The DV is volcano-sedimentary succession of basaltic - andesitic flows with minor occurrences of agglomerates, rhyolites, pillow basalts, radiolarian chert, jasper, and limestones. It is underlain by gabbro-norite cumulates, and contain slices of dismembered ophiolites (Thakur, 1981)
- The LPC is a tonalite-granodiorite-granite batholith, with occasional occurrences of gabbro, norite, anorthosite, and pyroxenite plutons and xenoliths of metamorphic and basic rocks can be found entrapped along its boundaries (Thakur, 1981)



Results

- Groundwater is circum-neutral to alkaline, and range in composition from Ca-HCO₃ to Ca-Mg-HCO₃ facies. Ca-Na-HCO₃ facies occurs minorly (Fig. 2a)
- Waters are transitional between global averaged silicate and carbonate weathering fields of the Na-normalised Ca vs. HCO₃ and Mg mixing diagram (Fig. 2b)
- Thermodynamic calculations suggests, samples are in equilibrium with kaolinite and in disequilibrium with feldspars (Fig. 2c)
- Mineralogically the DV rocks exhibits as greenschist facies assemblage consisting of albite, augite, epidote, chlorite, calcite, quartz, ± opaques. While the LPC is composed of quartz, plagioclase, alkali feldspar, biotite, hornblende ± muscovite, chlorite, apatite, zircon, monazite, and opaques

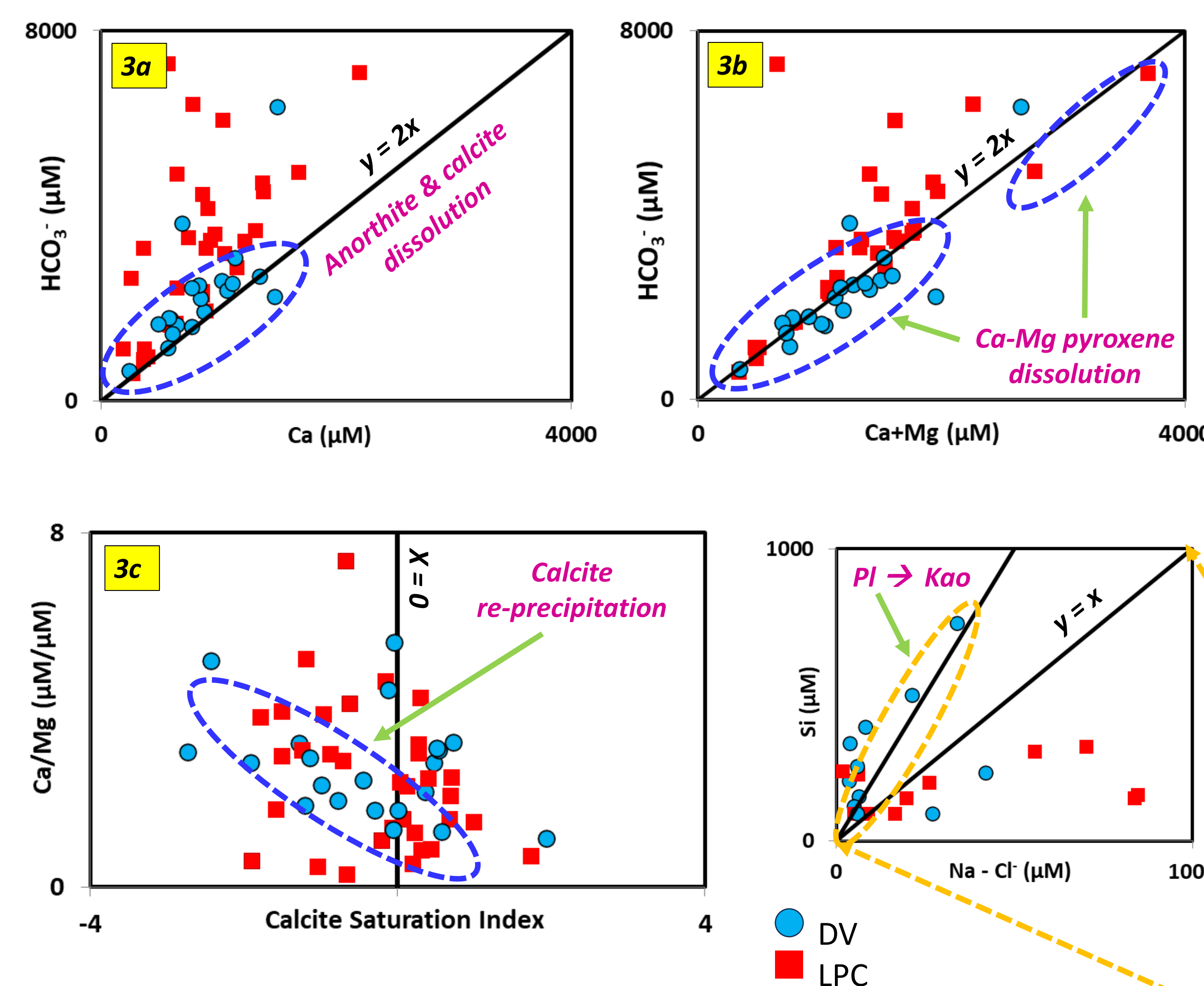


Conclusion and outlook

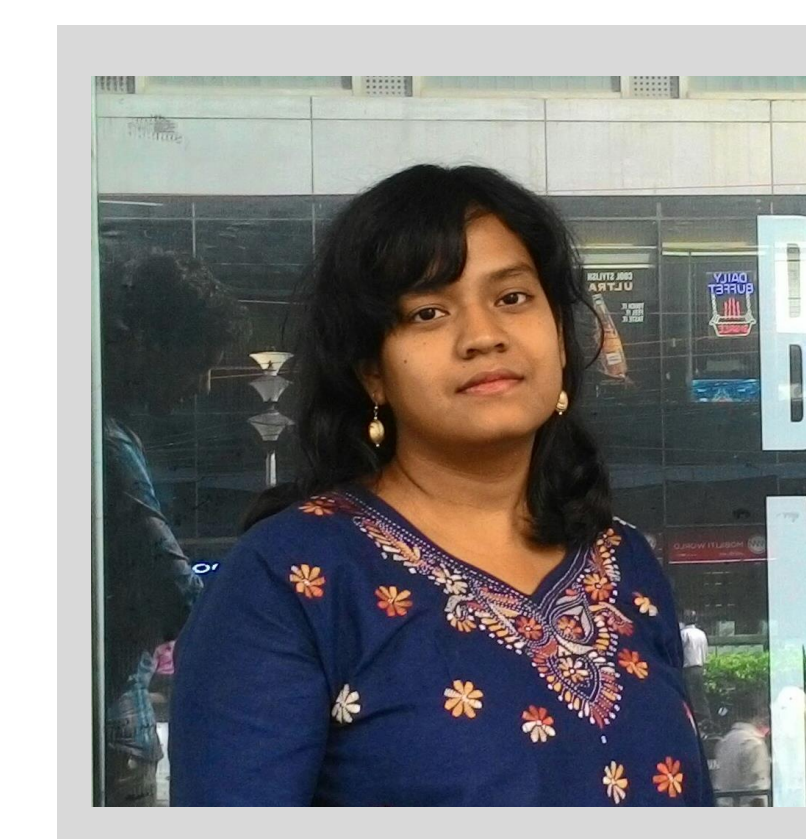
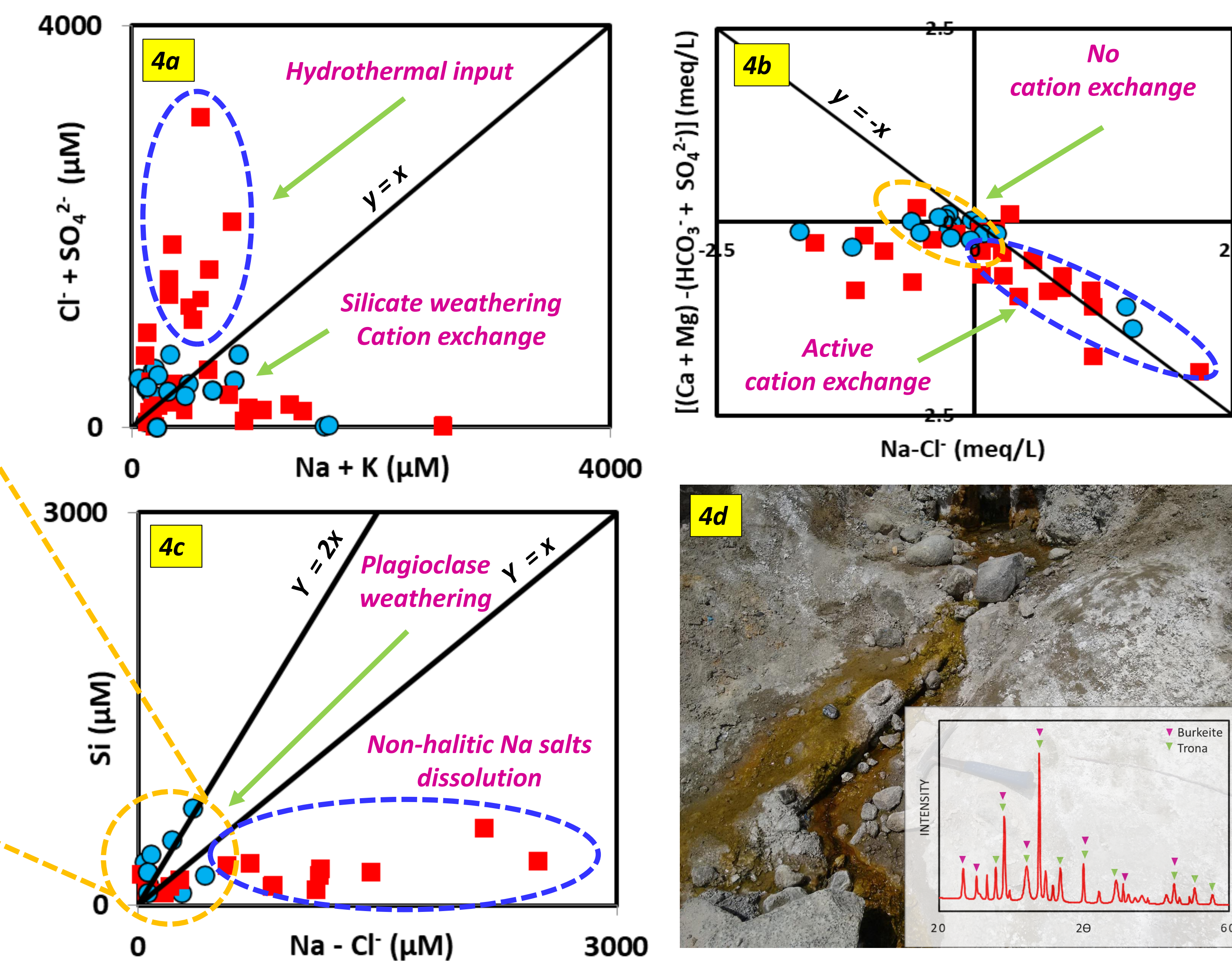
- Calcite, pyroxene, and albite weathering by groundwater releases solutes from the greenschist assemblage of the Dras Volcanics, while, a combination of feldspar - hydrothermal precipitates dissolution and cation exchange reactions supply solutes to the groundwater hosted in the aquifer of the Ladakh Plutonic Complex
- Expected solutes relations are often obscured, due to occasional occurrences of felsic and mafic lithologies in both units
- Interpretations pertaining to solute sources and mobilization mechanism made from solute inter-relations and thermodynamic calculation are at best qualitative to semi-quantitative, and require the usage of geochemical modeling or isotopic tracers to pinpoint sources and ascertain the role of phases not considered in this work

Discussion

- Calcium and Mg exhibits high degree of correlation an over all low Ca/Mg ratio
- Most DV and few LPC samples exhibit a Ca/HCO₃⁻ molar ratio of 1:2, indicative of both calcite and anorthite dissolution, since both processes gives out Ca and HCO₃⁻ in 1:2 ratio (Fig. 3a). Similar trend can be observed for molar ratios of Ca + Mg/HCO₃⁻, suggestive of Ca-Mg pyroxene weathering (Fig. 3b)
- Aquifer matrix mineralogy suggests, Ca-Mg-HCO₃⁻ ratios of DV waters are due to calcite and pyroxene dissolution, since all it plagioclase has been albitised. Calcite dissolution shifts some DV samples towards the carbonate dissolution field in Fig. 2b
- In the LPC, anorthite dissolution gives out Ca and HCO₃⁻ in 1:2 ratios. LPC samples plotting nearby the pyroxene dissolution line in Fig. 3b are probably influenced the minor mafic components occurring in this dominantly felsic unit
- Decreasing trend of calcite saturation with Ca/Mg for fraction of samples suggests Ca loss by re-precipitation for both suites (Fig. 3c)



- Molar Cl⁻ + SO₄²⁻ in excess of Na + K, (Fig. 4a) suggests hot springs and precipitates inputs, while a ratio <1, results from silicate weathering or cation exchange. Such springs are located in the south eastern part of the study area, and are most likely to affect LPC samples. DV waters with no 'Na excess' (Na - Cl), are probably not undergoing albite dissolution or cation exchange reactions (Fig. 4b)
- A good majority of samples have 'Na excess', which can be attributed to feldspar weathering.
- Dissolution Na-feldspars of to kaolinite or smectites, irrespective of their Ca/Na ratios gives out Si/Na molar ratios of 2 - 1.5. Few LPC and almost all DV samples trend along these lines in Fig. 4c
- Despite thermodynamic calculations predicting feldspar dissolution, the lack of distinct Na*-Si trends in LPC, is probably due Na addition through cation exchange reactions (Fig. 4b) or commonly observed non-halitic hydrothermal precipitates (Fig. 4d; inset: XRD pattern) such as borax, trona, burkeite dissolution
- Poor Cl-SO₄²⁻ correlation, suggests dissimilar provenance. High Ca/SO₄²⁻ ratio precludes gypsum/anhydrite dissolution, so excess SO₄²⁻ can stem from sulfide oxidation or thenardite, jarosite, burkeite dissolution



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