# Investigating the Metamorphic Evolution, Water-rock Interaction, and Geochemistry of Tso Morari UHP Terrane, NW Himalaya

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## Introduction

Collision of the Indian and Eurasian plates caused the uplift of the Tibetan Plateau, triggered volcanic eruptions and earthquakes, and led to global climate change. Accordingly, the Himalayan orogenic belt marks one of the largest sites of elemental cycling, crust-slab-mantle interactions, and areas of ultrahigh pressure (UHP) terranes on Earth.

This study aims to test the hypothesis that some microcontinents were subducted to mantle depths surrounded by oceanic crust prior to the large scale Indo-Asian continental collision by looking for clues in the mineralogy and geochemistry of exhumed UHP rocks from the Tso Morari terrane, NW India (Fig. 1).

## Study Area and Sampling

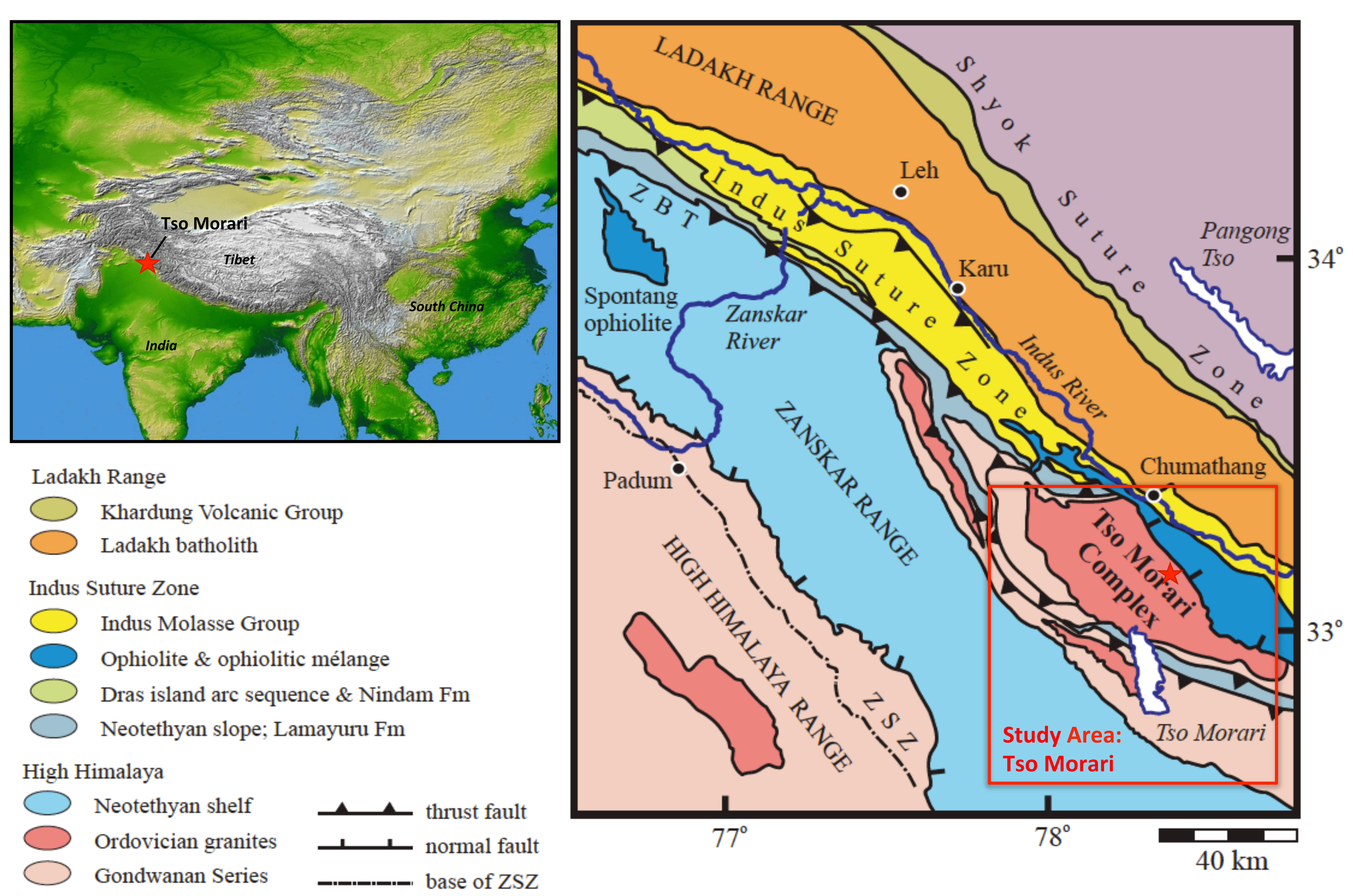


**Figure 1**. Geological map of the Himalayan orogenic belt and Tibetan plateau showing the rock units, the tectonic boundaries, and the location of the study area of Tso Morari *(St-Onge et al., 2013)*.

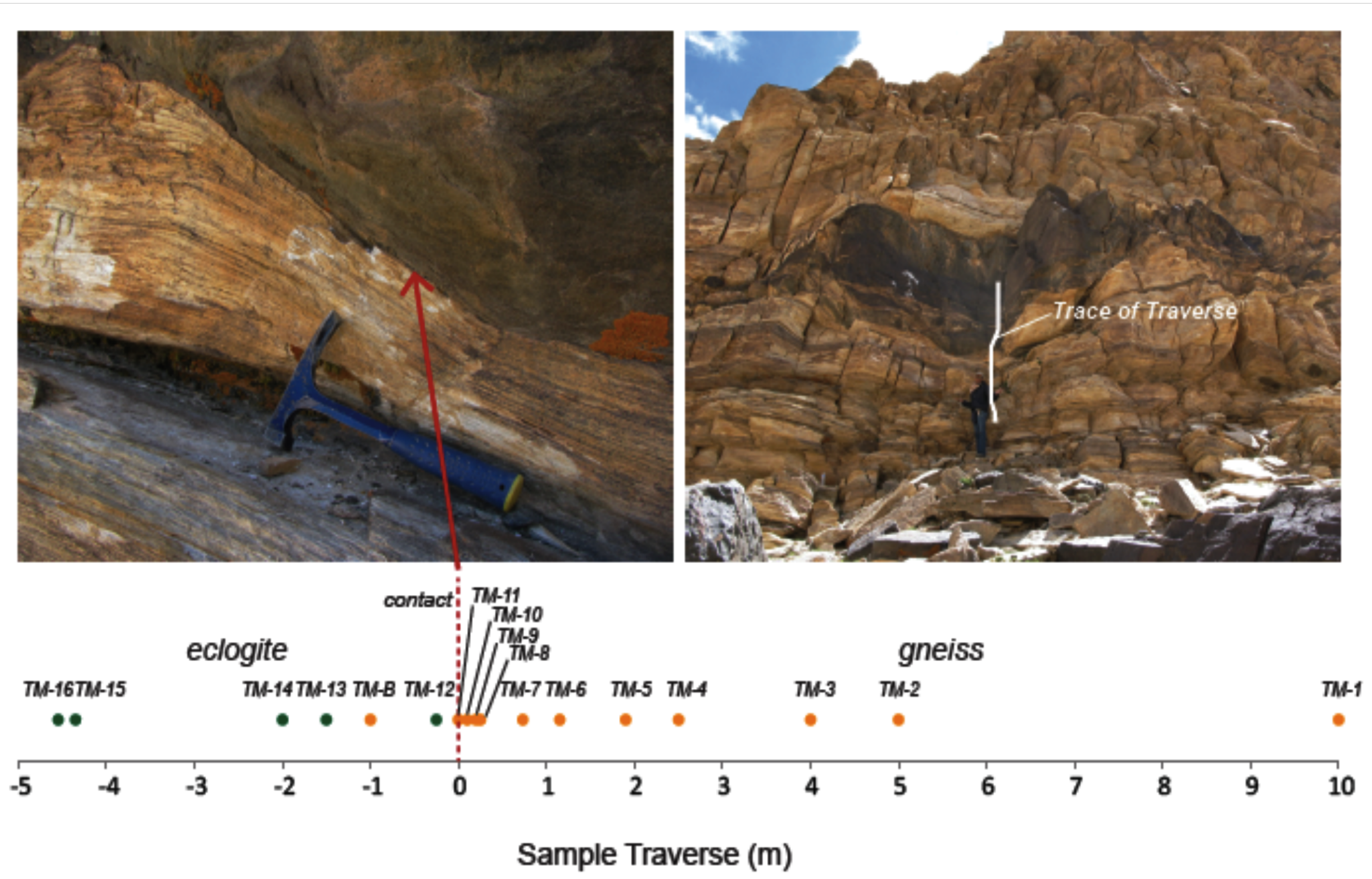


**Figure 2.** Sampling at contacts between felsic and mafic rocks

## Hypothesis

The subduction and exhumation of small masses of continental crust (microcontents, sliver of continental crust, etc.) can occur during oceanic subduction prior to final continental collision (Kylander-Clark et al. 2012). Fluids released by devolatilization of altered oceanic crust and sediments will interact with the subducted microcontinent in the subduction zone (Menold et al. 2016). Recrystallization at UHP depths and during exhumation will occur in the presence of these fluids, imparting a distinct geochemical signature. Because the Tso Morari UHP terrane has many of the hallmarks of the small, early terrane type described in Kylander-Clark et al. (2012), e.g., cool *P-T* path, short period of subduction and exhumation (<10 Myr) and a small area of exposure (<<5000 km$^2$), it is an excellent candidate for a study of HP/UHP fluids. We studied samples taken from a traverse across an eclogite and granitic gneiss from the Tso Morari to search for such a signal (Fig. 2).

## Trace Elements and Garnet Growth Zoning

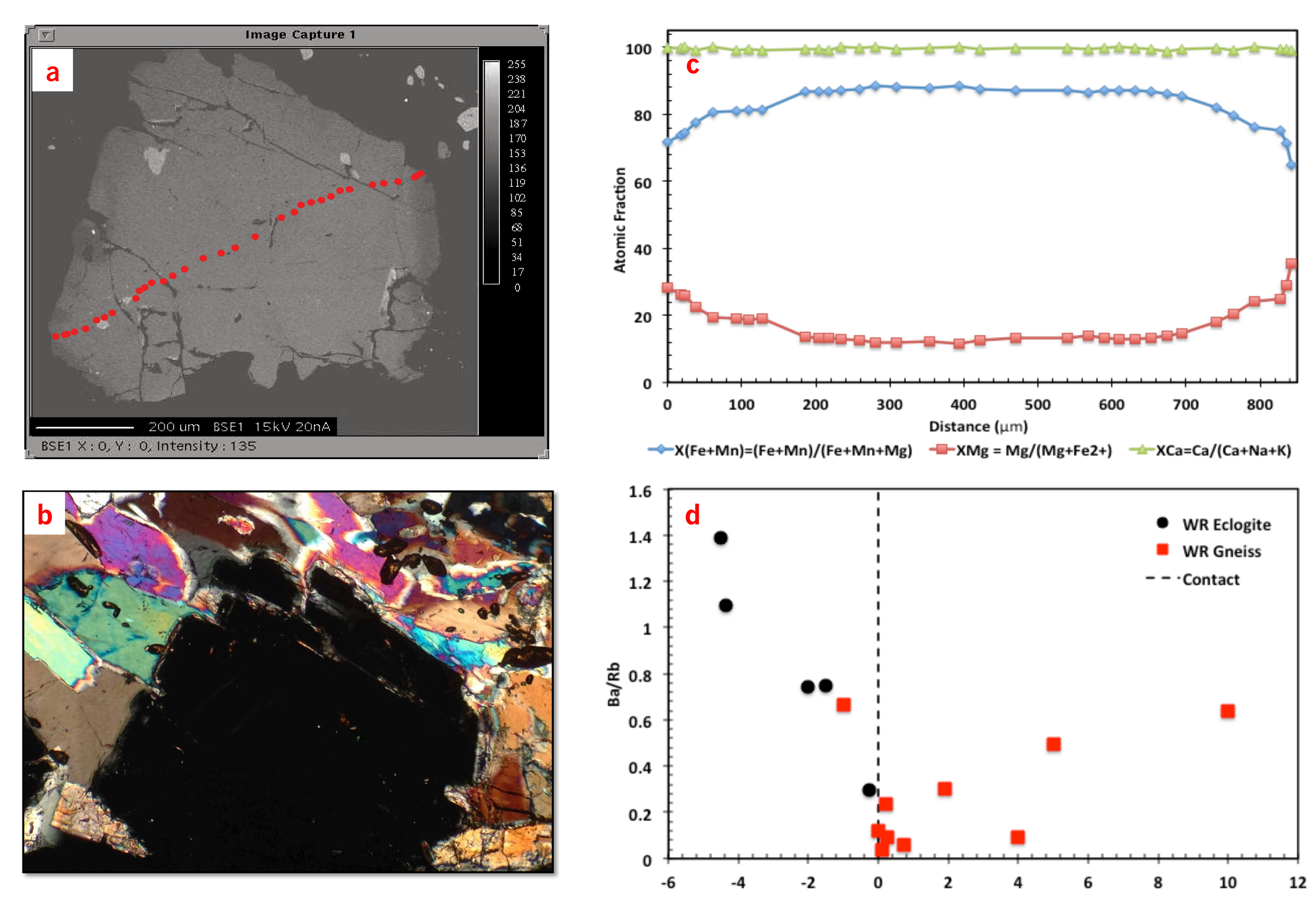


**Figure 3**. **(a)** Garnet back-scattered electron (BSE) image of Sample TM-15 (eclogite) showing a well-developed core-rim zoning. **(b)** TM-15 garnet thin section image in polarized light. **(c)** Garnet compositional zoning profile for TM-15, with the rim-to-rim variation of Fe, Ca, Mg and Mn expressed in cation mole fraction. **(d)** Element ratio diagram of whole rock Ba/Rb vs. distance.

Whole-rock trace elements were measured to examine the water-rock interactions, mineral phase change, and elemental behaviors affected by geofluids at the eclogite-gneiss contact. The geochemical data show that LILE (e.g. K, Rb, Cs, Sr, Ba) are enriched along the traverse and the Ba/Rb ratios are relatively lower at the contact (Fig. 3d). Fe isotope analyses of mineral separates in the eclogite close to the eclogite-gneiss contact also indicate interaction with a fluid at depth (Macris et al. 2016). All of these findings are consistent with fluid mediated exchange.

EPMA analyses reveal garnet zonation in the eclogite: the $X_{Fe+Mn}$*((Fe+Mn)/(Fe+Mn+Mg))* drops from 83-90 to ~60 while the $X_{Mg}$*(Mg/(Mg+Fe$^{2+}$))* increases from ~10 to ~30 from the core to rim (Fig.3 a-c). The compositional change in garnet rim is indicative of retrograde metamorphism (St-Onge et al, 2013).

## Metamorphic P-T Pseudosection

In order to estimate the *P-T* history of the rocks, we constructed metamorphic pseudosections using whole rock major element geochemistry (Fig. 4). Based on the mineral assemblages of the samples, mineral inclusions in the garnet core, and pseudosection calculations, we determined that the eclogite experienced peak metamorphism (P>24 kbar and T: 575-625°C; Fig. 4, bold line area) and likely some degree of retrograde metamorphism based on mineral inclusions and change of Mg/Fe ratio in garnet rims (Banno et al, 1986).

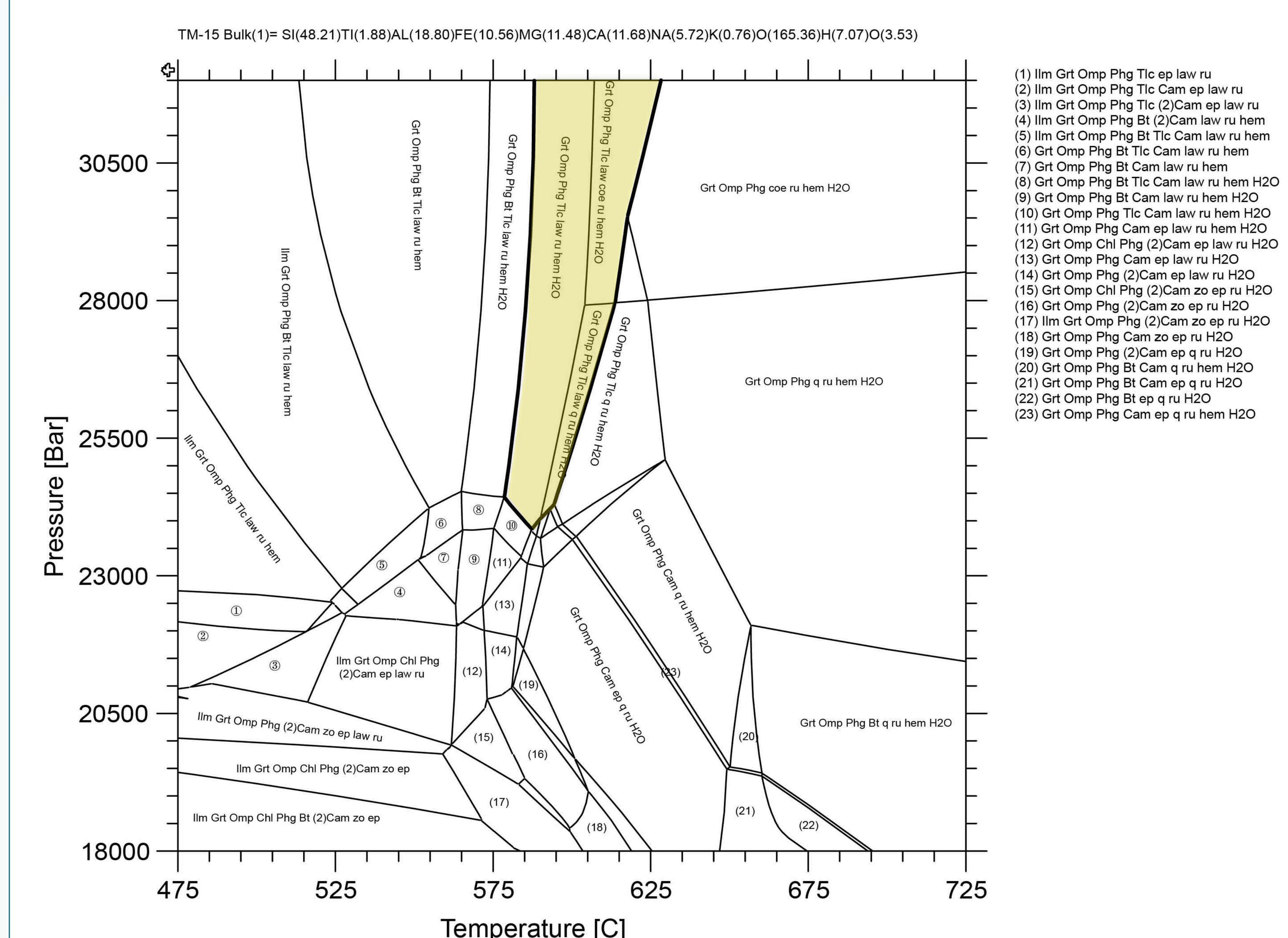


**Figure 4**. *P-T* pseudosection for eclogite sample TM-15, showing the change of mineral phases with *P-T* change. Using THERIAK-DOMINO program based on the NCKFMASHTO system and Datasets of tcds55 *(De Capitani, 1994; Holland & Powell, 1998)*.

## Future Work

- Investigate the samples for evidence of metasomatism at high *P* and *T*, and interpret associated processes using trace element analysis, and mineralogical and geochemical modeling.
- Fe isotope measurements of whole-rock and mineral separates to constrain the Fe isotopic variations of minerals during pro- and retro-grade metamorphism, and estimate the impact from metamorphic fluids and exhumation process.
- Laboratory high temperature-pressure experiments using a piston cylinder apparatus to further examine the suggested work above (e. g. mineralogical and chemical reactions of some associated minerals with aqueous fluids under high *P-T* conditions).

## References

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