Estimation of Flow Stress and Strain Rate from the Veins of an internal shear zone: Insights from Pelling-Munsiari thrust, Sikkim Himalaya

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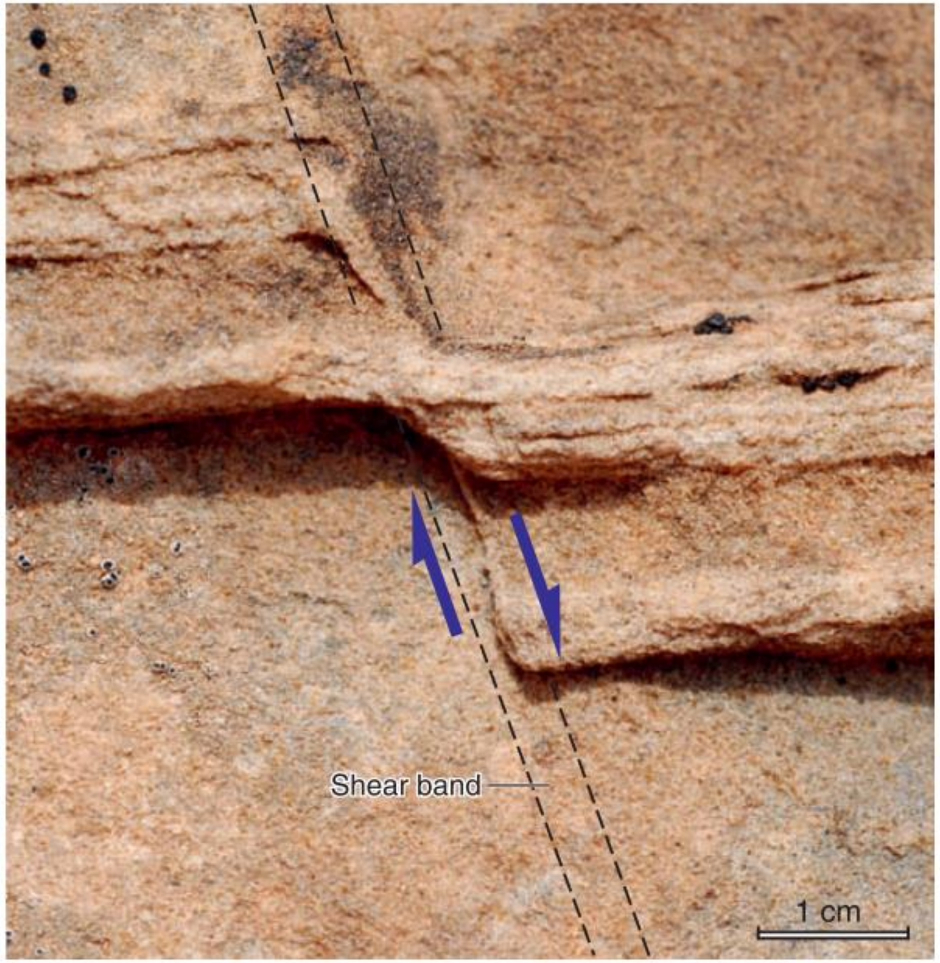
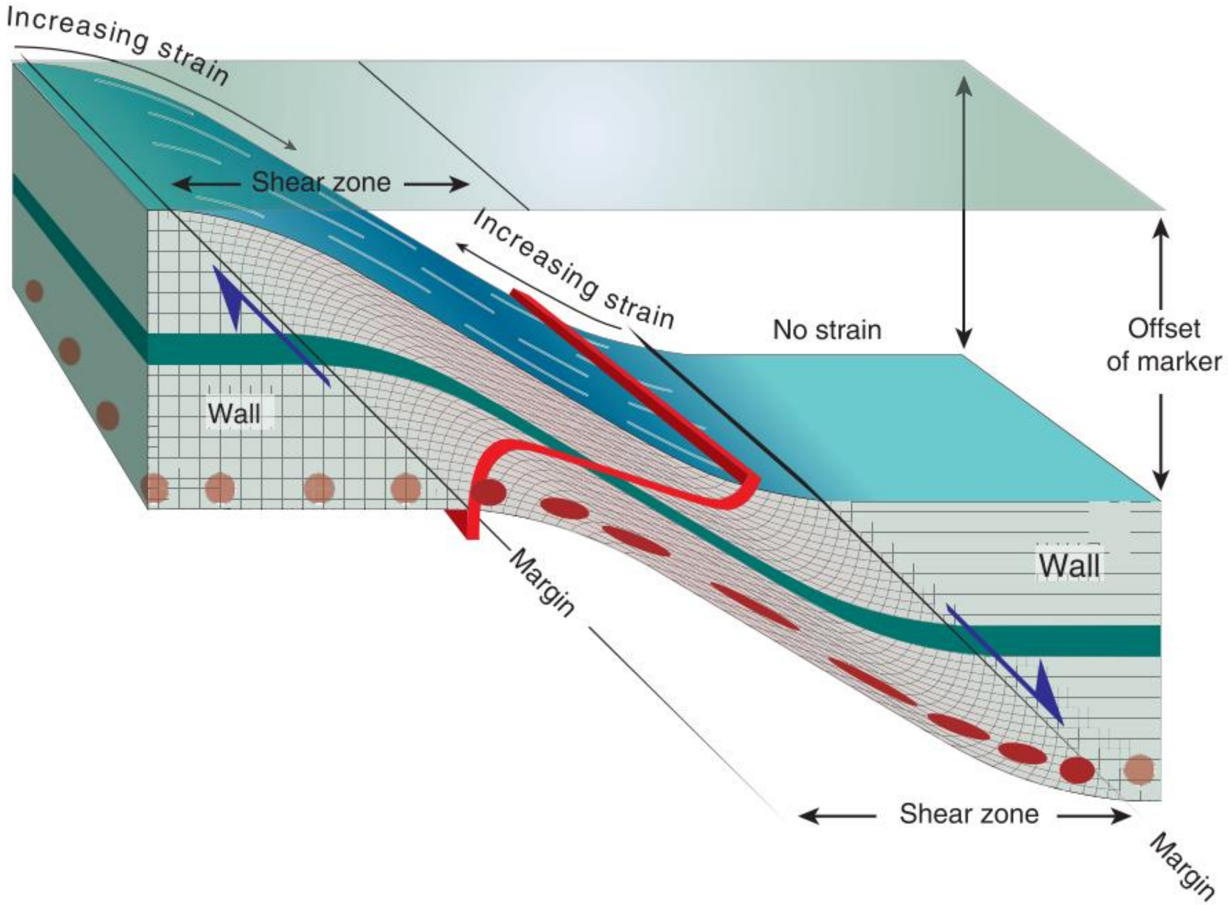
BACKGROUND

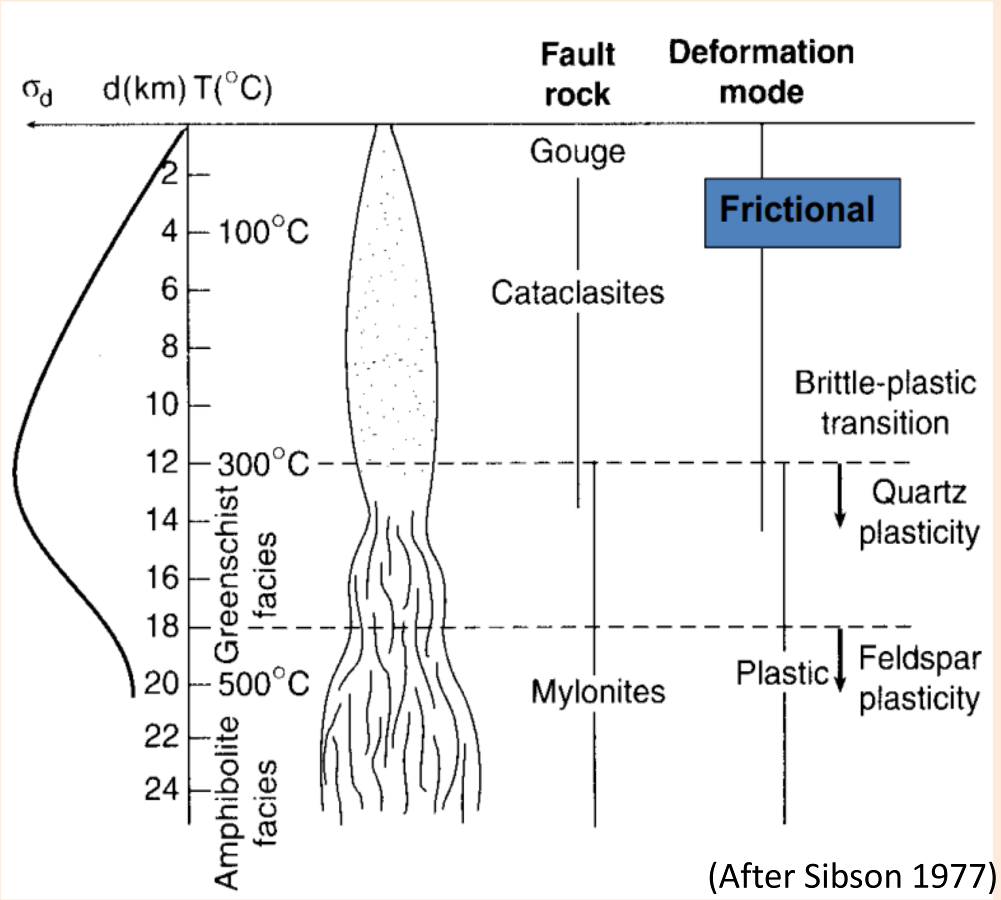




A shear zone is a zone in which strain is higher than the wall rock, and whose margins are defined by a change in strain, typically seen by rotation of preexisting markers or formation of a new fabric. (Fossen and Cavalcante, 2017)

(Fossen, 2010)

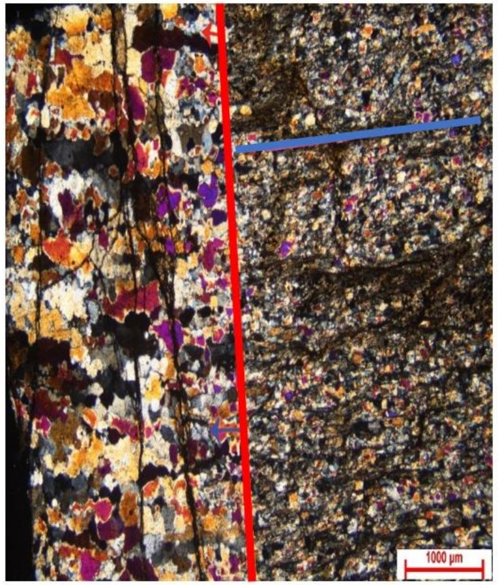
BACKGROUND



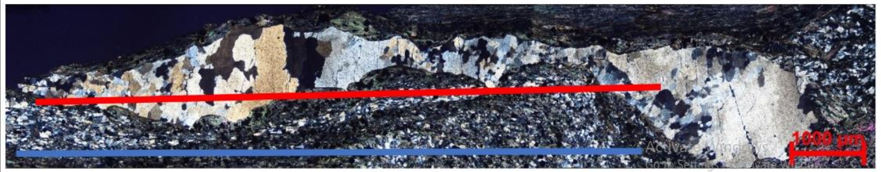
(After Sibson 1977)

In nature, shear zone rocks are recognized by characteristic fault rocks.

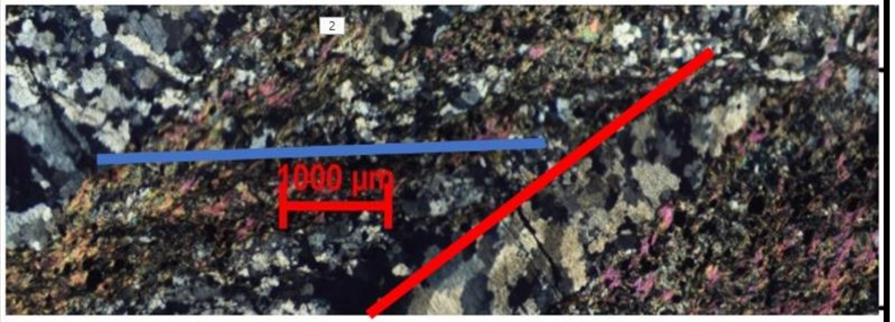
- Depending on the deformation mechanism and conditions of the shear zone, faults rocks can vary from gouge to cataclasites to mylonites.



High angle vein



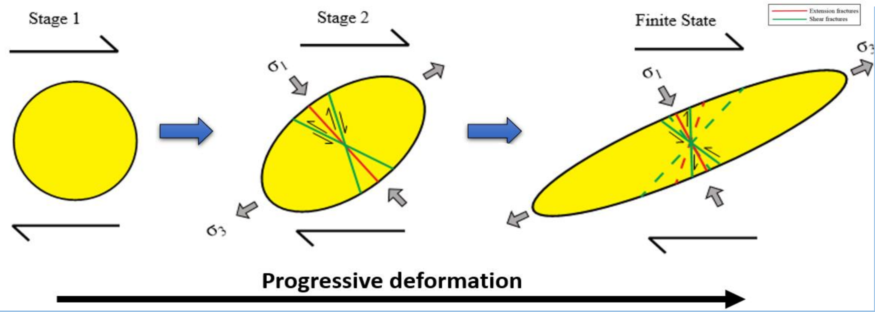
Low angle vein



Moderate angle vein

Often these fault rocks are associated with some other structures as are shown by coarser grain sections which are called Veins, which are commonly hosted by fractures.

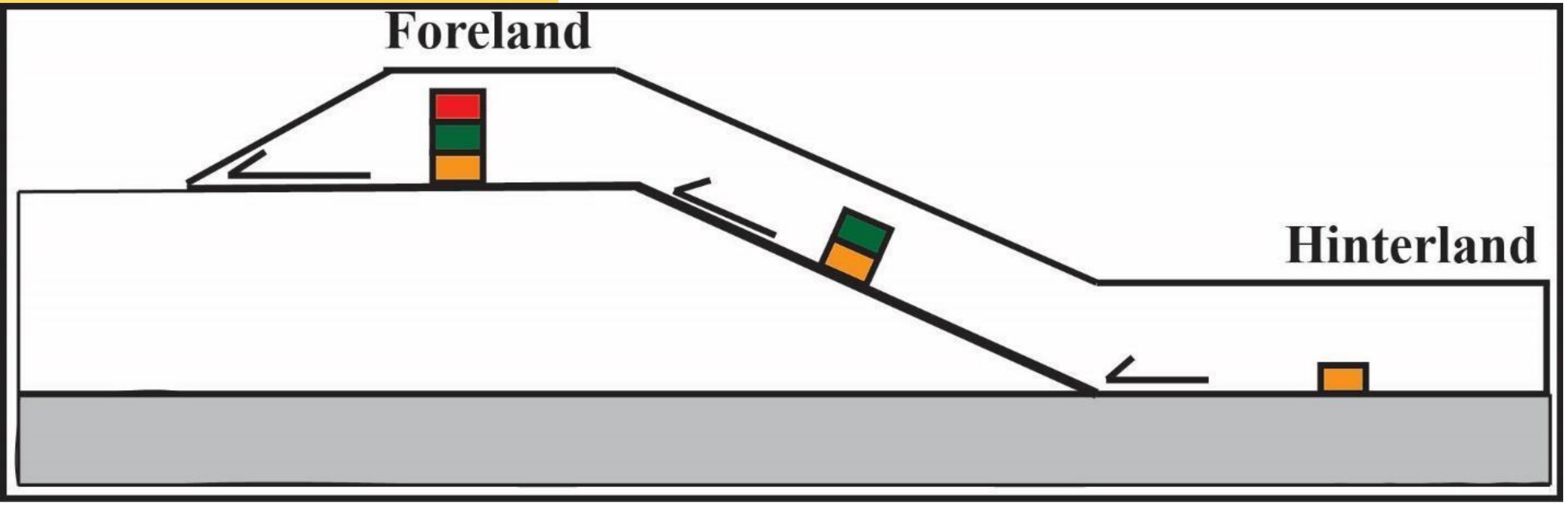
Photomicrograph of studied Fault rocks showing different orientation of veins.



Cartoons illustrating fracture formation of different orientations and population during progressive deformation in a shear zone

Some of these fractures may eventually be filled by secondary minerals to form veins. And therefore, these veins of different orientations can be used to estimate deformation condition.

BACKGROUND



Shear zones related to fold thrust belt, progressively bring deeper crustal rocks to shallow crustal conditions. During the process, often mylonites gets overprinted by cataclasites and new veins of different orientation forms overprinting the earlier ones.

Photomicrograph showing new fracture and veins overprinting earlier ones.

GAP AREAS

Few existing studies on flow stress and strain rate from the host mylonite. (Twiss 1977, Hirth et al., 2001; Francsis, 2012, Boutonnet et al., 2013; Ghosh et al., 2016; Kalita et al., 2021).

Fewer studies on flow stress and strain rate from the veins of mylonites (Stipp et al., 2002; Bose and Mukherjee, 2020)

Not a single study that have addressed flow stress and strain rate variation along the transport direction of a major shear zone from different structural positions.

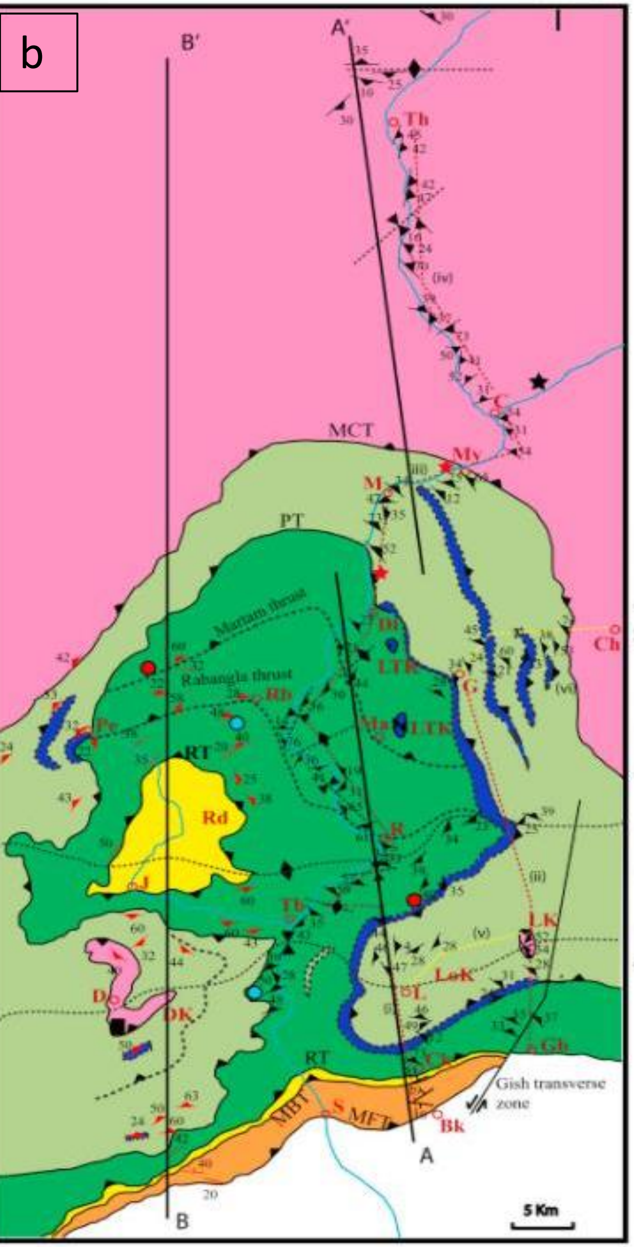
OBJECTIVES

- Microstructural analysis of veins from multiple locations along transport direction of a major shear zone
- To study the vein attributes at microstructural scale
- Estimating flow stress and strain rate of veins that formed through different stages of progressive deformation along the transport direction of a major shear zone from its internal to external location.
- How do these deformation conditions vary along the transport direction of a major shear zone?

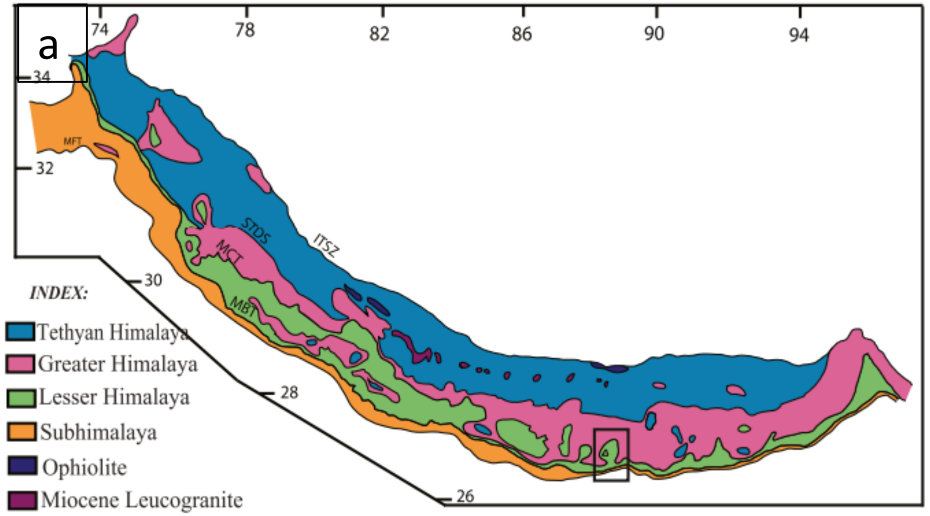
IMPLICATIONS

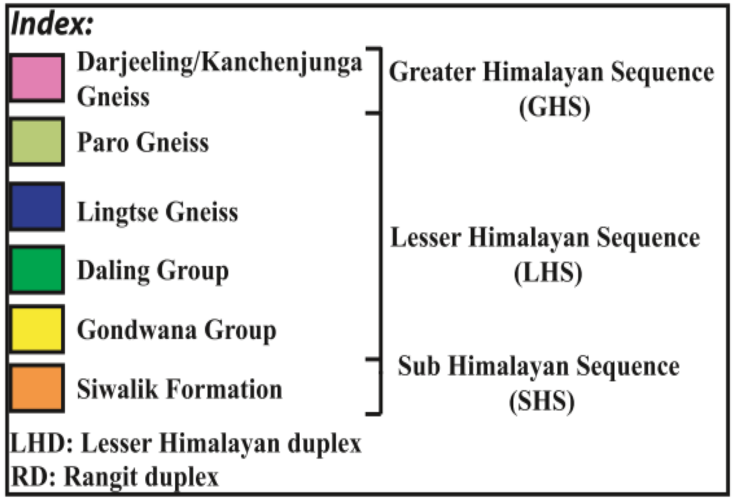
- First study to look at the variation in flow stress and strain rate from the veins of mylonites along the transport direction of a major shear zone from different structural positions.
- Give insights how deformation conditions vary in a major shear zone along the transport direction.
- Give insights into how footwall structures of shear zone affects the shear zone deformation at different location of shear zones.

STUDY AREA

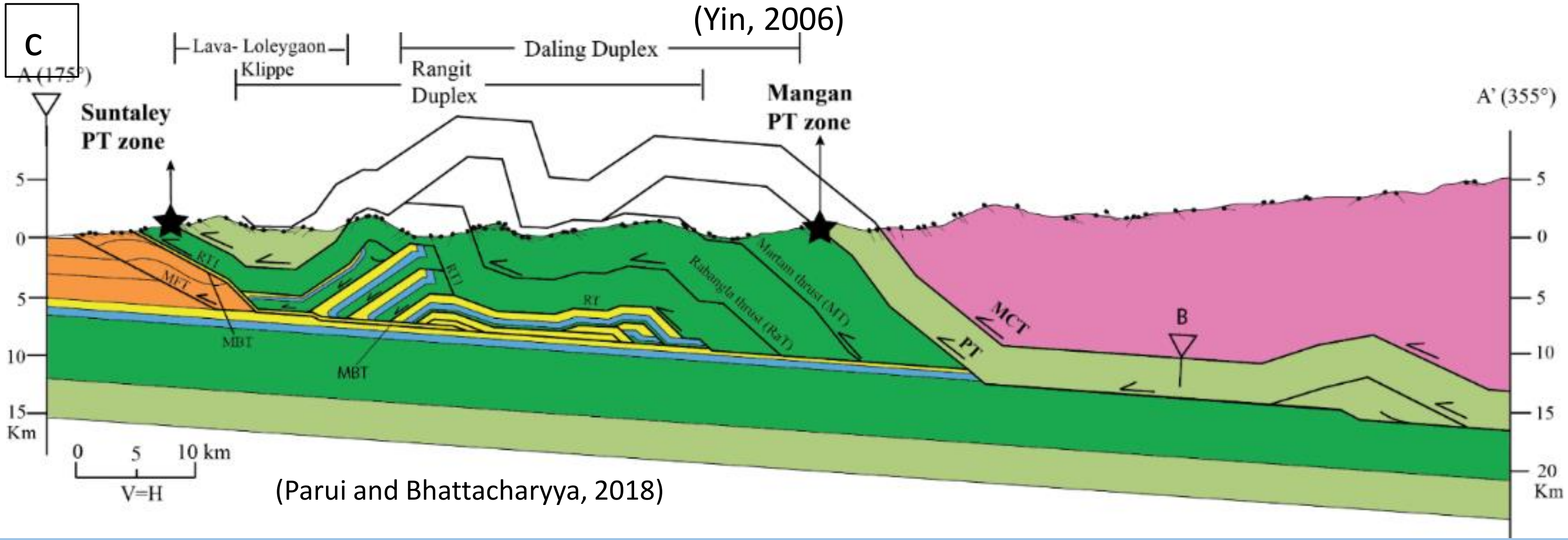


(Parui and Bhattacharyya, 2018)





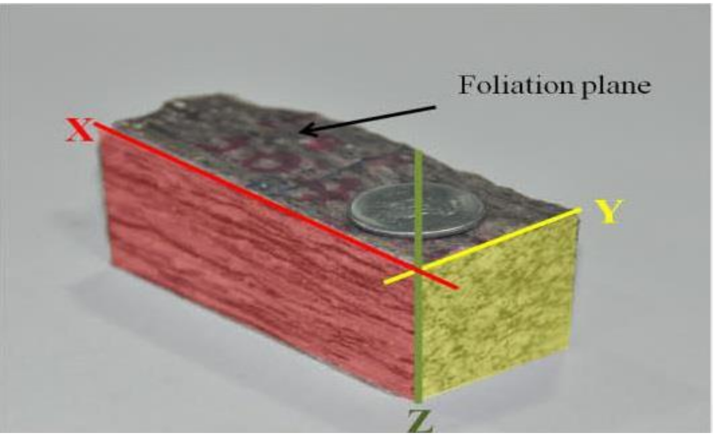
(Yin, 2006)

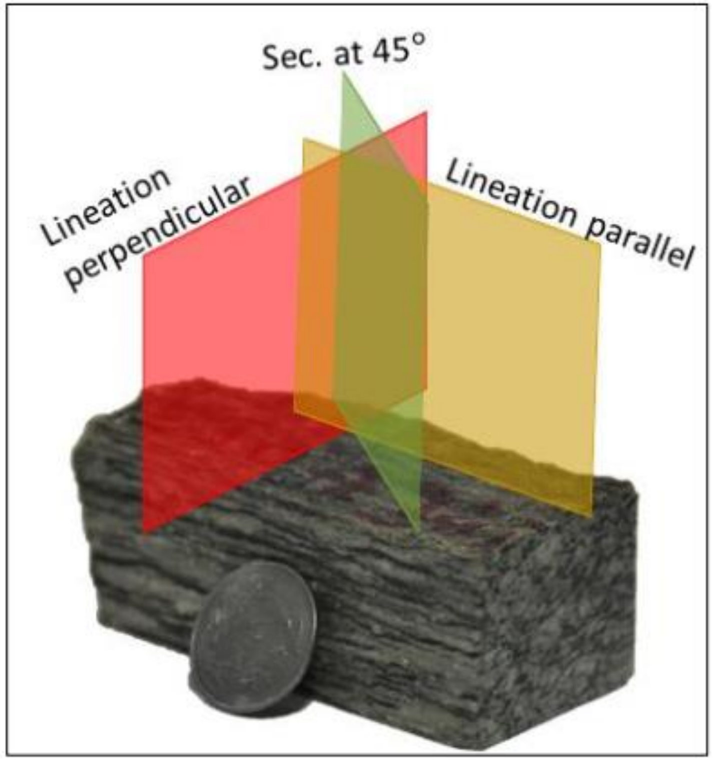


(Parui and Bhattacharyya, 2018)

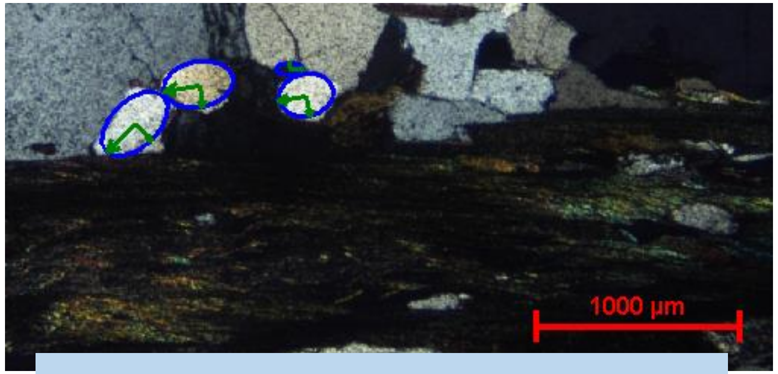
The Pelling-Munsiari Thrust (PT) is one major shear zone of the Darjeeling Sikkim Himalaya. For this study, I have targeted the PT shear zone due to its prolonged deformation history and well-studied in terms of structural geometry and kinematic evolution. It has undergone a minimum translation of nearly 100km. It is kinematically extremely important as it also acts as the roof thrust of the Lesser Himalayan duplex. *(a). Regional map of the Himalayan FTB (b)Regional map of Sikkim- Himalaya (c)* Transport-parallel, a regional balanced cross-section along A-A' of (b) *Sikkim Himalaya. Study area marked with black start.*

METHODS

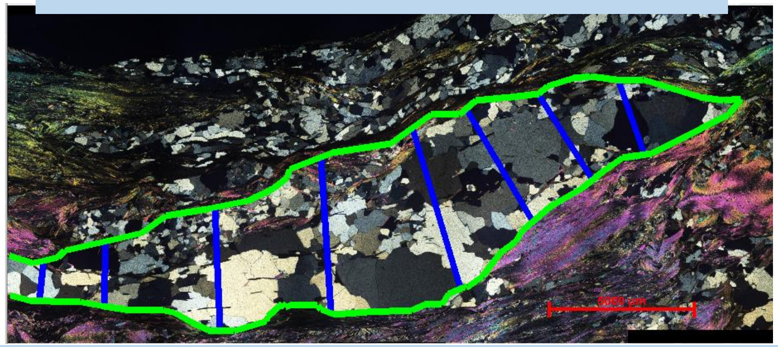




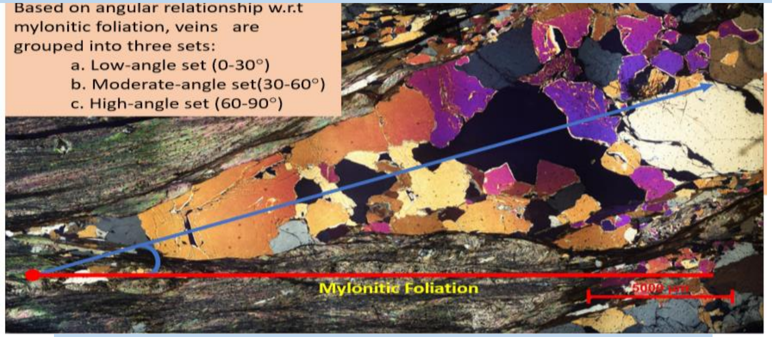
1. Thin Section Preparation



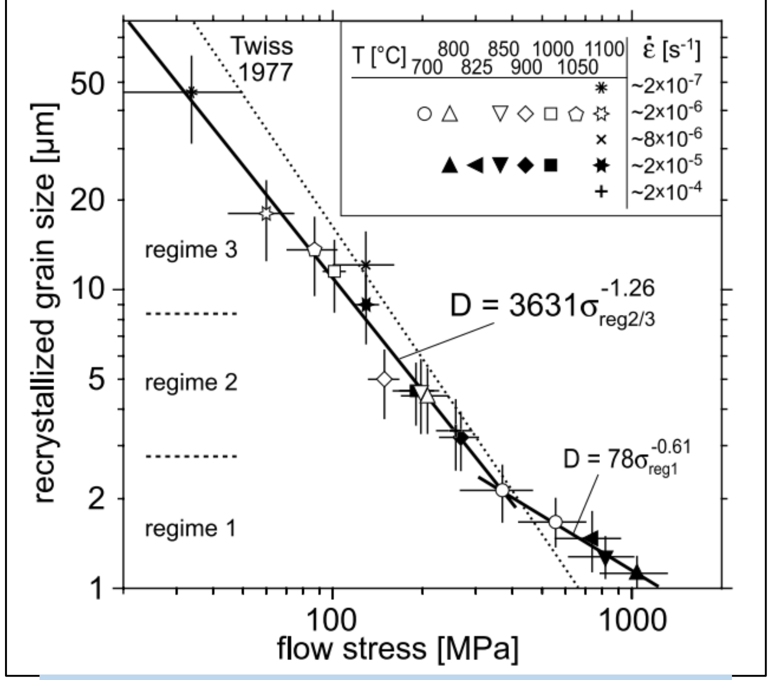
2. Estimation of grain size



3. Measurement of vein thickness



4. Angle measurement



5. Flow stress estimation

$$\dot{e} = A\sigma^n \exp(-Q/RT)$$

(Hirth et al., 2001)

- $\dot{e}$ = strain rate
- A= material constant
- σ = flow stress
- Q= creep activation energy
- n= stress exponent
- T= deformation temperature
- R= universal gas constant

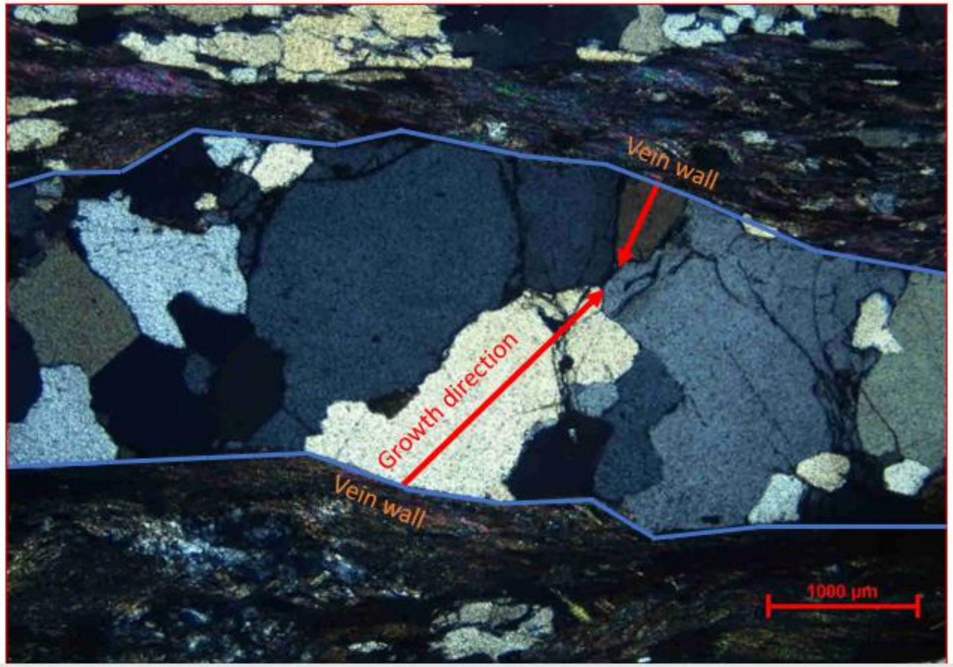
6. Strain rate estimation

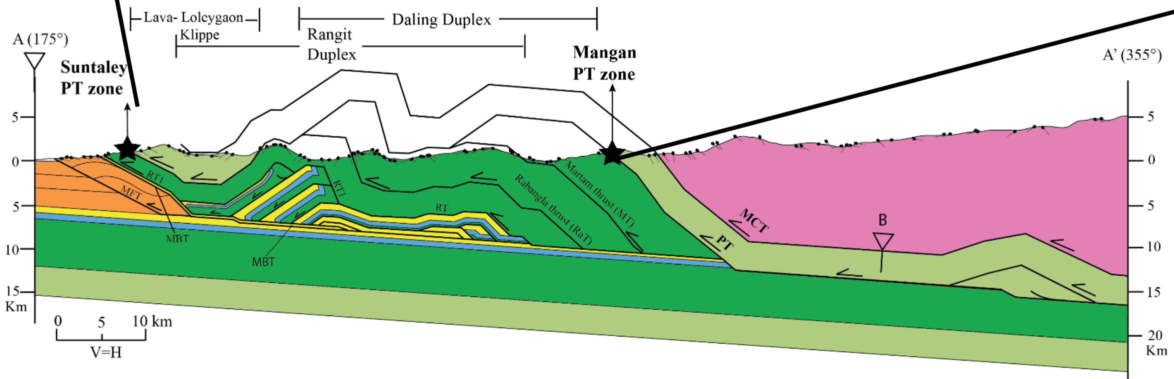
RESULTS AND DISCUSSIONS: MICROSTRUCTURAL ANALYSIS

Frontal (Suntaley Khola PT zone)

Transport direction

Internal (Mangan PT zone)

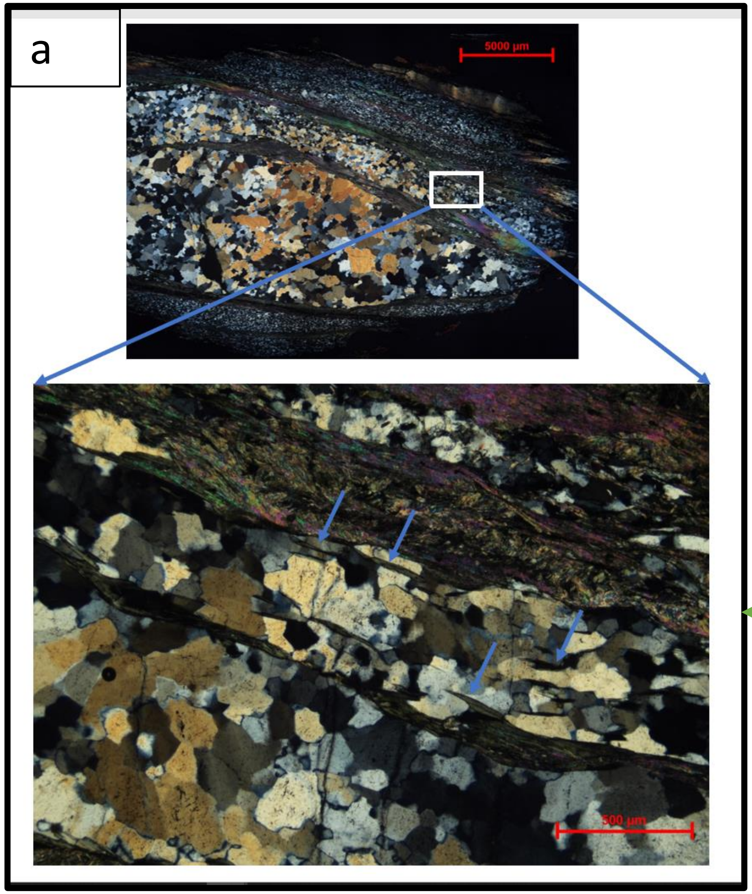




(Parui and Bhattacharyya, 2018)

Irrespective of vein orientation, both internal and frontal location of the PT shear zone show syntaxial texture.

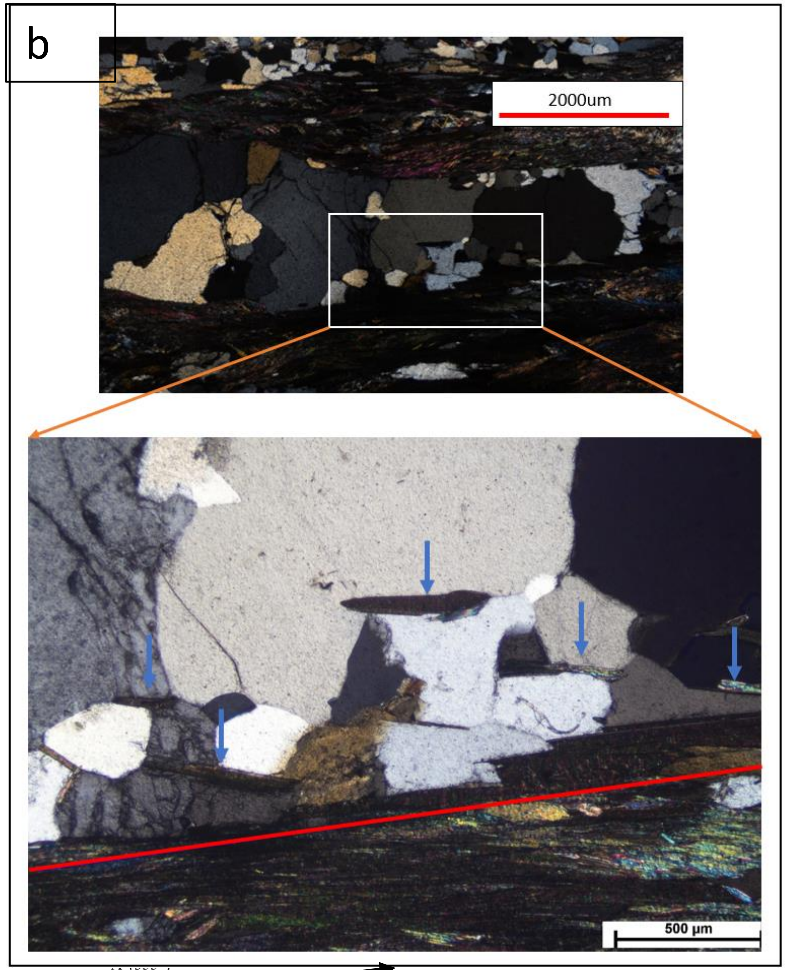
RESULTS AND DISCUSSIONS: MICROSTRUCTURAL ANALYSIS



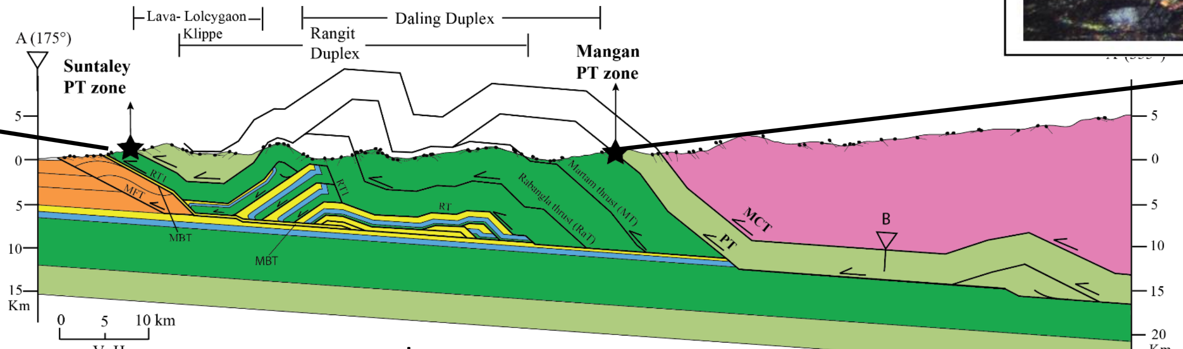
(b) Internal (Mangan PT zone):
- Irrespective of orientation of veins, I observed crack-and-seal evidence present in all the veins
- Crack-seal indicates vein formation by multiple events of opening and filling of vein minerals

(a) Frontal (Suntaley Khola PT zone):
- Few crack-and-seal evidence present only in the low-angle veins.

Transport direction

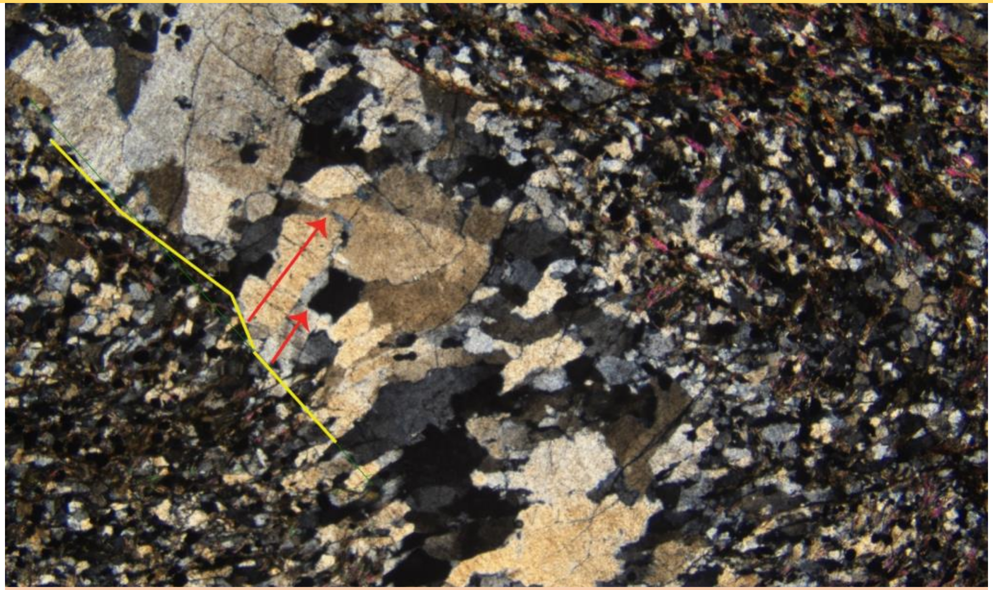


(Bons et al., 2012)



(Parui and Bhattacharyya, 2018)

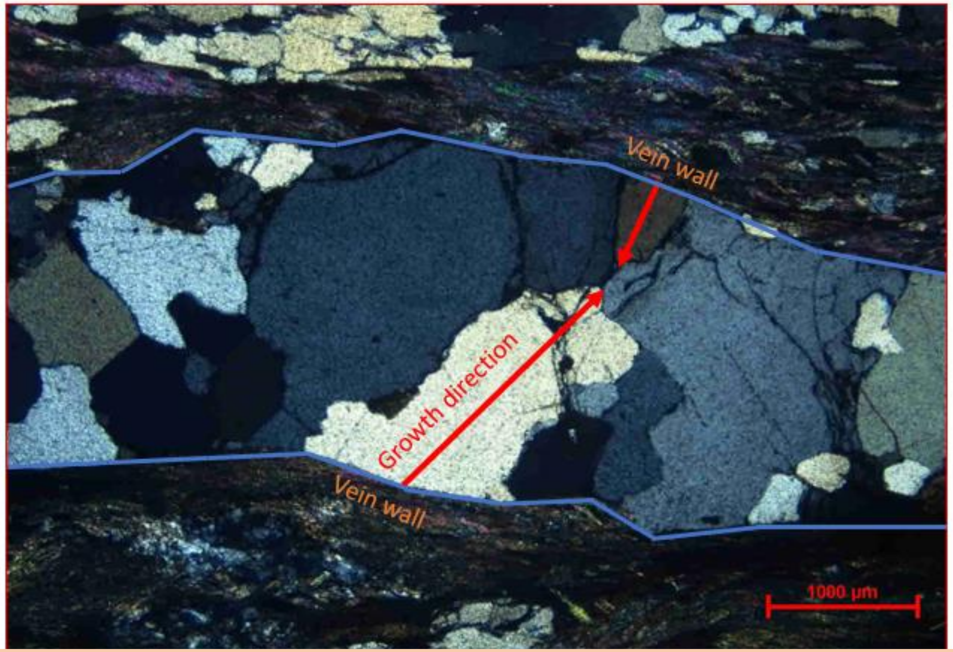
RESULTS AND DISCUSSIONS: MICROSTRUCTURAL ANALYSIS



Frontal (Suntaley Khola PT zone):

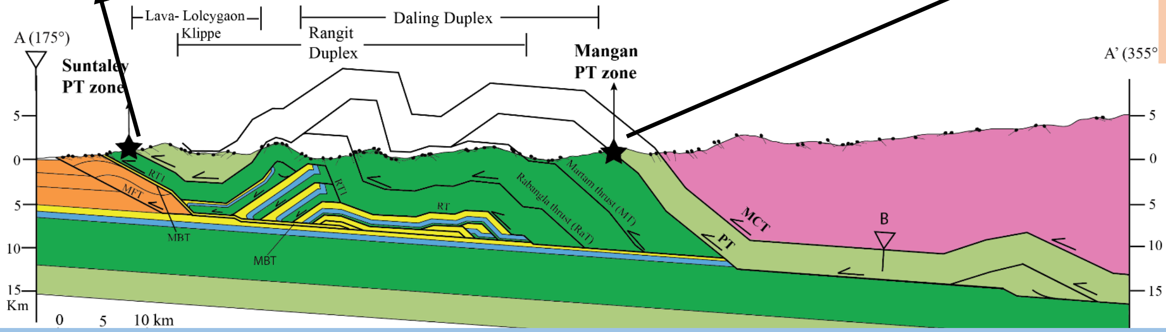
- Observed mostly elongate blocky texture irrespective of vein orientation
  - Indicate vein **opening by small increment**

Transport direction



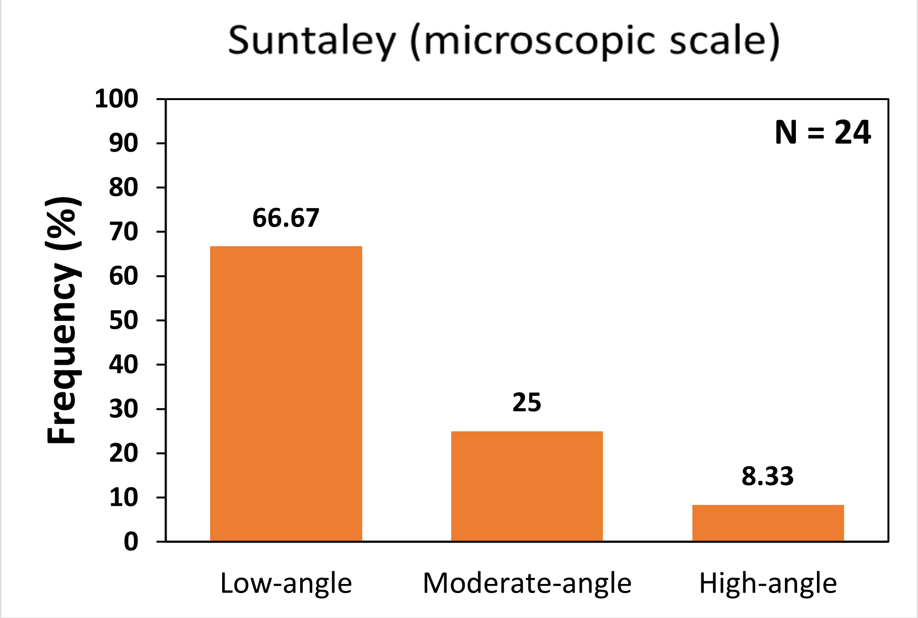
Internal (Mangan PT zone):

- Observed mostly blocky texture irrespective of vein orientation
  - Indicates vein growth **into an open cavity**, or **fast vein opening**.

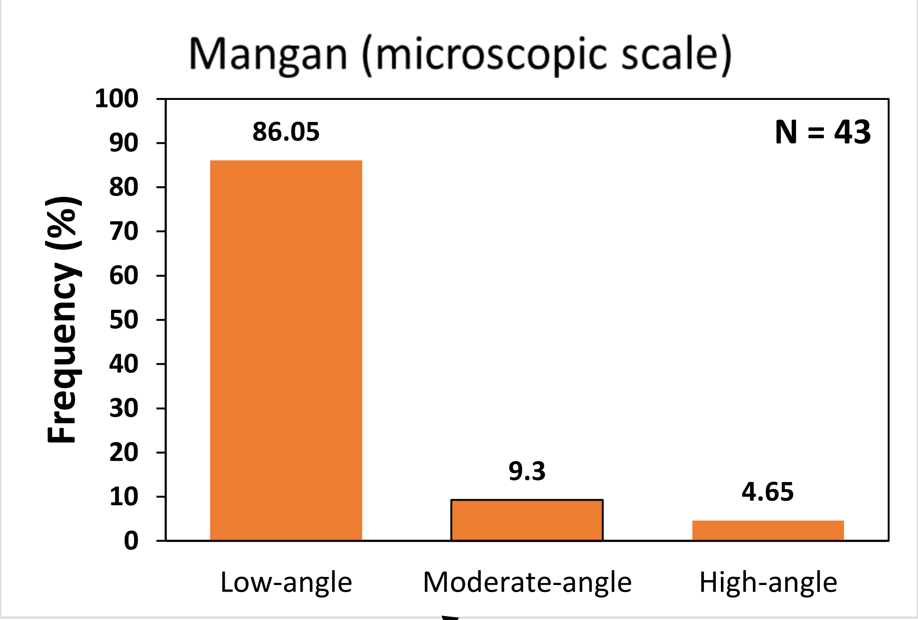


There is a variation in the microstructural textures indicating variation in deformation conditions along the transport direction.

RESULTS AND DISCUSSIONS: VEIN ATTRIBUTES



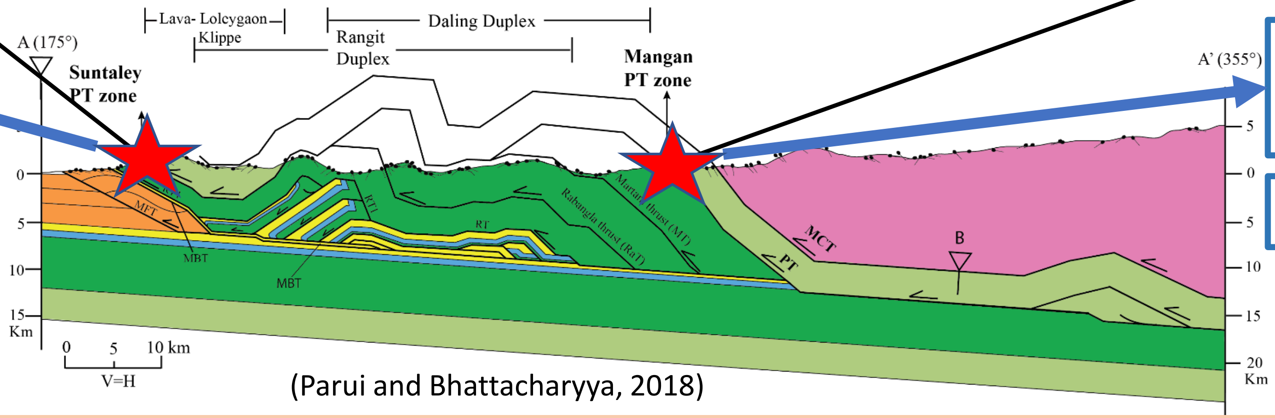
Transport direction



Shallow crustal conditions (~10 -12km)

Overburden: 29.6km → 13.34km

(Ghosh et al., 2020)



(Parui and Bhattacharyya, 2018)

Deeper crustal conditions (>12km)

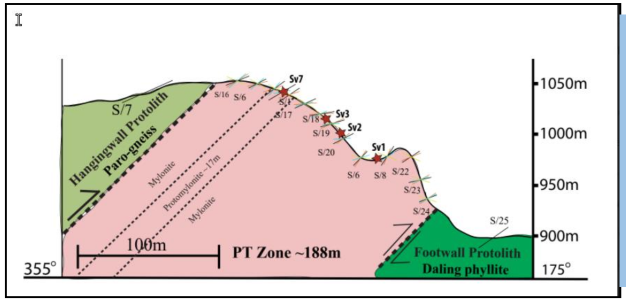
Overburden: 34km → 23km

(Ghosh et al., 2020)

Similar vein frequency distribution patterns observed at both internal and frontal part of the shear zone. However, we found an intriguing observation. We observed less number of veins in the frontal part than the internal part. But if veins are supposed to track fractures, we should expect more number of veins in the frontal than the internal location. Because frontal part representing shallower crustal condition while internal part representing deeper crustal condition. And also change in overburden is higher in the frontal part.

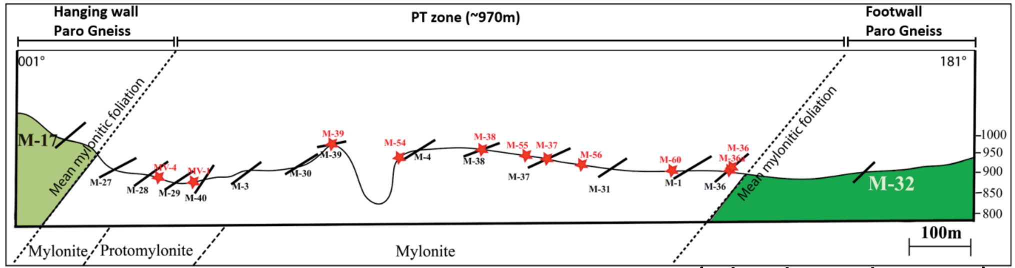
RESULTS AND DISCUSSIONS: VEIN ATTRIBUTES

Why lesser number of veins in the frontal part?

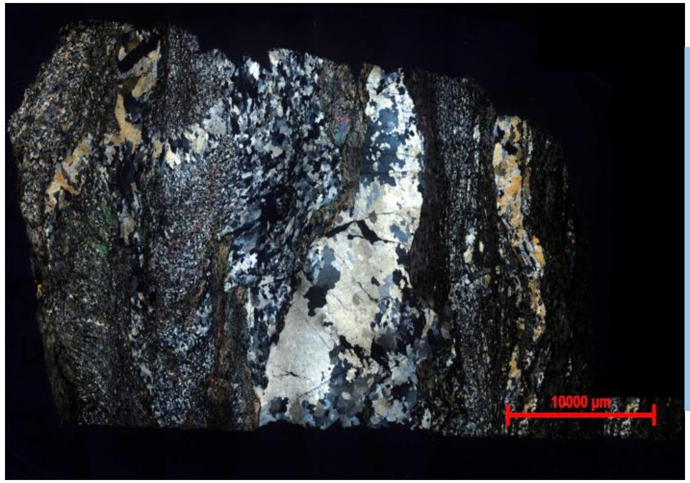


(Ghosh et al., 2020)

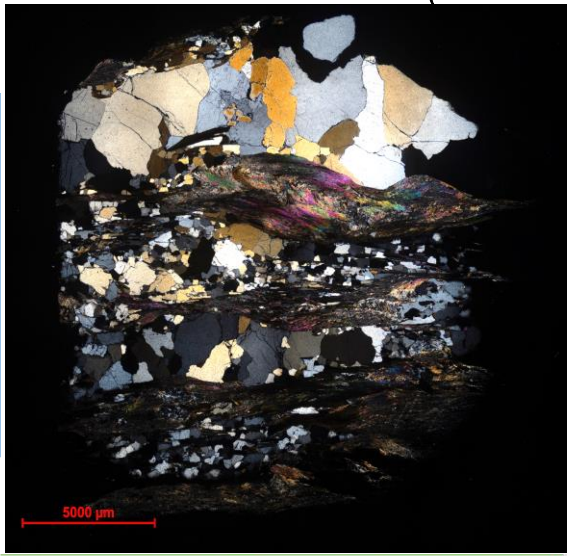
PT shear zone is thinner (~188m) in frontal part than internal (~970m) part which is the reflection of deformation mechanism (a & b).



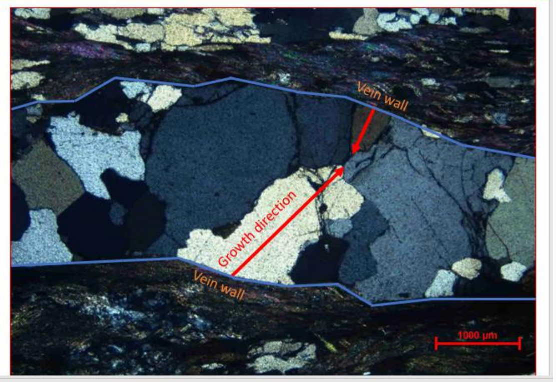
(Ghosh et al., 2020)



The dominant deformation mechanism in the frontal part pressure solution creep reflected as more number of pressure solution. On contrary, dislocation creep is dominant in the hinterland reflected as more number of recrystallized grain.

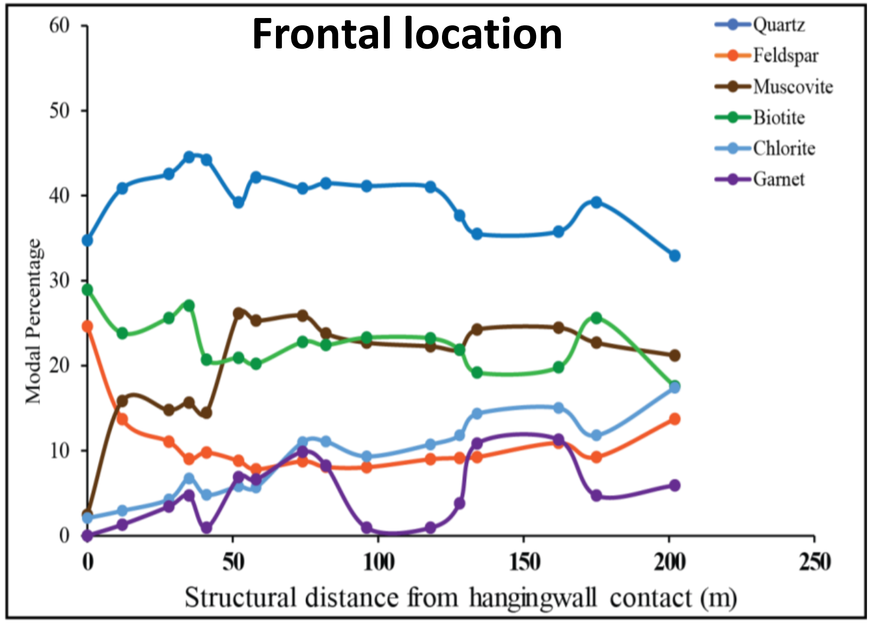


Additionally, in the frontal part, finer recrystallized grain size (~69um) of the host mylonite indicating susceptibility to pressure solution creep than coarser grain size (~89um) in the internal part.



RESULTS AND DISCUSSIONS: VEIN ATTRIBUTES

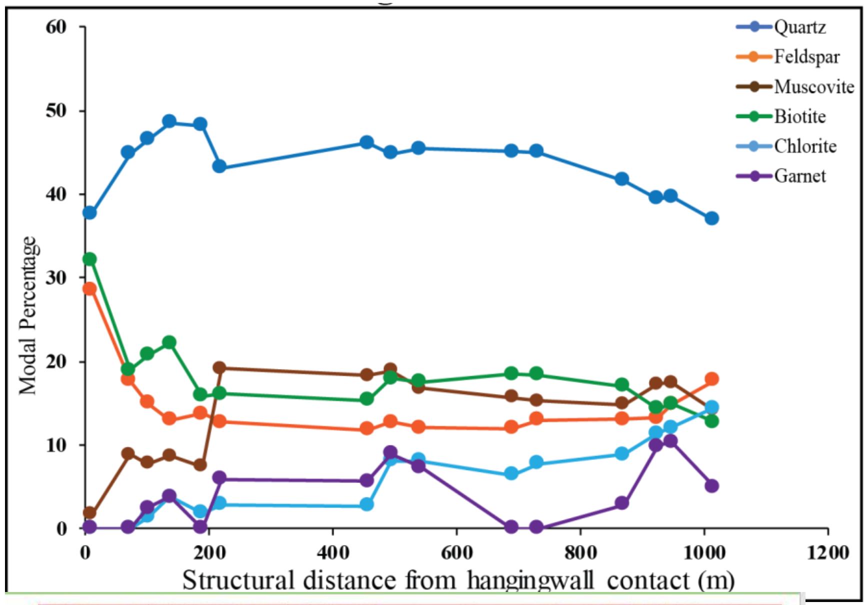
Why lesser number of veins in the frontal part?



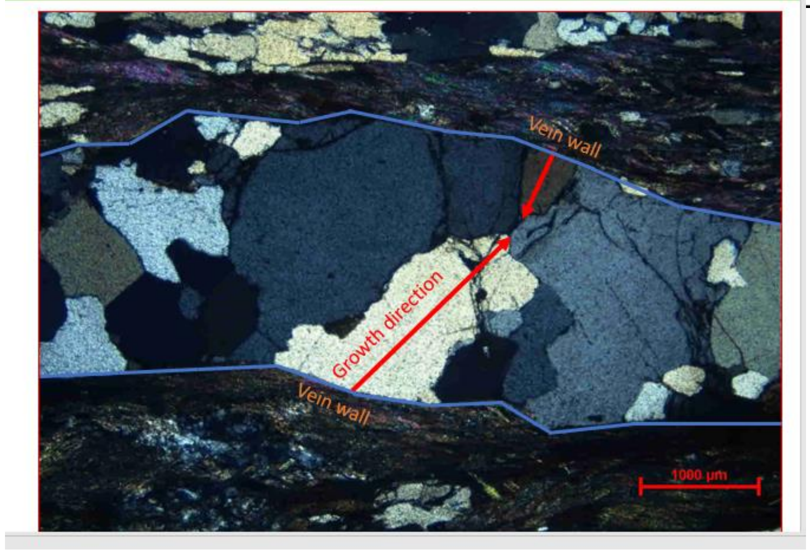
The subsequent increase in the modal percentage of the mica in the frontal part due to reaction softening makes the matrix rheologically weaker which blunts fractures and subsequent veins in the frontal part.

(Ghosh et al., 2020)

Internal location

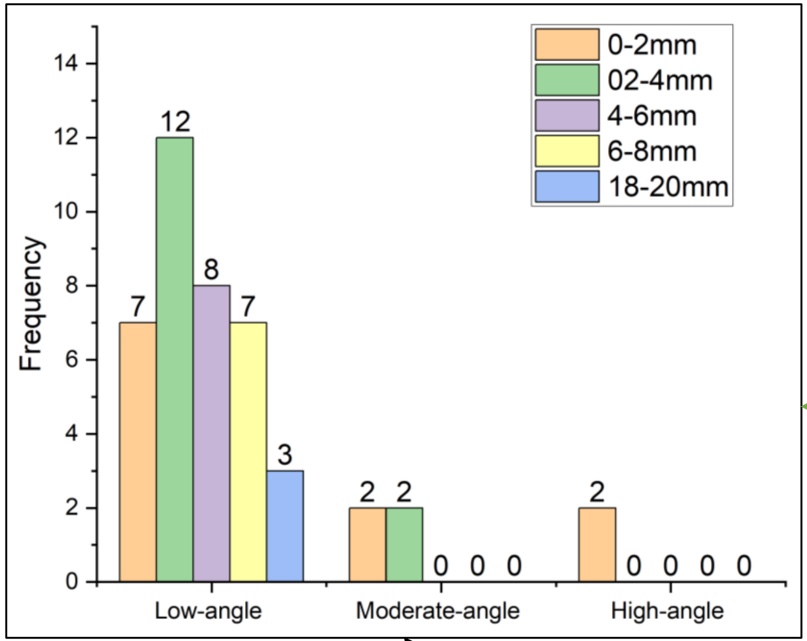


In the frontal part, we observed dominant blocky texture which indicates presence of pre-existing fractures.



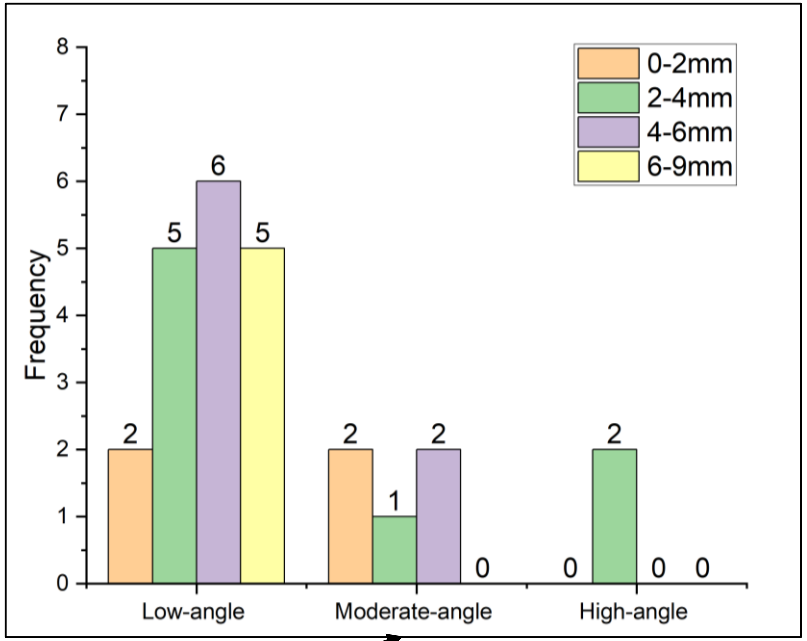
RESULTS AND DISCUSSIONS: VEIN ATTRIBUTES

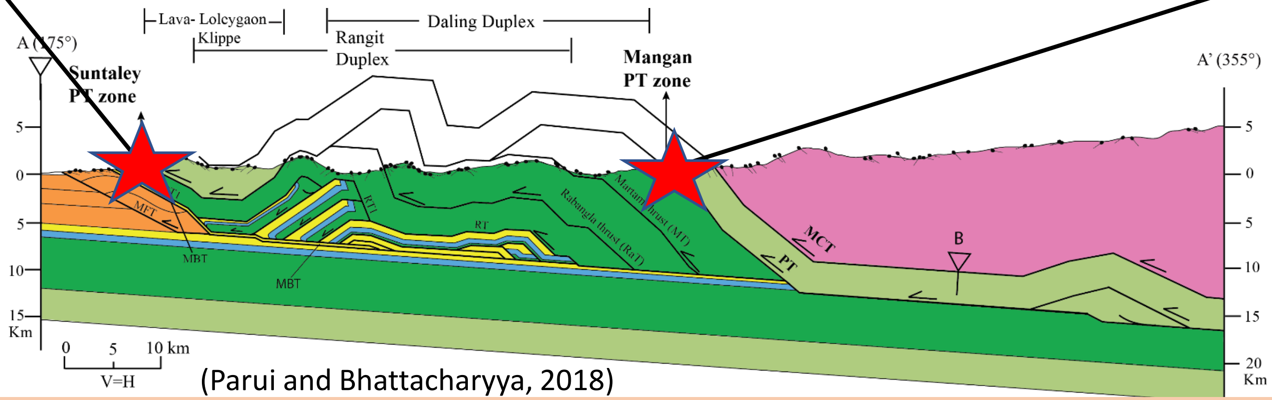
Frontal(Suntaley Khola PT zone)



Transport direction

Internal(Mangan PT zone)



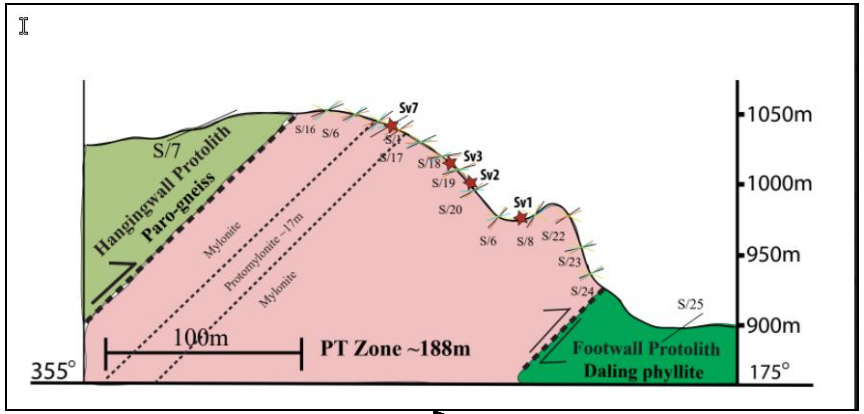


(Parui and Bhattacharyya, 2018)

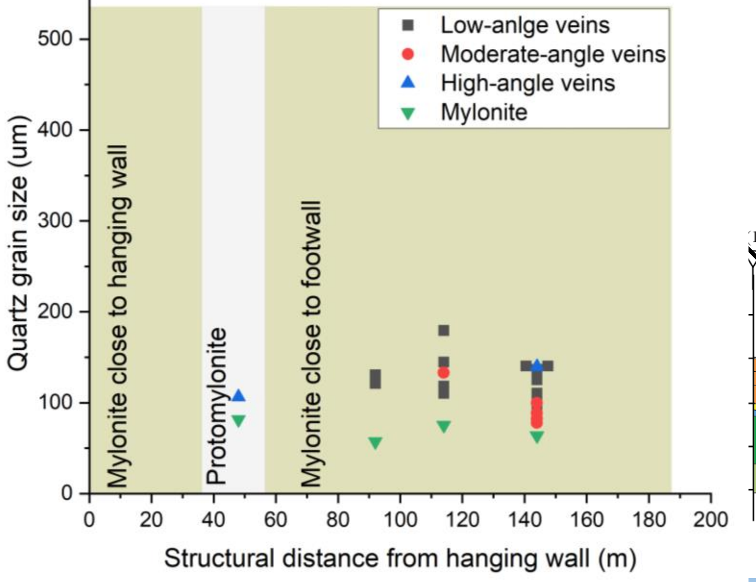
Low-angle veins are the thickest and also exhibit highest variation in thickness in both locations.

5. RESULTS AND DISCUSSIONS: GRAIN SIZE

Frontal(Suntaley Khola PT zone)

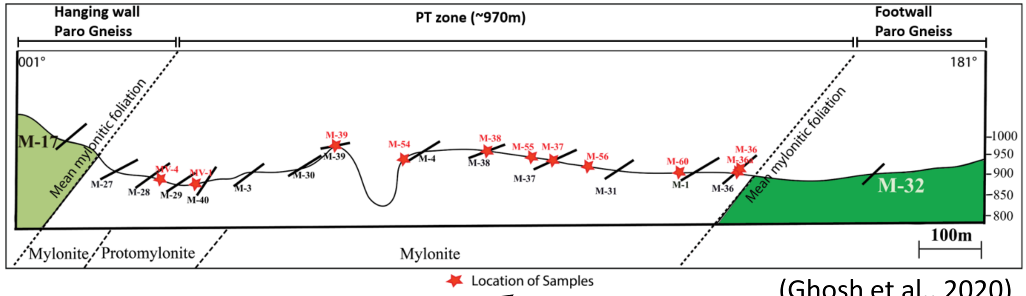


(Ghosh et al., 2020)

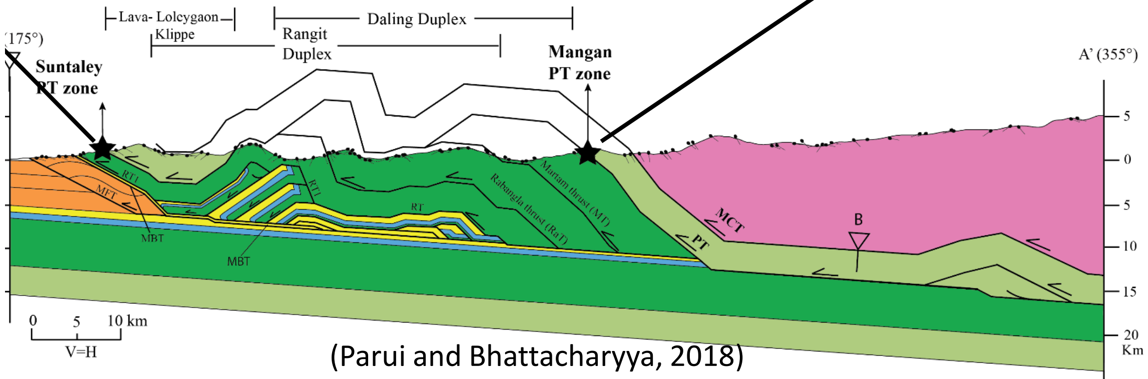


Transport direction

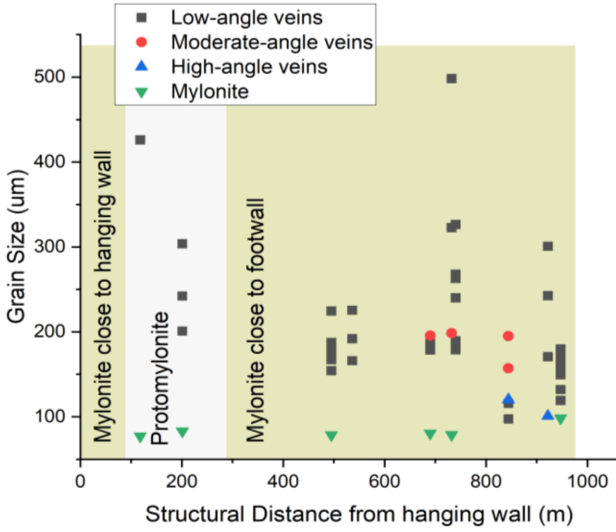
Internal(Mangan PT zone)



(Ghosh et al., 2020)



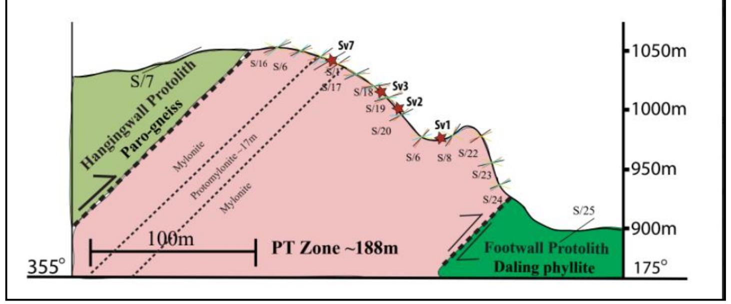
(Parui and Bhattacharyya, 2018)



In general, recrystallized grain sizes of both veins and the host mylonites decreased along the transport direction.

5. RESULTS AND DISCUSSIONS: FLOW STRESS

Frontal(Mangan PT zone)



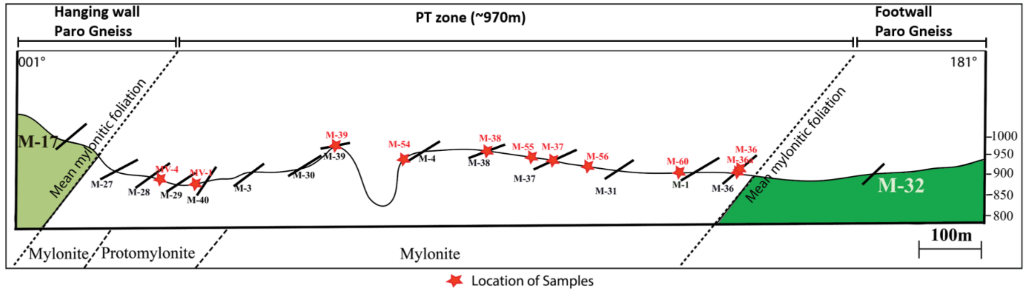
Stipp et al., 2003

$$\sigma = \left(\frac{3631}{D}\right)^{(1/1.26)}$$

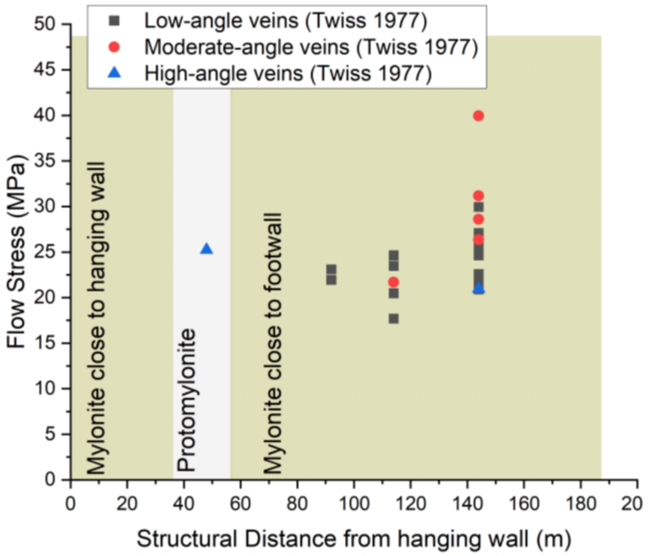
Twiss, 1977

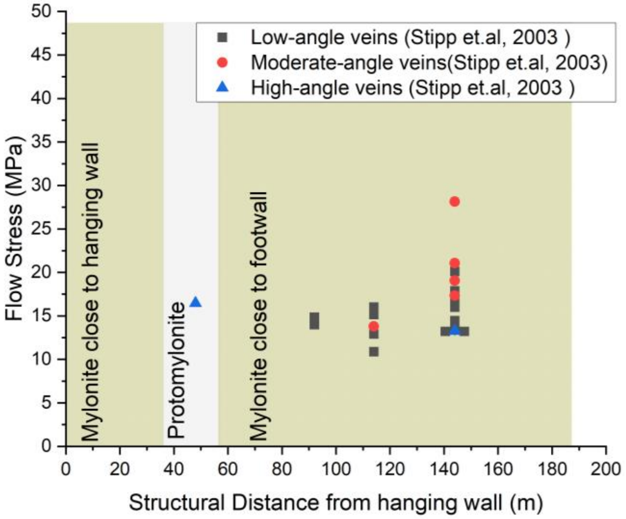
$$\sigma = 5.5D^{0.68}$$

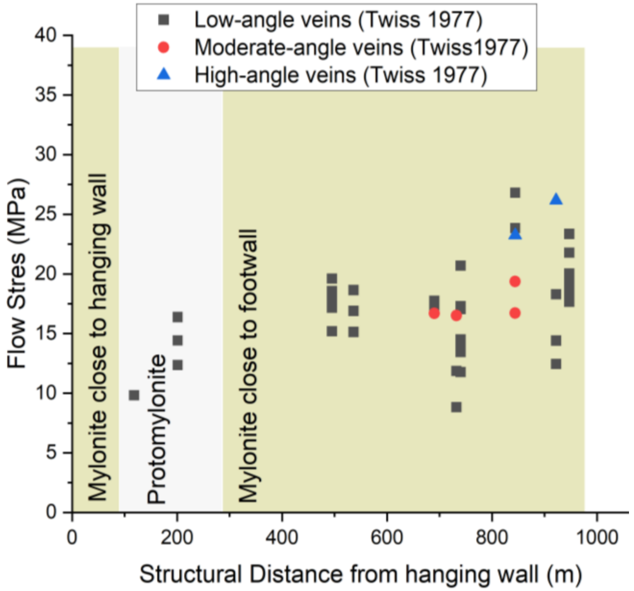
Internal(Mangan PT zone)

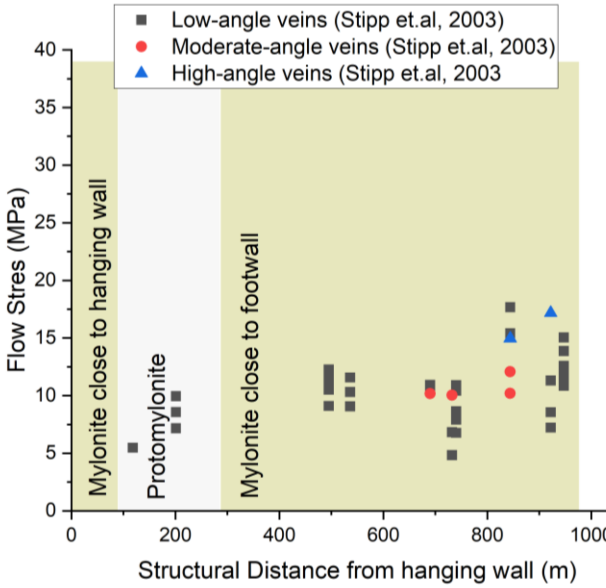


(Ghosh et al., 2020)







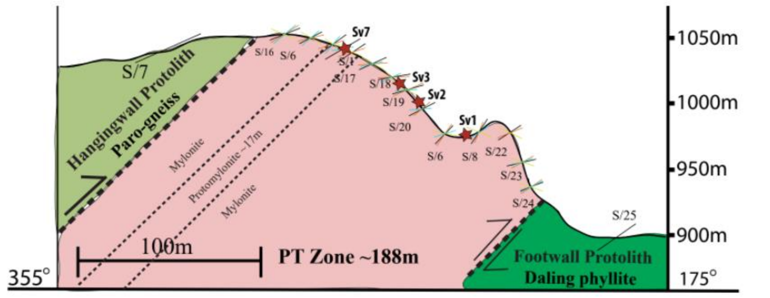


Flow stress variation in the veins of different orientations at a single location indicates that veins are tracking different stages of progressive deformation.

In general, Flow stress increases in veins along the transport direction.

5. RESULTS AND DISCUSSIONS: STRAIN RATE

Frontal(Suntaley Khola PT zone)



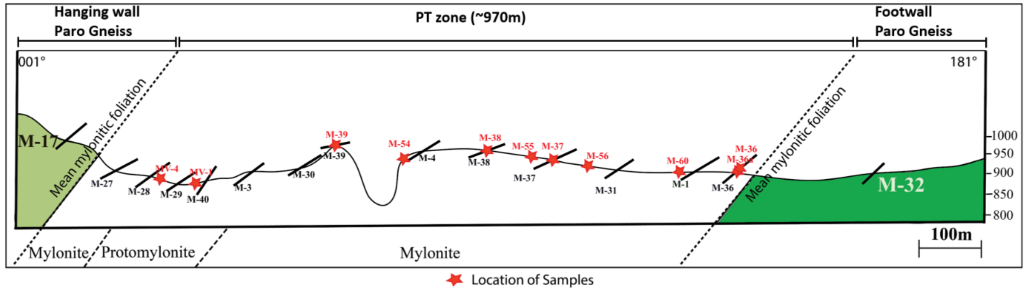
(Ghosh et al., 2020)

$$\dot{\varepsilon} = A f_{H_2O}^{m} \sigma^{n} \exp(-Q/RT)$$

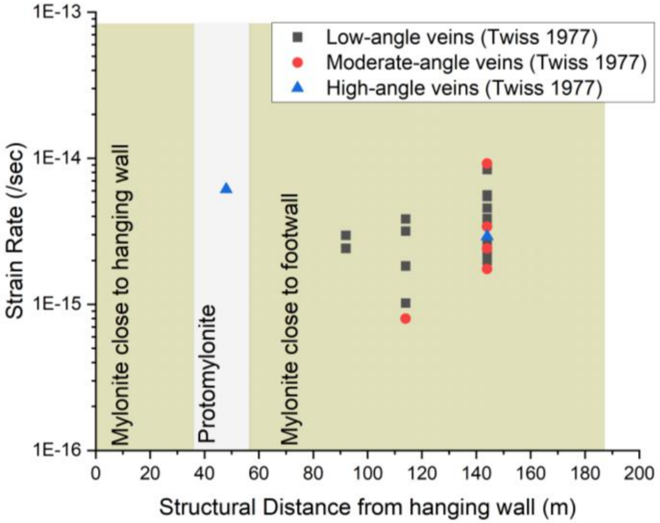
(Hirth et al., 2001)

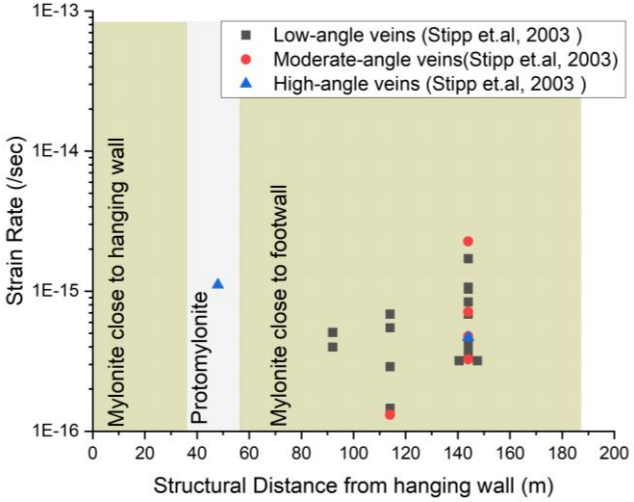
Transport direction

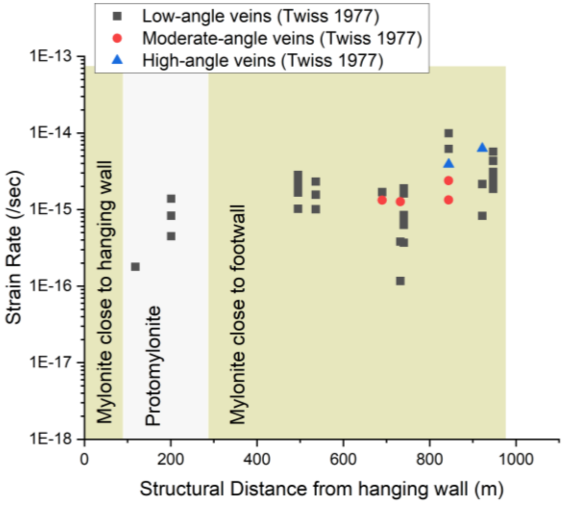
Internal(Mangan PT zone)

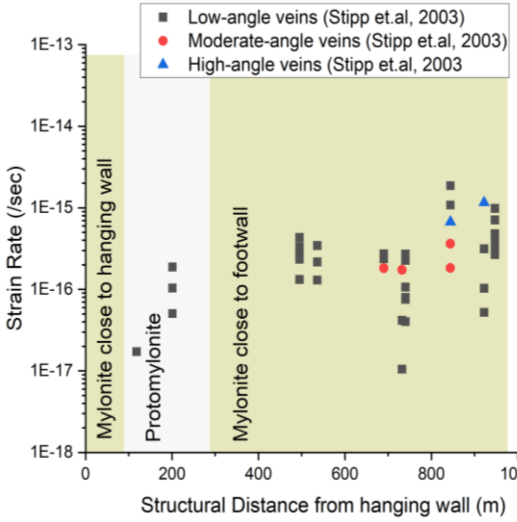


(Ghosh et al., 2020)





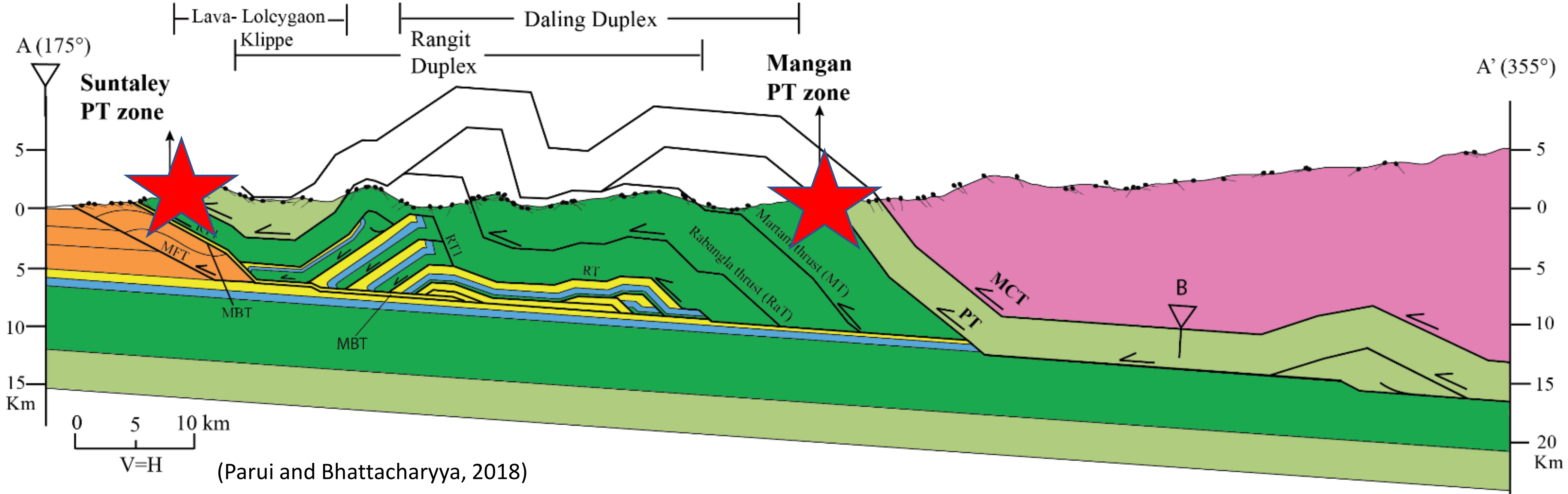




In general, strain rate increases in veins along the transport direction.

5. RESULTS AND DISCUSSIONS: STRAIN RATE

- Frontal part recorded all the slip transfer associated with the growth of the footwall duplex.
- Frontal part record less Crack-and-seal texture than the internal part.



(Parui and Bhattacharyya, 2018)

6. CONCLUSIONS

1. Veins are dominantly syntaxial in both internal and frontal locations of the PT zone.
2. In the hinterland, irrespective of the vein orientations, crack-and-seal textures are present indicating multiple events of opening and filling of veins. In contrast, in the frontal location, fewer crack-and-seal textures are restricted to the low-angle veins.
3. Irrespective of the orientation of the veins, blocky textures are predominant in the hinterland indicating vein growth into an open cavity or fast vein opening. In contrast, elongated blocky texture indicating vein opening by small increments are dominant in the frontal location.
4. In both the locations, highest population of veins are observed in low-angle veins followed by moderate-angle and high-angle. Microscopic and outcrop scale observations are in agreement.
5. Low-angle veins are the thickest and also exhibit highest variation in thickness and frequency in both locations.
6. Flow stress increases along the transport direction as recorded in the veins.
7. Strain rate increases from the hinterland to foreland along the PT zone as recorded in the veins due to the preservation of entire slip transfer from the immediate footwall imbricates in the frontal location as compared to the partial record preserved in the internal location of the PT zone.

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