The kinematic vorticity analysis of ductile shear zones of Ambaji Granulite, NW India and its tectonic implications

By

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Outline of the presentation

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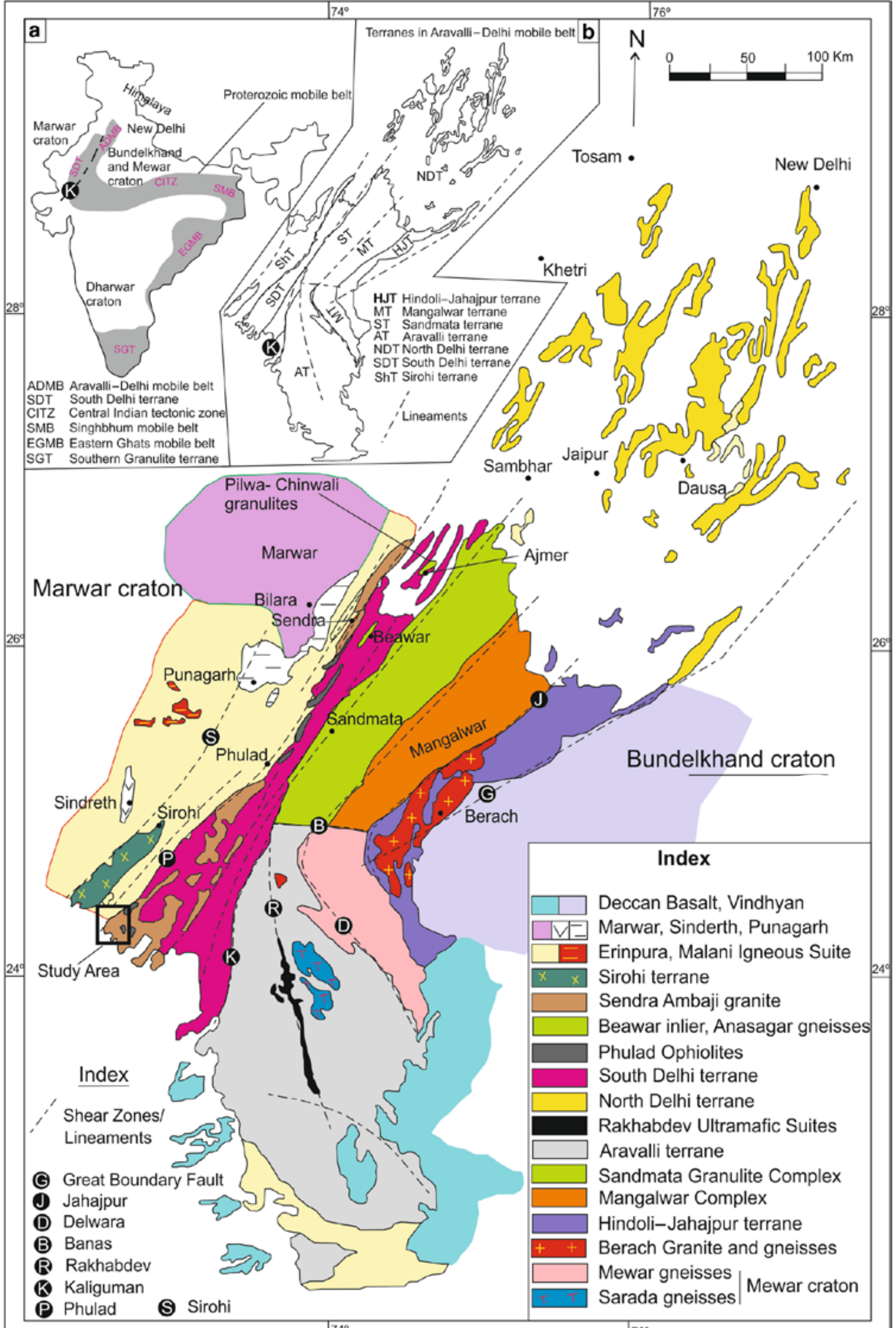
  - Microstructure and shear kinematics
  - Dynamic recrystallization mechanism of quartz
  - Vorticity analysis of shear zones
- ❖ **Tectonic evolution**
- ❖ **Conclusion**

Introduction and geology of study area



- The NE-SW trending Aravalli-Delhi Mobile Belt (ADMB) is located in the northwestern part of the Indian Peninsula
- The Neoproterozoic Ambaji Granulite (study area) is a tectonically exhumed block in the South Delhi terrane (SDT), ADMB in NW India.

Fig. Geology of Aravalli Delhi Mobile Belt (Tiwari and Biswal, 2019, JESS)

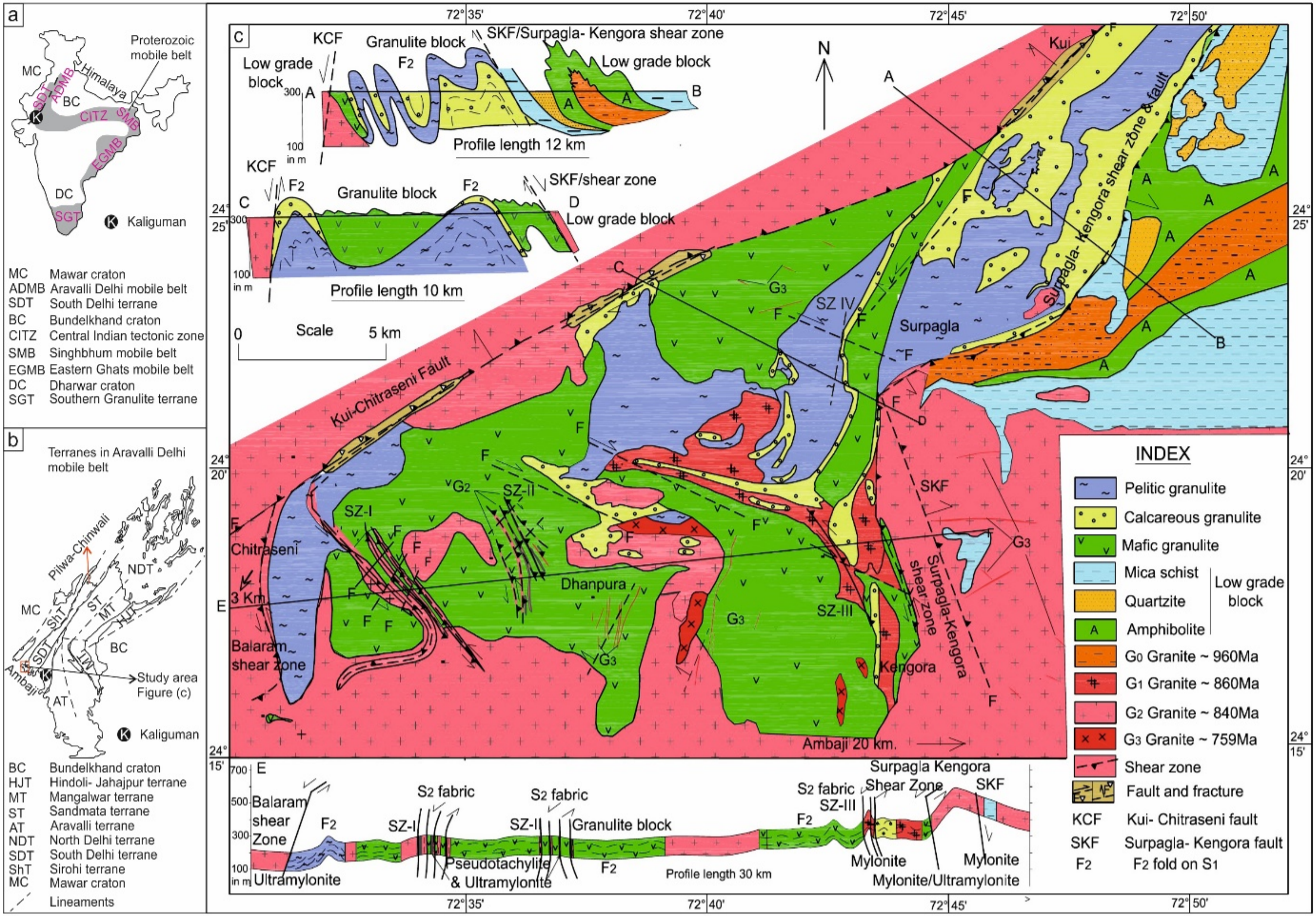


Fig. Geology of study area (Tiwari et al., 2020, JSG)

Table: Deformation phases with tectonic event and geochronological data in the Ambaji granulite. SHRIMP age (Singh et al., 2010, Prec. Res.), Monazite age (Tiwari and Biswal, 2019, Tectonics)

Deformation phases	Tectonic event	Geochronology
D1	F_1 folding, granulite facies metamorphism, G_1 granite	G_1, ca. 860 Ma (SHRIMP) Metamorphism, Ca. 875-857 Ma (Monazite)
D2	F_2 folding, G_2 granite, Ductile shearing.	G_2, ca. 840 Ma(SHRIMP) Ductile shearing Ca. 834 Ma- 778 Ma (Monazite)
D3	F_3 folding	---------
D4	Late stage brittle faults and fracture, G_3 granite occurs as dyke/vein along these faults and fracture	G_3, Ca. 759 Ma(SHRIMP) Fault and fracture, >=< Ca. 759 Ma. (SHRIMP) Ca. 764 Ma - 650 Ma (Monazite)

- Structural and Sample location map for vorticity analysis from Ambaji Granulite shear zones, NW India.
- Structural data are plotted in stereonets.

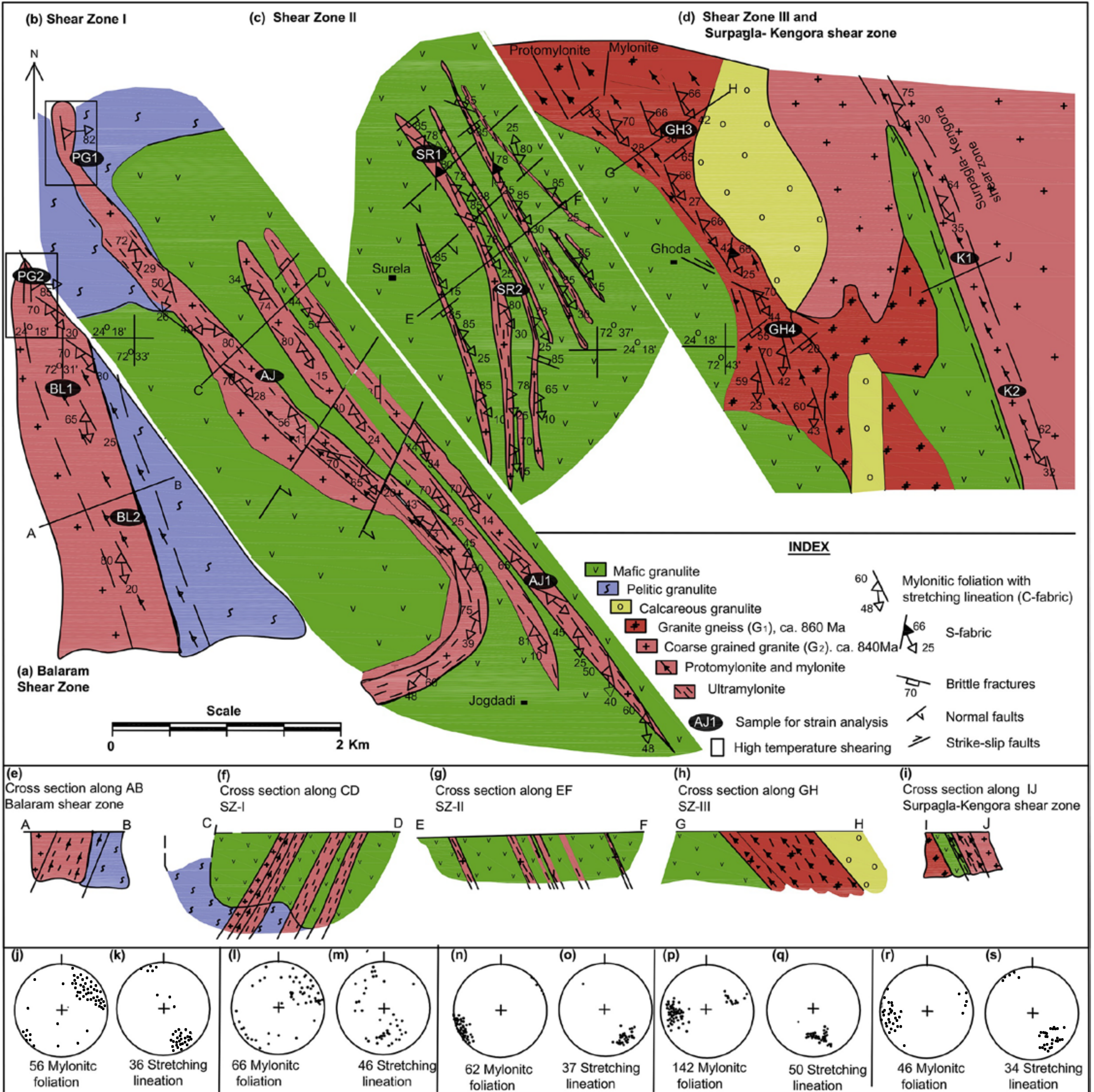


Fig. Detailed structural map of shear zones (Tiwari et al., 2020, JSG)

Objectives

- Our main question is how the lower crustal rocks like granulites which form at 25 km at depth, are now exhumed to the earth surface.
- Shear zones act as a path to exhume the lower crustal rocks to the earths surface.
- In this presentation, the ductile exhumation part of lower crustal rocks through shear zones has been discussed.
- Here we have quantified the variation in flow of vorticity in ductile shear zone and also reconstructed the tectonic evolution of Ambaji granulite.

Methodology

Material and methodology

- ❖ The samples were collected at a regular interval along 6 profiles, during a total of 15 weeks of fieldwork spread out over a 4 year period. The 12 most representative samples are described.
- ❖ The collected samples were cut into thin sections L (XZ) section and T (YZ) section. The XZ sections are used for vorticity analysis and microstructural studies.
- ❖ We have used clast-based RGN-Wm and the dynamically recrystallized quartz based microscopic foliation Rs/θ-Wm method.

Vorticity: Wm, is an approximate measure of the relative proportion between the simple shear and pure shear component of a rock.

<u>We used two methods:</u>

1) (Rigid grain rotation net) RGN (Jessup et al., 2007, JSG**),**

2) (Strain ratio) Rs/θ method (Fossen and Tikoff, 1993, JSG**)**

Criteria for Vorticity analysis

- ❖ For RGN method, presence of abundant rigid pre-deformational porphyroclasts.
- ❖ No mechanical interaction between porphyroclasts
- ❖ Significant quantity of porphyroclasts with a wide range of aspect ratio, i.e. the ratio of long to short axis.
- ❖ For Rs/θ method, we measured the dynamically recrystallized quartz grains on the same thin sections as for the RGN analysis. In most cases, the grains are stretched and elliptical showing no signs of shape change after deformation.

Shear Zones: Microstructure and shear kinematics

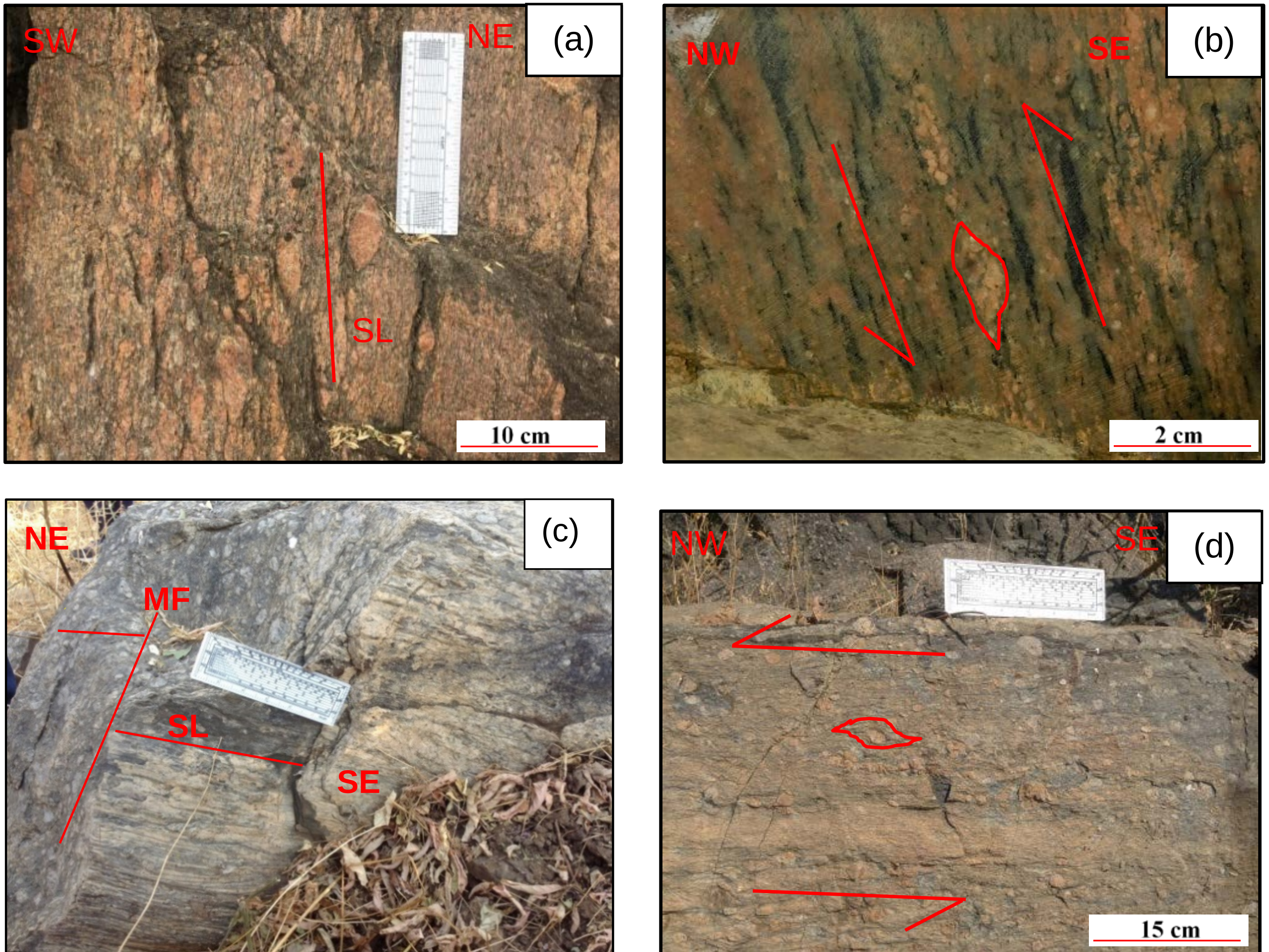


Fig. Field photographs of high (fig. a,b) and low (fig. c,d) temperature mylonites

Shear Zones: Microstructure and shear kinematics

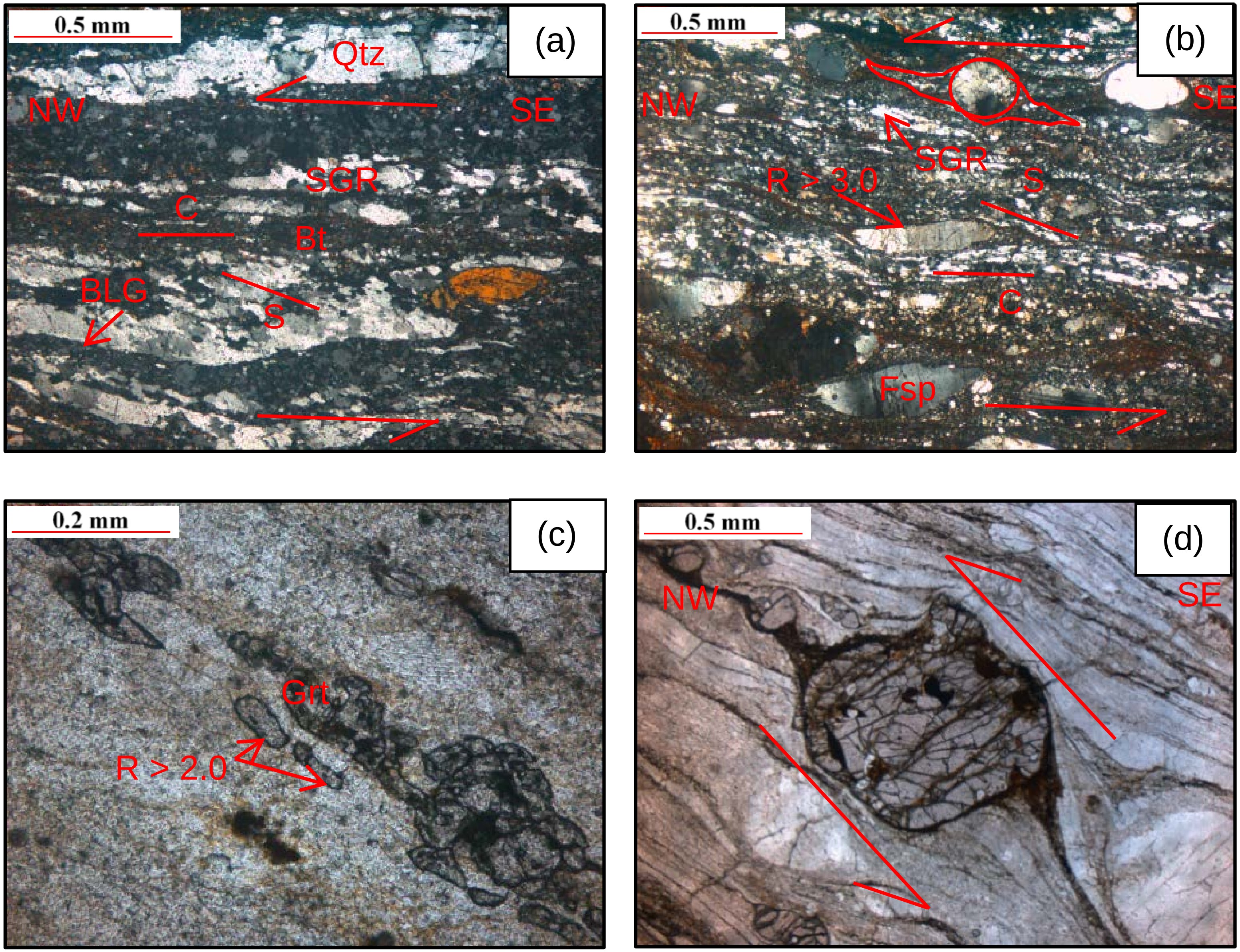


Fig. Thin section photographs low (fig a,b) and high (Fig c,d) temperature mylonites

Dynamic recrystallization mechanism of quartz

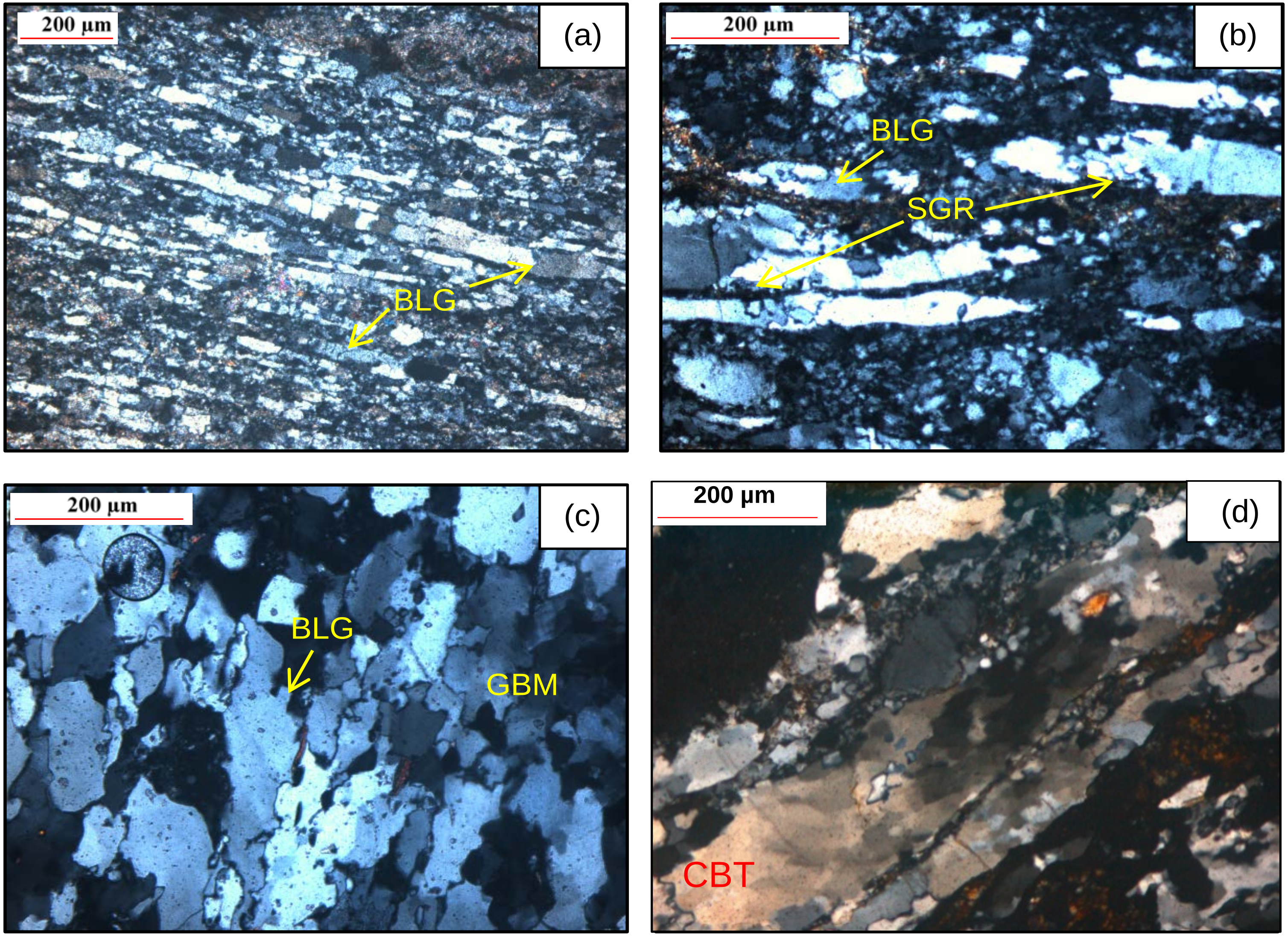
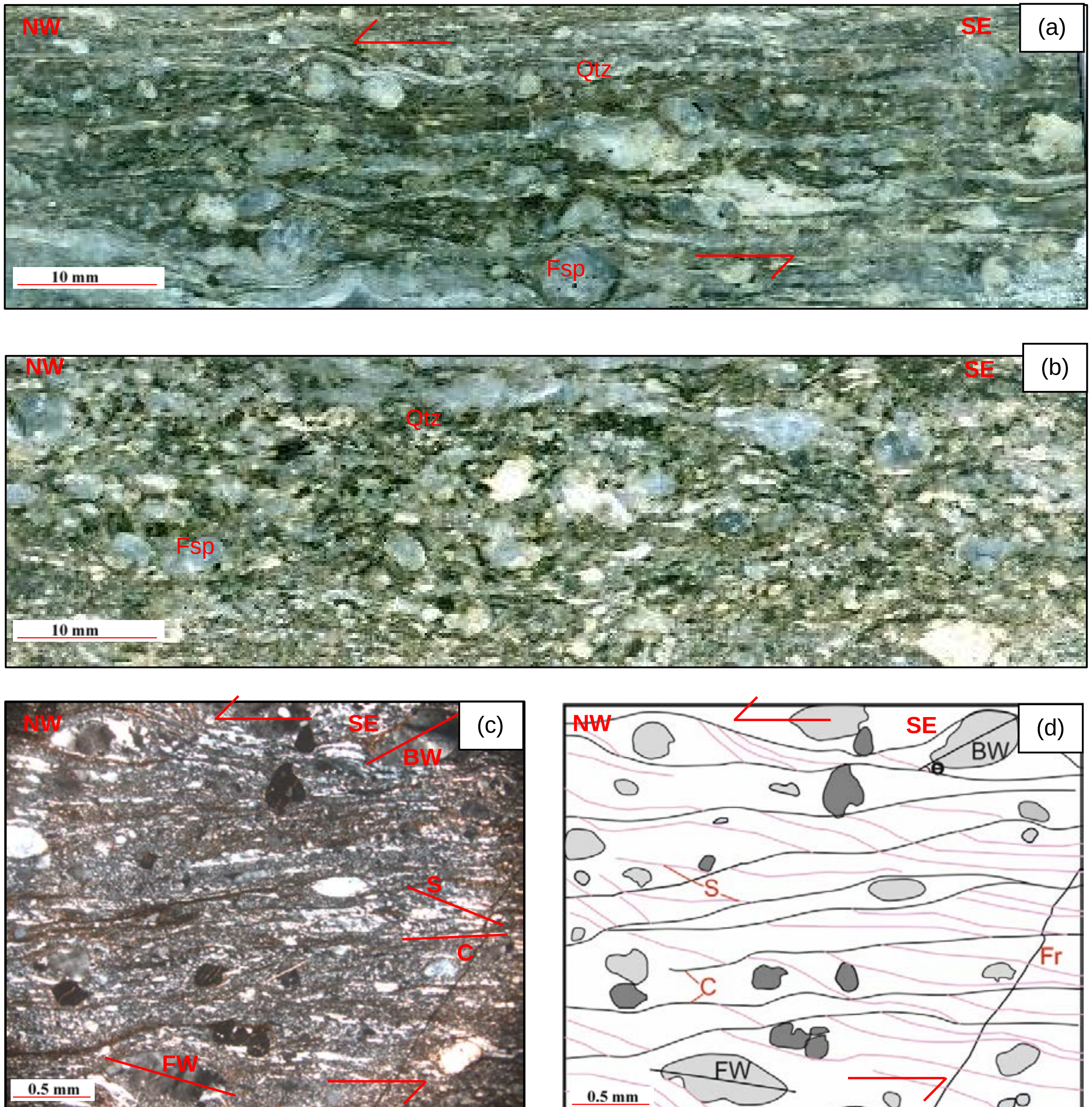


Fig. Optical photographs of mylonite under cross polarized light on XZ sections

Shear Zones: Vorticity analysis of shear zones



- We have used XZ section (Fig b, c, d) of mylonites for RGN(Wm) and Rs/θ (Wm) analysis.

Fig. Hand specimen photographs of mylonite (a, b). **(a)** XZ section **(b)** YZ section **(c)** Photomicrograph of XZ **(d)** Schematic diagram for Fig. c.

RGN (Wm) plot from different shear zones of Ambaji

RGN plot for porphyroclasts from all shear zones

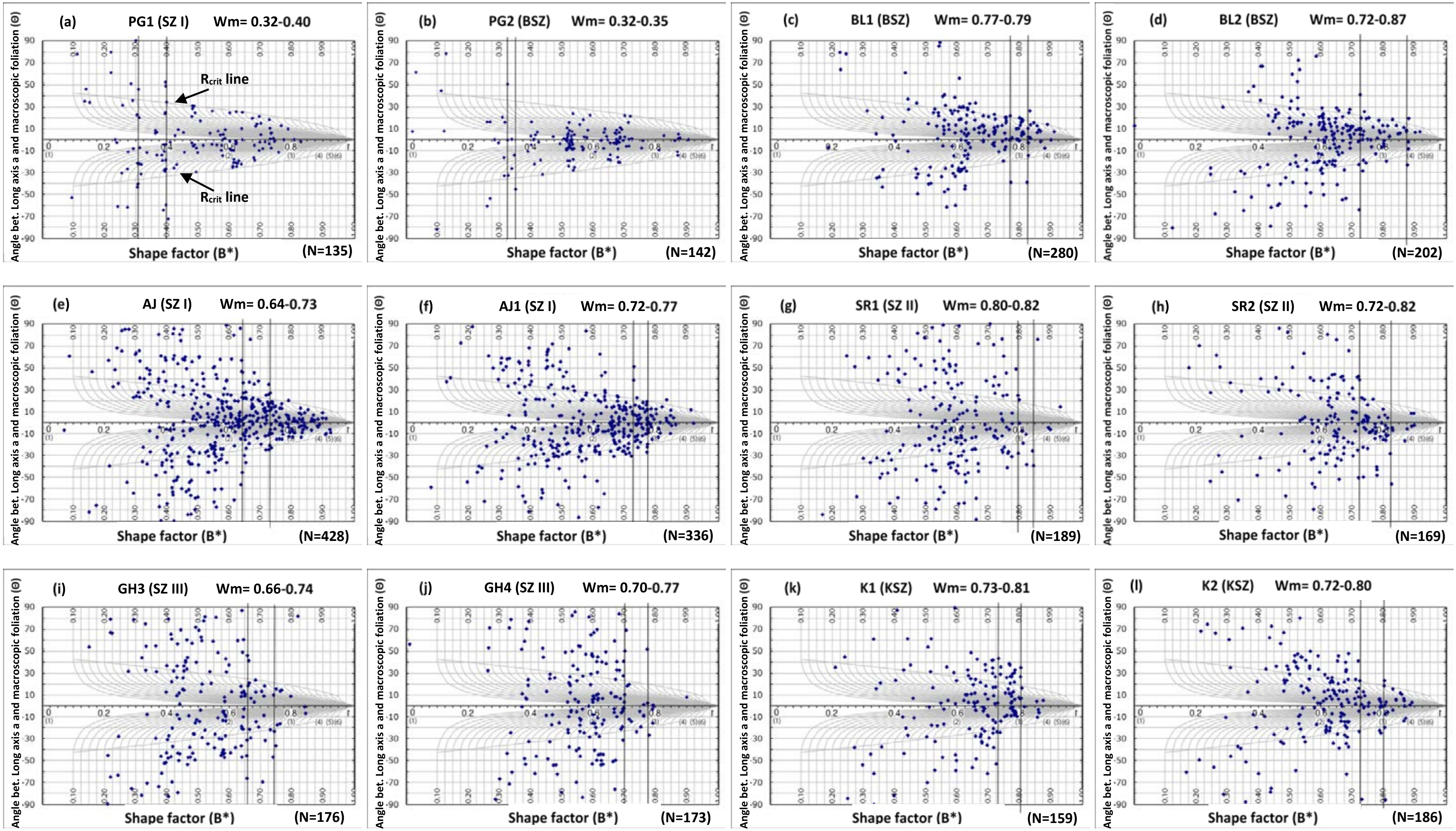


Fig. (a-i) *RGN* plot (after Jessup et al., 2007, JSG) of porphyroclasts from the mylonite and ultramylonite. The sample locations are shown in above fig. **(a)** and **(b)** correspond to samples of the high temperature mylonite **(c)-(l)** belong to samples of the low temperature mylonite. (Tiwari et al., 2020, JSG), see slide 6 for sample location.

Rs/θ (Wm) plot from different shear zones of Ambaji

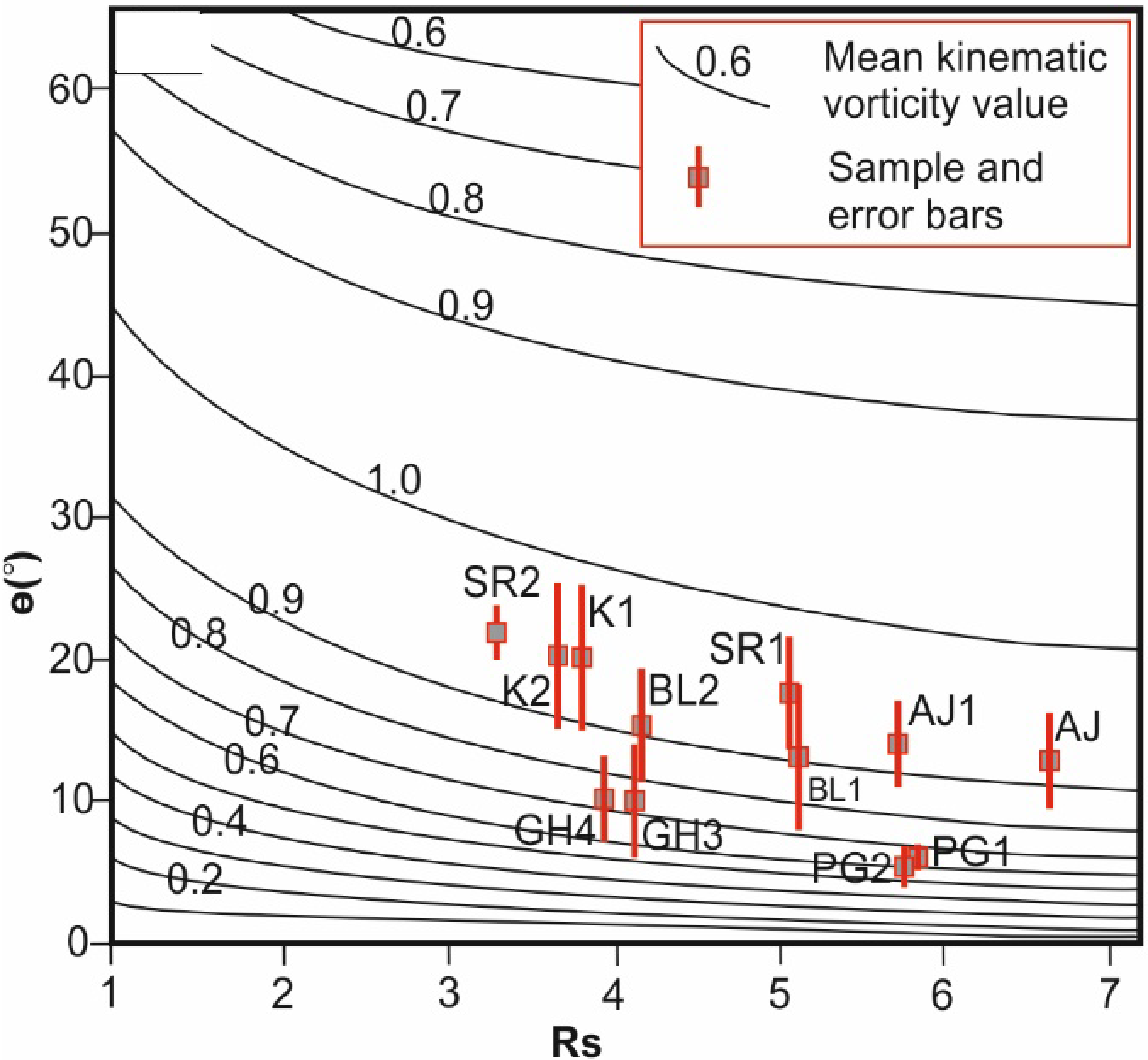


Fig. (a) *Rs* vs S-C angle (θ) plot, mean kinematic vorticity (*Wm)* curves are after, Fossen and Tikoff, 1993 (Tiwari et al., 2020, JSG).

Table: Comparison of Wm values from different shear zones of Ambaji

Sr No	Sample Name	Shear zones	Wm (RGN Method)	Pure (RGN) Shear %	Simple (RGN) Shear %	Rs	θ	Wm (Rs/θ Method)	Pure (Rs/θ) Shear %	Simple (Rs/θ) Shear %
1	PG1	SZ I	0.32- 0.40	73-79	21-27	5.86	6.1±2	0.6 – 0.7	51-59	41-49
2	PG2	Balaram	0.32- 0.35	77-79	21-23	5.78	5.3±3	0.45- 0.7	51-71	29-49
3	BL1		0.77-0.79	39-44	56-61	5.13	13.3±10	0.71-0.96	16-50	50-84
4	BL2		0.72-0.87	32-49	51-68	4.18	15.4±8	0.80-0.94	22-41	59-78
5	AJ	SZ I	0.64-0.73	48-56	44-52	6.65	13±7	0.85-0.95	20-34	66-80
6	AJ1		0.72-0.77	44-49	51-56	5.73	13.9±6	0.86-0.95	20-33	67-80
7	SR1	SZ II	0.80-0.82	39-41	59-61	5.08	17.5±8	0.92-0.97	11-25	75-89
8	SR2		0.72-0.82	43-49	51-57	3.33	21.7±4	0.93-0.96	16-24	76-84
9	GH3	SZ III	0.66-0.74	47-54	46-53	4.14	10±8	0.52-0.88	31-65	35-69
10	GH4		0.70-0.77	44-51	49-56	3.98	10.1±6	0.60-0.84	36-59	41-64
11	K1	Kengora	0.73-0.81	40-48	52-60	3.83	20.2±10	0.89-0.98	8-30	70-92
12	K2		0.72-0.80	41-49	51-59	3.70	20±10	0.89-0.98	8-30	70-92

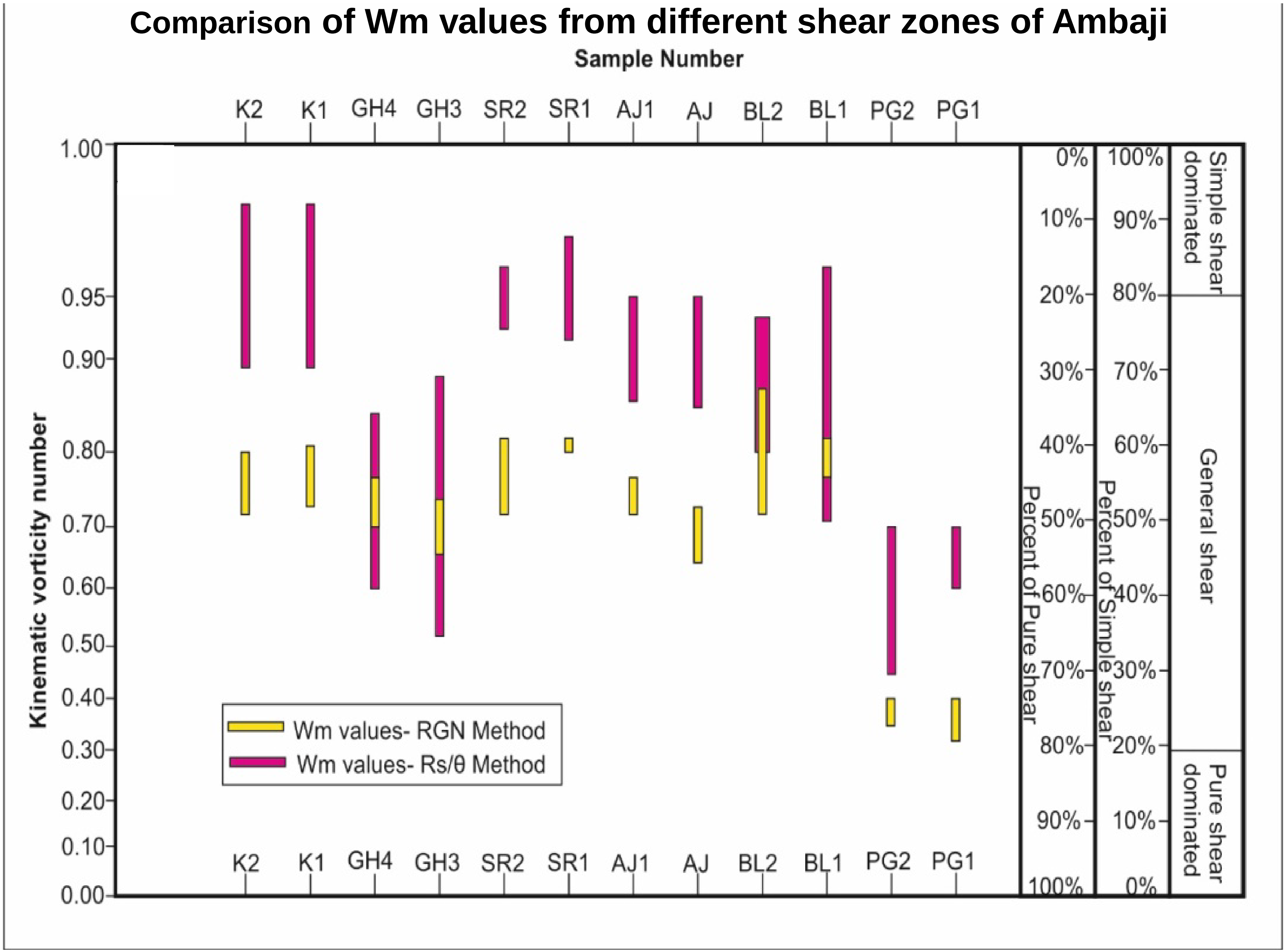
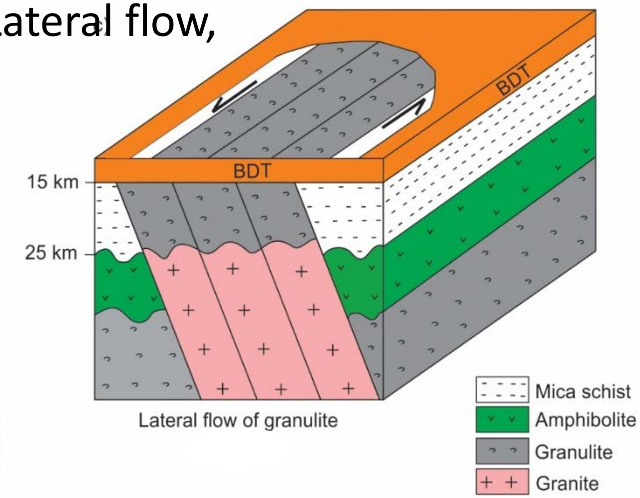


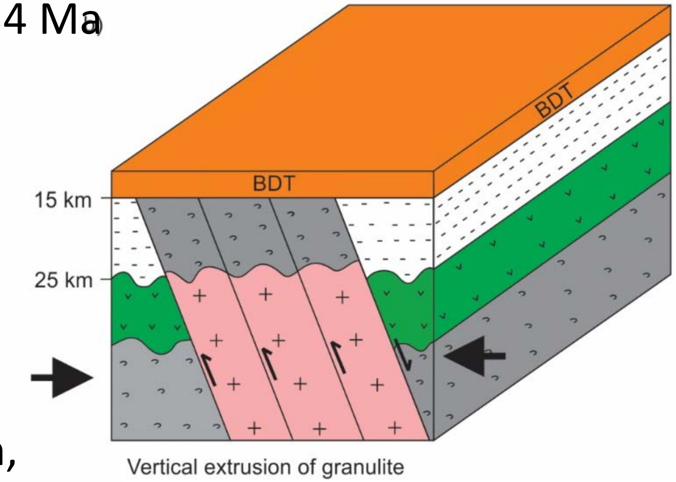
Fig. Graph illustrating the variation of "*RGN- Wm*" and "*Rs/θ- Wm*" across the granulite block. (Tiwari et al., 2020, JSG).

Tectonic evolution

Phase 2b: Lateral flow,
778 Ma



Phase 2a: Vertical extrusion,
834 Ma



Phase 1: Granulite formation,
860 Ma

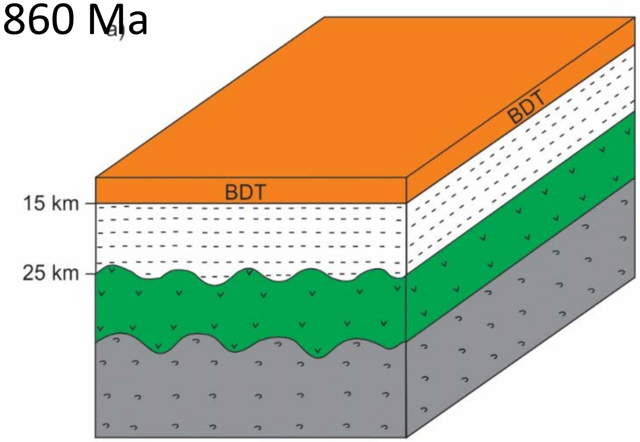
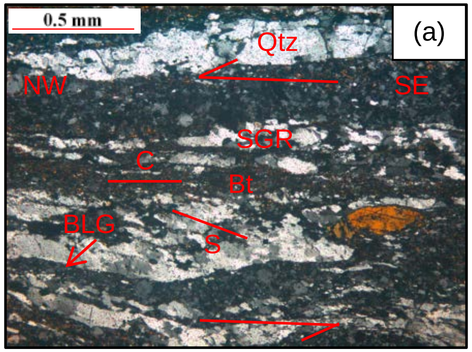


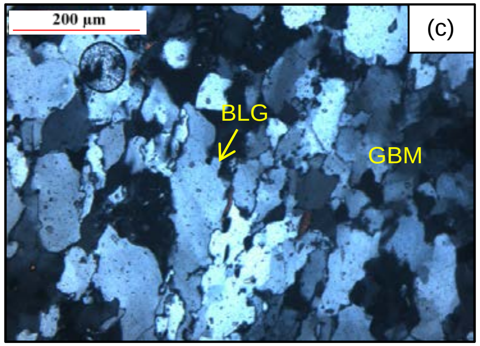
Fig. Showing the exhumation model with the help of vorticity analysis (Tiwari et al., 2020, JSG).

Summary and conclusion

- The shear zones are mostly low grade shear zones with a top-to- NW sinistral sense of shear.

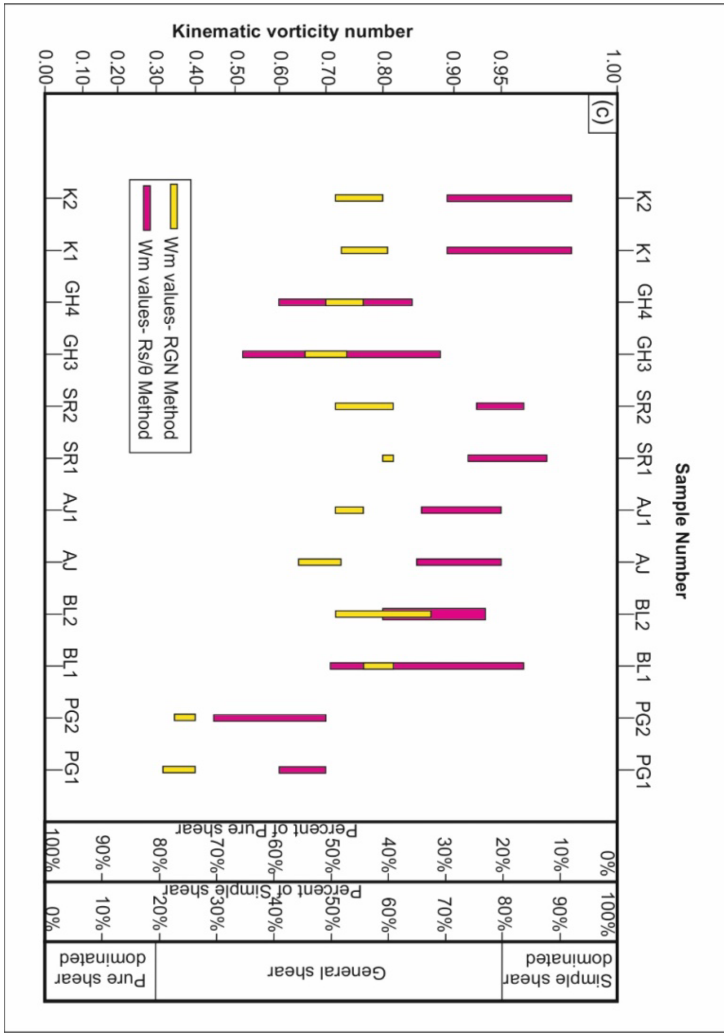
- The microstructural study of mylonite indicates that high temperature thrust slip shearing with GBM is preserved at few places. In most parts, the rocks have been extensively overprinted by low temperature strike slip shearing characterized by BLG-SGR recrystallization.





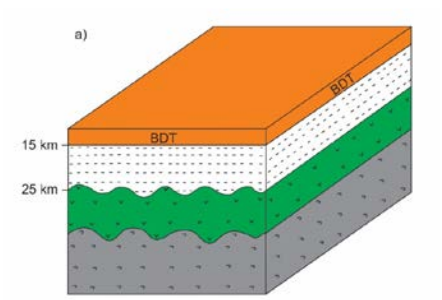
- An early high temperature shearing event yielded Wm values of 0.32-0.40 and 0.60, which suggests pure shear dominated transpression leading to horizontal shortening and vertical displacement of the granulite to upper crustal levels.

- A second low temperature retrograde shearing event overprinted the earlier phase at the brittle-ductile transition. Sinistral top-to-NW shearing yielded Wm estimates of 0.64-0.87 and ~ 1.0.



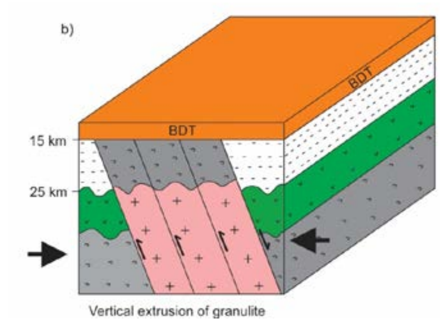
- The Ambaji Granulite shows a strain partitioning between pure shear dominated deformation, vertical displacement and crustal thickening in a large-scale thrust tectonic setting on one hand and general non-coaxial simple shear to true simple shear dominated deformation and lateral migration of the granulite in a large-scale strike-slip tectonic setting on the other hand.

Phase 1



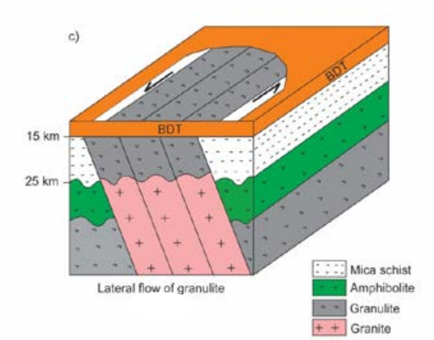
Granulite formation

Phase 2a



Vertical extrusion

Phase 2b



Lateral migration

References

Fossen, H., Tikoff, B., 1993. The deformation matrix for simultaneous simple shearing, pure shearing and volume change, and its application to transpression-transtension tectonics. **J. Struct. Geol.** 15, 413–422.

Jessup, M.J., Law, R.D., Frassi, C., 2007. The rigid grain net (RGN): an alternative method for estimating mean kinematic vorticity number (Wm). **J. Struct. Geol**. 29, 411–421.

Singh, Y.K., De Waele, B., Karmarkar, S., Sarkar, S., Biswal, T.K., 2010. Tectonic setting of the Balaram–Kui–Surpagla–Kengora granulites of the SDT of the Aravalli mobile belt, NW India and its implication on correlation with the east African orogen in the gondwana assembly**. Precambrian Res.** 183, 669–688.

Tiwari, S.K., Beniest, A., Biswal, T.K., 2020. Variation in vorticity of flow during exhumation of lower crustal rocks (Neoproterozoic Ambaji granulite, NW India). **J. Struct. Geol.** , 130. (https://doi.org/10.1016/j.jsg.2019.103912).

Tiwari, S.K., Biswal, T.K., 2019. Dynamics, EPMA Th-U-Total Pb Monazite Geochronology and Tectonic Implications of Deformational Fabric in the Lower-Middle Crustal Rocks: A Case Study of Ambaji Granulite, NW India. **Tectonics**, 38, 2232–2254 (https://doi.org/10.1029/2017TC004891).

Tiwari, S.K., Biswal, T.K., 2019. Paleostress and magma pressure measurement of granite veins in the Neoproterozoic Ambaji granulite, South Delhi terrane, Aravalli–Delhi mobile belt, NW India: Implication towards extension driven exhumation of middle-lower crustal rocks. **J. Earth Syst. Sci.**, 128(6), 1-13 (https://doi.org/10.1007/s12040-019-1187-5).