

Role of pre-existing fabric in abetting fracture formation, fluid flow and vein emplacement in the metavolcanics: a domain for shallow crustal gold mineralization in the Archean greenstone belt, India

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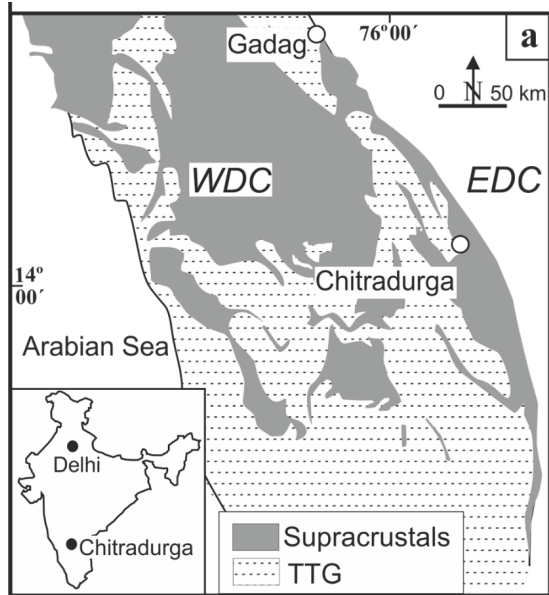
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- There can be a strong structural control on mineralization
- In the context of gold deposits fault-valve action involving repeated fracturing and sealing of faults can be important (Sibson, 1992)
- Relative stress and P_f conditions during vein emplacement can be evaluated using vein orientation data (McKeagney et al., 2004)

The upper crustal fluid flows are governed by the pre-existing anisotropy (fractures/foliations) in the rocks under a certain state of tectonic stress and fluid pressure condition

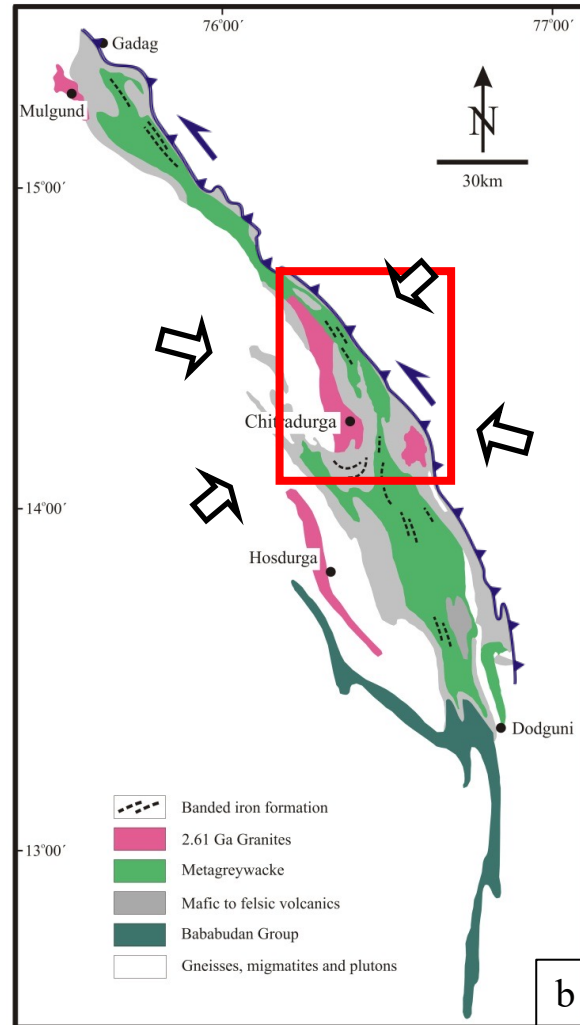
...thus understanding of rock fabric, its anisotropy and its influence on fluid flow are critical

Study area

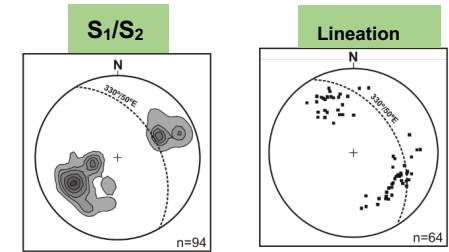


- **Peninsular Gneiss: 3.4-3.0 Ga in age**
- **Accretion of East & West Dharwar Craton: 2.75-2.51 Ga**
- **Metavolcanics & Granite of Gadag Schist Belt: ~2.5 Ga**

(a) Regional map of the Western Dharwar Craton, South Indian Shield (following Chadwick et al., 2003).
(b) Geological map of CSB (taken from Jayananda et al., 2013)

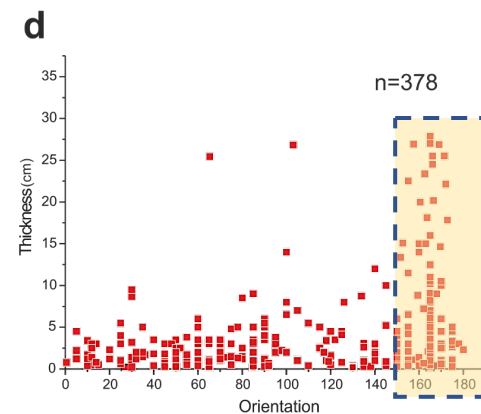
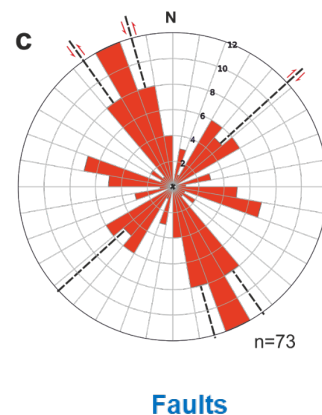
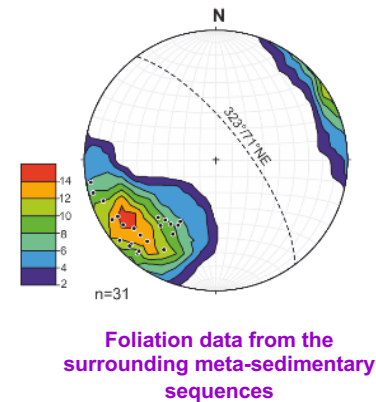
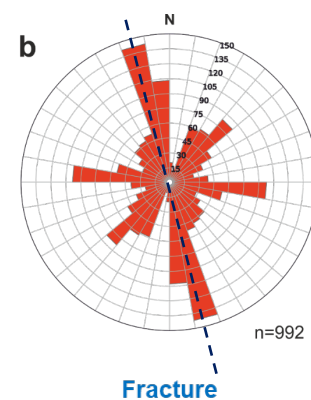
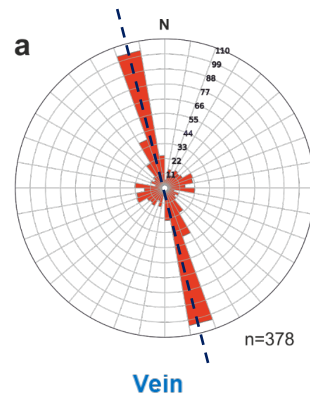
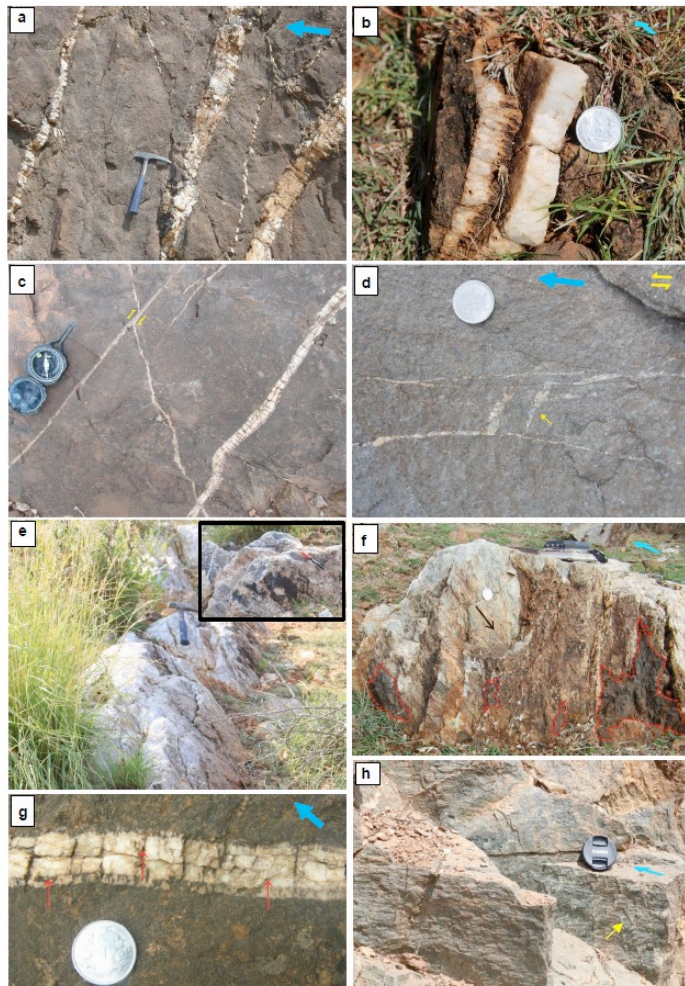


Chitradurga Schist Belt



- Three phases of deformation referred to as **D1**, **D2** and **D3** (Chakrabarti et al., 2006).
- **D1**, **D2** are **coaxial** with **NW striking axial plane**.
- **NE-SW compression** was responsible for NW-SE oriented structural elements in the Schist Belt (Chadwick et al., 2003).
- **D3** is characterized by regional warps and **dome-basin structures** in the region (Chakrabarti et al., 2006).

Structural data from metabasalts



Quartz Veins and Fractures in Metabasalt

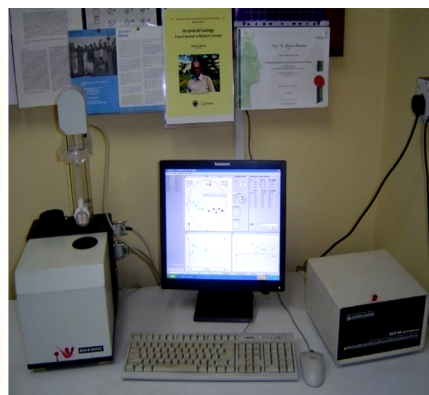
- Veins show some variation in orientation.
- Most of the veins are oriented along ~NW-SE to NNW-SSE direction.
- Fracture/fault orientations show a NW-SE maxima, NE-SW and WNW-ESE sub-maxima respectively.

Bhowmick, S. and Mondal, T. K., (2020), Solid Earth 11 (4).0000

Suggesting that there must have been structural control on mineralization

Anisotropy of Magnetic Susceptibility Study

Drilling for AMS analysis



KLY-4S Kappbridge (AGICO, Czech Republic)



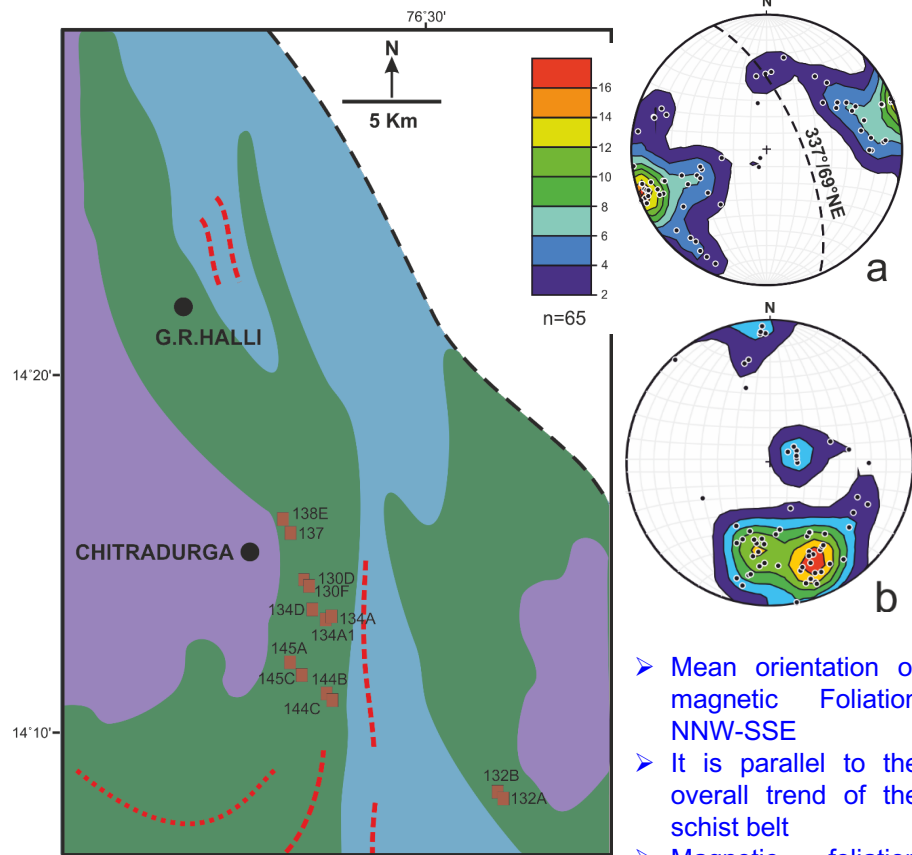
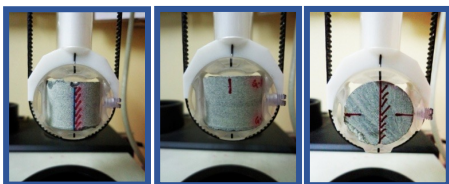
Diameter:
25.4 mm
Height:
22mm

$$K=M/H$$

K =magnetic susceptibility in SI units
 M =Induced Magnetization
 H =Intensity of external magnetic field

M is the magnetic dipole moment per unit volume (in A/m), H is the magnetic field strength (in A/m)

Magnitude and orientation of the three principal axes of the susceptibility ellipsoid K_1 , K_2 and K_3 , where $K_1 \geq K_2 \geq K_3$



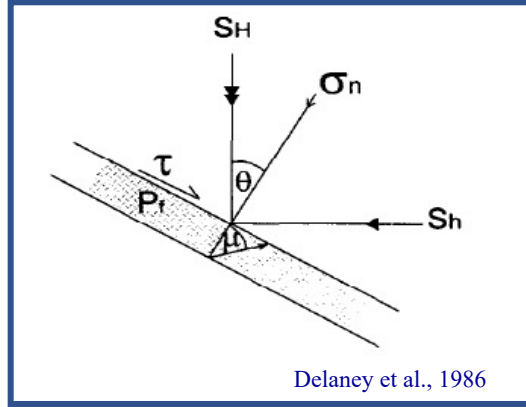
- K_m varies between 37 and 1280×10^{-6} SI units, with most of the samples having K_m below 1000×10^{-6} SI units. Paramagnetic and ferromagnetic minerals contribute significantly to the AMS

- Mean orientation of magnetic Foliation NNW-SSE
- It is parallel to the overall trend of the schist belt
- Magnetic foliation developed during regional D1/D2 deformation on account of NE-SW compression

Determination of fluid pressure conditions

Condition for the formation/reactivated fracture:

(Delaney et al., 1986)



Normal stress acting on the fracture can be expressed in terms of fracture orientation (θ), and the maximum and minimum principal stress.

S_H = Maximum Horizontal Compression = $\sigma_{\max}$

S_h = Minimum Horizontal Compression = $\sigma_{\min}$

τ = Shear stress

P_f = Fluid Pressure

R = Driving Stress ratio
($1 > R > -1$)

R' = Driving Pressure Ratio

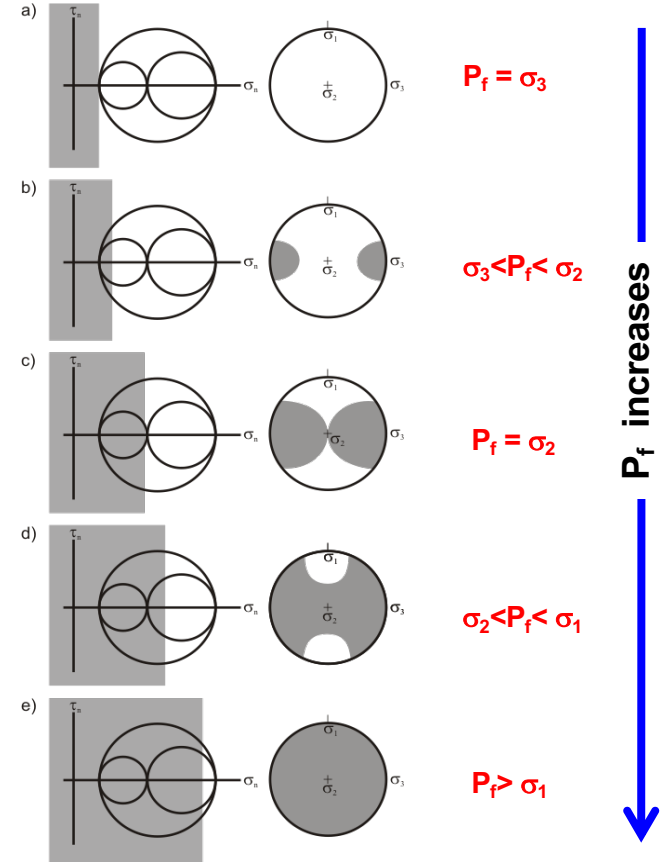
$$R' = \frac{P_f - \sigma_3}{\sigma_1 - \sigma_3} = \frac{1 + \cos 2\theta_2}{2}$$

(Baer et al., 1994)
(Jolly & Sanderson, 1997)

Φ = Stress Ratio

When $P_f < \sigma_2 \rightarrow \Phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} = \frac{1 + \cos 2\theta_2}{1 + \cos 2\theta_1}$

When $P_f > \sigma_2 \rightarrow \Phi = \frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} = 1 - \frac{1 - \cos 2\theta_2}{1 - \cos 2\theta_3}$



(Girdle vs. Clustered Distribution of poles)

Magnitude of Principal Stresses

Depth of faulting/fracturing in close vicinity of the study area ~ 2.4 km (Acharyaa and Mondal, 2019)

Maximum compressive stress (σ_1)

$$\sigma_1 = h\rho g$$

h = depth of fracturing in metabasalts (~2.4km)
 ρ = approximate bulk density of crust (2700 kg/m³)
 g = 9.8 m/sec²

In a normal faulting regime with $\sigma_v = \sigma_1 \geq 63.5 \text{ MPa}$ (we considered the limiting value)

Minimum compressive stress (σ_3)

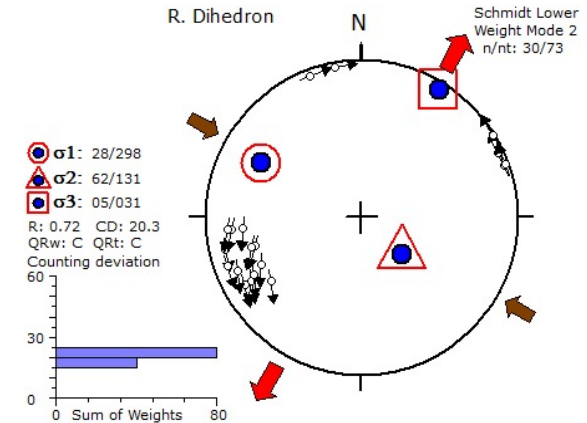
At crustal depth < 7km, the differential stress ($\Delta\sigma$) = $2\tau_m$, by McGarr (1980)
 τ_m is the shear stress at depth z (in km)

$$\tau_m = 5.0 + 6.6z, \quad z = 2.4\text{km}, \quad \Delta\sigma = 41.68 \text{ MPa}$$

$$\sigma_3 \approx 21.82 \text{ MPa}$$

- Magnitude for the intermediate compressive stress (σ_2) is determined using the respective stress ratios (ϕ) for both high and low P_f respectively.
- Estimated mode of failure in metabasalt is tensile, $\Delta\sigma = 41.68 \text{ MPa}$, $\sigma_1 - \sigma_3 < 4T$ (Sibson, 2000).

Paleostress condition



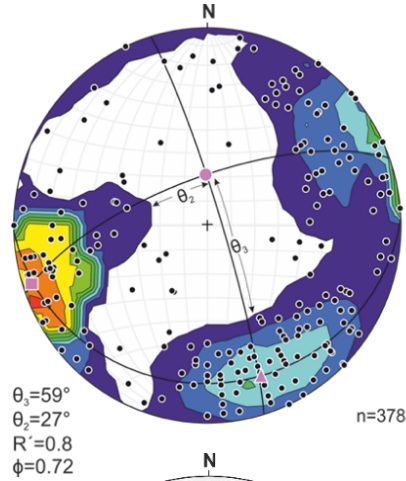
Paleostress analysis
'Win_Tensor' (version 5.8.6)
Delvaux and Sperner, 2003; Delvaux, 2011

- Fault-slip data
- NE-SW extension related to D3 compression

Stress regime index ($R'=1.25$)

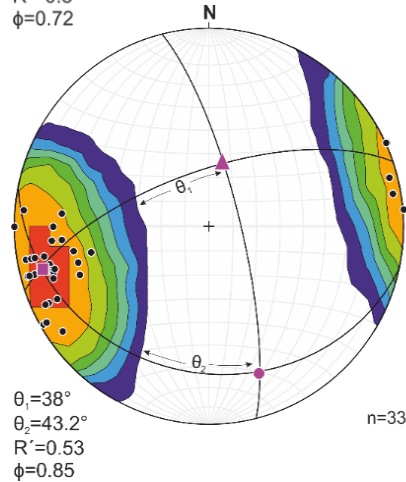
This indicates a transtensional to pure-strike slip domain.

Determination of fluid pressure conditions

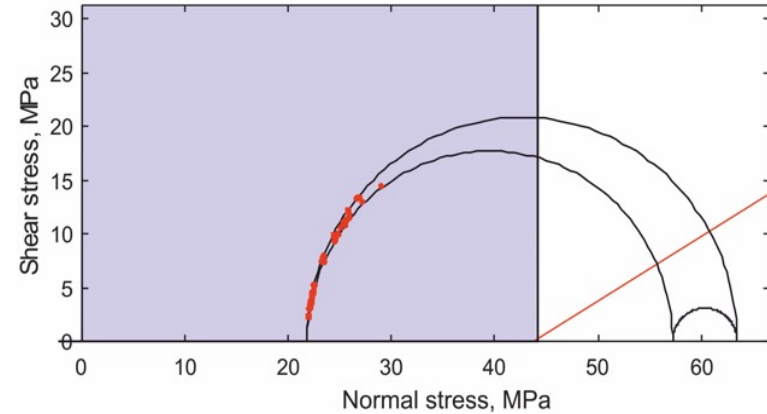
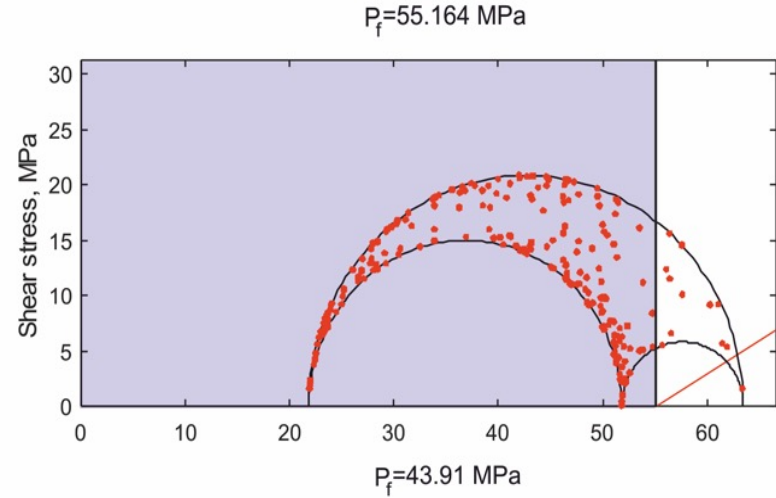


Girdle distribution

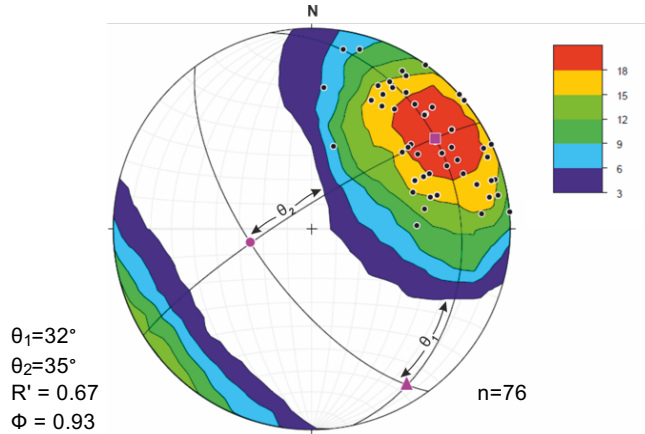
Pink circle: σ_1
 Pink triangle: σ_2
 Pink square: σ_3



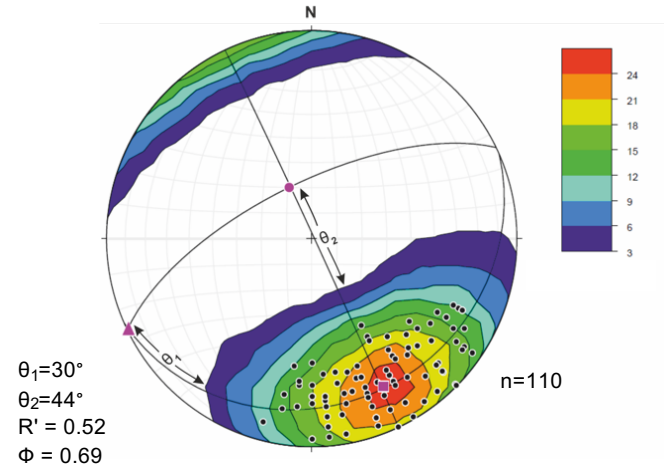
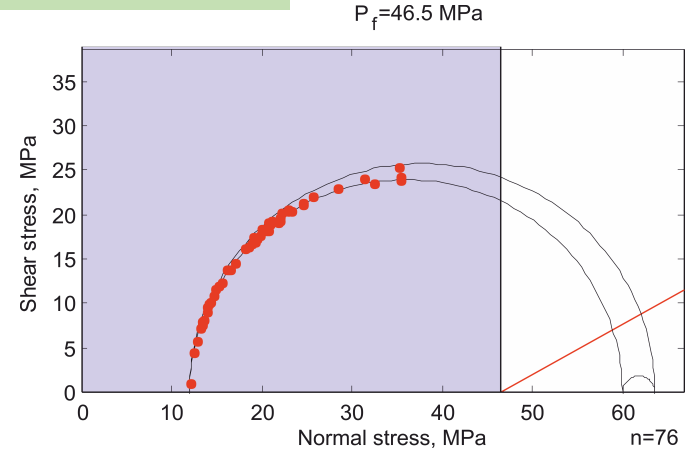
Clustered distribution (WSW cluster)



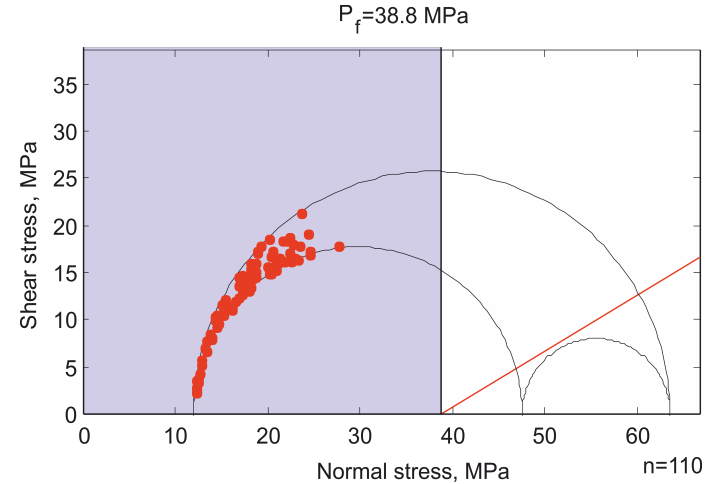
Determination of fluid pressure conditions



NE cluster



SE cluster



Reactivation Tendency

Dilation Tendency

$$T_d = (\sigma_1 - \sigma_n) / \sigma_D$$

where $(\sigma_D = \sigma_1 - \sigma_3)$

Slip Tendency

$$T_s = \sigma_s / \sigma_n$$

Fracture Susceptibility

$$S_f = \sigma_n - (\sigma_s / \mu_s)$$

μ_s static coefficient of friction

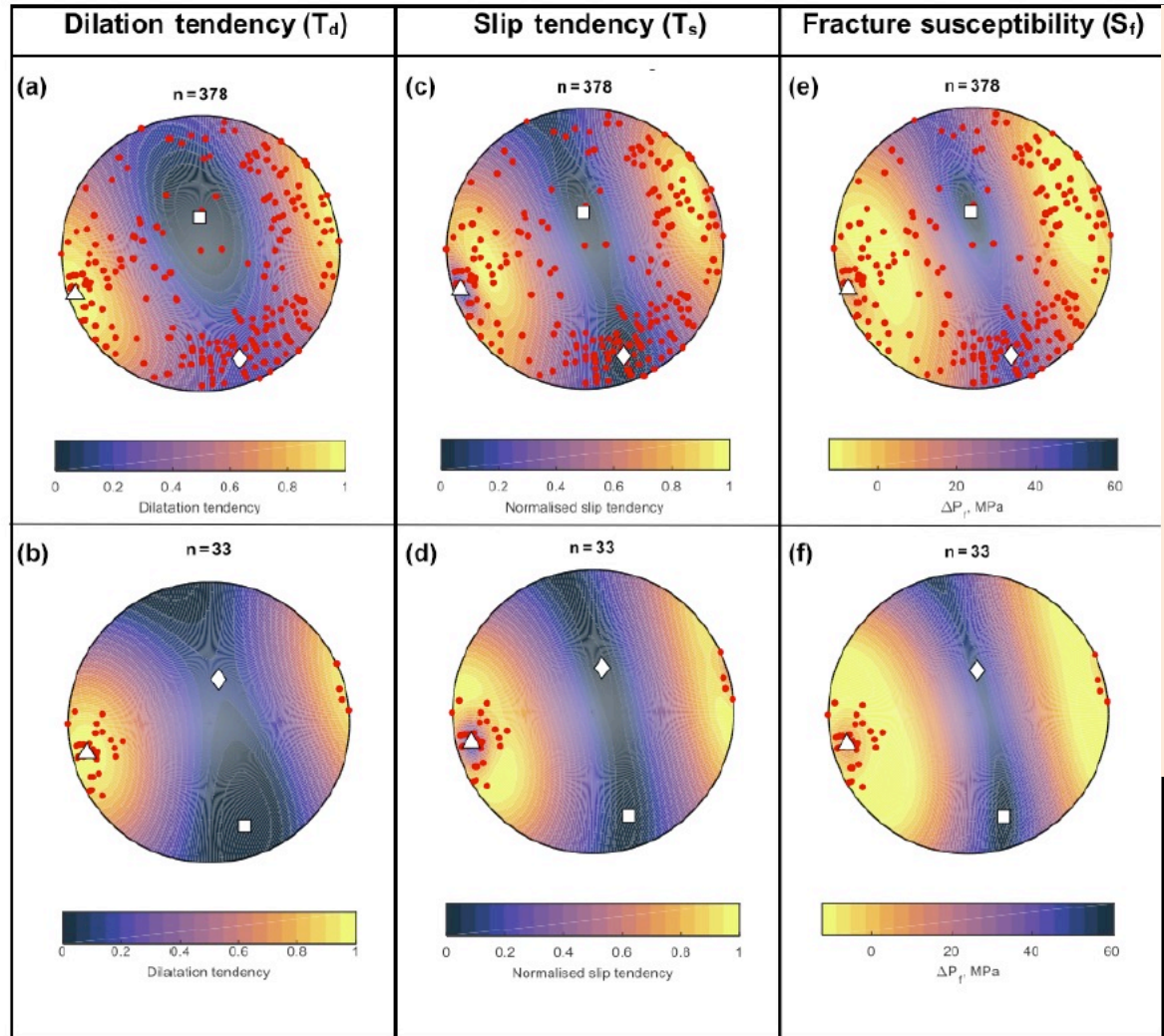
White square: σ_1 , White diamond: σ_2 White triangle: σ_3

Pole to fractures

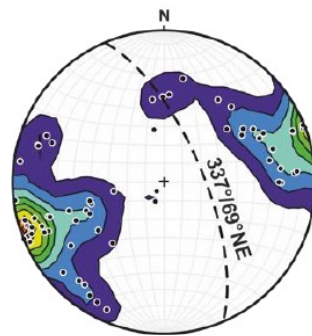
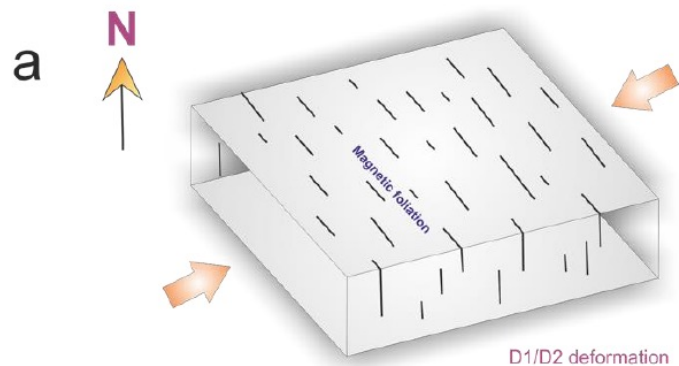
- Forming cluster around σ_3 , high dilation tendency/dilational opening.
- At a low angle to σ_3 , high slip tendency/shear opening.
- Fracture Susceptibility/ variation in fluid pressure low for both.
- Fluid-induced fracture reactivation.

High P_f

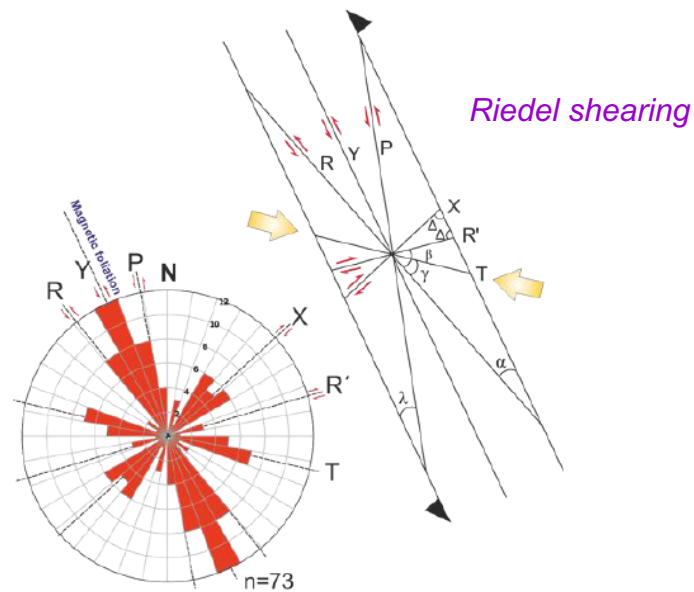
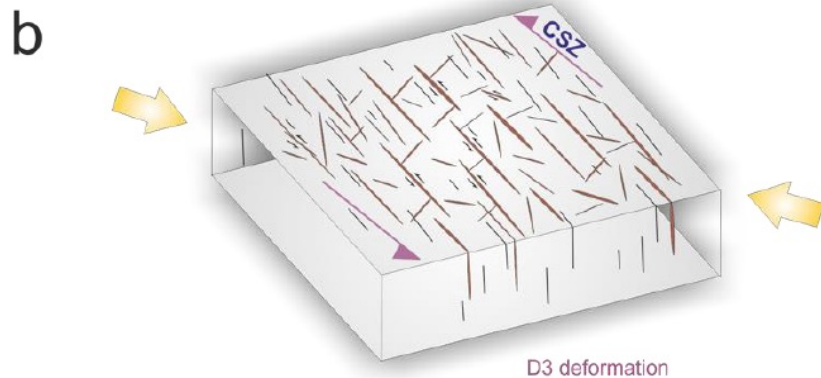
Low P_f



Schematic model showing formation/reactivation of fractures and faults vis-à-vis vein emplacement in metabasalts

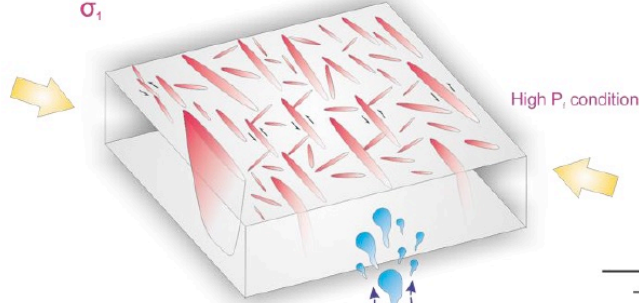
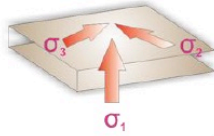


Magnetic fabric oriented ~ NW-SE

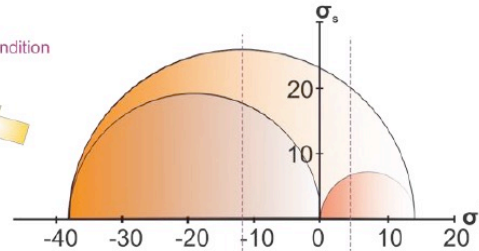


High and low P_f conditions for vein emplacement

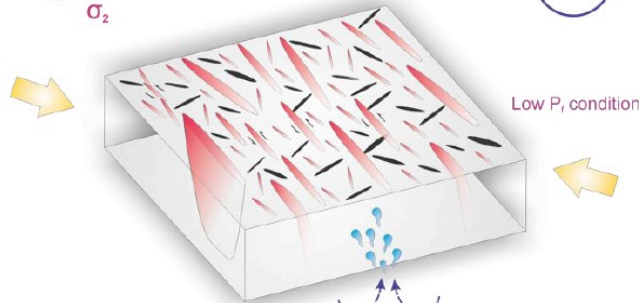
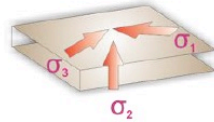
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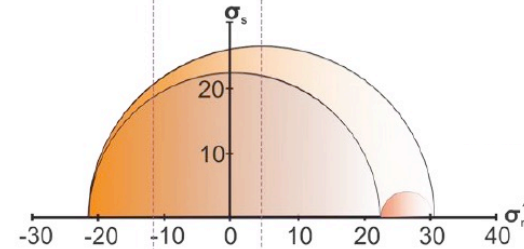
High P_f condition



d



Low P_f condition



SiO₂ rich fluid influx
under high P_f condition

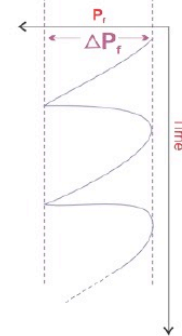
SiO₂ rich fluid influx
under low P_f condition

- σ_1 is vertical due to fluid overpressure (high P_f)
- Multiple orientations are reactivated
- P_f variation ($\Delta P_f \sim 11.25$ MPa)
- Multiple cycles of high and low P_f condition (n-times) justifying fault-valve action.

Pore fluid factor (Sibson, 2000)

$$\lambda_v = P_f / \sigma_v$$

λ_v varies from 0.68 to 0.87, supporting supra-hydrostatic fluid pressure condition.



Summary and Conclusions

- The ~NW-SE oriented magnetic fabric in the metabasalts is a product of the D1/D2 regional deformation. This fabric was favorably oriented and therefore, suitable for fracture propagation in relation to the prevailing stress field.
- The variably oriented fractures and faults i.e., the NNW–SSE to NW–SE (P , Y , R), WNW–ESE (T), NE–SW (X) and ENE–WSW (R') ones, are the riedel shear components.
- NNW–SSE trending orientations, having higher values of slip and dilation tendencies, channelized fluid during both high- and low P_f conditions, thereby attaining maximum vein thickness.
- Vein emplacement took place under both high and low P_f conditions. It is envisaged that multiple number of such alternating high and low P_f cycles prevailed in the region.
- The process of fracture formation, reactivation and faulting prevailed under a far-field compression related to late D3 deformation.

THANK YOU