ETH zürich

On the anisotropy of mechanical properties in Grimsel granite

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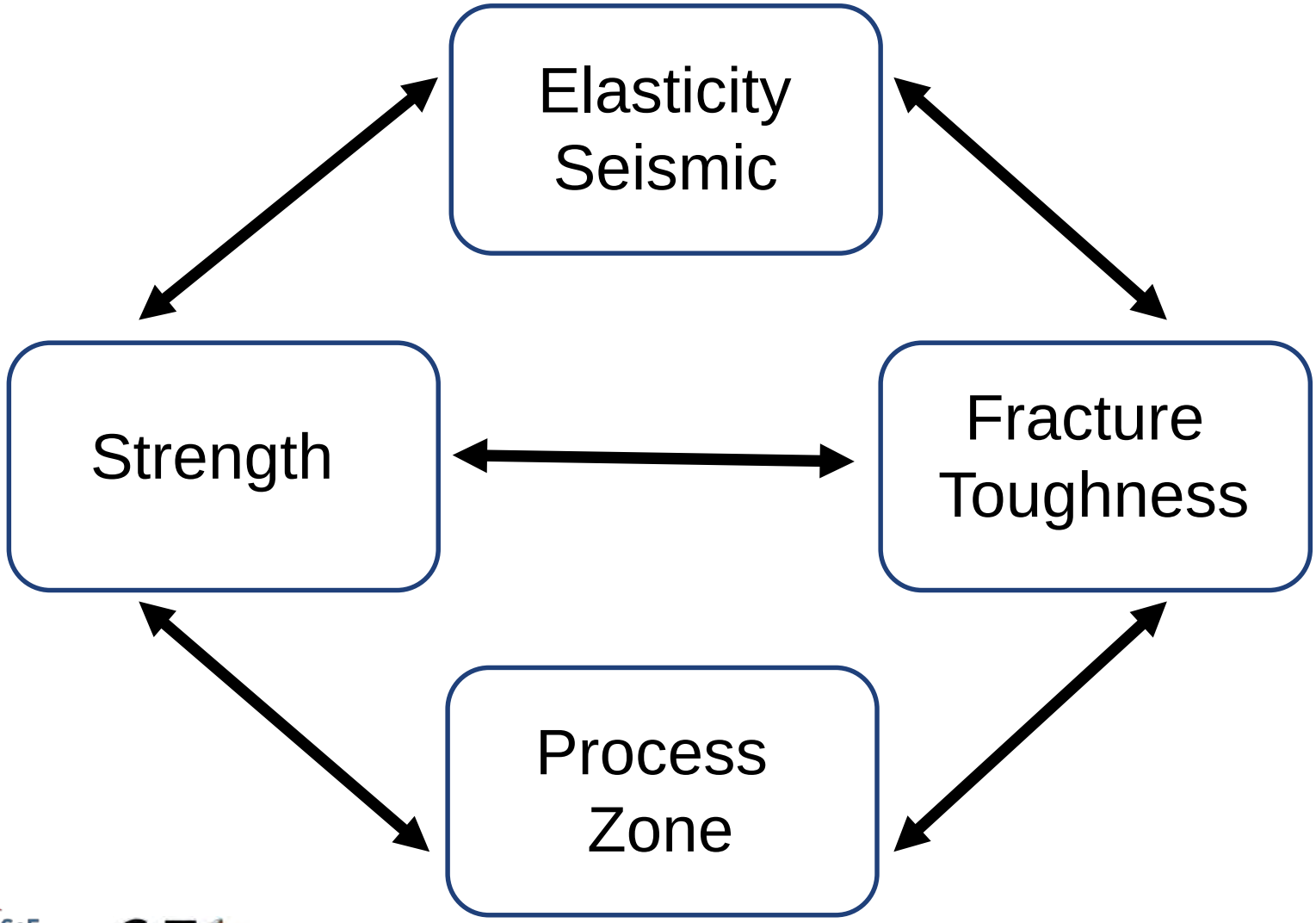
Anisotropy of rock properties

Anisotropy is the property of being directionally dependent

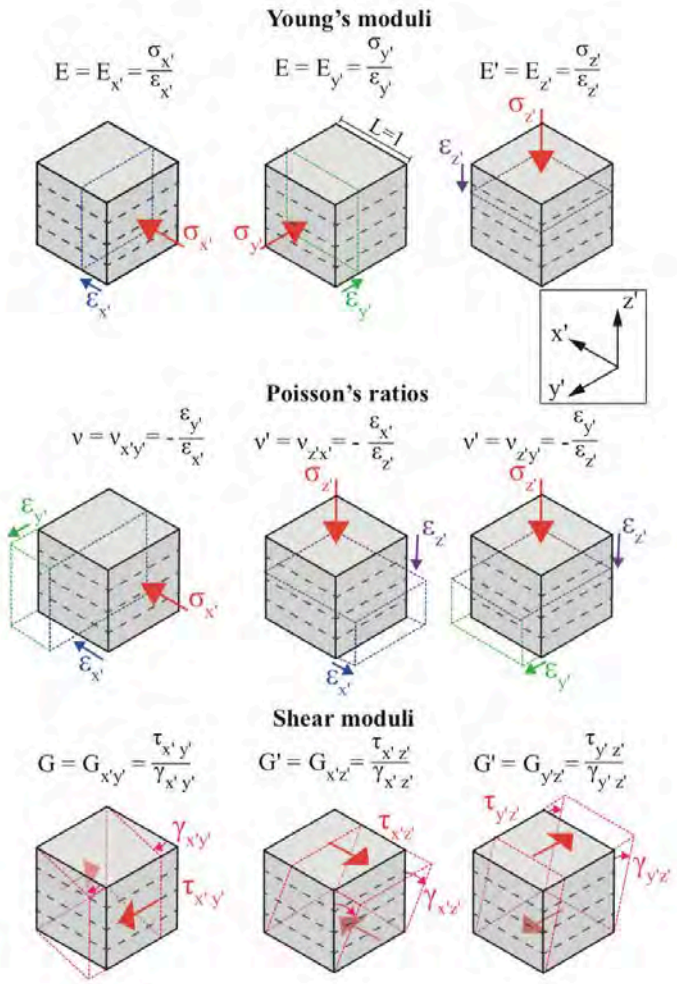
- **Mechanical properties**
  - Elasticity
  - Seismic
  - Strength
  - Fracture toughness
- **Thermal and hydraulic properties**
  - Permeability
  - Thermal conductivity

- Dutler, N., Nejati, M., Valley, B., Amann, F., Molinari, G., 2018, On the link between fracture toughness, tensile strength, and fracture process zone in anisotropic rocks, *Engineering Fracture Mechanics*, 201, 56-79.
- Dambly, L., Nejati, M., Vogler, D., Saar, M. O., 2018. On the direct measurement of the shear moduli in transversely isotropic rocks using the uniaxial compression test. *International Journal of Rock Mechanics and Mining Sciences*, Under Review.
- Nejati, M., Dambly, L., Saar, M. O., 2018. Measurement of elastic constants of transversely isotropic rocks from a single uniaxial compression test. *Rock Mechanics and Rock Engineering*, Under Review.

Mechanical anisotropy



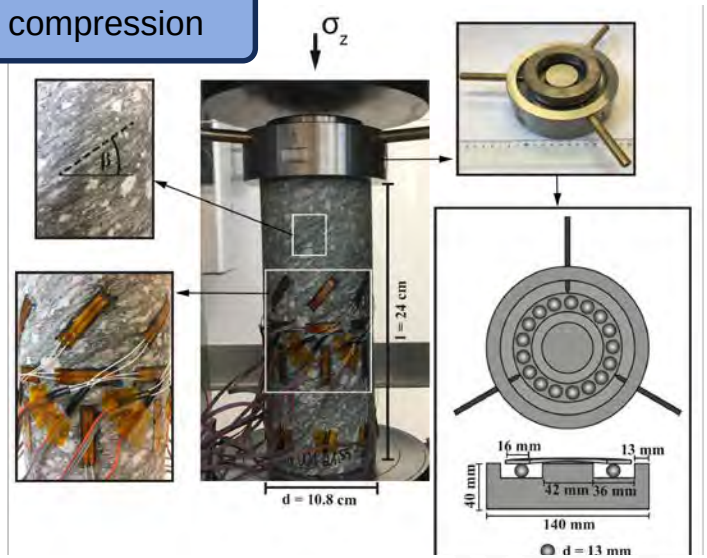
Elasticity anisotropy: Transverse isotropy

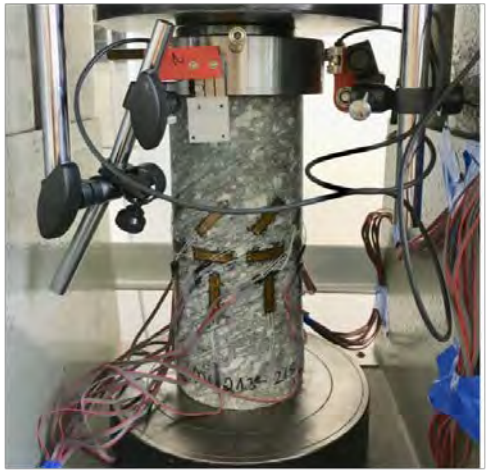


$$\underbrace{\begin{bmatrix} \epsilon_{x'} \\ \epsilon_{y'} \\ \epsilon_{z'} \\ \gamma_{y'z'} \\ \gamma_{x'z'} \\ \gamma_{x'y'} \end{bmatrix}}_{\boldsymbol{\epsilon}'} = \underbrace{\begin{bmatrix} \frac{1}{E} & -\frac{\nu}{E} & -\frac{\nu'}{E'} & 0 & 0 & 0 \\ & \frac{1}{E} & -\frac{\nu'}{E'} & 0 & 0 & 0 \\ & & \frac{1}{E'} & 0 & 0 & 0 \\ & & & \frac{1}{G'} & 0 & 0 \\ & & & & \frac{1}{G'} & 0 \\ & & & & & \frac{1}{G} \end{bmatrix}}_{\boldsymbol{S}'} \underbrace{\begin{bmatrix} \sigma_{x'} \\ \sigma_{y'} \\ \sigma_{z'} \\ \tau_{y'z'} \\ \tau_{x'z'} \\ \tau_{x'y'} \end{bmatrix}}_{\boldsymbol{\sigma}'}$$

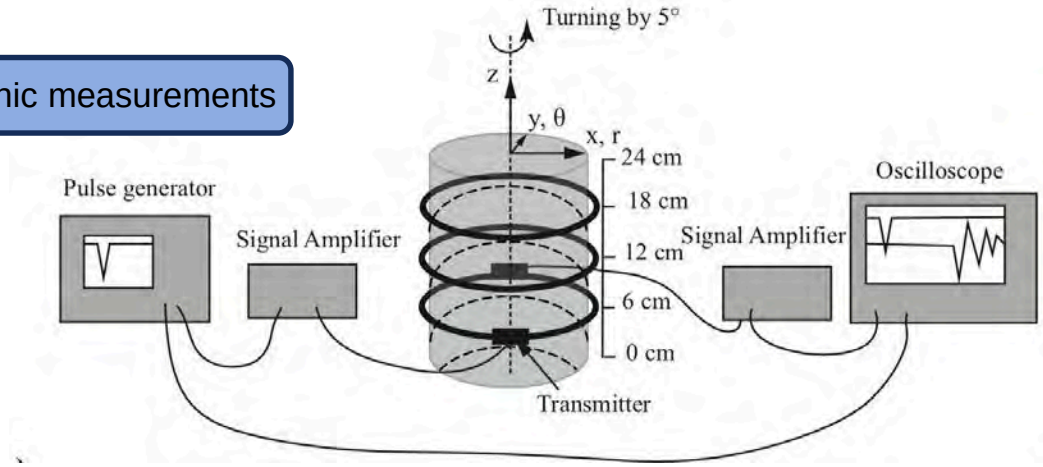
Elasticity anisotropy: Transverse isotropy

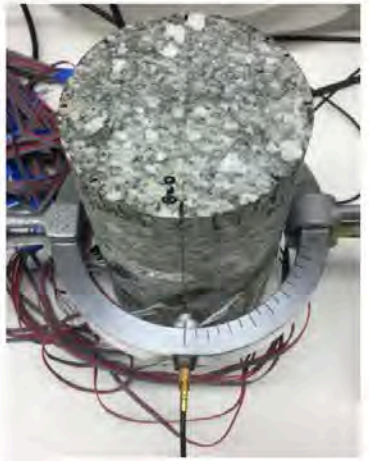
Uniaxial compression





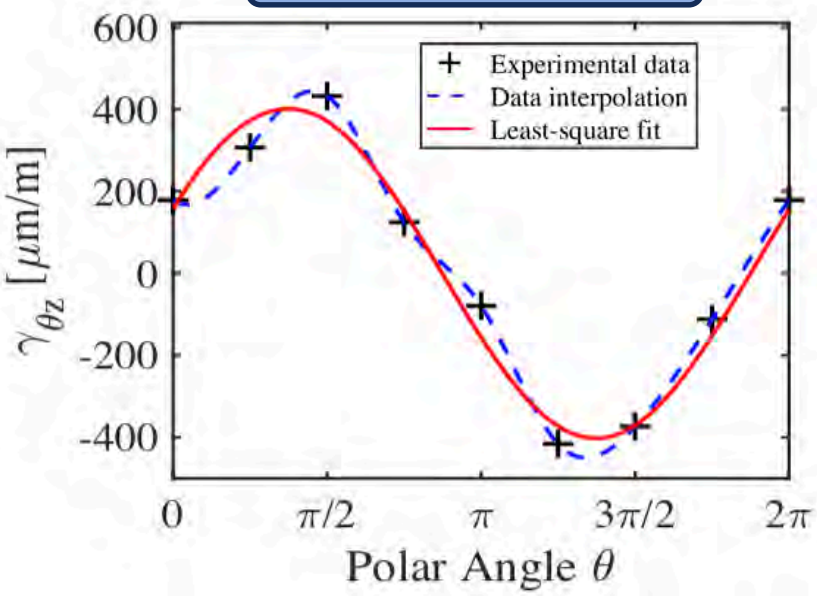
Ultrasonic measurements



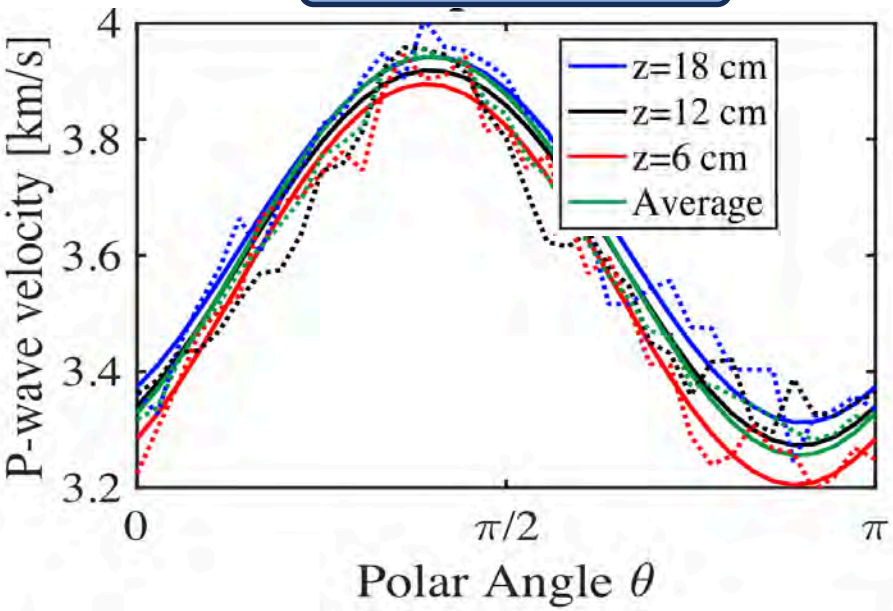


Elasticity anisotropy: Transverse isotropy

Uniaxial compression

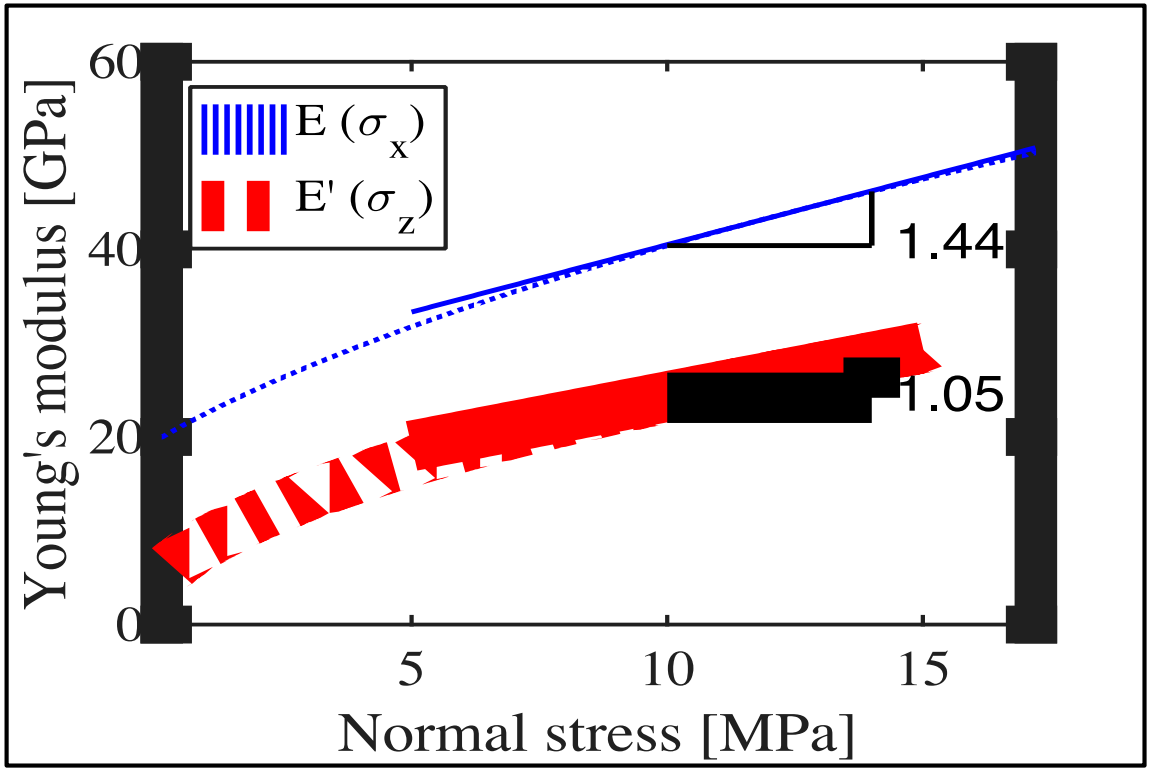


Ultrasonic measurements



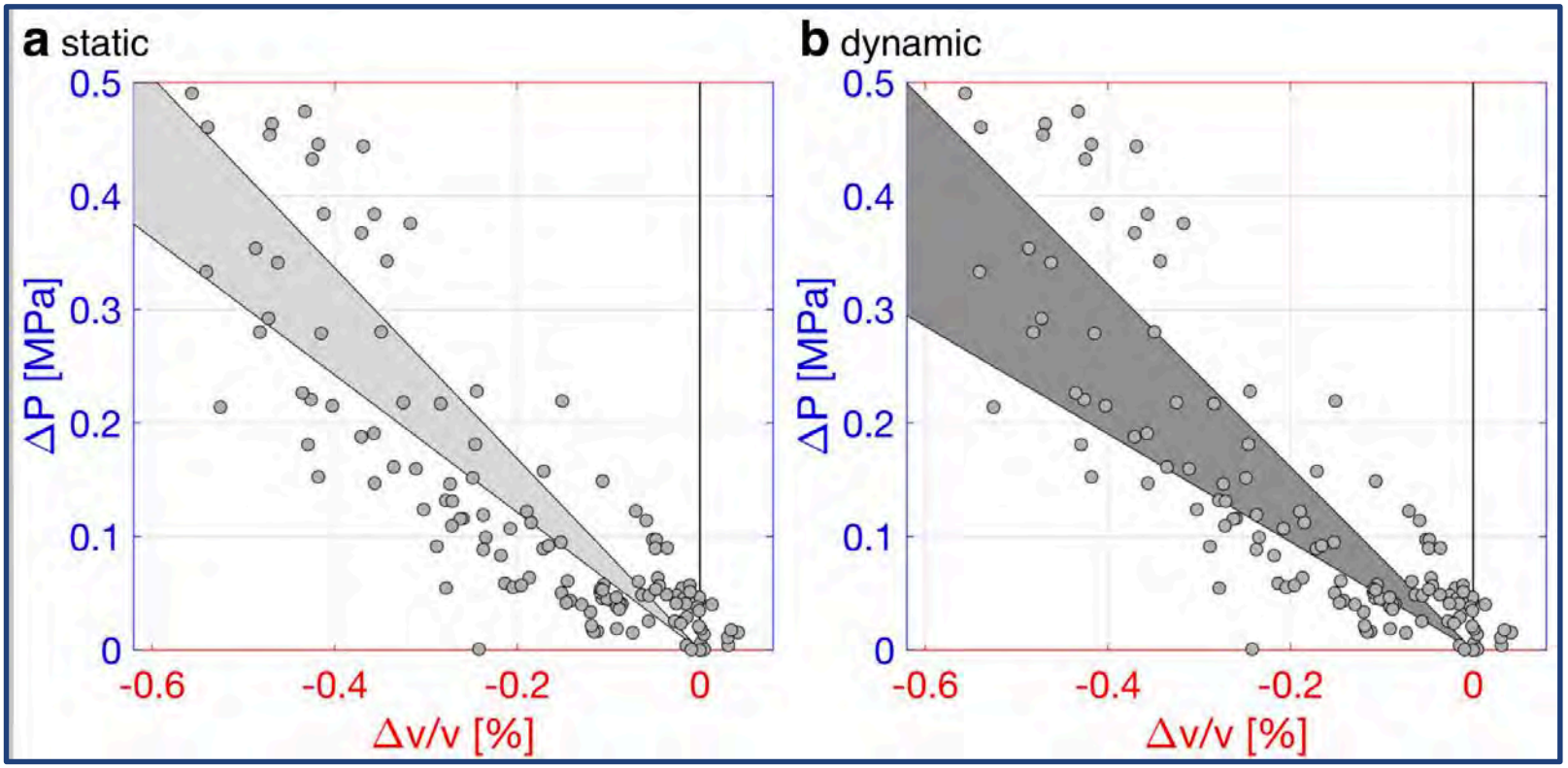
- **Conclusions:**
- Grimsel granite deformation can be characterized by the transverse isotropy model.
- The isotropy plane coincides with the foliation plane.

Elasticity: Significance of anisotropy and nonlinearity



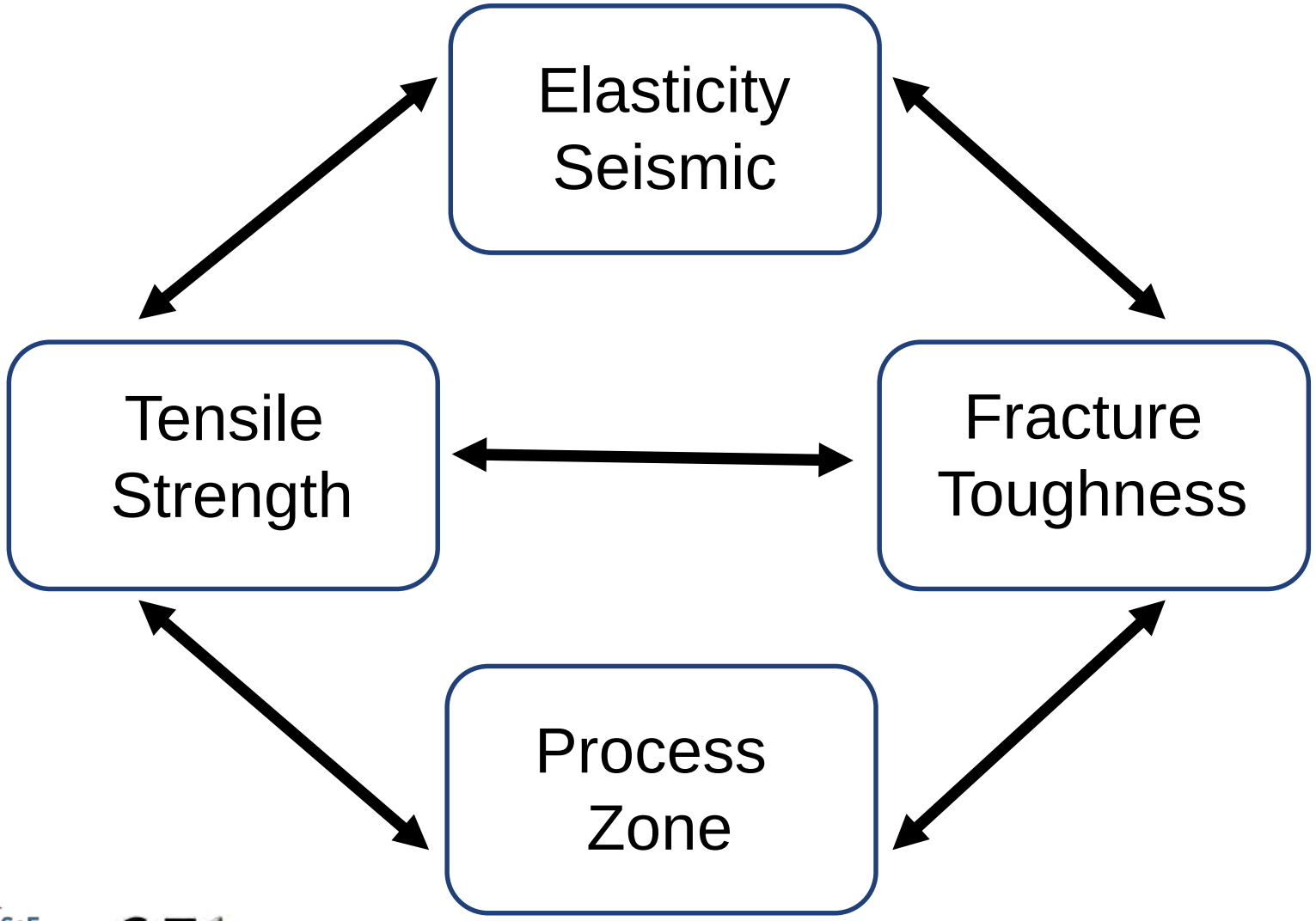
- **Conclusion:**
  - Elasticity of Grimsel granite is significantly anisotropic and non-linear.

Implications in GUG-Lab experiments

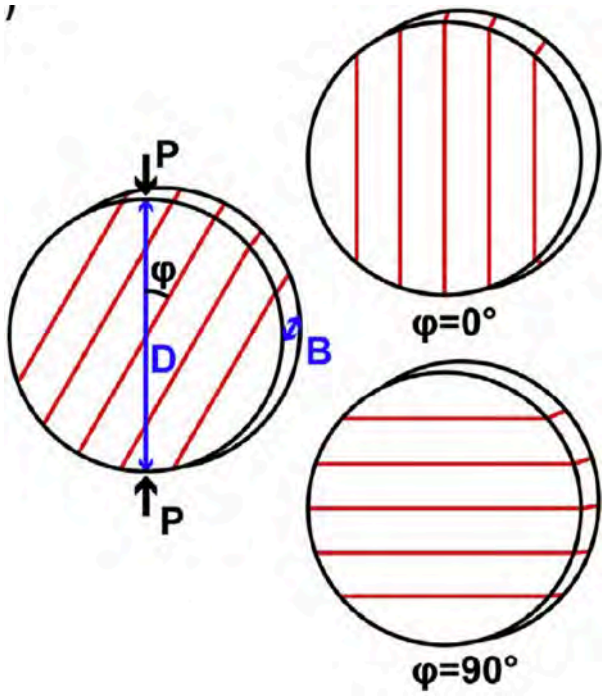


Doetsch, J., Gischig V.S., Villiger, L., Krietsch, H., Nejati, M., Amann, F., Jalali, M., Madonna, C., Maurer, H., Wiemer, S., Driesner, T., Giardini, D., Subsurface Fluid Pressure and Rock Deformation Monitoring using Seismic Velocity Observations, Geophysical Research Letters, Under Review.

Mechanical anisotropy

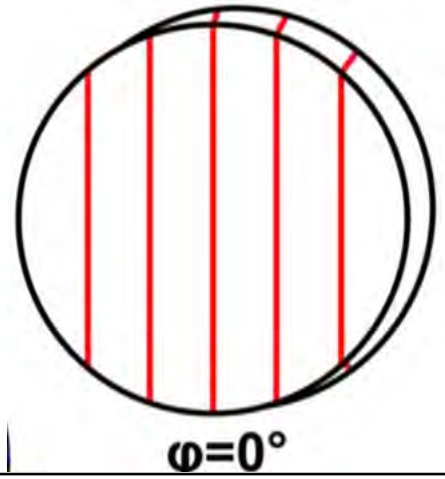


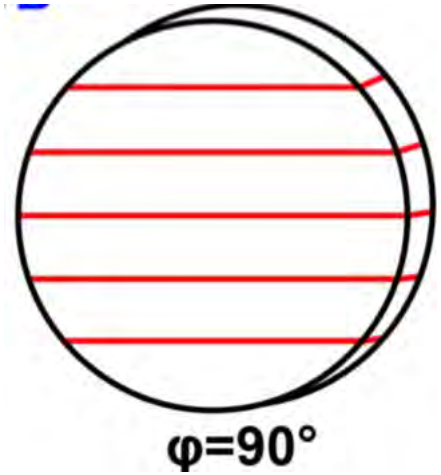
Tensile strength anisotropy



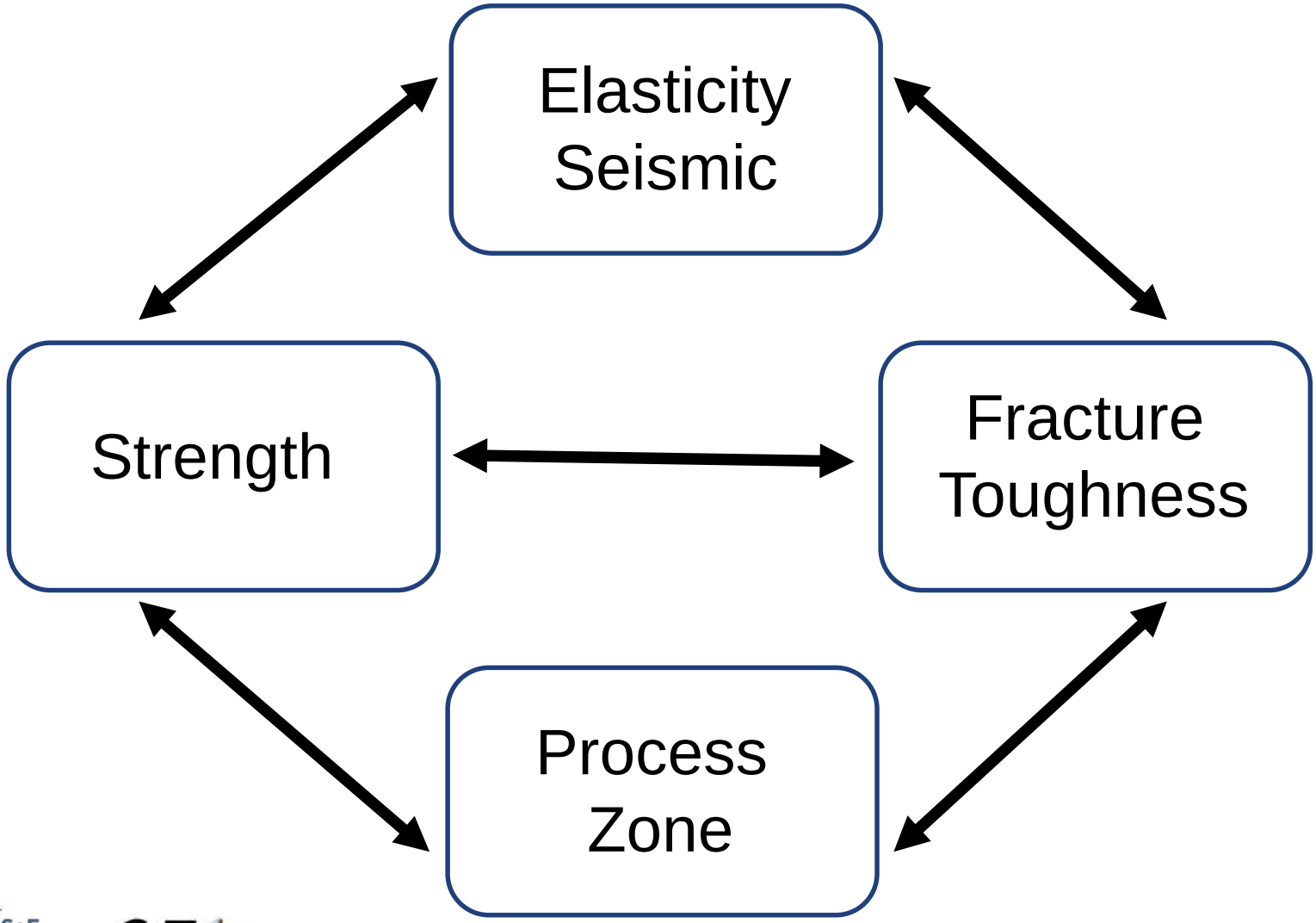
φ	B [mm]	P_m [kN]	σ_t [MPa]	Average σ_t [MPa]	Ratio
0°	39.5	32.39	5.50	5.63 ± 0.11	2.61
	38.6	34.3	5.68		
	40.3	36	5.71		
90°	38.9	74.2	16.07	14.69 ± 2.00	
	38.0	55.9	12.39		
	37.3	69.1	15.60		

Digital image correlation experiments

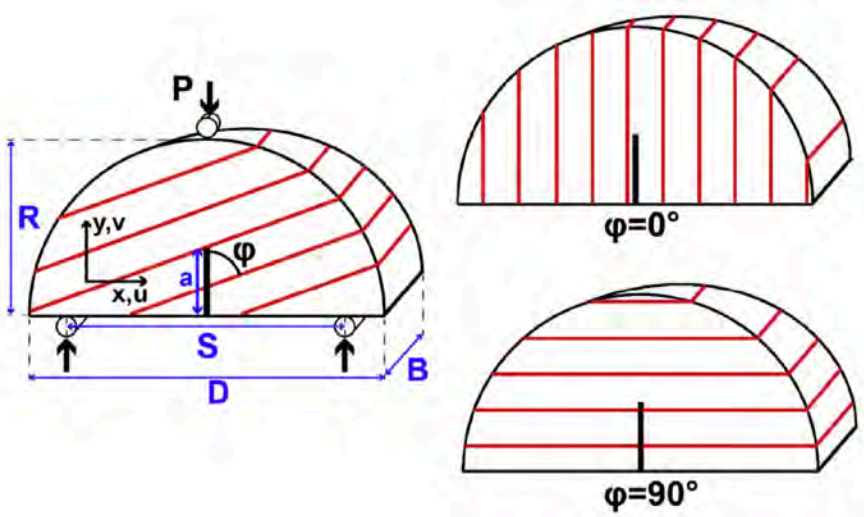


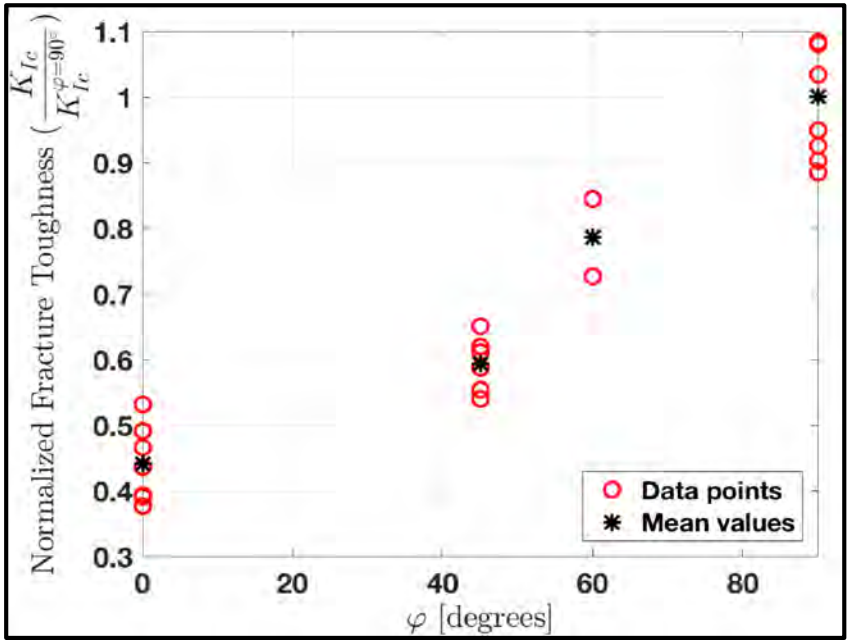


Mechanical anisotropy



Fracture toughness anisotropy





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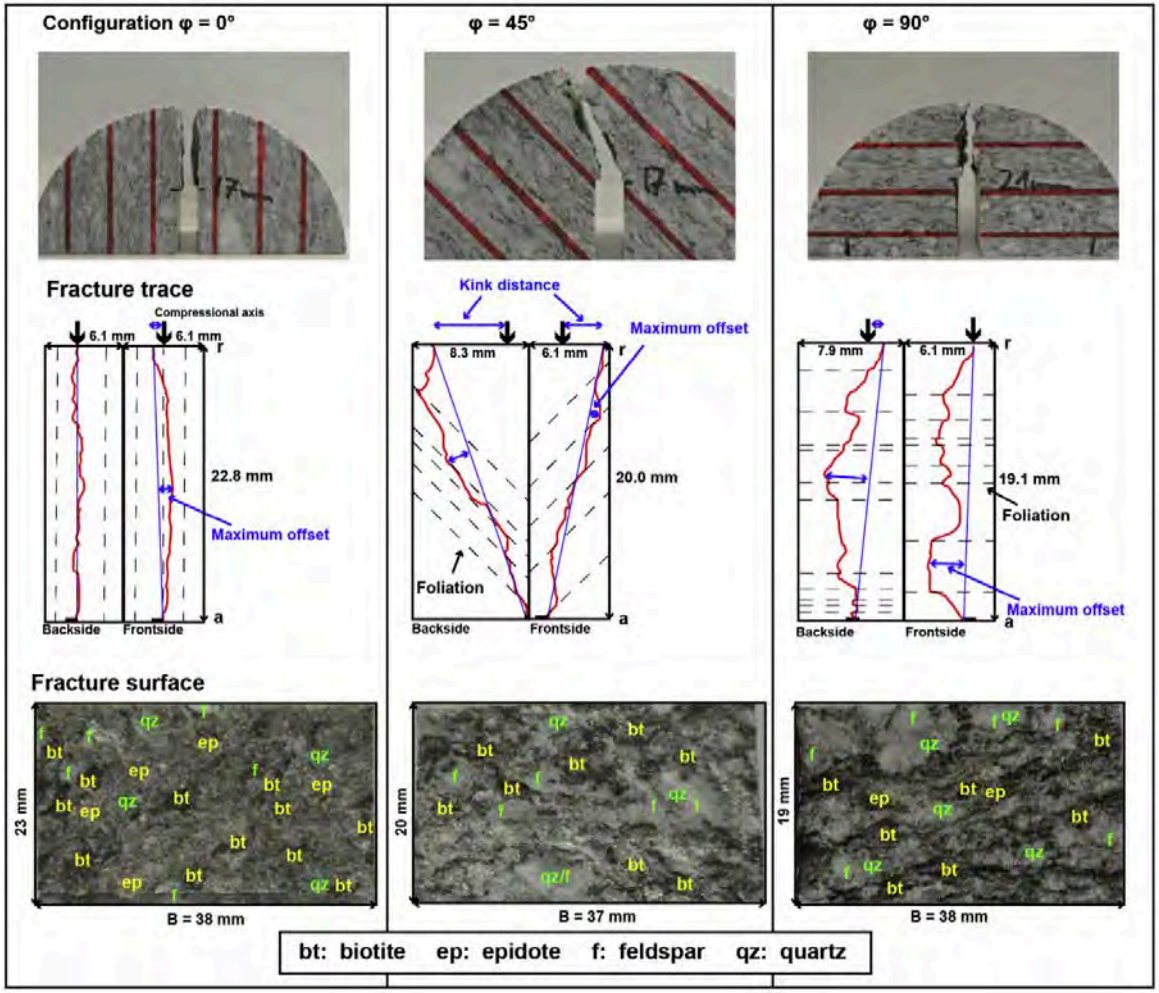
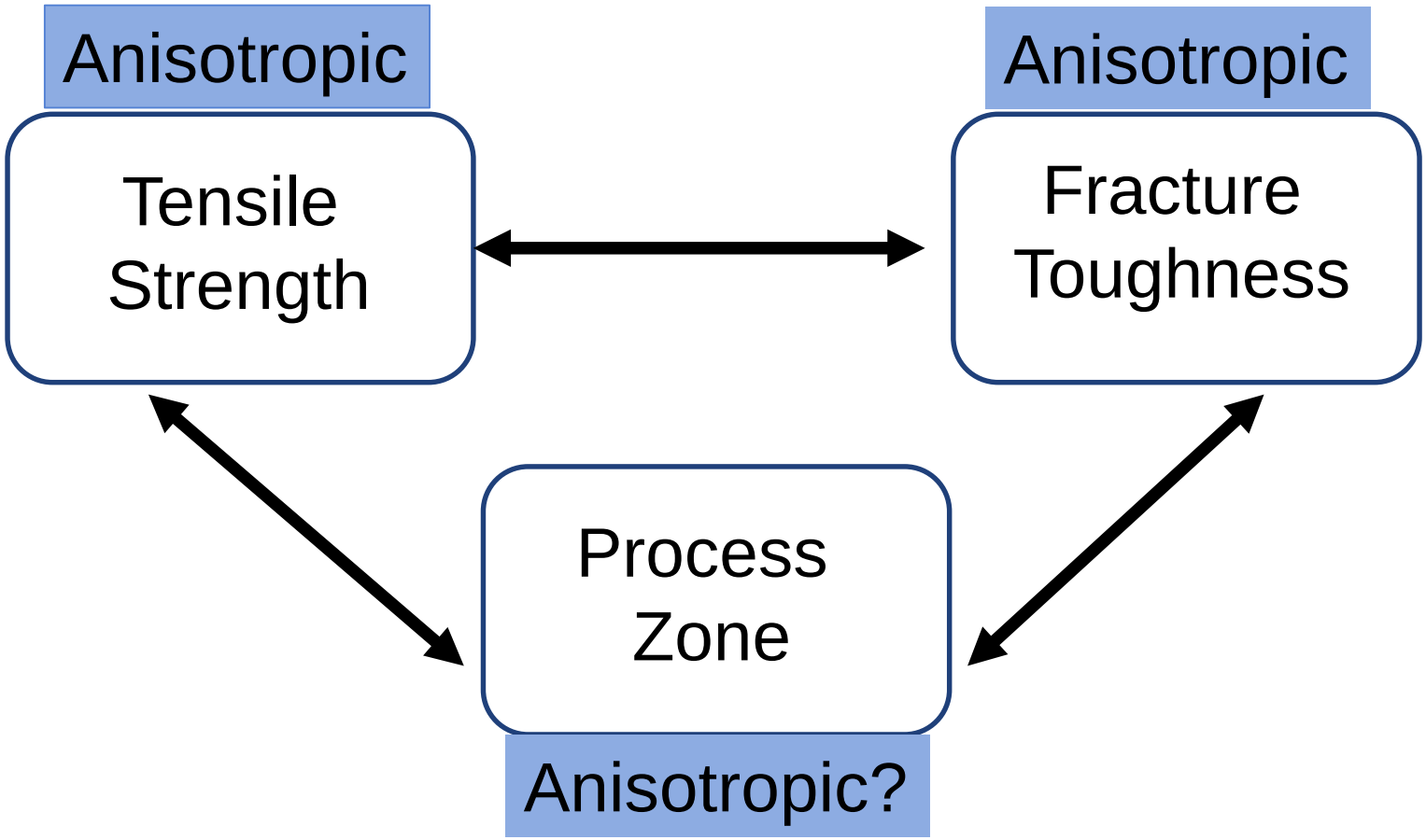
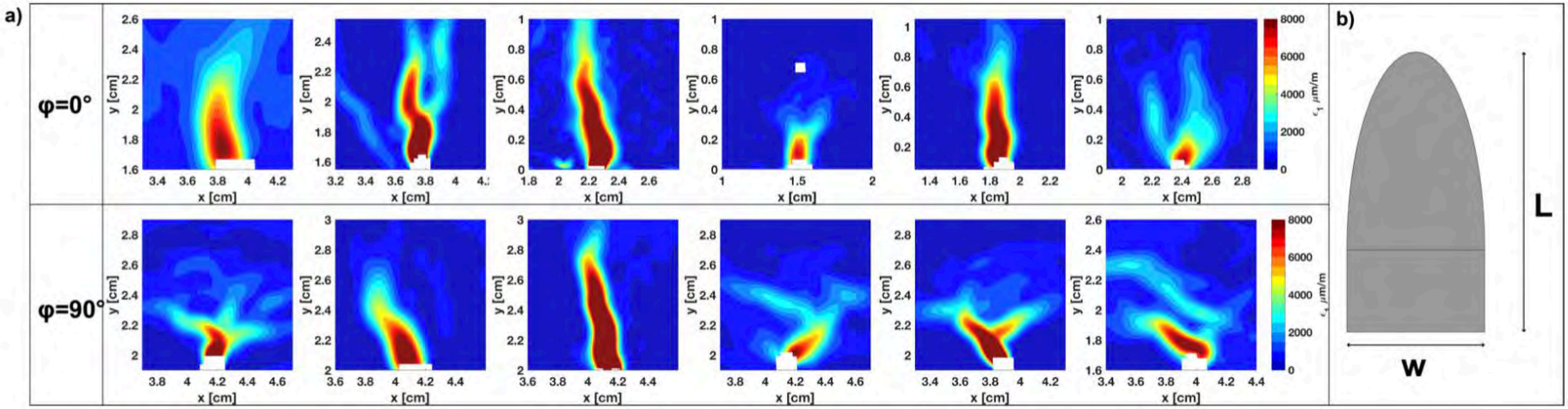
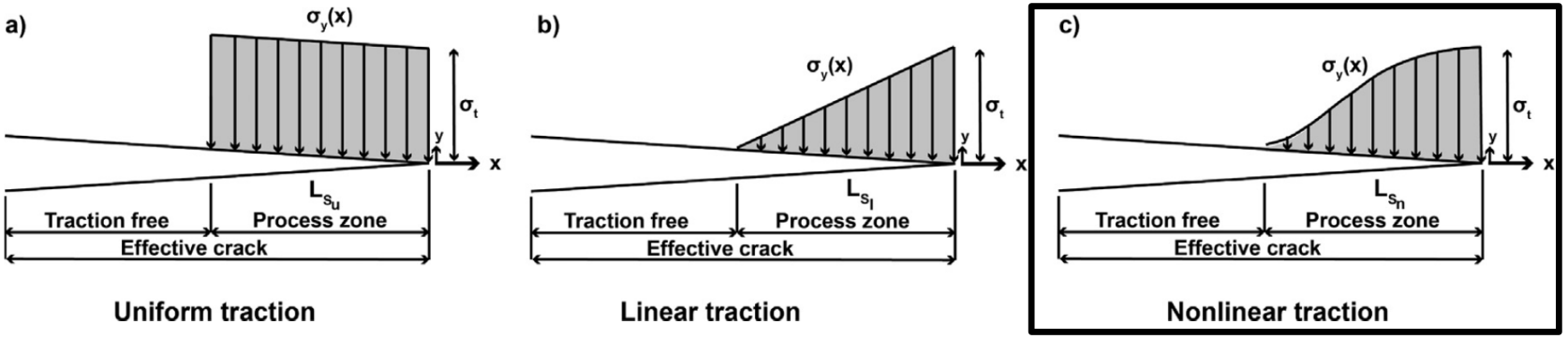


Anisotropy of fracture process zone



Fracture process zone anisotropy





Crack growth in anisotropic media

Anisotropy

Competing factors

in-situ stress

Conclusions:

- Nonlinearity and anisotropy are important features in Grimsel granite.
- Anisotropy can have significant effects of fracture growth near the borehole.
- Anisotropy must be considered in interpreting the results of DUG-Lab experiments.

Suggestion:

- We should plan laboratory measurements in the upcoming Bedretto ISC experiments.

Future research:

- Evaluate different criteria for predicting fracture growth in anisotropic rocks.
- Develop a numerical code to simulate fracture growth in anisotropic rocks.

For more details:

- Dutler, N., Nejati, M., Valley, B., Amann, F., Molinari, G., 2018, On the link between fracture toughness, tensile strength, and fracture process zone in anisotropic rocks, *Engineering Fracture Mechanics*, 201, 56-79.
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Thank you!