

## **Geotechnical and geomechanical characterization of the “fault gouge” of the “Alhama de Murcia” active fault, SE Spain.**

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Here we present the results of the mechanical and mineralogical study of the fault rock of the Alhama de Murcia fault. This fault is one of the most active faults in the Iberian Peninsula. It shows segments partially formed by exhumed fine grained fault rocks (fault gouge FG) with a thickness of more than 50 m developed mainly in a brittle regime. Several strength and strain tests have been carried out, both in-situ and in laboratory, considering different stress orientations in relation to the tectonic fabric. Undisturbed samples encountered from two fault observatory boreholes drilled near Lorca, (FAM-1 and FAMSIS-IGN, of 174 and 40 m depth, respectively) has been used for the laboratory tests. The FG shows a hard soil and soft rock like mechanical behavior with uniaxial compressive strength < 2 MPa and elastic moduli (E) < 12 GPa. The tenso-deformational behaviour at low confining stresses is mainly plastic, acquiring a strain-hardening behaviour at high shear strain. The FAM-FG shows a very notable tectonic fabric controlled by a frictionally weak preferential orientation of the plate like minerals arranged in an anastomosing texture that controls the mechanical strength. The results of the strength tests show the variability of the friction coefficient ( $\mu$ ) depending on the stress orientation in relation to this tectonic fabric. The FG exhibit mineral assemblage similar to the shicsts , suggesting that it has been developed mainly as a result of comminution mechanisms of the hanging wall protolite . The mineralogical composition of the FG contains mica minerals (muscovite and paragonite), quartz (mainly powdered) and traces of feldspar and carbonates. The predominant clay minerals are illite, paragonite, and, occasionally and some kaolinite. In some samples, it has been observed the presence of very sparse graphite and smectite. The plate like minerals are arranged in a preferred orientation (turbostatic microfabric), that surround the quartz porphyroclasts. The friction coefficient ( $\mu$ ) varies between very low values (0.29-0.49) for planes oriented favourably to the tectonic fabric (following the fault failure kinematic), to very high values (>1.19) for planes unfavourably oriented.

# Geotechnical and geomechanical characterization of the fault gouge

## from Alhama de Murcia fault, SE Spain.

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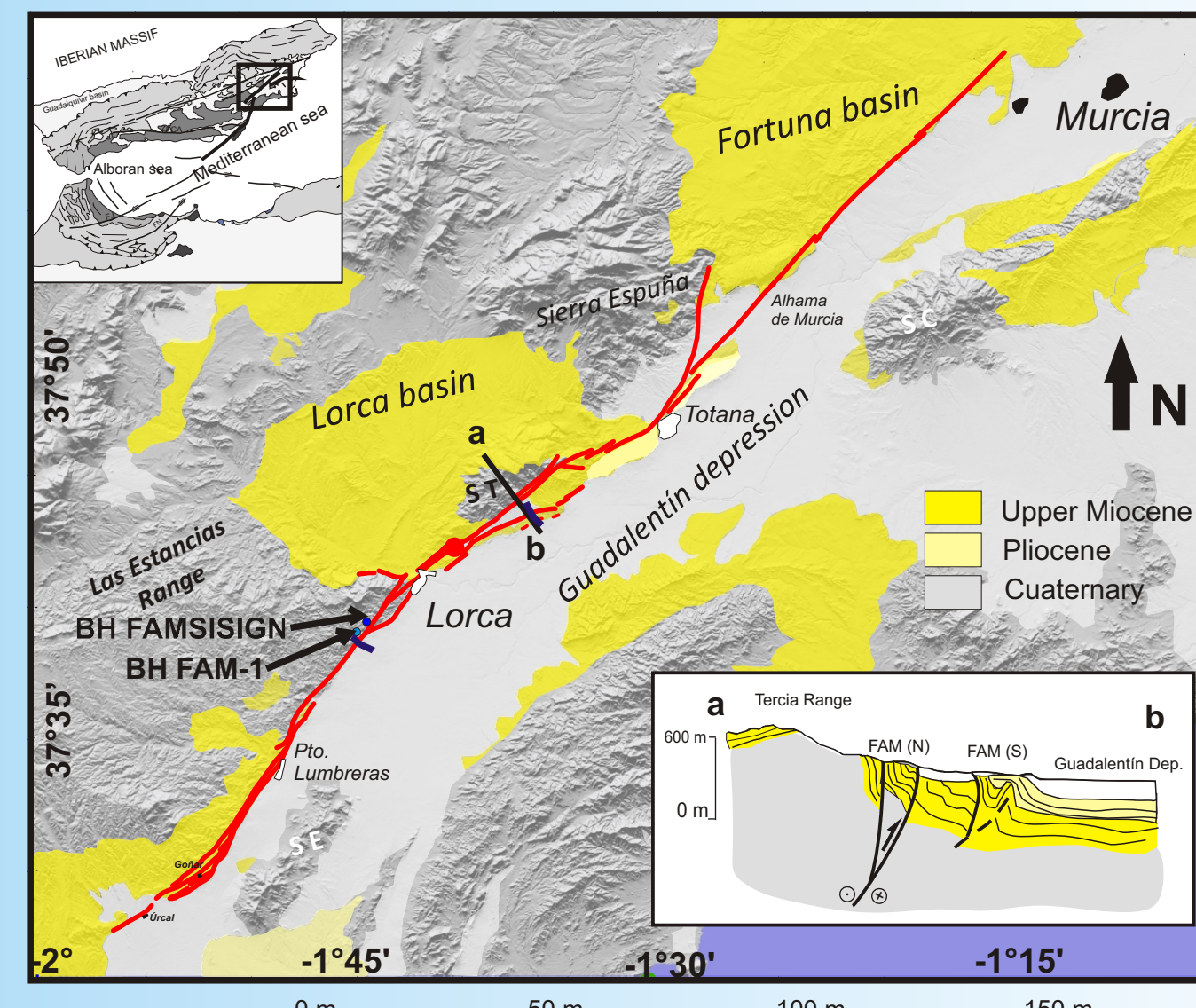
(4) Institute of Earth Sciences Jaume Almera, C.S.I.C., Barcelona. (5) Dpto. de Cristalografía y Mineralogía, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid. 28040 Madrid.



### Geological and Geographic Setting

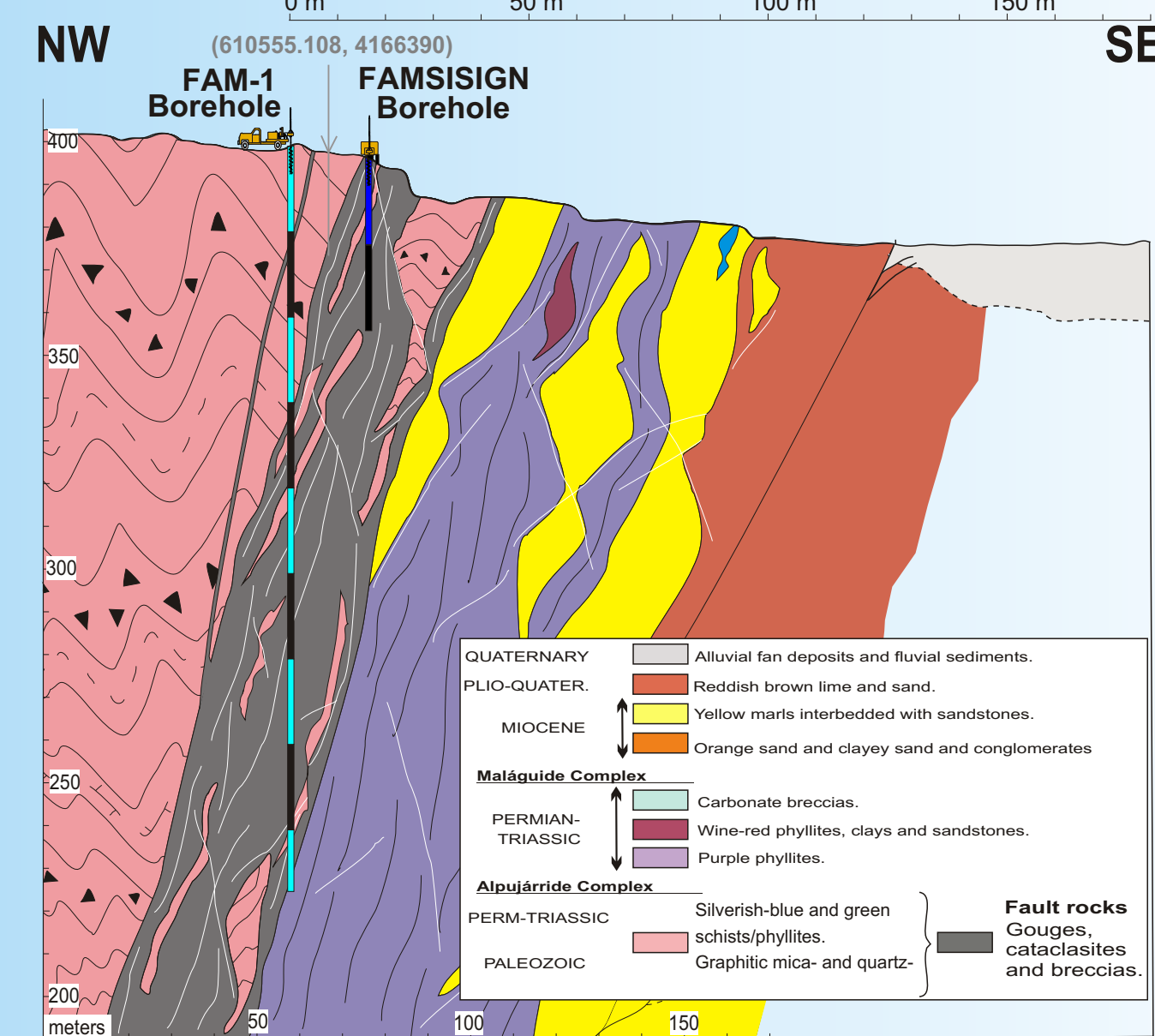
Located in the SE of Spain, the Alhama de Murcia Fault (FAM) is one of the most active faults in the Iberian Peninsula. It shows segments composed partially by exhumed fine grained fault rocks (fault gouge, FG), occasionally over 50m thick, and developed mainly in a brittle regime (Martínez-Díaz et al., 2012).

Location



Rodríguez-Escudero et al., 2014

Boreholes



FAM-1 is a 175 m deep survey using wire-line continuous sampling (PQ-3, 83 mm) until 119,55 m, where the core diameter becomes HQ-3 (61 mm).

FAMSISIGN is a 38 m deep survey using wire-line continuous sampling (PQ-3, 83 mm).

Fault gouge



Properties:  
Density  
 $\rho = 2,35-2,37 \text{ g/cm}^3$   
Atterberg Limits  
LL=25,84% LP=21,20%  
IP=4,64%

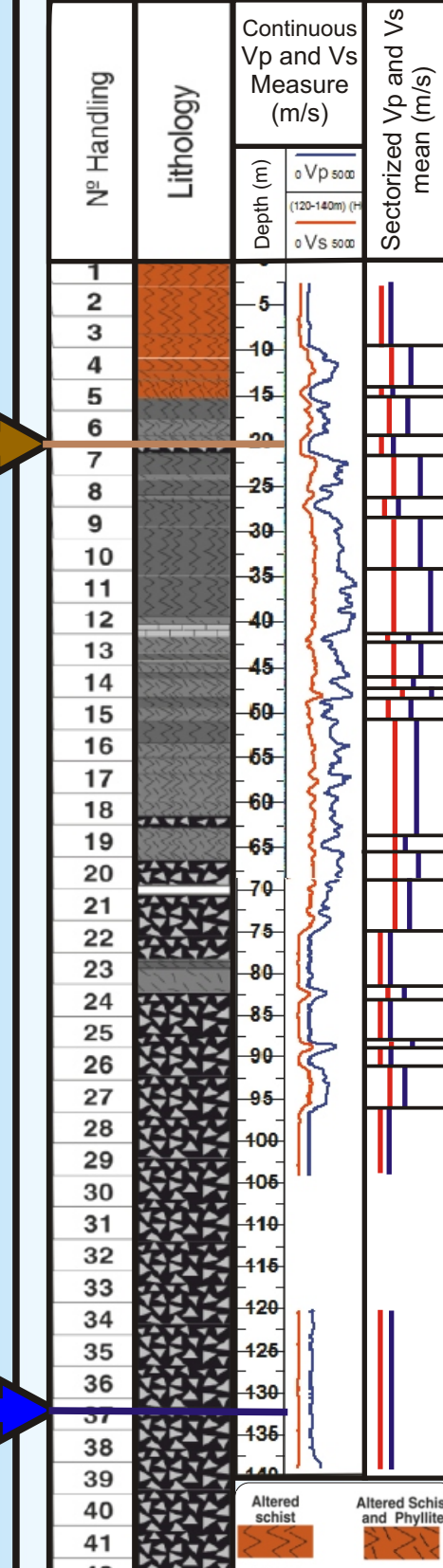
Rodríguez-Soto, 2016



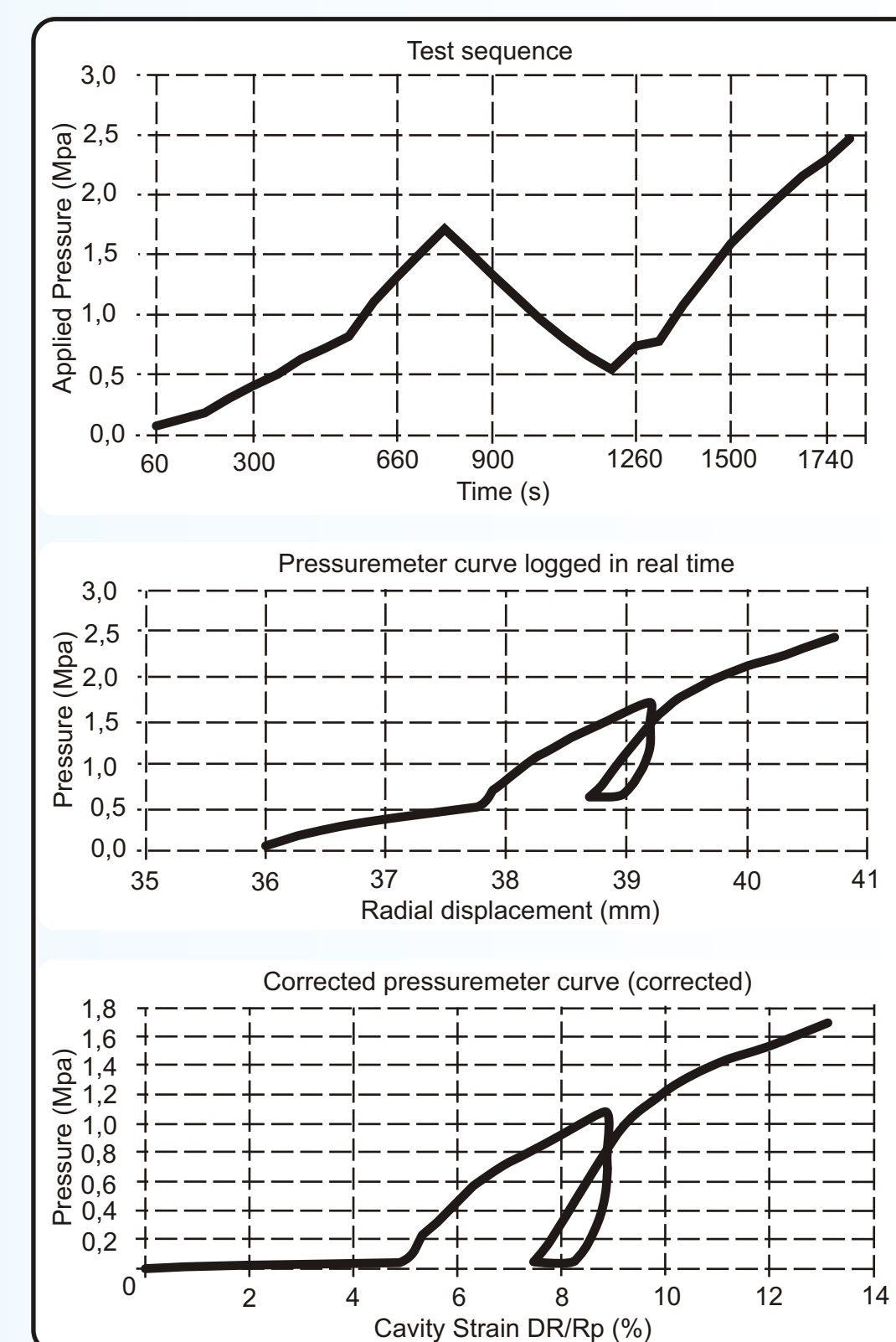
In situ tests



Heterogeneous core sample (Protolith + FG)



8m deep OYO pressuremeter performed in FAMSISIGN borehole.



Full waveform acoustic logs obtained in FAM-1 borehole.

**Acknowledgements:**  
This research was supported by interGEO project (Project: CGL2013-47412-C2-1-P) funded by the Spanish Ministry of Economy, Industry and Competitiveness

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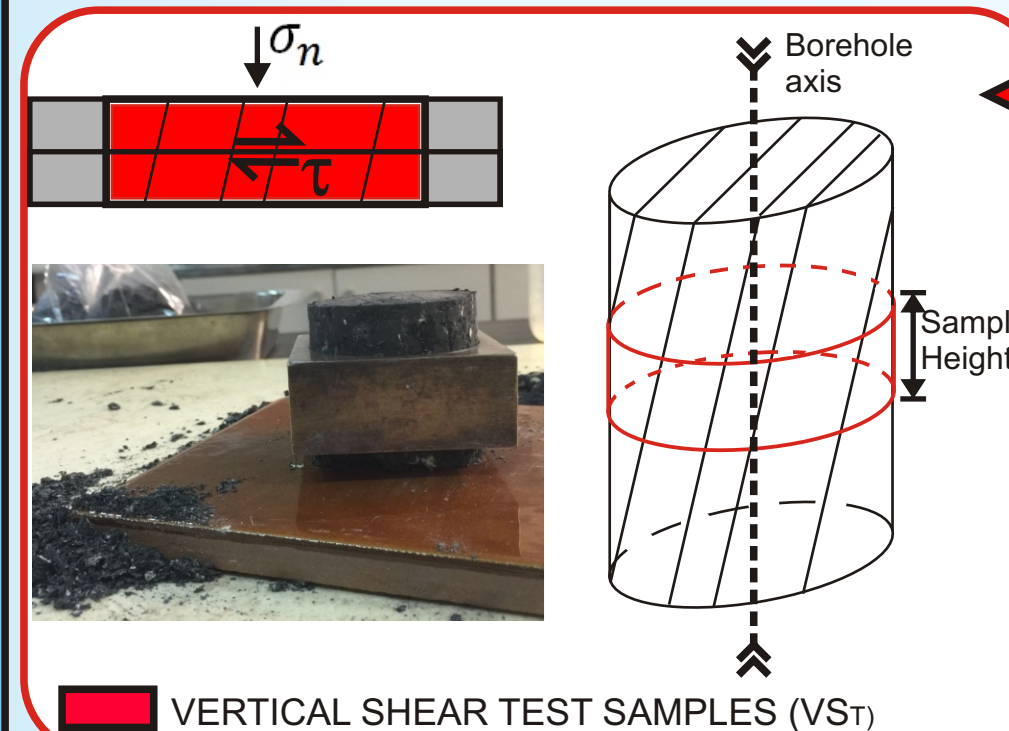
### Tests

Mineralogy and Microfabric

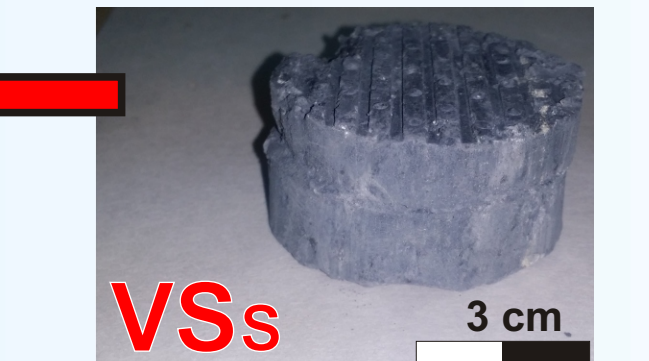
X-ray diffraction test, optic microscopy and Scanning Electron Microscopy

Strength tests

Shear tests

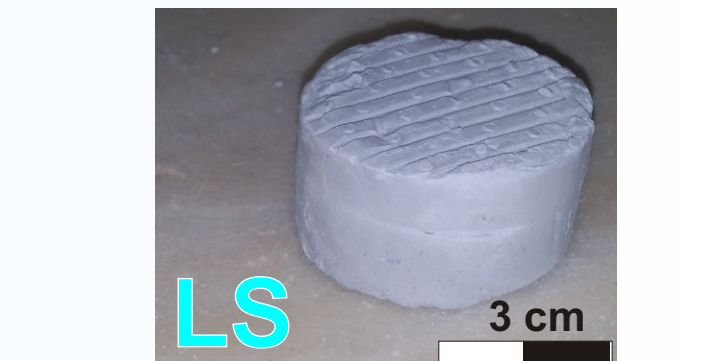


Undisturbed samples



For direct shear tests, slip surface is unfavorably oriented to the tectonic fabric in undisturbed samples. (VSs).

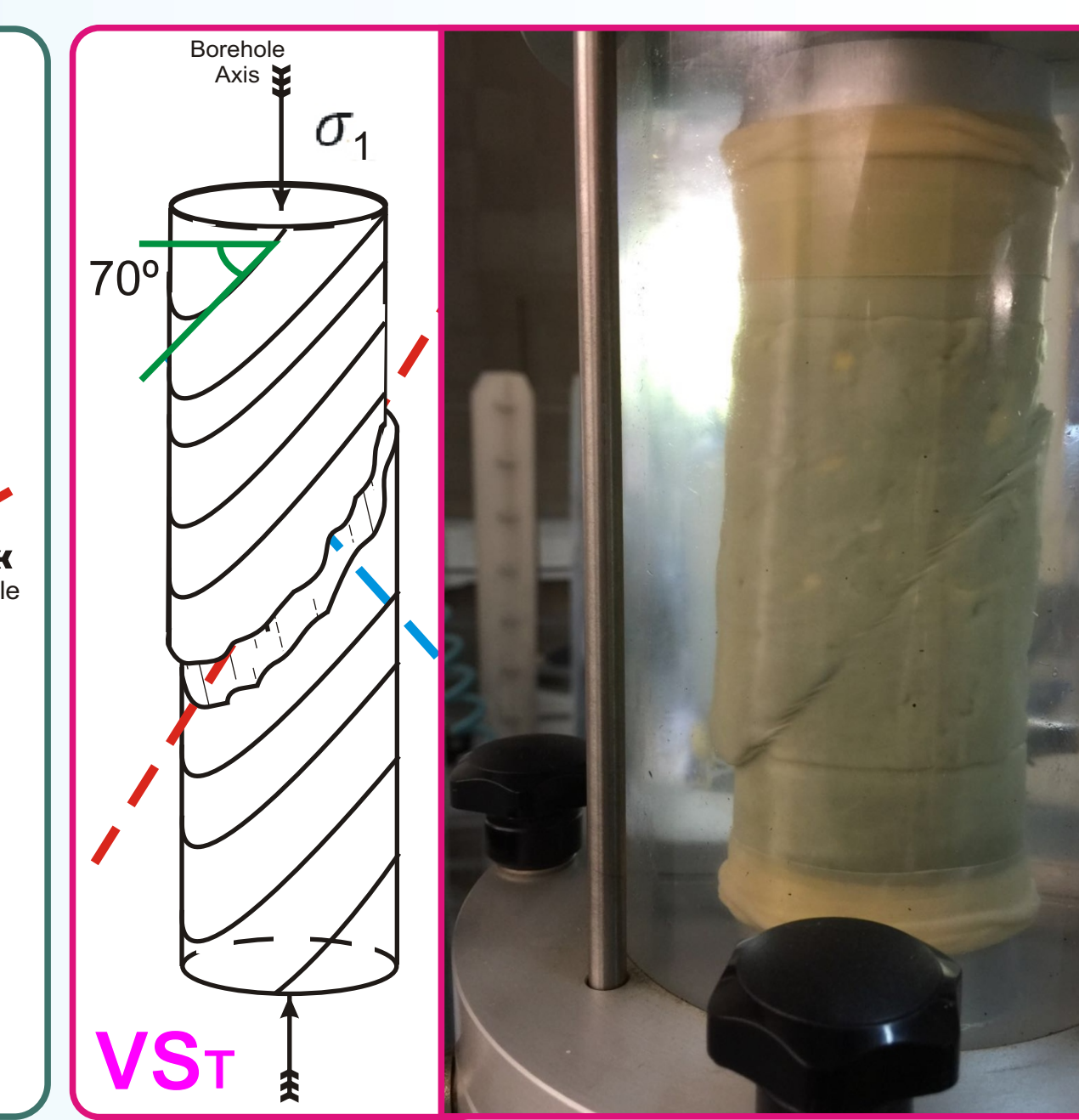
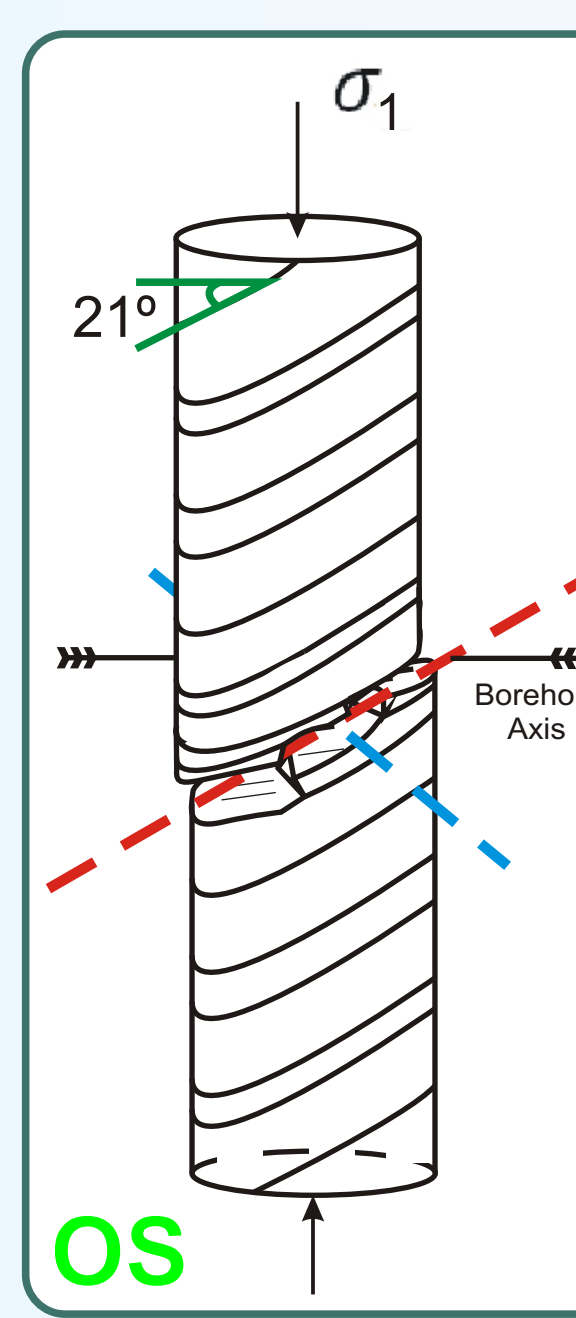
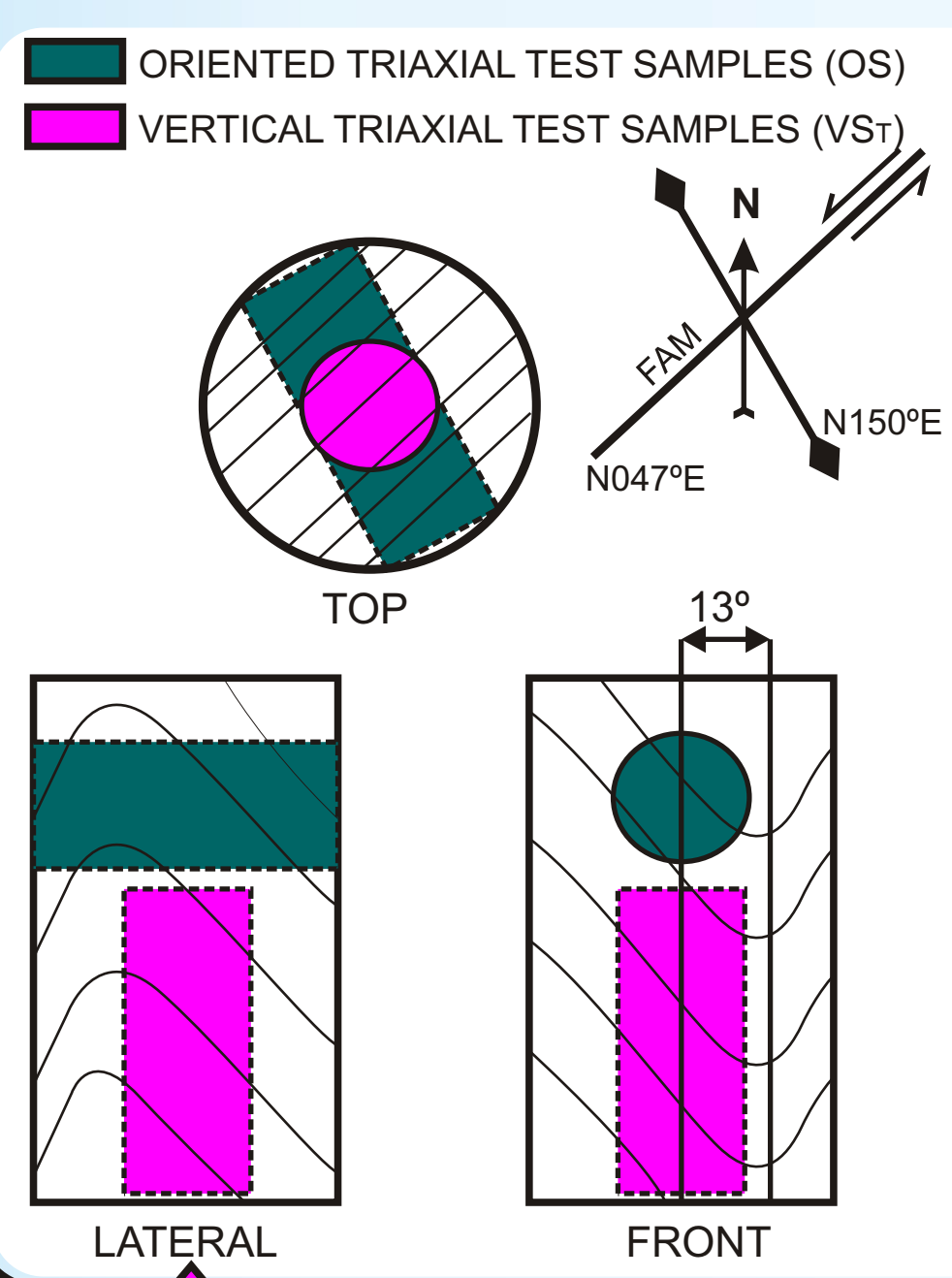
Reconstructed samples



Sieved (0,064mm) and reconstructed FG samples (LS) and pulverized FG quartz samples (QS) analyzed by direct shear tests.

Uniaxial and Triaxial compression tests

Uniaxial tests performed in vertical samples (VST). Consolidated Undrained Triaxial tests performed in vertical samples (VST) and in oriented in the current tectonic stress direction samples (OS).

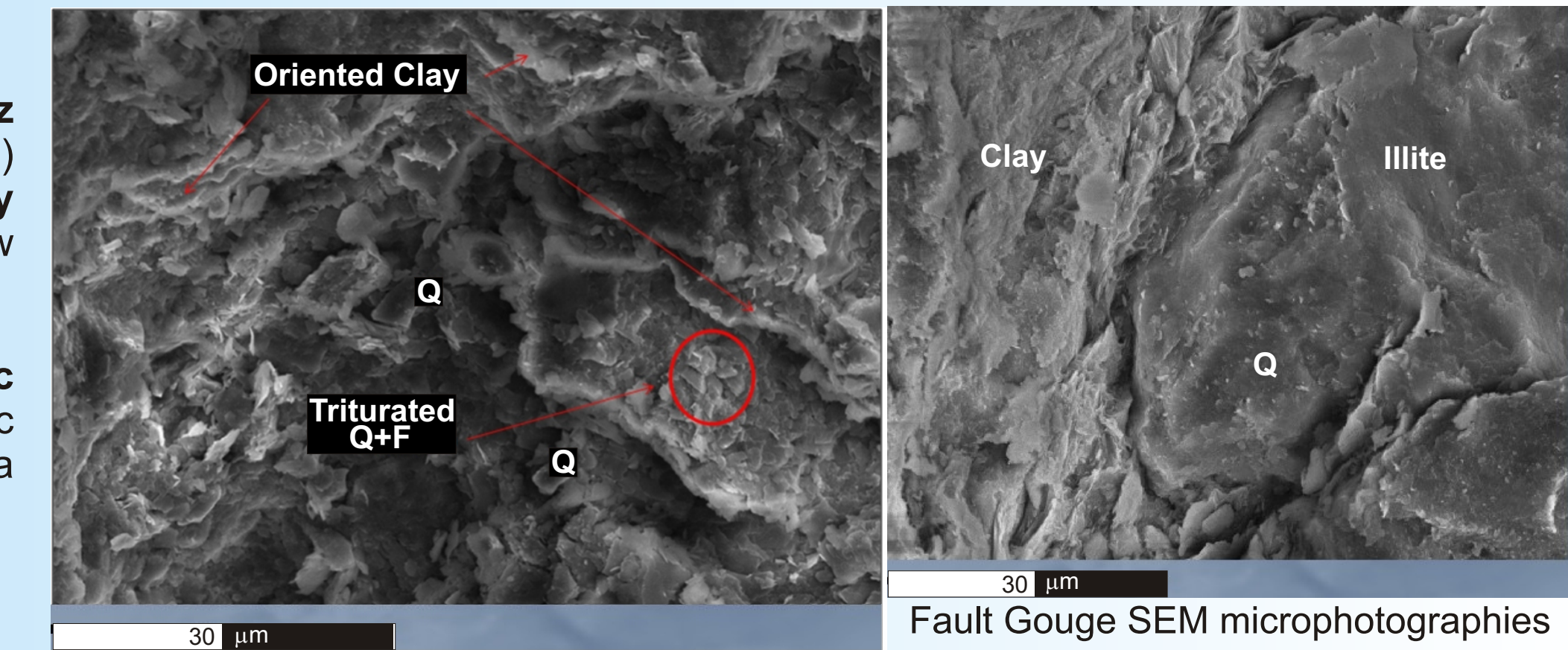


Mineralogy and Microfabric

FG mineralogy is represented mainly by potassic and sodic mica, quartz in similar proportions and carbonates (dolomite, calcite and ankerite) in a lower amount. Chlorite was also found in some samples. Clay minerals are mainly represented by illite and paragonite with a very low amount of kaolinite.

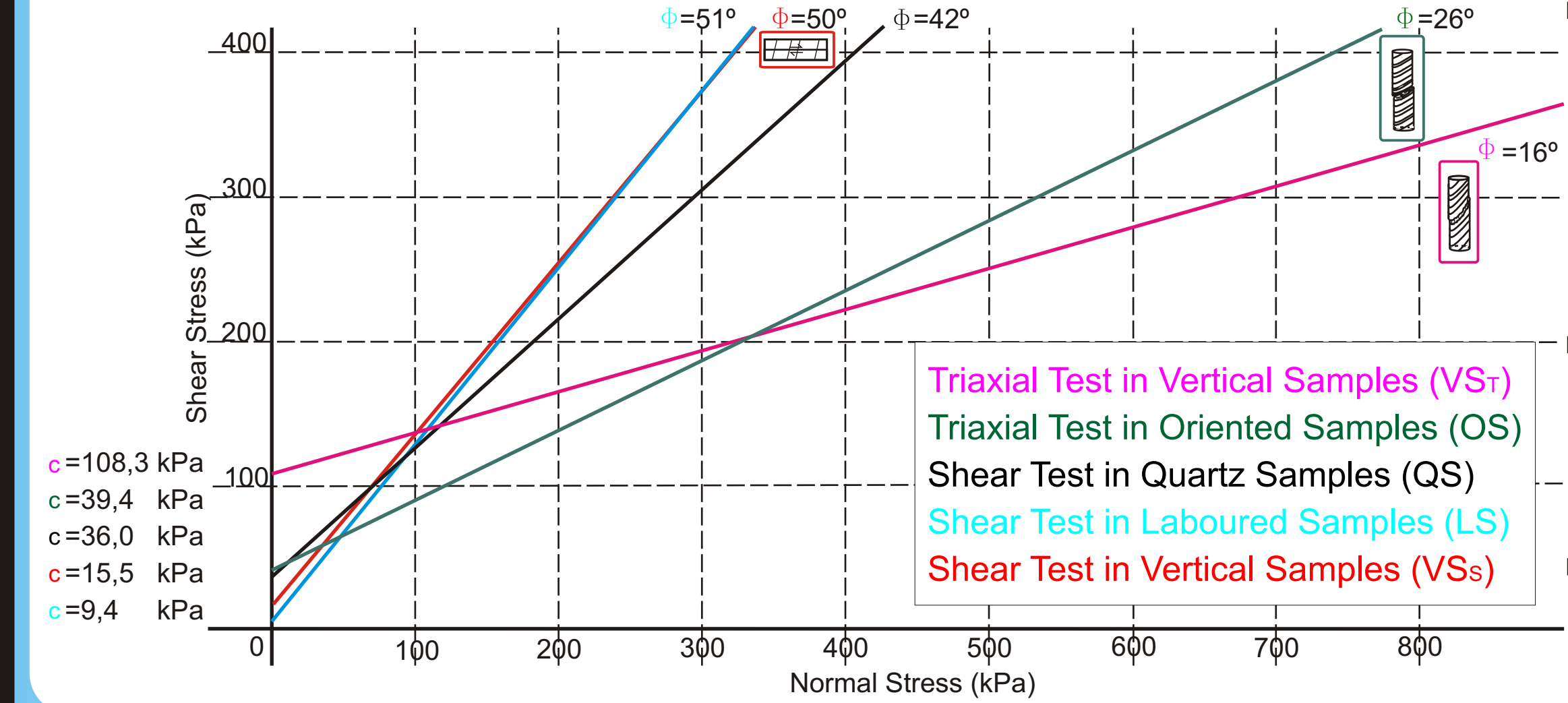
FG presents an anastomosing microfabric (turbostratic microstructure) with a very fine matrix. This matrix, with a cataclastic appearance, is composed by a mineral aggregates mixture with a preferred orientation which are coating a pulverized quartz.

### Results



Strength parameters

Shear stress vs. normal stress curves and c and φ values for the studied samples.



FG shows very low resistance to simple compression. Uniaxial tests show values of  $\sigma_c$  from 0,7 to 1,5 MPa. It was also obtained indirectly by triaxial tests. By this method  $\sigma_c$  fluctuates depending on the tectonic fabric orientation regarding to the axial stress ( $\sigma_c = 0,1 - 0,3 \text{ MPa}$ ).

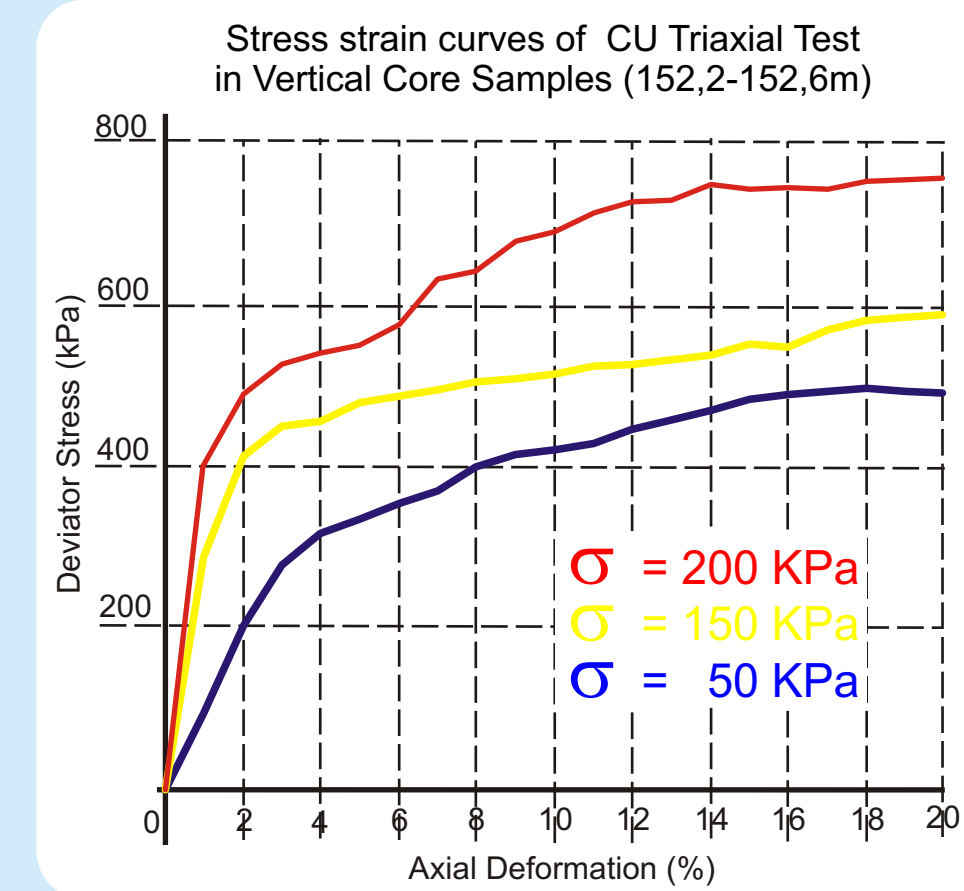
Cohesion values are remarkably low, mostly beneath 0,1 MPa, and fluctuate regarding tectonic fabric orientation.

Friction angles obtained also depend on fabric orientation and applied stresses.

Strain Hardening

FG presents a strain hardening behaviour with large deformation (>10%), manifested by a mild increase of cohesion which can be seen on the shear vs. normal stress curves.

Friction angles tend to stabilize for high deformations showing values around 22°.



Elastic Properties of FG from in situ tests

In situ Pressuremeter test

P1	0,04	Initial pressure of pseudo-elastic phase
P2	1,08	Final pressure of pseudo-elastic phase
P <sub>lim</sub>	2,5	Calculated limit pressure
Ep1	109,3	Cycle Pressuremeter Modulus
Ep	35,68	Pressuremeter Modulus
Gr1	41,2	Cycle Shear Modulus
G	13,8	Shear Modulus

In situ Geophysical velocity test

	Vs	Vp	Vp/Vs	v	E	K	G
	(m/s)	(m/s)			(GPa)	(GPa)	(GPa)
Minimum	891	1595	1,67	0,17	4,23	2,17	3,36
Medium	965	1742	1,80	0,28	4,77	3,56	3,95
Maximum	1138	1994	1,87	0,40	6,20	10,25	5,49

Vs: Secondary waves velocity, Vp: Primary waves velocity, v: Poisson ratio, E: Young Modulus, K: Bulk Modulus, G: Shear Modulus

Material velocity classification

Soil and rock type	Vp	Vs	Vp/Vs
Hard and massive rocks	6000-4200	4000-2700	1,45-1,5
Very stiff	4200-3000	2700-1500	1,5-2,0
Stiff	3000-2000	1500-700	2-3
Moderate stiff but altered	2000-1500	700-400	3-4
Loose and soft	1500-600	400-100	4-6
Soft and saturated	>1300	>100	5-8

Protolith: Fault gouge Salacik Mh., 2012

### Conclusions

- FAM Fault gouge has geomechanical and geotechnical properties between hard soil and soft rock ( $\sigma_c < 2 \text{ MPa}$ ).
- Samples exhibit dramatic differences in strength properties. Friction varies from  $\mu = 0,3$  to 1,2 depending on the applied stress orientation in relation to tectonic fabric. This is related to the phyllosilicates orientation.
- Strain hardening behavior was seen with large deformations which increases material rigidity by compaction. It has been observed in all samples that friction angles stabilize around 22°. This might be related to reorientation of the phyllosilicates.
- In situ, compressional and shear wave velocity and elastic modulus results, show an homogeneous material. However, there is a big difference between indirect and direct tests.

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