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Geophysical and geochemical tracing of fault-zone slip and seal mechanisms through diagenetic evolution

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Fault and fractures properties are responsible of a large part of the fluid transfer properties at all scales, especially in tight rocks. Fault reactivations increase the complexity of the fault zone structure and cause slip reactivation on previously formed fractures. Multiple fracture reactivations can deeply modify the initial fracture properties all along the rocks diagenetic history, leading to alternate periods of fractures sealing and seismic instability. For instance, each slip step may be associated with cementation/dissolution that can be traced through combined geophysical and geochemical analyses.
To that end, we studied a polyphased fault-zone outcropping on a quarry presenting a very smooth surface due to diamond wire saw exploitation of rock blocks. The quarry is composed of carbonates displaying non-porous inner-platform rudist facies of Late Cenomanian. Inside the fault zone, the rock is affected by two en-échelon fracture clusters, the first one being simply formed in mode 1 and cemented, the second one being polyphased (multiple reactivations, cementation and karstification phases). We performed a detailed structural and diagenetical characterization (fractures, karsts and stylolites digitalization on Gocad software; thin section and plug porosity), along with geochemical analyses of carbon and oxygen isotopes ratios on fracture fillings/cements and geophysical measurements at two scales.
First, 1298 ultrasonic P-wave velocity measurements using a piezoelectric source were performed on a rock block (2.4x1.5x1.1m parallelepiped sampled in the fault zone border), along a vertical cross section. Then, more than 200 seismic measurements using hammer source across the decameter scale outcrop. Source and receivers were precisely located using a LIDAR 3D model of the fault-zone outcrop.
First key results from ultrasonic measurements show that the fracture diagenetical/temporal evolution induces an anisotropic Vp variation regarding the dip angle of the raypaths:
- Fracture initial cementation, related to marine eogenetic diagenesis, leads to the obliteration of facies initial Vp variability.
- Multiple reactivations phases relate both to burial mesogenetic geochemical signature under warmer meteoric fluids and leads to angular Vp anisotropy (Vp crossing the reactivated fractures being in average 500m/s lower compared to non-reactivated fractures).
- Fracture meteoric karstification leads to a dramatic decrease of Vp, but slightly increases the overall Vp anisotropy.
Larger scale geophysical measurement will allow us to decipher the spatial evolution of rock and fractures properties across the whole fault-zone and characterize their impact on geophysical anisotropy and velocity magnitude. Thus, seismic anisotropy evolution may help detecting the degree of fracture sealing which is a crucial point in better understanding fluid natural and induced movements in the sub-surface fracture networks.