Characterization of the rock physical properties of a fault zone in the porous-fractured carbonate reservoir of Rustrel-LSBB by different micro-geophysical in-situ and laboratory studies.

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***Keywords**: Fault Zone,Microscale to Macroscale properties*

This study is an attempt to characterize the evolution of joints porosity and matrix micro-porosity (inter, intra and fringe-granular) within the same porous-fractures carbonate sedimentary layer and their impacts on the hydromechanical properties of a thrust-slip fault. Measurements were conducted in situ and in the laboratory by different methods: semi quantitative analyses of various fractures attributes, mechanical tests with a Schmidt hammer, accoustic sounding and porosity analyses on thin-sections. Main result is a strongly different macroscopic and microscopic fault zone's architecture. In the hanging wall, the fractures porosity decrease on a length of 2m from the core of the fault, and it is replaced by a microscopic damage zone, highlighted by a low fringe-granular porosity. This porosity is linked to the un-sticking of the cement to the grains surfaces during the deformation. The initial inter and intra-porosity remain intact. In the footwall, the fracture damage zone is developed over a length of 14m and it is accompanied by micro-pores preferential orientations which are mainly characterized by the fringe-granular porosity. The initial inter and intra-porosity are almost non-existent. The fringe-granular porosity and the micro-cracks have the same orientations. An exponential relationship between the orientation of the pores and their volume characterizes the evolution of these pores into micro-cracks and fractures. The well-preserved initial porosity and the fringe-granular porosity caused by faulting induce a drop of the ultrasound velocity and of the uniaxial compressive strength in the hanging wall rock matrix. In the footwall, the closing of the initial porosity results in an increase of the uniaxial compressive strength and ultrasound velocity. Thus, two properties' evolution of the same sedimentary layer across the fault zone appear characterized respectively by a fall of the macroscopic bulk modulus of about 30-40% linked to the fractures development and by an increase of about 10-20% of the microscopic bulk modulus linked to the initial porosity closing. That evolution is dissymmetric on both sides of the core fault.

INTRODUCTION

Faults are commonly described as zones consisting in a fault core, where most of the displacement is accommodated mainly upon a slip surface, and in a surrounding damage zone. Characterization of the fault zone rock physical properties is a major aim in various fields of earth sciences including the study of the mechanisms of mechanical instability and of fluid flow in reservoirs. Commonly, the fault zone rock physical properties are studied (i) at the laboratory scale on centimeter samples (ii) at the reservoir scale by seismic imaging methods. However, the fault zone properties result mainly in interactions between the matrix properties, joints properties and fault properties.

To improve the comprehension of these interactions, a fault zone was extensively studied at an intermediate scale of several meters by combination of in situ fractures and laboratory matrix deformation analyses. In situ, mechanical tests were conducted with a Schmidt hammer and an acoustic sounding device (Pundit). In the laboratory, porosity analyses on thin sections were carried out on pluri-centimeter square samples. The studied fault zone is located 200 m deep in the *Laboratoire Souterrain à Bas Bruit* (LSBB) of Rustrel (France). It has a pluri-hectometer extension and it affects porous cretaceous limestones of grainstone facies. The fault is N25-80E oriented and it presents a thrust-slip dextral movement with an offset of about one meter. The damage zones thicknesses are asymmetric, respectively of 14m in the footwall and of 2m in the hanging wall. The fault core displays a breccias lens with a length of 5m, with the main slip surface, a clay smear and a fault gouge located in the middle.

FRACTURE MACRO-POROSITY

The fracture porosity has been quantified by adapting the Barton's method of rock mass characterization (Barton, 1991). That method allows define the rock mass quality Q-value from macroscopic joint's descriptions based on tables. The parameters used are the faulting degree (RQD), the joint roughness (JRC), the joint filling (Ja) and the joint set number (Jn). In the fault core, RQD is very low (RQD = 0), the clay content is high (Ja = 4), the joint's roughness are smooth and planar (JRC = 0.5), and high water outflows have been observed during infiltration periods. In the damage zones, RQD decreases steadily on 14 meters in the footwall, and on 2 meters in the hanging wall (Fig1A&B). Joints display a slight alteration of their surfaces, that become more undulating and more rough (JRC= 3; Ja=1) far from the fault core. Many micro-cracks are visible in the footwall damage zone, with an almost null aperture.

MATRIX MICROPOROSITY

The total porosity is of 5 to 20%. It is composed of an intra-porosity (in the micrite grains), a fringe-porosity (pores around the grain surface) only visible in the fault zone and an inter-porosity (pores between the grains). The intra-porosity and fringe-porosity percentages are almost the same in the hanging wall (4-5%) and increase toward the fault core (10-12%). In the footwall, the intra and inter-porosity tend to disappear while only the fringe-porosity remains well-developed (Fig1.C). An exponential relationship is observed between the pores orientation and their volume. Numerous micro-cracks are observed with an orientation that is similar to the orientation of the fringe-porosity biggest pores. Moreover, micro-cracks are mainly localized on the fringe of the grains following their curvature and it can be concluded that they result from the evolution of the fringe porosity.

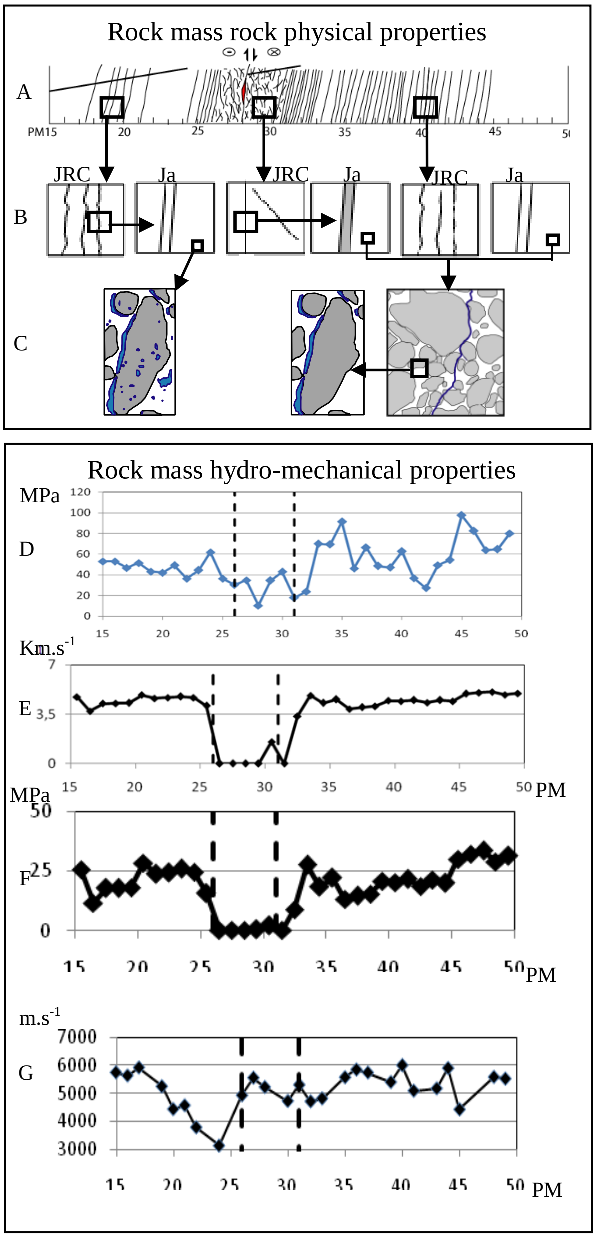

Figure 1 : Rock mass rock physical properties across the fault zone (A)faulting degree (RQD) ; (B) joints roughness (JRC) ; joint alteration here no filling or clay (Ja) ; (C) : micro-porosity evolution and relationship with the micro-cracks ; (D) uniaxial compressive strength ;(E) V_P for rock mass; (F) Young modulus rock mass, (G) Vp on sample .

HYDROMECANICAL PROPERTIES

A series of measures of the uniaxial compressive strength (σ_c, carried out in situ with a Schmidt hammer) have been realized across the fault zone every 10 cm, and values have been averaged every meter (Fig1.D). In the hanging wall, the σc values are almost constant and decrease linearly from 55 to 10 Mpa towards the fault core. In the footwall, values remain high and heterogeneous respectively of 20 MPa near the fault core, 70-90 MPa in the three following meters, and 55MPa in the rest of the zone. The macroscopic rock mass hydromechanical properties have been estimated from the Q-value and from σc (Barton, equation 1 & 2; Fig1.E & F):

$$V_p \approx \log_{10} Q_c + 3{,}5 \text{ (km/s)} \qquad (1)$$

$$E_{mass} = 10\, Q_c^{1/3} \text{ (GPa)} \qquad (2)$$

At the laboratory scale, the acoustic velocities show a high Vp dissymmetry of both sides of the fault characterized by a Vp reduction from 5500 $m.s^{-1}$ to 3000 $m.s^{-1}$, from PM 20 to 24 in the hanging wall (Fig1.G).

CONCLUSION

That study show how important is the scale to characterize fault zone properties. At the macroscopic scale, the Barton's method of rock mass characterization reveals the influence of the jointing dissymmetry of the fault compartments on the bulk modulus. At the microscopic scale, mechanical tests show the influence of pores deformation on the micromechanical's properties. Indeed, we highlight a macro and microscopic asymmetric fault zone with different matrix-fractures interactions depending on the fault compartment: in the footwall, micro-cracks and fractures develop from the fringe-porosity and the initial porosity is closed; in the hanging wall, a fracturing attenuation occurs over a short distance and it is replaced by the development of a microscopic damage zone.

REFERENCES

Barton N. Geotechnical Design ; World Tunneling, 1991, p.410-6.

Barton N. Some new Q-value correlations to assist in site characterization and tunnel design, Int J Rock Mech Mining Sci, 2002; 39: 185-216.

Acknowledgements :

This work is funded by the ANR-CO_2 within the frame of the "HPPP-CO_2" 2008-2012 project.