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Fault Zone Structure and Diagenetic Evolution in Porous Carbonate Rocks, Provence, France

R. Soliva* (University of Montpellier II), P. Labaume (University of Montpellier II), L. Ducarme (Beicip), J. Lamarche (University of Provence Aix-Marseille 1) & J.P. Masse (University of Provence Aix-Marseille 1)

SUMMARY

We provide an analysis of normal fault zones exceptionally well exposed in porous calcarenites from La Fare les Oliviers (Provence, France). The fault zones crop out along their entire length due to their higher resistance to erosion compared to the porous host rock, and provide excellent exposures for detailed study. This high resistance to erosion is due to significant diagenetical and lithological modifications of the fault damage zone (i.e. pore cementation and sediment infiltration from the surface). The fault core zone is characterized by cataclastic shear and constitutes a vertical path for late gravity-driven oxidant fluids assisting karstification. The fault zone composition and structure is therefore the result of the interplay between the fault zone mechanical behaviour and the the Earth surface environement (marine vs continental).

Introduction

Because of the progressive exhaustion of hydrocarbon resources and the increasing exploitation of faulted and fractured reservoirs, the optimization of productivity depends nowadays on the understanding of faults and fractures architecture and composition. Many works based on bore hole data and seismic survey have shown that fault zones may constitute drains or permeability barriers to fluid flow in natural reservoirs. The knowledge about fault zones in siliciclastic context (porous sandstones or layered sandstone/clays units) gave the opportunity to estimate their role on fluid migration or trapping. However in carbonate rocks, the structure and petrophysical properties of fault zones, as well as the mechanisms governing the development of normal faults are not well known although they become important issues to understand fluid migration in such reservoirs.

We provide an analysis of normal fault zones exceptionally well exposed in porous calcarenites from La Fare les Oliviers (Provence, France). The fault zones crop out along their entire length due to their higher resistance to erosion compared to the porous host rock, and provide excellent exposures for detailed study (Figure 1). The normal fault zones formed during the middle Cretaceous as the result of a pre-Pyrenean extension ("phase durancienne").

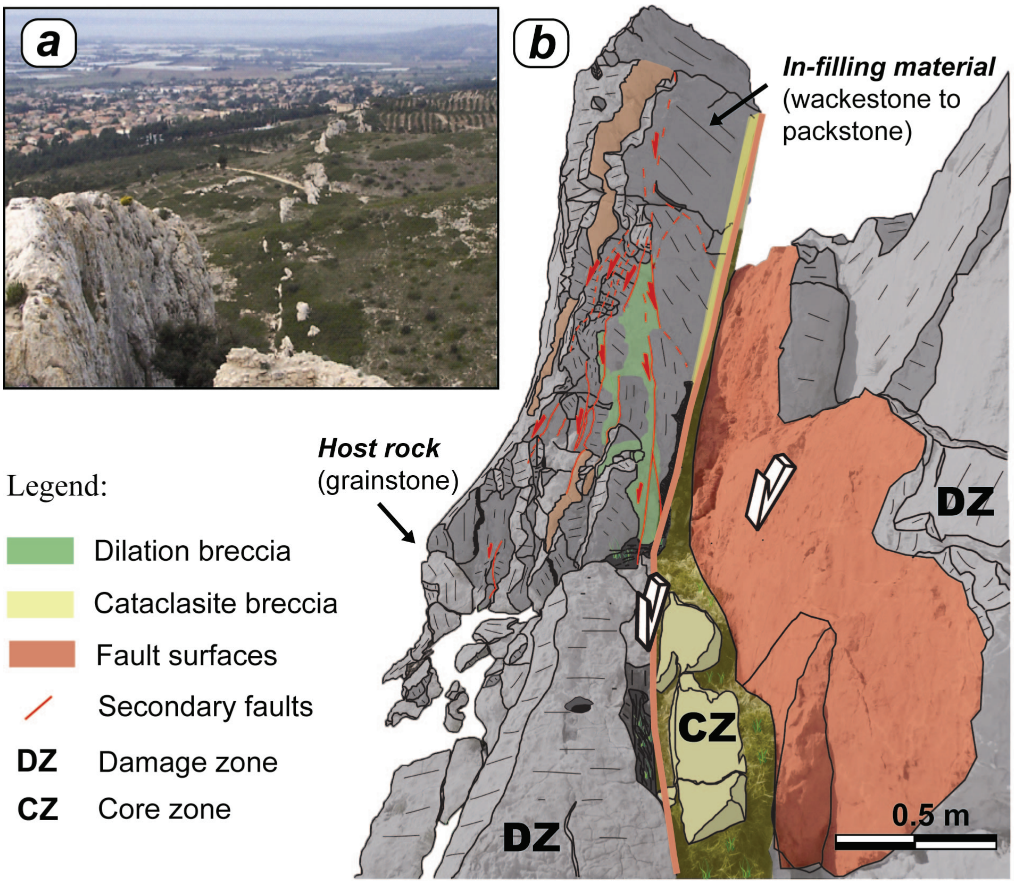

__Figure 1__ (a) Overview of the Castellas fault cropping out as a resistant relief along its entire length compared to the eroded porous host grainstone. The background shows the village of La Fare les Oliviers and the Etang de Berre. (b) Scheme of the studied Belvedere fault zone showing the compartmentalisation of the deformation.

Field work

The « Belvédère fault » exposure (see Figure 1b) has been inspected in detail in the field and in the laboratory on ~30 macroscopic samples and more than 50 thin-sections. The analysis reveals changes both in lithology and compartmentalisation of the deformation. Outside the fault zone, the host grainstone ranges from 5 to 15% of porosity, whereas in the damage zone (see Figure 1b), these pores are sealed by calcite cement. In addition to these diagenetic changes, the damage zone is characterized by non-porous marine wackestones and packstones in-filling, infiltred in opened fractures (tens of cm opening) affecting the host grainstone. Cathodoluminescence analysis suggests that the sparite cement sealing the pores of the damaged grainstone is in chemical equilibrium with the wackestone – packstone infiltred sediment. The damage zone is also affected by late secondary faulting allowing the formation of an isotropic dilation breccia in extensive quadrants. This dilation breccia is formed by coalesced mode I fractures, which created voids sealed by mudstones laminations and coarse sparite. The gravity-driven distribution of the mudstones and desiccation cracking observed in the laminations suggest a vadose context of deposition/precipitation in the dilated volumes. The core zone is a shear and compactant (solution seams) cataclastic breccia composed of micrometric to centimetric size elements of various material from the damage zone. The core zone also shows post-faulting alteration related to micro-karstification. X-ray diffraction analysis reveals that the mineralogy of the micro-karst deposits has similar composition than the iron oxides observed along the regional mid-Cretaceous unconformity lying above the studied formation. This reveals that the cataclastic fault core constituted a preferential vertical path for post-faulting oxidizing fluids incoming from the earth surface in a continental arid environment.

Discussion

The observed variations of fault rock diagenesis and lithology partly reflects changes in fault zone mechanical behaviour. The fault zone reveals a shallow deformation depth (maximum 400 m) progressively evolving from (1) an early stage of opening deformation associated to sediment infiltration, to (2) an intermediate dilational-shear stage, and (3) to a final cataclastic compactant faulting associated to solution seams. Therefore, non-isochore deformation in association with various diagenetic processes (sediment infiltration, cementation and pressure-solution) characterizes the fault zone behaviour from its initiation to the last faulting stages. The early opening deformations require the rock to be brittle and tensile stresses to be applied. This is a reasonable hypothesis which may be inherent to the initiation of fault zones in a shallow context in early-lithified carbonate rocks. In contrast, later stages of fault development evolve as frictional shear, then probably under a compressive state of stresses allowing fault zone compaction without evidences of fluid transfers from the earth surface.

The observed variations of fault rock diagenesis and lithology are also dependent on the surface environment (marine vs continental), since the fault zone has been in connection with the surface. Opening fractures inherent to the early stages are conducts for gravity-driven sediment infiltration from the sea bottom, which provides strong diagenitic and lithologic modification of the fault rock in a wide part of the fault damage zone. In contrast, the cataclastic core zone constitutes vertical path for late, gravity-driven circulation of continental fluids assisting the formation of micro-karsts.

The diagenetic and lithological changes observed in space and time are the results of the interplay between fault zone mechanical behaviour, diagenesis and earth surface environment. These variations may imply strong petrophysical modifications of the fault rock and potentially provide traps or barriers for fluid migrations within the porous host grainstone.