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Mass transfers and volume changes related to pressure solution–fracturing interactions in carbonate rocks: Example of the Oligocene deformation of the Coniacian chalk from the Omey area (Paris Basin, France)

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ABSTRACT

The present contribution documents the interactions between pressure solution and fracturing in carbonate rocks by studying the mass and volume changes caused by the Oligocene deformation of the Coniacian chalk from the Omey area. The isocon method allowed to establish that the decreases in interstitial fluid pressure resulting from the development of one normal fault and related tension gashes within a 11.4 m wide zone induced mass and volume changes within a 30.2 ± 3.5 m wide zone. In the hangingwall as well as in the footwall, the deformed zones adjacent to the fault plane exhibit mass gains (up to 58%) while the outermost deformed zones show mass losses (up to 36%). The pressure solution–fracturing interactions caused a mass redistribution from the most porous zones (outermost deformed zones) to the least porous zones (deformed zones adjacent to the fault plane) linked to differences in stress–strain energy of grain aggregates. The mass transfers strongly controlled the volume changes. Chemical compaction occurred only within the outermost deformed zones where mass losses took place in response to the reduction in solid–solid contacts. The zones affected by chemical compaction show equal mass and volume losses.

1. Introduction

Pressure solution (fluid-enhanced deformation) is considered to be a major mechanism of rock deformation. In the upper crust, pressure solution often plays an important role within zones where it is spatially associated with brittle deformation (Gratier et al., 1999). Therefore, it is crucial to examine how these two mechanisms of deformation, operating at two time scales, interact in order to better understand the complex mechanical behaviour of the upper crust.

Several contributions have focussed on the interactions between pressure solution and fracturing processes by studying natural or experimental deformation in carbonates (Mimran, 1975, 1977; Jones et al., 1984; Carrio-Schaffhauser and Gaviglio, 1990; Gaviglio et al., 1993, 1997, 1999; Richard et al., 2002; Hellmann et al., 2002a,b; Angelier et al., 2006). These studies have provided important data about the pressure solution–fracturing interactions in carbonates rocks but the mass and volume changes due to these mechano-chemical interactions were poorly documented. The present contribution attempts to document these mass and volume changes by studying the Oligocene deformation of the Coniacian chalk from the Omey area (eastern part of the Paris Basin). Previous works (Richard et al., 1997, 1999, 2002) highlighted the interest of this case study in order to examine the interactions between pressure solution and fracturing processes in carbonate rocks. The purpose of this paper is (1) to quantify the mass transfers and volume changes caused by the development of one normal fault and related tension gashes within a 11.4 m wide zone, (2) to determine the spatial distribution of these mass transfers and volume changes, (3) to examine the relationships between the mass and volume changes and fracturing, and (4) to propose a physico-chemical model of the deformation mechanism.

2. Geological setting

An extensional stress field associated with the development of the West-European Rift affected the West-European Platform during the Oligocene (Bergerat, 1987a,b; Coulon and Frizon de Lamotte, 1988a; Coulon, 1992). In the eastern part of the Paris Basin, this extension led to the formation of the Mayence-Sancerre Fault Zone (Coulon, 1992; Fig. 1).

In the Omey area, the chalk is fractured in a 6-km wide N060°E zone which follows the trace of the Omey Fault, the northern border of the Mayence–Sancerre Fault Zone (Coulon and Frizon de

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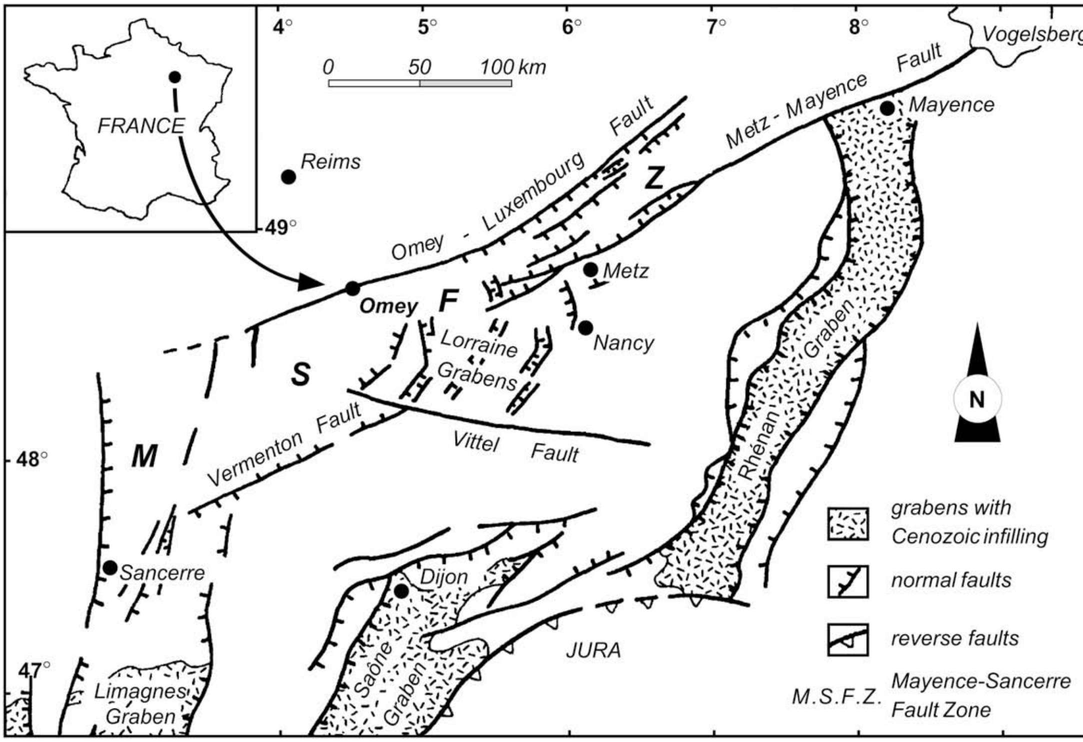

Fig. 1. Structural map of the eastern part of the Paris Basin (modified after Coulon, 1992) showing the Mayence–Sancerre Fault Zone (M.S.F.Z.) resulting from the Oligocene extensional stress field associated with the development of the West-European Rift.

Lamotte, 1988b; Coulon, 1992; Figs. 1 and 2). In this area, the Oligocene extension reactivated a basement fault that led to the development of normal faults and tension gashes at depths estimated between −150 and −250 m (Coulon and Frizon de Lamotte, 1988a,b; Coulon, 1992). These fractures grew in an unconfined phreatic zone where the interstitial fluid was meteoric (Richard et al., 1999).

3. Sampling, methods and analytical techniques

3.1. Sampling

Sixty samples of Coniacian chalk were collected along a 100 m wide working face (Fig. 3A) in the Marson Quarry (Fig. 2). This outcrop shows a 11.4 m wide fractured zone with one normal fault

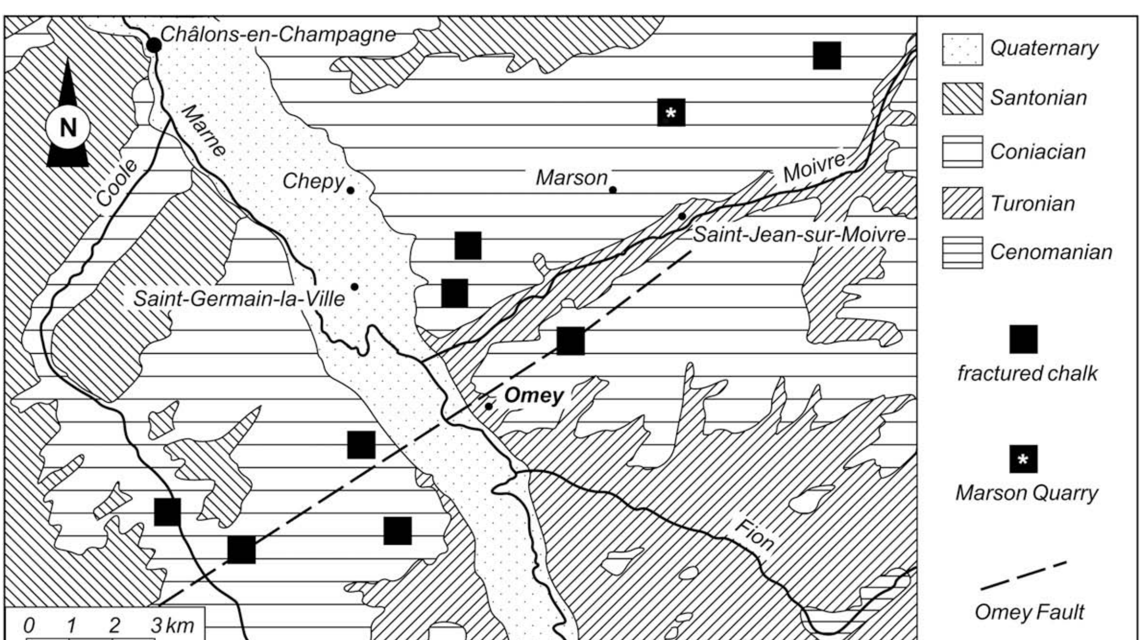

Fig. 2. Geological map of the Omey area with location of the Marson Quarry (modified after Coulon and Frizon de Lamotte, 1988b). The chalk is fractured in a 6-km wide N060°E zone which follows the trace of the Omey Fault (northern border of the Mayence–Sancerre Fault Zone).