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Faulting and deformation in chalk

P. Gaviglio [a,b,*], S. Bekri [c], S. Vandycke [d], P.M. Adler [e], C. Schroeder [f,h], F. Bergerat [g], A. Darquennes [h], M. Coulon [i]

[a] EA 2642 Géosciences, Université de Franche-Comté, 16 Route de Gray, 25030 Besançon cedex, France
[b] IUFM, Fort Griffon, 25042 Besançon cedex, France
[c] Institut Français du Pétrole, 1 et 4, avenue du Bois-Préau, 92852 Rueil-Malmaison cedex, France
[d] FNRS, Faculté Polytechnique de Mons, Géologie Fondamentale et Appliquée, 9 rue de Houdain, 7000 Mons, Belgique
[e] Sisyphe, UMR 7619 CNRS, Université Pierre et Marie Curie, case 123, 4 place Jussieu, 75252 Paris, France
[f] UCL, Dépt Génie Civil & Environnement, 1459 Louvain-La-Neuve, Belgique
[g] Laboratoire de Tectonique, UMR 7072 CNRS Université Pierre et Marie Curie, case 117, 4 place Jussieu, 75252 Paris, France
[h] Service BATir Université Libre de Bruxelles 50, av. Roosevelt, 1050 Bruxelles, Belgique
[i] Laboratoire des Sciences de la Terre, CRA, 2, esplanade Roland Garros, 51100 Reims, France

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ABSTRACT

In chalk, strong deformation at the grain level is associated with faulting. Within a 5–10 cm thick fringe on each side of normal faults, texture modifications were documented and analysed in samples from the Campanian White Chalk. We used SEM observations, image analysis, reconstruction of the porous media and physical measurements. Dissolution and cementation features, together with a reorganisation of the pore space, can be explained by massive fluid transfers. Faulting is interpreted as ductile shearing, which involves slip and dissolution first in shear deformation bands and then along a single fault plane.

1. Introduction

During fault propagation in the brittle field, deformation is distributed along several discontinuities. Generally in the first steps, en échelon arrays of tension cracks and shear fractures, are formed; depending on the mechanical conditions and heterogeneities (lithology, cementation, thickness variations), various associations of fractures may develop and produce different patterns, with transpression and transtension zones with consistent orientations (Hancock, 1972; Segall and Pollard, 1980; Gamond, 1983). When the slip surfaces are able to link to one another, creating more or less lens shaped blocks (Tchalenko, 1970), the displacements increase and the faulted zones become wider. Displacements beside the main fault are distributed over an increasing number of structures (Shipton and Cowie, 2001; Du Bernard et al., 2002). These structures are either sharp discontinuities or deformation bands (Aydin et al., 2006). In deformation bands the texture of the parent rock is modified. Translation and rotation, fracturing of grains and dissolution are the main modes of deformation at the grain scale. The change in texture commonly produces a change in porosity (e.g. Aydin et al., 2006).

At low confining pressure, little or no cataclasis is involved and porosity increases, dilatancy occurs. At high confining pressure, compaction and cataclasis produce a decrease in porosity (Antonellini et al., 1994; El Bied et al., 2002) but the experimental approach shows that dilatancy is produced on each side of the compacted slip bands (El Bied et al., 2002). In limestones, fault zones are common and cataclasis seems to be the predominant phenomenon along the shear fractures, especially in well-cemented rocks. However, dissolution and precipitation are commonly associated, and stylolites and tension gashes are common features (Hancock, 1985).

* Corresponding author. IUFM de Franche Comte, Fort Griffon, 25042 Besancon, France. Tel.: +33 3 81 65 71 82; fax: +33 3 81 82 02 55.

E-mail addresses: patrick.gaviglio@fcomte.iufm.fr (P. Gaviglio), samir.bekri@ifp.fr (S. Bekri), sara.vandycke@fpms.ac.be (S. Vandycke), pierre.adler@upmc.fr (P.M. Adler), christian.schroeder@ulg.ac.be (C. Schroeder), francoise.bergerat@upmc.fr (F. Bergerat), adarque@ulb.ac.be (A. Darquennes), michel.coulon@univ-reims.fr (M. Coulon).

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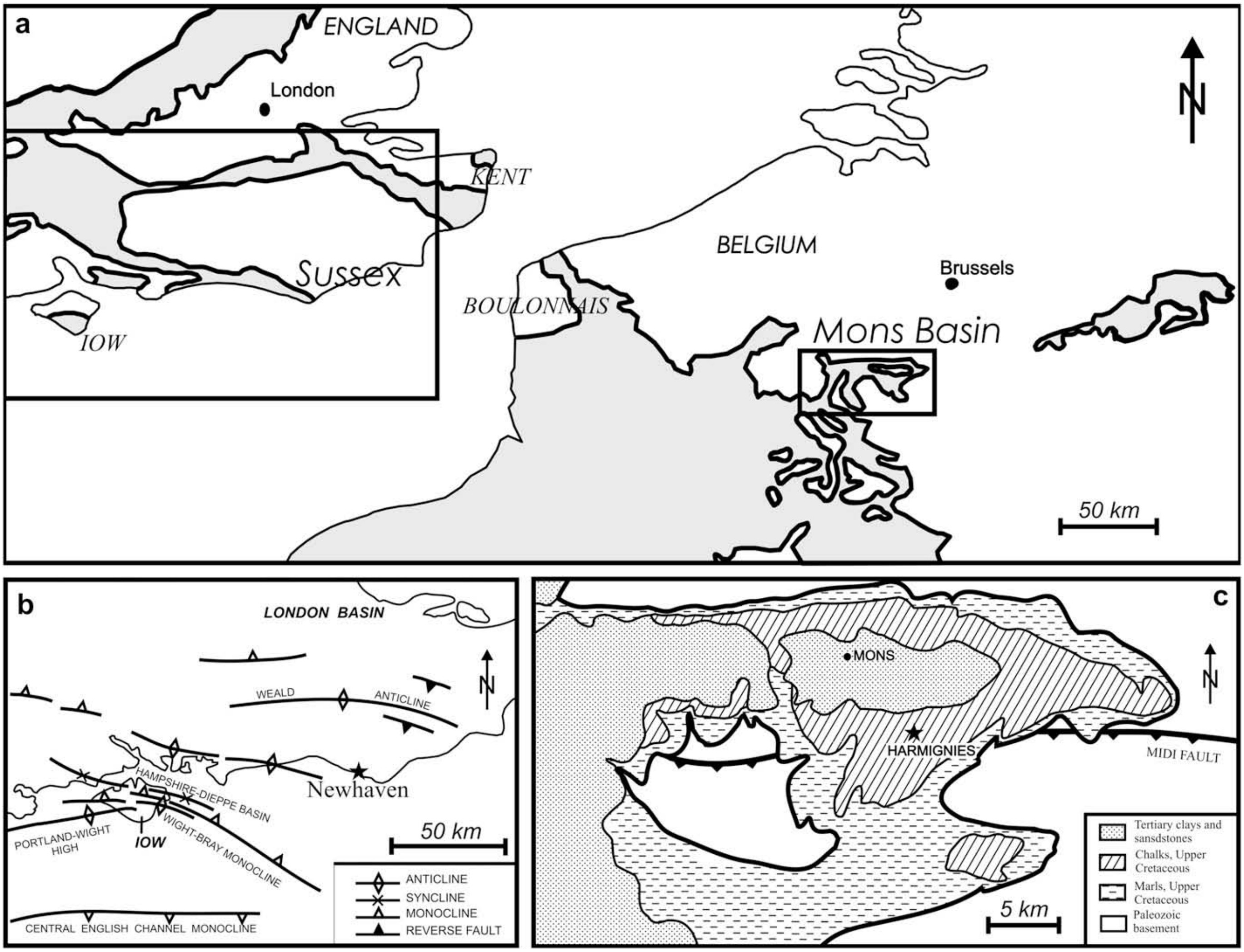

Fig. 1. Regional setting. (a) Location of the chalk basin (grey areas) in northwestern Europe. (b) Sussex. (c) Mons basin. IOW: Isle of Wight; stars: locations of the investigated sites (Newhaven and Harmignies).

Tondi et al. (2006) reported three major processes involved in faulting of grainstones: strain localisation (forming compaction bands), pressure solution and shearing of stylolites. When pressure solution occurs inside the compaction bands, it induces shearing and massive cataclasis with stylolites. Tondi (2007) emphasises the effect of the pressure solution overprinting earlier compactive shear bands.

Fluid circulation is a major factor in faulting; crystallisation features at any scale are evidence of the close relation between block displacements and fluid migrations. Fault-related permeability is obviously a predominant factor in rock deformations. Caine et al. (1996) reported that the fault core (where cataclasis and anastomosed slip surfaces are predominant) and the damage zone (formed by related microfaults and tension gashes) form contrasted media. The permeability in the fault core is bound to be lower than in the damage zone. The actual behaviour of the fault depends on geometry, thickness and connection of the two zones. In any case, a fault or a fault zone is a discontinuity that may modify fluid circulations. It may be a conduit or a barrier, or behave as a combined barrier–conduit system.

Chalk is a homogeneous material in which macroscopic and microscopic observations do not allow detection of major modifications as they do in sandstones or even carbonate grainstones. Diagenetic and tectonic strains in chalk can be detected and quantified using SEM observations or physical measurements (Mimran, 1975; Mimran and Michaeli, 1986; Jones and Leddra, 1989; Matthews et al., 1996; Borre and Lind, 1996). The mechanical behaviour of chalk is multimechanism stress dependent, with a strong hydro-mechanical coupling: it exhibits elasto-brittle behaviour at low to mean stress levels. At high stress levels the chalk follows an elastoplastic constitutive law with pore collapse followed by hardening (Schroeder, 2003). Field observations and measurements of physical characteristics carried out on White Chalk from the Mons Basin have shown evidence of significant horizontal shortening by dissolution against fault planes (Gaviglio et al., 1999; Angelier et al., 2006); the matrix strains detected are concentrated in 50 mm thick bands bordering the fault planes on either side. By studying this material our purpose was to try to understand the interactions at the grain scale between the fault plane and the calcite matrix and to propose a model for this atypical faulting process. Faults having undergone only one brittle deformation phase were selected.

2. Investigated sites

Two sites with well known normal faulting were selected in the Campanian White Chalk (Fig. 1). In both cases this chalk is a very pure material with a porosity close to 40%: