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Morphology, intersections, and syn/late-diagenetic origin of vein networks in pelites of the Lodève Permian Basin, Southern France

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Abstract

This paper presents the results of a field study aiming to describe and to interpret new types of relationships between vein sets. Three vein sets of the Lodève Permian Basin (Languedoc, Southern France) were studied. They consist of a family of N100E–N120E, widely opened sinuous veins with a composite infilling (sparite, calcite fibres, barite), hereafter called Sparitic Sinuous Veins, and of two orthogonal families of slim veins presenting a fibrous infilling of calcite, and oriented N10E–N20E and N90E–N100E, respectively. These two latter families are hereafter called N20 Fibrous Slim Veins and N90 Fibrous Slim Veins. The intersections between the three vein sets are shown to be original and more complex than those classically observed in the case of joint sets (abutting, crosscutting, …). The analysis of these intersections permitted a relative chronology of formation of the different vein sets to be established: the N20 Fibrous Slim Veins post-date the N90 Fibrous Slim Veins, which themselves post-date the Sparitic Sinuous Veins, the two former vein sets being shown to reopen contemporaneously.

Furthermore, the vein intersections were not as simple as expected. Indeed, the successive propagating cracks of one set could in certain cases crosscut the pre-existing veins of an earlier set, or could be stopped at contact with earlier veins in other cases. This implies a physical change in the interface between the pre-existing veins and the host rock (pelites) during the formation of the latest cracks.

Taking into account the well-known tectonic history of the Lodève basin, and the field observations (vein features, intersections, …), the origin of each vein set is discussed. We put forward that the Sparitic Sinuous Veins formed during the burial history of the basin: their morphological characteristics suggest that they appeared during the phase of active compaction of the basin, in response to the Permo-Triassic NS extension, and that their formation was assisted by fluid pressure. Second, we propose that the two orthogonal sets of Fibrous Slim Veins formed during the same extensional phase, their formation being favoured by the tectonic relaxation occurring at the beginning of the uplift of the basin at the end of the Permian. We attribute their particular characteristics (straight morphology of joints but systematic mineral infilling) to their origin in a medium already compacted but still incompletely lithified, and containing a large amount of fluids. We suggest that the fracturing history of the Lodève basin occurred in the time interval between the Late Permian (Thuringian) and the Middle Triassic (Anisian).

Finally, the observed evolution in the propagation path between the Sparitic Sinuous Veins and the N90 Fibrous Slim Veins is discussed, and bears out the idea that the rock material was not completely lithified when the vein sets formed.

Keywords: Vein intersections; Pelites; Lodève basin; Compaction; Burial and uplift; Thuringian; Anisian

1. Introduction

In spite of a hundred years' studies on joints (Pollard and Aydin, 1988) and veins (Durney and Ramsay, 1973; Hancock and Atiya, 1975; Ramsay, 1980; Cox, 1987; Urai et al., 1991) many fundamental aspects of mode I fracture morphology and genesis still have to be understood. A basic one is that of the morphological and mechanical transitions between joints (long and straight planar discontinuities showing opening displacements with no appreciable shear displacement) and veins (discontinuities often presenting en-échelon or sinuous geometries and significant opening but no shear displacement, filled by a cement derived from hydrothermal processes). These two fracture types are

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usually considered as end members of mode I fractures (Bahat, 1991; Rives, 1992). However 'transitional' geometries (i.e. veins presenting morphological characteristics close to that of joints) are scarce. They deserve special attention in that they could help to determine the driving mechanisms leading to the various types. What do individual 'transitional' fractures and corresponding fracture network look like? Are they linked to given rock types or rheology? More generally, the mechanisms leading to mode I fracturing remain most often obscure and it would help to establish whether, in particular conditions, tensile stress of particular origins could generate particular types of mode I fractures, thus escaping the equifinality principle often evoked about jointing (Engelder, 1985, 1987; Laubach et al., 1998). Such an approach aiming to link a fracture network to its driving mechanisms needs a sharp and multiscale definition of 3D architecture of the fracture network including fractography and infilling within a well defined thermo-hydro-mechanical context.

In this paper we present such an attempt, based on the analysis of a fracture network developed in the Lodève Permian basin (Southern France), in a siliclastic environment (pelites and sandstones). The studied fractures consist of a nearly orthogonal network of mode I fractures. Some of them are clear veins, and others exhibit the rectilinear geometry and parallel distribution of joints but limited length, variable opening and calcite infilling, which may be seen as characters of veins. Thus they correspond to transitional mode I fractures, called 'Slim Veins' hereafter. The particular case of the Lodève basin enables us to address the following questions:

- What can we learn about the relative chronology and mechanisms of various mode I fracture sets when vein intersections are varied enough to push the analysis beyond the simple abutting/crosscutting relationships criteria (Hancock, 1985; Bahat, 1987; Rives et al., 1994)?
- What is the impact of high clay content both on morphology and driving mechanisms of mode I fractures, especially in the early steps of deformation?
- What are the characteristics of tectonic-related veins formed in incompletely lithified rocks, given that the aspects of soft-sediment deformation already described in the literature do not consist of organized fracture sets but include sedimentary structures [sediment flows (Jones and Omoto, 2000; Van Loon, 2002), loadcasts (Van Loon, 2002; Nogueira et al., 2003), slumps (Schwehr and Tauxe, 2003), laminations (Kawakami and Kawamura, 2002), …] and particular brittle structures [kink bands (Kimura et al., 1989), sigmoidal veins (Kimura et al., 1989; Brothers et al., 1996), faulting (Petit and Laville, 1987; Jones and Omoto, 2000; Van Loon, 2002), shear zones (Maltman, 1988; Kimura et al., 1989), …]?

At Lodève, the excellent outcropping conditions linked with quick erosion of the pelites in a Mediterranean climate permit the analysis of fractures sharply defined by their white calcite infilling within red pelites. This situation has triggered numerous field investigations concerning various aspects of the fracturing of the Lodève Permian basin such as geometry, organization, fractography, present-day fluid circulation, etc. (Santouil, 1980; Lopez, 1987; Rives, 1988; Pueo, 1993; Petit et al., 1994; Salti, 1995; Bruel, 1997; de Joussineau and Bazalgette, 1998; Jalabert, 1998; Bruel et al., 1999; Bazalgette, 2000). The widely studied regional context in terms of main tectonic events (listed in Saint Martin, 1992), sedimentology (Laversanne, 1976; Capus, 1979; Clément, 1986; Odin, 1986; Odin et al., 1986; Rolando et al., 1988; Lopez, 1992; Becq-Giraudon and Van Den Driessche, 1993) and geochemistry (Maury and Mervoyer, 1973; Bellon et al., 1974; Lancelot et al., 1984; Lévêque et al., 1988; Lancelot and Vella, 1989) help to discuss the tectono-mechanical origin of each fracture set and to propose a possible scenario in relation to the mechanical evolution at basin scale (Santouil, 1980; Horrenberger and Ruhland, 1981; Balmelle, 1989; Lopez, 1992).

Finally the studied fractured rocks, because of their clay content, raise the question of their top-seal properties in a half-graben basin, which can be seen as an excellent analogue of siliclastic oil and gas reservoirs.

2. Regional geologic setting

The studied areas are located in the 150-km^2 Lodève Permian basin, 60 km northwest from Montpellier, in southern France (Fig. 1a). The Lodève Permian basin forms a south dipping half graben covered unconformably by a thick horizontal Mesozoic cover (Fig. 1b). This cover is presently largely eroded, allowing the exposure of the basement and the Permian deposits. To the north, the Permian deposits onlap moderately folded non-metamorphic Cambrian carbonates and epimetamorphic Precambrian schists with vertical to moderate south dip. To the south and the east the EW-trending Les Aires Fault and the NE–SW-trending Cevennes Fault, respectively, limit the basin. These faults record both Upper Liassic extension and Pyrenean shortening, which preclude the observation of the original listric fault supposed to accommodate the southward tilting of the basement during the Permian (Saint Martin et al., 1990; Lopez, 1992).

2.1. Sedimentary architecture and stratigraphy of Permian deposits

The infilling of the basin is mainly composed of continental shales and pelite deposits that represent a present day thickness of more than 3000 m in the southern