Distribution of calcite cements in a folded alluvial-fluvial succession: the Puig-reig anticline (South-eastern Pyrenees).

Distribución de cementos de calcita en un sistema aluvial-fluvial: el anticlinal de Puig-reig (Pirineos Surorientales).

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Resumen: *Como mineral autigénico predominante, el cemento de calcita tiene un efecto muy significativo en la potencial calidad como reservorio del anticlinal de Puig-Reig, que constituye un excelente análogo para el estudio de la distribución de cementos en diferentes facies sedimentarias gracias a la cantidad y calidad de los afloramientos. Tras un exhaustivo estudio estratigráfico y de recogida muestras, se han realizado análisis petrográficos con microscopio óptico y de cátodo-luminiscencia de facies y sus cementos. Se han identificado dos generaciones principales de cementación calcítica que se desarrollaron durante y después del crecimiento del anticlinal, aunque la mayor parte del cemento cristalizó de manera simultánea a su formación. La distribución del cemento está controlada por la posición estructural dentro del pliegue y por las facies y litofacies de la roca encajante. Los depósitos de canales fluviales en la cresta del anticlinal, de grano especialmente grueso, tienden a desarrollar más cementación. Es necesario profundizar en el estudio de las características de la cementación de calcita para producir mejores estimaciones sobre la calidad de los reservorios y para guiar las actividades de exploración relacionada con los hidrocarburos o el almacenamiento geológico de* CO_2 *en estructuras subterráneas similares.*

Palabras clave: *cementación de calcita, depósitos fluviales y aluviales, fluidos, Pirineos*.

Abstract: *As the most prevalent authigenic mineral, calcite cement exerts a significant effect on reservoir quality of the Puig-reig anticline, which is an excellent outcrop analogue to study calcite cement distribution due to good and continuous exposure. After stratigraphic logging and rock sampling, two major generations of calcite cementation have been identified using petrographic observations under optical and cathodoluminescence microscopes. They formed during and after anticline growth, respectively. Most calcite cement formed simultaneously with the anticline. Calcite cement distribution is controlled by the structural position of sediments in the fold and also by host sedimentary facies and lithofacies. Fluvial channel deposits of the anticline crest, especially relatively coarse deposits, tend to host more calcite cement. A more detailed study on calcite cementation is required to predict high-quality reservoirs and further guide petroleum exploration or carbon storage in similar subsurface structures.*

Key words: *calcite cementation, fluvial and alluvial fan deposits, fluids, Pyrenees.*

INTRODUCTION

Calcite is one of the most predominant authigenic minerals cementing clastic rocks and thus exerts significant effects on reservoir properties, fluid flow and solute transport (Dutton et al., 2002; Davis et al., 2006), thus becoming a key concern in hydrocarbon exploration and carbon sequestration. However, calcite cementation tends be heterogeneously distributed and be controlled by many factors, such as the tectonic settings, stratigraphic framework, sedimentary facies and lithofacies and fluid flow (Morad, 1998; Taylor et al., 2000; Cruest et al., 2016). Therefore, a comprehensive study of calcite distribution is a fundamental requirement for reservoir prediction.

GEOLOGICAL SETTINGS

The Puig-reig anticline is located in the south-eastern Pyrenean fold-and-thrust belt and the north-eastern part of the Ebro Basin. It formed above a thrust ramp consisting of middle and upper Eocene deltaic sandstones and marine marls, which changed into the alluvial-fluvial sediments of the Berga and Solsona formations after a rapid transition from marine to continental sedimentation (Williams et al., 1998; Sáez et al., 2007; Barrier et al., 2010). Alluvial fan deposits of the Berga Formation mainly formed in unconfined flash and sheet floods and are distributed on the proximal backlimb of the Puig-reig anticline, connecting north to the outer Pyrenean thrust sheets. Fluvial fans, consisting of distributary channel deposits and overbank deposits of the Solsona Formation spread over the whole anticline except for the most proximal backlimb. Only proximal-medium fluvial fan deposits developed on the anticline while distal fluvial fan deposits and lacustrine facies dominate towards the Ebro Basin.

METHODS

The study area presents excellent outcrops along roads that cut through the Puig-reig anticline. Seven high-resolution (decimetre-scale) stratigraphic logs with a total length exceeding 3000 m were analysed in detail. We recorded the thickness, grain size, sedimentary structures and bioturbations, which collectively allowed the identification of sedimentary facies and stratigraphic correlations. Petrographic observations were made using optical and cathodoluminescence microscopy to distinguish carbonate cement generations and determine their relative content in host rocks and veins. Forty polished thin sections from different structural positions of the anticline, and representing different sedimentary facies and lithofacies were analysed using a Zeiss Axiophot optical microscope and a Technosyn Cold Cathodoluminescence microscope, model 8200 Mk5-1 operating 16 to 17 kV and 270 to 290 μA gun current.

RESULTS AND DISCUSSION

Calcite is the most prevalent diagenetic mineral in the Puig-reig anticline. Two major generations of calcite cementation have been recognized from petrographic observations. The dominant calcite cement, which appears filling pores, replacing clasts and forming vein and micro-vein fillings (Fig. 1a-d), is closely related to fluid flow during the structural evolution of the Puig-reig anticline. This cement presents blocky crystal morphology and luminescence ranging from dull or bright orange to yellow colour. The second generation calcite is non-luminiscent and presents euhedral blocky structure. It is only found in veins filling the first vein generation (Fig. 1e and f), revealing that it formed in more recent periods, probably due to rock exposure after tectonic uplift.

The content of calcite cements mainly ranges from 3% to 20% of the total rock volume, and their distribution is controlled by several factors, such as the structural position in the fold and the host sedimentary facies and lithofacies. The anticline crest tends to have more calcite cements than the rocks of the backlimb and forelimb. Meanwhile, the far distal forelimb presents a minimum volume of cement, mainly because the crest experienced more intense tectonic fracturing and associated fluid flow. On the other hand, proximal-medium fluvial channel deposits and alluvial clast-supported deposits contain more calcite cement than fluvial overbank and alluvial matrix-supported deposits. Meanwhile, calcite veins appear preferentially developed in conglomerates and coarse sandstones rather than in fine and clay deposits. This reveals that sedimentary facies and primary lithofacies probably affected the pore structure, the degree of fracturing and fluid flow, thus controlling calcite cementation. A comprehensive study of calcite distribution on this kind of outcrop analogue is conducive to identify high-quality reservoirs for petroleum exploration or carbon storage in similar subsurface structures.

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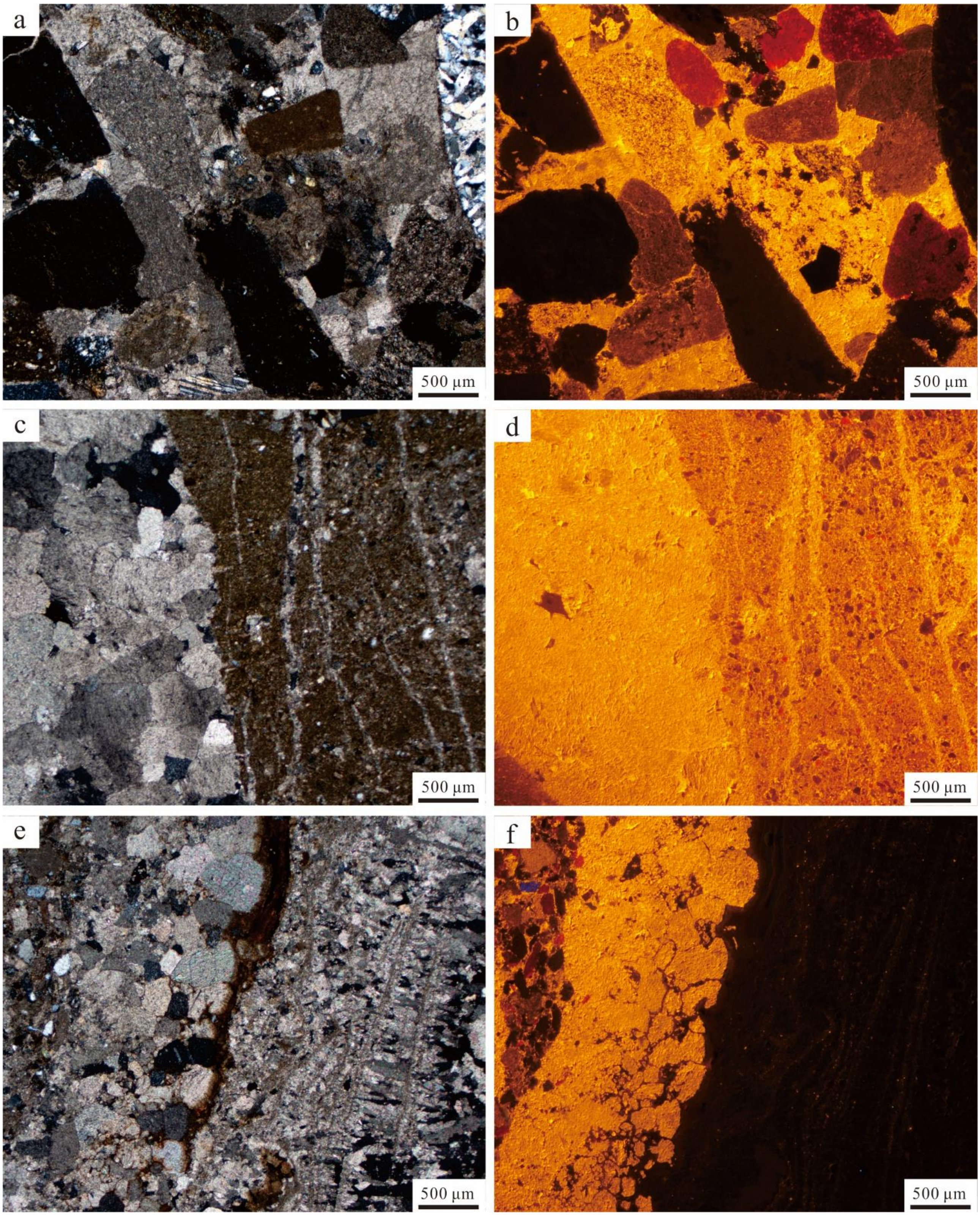

FIGURE 1. *Images of polarizing optical microscope and cathodoluminescence (a-b) prevalent pore filling calcite cements; (c-d) similar luminescence of calcite cement in vein, micro vein and pore filling; (e-f) non-luminous vein covering previous vein with yellow luminescence.*