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

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

X. Sun[1], E. Gomez-Rivas[1], J. Alcalde[2], D. Cruset[1], D. Muñoz-López[1], I. Cantarero[1], J.D. Martín-Martín[1] y A. Travé[1]

1 Departament de Mineralogia, Petrologia i Geologia Aplicada, Universitat de Barcelona (UB), 08028 Barcelona. xiaolong.sun@ub.edu e.gomez-rivas@ub.edu munoz-lopez@ub.edu i_cantarero@ub.edu juandiegomartin@ub.edu atrave@ub.edu

2 Geosciences Barcelona (GEO3BCN-CSIC), 08028 Barcelona. jalcalde@geo3bcn.csic.es dcruset@geo3bcn.csic.es

Resumen: El cemento de calcita, como mineral autigénico predominante, 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 de facies y sus cementos con microscopio óptico y de cátodo-luminiscencia. 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 obtener mejores estimaciones sobre la calidad de los reservorios y para guiar las actividades de exploración de hidrocarburos o el almacenamiento geológico de CO_2 en estructuras subterráneas similares.

Palabras clave: cementación de calcita, depósitos fluviales, 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.*

Keywords: *calcite cementation, fluvial 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; Cruset et al., 2016). Therefore, a comprehensive study of calcite distribution is a fundamental requirement for reservoir prediction.

GEOLOGICAL SETTING

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 Group and the Solsona Formation after a rapid transition from marine to continental sedimentation (Williams et al., 1998; Sáez et al., 2007; Barrier et al., 2010). In this study, we focus on the Camps de Vall-Llonga Formation, a sub-unit of the Berga Group, and the Solsona Formation. These formations were deposited from a proximal-medial fluvial system. The proximal fluvial deposits, concentrating in the north limb of the anticline, represent sedimentary environments of unconfined flash floods or wide-shallow channel streams. The medial fluvial deposits, covering the rest of the anticline, represent sedimentary environments of braided channel streams and overbanks. The distal fluvial deposits are composed of terminal lobes and deltas, which are located southward of this anticline (Sáez et al., 2007).

METHODS

The study area presents excellent outcrops along roads that cut through the Puig-reig anticline. Seven high-resolution (decimeter-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 microvein 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 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.

In host rocks, the content of calcite cements mainly ranges from 5% to 15% of the total rock volume, which resulted in

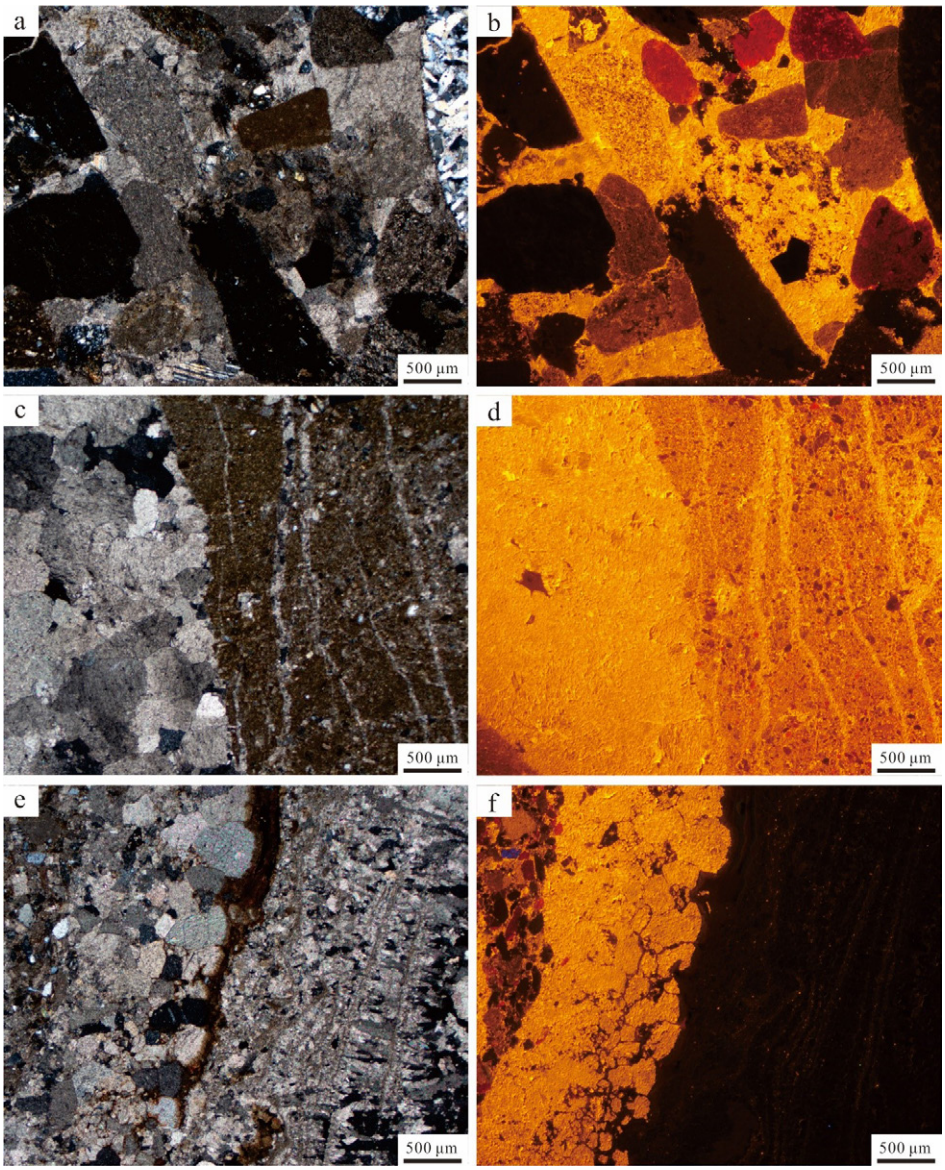

FIGURE 1. Images of polarizing optical microscope and cathodoluminescence of calcite cements from the Puig-reig anticline: (a-b) prevalent pore filling calcite cements; (c-d) similar luminescence of calcite cement in vein, micro vein and pore filling; (e-f) non-luminous vein covering previous vein with bright orange luminescence.

the overall low matrix porosity. The distribution of calcite cements 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 limbs because the crest experienced more intense tectonic fracturing and associated fluid flow. On the other hand, medial fluvial channel deposits contain more calcite cements than overbank deposits and proximal fluvial 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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