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From rock-buffered to open fluid system during emplacement of the Lower Pedraforca thrust sheet (South Pyrenees)

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Abstract. The evolution of fluid flow during the emplacement of the Lower Pedraforca thrust sheet is inferred from fracture data, petrography and geochemistry of calcite cements.

The results show that during the earlier stages of compression, fluids migrating along fractures were in equilibrium with their adjacent host rocks. In contrast, external fluids in disequilibrium with their adjacent host rock migrated along fractures during the later stages of emplacement of the thrust sheet.

Similar evolution has been observed in other areas of the Pyrenees and other orogens worldwide.

Keywords: South Pyrenean fold and thrust belt, Fluids, Fractures.

1 Introduction

The cements precipitated in fractures record the composition and evolution of fluids during the tectonic history of fold and thrust belts [1].

In this work we define the evolution of fluids during the development of the Lower Pedraforca thrust sheet (South Pyrenees) integrating structural, petrographic and geochemical data. The results are compared with previous works done in the Southern Pyrenees (Jaca, Vallfogona and L'Escala thrusts, Ainsa Basin and Puig-reig anticline) and other orogens worldwide (Bighorn Basin and North Oman and Canadian Rocky Mountains) [2].

2 Geological setting

The south Pyrenean fold and thrust belt (SPFTB) consists of a south-directed thrust system emplaced from Late Cretaceous to Oligocene detached predominantly above Triassic and Eocene evaporites [3].

The studied structure is the Lower Pedraforca thrust sheet (LPTS), an imbricated thrust system emplaced during the Lutetian (Middle Eocene) [4]. It consists of an allochthonous klippe detached above Eocene sediments and constituted of Lower Triassic

38 evaporites, Lower Jurassic limestones and dolostones, Upper Cretaceous limestones
 39 (Areny Fm.), Paleocene continental deposits (Garumnian) and Eocene syn-orogenic
 40 sediments deposited in the thrust front [3].

41 3 Methodology

42 Field work consisted of fracture data acquisition (dip directions and dips) and sampling
 43 of calcite cements precipitated in fractures and host rocks for petrographic and geo-
 44 chemical studies. Fracture data were plotted in stereograms and restored with respect
 45 to host rock bedding to define different fracture sets. Petrographic observations of 26
 46 polished thin sections were made using optical and cathodoluminescence microscopy
 47 to define different calcite cements and their crosscutting relationships. The Geochemi-
 48 cal characterization of fluids consists of carbon- and oxygen-isotope analysis of frac-
 49 ture-filling cements and their adjacent carbonate host rocks.

50 4 Fractures and cements

51 Up to seven fracture sets have been identified in the studied area. F1 and F2 fractures
 52 comprise N-S and E-W bed-perpendicular veins, respectively. F2 is abutting F1, indi-
 53 cating a later time of formation. F3 fractures consist of bed-parallel slip surfaces. F4
 54 consists of conjugated NW-SE and NE-SW bed-perpendicular veins abutting F1 and F2.
 55 F5 consists of conjugated NNE-SSW and NW-SE veins associated to major thrusts
 56 cross-cutting bedding at high angle. F6 and F7 include small and major south-verging
 57 thrusts and strike-slip faults cross-cutting bedding at high angle, respectively.

59
 60 **Fig. 1.** A) $\delta^{18}\text{O}$ vs $\delta^{13}\text{C}$ cross-plot of calcite cements and host rocks and B) $\delta^{18}\text{O}_{\text{calcite cement}}$ VS
 61 $\delta^{18}\text{O}_{\text{host rock}}$ cross-plot from calcite cements of the LPTS.

The petrographic study of fracture fillings in the LPTS have allowed to identify six types of calcite cements. Cc1 consists of non-luminescent microsparite precipitated in the intergranular and moldic porosity of the Areny Fm. Cc2 consists of non-luminescent sparite precipitated in vug porosity affecting the Garumnian. Cc3 consists of orange luminescent sparite crystals, blocky or elongated parallel to fracture walls precipitated in F1, F2 and F3 fractures and vug porosity postdating Cc1 and Cc2. Cc4 consists of dull to orange luminescent sparite precipitated in F1, F2 and F4 affecting Eocene syn-orogenic sediments. Cc5 consists of zoned non-luminescent to dull orange cement precipitated in F1, F2 and F4 fractures postdating the previous cements. Cc6 consists of dull-brown sparite precipitated in F4, F5, F6 and F7 postdating Cc5.

Marine carbonates from the Areny Fm. have $\delta^{13}\text{C}$ between +1.5 and +1.7 ‰ VPDB and $\delta^{18}\text{O}$ between -4.5 and -3.2 ‰ VPDB. Garumnian palustrine limestones have $\delta^{13}\text{C}$ between -17.5 and -3.7 ‰ VPDB and $\delta^{18}\text{O}$ between -8.2 and -4.8 ‰ VPDB (Fig. 1A). Cc1 has a $\delta^{13}\text{C}$ of +1.5 ‰ VPDB and $\delta^{18}\text{O}$ of -5.2 ‰ VPDB. Cc2 has a $\delta^{13}\text{C}$ of -10.1 ‰ VPDB and $\delta^{18}\text{O}$ of -6 ‰ VPDB. For Cc3, the $\delta^{13}\text{C}$ ranges between -10.8 and -0.4 ‰ VPDB and the $\delta^{18}\text{O}$ between -5.5 and -3.9 ‰ VPDB. Cc4 has $\delta^{13}\text{C}$ values between -5.9 and -3.7 ‰ VPDB and $\delta^{18}\text{O}$ between -5.9 and -2.6 ‰ VPDB. Cc5 has $\delta^{13}\text{C}$ values between +0.8 and +1.6 ‰ VPDB and $\delta^{18}\text{O}$ ranging between -5.7 and -4.4 ‰ VPDB. For Cc6, the $\delta^{13}\text{C}$ ranges between -15.2 and +1.8 ‰ VPDB and the $\delta^{18}\text{O}$ between -9.2 and -6.1 ‰ VPDB.

5 Discussion

Crosscutting relationships between fractures and bedding in the LPTS indicates that F1 to F4 formed during the first stages of compression, whereas F5 to F7 formed during the last stages of deformation once strata were already folded [5].

The $\delta^{13}\text{C}$ of all the calcite cements are similar to their host rocks, indicating a rock-buffered system. Likewise, the $\delta^{18}\text{O}$ values of Cc2 and Cc3 are also in equilibrium with their host rocks (Fig. 1B), indicating a rock-buffered fluid system during calcite precipitation in the early vug porosity and also during formation of F1 to F3. In contrast, in calcite cements Cc5 and Cc6, the $\delta^{18}\text{O}$ is gradually more depleted with respect to their adjacent carbonate host rocks, indicating the opening of the system to exotic fluids as F4 to F7 formed (Fig. 1B). This trend has already been reported in other areas of the SPFTB like the Jaca, Vallfogona and L'Escala thrusts, Ainsa Basin and Puig-reig anticline [2, 6, 7] as well as in other orogens worldwide such as the Bighorn Basin and North Oman and Canadian Rocky Mountains [2, 8, 9], where it has been interpreted as the input of upward migrating hot and saline fluids mixed at depth with progressively more abundant meteoric waters, probably linked to the emersion of the structure.

6 Conclusions

During the early compression of the LPTS, fluids in equilibrium with their adjacent host rock migrated along N-S and E-W bed-perpendicular veins and bed-parallel slip surfaces. The progressive precipitation of $\delta^{18}\text{O}$ -depleted calcite cements in the faults

formed during the late stages of compression, indicate the input of external fluids into the system. This evolution of fluid behavior, also observed in other areas of the SPFTB and worldwide, is interpreted as the input of hot and saline fluids mixed at depth with progressively more abundant meteoric waters during the emersion of the structure.

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