Petrology and provenance as a key to interpret albitization: a case study from syn-rift Lower Cretaceous sandstones, Maestrat Basin, Iberian Range

Influencia de la composición petrológica y procedencia en la albitización de las areniscas sin-rift del Cretácico inferior, Cuenca del Maestrazgo, Cadena Ibérica

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Abstract: Lower Cretaceous sandstones from the Maestrat Basin are characterized by differences in detrital composition, provenance and degree of albitized feldspars (partial to complete). Petrological composition of Lower Cretaceous sandstones revealed a mixed provenance from plutonic and metamorphic source areas. A progressively major influence of granitic source rocks was detected from the lowermost Mora petrofacies toward the uppermost El Castellar and Camarillas petrofacies. Albitization of detrital feldspars occurred in all the studied sandstones, but feldspars were completely albitized in the lowermost Mora Fm. and only partially albitized in the overlying Castellar and Camarillas formations. However, all the Lower Cretaceous sandstones underwent, approximately, the same burial and thermal conditions (119-134ºC; based on vitrinite reflectance and thermal modelling). The decrease in replacive albite/detrital feldspars ratio from the lowermost Mora Fm. toward the uppermost Camarillas Fm. was related to differences in detrital composition and provenance of sandstones. Albitization was pervasive in the Mora Fm. sandstones because of its dominant metamorphic source areas, which implies a relative low abundance of K-feldspar compared to plagioclase. In contrast, the abundance of K-feldspars in Castellar and Camarillas formations prevented the complete albitization of feldspars. Thus, differences in original composition and provenance of sandstones influenced significantly the different degree of albitization for comparable burial and thermal rates.

Key words: provenance, albitization, composition driven diagenesis, Maestrat Basin.

Resumen: *Las areniscas del Cretácico inferior de la Cuenca del Maestrazgo presentan diferencias en su composición detrítica, procedencia y grado de albitización de los feldespatos. La composición petrológica indica una mezcla de aportes de rocas metamórficas (dominantes en la Fm. Mora, Berriansiense-Valanginiense) y plutónicas (progresiva mayor contribución hacia las fms. Castellar y Camarillas, Valanginiense-Barremiense). La albitización de los feldespatos detríticos se observa en todas las areniscas, pero sólo la Fm. Mora presenta feldespatos completamente albitizados, mientras que las fms. Castellar y Camarillas la albitización es parcial. Uno de los factores que controla el proceso de albitización es la temperatura, sin embargo, todas las areniscas del Cretácico inferior estuvieron sometidas a condiciones de enterramiento y temperatura similares (119-134ºC; basadas en reflectancia de vitrinitas y modelización térmica). La disminución de grado de albitización hacia las fms. Castellar y Camarillas estaría relacionada con las diferencias en composición y procedencia de las areniscas. La albitización fue completa en la Fm. Mora debido a la mayor presencia de aportes de rocas metamórficas, lo que implica una mayor abundancia de plagioclasas. Por el contrario, la mayor abundancia de feldespato-K en las fms. Castellar y Camarillas impidió la completa albitización de los feldespatos. Por tanto, las diferencias en la composición y procedencia de las areniscas influyeron significativamente en el grado de albitización de los feldespatos en condiciones similares de enterramiento y temperatura.*

Palabras clave: *procedencia, albitización, diagenesis influenciada por composición, Cuenca Maestrazgo.*

INTRODUCTION

In the last decades, diagenetic albitization of detrital feldspars has been recognized in sandstones and reservoir rocks from different ages and depositional environments. One of the most relevant diagenetic processes is the increase in the percentage and degree (partial to complete) of albitized feldspars with depth (Saigal *et al.*, 1988). Empirical modelization revealed that the albitization process depends more on temperature

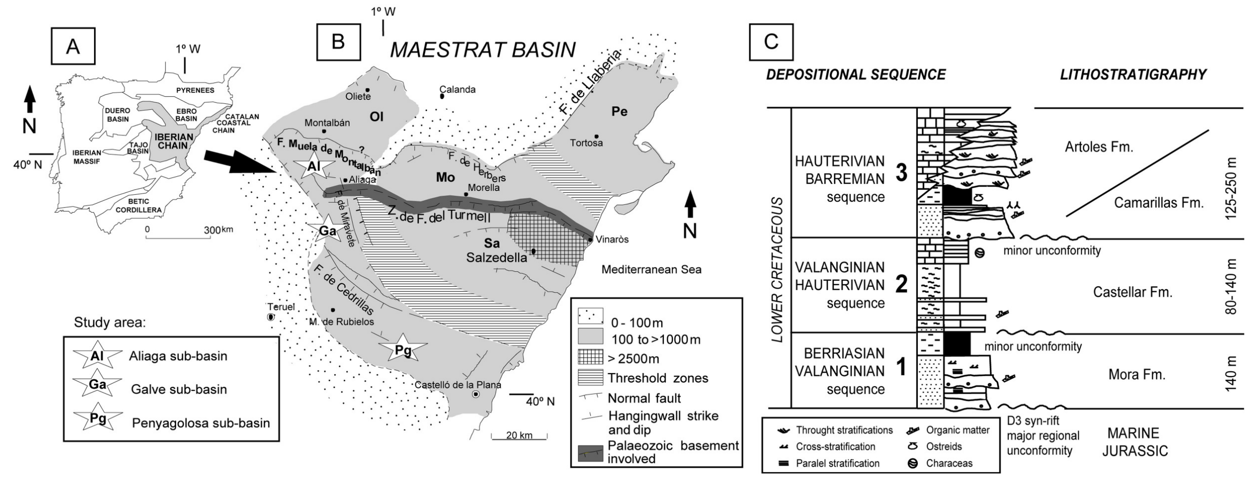

FIGURE 1. *(A) Simplified map of the Iberian Peninsula showing the main structural units; (B) Detail corresponding to the Maestrat Basin located in the Iberian Chain (modified from Salas et al., 2001). The Maestrat Basin has been subdivided into the following seven sub-basins: Oliete (Ol), Morella (Mo), Perelló (Pe), Salzedella (Sa), Penyagolosa (Pg), Galve (Ga), and Aliaga (Al). The last three sub-basins are the study area. Thickness represented corresponds to Early Cretaceous sediments; (C) Schematic stratigraphic column of the Lower Cretaceous formations showing the main unconformities (modified from Caja, 2004).*

and heating rate, than time and fluid chemistry (Perez and Boles, 2005).

In this paper, diagenetic albitization is studied in sandstones with different detrital composition, provenance and degrees of albitized feldspars (partial to complete). However, all these sandstones underwent, approximately, the same burial and thermal conditions.

The study area corresponds to the Maestrat Basin, which lies in the eastern sector of the Iberian Range and contains almost 6000 m Mesozoic sediment (Fig. 1A and B). Syn-rift subsidence began during the Upper Oxfordian age, and was characterised by an initial period of rapid, fault-controlled syn-rift subsidence (Upper Oxfordian to Middle Albian) in a series of fault-limited blocks, followed by a post-rift interval of diminishing subsidence (Upper Cretaceous), which was in turn controlled by thermal relaxation of the lithosphere (Salas *et al.*, 2001). These fault-limited blocks (i.e. sub-basins) were filled during Lower Cretaceous by the so called Weald facies (Fig. 1C).

SAMPLES AND ANALYTICAL METHODS

Nine representative stratigraphic sections were studied in the Aliaga, Galve and Penyagolosa sub-basin from the Maestrat Basin. Sampling was focused on the Lower Cretaceous sandstones from the Mora, El Castellar and Camarillas formations (125 sandstones samples). Analytical methods used in this paper were: i) Petrographic and cathodoluminescence (CL) study of thin sections and modal analyses of medium-size sandstones counting up to 400 points in 49 samples; and ii) Electron microprobe analyses and back-scattered imaging (BSE) on albite grains. For a more detailed description of samples and analytical methods see Caja (2004).

RESULTS

Petrology of sandstones

Modal analyses together with petrographic and cathodoluminescence observations allowed the definition of three quartz-feldspathic petrofacies and the identification of diagenetic processes that modified the original framework composition (for detailed descriptions see Caja *et al.*, 2007). The average "restored" petrofacies are: Mora petrofacies with P/F >1 and $Q(r)_{70}$ $F(r)_{22}$ $R(r)_{9}$; El Castellar petrofacies with P/F >1 and $Q(r)_{57}$ $F(r)_{25}$ $R(r)_{18}$; and Camarillas petrofacies with P/F~ zero and $Q(r)_{64}$ $F(r)_{28}$ $R(r)_{7}$ (P, plagioclase; F, feldspar; Q, quartz; R, rock fragments; r, restored composition; Fig. 2).

Albitization

Plagioclase grains of Mora sandstones are untwined, frequently euhedral-subeuhedral, clouded by tiny vacuoles and partially replaced by chlorite, kaolin or calcite. Microprobe analyses of completely albitized grains revealed a near pure albite end member composition ($Or_{0.1}$ $Ab_{99.7}$ $An_{0.2}$; average of 63 analyses; Fig. 2). BSE imaging revealed abundant micropores, aligned parallel to cleavage planes or microfractures. Under the CL, the albite grains are non-luminescent.

The plagioclase grains of Castellar sandstones are angular and subeuhedral, partially replaced by calcite and, in some cases, embedded in the clay mineral matrix. Polysynthetically twined grains have clean surfaces and untwined grains are clouded by tiny vacuoles, most likely microporosity. Microprobe analyses of plagioclase revealed an albite composition: $Or_{0.9}$ $Ab_{96.7}$ $An_{2.4}$ (average values of 59 analyses; Fig. 2). The plagioclase grains are green or non-luminescent under the CL, sometimes both of them exist in the same grain. Green luminescent plagioclase grains have the highest Ca content ($Or_{1.6}$ $Ab_{94.2}$ $An_{4.2}$; average values of 2 analyses). The scarce K-feldspars display bright blue luminescence or dark blue luminescence. Occasionally, K-feldspar display albite patches, which are associated and aligned to the exfoliation planes and twins.

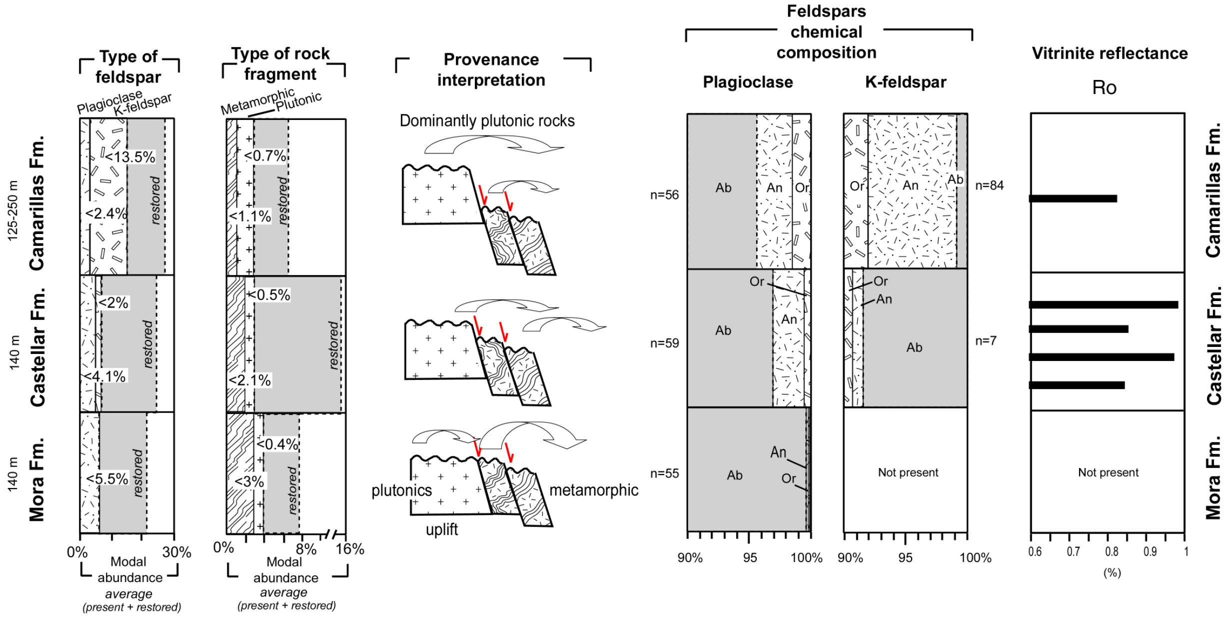

FIGURE 2. *Synthesis of the modal abundance of feldspars (considering diagenetic effects) and rock fragments; provenance interpretation (modified from Caja et al., 2007), chemical composition of feldspars and vitrinite reflectance values (Caja, 2004).*

Detrital K-feldspars of Camarillas sandstones, in the three studied sub-basins, are orthoclase and microcline (Fig. 2) showing bright blue luminescence and dark blue luminescence. Most of them show albite exsolution lamellae in perthites with chemical composition of $Or_{1.6}$ $Ab_{96.4}$ $An_{1.9}$ (average values of 8 analyses). Occasionally, albite patches with a near pure albite end member composition ($Or_{0.2}$ $Ab_{99.5}$ $An_{0.3}$; average values of 4 analyses) are associated and aligned to the exfoliation planes, twins or microfractures. Plagioclase grains are scarce in Camarillas sandstones and present a chemical composition of $Or_{1.7}$ $Ab_{95.1}$ $An_{3.3}$ (average values of 63 analyses). Polysynthetically twined and untwined plagioclase grains display under CL non-luminescence ($Or_{0.8}$ $Ab_{93.3}$ $An_{6.0}$ value of 4 microprobe analysis) or show green luminescence colors ($Or_{1.4}$ $Ab_{88.1}$ $An_{10.5}$; average values of 6 microprobe analyses).

DISCUSSION AND CONCLUSIONS

The three defined petrofacies suggest a mixed provenance from plutonic and metamorphic source rocks. However, a progressively major influence of granitic source rocks was detected from the lowermost Mora petrofacies toward the uppermost Camarillas petrofacies (Fig. 2). This provenance trend is consistent with the uplift and erosion of the Iberian Massif, which coincided with the development of the latest Berriasian synrift regional unconformity and affected all of the Iberian intraplate basins (Salas *et al.*, 2001). The uplifting stage of Iberian Massif pluton caused a significant dilution of Paleozoic metamorphic source areas, which were dominant during the sedimentation of the lowermost Mora and El Castellar petrofacies (Caja *et al.*, 2007; Fig. 2).

The Mora Fm. plagioclases have several typical characteristics of diagenetic albite. The main evidences are (Saigal *et al.*, 1988; Morad *et al.*, 1990; Ramseyer *et al.*, 1992; and references herein): (i) the idiomorphic shape of albite crystals, (ii) the pure albite chemical composition, (iii) non-luminescence, (iv) untwined, (v) the development of completely albitized grains, (vi) the intragranular microporosity due to the molar volume reduction involved in albitization reaction and (vii) the generation of calcite, chlorite and kaolin as by-products during albitization replacement. Conversely, feldspars in the overlying Castellar and Camarillas formations lack these features, which are characteristic of albitized grains. Only, albite patches in detrital Castellar and Camarillas k-feldspars present typical features of diagenetic albitization. In general, original features of detrital feldspar from source rocks have been preserved in Castellar and Camarillas sandstones, but not in Mora Fm. feldspars.

The burial and thermal model of Penyagolosa sub-basin (Caja, 2004) reveals that Castellar and Camarillas formations were buried around 1600 m of depth and reached a maximum temperature of 62ºC (Fig. 3). However, this "calculated" model does not permit explain the vitrinite values of the Lower Cretaceous mudstones from Castellar and Camarillas formations (Fig. 2). If the "calculated" model is constrained with vitrinite reflectance values, then Castellar and Camarillas formations would have reached a burial temperature from 119 to 134ºC (Barker and Pawlewicz, 1994; Fig. 3). The Mora Fm. is not represented in the burial and thermal model because it was eroded or not deposited in the eastern part of the Penyagolosa sub-basin, and then is not considered in the modelized stratigraphic section. However, vitrinite reflectance values in Castellar and Camarillas formations and the thermal gradient observed in the constrained model suggests

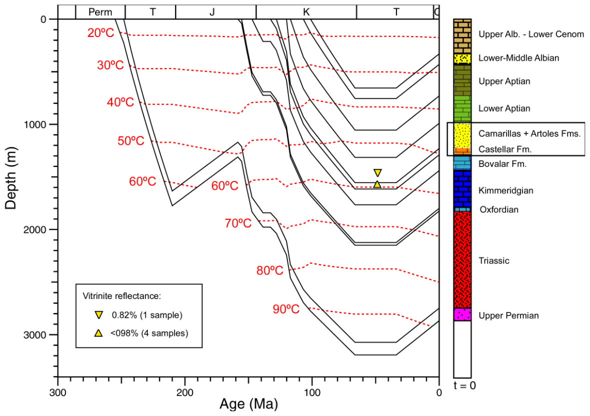

FIGURE 3. *Burial and thermal model for Penyagolosa sub-basin (modified from Caja, 2004) considering a thermal gradient typical for rift basins (27-30ºC/km). Note that vitrinite reflectance values reveal burial temperatures from 119 to 134ºC (Barker and Pawlewicz, 1994), which are higher than temperatures of the*

that Mora Fm. sandstones reached temperatures of 119-134ºC as well. This thermal gradient value exceed 30ºC/km, which is estimated by subsidence analysis, vitrinite reflectance, the stretching factor of the rift basin, the related surface heat flow and thermal conductivity values during syn-rift stage 2 (Salas *et al.*, 2005). Thus, if Mora, Castellar and Camarillas sandstones experienced the same degree of heating during burial, the decrease in replacive albite/detrital feldspars ratio from the lowermost Mora Fm. toward the uppermost Camarillas Fm. is related to differences in detrital composition and provenance of sandstones (i.e. progressively major influence of granitic source rocks from the lowermost Mora petrofacies toward the uppermost Camarillas petrofacies). Thus, the abundance of K-feldspars in Castellar and Camarillas formations, which are more difficult to albitized than plagioclase, prevented the complete albitization of feldspars. The compositional variations (e.g. detrital mineralogy, textures, grain sizes,…) of sandstones within and between different units can produce significantly different paragenetic histories for comparable burial rates (Thyne *et al.,* 2003; Perez and Boles, 2005).

Future work will involve the application of a general multi-mineralic water-rock interaction simulator that implements advective and diffusive mass-transfer, and kinetic and equilibrium reactions among minerals and water in order to evaluate the role of detrital composition and temperature on the extension of albitization.

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