Diagenesis, carbonate cementation and resevoir quality evolution of Eocene deep-water marine turbidite sandstones of the Hecho Group, South-Central Pyrenees

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ABSTRACT

Sandstone turbidites from the Hecho Group in the South-Central Pyrenees are considered exceptional examples for reservoir modelling and outcrop analogous studies. The Hecho Group is divided into four major tectosedimentary units (TSU-2 to TSU-5) and the sandstone composition varies from quartzarenites to arkoses (TSU-2), lithoarenites to hybrid arenites (TSU-3 and TSU-4), and hybrid arenites (rich in carbonate bioclasts; TSU-5). In TSU-2, the lowermost and most deformed unit, calcite cement precipitation was related to tectonic deformation. In the other turbidite systems (TSU-3, 4 and 5) eodiagenesis is evidenced by precipitation of dolomite cement and pyrite, which are locally abundant in all sandstones. Overall, compaction was more important than cementation in destroying porosity. However, the precipitation of dolomite overgrowth and intragranular mesogenetic ferroan calcite occluded nearly completely the remaining porosity and halted further compaction. Dissolution of calcite and dolomite cements has resulted in creation of minor amounts of secondary porosity.

Key words: *carbonate cementation, compaction, sandstones, turbidite systems, Hecho Group South-Central Pyrenees.*

INTRODUCTION

The deep-water turbiditic sandstones are increasingly becoming major hydrocarbon targets for the oil companies (Pettingill, 2000). Reservoir modelling is a powerful method in deciphering reservoir compartmentalization and good outcrop analogous models are crucial for better understanding complicated subsurface geometries. Diagenetic alterations are of key importance in understanding the dynamics of sedimentary basins and their reservoir quality evolution. For better elucidation of porosity and permeability evolution within hydrocarbon reservoir, diagenetic pathways must be integrated into conventional sedimentological models. Turbidite sandstones of the Hecho Group, South-Central Pyrenees (Fig. 1) is a potential analogue for the study of other deep-sea reservoirs in similar basinal settings in which reservoir quality assessment is biased by great deal of uncertainties. The carbonate rich sandstones with abundant extrabasinal limestones and dolostones occur within the orogenic settings, as the survival of chemically unstable carbonate grains depend on rapid erosion, transport and burial. Although these hybrid arenites are common in deep-sea environments, their diagenetic alteration is poorly explored in the literature (Spadafora *et al.*, 1998). In this paper, main diagenetic alterations (carbonate cementation and compaction) of the Eocene (lower Ilerdian to the upper Lutetian) turbiditic sandstones, which are responsible in destroying reservoir quality will be quantified and discussed. Diagenetic processes and fluid evolution will be discussed within the geological context of the Pyrenees Basin.

SAMPLING AND ANALYTICAL METHODS

The turbidite systems from the Hecho Group were studied and sampled in several locations: TSU-2 turbidite system (early Eocene) was sampled in the Torla, Gerbe, Castilgaleu and Figols sections. TSU-3, early Eocene in age, comprised the Arro channels, the upper Broto channel-lobe transition and the Broto-Fanlo lobes. TSU-4, early-middle Eocene, is made up of the Banaston 1 to 4, all of them corresponding to

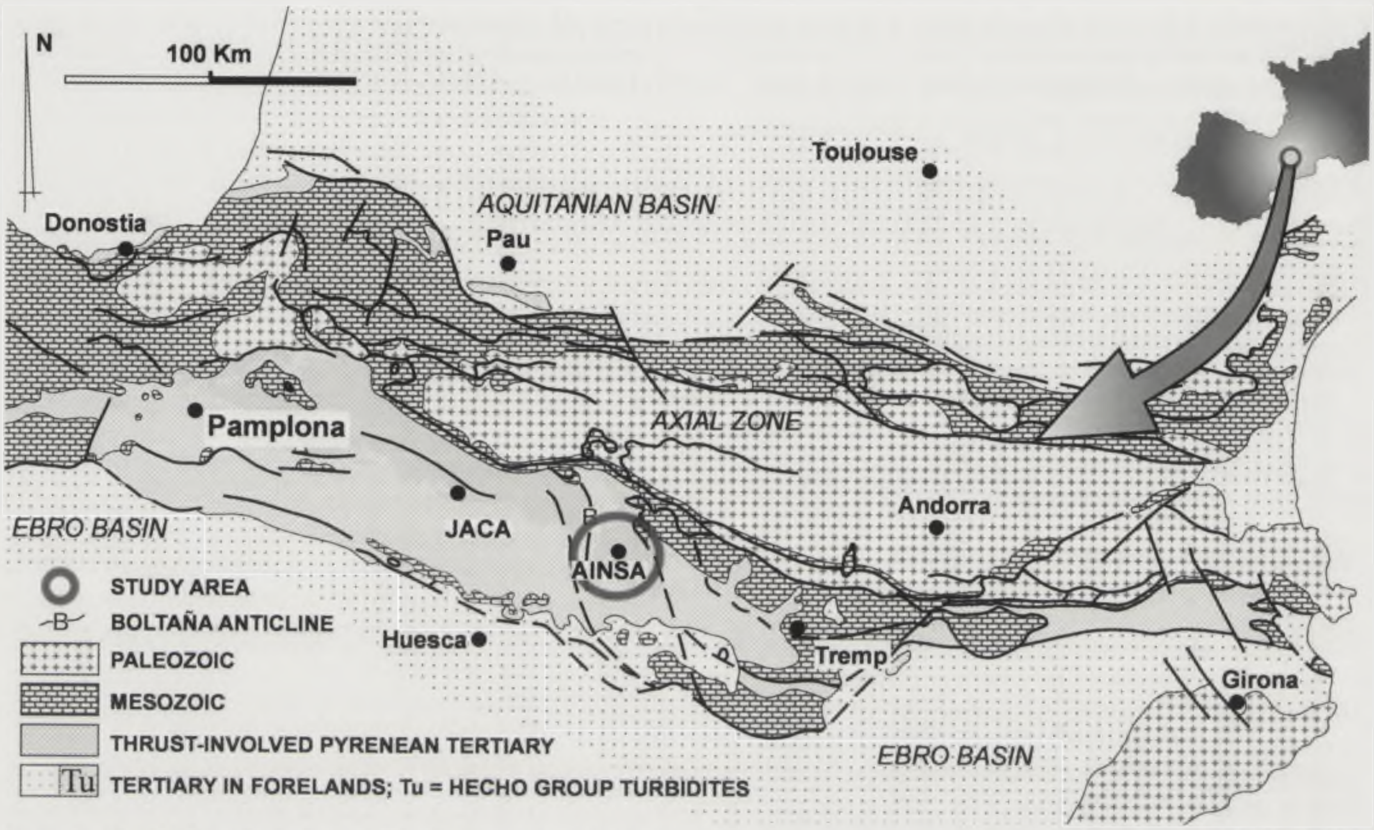

FIGURE 1. *Simplified geological map of the Tertiary belt of the South-central Pyrenees, showing the Eocene turbidite systems of the Hecho Group (Tu), and the study area.*

channel levee facies. Finally, the turbidite system TSU-5, middle Eocene, include the Ainsa channel-lobe transition facies, the Morillo point-bars and the Guaso channel sediments (Remacha *et al*., 2005). A total 241 sandstone samples were collected. Doubled-polished thin sections were prepared from each sample and stained for carbonates (alizarine red-s and potassium ferricyanide). Sandstones are very fine to coarse-grained. Modal analyses were only performed in 78 selected samples with medium grain size (0.25 to 0.5 mm) in order to minimize compositional differences due to sorting. Quantification of framework grains and authigenic cements was achieved by counting 300 points per thin section. Cathodoluminescence (CL) microscopy was carried out using a Technosyn 8200 MkII. The chemical composition of carbonate cements was determined by electron microprobe analysis using a *Jeol JXA-8900*. Operation conditions were 15 kV accelerating voltage, 20 nA beam current and 10 μm bean size. Detection limits were approximately 250 ppm for Mn, 200 ppm for Fe, 100 ppm for Mg, 400 ppm for Ca, and 270 ppm for Sr.

RESULTS

Sandstone composition

A first-order NCE (Non Carbonate Extrabasinal), CE (Carbonate Extrabasinal), CI (Carbonate Intrabasinal) classification of the studied Hecho group arenites reveals that TSU-2 are quartzarenites-arkoses NCE_{80} CE_{17} CI_3 (n = 6). TSU-3 (upper Broto and Arro) are lithoarenites to slightly hybrid arenites, NCE_{64} CE_{32} CI_4 (n = 29). TSU-4 arenites (Banaston 1 to 4) are classified as lithoarenites, NCE_{60} CE_{31} CI_9 (n = 25). TSU-5 arenites (Ainsa, Morillo and Guaso) are classified as lithoarenites to hybrid arenites, NCE_{48} CE_{31} CI_{21} (n = 24).

Carbonate cements

Carbonate cement in the turbidite sandstones comprise calcite and subordinate dolomite. There are important textural and compositional differences between studied carbonate cements:

Calcite cement

Fibrous to bladed radioaxial red luminescent calcite cements (40-60 mm), is present exclusively in TSU-2, i.e. in the lowermost –and indeed most deformed– unit. This cement appears as pressure shadows around carbonate lithoclasts, and is stretched by mechanical stress.

Intraparticle ferroan calcite cement has precipitated in moldic porosity, which is associated with fossils, mainly foraminifera. These bioclasts are completely filled by an early pyrite cement phase post-dated by ferroan calcite cement having a reddish-brown luminescence and an equant mosaic texture. The chemical composition of this calcite is similar in all the studied turbidite systems. The average chemical composition for TSU-3, 4 and 5 is ($Ca_{0.961}$ $Mg_{0.017}$ $Fe_{0.019}$ $Mn_{0.001}$ $Sr_{0.002}$) $(CO_3)_2$ (n = 42).

Interparticle blocky ferroan calcite cement is the most common cement type in all the studied sandstones, which is occluding completely intergranular porosity. This cement is characterised by equant to poikilotopic calcite crystals mosaic and occasionally by a patchy texture. These crystals show zoned dark red to orange luminescence. Modal abundance of this cement in TSU-3 arenites is <33%, average 17.2%, in TSU-4 <26%, average 12.9% and in TSU-5 <26.7%, average 16.5%. Average chemical composition is: TSU-3: ($Ca_{0.961}$ $Mg_{0.015}$ $Fe_{0.020}$ $Mn_{0.001}$ $Sr_{0.003}$) $(CO_3)_2$ (n = 27); TSU-4: ($Ca_{0.972}$ $Mg_{0.012}$ $Fe_{0.014}$ $Mn_{0.001}$ Sr_0) $(CO_3)_2$ (n = 32); TSU-5: ($Ca_{0.973}$ $Mg_{0.005}$ $Fe_{0.020}$ $Mn_{0.001}$ $Sr_{0.001}$) $(CO_3)_2$ (n = 14).

Dolomite cement

Dolomite precipitated as small (<20 mm) single crystals, or groups few crystals, occasionally riming detrital framework grains. These discrete dolomite rhombs occur in all TSUs in small amounts, less than 2%. When it occurs, it is post-dated by interparticle ferroan calcite cement.

Dolomite cements overall occur as overgrowths on single detrital dolomite grains and is common in most of the studied sandstones. The modal abundance in TSU-3 is <2.7%, average 1.2%, in TSU-4 <2.7%, average 1.3%, and in TSU-5: <2.3%, average 1.5%. Under backscattered electron imaging, two generations of dolomite overgrowth was possible to distinguish. Using CL, the core of the dolomite is not luminescent and the overgrowth is orange. The average chemical composition of the first stage dolomite overgrowth is ($Ca_{0.563}$ $Mg_{0.313}$ $Fe_{0.116}$ $Mn_{0.002}$ $Sr_{0.001}$) $(CO_3)_2$ (n = 16) and the second one is ($Ca_{0.573}$ $Mg_{0.283}$ $Fe_{0.134}$ $Mn_{0.004}$ Sr_0) $(CO_3)_2$ (n = 5).

Compaction versus cementation

A plot of the total intergranular volume (IGV) versus intergranular cements (dolomite and calcite cements, Fig. 2; Houseknecht, 1988; modified by Ehrenberg, 1989) indicates that mechanical compaction was far more important than

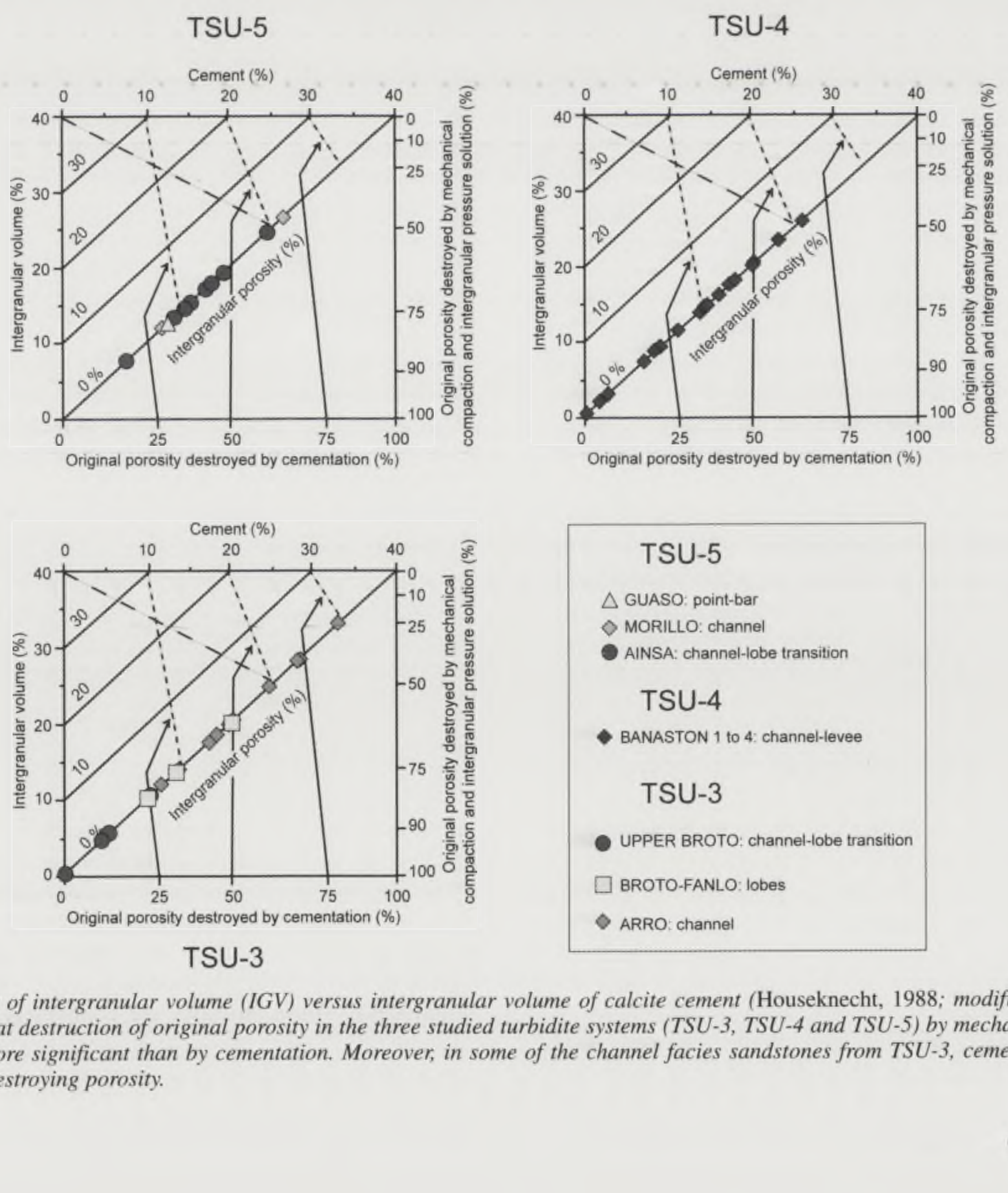

FIGURE 2. *Plot of intergranular volume (IGV) versus intergranular volume of calcite cement (*Houseknecht, 1988*; modified by* Ehrenberg, 1989*). Note that destruction of original porosity in the three studied turbidite systems (TSU-3, TSU-4 and TSU-5) by mechanical compaction was overall more significant than by cementation. Moreover, in some of the channel facies sandstones from TSU-3, cementation was more important in destroying porosity.*

cementation in destroying intergranular porosity in all the studied sandstones. However, in some channel-deposited sandstones of the TSU-3, cementation was more important than mechanical compaction in deteriorating porosity. It also appears that the primary porosity was nearly completely destroyed in all the studied sandstones and only minor secondary porosity (1-2%) after dissolution of calcite and dolomite cements is present. Some key petrographic observations (such as: the occurrence of linear grain contacts, and occasionally pressure-dissolution contacts, the absence of floating grains in sandstones with the highest carbonate cement modal abundance, and occasionally the precipitation of calcite cement in grain breakage) suggest that most mechanical and chemical compaction preceded carbonate cementation.

DISCUSSION

In TSU-2, the diagenetic evolution is severely obscured by tectonic effects (thrusting) and the most abundant cements are those due to deformation (calcite fibrous rims). In the TSU-3, 4 and 5, early diagenetic processes are represented by framboidal pyrite (sulfidic and anoxic environments) and dolomite cements that precipitated locally in the sandstones, which is typical of early stages of dolomite precipitation in deep-sea sediments (Coniglio and James, 1987).

Although it is not possible to determine the precise timing of calcite cements precipitation, the textural relationships between interparticle calcite cements and framework grains suggest that compaction took place before this calcite cementation. Furthermore, the chemical composition in major and trace elements of the interparticle calcite cement are comparable to those intra-skeletal ferroan calcite cements associated to fossils, suggesting that they precipitated synchronously from the same fluid, under similar reducing conditions, probably from seawater evolved to formation water during burial. The source of calcium is probably pressure-dissolution and reprecipitation from detrital carbonate rock fragments that occur in the sandstones and in the intercalated claystones and siltstones (Dutton and Barton, 2001). The source of Mg and Fe involved in dolomite cement could be related to the detrital dolostone and dolomicrite, which are common in the sandstone. The interbedded claystones could also be additional source for Mg and Fe. Zoning patterns of overgrowth in dolomites indicate that this growth occurred in various steps, in increasingly Fe-rich pore waters, hence presumably under increasingly reducing conditions.

Since most of the studied sandstones lacked, evenly distributed and sufficient early diagenetic rigid cement, which is capable of preventing mechanical compaction (e.g., calcite cement) compaction dominated the porosity loss. However, during deep-burial diagenesis, mechanical compaction was hindered locally by the precipitation of dolomite overgrowth and late ferroan calcite cement, as suggest by the petrographic observations, thus limiting pressure solution to grain-to-grain contacts (Fontana *et al.*, 1989).

CONCLUSIONS

The petrological and geochemical study of the Hecho Group Eocene turbiditic sandstones has revealed that diagenetic processes started very early with the precipitation dolomite cements and pyrite locally in all the sandstones. After that, compaction dominated the porosity loss. However, compaction was hampered by the precipitation of dolomite overgrowth and intraparticle late ferroan calcite cement during burial under reducing conditions. These cements occluded completely intergranular porosity and only some minor secondary porosity after dissolution of calcite and dolomite cements is present in Hecho group turbiditic sandstones.

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